Hornsea Project Three
Offshore Wind Farm

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Environmental Statement:
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Hornsea 3
Offshore Wind Farm

Ørsted

Environmental Impact Assessment

Environmental Statement

Volume 5

Annex 4.1 – Marine Mammal Technical Report

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Liability

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Glossary

Term	Definition
Benthic	Organisms that live on the sea bed.
Cetacean	Whale, dolphin or porpoise.
Hydrophone	A microphone that detects sound waves under the water.
Pinniped	Member of pinniped family (e.g. seal).
Sea state	The degree of turbulence at sea.
Telemetry	Study of animals involving the transmission of signals from tags attached to the animal.

Acronyms

Acronym	Definition
ASCOBANS	Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas
CI	Confidence Interval
CODA	Cetacean Offshore Distribution and Abundance
COWRIE	Collaborative Offshore Wind Research Into the Environment
cSAC	candidate Special Area of Conservation
CV	Coefficient of variance
DECC	Department of Energy and Climate Change
EIA	Environmental Impact Assessment
ESAS	European Seabirds at Sea survey methodology
ESW	Effective Strip Width
EWG	Marine Mammal Expert Working Group
FCS	Favourable Conservation Status
FOCI	Features of Conservation Importance
g(0)	Detection Function
GAM	General Additive Models
GLNP	Greater Lincolnshire Nature Partnership
GPS	Global Positioning System
IAMMWG	Interagency Marine Mammal Working Group

Acronym	Definition
IUCN	International Union for Conservation of Nature
JCP	Joint Cetacean Protocol
LNR	Local Nature Reserve
MCZ	Marine Conservation Zone
MRDS	Mark Recapture Distance Sampling
MU	Management Unit
NBIS	Norfolk Biodiversity Information Service
NNR	National Nature Reserve
PAM	Passive Acoustic Monitoring
PEIR	Preliminary Environmental Impact Report
pSCI	Proposed site of community importance
QA	Quality Assurance
rMCZ	Recommended Marine Conservation Zone
RSPB	Royal Society for the Protection of Birds
SAC	Special Area of Conservation
SCANS	Small Cetaceans in the North Sea
SCI	Site of Community Importance
SCOS	Special Committee on Seals
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
SMRU	Sea Mammal Research Unit
VER	Valued Ecological Receptor
WWT	Wetland and Wildlife Trust

Units

Unit	Description
cm	Centimetres
dB	Decibel
GW	Gigawatt (power)
kg	Kilogram
km	Kilometres
km^2	Kilometres squared
km per hour	Kilometres per hour
kHz	Kilohertz
knots	Unit of speed equal to one nautical mile per hour
kV	Kilovolt (electrical potential)
kW	Kilowatt (power)
m	Metres
m^2	Metres squared
ms^{-1}	Metres per second
NM	Nautical miles

1. Introduction

1.1 Project background

1.1.1.1 Ørsted is promoting the development of the Hornsea Project Three Offshore Wind Farm (hereafter referred to as Hornsea Three). Hornsea Three is a proposed offshore wind farm project within the former Hornsea Zone, and includes the associated offshore cable corridor and onshore infrastructure. The proposal is for a wind farm which will be situated within the Hornsea Three array area (covering 696 km^2) in the east of the former Hornsea Zone. Hornsea Three is located in the central region of the North Sea, approximately 140 km to the east of the East Riding of Yorkshire coast and approximately 10.1 km west of the median line between UK and Netherlands waters (Figure 1.1).

1.1.1.2 A marine mammal characterisation study of the Hornsea Three site and surrounding area has been undertaken. This included a detailed desktop study of the marine mammal ecology of the area, and considers and incorporates data from third party organisations such as the Sea Mammal Research Unit (SMRU), Friends of Horsey Seals, and Marine Life as well as a number of surveys previously undertaken across the former Hornsea Zone. This study also incorporates aerial survey data for marine mammals collected over the Hornsea Three array area plus 4 km survey buffer. This aerial survey data was collected over 20 months between April 2016 and November 2017 and covered the Hornsea Three array area only, and not the offshore cable corridor. The Hornsea offshore cable corridor area was characterised using published data sources.

1.2 Aims and objectives

1.2.1.1 The aim of this study was to provide an up to date characterisation of marine mammals within the regional marine mammal study area (see paragraph 2.1.1.1 below for a description of the regional marine mammal study area), to evaluate species' importance as Valued Ecological Receptors (VERs) for consideration in the Environmental Impact Assessment (EIA) (see volume 2, chapter 4: Marine Mammals).

1.2.1.2 To fully characterise the area, the following has been undertaken:

- A description of the marine mammal species present, their distribution and seasonality throughout the Hornsea Three marine mammal study area (see paragraph 2.1.1.1 for a description of the study areas);
- Density maps have been presented for each of the key species to indicate, on a spatial scale, which areas of the Hornsea Three array area may be the most important and the potential usage across the area;
- An assessment of the potential for connectivity of the Hornsea Three array area and offshore cable corridor with European sites which have marine mammals listed as notified interest features; and
- A comparison of the Hornsea Three marine mammal study area with the regional marine mammal study area, to assess the relative importance of Hornsea Three to marine mammals.

1.2.1.3 To achieve the above, the following has been undertaken:

- Aerial surveys were undertaken over the Hornsea Three array area plus a 4 km buffer (April 2016 to November 2017);
- Boat-based visual and acoustic surveys were undertaken over the former Hornsea Zone plus a 10 km buffer (monthly between March 2010 and February 2013);
- Desktop review of marine mammal ecology, abundance and density in the regional marine mammal study area; and
- Analysis of available published datasets.

1.2.1.4 Guidance on the issues associated with offshore renewable energy developments in general have been obtained through reference to the Overarching National Policy Statement (NPS) for Energy (EN-1; Department for Energy and Climate Change (DECC), 2011a) and the NPS for Renewable Energy Infrastructure (EN-3, DECC, 2011b). Further advice in relation to Hornsea Three specifically has been sought through consultation with the statutory consultees through the Evidence Plan process, from the Scoping Opinion received with respect to Hornsea Three (PINS, 2016) and relevant Section 42 consultation feedback on the PEIR.

1.2.1.5 Guidance on the EIA process will be sought from the following resources:

- Guidelines for Ecological Impact Assessment in the UK and Ireland. Terrestrial, Freshwater and Coastal, Second Edition (Chartered Institute of Ecology and Environmental Management (CIEEM) 2016); and
- Guidance note for Environmental Impact Assessment in Respect of FEPA and CPA Requirements (Cefas *et al*., 2004).

In addition, the EIA has regard to the legislative framework as defined by the Offshore Marine Conservation (Natural Habitats, & c.) Regulations 2007, the Conservation of Habitats and Species Regulations 2010 (Habitats Regulations), the Wildlife and Countryside Act 1981 (as amended), and the Marine and Coastal Access Act, 2009, where these relate to EIA.

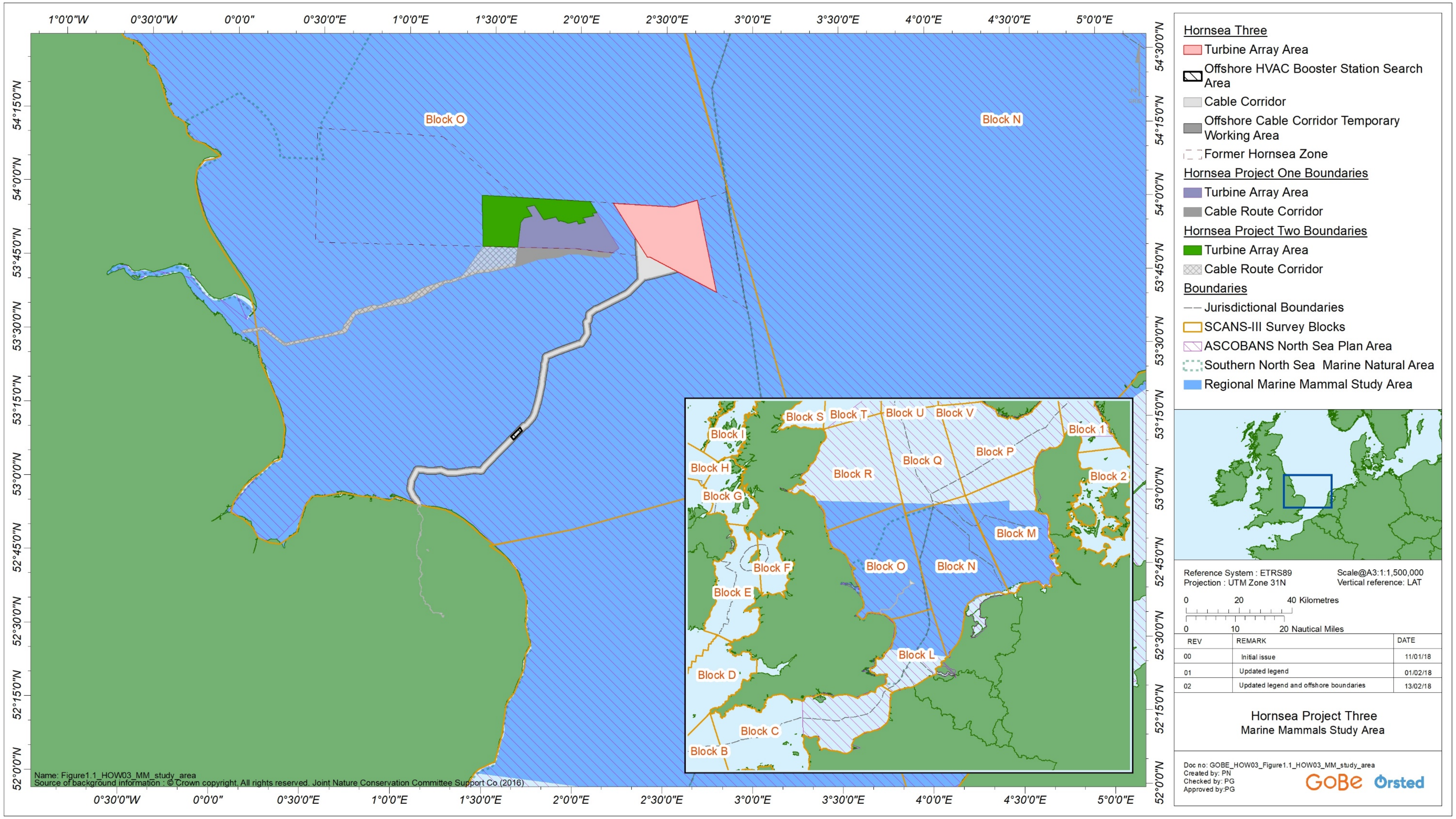


Figure 1.1: Location of the Hornsea Three marine mammal study area (within which is the Hornsea Three array area and offshore cable corridor) and location of the regional marine mammal study area.

2. Methods

2.1 Marine mammal study area

2.1.1.1 For the purposes of the marine mammal characterisation, the study area was defined in two ways:

- Hornsea Three marine mammal study area – this study area encompasses the Hornsea Three array area and offshore cable corridor and temporary working areas. The area also includes the former Hornsea Zone plus a 10 km buffer around its perimeter which is the area over which field surveys were undertaken; and
- Regional marine mammal study area – this area is represented largely by SCANS II Block U as the central point of focus, and extends further east and south to ensure that all key areas within the southern North Sea are encompassed. The regional marine mammal study area provides a wider geographic context for comparison with Hornsea Three data in terms of the species present and their estimated densities and abundance. Sites designated for conservation of marine mammal features within this region provide a useful context for understanding the relative importance of marine mammal species found within the southern North Sea, and consequently within the Hornsea Three marine mammal study area. It should be noted that the regional study area does not delineate populations of marine mammals, but does provide a sufficiently large area, within which ecological patterns in the key species can be understood. The most useful population-level information was referenced to the MUs for each of the key species, and the spatial extent and abundance of individuals within the MUs is detailed in section 3.2.

2.2 Evidence Plan

2.2.1.1 The purpose of the Hornsea Three Evidence Plan process (see Draft Evidence Plan (DONG Energy, 2017)) is to agree the information Hornsea Three needs to supply to the Secretary of State, as part of a Development Consent Order (DCO) application for Hornsea Three. The Evidence Plan seeks to ensure sufficient evidence is included in an application for Development Consent, and that this evidence complies with the EIA and Habitat Regulations Assessment (HRA) requirements.

2.2.1.2 As part of this process, a Marine Mammal Expert Working Group (EWG) was established with representatives from the key regulatory bodies, statutory nature conservation bodies and non-statutory parties, including Marine Management Organisation (MMO), Natural England and The Wildlife Trust. The Joint Nature Conservation Committee (JNCC) are not part of the Marine Mammal EWG as they have delegated to Natural England, however Natural England will liaise with JNCC as part of the process.

2.2.1.3 A number of meetings have been held in order to discuss and agree key elements of the marine mammal EIA. Meetings with key stakeholders commenced in March 2016 and have continued throughout 2016 and 2017. It has been agreed, through the Evidence Plan process, that the following datasets will provide a robust characterisation of the baseline:

- Boat based survey data from the wider Hornsea Zone plus a 10 km buffer (see sections 2.4.2 and 2.4.3 below) should be utilised to ensure a robust and thorough characterisation of Hornsea Three;
- Further survey data from aerial surveys of the Hornsea Three array area plus a 4 km buffer (the scope of which have been agreed with the EWG) should be used to inform the baseline (particularly in relation to harbour porpoise) (see section 2.4.4 below); and
- Data from third party organisations could provide useful contextual information, and additional quantitative information, therefore where available and appropriate to do so, third party information has been incorporated. This includes publically available information used to define the reference populations (section 3.2), which were also discussed and agreed as part of the Marine Mammal EWG process.

2.3 Desktop review

2.3.1 Background

2.3.1.1 Data was gathered for the regional marine mammal study area through a desktop review. All of the key marine mammal species discussed within this technical report are highly mobile, and may range considerable distances. An understanding of their behaviour throughout their natural range is therefore presented.

2.3.1.2 Following scoping, and discussion and agreement with the Marine Mammal EWG, five species of marine mammal are the focus of this study: harbour porpoise *Phocoena phocoena,* white-beaked dolphin *Lagenorhynchus albirostris*, minke whale *Balaenoptera acutorostrata*, grey seal *Halichoerus grypus*, and harbour seal *Phoca vitulina*. A literature review focussing on the above five marine mammal species has been undertaken. Marine mammal ecology including life history parameters, reproduction, moulting behaviour (seals), target prey species, distribution, abundance/density, threats, and conservation status, were gathered for each species. Historical information was available from annual reports by the Special Committee on Seals (SCOS) (SCOS, 2010; 2011; 2012; 2015); the Atlas of Cetacean Distribution in north west European Waters (Reid *et al.,* 2003); the UK Cetacean Status Review (Evans *et al.,* 2003); and examination of published Environmental Statements produced for other offshore wind farms in the Greater Wash region (SMart Wind, 2013; Centrica Energy, 2007, 2008, 2009; DONG Energy, 2009; Dudgeon Offshore Wind Farm Ltd, 2009; Humber Wind Ltd, 2008; and Scira Offshore Energy Ltd, 2006).

2.3.1.3 Existing data and information from published databases were also collated to supplement the boat-based survey data collected over the former Hornsea Zone plus a 10 km buffer and the aerial survey data collected between April 2016 and November 2017 across Hornsea Three array area plus a 4 km buffer (section 2.4). The key desktop data sources are described briefly below.

2.3.2 SCANS data

2.3.2.1 To estimate the abundance of small cetaceans across the North Sea, the SCANS project was initiated in 1994. Standard boat-based line transect surveys and aerial transect surveys based on the specific methods of Hiby and Lovell (1998) were first conducted across the North Sea during the summer of 1994 (Hammond *et al.,* 2002b). The Hornsea Three site was within SCANS survey Block G which was surveyed by vessel and consisted of a searching effort of 3,372 km (Hammond *et al.,* 2002).

2.3.2.2 In 2005, a second SCANS project (SCANS II) was conducted using modified survey techniques, including density surface modelling and re-analysis of the 1994 SCANS data, to assess how the distribution and abundance of cetaceans had changed in the intervening decade (Hammond, 2006). The Hornsea Three site is situated within SCANS II survey Block U which was surveyed by vessel and covered a surface area of 156,972 km^2 with a total survey effort of 2,246 km (Hammond *et al.,* 2006).

2.3.2.3 SCANS III was conducted in 2016 with the primary aim to provide estimates of cetacean abundance to inform the Marine Strategy Framework Directive (MSFD) assessment of Good Ecological Status (GES) in European Atlantic waters in 2018. The Hornsea Three site is situated within SCANS III survey block O which was surveyed by plane and consisted of a survey area of 60,198 km^2, a primary search effort of 3,242.8 km and a trailing search effort of 62.7 km (Hammond *et al.,* 2017). Only three species of cetacean were sighted in SCANS III Block O (harbour porpoise, white-beaked dolphins and minke whales) which is in alignment with the species included for assessment in this baseline.

2.3.2.4 While the SCANS surveys provide sightings, density and abundance estimates for marine mammals present in the North Sea and European Atlantic continental shelf waters, the surveys are conducted during a single month, every 11 years and therefore do not provide fine scale temporal or spatial information on species abundance and distribution.

2.3.2.5 Data from SCANS have been an important contributor to estimating the reference populations of key marine mammal species within UK waters (see information on MUs; section 3.2). These data provide a regional context for understanding the importance of the Hornsea Three marine mammal study area within the context of the regional marine mammal study area (south central North Sea).

2.3.3 Joint Cetacean Protocol

2.3.3.1 The Joint Cetacean Protocol (JCP) is an international approach to monitoring cetaceans in the UK and the wider north east Atlantic to provide distribution, abundance and population trends for cetacean species and includes a database of cetacean monitoring data. The JCP Phase III analysis included analysis of datasets from 38 data sources, totalling over 1.05 million km of survey effort between 1994 and 2010 (Paxton *et al.,* 2016). The JCP Phase III analysis was conducted to combine these 38 data sources to estimate spatial and temporal patterns of abundance for seven species of cetaceans: harbour porpoise, minke whale, bottlenose dolphin, short-beaked common dolphin, Risso's dolphin, white-beaked dolphin and Atlantic white-sided dolphin. The data are divided into areas of interest (such as areas of interest for offshore development) for which seasonal estimates of abundance are provided for winter (January-March), spring (April-June), summer (July-September) and autumn (October-December). The Hornsea Three project is located within the commercial area of interest referred to as "south Dogger Bank", for which seasonal density estimates are provided for harbour porpoise, minke whales and white-beaked dolphins.

2.3.4 JNCC Report 544: Harbour Porpoise Density

2.3.4.1 Heinänen and Skov (2015) conducted a detailed analysis of 18 years of survey data on harbour porpoise around the UK between 1994 and 2011 held in the JCP database. The goal of this analysis was to try to identify "discrete and persistent areas of high density" that might be considered important for harbour porpoise with the ultimate goal of determining Special Areas of Conservation (SACs) for the species. The approach involved constructing predictive models using corrected sightings rates analysed with respect to topographic, hydrodynamic and anthropogenic covariates and then generating predicted distribution maps of density estimates for the waters around the UK.

2.3.4.2 The analysis grouped data into three subsets: 1994-1999, 2000-2005 and 2006-2011 to account for patchy survey effort and analysed summer (April-September) and winter (October-March) data separately to explore whether distribution patterns were different between seasons. The authors note that "due to the uneven survey effort over the modelled period, the uncertainty in modelled distributions vary to a large extent." Section 4.2.2 presents these data and further outlines the associated assumptions and limitations of this analysis.

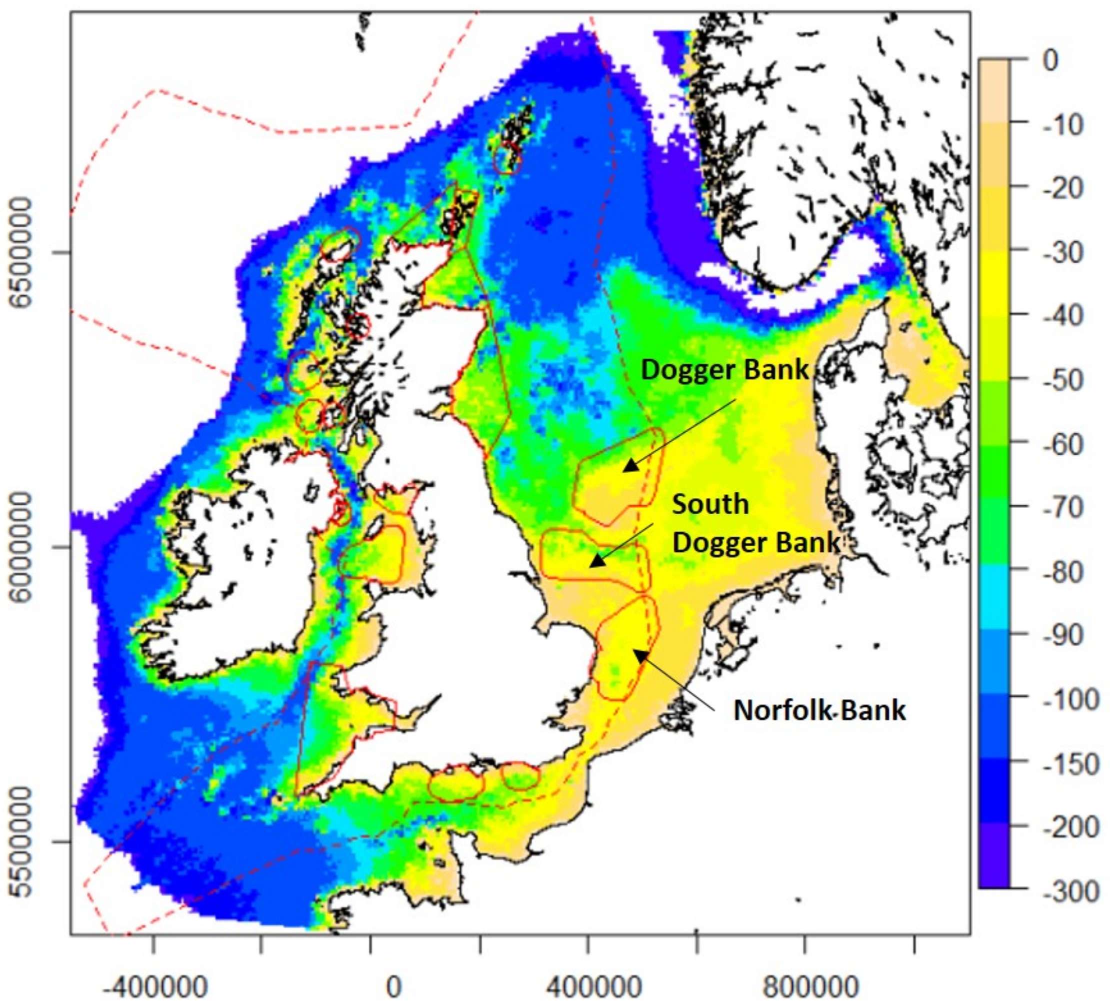


Figure 2.1: A close up of the core JCP Phase III region showing (red) areas of interest for offshore development where estimates of abundance are of special commercial interest. The coloured area (with depth shaded in m) indicates the region of collected survey effort.

2.3.5 Wildfowl and Wetland Trust cetacean surveys

2.3.5.1 The Wildfowl and Wetlands Trust (WWT) was consulted to gather available data on presence and distribution of marine mammal species within the regional marine mammal study area. Data on the distribution and abundance of cetaceans and seals in UK waters were collected by the Wildfowl and Wetlands Trust opportunistically, during aerial surveys for waterbirds, between 2001 and 2008 (WWT Consulting, 2009).

2.3.5.2 The aerial and boat survey data (see section 2.4) were also supplemented by historical sightings records (2004 to 2006) of cetaceans across the whole of the Greater Wash from the WWT coastal aerial surveys (WWT Wetlands Advisory Service, 2005). This provided useful context on marine mammal presence and distribution, particularly near the coast and for areas where dedicated boat-based surveys were not carried out, such as the Hornsea Three offshore cable corridor.

2.3.6 Horsey seal data

2.3.6.1 Friends of Horsey Seals were consulted to gather recent information on the abundance and distribution of grey seal in the Horsey area. Data has been collected annually since 2002. In the most recent survey period (2016/2017), counts were carried out over a 13 week period between 27 October 2016 and 19 January 2017. Counts were made weekly by land-based visual observation by a team of two people on the same day. The census noted the following age classes of grey seal: adults, weaned pups, suckling pups, and new born pups.

2.3.6.2 Grey seal pup deaths were noted where carcasses were still available, attempting to distinguish between those counted previously and any new deaths since the previous week. Pups rescued were also noted, particularly where these were less than seven days old.

2.3.6.3 Data are routinely submitted to the SMRU for compilation into the national database, managed as part of the SCOS programme. Grey seal pup production data were therefore available from SMRU for Horsey since 2002/2003.

2.3.7 Lincolnshire Environmental Records Centre

2.3.7.1 Lincolnshire Environmental Records Centre provided data for all cetacean species recorded over the last 20 years within their database within Hornsea Three. Contributors to the database included:

- Biological Records Centre (BRC);
- Greater Lincolnshire Nature Partnership (GLNP);
- Lincolnshire Biodiversity Partnership (LBP);
- Lincolnshire Wildlife Trust (LWT);
- Natural England; and
- Royal Society for the Protection of Birds (RSPB).

2.3.8 National Trust seal data for Blakeney

2.3.8.1 The National Trust (Blakeney Point) (SMRU, 2011; LWT pers. comm.) collects seal pup production data at Blakeney Point by carrying out ground counts. These are combined with data from Lincolnshire Wildlife Trust (Donna Nook) and Natural England (East Horsey) by SMRU to provide data on pup production on the English East coast. These are presented as part of SCOS reporting.

2.3.9 National seal data from SMRU

2.3.9.1 SMRU was contacted to obtain the most recent harbour and grey seal count data for the east coast of England population including the Horsey and Blakeney seal populations. The data, managed as part of SCOS, provided counts of new born grey seal pups at the main east coast colonies: Farne Islands, Donna Nook, Blakeney Point and Horsey. In addition, counts were provided for the annual moult (August) aerial surveys of the harbour seal east coast population between Donna Nook in Lincolnshire and Scroby Sands, off the Suffolk coast. Further data on counts of pups during end June/early July, were available from the latest SCOS report (Thompson, 2015). Data on harbour seal population estimates were also available from the latest SCOS report (2016).

2.3.9.2 Surveys of harbour seals are carried out during the summer months. The main population surveys are carried out when harbour seals are moulting, during the first three weeks of August, as this is the time of year when the largest numbers of seals are ashore. To maximise the numbers of seals on shore and to reduce the effects of environmental variables on counts, surveys are restricted to within two hours either side of afternoon low tides on days with no rain. Grey seals are also counted on all harbour seal surveys, although these data do not necessarily provide a reliable index of population size. The counts obtained represent the number of seals that were on shore at the time of the survey and are an estimate of the minimum size of the population. They do not represent the total size of the local population since a number of seals would have been at sea at the time of the survey. However, telemetry data from tagged seals on the relative proportion of time spent at sea and hauling out can be used to scale this estimate to take account of the proportion of animals at sea at the time of survey. Data from SMRU telemetry studies in the relevant areas are used to correct survey data for both species of seal. It is noted that these data represent the numbers of seals found within the surveyed areas only at the time of the survey; numbers may differ at other times of the year.

2.3.9.3 Grey seals aggregate in the autumn to breed at traditional colonies. Their distribution during the breeding season can be very different to their distribution at other times of the year. SMRU's main surveys of grey seals are designed to estimate the numbers of pups born at the main breeding colonies around Scotland. Breeding grey seals are surveyed bi-annually between mid-September and late November using large-format vertical photography from a fixed-wing aircraft. Over 60 colonies are surveyed annually between three and seven times, at 10 to 12 day intervals, through the breeding season. Total pup production for each colony is derived from the series of counts obtained. Approximately 40 additional colonies are surveyed less regularly. The main grey seal breeding colonies in Shetland, England, Wales and Northern Ireland are counted by local organisations.

2.3.10 Sea Mammal Research Unit (SMRU) Seal Telemetry Data

2.3.10.1 In the UK, SMRU has deployed telemetry tags on grey and harbour seals since 1988 and 2001, respectively. These tags transmit data on seal locations with the tag duration (number of days) varying between individual deployments.

2.3.10.2 Telemetry data within Hornsea Three have been summarised by SMRU to illustrate seal movements within the former Hornsea Zone (SMRU, 2017).

2.3.10.3 Twenty five harbour seals were tagged in The Wash in 2012 (SMRU, 2017). Two of these tags failed resulting in a total of 23 tagged animals transmitting data. Of these animals, 12 were female aged over one year, and 11 were male aged over one year. These animals had a mean tag duration of 95.2 days (range: 2 to 171 days).

2.3.10.4 Ten harbour seals were also tagged in the Thames in 2012. These comprised five females aged over one year, and five males aged over one year. The mean tag duration was 97.7 days (range 62 to 136 days). Two of these animals had ranges that overlapped with the regional marine mammal study area.

2.3.10.5 Twenty adult grey seals were tagged at Blakeney and Donna Nook in May 2015 (ten animals from each location) (SMRU, 2017). Thirteen animals were female aged over one year, and seven were male aged over one year. The mean tag duration was 169.75 days (range 5 to 238 days). Of these, eight of the animals tagged at Blakeney had tracks that entered Hornsea Three marine mammal study area, and one of the animals tagged at Donna Nook entered Hornsea Three marine mammal study area.

2.3.10.6 In 2016, a total of 20 harbour seals were tagged in The Wash as part of the Race Bank Offshore Wind Farm post-consent monitoring. A total of 15 were female and 5 were male and the mean tag duration was 138.4 days (range 43 – 244 days). Of the 20 tagged harbour seals, 16 had Global Positioning System (GPS) tracks and positions that overlapped with the scoping boundary area that covers the Hornsea Three array area and offshore cable corridor.

2.3.11 Seal at-sea usage maps

2.3.12 Russell *et al.* (2017) have produced revised estimated at-sea distribution usage maps for both grey and harbour seals. The revised maps contain telemetry data from 270 grey seals and 330 harbour seals tagged within the UK, incorporating count data between 1996 and 2015. The at-sea usage maps represent the number of grey and harbour seals estimated to be in the water in each grid cell at any given time. The assumptions and limitations of the model used to estimate the at-sea usage are presented in Russell *et al*. (2017) and includes assumptions on the relationship between usage and distance to haul-outs for grid cells containing a haul-out but no telemetry data. The at-sea usage maps do not distinguish between types of usage (foraging or travelling) and the usage estimate per grid cell could represent either a small number of animals using the area intensely or a large number of animals using the area a small amount. The data represent the expected number of seals per grid cell at any given time and so no temporal variation is represented in the maps, and, since only UK telemetry and count data were used in the model, the usage does not reflect that of seals from continental Europe. Since seals can be hauled-out on land or at sea, the model was not able to use land as a barrier to usage and so a small amount of usage is predicted on land which might result in an underestimation of the at-sea usage in coastal areas.

2.3.13 Marine Life

2.3.13.1 Marine Life provided data on marine mammal sightings from boat-based data (Immingham- Brevik freight ferry, Immingham – Esbjerg freight ferry, Immingham-Gothenburg freight ferry, and Cefas North Sea Fish surveys from the R/V Endeavour (Marine Life, 2017). Surveys were undertaken monthly from these routes between 2010 and 2016. Survey effort ranged each year and by month, peaking in 2013 (2,372 km surveyed) and with the greatest effort during April to September. The total survey effort over all years was 8,510 km and the average effort per year was 1,215 km.

2.4 Field surveys

2.4.1.1 Field surveys were undertaken to inform the marine mammal baseline across the Hornsea Three marine mammal study area. Boat-based surveys were conducted across the wider Hornsea Zone plus a 10 km buffer, whilst more recent aerial surveys focussed on the Hornsea Three array area plus a 4 km buffer. Full details of the methods are presented here.

2.4.2 Boat-based visual surveys

2.4.2.1 Boat-based surveys were carried out for Hornsea Project One and Hornsea Project Two on a monthly basis between March 2010 and February 2013. The surveys covered the former Hornsea Zone plus a 10 km buffer and therefore data were collected over the Hornsea Three array area.

2.4.2.2 A series of transects running in a north-south direction, spaced at 6 km apart over the former Hornsea Zone plus a 10 km buffer were surveyed over the three years (Figure 2.2). Additional data were also collected from surveys conducted along transects spaced at 2 km apart over the Hornsea Project One and Hornsea Project Two array Study Areas. Surveys did not cover the offshore cable corridor (Figure 2.2). Survey method, extent and effort were agreed in advance through consultation with the Joint Nature Conservation Committee (JNCC) in February 2011 following guidance from the standard Collaborative Offshore Wind Research Into the Environment (COWRIE) (Camphuysen *et al.,* 2004).

2.4.2.3 During the surveys, marine mammals (cetaceans and pinnipeds) and seabirds were recorded concurrently by the same observation team. Surveys were conducted from the M.V. Southern Star. This vessel has two custom built surveyor platforms (one on each side of the boat) with an eye height of greater than 5 m, as recommended for European Seabirds At Sea (ESAS) surveys (Webb and Durinck, 1992; Camphuysen *et al.*, 2004). Marine mammals were recorded using an adaptation of the standard JNCC ESAS survey method (Webb and Durinck, 1992), with modifications for recording angle and distance to marine mammals (see paragraph 2.4.2.5). This is standard distance sampling procedure and was discussed and agreed with Statutory Nature Conservation Bodies (SNCBs) for Hornsea Project One and Hornsea Project Two. Species identification, number of animals, direction of travel and behaviour were recorded along each transect. Binoculars were used to confirm identification as well as to scan ahead for species. Counts were conducted at one minute intervals, and synchronised GPS recorders were used to record the vessels position every minute.

2.4.2.4 Transects were surveyed using two ESAS accredited surveyors on a single platform located on one side of the survey vessel in a 90 degree arc (Camphuysen *et al.,* 2004). Where possible, three ESAS accredited surveyors were on-board for all surveys, although there were occasions when only two ESAS accredited surveyors were available for logistical reasons. In total, over the whole survey period, there were 17 days on which only two observers were present. At any one time, one surveyor acted as the primary observer, with the other acting as scribe and secondary observer. Where possible, and when weather forecasts indicated suitable weather conditions (i.e. sea state 3 or less), a fourth surveyor joined the survey team to conduct dedicated marine mammal observations.

2.4.2.5 Distance and angle to the first sighting cue (i.e. breaking the surface) were measured using a rangefinder and angleboard, respectively (Leaper and Gordon, 2001). If the horizon was not visible then a visual estimate in metres was recorded. If a group of cetaceans was encountered, then the distance to the centre of the group was measured. Measurement to the first cue is important since one of the assumptions in the subsequent analysis is that animals are detected at their initial location before responsive movement occurs. If animals move underwater prior to the cue, this is not an issue as long as the movement is random, and not responsive. As long as the vessel is moving faster than the animal then generally the animal can be detected before a responsive movement occurs. Any marine mammals seen on the 'non-survey' side of the vessel were also recorded in the same manner, the purpose of which was to document the presence of any rare species as a sighting rather than for use in the analyses.

2.4.2.6 Environmental conditions such as wind direction and force, Beaufort sea state, swell height and visibility were recorded every 15 minutes throughout the survey. To maximise detection of marine mammals on the water, surveys were carried out in good weather wherever possible. Surveys were halted if sea state exceeded sea state 4, as recommended in Camphuysen *et al.* (2004). Harbour porpoise are difficult to detect during visual surveys due to their small size and inconspicuous surfacing behaviours. The detection probabilities for harbour porpoise, are estimated to decrease with increasing sea state (e.g. Palka 1996) The difference in sightings probability in relation to sea state was accounted for in the analysis of the boat based survey data by producing sea state specific g(0) values for harbour porpoise.

2.4.3 Boat-based acoustic surveys

2.4.3.1 Acoustic surveys were also undertaken during the boat-based surveys to detect cetaceans that may have been less visible at times when the sea state was not calm. The visual marine mammal survey data was therefore augmented by this acoustic data. Acoustic surveys commenced in March 2011 and continued until the end of February 2013. A towed hydrophone was used to record cetacean vocalisations, in particular those made by harbour porpoise and dolphin species, although, it is recognised that animals do not vocalise at all times. The acoustic analysis primarily detected the presence of harbour porpoise and these data were used to provide a density estimate. Other cetacean species were infrequently recorded during the acoustic surveys, and the data were insufficient to use for analysis.

2.4.3.2 The passive acoustic detection system used for this work was a development of that employed during the SCANS surveys (Cucknell *et al.,* 2016; Hammond *et al.,* 2013). This consisted of a standard Ecologic high frequency stereo hydrophone comprising a streamlined oil filled sensor unit towed on a 200 m long Kevlar strengthened cable. The sensor streamer contained a depth sensor as well as two broadband Magrec HP03 hydrophone units each consisting of a spherical ceramic and an HP02 preamplifier with 28 decibel (dB) gain and a 2 kilohertz (kHz) low cut filter. A recording station with signal conditioning electronics, digitisers, and a computer was established in a protected space towards the rear of the vessel. Signals from the hydrophones were amplified using a Magrec HP27ST amplifier and filtered with a 20 kHz high pass filter before being digitised at 500 kHz per channel using a National Instruments Universal Serial Bus (USB)-5251 DAQ (Data Acquisition). A computer running a PAMGUARD configuration, open-source passive acoustic monitoring (PAM) software, made continuous recordings to a hard drive whilst also running a click detector and collecting GPS data. Full bandwidth recordings were made continuously as '.wav' files using PAMGUARD software whenever the hydrophones were deployed at sea. Hard drives were backed up before being sent by post to Marine Ecological Research (MER) for analysis.

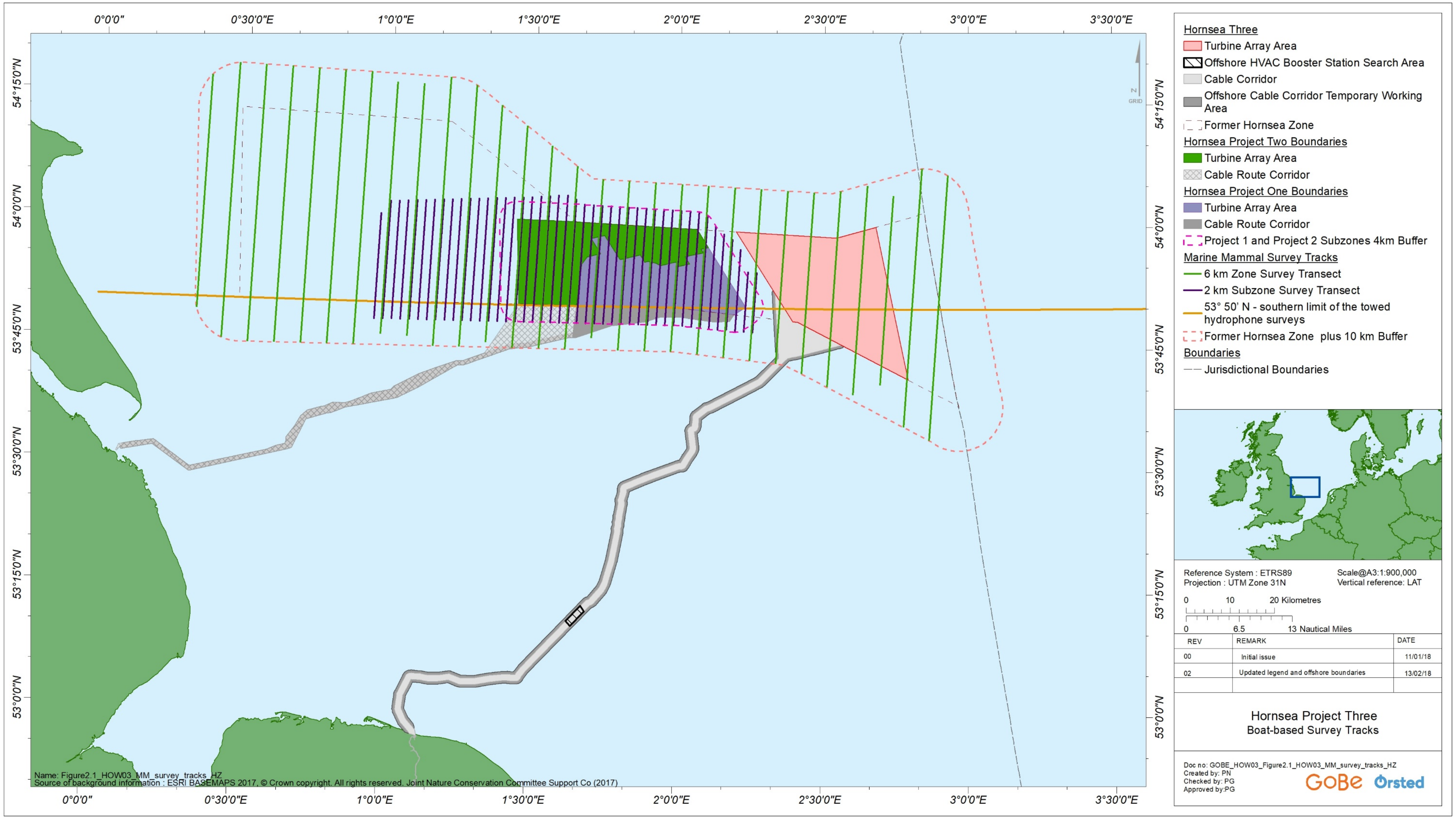


Figure 2.2: Survey tracks for the three years of boat-based surveys across the former Hornsea Zone plus a 10 km and across the array areas for Hornsea Project One and Hornsea Project Two Study Areas. Surveys did not cover the Hornsea Three offshore cable corridor.

2.4.4 Aerial surveys

2.4.4.1 Aerial surveys of seabirds and marine mammals commenced in April 2016 and were completed in November 2017. Aerial surveys were conducted from an aircraft fitted with a GEN II camera rig comprising four extreme high-resolution digital video cameras (equivalent to 16 x HD quality). Survey altitude was 550 m above sea level (ASL) and the aircraft operational speed was 220 km per hour (equivalent to 120 knots) (Figure 2.3). At this altitude, the HiDef cameras and lenses each survey a strip of approximately 125 m with a ground sample distance resolution of 2 cm. For these surveys, data from two of the cameras were processed, giving a total strip width of 250 m, with the other two camera collecting data as a backup.

2.4.4.2 The survey design was a non-stratified series of parallel transects, spaced approximately 2.5 km apart across the Hornsea Three array area plus a 4 km buffer (Figure 2.4). The transects covered 122.95 km^2; equivalent to ~10% of the 1,229.97 km^2 area surveyed. Data were collected over this study area on a monthly basis. Minimum acceptable weather conditions for the survey are shown in Table 2.1. Although sea state 6 is defined as a maximum, in practice this was rarely experienced, with the majority of surveys (87.4%) conducted in sea states of 4 or less.

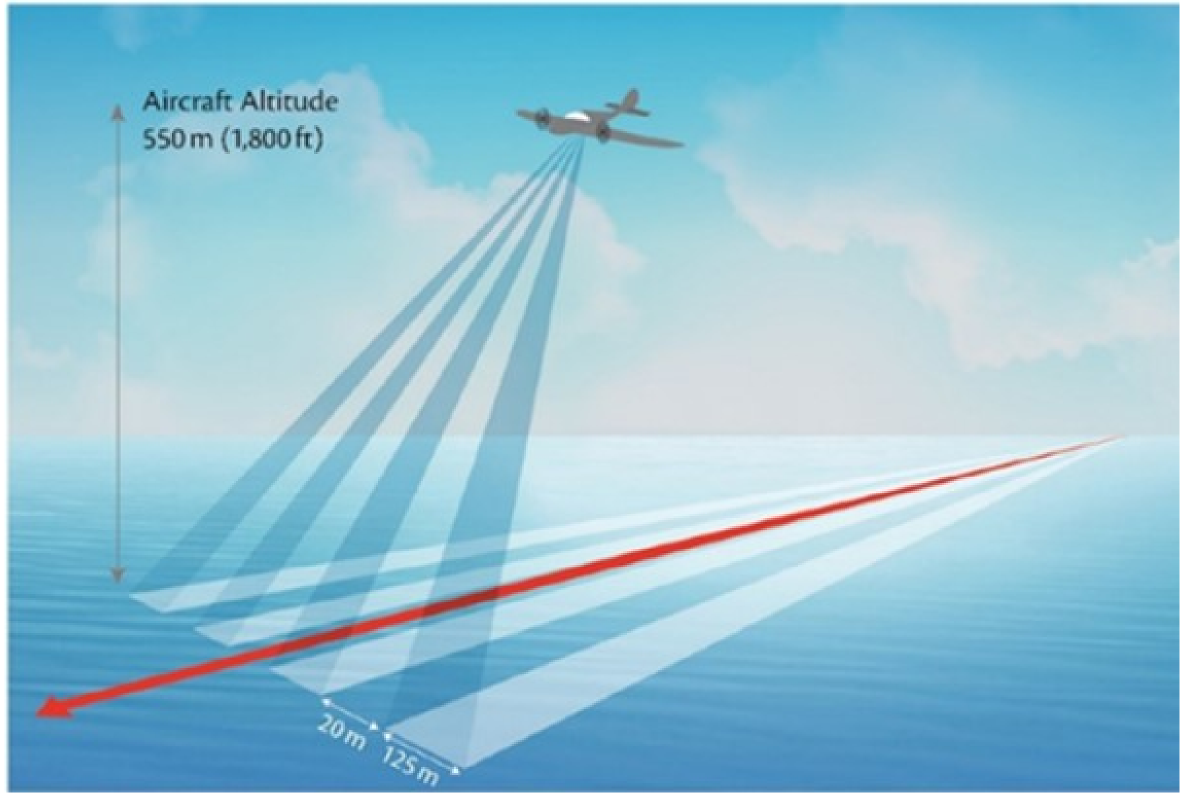


Figure 2.3: Illustration of the survey swathe for HiDef's Gen II camera rig.

Table 2.1: Weather conditions defined for HiDef aerial survey.

Parameter	Minimum acceptable weather
Cloud	Cloud base above survey altitude
Precipitation	Nil
Wind	Less than 30 mph
Sea state	Up to 6 (as per World Meteorological Organisation sea state codes)
Time	Not before 1.5 hours after sunrise Not before 1.5 hours before sunset If east - west transects, no nearer than 1 hour to the Sun's zenith

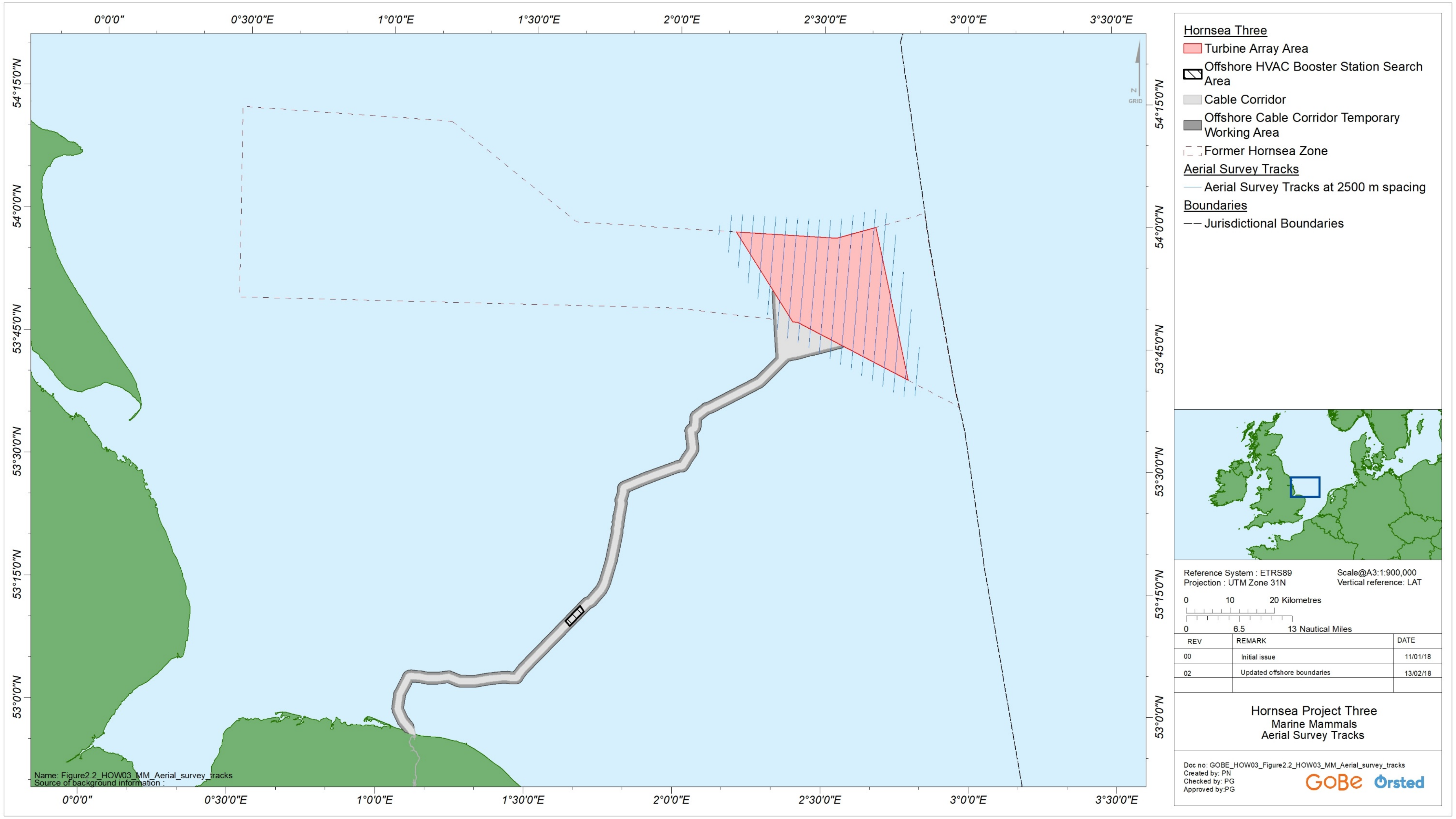


Figure 2.4: Aerial survey tracks across the Hornsea Three array area plus a 4 km buffer.

2.5 Data handling and analyses

2.5.1 Boat-based data

Distance analysis

2.5.1.1 Distance analysis was used as the first stage of analyses for the boat-based data in order to estimate a number of key parameters that were required for the final output: production of smoothed surface density estimates for each species across the former Hornsea Zone plus a 10 km buffer. Visual boat-based data (and acoustic data for harbour porpoise) were imported into the programme Distance (Thomas, 1999; Thomas *et al.,* 2010) and analyses were undertaken to fit detection functions, estimate strip width and where possible, calculate the detection probability for each species.

2.5.1.2 The detection function (g(x)) is a curve fitted to the data that represents the probability of detecting an animal that is at distance 'x' from the trackline. The assumption in fitting this graph is that all animals on the trackline (i.e. at zero distance) are detected, such that g(0)=1. From the detection function graph, the effective strip width (ESW) can also be estimated. This is defined as the point at which as many animals are seen beyond an estimated distance as are missed within this estimated distance. In other words, it is the perpendicular distance from the trackline that has been effectively surveyed. In marine mammal surveys, a fixed transect width is not specified and therefore the detection function graph may be characterised by a small number (or frequency) of detections at large distances from the trackline. This has the effect of right-skewing the graph, making the detection function curve problematic to fit to the data and leading to a statistically poor model fit. In order to overcome the problem of these outliers in distance analysis, data can be truncated, and as a rule of thumb, it is often the case that 5 to 10% of objects detected at larger distances are discarded prior to analyses.

2.5.1.3 A common problem in marine mammal surveys is that for many species g(0) is less than 1, simply because marine mammals spend long periods underwater and therefore even if they occur within the trackline, these animals are unavailable for counting. This is called availability bias. There are also a proportion of sightings that will be missed by observers, this is called perception bias. Therefore, in order to calculate absolute densities, as opposed to relative densities (which are just a reflection of those animals available at the surface to count), a correction factor has to be applied. It is important to achieve a measure of absolute density where possible because it is only this that allows comparison between data collected on different surveys within the same area, or by different teams in different areas. The most common approach for marine mammals is to use a 'double-platform' approach during the boat-based surveys so that capture-mark-recapture methods can be used to estimate the detection probability (g(0)) of animals specific to that survey.

2.5.1.4 As outlined above (paragraph 2.4.2.1), the visual surveys involved a single platform and therefore, in order to calculate g(0) for harbour porpoise, the approach used the visual and acoustic data as a double platform (whereby acoustic and visual data were used as independent observations) (Appendix B). The analysis was based on Mark Recapture Distance Sampling (MRDS) techniques, with each survey method (i.e. visual and acoustic), used to generate a set of trials which could be used to estimate what proportion of these were detected by the other method. The trials were then investigated for duplicate detections allowing for time delays between visual and acoustic detections due to vessel speed, estimated distance ahead of the vessel, and the length of the hydrophone being towed.

2.5.1.5 This information was fed into an equation to estimate detection probability using the method of Buckland *et al.* (1993), where g(0) for method A (where methods are either the visual or acoustic surveys and then vice versa) is given by:

$$g_A(0) = \frac{n_{AB} w_B}{n_B w_{AB}}$$

Where n_{AB} is the number of duplicates detected by both methods, n_B is the number of trials based on detections by method B, w_{AB} is the strip width of the duplicated data and w_B is the strip width of the trial data from method B.

2.5.1.6 Density estimates of harbour porpoise were made from both the visual and acoustic datasets, correcting for g(0) in each case. Variance of the density estimates were calculated using information on the variance in encounter rate, variance in ESW, variance in mean group size and variance in g(0). Variance in the density estimates was expressed as a coefficient of variation (CV) and 95% Confidence Intervals (CI) for both visual and acoustic data. Whilst the analyses focused on density estimates for the former Hornsea Zone plus 10 km to feed into the next stage of analyses (i.e. production of the surface density maps), there were sufficient sightings of harbour porpoise across Hornsea Three marine mammal survey area to generate a specific density estimate in Distance for this area alone. The values of g(0) to correct the densities for Hornsea Three array area plus buffer were however, taken from the whole dataset as this was considered to be a more robust approach.

2.5.1.7 It was not possible to use this 'double platform' approach for other species of cetacean due to the low densities recorded during the surveys and therefore for all other cetaceans, relative (rather than absolute) density estimates were produced. For white-beaked dolphins, detection probability is likely to be relatively high and estimates of densities may be positively biased due to responsive movement towards vessels, although this is overcome during the surveys by every effort being made to detect animals before responsive movement occurs. For minke whales the detection probability is likely to be low and therefore the relative density estimates may be negatively biased. In order to put the relative density estimates into context here, a literature review was undertaken to determine the value of published estimates of detection probability for minke whales and white-beaked dolphins. Whilst it is not necessarily scientifically robust to use published values from other studies in this analysis (as there may be differences in the survey methodology) it does provide a context for understanding how the relative density estimates may translate into absolute density estimates for these species.

2.5.1.8 For grey seals, a different approach to calculating detection probability was employed based on the time that individuals spend on the surface. Unlike harbour seals, grey seals remain on the surface longer between dives and therefore in relative terms, perception bias for a grey seal at the surface will be small. Subsequently, the detection probability for grey seals was based on their availability to be detected between dives. The analyses and resulting detection function is described in full in Appendix E *et seq*.

2.5.1.9 Harbour seal density estimates were not corrected for g(0) as detection probability could not be calculated for this species since there was no published information on availability between dives. The estimated value of g(0) calculated for grey seal was therefore used to put the relative values of density for harbour seal into context.

2.5.1.10 Mean density was calculated for both species of seal, and also a corrected density was calculated over the former Hornsea Zone plus a 10 km buffer. This was based on allocating a proportion of the unidentified seals to each of the grey seal and harbour seal population, based on the relative proportion that each species contributed to the overall number of identified seals present, so that all seal sightings were used to calculate densities.

2.5.1.11 Densities of white-beaked dolphin, minke whale, grey seal and harbour seal could not be generated using distance due to the lower number of sightings across the survey area. Therefore, estimates of mean density for these species were derived from the model-based surface density estimates as described in paragraph 2.5.1.17.

Generalised additive modelling (GAM)

2.5.1.12 Model-based methods provide a standard framework for scaling up from densities obtained from the surveyed line transects to density across a wider study area. Model-based methods are often advantageous where spatially indexed covariates are used and hence a spatial density surface model can be fitted. This approach allows for the fact that animal density may be related to habitat and environmental variables such as wind force and sea state, and thus may potentially increase precision and understanding of factors affecting abundance.

2.5.1.13 GAMs in the mixed GAM computation vehicle (mgcv) package (Wood, 2006) in the statistical computer programme 'R' were run for each species. Detection probability (g(0)) was incorporated as a multiplier (where available for a species) so that the resulting densities were representative of absolute, rather than relative numbers of animals.

2.5.1.14 The realised trackline was divided into small segments (in this case each one minute of effort equivalent to an average trackline of 285 m) and the response variable in the statistical model was the estimated density (number/size of segment) of objects (clusters or individual animals) in each segment. For each segment there were also a number of associated locational and environmental variables (e.g. depth, distance to land etc.). The estimated number of objects in a segment was obtained prior to the density surface modelling from a detection function model (Buckland *et al.,* 2001). The density surface model is then used to predict density of objects over the region of interest; abundance was obtained by integrating under this surface.

2.5.1.15 The GAMs for each species were based on a 'logit link' function. A number of covariates (explanatory variables) recorded during the surveys, were incorporated in order to provide a more robust model accounting for those environmental factors that may explain the observed encounter rate and subsequently help to explain the spatial and temporal patterns in density (Table 2.2). For all species, exploratory models included tidal and topography covariates. All covariates were included as one-dimensional smooths (thin-plate splines) except for latitude and longitude which were two-dimensional. Julian day was a cyclic smooth on the basis that if patterns were seasonal the situation on 1 January should be the same as 31 December. Longitude was transformed by multiplying by cosine (latitude) to give it the same scale as latitude.

2.5.1.16 The surface density model outputs of the GAMs were clipped to the former Hornsea Zone plus a 10 km buffer survey area. This was due to the inherent low confidence in the reliability of the model outputs within the 'extrapolated' areas outside the area surveyed. As the models tended to show high values of densities within these extrapolated areas due to strong features in these areas (e.g. sandbanks) this had the effect of tending to obscure finer detail in the density distributions within the surveyed area and, as such, these data have not been presented. Furthermore, a lack of covariate data in the area to the east of the surveyed area (i.e. in non-UK waters) resulted in a lack of model predictions in this area, providing further support for restricting the presented density surface modelled data to the former Hornsea Zone plus a 10 km buffer.

Table 2.2: Covariates recorded for each 'on-effort' minute segment which were subsequently used in spatial modelling.

Parameter	Source
Latitude/Longitude[a]	GPS
Days from start	GPS (the overall date within the whole study area)
Hour	GPS (the time of the day in integer hours)
Julian day[b]	The day of the year
Tidal time	Relative time within the ~12.5 hour tidal cycle based on tide times at Filey Bay, located south of Scarborough. Calculated from tide table data (UK Hydrographic Office).
Tidal phase	Time within the ~29.5 day lunar cycle calculated from lunar intervals
Tidal range/height	Tide table data
Depth/aspect/slope	Gridded Bathymetry from Seazone Marine Digimap 6 arc second (approximately 180 m) cell size
Bottom sediment type	Geology, Seazone, Marine Digimap
Sea bottom type	Marine Landscape, Seazone, Marine Digimap
Sea state	Recorded by visual observers
Swell height	Recorded by visual observers

a Longitude was adjusted so that units represent the same physical distance as that for latitude.
b Cyclic smooth in the GAM model.

2.5.1.17 For all species, the GAM was run using all data pooled for the surveys across the former Hornsea Zone plus a 10 km buffer. It was not possible to run GAMs using just data within the Hornsea Three array area plus a 4 km buffer due to the lower number of sightings over this area (due to lower effort). Therefore, the mean density of harbour porpoise for Hornsea Three array area plus a 4 km buffer was taken from the Distance analysis (paragraph 2.5.1.6). To estimate densities of minke whale, white-beaked dolphin, grey seal and harbour seal within Hornsea Three array area plus a 4 km buffer, this area was 'cut-out' from the surface density maps of the whole former Hornsea Zone plus a 10 km buffer, and the densities within the cells that fell within the 'cut-out' area were averaged for each species.

Seasonal Variation

2.5.1.18 Some species, such as white-beaked dolphin and minke whale are known to have strong seasonal patterns in their abundance in the southern North Sea. Harbour and grey seal would also be expected to show some seasonal patterns in offshore abundance because of periods of moulting or pupping, when a proportion of the population becomes largely land-based. Investigating the seasonal patterns in density was therefore an important aspect of the GAM analyses.

2.5.1.19 In addition to seasonal variation there is the possibility of longer term trends in numbers, or fluctuations or trends within the three years of field survey data collected. Models were fitted with either 'Julian day' or 'days from start' of the survey. Model fitting with Julian day forces each data point into a particular day of the year from day one (1 January) and is useful in identifying seasonal patterns at particular times of year. Model fitting with days from start is more flexible and free-fitting, allowing fluctuations over the year and more general trends to become apparent. If days from start showed a monotonic trend then this was included in a model with Julian day to allow for an overall trend and seasonal variation.

Effect of Sea State

2.5.1.20 Surveys were conducted in different sea states across the survey period. This has an effect on the detectability of marine mammals and therefore was included as a covariate in the GAM models for each species. Harbour porpoise, in particular, are small and difficult to see, and there are very large differences in raw sightings rates with sea state. For example the raw sightings rate in sea states 3 and 4 is less than 5% of that in sea state 0. Accurate recording of sea state is very difficult and subjective. In order to demonstrate the effect of sea state on sightings, the relative sighting rate with increasing sea state was plotted for harbour porpoise. Relative sighting rate was calculated by dividing the total sightings for each sea state with the total sightings in sea state '0' to give a proportional value.

2.5.1.21 Sea state affects the way in which the detection probability for porpoise changes with distance (the detection function) and also the overall detection probability for animals directly on the trackline, g(0). The combination of both these factors will affect the overall probability of detection and therefore must be accounted for in density estimation. In order to explore this, the Distance and GAM analyses were repeated to produce detection functions for harbour porpoise and calculate ESW, g(0) and density, this time stratifying by sea state.

2.5.1.22 The use of combined visual and acoustic methods allowed estimates of detection probability to be calculated (Appendix B). Stratifying estimates by sea state allows a useful validation of internal consistency of the dataset (i.e. if the density predictions for each sea state are each similar to the overall modelled density estimate with sea state included as an environmental variable, then the model would be considered to be robust).

2.5.1.23 Most importantly, obtaining absolute estimates allows comparison of estimates between different studies. Comparing raw sighting rates between studies is problematic due to different interpretations of sea states and potential differences in sighting efficiency between different platforms and observation teams.

2.5.2 Aerial data

Data review and identification

2.5.2.1 The HiDef digital video data were reviewed by trained, experienced reviewers using high resolution viewing screens and an image management software package that allows the reviewer to adjust and control the appearance of the images to allow identification of the object. The reviewers mark each object to record location as an image requiring further analysis and a quality assurance (QA) system is then undertaken to sample a minimum 20% of the material. If agreement is <90% a second review of the images will take place, and training initiated as required.

2.5.2.2 The second stage of the process was species identification. The tagged objects were passed to a team of experienced marine surveyors, who had both field survey experience and were trained in identification using high definition video imagery. Surveyors identified to species level where possible, and where necessary, support was sought from external marine mammal experts. The presence of other features (such as fixed structures, fishing vessels, dredgers, construction vessels, ferries, yachts or recreational vessels, etc.) was also recorded.

2.5.2.3 For marine mammals, surveyors assigned the following classifications to the image:

- 'Surfacing at red line' - the dorsal fin (cetaceans) or head (pinnipeds) was above the water surface in the middle frame of the video sequence;
- 'Surfacing' - part of the animal appeared above the surface in any of the frames, but not the dorsal fin or head in the middle frame of the sequence; or
- 'Submerged' - no part of the animal appeared above the surface in any of the frames.

2.5.2.4 A qualitative measurement of the confidence in the identification was also provided as follows:

- 'Definite' – as certain as is reasonably possible;
- 'Probable' – very likely to be this species or species group; or
- 'Possible' – more likely to be this species or species group than anything else.

2.5.2.5 In the majority of cases for harbour porpoise (80.5%) the confidence in the identification was high, with most classed as 'probable', (Table 2.3). Only a small percentage of the harbour porpoise sightings were classed as 'possible' (8.9%) or 'definite' (10.6%). Since it was not possible to identify the factors causing this variability, all detections identified as porpoise were treated as definite.

2.5.2.6 10 % of the aerial survey footage was analysed – this is standard practice for digital video aerial survey methodology in the UK and was considered sufficient to characterise the baseline given the numbers of harbour porpoises observed and was agreed by the EWG on the 13th April 2016. The numbers of other species detected were considered insufficient to yield enough data for meaningful analyses.

Table 2.3: Number of identifications of each species sighted by level of confidence. Def = Definite, Prob = Probable, Poss = Possible.

	Harbour Porpoise			White-Beaked Dolphin			Grey Seal			Harbour Seal			Minke Whale		
Survey Month	Def	Prob	Poss	Def	Prob	Poss	Def	Prob	Poss	Def	Prob	Poss	Def	Prob	Poss
Apr-16	3	45	0	0	0	0	0	0	0	0	0	0	0	0	0
May-16	19	167	0	0	0	0	0	1	0	0	0	0	0	0	0
Jun-16	31	109	0	0	0	0	0	1	0	0	0	0	0	1	0
Jul-16	0	80	7	0	0	0	0	0	0	0	0	0	0	0	0
Aug-16	5	54	6	0	0	0	0	0	0	0	0	0	0	0	0
Sep-16	28	9	3	0	0	0	0	0	0	0	0	0	0	0	0
Oct-16	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
Nov-16	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Dec-16	2	6	1	0	0	0	0	0	0	0	0	0	0	0	0
Jan-17	1	12	1	0	0	0	0	0	0	0	0	0	0	0	0
Feb-17	0	34	2	0	0	0	0	0	0	0	0	0	0	0	0
Mar-17	0	1	68	0	0	0	0	1	1	0	1	0	0	0	0
Apr-17	0	23	1	0	0	0	0	2	0	0	0	0	0	0	0
May-17	0	110	5	0	0	0	0	0	1	0	0	1	0	0	0
Jun-17	0	27	0	0	0	0	0	0	0	0	0	0	0	0	0
Jul-17	3	16	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug-17	0	72	0	0	1	0	0	1	0	0	0	0	0	0	0
Sep-17	19	99	2	0	0	0	0	0	0	0	0	0	0	0	0
Oct-17	0	10	2	0	0	0	0	0	0	0	0	0	0	0	0
Nov-17	6	9	0	0	4	0	0	0	0	0	0	0	0	0	0
Total	*117*	*890*	*98*	*0*	*5*	*0*	*0*	*6*	*2*	*0*	*1*	*1*	*0*	*1*	*0*
Total	*1,105*			*5*			*8*			*2*			*1*		

2.5.2.7 As before, the QA process required a randomly selected sample of at least 20% of material to be identified independently by a separate group of experts and this required that there was no more than 10% disagreement with the first identification of marine mammals (and birds). The output of these results were then compared and any discrepancies reviewed by a further set of experts. In the case of any significant discrepancies (i.e. more than 10% disagreement for the whole audit), then the images were re-reviewed by a third expert who acted as an adjudicator in the process to make a decision on the correct observations.

2.5.2.8 In addition to species identification, for each 250 m segment of trackline flown, a number of environmental parameters were assigned *post hoc* (Table 2.2).

Correction factors

2.5.2.9 During aerial surveys, animals are available for detection if they are at the surface or sufficiently shallow to enable detection. To calculate absolute density or abundance, a correction factor (based on the proportion of time that animals are breaking the surface or the proportion of time that animals are visible underwater) would need to be applied to the relative density/abundance estimates. In order to generate a survey specific correction factor for detection probability, either a measure of the visible depth of the water column would be required for each survey, or a double observer trial would be required in order to collect data suitable for applying a mark-recapture method (Borchers *et al.,* 1998). Robust methodology for these have not yet been developed for digital video aerial surveys.

2.5.2.10 The potential for deriving an appropriate correction factor was explored and subsequently discussed and agreed with the Marine Mammal EWG on the 28th March 2017.

2.5.2.11 The recommended approach for deriving detection probability for line transect surveys is by way of applying a mark-recapture method (Borchers *et al.,* 1998) however, as mentioned above, this was not possible for the digital video aerial surveys. Another approach that has been applied to digital survey studies in the past, including other offshore wind farm surveys was therefore considered and discussed with the Marine Mammal EWG. This approach considers the proportion of time that harbour porpoises are estimated to spend at or near the surface derived from telemetry studies of the diving behaviour of harbour porpoise. Typically, porpoise diving behaviour involves a deep extended dive (the "dive section") lasting a minute or so, followed by a "breathing section", during which a series of short dives of 5 to 20 seconds are interspersed by brief surfacing events during which a single breath is taken. Porpoise do not dive deep during the breathing section of their dive cycle and thus may be visible from the air at these times if water visibility is adequate. There is evidence from telemetry data that porpoise remain close to the surface except when on a deep dive, when porpoise descend or ascend relatively quickly (Teilman *et al.,* 2013; Westgate *et al.,* 1995). Hence there may be a small proportion of the time when an animal is close to the surface and a proportion of time when porpoise descend and ascend rapidly at the start and end of their long dives. If descent/ascent time is ignored then the probability of detection G (which is essentially equivalent to g(0) for a Distance sampling survey) can be expressed as:

$$G = S_D P_D$$

Where S_D is the proportion of time spent closer to the surface than depth D and P_D is the probability of detection for an animal at a shallower depth than D.

2.5.2.12 The extent to which harbour porpoise are visible during the surfacing times will depend on the depth of the short dives as well as factors such a turbidity and lighting conditions. If it is assumed that all animals closer to the surface than depth *D* are detected regardless of light conditions, sea state or turbidity then $P_D = 1$. There is currently no published information on P_D but an examination of a small sample of recently collected DTag telemetry data showed that harbour porpoise remain within 1 m of the surface on a high proportion of short dives (Figure 2.5).

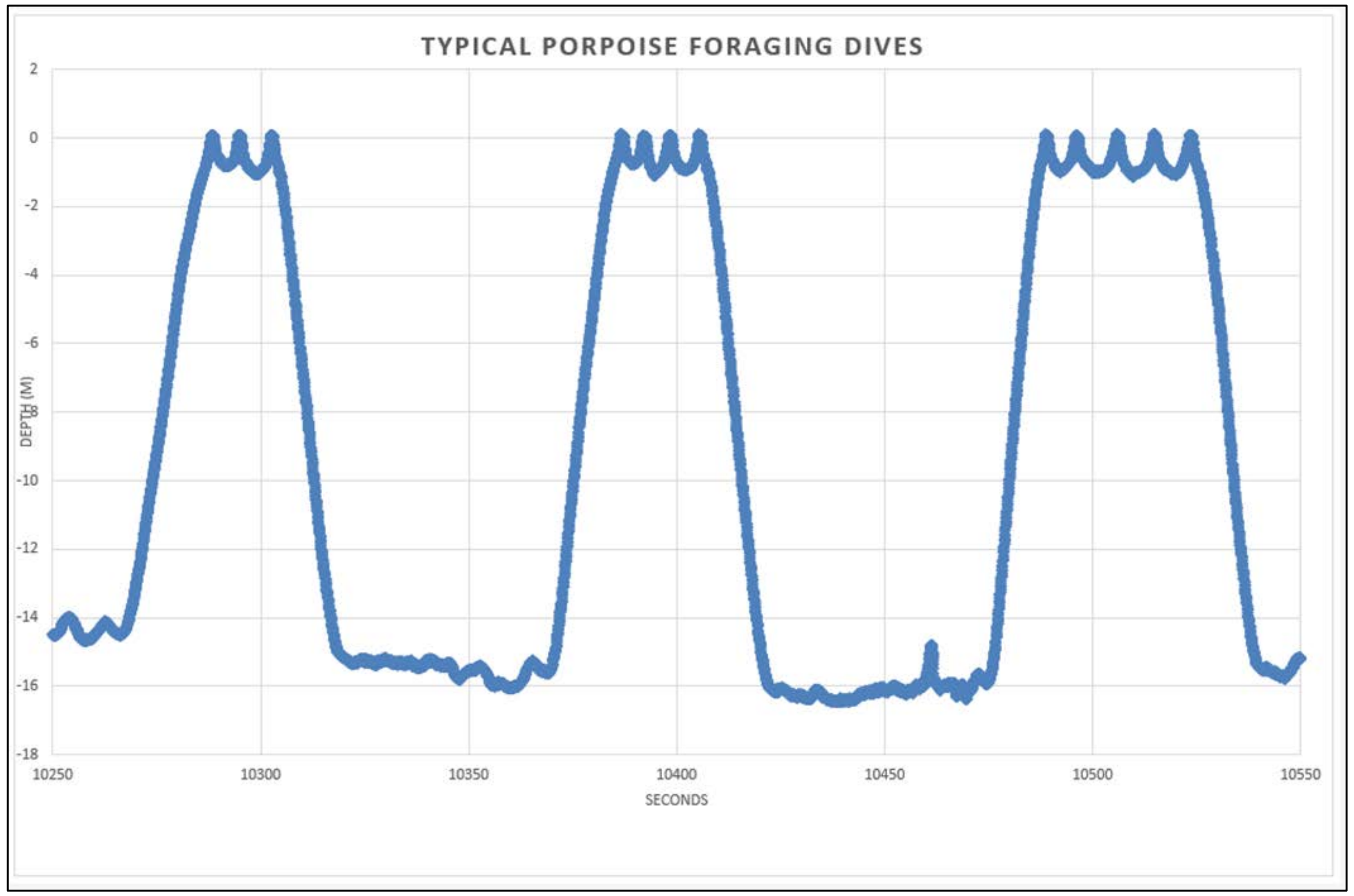


Figure 2.5: Typical dive profile for harbour porpoise tagged in inner Danish waters believed to be foraging. Short sequence of detailed telemetry data from dTag provided by Mark Johnson, SMRU.

2.5.2.13 Assuming $P_D = 1$, it was then possible to look at correction factors based on the duration of time that harbour porpoise spend at or near the surface from existing telemetry data as a means of converting relative density and abundance to absolute density and abundance. Table 2.4 summarises a number of available correction factors from various studies. Whilst none use data collected from the former Hornsea Zone, there were data available from the Baltic/North Sea (Teilman *et al.,* 2013). Notably, in this study Teilman *et al.* (2013) found no significant difference in diving behaviour between geographic areas or in relation to the size of the animals, although there was a significant seasonal difference in diving behaviour with April showing the highest values of time at 0-2 m (61.5%) and February with the lowest values of time at the 0-2 m (42.5%). It was hypothesised that this may be due to the lower temperatures in autumn and winter which would require additional foraging time in order to maintain the thickness of the insulating blubber layer. In summer, the thickness of this layer can be reduced and therefore porpoise do not need to spend excess time foraging.

Table 2.4: Correction factors derived from published studies of harbour porpoise.

Reference	Area	Min S_2	Mean S_2	Max S_2	Description
Westgate *et al.* (1995)	Bay of Fundy, Canada	0.33	0.43	0.60	Mean and maximum dive depth and duration recorded for 7 tagged porpoise over ~106 hours using time-depth recorders.
Teilmann *et al.* (2007)	Kattegat, Skagerrak and Belt Seas (Denmark)	0.45	0.55	0.63	Number of dives per hour, dive duration, surface time of 14 satellite-tagged porpoise during April to August.
Teilmann *et al.* (2013)	Baltic and North Sea	0.43	0.50	0.55	35 porpoise tagged over 25-349 days using Argos satellite transmitters to estimate surfacing and diving durations over a 1 year period.

2.5.2.14 Based on the data presented above, it is considered an appropriate approach to use the Teilmann *et al.* (2013) study of harbour porpoise in the Baltic and North Sea as the basis for deriving a correction factor to apply to the Hornsea Three aerial data. Although it is recognised that this is not a survey specific value for detection probability, the results from various telemetry studies suggest that surfacing and diving behaviour do not appear to differ vastly on a geographic scale (e.g. mean values of S_2 presented in Table 2.4 are 0.43, 0.50 and 0.55). Instead, these studies suggest that variation in diving behaviour is more likely to occur seasonally (paragraph 2.5.1.17) and, to a lesser extent, diurnally (Teilman *et al.,* 2013; Teilman *et al.,* 2007; Westgate *et al.,* 1995). Therefore, applying the correction factor at the lower end of the scale ($S_2 = 0.425$), which is based on the winter months when surfacing time was found to be lower (Teilman *et al.,* 2013), would be considered to generate a more precautionary estimate of absolute abundance. The application of the correction factor from Teilmann *et al.* (2013) was discussed and agreed with the Marine Mammal EWG (meeting dated 28 March 2017).

2.5.2.15 It is important to note the limitations and assumptions behind this approach. This correction factor approach assumes that the HiDef images can detect all harbour porpoise within the top 2 meters of the water column. However, this assumption remains untested at the survey site and in differing environmental conditions. As discussed further in section 2.6.6, unvalidated assumptions such as these can result in large biases in the resulting density estimates.

2.6 Assumptions and limitations

2.6.1 Survey design

Boat-based data

2.6.1.1 The design of the boat-based survey was primarily to record bird sightings, with marine mammals to be recorded if also observed As the surveys were not dedicated marine mammal surveys, this may lead to the possibility of animals being missed, although it is not possible to quantify this.

2.6.1.2 Most line transect surveys for cetaceans observe on both sides and ahead of the vessel, whereas most bird surveys just observe on one side. As discussed in paragraph 2.4.2.4, the transects for the former Hornsea Zone were surveyed from a single platform located on one side of the survey vessel (i.e. in a 90° arc). For mobile species this can lead to a tendency to include incidental sightings of animals from the non-surveyed side of the line which exaggerates counts near the line; the effect that this has on the detection function curve may lead to an error in density estimates, partly because the encounter rate is inflated, but primarily because detection probability is not accurately estimated. The size of this effect will depend on swim speed of the animals relative to survey speed, the probability of detecting any surfacing event, and the diving pattern of the animals. Simulations were conducted to investigate this for harbour porpoise and indicated biases would be around 10% for typical swim speeds and dive times (Appendix C). This potential bias in the data could not be corrected for, and is a limitation of this data set.

Aerial data

2.6.1.3 The camera resolution was specified to capture images of seabirds and therefore was a higher resolution than required for marine mammals. Whilst this was useful for increasing the accuracy of identification of marine mammals, the drawback was that it reduced the length of time that points were available on the trackline and therefore only captured a small proportion of the short "breathing" dive sequence for harbour porpoise.

2.6.2 Survey restrictions

Boat-based data

2.6.2.1 For the majority of the survey period the boat-based visual surveys were achieved in sea states of less than 3. Any data collected from sea states above 3 were excluded from data analysis, following published guidelines (Camphuysen *et al.,* 2004).

2.6.2.2 For the first six months of survey, the hydrophone was deployed continuously throughout the survey area. After this period, towed hydrophone surveys were conducted only to the north of latitude 53° 50' N due to concerns raised by local fishermen that the hydrophone was interfering with fishing gear. This necessitated routine deployment and retrieval on some transect lines and a powered winch was fitted to allow this to occur without having to slow the vessel.

2.6.2.3 Missing survey segments could have an effect on the variance in the model predictions. The main issue would be if the areas not sampled represented a different range of predictor variables to those sampled over the rest of the site. For example, the area not surveyed could be a different depth, sediment type, slope etc., than the rest of the area that was surveyed. It is important to sample the full range of environmental variables as it is these environmental predictors that enable the GAM to estimate densities of animals in areas not sampled. If, hypothetically, deeper areas are not sampled then there would be gaps in the information on what the encounter rate is likely to be in any deeper waters and therefore the model would not be able to accurately predict the occurrence of marine mammals in missing areas. Nonetheless, the environmental predictors in this area to the south of latitude 53° 50' N (e.g. water depth, slope, sediment type) are not considered to be characteristically different to those which are present across the rest of the area surveyed. Furthermore, these areas to the south of latitude 53° 50' N were sampled using the data collated during the first six months and since all the data were pooled over the three years then this does not represent a gap in the data, only an area of lower survey effort.

Aerial data

2.6.2.4 Unlike the boat-based surveys, aerial surveys can be carried out in sea states of up to 6. The effect of sea state on detection probability of marine mammals has not been as well-explored for aerial surveys as it has for boat based surveys. The sea state recorded for all aerial surveys undertaken was 6 or less. The effect of sea state was investigated for the aerial data by dividing the effort and sightings by sea state and producing a sea-state specific sightings rate. The data showed higher mean sightings rates of porpoise across all surveys in sea state 2 (0.21 porpoise/km) compared to sea state 5 or 6 (0.054 and 0.023 porpoise/km). This means that harbour porpoise sightings rates were 9.13 times higher at sea state 2 compared to sea state 6, although this comparison is hampered by a low sample size in sea states 2 or below. Only 15.6% of the total effort was conducted at sea state 2 or below. Most survey effort was conducted in sea state 3 or 4 (71.8%), with very little in these higher sea states with reduced sightings rates. HiDef report that the detection probability of marine mammals does not vary within this level of variation in seastate however robust analyses have not been carried out to demonstrate this. There is a possibility of uncorrected biases in the aerial survey density estimates as a result of varying detection probabilities related to sea state.

2.6.3 Survey timings

Boat-based data

2.6.3.1 The boat-based data were collected on a monthly basis between March 2010 and February 2013 and therefore these data are now four years old. Since this time there may be changes in the distribution and abundance of marine mammals across the former Hornsea Zone plus 10 km.

Aerial data

2.6.3.2 The aerial data analysed are from 20 months of surveys since April 2016. Aerial data represents a snapshot over a large area over a single survey day (whereas the boat-based surveys take several days to cover an equivalent area). It was therefore not possible to explore any effects that environmental conditions may have on sightings rate within a given survey day, and effects had to, instead, be explored across survey months, when changes in sightings rate and distribution may be also influenced by season.

2.6.4 Species identification

Boat-based data

2.6.4.1 During the boat-based surveys it was not always possible to identify individuals to species level and therefore when species identification was not possible, these individuals were broadly categorised as whales, dolphins or pinnipeds. For cetaceans, since only a small number of individuals were unidentified to species level these were removed from the analyses as their inclusion would not substantially affect the error estimates. For pinnipeds, a larger proportion of individuals were unidentified to species-level compared with cetaceans and therefore the unidentified seals were allocated to each species (grey and harbour seal), based on the relative proportion that each species contributed to the overall number of identified seals present. In this way, all seal sightings were used in the data analyses.

Aerial data

2.6.4.2 The identification of harbour porpoise sightings was allocated a confidence level of 'definite', 'probable' or 'possible' (Table 2.3), however, for the purposes of analyses all identifications were treated as definite. Although it is recognised that this could lead to over- or underestimates of the counts of a given species, a third party review of the video files by MER demonstrated that for both probable and possible confidence levels, there was a high degree of certainty that animals were being identified to the correct species level.

2.6.5 Data measurement and recording

Boat-based data

2.6.5.1 One of the key assumptions which is important to achieving reliable estimates of density is that measurements are accurate (i.e. distance, angle and cluster size). However, distance at sea is difficult to estimate and any bias in distance estimates (i.e. using a rangefinder) will be reflected in a proportional bias in abundance. Measuring errors in distance estimation to animals during surveys is difficult but was achieved on the SCANS-II and -III surveys. During these surveys there was no significant relationship between estimated and measured distances for distances estimated by the naked eye within 500 m (Leaper *et al.,* 2011). Estimation of angles is also difficult and prone to error. These results indicate that strip widths based on naked eye estimates of distance are likely to have a high degree of uncertainty and potential for bias. There are also likely to be uncertainties in relation to the estimated perpendicular distances from the acoustic data but it is not possible to quantify.

2.6.5.2 Another key assumption for achieving reliable estimates of density is that individuals are detected at their initial locations and that there is no responsive movement to the presence of the vessel. If evasive movement occurs prior to detection, as has been suggested may occur for harbour porpoise (e.g. Sveegaard *et al.,* 2013), the results of the estimate of density will be biased low. If, however, animals move towards the observer prior to being detected a positive bias in estimated density can be expected.

2.6.5.3 Interpretation of seasonal and spatial patterns in density relies on allowing for covariates which affect the detection probability for both visual and acoustic data. In the case of visual surveys, for all species, sea state was determined from GAMs to have a large impact on detection probability, with an order of magnitude difference for harbour porpoise between sea states 0 and 1 and sea states 2 to 4. However, as there was relatively little effort in sea states 0 and 1, this could have large implications for the results if the model did not accurately account for the effects of covariates. Less is understood about the factors affecting the detection probability of the acoustic dataset.

Aerial data

2.6.5.4 One of the strengths of the aerial video data is that it provides a very precise measure of survey effort: a known area of sea is sampled for a known period of time and within this time and space it is reasonable to assume that all cetaceans at the surface will have been seen, although as mentioned above, the effect of sea state on the detectability of marine mammals during aerial surveys has not been well explored to date.

2.6.6 Bias and uncertainty in g(0) estimation

Boat-based data

2.6.6.1 The method of estimation of g(0) for harbour porpoise relies on the ability to reliably match duplicate detections between the visual and acoustic data. The potential sources of error in the estimated time of an animal coming into the detection range of the hydrophone include; errors in sighting time, estimation of distances and angles, and animal movement. In this study recording followed current standards including timing recorded to the minute, therefore there will be some timing errors and associated uncertainty in g(0). However, the effect of such timing errors were minimised as far as possible; to minimise the occurrence of false positives, trials were only considered on occasions when no detections were made by the trial method for three minutes either side of the trial detection.

2.6.6.2 In addition to this, there are potential uncertainties relating to the analysis of the acoustic data and uncertainty as to assumptions made during the analysis may have affected the resulting density estimates. For example, cluster size was used as a multiplier to estimate the number of animals detected. The cluster size used to correct the acoustic data was obtained from the mean number of visual detections within a one minute segment for sightings in sea state 0. However, only 0.9% of the survey effort was conducted at sea state 0 resulting in a small dataset which was not sufficient to obtain a g(0) estimate (see Table B.1 in Appendix B). In addition, the unusually high detection ranges recorded (~1000 m) may indicate potential inaccuracies in the click detector and localiser, introducing uncertainty into the g(0) calculations.

Aerial data

2.6.6.3 Two of the key biases in distance sampling are perception and availability bias. Perception bias is when animals are available to be detected but are missed by the observer, and availability bias is when animals are unavailable for detection. In digital aerial surveys there is no perception bias because all animals within the surveyed area that are at the surface should be detected in the video/images. However, availability remains an issue for digital aerial surveys for marine mammals.

2.6.6.4 In recent years there have been attempts to obtain absolute density estimates for marine mammals from digital aerial surveys through the use of correction factors (e.g., aerial digital still surveys (e.g. Voet *et al.,* 2017). This correction factor is based on the assumption that the digital still images provide full visibility of the top 2 m of the water column and 100% detection. Availability bias is then corrected (based on animal-borne telemetry data from Teilmann *et al.* (2007) and Teilmann *et al.* (2013) for the proportion of time that harbour porpoise spend below 2 m water depth and that are not available for detection. The assumption of 100% detection in the top 2 m of the water column is fundamental to the accuracy of the density estimates generated, however there is no evidence to support the assumption that the depth visible is consistently 2 m. Specifically, Teilmann *et al.* (2013) states that "*during aerial surveys they may be seen down to 2 m below the surface*" and that "*The water clarity may change between areas and seasons due to algae blooms, but aircraft observations made during summer in the study area indicate that porpoises can be seen down to a depth of approximately 2 m (Heide-Jørgensen* et al.*, 1993, Teilmann* et al.*, 2007)*". The blanket adoption of a correction factor based on the proportion of time porpoise spend in the top 2 m is reliant on excellent water clarity in the top 2 m of water. While these data represent a step forward in correcting survey biases in aerial survey data, we would expect that the visible depth varies between surveys and therefore there may be some uncertainty associated with the application of a correction factor.

2.6.6.5 A recent study validating the assumptions of availability bias during aerial surveys for dugongs in Australia resulted in a 5-6 factor increase in the resulting population estimate (Marsh *et al.,* 2017). The original population estimate was negatively biased as the distance analysis had not accounted for variations in detectability with varying conditions (such as bathymetry). Marsh *et al.* 2017, were able to validate their assumptions on availability bias, by conducting physical experiments of visibility and could therefore quantify the amount of time that dugongs were available to be sighted (Hagihara *et al.,* 2016, Marsh *et al.,* 2017). Their physical experiments and telemetry data showed that dugongs in the specific survey area spent more time out of the sight of aerial observers than had previously been assumed.

2.6.6.6 While site and survey specific visible water depth recordings are not available, a study by Capuzzo et al. (2015) has shown that mean secchi depth estimates (measures of the vertical visibility of the water column) collected post 1950 for the "intermediate zone" of the central and southern North Sea (within which Hornsea Three is located) range between 3.6 m in the winter and 5 m in the summer. If this is representative of the water visibility during the aerial surveys then the assumption of only 2 m visibility would lead to an overestimate of porpoise density, indicating that the aerial survey density would be precautionary.

2.6.6.7 Because the assumptions surrounding correction factors for availability bias cannot be directly validated, it is recommended that these density estimates are viewed with some uncertainty.

2.6.7 Summary

2.6.7.1 The assumptions and limitations highlighted above are typical of difficulties encountered with undertaking field surveys of marine mammals using aerial and boat-based methods. The approaches used were largely based on tried and tested methodologies, and where adaptations had to be made e.g. the use of acoustic and visual data as a double platform, these have been discussed and agreed with the SNCBs. Boat-based data provided a double platform, continuous survey, over a period of months, and allowed for a survey specific detection function, g(0), to be calculated for harbour porpoise. However, limitations of boat-based surveys include sea state, length of time since surveys were carried out, natural difficulties in estimating distance of sighting from observer, accurate matching of acoustic and visual detections and potential for presence of survey vessel to affect behaviour of animals and therefore likelihood of detection. Aerial surveys provided a more contemporary snap shot, on a monthly basis for a period of 17 months, surveys could be carried out in up to sea state six, distance to animal was consistent and there is no detectable impact of survey plane on animals. Limitations of the aerial survey included reduced species identification and uncertainties in relation to the proportion of animals available to be detected during surveys. No marine mammal survey is without its limitations but by the inclusion of a range of estimates, from a range of methods, the characterisation of the baseline as robust as it can possibly be.

3. Results

3.1 Designations and legislation

3.1.1.1 Cetaceans and pinnipeds are protected under National, European, and International legislation (Table 3.3), and as the five focus marine mammal species are highly mobile and range throughout the Greater Wash area and beyond, all levels of legislation in relation to marine mammals must be considered.

3.1.2 Legislation

National Legislation

3.1.2.1 The UK transposes "the Conservation of European Wildlife and Natural Habitats" (the Bern Convention) into National law through the Wildlife and Countryside Act 1981 (as amended in Scotland and England). It is an offence under this act, to intentionally kill, injure or take any wild animal listed on Schedule V of this Act. This includes all cetaceans, marine turtles and basking sharks. It also provides protection for these species' places of shelter and specifically prohibits damage or disturbance to these places of shelter as well as disturbing animals whilst they are in these places of shelter. Sites of Special Scientific Interest (SSSIs) are also designated under the Wildlife and Countryside Act 1981.

3.1.2.2 Specific to seals, England and Wales also have the Conservation of Seals Act 1970, which protects seals in England and Wales (and adjacent territorial waters) by providing annual closed seasons for both grey and harbour seals. During the closed seasons, it is an offence to take or kill and seal except under licence.

European Legislation

3.1.2.3 The Conservation of Species and Habitats Directive (Habitats Directive) provides for protection of animals and plants throughout EU member states through both the designation/classification of European Sites as well as the protection of European Protected Species.

3.1.2.4 The Habitats Directive is transposed into UK law through the Conservation (Natural Habitats, &c.) Regulations 1994 (as amended 2007). In England and Wales, the 1994 Regulations have been superseded by the 2017 consolidation regulations: Conservation of Habitats and Species Regulations 2017. These Regulations extend to 12 NM offshore.

3.1.2.5 In the UK waters beyond 12 NM, the Habitats Directive is transposed into law through the Offshore Marine Conservation (Natural Habitats &c.) Regulations 2007.

3.1.2.6 All of the above UK Regulations allow for the designation or classification of European Sites as specified under the Habitats Directive including SACs, Special Protection Areas (SPAs), and Ramsar sites.

3.1.3 Designated sites

3.1.3.1 There are a number of sites in proximity to Hornsea Three that list marine mammals as a notified interest feature. Table 3.1 and Figure 3.1 summarise these sites, with further detail provided in the following section.

European Sites - Natura 2000

3.1.3.2 Of the focus species listed, harbour porpoise, harbour seal and grey seal require the UK government to consider designation of SACs. Taking into account the wide ranging nature of the species involved, the location of the SACs/Sites of Community Importance (SCIs)/preliminary SCIs (pSCIs), and the location of Hornsea Three, Table 3.1 below provides a summary of the European Sites considered relevant to the project.

Table 3.1: European sites (Natura 2000) with marine mammal notified interest features.

Special Area of Conservation (SAC)	Relevant Notified Interest Feature(s)	Distance from Hornsea Three from the nearest point (km)
Southern North Sea candidate SAC (UK)	Harbour porpoise	0 (within Hornsea Three offshore cable corridor)
The Wash and North Norfolk Coast SAC (UK)	Harbour seal (primary reason for site selection)	0 (within Hornsea Three offshore cable corridor)
Klaverbank pSCI (Dutch)	Grey seal; harbour seal; harbour porpoise	11 (Hornsea Three array area)
Dogger Bank SCI (Dutch)	Grey seal; harbour seal; harbour porpoise	42 (Hornsea Three array area)
Humber Estuary SAC (UK)	Grey seal	74 (Hornsea Three offshore cable corridor)
Noordzeekustzone II SCI (Dutch)	Grey seal; harbour seal; harbour porpoise	138 (Hornsea Three array area)
Wadenzee SCI (Dutch)	Grey seal; harbour seal	146 (Hornsea Three array area)
Noordzeekustzone SAC (Dutch)	Grey seal; harbour seal; harbour porpoise	148 (Hornsea Three array area)
Dogger Bank SCI (German)	Harbour seal	183 (Hornsea Three array area)
Berwickshire and North Northumberland Coast SAC	Grey seal (primary reason for site selection)	286 (Hornsea Three array area)

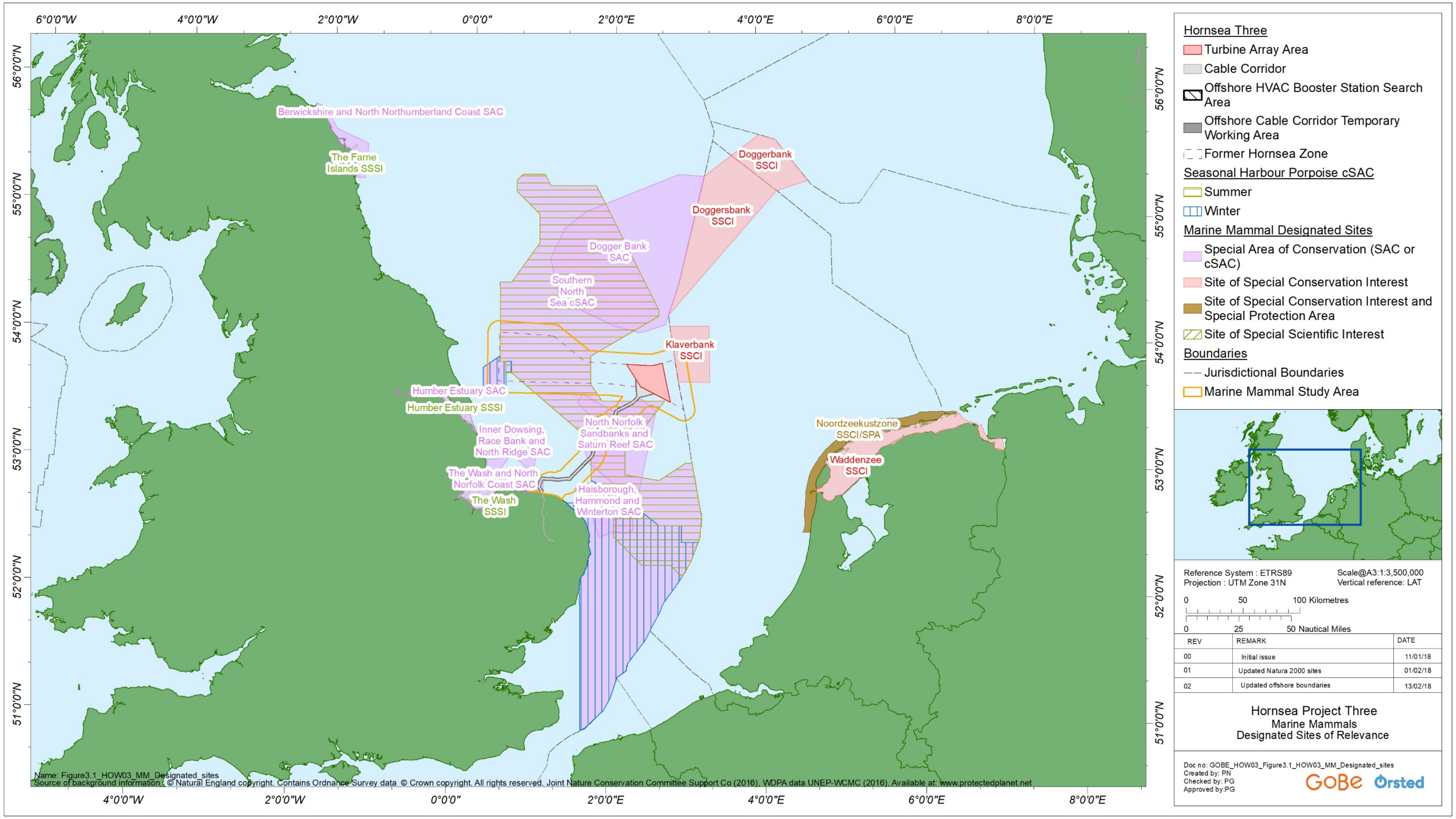


Figure 3.1: Designated sites in proximity to Hornsea Three.

3.1.3.3 The Habitats Directive (Article 6(3)) and the Habitats Regulations require that, where a plan or project that is not directly connected with or necessary for the management of a Natura site, but which is likely to have a significant effect on the site, either individually or in combination with other plans or projects, will require an appropriate assessment of the impact of that plan or project on the qualifying interests of the Natura site. An assessment of the potential impacts of Hornsea Three on the qualifying interests of relevant SACs has therefore been undertaken and is presented in the Hornsea Three "Report to inform Appropriate Assessment".

Berwickshire and North Northumberland Coast SAC

3.1.3.4 The Berwickshire and North Northumberland Coast SAC, stretches 115 km along the southern Scottish and northern English coastlines from Alnmouth in Northumberland to Fast Castle Head in Berwickshire. It encompasses an area of 635 km^2 of coastal and marine habitat. Grey seal is a primary reason for site selection (English Nature and Scottish Natural Heritage, 2000).

3.1.3.5 Grey seal breeding colonies within the Berwickshire and North Northumberland Coast SAC are among the largest in the UK, producing around 2.5% of grey seal pups born each year. Within the SAC there are two major grey seal breeding groups - the Farne Islands and the mainland coast at Fast Castle.

3.1.3.6 The Farne Islands and the coast at Fast Castle are suitable habitats for grey seal pupping and moulting as they are both sheltered and undisturbed areas (English Nature and Scottish Natural Heritage, 2000). The Farne Island breeding population is well established and as such has been monitored closely since the late 1950s. Recent pup counts here show that between 1998 and 2008 pup production was reasonably steady, levelling out at between around 1,000 and 1,400 pups per annum. Prior to this, the population had suffered a significant decline, following intensive culling from the late 1960s to 1984. Since 1984 pup production has gradually increased at this site at just under 2% per annum. The most recent available pup count in 2008 recorded approximately 1,300 pups (Thompson and Duck, 2010).

3.1.3.7 Out with the breeding season, grey seal haul-out on the shore regularly to rest. There are several sites located along the eastern coast of the UK, including some within the Berwickshire and North Northumberland Coast on the Farne Islands, Coquet Island, and at Lindisfarne. There are no other haul-out sites on the eastern UK coast between Coquet Island and the Humber Estuary and as such the Berwickshire and North Northumberland Coast SAC is regarded as an important haul-out area for grey seal (Thompson and Duck, 2010).

Humber Estuary SAC/Ramsar site

3.1.3.8 The Humber Estuary SAC is situated on the eastern English coastline and covers an area of 366.6 km^2. This site is also designated as a Ramsar site, primarily for wetland birds.

3.1.3.9 Grey seal is a qualifying feature of the SAC, supporting the second largest breeding grey seal colony in England, at Donna Nook. In the UK, Conservation Objectives (CO) are generic, for example for all SACs with a species notified interest feature. Conservation Objectives for the SAC are:

- Pup production within the SAC – a stable or increasing number of breeding female grey seals in the SAC/SSSI (baseline 34 pups in 1981);
- Distribution of grey seal pups within the SAC – a stable or increasing area of usage within the SAC; and
- Accessibility of the SAC for breeding – an accessible breeding site.

3.1.3.10 The most recent count of grey seal pups at this site was 1,358 taken in 2008 (Humber Environmental Management Scheme, 2012). The colony at this site has shown a rapid and continual increase since the early 1980s. As with the colony at Fast Castle, it is thought that this increase is mostly due to the immigration and recruitment of females from the Farnes and Isle of May (Thompson and Duck, 2010).

Southern North Sea candidate SAC (cSAC)

3.1.3.11 The Southern North Sea cSAC covers an area of 36,951 km^2 and crosses the boundaries of four other SACs, all of which are designated for either 'Sandbanks which are slightly covered by sea water all the time' or 'Reef' habitats. The cSAC lies immediately to the west of the southeastern corner of the Hornsea Three development area, but also extends north and south of Hornsea Three. The proposed Hornsea Three offshore cable corridor crosses the cSAC.

3.1.3.12 The Southern North Sea cSAC is a single feature SAC and it spans both UK territorial waters and offshore waters. It is recognised as one of the areas around the UK coastline which supports "persistent high densities" of porpoise. The northern two thirds of the site are recognised as important for harbour porpoise during the summer months (April to September inclusive), with the southern third being more important during the winter months (October to March inclusive) (JNCC, 2017).

3.1.3.13 JNCC advise that the site supports approximately 18,500 individuals (95% CI: 11,864 to 28,889) (SCANS II) for at least part of the year. It expected that there will be seasonal differences in occurrence, however it estimated that these numbers represent approximately 17.5% of the population within the UK part of the North Sea MU.

The Wash and North Norfolk Coast SAC

3.1.3.14 The Wash and North Norfolk Coast SAC covers an area of 1,077.6 km^2 (JNCC, 2011d). It is located along the northern Norfolk coast. Generally, it is considered to be one of the most important marine areas on the North Sea coast (Defra, 2010b). The presence of the largest UK colony of harbour seal is a primary reason for the selection of this SAC (JNCC, 2011d). Areas within this site are also classified as a Ramsar site, National Nature Reserves (NNRs), and a SSSI (Defra, 2010b).

3.1.3.15 The Wash and North Norfolk Coast SAC holds approximately 7% of the UK population of harbour seal, making it the largest colony in the UK. 90% of the English population of harbour seal occur at this site, most of which are present at The Wash haul-out site (English Nature and Environment Agency, 2003). The extensive intertidal flats of The Wash and North Norfolk Coast SAC provide ideal conditions for breeding and hauling out by harbour seal. Pupping and lactation occurs between June and July, with birth sites tending to be located near the top of the bank. Following weaning and breeding, harbour seal haul-out on the intertidal flats to begin their annual moult which can last until September. Intertidal mudflats and sandflats also provide an important habitat for seal throughout the year as they spend up to 50% of their time hauled out (English Nature, 2000; Mortimer, unpublished).

Klaverbank SCI

3.1.3.16 The Klaverbank (or Cleaver Bank) SCI covers an area of approximately 1,235 km^2 and lies partly in the UK sector and partly in the Dutch sector of the North Sea (Noordzee Natura 2000, 2012a). Grey seal, harbour seals, and harbour porpoise are all qualifying interest features of this site.

3.1.3.17 Overall, there are estimated to be approximately 1,700 grey seal in the Dutch North Sea (Noordzee Natura 2000, 2012a). However, since grey seal are relatively recent inhabitants along the Dutch coast, little more is known about the distribution and variation of populations in this region. During an aerial survey, a high density of grey seal was observed in the Klaverbank SCI, particularly to the north of the site (Deerenberg *et al.,* 2010). The Dutch conservation objective with regards to this species is to preserve the size and quality of its habitat in order to maintain the population (Zeeinzicht, 2008).

3.1.3.18 The harbour seal is the most abundant seal species in the Netherlands, with an estimated 6,000 individuals inhabiting the Dutch section of the North Sea and Wadden Sea. In the Klaverbank SCI, a medium density (0.46 to 0.6 animals km^{-2}) of seals was observed (Deerenberg *et al*., 2010). The national conservation objective for this species is to maintain its distribution and to expand the size and quality of its habitat in order to expand the population (Zeeinzicht, 2008).

3.1.3.19 The harbour porpoise occurs regularly in Dutch waters, either alone or in small groups. There has been an increase in sightings in this area since 1990; the current population estimate in Dutch waters lies between 15,000 and 19,000 individuals. During an aerial survey, a medium density (0.46 to 0.6 animals km^{-2}) of harbour porpoise was recorded in the Klaverbank SCI. To the north of the site, a high density was counted (1.06 to 1.25 animals km^{-2}) (Deerenberg *et al*., 2010). The Dutch conservation objective for this species is to maintain its distribution by preserving the size and quality of its habitat (Zeeinzicht, 2008).

The Dutch Doggersbank SCI and German Doggerbank SCI

3.1.3.20 The Dutch Doggersbank SCI covers an area of around 4,715 km^2 (Noordzee Natura 2000, 2012b) and borders the UK Dogger Bank SCI. The German Doggerbank SCI, which borders the Dutch Dogger Bank SCI, is located in German waters and covers an area of 1,624 km^2 (BFN, 2004).

3.1.3.21 In the Dutch Dogger Bank SCI, harbour porpoise is a primary reason for site selection, and harbour seal and grey seal are both qualifying interest features of the site. In the German Dogger Bank SCI, harbour porpoise are listed as a primary reason for site selection and harbour seal is listed as a qualifying interest feature.

3.1.3.22 An aerial survey of the Dutch Dogger Bank SCI revealed a low density of harbour seal, and a high density of grey seal (Deerenberg *et al*., 2010). Harbour seal have also been observed in the German Dogger Bank SCI, although not in high numbers (BFN, 2004). As with the UK Dogger Bank SCI to the west, it is currently not possible to estimate the number of harbour seal or grey seal occurring in either the Dutch or German Dogger Bank SCIs or the importance of these sites to these species with regards to foraging and reproduction. It is thought that individuals observed in these sites originate from the large haul-out sites on the Norfolk coast (Deerenberg *et al*., 2010).

3.1.3.23 Harbour porpoise numbers are also difficult to estimate; in the Dutch Dogger Bank, harbour porpoise density was observed as high (1.08 to 1.25 animals km^{-2}) during the aerial survey conducted by Deerenberg *et al*. (2010), particularly to the west of the site along the UK/Netherlands transboundary line (Deerenberg *et al*., 2010). Similarly, high densities (average 2.12 animals km^{-2}, 95% CI 0.95 to 4.53) and abundance (average 14,322 individuals, 95% CI 6,457 to 30,654) of harbour porpoise were observed during aerial surveys of the German Dogger Bank SCI in the summer of 2011 (ASCOBANS, 2011).

3.1.3.24 A conservation objective of both the Dutch and German Dogger Bank SCIs is to maintain the size of the site and to restore the habitat in order to maintain marine mammal populations in the central North Sea (BFN, 2004; Jak *et al*., 2009).

Waddenzee SAC

3.1.3.25 The Waddenzee SAC is located to the east of the Hornsea Three array area. Grey seal and harbour seal are the primary reasons for site selection.

3.1.3.26 The potential for connectivity of the Hornsea Three array area and the Wadenzee SAC was assessed for Hornsea Project Two by looking at telemetry data collected between 2005 and 2008. This showed that of 11 seals tagged in the Waddenzee SAC, three crossed the North Sea to UK waters and haul-out sites in the Moray Firth, Farne Islands and Orkney (Brasseur *et al*., 2010). None of these tracks, however, passed through the former Hornsea Zone, and as such it is not considered likely that the areas in the vicinity of the former Hornsea zone are important for individuals originating from these colonies. Similar tracking studies of harbour seal in the Wadden Sea in 2002/2003 showed that, although some individuals make foraging trips to UK waters, on the whole the at-sea distribution of this species is concentrated on the waters of Wadden Sea.

Noordzeekustzone SAC

3.1.3.27 The Noordzeekustzone SAC is located to the east of Hornsea Three. The site has an area of 1,444.75 km^2 and lies in the Dutch sector of the North Sea. Harbour porpoise, grey seal and harbour seal are all listed as primary reasons for site selection.

3.1.3.28 As discussed above in paragraph 3.1.3.19, harbour porpoise occur regularly in Dutch waters, either alone or in small groups and the Dutch conservation objective for this species is to maintain its distribution by preserving the size and quality of its habitat (Zeeinzicht, 2008). The resident populations of harbour seal and grey seal in the Noordzeekustzone SAC are 9,500 and 2,000 individuals, respectively.

Noordzeekustzone II pSCI

3.1.3.29 The proposed Noordzeekustzone II SCI is located 192 km to the east of Hornsea Three. The site has an area of 1,186.58 km^2 and lies in the Dutch sector of the North Sea. As with the Noordzeekustzone SAC, harbour porpoise, grey seal and harbour seal are all listed as primary reasons for site selection. The resident populations of harbour seal and grey seal for this pSCI are given as 5,300 and 1,786 respectively.

Nationally designated sites

3.1.3.30 Within the regional marine mammal study area (i.e. the south Central North Sea) there are also nationally designated sites with marine mammal features, these include: SSSIs, National Nature Reserves (NNRs). The SSSIs are detailed below. NNRs are underpinned by other designated areas such as SSSIs, SACs or SPA, and any potential impact on these sites will be considered through the underpinning designated site. No further details are therefore provided for NNRs.

Humber Estuary SSSI

3.1.3.31 The Humber Estuary SSSI was notified as a SSSI in 2004 and covers an area of approximately 370 km^2 and is fully encompassed within the Humber Estuary SAC. As discussed in paragraphs 3.1.3.8 to 3.1.3.10 the estuary and its extensive intertidal mudflats and sandflats is of national importance for a breeding colony of grey seal (Natural England, 2013a).

Farne Islands SSSI

3.1.3.32 The Farne Islands SSSI comprises a group of rocky offshore islands and stacks lying off the Northumberland coast. The site covers an area of approximately 0.97 km^2 and is important as a breeding site for grey seal (Natural England, 2013b). The Farne Islands SSSI lies 258 km to the north of the former Hornsea zone.

The Wash SSSI

3.1.3.33 The Wash SSSI was notified as a SSSI covers an area of approximately 631 km^2. The site is fully encompassed within The Wash SAC and is an area of exceptional biological interest. The Wash provides an important breeding ground for harbour seal (Natural England, 2013c). The Wash SSSI lies immediately adjacent to the proposed Hornsea Three offshore cable corridor.

Locally Designated Sites

Havenside Local Nature Reserve (LNR)

3.1.3.34 The Havenside LNR is located just outside the boundary of The Wash SAC, and in close proximity to the Hornsea Three offshore cable corridor. Harbour seal may be found within the estuary and mudflat habitats.

Marine Conservation Zones (MCZs)

3.1.3.35 As part of the Marine and Coastal Access Act (2009), The UK government has signed up to international agreements to establish an 'ecologically coherent network of Marine Protected Areas (MPAs) by 2012, to be delivered through the Marine and Coastal Access Act (2009). The MPA network will comprise several types of designated areas including the new MCZs, European Marine Sites, SSSIs and Ramsar sites. MCZs are a type of designation which will aim to protect nationally important marine wildlife, habitats, geology and geomorphology. The designation of entire areas rather than particular rare or threatened species allows for a full range of wildlife to be protected, in order to protect the integrity of the entire habitat and ecosystem itself, so that the area will continue to support a diverse array of flora, fauna and geological marine features.

3.1.3.36 The criteria for selection of an MCZ is for representation of broadscale habitats, with particular attention on key features (habitats and species) of conservation importance (FOCI). The species FOCI are primarily benthic species that are sessile or do not range widely. However, whilst protecting a range of habitats and species, MCZs also support higher trophic organisms, including marine mammals, which rely on these habitats, and may be key areas for activities such as foraging or breeding.

3.1.3.37 There are a total of 16 MCZs and recommended MCZs (rMCZs) in the regional marine mammal study area (south central North Sea). Nine are now designated as MCZs. Thirteen of the sites are of general interest for marine mammals (Table 3.2).

3.1.3.38 A summary of the marine mammal features of interest within each of these areas is given in Table 3.2. Swallow Sand MCZ has also been considered within this marine mammal assessment despite the site description information not specifically referencing the importance of the site for marine mammals.

Table 3.2: Summary of the MCZs and rMCZs in the regional marine mammal study area.

Site	Potential interest for marine mammals	Distance to Hornsea Three (km)
SSSIs		
The Wash	Important breeding ground for harbour seals	38.5 (Hornsea Three offshore cable corridor)
Humber Estuary	Important breeding area for grey seals	74 (Hornsea Three offshore cable corridor)
Farne Islands	Important breeding site for grey seals	306 (Hornsea Three array area)
LNRs		
Havenside	Harbour seals	71 (Hornsea Three offshore cable corridor)
MCZ		
Cromer Shoal Chalk Beds	Important foraging ground for grey seals, harbour seals and harbour porpoises.	0 (within Hornsea Three offshore cable corridor)
Holderness Inshore	Important for grey seals, harbour seals, harbour porpoises and minke whales.	135 (Hornsea Three array area)
Swallow Sand	Sandy, gravelly seabeds within the site attract spawning mackerel and sprat, which are important prey items for marine mammals.	177 (Hornsea Three array area)
Runswick Bay	Spawning and nursery grounds for several fish species: important foraging grounds for marine mammals	194 (Hornsea Three array area)
North East of Farnes Deep	White-beaked dolphins, harbour porpoises, minke whales and humpback whales observed in area.	252 (Hornsea Three array area)
Coquet to St Mary's	White-beaked dolphins, harbour porpoises and several whale species observed in area.	258 (Hornsea Three array area)
Farnes East	Foraging and breeding white-beaked dolphins.	272 (Hornsea Three array area)
rMCZs		
Markham's Triangle	Large sandeel population: key prey resource for marine mammals.	0 (within Hornsea Three array area)
Wash Approach	Important foraging ground for grey seals, harbour seals and harbour porpoises.	10 (Hornsea Three offshore cable corridor)
Lincs Belt	Grey seal breeding ground.	55 (Hornsea Three offshore cable corridor)
Holderness Offshore	Important for grey seals, harbour seals, harbour porpoises and minke whales.	65 (Hornsea Three offshore cable corridor)
Silver Pit	White-beaked dolphins, minke whales and harbour porpoises have been sighted in small numbers within the site, with the latter more abundant.	70 (Hornsea Three offshore cable corridor)
Compass Rose	Spawning and nursery grounds for several fish species: important foraging grounds for marine mammals.	116 (Hornsea Three array area)
Castle Ground	Marine mammals, including harbour porpoises and minke whales are common in the area particularly to the east of the site. The site is also a foraging ground for grey and harbour seals.	162 (Hornsea Three array area)

3.1.4 Favourable conservation status

3.1.4.1 The concept of favourable conservation status (FCS) is central to the Habitats Directive. Article 2, which states the aim of FCS to be:

- "Measures taken pursuant to this Directive shall be designed to maintain or restore, at FCS, natural habitats and species of wild fauna and flora of Community interest."

3.1.4.2 The conservation status of species is a judgment on the integrity of the species and is assessed against the requirements of the Habitats Directive. It is defined in Article 1(i) of the Habitats Directive as:

- "The sum of the influences acting on the species concerned that may affect the long-term distribution and abundance of its populations within the territory referred to in Article 2".

3.1.4.3 The conservation status of a species is considered to be favourable when:

- Population dynamics data indicate that it is sustaining itself as a long-term and viable component of its natural habitats;
- The natural range of the species is not being reduced or is likely to be reduced in the near future; and
- There is and will remain to be sufficient habitat for the species to maintain its populations on a long-term basis.

3.1.4.4 The FCS parameters provide a basis against which potential changes in the population resulting from a proposed development can be compared as part of the EIA process.

3.1.4.5 It is important to note that these assessments of conservation status for both species and habitats not only include consideration of current conditions, but also incorporate an element of future predictions based on a potential influences on the species or habitat concerned.

3.1.4.6 An assessment of the conservation status for each of the key species is provided later in this report in the discussion (section 4).

3.1.5 Summary of legislation for key species

3.1.5.1 A summary of the legislation relevant to the protection of the five focus marine mammal species is given in Table 3.3.

Table 3.3: Summary of key legislation pertaining to focus marine mammal species.

Species	Bonn Convention	Bern Convention	ASCOBANS	OSPAR	CITES (Appendix)	EC Habitats Directive	WCA 1981 (amended)	CRoW Act 2000	Habitats Regulations	Offshore Habitats Regulations	Conservation of Seal Act 1970	UK BAP
Harbour porpoise	II	II	Yes	V	II	II & IV	5 & 6	Yes	2	1	-	HP
White-beaked dolphin	II	II	Yes	-	II	IV	5	Yes	2	1	-	SD
Minke whale	-	III	-	-	I	IV	5	Yes	2	1	-	BW
Harbour seal	II	III	-	-	-	II & V	-	-	4	3	Yes	-
Grey Seal	II	III	-	-	-	II & V	-	-	4	3	Yes	-

SD – small dolphins grouped plan.
HP – harbour porpoise species plan.
BW – Baleen whales grouped plan.

3.2 Marine mammal management units (MUs)

3.2.1.1 The Inter-Agency Marine Mammal Working Group (IAMMWG) has recommended MUs for the most common species of marine mammals in the UK (IAMMWG, 2013), with a supplementary report provided in 2015 providing revised cetacean MUs (IAMMG, 2015). The papers estimate the populations within each of the MUs for each species of marine mammal, and these are given as the recommended reference populations against which to measure potential effects of development.

3.2.1.2 Currently, the MUs in UK waters extend to 12 nautical miles (NM) - the limit of territorial water. IAMMWG also state that the current boundaries (as set out in IAMMWG 2013 and IAMMWG 2015) will not change until formal review. This is expected to take place every five years, with the first review expected for seals in 2018 and cetaceans in 2019.

3.2.1.3 Species MUs are delineated through an understanding of the ecology of the species so that natural biological populations can be defined, as well as considering the geographic areas that have been established to manage the impacts of human activities on each species. Population estimates for each MU have been derived primarily from the most recent modelled abundance estimates for SCANS-II (Hammond *et al.*, 2013). Where MU's extend further into offshore waters, data from the Cetacean Offshore Distribution and Abundance (CODA) in the European Atlantic was also used to estimate abundances (see http://biology.st-andrews.ac.uk/coda/). Since the SCANS-III surveys, a new MU estimate has been provided for the ICES North Sea Assessment Unit for harbour porpoise (Hammond *et al*., 2017) which has been presented here instead of the IAMMWG (2015) MU.

3.2.1.4 Geographic coverage of each MU is presented in the associated species account (section 4.1) The assessment of impact for each species is undertaken against the agreed MU abundance (Table 3.4) and geographic area for each species (Figure 4.14; Figure 4.19; Figure 4.24; Figure 4.32).

Table 3.4: IAMMWG MUs for focus species, and associated estimated abundance (Sources: IAMMWG, 2015; Hammond *et al*., 2017, SCOS 2016 and SMRU seal data 2017).

Species	MU code	Total Population estimate	Coefficient of Variation	95% CI
Harbour porpoise	ICES Assessment Unit North Sea (NS)[1]	345,373	0.18	246,526 to 495,752
White-beaked dolphin	Celtic and Greater North Seas (CGNS)	15,895	0.29	9,107 to 27,743
Minke whale	Celtic and Greater North Seas (CGNS)	23,528	0.27	13,989 to 39,572
Grey seal	South East England (SEE) and North East England (NEE) combined (using 2016 August haul out counts)	40,040	-	36,879 to 43,794
Harbour seal	South-East England (SEE) (using 2016 moult counts)	6,799	-	5,563 to 9,065

[1] SCANS III (Hammond *et al*. (2017)

3.3 Overview of marine mammals in the regional marine mammal study area

3.3.1.1 Within the North Sea, 13 species of marine mammal have been recorded, and eight of these are considered to occur regularly including both grey and harbour (common) seal, and the following cetacean species: harbour porpoise; bottlenose dolphin *Tursiops truncatus*; white-beaked dolphin; Atlantic white-sided dolphin *Lagenorhynchus acutus*; minke whale; and killer whale *Orcinus orca* (Hammond *et al.,* 2001, 2013). According to the most recent SCANS-III report, harbour porpoise is the most common cetacean in the North Sea with densities highest in the central North Sea (Hammond *et al.,* 2017). Harbour and grey seals are also common throughout the North Sea. Approximately 30% of European harbour seals are found in the UK and approximately 38% of the world's grey seals breed in the UK, with 88% of these breeding at colonies in Scotland (SCOS, 2016).

3.3.1.2 Records of land-based sightings between 1995 and 2015 provided by the GLNP and the Norfolk Biodiversity Information Service (NBIS), confirmed the presence of the main eight species listed above along the Lincolnshire and Norfolk coastal waters. Incidental sightings of Northern bottlenose whale *Hyperoodon ampullatus*, Cuvier's beaked whale *Ziphius cavirostris*, fin whale *Balaenoptera physalus*, long-finned pilot whale *Globicephala melas*, sperm whale *Physeter macrocephalus*, and short-beaked common dolphin *Delphinus delphis* were also recorded.

3.3.1.3 Of the land-based sightings provided (see section 2.3), most species were recorded only infrequently over the period 1995 to 2015, and many not within the last ten years (although this may result from low detection from land of those species with natural ranges in deeper offshore waters). Harbour porpoises, grey seals and harbour seals however, were all recorded regularly from land-based surveys.

3.3.1.4 Boat-based surveys carried out by Marine Life, recorded eight species of marine mammal over a seven year period (2010 to 2016 inclusive) (Marine Life, 2017). The species recorded are summarised below in Table 3.5 and shown in Figure 3.2 and confirm the trend in species occurrence suggested in the above datasets. Harbour porpoise was the most commonly sighted marine mammal with a total of 291 animals recorded over the seven year period.

3.3.1.5 The infrequent sightings of whales and dolphins is unsurprising when compared to the Atlas of Cetacean distribution maps and SCANS data which suggest that most of these species have a more northerly and westerly distribution in European waters (Reid *et al.,* 2003; Hammond *et al.,* 1995; SCANS-II, 2006). In Britain confirmed sightings of fin whale, sperm whale, Cuvier's beaked whale, long-finned pilot whale, northern bottlenose whale and Atlantic white-sided dolphin are primarily restricted to the Northern Isles of Scotland and/or western Scotland and Ireland (Evans *et al.,* 2003; Reid *et al.,* 2003). Bottlenose dolphins and short-beaked common dolphins are also distributed mainly north and west of the British Isles, although these species are also commonly found in the southwest of the UK (Reid *et al.,* 2003).

Table 3.5: Summary of species recorded during Marine Life surveys, 2010 to 2016.

Species	Number of sightings	Number of animals
Bottlenose dolphin	4	12
Common dolphin	5	18
Harbour porpoise	144	291
White-beaked dolphin	5	11
Humpback whale	1	1
Minke whale	17	20
Dolphin sp.	9	28
Cetacean sp.	1	1
Grey seal	8	47
Harbour seal	2	121
Seal sp.	2	2
Total	198	552

3.3.1.6 Although there are also very few records of minke whales and white-beaked dolphins held by the GLNP and NBIS, both species may occur within the Greater Wash since these species are common and widely distributed around Britain and Ireland. The Greater Wash represents the southern limit of the distribution of these species within the North Sea since in both cases these species tend to occur mostly in the central and northern North Sea, with more limited distribution in the southern North Sea (Evans *et al.,* 2003; Reid *et al.,* 2003; Hammond *et al.,* 2001). SCANS-II data for minke whales shows that the highest density areas in the central North Sea occur further offshore in deeper waters (SCANS-II, 2006).

3.3.1.7 During three years of monthly boat-based visual surveys within the former Hornsea Zone plus a 10 km buffer, a total of five marine mammal species were recorded regularly as follows: harbour porpoise, white-beaked dolphin, minke whale, harbour seal and grey seal. Two other species were recorded infrequently and in very low numbers during these surveys: bottlenose dolphin and short-beaked common dolphin.

3.3.1.8 Only one sighting of a pod of three bottlenose dolphins was recorded during the first year of the boat-based surveys in the former Hornsea Zone plus a 10 km buffer (March 2010 to February 2011). Data from other offshore wind farm surveys in the area also show that numbers of bottlenose dolphin are very low in proximity to the regional marine mammal study area. Only one individual was sighted during the 36 surveys carried out over a two year period (2008 to 2009) at the Triton Knoll offshore wind farm. There were no sightings of bottlenose dolphins during the monthly boat-based surveys carried out over a two year survey period at Race Bank (2005 to 2007), Docking Shoal (2004 to 2006) or Humber Gateway (2003 to 2005) offshore wind farms. Furthermore, no sightings of bottlenose dolphins were made during SCANS-II surveys of Block U (covering the south central North Sea) and estimated densities were highest in the coastal waters of southwest France, Spain and Portugal and in the Celtic Sea (SCANS-II, 2006; Hammond *et al.*, 2013).

3.3.1.9 A total of three short-beaked common dolphins were recorded in the third year of the surveys of the former Hornsea Zone plus a 10 km buffer (March 2012 to February 2013) and none recorded in either of the first two years. As described for bottlenose dolphin, the SCANS-II surveys of Block U made no sightings of common dolphins during the 2005 ship-based surveys therefore no density estimates were made for the southern and central North Sea (SCANS-II, 2006; Hammond *et al.,* 2013). Highest densities of common dolphins were estimated for the west of Ireland and in coastal waters of southwest France, Spain and Portugal.

3.3.1.10 Based on the historic records of marine mammals in the southern North Sea, SCANS-II survey data, aerial survey data from Hornsea Three array area plus a 4 km buffer, and marine mammal surveys within the former Hornsea Zone plus a 10 km buffer, the following five species of marine mammal have been identified as potentially important receptors within the regional marine mammal study area and will be the focus of this Assessment:

- Harbour porpoise;
- White-beaked dolphin;
- Minke whale;
- Harbour seal; and
- Grey seal.

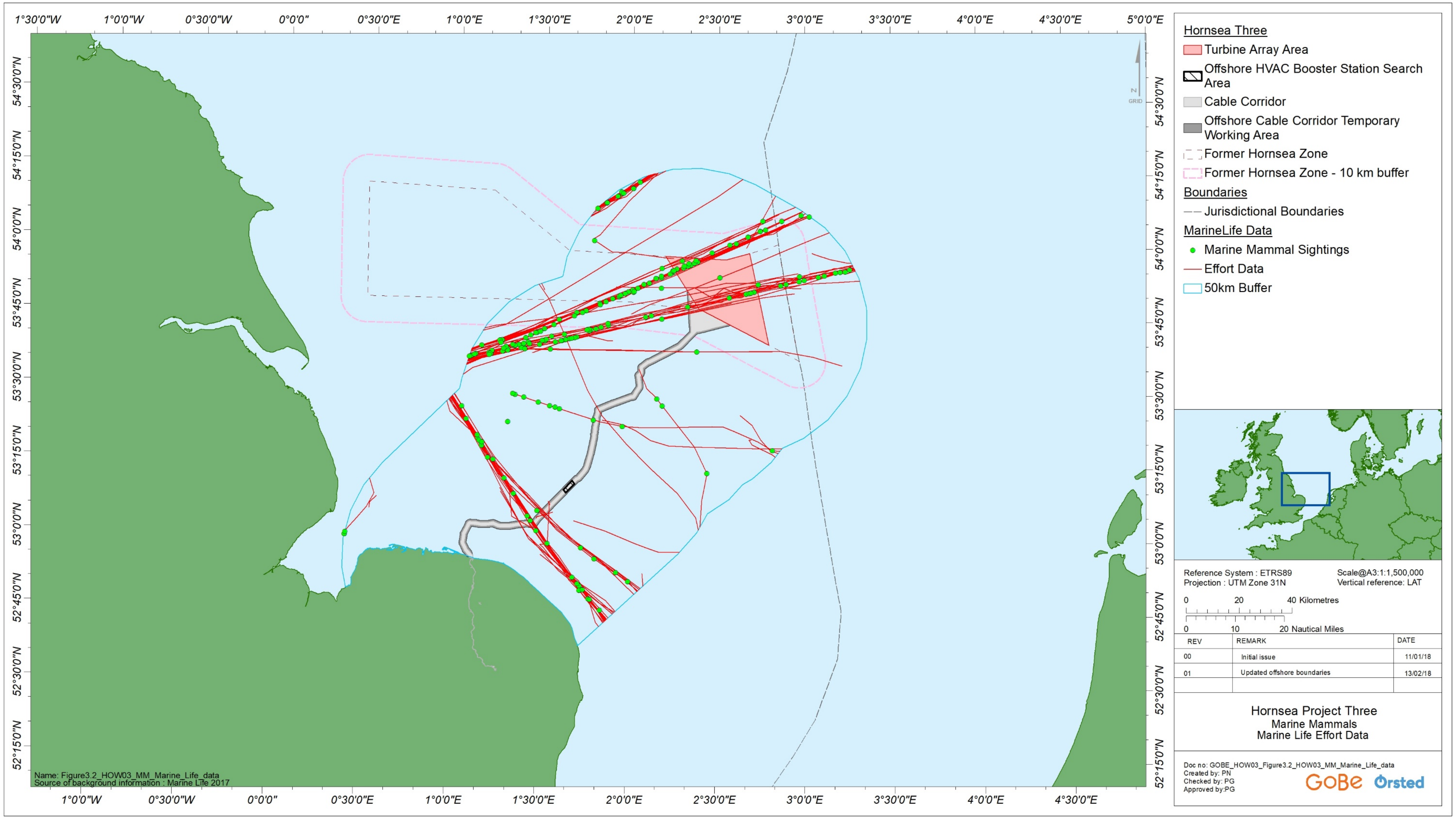


Figure 3.2: Summary of survey effort and marine mammal sightings from Marine Life survey data, 2010 to 2016 (source: Marine Life 2017).

3.4 Field surveys results

3.4.1 Boat-based data

Survey effort

3.4.1.1 Over the whole former Hornsea Zone plus a 10 km buffer, the total survey effort in each year varied between 16,368 km and 18,893 km (Table 3.6). Years in which survey effort was lower were due to logistical limitations arising from vessel availability and weather downtime. For example, in 2011/2012 and 2012/2013 there were several occasions over the winter months when none of the 6 km spaced transects across the former Hornsea Zone plus a 10 km buffer were completed. The 2 km spaced transects surveyed across the Hornsea Project One and Hornsea Project Two array areas Study Areas, however, extended into the wider former Hornsea Zone and therefore some coverage was obtained. As the data was pooled across the three years and for all surveys, this was not an issue for subsequent analyses. The total effort within the former Hornsea Zone plus a 10 km buffer from all pooled data across the surveys was 53,518 km. Within this area, the total pooled survey effort in the Hornsea Three marine mammal survey area was calculated as 5,125 km (Table 3.7). Visual marine mammal data was collected over all survey tracks, however, acoustic data was limited at the end of 2010 due to concerns regarding entanglement with fishing gear in the south of the former Hornsea Zone, and therefore the acoustic survey effort for the Hornsea Three marine mammal survey area, which commenced in July 2010 was 2,141 km (Figure 2.4). It should also be highlighted that due to the limitations mentioned above regarding vessel availability and weather downtime, survey effort was not consistent throughout the year. Most survey effort was conducted in the summer months between June and August (35%) compared to the lowest effort in the winter months between December and February (14%). This will result in higher levels of variance, and lower levels of confidence around estimates of density over the winter months, relative to those in summer months.

Marine mammal observations

Total counts and group size

3.4.1.2 The boat-based visual surveys recorded counts of seven species of marine mammals over the survey period. A total of 7,475 counts were made across the former Hornsea Zone plus a 10 km buffer for all data pooled. This total did not include any off-effort sightings which were made outside of the 90 degree arc or on the other side of the boat. Incidental and off-effort sightings of marine mammals totalled 1,573 over the entire survey period and the same species were recorded as those recorded on-effort. Incidental and off-effort sightings were not included in the analyses since animals surveyed in this way did not follow the standard protocol (e.g. surveyors tended to just note animals close to the trackline and only during times when they were not busy recording sightings on-effort).

Table 3.6: Total survey effort (in km) for the boat-based surveys including 6 km spaced transects across the former Hornsea Zone plus a 10 km buffer and the 2 km spaced transects within the Hornsea Project One and Hornsea Project Two array areas Study Areas.

Month	2010/2011	2011/2012	2012/2013
March	2,431.41	1,289.94	1,789.56
April	1,355.31	2,029.7	1,538.09
May	1,359.45	2,026.56	1,992.59
June	1,363.77	2,440.64	2,201.3
July	1,369.13	2,526.56	2,633.86
August	1,378.65	2,573.33	2,666.42
September	1,819.31	696.32	1,285.89
October	1,366.21	1,113.81	1,567.84
November	1,102.91	1,411.88	639.69
December	1,197.62	95.89	350.64
January	1,021.59	881.65	1,334.42
February	603.47	1,169.91	893.63
Total	*16,368.83*	*18,256.19*	*19,893.93*

Table 3.7: Total visual survey effort by sea state included in the analysis for boat-based data within the Hornsea Three marine mammal survey area.

Sea state	km effort	% of total effort
0	44	0.9%
1	454	8.9%
2	1509	29.4%
3	1985	38.7%
4	1133	22.1%
Total	*5125*	

3.4.1.3 Only 39% of the visual survey effort was conducted in sea state 2 or less, which is the recommended limit for harbour porpoise visual surveys (e.g. Palka, 1996, Hammond *et al.,* 2006).

3.4.1.4 The most commonly recorded species across all surveys was harbour porpoise, where large numbers (total of 6,504 individuals) were counted each year across the former Hornsea Zone plus a 10 km buffer (Table 3.8). This species, on average, accounted for 87.0% of the total number of marine mammals sighted across all surveys and all areas. White-beaked dolphin was the second most commonly recorded marine mammal with 298 animals accounting for an average of 4.0% of the total. Minke whale was also one of the more common species with a total of 158 animals accounting for 2.1% of the total. Both species of seal were also regularly noted during the surveys with total counts of 247 grey seal and 147 harbour seal accounting for 3.3% and 2.0% of marine mammals across all surveys. A monthly log of the counts per kilometre of trackline of the five most commonly recorded species is presented in Appendix C.

Table 3.8: Total counts of each species for the pooled data from the boat-based visual surveys across the former Hornsea Zone plus a 10 km buffer.

Species	2010/2011	2011/2012	2012/2013	Subtotal
Harbour porpoise	2,275	1,758	2,471	6,504
White-beaked dolphin	96	91	111	298
Common dolphin	0	0	3	3
Bottlenose dolphin	3	0	0	3
Unidentified dolphin spp.	16	4	2	22
Minke whale	32	44	82	158
Unidentified whale spp.	1	1	1	3
Unidentified cetacean spp.	11	8	6	25
Harbour seal	34	53	60	147
Grey seal	39	72	136	247
Unidentified seal spp.	7	30	31	68
Total	*2,514*	*2,061*	*2,903*	*7,478*

3.4.1.5 Species recorded infrequently during the surveys and in very low numbers included: common dolphin (three individuals) and bottlenose dolphin (three individuals) (Table 3.8).

3.4.1.6 On average, white-beaked dolphin occurred in the largest groups with a mean group size of 2.63 individuals across the former Hornsea Zone plus a 10 km buffer and for all months pooled (Table 3.9). Harbour porpoise were often recorded in small groups and, using the visual data, averaged a mean group size of 1.59 individuals. All other species were more likely to be sighted singly (Table 3.9).

3.4.1.7 Estimating group sizes of porpoise is not possible using acoustic data, however, an approximation of 'cluster' size can be derived from the visual data. A mean value of cluster size, defined as the number of porpoise recorded within 1 minute (equivalent to approximately 300 m of trackline), was calculated from the visual data. Cluster size is slightly different from actual group size, and will always be greater because the animals seen within a minute may be in more than one group. In addition, cluster size is preferable to group size because of the difficulties of estimating group size during harbour porpoise surveys; in the field it can be difficult to define a group or to decide whether multiple animals some distance apart should be classified as a group or separate detections.

Table 3.9: Mean group size of each of the key species for the pooled data from the boat-based visual surveys across the former Hornsea Zone plus a 10 km buffer.

Species	Mean group size	Range (minimum to maximum)	Standard deviation
Harbour porpoise	1.59	1 – 20	1.11
White-beaked dolphin	2.63	1 – 11	1.59
Minke whale	1.03	1 – 6	0.35
Grey seal [a]	1.02	1 – 2	0.13
Harbour seal [a]	1.01	1 - 2	0.07
a Numbers include unidentified individuals allocated by proportion.			

3.4.1.8 One option for correcting the acoustic data (i.e. where cluster size is a multiplier to calculate total number of animals) is to use the mean cluster size from the visual data across all data pooled. Visual recording of cluster size is, however, affected by sea state and therefore the best approximation for the number of animals that are actually present in a 300 m segment of track, given that at least one is detected, will be to use the mean cluster size estimates from the visual data collected in sea state 0 only (Figure 3.3). Consequently, cluster size of harbour porpoise for acoustic data was estimated based on the mean number of visual detections within a one minute segment for sightings in sea state 0, and was calculated for all survey areas as 2.15 (Table 3.10).

3.4.1.9 Larger group size may in some cases be accounted for by the presence of females with calves, however, this was difficult to assess since most individuals (89% of the total) could not be allocated an age class.

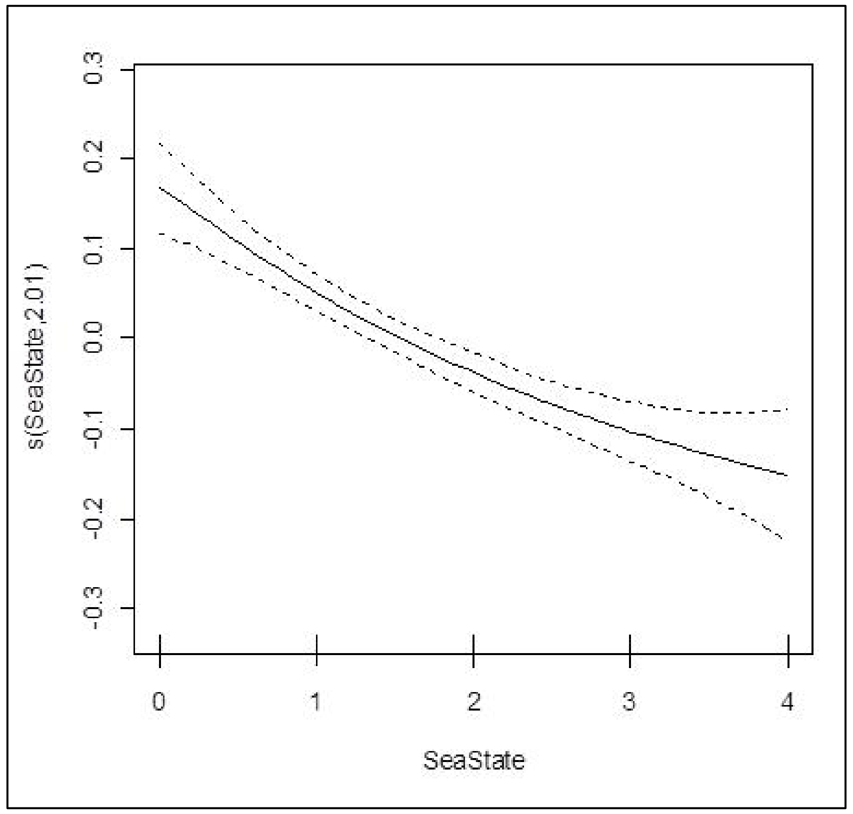


Figure 3.3: Smoothed function of a GAM with mean porpoise cluster size as the variable with sea state as an environmental predictor.

Table 3.10: Mean cluster size of each of the key species recorded within one minute segments of trackline (average=275 m) derived from data within the former Hornsea Zone plus10 km buffer.

Species	Mean	Range	Standard deviation
Harbour porpoise (acoustic) [a]	2.15	-	-
Harbour porpoise (visual)	1.76	1 to 20	1.32
White-beaked dolphin	2.92	1 to 11	1.82
Minke whale	1.07	1 to 6	0.45
Grey seal [b]	1.04	1 to 2	0.20
Harbour seal [b]	1.01	1 to 2	0.12

a Estimated cluster size derived from visual data.

b Numbers include unidentified individuals allocated by proportion.

Distribution of sightings

3.4.1.10 Sightings of the most commonly encountered species, harbour porpoise, were distributed widely across the entire former Hornsea Zone plus 10 km survey area (Figure 3.4). This was validated by the acoustic recordings of harbour porpoises which were also distributed across the survey area and also demonstrated a greater number of detections in the west of the former Hornsea Zone compared to the visual data (Figure 3.4).

3.4.1.11 Sightings of white-beaked dolphins were predominantly distributed in the western half of the former Hornsea Zone with a few sightings in the southern part of the Hornsea Three array area (Figure 3.4). Furthermore, the number of sightings of unidentified dolphin species was low. As with white-beaked dolphin, the distribution of minke whale sightings was predominantly in the western half of the former Hornsea Zone, and to a lesser extent the central part of the former Hornsea Zone; sightings within the Hornsea Three array area were, on the whole, low (Figure 3.5).

3.4.1.12 The majority of sightings of seals were made along the southern boundary and to the west of the former Hornsea Zone (Figure 3.5). This was also true of sightings of unidentified species of seal. Sightings of both harbour and grey seals were relatively low within the Hornsea Three array area; grey seals appeared to be more widely distributed across the former Hornsea Zone compared to harbour seals, whose distribution was concentrated along the southern boundary (Figure 3.5).

3.4.1.13 Modelled surface density estimates (absolute density) for harbour porpoise across the former Hornsea Zone plus a 10 km buffer based on three years of boat based data showed very similar spatial patterns between visual data and acoustic data (Figure 3.6).

Parameters in density estimate models

Detection function

3.4.1.14 Detection function (g(x)) curves were fitted to the data using Distance (Thomas, 1999; Thomas *et al.*, 2010) to represent the probability of detecting an animal given that is at distance '*x*' from the trackline. Detection functions were fitted to sighting and acoustic data for individuals and groups. Distance selected the most appropriate model for each detection function curve based on the lowest Akaike's Information Criterion (AIC) value which gives a measure of the model fit based on the maximised likelihood and the number of parameters in the model. For all species the most appropriate model was fitted using a half-normal as the key function with a cosine adjustment term. The only difference was in the number of orders within the cosine adjustment term for each species.

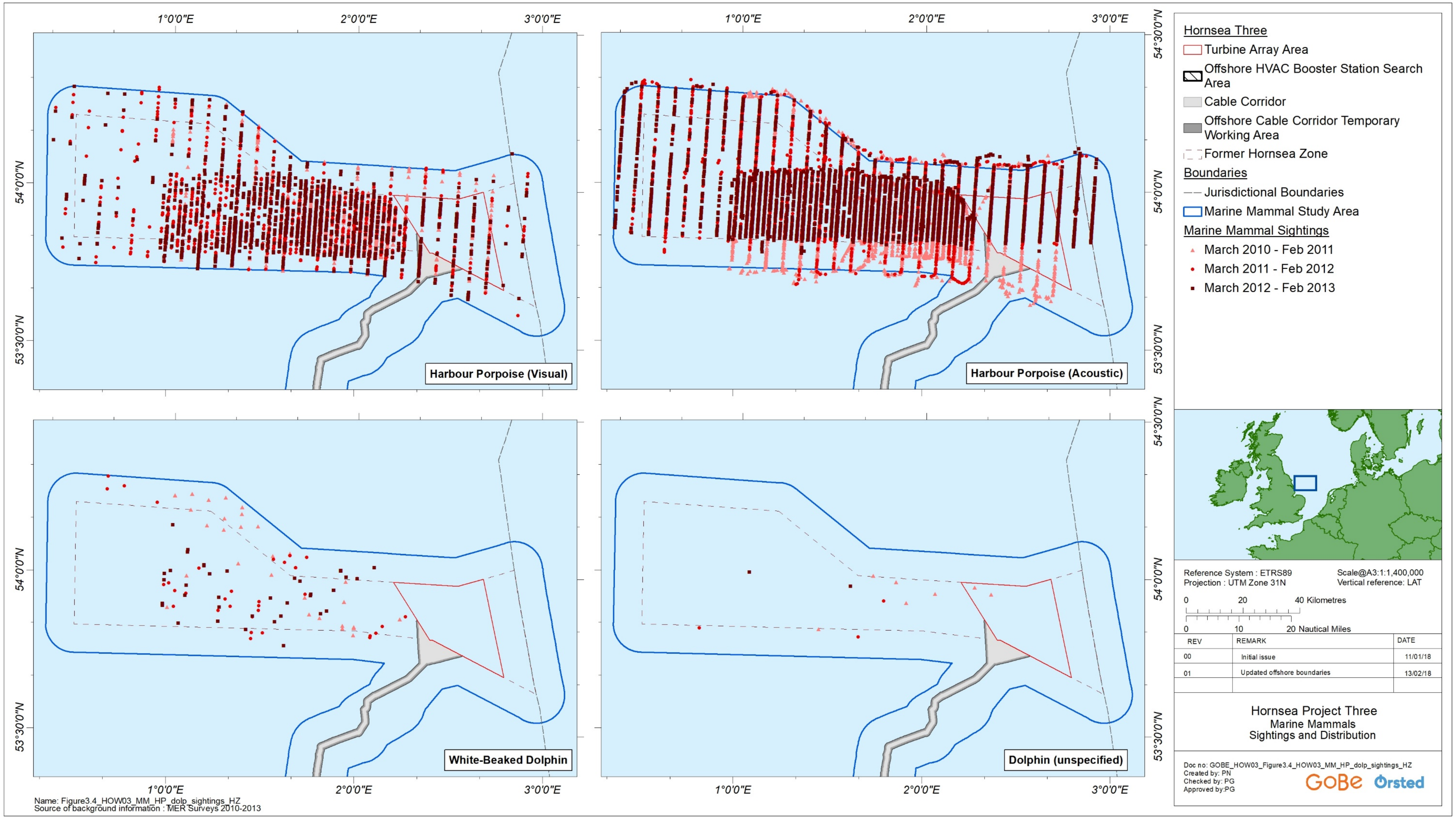


Figure 3.4: Distribution of sightings of harbour porpoise (visual and acoustic), white-beaked dolphin and dolphin (unspecified species) across the former Hornsea Zone plus a 10 km buffer (all data pooled across 3 years).

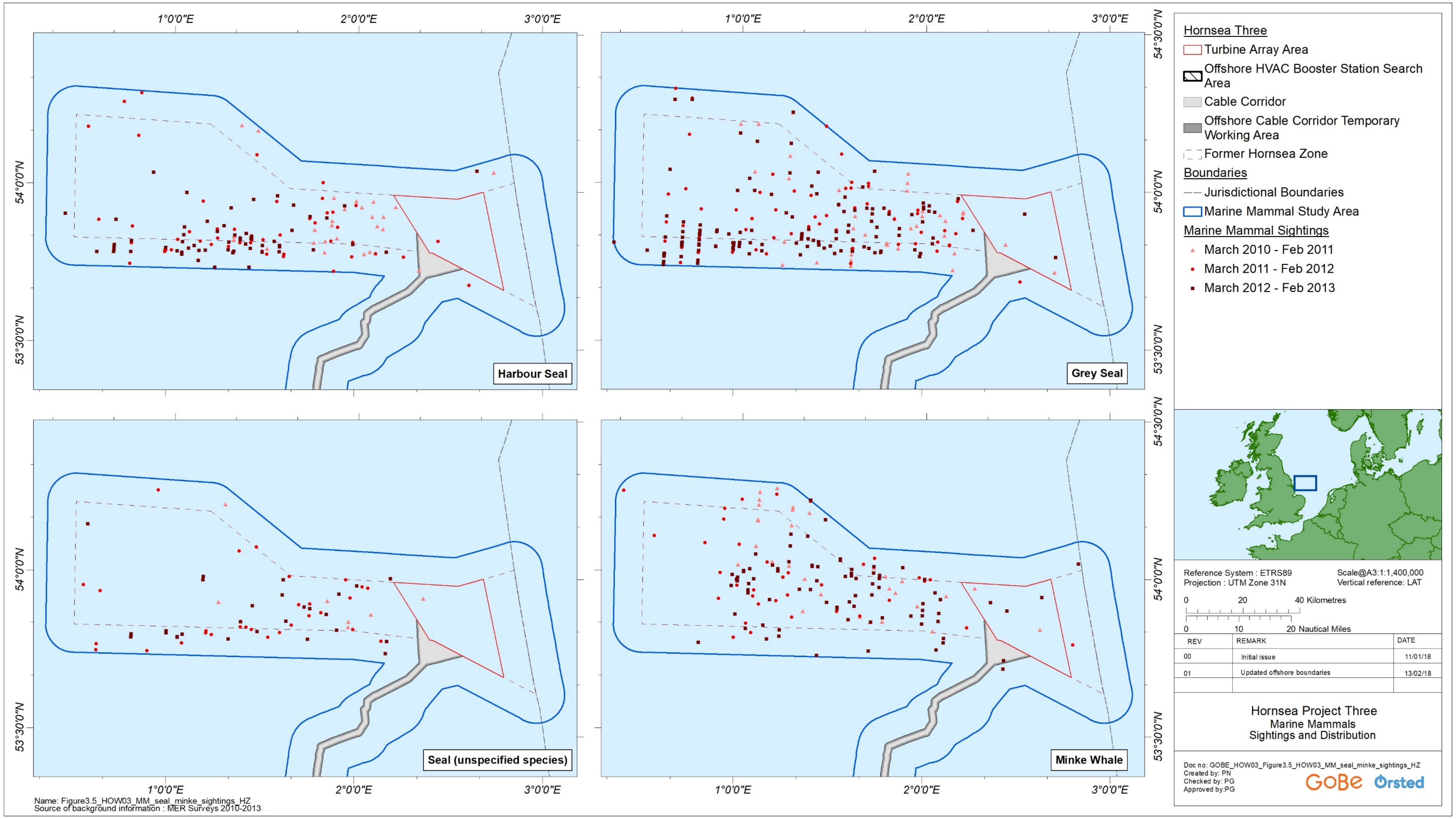


Figure 3.5: Distribution of sightings of minke whale, harbour seal, grey seal and seal (unspecified species) across the former Hornsea Zone plus a 10 km buffer.

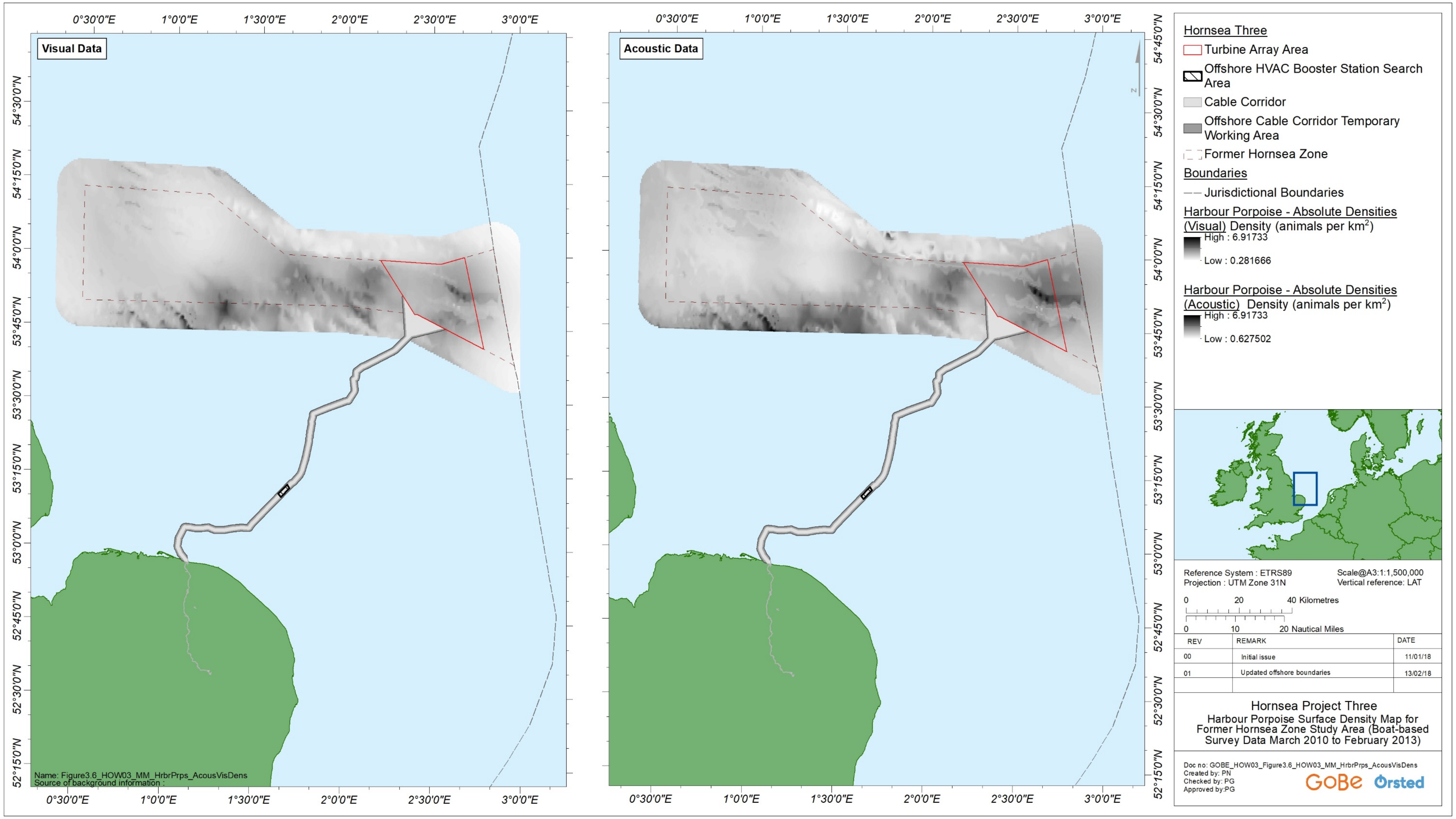


Figure 3.6: Modelled surface density estimates for harbour porpoise across the former Hornsea Zone plus a 10 km buffer based on three years of boat based (visual and acoustic) data.

3.4.1.15 Chi-squared goodness of fit tests were performed for each model fit and with the exception of harbour porpoise (acoustic) and white-beaked dolphin, all the models were a statistically good fit. Harbour porpoise (acoustic) and white-beaked dolphin did not show such a good model fit due to the irregularity observed in the frequency of detections in the bins closest to the trackline. For the acoustic data the detection function suggested a reduction in detections within 100 m of the hydrophone. This observation is typical of porpoise acoustic detection functions and has been seen in data from SCANS and from several other studies. It may reflect both responsive movement (avoidance) away from the vessel and the effect of vocalising animals being at depth and not at the surface. For white-beaked dolphin, there was a high frequency of sightings up to 150 m from the trackline may be due to responsive movement towards the boat.

Effective strip width (ESW)

3.4.1.16 One of the key parameters in estimating abundance from line-transect surveys is the ESW, which provides a measure of how far animals are seen from the transect line and, therefore, how much area has been effectively searched. ESWs were calculated for the five key marine mammal species from the detection functions (Table 3.11). As sightings effort was to one side of the vessel the values given are for the half strip width. The towed hydrophone detected harbour porpoise to both sides of the vessel, however, half strip width has been presented for the acoustic detections in order to allow comparison with visual data for this species.

Table 3.11: ESWs based on the detection functions of the key species found within the former Hornsea Zone plus a 10 km buffer together with 95% CIs (variation in ESW) and Coefficient of Variation (precision of estimates). Values are ESW.

Species	Number	ESW	CV	95% CI
Harbour porpoise sightings, no calves, truncated 1,000 m (N total = 4,011)	3,892	352	0.029	333 to 373
Harbour porpoise acoustic detections truncated 1,000 m	5,131	722 [a]	0.030	340 to 383
Minke whale sightings truncated 1,000 m (N total = 153)	148	471	0.127	367 to 604
White-beaked dolphin sightings truncated 700 m (N total = 117)	105	351	0.066	308 to 400
Grey seal sightings truncated at 1000m (N total = 235)	233	291	0.052	262 to 322
Harbour seal sightings no truncation (all <700 m)	139	181	0.076	156 to 211
a The acoustic survey detected animals both sites of the vessel. The ESW given is therefore for a whole strip width rather than a half.				

3.4.1.17 The largest mean ESW was calculated for minke whale (471 m). With respect to harbour porpoise, the ESW calculated from the acoustic data was marginally higher (361 m) than from the visual data (352 m). The smallest calculated mean ESW was for harbour seal (181 m). A measure of the precision of the estimates for ESW is expressed as the CV (see Table 3.11). The 95% CI for minke whale was greater than that observed for other species (367-604 m) and accordingly the CV for this species was also higher at 0.127.

Detection probability

3.4.1.18 As discussed in paragraphs 2.5.1.2 and 2.5.1.3, a common problem with marine mammal surveys is that, for many species, g(0) is less than one. The application of g(0) as a correction factor is important in estimating absolute, rather than relative, densities. Estimates of g(0) were only possible for harbour porpoise (see paragraph 2.5.1.4) and grey seal (see paragraph 2.5.1.8) and are presented below. For the remaining species, as it was not possible to calculate g(0) from the data collected across the former Hornsea Zone using the double platform due to the low densities of these species recorded during the surveys, published values of g(0) are discussed together with the implications that these have for the densities within the former Hornsea Zone.

Harbour porpoise

3.4.1.19 The results of the analyses to calculate detection probability for harbour porpoise using the visual and acoustic data as a double platform are provided in Appendix B. In summary, the estimated values of g(0) for harbour porpoise in all sea states were calculated as 0.201 (CV = 0.13) for the visual survey and 0.374 (CV = 0.09) for the acoustic survey (Appendix B). Detection probability was also calculated in different sea states for the visual data (see paragraph 2.5.1.21) and the results showed that as sea state increased the estimates for g(0) decreased (Table B.1, Appendix B). There were too few trials conducted at sea state 0 to calculate a g(0) at this sea state. The g(0) estimate at sea state 1 was 0.576, at sea state 2 was 0.224 and at sea state 3 was 0.143.

3.4.1.20 As a comparison with the former Hornsea Zone estimates, the value for g(0) calculated from the SCANS-III data for ship based visual surveys was 0.221 and for visual aerial surveys was 0.364 in good conditions and 0.279 in moderate conditions. These values are very similar to the former Hornsea Zone estimate of detection probability for the visual surveys in all sea states and therefore would result in a similar density estimate if applied to these data.

Grey seal

3.4.1.21 Detection probability of grey seals was based on availability bias of grey seals during dive cycles. Telemetry data from tags deployed by SMRU were available for 1,551 dive cycles in the North Sea (over similar depths as the former Hornsea Zone) and the proportion of time spent performing dives was therefore estimated. This assumes that all animals on the surface were available for detection (i.e. no perception bias). The estimated detection probability using this approach was g(0)=0.46 and is detailed in Appendix E.

Other species

3.4.1.22 For all other species, it was not possible to estimate survey specific values for g(0) therefore the density estimates presented here are relative values. For harbour seals, however, it was assumed that the dive cycle was similar to that of grey seals and therefore a correction factor of g(0)=0.46 was applied to the final density estimate. A literature review of field studies of white-beaked dolphin suggest that the estimates of dolphin density may be positively biased and therefore g(0) approaches 1. SCANS-II data for minke whale provides an estimate of g(0)=0.55 which may give a crude approximation of minke whale densities for Hornsea Three. A full review is provided in Appendix E.

Density Estimate Model Results

Design-based approach

3.4.1.23 Mean absolute density estimates for harbour porpoise were made from both the visual and acoustic datasets, correcting for g(0) in each case. Detection probabilities (g(0)) were also calculated for grey seal using the methodology outlined in section Appendix E *et seq*., and as such the density estimates for this species could also be corrected for g(0). As detection probabilities could not be calculated for minke whale, white-beaked dolphin and harbour seal, only relative densities are presented in Table 3.12 for these species.

3.4.1.24 Absolute density estimates for harbour porpoise were consistently higher for the acoustic data (Hornsea Three plus 4km buffer: 2.87 porpoise km^{-2}) compared to the visual data (Hornsea Three plus 4km buffer: 1.76 porpoise km^{-2}). There was a higher estimate for density of harbour porpoise in the Hornsea Three array area plus a 4 km buffer compared to the former Hornsea Zone plus 10 km using the acoustic data (2.87 porpoise/km^2 and 2.22 porpoise/km^2 respectively). The absolute density estimates for harbour porpoise using the boat-based data suggest that the former Hornsea Zone (including the Hornsea Three array area) is important for harbour porpoise since the densities are higher than the average density of 0.888 animals/km^2 recorded for SCANS III Block O (Hammond *et al.,* 2017).

3.4.1.25 The relative density estimates for white-beaked dolphin were fairly consistent across the former Hornsea Zone plus a 10 km buffer although the numbers were lower in Hornsea Three array area plus a 4 km buffer with an average density of 0.008 animals km^{-2} compared to the former Hornsea Zone plus a 10 km buffer where the average was estimated as 0.016 animals km^{-2} (Table 3.12). By comparison, these density estimates are slightly higher than those obtained from the SCANS III surveys for block O of 0.002 white-beaked dolphins/km^2 (Hammond *et al.,* 2017).

3.4.1.26 The relative density estimates for minke whale across the former Hornsea Zone plus a 10 km buffer and Hornsea Three array area plus a 4 km buffer were low at 0.006 animals km^{-2} and 0.012 animals km^{-2} respectively (Table 3.12). However, the limitation of not correcting for g(0) for this species is acknowledged and, as discussed in paragraph 2.5.1.7, relative density provides a minimum estimate of density in the area. Using the g(0) of 0.55 from SCANS-II as a crude approximation for minke whale (see Appendix E), the minke whale density would be approximately 0.01 animals km^{-2} which is consistent with the overall minke whale density estimated by SCANS-III in Block O of 0.010 animals km^{-2} (Hammond *et al.,* 2017).

3.4.1.27 Table 3.12 shows that the relative mean density of grey seals (including the allocated proportion of unidentified seal) in the former Hornsea Zone plus a 10 km buffer was estimated at 0.019 animals km^{-2}. Correcting this for g(0) = 0.46 gave an absolute mean density of 0.040 animals km^{-2}. For the Hornsea Three array area plus a 4 km buffer the mean relative density of grey seals was estimated at 0.052 animals km^{-2} with a corrected absolute density of 0.113 animals km^{-2}.

3.4.1.28 The relative mean density of harbour seals was 0.014 animals km^{-2} for Hornsea Three array area plus a 4 km buffer and 0.018 animals km^{-2} in the former Hornsea Zone plus a 10 km buffer (Table 3.12). As discussed in Appendix E, although it was not possible to calculate g(0) for harbour seals, if we assume that it is similar to grey seals (i.e. 0.46) then the associated corrected density estimates would be 0.030 and 0.039 animals km^{-2} for Hornsea Three array area plus a 4 km buffer and the former Hornsea Zone plus a 10 km buffer, respectively.

Table 3.12: Average relative (uncorrected) density estimates and absolute (corrected for g(0)) density estimates over the three-year survey period. Total effort relates to all 2 km and 6 km spaced transects that fall within the former Hornsea Zone plus a 10 km buffer or Hornsea Three array area plus a 4 km buffer. ESW for visual estimates is presented as half strip width since observations were only made on one side of the vessel. Cluster size refers to the number of animals recorded in a one minute segment of survey track (equivalent to an average of 275 m).

Species	Total effort (km)	ESW (km)	Total number of groups	Total number of animals	Mean cluster size	Uncorrected density (animals km^{-2})	g(0)	Density corrected for g(0) (animals km^{-2})
Hornsea Three array area plus a 4 km buffer								
Harbour porpoise (visual) [a]	5,125	0.352	332	570	1.72	0.316	0.20 (overall) [b]	1.76
Harbour porpoise (acoustic)	2,141	0.722 [c]	955	1,643	1.72	1.063	0.37	2.87
White-beaked dolphin	5,125	0.244	1	3	3	0.008	-	
Minke whale	5,125	0.385	6	6	1	0.012	-	
Grey seal	5,125	0.270	12	12	1	0.052	0.46	0.11
Harbour seal	5,125	0.181	2	2	1	0.014	-	
Former Hornsea Zone plus a 10 km buffer								
Harbour porpoise (visual)	53,700	0.352	3,696	6,504	1.76	0.345	0.20	1.72
Harbour porpoise (acoustic)	20,773	0.722 [c]	5803	-	2.15	0.830	0.37	2.22
White-beaked dolphin	53,700	0.351	102	298	2.92	0.016	-	-
Minke whale	53,700	0.471	148	158	1.07	0.006	-	-
Grey seal	53,700	0.291	-	290	1.04	0.019	0.46	0.04
Harbour seal	53,700	0.181	-	172	1.01	0.018	-	-

a Data from sea states <4 included in the analyses.

b g(0) is here is the mean value over all sea states, however, for the analyses the densities were estimated for each sea state and corrected according to the g(0) value for that sea state.

c The acoustics detect animals both sides of the vessel. The ESW for the acoustic data is therefore for a total strip width.

Model-based approach

3.4.1.29 The GAM models incorporated a number of covariates as explanatories for density in each species (Table 2.2; Appendix E). None of these covariates were found to have significant explanatory power except for depth and in the case of harbour seal, tidal range. Sea state was found to be a better indicator of observed encounter rate than wind force in all models, and swell height was not a significant factor in any model. This left a family of simple models based on sea state to model observed encounter rate, with latitude, longitude and depth as spatial components, and days from start, Julian day and hour as temporal components (Table 3.13).

Table 3.13: Final fitted density surface models for all species. All models fitted were binomial with a logit link function.

Species	Model	N (minutes segment of track)	% Explained Deviance
Harbour porpoise (visual_1)	s(Latitude, IsoLong) + s(Year) + s(SeaState, k = 5) + s(Depth) + s(DaysFromStart)	200,593	11.2
Harbour porpoise (visual_2)	s(Latitude, IsoLong) + s(SeaState, k = 5) + s(Depth) + s(JulianDay)	200,593	11.1
Harbour porpoise (acoustic_1)	s(Latitude, IsoLong) + s(Depth) + s(DaysFromStart)	77,226	2.8
Harbour porpoise (acoustic_2)	s(Latitude, IsoLong) + s(Depth) + s(JulianDay)	77,226	2.7
Minke whale	s(Latitude, IsoLong) + s(SeaState, k = 5) + s(Julian day)	200,593	8.2
White-beaked dolphin	s(Latitude, IsoLong) + s(SeaState, k = 5) + s(Julian day)	200,593	10.0
Grey seal	s(Latitude, IsoLong) + s(SeaState, k = 5) + s(Depth) + s(Julian day) + s(DaysFromStart)	200,593	12.6
Harbour seal	s(Latitude, IsoLong) + s(SeaState, k = 5) + s(Depth) + s(Julian day)	200,593	7.4

3.4.1.30 It should be noted that since the data were collected monthly over a three year period this is rather different from single surveys typically used to estimate abundance that are more representative of a snapshot of what is present at the time of the survey (e.g. SCANS surveys). The former Hornsea Zone plus a 10 km buffer is also very small compared to the extent of similar habitat and the range of populations of species within the North Sea. For these reasons, the densities in the former Hornsea Zone plus a 10 km buffer may fluctuate substantially with small shifts in the distribution of the population.

3.4.1.31 Despite the visual model incorporating sea state as the covariate that best explained encounter rate, visual estimates of density still show much greater variability than the acoustic estimates. This suggests that factors that affect visual detection have not been fully taken into account within the model. The data collected did include swell height and glare but these did not help to explain the variability within the models tested.

3.4.1.32 There was no correlation between visual and acoustic density estimates and the average of the two shows the lowest variability. This suggests much of the apparent variability is likely to be caused by un-known effects on detection probability rather than changes in porpoise numbers.

Seasonal variation

3.4.1.33 For harbour porpoise, two different models were fitted to compare days from start with Julian day as temporal covariates in the model. Days from start gives a better representation of the overall fluctuations in encounter rate over time whilst Julian day was useful in identifying the exact times of year when seasonal peaks may occur as the data is forced into a particular day (Table 3.14). The deviance explained was slightly better for days from start as the temporal component and therefore this was selected as the preferred model. It should be noted, however, that for binomial models, such as these, the deviance explained is difficult to interpret and is not necessarily always a good representation of the fit of the model.

3.4.1.34 The acoustic data show little evidence of seasonal patterns whereas the visual data show a clear summer peak (Table 3.14). The only sighting condition covariate included in the model was sea state. If lighting conditions or some other weather-related factors influence the detectability of harbour porpoise this might explain the lower estimated densities in winter from the visual data. Alternatively, if vocal behaviour differed between seasons then that may influence acoustic estimates. If there were un-modelled factors affecting visual detection probability this would be expected to show up in different g(0) estimates for summer and winter in equivalent sea states. To investigate this, the number of animals detected visually as a proportion of the number of acoustic trials was compared between summer and winter in different sea states (Table 3.14). The proportions were used as a proxy for g(0) since with small samples sizes, (due to dividing the data by sea state and season), it was not possible to calculate g(0) accurately. The resulting proportions show that there is some evidence of lower detectability in winter compared to summer, but when tested statistically, these differences were not significant.

Table 3.14: Number of visual trials as a proportion of acoustic trials (as a proxy for detection probability) in winter compared to summer for equivalent sea states.

Environmental conditions	Number of acoustic trials	Number of visual trials	Proportion of trials
Sea state 1			
Winter	52	12	0.231
Summer	221	58	0.262
Sea state 2			
Winter	215	19	0.088
Summer	532	42	0.079
Sea state 3			
Winter	299	9	0.030
Summer	712	37	0.052

Effect of sea state on density estimates

3.4.1.35 The effect of sea state was investigated for the most commonly occurring species, harbour porpoise, using the first two years of data for the former Hornsea Zone plus a 10 km buffer (Appendix G). Accurate recording of sea state is very difficult and subjective. Harbour porpoise are small and difficult to see and large differences in the raw sightings rates were observed with sea state. For example, the raw sightings rate in sea states 3 and 4 is less than 5% of that in sea state 0.

3.4.1.36 Estimates of g(0) in different sea states shows that detection probability falls off with increasing sea state. When density was corrected for g(0) in the different sea states there was little variation in the corrected estimates (Table G.3 in Appendix G).

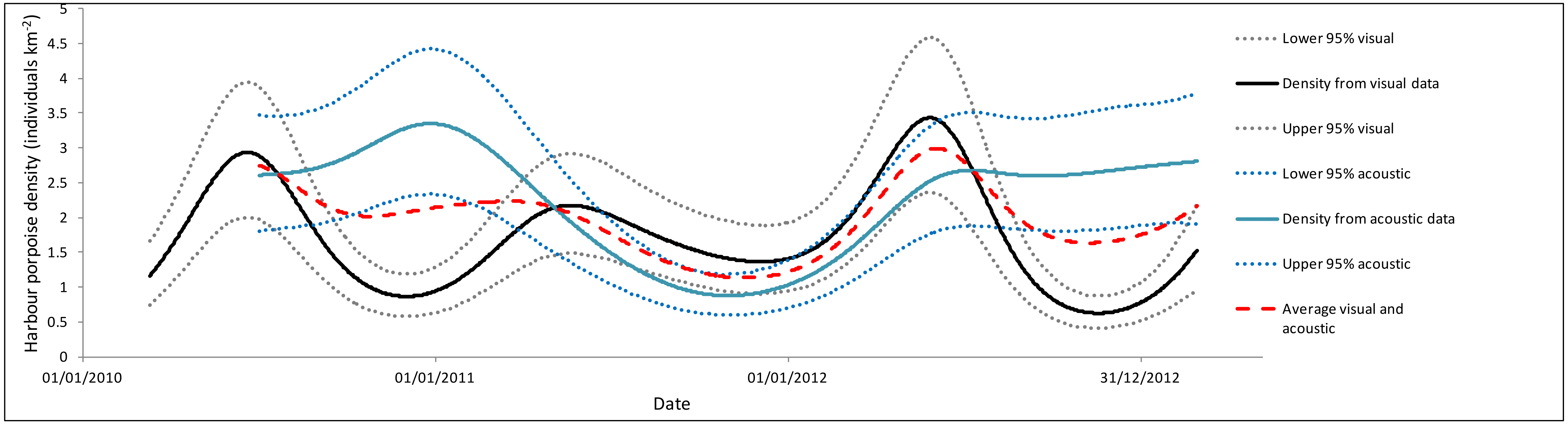


Figure 3.7: Variation in harbour porpoise density estimates over the survey period (averaged across the former Hornsea Zone plus a 10 km buffer) from boat based survey visual and acoustic data using days from start as a covariate within the GAM model.

3.4.2 Aerial data

Survey effort

3.4.2.1 The survey effort varied slightly between survey month, with a mean on-effort survey distance of 503.3 km (range 489.5 to 526.8 km). The total effort by month and in different sea states is shown in Table 3.15. The distribution of effort by sea state varied across months with only 15.6% of the total effort conducted at sea state 2 or below and 50.0% of the effort conducted at sea state 4 and above. Most survey effort was conducted in sea state 3 or 4 (71.8%).

Spatial distribution patterns and density estimates

3.4.2.2 As can be seen in Figure 3.8, harbour porpoise were sighted throughout the Hornsea Three zone plus the 4 km buffer. There were more sightings recorded in the eastern side of the surveyed area compared to the western area.

3.4.2.3 The relative density estimate for the Hornsea Three array area plus a 4 km buffer was calculated from the aerial sightings data by dividing the total sightings by the area surveyed (total track length*strip width of 0.25 km).

3.4.2.4 The relative density by survey month and by sea state is presented in Table 3.16. The mean relative density was highest between sea states 1 to 4 across all surveys (between 0.324 and 0.602 sightings/km^2). The highest relative density in any one survey month (summed across all sea states) was 1.492 sightings/km^2 in May 2016 and lowest in November 2016 with only 0.023 sightings/km^2. The overall relative density across all survey months and across all sea states was 0.441 sightings/km^2 and across sea states 0-4 was 0.487 sightings/km^2.

3.4.2.5 A correction factor was applied to these data to account for porpoise that are below the top 2 m of the water column (and therefore not detected by the surveys). As discussed in section 2.5.2 and 2.6.6 this requires the assumption that all porpoise within the top 2 m of the water column were detected in the HiDef images (and none below 2 m were detected). However, this assumption remains untested at the specific survey site or over the full range of environmental conditions. Nevertheless, the corrected densities have been calculated and presented to provide additional context for the Hornsea Three boat based visual and acoustic survey data. Only data obtained in sea states 0-4 have been used to calculate the corrected densities.

Table 3.15: Total effort (km) in each month survey by sea state categories. A blank cell means no survey effort at that sea state in that month.

	Effort (km) by Sea State							
Survey Month	0	1	2	3	4	5	6	Total Effort (km)
Apr-16			2.1	149.6	344.8			496.5
May-16				473.1	25.7			498.8
Jun-16		291.5	191.6	15.5				498.6
Jul-16	1.4		63.0	396.1	36.4			496.9
Aug-16		27.5	288.9	180.4				496.8
Sep-16	34.2	89.6	191.6	191.1				506.5
Oct-16			9.2	435.5	47.1			491.8
Nov-16				9.3	175.1	326.2	5.0	515.6
Dec-16				246.5	242.9			489.5
Jan-17		4.8		503.5	9.6			517.8
Feb-17					489.2	33.5		522.7
Mar-17		4.7	72.0	270.2	151.6			498.4
Apr-17				10.4	481.1			491.6
May-17					526.8			526.8
Jun-17				24.7	120.5	314.8	42.6	502.6
Jul-17				10.0	491.8			501.8
Aug-17				49.9	450.6			500.5
Sep-17		4.8	289.1	209.8				503.7
Oct-17					4.6	493.3	4.8	502.6
Nov-17				290.7	163.8	52.8		507.3
Total	*35.6*	*422.8*	*1107.5*	*3466.3*	*3761.6*	*1220.6*	*52.4*	*10066.8*
% of total effort	*0.4*	*4.2*	*11.0*	*34.4*	*37.4*	*12.1*	*0.5*	

Table 3.16: Number of porpoise sightings (#/hp) and the relative densities (rDens, sightings/km^2) by survey month and by sea state. A blank cell denotes no survey effort at that sea state.

	Sea State 0		Sea State 1		Sea State 2		Sea State 3		Sea State 4		Sea State 5		Sea State 6		
Survey Month	# Hp	rDens	# Hp	rDens	# Hp	rDens	# Hp	rDens	# Hp	rDens	# Hp	rDens	# Hp	rDens	Overall rDens
Apr-16					0	0.000	20	0.535	28	0.325					0.387
May-16							173	1.463	13	2.023					1.492
Jun-16			105	1.441	33	0.689	2	0.516							1.123
Jul-16	0	0.000			11	0.698	70	0.707	6	0.659					0.700
Aug-16			1	0.145	35	0.485	29	0.643							0.523
Sep-16	2	0.234	8	0.357	24	0.501	6	0.126							0.316
Oct-16					0	0.000	4	0.037	0						0.033
Nov-16							0	0.000	1	0.023	2	0.025	0	0.000	0.023
Dec-16							5	0.081	4	0.066					0.074
Jan-17			0	0.000			14	0.111	0	0.000					0.108
Feb-17									35	0.286	1	0.119			0.275
Mar-17			0	0.000	18	1.000	38	0.563	13	0.343					0.554
Apr-17							0	0.000	24	0.200					0.195
May-17									115	0.873					0.873
Jun-17							0	0.000	5	0.166	19	0.241	3	0.281	0.215
Jul-17							2	0.798	17	0.138					0.151
Aug-17							1	0.080	75	0.666					0.607
Sep-17			0	0.000	61	0.844	59	1.125							0.953
Oct-17									0	0.000	12	0.097	0	0.000	0.095
Nov-17							13	0.179	1	0.024	1	0.076			0.118

3.4.2.6 The resulting corrected density estimate for the Hornsea Three site across all survey months for data collected in sea states 0 to 4 is 1.019 porpoise/km^2 (Table 3.17).

Table 3.17: Uncorrected relative densities and corrected densities of harbour porpoise obtained from the HiDef surveys between April 2016 and August 2017. Sightings and effort at sea states 5 and 6 have been removed.

Survey Month	Area surveyed (km^2)	Uncorrected sightings	Uncorrected density (#/km^2)	Corrected sightings	Corrected density (#/km^2)
Apr-16	124.1	48	0.387	113	0.910
May-16	124.7	186	1.492	438	3.510
Jun-16	124.7	140	1.123	329	2.643
Jul-16	124.2	87	0.700	205	1.648
Aug-16	124.2	65	0.523	153	1.231
Sep-16	126.6	40	0.316	94	0.743
Oct-16	122.9	4	0.033	9	0.077
Nov-16	46.1	1	0.022	2	0.051
Dec-16	122.4	9	0.074	21	0.173
Jan-17	129.5	14	0.108	33	0.254
Feb-17	122.3	35	0.286	82	0.673
Mar-17	124.6	69	0.554	162	1.303
Apr-17	122.9	24	0.195	56	0.460
May-17	131.7	115	0.873	271	2.054
Jun-17	36.3	5	0.138	12	0.324
Jul-17	125.5	19	0.151	45	0.356
Aug-17	125.1	76	0.607	179	1.429
Sep-17	125.9	120	0.953	282	2.242
Oct-17	1.1	0	0.000	0	0.000
Nov-17	113.6	14	0.123	33	0.290
min			*0.000*		*0.000*
mean			*0.433*		*1.019*
max			*1.492*		*3.510*

3.4.3 Comparison of boat-based and aerial data

3.4.3.1 The boat-based survey has provided a longer duration data set than aerial surveys, with a total survey effort of 19,893.93 km. Aerial surveys have provided a total survey effort of 10,066.8 km. Boat-based surveys have recorded a total of 7,478 marine mammal sightings whereas aerial surveys have recorded a total of 1,109 harbour porpoise sightings.

3.4.3.2 Harbour porpoise were recorded throughout the respective survey areas during both boat-based and aerial surveys. A comparison of the boat-based data with the aerial data (re-scaled) identified that the pattern of distribution of harbour porpoise densities across the Hornsea Three array area plus a 4 km buffer was similar to those of boat-based data from surveys of the former Hornsea Zone (both visual and acoustic), with broad similarities between the high density areas predicted (Figure 3.10). This suggested that the distribution of harbour porpoise has remained relatively consistent over the Hornsea Three array area.

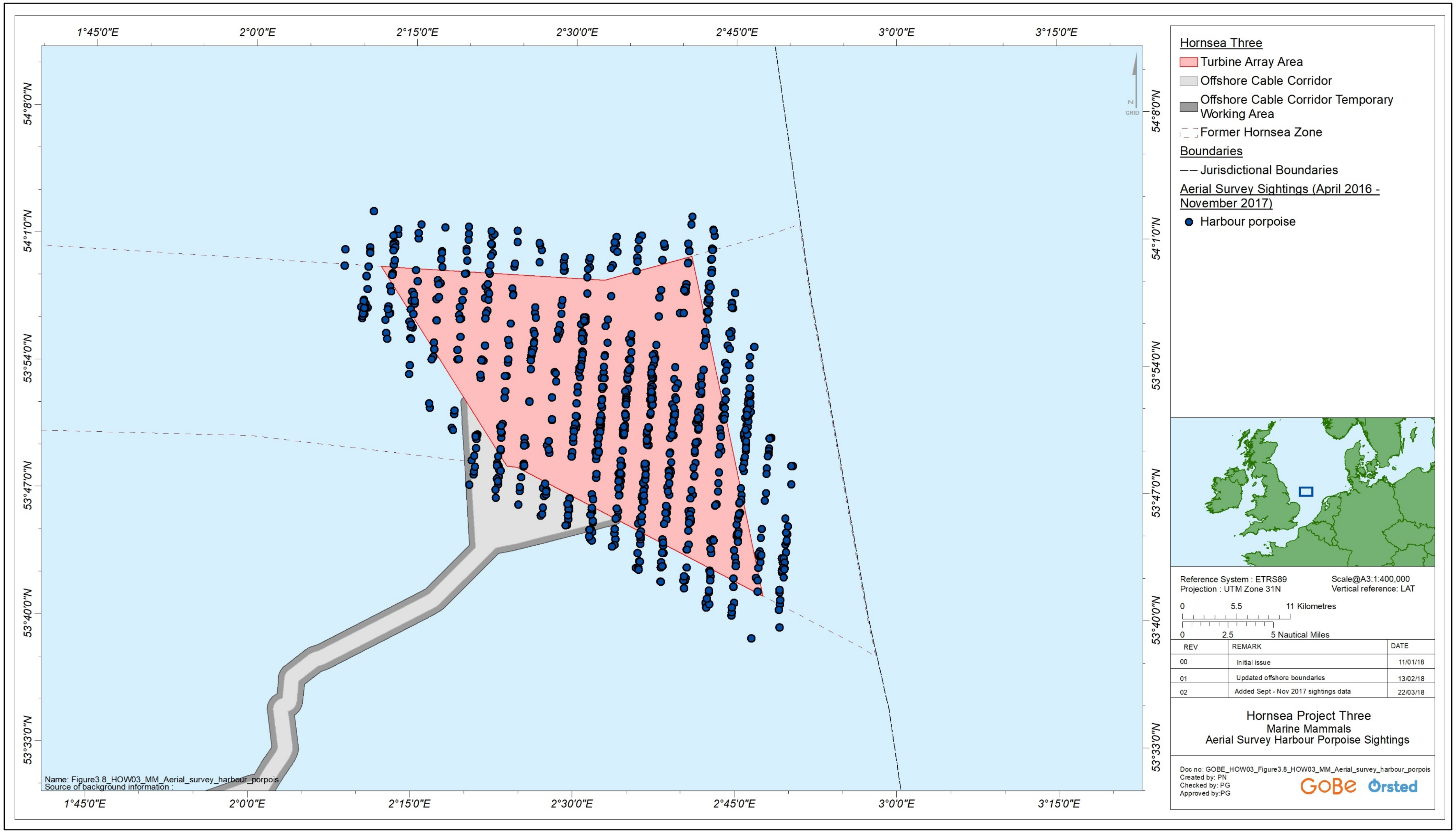


Figure 3.8: All harbour porpoise sightings recorded during the HiDef aerial surveys of Hornsea Three + 4km buffer between April 2016 and November 2017.

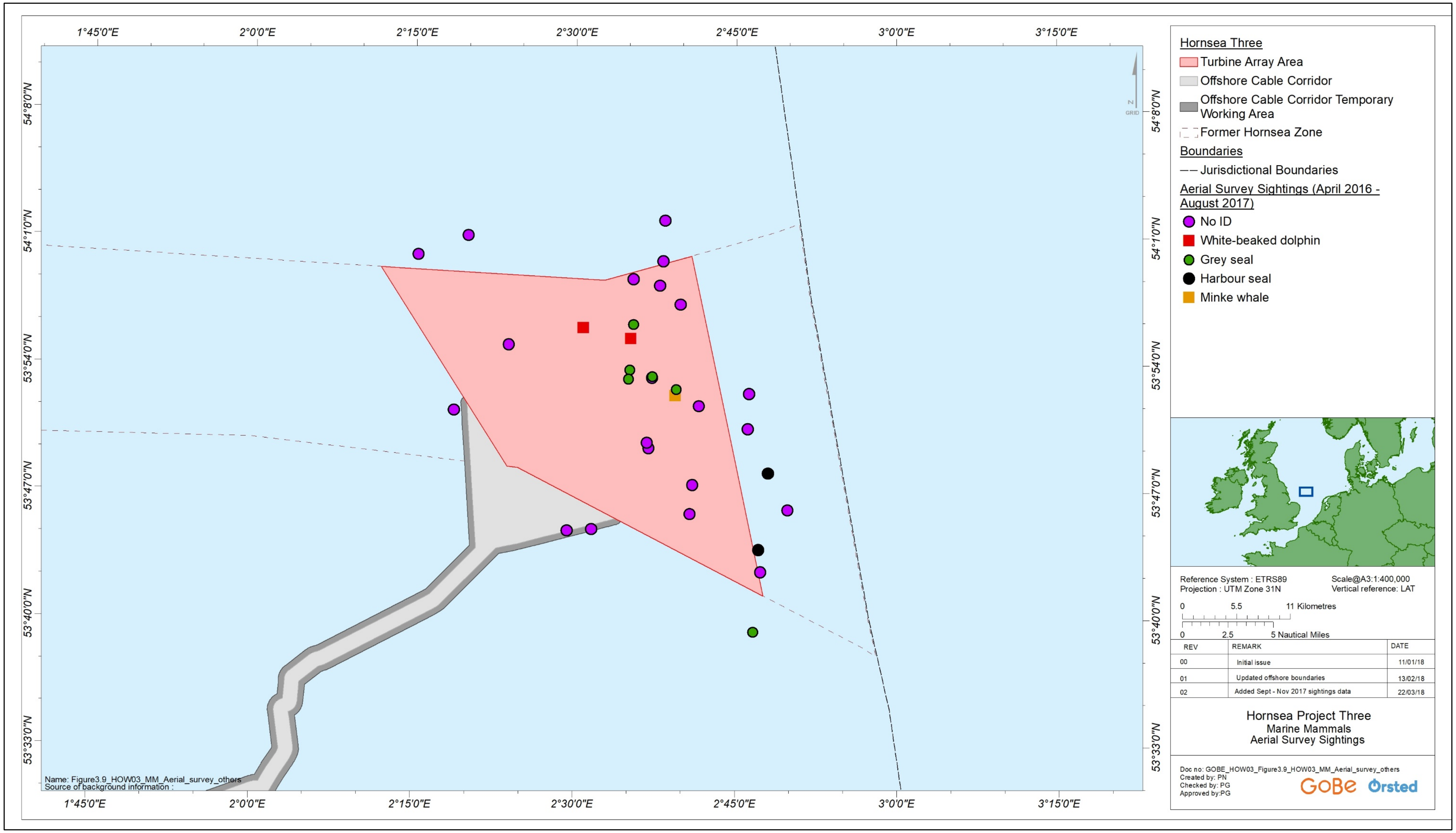


Figure 3.9: All grey seal, harbour seal, minke whale, white-beaked dolphin and "No ID" sightings recorded during the HiDef aerial surveys of Hornsea Three + 4km buffer between April 2016 and November 2017.

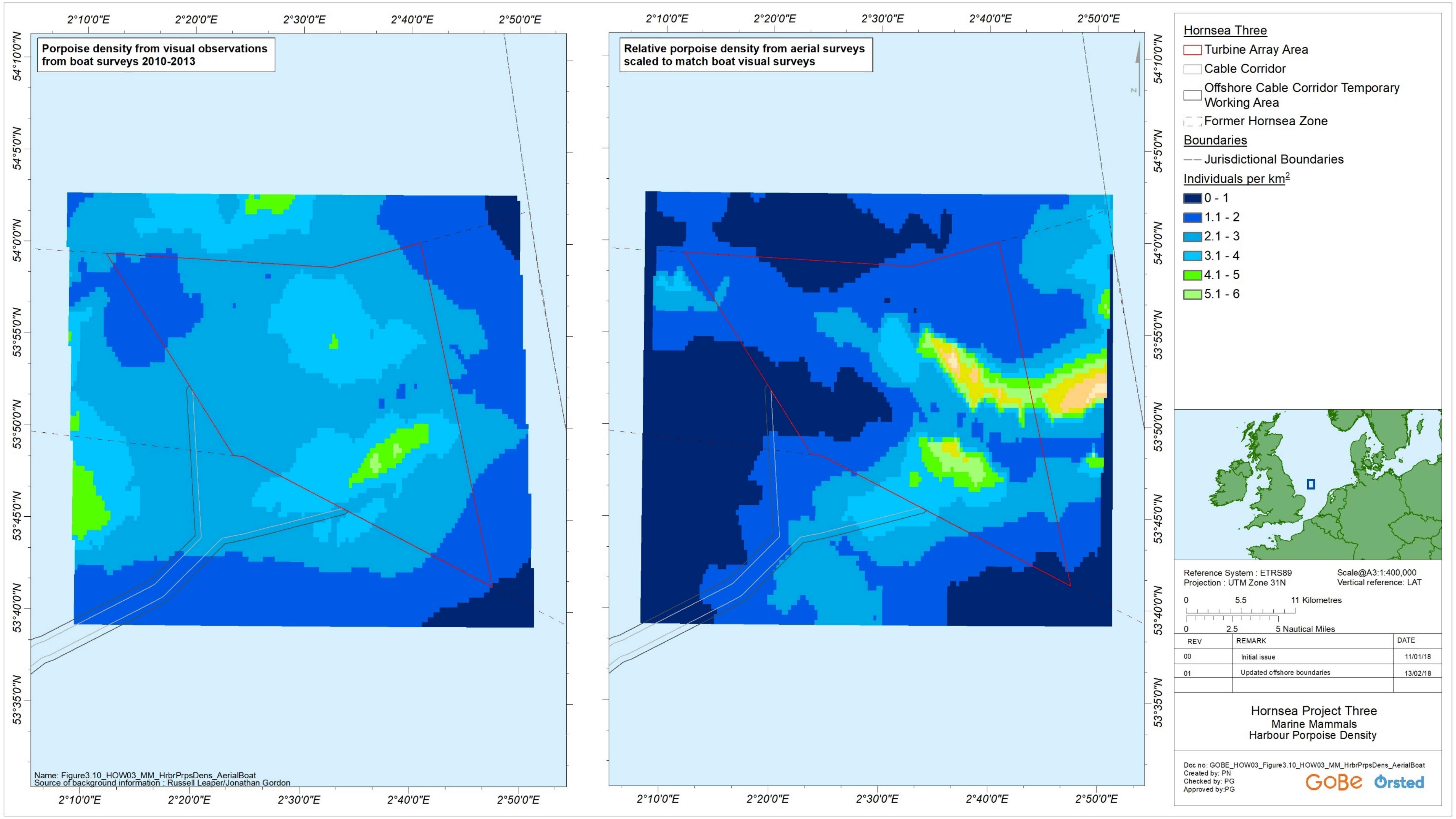


Figure 3.10: Surface density maps for harbour porpoise for Hornsea Three array area plus a 4 km buffer with aerial data scaled to give the same mean density as the boat based data for comparative purposes.

4. Discussion (Species Accounts)

4.1 Overview

4.1.1.1 Each of the species included in the detailed accounts below constitutes a VER as defined by CIEEM (2016). The value of each ecological receptors is dependent on their ecology, distribution, abundance, density and protected status. Details of each of these considerations is outlined below for each species. As all marine mammal species detailed below have both International and National importance, the five species occurring most frequently within the regional marine mammal study area are deemed to be VERs.

4.2 Harbour porpoise

4.2.1 Ecology

4.2.1.1 Porpoise comprise a group of relatively small-bodied Odontoceti (toothed) cetaceans within the family Phocoenidae. The harbour porpoise is one of the smallest cetacean species, reaching a maximum length of 1.9 m. On average females grow to a length of 1.6 m whilst males reach 1.45 m in length (Lockyer, 1995). Although the recorded longevity is 24 years, most individuals do not live past 12 years of age (Lockyer, 2003).

4.2.1.2 Often living in cool waters, porpoise have a higher metabolic rate than dolphins and therefore need to feed more frequently and consume more prey per unit body weight in order to maintain their body temperature and other energy needs. For this reason, porpoise may be highly susceptible to changes in the abundance of prey species. Harbour porpoise feed on a wide range of fish species, but mainly small shoaling species from demersal or pelagic habitats (Santos and Pierce, 2003; Aarfjord, 1995). Since porpoise swallow their prey whole there is a natural limit to the size they are able to consume and in a study of the length distribution of key prey items Andreasen (2009) found that 94% of prey consumed was less than 45 cm in length. This means that most herring *Clupea harengus*, gobies Gobiidae and sandeels Ammodytidae are available as prey items, however, adult cod and whiting reach sizes that are too large (approximately 100 cm and 70 cm, respectively) for harbour porpoise to consume.

4.2.1.3 Studies of harbour porpoise off the east coast of Scotland have shown that dominant prey items include whiting *Merlangius merlangus* during winter months and sandeels during the summer months (Santos *et al.*, 2006). In the east of the North Sea, key prey items are whiting, cod *Gadus morhua* and long rough dab *Hippolossoides platessoides* (Aarefjord *et al.,* 1995). Young porpoise tend to target smaller species such as gobies and small crustaceans. A detailed study on the prey availability and preferences of harbour porpoise in Danish waters found that the significance of prey species may change both spatially and temporally according to the availability of prey (Sveegaard *et al.*, 2011a). For example, whilst cod were a key prey item year-round (in terms of the percentage of biomass consumed), herring was an important prey species in the first and second quarter of the year, gobies were also important in the second and fourth quarter, and whiting was a key prey item in the third quarter (Sveegaard *et al.*, 2011a).

4.2.1.4 Studies of the diet of harbour porpoise in the north east Atlantic suggest that there has been a long-term shift in prey items from clupeids (e.g. herring) to gadoids and sandeels. This is possibly related to the decline in the herring stocks since the mid-1960s (Santos and Pierce, 2003). Furthermore, a study of the diet of cetaceans in the southern North Sea suggested that harbour porpoise have been feeding at lower trophic levels since 1998. This reflects a higher availability of low trophic level prey items, such as zooplanktivorous fish (Das *et al.*, 2003). It has been suggested that this shift may be due to overfishing of trophic levels at which harbour porpoise prefer to feed (Christensen and Richardson, 2008).

4.2.1.5 Harbour porpoise regularly forage around tidal races, overfalls and upwelling zones during the ebb phase of the tide. For example, in south Ramsey Sound a successful foraging strategy involves exploiting prey species that are concentrated within seabed trenches and associated fast-moving tidal streams (Pierpoint, 2008). Although harbour porpoise generally hunt alone or in small groups, this species is often seen in larger aggregations of fifty or more individuals either associated with food concentrations or seasonal migrations. Within these loose aggregations, segregation may occur, with females travelling with their calves and yearlings, and immature animals of each sex being segregated into groups.

4.2.1.6 The age at sexual maturation for the harbour porpoise is approximately three to four years and reproduction is strongly seasonal with mating occurring between June and August (Lockyer, 1995). Gestation is 10 to 11 months and there is a peak in birth rate during the months of June to July around the British Isles (Boyd *et al.*, 1999).

4.2.1.7 The main threat to the harbour porpoise in the North Sea is incidental catch in fishing gear, particularly gill nets. Other major threats include: prey depletion; acoustic pollution/harassment; chemical pollution; ship strikes; habitat destruction; and climate change (Reijnders *et al.*, 2009). In order to address these threats, ASCOBANS (Agreement on the Conservation of small cetaceans of the Baltic, North East Atlantic, Irish and North Seas) has called for a conservation plan for harbour porpoise in the North Sea in order to aid their population recovery (Reijnders *et al.,* 2009).

4.2.1.8 Due to the anthropogenic threats it faces the harbour porpoise is currently listed on Appendix II of CITES (species not currently threatened with extinction but may become so if exploitation continues) and on the International Union for Conservation of Nature (IUCN) Red List of threatened species as Least Concern (LC) (Hammond *et al.*, 2008a).

4.2.2 Distribution

4.2.2.1 Harbour porpoise are widespread throughout the temperate waters of the North Atlantic and North Pacific. In the North Atlantic waters the entire North Sea coast of the UK is considered an important area for this species (Figure 4.1).

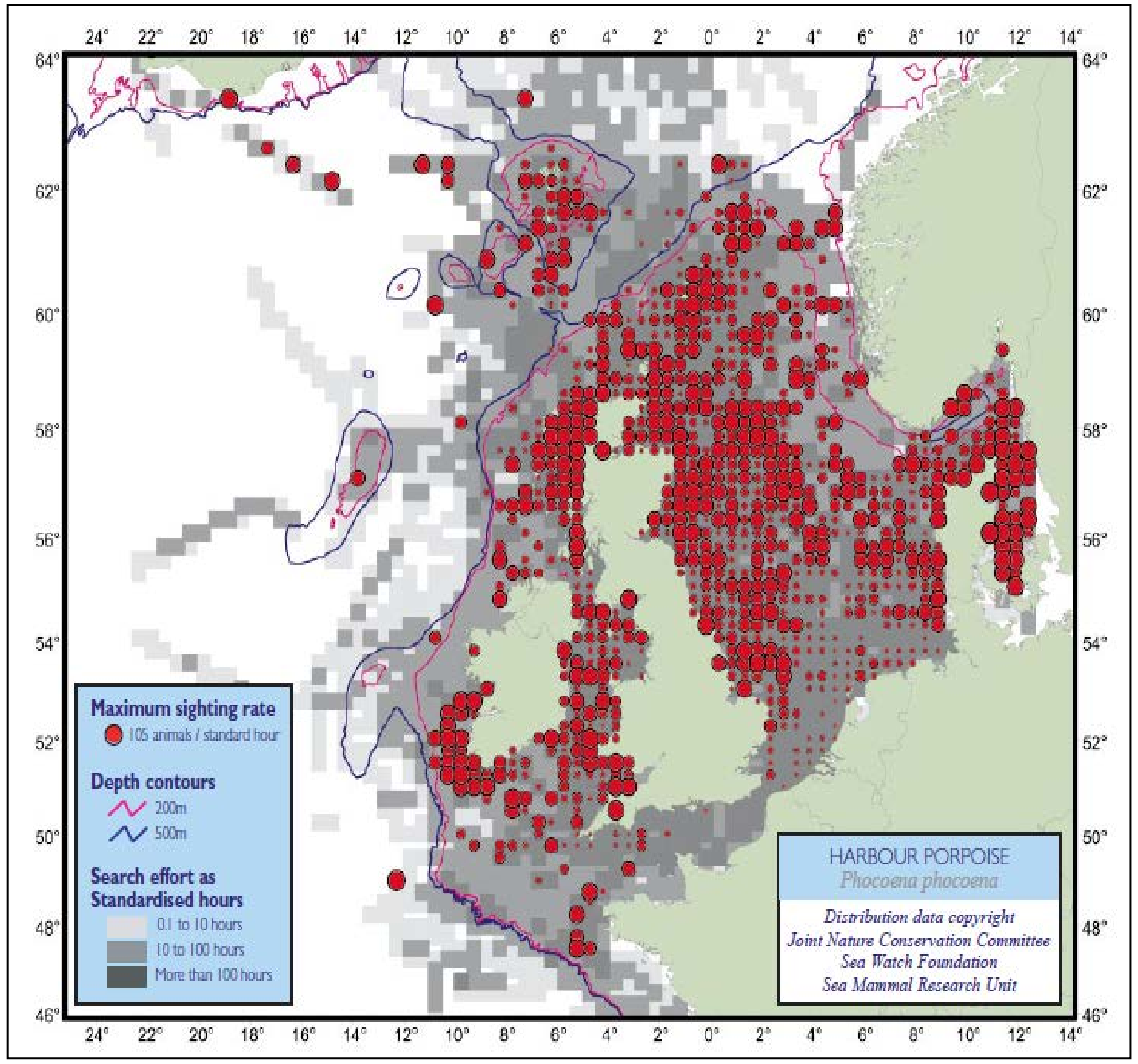


Figure 4.1: Distribution of harbour porpoise around the UK coast (Reid *et al*., 2003).

4.2.2.2 Tagging studies in Denmark suggest that the distribution of porpoise may occur within defined sub-populations. For example, in Danish waters two sub-populations have been identified: an Inner Danish Waters population, which includes the Kattegat, Belt Sea and Western Baltic; and a Skagerrak population, which includes northern Kattegat, Skagerrak and the northeastern North Sea (Sveegaard *et al.*, 2011b). Within these two sub-populations, harbour porpoise were not evenly distributed throughout their ranges and analysis using kernel density estimation software showed that nine hotspots of high density occurred across the Danish study area (Sveegaard *et al.,* 2011b). Since harbour porpoise distribution is thought to be strongly linked to the distribution of prey species (Gaskin, 1982) it is likely that these hotspots reflect key feeding areas for porpoise. The Danish study compared the distribution of porpoise across the two sub-populations on a seasonal basis and found a significant difference in the distribution within each population between certain seasons (Sveegaard *et al.,* 2011b). For the Inner Danish Waters population the density hotspots shifted gradually south from spring through to winter and analyses showed significant differences along this latitudinal gradient between spring/summer to autumn/winter. The Skagerrak population showed a longitudinal cline in distribution with density hotspots moving gradually west from spring through to winter and again significant differences were found between the spring/summer to autumn/winter distribution.

4.2.2.3 Since the Skaggerak population moves along a longitudinal cline into the North Sea, it was also useful to examine the distances travelled by individuals from this population given that there is a paucity of information on harbour porpoise movement in the wider southern North Sea in general. Through consultation with the author of this study it was ascertained that the distances travelled by individuals from the Skagerrak population ranged between 9.5 to 58.1 km per day on average, with an overall mean of 24.5 km per day (S. Sveegaard, pers. comm.). There was also a great deal of variation in the maximum distance travelled from the tagging location by an individual, where the distances ranged from 61.0 to 859.6 km, with an average of 370.6 km over the entire study period (Figure 4.2). It was found that immature porpoise (particularly males) were likely to have considerably larger home ranges (up to four times greater) compared to mature porpoise. These results indicate that immature and therefore inexperienced porpoise may have to travel greater distances to locate prey compared with more mature individuals that may effectively forage in a preferred area (Sveegaard *et al.*, 2011b).

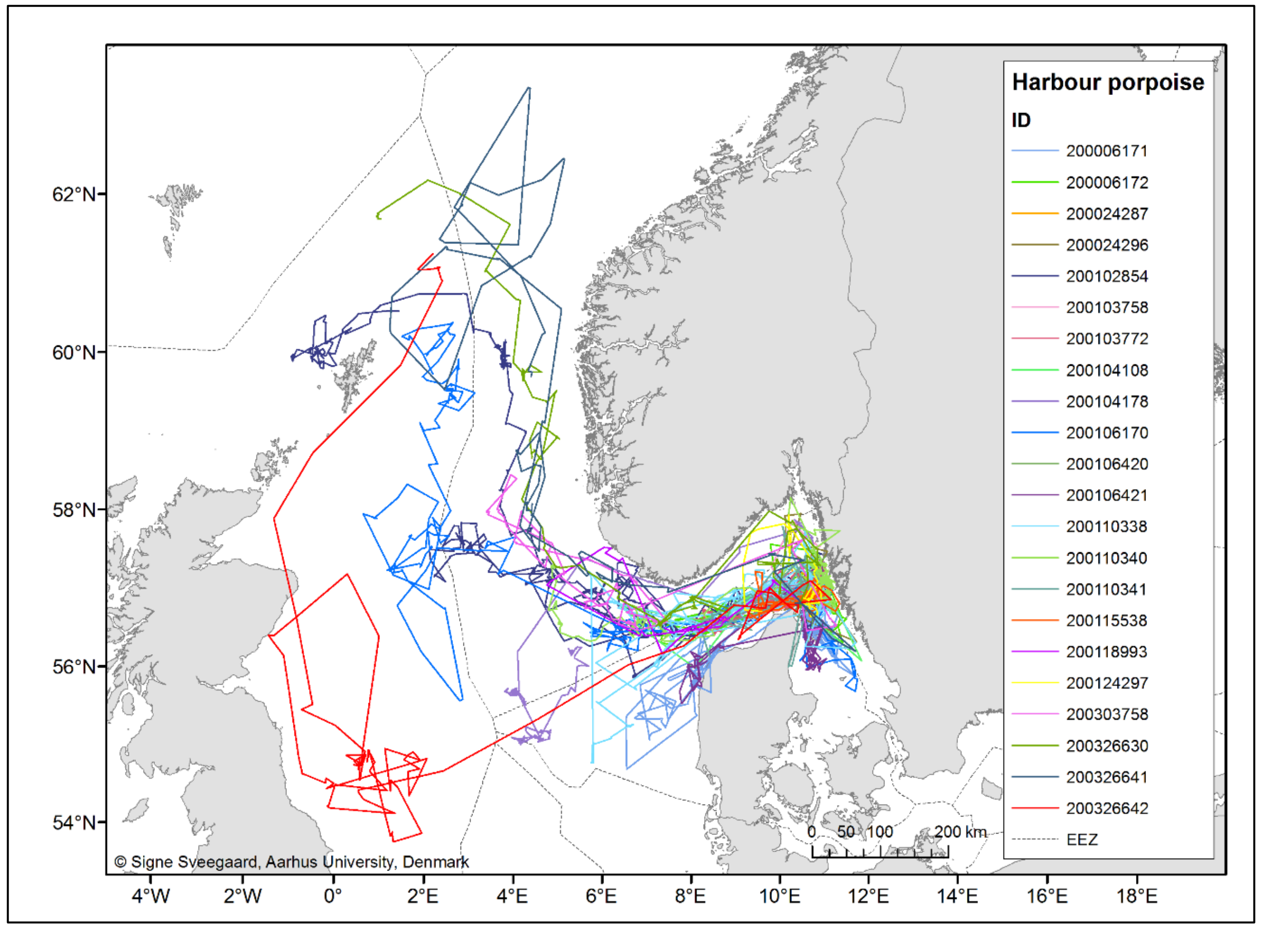


Figure 4.2: Movements of individual harbour porpoise tagged in Skaggerak, Denmark, into the northern North Sea. Longer distance movements are made by immature individuals, whilst mature porpoise did not move west of 6ºE and therefore did not venture into UK waters (Source: S. Sveegaard, Aarhus University).

4.2.2.4 Although there may be some degree of stock structure within the wider North Sea, there is insufficient information to define any sub-populations here and therefore any divisions into the northern North Sea, central and southern North Sea and Celtic Sea are for management purposes only (Reinjders *et al.*, 2009). SCANS surveys of the whole of the North Sea show a southwards shift in distribution of the North Sea population between the survey years of 1996 and 2005; this pattern of higher densities in the southern North Sea persisted in the 2016 surveys (Figure 4.3; Hammond *et al.*, 2002b; Hammond, 2006, Hammond et al., 2017). In recent years, the highest densities of harbour porpoise are therefore in the central and southern North Sea (i.e. the regional marine mammal study area). This southward shift is corroborated by increased sightings and strandings along German, Dutch, Belgian and English coastlines over the last decade (Reijnders *et al.,* 2008). The cause of this shift in distribution is unclear but data from the International Council for the Exploration of the Seas (ICES, 2008) shows a decline in key prey species, such as sandeel and whiting, in the northern North Sea which may in part explain the decrease of harbour porpoise to the north (MCR, 2012).

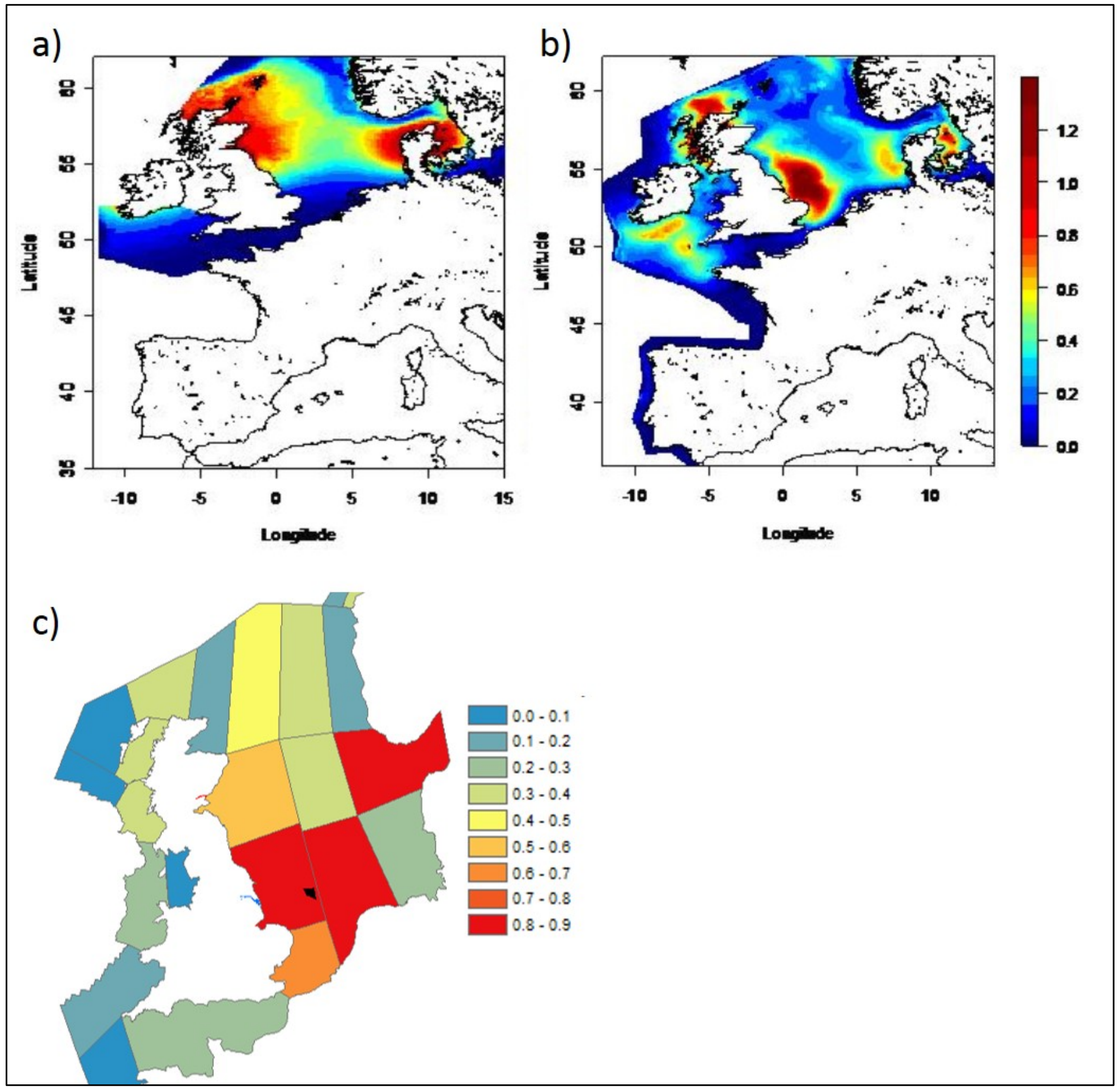


Figure 4.3: Harbour porpoise density estimates a) modelled density surface for SCANS-I 1994 data, b) modelled density surface for SCANS-II 2005 data, c) block wide density estimates for SCANS-III 2016 data.

4.2.2.5 The shift in distribution of porpoise in the North Sea and the seasonal clines observed in the Danish populations demonstrates the fluidity in distribution of harbour porpoise and suggests that some underlying factor (such as environmental conditions or prey distribution) is likely to influence their position rather than any inclination towards site fidelity. Attempts to explain distribution of porpoise have been undertaken through modelling work using environmental variables as predictors, which are themselves a proxy for variation in the assemblages of prey species. For example, a maximum entropy model (Maxtent), used to determine which environmental variable best explained the distribution of porpoise in Danish waters, found that distance to coast and bottom salinity were the strongest predictors of distribution across most seasons (Edrén *et al.*, 2010). Other modelling studies in both Danish and Scottish Waters also found salinity to be a strong predictor of harbour porpoise distribution, and other key explanatory variables included depth, tidal state and sediment state (MacLeod *et al.*, 2007; Marubini *et al.*, 2009, Bailey and Thompson, 2009, Embling *et al.*, 2010). The GAM analyses undertaken for Hornsea Three also used environmental variables to predict densities of harbour porpoise across the study area and found that the best predictors were: depth, latitude/longitude, and days from the start.

4.2.2.6 The sightings maps based on visual and acoustic data showed that harbour porpoise are widely distributed across the study area (Figure 3.4). Similarly, historical sightings data (mainly land-based) from The Greater Wash demonstrated that harbour porpoise is commonly sighted along coastal waters (Figure 4.6). This is validated by aerial survey data from WWT which show that harbour porpoise are regularly sighted along the inshore areas of the East coast and therefore in proximity to where the cable route corridor crosses (Figure 4.7).

4.2.2.7 The Heinänen and Skov (2015) analysis concluded that in the summer months, harbour porpoise presence in the North Sea MU was best predicted by season, water depth, surface salinity and eddy potential, while the density was best predicted by season, the water depth and the vertical temperature gradient. For the summer months the modelling showed a peak in densities at the inner shelf waters (30-50 m depth) and that animals seemed to avoid well mixed areas and waters with high current speeds as well as avoiding areas with muddy or hard bottom substrates.

4.2.2.8 In the winter months the presence of harbour porpoise was best predicted by the season, water depth, eddy potential and the surface sediments. For the winter months the modelling showed a peak in presence was observed at water depths of 30-40 m and that animals seemed to avoid waters with high current speeds as well as avoiding areas with muddy bottom substrates.

4.2.2.9 Overall, this analysis predicted varying densities in both the summer and winter months in the central part of the North Sea MU (Figure 4.5). The density estimates within the Hornsea Three area were highest in the winter of 2004 where predicted densities reached up to 3 porpoise/km^2 and in the summers of 2003 and 2009 where densities reached up to and over 3 porpoise/km^2; though it is important to note that the authors stated that "model uncertainties are particularly high during winter". It is also worth highlighting here that the analysis presented in Heinänen and Skov (2015) relies on extensive extrapolation of survey data over space and time. Any such extrapolation is sensitive to the covariates used in models, as opposed to predictions within the support of the data. Subjective decisions in the retention of covariates in Heinänen and Skov (2015) calls into question the validity of such extrapolation. However, there was a large amount of survey effort across the southern North Sea which may allow a degree of confidence in the predictions in this area.

4.2.2.10 Hornsea Three is located immediately adjacent to the persistent high-density area identified and selected in the southern North Sea MU during the winter (Figure 4.4); which has since been put forward as a cSAC as a result of these data.

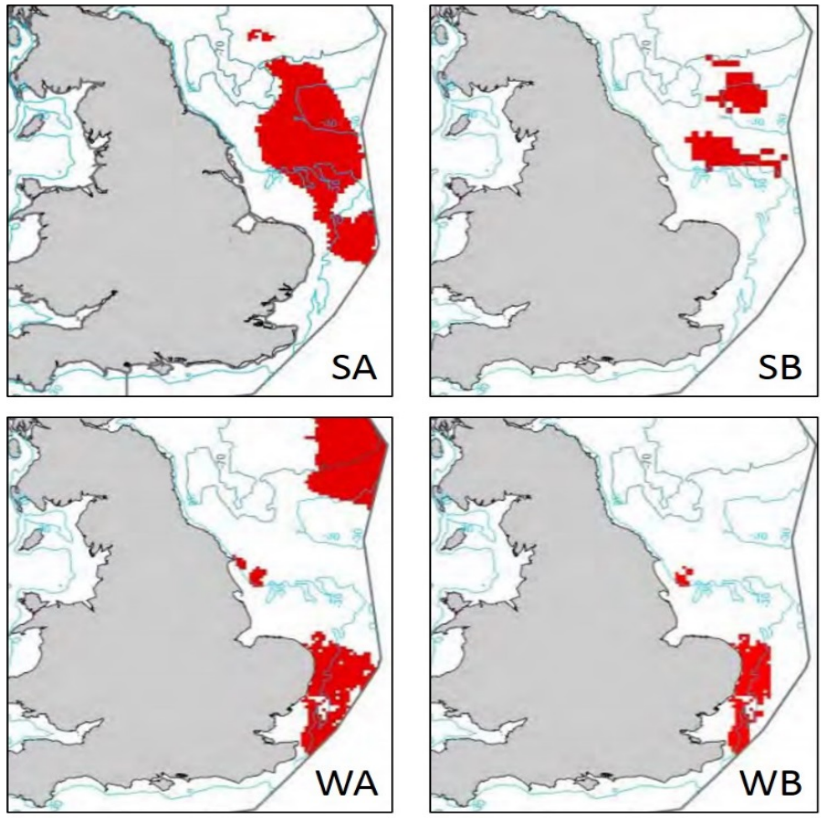


Figure 4.4: Predicted persistent high-density areas identified and selected in the North Sea MU during summer (S) and winter (W). Map A identifies areas with persistent high densities as defined by the upper 90th percentile. Map B identifies persistent high-density areas with survey effort from 3+ years.

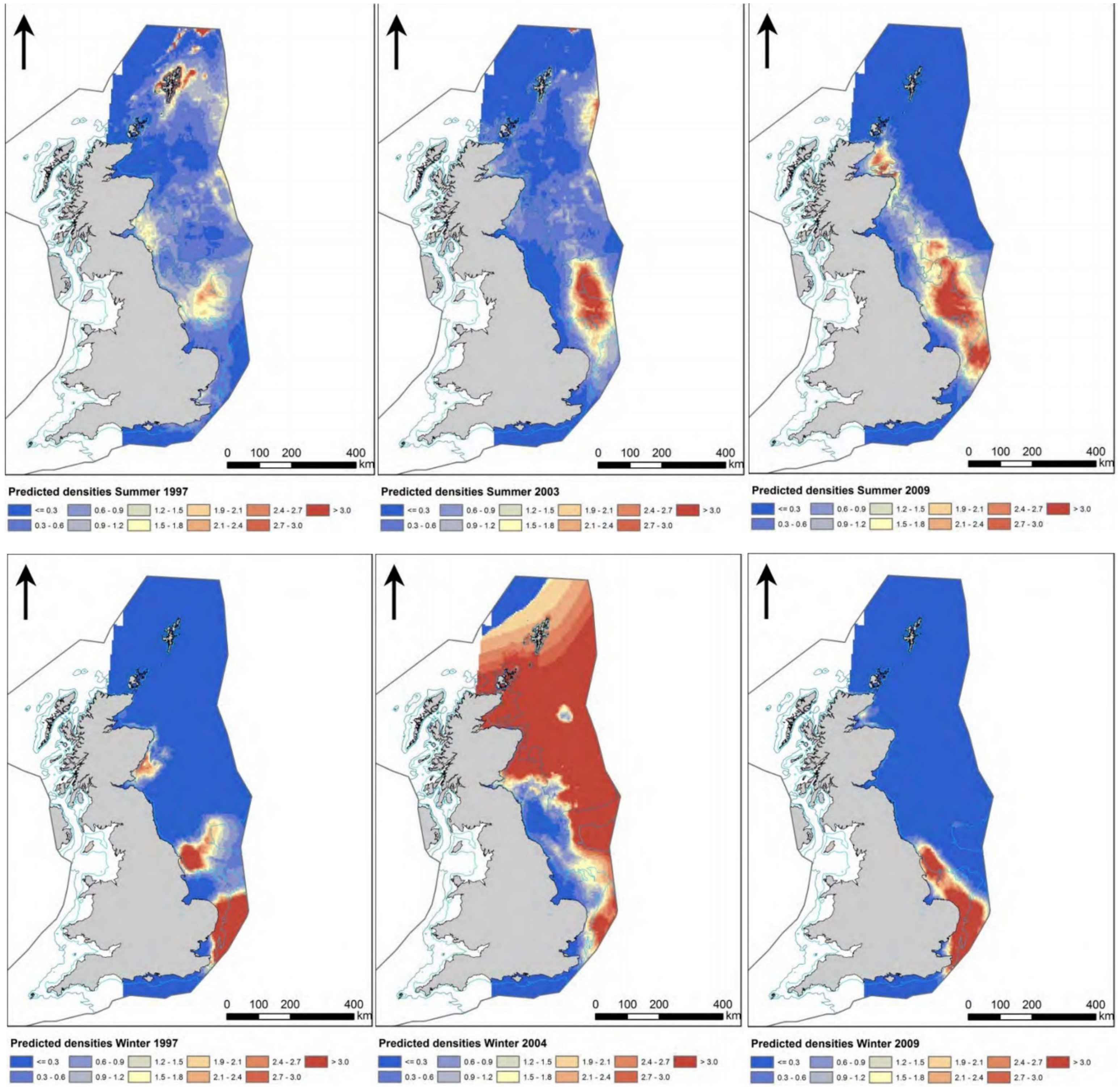


Figure 4.5: Predicted densities (number/km^2) during summer (top) and winter (bottom) in the North Sea MU for three different years in each model period (Heinänen and Skov 2015).

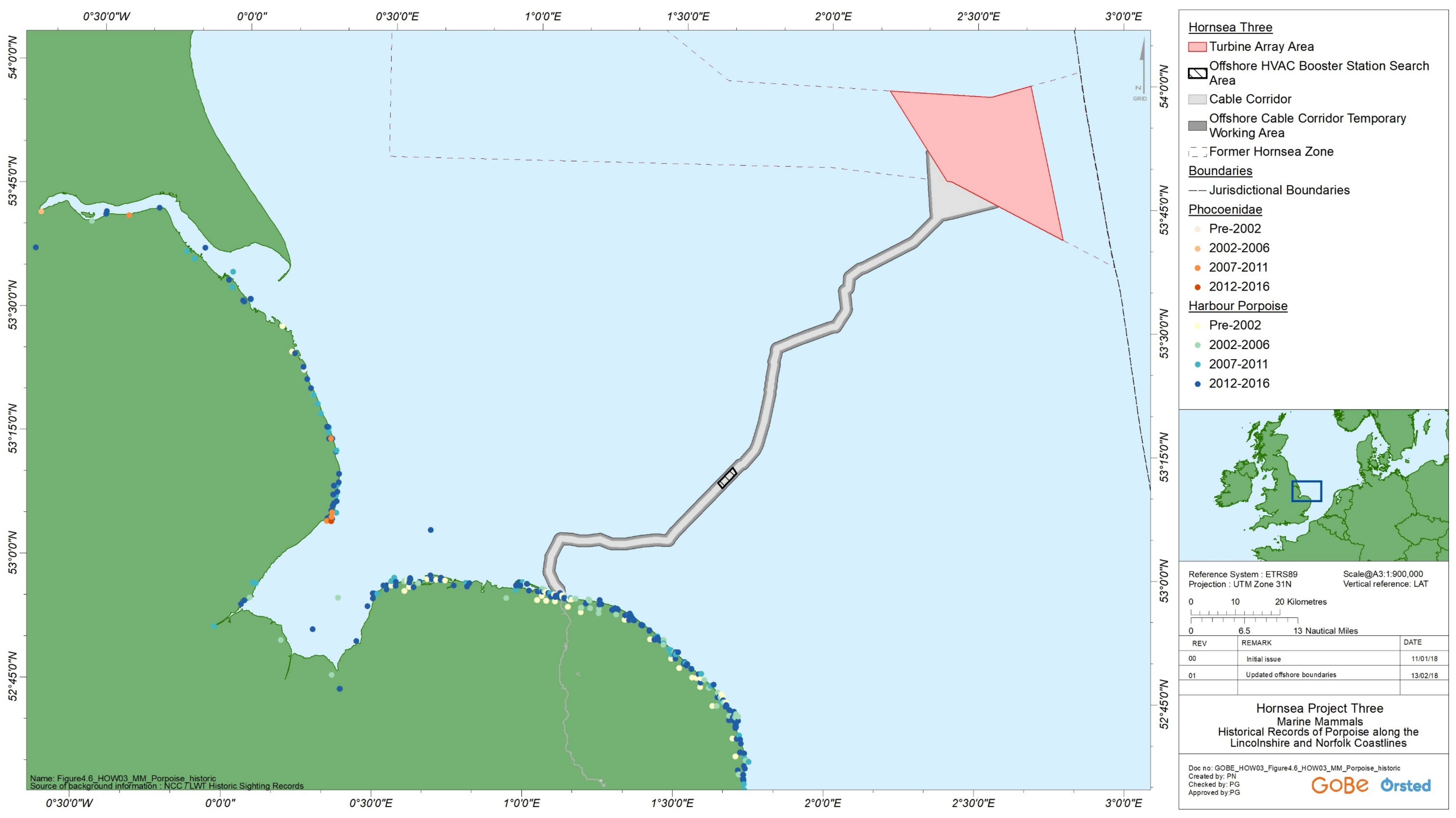


Figure 4.6: Historical sightings of harbour porpoise along the Lincolnshire and Norfolk coastlines between 2002 and 2016. The positions marked indicate the centre of the grid reference describing observer position, thus some locations appear on land.

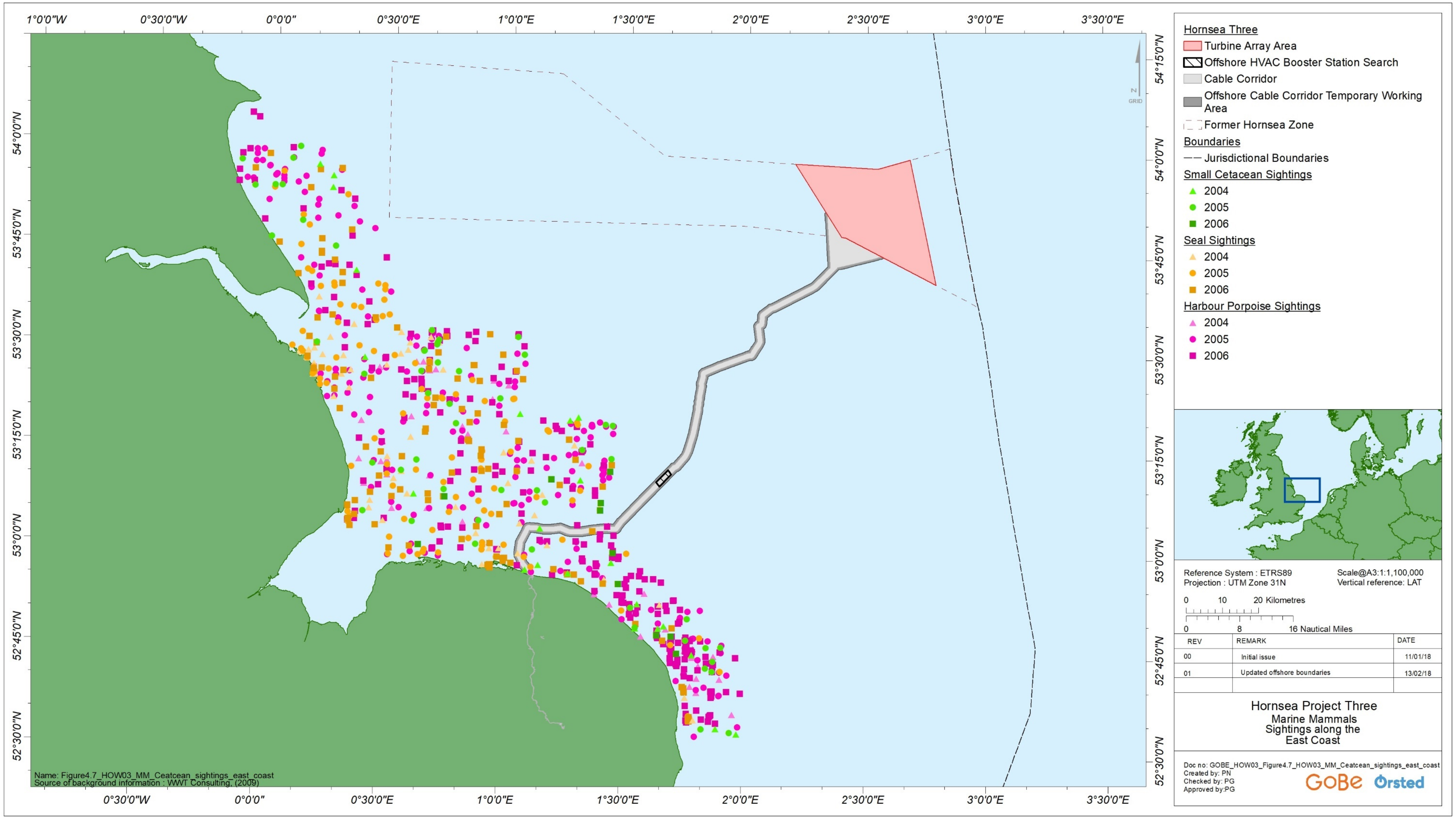


Figure 4.7: Aerial sightings of harbour porpoise (and other small cetaceans and pinnipeds) along the inshore waters of the east Coast between 2004 and 2006.

4.2.3 Abundance

4.2.3.1 Harbour porpoise are the most abundant cetacean in UK waters. In the North Sea ICES Assessment Unit the SCANS-III study estimated a population of 345,373 individuals (CL: 246,526 – 495,752) with a density of 0.52 porpoise/km^2 (Hammond *et al*., 2017). In SCANS III block O an abundance of 53,485 individuals (CL: 37,413 – 81,695) with a density of 0.888 porpoise/km^2 was estimated. This density estimate for block O is higher than the average density estimate across the ICES North Sea Assessment Unit (0.888 compared to 0.52).

4.2.3.2 Abundances of harbour porpoise using the site specific survey data were calculated by multiplying the average density estimates for visual and acoustic boat-based data (corrected for g(0)). Abundance estimates of harbour porpoise vary hugely depending on the dataset with the largest estimates produced using the acoustic boat-based data (3,530 porpoise in Hornsea Three array area plus a 4 km buffer) and the smallest estimates using the aerial survey data (1,253 porpoise in the Hornsea Three array area plus a 4 km buffer) (Table 4.1).

Table 4.1: Summary of absolute abundance and density estimates of harbour porpoise across the different survey areas and based on three datasets: boat-based visual, boat-based acoustic and aerial video.

Data source	Area (km^2)	Density (#/km^2)	Abundance
Former Hornsea Zone plus a 10 km buffer			
Visual boat-based	9,276	1.72	15,955
Acoustic boat-based	9,276	2.22	20,593
Hornsea Three array area plus a 4 km buffer			
Visual boat-based	1,230	1.76	2,165
Acoustic boat-based	1,230	2.87	3,530
Aerial video	1,230	1.019	1,253

4.2.4 Encounter Rate

4.2.4.1 Another useful way to look at the data is to estimate the encounter rate, which is simply the number of animals per kilometre travelled. Encounter rates can be a useful metric to compare variation over time within a given area. For example, Figure 4.8 shows the monthly encounter rate within the former Hornsea Zone plus a 10 km buffer, for sea states 0 to 3 only, across the survey years (2010 to 2013).

4.2.4.2 During surveys, visual observations in sea states 0 to 3 showed little variation in encounter rate across the former Hornsea Zone plus a 10 km buffer in 2011/2012, but peaks in June and July were observed in 2010/2011 (Figure 4.8). The encounter rate in 2012/2013 was greatest during the spring months of March to May, with a noticeable peak in May. The encounter rate for the remainder of 2012/2013 was, on the whole, lower than that calculated for the previous two years. The encounter rate across all years was lowest during the winter months (Figure 4.8). The mean encounter rate for the former Hornsea Zone plus a 10 km buffer over all three years was 0.132 animals/km.

4.2.4.3 During the aerial surveys, harbour porpoise observations varied across the months with the highest number of animals counted in May 2016 (186 porpoise, encounter rate of 0.37 animals/km) and June 2016 (140 porpoise, encounter rate of 0.28 animals/km) (Table 3.17). The lowest numbers were counted in the winter months between October and January where encounter rates ranged between 0.006 and 0.03 animals/km(Table 3.17). The encounter rates for the aerial surveys show a similar temporal pattern to the boat-based data, with higher encounter rates over the summer months compared to the winter months (Figure 4.9). The overall encounter rate across all 20 months of aerial surveys and across all sea states was 0.110 animals/km.

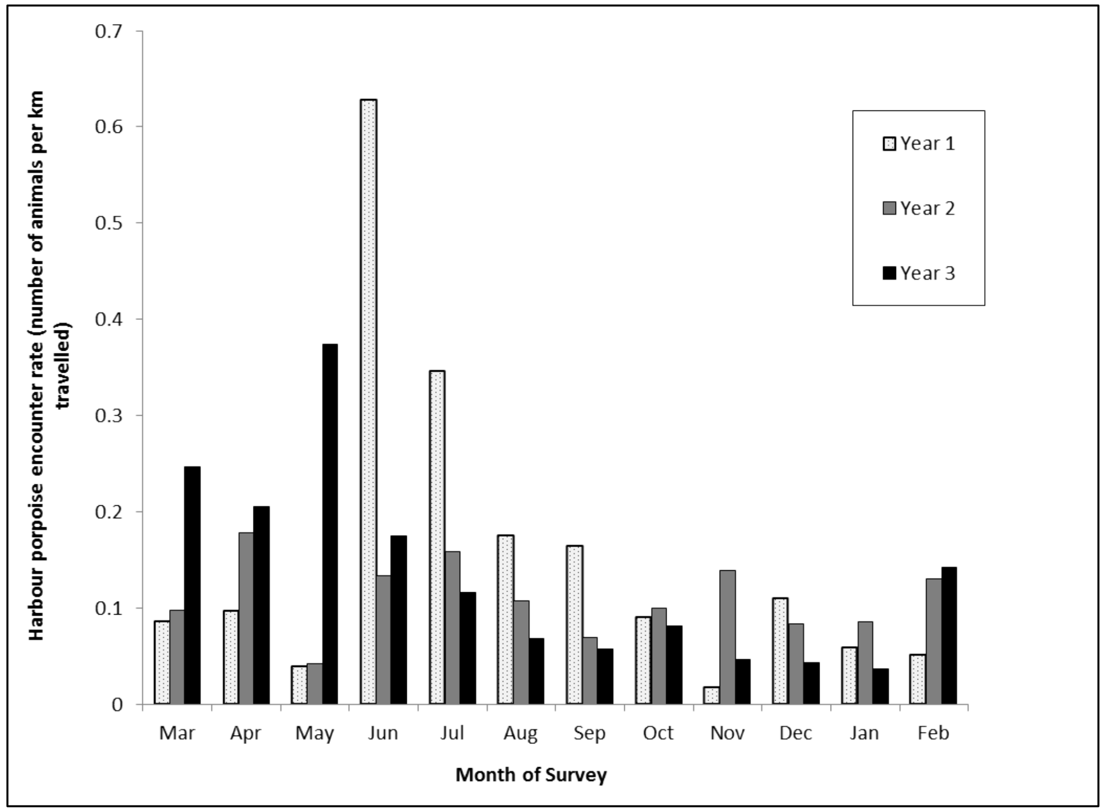


Figure 4.8: Monthly mean encounter rate of harbour porpoise within the former Hornsea Zone plus a 10 km buffer in years one (2010/2011), two (2011/2012), and three (2012/2013). Data presented are for Beaufort Sea States of 0 to 3.

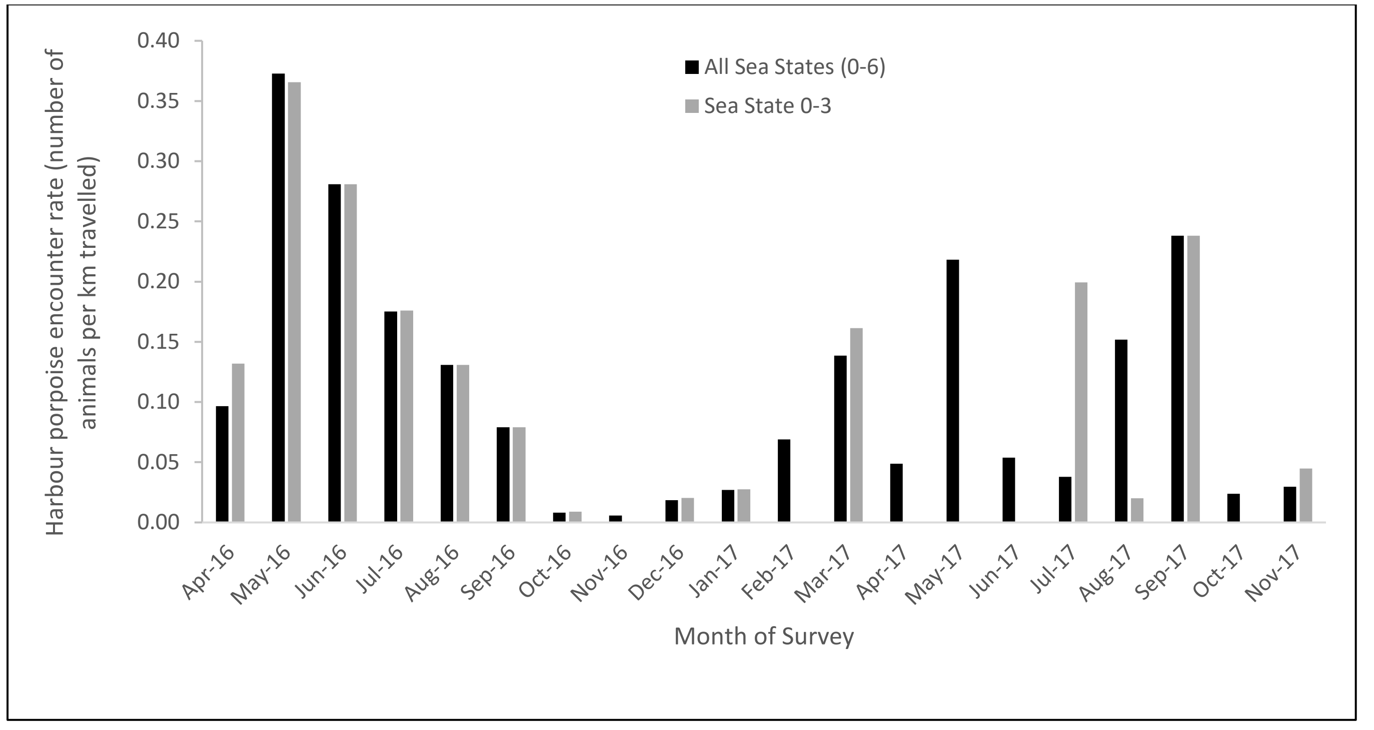


Figure 4.9: Monthly encounter rates of harbour porpoise obtained during the HiDef aerial surveys between April 2016 and November 2017. Data presented show the overall encounter rate across all sea states (0-6) and the overall encounter rate for sea states 0-3.

4.2.4.4 Encounter rates for other offshore wind farms were also examined, although it is worth noting that this cannot be directly compared due to differences that are likely to occur between different surveys and differences in the survey methods themselves. The encounter rate of harbour porpoise varied considerably across other offshore wind farms in the vicinity ranging from 0.08 to 0.385 animals km^{-1} (RWE npower, 2003). A high annual variation was observed at all offshore wind farm survey sites with peaks in numbers occurring mostly during the summer months. However, it is likely that observations would naturally be higher during the summer months simply because the sea conditions tend to be better then so it is difficult to disentangle these two potentially confounding factors.

4.2.4.5 A total of 552 observations of harbour porpoise were made during the Greater Wash WWT surveys during winter 2004/2005 (WWT, 2005; Figure 4.7), which equated to an encounter rate of 0.007 animals km^{-1}. This is considerably lower than the mean encounter rate calculated for the former Hornsea Zone plus a 10 km buffer, Hornsea Three array area plus a 4 km buffer and other offshore wind farm surveys suggesting that harbour porpoise favour offshore areas rather than the shallower coastal waters in this part of the southern North Sea. However, this finding should be interpreted with caution as the WWT surveys were focussed on seabirds with incidental recordings of marine mammals and therefore it is possible that marine mammals may have been under-recorded during the survey.

4.2.4.6 Over the summer months in the former Hornsea Zone plus a 10 km buffer there was an increase in mean group size for each harbour porpoise sighting (Figure 4.10). An increase in both encounter rate and group size during the summer months may reflect an increase in the number of calves recorded during this period. Figure 4.11 shows an increase in the proportion of calves observed as a fraction of the total number of porpoise, including sea state and day of the year (Julian day) as covariates. Sea state was not a significant predictor of the number of calves but there were significant seasonal patterns with lows in April during late pregnancy and a peak proportion of calves around day 200 (in mid-July).

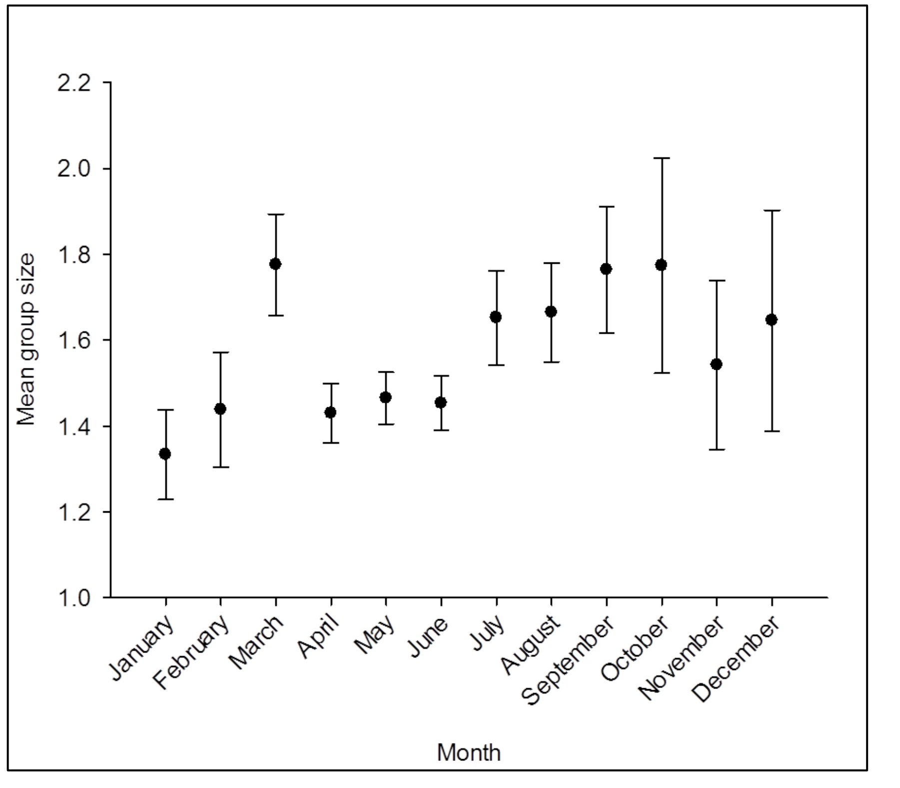


Figure 4.10: Mean group size of harbour porpoise across the year. Data were averaged over three years (2010 to 2013).

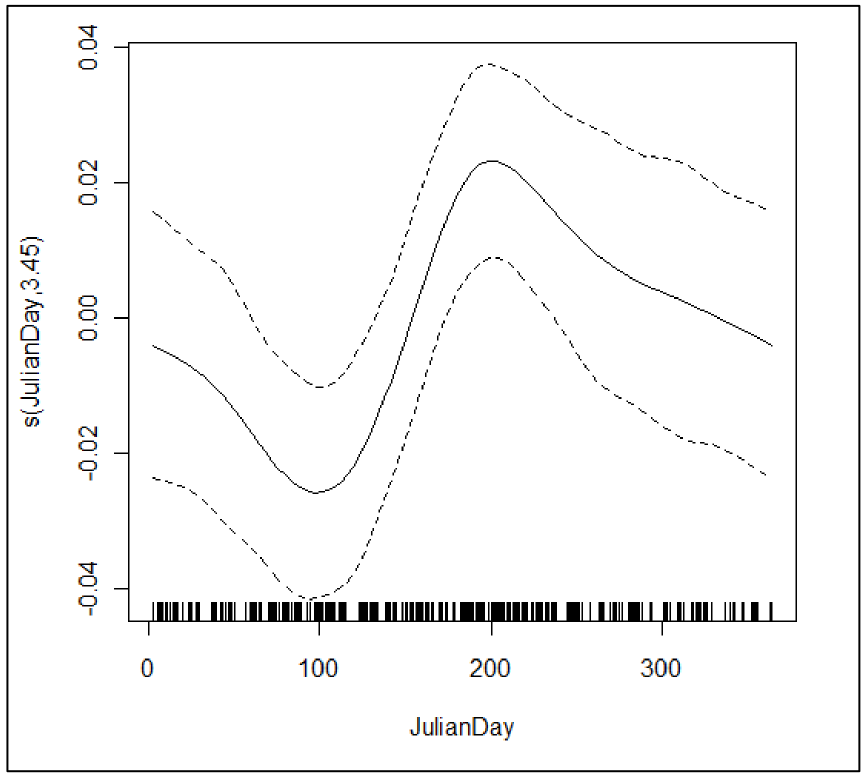


Figure 4.11: Variation in the number of calves (as a proportion of the total number of porpoise) over the days of the year.

4.2.5 Density

4.2.5.1 Estimated densities of harbour porpoise for the Hornsea Three zone varied considerably by survey method. The highest density estimate was obtained using the acoustic data, which provided a density in Hornsea Three plus 4 km buffer of 2.87 porpoise/km^2 and for the former Hornsea Zone plus 10 km buffer of 0.22 porpoise/km^2. The boat based visual surveys provided lower density estimates of 1.76 and 1.72 porpoise/km^2 in Hornsea Three array area plus a 4 km buffer and the former Hornsea Zone plus a 10 km buffer respectively. The lowest site specific density estimates were obtained during the aerial surveys with a corrected density estimate of 1.019 porpoise/km^2. These data represent a large range of density estimates, each of which has associated assumptions, uncertainties and potential biases (as detailed in section 2.6).

4.2.5.2 The SCANS-III survey data for Block O in the south central North Sea provided an estimated harbour porpoise density of 0.888 porpoise/km^2 (CV = 0.21, mean group size 1.31). (Hammond *et al*., 2017). This density estimate is similar to the Hornsea Three aerial survey estimated corrected density of 0.99 porpoise/km^2.

4.2.5.3 The JCP Phase III report provides abundance and density estimates for the "south Dogger Bank" area in which Hornsea Three is located. These estimates are for the number of animals present in each season in 2010. These data predict a density of up to 1.29 (0.88 – 1.84) porpoise/km^2 in the winter with lower densities in the other seasons (Table 4.2).

Table 4.2: Harbour porpoise abundance and density estimates for the south Dogger Bank area of commercial interest in 2010, as presented in Paxton et al. (2016).

	Winter		Spring		Summer		Autumn	
	Abundance	Density	Abundance	Density	Abundance	Density	Abundance	Density
point estimate	18400	1.29	7000	0.49	9700	0.68	5000	0.35
2.5%	12500	0.88	4000	0.28	6700	0.47	3700	0.26
97.5%	26300	1.84	13600	0.95	13100	0.92	7400	0.52

4.2.5.4 The density of porpoise at a wider scale has also been included here to provide context relative to other parts of the North Sea. Density values for harbour porpoise were available for the coastal inshore waters through which the Hornsea Three offshore cable corridor passes (RWE npower, 2003). These were based on the WWT aerial survey data shown in Figure 4.6 and the relative density was calculated as 0.04 animals km^{-2}, on average, across the entire region (RWE npower, 2003). Most sightings were encountered in the first distance band (0 to 50 m) and the absolute densities were calculated by fitting a detection function and scaling up for estimates of g(0) ranging between 0.1 and 1 (in the absence of a value of g(0) specific to the former Hornsea Zone). There are limitations with aerial surveys in that animals may be missed since even with the corrections the densities appear to be considerably lower along the inshore areas compared with the former Hornsea Zone. Therefore, as a precautionary estimate, the absolute density was given as 0.459 animals km^{-1} based on the upper confidence limit for the lowest value of g(0), (i.e. g(0) = 0.1). As a comparison, the absolute density estimate for coastal inshore waters is slightly less than the average for SCANS-III Block O of 0.888 animals/km^2(CV = 0.21) (Hammond *et al*., 2017).

4.2.5.5 Comparison was also made with data collected over the Dogger Bank in the southern North Sea. This area is considered to be important for harbour porpoise and as such the German Dogger Bank SCI lists harbour porpoise as a primary reason for site selection, whilst the Dutch Dogger Bank SCI lists harbour porpoise as a qualifying feature (Table 3.1). Harbour porpoise is listed as a non-qualifying feature of the UK Dogger Bank SCI. Data from aerial surveys of the Dogger Bank in 2011 were used to estimate a porpoise density in the whole study area of 1.82 animals km^{-2} (95% CI: 1.01 to 3.51; CV = 0.31) (Gilles *et al.,* 2012). Highest densities were estimated for the western and north eastern part of the survey area with a peak of 3.14 animals km^{-2} (95% CI: 1.59 to 6.36; CV = 0.36). These density estimates are comparable to the former Hornsea Zone plus a 10 km buffer estimates suggesting that both areas are of importance to harbour porpoise within the south central North Sea.

4.2.5.6 The distribution and density of harbour porpoise over Dogger Bank and surrounding waters was assessed in November 2011 by Cucknell *et al*. (2016) using both visual and towed acoustic methods. A total of 653 km were surveyed visually resulting in nine harbour porpoise sightings with mean group size 1.6 (SD 1.3, range 1 to 6) however, most effort was conducted in sea state 3 or above which is less suitable for visual surveying of harbour porpoise. A total of 2980 km of effort was conducted with a towed hydrophone which resulted in 769 detections. The acoustic detections were truncated at 450 m (the maximum detection range) and a g(0) of 0.46 (95% CI 0.19 to 0.75) was estimated using the visual sightings as trials. A value of 1.6 was used to correct for group size to calculate absolute abundance and density estimates. The resulting density estimates (and 95% CI) were: 0.90 porpoise/km^2 (0.34 to 2.34) for the western central North Sea, 0.46 porpoise/km^2 (0.18 to 1.16) for the eastern North Sea and an overall 0.63 porpoise/km^2 (0.27 to 1.52) for the central North Sea. These values are very similar to the SCANS II Block U density estimate of 0.6 porpoise/km^2 and the SCANS-III Block O density of 0.888 porpoise/km^2. The density estimate for the UK Dogger Bank SAC was 0.49 porpoise/km^2 (95% CI 0.16 to 1.49) and for the south-west part of the Dogger Bank was 1.21 porpoise/km^2 (95% CI 0.52 to 2.84). These results (Figure 4.4) mirror previous surveys that have found higher densities in the west of the North Sea, especially to the west of Dogger Bank (e.g. SCANS II (Hammond *et al*., 2013) and DEFRA/IMARES surveys (Geelhoed *et al*., 2014).

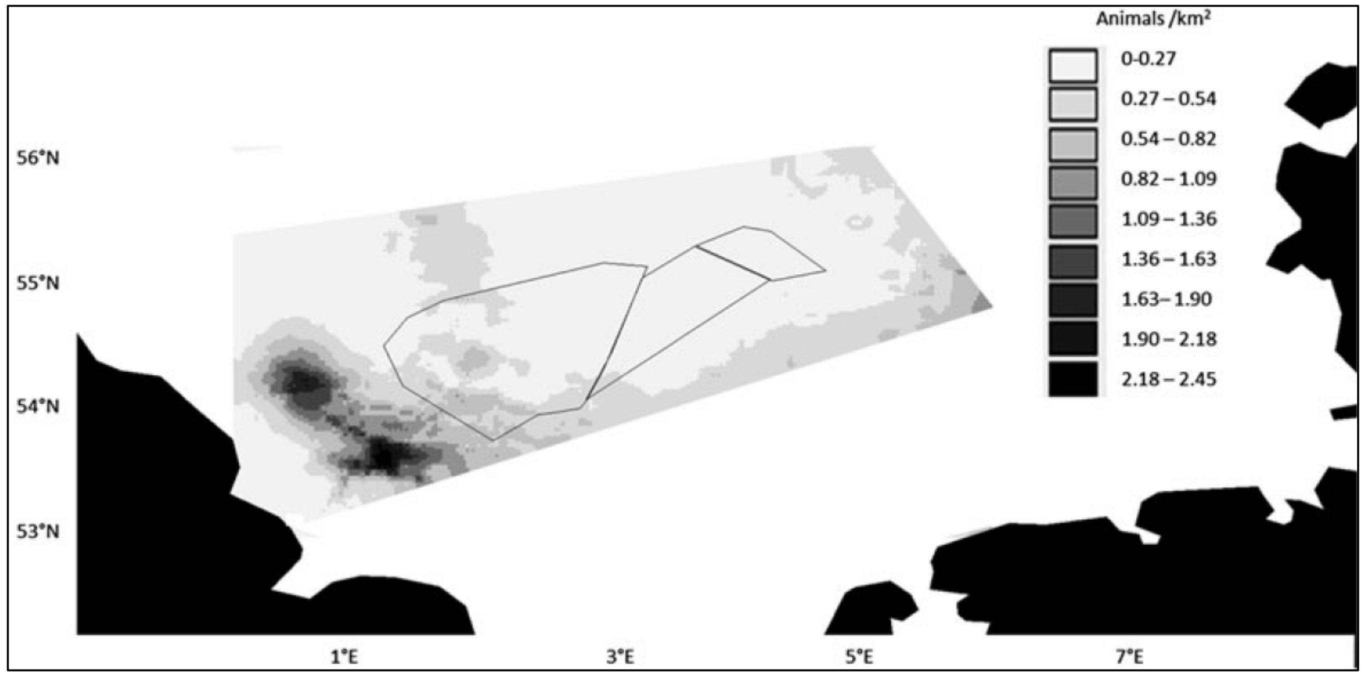


Figure 4.12: Map of the predicted density of harbour porpoises across the ‘central North Sea’ survey area created from density surface modelling using depth, latitude and longitude as covariates (Cucknell et al., 2016). The black lines denote the Dogger Bank areas of the UK, Netherlands and Germany (from left to right respectively).

4.2.5.7 By comparison, aerial surveys conducted by Hi-Def at the Dogger Bank Zone between 2009 and 2011 showed large variation in porpoise abundance and density between survey years. As such, given the high degree of inter-annual variation in the spatial distribution and the variation in monthly abundance, average densities were calculated for both the Dogger Bank Creyke Beck site and the Teesside site. This resulted in an average absolute density of 0.569 individuals/km^2 (95% CI 0.508 to 0.657) at Creyke Beck (Forewind 2013) and 0.641 individuals/km^2 (95% CI 0.578 to 0.714) at Teesside (Forewind 2014). These density estimates are similar to those obtained by Cucknell *et al*. (2016) for the central North Sea and SCANS-III block O (Hammond *et al*., 2017) (0.63 and 0.888 respectively).

4.2.5.8 Data from the East Anglia THREE site are also available for comparison. A digital aerial survey was conducted by APEM over 24 months between September 2011 and August 2013, covering the East Anglia THREE site plus a 4 km buffer. Abundance estimates were calculated by multiplying the mean number of marine mammals per image by the total number of images required to cover the entire study area and non-parametric bootstrap methods were used for variance estimation. Counts of surfacing individual porpoise were corrected using Paxton *et al*'s (2011) availability correction factor (0.32) to account for individuals below the surface that were not available to be counted. Using this method the mean estimated density across the East Anglia THREE site plus the 4km buffer across both survey years was 0.179 porpoise/km^2 (Hubble *et al*., 2015). These density estimates are considerably lower than those for the Dogger Bank (Cucknell *et al*., 2016), SCANS-III block O (Hammond *et al*., 2017) or the Hornsea Three site specific boat based surveys. The density maps based on the boat-based data showed a range in values across the former Hornsea Zone plus a 10 km buffer and both the visual and acoustic data revealed localised areas of higher density (Figure 3.6). Relatively high densities were predicted in the area to the east of Hornsea Three and also in the southwest of the former Hornsea Zone. The areas of higher density typically corresponded to areas of shallower water and, in the wider former Hornsea Zone; the areas of higher density appeared to coincide with known areas of sandbanks such as those immediately to the south of Markham's Triangle in the east of the former Hornsea Zone. Notably, both the visual and acoustic datasets indicated low densities of harbour porpoise in the deeper waters immediately to the north and northeast of the former Hornsea Zone as well as the deeper waters in the west of the former Hornsea Zone (Figure 3.6). There was no apparent relationship between density and substrate type or any tidal variables. In addition, there was no information available on the presence of tidal races (rapids) which may attract foraging porpoise to provide explanation of areas of high density.

4.2.5.9 In summary, there have been several studies that have produced density estimates for harbour porpoise in the vicinity of Hornsea Three, using a variety of survey methods and resulting in a wide range of density estimates from 0.11 porpoise/km^2 (JCP Phase-III scaled density map) to 2.87 porpoise/km^2 (Hornsea Three + 4 km buffer acoustic estimate) (Table 4.3). Each of these surveys have been conducted differently and different data analysis methods have been applied to the data, each of which differ in terms of assumptions such as cluster size, g(0) estimates etc. None of the density estimates can be considered to accurately reflect "true density" and the assumptions behind the density estimates and the level of confidence in those estimates needs to be considered. Much of the data collected to provide these density estimates are from relatively old datasets, for example, the Hornsea zone vessel surveys were conducted between 2010 and 2013, which are now between four and seven years old. The most recent data available are the SCANS-III block O data (2016) which estimated 0.888 porpoise/km^2 and the HiDef Hornsea Three surveys (2016-2017) which estimated 1.019 porpoise/km^2. Given the uncertainties, it is recommended that a range of density estimates are taken forward into the quantitative impact assessment, with emphasis placed on the more recent site specific estimates (HiDef Aerial survey) and the SCANS III estimates for the wider area beyond the range of these surveys.

4.2.5.10 The density estimates obtained from the Hornsea Three and Hornsea Zone site specific surveys provide fine temporal and spatial scale data, the surveys did not extend far enough from the Hornsea Three site to provide reliable density estimates for the entire potential behavioural impact zones for the noise impact assessment. Since harbour porpoise densities are known to vary considerably both spatially and temporally, it would not be appropriate to extrapolate the site specific density estimates to areas that were not surveyed. As such, broader scale density estimates from SCANS III will be incorporated into the assessment.

Table 4.3: Density estimates obtained from various studies in the vicinity of Hornsea Three that could be considered for impact assessment.

Location	Survey Year(s)	Survey method	Source	Density (#/km^2)	95% CI	CV
Hornsea Three array area plus a 4 km buffer	2010 - 2013	vessel	Hornsea Three	1.76		
Hornsea Three array area plus a 4 km buffer	2011 - 2013	acoustic	Hornsea Three	2.87		
Hornsea Three array area plus a 4 km buffer	2016 – 2017	aerial	Hornsea Three	1.019		
Former Hornsea Zone plus a 10 km buffer	2010 - 2013	vessel	Hornsea Three	1.72		
Former Hornsea Zone plus a 10 km buffer	2010 - 2013	acoustic	Hornsea Three	2.22		
South Dogger Bank area of commercial interest from JCP	1994 - 2010	Vessel	Paxton et al. (2016)	1.29	0.88 – 1.84	
Western central North Sea	2011	acoustic	Cucknell *et al*. (2016)	0.9	0.34 - 2.34	
Block O (western central North Sea)	2016	aerial	SCANS-III	0.89		0.21

4.2.6 Seasonal variation

4.2.6.1 As shown in Figure 4.13, average harbour porpoise density, as determined from boat-based visual data, peaked during the summer months. Likewise, the porpoise encounter rates peaked in the summer months during the aerial surveys (Figure 4.9). The boat-based visual data showed a large and distinct peak in density during the month of June which is likely to have been driven by the comparatively higher number of sightings (and higher encounter rate) of harbour porpoise during June of 2010/2011 (Figure 4.8). This corresponds to the harbour porpoise life cycle at this time of year when females are nursing calves and are being escorted by males. In comparison, the acoustic data showed no distinct seasonal peaks (Figure 4.13). The reason for this is unknown; however, one possibility is that there may be differences in the vocal behaviour between seasons that masks patterns in encounter rate. The factors affecting seasonal variation for acoustic and visual data is discussed in paragraph 3.4.1.34, and it is likely that some of the variance in the model will be due to environmental conditions other than those measured and accounted for as covariates in the GAM model.

4.2.6.2 Visual sightings rates varied significantly during the day with a peak at midday which may have been attributable, at least in part, to better light levels aiding visual observations at this time of day. The acoustic detections similarly varied during the day but in contrast to the visual sightings, a low point was observed in mid-afternoon which was not unexpected as other studies have shown porpoise to be more vocally active at night (Todd *et al.*, 2009).

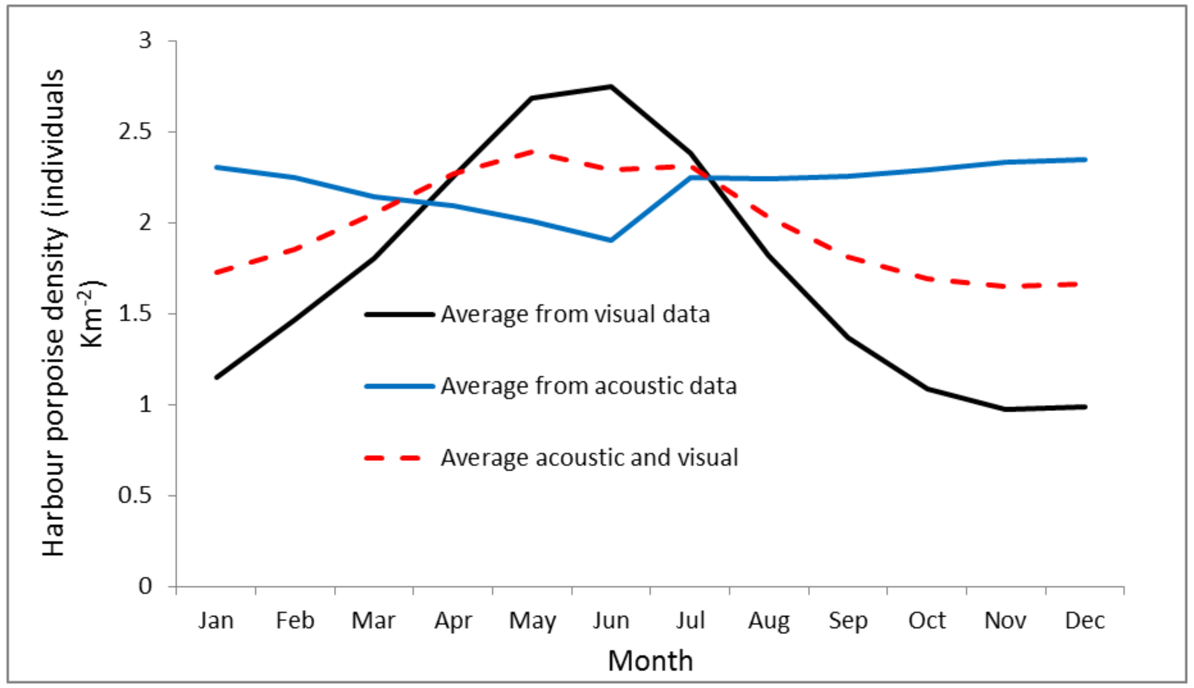


Figure 4.13: Patterns in monthly variation of harbour porpoise across former Hornsea Zone plus a 10 km buffer from model based estimates of visual and acoustic data.

4.2.6.3 To investigate inter-annual variability, density variation throughout the three year survey period was plotted using surface-modelled density estimates from the visual and acoustic data (Figure 4.13). As seen with the abundance data, the seasonal peak in June from the visual data was less pronounced in 2011/2012 compared with 2010/2011. The peak in 2012/2013 was comparable with that observed in 2010/2011, albeit the predicted harbour porpoise density was slightly lower than 2010/2011. These summer peaks fit well with the porpoise life cycle as at this time of year.

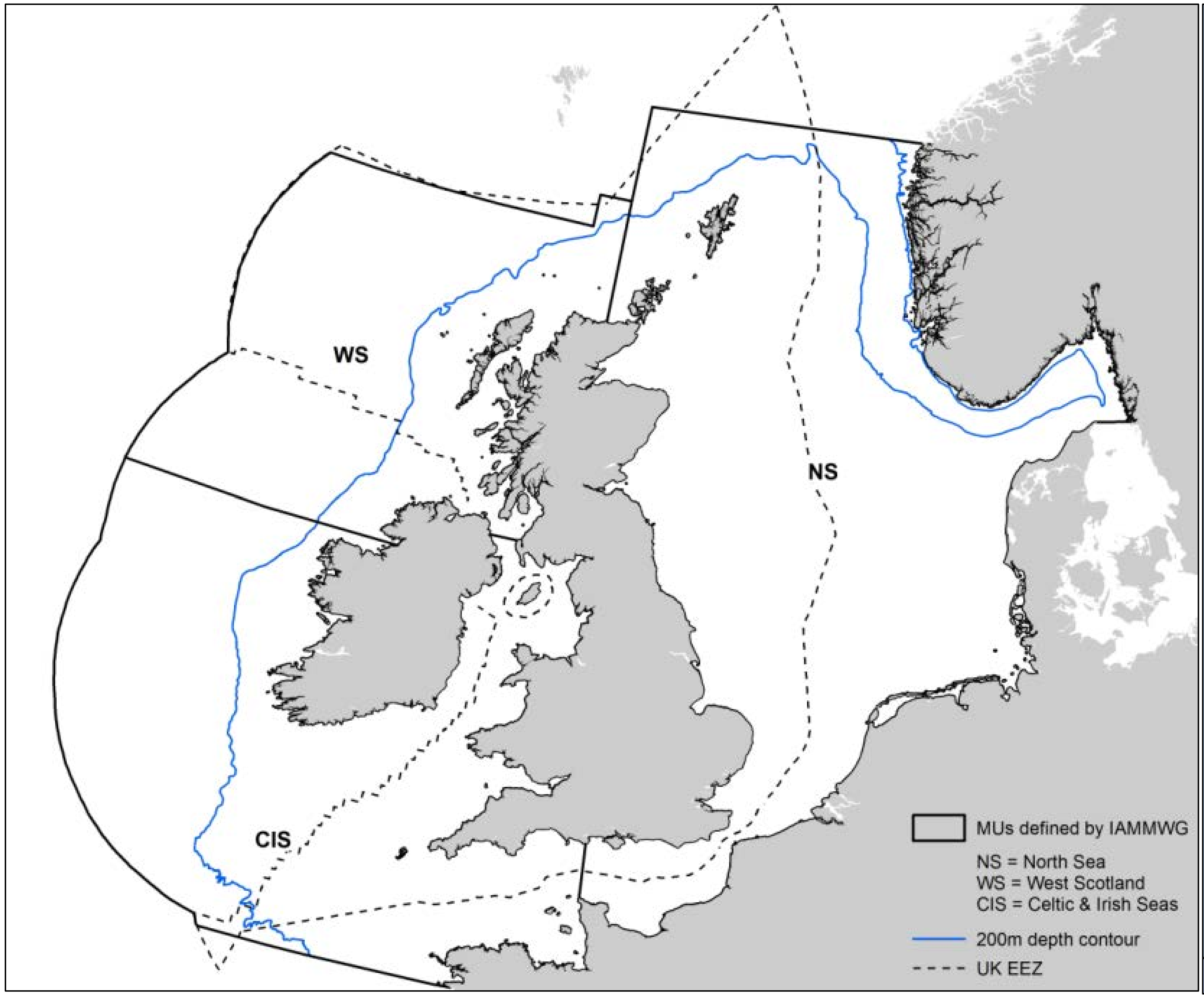
4.2.6.4 The predicted densities from the acoustic data showed less pronounced inter-annual variability although the largest peak in the modelled density estimate from this data was in June of 2010/2011 which coincided with the seasonal peak from the visual data. Other than June of 2010/2011, surprisingly the trend in the predicted densities from the acoustic data demonstrated no correlation with the predicted densities from the visual data (Figure 3.7). The greater variability in the visual estimates of density, compared to the acoustics, suggests that factors affecting visual detection were not fully taken into account within the model, (despite the visual model incorporating sea state as the covariate that best explained sightings probability). Furthermore, as the average of the two datasets showed the lowest variability (Figure 3.7 and Figure 4.13); this suggests that much of the apparent variability is likely to be caused by un-modelled effects on detection probability rather than changes in harbour porpoise numbers.

4.2.6.5 Whilst significant patterns in seasonal distribution have been observed, these are not simple winter and summer bias. It seems possible that aggregations of harbour porpoise move across the area, but this may not be a predictable seasonal effect. The Hornsea Three marine mammal survey study area is relatively small in terms of the large-scale spatial movements of harbour porpoise within the south central North Sea and small shifts in distribution could generate the observed changes.

4.2.7 Management unit

4.2.7.1 Harbour porpoise in the Northeast Atlantic, from the French coasts of the Bay of Biscay northwards to the Arctic waters of Norway and Iceland, are generally considered to behave as a continuous population. SCANS-II data provide further support for a large population as there is a near continuous distribution of sightings throughout the central and southern North Sea and up along the east coast of the British Isles (see Figure 4.1).

4.2.7.2 The IAMMWG has identified three MUs as appropriate for harbour porpoise: North Sea (NS), West Scotland (WS) and Celtic and Irish Seas (CIS). Hornsea Three falls within the North Sea MU which extends from the southeast coast up to the northern tip of Scotland and comprising the ICES areas IV, VIId and Division IIIa (Figure 4.14). Population estimates for this area were based on the most recent analysis of the SCANS-II data (Hammond *et al.*, 2013). The total harbour porpoise abundance for the North Sea MU was estimated as 227,298 animals (IAMMWG, 2015) (Table 3.4). A more recent MU abundance estimate has been calculated using the SCANS-III data (Hammond *et al.*, 2017). This provides an abundance estimate for the ICES North Sea Assessment Unit of 345,373 (95% CI 246,526 – 495,752).



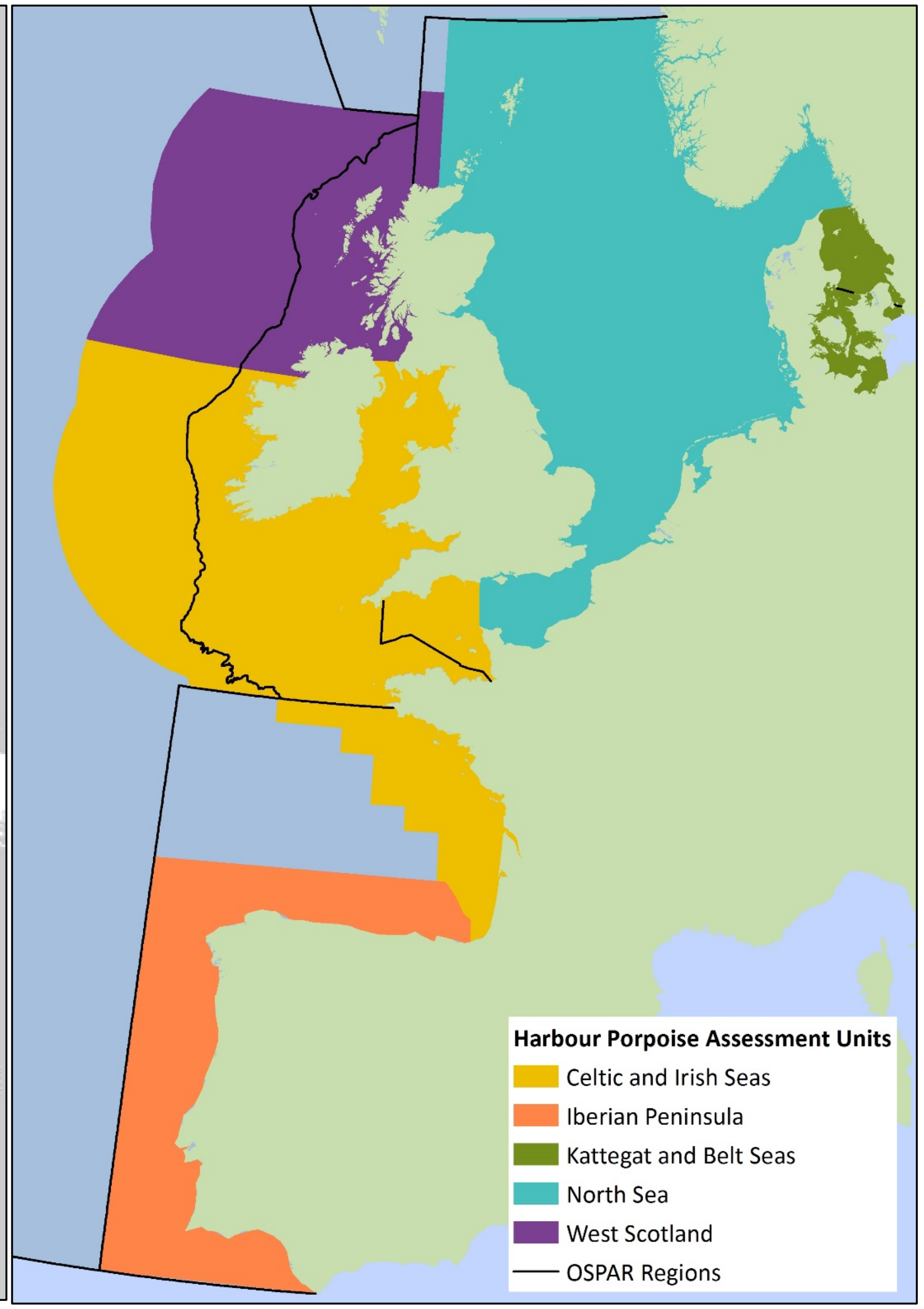


Figure 4.14: Harbour porpoise MUs as defined by IAMMWG, 2015 (left) and by ICES, 2014 (right).

4.2.8 Favourable Conservation Status

4.2.8.1 JNCC report that the Conservation Status of harbour porpoise is Favourable for range, population, habitat, future prospects and overall assessment.

4.2.9 Links between Hornsea Three marine mammal study area and European Sites

4.2.9.1 Harbour porpoise is the single qualifying interest feature of the Southern North Sea cSAC. The Hornsea Three offshore cable corridor transects the cSAC.

4.2.9.2 Harbour porpoise are a qualifying interest feature of the Klaverbank pSCI which lies approximately 11 km to the east of the Hornsea Three array area and of the Dutch Dogger Bank SCI which lies approximately 42 km north and east of the Hornsea Three array area.

4.2.9.3 Harbour porpoise are a primary reason for site selection of the Noordzeekustzone SAC and the Noordzeekustzone II pSCI, which lie approximately 148 km and 138 km respectively from the Hornsea Three array area.

4.2.9.4 The Vadehavet med Ribe Ấ SAC which lies approximately 381 km from the Hornsea Three array area also has harbour porpoise as a primary reason for site selection.

4.2.9.5 Distribution of harbour porpoise is thought to follow the distribution of key prey species (Sveegaard *et al.*, 2011b) and make longer distance movements between key areas. It is therefore considered likely that connectivity exists between Hornsea Three and areas designated for harbour porpoise.

4.3 White-beaked dolphin

4.3.1 Ecology

4.3.1.1 The white-beaked dolphin is one of the most abundant delphinid species in the shelf waters of the British Isles and Republic of Ireland (Hammond *et al.*, 2002b).

4.3.1.2 White-beaked dolphins can grow up to 3.5 m for males and 3.05 m for females. Maximum recorded age is 37 years (Kinze, 2009) and adults become sexually mature at a length of approximately 2.6 m and at approximately 12-13 years of age (Reeves *et al*., 1999b). White-beaked dolphin mating occurs during the warmer months, with calving occurring during the summer between June and September (Kinze *et al.*, 1997). Gestation period is approximately 11-12 months duration. Little is known about the reproductive behaviour of this species and whilst it is thought that births often occur offshore in the northern North Sea (Evans, 1991), there is also evidence to suggest that females move into inshore waters to give birth (Canning *et al.*, 2008; Weir *et al.*, 2007).

4.3.1.3 The main prey species for white-beaked dolphin in Scottish waters is whiting, but this species also consume other clupeids (e.g. herring), gadoids (haddock, cod) and scad (Canning *et al.*, 2008; Santos *et al.*, 1994). Although the distribution and abundance of prey species affects the distribution and abundance of white-beaked dolphin, this species tends to be influenced by temperature with larger numbers and group sizes associated with cooler temperatures (Evans, 1990; Weir *et al.*, 2007; Canning *et al.*, 2008).

4.3.1.4 Due to gaps in knowledge about the ecology of this species, the conservation status of the white-beaked dolphins within North Sea waters is currently unknown (Weir *et al.*, 2007). Whilst there are no reported decreases in the global abundance of this species, there are concerns about the potential impact of climate change causing a reduction in its range (MacLeod *et al.*, 2005; see paragraph 4.3.2.1).

4.3.2 Distribution

4.3.2.1 The white-beaked dolphin is distributed throughout the temperate and sub-polar seas of the Northern Atlantic (Reeves *et al.*, 1999). It is found primarily in waters of 50 to 100 m deep and occurs over a large part of the European continental shelf. Atlantic white-beaked dolphin are only common in waters cooler than 14°C and are absent in regions where the temperature exceeds 18°C (MacLeod *et al.*, 2008; Parsons *et al.*, 2012a). Temperature is the most important factor in shaping the distribution of this species (Canning *et al.*, 2008; MacLeod *et al.*, 2008) and during the warmer summer months it is likely that white-beaked dolphin in the North Sea will be restricted to more northerly areas (Canning *et al.*, 2008) (Figure 4.15).

4.3.2.2 The requirement for cooler waters means that this species is one of the cetaceans most vulnerable to the effects of climate change. An increase in sea temperature in north west Europe's continental shelf of one to 2 °C has resulted in a northward shift in their distribution with the result that white-beaked dolphin are no longer present in much of western Scotland, where once the densities were the highest in the world (MacLeod *et al.*, 2005; Parsons, 2012a). The northern North Sea is now the most important region for this species within UK waters (Figure 4.15).

4.3.2.3 Historical data provided by the GLNP based on land-based sightings confirm the presence of white-beaked dolphin within the Greater Wash area (Figure 4.16) between 2002 and 2016. It is therefore considered possible that white-beaked dolphin could be present within the Hornsea Three array area and offshore cable corridor.

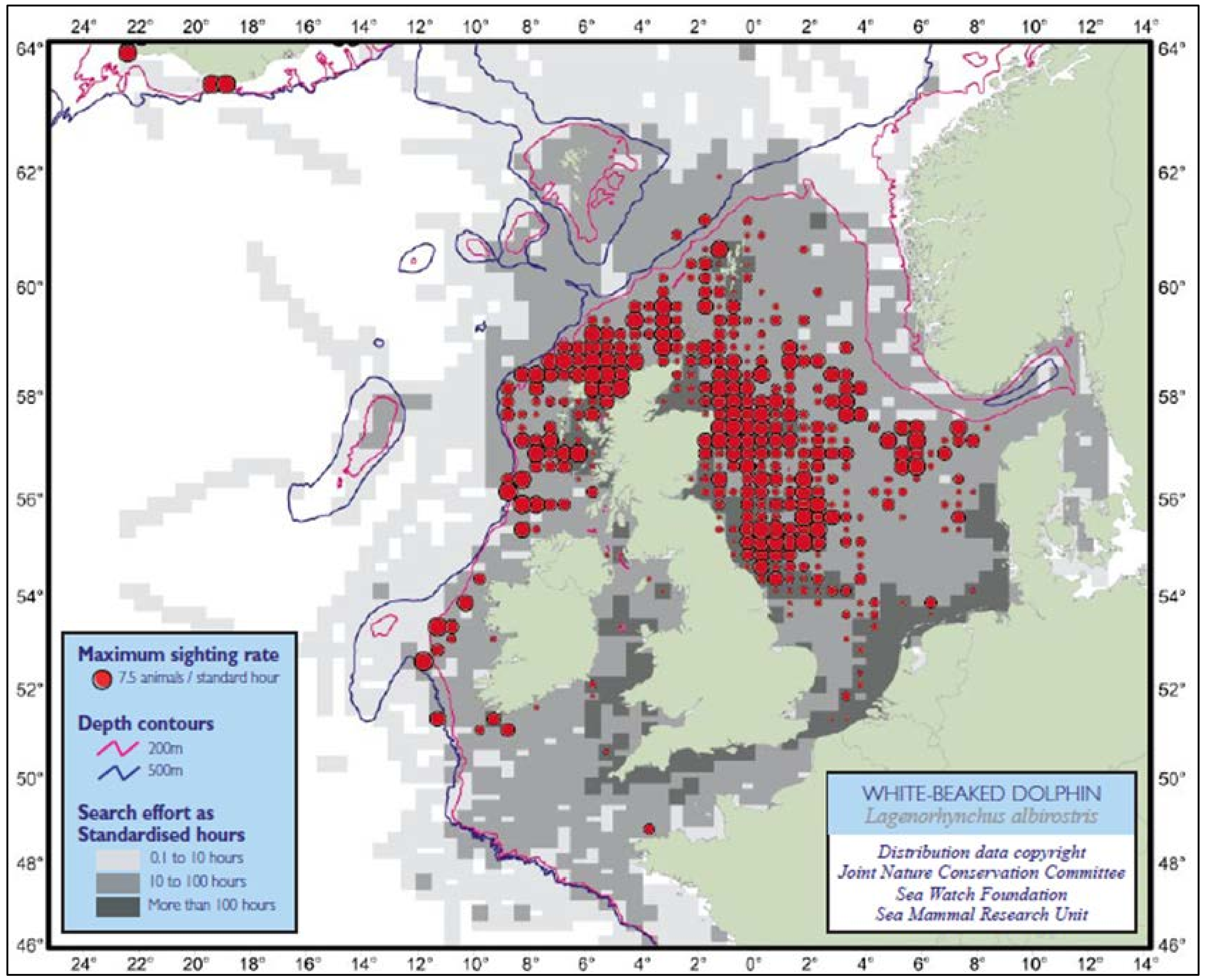


Figure 4.15: Distribution of white-beaked dolphin around the UK coast (Reid *et al.*, 2003).

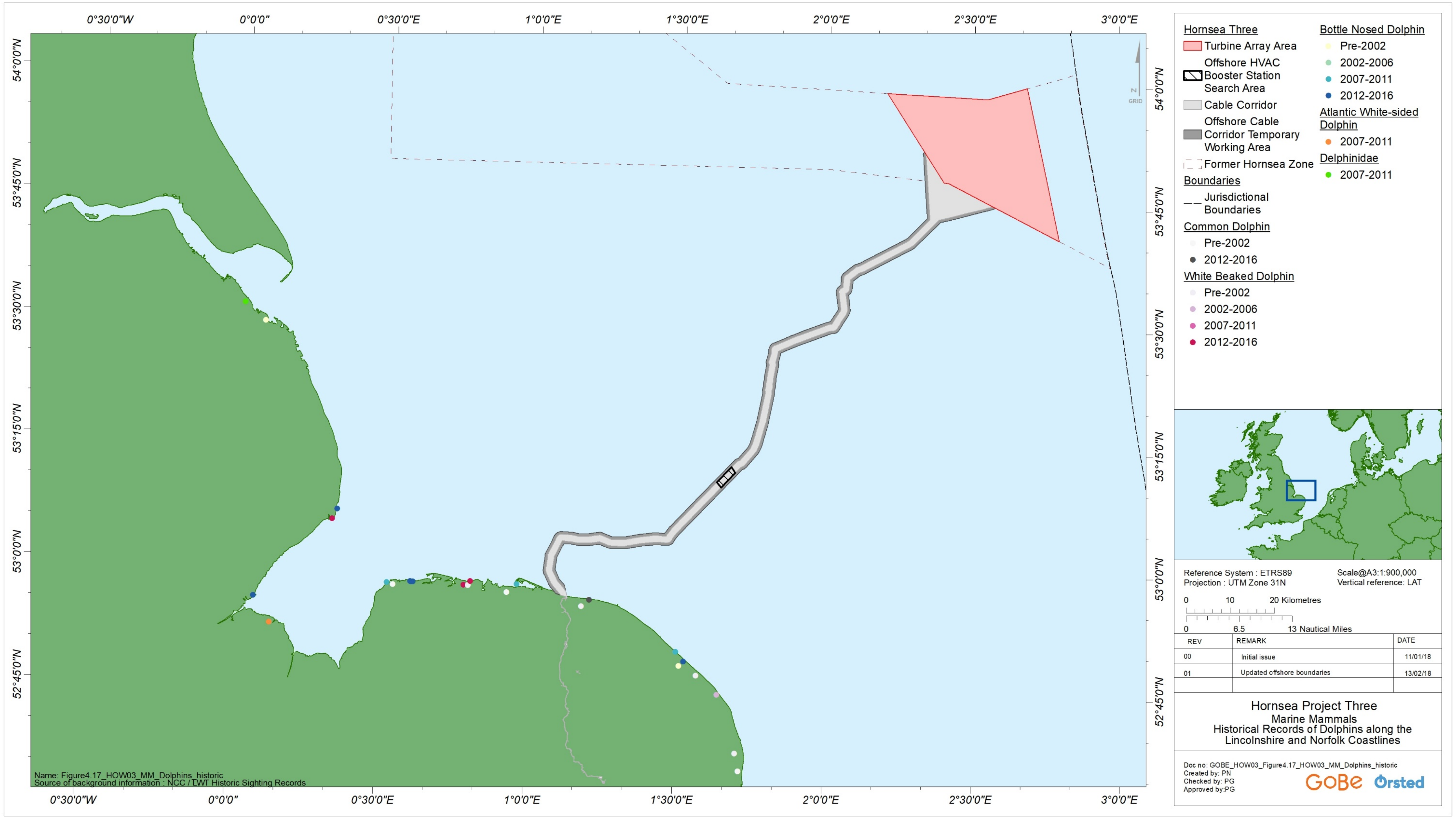


Figure 4.16: Historical records of dolphins along the Lincolnshire and Norfolk coastlines. The positions marked indicate the centre of the grid reference describing observer position, thus some locations appear on land.

4.3.3 Abundance

4.3.3.1 The population estimate for the Celtic and Greater North Seas MU for white-beaked dolphin is 15,895 individuals (IAMMWG, 2015). The SCANS III surveys estimated an abundance of 143 white-beaked dolphins in survey block O (CL: 0 – 490) (Hammond *et al*., 2017). During the boat-based surveys of the former Hornsea Zone plus a 10 km buffer, white-beaked dolphin were recorded in most months with the most notable exceptions being July to October for almost all years (Figure 4.17). Sightings of white-beaked dolphin was greatest in winter, although there was also a peak in sightings in 2012/2013 early summer (June). In total, 298 individuals were recorded in the former Hornsea Zone plus a 10 km buffer during visual surveys, with a mean cluster size of 2.92 animals. On the whole, numbers of white-beaked dolphin were lowest in 2010/2011 and highest in 2012/2013.

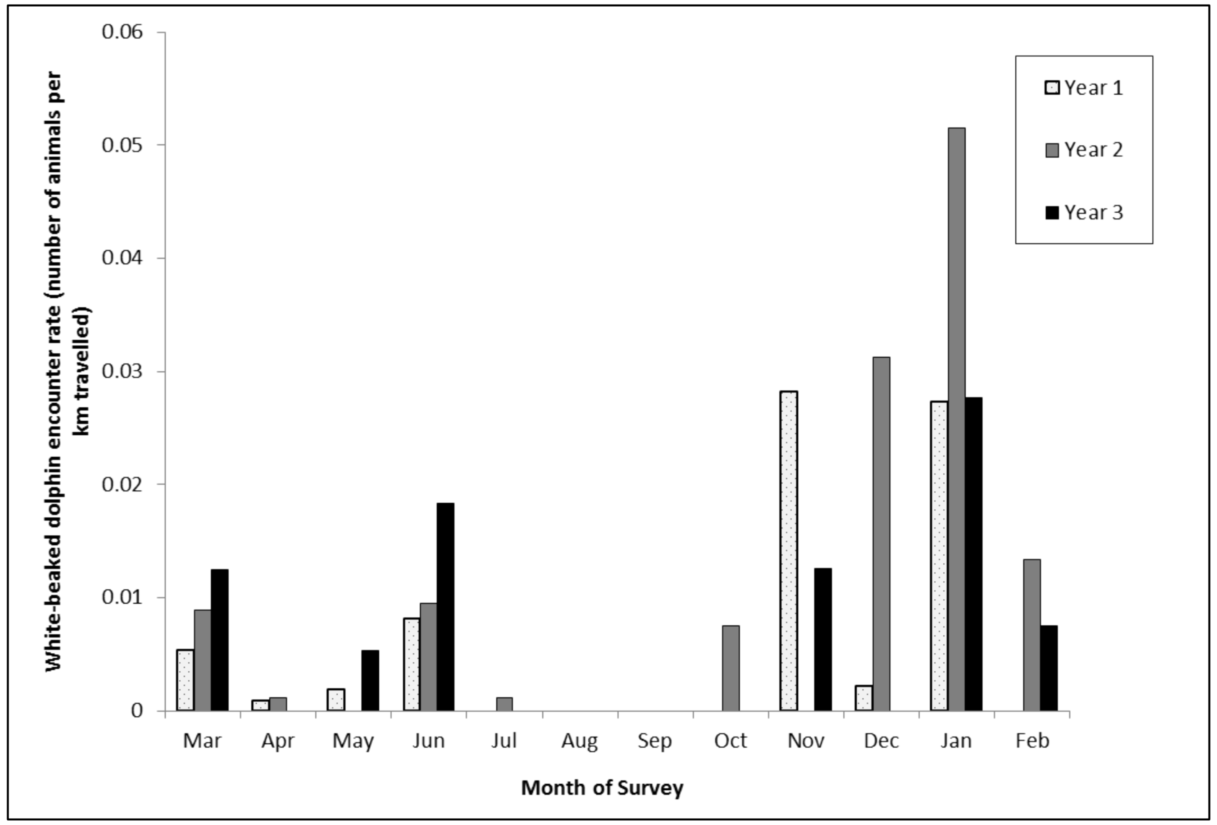


Figure 4.17: Monthly mean encounter rate of white-beaked dolphin within the former Hornsea Zone plus a 10 km buffer in Years one (2010/2011), two (2011/2012) and three (2012/2013). Data presented are for sightings in Beaufort sea states of 0 to 3.

4.3.3.2 Abundance of white-beaked dolphin in the former Hornsea Zone plus a 10 km buffer was calculated by multiplying the average density estimate (see Table 3.12) by the area (9,276 km^2). In this way, the total abundance was calculated 149 for the former Hornsea Zone plus a 10 km buffer.

4.3.3.3 During the surveys of the former Hornsea Zone plus a 10 km buffer, visual observations in sea states 0 to 3 showed peaks in the winter months of December and January and the encounter rate was highest in 2011/2012 during this time. The mean encounter rate for the former Hornsea Zone plus a 10 km buffer across all three years was 0.008 animals km^{-1}.

4.3.3.4 It is notable that only five white-beaked dolphin sighting were recorded during the 20 months of Hornsea Three aerial surveys. These sightings were recorded in August 2017 (n=1) and November 2017 (n=4).

4.3.4 Density

4.3.4.1 The mean relative density of white-beaked dolphin across the former Hornsea Zone plus a 10 km buffer is 0.016 animals km^{-2} (Table 3.12). White-beaked dolphin are known to be attracted to small vessels (Palka and Hammond, 2001) and so it cannot be determined whether this estimate is negatively biased due to the fact that g(0) will be less than one, or positively biased due to responsive movement towards the vessel. The narrow ESW (0.351 m) for this species, and the high proportion of sightings close to the trackline are indicative of movement towards the vessel prior to detection.

4.3.4.2 The density for SCANS III Block O as estimated by the SCANS-III surveys was 0.002 animals km^{-2} (Hammond *et al*., 2017). Whilst the average relative density for the former Hornsea Zone plus a 10 km buffer is greater than the SCANS-III estimate, this is likely to be a function of SCANS III surveys being undertaken in the summer (July) when white-beaked dolphin numbers were not expected to be high in the area.

4.3.4.3 The JCP Phase III report provides abundance and density estimates for the "south Dogger Bank" area in which Hornsea Three is located. These estimates are for the number of animals present in each season in 2010. These data predict a density of up to 0.05 (0.02 – 0.13) white-beaked dolphins/km^2 in the spring with lower densities in the other seasons (Table 4.4).

Table 4.4: White-beaked dolphin abundance and density estimates for the south Dogger Bank area of commercial interest in 2010, as presented in Paxton *et al.* (2016).

	Winter		Spring		Summer		Autumn	
	Abundance	Density	Abundance	Density	Abundance	Density	Abundance	Density
point estimate	170	0.01	710	0.05	290	0.02	220	0.02
2.5%	80	0.01	290	0.02	170	0.01	90	0.01
97.5%	380	0.03	1790	0.13	610	0.04	420	0.03

4.3.4.4 Density estimates for white-beaked dolphin distributions were corrected for survey effort using information on the number of detections per unit length of survey trackline (Figure 4.18). There is a clear density gradient across the former Hornsea Zone plus a 10 km buffer, with highest numbers to the northwest of the former Hornsea Zone plus a 10 km buffer (0.12 animals km^{-2}) dropping to zero animals km^{-2} in the southeast of the former Hornsea Zone (Figure 4.18). There was no significant relationship with depth or bottom type.

4.3.5 Management unit

4.3.5.1 A workshop held by ASCOBANS and the Helsinki Commission (HELCOM) in 2009 identified two distinct ecological populations in the Northeast Atlantic: one in the coastal areas of Norway and the other in waters surrounding UK and Ireland and extending to the European coastal areas of the North Sea.

4.3.5.2 The IAMMWG has therefore identified a single MU for white-beaked dolphin encompassing all UK waters and extending to the seaward boundary used by the EC Habitats Directive reporting (IAMMWG, 2015) (Figure 4.19). Population estimates for the Celtic and Greater North Sea MU (CGNS) were based on the most recent analysis of the SCANS-II data (Hammond *et al.*, 2013). The total abundance of white-beaked dolphin in the CGNS MU was estimated as 15,895 animals.

4.3.5.3 The abundance of white-beaked dolphin within the UK part of the overall CGNS MU is 11,694 (95% CI - 6,578-20,790) (IAMMWG, 2015).

4.3.6 Favourable Conservation Status

4.3.6.1 JNCC report that the conservation status for white-beaked dolphin is favourable for range, population, habitat, future prospects and overall assessment.

4.3.7 Links between Hornsea Three marine mammal study area and European Sites

4.3.7.1 There are no designated European sites with white-beaked dolphin as a notified interest feature.

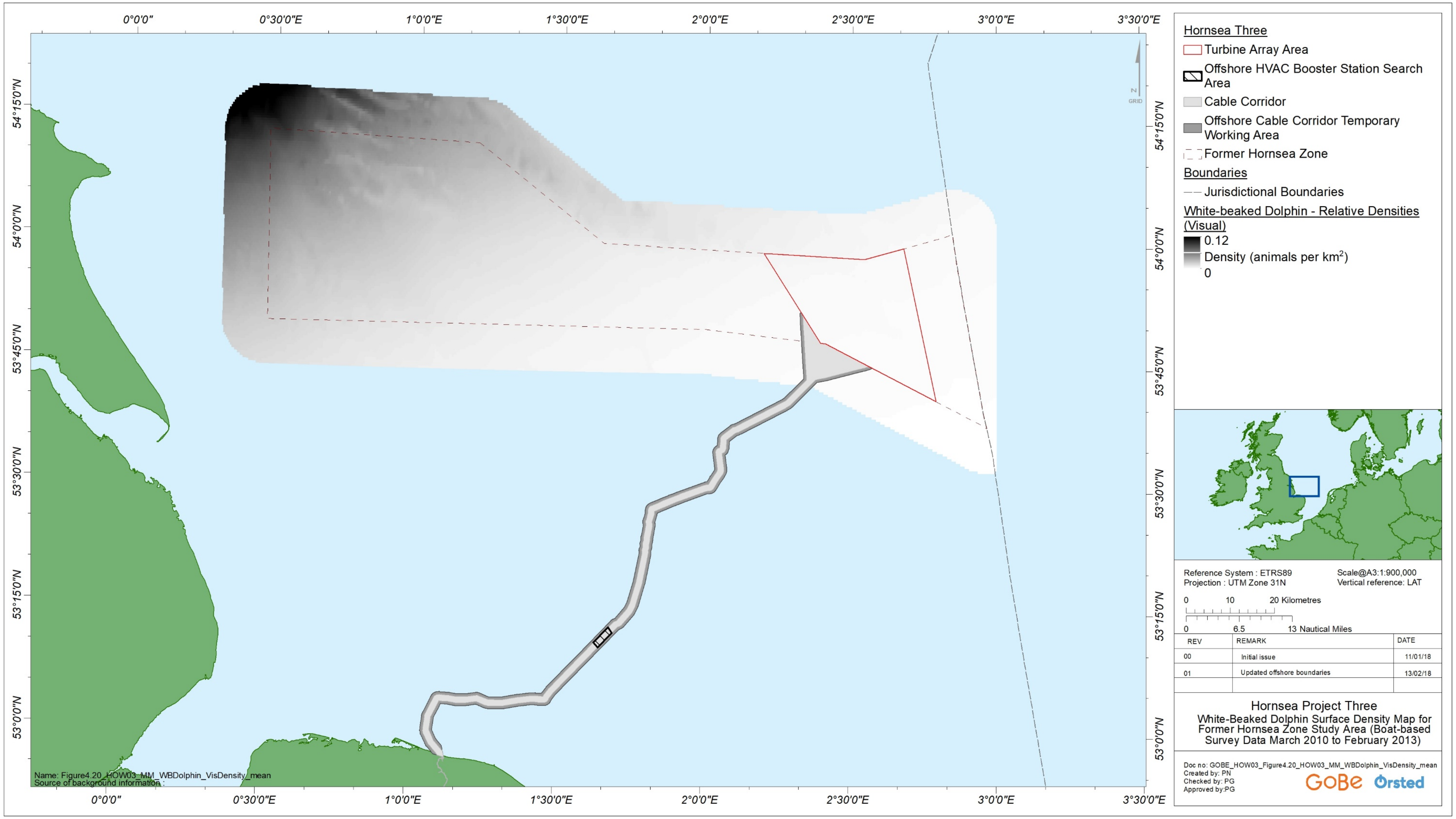


Figure 4.18: Modelled surface density estimates (relative densities) for white-beaked dolphin across the Hornsea Zone plus a 10 km buffer, based on three years of survey data (2010 to 2013).

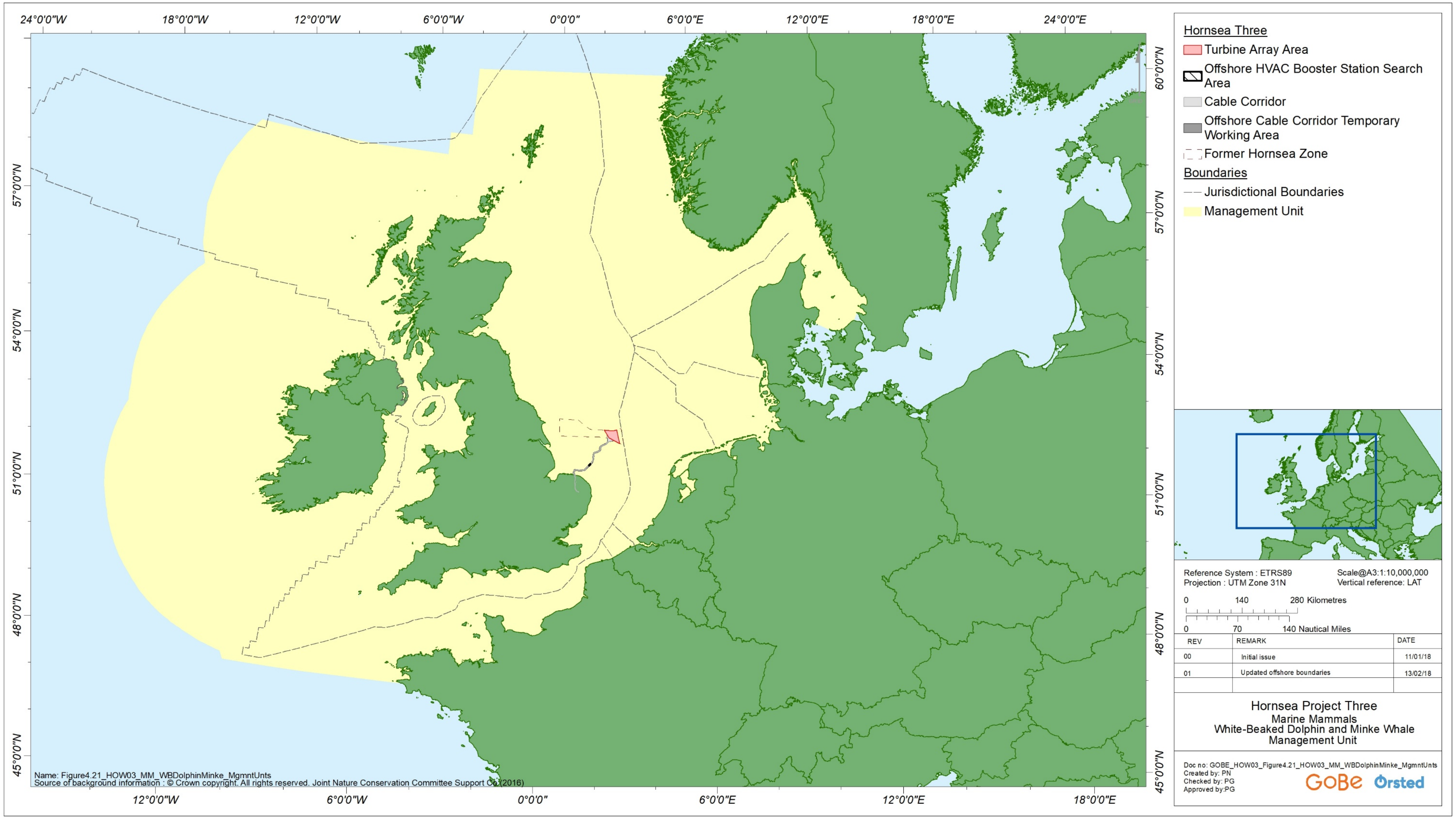


Figure 4.19: White-beaked dolphin MU - Celtic and Greater North Seas (CGNS) (IAMMWG, 2015).

4.4 Minke whale

4.4.1 Ecology

4.4.1.1 The minke whale is the smallest of the mysticetes, or baleen whales, and is widely distributed along the Atlantic coastline of Britain and Ireland, as well as in the northern and central North Sea (Reid *et al.*, 2003). Minke whales typically live up to 60 years. Male minke whales reach sexually maturity at approximately 6.9 m in length (aged five to eight years) and females at about 7.3 m in length (aged six to eight years). Breeding occurs throughout the year, although there is typically a peak in winter. Gestation occurs over a ten month period whereupon mothers give birth to a single calf. The calf is weaned at three to six months and will stay with its mother for up to two years. Calves are typically produced every two to three years. The geographic identity of breeding populations of this species within the North Atlantic is not known and no calving areas have yet been identified in the North Sea (Reid *et al.*, 2003).

4.4.1.2 This species is often known to exploit prey resources through other species that herd prey, enabling a low energy foraging strategy. Minke whale follow prey distribution and sandeel (*Ammodytes* sp.) are the key food resource in the North Sea, with sprat (*Sprattus sprattus*), shad (*Alosa* spp.) and herring (*Clupea harengus*) also preferred prey items (Robinson and Tetley, 2005; Gill *et al*., 2000).

4.4.1.3 This species tends to be observed either solitarily or in pairs or threes. However, in higher latitudes, including Northern Scotland, larger groups of ten to 15 individuals can be seen, particularly in areas of high prey density (Anderwald and Evans, 2007). Minke whales can be inquisitive, and have been observed approaching slow moving boats or stationary vessels.

4.4.2 Distribution

4.4.2.1 Minke whales are widely distributed around the Atlantic seaboard of Britain and Ireland, occurring regularly in the northern and central North Sea (Evans *et al.*, 2003; Reid *et al.*, 2003) (Figure 4.20). Their distribution in the North Sea varies annually but is most likely to be related to the variation in distribution of their prey species (Hammond, 2007). Most sightings within continental shelf waters occur between May and September, with numbers peaking between July and September, depending on the region (Evans *et al.*, 2003). In the North Sea, minke whales are often spotted close to the coast during the summer months when sandeel populations are at their year high.

4.4.2.2 Historical data provided by the GLNP, based on land-based sightings, confirm the presence of minke whale within the Greater Wash area (Figure 4.21) between 2002 and 2016. It is therefore considered possible that minke whale could be present within the Hornsea three array area and offshore cable corridor.

4.4.2.3 Data from surveys carried out over the Hornsea Zone plus a 10 km buffer indicated that minke whale is distributed throughout the former Hornsea Zone plus a 10 km buffer (Figure 4.23).

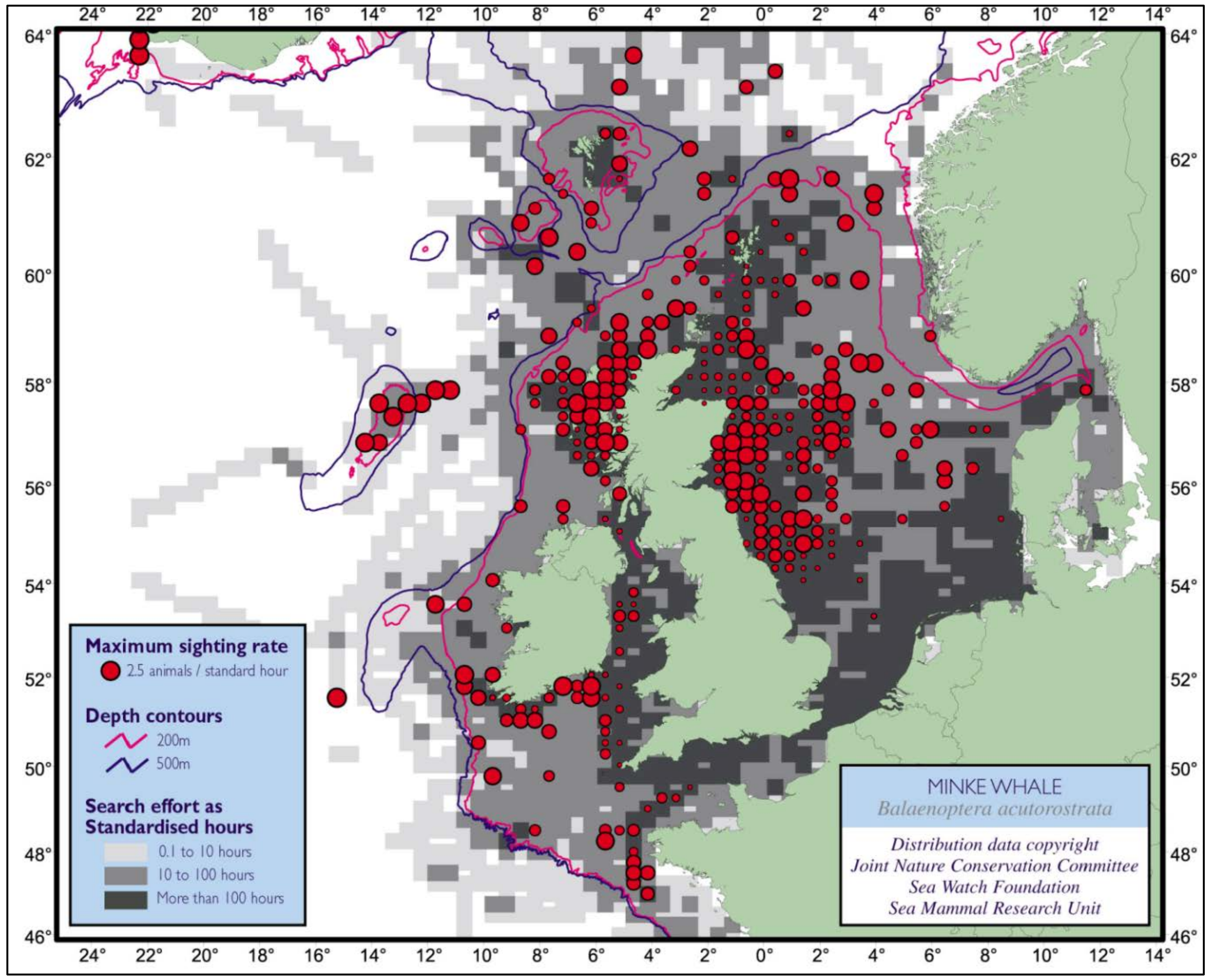


Figure 4.20: Distribution of minke whale around the UK coast (Reid *et al.*, 2003).

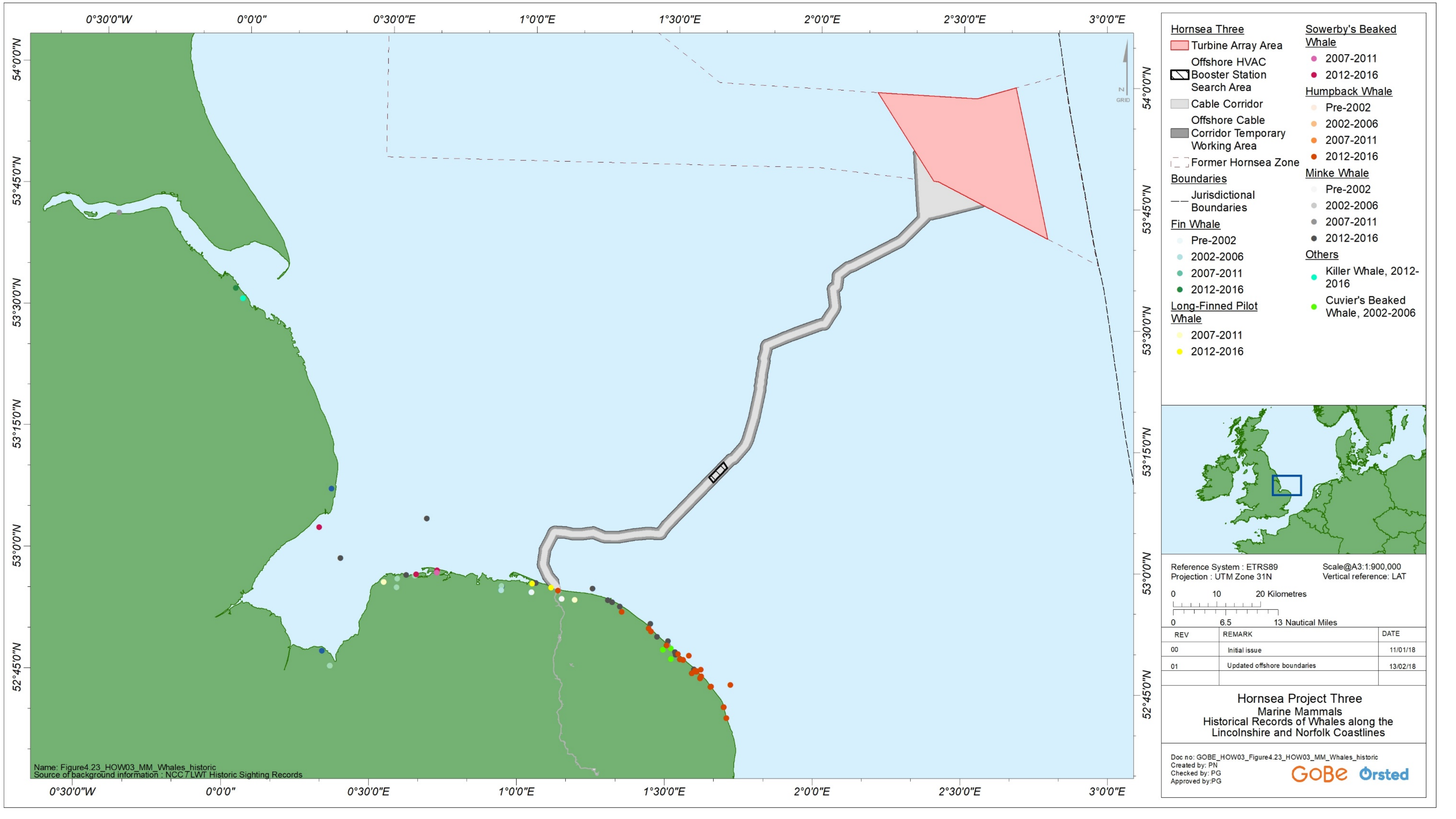


Figure 4.21: Historical records of whales along the Lincolnshire and Norfolk coastlines between 2002 and 2016. The positions marked indicate the centre of the grid reference describing observer position, thus some locations appear on land.

4.4.3 Abundance

4.4.3.1 The total abundance for the minke whale Celtic and Greater North Seas (CGNS) MU is estimated as 23,528 animals (IAMMWG 2015). The SCANS-III survey produced an estimate of 603 minke whales in block O (CL: 109 – 1,670) (Hammond *et al*., 2017). The SCANS III report stated that the distribution of minke whales in 2016 was similar to that in 2005 in the North Sea and the abundance data show no support for a change in abundance since 1989.

4.4.3.2 A total of 158 minke whales were observed in the former Hornsea Zone plus a 10 km buffer over the three year survey period, with a mean cluster size of 1.07 animals. Abundance of minke whale was calculated by multiplying the average density estimate for the former Hornsea Zone plus a 10 km buffer (see Table 3.12) by the area (9,276 km^2). In this way, the total abundance for the former Hornsea Zone plus a 10 km buffer was calculated as 56 individuals.

4.4.3.3 Figure 4.22 shows the monthly encounter rate within the former Hornsea Zone plus a 10 km buffer, for sea states 0 to 3 only, across 2010 to 2013. The mean encounter rate in the former Hornsea Zone plus a 10 km buffer was 0.0030 animals km^{-1}. The encounter rate fluctuated over the months across the former Hornsea Zone plus a 10 km buffer, with a peak in sightings in July, particularly in 2012/2013. Minke whale were notably absent from the former Hornsea Zone plus a 10 km buffer during the winter months (Figure 4.22).

4.4.3.4 It is notable that only one minke whale sighting was recorded during the 20 months of Hornsea Three aerial surveys. This sighting was recorded in June 2016.

4.4.4 Density

4.4.4.1 The JCP Phase III report provides abundance and density estimates for the "south Dogger Bank" area in which Hornsea Three is located. These estimates are for the number of animals present in each season in 2010. These data predict a density of up to 0.02 (0.01-0.07) minke whales/km^2 in the summer with lower densities in the other seasons (Table 4.5).

Table 4.5: Minke whale abundance and density estimates for the south Dogger Bank area of commercial interest in 2010, as presented in Paxton et al. (2016).

	Winter		Spring		Summer		Autumn	
	Abundance	Density	Abundance	Density	Abundance	Density	Abundance	Density
point estimate	0	0.00	70	0.00	310	0.02	20	0.00
2.5%	0	0.00	10	0.00	170	0.01	0	0.00
97.5%	100	0.01	650	0.05	1000	0.07	60	0.00

4.4.4.2 The SCANS-III surveys estimated a minke whale density in Block O of 0.010 animals km^{-2} (Hammond *et al*., 2017), which is only very slightly higher than the average density estimate from the surveys within the former Hornsea Zone plus a 10 km buffer (0.006 animals km^{-2}) (Figure 4.23). There was not considered however to be a real difference in density within the former Hornsea Zone plus a 10 km buffer compared to the wider SCANS-III survey area because:

- The SCANS densities are based on just summer surveys when numbers appear to be higher, whereas the former Hornsea Zone plus a 10 km buffer density estimates are based on a year-round average; and
- SCANS density estimates have been corrected for g(0), whereas the former Hornsea Zone plus a 10 km buffer density estimates are relative densities.

4.4.4.3 Density estimates for minke whale distribution in the former Hornsea Zone plus a 10 km buffer were corrected for survey effort using information on the number of detections per unit length of survey trackline. The surface density maps (Figure 4.23) show that the highest areas of density occur to the north of the site, which would be expected if minke whale were at the southern limit of their distribution in this part of the south central North Sea.

4.4.4.4 The averaged density across Hornsea Three array area plus a 4 km buffer taken from the surface density map was 0.012 animals km^{-2} which is double the estimate for the former Hornsea Zone plus a 10 km buffer (0.006 animals km^{-2}) (Table 3.12).

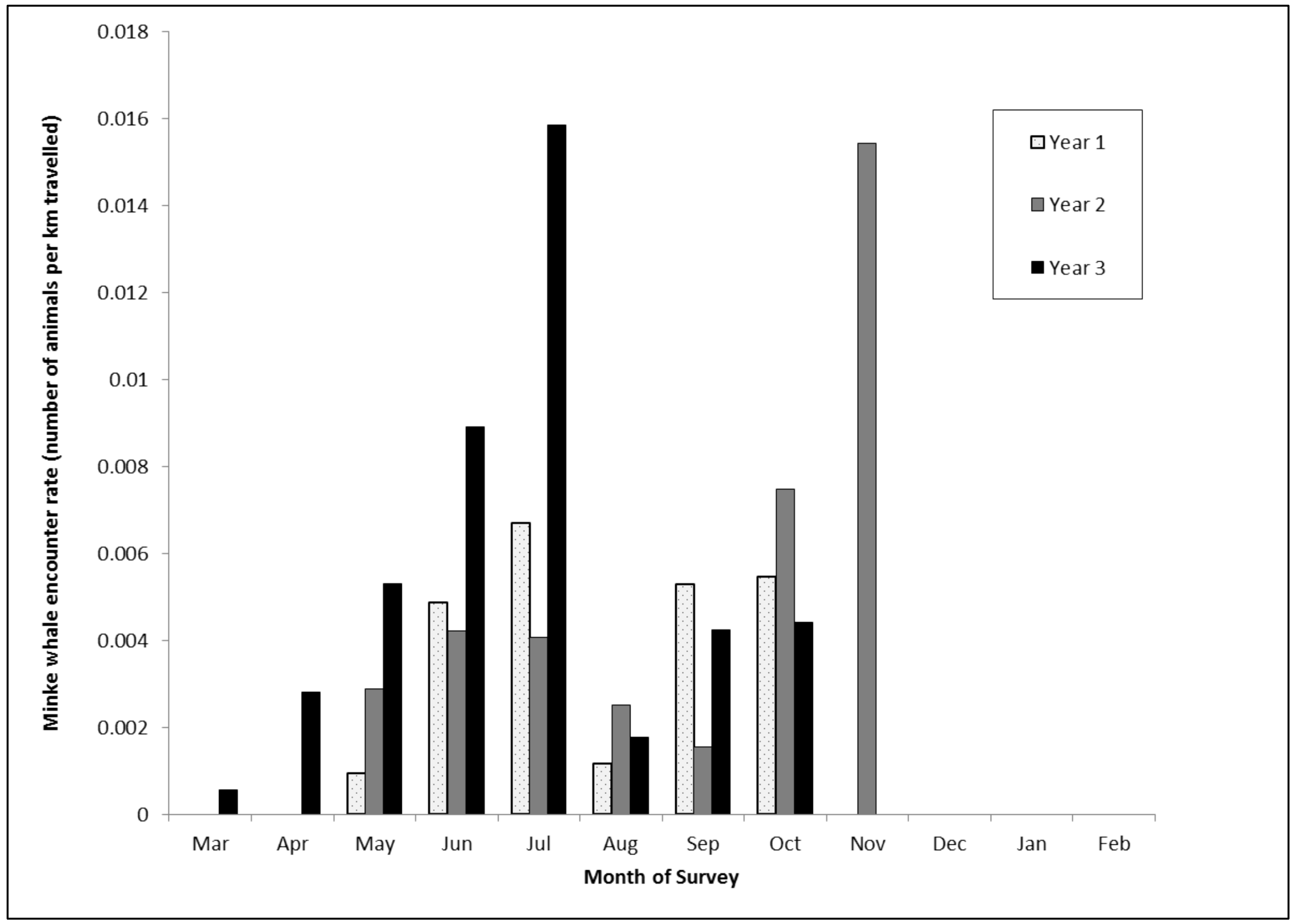


Figure 4.22: Monthly mean encounter rate of minke whale in the former Hornsea Zone plus a 10 km buffer in Years One (2010/2011), Two (2011/2012) and Three (2012/2013). Data presented are for sightings in Beaufort sea states of 0 to 3.

4.4.5 Management unit

4.4.5.1 Minke whale is widely distributed throughout the Northeast Atlantic. Based on the distribution within summer feeding grounds, the IWC recognises three biological populations: Western population (includes Canada and West Greenland), Central population (includes East Greenland and Iceland) and Eastern population (includes Norway).

4.4.5.2 Due to the limited data on anthropogenic threats, the IAMMWG has identified a single MU for minke whales encompassing the CGNS (IAMMG, 2015) (Figure 4.24, Table 3.4). The abundance for this unit was based on both SCANS-II data (Hammond *et al.*, 2013) and CODA estimates for areas where SCANS-II data were not available. As described previously, the abundance estimates were adjusted pro rata by area for those blocks that did not fall entirely within the MU. The total abundance for the CGNS MU was estimated as 23,528 animals.

4.4.5.3 The abundance of minke whale within the UK part of the overall CGNS MU is 12,295 (95% CI 7,176-21,066) (IAMMG, 2015).

4.4.6 Favourable Conservation Status

4.4.6.1 JNCC report that the conservation status for minke whale is favourable for range, population, habitat, future prospects and overall assessment.

4.4.7 Links between Hornsea Three marine mammal study area and European Sites

4.4.7.1 There are no designated European sites with minke as a notified interest feature.

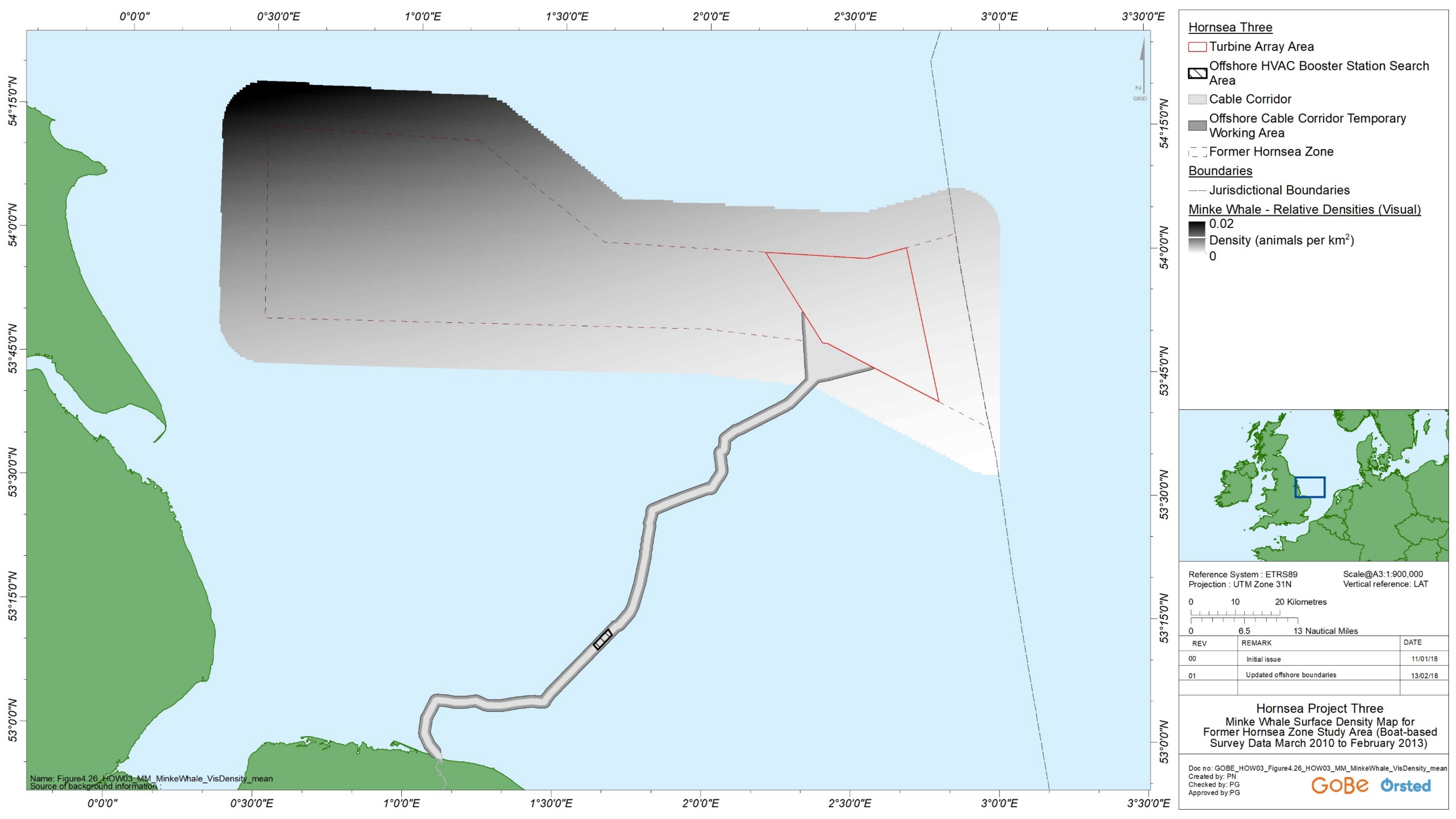


Figure 4.23: Modelled surface density estimate (relative densities) for minke whale across the former Hornsea Zone plus a 10 km buffer, based on three years of survey data (2010 to 2013).

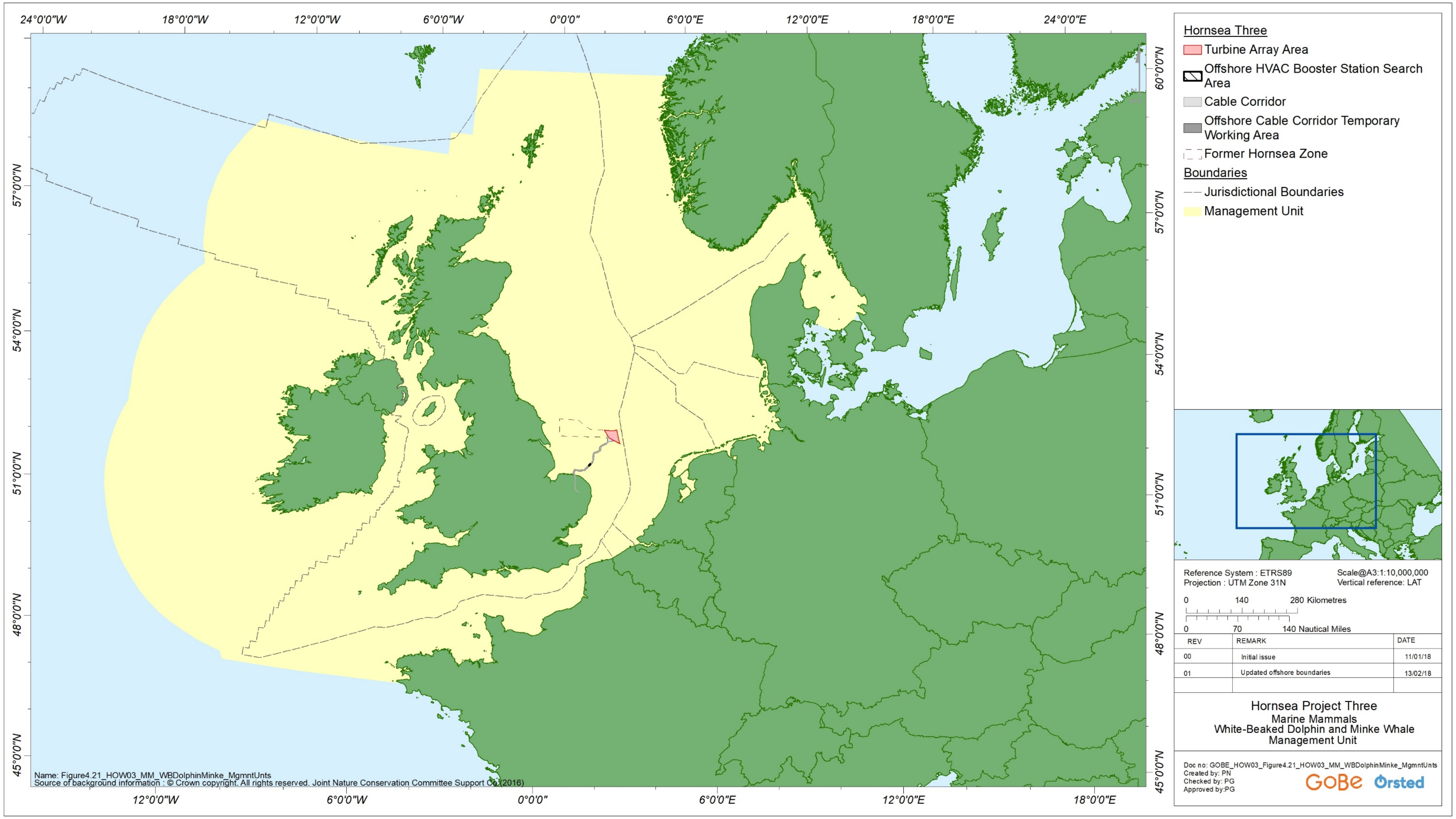


Figure 4.24: Minke whale Celtic and Greater North Seas (CGNS) MU.

4.5 Grey seal

4.5.1 Ecology

4.5.1.1 The grey seal is the larger of the two species of seal that breed around the coast of the British Isles. They are common within the North Sea and gather in large aggregations at traditional colonies on remote islands or coastlines during the breeding/pupping season. Figure 4.25 shows the location of grey seal breeding colonies in Great Britain and Northern Ireland (SCOS, 2016).

4.5.1.2 Pupping in the southern North Sea occurs in January with the moulting season in February and March, whereas pupping in the northern North Sea occurs from October. Grey seal spend longer hauled out during their annual moult (December to April) and their breeding season compared to other times of year (SMRU, 2011). Grey seals can live for over 20 – 30 years, with females tending to live longer than males (SCOS, 2016). Sexual maturity is reached at approximately ten years in males, and five years in females (SCOS, 2016) and gestation occurs over 10-11 months.

4.5.1.3 On the Lincolnshire coast, grey seals start to aggregate in mid-September for breeding. Breeding commencement date on the English East coast varies with location. For example breeding and pupping at Donna Nook (Figure 4.28) commences in late October and runs until December (LWT, pers. comm.), whereas further south breeding season commences slightly later in North Norfolk with pupping occurring at the end of October/early November and finishing in January (LWT, pers. comm.). During these periods, the majority of the breeding population will be on land for several weeks. Subsequently densities at sea will be much lower at this time when compared to other times of year.

4.5.1.4 Female grey seals return to the same haul-out site at which they bred in order to give birth. Grey seal give birth to a single, white-coated pup. Pups are weaned over a period of 16 to 21 days, with the pups leaving the breeding site for the sea after approximately one month. Following this, the female comes into oestrus and mating occurs, after which adult grey seal return to sea to forage and build up fat reserves. Just before weaning the pups shed their white natal coat (or lanugo) and develop their first adult coat. Moult occurs in stages at the colony with juvenile seal moulting first, followed by adults.

4.5.1.5 Female grey seals are capital breeders, storing fat reserves prior to lactation so that there is no necessity to forage at this crucial time. Survival success of grey seal pups is related to a number of factors but fatter weaned pups have a higher survival rate than thinner ones. This demonstrates the importance of the lactation period in laying down fat reserves on pups (Hall *et al.*, 2001). Successful lactation therefore requires the female to forage efficiently during pregnancy in order to build up sufficient body mass (Iverson *et al.*, 1993; Mellish, Iverson and Bowen, 1999; Pomeroy *et al.*, 1999). Thus, grey seals may be particularly vulnerable to anthropogenic disturbances during their time spent at sea foraging both before and after breeding as opposed to during the breeding season itself.

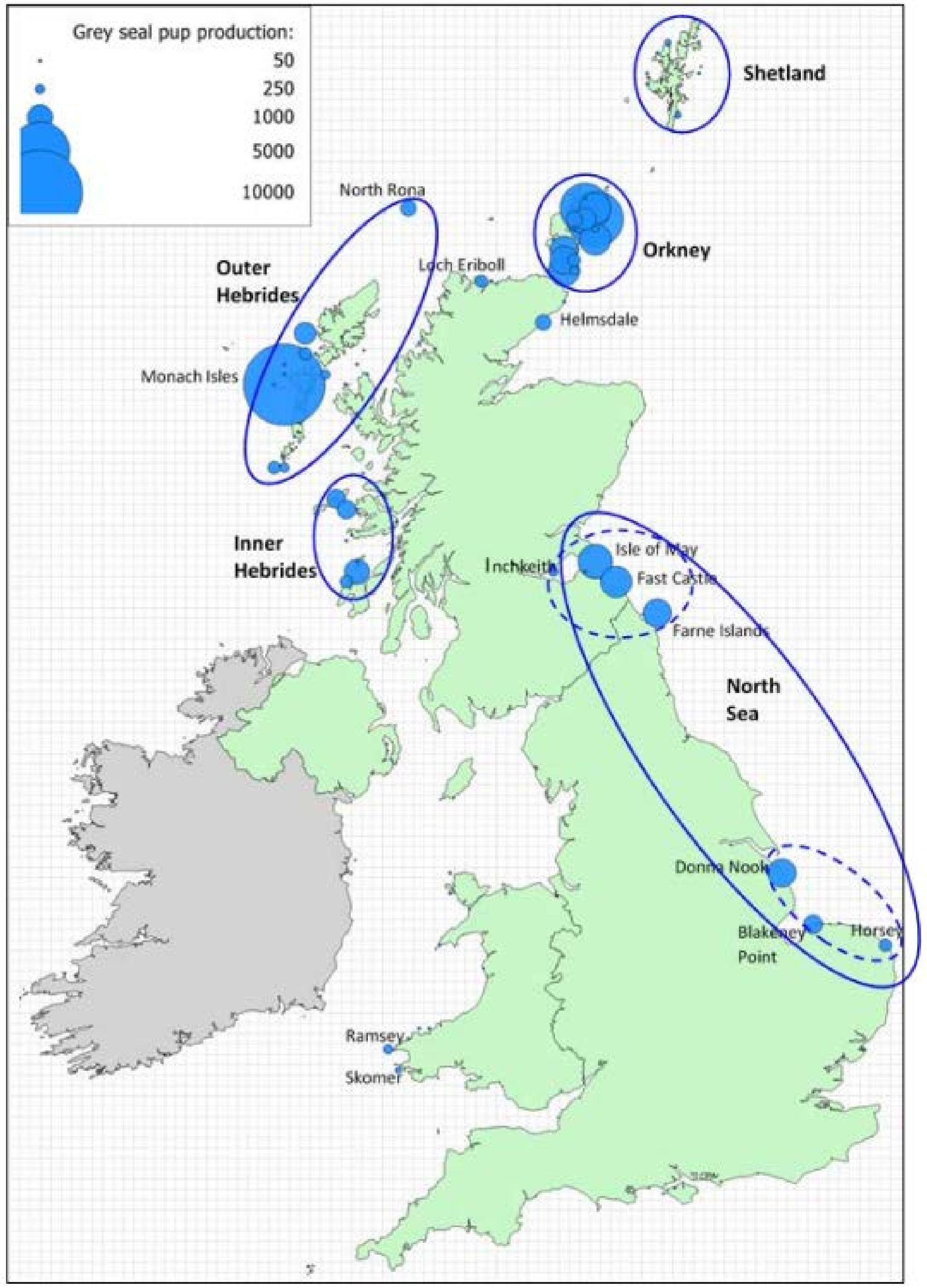


Figure 4.25: Size and distribution of grey seal breeding colonies (SCOS, 2016). Blue ovals indicate groups of colonies within each region.

4.5.1.6 Most grey seal colonies are highly sensitive to disturbance by humans and tend to breed in remote locations. The colony at Donna Nook is an exception to this: its proximity to a Royal Air Force bombing range and influx of over 70,000 visitors each year does not appear to affect breeding success, suggesting that this colony has habituated to disturbance on land (SMRU, 2011).

4.5.1.7 Sandeels account for approximately 50% of prey consumption of grey seal but whitefish and flatfish are also important prey items (in order of importance) although seasonal and regional variations may occur (Hammond *et al.,* 2001). At Donna Nook, for example, sandeels and common sole *Solea solea* are the staple diet of grey seal. Sandeel habitat occurs widely throughout the south central North Sea. High intensity sandeel spawning areas are present to the north of the Hornsea Three array area, and low intensity spawning and nursery areas coinciding with the Hornsea Three offshore cable corridor (see Figure 3.23 in annex 3.1: Fish and Shellfish Technical Report).

4.5.1.8 Grey seal movements offshore tend to fall into two categories: long distance travel (up to 2,100 km), and local repeated trips to discrete offshore areas (88% of trips). However, most foraging ranges have generally been recorded as up to 145 km from their haul-out sites (Thompson *et al.*, 1996). Such large distances travelled suggest that populations are not isolated. Grey seals from the large colony at Donna Nook have been shown to regularly travel 230 km out to sea from their haul-out site (SCOS, 2012).

4.5.1.9 Of all grey seals tagged in either the southeast or the northeast England MU since 1994 (n=113), the telemetry data show tracks from 16 grey seals within the Hornsea Three Scoping Site boundary and 19 within a 25 km buffer around the Scoping Site Boundary. Of the most recent telemetry data, eight out of ten adult seals tagged at Blakeney Point in 2015 had telemetry tracks entering or crossing the Hornsea Three Scoping Site Boundary however, only one of the ten animals tagged at Donna Nook in 2015 entered the Hornsea Three Scoping Site Boundary (Figure 4.28) (SMRU, 2017). The telemetry data show connectivity between the Hornsea Three Scoping Site Boundary and both the Humber Estuary and the Berwickshire and North Northumberland Coast SACs. Of the 16 grey seals that had telemetry tracks within the Hornsea Three Scoping Site Boundary, six entered into the Berwickshire and North Northumberland Coast SAC where they recorded between 3 and 57% of their total GPS locations.

4.5.1.10 When assessing the telemetry data and the movement of grey seals within the North Sea, it should be noted that due to the limited English east coast tagging locations targeted to date (Donna Nook and Blakeney Point), these data may not be representative of grey seal movement patterns from other sites such as The Farnes, East Horsey or Scroby Sands.

4.5.1.11 Tracking studies undertaken by SMRU for the Dogger Bank Creyke Beck offshore wind farm also showed that seals transited between haul-outs at Donna Nook and Dogger Bank (moving across the centre of the former Hornsea Zone) (Forewind, 2013).

4.5.2 Distribution

Onshore

4.5.2.1 The most important haul-out sites in the southern North Sea (within 100 km from the landfall site), are those at Donna Nook, Blakeney Point, East Horsey, Scroby Sands and The Wash on the Lincolnshire coastline (Figure 4.26 and Figure 4.28). At these sites, grey seals haul-out during September to December for pupping and breeding and are also known to haul out in August as they have been counted during the annual harbour seal moult surveys A total of 5,158 grey seals were hauled out along the North Norfolk and Lincolnshire coastlines in August 2016 (including Donna Nook, The Wash, Blakeney Point and Scroby Sands) (Table 4.6).

4.5.2.2 The grey seal haul out at Blakeney Point is adjacent to the Hornsea Three export cable scoping boundary. This is a key grey seal haul-out site not only during the pupping season but also outside of the breeding season. Surveys of grey seals during the pupping season have resulted in a pup production estimate at Blakeney Point of 2,404 pups in 2016 (Table 4.7) and in August 2016 (during the annual harbour seal moult count) a total of 533 grey seals were counted at Blakeney Point.

4.5.2.3 The Donna Nook haul-out is approximately 76 km from the Hornsea Three export cable scoping boundary. In 2016 the grey seal pup production estimate for Donna nook was 1,989 pups (Table 4.7) and the August haul out count was 3,640 grey seals (Table 4.6).

4.5.2.4 Grey seals haul-out in The Wash which is between approximately 50 and 60 km from the Hornsea Three export cable scoping boundary. In August 2016 a total of 370 grey seals were counted in The Wash during the annual harbour seal moult count (Table 4.6).

4.5.2.5 The grey seal haul out at Scroby Sands is approximately 55 km from the Hornsea Three export cable scoping boundary and in August 2016 (as recorded during the annual harbour seal moult count) a total of 615 grey seals were counted at this site (Table 4.6).

4.5.2.6 The grey seal haul out at East Horsey is not included in the August haul-out survey, however, the site is surveyed as part of the grey seal pup count surveys, and in 2016 the pup production estimate for this site was 1,526 pups (Table 4.7).

Table 4.6: Grey seal haul out counts along the North Norfolk and Lincolnshire coastlines in August 2016.

Location	Haul out Name	Lat	Long	Count	Total Count
Donna Nook	Donna Nook 1	53.48762	0.158056	2976	3640
	Donna Nook 2	53.44226	0.201667	664	
The Wash	Outer Knock	53.0701	0.3841	115	370
	Inner Dogs Head	53.03553	0.3763	180	
	Long Sand Middle	53.00527	0.296667	1	
	Gat Sand	52.93457	0.198333	22	
	Nene Channel 1(or pooled)	52.87508	0.219917	1	
	Seal sand (East and West)	52.8808	0.352433	46	
	Black Guard	52.88285	0.3721	1	
	Stylemans Middle	52.88678	0.380367	4	
Blakeney Point	Blakeney Point	52.97533	0.95286	533	533
Scroby Sands	Scroby Sands	52.60907	1.790121	615	615

4.5.2.7 Friends of Horsey Seals report that there has been a small grey seal breeding site in the Horsey area since 2002. The number of overall births increased from 1,236 in 2015/2016, to 1,487 (new born recorded) in 2016/2017. Including the counts for new born deaths, this 2016/2017 figure increases to 1,526 (Friends of Horsey Seals Report, 2017). Pup count peaked in early December 2016. Pup mortality peaked in mid-December. It is considered that this may be due to increased anthropogenic disturbance at the breeding site; however there is no conclusive evidence of this (Friends of Horsey Seals Report, 2017).

4.5.2.8 The GLNP provided historic land-based sightings data for seal (Figure 4.27) along the coast to the north and south of the Hornsea Three landfall area. Grey seal (grey circles) have been recorded within proximity of the Hornsea Three landfall area, from 2002 until 2016, therefore it is considered likely that grey seals could be present within the Hornsea Three landfall area.

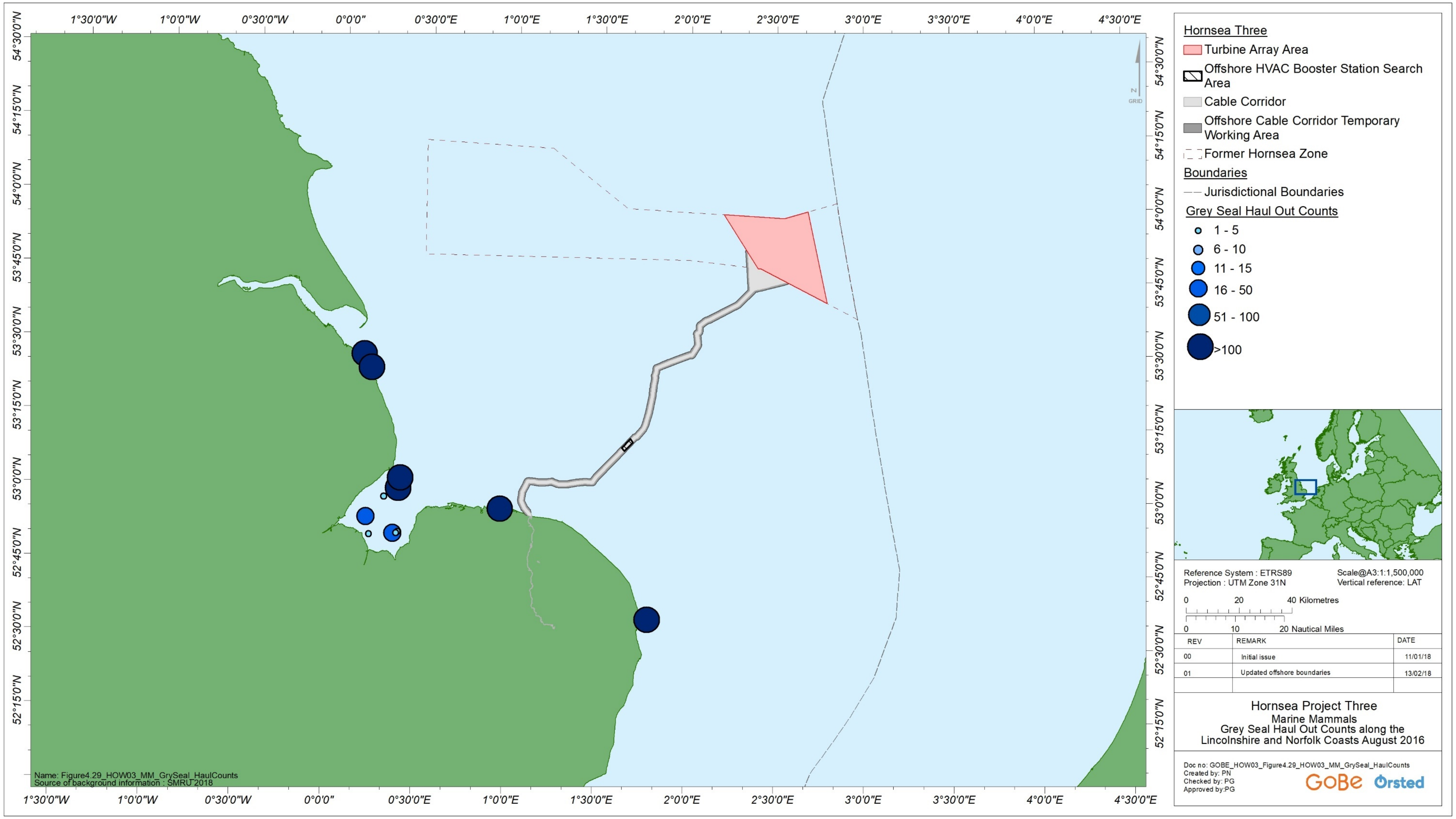


Figure 4.26: Grey seal haul out counts along the North Norfolk and Lincolnshire coastlines in August 2016 and in relation to the Hornsea Three export cable scoping boundary and landfall area.

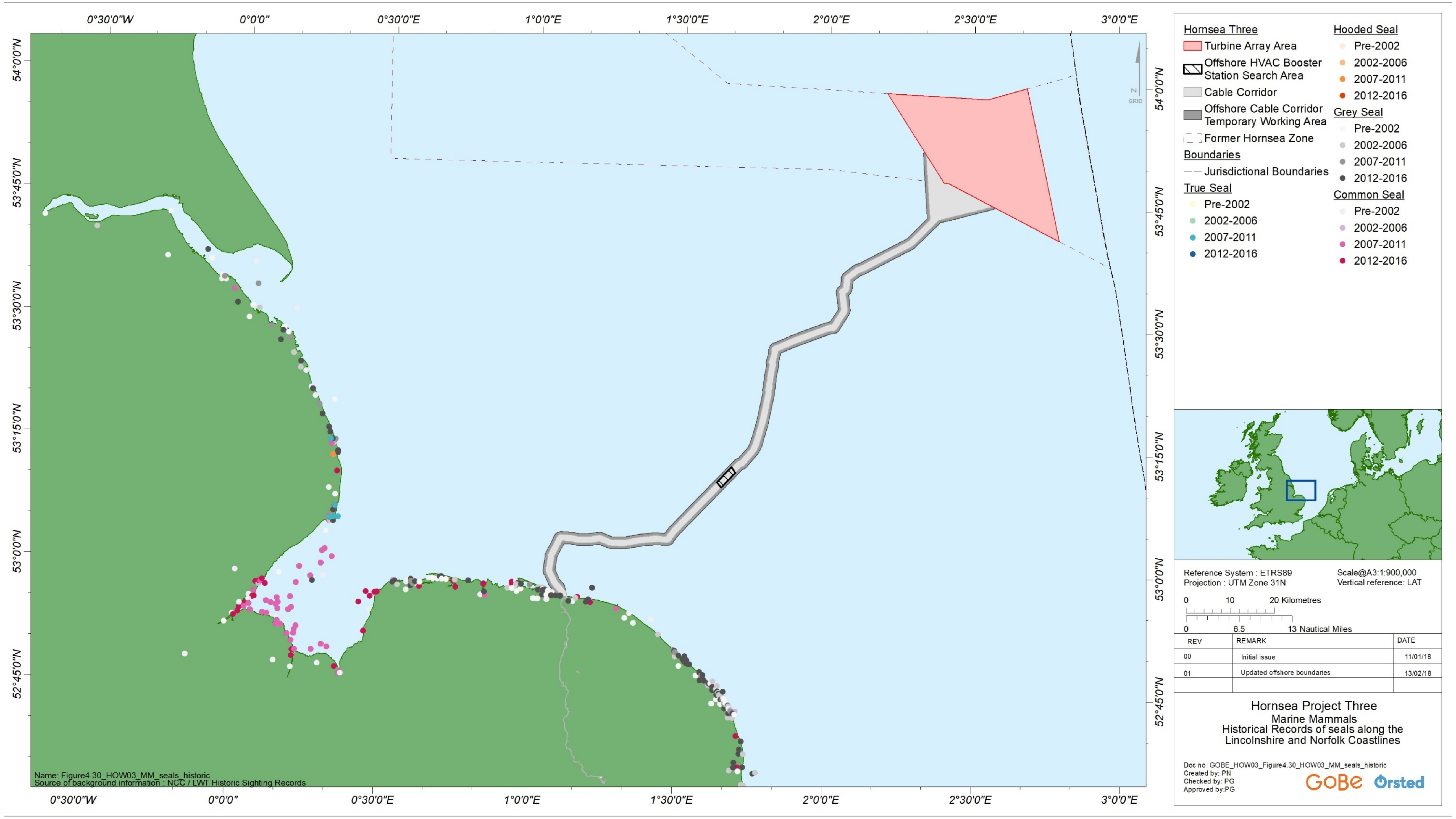


Figure 4.27: Historical records of seal species along the Lincolnshire and Norfolk coastlines between 2002 and 2016. The positions marked indicate the centre of the grid reference describing observer position, thus some locations appear on land.

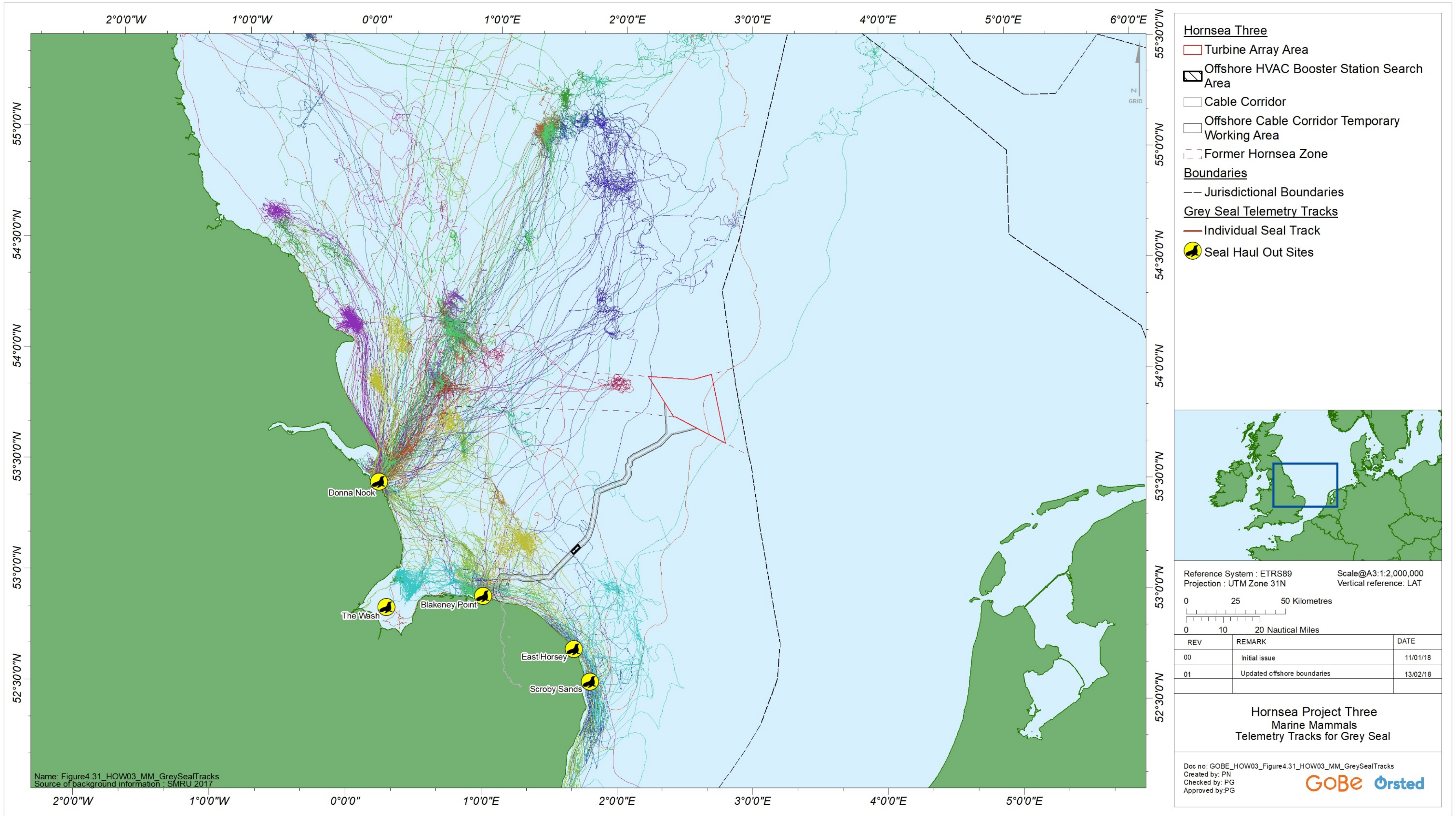


Figure 4.28: Tracks of 20 grey seal tagged at Donna Nook and Blakeney haul-outs. Each seal is represented by a different colour (SMRU, 2017).

Offshore

4.5.2.9 Grey seals were recorded throughout the three years of monthly boat-based former Hornsea Zone plus a 10 km buffer surveys, and accounted for 3.1% of marine mammals recorded across all surveys. The majority of sightings of grey seal were in the southwest corner of the former Hornsea Zone plus a 10 km buffer. Offshore abundances varied seasonally: the mean encounter rate decreased considerably during September to December coinciding with the main haulout period, and peaked in July and February for all three survey years.

4.5.2.10 Historical WWT aerial survey data (WWT, 2005) also recorded seals along the coastline to the north and south of The Wash (Figure 4.7), and in the area coinciding with the Hornsea Three offshore cable corridor. Given the proximity of known breeding colonies in the region, it is considered likely that grey seals will regularly occur within the Hornsea Three offshore cable corridor.

4.5.2.11 Grey seal at sea usage data provided by SMRU, indicate that grey seals are present throughout the Hornsea Three array area and Hornsea Three offshore cable corridor (Figure 4.31). At-sea usage is highest in the southwest corner of the former Hornsea Zone near the Donna Nook haul-out site and the Wash. This suggests that distribution of grey seals is highest near to main haul out and breeding sites, particularly Donna Nook and The Wash haul outs.

4.5.2.12 SMRU seal telemetry data presented in Figure 4.28 and in Appendix A show that individuals travel to and pass through the Hornsea Three array area, as well as passing through the Hornsea Three offshore cable corridor from haul out sites at Donna Nook, the Wash and Blakeney. Seals passing through the array area and cable corridor also hauled out at the Farne Islands and occasionally further away on the east coast of Scotland. However, tracks show higher usage of areas to the north of the Hornsea Three array area, and immediately adjacent to the coast near Scroby sands and East Horsey. It is considered likely therefore that grey seals will be distributed throughout the Hornsea Three array area and Hornsea Three offshore cable corridor.

4.5.3 Abundance

Onshore

4.5.3.1 It is estimated that there are approximately 300,000 grey seals in North Atlantic, of which 70,000 are associated with haul-outs in the North Sea (Hammond *et al.*, 2001). The northeast Atlantic population is understood to be increasing at a rate of approximately 6% per year. SCOS (2016) advise that there are 139,800 grey seals (1+ aged population) in the UK (approximate 95% CI 116,500 to 167,100).

4.5.3.2 Abundance of grey seals onshore and offshore will vary seasonally depending on whether individuals are hauled-out or foraging at sea. Onshore counts are made during the breeding season and during August (the harbour seal annual moult survey) in order to provide population estimates.

4.5.3.3 Pup production along the English coast has shown a steady increase over the past 15 years, particularly at Donna Nook (Figure 4.29; Table 4.7) These data were collected from ground counts carried out during the grey seal breeding season (September to December) by the Lincolnshire Wildlife Trust (Donna Nook), Natural England (East Horsey) the National Trust (Blakeney Point) (SMRU, 2011; LWT pers. comm.); and Friends of Horsey Seals (2017). These data are processed by SMRU for inclusion in SCOS reporting. SCOS states that this steady increase in pup production is likely to be reflected closely in increasing population size, with the potential for high population increases being related to immigration from other colonies.

Table 4.7: Grey seal pup production estimates since 2002 on the East coast of England (source: Chris Morris, SMRU, 2017).

Colony	Donna Nook	East Horsey	Blakeney Point	Farne Islands	Total
2002	709	52	50	1,200	2,011
2003	792	68	80	1,266	2,206
2004	998	78	100	1,133	2,309
2005	995	106	175	1,138	2,414
2006	1,070	133	234	1,254	2,691
2007	1,194	168	278	1,164	2,804
2008	1,318	202	433	1,318	3,271
2009	1,371	294	579	1,346	3,590
2010	1,417	402	747	1,499	4,065
2011	1,438	500	932	1,555	4,425
2012	1,525	612	1,222	1,603	4,962
2013	1,676	728	1,560	1,575	5,539
2014	1,799	803	2,425	1,600	6,627
2015	1,892	1,236	2,343	1,876	7,347
2016	1,989	1,526	2,404	2,238	8,157

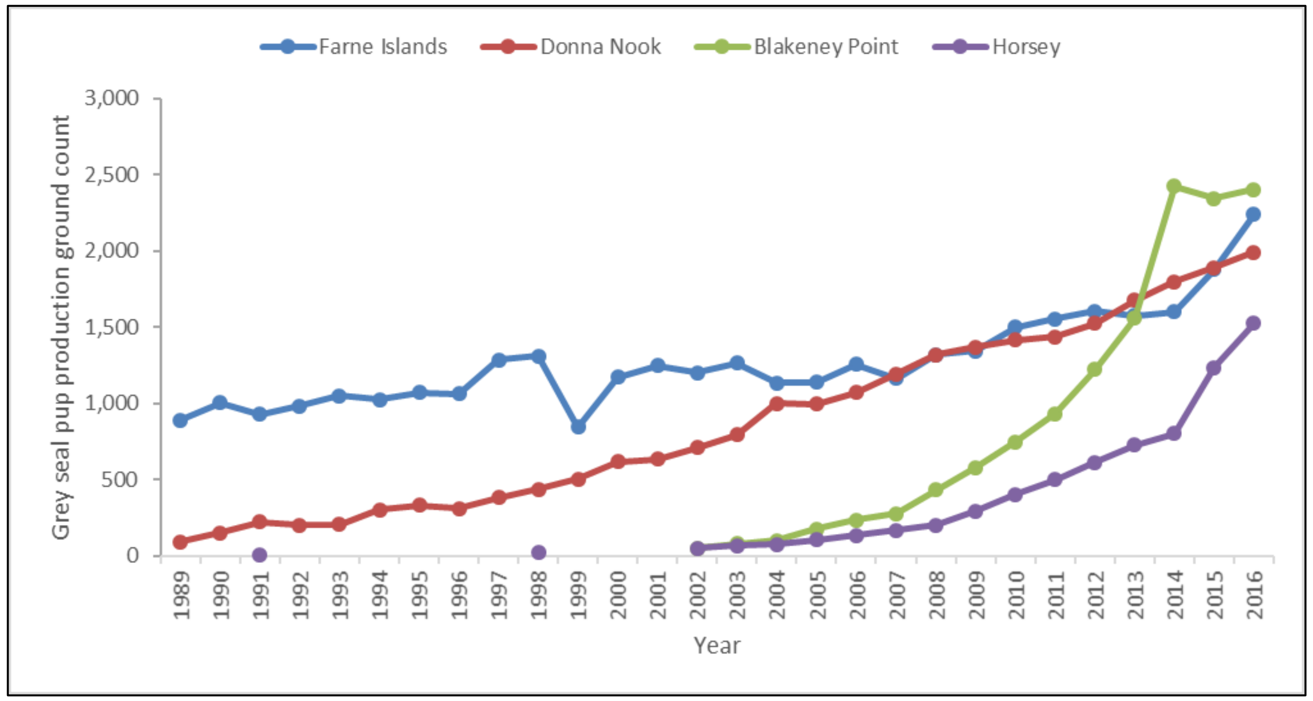


Figure 4.29: Trends in grey seal pup production at breeding colonies on the east coast of England between 1989 and 2016.

Offshore

4.5.3.4 A total of 247 grey seals were observed during boat based surveys of the former Hornsea Zone plus a 10 km buffer. with a mean group size of 1.04.

4.5.3.5 The abundance of grey seals in the former Hornsea Zone plus a 10 km buffer was calculated by multiplying this area (9,276 km^2) by the average density estimate of 0.034 animals km^{-2} (Table 3.12) giving a total abundance of 372 grey seals.

4.5.3.6 Only eight grey seal sightings were recorded during the 20 months of HiDef aerial surveys of the Hornsea Three zone.

4.5.3.7 Using SMRU average modelled surface densities total abundance of the former Hornsea Zone plus a 10 km buffer was calculated as 546.0 animals.

4.5.4 Density

4.5.4.1 Absolute density of grey seals in the former Hornsea Zone plus a 10 km buffer was calculated as 0.04 animals km^{-2} (Table 3.12). Figure 4.28 shows that an area of high density exists in the west of the former Hornsea Zone, where maximum densities are estimated at 0.39 animals km^{-2}. This is consistent with SMRU telemetry data which shows grey seal either travelling through the west of the Hornsea Three marine mammal study area, possibly to forage on Dogger Bank; or travelling north or south from Donna Nook and Blakeney (Figure 4.28).

4.5.4.2 The updated at-sea seal usage maps (Russel *et al*., 2017) also show highest densities at Donna Nook, where the largest colony is located (Figure 4.31). However, the at-sea usage maps predict much higher usage within the Former Hornsea Zone plus a 10 km buffer compared to the boat-based survey density surface. The highest predicted usage within the Former Hornsea Zone plus a 10 km bufferwas in the western part of the area and also in an area to the west of the Hornsea Three array area. The highest density within the Former Hornsea Zone plus a 10 km bufferwas predicted to be 2.92 grey seals/km and the average predicted density across the entire Former Hornsea Zone plus a 10 km bufferwas 0.30 grey seals/km^2. There was very little predicted usage within the Hornsea Three array area with maximum densities reaching 0.18 grey seals/km^2 with an average of 0.02 grey seals/km^2 across the Hornsea Three array area.

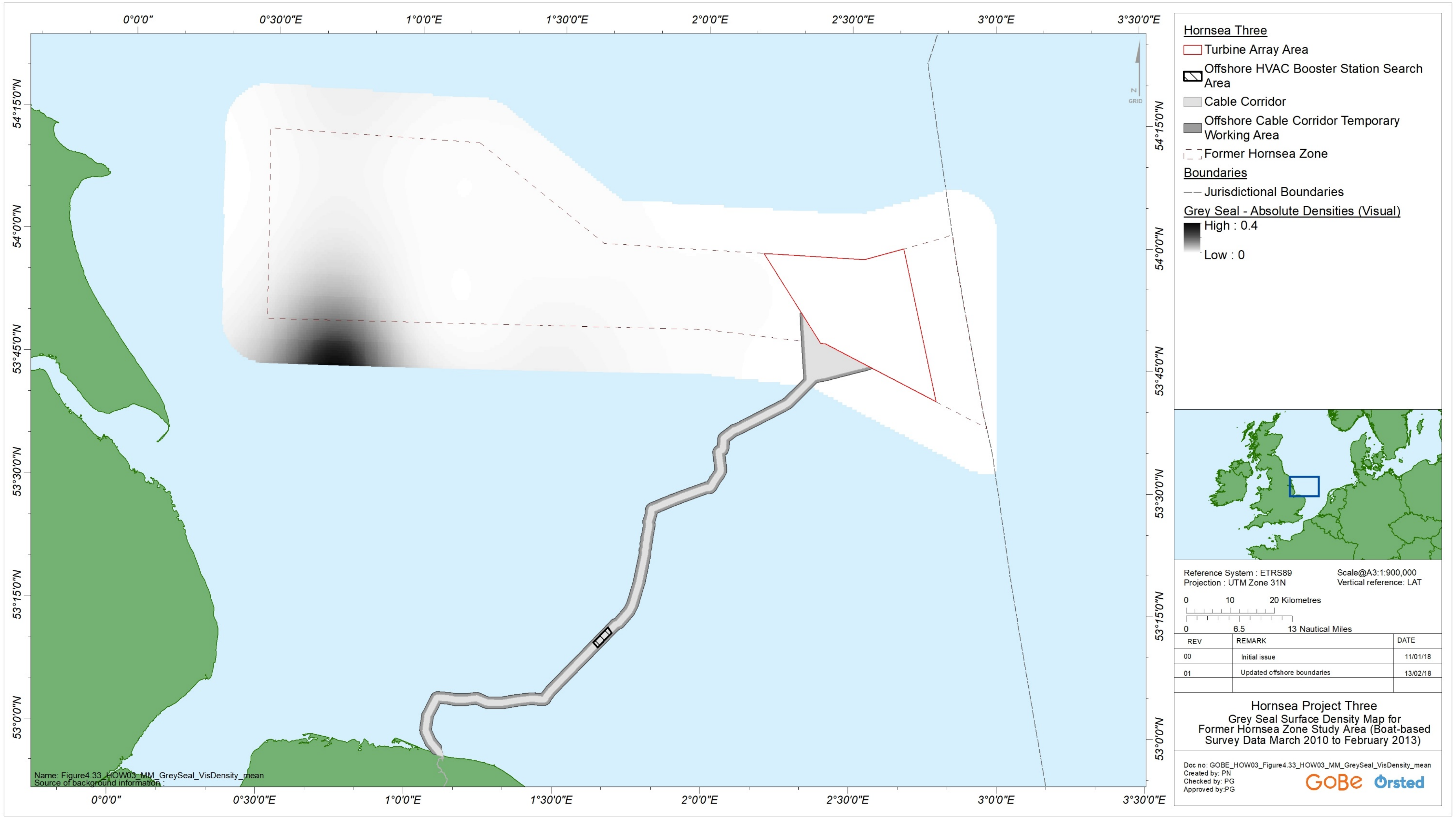


Figure 4.30: Modelled surface density estimates (absolute densities) for grey seals across the former Hornsea Zone plus a 10 km buffer based on three years of survey data (2010 to 2013).

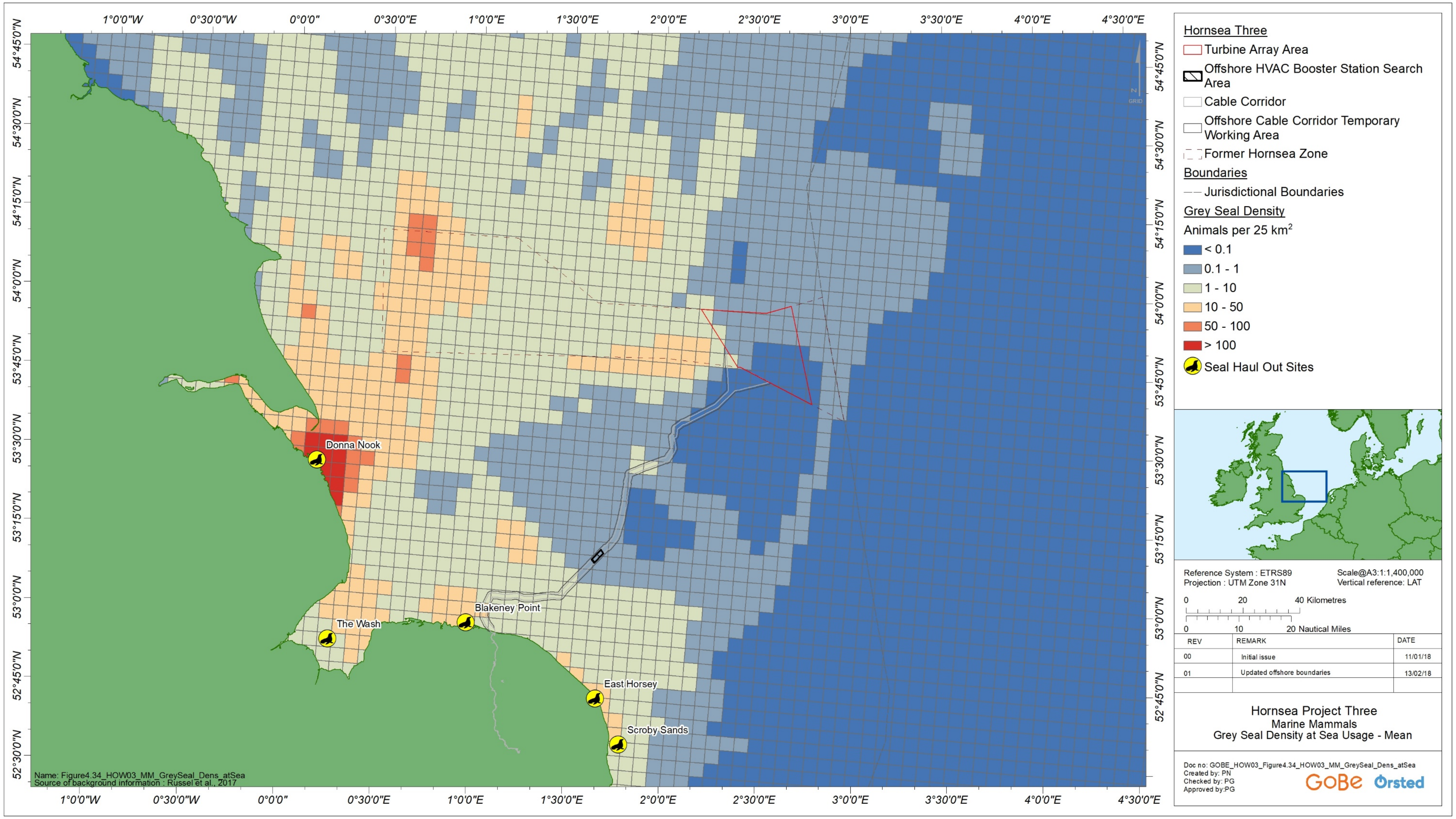


Figure 4.31: Grey seal density at-sea usage - mean (per 25km^2) for the regional marine mammal study area (Russell *et al*., 2017).

4.5.5 Management unit

4.5.5.1 Eleven MUs have been agreed for seal species' around the UK coastline and are identical for grey and harbour seal. Hornsea Three array area and Hornsea Three offshore cable corridor lies within the South East England MU but are close to the border of the North East England MU (IAMMG 2013) (Figure 4.32,Table 3.4). The division between these seal MUs does not take into account movement of seals between these MUs. Grey seals are known to regularly travel up to 145 km on foraging trips, but trips can be up to 2,100 km (Thomson *et al*., 1996). Both MUs are considered to be within normal foraging range of the Hornsea Project Three array area and offshore cable corridor and published telemetry data shows movement of grey seals between these two MUs (Russell and McConnell, 2014; Appendix A).

4.5.5.2 Following discussion with the marine mammal EWG, advice from SNCBs is that the assessment of impacts of the Hornsea Three on grey seal should be carried out against both the South East England MU and North East England MU combined (Figure 4.32).

4.5.5.3 Grey seal counts are normally derived from the numbers of pups counted during the breeding season, using age specific fecundity rates and both pup and non-pup survival rates. The latest pup production count for Donna Nook and East Anglia (South East England MU) in 2016 produced an estimate of 5,919 pups and an estimate of 2,238 pups at the Farne Islands (North East England MU). In order to convert pup production into total population size (aged 1+ population) a mathematical model is used; however, this has only been conducted on the pup production data up to 2014. The most recent pup counts have not yet been modelled to obtain the estimated population size. The most recent population size estimate as obtained by modelling the 2014 pup production counts provided an estimate of 33,700 grey seals in the North Sea at the start of the 2015 breeding season (95% CI: 26,200 to 41,400) (SCOS, 2016).

4.5.5.4 Grey seal distribution during the breeding season is, however, very different to their distribution at other times of the year. Therefore SCOS provides a summer population estimate for grey seal. This estimate was derived from the number of grey seal counted during the summer surveys (for moulting harbour seals) and converted to a population size using a scaling factor where the approximate proportion of animals hauled out at the time out the count was 0.35 (95% CI 0.32 to 0.38) (Lonergan *et al.*, 2011). A total of 6,999 and 7,015 grey seals were counted in the North East England MU and the South East England MU respectively during the 2016 August surveys, creating a combined East England MU count of 14,014 grey seals (data provided by Chris Morris, SMRU, 2017). This is scaled to an estimated population size for the combined East England MUs of 40,040 grey seals (95% CI 36,879 to 43,794).

4.5.5.5 The total grey seal population abundance within the South East England MU plus the North East England MU is 40,040 (Table 3.4).

4.5.6 Favourable Conservation Status

4.5.6.1 JNCC report that the Conservation Status for grey seal is favourable for range, population habitat, future prospects and overall assessment.

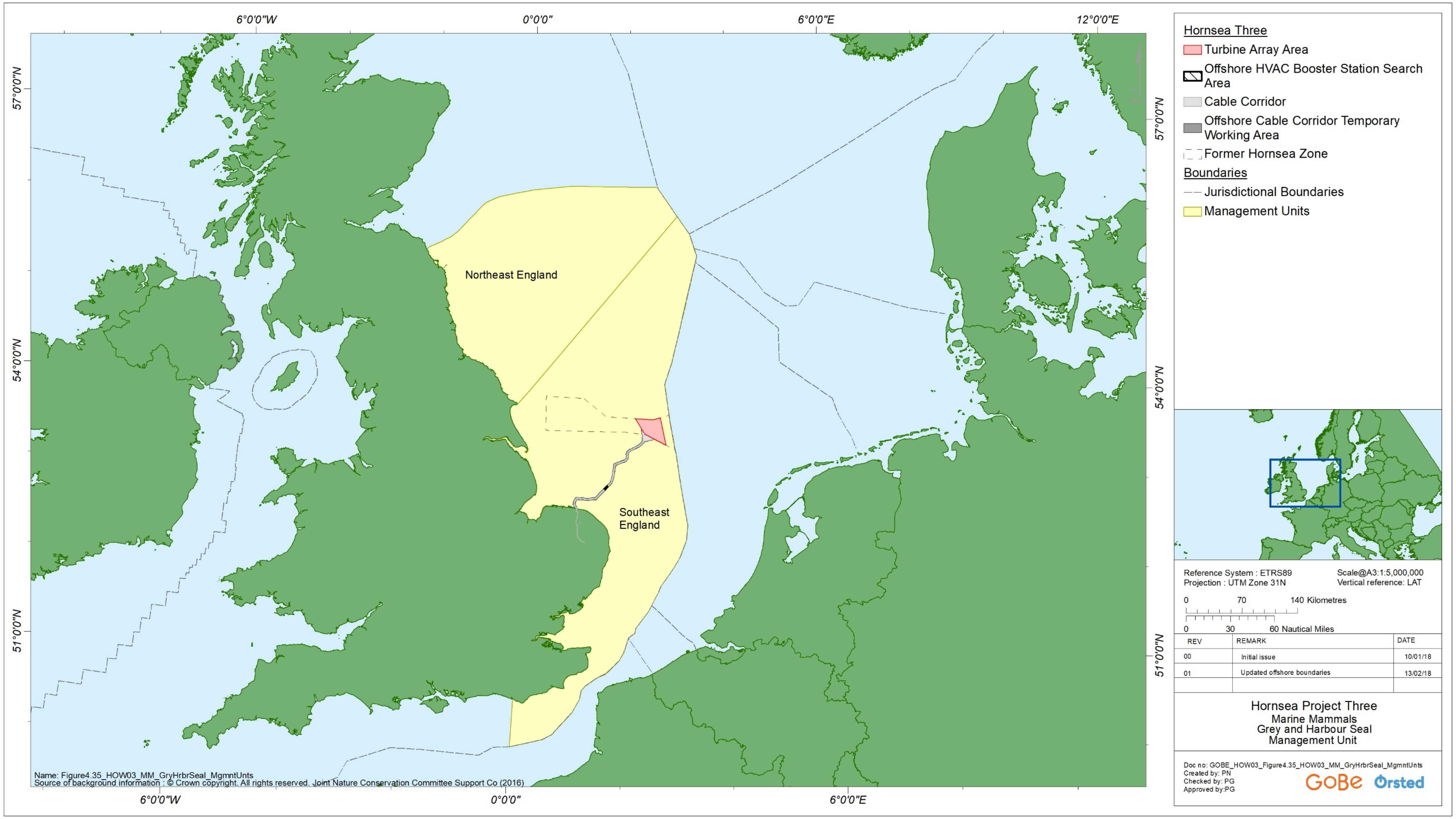


Figure 4.32: Seal MUs – Grey seal (Southeast England (SE) and Northeast England combined); Harbour seal (Southeast England).

4.5.7 Links between the Hornsea Three marine mammal study area and European Sites

4.5.7.1 The Berwickshire and North Northumberland Coast and Humber Estuary SACs, located approximately 286 km and 74 km respectively from Hornsea Three, support two of the largest grey seal breeding colonies in the UK (Thomson and Duck, 2010; JNCC, 2010b; Figure 3.1). A breeding colony of between 400 and 500 grey seal has also been recorded adjacent to the Haisborough, Hammond and Winterton SCI, located 88 km from the closest point to the Hornsea Three array area and offshore cable corridor, although grey seal is listed as a non-qualifying species in this SCI.

4.5.7.2 Appendix A demonstrates that seals spending time in the Hornsea Three array area and offshore cable corridor also hauled out at both of these SACs, with a greater degree of overlap with the Humber Estuary SAC, likely due to its closer proximity.

4.5.7.3 Grey seal are also listed as a primary reason for selection of the Waddenzee SCI, the Noordzeekustzone SAC and the Noordzeekustzone pSCI in Dutch waters which are located approximately 38 to 148 km to the east of Hornsea Three. Grey seal is also listed as a qualifying feature of the Klaverbank pSCI (11 km from Hornsea Three) and the Dutch Dogger Bank SCI (42 km from Hornsea Three). Appendix A demonstrates that a single UK tagged grey seal briefly visited the Noordzeekustzone SAC and Waddezee SCI. Studies of grey seals tagged in Dutch waters revealed that seals tracked from the Waddenzee also crossed the Hornsea Three array area and offshore cable corridor (Kirkwood *et al*., 2014; Brasseur, 2017).

4.5.7.4 Table 4.8 summarises the European sites with grey seal listed as a qualifying interest feature within normal foraging range of Hornsea Three.

Table 4.8: European sites with grey seal as a qualifying interest feature within normal foraging range of Hornsea Three.

Site Name	Distance from Hornsea Three array area and offshore cable corridor (km)
Klaverbank pSCI	11
Dogger Bank SCI (Dutch)	42
Humber Estuary SAC	74
Noordzeekustzone SAC	148
Noordzeekustzone II SCI	138
Wadenzee SCI	146
Berwickshire and North Northumberland Coast SAC	286

4.6 Harbour seal

4.6.1 Ecology

4.6.1.1 Harbour (common) seal is the smaller of the two species of pinnipeds that breed in the UK, typically weighing between 80 to 100 kg (SCOS, 2016). As with grey seal, the majority of the UK population is found in Scottish waters although the densest concentration of harbour seal haul-out sites are found along the tidal sand banks and mud flats of the Wash in East Anglia (SMRU, 2004) (Figure 4.33). These sites are used in August during the annual moult when seals gather in large numbers at key sites, and during breeding season when females disperse more widely to give birth. Most harbour seal haul-out sites are used daily with individuals showing a great degree of site fidelity (Yochem *et al.*, 1987).

4.6.1.2 Female harbour seal become sexually mature at three to five years of age and gestation lasts between 10.5 to 11 months (Thompson and Härkönen, 2008). Harbour seal are long-lived animals with individuals estimated to live to between 20 and 30 years (SCOS, 2016).

4.6.1.3 Harbour seal breed in small groups scattered along the coastline. Pups are born in June and July having moulted their white coats prior to birth. This allows harbour seal pups to swim within a few hours of birth (Burns, 2002). During lactation females spend much of their time in the water with their pups, and although they will forage during this period, distances travelled at this time are more restricted than during other periods (Thompson *et al.*, 1994). Harbour seal are "income breeders" and rely on building up fat reserves prior to lactation. Income breeding is a beneficial strategy in a predictable environment without limited food resources, however, when food availability is less predictable, income breeding may be costly (Jönsson, 1997). For this reason, harbour seal may be sensitive to disturbance during the breeding period since the energetic costs of a reduction in foraging could affect survival rate in pups (Lusseau *et al.*, 2012).

4.6.1.4 Harbour seal are generalist feeders and their diet varies both seasonally and from region to region (Hammond *et al.*, 2001). A wide variety of prey items are exploited by harbour seal. These includes species from the surface, mid-water and benthic habitats including sandeels; whitefish; herring; sprat; common octopus; and squid (SCOS, 2010). Tagging studies of harbour seal in the UK have revealed differing maximum foraging ranges. The SCOS (2016) report that harbour seal tend to forage within 40 or 50 km of their haul-out sites. Harbour seal hauled out in the Greater Wash (which encompassed the North Norfolk and Lincolnshire coastlines) however, were found to travel between 75 and 120 km offshore to what was assumed to be foraging locations. Some individuals were recorded travelling as far as 220 km (SMRU, 2011). The duration of these foraging trips was on average 8.3 days, with an individual maximum of 16 days on average (SMRU, 2011).

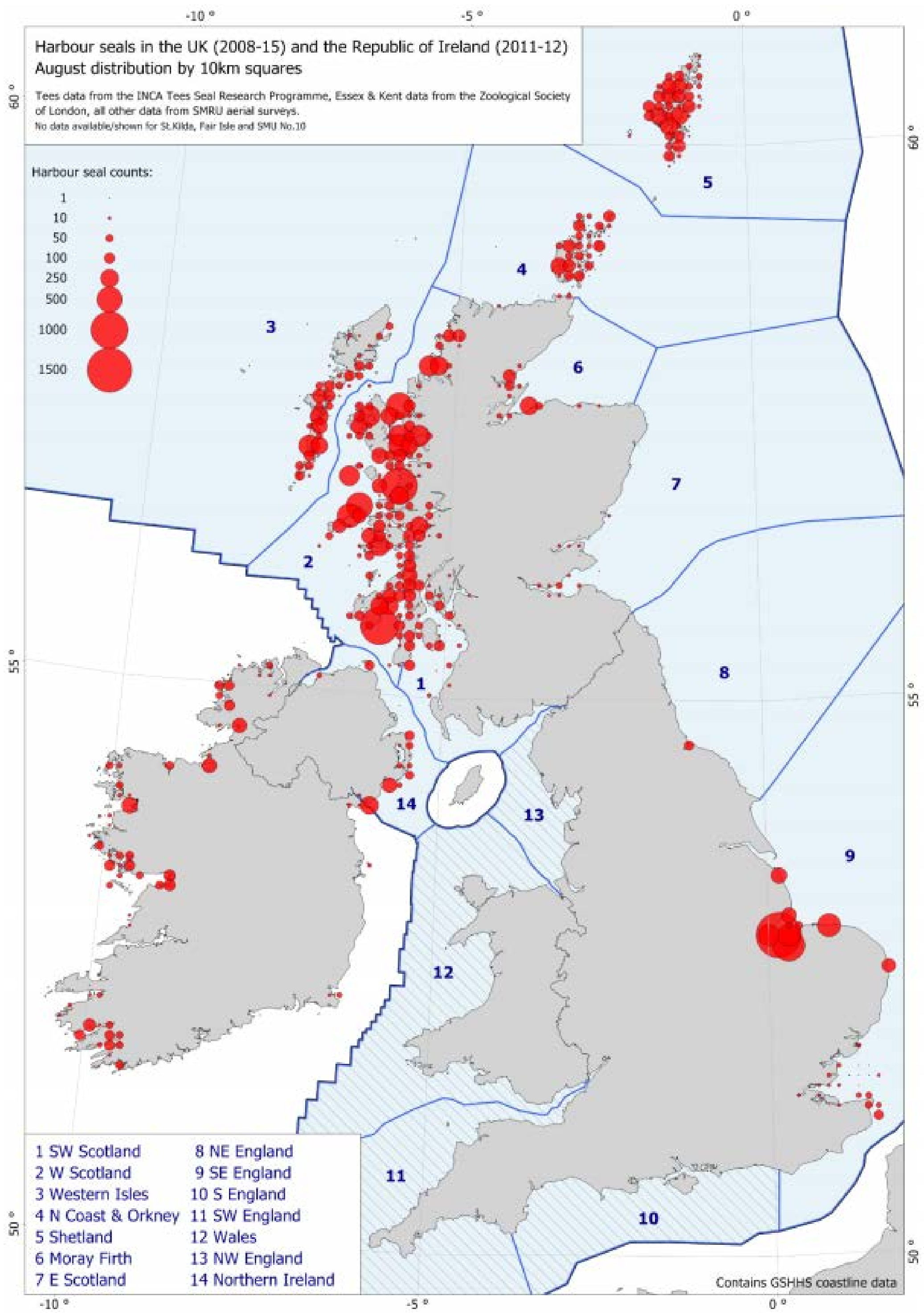


Figure 4.33: The distribution and number of harbour seal in Great Britain and Northern Ireland in August, by 10 km squares, from surveys carried out between 2008 and 2015 (SCOS, 2016).

4.6.1.5 Telemetry studies have also shown that harbour seal often return to particular feeding areas which are associated with habitats such as rocky reefs and sandbanks (Thomson and Miller, 1990). The time harbour seal spend on land is generally less than eight hours at any one time, and time at sea is usually no more than 12 hours (Thompson and Miller, 1990). However, individuals may occasionally spend up to six days at sea. These trips are likely to be associated with long distance movements (Thompson and Miller, 1990).

4.6.1.6 Harbour seal is listed as 'Least Concern' (LC) on the IUCN Red List of Threatened Species due to their stable or increasing population worldwide. However, within UK water there is concern over localised declines in numbers (Thompson and Härkönen, 2008). There have been major declines in numbers documented for Orkney (decline of 76% since 2001); Shetland (decline of over 30% between 2000 and 2009), and the Firth of Tay (decline of 92% between 2002 and 2013) (SCOS, 2015).

4.6.1.7 Major threats to harbour seal in the UK include: conflict with fisheries (e.g. by-catch, entanglement); hunting; pollution, including from oil spills, polychlorinated biphenols (PCBs), and pollutants from industrial or agricultural run-off; and mass outbreaks from viral disease (Thompson and Härkönen, 2008). Other causes of decline in the UK may include predators and competition with grey seal.

4.6.2 Distribution

Onshore

4.6.2.1 The data shown in (Figure 4.33) represent the distribution of harbour seals during the annual moult in August when the seals aggregate in large numbers at their preferred haul-out sites.

4.6.2.2 Within the southern North Sea, the main August haul-out sites are located in The Wash, Blakeney Point, Donna Nook, and Scroby Sands (Figure 4.34). The Wash and North Norfolk Coast SAC is home to the largest colony of harbour seals in the UK, and hosts 7% of the total UK population of this species. The tidally exposed sandbanks and mudflats within this SAC provide an extensive habitat for this species (English Nature and Environment Agency, 2003). Spatial and temporal variations in haul-out activity are related to factors such as breeding activity, seasonal changes in prey resources, and tidal cycle (Thompson *et al.*, 1989).

4.6.2.3 The closest haul-out site to the Hornsea Three marine mammal study area is at Donna Nook. This haul-out is also an important breeding site for both harbour and grey seals in the south central North Sea.

Offshore

4.6.2.4 The results of the boat-based surveys determined that harbour seals are distributed throughout Hornsea Three marine mammal study area (including within the vicinity of the Hornsea Three offshore cable corridor (Figure 4.36). Harbour seals were recorded throughout the area and comprised 1.9% of all marine mammals recorded across all surveys.

4.6.2.5 During surveys of the former Hornsea Zone plus a 10 km buffer, a few seals were also recorded crossing the survey area to reach offshore waters to the north. Sightings of harbour seals to the north and east of the former Hornsea Zone were low.

4.6.2.6 Only two harbour seal sightings were recorded during the 20 months of HiDef aerial surveys of the Hornsea Three zone.

4.6.2.7 Historical WWT aerial survey data (WWT, 2006) also recorded seals along the coastline to the north and south of The Wash (Figure 4.7), and in the area coinciding with the Hornsea Three array area and offshore cable corridor.

4.6.2.8 Harbour seal at-sea usage data provided by SMRU, indicate that harbour seal are present throughout the Hornsea Three array area and offshore cable corridor (Figure 4.37). At-sea usage is highest in The Wash to the southwest of the former Hornsea Zone (Figure 4.37). This suggests that distribution of harbour seal is highest near to main haul out sites, in particular The Wash haul outs. However, harbour seal at-sea usage is spread throughout the Hornsea Three array area and the offshore cable corridor.

4.6.2.9 SMRU seal telemetry data presented in (Figure 4.34) show that a few individual seals do travel to the Hornsea Three array area or close to it, from the Wash and Blakeney point haulouts. A number of individuals do however, cross the Hornsea Three offshore cable corridor, in particular close to the coast. It is considered likely therefore, that harbour seals will be distributed throughout the Hornsea Three offshore cable corridor, with some animals utilising the Hornsea Three array area.

4.6.2.10 The historical WWT aerial survey data (WWT, 2009) also recorded seals along the coastline to the north and south of The Wash and in the area coinciding with the Hornsea Three offshore cable corridor (Figure 4.27). Given the proximity of known breeding colonies in the region, as well as the telemetry data for harbour seal tagged in The Wash (Figure 4.34) it is considered likely that harbour seal will regularly occur within the Hornsea Three array area, and offshore cable corridor.

4.6.3 Abundance

Onshore

4.6.3.1 Approximately 30% of European harbour seal are found in UK waters, with 16% of this proportion located within England (SCOS 2016). SCOS (2016) reported an abundance of 43,300 (approximately 95% CI 35,500 to 59,000) for harbour seal in the UK in 2015. Observed declines in harbour seal numbers from 2000 has led to an increase in survey effort by SMRU. Counts are made during harbour seal moult (August) when the largest proportion of animals are on land and therefore visible to be counted, however counts must be corrected for the proportion of animals that will be at-sea. Results indicate that 72% of the population will be hauled out and therefore be available to be counted during moult survey periods (SCOS, 2011). Despite the historic declines due to outbreaks of the phocine distemper virus (PDV) in 1988 and 2002, the population has been gradually increasing and recent estimates indicate that the total east coast population has recovered to pre-epidemic levels. However due to 80% of the harbour seal population being present in Scotland showing a severe decline, the assessment of overall population trend for harbour seal in the UK is decreasing (SCOS, 2016).

4.6.3.2 The densest concentration of haul-out sites along the North Sea UK coastline is found in The Wash in East Anglia (SMRU, 2004). In The Wash, harbour seal haul out during June and July to give birth to pups and to breed, and also during the August moult. The Wash and North Norfolk Coast SAC is home to the largest breeding colony of harbour seal in the UK, and hosts 7% of the total UK population of this species.

4.6.3.3 A total of 147 harbour seals were recorded during the three years of monthly boat-based surveys of the Hornsea Zone plus a 10 km buffer, with a mean group size of 1.01. This accounted for 1.87% all of marine mammals sightings across all surveys.

4.6.3.4 Modelled surface density estimates for harbour seal are shown in Figure 4.36. The highest harbour seal densities were in the southwest region of the former Hornsea Zone and no animals were recorded in the northeast region of the former Hornsea Zone (i.e. in the area coinciding with the Hornsea Three array area). The relative mean densities within the former Hornsea Zone plus a 10 km buffer was 0.018 animals km^{-2}. The mean number of animals estimated to occur offshore within the former Hornsea Zone plus a 10 km buffer, is 167.2 individuals.

4.6.3.5 Harbour seal numbers during August haul-out surveys have remained relatively stable at Donna Nook, Blakeney Point and Scroby Sands, however there has been a recent increase in The Wash. Table 4.9 and Figure 4.35 present data provided by Callan Duck, SMRU, 2017.

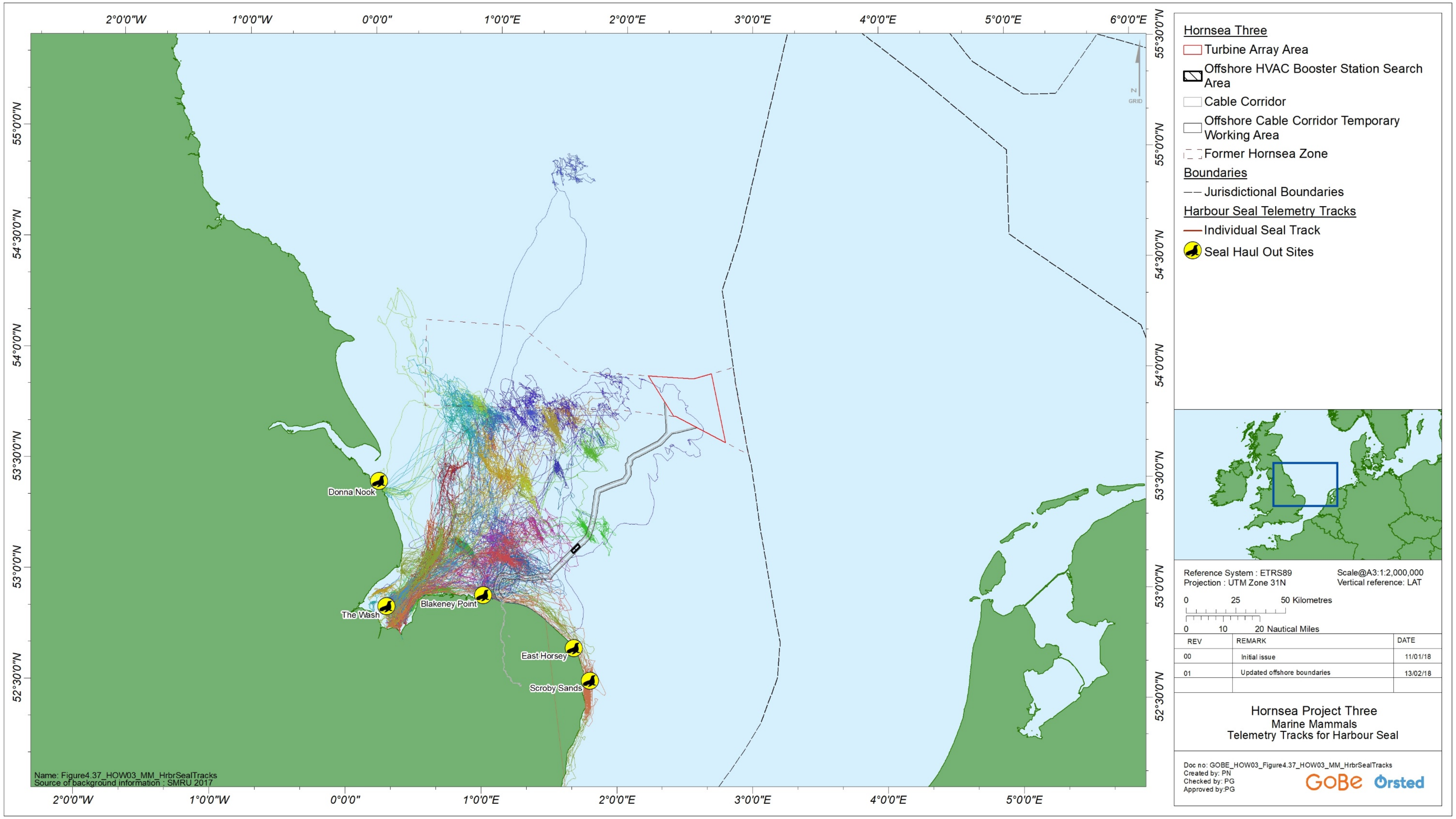


Figure 4.34: Tracks of the 23 harbour seals which were tagged in The Wash in 2012. Each seal is represented by a different colour.

Table 4.9: Trends in harbour seal counted at haul out sites in South East England (source: SMRU, 2017).

Year	Donna Nook	The Wash	Blakeney Point	Scroby Sands	Essex & Kent	Total
1988	173	3,035	701			3,909
1989	126	1,555	307			1,988
1990	57	1,543				1,600
1991		1,398				1,398
1992	32	1,671	217			1,920
1993	88	1,884	267			2,239
1994	103	2,011	196	61		2,371
1995	115	2,084	415	49		2,663
1996	162	2,151	372	51		2,736
1997	250.5	2,465	310	65		3,091
1998	247.5	2,374	636	52		3,310
1999	303.5	2,392	658	71		3,425
2000	390	2,778	895	46		4,109
2001	233	3,194	772	75		4,274
2002	341	2,976	488			3,805
2003	231	2,512	399	38	180	3,360
2004	294	2,146	646	56		3,142
2005	421	1,946	709	55	101	3,232
2006	299	1,695	719	71		2,784
2007	214	2,162	550			2,926
2008	191	2,010	580	81	319	3,181
2009	267	2,829	372	165		3,633
2010	176	2,585	391	201	379	3,732
2011	205	2,894	349	119		3,567
2012	192	3,372	409	161		4,134
2013	396	3,174	304	148	482	4,504
2014	353	3,086	468	285	489	4,681
2015	228	3,336	455	269	451	4,739
2016	462	3762	460	211	694	5,589

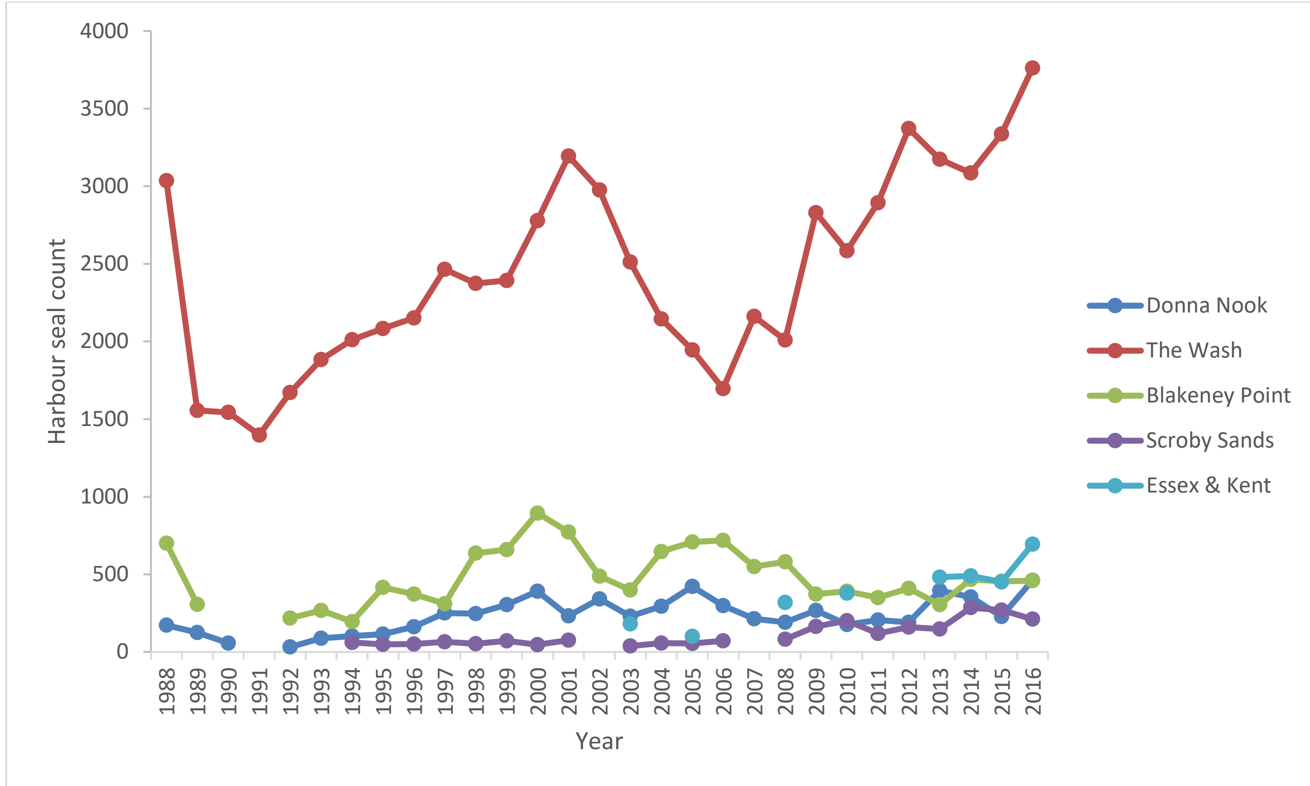


Figure 4.35: Trends in number of harbour seal counted in South East England haulouts, 1988 - 2016 (data provided by SMRU). The lines fitted to the data are to identify trends and have no biological significance.

4.6.3.6 Harbour seal pup production has continued to increase at the east of England colonies from a low point in 2006. The most recent count from 2016 has harbour seal counts at 5,589 – the highest since counts began. SCOS (2015) also reports an increase in the ratio of pups to total population since 2001, suggesting a possible increase in fecundity over the last 14 years (SCOS 2015).

Offshore

4.6.3.7 Harbour seals were recorded throughout the former Hornsea Zone plus a 10 km buffer in all years of survey. These surveys recorded a total number of 147 individuals, with a mean group size of 1.01, therefore the majority of sightings were of individual animals.

4.6.3.8 Total abundance using the SMRU at-sea usage maps across the former Hornsea Zone plus a 10 km buffer was calculated as 315.5 animals. No harbour seals were recorded during aerial surveys of Hornsea Three array area plus a 4 km buffer.

4.6.4 Density

4.6.4.1 The average relative density estimates for harbour seals over across the former Hornsea Zone plus a 10 km buffer was at 0.018 km^{-2} (Table 3.12). Correcting these for detection probability, based on the same value for grey seals (g(0)=0.46), gives approximate absolute estimates of 0.039 animals km^{-2}. This value is similar to the density estimates calculated from the WWT aerial survey data (Figure 4.36), which shows an average across the whole survey area of 0.03 animals km^{-2} (RWE npower, 2003). Harbour seal surface densities show a clear density gradient across the former Hornsea Zone with the highest harbour seal densities in the southwest (0.28 animals km^{-2}) and the lowest densities in the north and east (0.0 animals km^{-2}) (Figure 4.36). The observed gradient in density is consistent with telemetry data collected previously by SMRU which showed seals from The Wash foraging in the southwest of the Hornsea Three array area, crossing it occasionally (Figure 4.34).

4.6.4.2 The updated at-sea seal usage maps (Russell *et al*., 2017) also show a similar pattern in predicted at-sea densities with the highest densities within The Wash, where the largest colony is located (Figure 4.37). Usage of the Former Hornsea Zone plus a 10 km bufferwas low, with highest predicted densities along the very south-western edge of the area where predicted densities reached a maximum of 0.80 harbour seals/km^2. The average predicted density across the entire Former Hornsea Zone plus a 10 km buffer was 0.04 seals/km^2. There was almost no predicted usage within the Hornsea Three array area with maximum densities reaching 0.01 seals/km^2 with an average of 0.00 seals/km^2 across the Hornsea Three array area.

4.6.4.3 Density estimates presented from the SMRU dataset and boat-based analysis from the former Hornsea Zone plus a 10 km buffer differ due to differences in survey approach and analysis assumption. Both are presented here to provide an overall picture.

4.6.5 Management unit

4.6.5.1 Eleven MUs have been agreed for seal species' around the UK coastline and are identical for grey and harbour seals. Hornsea Three array area and offshore cable corridor lies within the South East England MU for seal species (IAMMWG 2013) (Figure 4.32; Table 3.4). The latest harbour seal count for the South East England MU was 4,895 in 2016 (Table 4.9). This value was then scaled by the estimated proportion hauled out (0.72, 95% CI 0.54 – 0.88) to obtain a population estimate of 6,799 (95% CI 5,563 – 9,065).

4.6.5.2 Advice from UK SNCBs is that the assessment of impacts of Hornsea Three on harbour seals should be carried out against the South East England MU.

4.6.6 Favourable Conservation Status

4.6.6.1 JNCC report that the Conservation Status for common seal (harbour seal) is favourable for range, inadequate for population, unknown for habitat and future prospects, and inadequate for overall assessment.

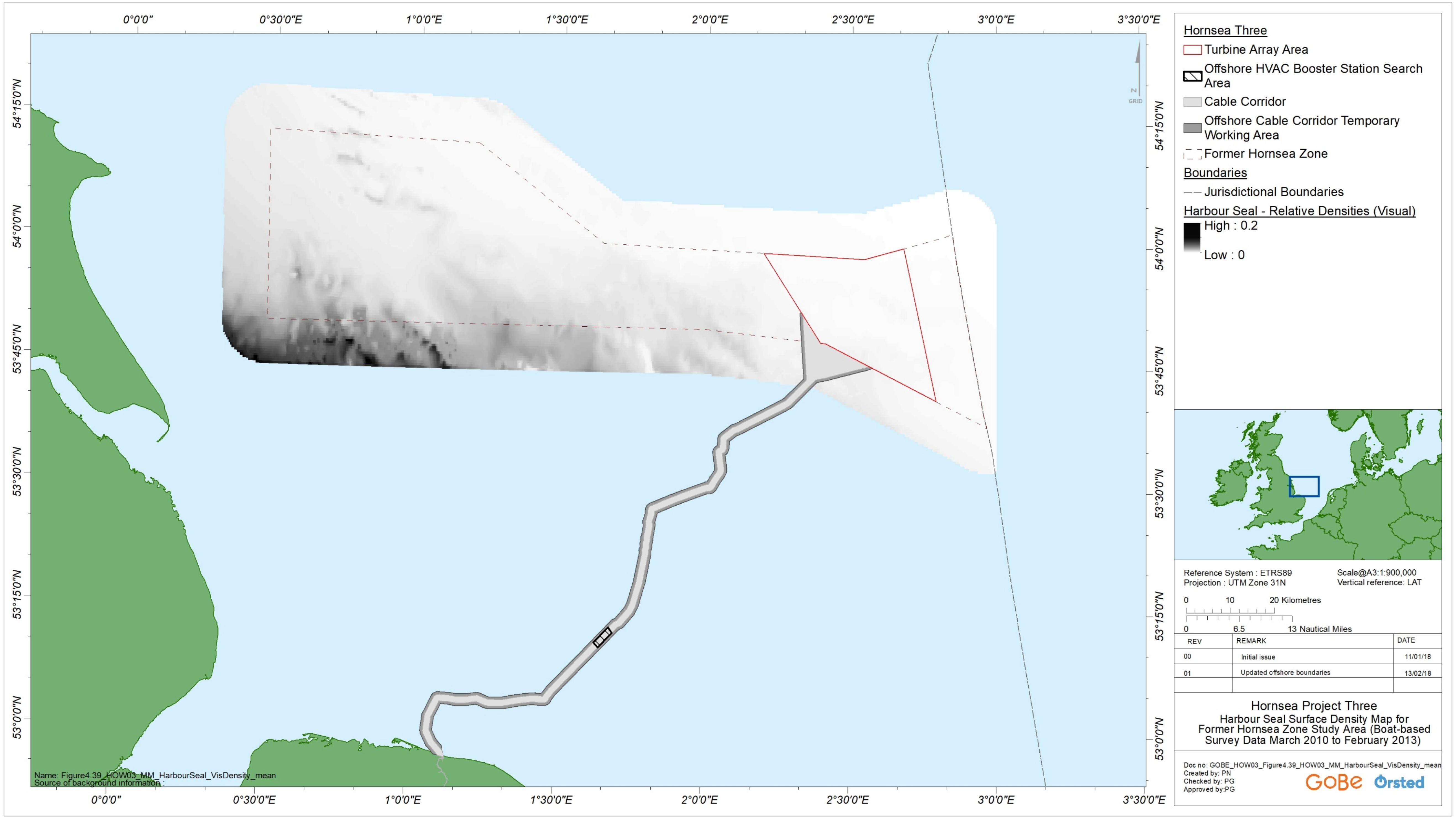


Figure 4.36: Modelled surface density estimates (relative densities) for harbour seal across the former Hornsea Zone plus a 10 km buffer, based on three years of survey data (2010 to 2013).

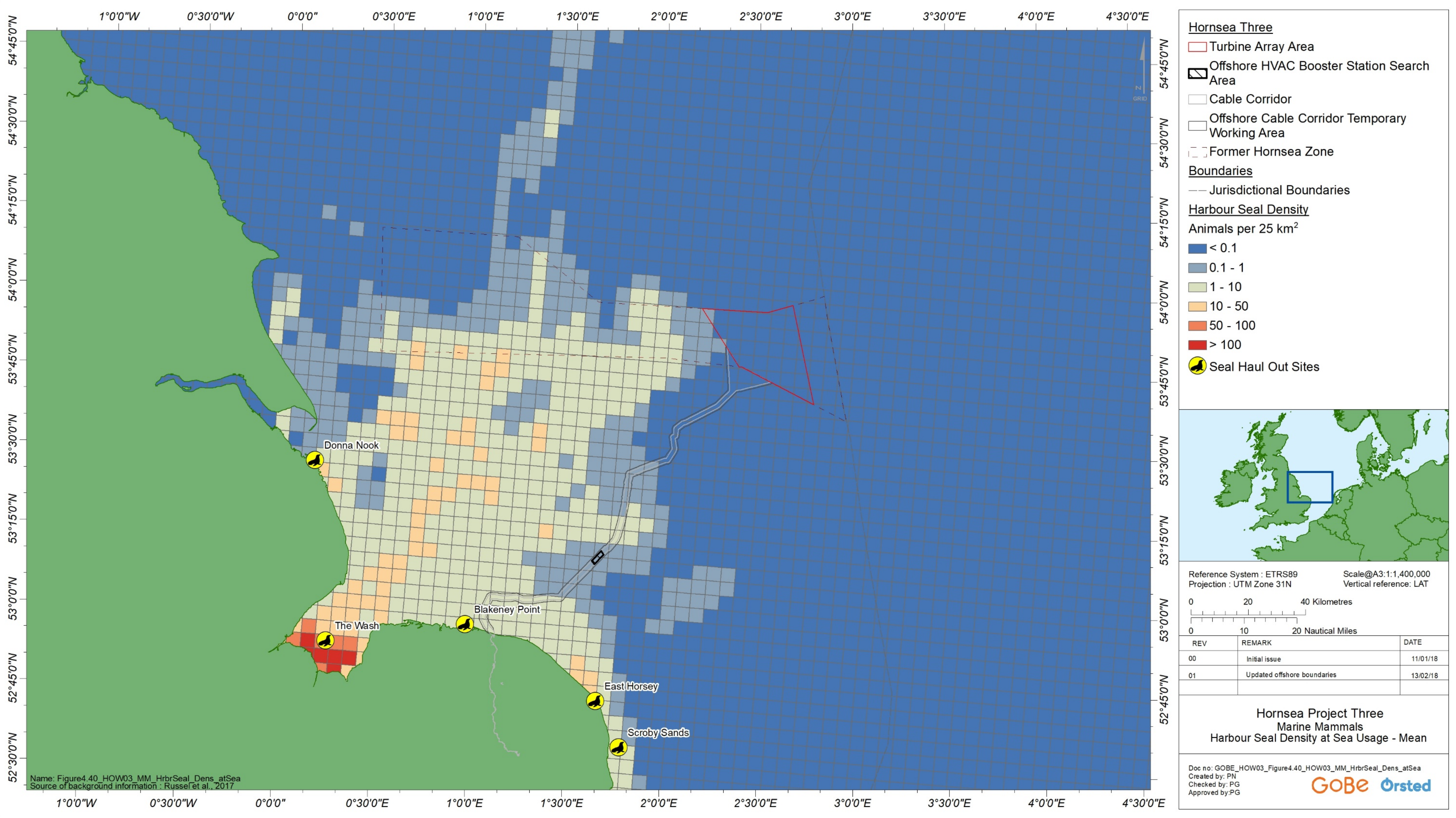


Figure 4.37: Mean harbour seal at-sea densities (25km-2) for the former Hornsea zone (Russell *et al*., 2017).

4.6.7 Links between the Hornsea Three marine mammal study area and SACs/SCIs

4.6.7.1 The Wash and North Norfolk Coast SAC overlaps the Hornsea Three offshore cable corridor. It is home to the largest colony of harbour seals in the UK, holding 7% of the total UK population and 90% of the English population (Defra, 2010b). The extensive intertidal flats at this site provide ideal conditions for breeding and hauling out by this species. A population estimate of 4,681 individuals was reported during counts between 2007 and 2014 at in the South East England MU, primarily in The Wash and North Norfolk coast SAC (SCOS, 2015). Pupping and lactation here occurs between June and July, with birth sites tending to be located near the top of the bank. Although harbour seals within this SAC have been reported to spend up to 50% of their time hauled out, individuals from The Wash and North Norfolk coast SAC have been recorded regularly in the regional marine mammal study area during foraging trips (SMRU, 2011; English Nature, 2000; Mortimer, no date).

4.6.7.2 Appendix A demonstrates that seals spending time in the Hornsea Three array area and offshore cable corridor largely hauled out within this SAC.

4.6.7.3 Harbour seal is a qualifying interest feature of the German and Dutch Dogger Bank SCIs located 183 km and 42 km from Hornsea Three array area respectively. An aerial survey of the Dutch Dogger Bank SCI revealed a low density of harbour seal (Deerenberg *et al.,* 2010), although, it is currently not possible to estimate the numbers of harbour seal which use the site. It is thought that individuals observed in this area are likely to have come from large haul-out sites on the English east coast.

4.6.7.4 Harbour seal is also listed as a primary reason for site selection of the Waddenzee SCI (146 km from Hornsea Three), the Noordzeekustzone SAC, Noordzeekustzone II SCI (148 km and 138 km from Hornsea Three respectively) in Dutch waters and the Vadehavet med Ribe Å, Tved Å og Varde Å vest for Varde SAC (381 km from Hornsea Three) in Danish waters.

4.6.7.5 Appendix A demonstrates that no UK tagged harbour seals visited any of these sites. Studies of harbour seals tagged in Dutch waters revealed that seals tracked from the Waddenzee also crossed the Hornsea Three array area and offshore cable corridor (Kirkwood *et al*., 2014; Brasseur, 2017).

4.6.7.6 The presence of harbour seal is a qualifying interest feature for the selection of the Klaverbank pSCI, located 11 km from Hornsea Three.

4.6.7.7 Table 4.10 below summarises distances from Hornsea Three to protected sites for harbour seal.

Table 4.10: European sites with harbour seal as a notified interest features within normal foraging range of Hornsea Three.

Site Name	Distance from Hornsea Three (km)
The Wash and North Norfolk Coast SAC	0 (within Hornsea Three offshore cable corridor)
Klaverbank pSCI	11 (Hornsea Three array area)
Dogger Bank SCI (Dutch)	42 (Hornsea Three array area)
Noordzeekustzone II SCI	138 (Hornsea Three array area)
Wadenzee SCI	146 (Hornsea Three array area)
Noordzeekustzone SAC	148 (Hornsea Three array area)
Dogger Bank SCI (German)	183 (Hornsea Three array area)
Vadehavet med Ribe Å, Tved Å og Varde Å vest for Varde SAC	381 (Hornsea Three array area)

5. Conclusion

5.1.1.1 Site specific surveys of the former Hornsea Zone plus a 10 km buffer suggested that the area may be important for harbour porpoise, with higher average densities here than in the rest of the reference population MU (North Sea). This is reflected by a number of other data sets describing harbour porpoise abundance and distribution of harbour porpoise in the North Sea. The Southern North Sea cSAC designated for harbour porpoise lies immediately south of the Hornsea Three array area and overlaps part of the Hornsea Three offshore cable corridor.

5.1.1.2 Key species identified for impact assessment are harbour porpoise, minke whale, white-beaked dolphin, grey seal, and harbour seal.

5.1.1.3 A number of designated sites which list grey seal and/or harbour seal as qualifying interest features occur within normal foraging range of these species from the Hornsea Three array area and/or offshore cable corridor. There are seven designated sites with grey seals listed as a qualifying interest feature, and four with harbour seals listed as a qualifying interest feature (Table 3.1).

5.1.1.4 The densities proposed for use in the impact assessment are based on the best available data, with consideration given to the most up to date information together with the necessary precaution applied where there is uncertainty (i.e. where density estimates vary considerably between data sources, a range of estimates will be presented in the impact assessment, with the focus being on more recently collected data sets) (Table 5.1). While the density estimates obtained from the Hornsea Three and Hornsea Zone site specific surveys provide fine temporal and spatial scale data, the surveys are now several years old and therefore more recent site specific aerial surveys represent the most up to date estimates of density at the Hornsea Three array area. None of the site specific surveys extend far enough from the Hornsea Three site to provide reliable density estimates for the entire potential behavioural impact zones for the noise impact assessment, and as such, broader scale density estimates from SCANS III will be incorporated into the assessment for cetacean species comparison.

Table 5.1: Summary of the density estimate for each of the key species to be used in the impact assessment together with the reference population against which impacts have been assessed.

Species	Density estimate to be used in impact assessment	Source of density estimate	Relevant MUs for reference population	Abundance of reference population
Harbour porpoise	grid cell specific density	Modelled surface density estimates from the boat-based acoustic surveys of former Hornsea Zone plus a 10 km buffer	North Sea (NS)	345,373 (246,526 – 495,752)
	1.019 individuals km^{-2}	Hornsea Three aerial surveys		
	0.888 individuals km^{-2}	SCANS-III Block O		
White-beaked dolphin	grid cell specific density	Modelled surface density estimates from the boat-based acoustic surveys of former Hornsea Zone plus a 10 km buffer	Celtic and Greater North Seas (CGNS)	15,895 (9,107 – 27,743)
	0.002 individuals km^{-2}	SCANS-III Block O		
Minke whale	grid cell specific density	Modelled surface density estimates from the boat-based acoustic surveys of former Hornsea Zone plus a 10 km buffer	Celtic and Greater North Seas (CGNS)	23,528 (13,989 – 39,572)
	0.010 individuals km^{2}	SCANS-III Block O		
Grey seal	25km^{2} grid cell specific density surface	Russell *et al.*, 2017	South-East England (SEE) and North East England (NEE) combined	40,040
Harbour seal	25km^{2} grid cell specific density surface	Russell *et al.*, 2017	South-East England (SEE)	6,799 (5,563 – 9,065)

6. References

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Appendix A Grey and Harbour Seal Telemetry Report

Seal telemetry data in relation to the Hornsea Three

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A.1 Introduction

A.1.1.1 RPS approached SMRU Consulting in March 2017 with a request to provide seal telemetry data in relation to Hornsea Three. The following telemetry data were requested: tracks from tagged harbour and grey seals tagged at haul out sites in the vicinity of the specified area (Hornsea Three array area and offshore cable corridor), collected since the last dataset supplied under agreement 52.08.12.Hornsea in August 2012.

A.2 Methods

A.2.1.1 The SMRU has deployed telemetry tags on grey seals (and harbour seals) in the UK since 1988. These tags transmit data on seal locations with the tag duration (number of days) varying between individual deployments. There are two types of telemetry tag which differ by their data transmission methods. Data transmission can be through the Argos satellite system (Argos tags) or GPS Phone tags which combine GPS quality locations with transmission of data using the GSM mobile phone network. Both types of transmission result in location fixes, but data from GPS phone tags comprise better quality and more frequent locations by the incorporating the Fastloc GPS system (Wildtrack Telemetry Systems, UK) which obtains the GPS location within a fraction of second and therefore collects data even when the animal surfaces for a short period. The GPS tags attempt to collect location data every five minutes. Both types of tags use precision wet/dry sensors as well as pressure and temperature sensors to obtain detailed individual dive (max depth, shape, time at depth, etc.) and haulout records. Data are stored on board the tags and then relayed by a satellite (Argos tags) or by quad-band GSM mobile phone module to SMRU when the animal is within range of the GSM mobile phone network. The data are then stored in databases, cleaned according to methods described in Russell *et al*. (2011) and processed for analysis.

A.2.1.2 The telemetry database was queried to obtain any telemetry data for seals tagged at The Wash, Donna Nook and Blakeney and any other sites where tagged seals overlapped with the Hornsea Project 3 Scoping Boundary that have been collected since the provision of the previous data request (Jones and Matthiopoulos, 2012). This resulted in four datasets: harbour seals tagged in The Wash in 2012, harbour seals tagged in the Thames in 2012, harbour seals tagged in The Wash in 2016 and grey seals tagged at Blakeney and Donna Nook in 2015.

A.3 Harbour Seals Tagged at The Wash 2012 & 2016

A.3.1.1 In January 2012 SMRU tagged 25 adult harbour seals in the Wash. Two of the tags failed to work correctly and so a total of 23 tagged seals transmitted data (Table A.1). Of these, 12 were females aged 1+ and 11 were males aged 1+. The mean tag duration was 95.2 days (range: 2-171 days). Of the 23 tagged harbour seals, eight had GPS tracks and positions that overlap with the scoping boundary area that covers the Hornsea Three array area and offshore cable corridor (Figure A.1 and Figure A.2). Most of the overlap with the Scoping Boundary was within the offshore export cable corridor, while only one harbour seal showed any overlap with the actual wind farm site.

A.3.1.2 Another tagging deployment was conducted by SMRU on the 11th of October 2016 as part of the Race Bank Offshore Wind Farm post consent monitoring. This involved the tagging of 20 harbour seals, of which, 19 were adult seals and one was a juvenile with the majority of the seals being female (n=15). The mean tag duration was 138.4 days (range 43 – 244 days) (Table A.2). Of the 20 tagged harbour seals, 16 had GPS tracks and positions that overlap with the scoping boundary area that covers the Hornsea Three array area and offshore cable corridor (Figure A.3 and Figure A.4). These data show that a higher proportion of the tagged seals in 2016 showed overlap with the Hornsea Three Scoping Boundary (80%) compared to the 2012 dataset (35%). As with the 2012 data, most of the overlap with the Scoping Boundary was within the offshore export cable corridor, while only one harbour seal showed any overlap with the actual wind farm site.

Table A.1: Details of the 23 harbour seals tagged at The Wash in January 2012. Those seals that had GPS positions that overlapped with the Hornsea Three scoping boundary are highlighted in green.

Seal ID	Tagging date	End date	Tag duration (days)	Age class	Sex
pv42-156-12	2012-01-24	2012-01-26	2	1+	M
pv42-162-12	2012-01-23	2012-07-01	160	1+	F
pv42-165-12	2012-01-21	2012-05-15	115	1+	F
pv42-194-12	2012-01-23	2012-05-17	115	1+	M
pv42-198-12	2012-01-24	2012-06-03	131	1+	M
pv42-220-12	2012-01-24	2012-06-16	144	1+	M
pv42-221-12	2012-01-24	2012-03-14	50	1+	M
pv42-266-12	2012-01-24	2012-04-18	85	1+	F
pv42-277-12	2012-01-23	2012-06-29	158	1+	F
pv42-287-12	2012-01-24	2012-02-11	18	1+	M
pv42-288-12	2012-01-21	2012-07-10	171	1+	F
pv42-289-12	2012-01-25	2012-04-13	79	1+	M
pv42-290-12	2012-01-25	2012-03-23	58	1+	F
pv42-291-12	2012-01-23	2012-05-11	109	1+	F
pv42-292-12	2012-01-24	2012-05-08	105	1+	M
pv42-293-12	2012-01-25	2012-04-04	70	1+	F
pv42-294-12	2012-01-25	2012-05-08	104	1+	M
pv42-295-12	2012-01-25	2012-04-03	69	1+	F
pv42-316-12	2012-01-22	2012-05-07	106	1+	M
pv42-317-12	2012-01-23	2012-05-15	113	1+	F
pv42-318-12	2012-01-23	2012-06-11	140	1+	F
pv42-319-12	2012-01-22	2012-05-15	114	1+	M
pv42-320-12	2012-01-21	2012-05-07	107	1+	F

Table A.2: Details of the 20 harbour seals tagged at The Wash in October 2016. Those seals that had GPS positions that overlapped with the Hornsea Three scoping boundary are highlighted in green.

Seal ID	Tag duration (days)	Age class	Sex
pv63-373-16	86	1+	M
pv63-374-16	223	1+	F
pv63-375-16	46	1+	F
pv63-376-16	90	1+	F
pv63-377-16	233	1+	F
pv63-378-16	69	1+	F
pv63-379-16	132	1+	F
pv63-380-16	221	1+	F
pv63-381-16	52	1+	F
pv63-382-16	122	1+	M
pv63-383-16	56	1+	F
pv63-384-16	145	1+	M
pv63-385-16	244	1+	F
pv63-386-16	133	1+	M
pv63-387-16	43	1+	F
pv63-388-16	201	Juvenile	F
pv63-389-16	120	1+	F
pv63-390-16	146	1+	F
pv63-391-16	170	1+	M
pv63-392-16	236	1+	F

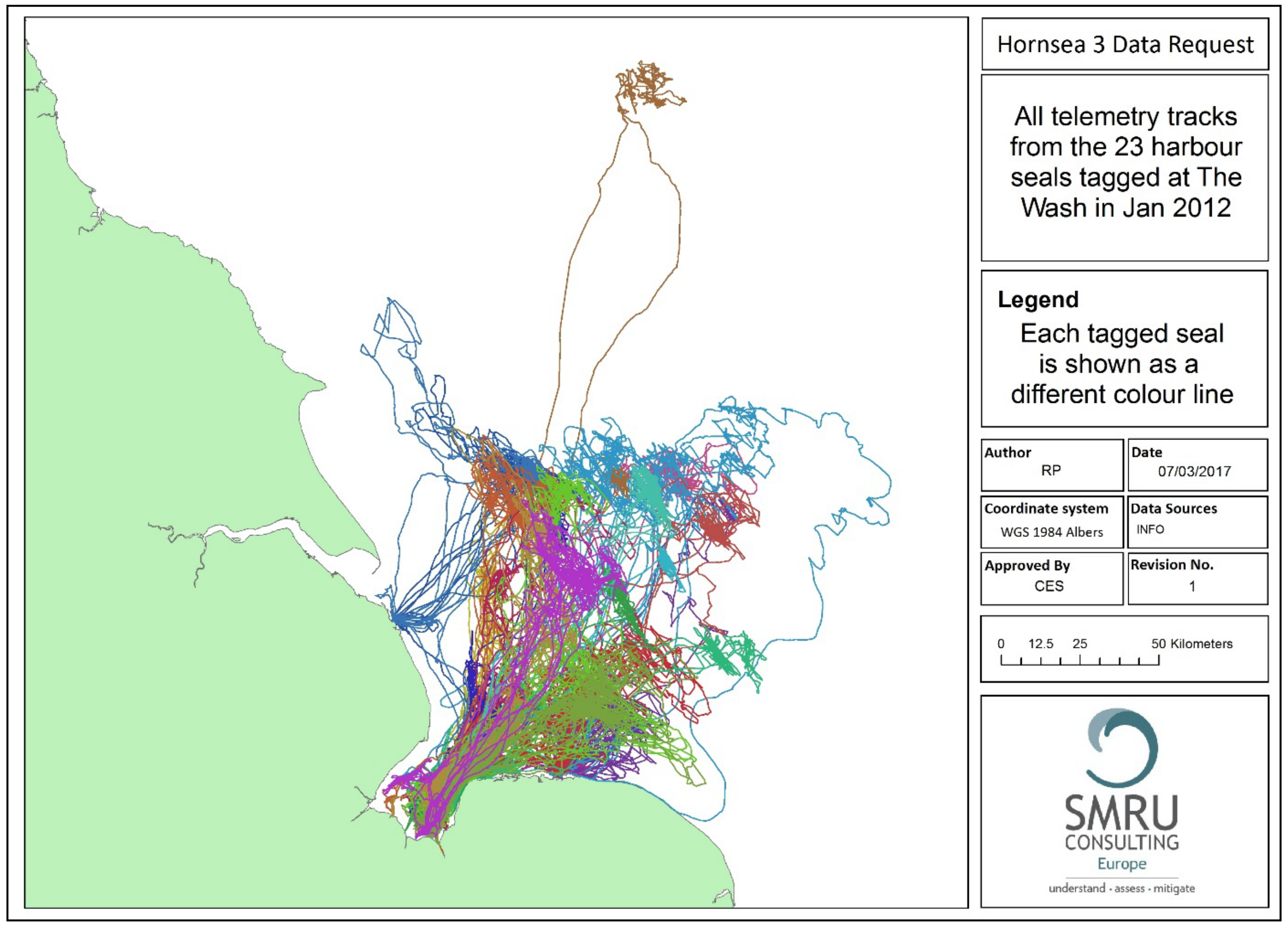

Figure A.1: Telemetry tracks from the 23 harbour seals tagged at The Wash in January 2012.

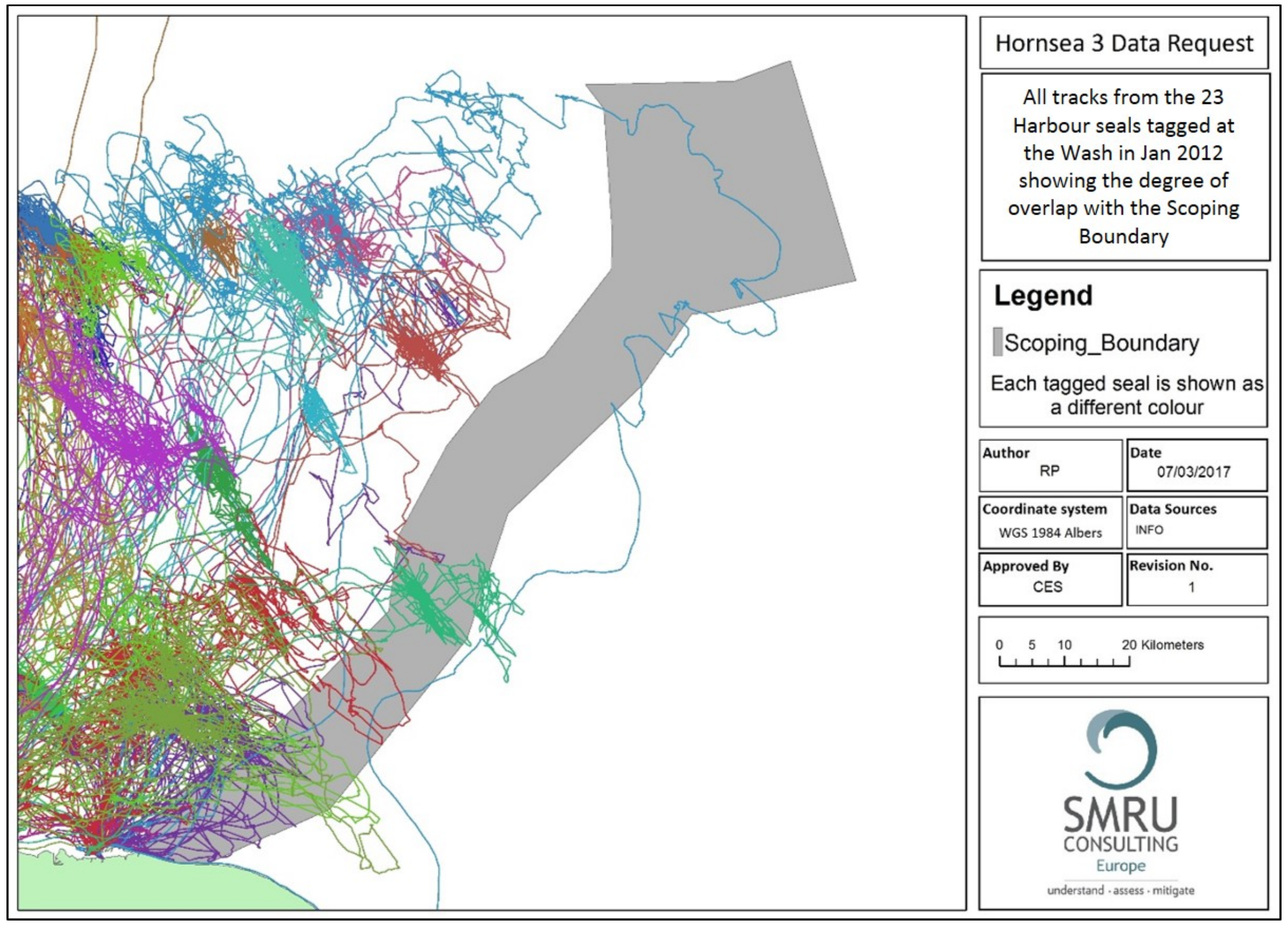

Figure A.2: Telemetry tracks from the 23 harbour seals tagged at The Wash in Jan 2012 showing the degree of overlap with the Hornsea Three scoping boundary.

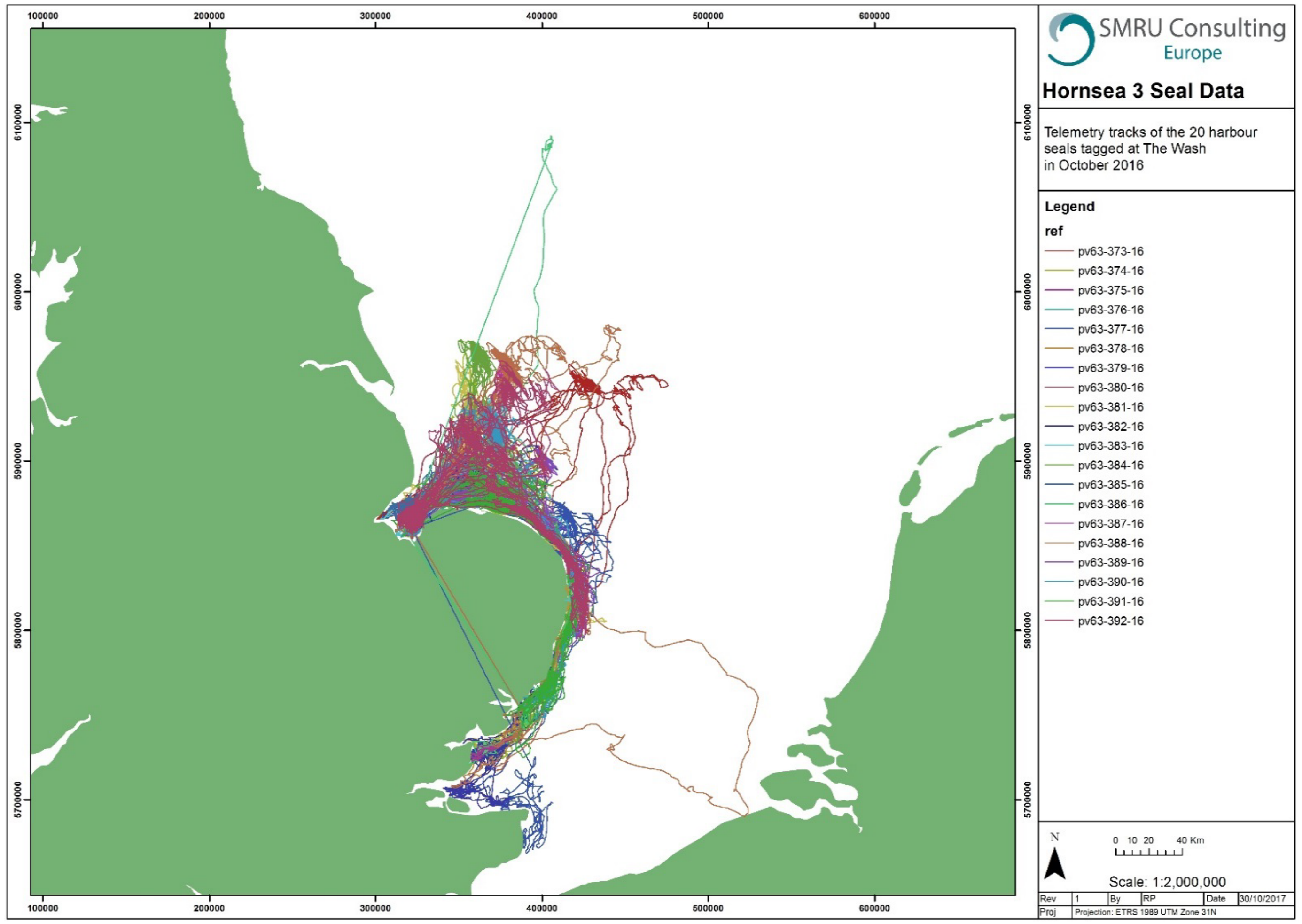

Figure A.3: Telemetry tracks from the 20 harbour seals tagged at The Wash in October 2016.

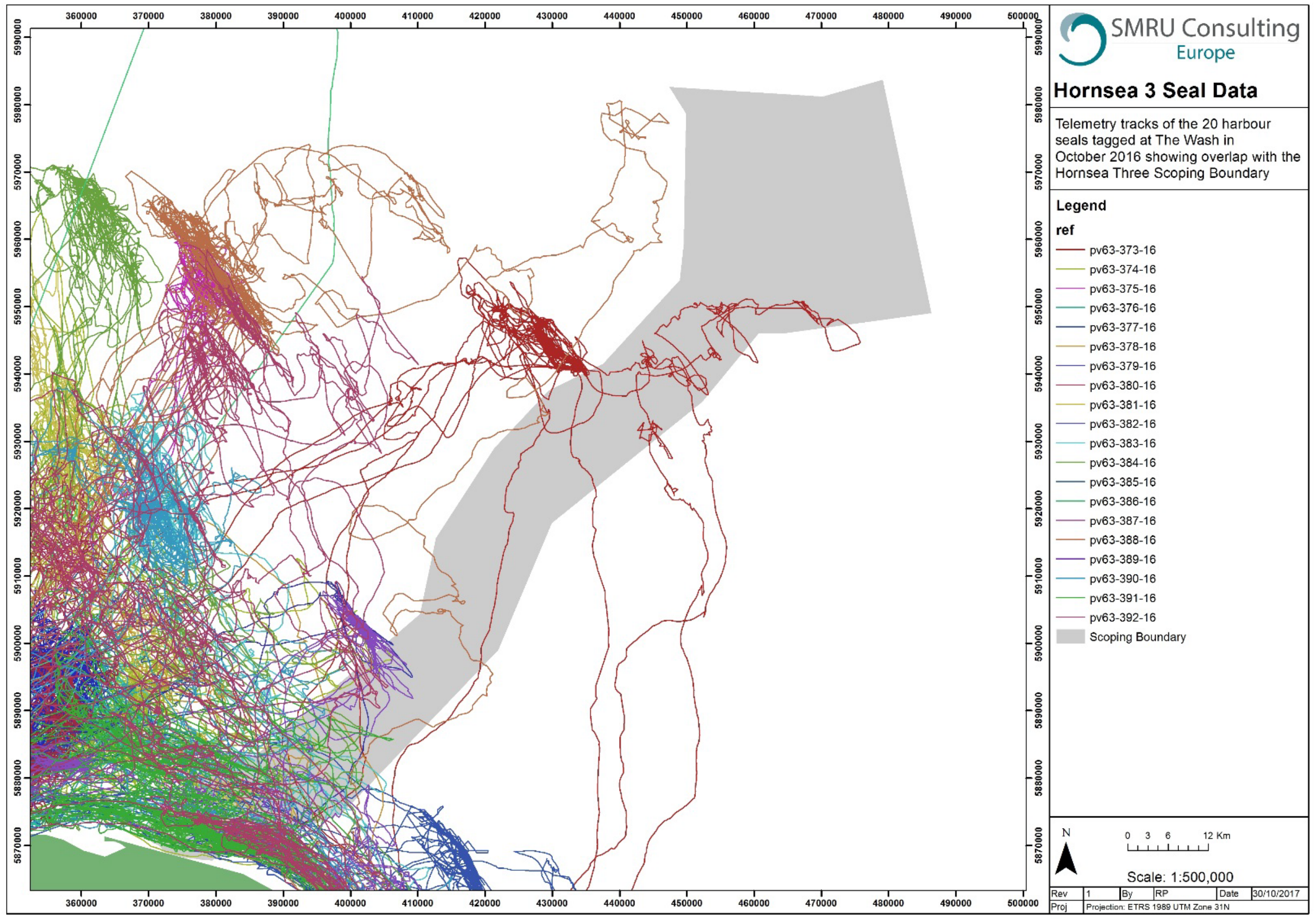

Figure A.4: Telemetry tracks from the 20 harbour seals tagged at The Wash in October 2016 showing the degree of overlap with the Hornsea Three scoping boundary.

A.4 Harbour Seals Tagged at the Thames 2012

A.4.1.1 In January 2012 SMRU and ZSL tagged ten adult harbour seals at the Thames (Table A.3). Of these, five were females aged over one and five were males aged over one. The mean tag duration was 97.7 days (range: 62 to 136 days).

A.4.1.2 Of these tagged seals, two had tracks and GPS tracks and positions that overlapped with the Hornsea Three scoping boundary area that covers the Hornsea Three array area and offshore cable corridor (Figure A.5 and Figure A.6).

Table A.3: Details of the ten harbour seals tagged at the Thames in January 2012. Those seals that had GPS positions that overlapped with the Hornsea Three scoping boundary are highlighted in green.

Seal ID	Tagging date	End date	Tag duration (days)	Age class	Sex
Pv40-191-12	16/01/2012	14/04/2012	89	1+	F
Pv40-200-12	18/01/2012	24/05/2012	127	1+	F
Pv40-268-12	18/01/2012	02/06/2012	136	1+	F
Pv40-278-12	18/01/2012	14/04/2012	87	1+	F
Pv40-284-12	16/01/2012	22/03/2012	66	1+	F
Pv40-197-12	16/01/2012	13/04/2012	88	1+	M
Pv40-267-12	18/01/2012	20/03/2012	62	1+	M
Pv40-270-12	18/01/2012	22/04/2012	95	1+	M
Pv40-283-12	16/01/2012	02/05/2012	107	1+	M
Pv40-285-12	16/01/2012	15/05/2012	120	1+	M

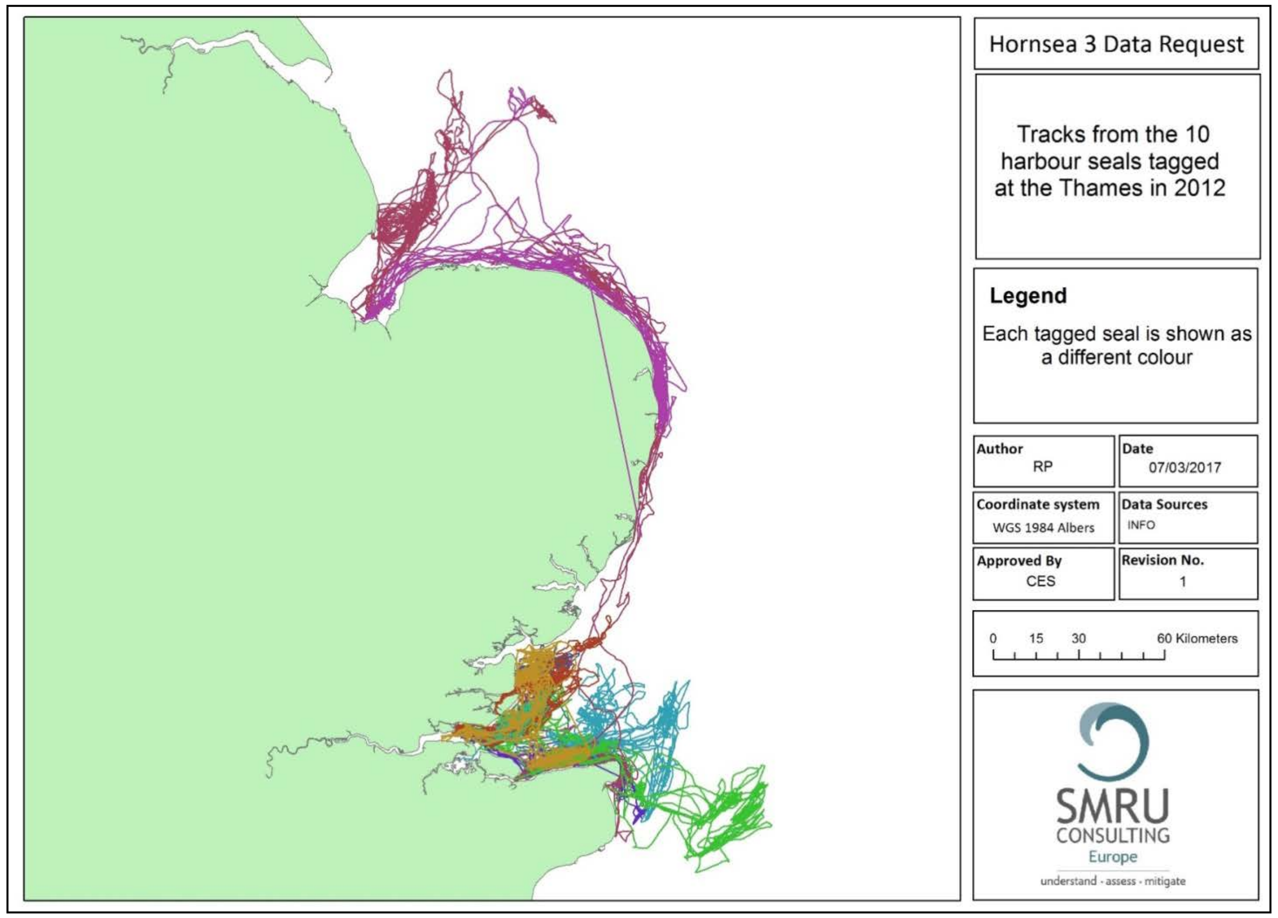

Figure A.5: Telemetry tracks from the ten harbour seals tagged at the Thames in January 2012.

Figure A.6: Tracks from the two harbour seals tagged at the Thames in January 2012 showing the degree of overlap with the Hornsea Three scoping boundary.

A.5 Grey Seals Tagged at Blakeney and Donna Nook 2015

6.1.1.1 In May 2015 SMRU tagged 20 adult grey seals at Blakeney and Donna Nook (ten from each site) (Table A.4). Of these, 13 were females aged over one and seven were males aged over one. The mean tag duration was 169.75 days (range: 5 to 238 days).

6.1.1.2 Of these tagged seals, eight of the ten tagged at Blakeney and one of the ten tagged at Donna Nook had GPS tracks and positions that overlapped with the Hornsea Three scoping boundary area that covers the Hornsea Three array area and offshore cable corridor (Figure A.7 and Figure A.8).

Table A.4: Details of the 20 grey seals tagged at Blakeney and Donna Nook in May 2015. Those seals that had GPS positions that overlapped with the Hornsea Three scoping boundary are highlighted in green.

Seal ID	Tagging date	End date	Tag duration (days)	Tagging location	Age class	Sex
hg48-009-15	2015-05-07	2015-12-15	222	Blakeney	1+	F
hg48-361-15	2015-05-07	2015-12-04	211	Blakeney	1+	F
hg48-362-15	2015-05-07	2015-11-10	187	Blakeney	1+	F
hg48-923-15	2015-05-07	2015-12-27	234	Blakeney	1+	F
hg48-925-15	2015-05-05	2015-11-24	203	Blakeney	1+	F
hg48-291-15	2015-05-05	2015-11-15	194	Blakeney	1+	M
hg48-315-15	2015-05-05	2015-08-27	114	Blakeney	1+	M
hg48-356-15	2015-05-05	2015-11-16	195	Blakeney	1+	M
hg48-357-15	2015-05-05	2015-11-24	203	Blakeney	1+	M
hg48-926-15	2015-05-07	2015-08-18	103	Blakeney	1+	M
hg48-011-15	2015-05-02	2015-05-07	5	Donna Nook	1+	F
hg48-342-15	2015-05-02	2015-11-30	212	Donna Nook	1+	F
hg48-345-15	2015-05-02	2015-05-25	23	Donna Nook	1+	F
hg48-359-15	2015-05-02	2015-10-19	170	Donna Nook	1+	F
hg48-360-15	2015-05-02	2015-12-26	238	Donna Nook	1+	F
hg48-363-15	2015-05-02	2015-10-31	182	Donna Nook	1+	F
hg48-364-15	2015-05-02	2015-09-02	123	Donna Nook	1+	F
hg48-924-15	2015-05-02	2015-12-11	223	Donna Nook	1+	F
hg48-010-15	2015-05-02	2015-09-29	150	Donna Nook	1+	M
hg48-358-15	2015-05-02	2015-11-21	203	Donna Nook	1+	M

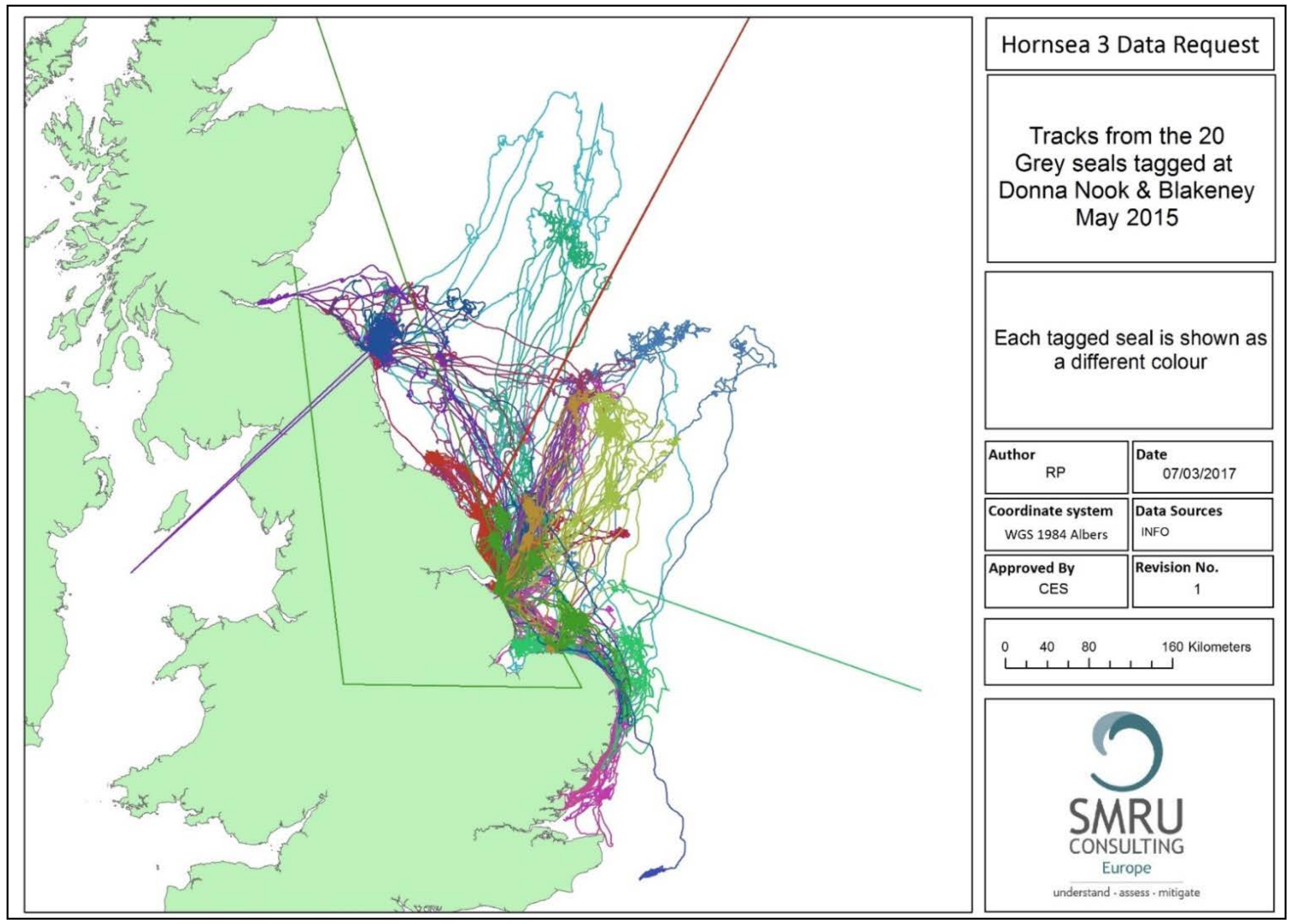

Figure A.7: GPS locations from the 20 grey seals tagged at Blakeney and Donna Nook in May 2015.

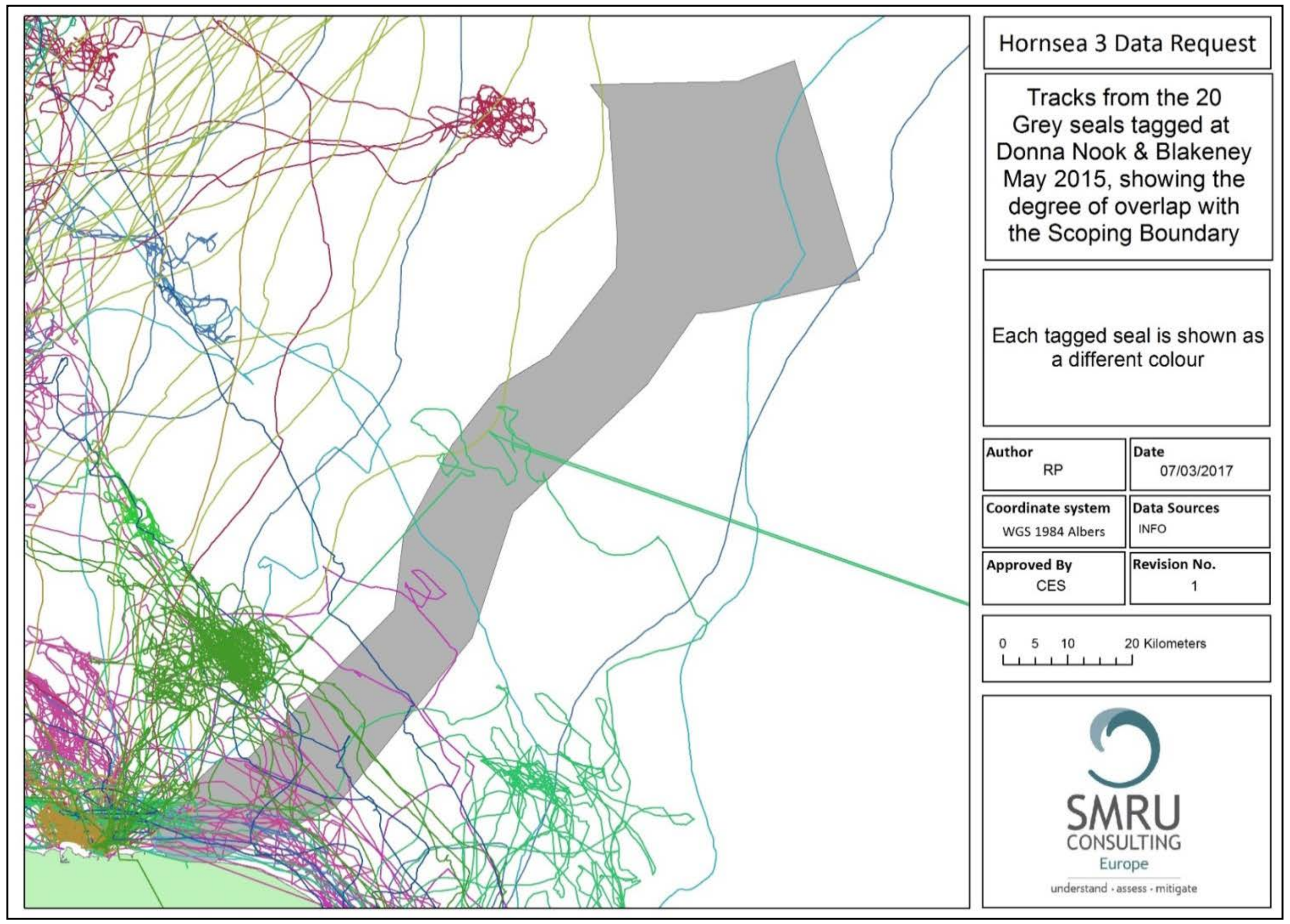

Figure A.8: GPS locations from the 20 grey seals tagged at Blakeney and Donna Nook in May 2015 showing the degree of overlap with the Hornsea Three scoping boundary.

A.6 Grey Seal Connectivity with the Berwickshire and North Northumberland Coast SAC

6.1.1.3 When all grey seal telemetry data held by SMRU were assessed, a total of 16 grey seal tracks overlapped with the Hornsea Three scoping boundary. Of these, 6 seals (38%) also spent time within the Berwickshire and North Northumberland SAC (Table A.5), though time spent at the SAC, ranged between 3% and 57% of their total recorded GPS locations (Figure A.9). This highlights that there is connectivity between the Hornsea Three scoping boundary (in the south east England seal MU) and the Berwickshire and North Northumberland SAC (in the north east England seal MU), providing justification for inclusion of both the southeast and the north east England grey seal MUs in the impact assessment for Hornsea Three.

Table A.5: Details of the 6 tagged grey seals that showed overlap with both the Hornsea Three Scoping Boundary and the Berwickshire and North Northumberland SAC.

Seal ID	Tagging Year	Tagging Location	Age	Total # GPS Locations	# GPS Locations within the SAC	% GPS Locations within the SAC
hg48-291-15	2015	Donna Nook	1+	10,044	273	3%
hg48-356-15	2015	Donna Nook	1+	16,951	3,535	21%
hg48-362-15	2015	Donna Nook	1+	12,626	2,216	18%
fa1-5813-91	1991	Farnes	1+	854	485	57%
fa4-1554-94	1994	Farnes	Pup	327	156	48%
im5-Kermit-02	2002	Isle of May	Pup	1,203	189	16%

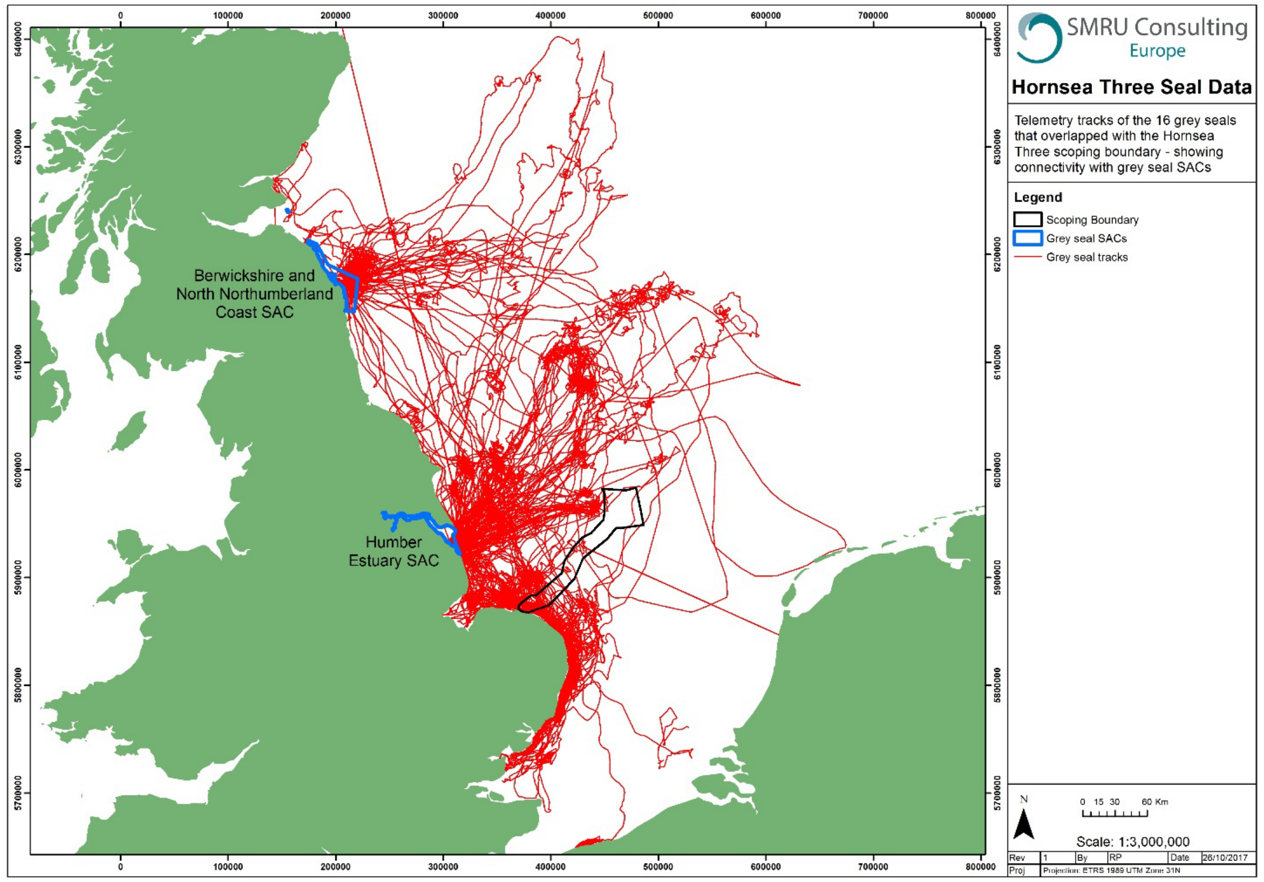

Figure A.9: GPS tracks from the 16 tagged grey seals that showed overlap with the Hornsea Three Scoping Boundary and in relation to grey seal SACs.

A.7 Literature Cited

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Appendix B Estimation of Detection Probability and Absolute Abundance of Harbour Porpoise

B.1 Introduction

B.1.1.1 Population surveys should, where possible, aim to provide measures of absolute abundance for the target species. In many situations, where estimating numbers affected by human activities or total population size is important, obtaining this level of information is the primary purpose of the survey. There may be cases where relative abundance indices might also be useful, for example when comparing between areas or for investigating trends over time. However, even in these instances it should be borne in mind that detection probability on surveys varies in ways that are poorly understood and can be affected by a range of factors, some of which are difficult to measure. Without a robust measure of detection probability made during a survey it can be very difficult to make reliable comparisons between surveys. Thus, where data allows, it is always valuable to measure both how detection probability varies with distance, the detention function, and the probability of detection for animals directly on the trackline, called g(0). A combination of a detection function which shows relative detection probability with perpendicular distance and the absolute value of this at zero perpendicular distance provides an estimate of actual detection probability. This paper focuses on the calculation of g(0) and outlines a new approach to making this important measurement.

B.1.1.2 G(0) is a difficult parameter to measure during line transect surveys. Usually “dual platform” techniques are employed requiring two independent observation platforms and two independent detection teams. However, many vessels cannot accommodate two sighting platforms and clearly, because a larger visual team will be required, there are costs implications. In addition, on many wind farm surveys marine mammal sightings are made by bird observers whose primary task is to count seabirds and the additional data collection tasks required for dual platform methods cannot be accommodated.

B.1.1.3 One approach to measuring g(0) with dual platform data uses a mark recapture methodology (Borchers *et al.*, 1998). With this method, detections made by one detection platform are considered to set up a series of “trials” for a second independent platform. If the second platform detects the same animal, termed a “duplicate” detection, then the trial is scored as a success, and if the animal is not detected it is scored as a failure. The proportion of all “trials” that were successful is then use to determine g(0). When both platforms are visual, it can be difficult to attain true independence in detection. Usually the two platforms are placed at different heights and one may be instructed to search ahead of the other (and provided with powerful binoculars to facilitate this) so that “trials” can be initiated beyond the normal field of view of the second platform.

B.1.1.4 For the method described here, the two independent platforms are provided by the visual detection team and the (largely automated) towed hydrophone passive acoustic detection system. Detections made by the visual team were considered to have initiated trials to determine acoustic g(0) while detections made acoustically initiated the trials to measure visual g(0). The use of two different modalities for detection, visual and acoustic, has the advantage of addressing some of the concerns about independence when both platforms were visual. However, because the hydrophone is towed behind the vessel (approximately 225 m in this case) and sightings are made ahead of the boat, detections by the two systems will always be separated in space and time and duplicates may consequently be more difficult to determine. There also may be factors, such as the orientation of the animal and their stage within the diving cycle that may mean that visual and acoustic detections are not truly independent (e.g. it is only animals that surface within a certain distance ahead of the vessel that are seen and vocalisations may also occur unevenly in the dive cycle). There may also be a response to the vessel. These factors may contribute to either greater or fewer than the expected number of duplicates under complete independence

B.2 Methods

B.2.1 Initiating trials to estimate g(0)

B.2.1.1 To establish “Trials” we examined the dataset post hoc and identified unambiguous instances where detections by one method could be used to test the performance of the other. Our aim was to avoid false positive in situations where another animal or group present in the area could be confused with the one used to initiate the trial. Thus, trials were only considered on occasions when no detections were made by the trial method for three minutes either side of the trial detection. This involved excluding some data from this analysis and reducing the sample size but it should not have introduced any bias.

B.2.2 Methods for g(0) estimation

B.2.2.1 G(0) was estimated using the method of Buckland *et al.* (1993) where g(0) for method A is given by:

$$g_A(0) = \frac{n_{AB} w_B}{n_B w_{AB}}$$

Where n_{AB} is the number of duplicates detected by both methods, n_B is the number of trials based on detections by method B, w_{AB} is the strip width of the duplicated data and w_B is the strip width of the trial data.

B.2.2.2 The delta method was used to estimate overall variance in density, $\hat{D}$ using the formula from Buckland (1993) as follows:

$$\widehat{var}(\hat{D}) = \hat{D}^2 \left\{ \frac{\widehat{var}(n)}{n^2} + \frac{\widehat{var}[\hat{f}(0)]}{[\hat{f}(0)]^2} + \frac{\widehat{var}[\hat{E}(s)]}{[\hat{E}(s)]^2} + \frac{\widehat{var}[\widehat{g(0)}]}{[\widehat{g(0)}]^2} \right\}$$

Where estimated strip half width is 1⁄(f(0)) and E(s) is the mean estimated school size (or cluster size for acoustic detections). This was taken to be the average number of sightings within a minute for minutes with at least one sighting.

B.2.3 Allowable timing error

B.2.3.1 Duplicates were identified by matching the time a sighting was expected to come abeam of the hydrophone with the actual time abeam for the closest acoustic detection.

B.2.3.2 Visual observers estimated the range and bearing for each sighting and, the hydrophone was towed 225 m behind the observers. The speed of the vessel logged continuously from the GPS. Thus, the expected time to come abeam of the hydrophones could be calculated for each sighting.

B.2.3.3 Some level of error in timing must be expected. The main contributions to this are likely to come from: inaccuracies in recording the time of visual sightings, inaccuracies in visual estimates of range and bearing (see Leaper *et al.*, 2011 for direct measures of these), the effect of animal movement on acoustically derived estimates of range from target motion analysis and the effects of animal movement changing its location between the time of the sightings and the acoustic detection. These are discussed in more detail in the following sections.

B.2.3.4 In terms of timing error, on most of the surveys the visual data were recorded as that of the previous whole minute, reflecting standard bird survey protocols. Thirty seconds was added to these times to remove bias in recorded time but a residual mean error would remain and this was assumed to be evenly distributed over the +/-30 s.

B.2.3.5 Predictions of animal movements can also introduce error. The hydrophone was towed 200m astern of the vessel and so around 225 m behind the observers. The average forward distance to sightings estimated by observers was 190 m. Travelling at approximately 10 knots (5 ms^{-1}) there will be an average of around 83 s between the visual sighting and the porpoise coming abeam of the hydrophone. Data from porpoise tracks collected during the SCANS-II survey indicated the highest average speed for a porpoise over a roughly straight track was 2.5 ms^{-1} over 85 seconds, and average speed for apparently reliable tracks of over a minute was 1.5 ms^{-1} (n=12, SD = 0.7; R Leaper *pers. comm.*). A porpoise at the average distance ahead swimming directly with the boat at a speed of 2 ms^{-1} would delay coming abeam by about 70 seconds which would be considered an extreme case.

B.2.3.6 Errors in distance and angle estimation are likely to cause errors of a similar magnitude. As times of observations were only recorded to the nearest minute, errors in the expected time of an animal passing the hydrophone of up to two minutes would not be unexpected.

B.2.3.7 Figure B.1 shows the number of duplicate detections falling within different time intervals of the predicted time abeam of the hydrophone array. The strong peak at zero time interval indicates that the presence of a larger number of real duplicates while the fairly consistent level of detections at intervals greater than approximately 80 s is indicative of a level of false positives reflecting the background density of animals in the area. Figure B.2 provides an alternative depiction of the same data. The expected number of detections based on the average overall density would be 13.2 visual detections of acoustic trials and 13.7 acoustic detections of visual trials. For an allowable error >100 s the number of duplicates is actually slightly lower than would be expected by chance. The plot shows a marked drop after 80 s giving support for choosing a +/- 80 s window for the allowable timing error.

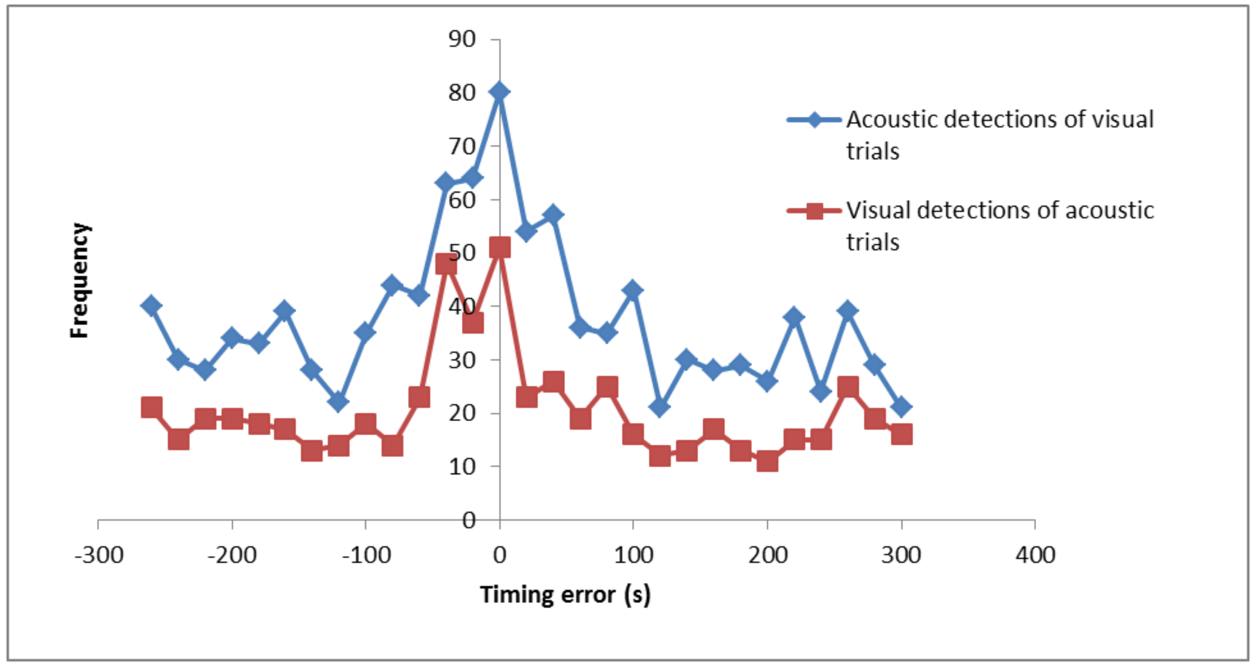

Figure B.1: Frequency of detections made by one modality within a certain time interval of the closest detection made by the other modality plotted against corrected time abeam. The peak time a time delay of zero indicates a large contribution from true duplicates, the fairly constant lower level with high time lags shows the background level of false duplicates.

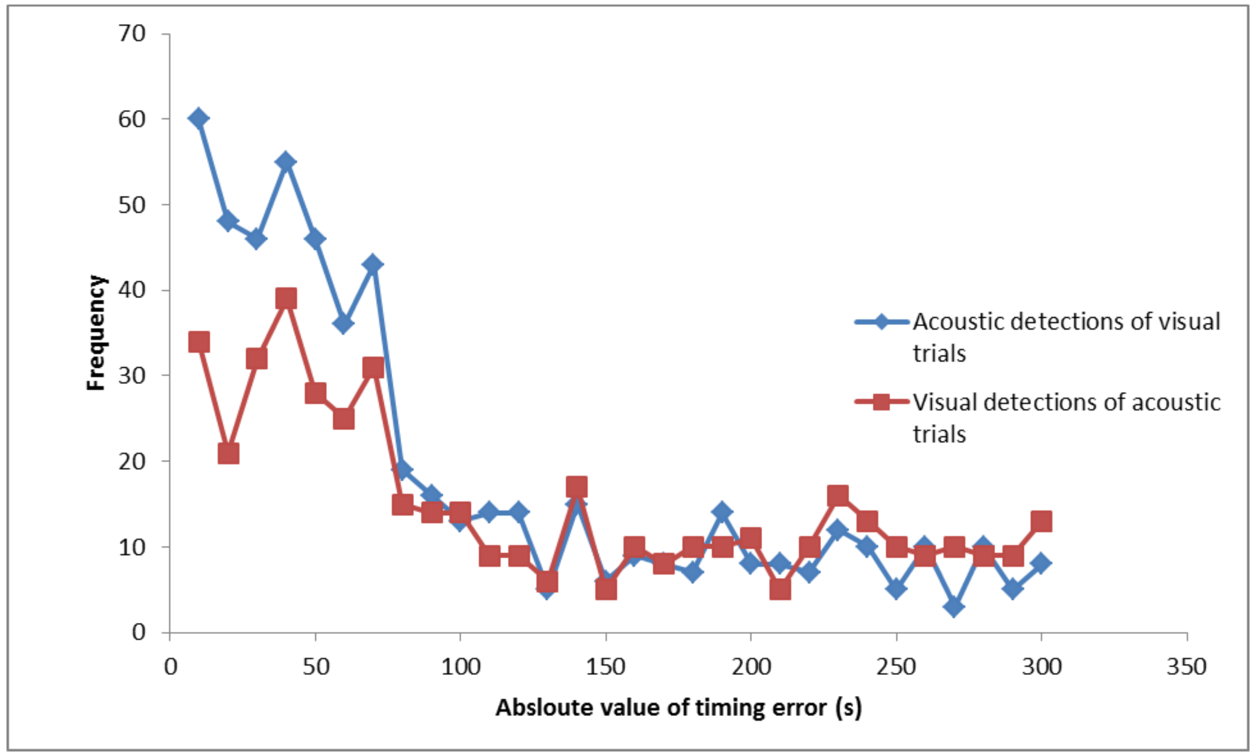

Figure B.2: The number of trials where there was a detection within each given 10 s time bin for absolute error relative to the expected time delay based on the visual sighting location and the estimated time for the acoustic detection to come abeam.

B.3 Results

B.3.1.1 Table B.1 and Table B.2 summaries all the visual and acoustic trials established over the course of the project and the mean values of g(0) for visual and acoustic detections and their associated CVs. The overall mean value of g(0) for visual detection was 0.201 with an estimated CV of 0.13 while the mean g(0) for acoustic detection was 0.374 with an estimated CV of 0.09. Visual g(0) was strongly influenced by sea state falling from 0.576 in sea state 1 to 0.143 in sea state 3 (Table 2). These values are used in earlier sections of this report to calculate density estimates.

B.3.1.2 There was insufficient survey effort in sea state 0 to generate a useful number of acoustic trials. However, assuming g(0)=1 for sea state 0 gives a similar density estimate to other sea states. An assumption of g(0)=1 in sea state 0 for small, difficult to see cetaceans has been used in Barlow (2013) to estimate values of g(0) at other sea states.

Table B.1: Estimates of g(0) for visual detections (+/- 80s timing error for duplicates).

Sea State	Number of trials	Detected trials	Proportion of trials detected	Acoustic strip width (m)	Duplicate strip width (m)	g(0)	CV of g(0)
All data	2,647	199	0.075	385	288	0.201	0.13
0	19	6	0.316	385	-	Too few trials	-
1	273	70	0.256	385	343	0.576	-
2	747	61	0.082	385	281	0.224	-
3	1,011	46	0.045	385	245	0.143	-
4	595	16	0.027	385	-	Too few trials	-

Table B.2: Estimates of g(0) for acoustic detections (+/- 80s timing error for duplicates).

Sea State	Number of trials	Detected trials	Proportion of trials detected	Visual strip width (m)	Duplicate strip width (m)	g(0)	CV of g(0)
All data	1,028	353	0.343	279	256	0.374	0.09

B.4 Discussion

B.4.1.1 The estimates of g(0) obtained from these studies (0.201 for visual observation and 0.374 for acoustic detections) are comparable to values from other studies using similar equipment and methods from small vessels. The confidence limits on all of the estimates are quite large and the variance is dominated by the binomial variance associated with the number of trials and proportion of successes. Hence, there is little that can be done to reduce the variance beyond collecting more data. However an additional source of uncertainty and potential bias is in the detection of duplicates and there may be some scope for reducing this with improved technique and appropriate protocols.

B.4.1.2 Estimation of g(0) for visual sightings or acoustic detections relies on detecting duplicate animals correctly. Porpoise distribution tends to be clustered, with animals occurring in loose aggregations. If a different individual within an aggregation is detected by the method for which g(0) is being estimated than the individual detected for the trial then this will contribute a false positive resulting in an overestimation of g(0). The criteria for trials that we applied here, that no porpoises should be detected for three minutes before or after, was a straight forward attempt to minimise the chance of false positives. However, with relatively low detection probabilities there is always the potential that there will be animals in the area that are not detected by the method used to set up trials. Survey effort was maximised to address this potential issue, and identification of duplicates was improved by accurate recording of time of surfacing and by accurate measurement of distance and angle. Rather than relying on visual estimates which are generally poor (Leaper *et al.,* 2011) photogrammetric methods could be used to provide very accurate measures of range and bearing to porpoises and other marine mammals at the surface (Leaper and Gordon, 2001).

B.4.1.3 Porpoises are believed to respond negatively to vessels. Studies of observed headings suggest a tendency to show avoidance and orientate away from the vessel (Palka and Hammond, 2001). Porpoise produce their clicks in a highly directional beam (Au *et al.*, 2006) and the intensity of the received acoustic signal will thus be influenced by the orientation of the animal relative to the hydrophone. If animals continue to point away from the vessel as they come close to the hydrophone then that will reduce the probability of acoustic detection, whereas if they have moved away and turn to head back to their original position then they may be more likely to be detected. Orientation and possibly vocal output is also likely to vary through the diving cycle. Porpoises are most frequently seen in the range 100-200 m ahead of the vessel when they are at the surface. This means that they will most likely be well into their diving cycle when they come closest to the hydrophone around 60 seconds later.

B.4.1.4 Some of these factors could be investigated by towing hydrophones at different lengths astern of the vessel to see if this affected g(0) estimates. A shorter tow length would reduce the time between visual sighting and acoustic detection but would increase the vessel noise on the hydrophone, resulting in lower acoustic detection probability.

B.4.1.5 If two hydrophones were towed at different lengths behind the vessel they could act as two independent acoustic platforms in a similar way to two-platform visual methods. The relative detection rates should provide some information on whether animals' responses to vessels, or stage in the diving cycle, consistently affects acoustic detection probability.

B.4.1.6 We have noted that very few porpoises appear to be detected acoustically whilst they are ahead of the vessel. This may be due to bubbles created by the propeller blocking sound from ahead of the vessel reaching the hydrophone. It is commonly observed that vessel noise is lower directly aft of the vessel due to this effect.

B.4.1.7 The dual modality survey methodology described here has proven particularly useful in allowing values of g(0) to be calculated during typical wind farm assessment surveys carried out on relatively small vessels offshore by teams of bird observers. While the methodology shows promise and the values for g(0) are in line with those obtained using established methodologies, these techniques are still under development so results should be treated with some caution and further work should be encouraged. However, this method does offer the chance to estimate absolute abundance which has not been possible previously from small vessels with insufficient room to have two fully independent visual observation platforms. Absolute abundance, where data allows, contributes to understanding how many animals may be affected by a development but can also be important where survey results are to be compared between areas and provides a more meaningful validation check on results than a simple index of abundance. For example, in this dataset we were able to provide separate density estimates for each sea state as a comparative diagnostic of the internal consistency of the data.

B.5 References

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Appendix C Simulation to Investigate the Effect of Observing on One Side of the Vessel

C.1 Simulation model and results

C.1.1.1 If observations are only made on one side of the transect line (as was the case on this survey) then random animal movement will result in more animals being seen within the observation area than half of the number that would be expected to be detected within the total strip width from observations both sides of the vessel. The size of this effect will depend on swim speed of the animals relative to survey speed, the probability of detecting any surfacing event and the diving pattern of the animals.

C.1.1.2 A general sighting simulation model (Leaper *et al.,* 2011) was used to estimate bias for different combinations of swim speed and dive time. Animals were assumed to move in straight lines and so the results will generally overestimate the effects of random animal movement. Responsive animal movement was not investigated but the relatively low number of detections close to the track line in the acoustic detection function shows some evidence of responsive movement occurring. Parameters were tuned to give a similar strip width to the observed data, in this case slightly greater than the observed at 415 m. Further simulation runs could be conducted for different combinations of parameters but it seems likely that the bias would be around 10% for typical swim speeds and dive times (Table C.1).

C.1.1.3 This issue has generally not arisen with previous analyses of similar datasets because only relative estimates of density were generated. In this case it is worth considering the bias because the dual platform data allows an estimate of g(0) and thus the calculation of absolute density.

Table C.1: Simulation results to investigate bias in density estimation caused by random animal movement if observations are only made on one side of the vessel.

Swim speed (ms^{-1})	Ship speed (ms^{-1})	Mean dive duration (s)	Number of surfacing's between dives	Ratio of density estimated from observations on one side to both sides
1	5	120	3	1.09
1	5	60	3	1.11
2	5	120	3	1.14
2	5	60	3	1.18

C.2 References

Leaper, R., Burt, L., Gillespie, D. and Macleod, K. (2011). Comparisons of measured and estimated distances and angles from sightings surveys. Journal of Cetacean Research and Management. 11(3):229-238

Appendix D Log of Marine Mammal Count per Unit Effort

Table D.1: Count per km trackline in the Hornsea Zone plus a 10 km buffer during 2010/2011 (sea states 0 to 3).

Species	March	April	May	June	July	August	September	October	November	December	January	February
Harbour porpoise	0.0894	0.0969	0.0389	0.6294	0.3450	0.1751	0.1638	0.0905	0.0169	0.1097	0.0585	0.0509
White-beaked dolphin	0.0060	0.0009	0.0019	0.0081	0.0000	0.0000	0.0000	0.0000	0.0282	0.0022	0.0273	0.0000
Minke whale	0.0000	0.0000	0.0009	0.0049	0.0067	0.0011	0.0052	0.0054	0.0000	0.0000	0.0000	0.0000
Grey seal	0.0011	0.0009	0.0046	0.0040	0.0008	0.0011	0.0007	0.0045	0.0000	0.0078	0.0026	0.0025
Harbour seal	0.0027	0.0037	0.0028	0.0016	0.0000	0.0034	0.0033	0.0009	0.0000	0.0011	0.0039	0.0025

Table D.2: Count per km trackline in the Hornsea Zone plus a 10 km buffer during 2011/2012 (sea states 0 to 3).

Species	March	April	May	June	July	August	September	October	November	December	January	February
Harbour porpoise	0.1040	0.1774	0.0417	0.1350	0.1578	0.1067	0.0696	0.0996	0.1385	0.0834	0.0852	0.1300
White-beaked dolphin	0.0150	0.0011	0.0000	0.0095	0.0012	0.0000	0.0000	0.0075	0.0000	0.0313	0.0515	0.0133
Minke whale	0.0000	0.0000	0.0029	0.0042	0.0040	0.0025	0.0015	0.0075	0.0154	0.0000	0.0000	0.0000
Grey seal	0.0047	0.0028	0.0014	0.0037	0.0058	0.0071	0.0015	0.0025	0.0019	0.0000	0.0059	0.0117
Harbour seal	0.0075	0.0039	0.0036	0.0037	0.0012	0.0033	0.0046	0.0025	0.0019	0.0000	0.0000	0.0033

Table D.3: Count per km trackline in the Hornsea Zone plus a 10 km buffer during 2012/2013 (sea states 0 to 3).

Species	March	April	May	June	July	August	September	October	November	December	January	February
Harbour porpoise	0.2788	0.2051	0.3730	0.1744	0.1165	0.0725	0.0573	0.0808	0.0468	0.0428	0.0361	0.1419
White-beaked dolphin	0.0101	0.0000	0.0053	0.0183	0.0000	0.0000	0.0000	0.0000	0.0126	0.0000	0.0277	0.0075
Minke whale	0.0007	0.0028	0.0053	0.0094	0.0158	0.0018	0.0042	0.0044	0.0000	0.0000	0.0000	0.0000
Grey seal	0.0060	0.0056	0.0090	0.0094	0.0148	0.0136	0.0011	0.0009	0.0018	0.0000	0.0060	0.0162
Harbour seal	0.0047	0.0028	0.0042	0.0028	0.0035	0.0057	0.0000	0.0018	0.0000	0.0000	0.0072	0.0025

Appendix E Calculation of Detection Probability

E.1 White-beaked dolphin

It was not possible to calculate g(0) for white-beaked dolphin using the former Hornsea Zone data. White-beaked dolphin is known to be attracted to vessels and the low strip widths estimated using Distance may be an indication of this (see Table 3.11 in section 3).

E.1.1.1 Estimates of abundance for dolphins may be biased upwards by responsive movement because of animals that are attracted to the vessel, although Distance sampling attempts to overcome this by recording an animal before responsive movement occurs. It is not always the case that white-beaked dolphin respond positively since whilst the SCANS survey in 1994 found significant evidence of attraction (Hammond *et al.,* 1995), the SCANS-II survey in 2005 found some evidence of avoidance (Hammond *et al.,* 2013). The response is likely to be very dependent on the behavioural state of the dolphins and the characteristics of the survey vessel. The SCANS modified logistic regression (MLR) analysis estimate of g(0) for white-beaked dolphin was 0.71 (CV=0.12) while the SCANS-II estimate was 0.58 (CV=0.26). Few other surveys have estimated g(0) for white-beaked dolphin or the effects of responsive movement. In comparison, for common dolphin, responsive movement has been shown to have a large effect on population estimates (Canadas *et al.,* 2004). These authors estimated g(0)=0.8 but found that estimated density was around six times higher than corrected estimates if responsive movement was not taken into account. Common dolphin generally appear more likely to approach boats than white-beaked dolphin, so it is not clear what the effects of responsive movement would be for white-beaked dolphin abundance estimates.

E.2 Minke whale

E.2.1.1 It was not possible to calculate g(0) for minke whale using the boat-based data. If a g(0) of 1 is assumed then calculated densities of minke whale are likely to be negatively biased compared with absolute numbers and therefore will provide a minimum estimate of density in the area.

E.2.1.2 There have been several surveys for minke whale that have estimated detection probability directly on the track line (g(0)). The most extensive surveys have been carried out by the International Whaling Commission (IWC) for Antarctic minke whale. Estimates of g(0) from these surveys are not considered relevant because in this region the cue is often a blow (rarely seen from minke whale in the North Atlantic), group sizes are usually greater than one and observers search with binoculars. Japanese surveys for minke whale in the North Pacific are more comparable because whales are detected by body cues and group size is usually one. However, during these surveys there are greater numbers of observers searching from three platforms which are all higher than that on the vessel used for the boat-based surveys. Estimates of g(0) for these surveys varied from 0.51 for one platform alone to 0.86 for all three platforms combined (Okamura *et al.,* 2010).

E.2.1.3 More comparable surveys to those carried out for the former Hornsea Zone have been conducted in the North Atlantic for minke whale including surveys undertaken by Norway (Skaug *et al.,* 2004), SCANS (Hammond *et al.,* 2002) and SCANS-II (Hammond *et al.,* 2013). Skaug *et al.* (2004) reported g(0) by a combination of platforms and weather covariates. Estimates of g(0) ranged from 0.25 to 0.72 with the most frequently encountered Beaufort 3 conditions giving a g(0) of 0.36. The most comparable estimates from the Norwegian surveys to conditions encountered in the former Hornsea Zone gave g(0) estimates in the range 0.28 to 0.44 suggesting 0.36 might be an appropriate value to use as a crude approximation from Norwegian surveys.

E.2.1.4 The SCANS survey in 1994 used two platform methods and MLR analyses to estimate g(0) for minke whale in the North Sea. These methods resulted in a calculation of g(0) of 0.82 (CV=0.17). The SCANS-II survey in 2005 produced a g(0) estimate of 0.55 (CV=0.29) (Hammond *et al.,* 2013).

E.2.1.5 There are no simple ways of selecting an appropriate estimate to use because probability of detection will be strongly influenced by conditions during the surveys. This is evident in the estimates of g(0) for harbour porpoise from the boat-based data which had sufficient sample sizes to allow this to be investigated by sea state. For sea state 1, g(0) was 0.58 dropping to 0.14 in sea state 3. The mean g(0) of 0.20 from visual data for the former Hornsea Zone plus a 10 km buffer for harbour porpoise was very similar to that from SCANS-II (0.22) suggesting overall similar sighting conditions. This might suggest that using the g(0) of 0.55 from SCANS-II could be an appropriate crude approximation for minke whale in the former Hornsea Zone plus a 10 km buffer.

E.3 Grey seal

E.3.1.1 Telemetry data from tags deployed by SMRU were used to estimate the effect of availability bias on g(0) for grey seal. Dive data were not available for the former Hornsea Zone plus a 10 km buffer but 1,551 dive cycles were available from similar depths in the northern North Sea for a period approximating to daylight hours (08:00 to 20:00 hours) (data records provided by SMRU). Sixty percent of surfacing periods were between 15 and 45 seconds with a median of 40 seconds. Dive times were more evenly distributed with a maximum of 496 seconds (Figure E.1).

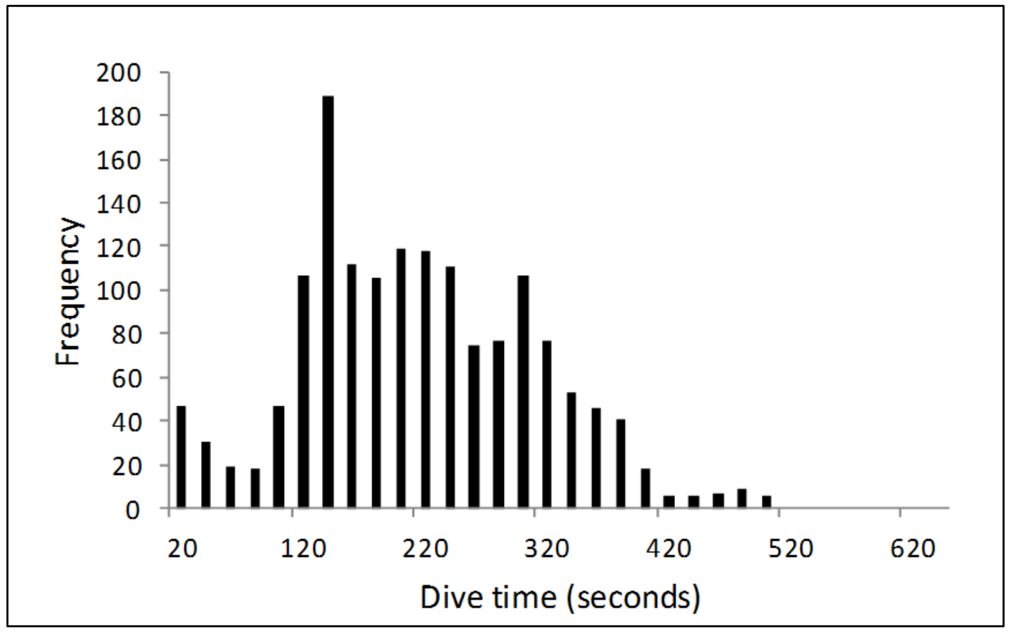

Figure E.1: Frequency of observed dive times for grey seal in the northern North Sea during daylight hours (08:00 to 2000hrs).

E.3.1.2 A crude model for estimating the likely effects of availability bias on g(0) can be derived by assuming a detection distance, 's' ahead of the vessel within which any seal directly on the trackline would be detected and outside which detection probability is zero. For a vessel travelling at 5 ms^{-1}, the time 't' for which a seal could surface and be detected is given by: 't=s/5'. For a dive of duration 'd', the probability 'pd' that the seal will not surface at some time within distance 's' ahead of the vessel is given as:

pd=(d-t)/d if d>t and pd=0 if d≤t.

E.3.1.3 A more complex approach would be to model the detection probability as a function of radial distance and combine this with the dive data into a full model incorporating availability bias. This is difficult because of the limited number of sightings on which to base a radial distance model. In addition, the observers tend to focus on the area 300 m ahead of the vessel for bird observations (for which the surveys were primarily designed). This is likely to result in a sharper drop in detection probability at distances greater than 300 m than might be expected with other observation protocols.

E.3.1.4 The total probability, 'P' that a seal would not be available for detection was calculated as:

$$P = \frac{1}{T}\sum_{d=dmin}^{d=dmax} p_d\, n_d t_d$$

E.3.1.5 There were 1,551 observed dives with 'nd' dives falling within each 20 second time band category. The midpoint, td, is shown in Figure E.1, and 'T' is the total observation period (i.e. the sum of all surface and dive intervals). The proportion of total time spent performing dives in duration band 'd' is thus given by:

$$\frac{n_d\, t_d}{T}$$

E.3.1.6 For a distance of 's' = 300 m this gave the total probability 'P' of 0.54 resulting in g(0)=0.46 for grey seal if no correction was made for perception bias.

E.3.1.7 The comparison of sightings rates and estimated strip widths for sea states 0 to 1, and sea states 2 to 4 gave a ratio of 0.9 between g(0) in sea states 2 to 4 to g(0) in sea states 0 to 1. It seems likely that a high proportion of grey seal at the surface on the trackline would be detected in sea states 0 and 1, which also suggests overall detection probability on the trackline is high. However, g(0) may be lower due to the number of seal that remain submerged during the passage of the vessel and are not available for detection.

E.4 Harbour seal

E.4.1.1 It was not possible to calculate g(0) for harbour seal using the boat-based data as there were no double platform counts for this species. Assuming that harbour seal had a similar g(0) to grey seal (i.e. 0.46) the calculations of absolute numbers would be approximately double those of the relative density estimates.

E.5 References

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Appendix F Modelling Approach for Examining Spatial and Temporal Patterns in Density

F.1 Introduction

F.1.1.1 The aim of the modelling was to try and identify co-variates which helped to explain variability in observed encounter rate in order to understand the spatial and temporal patterns in actual density. Observed encounter rate will be a function of the density of animals and the proportion of animals present that are detected. The proportion detected visually will be influenced by weather conditions and sea state.

F.1.1.2 The surveys were conducted approximately monthly over a three year period. Hence the analysis was rather different from single surveys typically used to estimate abundance that can be treated as a snapshot of what is there at the time of the survey. The survey area was also very small compared to the overall extent of similar habitat and the populations of all species in the North Sea. Thus the densities within the survey area may fluctuate substantially with small shifts in the distribution of the population.

F.1.1.3 Some species such as white-beaked dolphin and minke whale are known to have strong seasonal patterns in their abundance in the southern North Sea. Common and grey seal would also be expected to show some seasonal patterns in off-shore abundance because of periods of moulting or pupping, when a proportion of the population becomes largely land-based. Investigating the seasonal patterns in density within the study area was therefore an important aspect of the analysis. In addition to seasonal variation there is the possibility of longer term trends in numbers or fluctuations that do not follow seasonal patterns. It is not expected that seasonal patterns will be distinguishable from temporal fluctuations or trends with three years of data, as may be possible with much longer data sets. The survey effort and duration of surveys for Hornsea Three was discussed and agreed as appropriate by the Marine Mammal EWG for characterisation of the marine mammal baseline for Hornsea Three. Models were fitted with days from the start of the study or Julian day in order to see which gave the better fit for each species. If days from start showed a monotonic trend then this was included in a model with Julian day to allow for an overall trend and seasonal variation

F.2 Methods

F.2.1.1 One minute segments of survey track (average 285 m) were treated as binomial trials with either presence or absence of the species of interest. The covariates considered for inclusion in the model are listed in Table F.1. These were all included as one-dimensional smooths (thin-plate splines) except for Latitude and Longitude which were two-dimensional. Julian Day was a cyclic smooth on the basis that if patterns were seasonal the situation on 1st January should be the same as 31st December. Longitude was transformed by multiplying by cosine (Latitude) to give it the same scale as Latitude. The mgcv package (Wood, 2006) in R was used for all GAM models. The cost associated with fitting each degree of freedom (gamma) was also increased to 1.4 to minimise the risk of over-fitting (Wood, 2006).

F.3 Results

F.3.1.1 The parameters explored and included in the final models are listed in Table F.1 (full details of the model in each case are presented later in this Appendix). Note that for binomial models the deviance explained is difficult to interpret and is not necessarily a good representation of the fit of the model.

Table F.1: Model parameters in the Generalised Additive Model (GAM) for each species.

Parameter	Harbour porpoise acoustic_1 [d]	Harbour porpoise acoustic_2 [d]	Harbour porpoise visual_1 [d]	Harbour porpoise visual_2 [d]	Minke whale [d]	White-beaked dolphin [d]	Harbour seal [d]	Grey seal [d]
Latitude, Longitude [a]	X	X	X	X	X	X	X	X
Days from start	X		X					X [c]
Hour		X		X	X	X	X	X
Julian Day [b]								
Tidal time								
Tidal phase								
Tidal range								
Tidal height								
Depth	X	X	X	X			X	X
Aspect								
Slope								
Bottom sediment type (categorical)								
Sea bottom type (categorical)								
Sea state			X	X	X	X	X	X
Swell height								
N (minute segments of track)	77,226	77,226	200,593	200,593	200,593	200,593	200,593	200,593
Deviance explained	2.8%	2.7%	11.2%	11.1%	8.2%	10.0%	7.4%	12.6%

a Longitude was adjusted so that units represent the same physical distance as for Latitude.

b Cyclic smooth in the GAM model.

c Exponential change over time with numbers increasing at 24% per year.

d An "x" indicates that a variable had a sufficiently significant effect to be retained in the model. None of the other covariates listed in Table 2.2 were found to be significant and are therefore not listed here.

F.3.3 Model details

<u>PorpoiseAcoustic(DaysFromStart)</u>

Family: binomial
Link function: logit

Formula:
RANYP ~ s(Latitude, IsoLong, bs = "ts") + s(Depth, bs = "ts") + s(DaysFromStart, bs = "ts")

Parametric coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-2.63288	0.01506	-174.8	<2e-16 ***

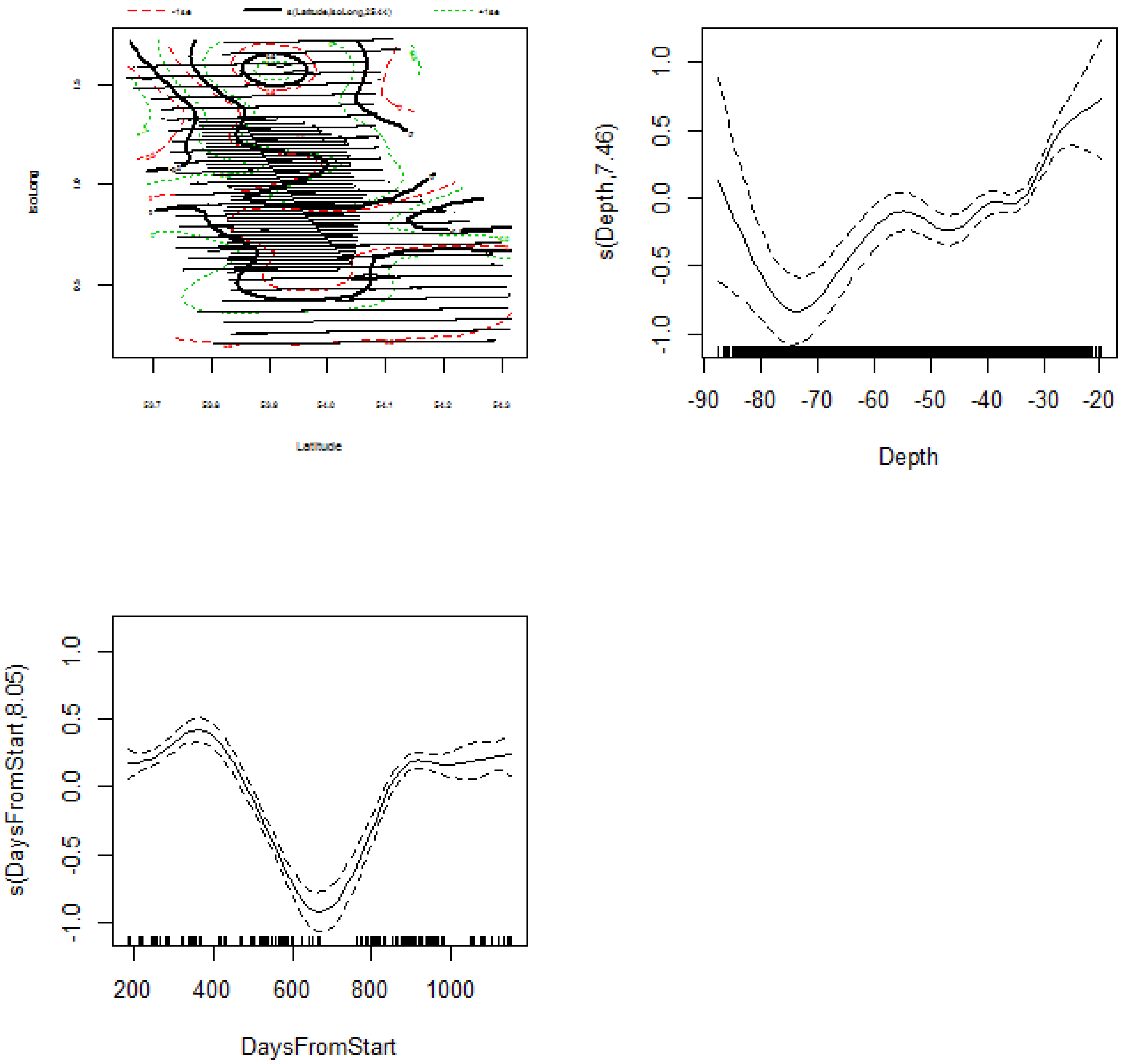
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:

	edf	Ref.df	Chi.sq	p-value
s(Latitude,IsoLong)	25.435	29	353.10	<2e-16 ***
s(Depth)	7.461	9	81.69	<2e-16 ***
s(DaysFromStart)	8.049	9	378.33	<2e-16 ***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) = 0.0139 Deviance explained = 2.84%
REML score = 19737 Scale est. = 1 n = 77226



PorpoiseAcoustic(JulianDay)

Family: binomial
Link function: logit

Formula:
RANYP ~ s(Latitude, IsoLong, bs = "ts") + s(Depth, bs = "ts") + s(JulianDay, bs = "cc")

Parametric coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-2.62291	0.01485	-176.6	<2e-16 ***

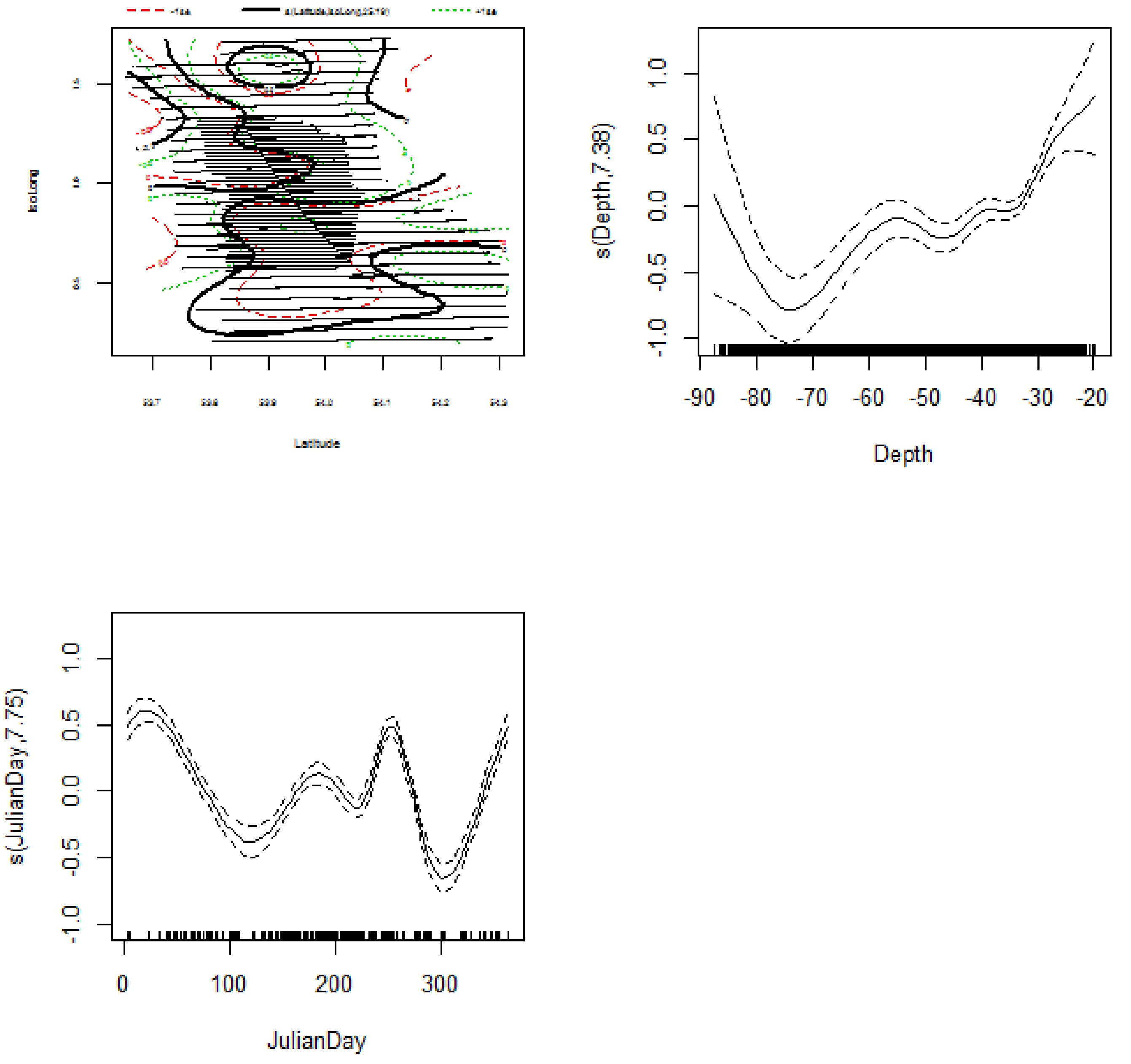
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:

	edf	Ref.df	Chi.sq	p-value
s(Latitude,IsoLong)	25.191	29	335.27	<2e-16 ***
s(Depth)	7.384	9	79.93	<2e-16 ***
s(JulianDay)	7.747	8	387.26	<2e-16 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) = 0.0143 Deviance explained = 2.73%
REML score = 19758 Scale est. = 1 n = 77226



PorpoiseVisual1(DaysFromStart)

Family: binomial
Link function: logit

Formula:
BinomialPorpoise ~ s(Latitude, IsoLong, bs = "ts") + s(SeaState, k = 5, bs = "ts") + s(Depth, bs = "ts") + s(DaysFromStart, bs = "ts")

Parametric coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-4.47172	0.02411	-185.5	<2e-16 ***

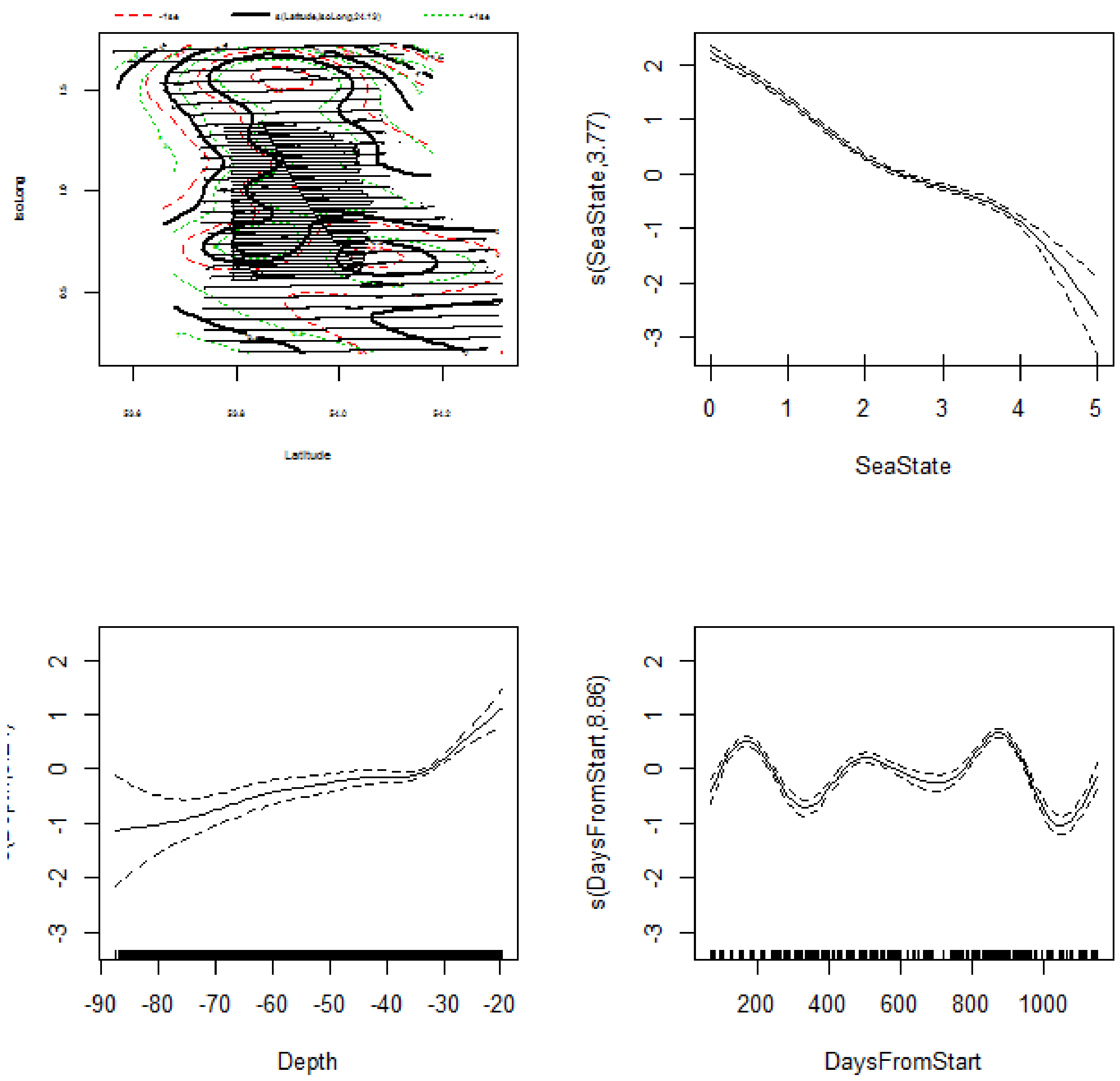
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:

	edf	Ref.df	Chi.sq	p-value
s(Latitude,IsoLong)	24.131	29	204.90	<2e-16 ***
s(SeaState)	3.774	4	2499.65	<2e-16 ***
s(Depth)	5.240	9	76.45	<2e-16 ***
s(DaysFromStart)	8.857	9	439.24	<2e-16 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) = 0.0378 Deviance explained = 11.2%
REML score = 16516 Scale est. = 1 n = 200593



<u>PorpoiseVisual2(JulianDay)</u>

Family: binomial
Link function: logit

Formula:
BinomialPorpoise ~ s(Latitude, IsoLong, bs = "ts") + s(SeaState, k = 5, bs = "ts") + s(Depth, bs = "ts") + s(JulianDay, bs = "cc")

Parametric coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-4.45392	0.02381	-187.1	<2e-16 ***

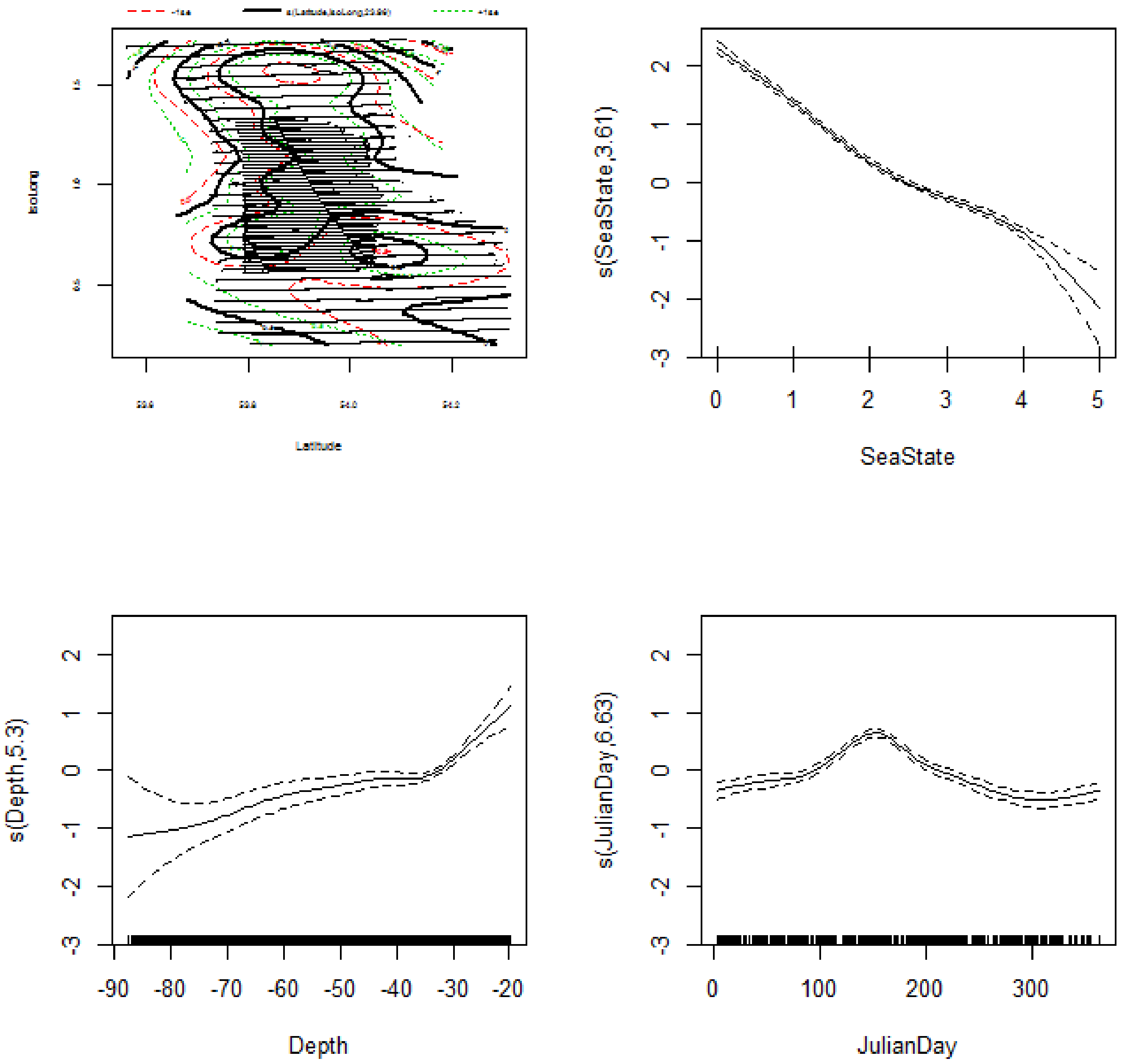
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:

	edf	Ref.df	Chi.sq	p-value
s(Latitude,IsoLong)	23.955	29	190.3	<2e-16 ***
s(SeaState)	3.612	4	2603.0	<2e-16 ***
s(Depth)	5.304	9	77.1	<2e-16 ***
s(JulianDay)	6.630	8	443.2	<2e-16 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) = 0.0367 Deviance explained = 11.1%
REML score = 16517 Scale est. = 1 n = 200593



<u>MinkeWhale</u>

Family: binomial
Link function: logit

Formula:
BinomialMinke ~ s(Latitude, IsoLong, bs = "ts") + s(SeaState, k = 5, bs = "ts") + s(JulianDay, bs = "cc")

Parametric coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-8.1747	0.2085	-39.2	<2e-16 ***

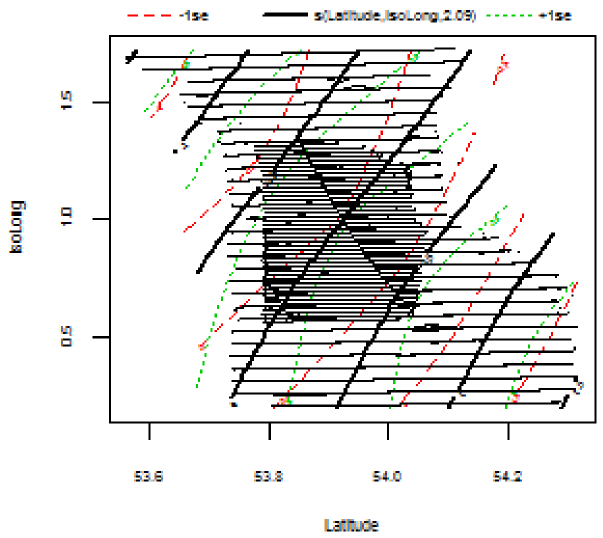
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

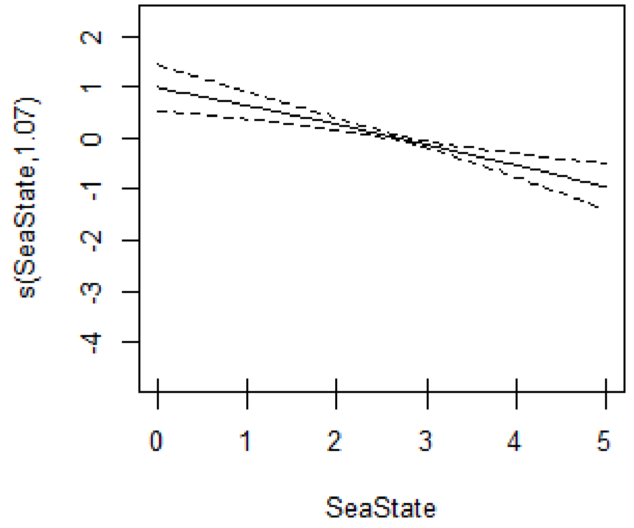
Approximate significance of smooth terms:

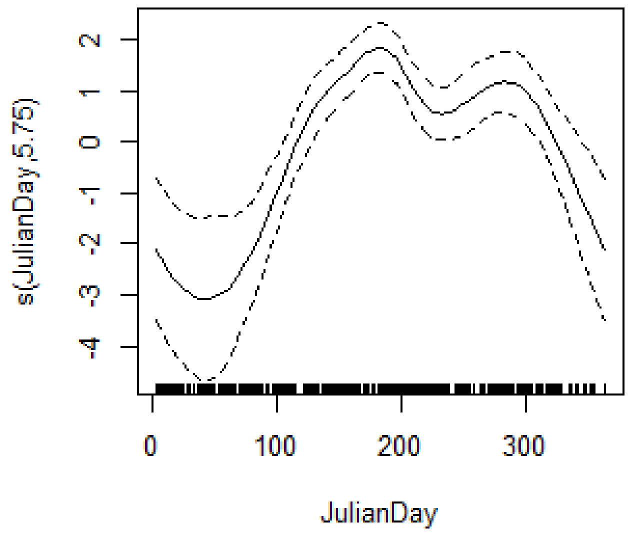
	edf	Ref.df	Chi.sq	p-value
s(Latitude,IsoLong)	2.088	29	36.46	3.91e-09 ***
s(SeaState)	1.075	4	23.64	7.20e-07 ***
s(JulianDay)	5.746	8	65.72	6.46e-14 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) = 0.00108 Deviance explained = 8.22%
REML score = 1141.9 Scale est. = 1 n = 200593







Whitebeaked dolphin

Family: binomial
Link function: logit

Formula:
BinomialWhitebeaked ~ s(Latitude, IsoLong, bs = "ts") + s(SeaState, k = 5, bs = "ts") + s(JulianDay, bs = "cc")

Parametric coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-8.6020	0.2056 -	41.83	<2e-16 ***

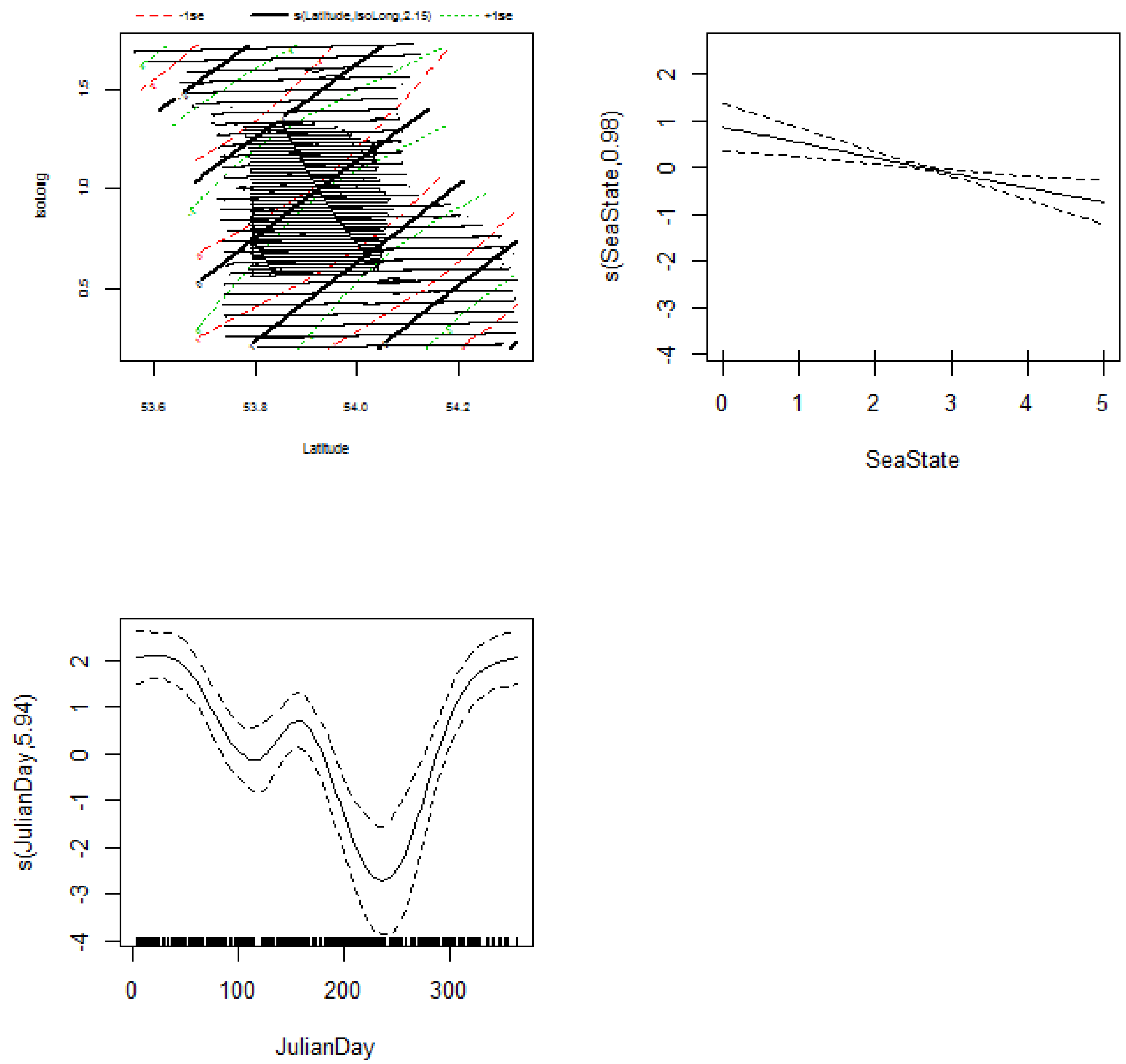
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:

	edf	Ref.df	Chi.sq	p-value
s(Latitude,IsoLong)	2.150	29	62.36	6.08e-15 ***
s(SeaState)	0.981	4	12.39	0.000241 ***
s(JulianDay)	5.943	8	83.22	< 2e-16 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) = 0.00108 Deviance explained = 10%
REML score = 808.65 Scale est. = 1 n = 200593



<u>CommonSeal</u>

Family: binomial
Link function: logit

Formula:
BinomialCommon ~ s(Latitude, IsoLong, bs = "ts") + s(SeaState, k = 5, bs = "ts") + s(Depth, bs = "ts") + s(JulianDay, bs = "cc")

Parametric coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-7.7991	0.1259	-61.93	<2e-16 ***

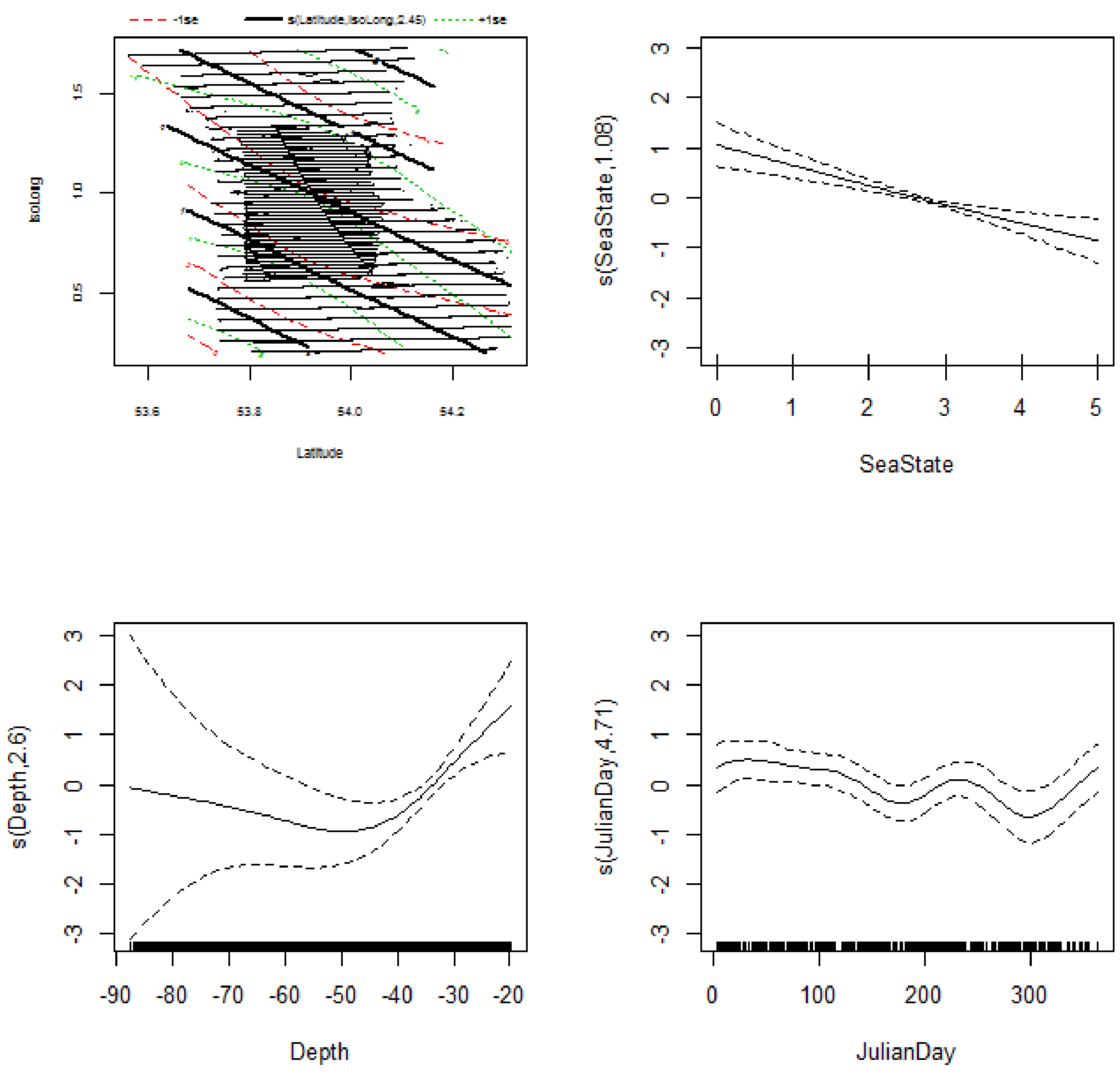
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:

	edf	Ref.df	Chi.sq	p-value
s(Latitude,IsoLong)	2.451	29	70.17	< 2e-16 ***
s(SeaState)	1.083	4	25.40	2.49e-07 ***
s(Depth)	2.600	9	18.65	3.76e-05 ***
s(JulianDay)	4.709	8	17.68	0.00106 **

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) = 0.00161 Deviance explained = 7.41%
REML score = 1129.6 Scale est. = 1 n = 200593



<u>GreySeal</u>

Family: binomial
Link function: logit

Formula:
BinomialGrey ~ s(Latitude, IsoLong, bs = "ts") + s(SeaState, k = 5, bs = "ts") + s(Depth, bs = "ts") + s(JulianDay, bs = "cc") + s(DaysFromStart, bs = "ts")

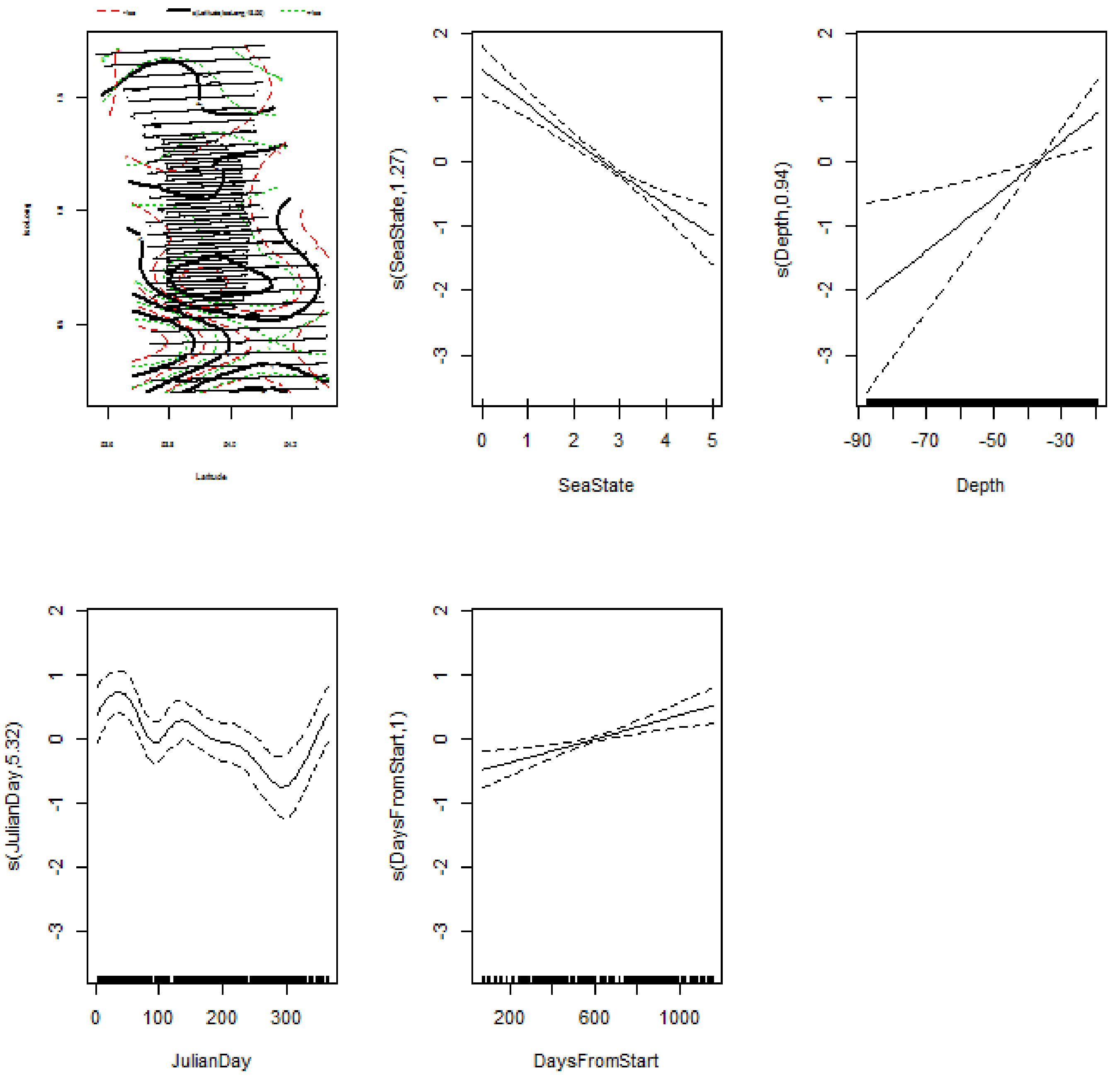
Parametric coefficients:
Estimate Std. Error z value Pr(>|z|)
(Intercept) -7.4014 0.1028 -72 <2e-16 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
edf Ref.df Chi.sq p-value
s(Latitude,IsoLong) 18.5615 29 287.843 < 2e-16 ***
s(SeaState) 1.2671 4 68.067 < 2e-16 ***
s(Depth) 0.9373 9 8.936 0.000686 ***
s(JulianDay) 5.3232 8 26.631 2.19e-05 ***
s(DaysFromStart) 0.9993 9 13.966 9.99e-05 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) = 0.0122 Deviance explained = 12.6%
REML score = 1661 Scale est. = 1 n = 200593



Appendix G Effect of Sea State on g(0)

G.1.1.1 Sea state has a noticeable effect on the relative sighting rates for harbour porpoise. As might be expected, harbour porpoise detectability falls dramatically by sea state 2 (Figure G.1). The major drop in detection rates between sea state 1 and 2 is also seen in other similar datasets of harbour porpoise visual detections.

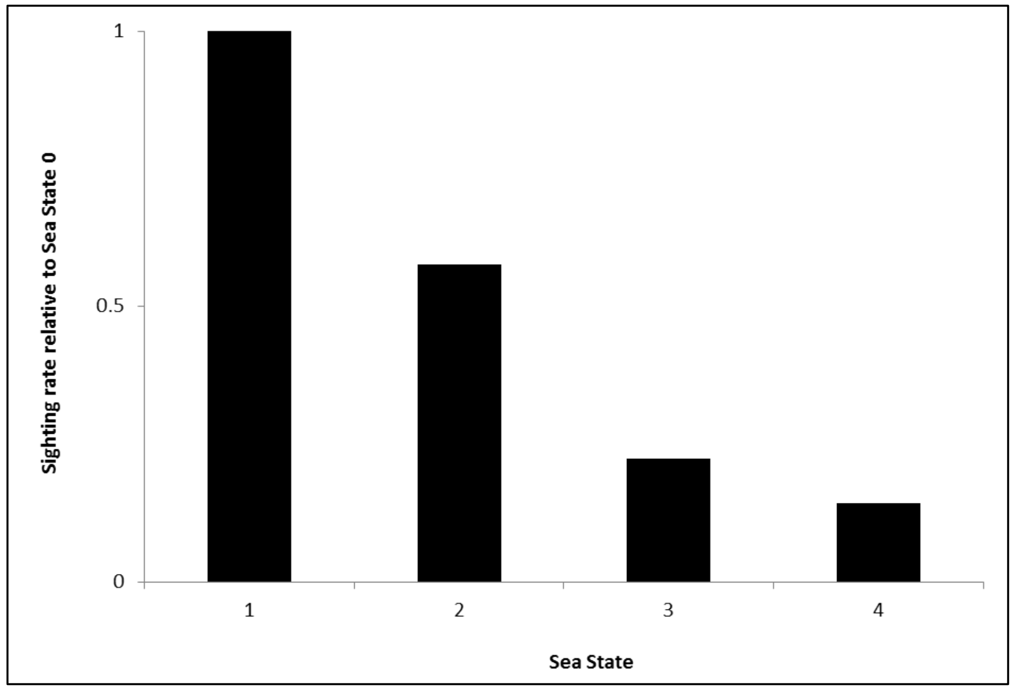


Figure G.1: Modelled sightings rate of harbour porpoise by sea state relative to sighting rate in sea state 0.

G.1.1.2 In order to explore the effect of sea state the analyses were repeated to ascertain the differences in a) ESW, b) detection probability, and c) average density estimates for harbour porpoise. ESW for harbour porpoise showed a monotonic decrease with increasing sea state from 523 m in sea state 0 to 200 m in sea states 4 (Table G.1). This is further illustrated by the shapes of the detection function graphs in sea states 0 through to 4 which show that the slope of the curve steepens and the 'shoulder' of the curve (the flattened area nearest to distance 0) narrows as sea state increases (Table G.2 to Table G.6). These results show that the ability to detect animals falls off rapidly moving further away from the trackline and the greater the sea state the more rapid the decline.

Table G.1: Estimated ESWs for harbour porpoise in different sea states.

Sea state	Number of animals	ESW (m)	CV	95% CI
0	491	523	0.035	488 to 560
1	1,441	400	0.018	386 to 415
2	1,064	326	0.039	302 to 352
3	743	230	0.024	220 to 240
4	243	220	0.044	202 to 240
All data	3,982	352	0.029	333 to 373

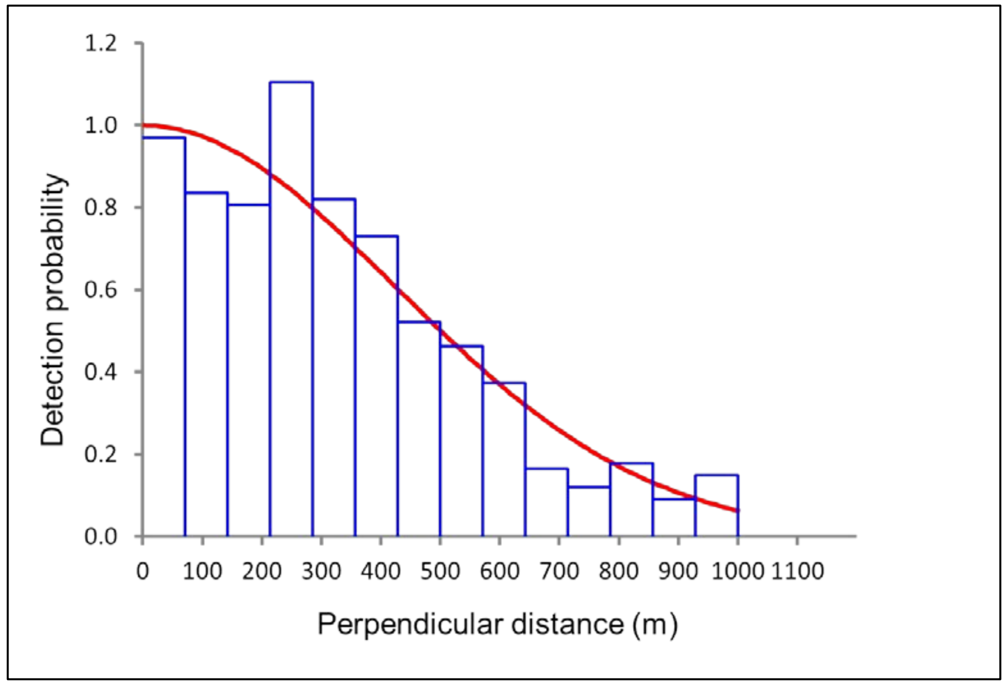


Table G.2: Detection function graph for harbour porpoise in sea state 0.

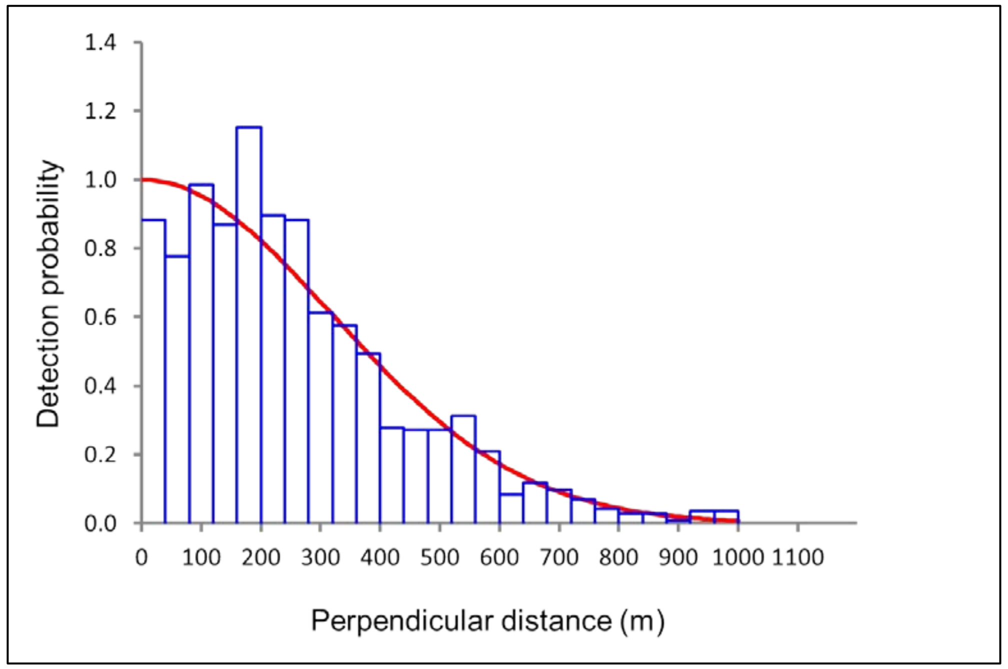


Table G.3: Detection function graph for harbour porpoise in sea state 1.

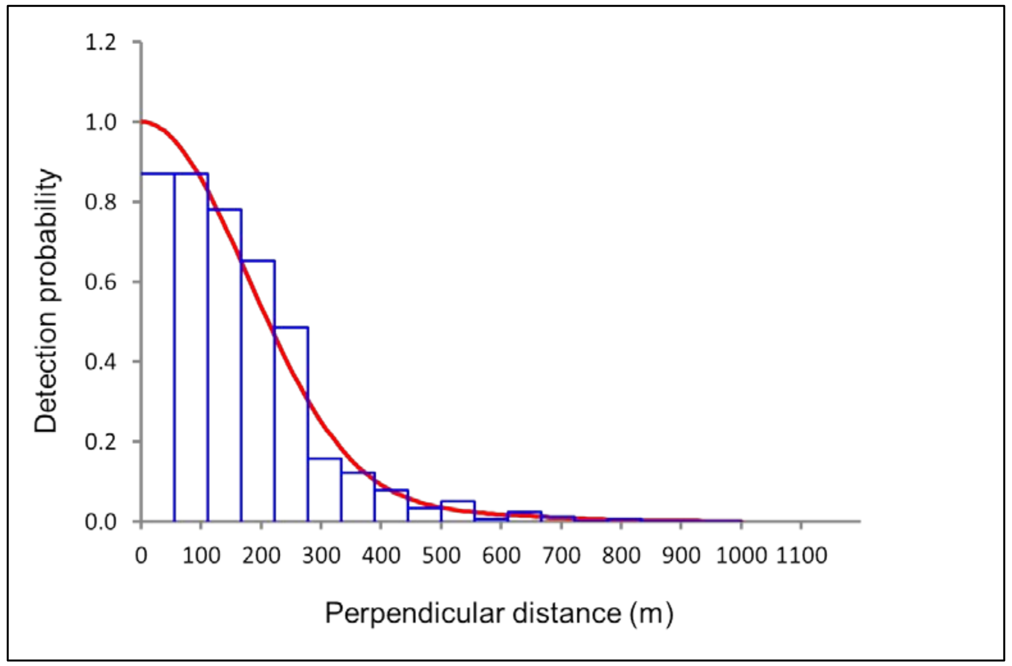


Table G.5: Detection function graph for harbour porpoise in sea state 3.

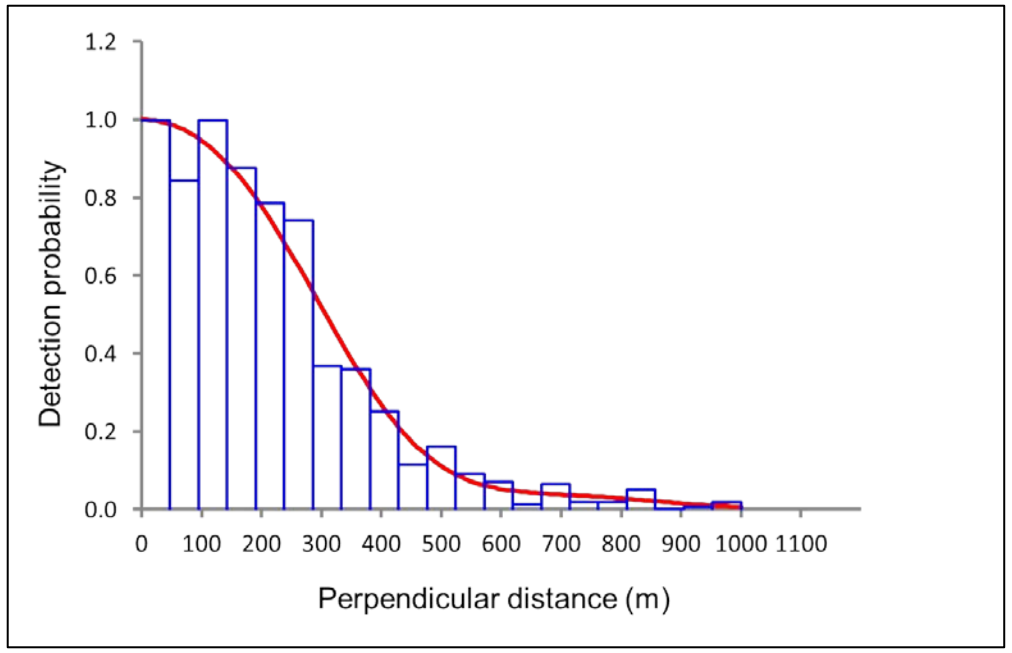


Table G.4: Detection function graph for harbour porpoise in sea state 2.

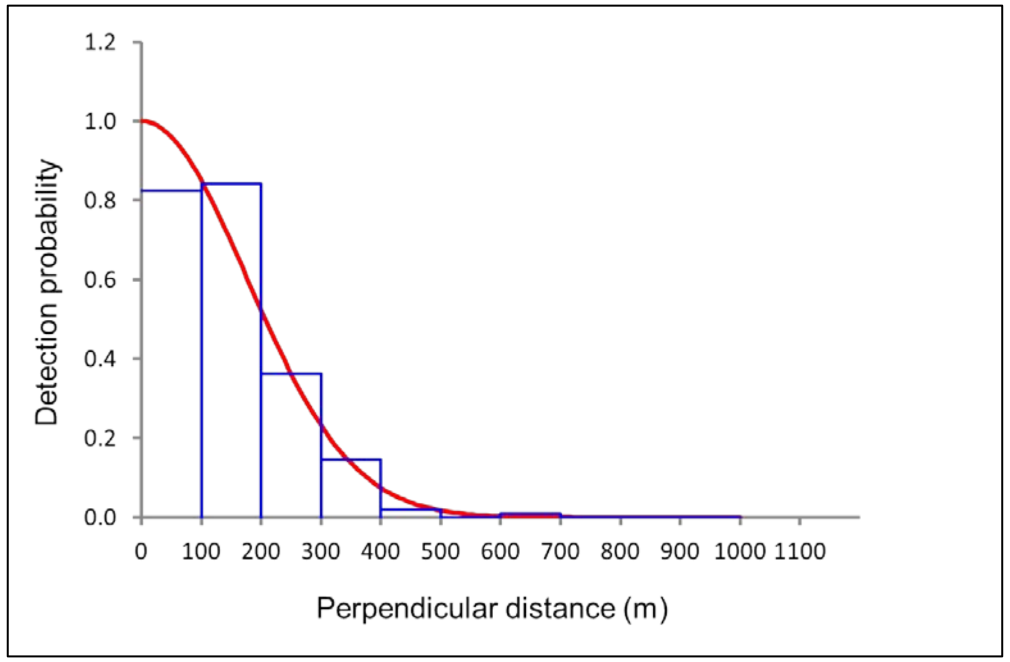


Table G.6: Detection function graph for harbour porpoise in sea state 4.

G.1.1.3 Estimates of g(0) also showed a monotonic decrease with increasing sea state (Table G.2). There was no obvious trend in corrected density estimates with sea state but sea state 0 is an obvious outlier (Table G.2). In this case g(0) is constrained because it cannot be greater than 1 and this suggests that g(0) in higher sea states may be overestimated. An alternative explanation is that, due to the particular difficulties of estimating distance in glassy calm conditions, harbour porpoise may be seen at greater distances in sea state 0 than at which they are estimated. This error would affect the ESW, which would lead to an overestimate of density since:

$$\widehat{D} = \frac{n}{2\hat{\mu}L}$$

Where $\widehat{D}$ is the estimated uncorrected density (animals km^{-2}); n is the total count of individuals, $\widehat{\mu}$ is the estimated ESW (km) and L is the effort (km).

Table G.2: Estimates of g(0) for harbour porpoise in different sea states based on visual detection of acoustic trials (± 80s allowable timing error). Acoustic trial strip width was estimated as 385 m for all sea states. It is assumed that g(0) in sea state 0 approaches 1.

Sea state	Total effort (km travelled)	Estimated number of animals	Uncorrected density (animals km^{-2})	g(0)	Density corrected for g(0) (animals km^{-2})
0	974	903	1.773	1.000	1.773
1	6,431	2,447	0.951	0.576	1.653
2	14,823	1,719	0.356	0.224	1.590
3	19,292	1,106	0.249	0.143	1.743
4	12,073	363	0.137	-	-
All data	53,626	6,538	0.346	0.201	1.723

G.1.1.4 Across the range of conditions likely to be encountered during vessel surveys g(0) may vary from close to 1 in sea state 0 to around 0.1 in sea state 4. Any comparison with estimates of g(0) from other surveys needs to take into account survey conditions as well as vessel type, speed and number of observers. Nevertheless the overall value of g(0) at 0.201 from the three years of survey data across the Hornsea Zone plus a 10 km buffer is very similar to that from SCANS-II of 0.22 (Hammond *et al.,* 2013). SCANS-II provides one of the most comparable surveys for which g(0) has been estimated effectively. Using the SCANS value for g(0) in place of the one measured during this survey would be unlikely to have a large influence on the overall density estimate.

G.1.1.5 Based on these preliminary estimates of g(0), the overall density estimates showed little variation with sea state (Table G.2) with the exception of sea state 0 (as discussed previously in section G.1.1.3). This provides a level of confidence in the recording of sea state and consistency of distance estimates in the surveys. However, the differences over time between visual and acoustic estimates of density indicate a more complex picture and suggest other factors may also influence detection probability, although, an accurate characterisation of all these factors is not possible to achieve due to the inherent difficulties in marine mammal surveys in general.

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