

Volume 4, Chapter 11

Marine mammals Appendices

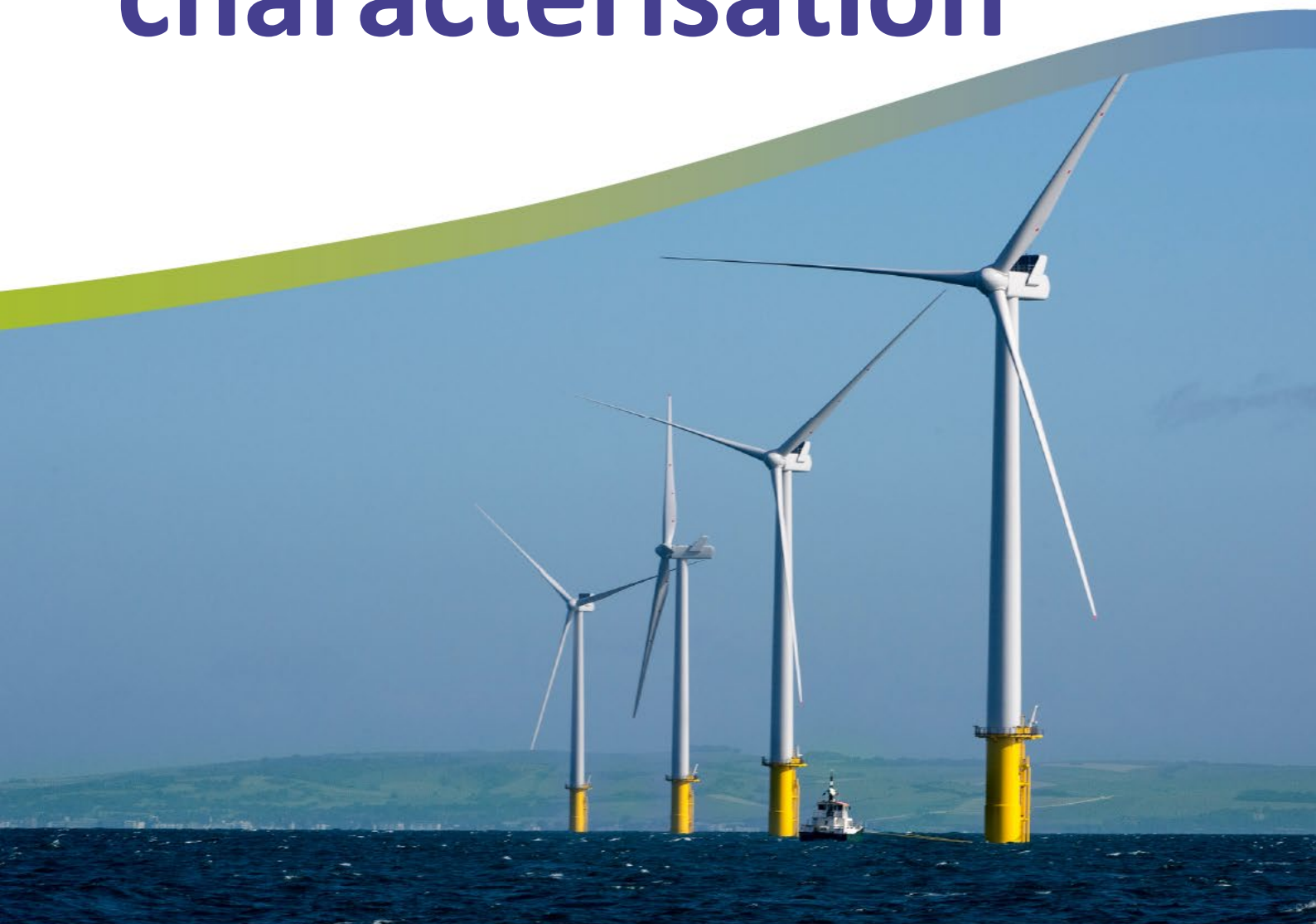


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Marine mammal baseline characterisation



Executive summary

This report has been produced for the purpose of characterising the marine mammal baseline environment for Rampion 2 and the surrounding area. The consideration of marine mammals for Rampion 2 has been discussed with consultees through the Evidence Plan Process (EPP) and baseline characterisation information has been compiled through a combination of a literature reviews and data obtained from site-specific digital aerial surveys. The marine mammal section of the Rampion 2 Scoping Report (RED, 2020) scoped in seven species of marine mammal to the assessment including: harbour porpoise, bottlenose dolphin, white-beaked dolphin, common dolphin, minke whale, harbour seal and grey seal. However, upon further consideration of the data sources, this baseline characterisation recommends that white-beaked dolphins are scoped out of assessment due to their rarity within the survey area.

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1. Introduction

- 1.1.1 The Sea Mammal Research Unit (SMRU) Consulting was commissioned by Rampion Extension Development Limited (RED) to undertake a characterisation of the marine mammal baseline environment of Rampion 2 and the surrounding area.
- 1.1.2 The consideration of marine mammals for Rampion 2 has been discussed with consultees through the Rampion 2 Evidence Plan Process (EPP); specifically with the Marine Mammal Expert Topic Group (ETG) of which Natural England, the Marine Management Organisation (MMO), Centre for Environment, Fisheries and Aquaculture Science (Cefas), and The Wildlife Trusts (TWT) were a part of.
- 1.1.3 The purpose of this document is to provide a characterisation of the baseline environment to understand the range of species, and the abundance and density of marine mammals that could potentially be impacted by the Proposed Development. The baseline data have been compiled through a combination of a literature reviews and data obtained from site-specific surveys.

2. Methodology

The Scoping Report (RED, 2020) identified seven marine mammal species to be present in the Rampion 2 area: harbour porpoise, bottlenose dolphin, white-beaked dolphin, common dolphin, minke whale, harbour seal and grey seal. Baseline information was gathered by a combination of desk-based review of existing data sources and consideration of site-specific-survey data. The existing sources reviewed, and the surveys carried out are described in detail below.

2.1 Study area

2.1.1 The marine mammal study area varies depending on the species, considering individual species ecology and behaviour. For all species, the study area covers the Rampion 2 array area and offshore export cable corridor and is extended over an appropriate area considering the scale of movement and population structure for each species. For each species, the area considered in the assessment is largely defined by the appropriate species Management Unit (MU). The study area for marine mammals has been defined at two spatial scales: the MU scale for species specific population units and the marine mammal survey areas for an indication of the local densities of each species. Details of the MU size and extent are provided in **Table 2-1** and **Graphic 2-1**.

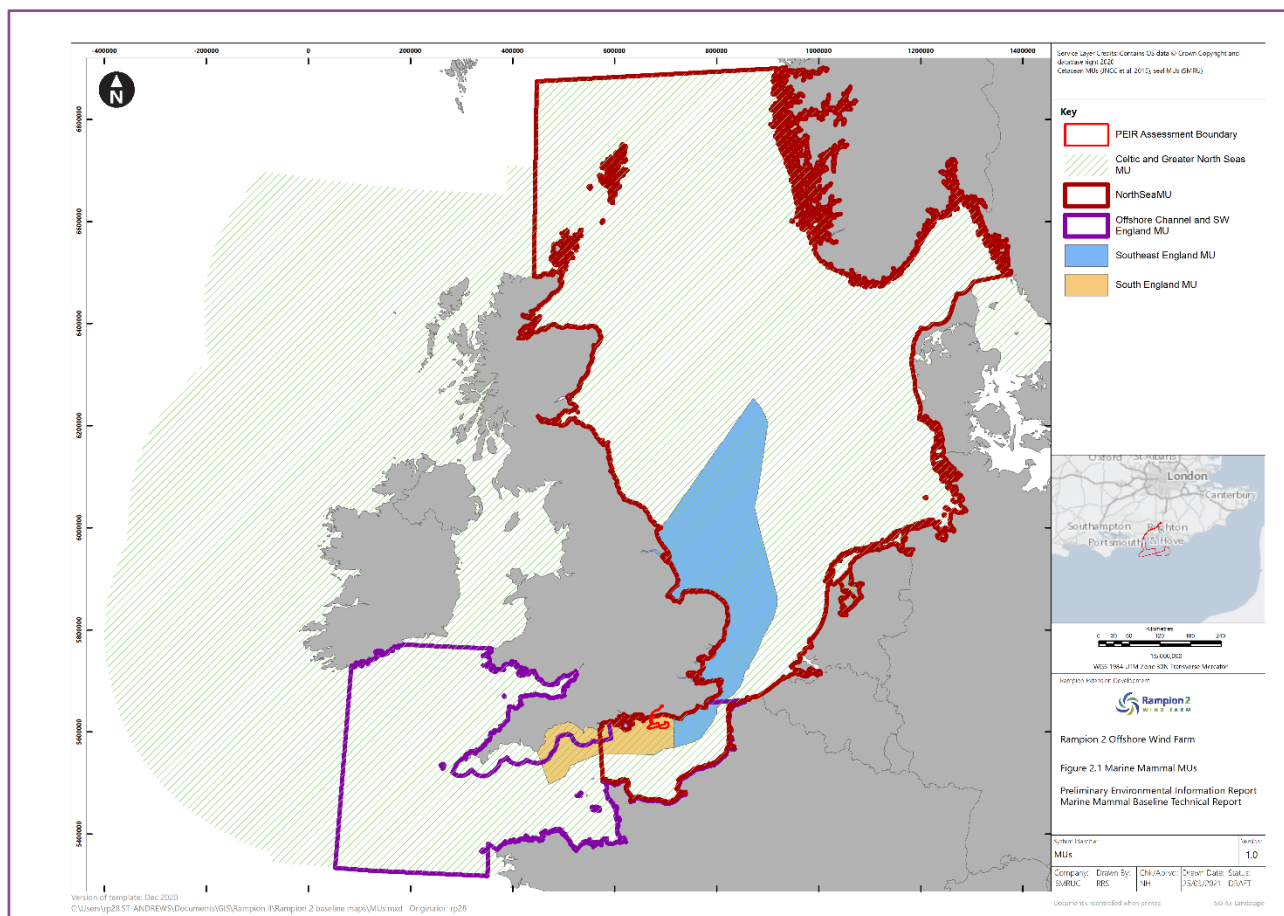
- at the MU scale, Rampion 2 is located within the following species specific MUs:
 - ▶ harbour porpoise: North Sea MU;
 - ▶ bottlenose dolphin: Offshore Channel and SW England MU;
 - ▶ white-beaked dolphin: Celtic and Greater North Seas MU;
 - ▶ common dolphin: Celtic and Greater North Seas MU;
 - ▶ minke whale: Celtic and Greater North Seas MU;
 - ▶ harbour seals: South and Southeast England MUs combined; and
 - ▶ grey seals: South and Southeast England MUs combined.
- The marine mammal survey area encompasses the Rampion 2 array area plus 4 kilometre (km) buffer in order to provide more temporal and spatial fine scale local data (**Graphic 2-3**).

Table 2-1 Management unit abundance estimates for the marine mammal species in the Rampion 2 area.

Species	MU	Abundance	Source
Harbour porpoise	North Sea	345,373	Hammond <i>et al.</i> (2017)

Species	MU	Abundance	Source
		95 percent confidence interval (CI): 246,526 to 495,752	
Bottlenose dolphin	Offshore Channel and SW England	4,856 95 percent CI: 1,638 to 14,398	Inter-Agency Marine Mammal Working Group (IAMMWG) (2015a) based on SCANS II data (Hammond <i>et al.</i> , 2013)
White-beaked dolphin	Celtic and Greater North Seas	15,895 95 percent CI: 9,107 to 27,743	IAMMWG (2015a) based on SCANS II data (Hammond <i>et al.</i> , 2013)
Common dolphin	Celtic and Greater North Seas	56,556 95 percent CI: 33,014 to 96,920	IAMMWG (2015a) based on SCANS II and CODA data (Hammond <i>et al.</i> , 2013, Macleod <i>et al.</i> , 2009)
Minke whale	Celtic and Greater North Seas	23,528 95 percent CI: 13,989 to 39,572	IAMMWG (2015a) based on SCANS II and CODA data (Hammond <i>et al.</i> , 2013, Macleod <i>et al.</i> , 2009)
Harbour seal	South and South-east England MUs combined	Count: 3,752 (SE) + 40 (S)	SMRU 2019 count data
Grey seal	South and South-east England MUs combined	Count: 8,667 (SE) + 25 (S)	SMRU 2019 count data

Graphic 2-1 Marine mammal Management Units.



2.2 Conservation status

- 2.2.1 The Joint Nature Conservation Committee (JNCC) provides the United Kingdom (UK) report on the conservation status of species. The latest assessments were conducted in 2019 and were submitted to the European Commission as part of the 2019 UK Reporting under Article 17 of the European Union (EU) Habitats Directive. Overall, most species have an unknown conservation status, apart from harbour seals, which have an unfavourable-inadequate status and grey seals which have a favourable status (**Table 2-2**).

Table 2-2 Conservation status of the marine mammals present in the Rampion 2 area.

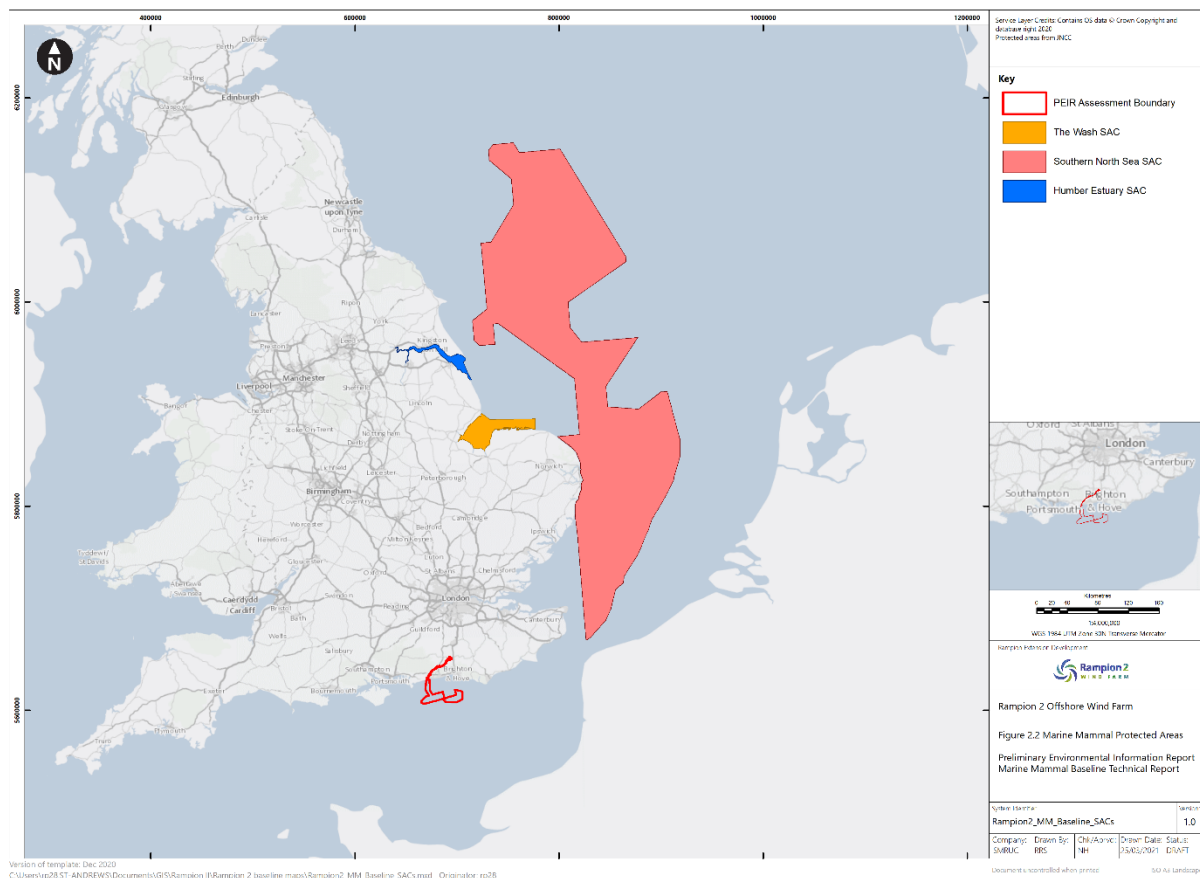
Species	Range	Population	Habitat	Future prospects	Conservation Status	Overall trend	Reference
Harbour porpoise	FV	XX	XX	FV	XX	XX	JNCC (2019c)
Bottlenose dolphin	FV	XX	XX	XX	XX	XX	JNCC (2019a)
White-beaked dolphin	FV	XX	XX	XX	XX	XX	JNCC (2019f)
Common dolphin	FV	XX	XX	XX	XX	XX	JNCC (2019b)
Minke whale	FV	XX	XX	XX	XX	XX	JNCC (2019g)
Harbour seal	FV	U1	XX	U1	U1	XX	JNCC (2019e)
Grey seal	FV	FV	FV	FV	FV	+	JNCC (2019d)

FV = Favourable, U1 = Unfavourable-Inadequate, XX = Unknown, + = Improving

2.3 Protected areas

- 2.3.1 In order to conserve biodiversity, by maintaining or restoring Annex II species to a Favourable Conservation Status (FCS), the Habitats Directive requires the designation of Special Areas of Conservation (SACs) for the harbour porpoise, the bottlenose dolphin the harbour seal and the grey seal.
- 2.3.2 Within the North Sea MU there is one SAC for harbour porpoise: The Southern North Sea SAC.
- 2.3.3 There are no harbour seal SACs in the South England MU. The closest harbour seal SAC is the Wash and North Norfolk Coast SAC which is located in the Southeast England MU >300km from the survey area.
- 2.3.4 There are no grey seal SACs in the South England MU. The closest grey seal SAC is the Humber Estuary SAC which is located in the Southeast England MU >300km from the survey area.

Graphic 2-2 Marine mammal protected areas (Special Areas of Conservation (SAC)) within the Study Area



2.4 Data sources

2.4.1 **Table 2-3** and the following sections provide detail on the key data sources used to characterise the baseline study area for marine mammals in relation to Rampion 2. This section details the survey and analysis methodology implemented in each study and the potential limitations associated with these. The actual results of the surveys in terms of the species presence is detailed subsequent species specific sections (**Section 3: Harbour porpoise baseline, Section 4: Bottlenose dolphin baseline, Section 5: White-beaked dolphin baseline, Section 6: Common dolphin baseline, Section 7: Minke whale baseline, Section 8: Harbour seal baseline and Section 9: Grey seal baseline**).

Table 2-3 Summary of the marine mammal data sources used for baseline characterisation

Data Source	Date	Summary	Coverage
Rampion 2 surveys	April 2019 to March 2021 (available data for this Preliminary Environmental	Digital aerial surveys	Rampion 2 + buffer

Data Source	Date	Summary	Coverage
	Information Report (PEIR) April 2019 to November 2020)		
Rampion 1 surveys	March 2010 to February 2012	Boat based visual surveys	Rampion 1 + buffer
SCANS III (Hammond <i>et al.</i>, 2017)	July 2016	Abundance estimates for small cetacean populations	UK wide
Joint Cetacean Protocol (JCP) Phase III (Paxton <i>et al.</i>, 2016)	1994 to 2010	Estimations of spatial and temporal abundance patterns	UK wide
JCP Phase III Data Analysis Product	1994 and 2010	JCP dataset: 38 sources, totalling over 1.05 million km from a variety of platforms	UK wide. Specific estimates provided for Hastings and Isle of Wight
Heinänen and Skov (2015)	1991 to 2011 (Summer: April to September, Winter: October to March)	Density surface maps produced from the JCP dataset.	UK wide
MERP Cetacean distribution maps (Waggitt <i>et al.</i>, 2020)	1980 to 2018	Species distribution maps available at monthly and 10 square kilometre (km ²) density scale	UK wide
Navitus Bay Survey Data	December 2009 and November 2011	Boat based visual and aerial surveys	Navitus Bay (West of the Isle of Wight)
Sea Watch Foundation sightings (Castles, 2020)	2007 to 2019	Sightings distribution maps	Waters around the Isle of Wight
ORCA sightings	2011 to 2020	Sightings and effort data from opportunistic ferry surveys.	Ferry route between Portsmouth and Caen

Data Source	Date	Summary	Coverage
Seal haul-out counts (provided by SMRU)	August counts: 1996 to 2020 (harbour and grey seal) Autumn counts: 1989 to 2020 (grey seal pups)	Haul-out count data for population estimates	UK wide
Seal telemetry (provided by SMRU)	1988 to 2018	Information on Global Positioning System (GPS) location, track data and dive data	UK wide
Sea at-sea usage (Russell <i>et al.</i>, 2017)	1991 to 2015	Average seal at-sea distribution estimates at a 5km grid resolution	UK wide
The Solent Seal Project (Castles <i>et al.</i>, in review, Chesworth <i>et al.</i>, 2010)	Counts: 1999 to 2019 Telemetry: 2009	Annual August haul-out counts of seals in the Solent. Telemetry data for five harbour seals tagged at Chichester and Langstone harbours	The Solent Sea
SAMM surveys (Laran <i>et al.</i>, 2017)	November 2011 to August 2012	Large scale aerial surveys	English Channel and the Bay of Biscay
French seal data (Vincent <i>et al.</i>, 2017)	1999 to 2014	45 grey and 28 harbour seals tagged	English Channel and French coast

Rampion 2 surveys

- 2.4.2 Monthly digital aerial surveys have been completed for Rampion 2. They commenced in April 2019 and concluded in March 2021, resulting in 24 surveys. At the time of PEIR, 20 months of data are available to include in the baseline characterisation (April 2019 to November 2020) (**Table 2-4**). The final baseline technical report for the Environmental Statement (ES) will be updated with the full 24 months of survey data.
- 2.4.3 The survey design consisted of nine transect lines within the survey area. Images were captured at points located approximately 3km apart (**Graphic 2-3**). Data collected were 2 centimetres (cm) ground sampling distance (GSD) digital still images. This resulted in coverage of 11.58 to 12.24 percent of the Rampion 2 survey area, mostly in Douglas sea states between 1 and 3.

- 2.4.4 Population estimates for each survey month were extracted by multiplying the mean number of animals per image, by the total number of images covering the study area. Using non-parametric, bootstrap methods, species-specific monthly abundance estimates were calculated from the raw count data, with upper and lower confidence limits included. Where appropriate, precision was also presented for each estimate. Dividing these estimates by the size of the area covered, generated the associated density estimates for all species.

Graphic 2-3 Transect lines of the aerial digital still imagery at Rampion 1 and Rampion 2 survey area

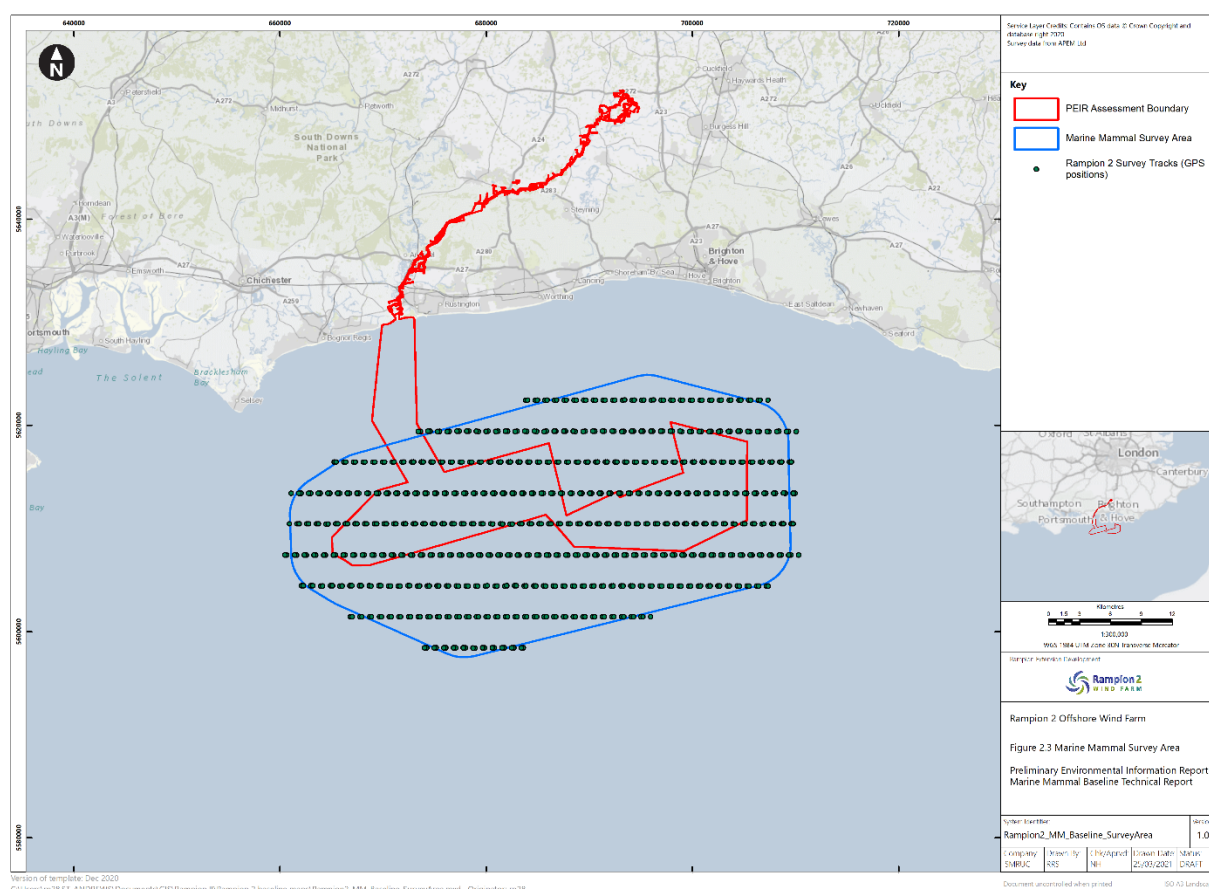


Table 2-4 Details of the monthly aerial surveys for Rampion 2

Survey number	Date	Douglas Sea State	Turbidity	# Images	Percentage coverage
1	26/04/2019	2	1	2058	11.58
2	14/05/2019	3 to 4	2	2061	11.59
3	14/06/2019	1	0	2061	11.59
4	09/07/2019	1	0	2151	12.1

Survey number	Date	Douglas Sea State	Turbidity	# Images	Percentage coverage
5	05/08/2019	3	2-3	2163	12.17
6	02/09/2019	1 to 2	1-2	2175	12.24
7	02/10/2019	1	1	2175	12.24
8	01/12/2019	1 to 2	1 to 2	2175	12.24
9	22/12/2019	3	2	2172	12.22w
10	15/01/2020	1 to 2	2	2175	12.24
11	07/02/2020	1 to 2	0	2175	12.24
12	09/03/2020	1 to 2	1	2175	12.24
13	26/03/2020	0 to 2	Not stated in monthly survey reports. Expecting information to be presented in the year 2 report.		12
14	29/05/2020	1			12
15	13/06/2020	2			12
16	14/07/2020	1			12
17	05/08/2020	0 to 2			12
18	01/09/2020	0.5			12
19	19/10/2020	3			12
20	11/11/2020	3			12

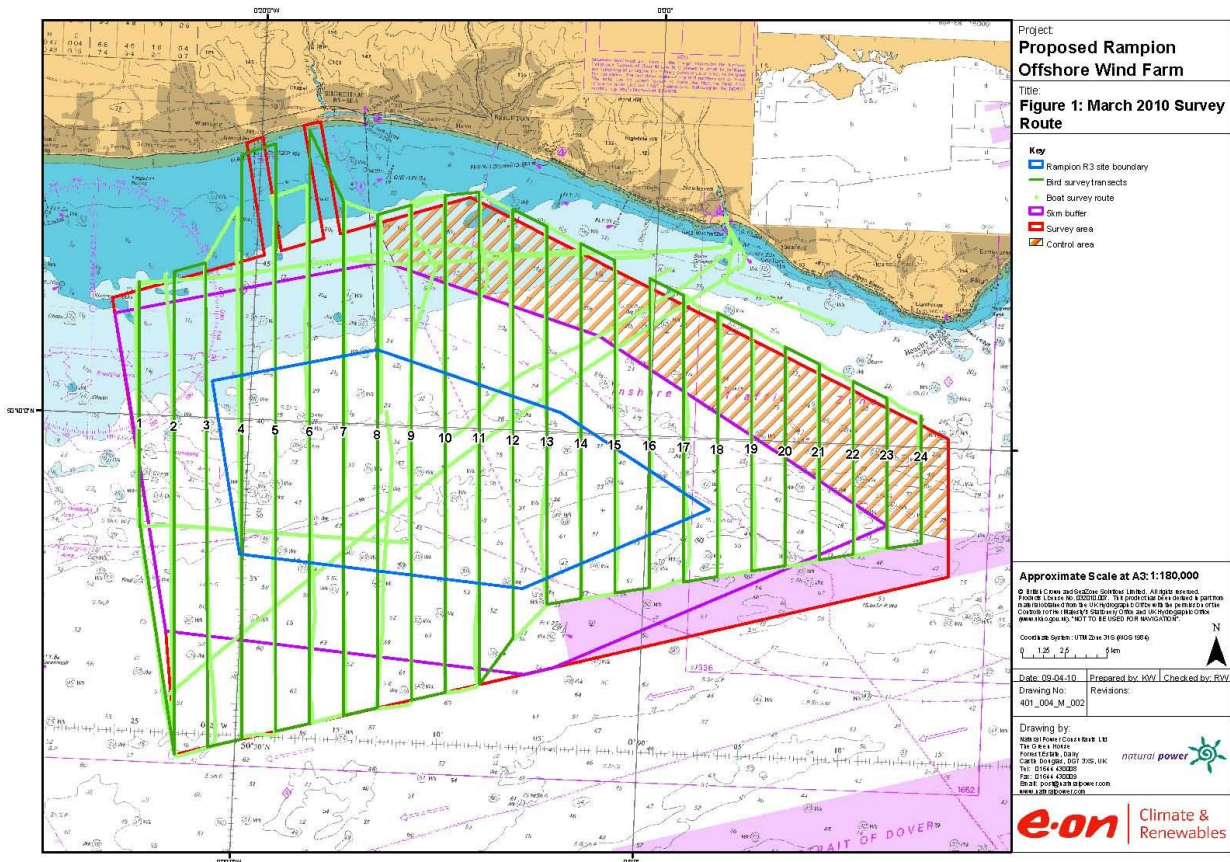
Douglas Sea State: 0 = Calm (Glassy); 1 = Calm (Rippled); 2 = Smooth; 3 = Slightly Moderate; 4 = Moderate

Turbidity scale: 0 = Clear; 1 = Slightly Turbid; 2 = Moderately Turbid; 3 = Highly Turbid

Rampion 1 surveys

- 2.4.5 Between March 2010 and February 2012 boat-based surveys were undertaken to characterise the marine mammal baseline for the existing Rampion 1 project. The survey area (red line **Graphic 2-4**) was sub-divided to include the Rampion Round 3 site (blue line **Graphic 2-4**), with a 5km buffer zone (purple line **Graphic 2-4**), control areas (red hatch **Graphic 2-4**) and the proposed export cable corridor. The survey design consisted of 30 transects. A total of 30 surveys were completed over 93 survey days equating to 788 hours of effort. Marine mammals were surveyed concurrently with the surveys for marine ornithology. The data were analysed to provide sightings rates per hour, uncorrected density estimates and partially corrected density estimates.

Graphic 2-4 Rampion 1 survey area



Small Cetaceans in European Atlantic waters and the North Sea (SCANS) III

- 2.4.6 The main objective of the SCANS surveys was to estimate small cetacean abundance and density in the North Sea and European Atlantic continental shelf waters. The SCANS I surveys were completed in 1994, SCANS II in July 2005 and SCANS III in July 2016 and all comprised of a combination of vessel and aerial surveys. Both aerial and boat-based survey methodologies were designed to correct for availability and detection bias and allow the estimation of absolute abundance (Hammond *et al.*, 2017). The aerial surveys involved a single aircraft method using circle-backs (or race-track) methods whereas the boat-based surveys involved a double platform 'primary' and 'secondary' tracker methodology. Rampion 2 is located in the SCANS III survey block C which covers an area of 81,297km², of which 2,834.2km was surveyed on primary search effort.
- 2.4.7 While the SCANS surveys provide sightings, density and abundance estimates at a wide spatial scale, the surveys are conducted during a single month, every 11 years and therefore do not provide any fine scale temporal or spatial information on species abundance and distribution. Furthermore, due to the change in survey blocks used across the SCANS surveys direct comparison between the surveys for abundance and density information is not possible.

Joint Cetacean Protocol (JCP) Data

Overview

- 2.4.8 The JCP Phase III analysis included datasets from 38 sources, totalling over 1.05 million km of survey effort between 1994 and 2010 from a variety of platforms (Paxton *et al.*, 2016). The JCP Phase III analysis was conducted to combine these data sources to estimate spatial and temporal patterns of abundance for seven species of cetaceans (harbour porpoise, minke whales, bottlenose dolphins, common dolphins, Risso's dolphins, white-beaked dolphins and white-sided dolphins). The JCP Phase III analysis provided abundance estimates for specific areas of interest for offshore development, including Hastings (region to the south of Sussex in which Rampion 2 is located) and Isle of Wight (region to the west of the Isle of Wight).
- 2.4.9 The JCP Phase III Data Analysis Product has been provided by JNCC to extract abundance estimates averaged for summer 2007 to 2010 and scaled to the SCANS III estimates for user specified areas¹. In order to extract data in relation to Rampion 2, the user specified area was defined as approx. a 26km buffer around the survey area.
- 2.4.10 It should be noted that there are significant limitations to the estimates provided by the JCP Phase III analysis. The authors state that the JCP database provides relatively poor spatial and temporal coverage, that the results should be considered indicative rather than an accurate representation of species distribution, and that due to the patchy distribution of data, the estimates are less reliable than those obtained from SCANS surveys. In addition, the authors categorically state that the JCP Phase III outputs cannot be used to provide baseline data to infer abundance at a finer scale than 1,000km² because of issues relating to standardizing the data (such as corrections for undetected animals and potential biases) from so many different platforms/methodologies and the strong assumptions that had to be made when calculating detection probability. The data included in the analysis are now between 10 and 26 years old and may not be representative of current cetacean distribution and densities. Finally, the density estimates obtained from the Data Analysis Tool are an averaged density estimate for the summer 2007 to 2010 and are therefore not representative of densities at other times of the year.

Porpoise high density areas

- 2.4.11 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 SACs for the species. The analysis grouped data into three subsets: 1994 to 1999, 2000 to 2005 and 2006 to 2011 to account for patchy survey effort and analysed summer (April to September) and winter (October to March) data separately to explore whether distribution patterns were

¹ Joint Cetacean Protocol Phase III Data Analysis Product available here: <https://hub.jncc.gov.uk/assets/01adfabd-e75f-48ba-9643-2d594983201e>

different between seasons and to examine the degree of persistence between the subsets. The authors note that “*due to the uneven survey effort over the modelled period, the uncertainty in modelled distributions vary to a large extent*”. In addition, the authors stated that “*model uncertainties are particularly high during winter*”. The uncertainties in the modelled distributions were taken into account when designating the draft SACs so that only areas with high confidence were retained (IAMMWG, 2015c).

Marine Ecosystems Research Programme (MERP) cetacean distribution maps

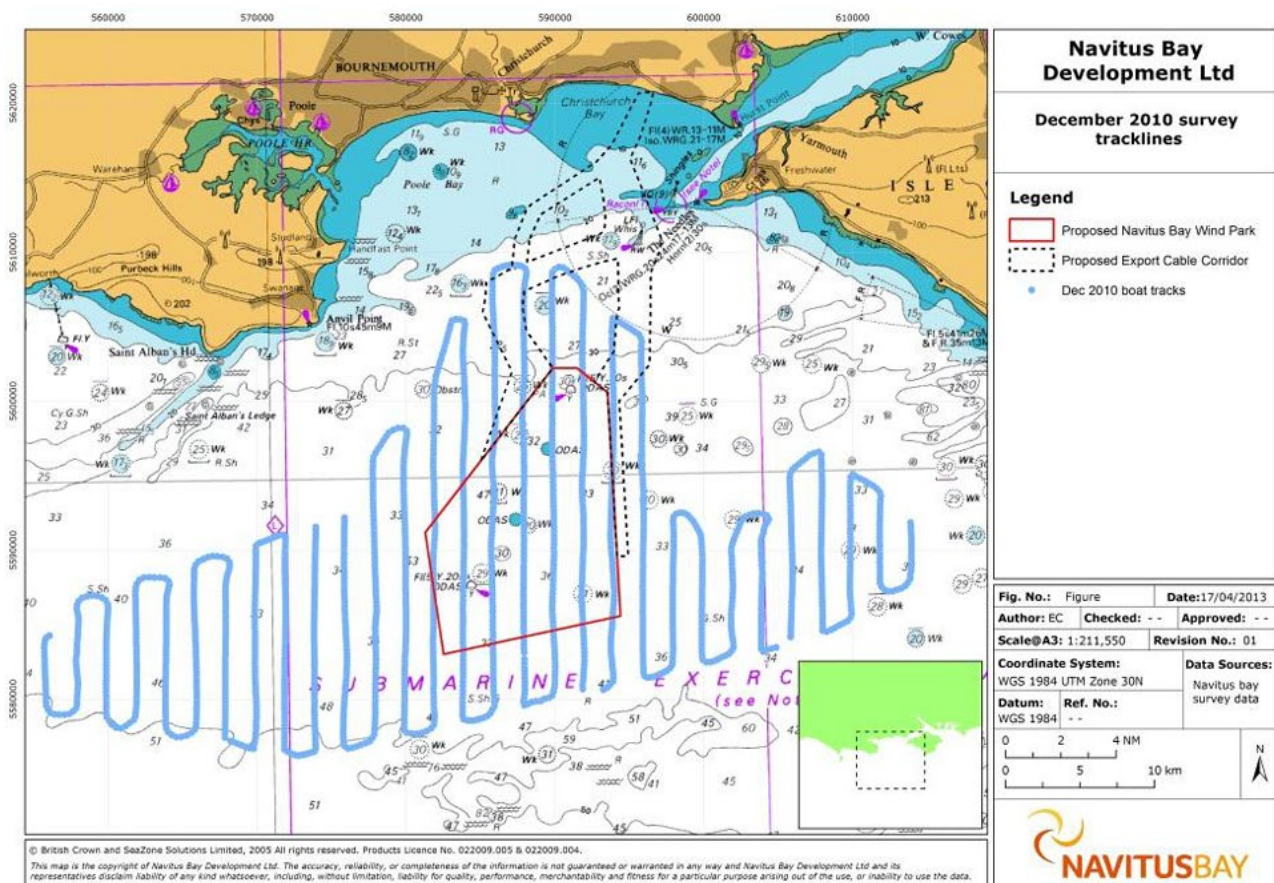
- 2.4.12 The aim of the MERP was to produce species distribution maps of cetaceans and seabirds at basin and monthly scales for the purposes of conservation and marine management. A total of 2.68 million km of survey data in the Northeast Atlantic between 1980 and 2018 were collated and standardized. Only aerial and vessel survey data were included where there were dedicated observers and where data on effort, survey area and transect design were available. The area covered by Waggitt *et al.* (2020) comprised an area spanning between Norway and Iberia on a north-south axis, and Rockall to the Skagerrak on an east-west axis.
- 2.4.13 Waggitt *et al.* (2020) predicted monthly and 10km² densities for each species (animals/km²) and estimated the probability of encountering animals using a binomial model (presence-absence model) and estimated the density of animals if encountered using a Poisson model (count model). The product of these two components were used to present final density estimations (Barry and Welsh, 2002). The outputs of this modelling were monthly predicted density surfaces for 12 cetacean species at a 10km resolution. There is no indication of whether the more recent sightings data are weighted more heavily than older data, which limits interpretation of how predictive the maps are to current distribution patterns. Therefore, while the density estimates obtained from these maps are representative of relative density compared to other sites around the UK, they are not considered to be suitable density estimates for use in quantitative impact assessment and are provided in this baseline characterisation for illustrative purposes only.

Navitus Bay surveys

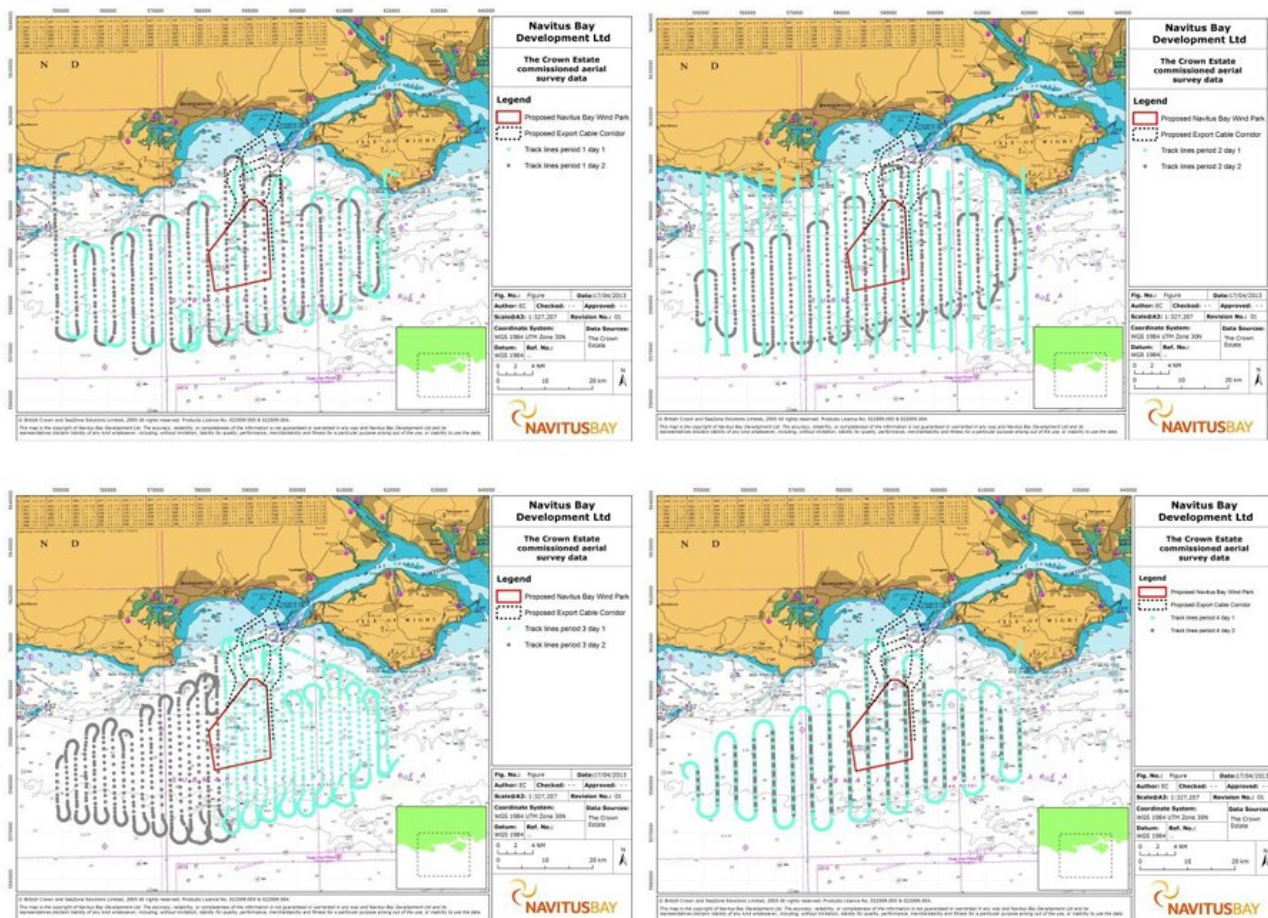
- 2.4.14 The Navitus Bay Wind Park was refused planning permission in 2015, however the baseline characterisation surveys (Lacey and Cox, 2014) conducted to inform the ES chapter are relevant to Rampion 2 given the proximity of the Navitus Bay survey area (located on the west side of the Isle of Wight). Site-specific surveys conducted at Navitus Bay included 23 boat-based surveys of the offshore development area between December 2009 and November 2011 (**Graphic 2-5**). Initially, surveys were primarily aimed at collating bird data, however marine mammal sightings were also recorded; then in April 2011 dedicated marine mammal observers were included in the surveys. These surveys covered between 252km and 478km of effort per survey, totalling 9,923km over 23 surveys. Marine mammal sightings during these surveys included: harbour porpoise, common dolphin, grey seal and unknown small cetacean. Encounter rates were calculated (# sightings/km) but no density estimates were calculated.

- 2.4.15 In addition to this, four aerial surveys were conducted by Wildfowl & Wetlands Trust (WWT) Consulting on behalf of The Crown Estate (TCE) between November 2009 and February 2010 that covered the Round 3 Offshore wind leasing area Zone 7 (which contained the Navitus Bay site). Visual aerial surveys were conducted at 80m height along transects 2km apart (**Graphic 2-6**). These surveys recorded the following marine mammal species: harbour porpoise, grey seals and unknown (cetacean, seal or shark). Additionally, three digital aerial surveys were conducted by HiDef between January and March 2011 (**Graphic 2-7**). The HiDef surveys recorded small cetacean and unknown (cetacean, seal or shark), with no sightings identified to species level. Encounter rates were calculated (# sightings/km) but no density estimates were calculated.
- 2.4.16 The applicability of these data is limited given that the survey areas did not overlap with Rampion 2, the data are now relatively old and because of the lack of dedicated marine mammal surveyors on most of the surveys. However, they do provide an insight into the species present in the general area.

Graphic 2-5 From Lacey and Cox (2014): Track lines sailed during the December 2010 survey of the Navitus Bay wind park site

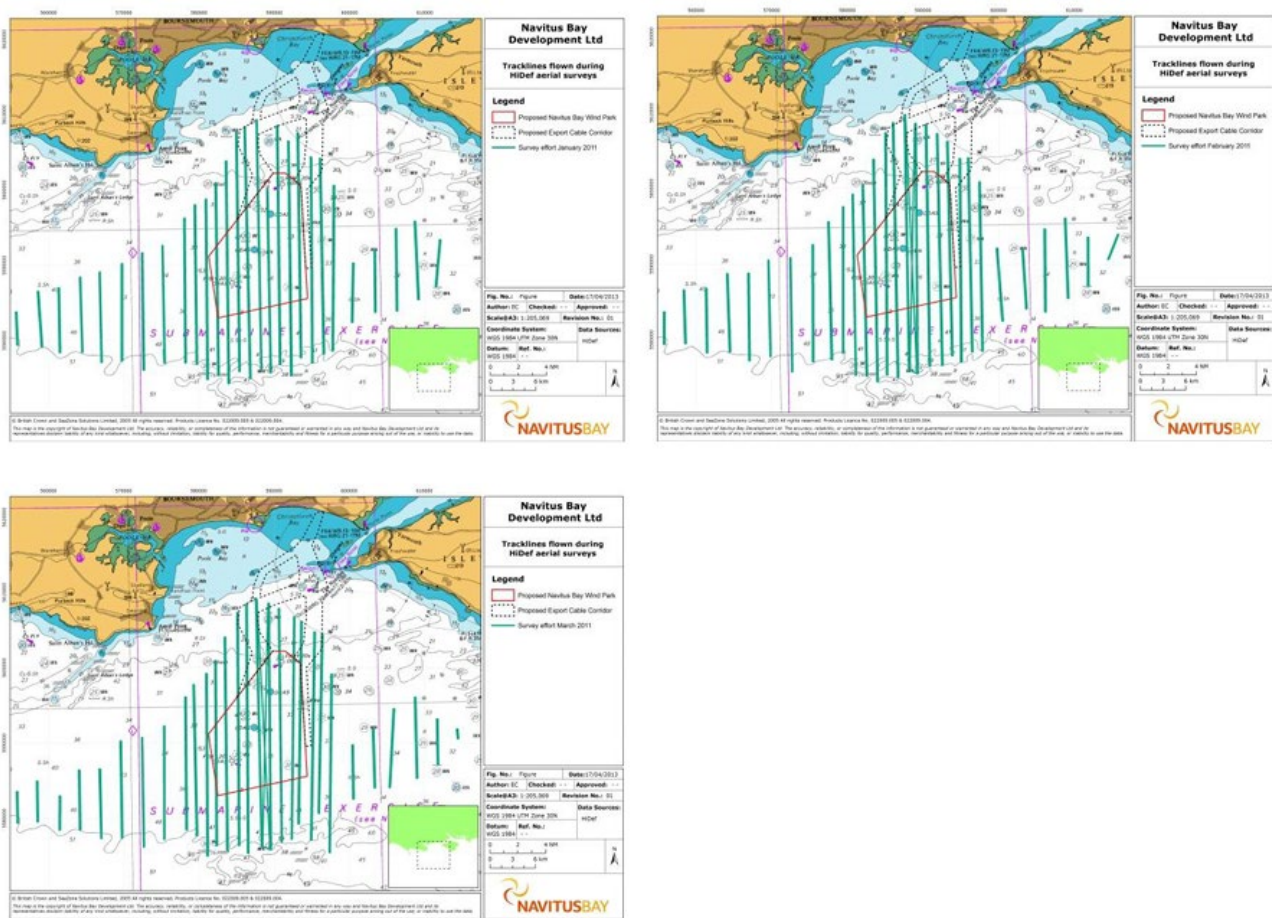


Graphic 2-6 From Lacey and Cox (2014): Aerial track lines flown during TCE commissioned surveys of the Navitus Bay wind park site



Note: Four surveys were conducted in all, each over two days. Surveys were conducted during November 2009 (top left), December 2009 (top right), January 2010 (bottom left) and February 2010 (bottom right).

Graphic 2-7 From Lacey and Cox (2014): Track lines flown during HiDef surveys of the Navitus Bay wind park site



Note: Three surveys were conducted during January 2011 (top left), February 2011 (top right), and March 2011 (bottom left).

Sea Watch Foundation sightings

2.4.17 The Sea Watch Foundation maintains a national sightings database. Rampion 2 is located in Sea Watch Foundation region 17 which is part of the Southern England Area (which includes Hampshire, west Sussex, east Sussex and Kent). In the Southern England area between 07 March 2018 and 30 August 2020, a total of 135 cetacean sightings events have been reported², consisting of the following species:

- harbour porpoise (180 individuals over 71 encounters);
- bottlenose dolphin (265 individuals over 31 encounters);
- common dolphin (205 individuals over 13 encounters);
- white-beaked dolphin (nine individuals over two encounters);
- long-finned pilot whale (18 individuals over two encounters);

² https://seawatchfoundation.org.uk/legacy_tools/region.php?output_region=7

- humpback whale (one individual over one encounter);
- dolphin species (111 individuals over 11 encounters); and
- cetacean species (78 individuals over four encounters).

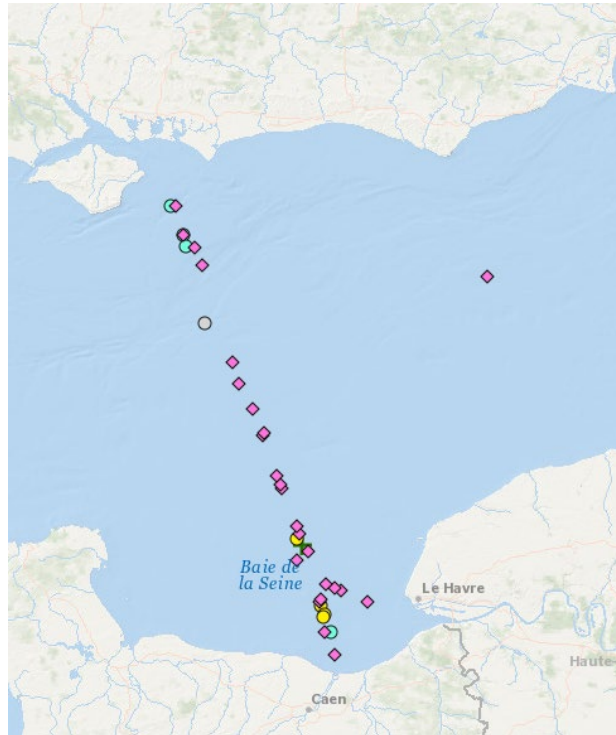
2.4.18 Records from the Sea Watch Foundation for cetaceans sighted around the Isle of Wight (114 sightings) since 2007 were collated and analysed by Castles (2020) to investigate spatio-temporal trends in the sightings. The dataset consisted of three cetacean species: bottlenose dolphin, harbour porpoise and common dolphin, as well as unidentified cetacean and unidentified dolphins.

ORCA sightings

2.4.19 ORCA conduct visual surveys from ferry platforms, using observers who have completed the ORCA Marine Mammal Surveyor course. The closest ferry route to Rampion 2 is the Portsmouth-Caen ferry route, run by Brittany Ferries, consisting of day sailing only (no nights). There are map data available on the ORCA website that shows sightings along this route in 2011, 2015 and 2016 (**Graphic 2-8**), and additionally there are recent survey reports for this route between 2018 to 2020 (**Table 2-5**). Data have shown that the following species have been sighted along this route: harbour porpoise, bottlenose dolphin and common dolphin (as well as unidentified dolphins, unidentified small cetaceans and unidentified seals). While this opportunistic data source provides useful information on the sightings of different species in the area, density estimates have not been provided, and as such they are only illustrate of the species seen.

2.4.20 Data from ORCA surveys in 2009 and 2010 are included in the Joint Cetacean Protocol Database (Paxton *et al.*, 2016). ORCA data collected between 2006 to 2015 were also one of the data sources incorporated into the modelling to produce species distribution maps presented by Waggitt *et al.* (2020).

Graphic 2-8 Marine mammal sightings on the Portsmouth-Caen ferry route (2011, 2015 and 2016)³



Note: Harbour porpoise = pink diamond, yellow circle = common dolphin, grey circle = bottlenose dolphin, turquoise circle = unidentified dolphin, green plus = small cetacean.

Table 2-5 Marine mammal sightings during the Portsmouth-Caen ferry trips 2018 to 2020⁴

Ferry route	Marine mammal sightings
2020-02-10 - Portsmouth-Caen	None
2020-02-06 - Portsmouth-Caen	None
2020-01-31 - Portsmouth-Caen	None
2019-09-27 - Portsmouth-Caen	Two incidental unidentified dolphins
2019-08-02 - Portsmouth-Caen	Bottlenose Dolphin x three Common Dolphin x 50 Harbour Porpoise x two Unidentified Dolphin x one
2019-07-26 - Portsmouth-Caen	Twelve Harbour Porpoises

³ Obtained from the ORCA interactive map on 07/12/2020:
<https://www.orcaweb.org.uk/species-sightings/sightings-map>

⁴ Obtained from the ORCA survey reports on 07/12/2020:
<https://www.orcaweb.org.uk/species-sightings/survey-reports/route-portsmouth-caen>

Ferry route	Marine mammal sightings
	One Unidentified Dolphin
2019-06-28 - Portsmouth-Caen	Two x Unidentified dolphins
2019-05-24 - Portsmouth-Caen	None
2019-04-26 - Portsmouth-Caen	Harbour Porpoise x one
2019-03-29 - Portsmouth-Caen	5 Bottlenose dolphins
2018-10-05 - Portsmouth-Caen	17 Bottlenose Dolphins Two Harbour Porpoise One unidentified seal
2018-09-21 - Portsmouth-Caen	None
2018-08-03 - Portsmouth-Caen	Harbour porpoise – eight sightings – 16 individuals Unidentified dolphin – three sightings – 14 individuals
2018-07-20 - Portsmouth-Caen	Harbour Porpoise x one
2018-06-22 - Portsmouth-Caen	Harbour Porpoise x one
2018-05-25 - Portsmouth-Caen	One incidental harbour porpoise
2018-04-27 - Portsmouth-Caen	Harbour Porpoise x one
2018-03-30 - Portsmouth-Caen	unidentified small cetacean

Special Committee on Seals (SCOS) reports

- 2.4.21 Under the Conservation of Seals Act 1970 (in England) and the Marine (Scotland) Act 2010, the Natural Environment Research Council (NERC) (now part of UK Research and Innovation) provides scientific advice to government on matters related to the management of UK seal populations through the advice provided by the SCOS. SMRU provides this advice to SCOS on an annual basis through meetings and an annual report. The report includes advice on matters related to the management of seal populations, including general information on British seals, information on their current status and addresses specific questions raised by regulators and stakeholders.

Sea Mammal Research Unit (SMRU) Seal haul-out counts

Harbour seals

- 2.4.22 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. The counts obtained represent the number of seals that were

onshore 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 are used to scale this estimate to take account of the proportion of animals at sea at the time of survey. It is noted that these data refer to the numbers of seals found within the surveyed areas only at the time of the survey; numbers and distribution may differ at other times of the year.

Grey seals

- 2.4.23 Grey seals are also counted on all harbour seal surveys, although these data do not necessarily provide a reliable index of population size. Grey seals aggregate in the autumn to breed at traditional colonies, therefore 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 biennially between mid-September and late November using large-format vertical photography from a fixed-wing aircraft. The SMRU grey seal pup counts round the UK are augmented by surveys conducted by NatureScot (formally Scottish Natural Heritage (SNH)), The National Trust, Lincolnshire Wildlife Trust and Friends of Horsey Seals.

SMRU Seal telemetry

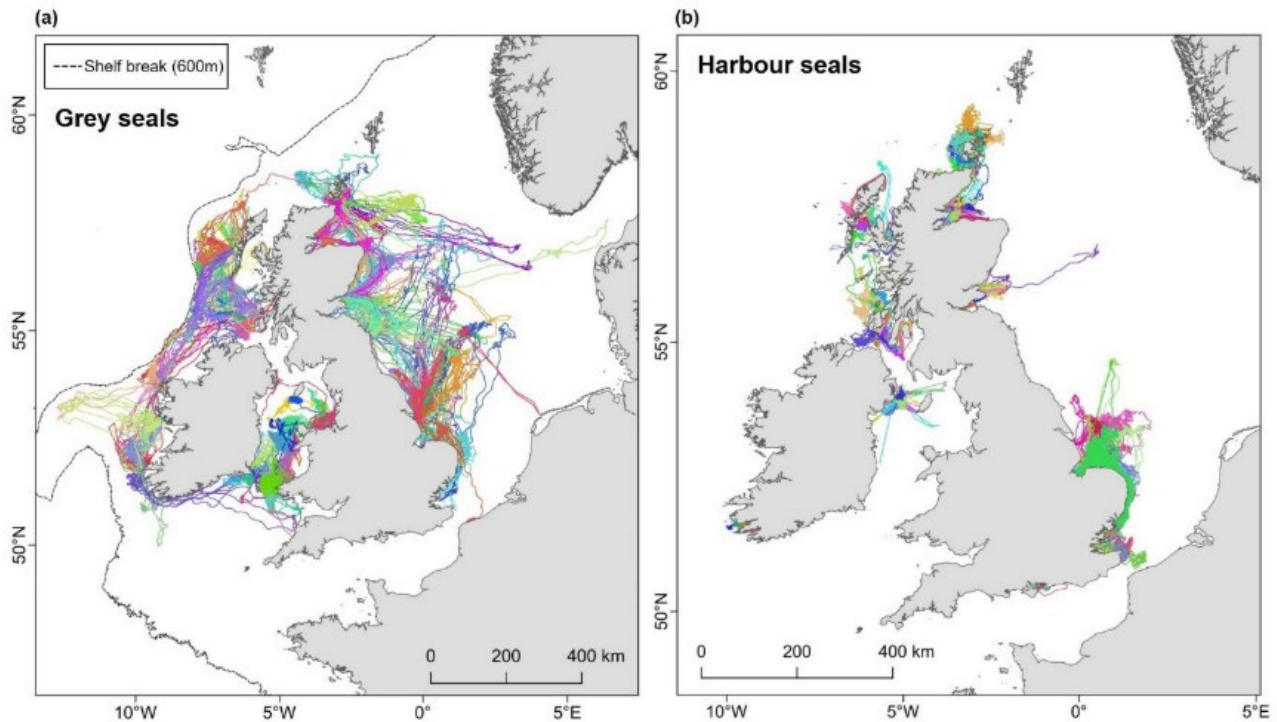
- 2.4.24 SMRU has deployed telemetry tags on grey seals and harbour seals in the UK since 1988 and 2001, respectively. These tags transmit data on seal locations with the tag duration (number of days) varying between individual deployments. There are two types of telemetry tag which differ by their data transmission methods. Data transmission can be through the Argos satellite system (Argos tags) or mobile phone network (phone tags). Both types of transmission result in location fixes, but data from phone tags comprise better quality and more frequent locations. The telemetry data were used to illustrate the distribution of seals at sea and to investigate the degree of connectivity between Rampion 2 and seal haul-out sites and SACs.

Seal at-sea usage and habitat preference

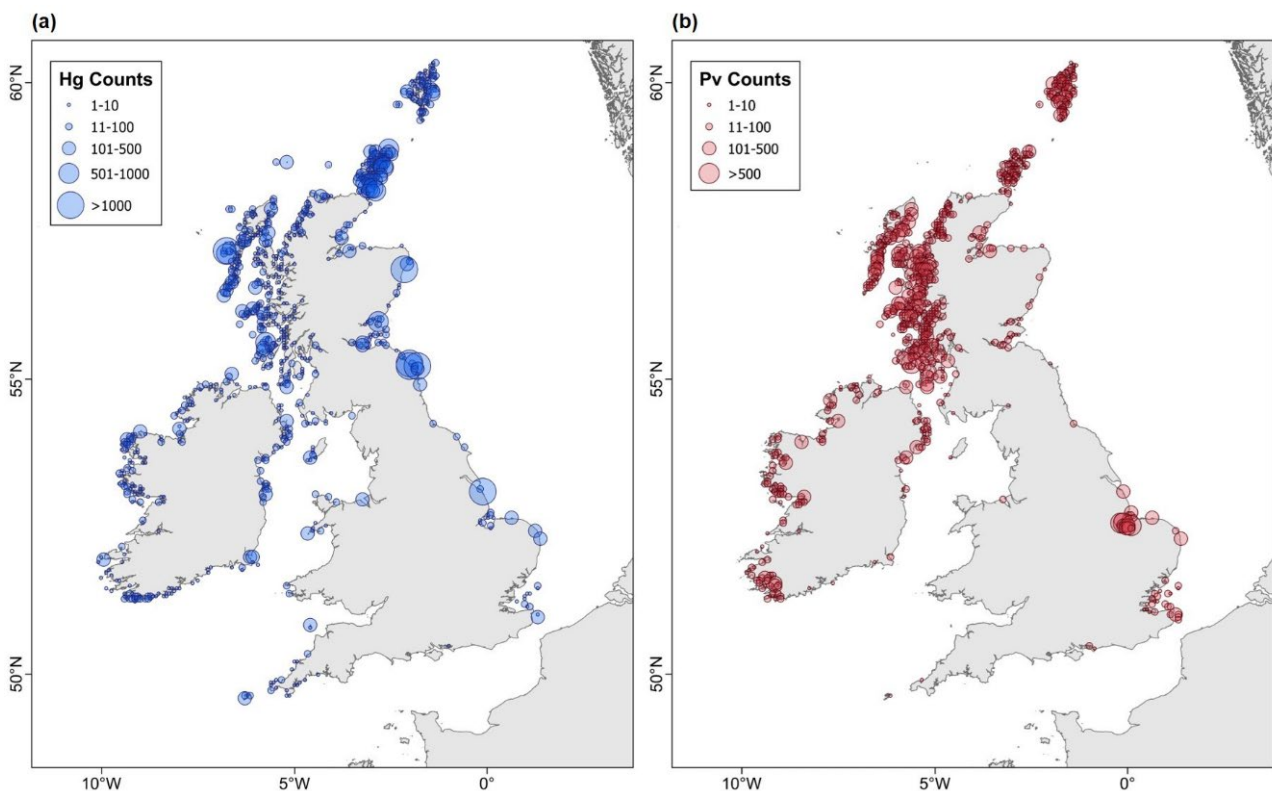
- 2.4.25 The seal at-sea usage maps were created in order to predict the at-sea density of seals in order to inform impact assessments and marine spatial planning. The original SMRU seal density maps were produced as a deliverable of Scottish Government Marine Mammal Scientific Support Research Programme (MMSS/001/01) and were published in Jones *et al.* (2015). These have since been revised to include new seal telemetry and haul-out count data and modifications have been made to the modelling process (Russell *et al.*, 2017). The analysis uses telemetry data from 270 grey seals and 330 harbour seals tagged in the UK between 1991 to 2015, and haul-out count data from 1996 to 2015 to produce UK-wide maps of estimated at-sea density with associated uncertainty. The combined at-sea usage and haul-out data were scaled to the population size estimate from 2015.

- 2.4.26 A key limitation of the at-sea usage maps is that there was a lot of “null usage” in the data, where only a subset of all available haul-out sites were visited by a tagged animal. For haul-out sites where no animal had been tagged, or where no tagged animal had visited, it had to be assumed that usage declined monotonically with distance from the haul-out which meant that potential hotspots around these haul-outs will have been missed.
- 2.4.27 Given the limitations of the at-sea usage maps, and the fact that the grey seal at-sea usage maps were informed mainly by old, low resolution tracking data, Department for Business Energy and Industrial Strategy (BEIS) funded a large-scale deployment of high resolution GPS telemetry tags on grey seals around the UK, and analyses to create up-to-date estimates of the at-sea distribution for both seal species (Carter *et al.*, 2020). Telemetry data from 114 grey seals and 239 harbour seals were included in the analysis (**Graphic 2-9**). To estimate the at-sea distribution, a habitat modelling approach was used, matching seal telemetry data to habitat variables (such as water depth, seabed topography, sea surface temperature) to understand the species-environment relationships that drive seal distribution. Haul-out count data (**Graphic 2-10**) were then used to generate predictions of seal distribution at sea from all known haul-out sites in the British Isles. This resulted in predicted distribution maps on a 5km x 5km grid.
- 2.4.28 The estimated density surface gives the percentage of the British Isles at-sea population (excluding hauled-out animals) estimated to be present in each grid cell at any one time during the main foraging season.
- 2.4.29 It is estimated that grey seals spent 77 percent of their time at sea on average, therefore, using the current best estimate of the grey seal population size in the British Isles (SCOS, 2020), the total at-sea population size for the British Isles is estimated to be ~150,700 individuals (Carter *et al.*, 2020).
- 2.4.30 It is estimated that harbour seals spend 83.4 percent of their time at sea on average (Russell *et al.*, 2015), therefore, using the current best estimate of the harbour seal population size in the British Isles (SCOS, 2020), the total at-sea population size for the British Isles is estimated to be ~42,800 individual harbour seals (Carter *et al.*, 2020).
- 2.4.31 The main limitation of this dataset is that only seals tagged in the British Isles were included in the analysis. Therefore, the habitat preference maps may underestimate the number of seals present in each grid cell as it does not account for those seals from haul-outs along the French coast or the Wadden Sea. In addition, there have been no tagging studies of grey seals in the south-England MU, and therefore the predicted at-sea distributions in this MU may not be representative of the true at-sea distribution.

Graphic 2-9 From Carter *et al.* (2020): GPS tracking data for (a) grey and (b) harbour seals available for habitat preference models



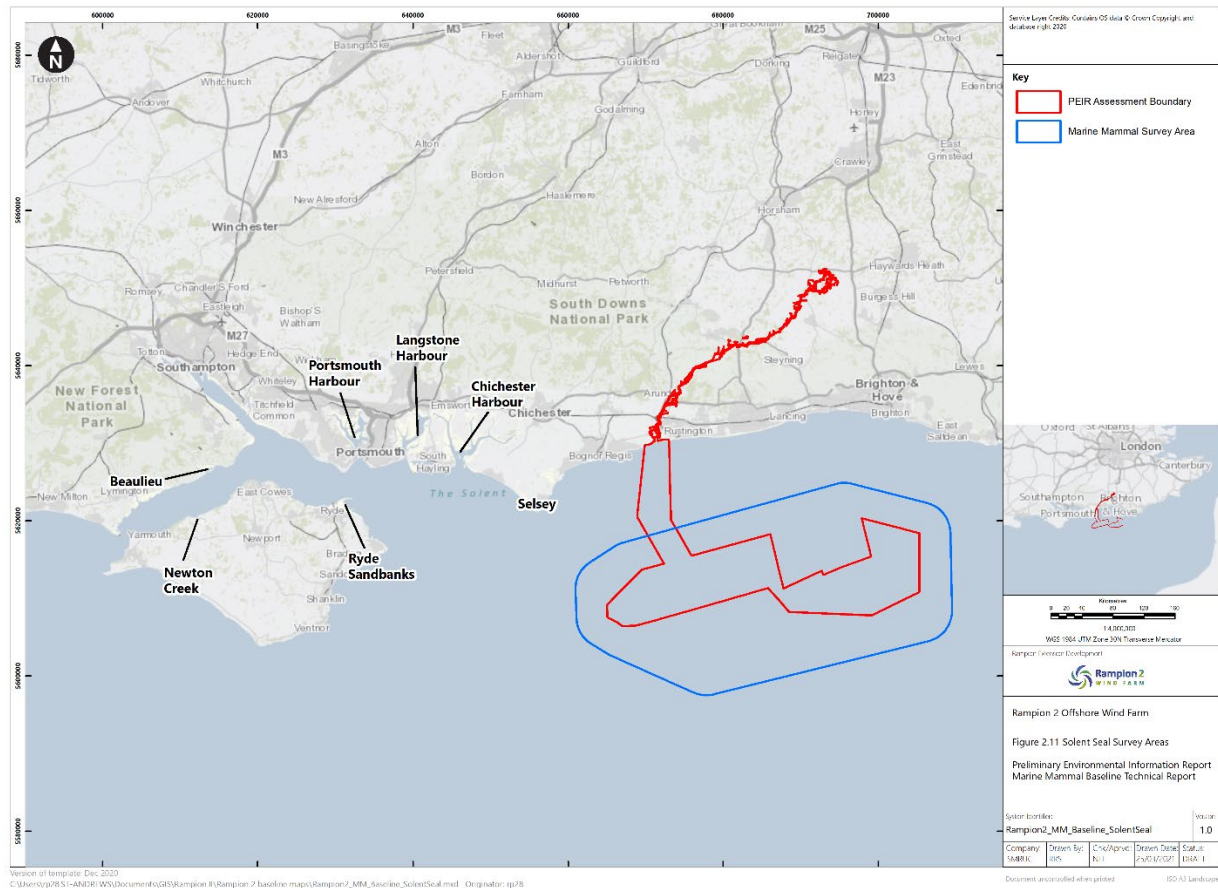
Graphic 2-10 From Carter *et al.* (2020): Most recent available August count data for (a) grey and (b) harbour seals per 5km x 5km haul-out cell used in the distribution analysis



The Solent Seal Project

- 2.4.32 Chichester Harbour Conservancy, Langstone Harbour Board and the Hampshire and Isle of Wight Wildlife Trust have been monitoring the Solent seal population since 1994, conducting annual aerial surveys during the August moult. In 2017 the areas surveyed included: Langstone Harbour, Chichester Harbour, Portsmouth Harbour, Ryde sand banks, Beaulieu and Newtown Creek (**Graphic 2-11**). Additionally, visual surveys have been conducted since 1999 at Chichester harbour and since 2009 at Langstone harbour using both vessel and shore-based methods by Portsmouth Outdoor Education Centre and the Langstone Harbour Board have submitted records for Langstone Harbour and Chichester Harbour Conservancy and the National Trust. In total 270 surveys were conducted between 1999 and 2019 (182 at Chichester and 88 at Langstone).
- 2.4.33 In March 2009 the Solent Seal Tagging Project was undertaken by the Hampshire & Isle of Wight Wildlife Trust in collaboration with Chichester Harbour Authority and the Sea Mammal Research Unit where five harbour seals (four adult males and one juvenile female) were tagged with GPS tags at Chichester and Langstone harbours. In total 520 days of data was collected with an average of ~3.5 months per seal. In addition to this, the Hampshire & Isle of Wight Wildlife Trust maintain an online public sightings scheme.

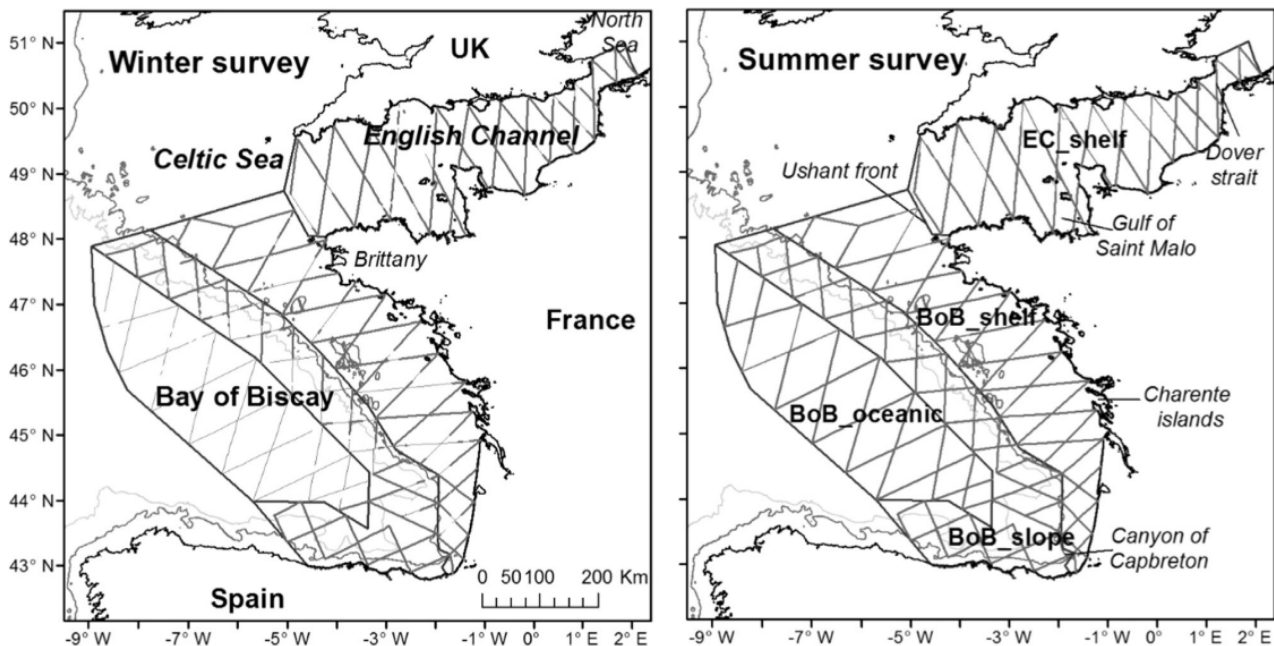
Graphic 2-11 Locations surveyed by the Solent Seal Project in August 2017



SAMM (Suivi Aérien de la Mégafaune Marine) surveys

- 2.4.34 The SAMM (aerial survey for marine megafauna) surveys were conducted in the English Channel and the Bay of Biscay in winter (November 2011 to February 2012) and summer (May to August 2012) using a systematic zig-zag survey design (Laran *et al.*, 2017) (**Graphic 2-12**). A total of 23,512km was surveyed in the winter surveys and 25,111km in the summer. Density estimates were calculated using correction factors from similar aerial surveys to account for availability bias. In the English Channel part of the survey region the following species were identified: harbour porpoise, common dolphins, bottlenose dolphins, Risso's dolphins, striped/common dolphins and minke whales.

Graphic 2-12 From Laran *et al.* (2017): Survey blocks with bathymetric strata and effort conducted during the winter survey (left) and summer (right) in good condition (selected for analyses: with sea state ≤ 3 Beaufort and subjective condition greater than medium)



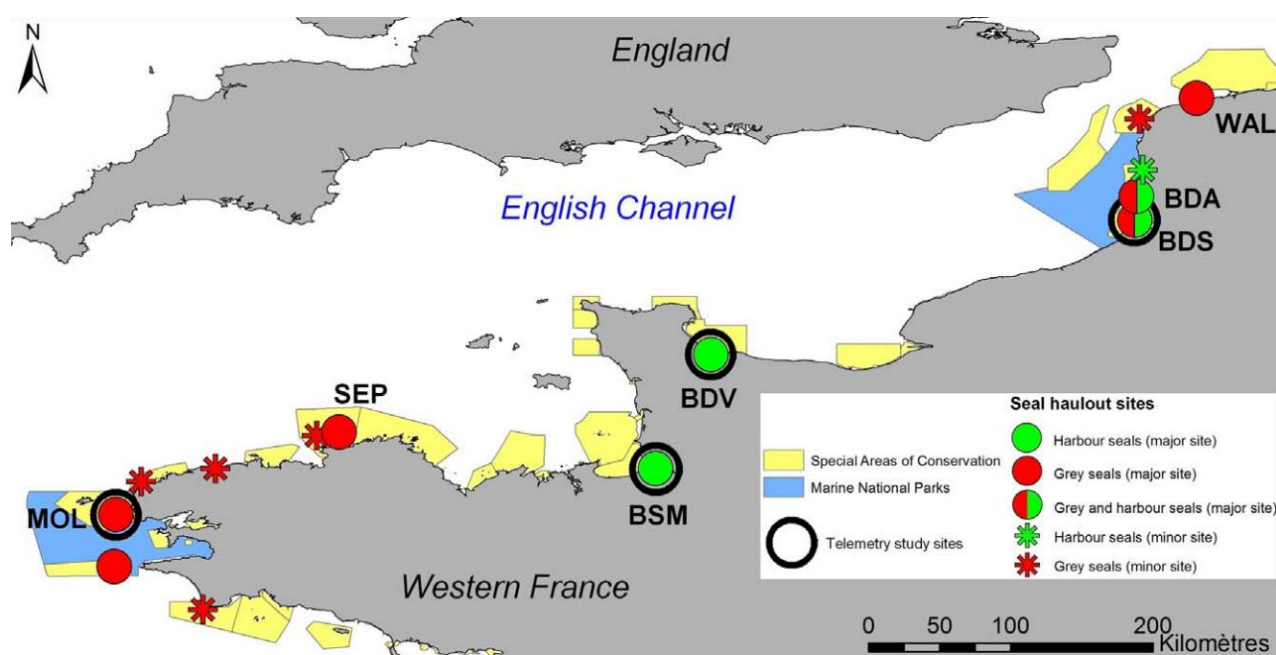
French seal data

- 2.4.35 Vincent *et al.* (2017) provide data on haul-outs and telemetry data for both harbour and grey seals along the French coast of the English Channel. Between 1999 and 2014 a total of 45 grey seals and 28 harbour seals were tagged and tracked for more than a month (**Table 2-6** and **Graphic 2-13**).
- 2.4.36 Measures were taken in order to avoid issues of over-estimation amongst coastal locations, created due to seals spending reduced amounts of time underwater at these locations, potentially transmitting GPS and Argos transmissions more frequently. The measures included that for each density map, only locations within a 20-minute interval were interpolated from the raw data. These maps were generated using the at-sea distribution of individuals, interpolated locations within 0.1 degree (°) grids which encompassed both the entire English Channel area and the southern Celtic Sea. All of these locations were weighted separately for grey and harbour seals by capture site. This took into account the abundance of days in which tracking data of seals was recorded for each study site. However, this did not involve the size of the haul-out sites which were estimated from on-shore count data.

Table 2-6 From Vincent *et al.* (2017): Number of seals tagged by species, sex, location and year, with deployment details (tag type and mean tracking duration).

Year of deployment	Species	Tag type	Number of tags	Sex ratio (M:F)	Mean tag lifespan (days)	Tagging locations	
						Full name	Code
1999	grey seals	SRDL	5	3:2	89	Molene archipelago	MOL
2002	grey seals	SRDL	8	6:2	119	Molene archipelago	MOL
2003	grey seals	SRDL	2	0:2	128	Molene archipelago	MOL
2006	harbour seals	GPS/GSM	4	2:2	68	Baie du Mont Saint-Michel	BSM
2007	harbour seals	GPS/GSM	2	1:1	148	Baie du Mont Saint-Michel	BSM
2007	harbour seals	GPS/GSM	7	4:3	142	Baie des Veys	BDV
2008	harbour seals	GPS/GSM	5	5:0	132	Baie des Veys	BDV
2008	harbour seals	GPS/GSM	10	9:1	134	Baie de Somme	BDS
2010	grey seals	GPS/GSM	2	2:0	57	Molene archipelago	MOL
2011	grey seals	GPS/GSM	8	6:2	182	Molene archipelago	MOL
2012	grey seals	GPS/GSM	2	2:0	184	Molene archipelago	MOL
2012	grey seals	GPS/GSM	11	11:0	161	Baie de Somme	BDS
2013	grey seals	GPS/GSM	7	6:1	196	Molene archipelago	MOL

Graphic 2-13 From Vincent *et al.* (2017): Map of all grey seal (red) and harbour seal (green) haul-out sites in metropolitan France.



Note: Circles indicate haul-out sites where the seasonal maximum number of seals exceeds 50 individuals. Stars indicate smaller haul-out sites used by fewer seals, not detailed in this study. Symbols surrounded by thick, black circles show the seal colonies where telemetry was conducted. Marine Protected Areas (MPAs) are also shown, including SACs and Marine National Parks. Nature Reserves are not visible but also encompass some haul-out sites, in Sept Iles archipelago (SEP), baie de Somme (BDS) and baie des Veys (BDV) for instance. Haul-out sites are: Molene archipelago (MOL), SEP, baie du Mont-Saint-Michel (BSM), BDV, BDS, baie d'Authie (BDA) and Walde (WAL).

3. Harbour porpoise baseline

3.1 Rampion 2

- 3.1.1 Harbour porpoises were the most commonly recorded marine mammal species during the Rampion 2 site-specific surveys (**Table 3-1**). Overall, these surveys only recorded very few harbour porpoise, with porpoise recorded in only six of the first 20 surveys. This resulted in a maximum density estimate of 0.02 porpoise per km² (/km²) within the survey area (Rampion 2 array area + 4km buffer) (**Table 3-1**), with no evidence of a spatial pattern in the distribution of sightings (**Graphic 3-1**).
- 3.1.2 These surveys also reported a number of sightings of unknown small cetaceans, speculated to be either dolphin or porpoise species, in six of the survey months. This resulted in a maximum dolphin/porpoise density estimate of 0.08 dolphin/porpoise/km² within the survey area (Rampion 2 array area + 4km buffer) (**Table 3-2**), with no evidence of a spatial pattern in the distribution of sightings (**Graphic 3-1**).

Table 3-1 Harbour porpoise sightings count and estimated abundance and density (Rampion 2 array area + 4km buffer)

Survey number	Date	Count	Abundance	Lower CI	Upper CI	Precision	Density
1	Apr-19	1	10	1	29	1.00	0.02
2	May-19	1	10	1	29	1.00	0.02
3	Jun-19	0	0	0	0	0.00	0.00
4	Jul-19	1	9	1	26	1.00	0.01
5	Aug-19	0	0	0	0	0.00	0.00
6	Sep-19	0	0	0	0	0.00	0.00
7	Oct-19	1	8	1	25	1.00	0.01
8	Nov-19	0	0	0	0	0.00	0.00
9	Dec-19	0	0	0	0	0.00	0.00
10	Jan-20	0	0	0	0	0.00	0.00
11	Feb-20	0	0	0	0	0.00	0.00
12	Mar-20	0	0	0	0	0.00	0.00
13	Apr-20	0	Not yet calculated				

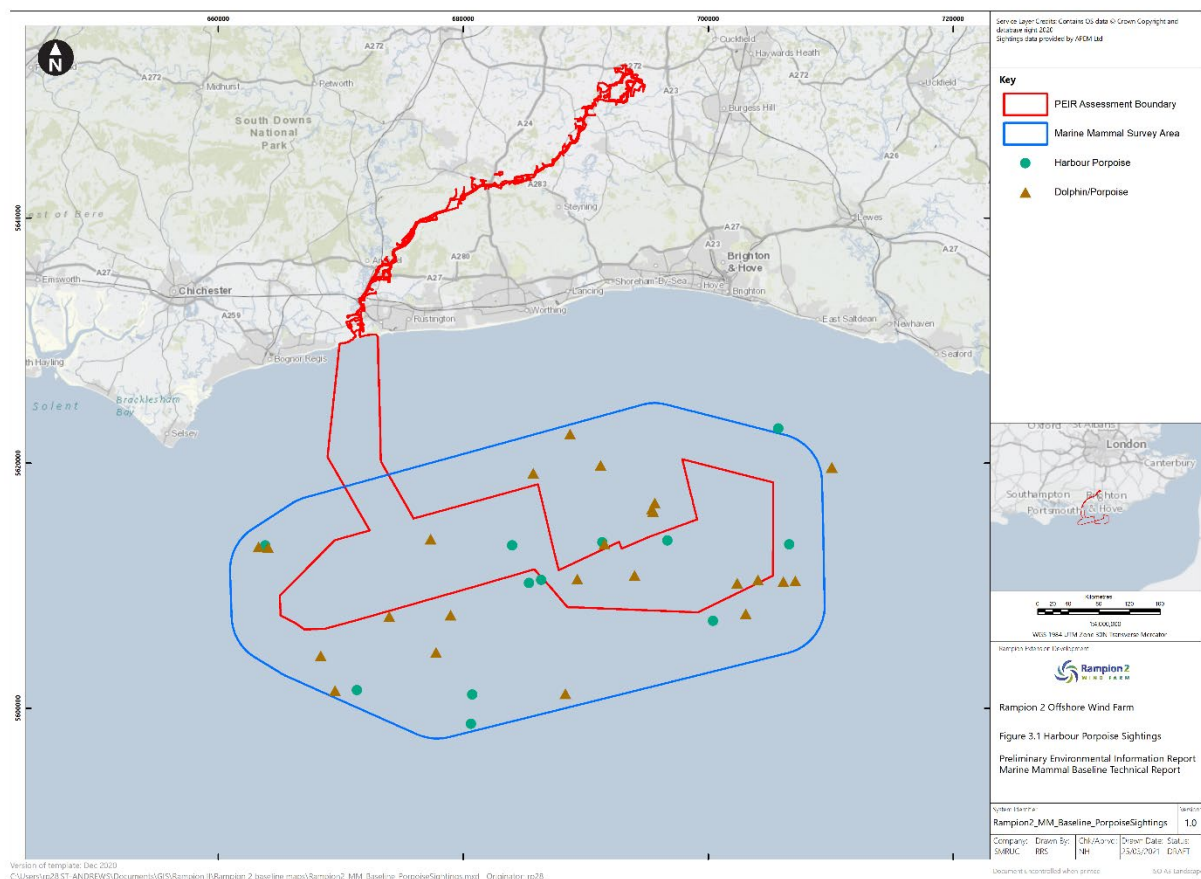
Survey number	Date	Count	Abundance	Lower CI	Upper CI	Precision	Density
14	May-20	0					
15	Jun-20	0					
16	Jul-20	0					
17	Aug-20	5					
18	Sep-20	1					
19	Oct-20	0					
20	Nov-20	0					

Table 3-2 Dolphin/porpoise sightings count and estimated abundance and density (Rampion 2 array area + 4km buffer)

Survey number	Date	Count	Abundance	Lower CI	Upper CI	Precision	Density
1	Apr-19	0	0	0	0	0.00	0.00
2	May-19	1	10	1	38	1.00	0.02
3	Jun-19	0	0	0	0	0.00	0.00
4	Jul-19	1	9	1	26	1.00	0.01
5	Aug-19	0	0	0	0	0.00	0.00
6	Sep-19	6	54	9	116	0.41	0.08
7	Oct-19	0	0	0	0	0.00	0.00
8	Nov-19	0	0	0	0	0.00	0.00
9	Dec-19	0	0	0	0	0.00	0.00
10	Jan-20	0	0	0	0	0.00	0.00
11	Feb-20	2	18	2	45	0.71	0.03
12	Mar-20	2	17	2	42	0.71	0.03
13	Apr-20	0	Not yet calculated				
14	May-20	0					
15	Jun-20	0					

Survey number	Date	Count	Abundance	Lower CI	Upper CI	Precision	Density
16	Jul-20	1					
17	Aug-20	0					
18	Sep-20	0					
19	Oct-20	1					
20	Nov-20	1					

Graphic 3-1 Sightings of harbour porpoise and dolphin/porpoise during the first 20 months of site-specific surveys at Rampion 2



3.2 Rampion 1

- 3.2.1 Surveys conducted as part of Rampion 1 surveys between 2010 and 2012 reported a total of 115 sightings for harbour porpoises within the survey area (**Table 3-3**). It is important to note for the results of these surveys, that when sightings are factored in at sea states of Beaufort scale 2 or less, only 43 sightings of harbour porpoises were recorded and included in subsequent analyses. Peak

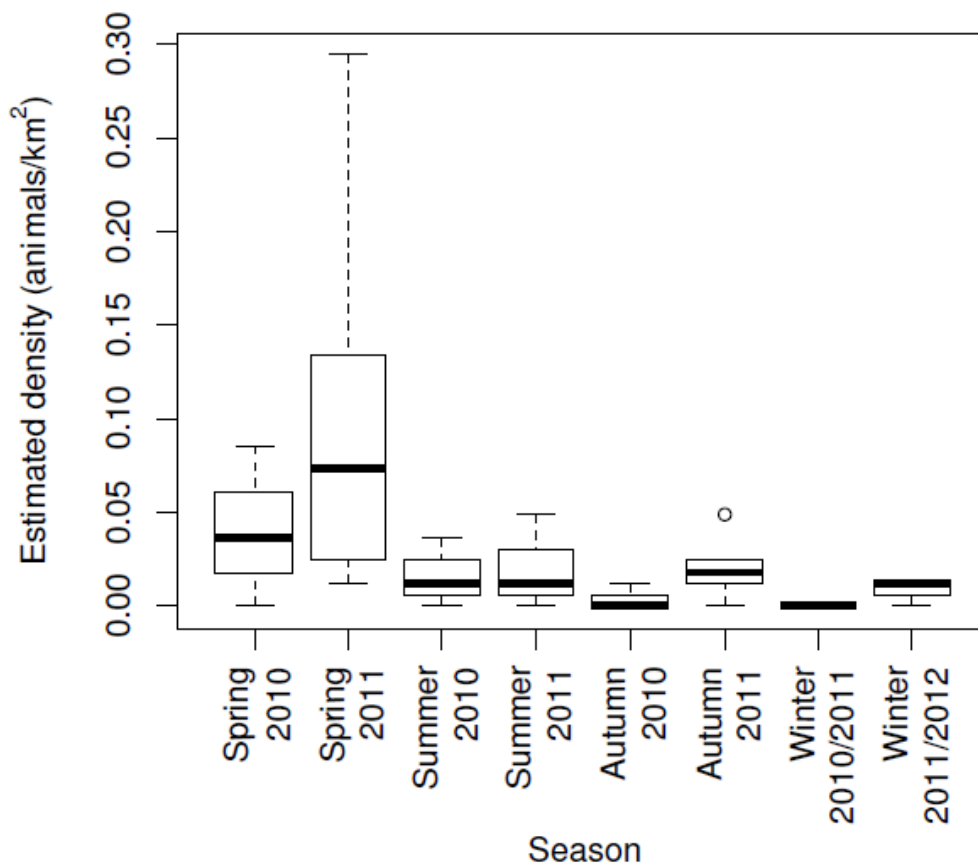
counts of harbour porpoises were reported in March 2011 which resulted in an estimated density of 0.073 porpoise/km² (**Graphic 3-1**), compared to estimates of 0.036 porpoise/km² reported from March 2010 in which only one survey was conducted. The survey report concluded that it is highly likely that the March 2011 counts were the result of increased survey effort. The increased harbour porpoise sightings coincided with changes in the environmental conditions in the English Channel, in the form of an early spring phytoplankton bloom. This early bloom was the result of increased stormy weather in the area which caused nutrients in the water column to surface at an increased rate as a result of mixing, this was immediately followed by calm water conditions which facilitated a peak in phytoplankton reproduction rates in the area.

Table 3-3 Harbour porpoise count during the Rampion 1 surveys.

	J	F	M	A	M	J	J	A	S	O	N	D
2010			6	13	1	2	5	0	0	1	0	0
2011	0	0	2 (34)	9 (9)	7 (1)	1	1	4	6 (5)	1 (1)	2 (0)	2
2012	0	2										

Note: Dark grey cell denotes no survey conducted. Numbers on brackets denote sightings count during the second survey conducted that month.

Graphic 3-2 Approximate relative density of harbour porpoises in the Project site survey area with correction factor

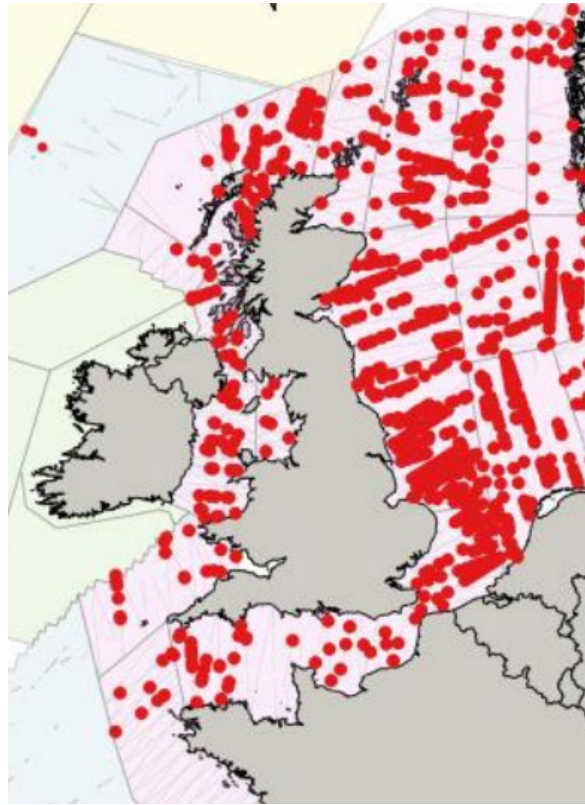


Note: Median values are shown as a thick line, minimum and maximum data values as whiskers, interquartile range as boxes, and outliers as dots.

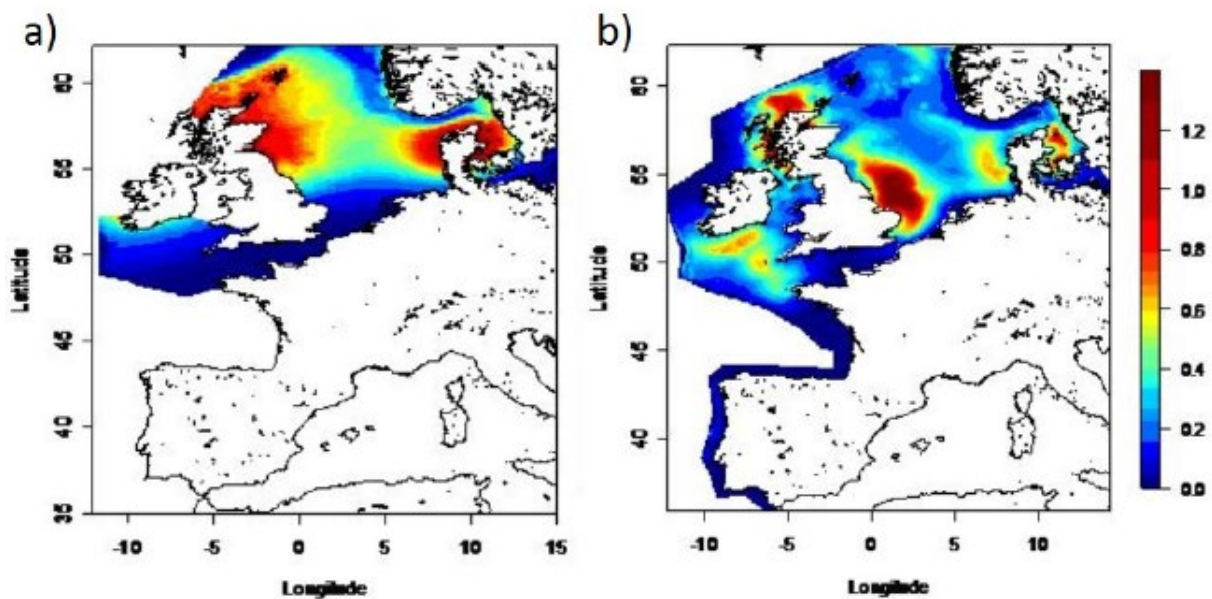
3.3 SCANS III

- 3.3.1 Harbour porpoise were detected in SCANS III survey block C (**Graphic 3-3**), resulting in a block-wide abundance estimate of 17,323 porpoise (95 percent CI: 8,853 to 29,970, coefficient of variation (CV): 0.30) with a density of 0.213 porpoise/km². The SCANS surveys have shown a southern shift in the distribution of harbour porpoise within the North Sea between SCANS I in 1994 and SCANS II in 2005 (**Graphic 3-4**), and more sightings of harbour porpoise occurred in the English Channel in 2016 compared to 2005. However, densities within the English Channel and in the vicinity of Rampion 2 are low in comparison to the rest of the southern North Sea where densities can reach 0.888 porpoise/km² (SCANS III block O).

Graphic 3-3 From Hammond *et al.* (2017): Distribution of harbour porpoise sightings during the SCANS III surveys



Graphic 3-4 From Hammond *et al.* (2017): Harbour porpoise density estimates a) modelled density surface for SCANS-I 1994 data, b) modelled density surface for SCANS-II 2005 data



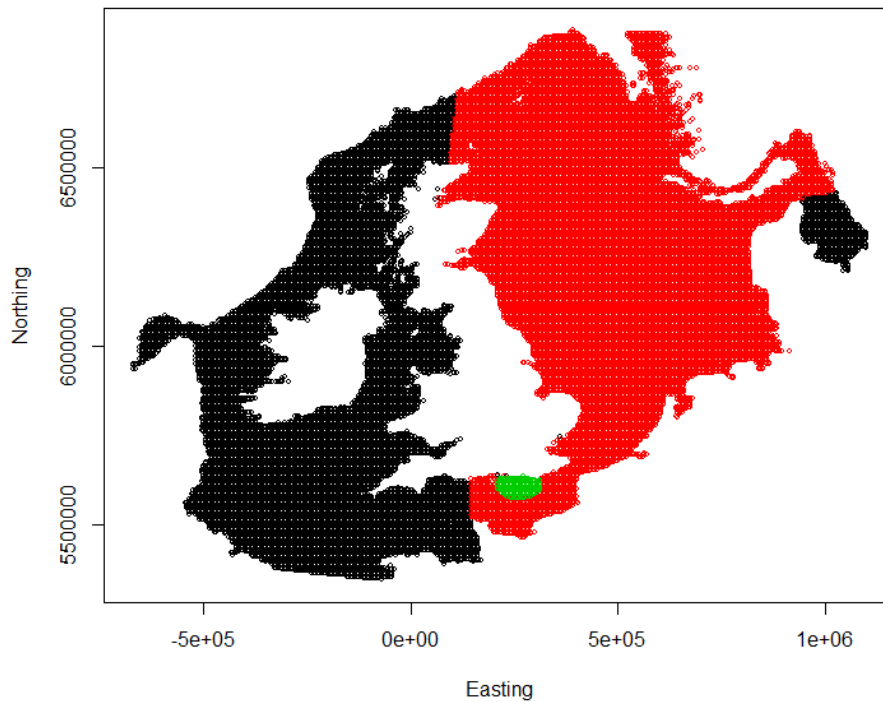
3.4 JCP

- 3.4.1 Density estimates provided for Hastings (region to the south of Sussex in which Rampion 2 is located) and Isle of Wight (region to the west of the Isle of Wight) showed that harbour porpoise density was higher in the winter months and reached an estimated maximum of 0.202 porpoise/km² (in 2010) (**Table 3-4**) (Paxton *et al.*, 2016).
- 3.4.2 Utilising the JCP data analysis tool for the user specified area (**Graphic 3-5**), harbour porpoises had a density point estimate of approximately 0.142 porpoise/km² averaged for summer 2007 to 2010 (95 percent CI 0.071 to 0.213 porpoise/km²), which is not dissimilar to that estimated for the summer months in Hastings and Isle of Wight.
- 3.4.3 The analysis conducted by Heinänen and Skov (2015) showed that harbour porpoise density estimates in UK waters vary year to year and between summer and winter (**Graphic 3-6**). There are high density estimates throughout parts of the North Sea in both summer and winter (>2 porpoise/km², which led to the designation of the southern North Sea SAC), however the density estimates in the English Channel and in the vicinity of Rampion 2 are significantly lower year round and across all years, with estimated densities of only 0.01 to 0.1 porpoise/km².
- 3.4.4 All analysis of the JCP dataset have shown that density estimates in the English Channel and in the vicinity of Rampion 2 are low in comparison to other areas such as the southern North Sea, and as such, is not considered to be an important area for this species.

Table 3-4 JCP Phase III abundance and density estimates for harbour porpoise in 2010 (Paxton *et al.*, 2016)

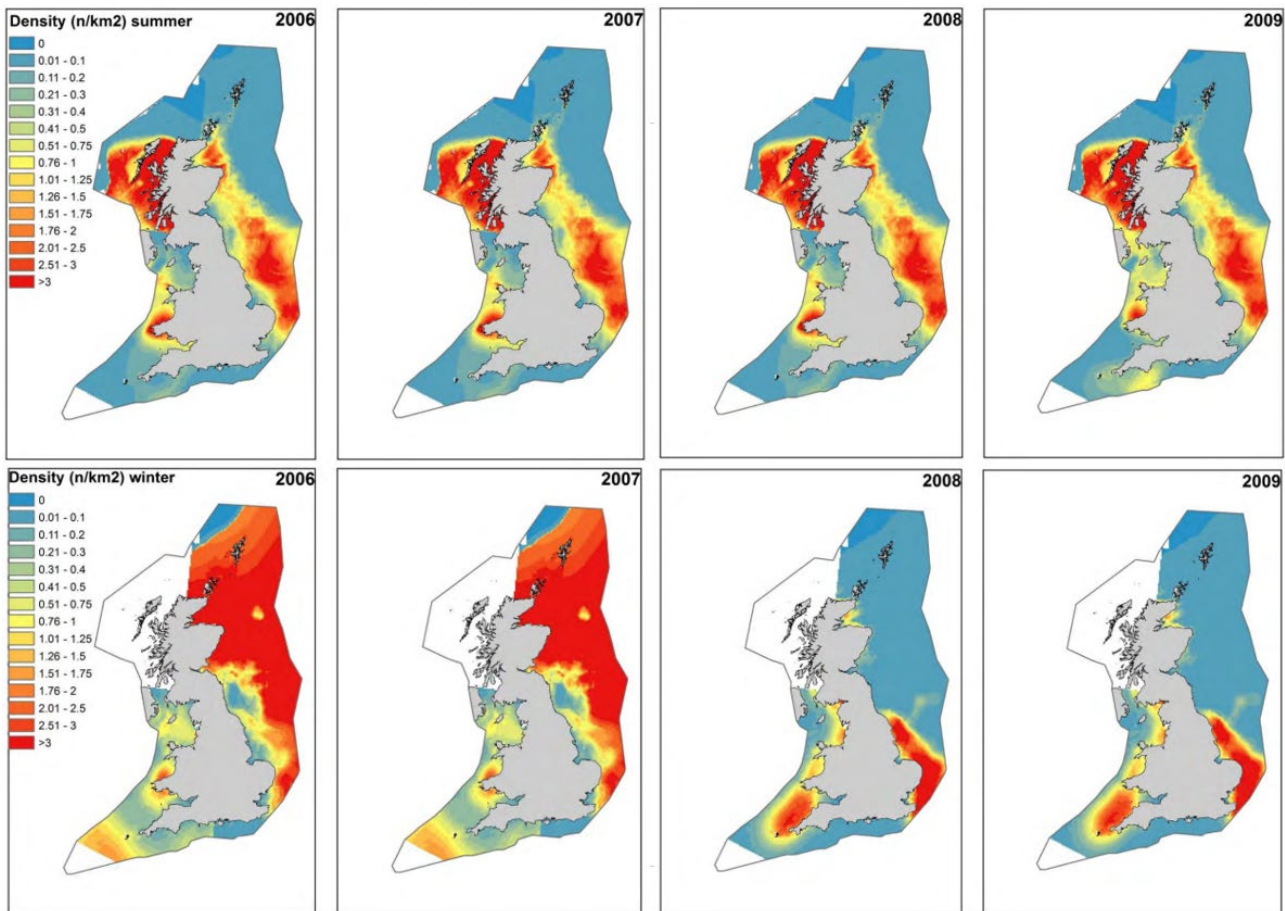
		Winter	Spring	Summer	Autumn
Hastings	Abundance point estimate	300	200	200	200
	Density Estimate (#/km ²)	0.121	0.080	0.080	0.080
Isle of Wight	Abundance point estimate	900	600	800	600
	Density Estimate (#/km ²)	0.202	0.135	0.179	0.135

Graphic 3-5 The user specified area used to extract cetacean abundance and density estimates from the JCP III Data Analysis Product



Note: The map shows the whole area under consideration (black), the harbour porpoise North Sea MU (red) and the specific area of interest (green).

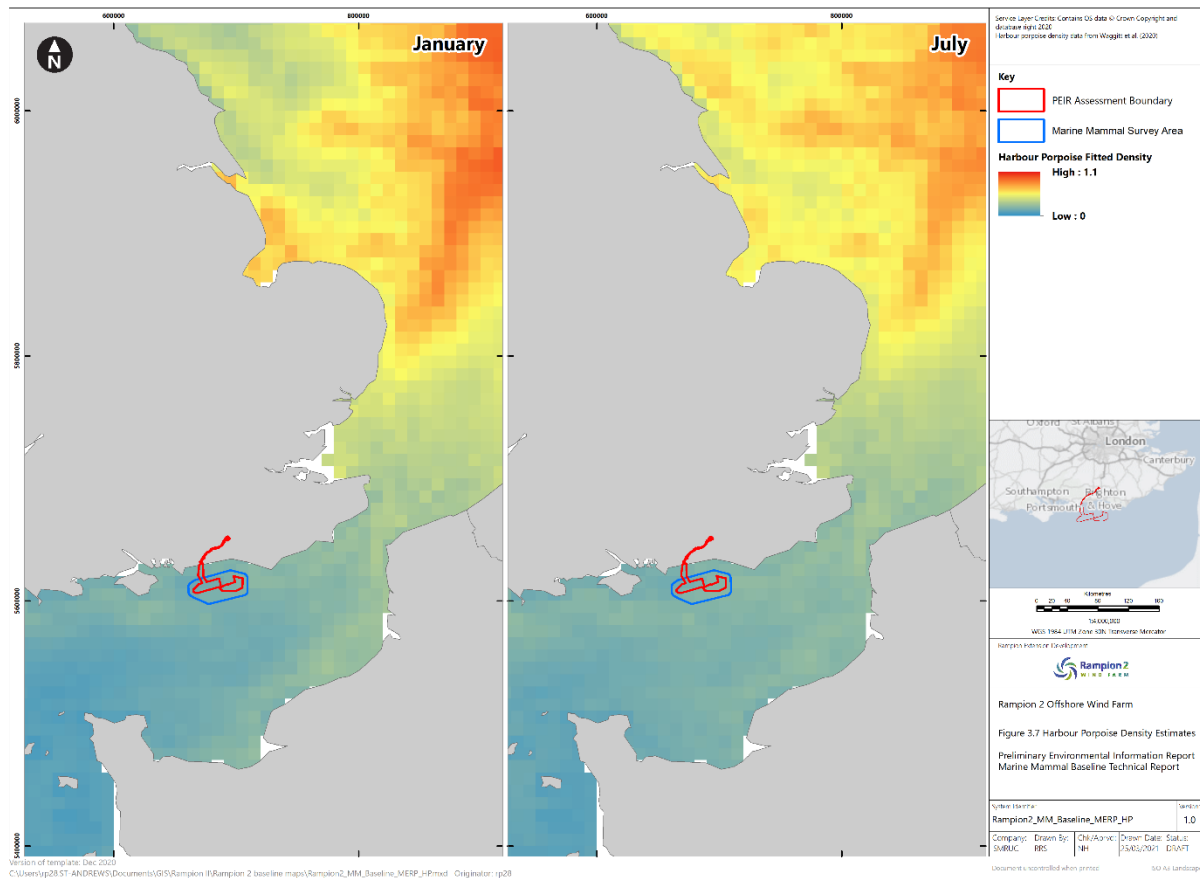
Graphic 3-6 From Heinänen and Skov (2015): Harbour porpoise predicted mean density estimates summer (top) and winter (bottom) 2006 to 2009



3.5 MERP

- 3.5.1 As with the SCANS III and JCP datasets, the MERP analysis of porpoise distribution shows considerably lower density estimates in the English Channel and in the vicinity of Rampion 2 compared to the southern North Sea SAC area. Density estimates within the Rampion 2 survey area showed little seasonal variation between January and July (**Graphic 3-7**). As outlined previously, the distribution maps are not considered to provide suitable density estimates for use in quantitative impact assessment and are provided in this baseline characterisation for illustrative purposes only to distribution levels relative to the rest of the southern North Sea and the English Channel.

Graphic 3-7 Harbour porpoise fitted density (#/km²) for January and July (Waggitt *et al.*, 2020)



3.6 Sea Watch Foundation

- 3.6.1 Castles (2020) used 29 harbour porpoise sightings from the Sea Watch Foundation data around the Isle of Wight to investigate spatio-temporal trends. Sightings were higher in the southeast of the Isle of Wight with significantly more sightings in the summer. No density estimate was provided for this dataset.

3.7 ORCA

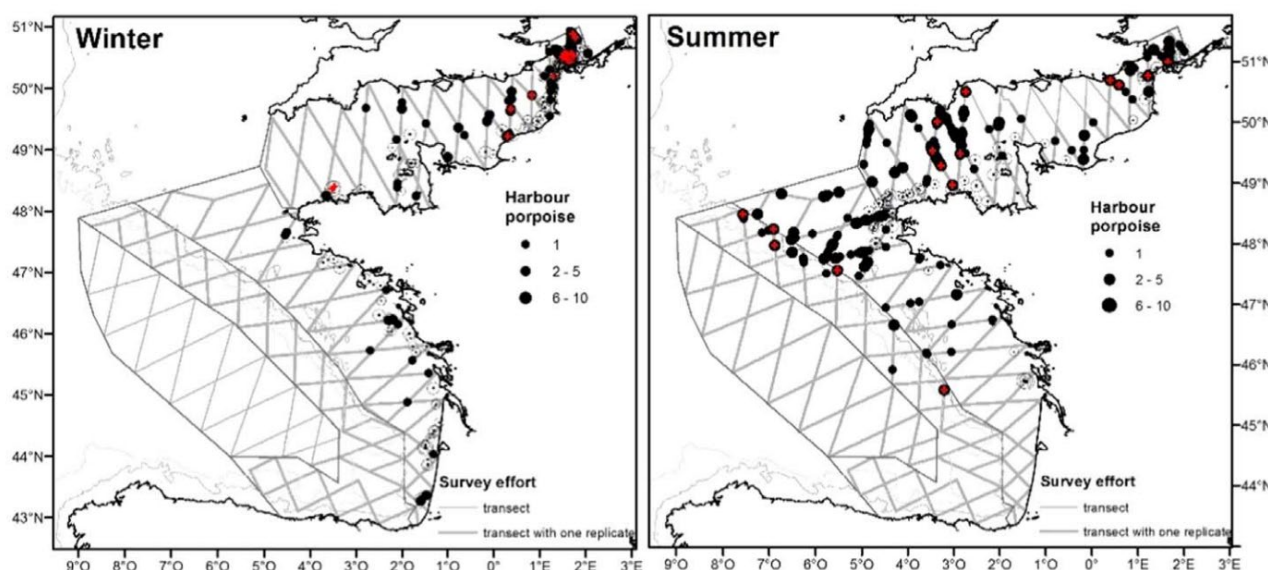
- 3.7.1 Harbour porpoise was the main species sighted during the surveys conducted on the Portsmouth to Caen ferry route (**Graphic 2-8**). No density estimate was provided for this dataset.

3.8 SAMM surveys

- 3.8.1 A total of 551 sightings of harbour porpoise occurred in the Eastern North Atlantic during the SAMM surveys (**Graphic 3-8**). Harbour porpoises exhibited seasonal distributions, showing preference for coastal waters in the winter. In the summer months, harbour porpoise were sighted in both the coastal waters and waters further offshore. Despite the reported changes in harbour porpoise spatial

distributions in the English Channel, there was no reported seasonal change in their abundance within the English Channel, with a winter density estimate (corrected for availability bias) of 0.192 porpoise/km² compared to a summer density of 0.198 porpoise/km². This resulted in an adjusted abundance estimate for the English Channel of 17,829 porpoise in the winter (95 percent CI: 11,340 to 28,031) and 18,429 porpoise in the summer (95 percent CI: 13,496 to 25,167) (Laran *et al.*, 2017).

Graphic 3-8 From Laran *et al.* (2017): Distribution of sightings and effort for winter and summer surveys for harbour porpoise (with red dot for calf/young occurrence)



3.9 Summary

3.9.1 In conclusion, harbour porpoise are expected to be present in the English Channel and in the vicinity of Rampion 2 year round, though with relatively low densities compared to areas such as the Southern North Sea. The Rampion 2 and surrounding area is reported to have estimated densities ranging between 0 to 0.213 porpoises/km² (**Table 3-5**). Given the range of density estimates available, it is considered precautionary to take forward the SCANS III density estimate for use in the quantitative impact assessment for Rampion 2.

Table 3-5 Harbour porpoise density estimates

Data source	Density Estimate (porpoise/km ²)
Rampion 2	0.00 to 0.02 (porpoise) 0.00 to 0.08 (dolphin/porpoise)
Rampion 1	0.000 to 0.073
SCANS III Block C	0.213
JCP Phase III Hastings	0.080 (spring, summer and autumn)

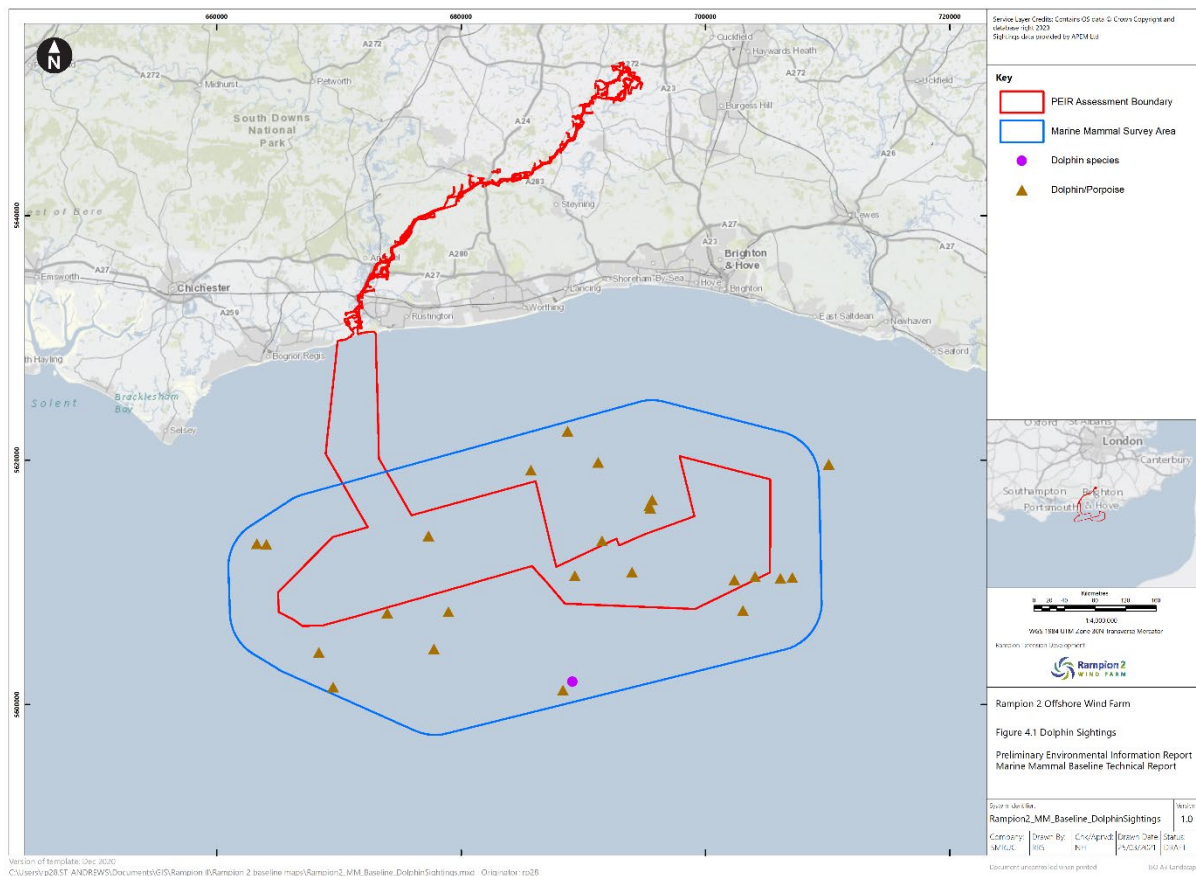
Data source	Density Estimate (porpoise/km ²)
	0.121 (winter)
JCP Phase III Isle of Wight	0.135 (spring & autumn) 0.179 (summer) 0.202 (winter)
JCP III Data Analysis Product	0.142
SAMM survey (English Channel)	0.086 (winter) 0.089 (summer)

4. Bottlenose dolphin baseline

4.1 Rampion 2

- 4.1.1 No bottlenose dolphins have been sighted during the first 20 months of the Rampion 2 aerial surveys. There were, however, a sighting of an unknown dolphin and some sightings of unknown small cetaceans which could have been either a dolphin species or a porpoise (**Graphic 4-1**). If it is assumed that the unknown dolphin/porpoise were bottlenose dolphins then maximum density estimate is 0.08 dolphins/km² (**Table 3-2**).

Graphic 4-1 Sightings of unidentified dolphins and dolphin/porpoise during the first 20 months of site-specific surveys at Rampion 2



4.2 Rampion 1

- 4.2.1 The surveys conducted for Rampion 1 reported several sightings of bottlenose dolphins, and found that when they were sighted, bottlenose dolphins were often in large groups. Encounters with bottlenose dolphins during surveys occurred at various times throughout the year, with peak counts of dolphins reported in July 2010 (**Table 4-1**). Some sightings had uncertainty for the species identification of the animal and were listed as 'probable bottlenose dolphin'. In

total, the surveys reported a count of 65 to 71+ bottlenose dolphins and 15 to 22 probable bottlenose dolphins. No density estimate was calculated from these data, but the data do confirm the presence of bottlenose dolphins in the area, occasionally in large groups.

Table 4-1 Bottlenose dolphin count during the Rampion 1 surveys.

	J	F	M	A	M	J	J	A	S	O	N	D
Bottlenose dolphin												
2010			0	0	0	0	30+	0	0	0	17 to 18	0
2011	0	1	0 (0)	0 (0)	0 (0)	0	15 to 20	2	0 (0)	0 (0)	0 (0)	0
2012	0	0										
Probable bottlenose dolphin												
2010			0	4 to 5	4 to 5	0	0	0	0	0	5 to 10	0
2011	0	0	0 (0)	0 (0)	0 (0)	0	0	2	0 (0)	0 (0)	0 (0)	0
2012	0	0										

Note: Dark grey cell denotes no survey conducted. Numbers on brackets denote sightings count during the second survey conducted that month.

4.3 SCANS III

- 4.3.1 No bottlenose dolphins were sighted in SCANS III survey block C, within which Rampion 2 is located.

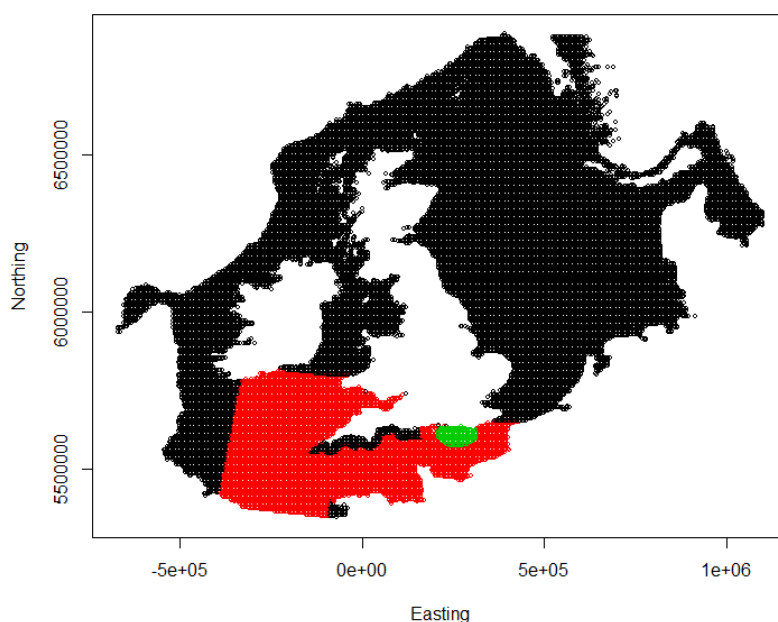
4.4 JCP

- 4.4.1 Density estimates provided for Hastings (region to the south of Sussex in which Rampion 2 is located) and Isle of Wight (region to the west of the Isle of Wight) showed that bottlenose dolphin density was higher in the summer months and reached an estimated maximum of 0.011 dolphins/km² (in 2010) (**Table 4-2**) (Paxton *et al.*, 2016). Utilising the JCP data analysis tool for the user specified area, bottlenose dolphins in the Rampion 2 area were reported to have a density point estimate of approximately 0.002 dolphins/km² (95 percent CI: 0.001 to 0.003 dolphins/km²).

Table 4-2 JCP Phase III abundance and density estimates for bottlenose dolphins in 2010
 Table 4-3 JCP Phase III abundance and density estimates for bottlenose dolphins in -2010

		Winter	Spring	Summer	Autumn
Hastings	Abundance point estimate	0	0	10	2
	Density Estimate (#/km ²)	0.000	0.000	0.004	0.001
Isle of Wight	Abundance point estimate	30	40	50	20
	Density Estimate (#/km ²)	0.007	0.009	0.011	0.004

Graphic 4-2 The user specified area used to extract cetacean abundance and density estimates from the JCP III Data Analysis Product

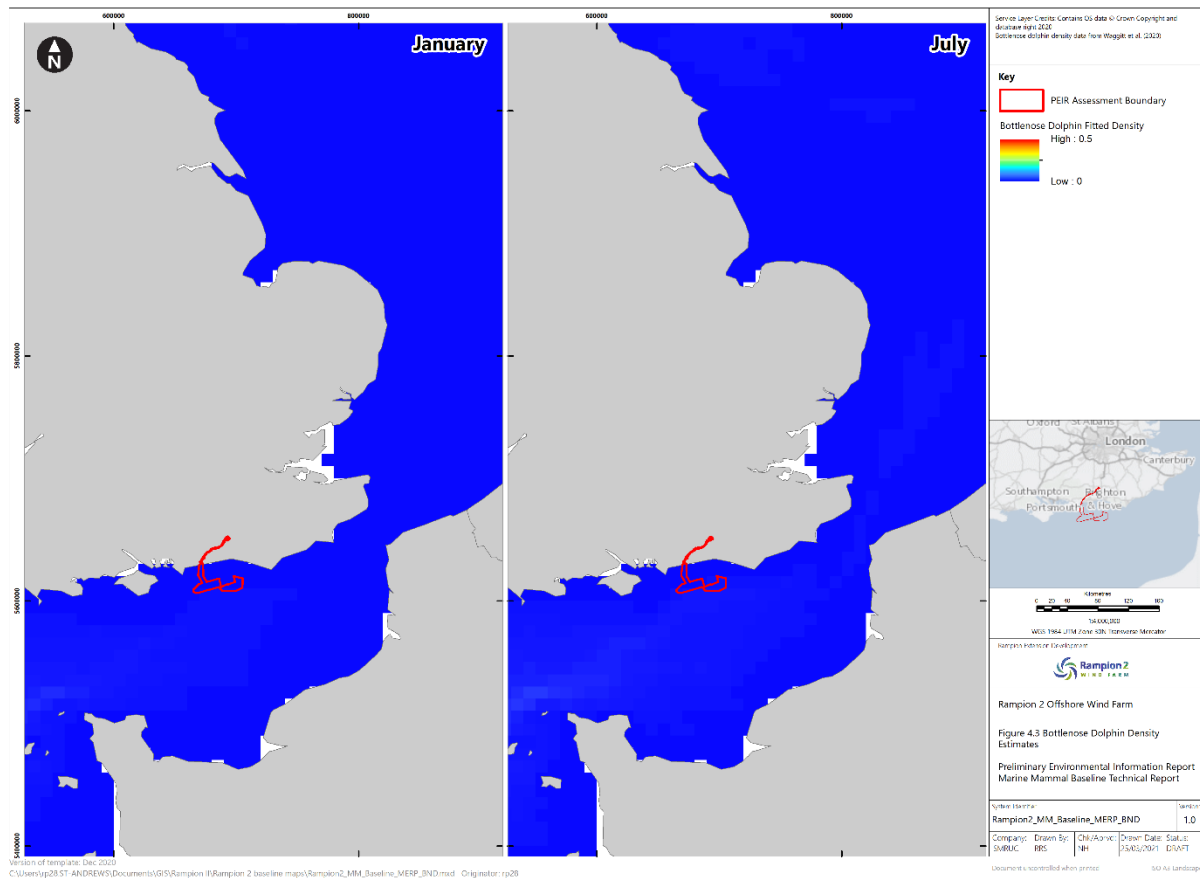


Note: The map shows the whole area under consideration (black), the bottlenose dolphin MU (red) and the specific area of interest (green).

4.5 MERP

4.5.1 As with the SCANS III and JCP datasets, the MERP analysis of bottlenose distribution shows very low density estimates in the English Channel and in the vicinity of Rampion 2, with no evidence of seasonal variation (**Graphic 4-3**). As outlined previously, the distribution maps are not considered to provide suitable density estimates for use in quantitative impact assessment and are provided in this baseline characterisation for illustrative purposes only to distribution levels relative to the rest of the southern North Sea and the English Channel.

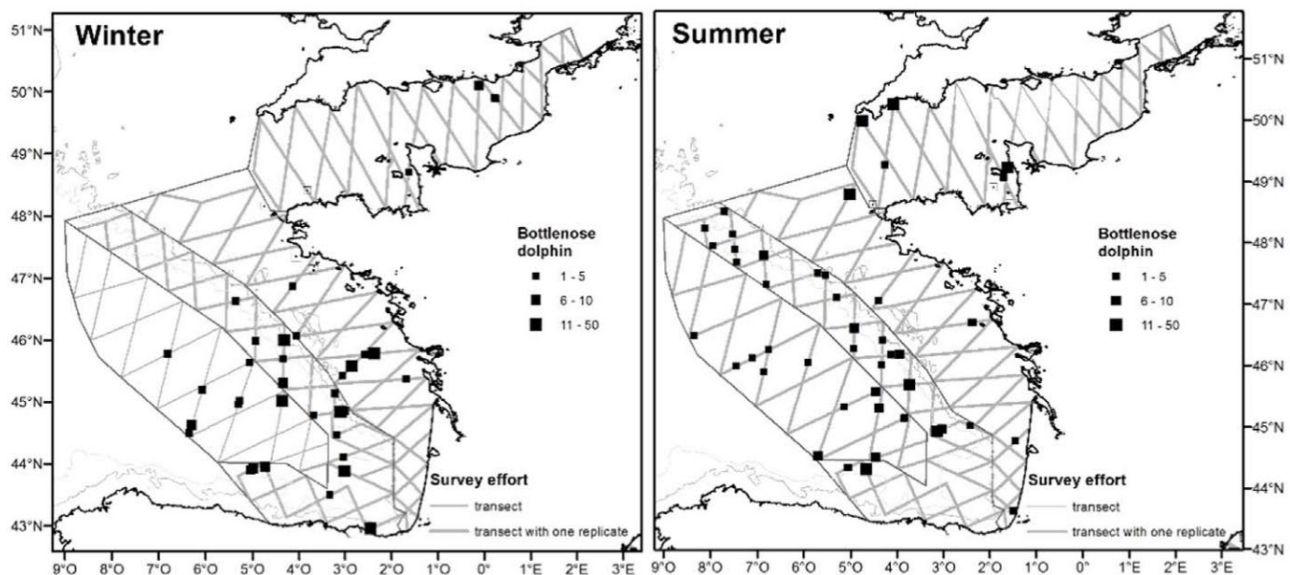
Graphic 4-3 Bottlenose dolphin (offshore ecotype) fitted density (#/km²) for January and July (Waggitt *et al.*, 2020)



4.6 SAMM surveys

- 4.6.1 In total there were 111 sightings of bottlenose dolphins in the Eastern North Atlantic during the SAMM surveys. While most of these sightings were within the Bay of Biscay area, there were sightings of bottlenose dolphins in the English Channel and the Rampion 2 area in the winter surveys (**Graphic 4-4**). Bottlenose dolphin mean school size varied across a range of 2.6 to 6.2 individuals. While estimated densities (corrected for availability bias) within the English Channel varied between 0.010 dolphins/km² in the winter, and 0.037 dolphins/km² in the summer, there was found to be no significant seasonal difference in bottlenose dolphin densities across the Eastern-North Atlantic survey area as a whole. Corrected abundances of individuals within the English Channel were 915 dolphins (95 percent CI: 323 to 2,589) in the winter and 3,544 dolphins (95 percent CI: 1,121 to 11,202) in the summer (Laran *et al.*, 2017).

Graphic 4-4 From Laran *et al.* (2017): Distribution of sightings and effort for winter and summer surveys for bottlenose dolphins



4.7 Sea Watch Foundation

- 4.7.1 Castles (2020) used 61 bottlenose dolphin sightings from the Sea Watch Foundation data around the Isle of Wight to investigate spatio-temporal trends. Most of the bottlenose dolphin sightings occurred in the northeast area of the Isle of Wight with significantly more sightings in the summer. No density estimate was calculated for this dataset.

4.8 ORCA

- 4.8.1 The ORCA surveys have reported bottlenose dolphin sightings along the Portsmouth-Caen ferry route (**Graphic 2-8** and **Table 2-5**). No density estimate was calculated for this dataset.

4.9 Summary

- 4.9.1 The population of bottlenose dolphins in the Offshore Channel and SW England MU is not well studied in comparison to other UK MUs such as the Coastal East Scotland MU and the Irish Sea MU, which has resulted in wide confidence intervals for abundance estimates for this population. For example the IAMMWG (2015b) abundance estimate for the Offshore Channel and SW England MU has confidence intervals of 1,638 to 14,398. In addition, there are few studies in the English Channel that have provided reliable density estimates. The data that are available from the JCP database and the SAMM surveys indicate that densities are higher in the English Channel in the summer months, with densities of up to 0.037 dolphins/km². Since there is a large degree of uncertainty associated with the bottlenose dolphin abundance and density estimates for this area (**Table 4-3**), it is precautionary to take forward the highest density estimate (0.037 dolphins/km²) for use in the quantitative impact assessment for Rampion 2.

Table 4-4 Bottlenose dolphin density estimates

Data source	Density Estimate (dolphins/km ²)
Rampion 2	None
Rampion 1	Not estimated
SCANS III Block C	None
JCP Phase III Hastings	0.000 (winter & spring) 0.001 (autumn) 0.004 (summer)
JCP Phase III Isle of Wight	0.004 (autumn) 0.007 (winter) 0.009 (spring) 0.011 (summer)
MERP density map	0.000 to 0.004 (Jan) 0.001 to 0.008 (Jun)
SAMM survey (English Channel)	0.010 (winter) 0.037 (summer)

5. White-beaked dolphin baseline

5.1 Rampion 2

- 5.1.1 No white-beaked dolphins were sighted during the first 20 months of the Rampion 2 aerial surveys.

5.2 Rampion 1

- 5.2.1 During the 30 surveys, only a single white-beaked dolphin was seen on one occasion at the site in November 2011.

5.3 SCANS III

- 5.3.1 No white-beaked dolphins were sighted in SCANS III survey block C.

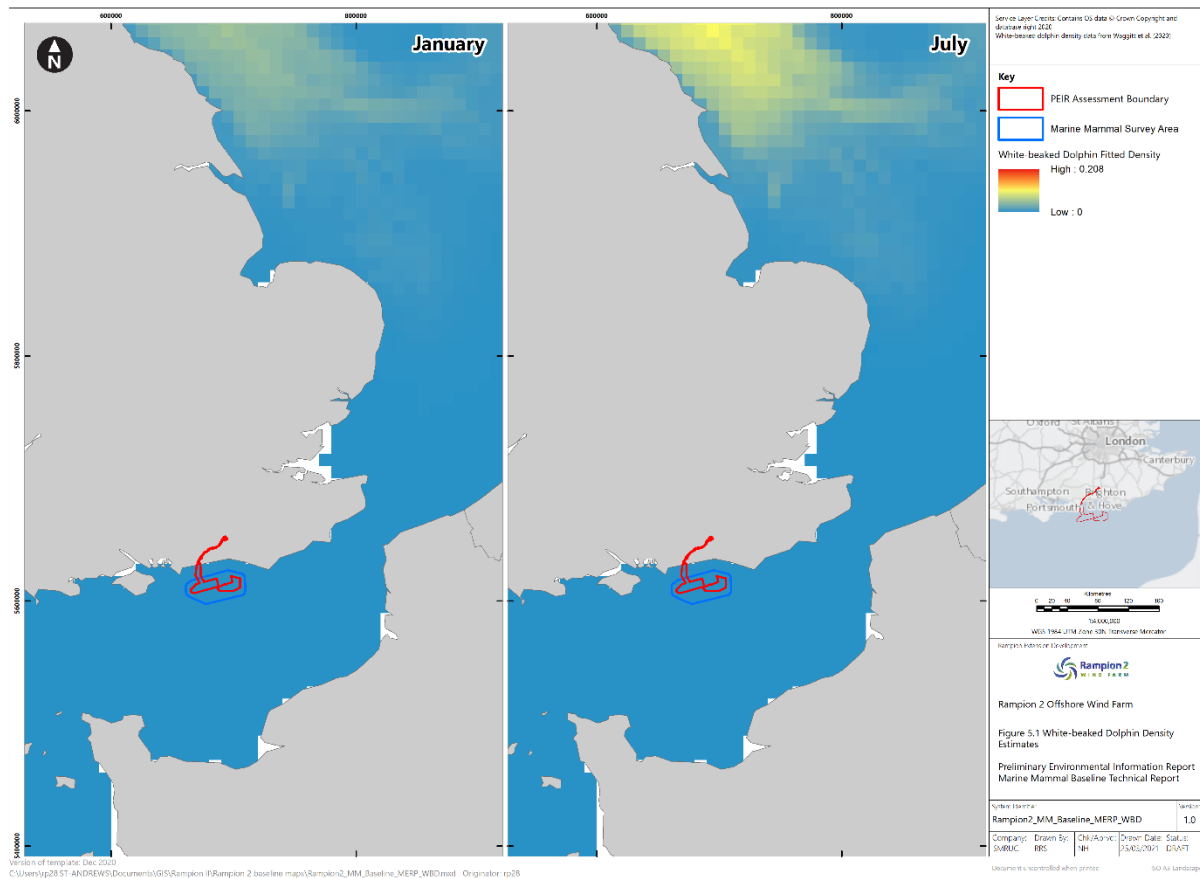
5.4 JCP

- 5.4.1 No white-beaked dolphins were predicted to be in the Hastings of Isle of Wight areas of interest for offshore development in the JCP Phase III analysis.
- 5.4.2 No white-beaked dolphins were estimated to be within the user specified area using the JCP Phase III Data Analysis Product.

5.5 MERP

- 5.5.1 The MERP density surfaces for white-beaked dolphins also highlight the lack of data on this species in the English Channel. Density estimates were very low year round in the Rampion 2 area (**Graphic 5-1**). As outlined previously, the distribution maps are not considered to provide suitable density estimates for use in quantitative impact assessment and are provided in this baseline characterisation for illustrative purposes only to distribution levels relative to the rest of the southern North Sea and the English Channel.

Graphic 5-1 White-beaked dolphin (offshore ecotype) fitted density ($\#/km^2$) for January and July (Waggitt *et al.*, 2020)



5.6 Sea Watch Foundation

- 5.6.1 Between March 2018 and August 2020 (inclusive) a total of nine individual white-beaked dolphins (over two encounters) have been reported by the Sea Watch Foundation for the Southern England Area. No density estimate was provided for this dataset.

5.7 ORCA

- 5.7.1 No white-beaked dolphins were included in the ORCA sightings map or recent survey reports for the Portsmouth to Caen ferry route (2011, 2015, 2016, 2018, 2019 and 2020). No density estimate was provided for this dataset.

5.8 Summary

- 5.8.1 Given the lack of white-beaked dolphin sightings in the area from the survey sources (Rampion 2 surveys, SCANS III, JCP data and SAMMS surveys) it is concluded that **white-beaked dolphins can be scoped out of assessment for Rampion 2.**

6. Common dolphin baseline

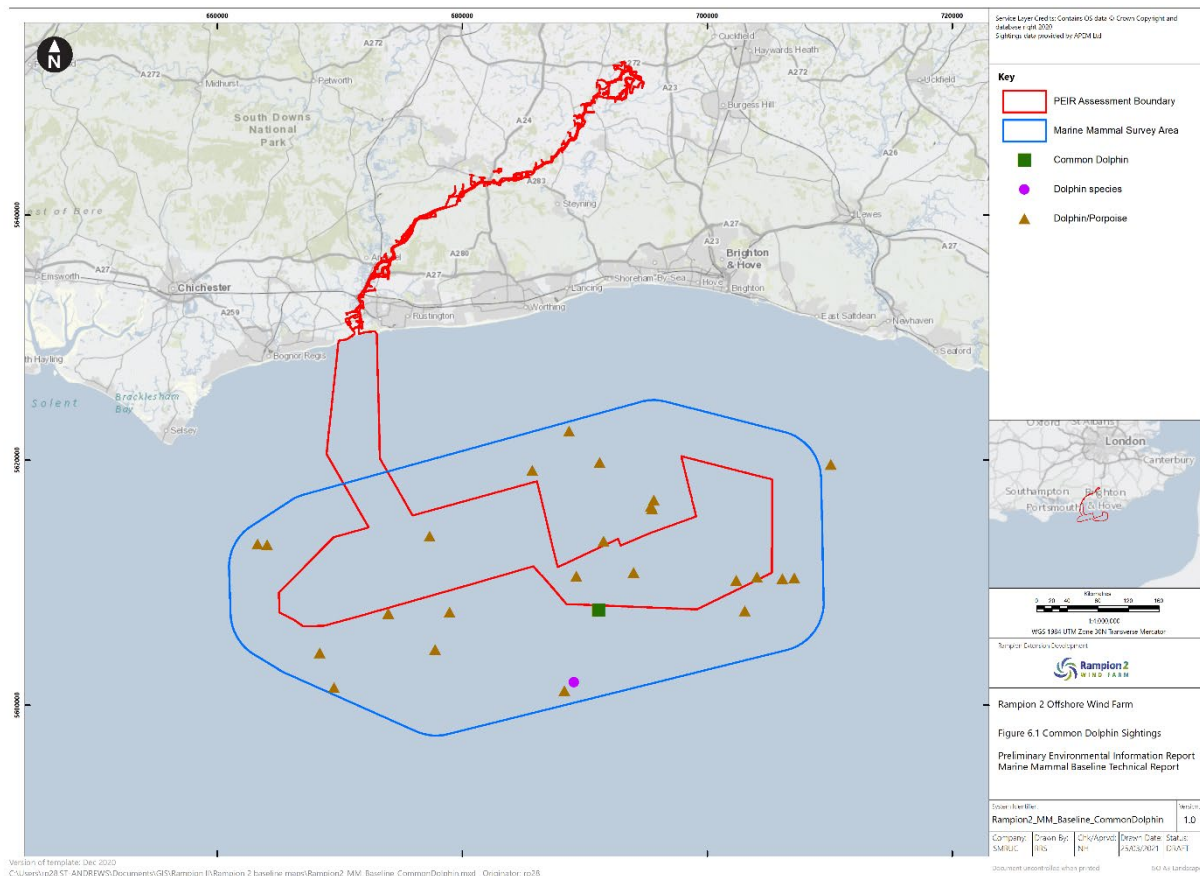
6.1 Rampion 2

- 6.1.1 Only one common dolphin was sighted during the first 20 months of Rampion 2 aerial surveys (**Graphic 6-1**). This was a sighting of a single individual in October 2019, resulting in a density estimate that month of 0.01 dolphins/km² (**Table 6-1**). In addition, there were some sightings of unknown small cetaceans which could have been either a dolphin species or a porpoise.

Table 6-1 Common dolphin sightings count and estimated abundance and density (Rampion 2 array area + 4km buffer)

Survey number	Date	Count	Abundance	Lower CI	Upper CI	Precision	Density
1-6	Apr-19 to Sep-10	0	0	0	0	0.00	0.00
7	Oct-19	1	8	1	25	1.00	0.01
8-20	Nov-19 to Dec-20	0	0	0	0	0.00	0.00

Graphic 6-1 Sightings of common dolphins, unidentified dolphins and dolphin/porpoise during the first 20 months of site-specific surveys at Rampion 2



6.2 Rampion 1

6.2.1 No common dolphins were sighted during the Rampion 1 surveys.

6.3 SCANS III

6.3.1 No common dolphins were sighted in SCANS III survey block C. However unidentified common or striped dolphins were detected in block C, resulting in a block wide abundance estimate of 1,765 common/striped dolphins (95 percent CI: 0 to 5,494, CV: 0.85) and a density of 0.022 common/striped dolphins/km².

6.4 JCP

6.4.1 No common dolphins were estimated to be present in the Hastings area (region to the south of Sussex in which Rampion 2 is located) (**Table 6-2**) (Paxton *et al.*, 2016). In the Isle of Wight area (region to the west of the Isle of Wight) common dolphin density was low, with maximum density estimates of only 0.004 dolphins/km² (in 2010) (**Table 6-2**) (Paxton *et al.*, 2016). No common dolphins were estimated to be within the user specified area using the JCP Phase III Data Analysis Product.

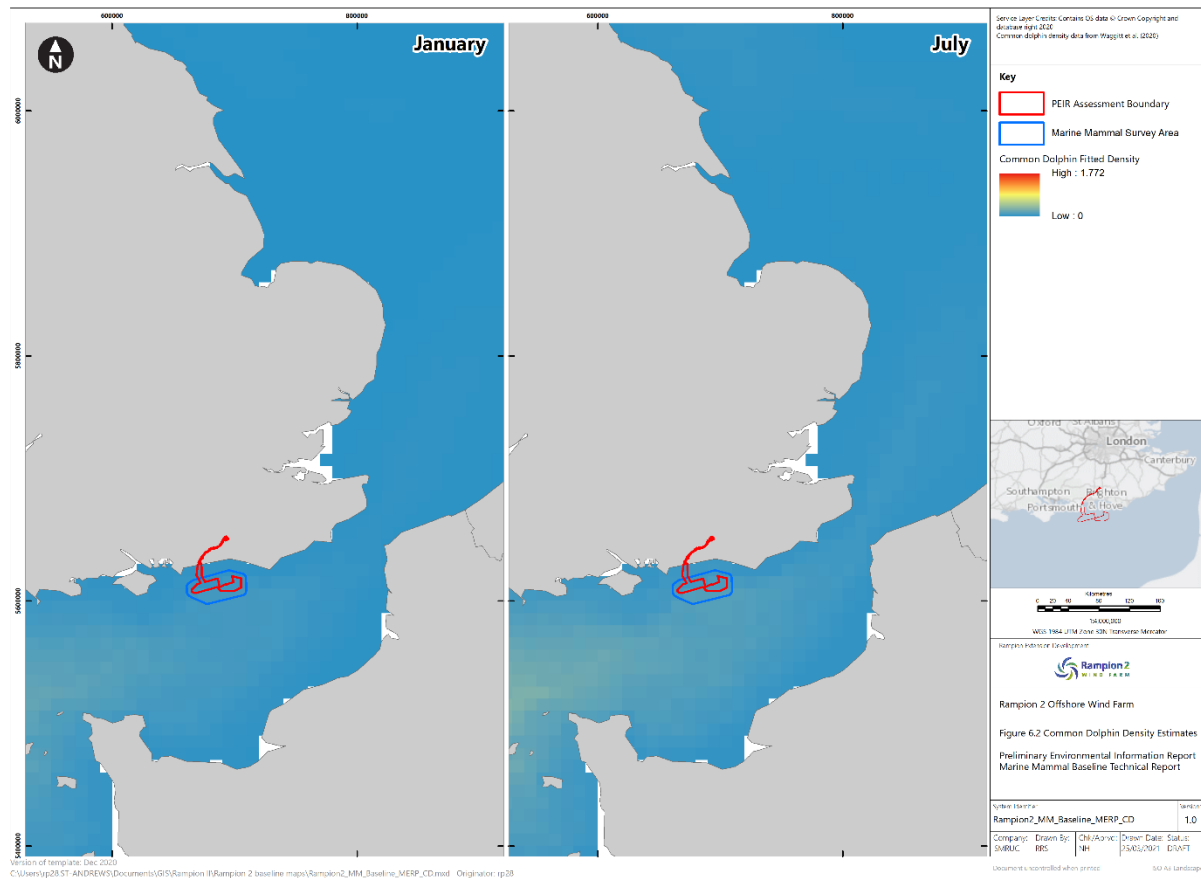
Table 6-2 JCP Phase III abundance and density estimates for common dolphins in 2010

		Winter	Spring	Summer	Autumn
Hastings	Abundance point estimate	0	0	0	0
	Density Estimate (#/km ²)	0.000	0.000	0.000	0.000
Isle of Wight	Abundance point estimate	0	0	10	20
	Density Estimate (#/km ²)	0.000	0.000	0.002	0.004

6.5 MERP

- 6.5.1 As with the SCANS III and JCP datasets, the MERP analysis of common dolphin distribution shows low density estimates in the English Channel and in the vicinity of Rampion 2, with little seasonal variation between January and July. The cetacean distribution maps provided by Waggitt *et al.* (2020) estimate highest common dolphin densities to the south and west of the UK, there are estimated to be high densities in offshore waters and off Ireland and in the Bay of Biscay, with much lower densities within the English Channel (**Graphic 6-2**). As outlined previously, the distribution maps are not considered to provide suitable density estimates for use in quantitative impact assessment and are provided in this baseline characterisation for illustrative purposes only to distribution levels relative to the rest of the southern North Sea and the English Channel.

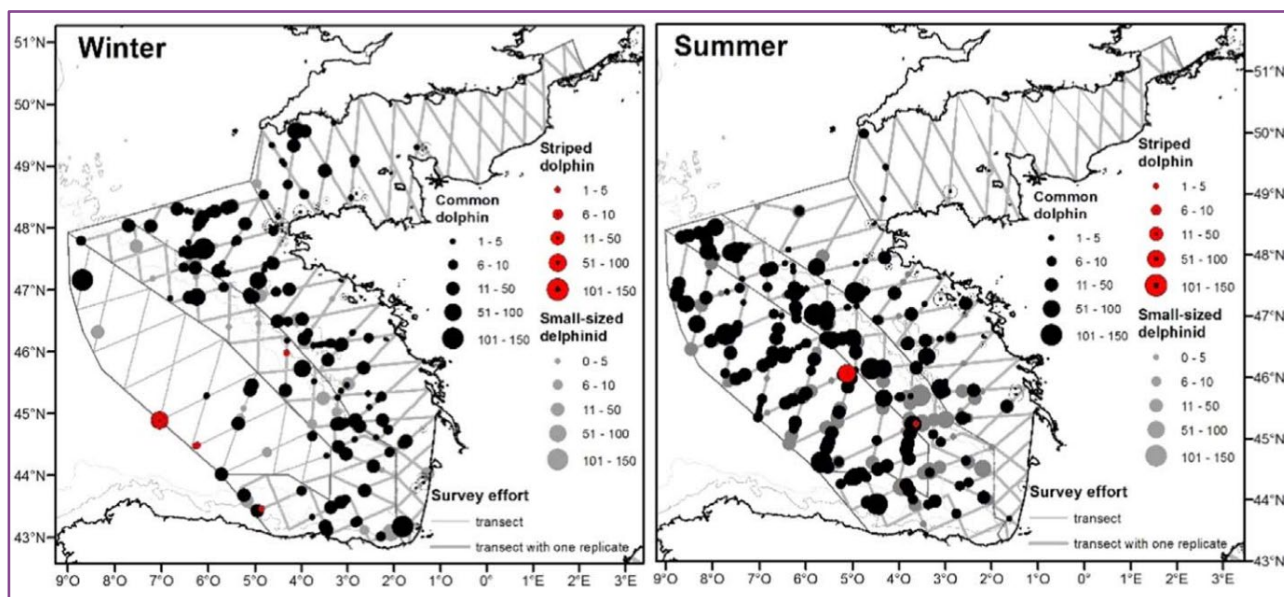
Graphic 6-2 Common dolphin fitted density (#/km²) for January and July (Waggitt *et al.*, 2020)



6.6 SAMM surveys

- 6.6.1 There were 1,122 sightings of “*small delphinids*” in the Eastern North Atlantic during the SAMMs surveys, consisting of a mixture of common dolphins (76 percent), striped dolphins (1 percent) and unidentified small-sized delphinids (23 percent), however these delphinid sightings were restricted to the Bay of Biscay and the western English Channel, with no sightings in the eastern parts of the English Channel (**Graphic 6-3**). In general, small delphinids were sighted on the shelf and slope of the Bay of Biscay and the southern Celtic Sea, however in the summer sightings were more offshore on the slope and oceanic strata of Bay of Biscay. Small-sized delphinids displayed densities which varied significantly by season within the English Channel, with winter corrected densities for combined common/striped dolphins of 0.171 individuals/km², compared to summer densities of 0.011 individuals/km²; resulting in abundance estimates of 15,908 common/striped dolphins in the winter (95 percent CI: 7,033 to 35,986) and 1,023 common/striped dolphins in the summer (95 percent CI: 255 to 4,092) (*Laran *et al.*, 2017*).

Graphic 6-3 From Laran *et al.* (2017): Distribution of sightings and effort for winter and summer surveys for common, striped and small sized delphinids



6.7 Sea Watch Foundation

- 6.7.1 Castles (2020) used 14 common dolphin sightings from the Sea Watch Foundation data around the Isle of Wight to investigate spatio-temporal trends. Sightings occurred around the Isle of Wight with significantly more sightings in the summer. No density estimate was provided for this dataset.

6.8 ORCA

- 6.8.1 The ORCA surveys have reported common dolphin sightings along the Portsmouth-Caen ferry route (**Graphic 2-8** and **Table 2-5**). No density estimate was provided for this dataset.

6.9 Summary

- 6.9.1 There are few studies that provide robust density and abundance estimates for common dolphins in the English Channel area. Based on the limited data outlined above, common dolphins are present in the area with estimated densities ranging between 0.000 to 0.171 dolphins per km² (**Table 6-3**). Given the lack of density estimates for common dolphins, it is considered to be precautionary to take forward to impact assessment the common/striped dolphin density estimate obtained from the SAMMS surveys.

Table 6-3 Common dolphin density estimates

Data source	Density Estimate (dolphins/km ²)
Rampion 2	0.00 to 0.01 (common dolphin) 0.00 to 0.07 (dolphin/porpoise)

Data source	Density Estimate (dolphins/km ²)
Rampion 1	None
SCANS III Block C	0.000 (common) 0.022 (common/striped)
JCP Phase III Hastings	None
JCP Phase III Isle of Wight	0.000 (winter & spring) 0.002 (summer) 0.004 (autumn)
JCP III Data Analysis Product	None
SAMM survey (English Channel)	0.171 (winter, common/striped) 0.011 (summer, common/striped)

7. Minke whale baseline

7.1 Rampion 2

- 7.1.1 No minke whales were sighted in any of the first 20 months of site-specific Rampion 2 aerial surveys.

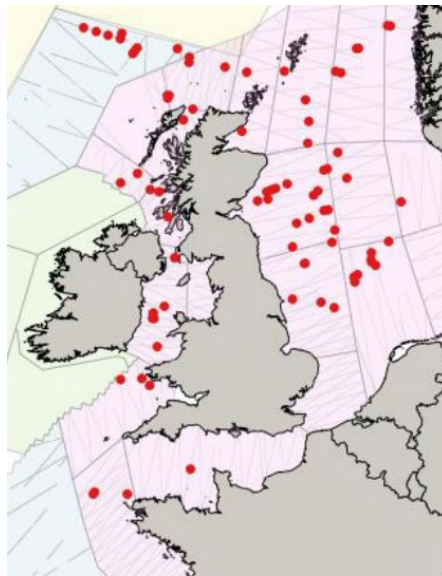
7.2 Rampion 1

- 7.2.1 In the 30 surveys, only a single unidentified whale (probably minke whale) was observed during the Rampion 1 baseline surveys.

7.3 SCANS III

- 7.3.1 Minke whales were detected in SCANS III survey block C (**Graphic 7-1**), resulting in a block-wide abundance estimate of 186 whales (95 percent CI: 0 to 819, CV: 1.12) with a density of 0.002 whales/km². It is worth noting however that none of the sightings within the survey block were in the vicinity of Rampion 2.

Graphic 7-1 From Hammond *et al.* (2017): Distribution of minke whale sightings during the SCANS III surveys



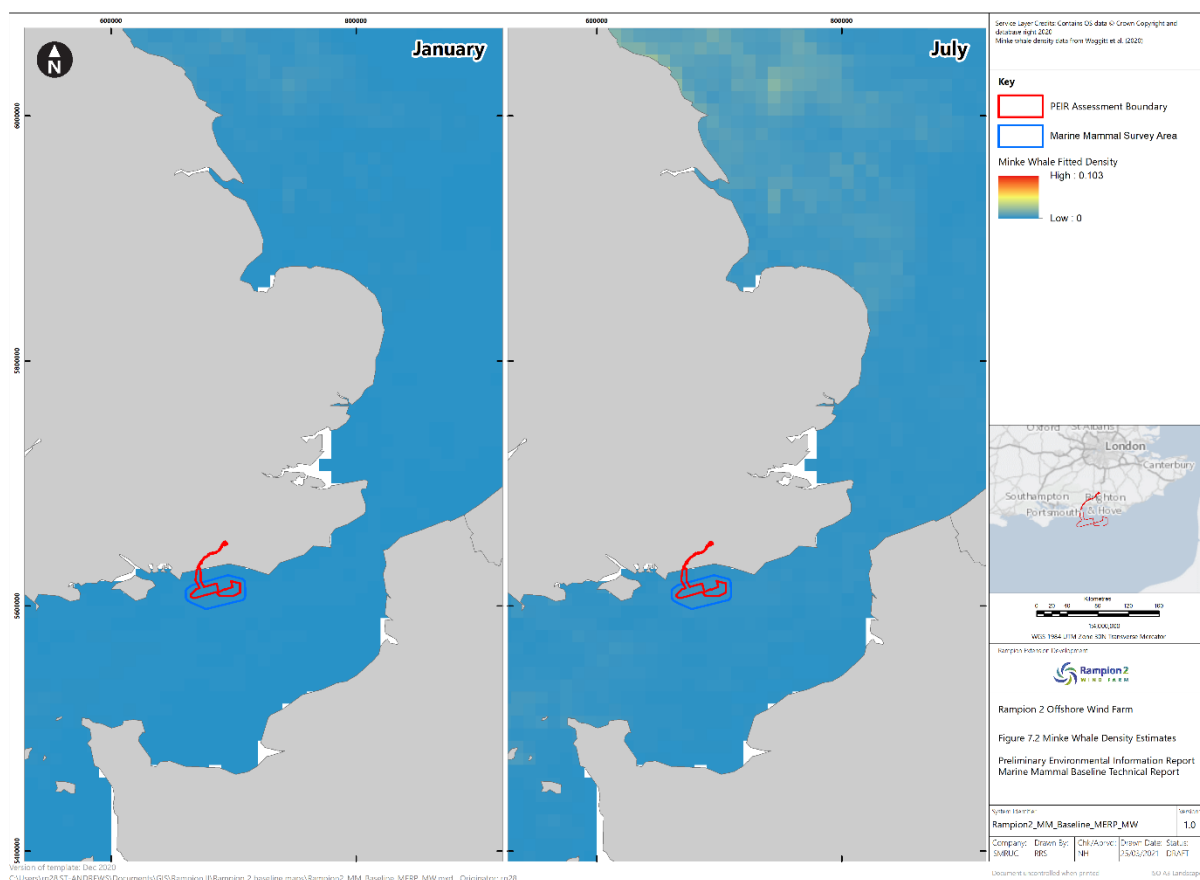
7.4 JCP

- 7.4.1 No minke whales were predicted to be in the Hastings of Isle of Wight areas of interest for offshore development in the JCP Phase III analysis.
- 7.4.2 No minke whales were estimated to be within the user specified area using the JCP Phase III Data Analysis Product.

7.5 MERP

- 7.5.1 The MERP density surfaces for minke whales highlight the low densities expected in the English Channel, with evidence of slightly higher densities in the North Sea in the summer (**Graphic 7-2**). As outlined previously, the distribution maps are not considered to provide suitable density estimates for use in quantitative impact assessment and are provided in this baseline characterisation for illustrative purposes only to distribution levels relative to the rest of the southern North Sea and the English Channel.

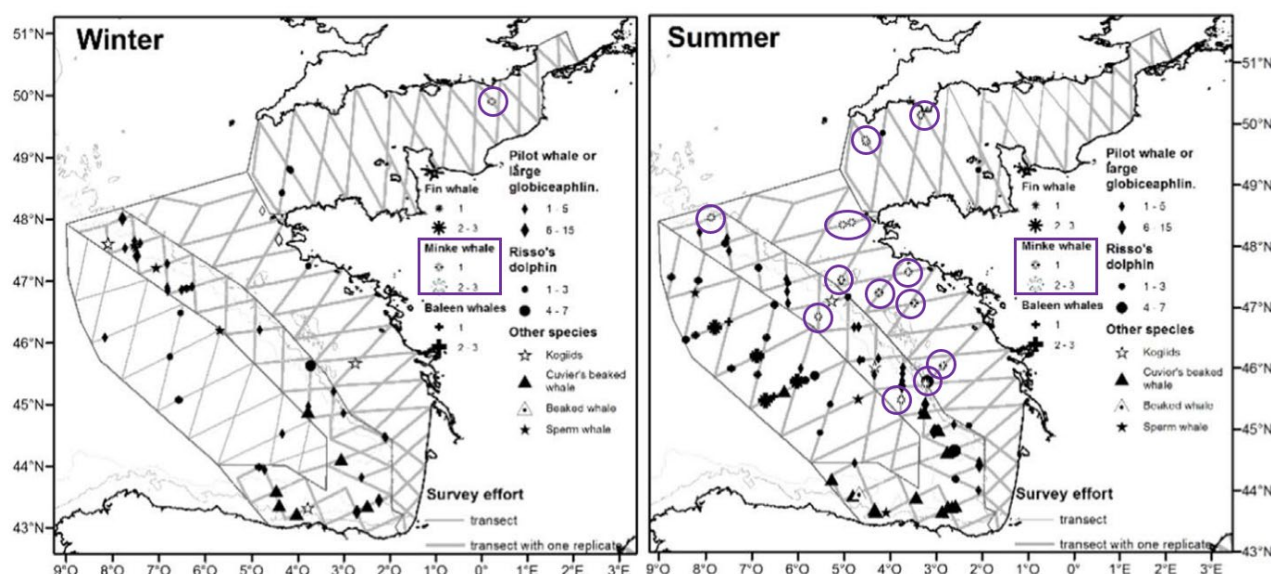
Graphic 7-2 Minke whale fitted density ($\#/km^2$) for January and July (Waggitt *et al.*, 2020)



7.6 SAMM surveys

- 7.6.1 Minke whale sightings were always single individuals, showing preference for areas within the continental shelf. In the English Channel, there was one singular sighting made for minke whales during the winter and three individuals sighted in the summer (**Graphic 7-3**). The English Channel summer corrected abundance was estimated to be approximately 1,077 minke whales (95 percent CI: 351 to 3,299). The English Channel also comprised of 26 percent of the summer abundance of minke whales, with a summer corrected density of 0.012 individuals/ km^2 (Laran *et al.*, 2017).

Graphic 7-3 From Laran *et al.* (2017): Distribution of sightings and effort for winter and summer surveys for minke whales (and various other species)



Note: To better distinguish the minke whale sightings, the maps have been annotated with purple circles.

7.7 Sea Watch Foundation

7.7.1 No minke whale sightings have been reported by the Sea Watch Foundation between March 2018 and August 2020 inclusive. No density estimate was provided for this dataset.

7.8 ORCA

7.8.1 No minke whales were included in the ORCA sightings map or recent survey reports for the Portsmouth to Caen ferry route (2011, 2015, 2016, 2018, 2019 and 2020). No density estimate was provided for this dataset.

7.9 Summary

7.9.1 In conclusion to the data outlined above, all surveys found very low abundances of minke whales, with reported estimated densities ranging between 0.000 to 0.012 whales/km² (Table 7-1). From this, it is recommended that the best density estimate for these individuals is that of SCANS III Block C. The SCANS III data is the most recent (2016) and so is considered to be more reflective of current minke whale usage.

Table 7-1 Minke whale density estimates

Data source	Density Estimate (whales/km ²)
Rampion 2	None

Data source	Density Estimate (whales/km ²)
Rampion 1	Not estimated
SCANS III Block C	0.002
JCP Phase III Hastings	None
JCP Phase III Isle of Wight	None
JCP III Data Analysis Product	None
SAMM survey (English Channel)	0.000 (winter) 0.012 (summer)

8. Harbour seal baseline

8.1 Rampion 2

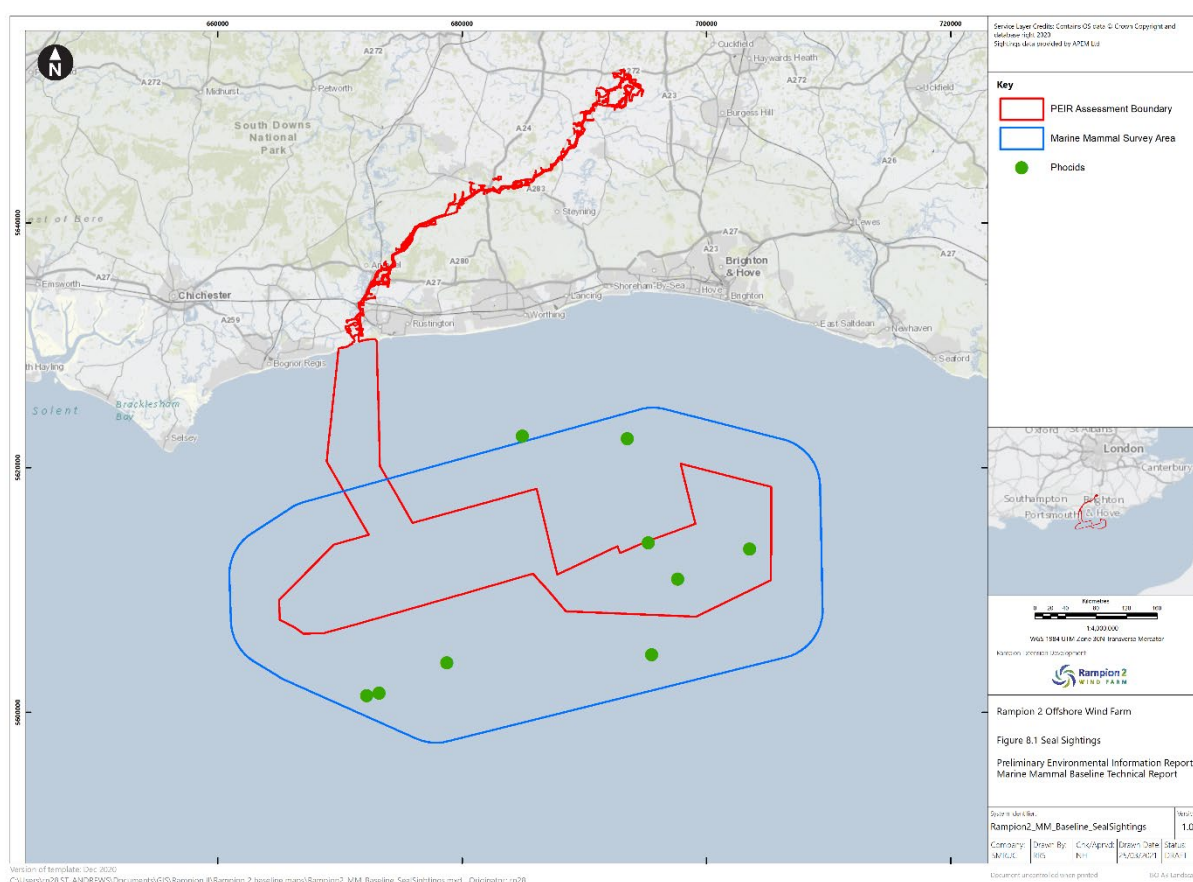
8.1.1 During the Rampion 2 site-specific surveys seals were reported (**Graphic 8-1**), however none of the sightings were able to be identified to species level. There was a peak count of seals in July, where three seals were counted, resulting in a monthly density of 0.04 seals/km² (**Table 8-1**).

Table 8-1 Seal sightings count and estimated abundance and density (Rampion 2 array area + 4km buffer)

Survey number	Date	Count	Abundance	Lower CI	Upper CI	Precision	Density
1	Apr-19	0	0	0	0	0.00	0.00
2	May-19	0	0	0	0	0.00	0.00
3	Jun-19	0	0	0	0	0.00	0.00
4	Jul-19	3	26	3	62	0.58	0.04
5	Aug-19	0	0	0	0	0.00	0.00
6	Sep-19	0	0	0	0	0.00	0.00
7	Oct-19	0	0	0	0	0.00	0.00
8	Nov-19	0	0	0	0	0.00	0.00
9	Dec-19	0	0	0	0	0.00	0.00
10	Jan-20	0	0	0	0	0.00	0.00
11	Feb-20	1	9	1	27	1.00	0.01
12	Mar-20	0	0	0	0	0.00	0.00
13	Apr-20	0	Not yet calculated				
14	May-20	0					
15	Jun-20	0					
16	Jul-20	0					
17	Aug-20	1					
18	Sep-20	0					

Survey number	Date	Count	Abundance	Lower CI	Upper CI	Precision	Density
19	Oct-20	0					
20	Nov-20	0					

Graphic 8-1 Sightings of seals during the first 20 months of site-specific surveys at Rampion 2



8.2 Rampion 1

8.2.1 Surveys conducted as part of the data collection for Rampion 1 concluded a total of two sightings of harbour seals in March and April 2011 as well as three sightings of unidentified seal species.

8.3 Haul-out counts

8.3.1 Rampion 2 is located within the South England MU; however, it is located adjacent to the boarder of the South-east England MU, therefore discussions were had with Natural England regarding the most suitable reference population against which to assess impacts. Through consultation with the ETG for marine mammals, Natural England have provided the following advice:

“Given Rampion 2’s proximity to both the south and south-east draft seal management units, Natural England consider it would be pragmatic in this instance for the reference population for the seal assessments to be comprised of 50 percent of the south management unit population + 50 percent of the south-east management unit population. The project has the potential to impact both management unit populations”.

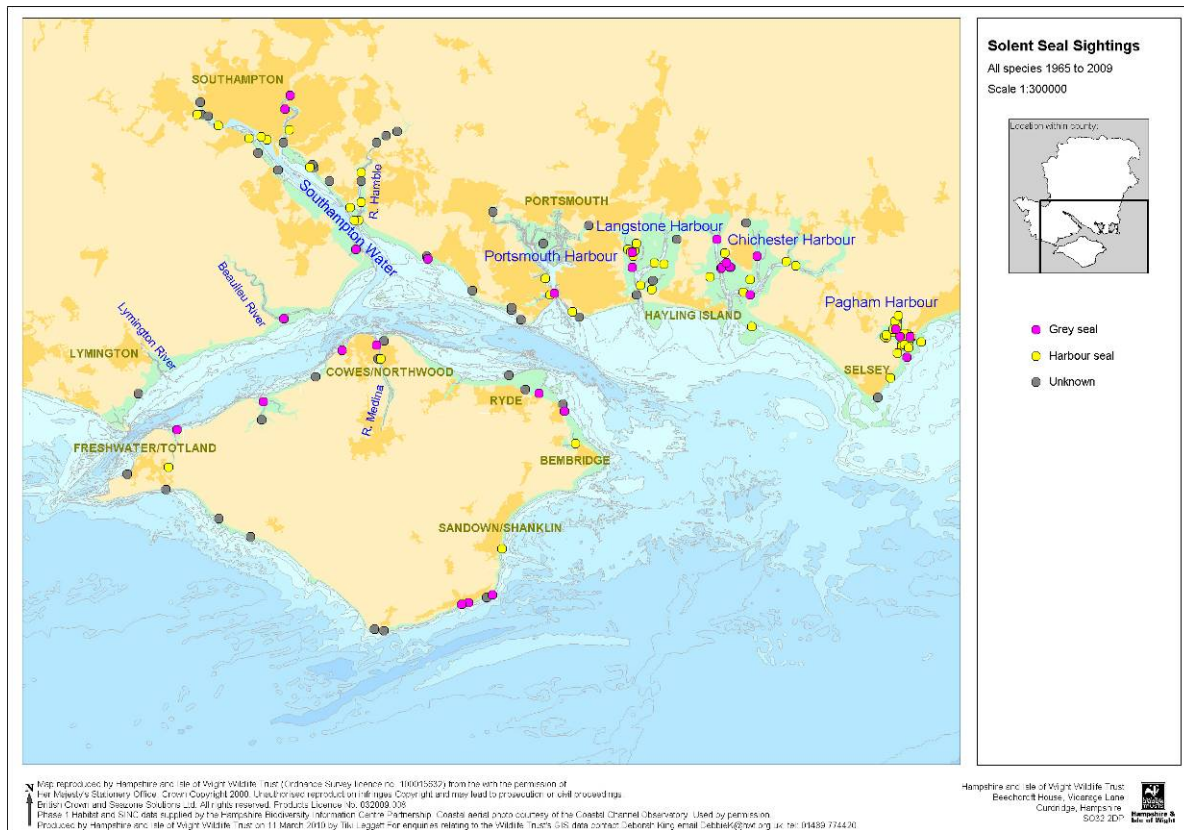
8.3.2 As such, information on both MUs are presented here for harbour seals.

South England MU

- 8.3.3 There are no harbour seal surveys conducted by SMRU in the South England MU and as a result, there are reduced data available for this area. SCOS (2020) (reporting on seal data up to and including 2019) reports that the estimate for the South England MU (number (n)=40) was *“compiled from counts shared by other organisations (Langstone Harbour Board & Chichester Harbour Conservancy) or found in various reports & on websites (Boyle, 2012; <http://hilbrebirdobs.blogspot.com/>, 2012, 2013; Sayer, 2010, 2011; Sayer et al., 2012; Westcott, 2002)”* (SCOS, 2020).
- 8.3.4 The Solent Seal Project August counts have increased over time from just three seals in 1994 to a minimum of 49 harbour seals in 2017⁵. Records from public sightings show that seals have been sighted throughout the Solent and the Isle of Wight (**Graphic 8-2**).
- 8.3.5 Three years of photo-ID surveys at Chichester harbour between 2016 to 2018 have identified 68 individual harbour seals, 16 of which were re-sighted within the three year study (Castles *et al.*, in review). While only three years of photo-ID data are available to date, these preliminary results indicate site fidelity in Chichester harbour (Castles *et al.*, in review).

⁵ <https://www.hiwwt.org.uk/news/secret-lives-our-local-seals-revealed>

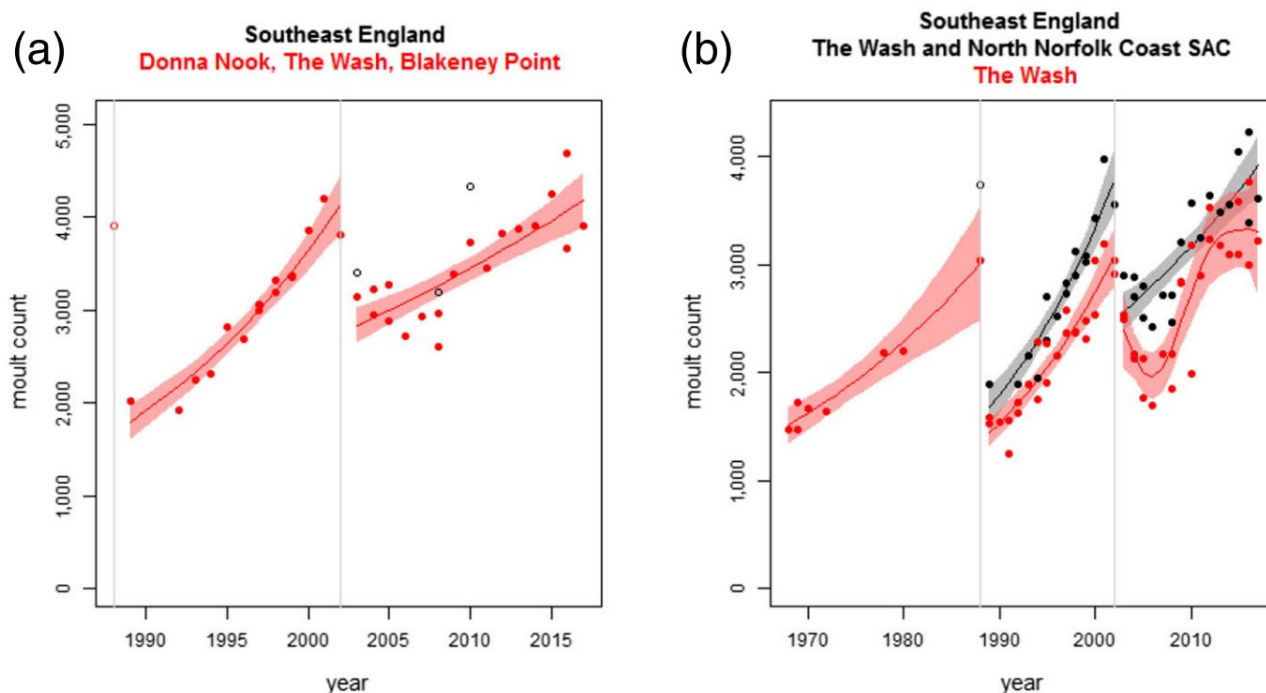
Graphic 8-2 From Chesworth *et al.* (2010): Locations of public sightings of seals from 1997 to 2009



South-East England MU

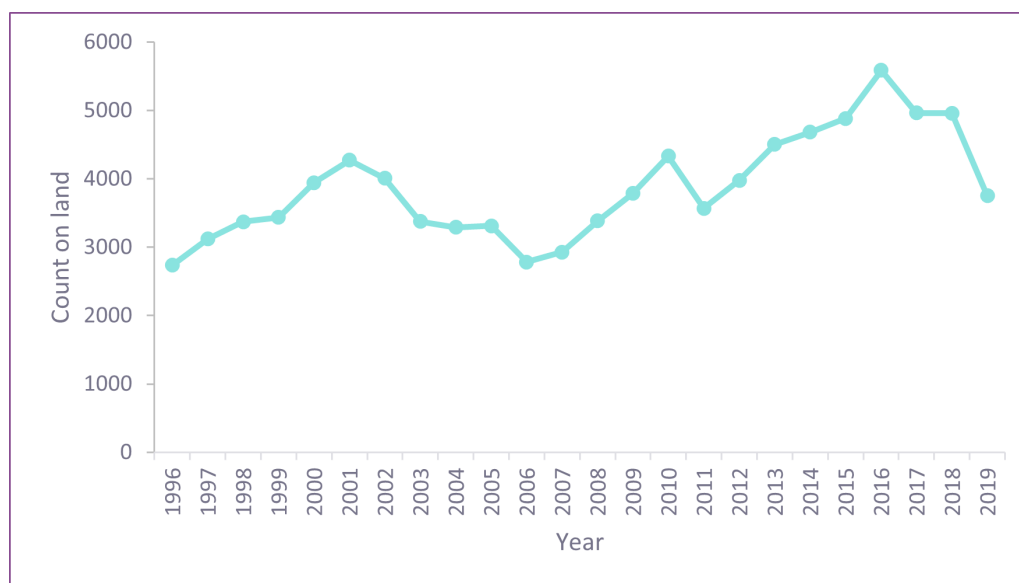
- 8.3.6 The South-East England MU consists of five geographically categorised haul-out groups including: Donna Nook, The Wash, Blakeney Point, Scroby Sands and the Greater Thames Estuary. The population trend model selected for the Thompson *et al.* (2016) analysis for the combined counts of harbour seals in this area incorporated two periods of exponential increase in the abundance of harbour seals, one from 1989 to 2002 with a 6.6 percent per annum (p.a.) (95 percent CI: 5.3, 7.9 percent p.a.), and one from 2003 to 2017 with a 2.8 percent p.a. (95 percent CI: 1.3, 4.3 percent p.a.). These two periods were differentiated by a step change decrease of approximately 30 percent which occurred between 2002 and 2003, coincident with the second phocine distemper virus (PDV) epidemic. From 2003 to 2017, there was evidence of a non-linear trend occurring with a constant abundance of harbour seals, followed by an increase and finishing with a levelling off of counts in recent years.
- 8.3.7 More recent data in harbour seal counts suggest that the South-east England population growth is slowing, and the latest haul-out count in August 2019 was 3,752 harbour seals which is lower than the previous three annual counts (**Graphic 8-4**).

Graphic 8-3 From Thompson *et al.* (2019): Harbour seal survey counts and fitted trends (shown in black)



Note: Counts not used in model fits are shown as open dots. Where a robust model could not be fitted to the overall MU, the counts and model fit for a subset of the region is shown in red. (a) Combined South-East England region (1988 to 2017); (b) The Wash and North Norfolk Special Area of Conservation (SAC; 1988 to 2017) and The Wash (1967 to 2017).

Graphic 8-4 Harbour seal August haul-out counts in the South-east England MU between 1996 and 2019. Data provided by Chris Morris at SMRU



Combined South and South-east MUs

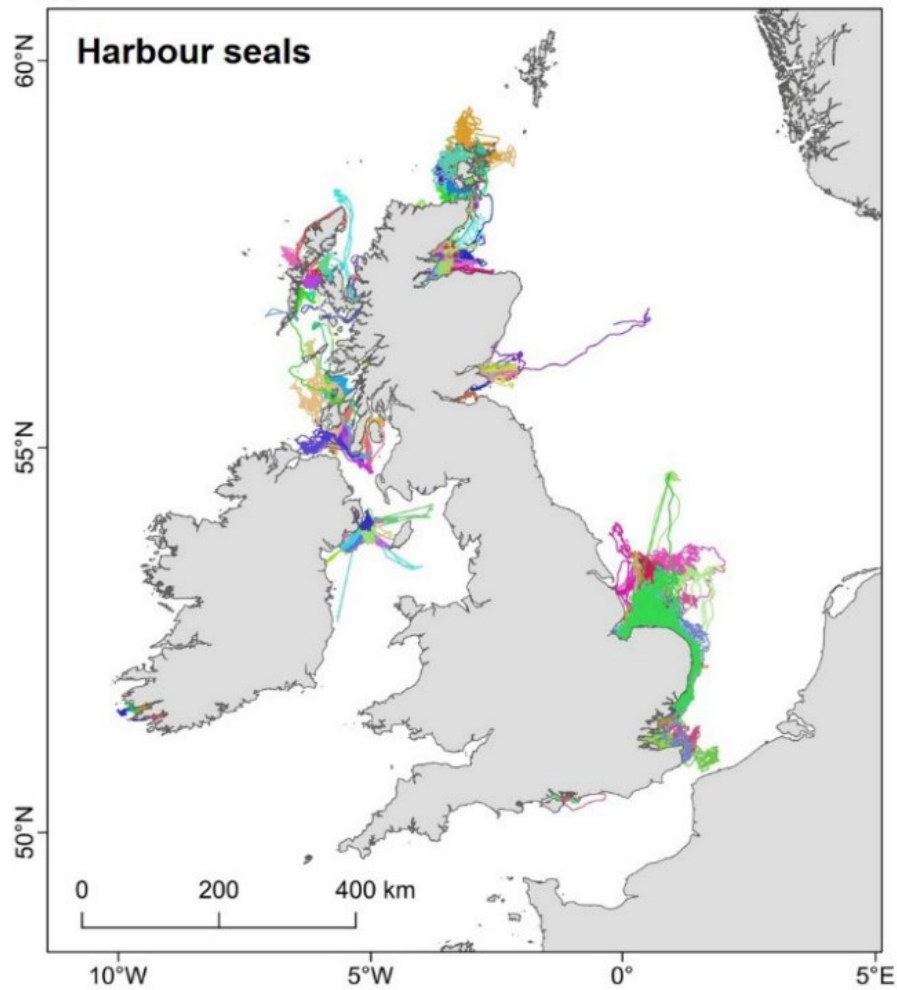
8.3.8 To estimate the South England MU size, the haul-out counts (n=40 in South England MU and n=3,752 in South-east England MU) can be scaled by the

estimated proportion hauled out at the time of the survey (0.72, 95 percent CI: 0.54 to 0.88) to produce an MU population estimate. This results in an estimated MU size of 56 (95 percent CI: 45-75) harbour seals for the South England MU and an estimated 5,211 (95 percent CI: 4,264 to 6,948) harbour seals for the South-east England MU. Since Natural England advise that 50 percent of both MUs should be included in the reference population, this represents a total combined reference population of 2,633 harbour seals (95 percent CI: 2,155 to 3,511).

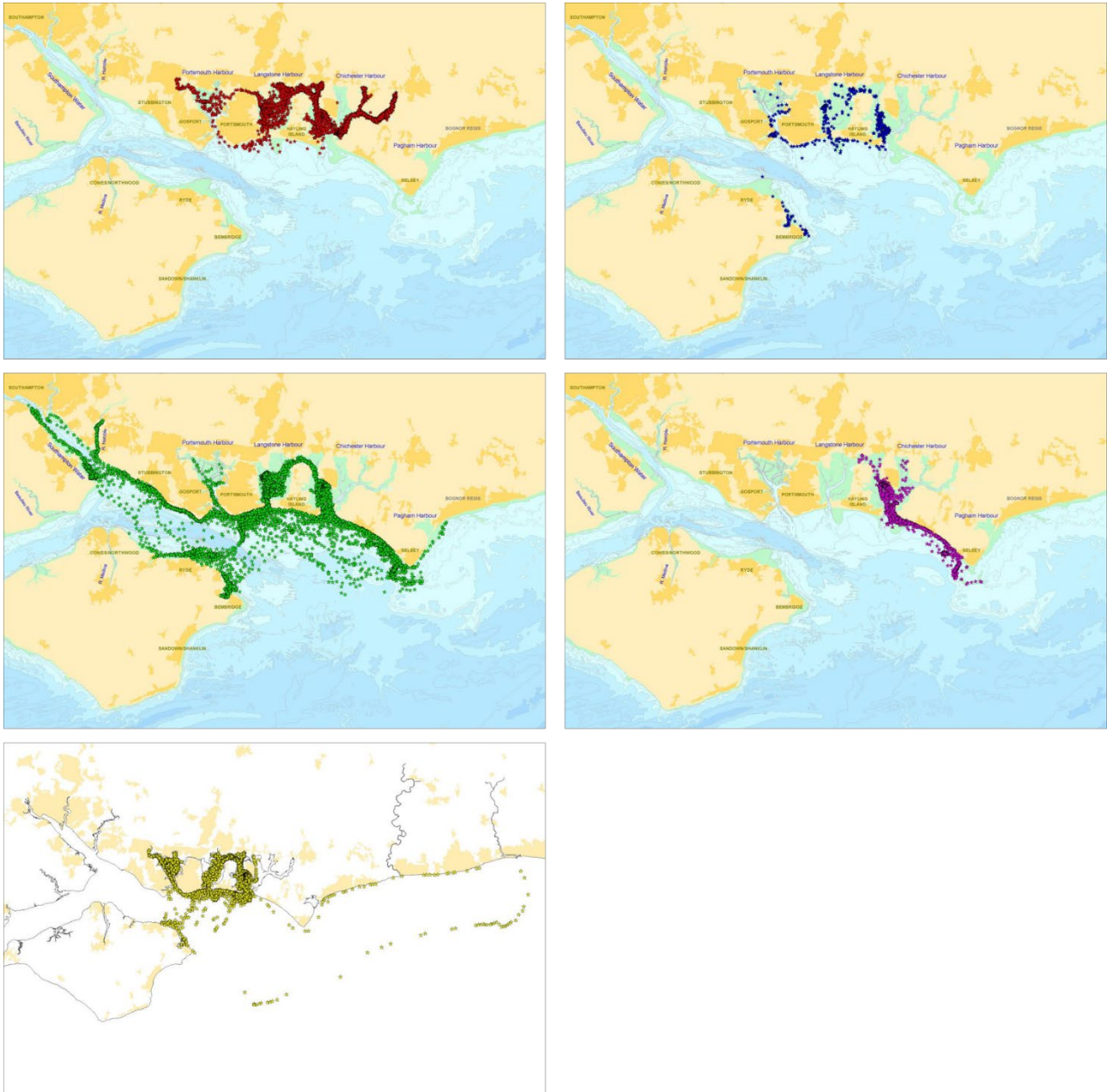
8.4 Telemetry

- 8.4.1 None of the harbour seals tagged with GPS tags at the Thames (n=10) or The Wash (n=37) have recorded any GPS locations within the South England MU (**Graphic 8-5**). Therefore, there is no evidence from this data set of connectivity between the Rampion 2 site and the Southeast England MU or The Wash SAC.
- 1.1.1 The tagging of five harbour seals in the Solent Sea in 2009 showed very limited movement. The seals stayed primarily in the Portsmouth, Langstone and Chichester harbours, and in the eastern Solent, from Southampton water to Selsey Bill (**Graphic 8-6**). One of the seals left the eastern Solent and travelled as far as Brighton before returning to the Solent (**Graphic 8-6**). Though this dataset is limited, there is no evidence of connectivity between the Solent Seals and Southeast England MU or The Wash SAC.

Graphic 8-5 From Carter *et al.* (2020): GPS tracking data for harbour seals available for habitat preference models



Graphic 8-6 From Chesworth *et al.* (2010): GPS positions of the five harbour seals tagged as part of the Solent Seal Tagging Project in March 2009

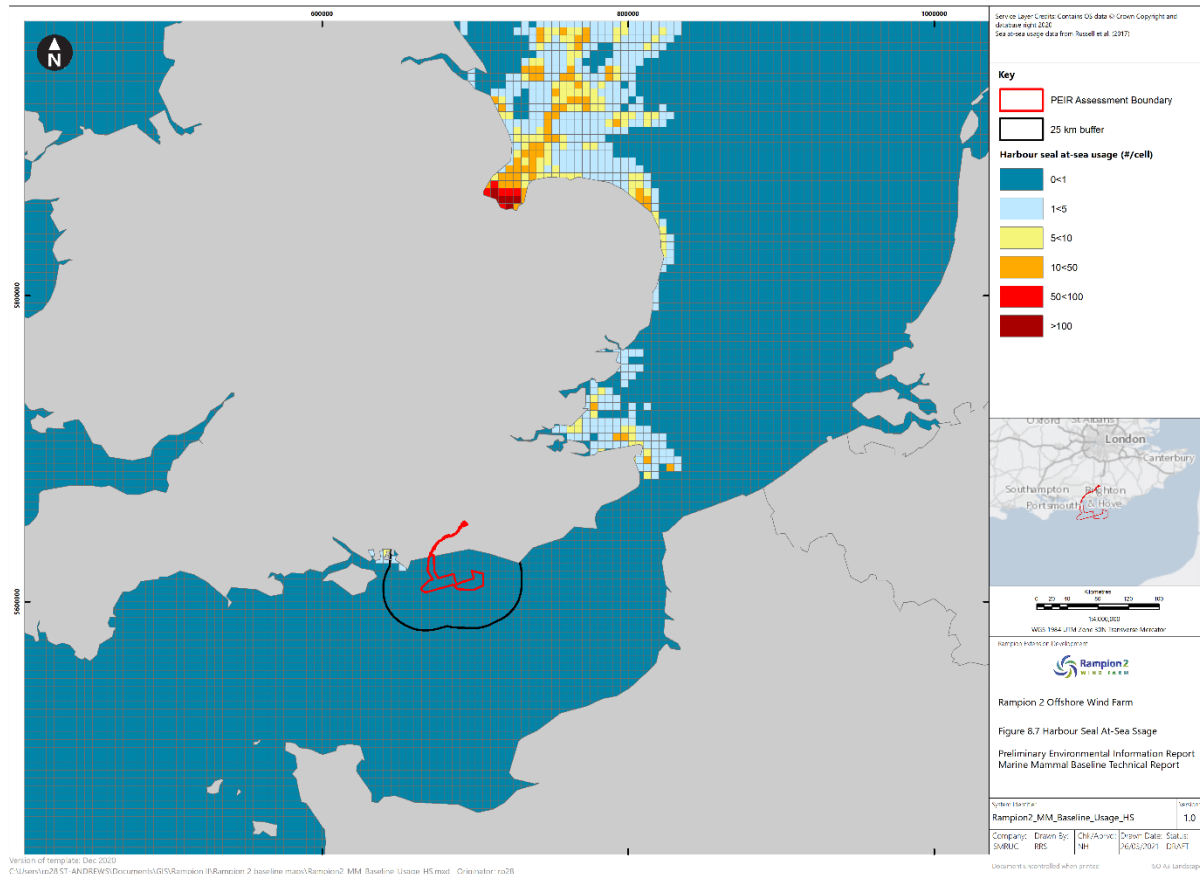


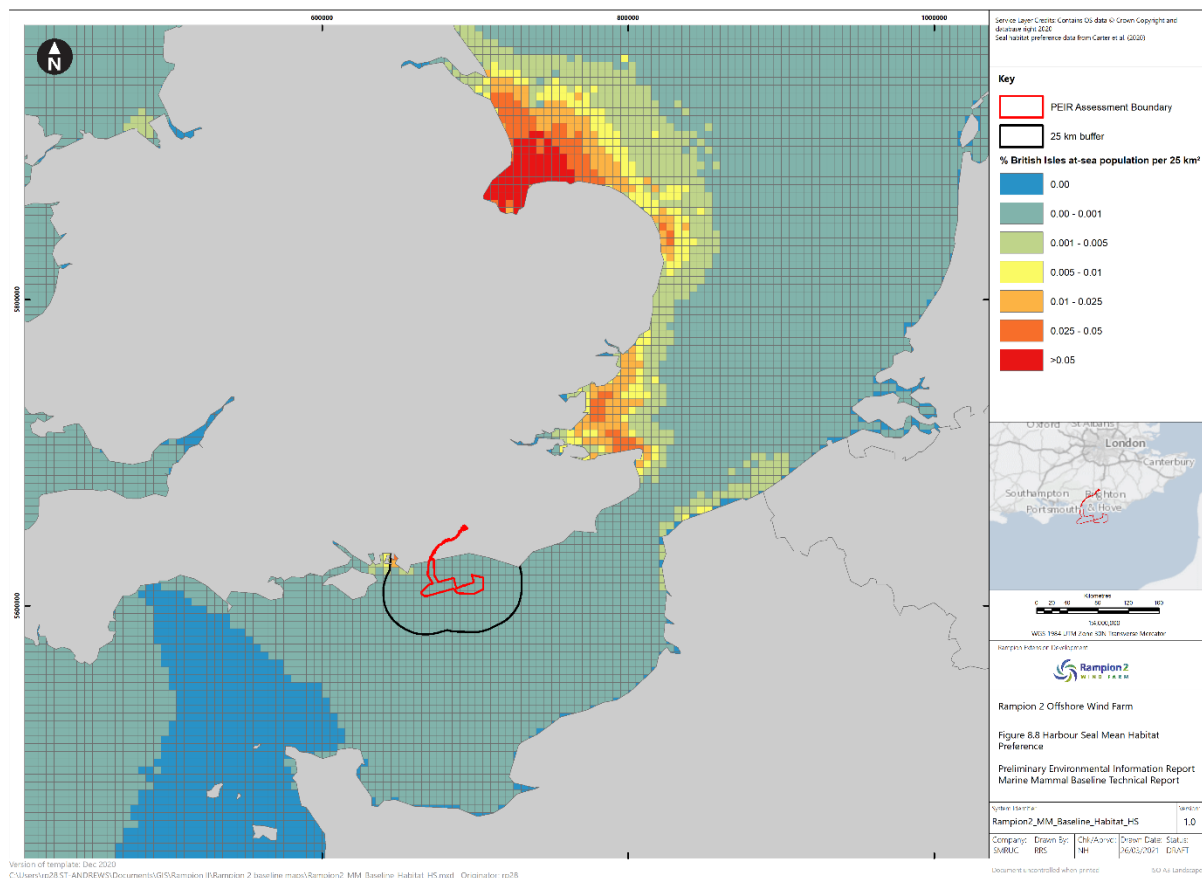
8.5 At-sea density

- 1.1.2 Data availability for the at-sea usage of harbour seals in this area is relatively low. There were only three haul-out locations reported for harbour seals in the south England MU, with very little accompanying telemetry data for harbour seal movement patterns, with only five individuals tagged in this area. The at-sea usage maps estimated 12 harbour seal within a 25km buffer of the Rampion 2 windfarm array area, which equates to an average of 0.003 seals/km² (). The habitat preference maps provided by Carter *et al.* (2020) predicted there to be 27 harbour seals within a 25km buffer of the site, which equates to an average density of 0.007 seals/km² (**Graphic 8-8**).

- 8.5.1 While the at-sea density estimate is very low for harbour seals within the survey area, this may not necessarily be representative of a true lack of usage, since none of the data from harbour seals tagged in France or the Wadden Sea were included in the habitat preference analysis to inform the usage in this area.

Graphic 8-7 Harbour seal at-sea usage estimates (Russell *et al.*, 2017)

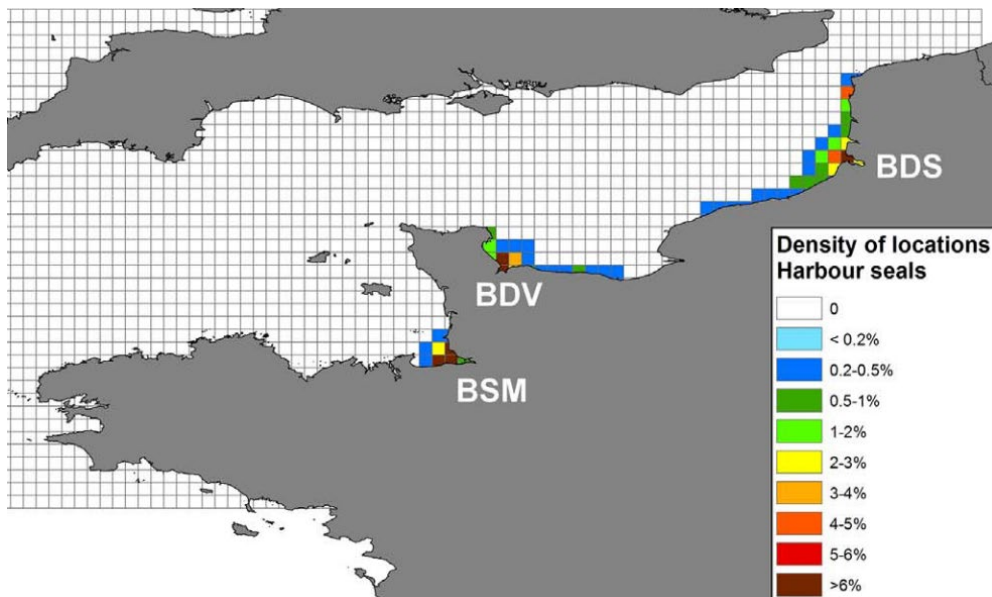


Graphic 8-8 Harbour seal habitat preference map (Carter *et al.*, 2020)

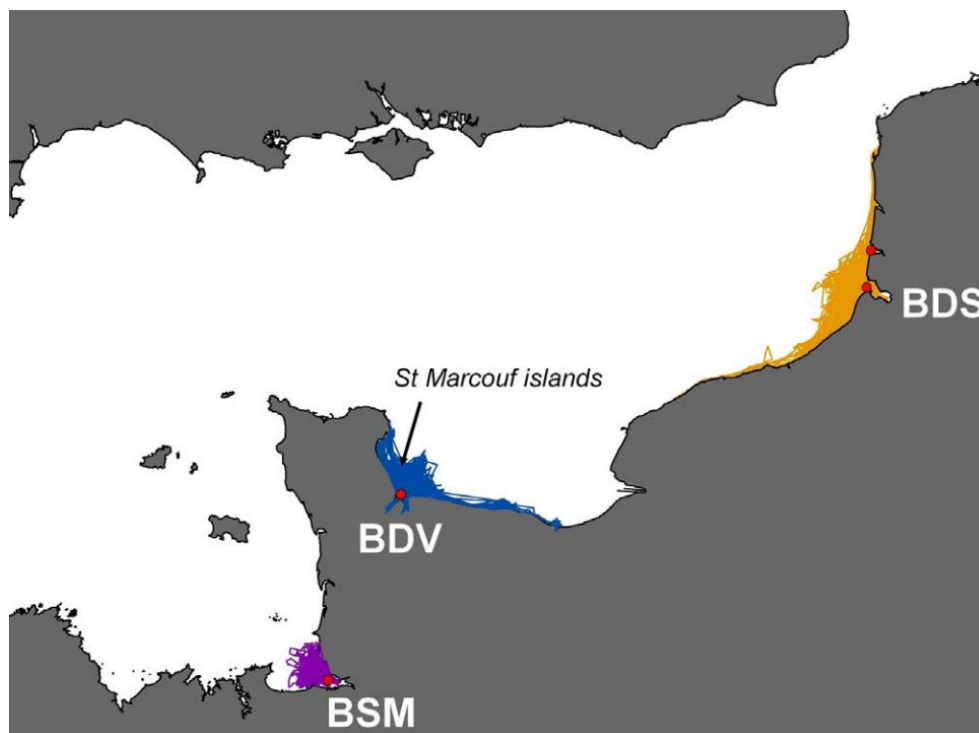
8.6 French seal data

- 8.6.1 In a study conducted by Vincent *et al.* (2017) on the abundance of harbour and grey seals along the French coast of the English Channel, it was found that harbour seals remain very much coastal for the majority of time and in close proximity to their respective haul-out sites (**Graphic 8-9** and **Graphic 8-10**). The findings of this study showed no connectivity between harbour seals tagged at French haul-out sites and the Rampion 2 area (**Graphic 8-10**).

Graphic 8-9 From Vincent *et al.* (2017): Density of harbour seal locations (per grid cell) obtained by telemetry from 2006 to 2010, from individuals captured in BSM, BDV and BDS



Graphic 8-10 From Vincent *et al.* (2017): Harbour seal telemetry tracks



Note: BSM = six individuals tracked in 2006 and 2007, in purple. BDV = 12 individuals tracked in 2007 and 2008, in blue. BDS = ten individuals tracked in 2010, in orange. Red dots indicate haul-out locations of the seals. Seals tracked for less than a month are not shown here.

9. Grey seal baseline

9.1 Rampion 2

- 9.1.1 During surveys conducted for Rampion 2, seals were reported, however, each reporting did not include a species identification. There was a peak count of seals in July, where three seals were counted, resulting in a monthly density of 0.04 seals/km² (**Table 8-1**). The average density estimate across all 15 surveys was 0.003 seals/km².

9.2 Rampion 1

- 9.2.1 Surveys conducted as part of the data collection for Rampion 1 recorded a total of one sighting for grey seals in March 2011, as well as three sightings of unidentified seal species.

9.3 Haul-out counts

- 9.3.1 Rampion 2 is located within the South England MU but is adjacent to the border of the South-east England MU. Given knowledge of the wide-ranging behaviour of grey seals (they frequently travel over 100km between haul-out sites) (SCOS, 2020), and the degree of connectivity between the English Channel and South-east of England (see telemetry data in **Section 9.6**), the South England MU alone is not an appropriate reference population against which to assess impacts. Therefore, the recommended reference population is a combination of both the South and the South-east England MUs.

South England MU

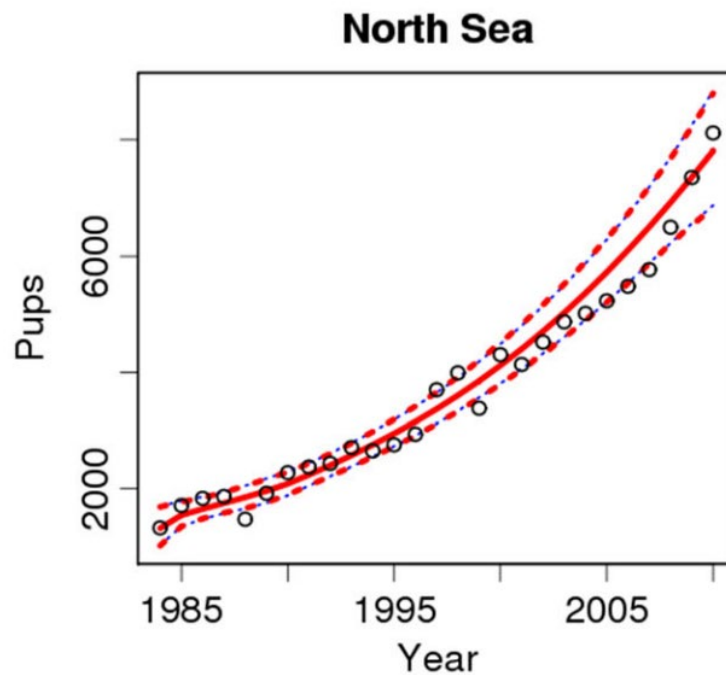
- 9.3.2 There are no grey seal surveys conducted by SMRU in the South England MU and as a result, there are reduced data available for this area. SCOS (2020) (reporting on seal data up to and including 2019) reports that the estimate for the South England MU (n=25) was “*compiled from counts shared by other organisations (Langstone Harbour Board & Chichester Harbour Conservancy, Natural England, Natural Resources Wales, RSPB) or found in various reports and on websites (Boyle, 2012; Büche & Stubbings, 2019; Hilbrebirdobs blogspot 2013; Leeney et al., 2010; Sayer, 2010, 2011, 2012a, 2012b; Sayer et al., 2012; Westcott, 2002, 2009; Westcott & Stringell, 2004; Woodfin Jones, 2017)*”.
- 9.3.3 In the Solent, the first hauled-out grey seal was recorded at Chichester harbour in July 2008. Since then there has been a significant increase in grey seal counts to a mean count of 12 individuals in 2019 (Castles *et al.*, in review).

South-east England MU

- 9.3.4 Grey seal pup production estimates in the North Sea have indicated that the North Sea population has increased almost constantly since pup count records began in 1984 (Thomas *et al.*, 2019) (**Graphic 9-1**). This is also reflected in the annual

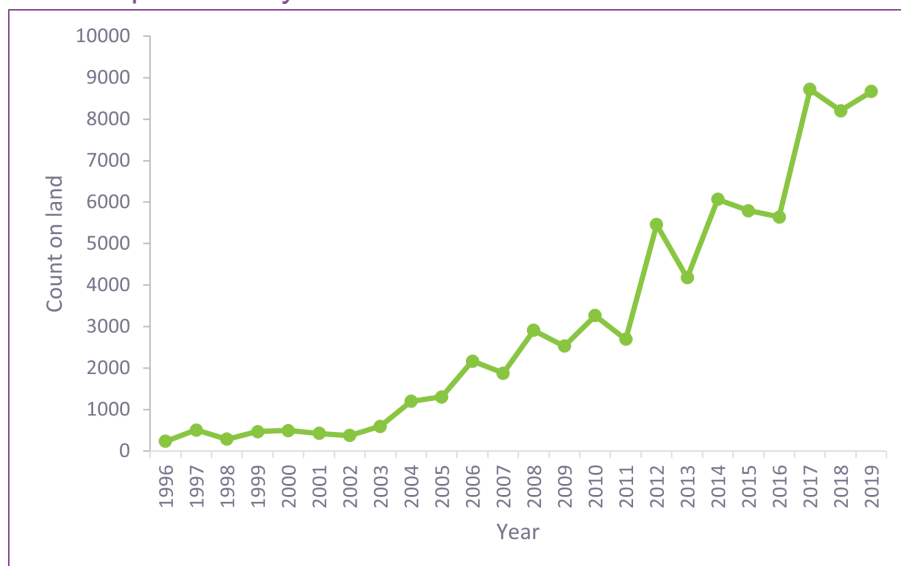
haul-out count (when grey seals are counted during the August harbour seal surveys) (**Graphic 9-2**). The latest grey seal haul-out count in 2019 for the South-east England MU was 8,667 grey seals (data provided by Chris Morris at SMRU).

Graphic 9-1 From Thomas *et al.* (2019): Posterior mean estimates of regional pup production (solid lines) from the state-space model, with 95 percent credible intervals (dashed lines)



Note: Thick red lines show the results from a model fitted to pup production plus the total population estimate from 2008; thinner blue lines show the fit to pup production alone. The two sets of lines are nearly identical, so the blue lines are partly hidden. Circles show pup production data.

Graphic 9-2 Grey seal August haul-out counts in the South-east England MU between 1996 and 2019. Data provided by Chris Morris at SMRU



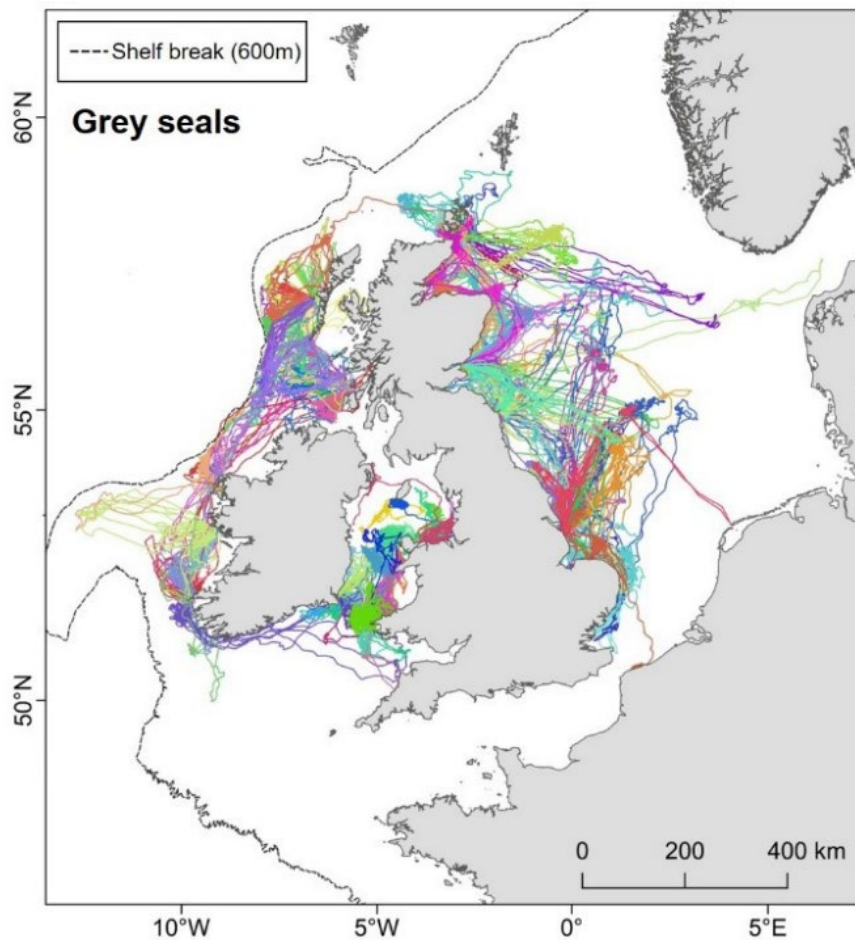
Combined South and South-east England MUs

- 9.3.5 To estimate the relevant MU size, the haul-out counts (n=25 in South England MU and n=8,667 in South-east England MU) can be scaled by the estimated proportion of time hauled-out (23.9 percent, 95 percent CI: 19.2 to 28.6 percent) (Russell *et al.*, 2016) to produce an MU population estimate. This results in an estimated MU size of 105 (95 percent CI: 87-130) grey seals for the South England MU and an estimated 36,264 (95 percent CI: 30,304 to 45,141) grey seals for the South-east England MU. This represents a total combined reference population of 36,368 grey seals (95 percent CI: 30,392 to 45,271).

9.4 SMRU Telemetry

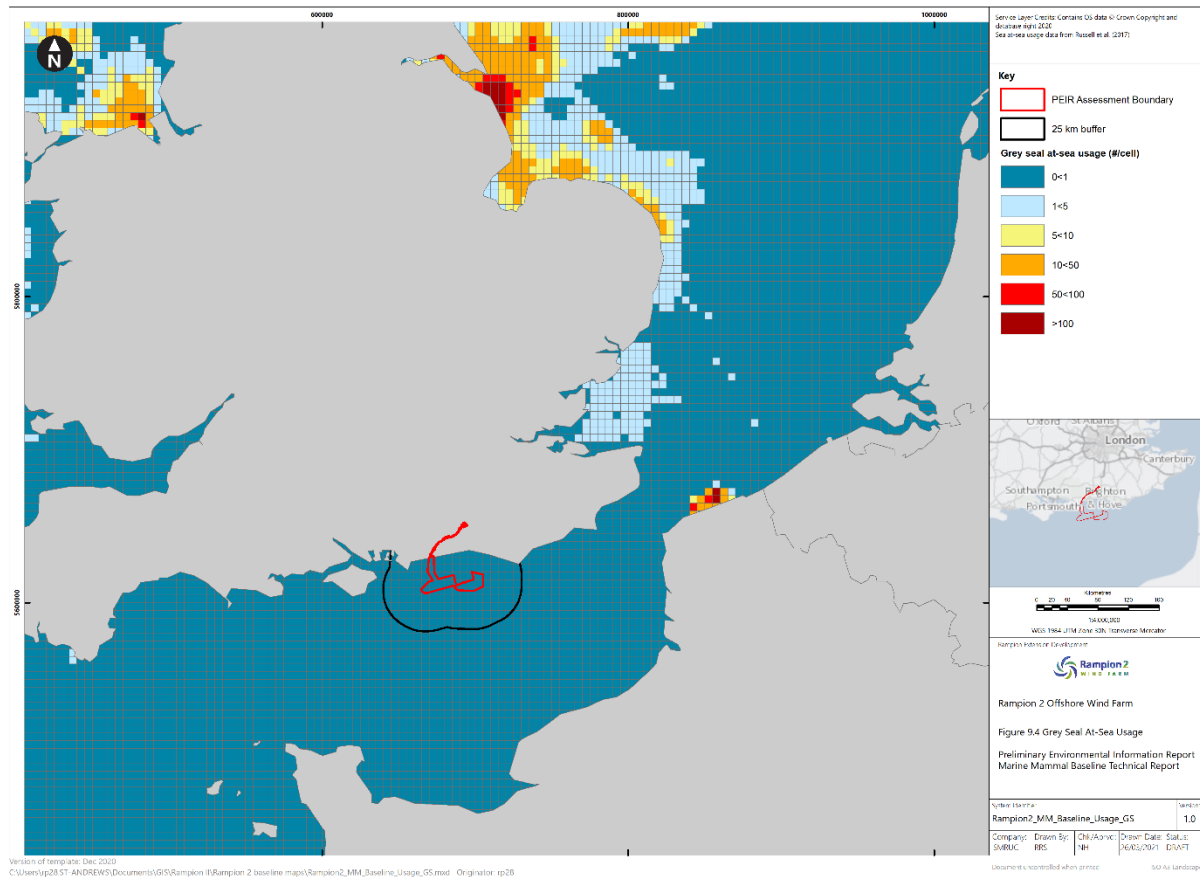
- 9.4.1 No grey seals have been tagged in the South England MU. None of the grey seals tagged with GPS tags at Donna Nook/ Blakeney Point in 2015 (n=24) recorded GPS locations within the South England MU (**Graphic 9-3**). Therefore, there is no evidence from this telemetry dataset of any connectivity between the Rampion 2 site and the Humber Estuary SAC.

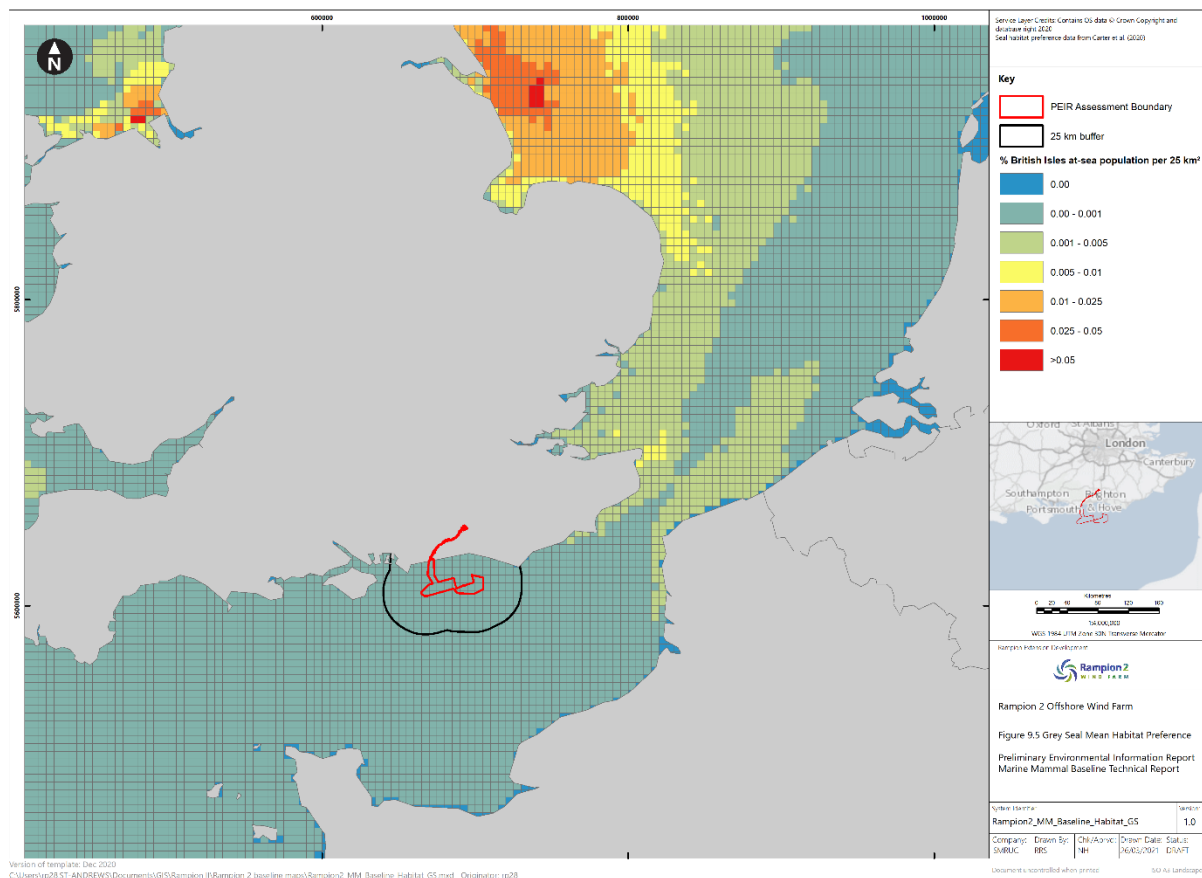
Graphic 9-3 From Carter *et al.* (2020): GPS tracking data for grey seals available for habitat preference models



9.5 At-sea density

- 9.5.1 The at-sea usage maps estimated <1 grey seal within a 25km buffer of the Rampion 2 windfarm array area, which equates to an average of 0.00005 seals/km² (**Graphic 9-4**). The habitat preference maps presented in Carter *et al.* (2020) predicted there to be eight grey seals within a 25km buffer of the site, which equates to an average density of 0.002 seals/km² (**Graphic 9-5**).
- 9.5.2 While the at-sea density estimate is very low for grey seals within the survey area, this may not necessarily be representative of a true lack of usage, since there were no telemetry or haul-out data from the South England MU included in the analysis to inform the usage in this area. In addition, none of the data from grey seals tagged in France or the Wadden Sea were included in the habitat preference analysis to inform the usage in this area.

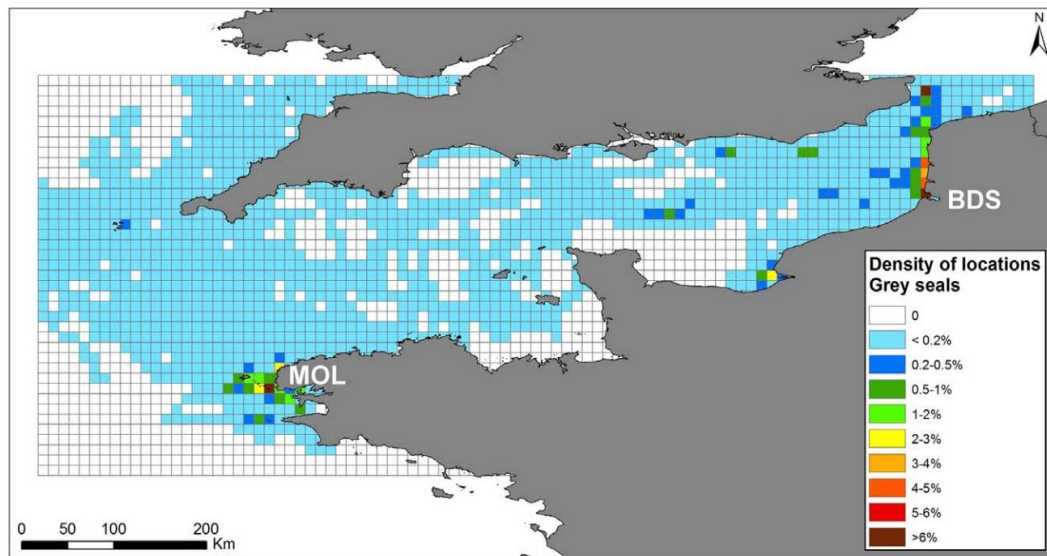
Graphic 9-4 Grey seal at-sea usage estimates (Russell *et al.*, 2017)

Graphic 9-5 Grey seal habitat preference map (Carter *et al.* 2020)

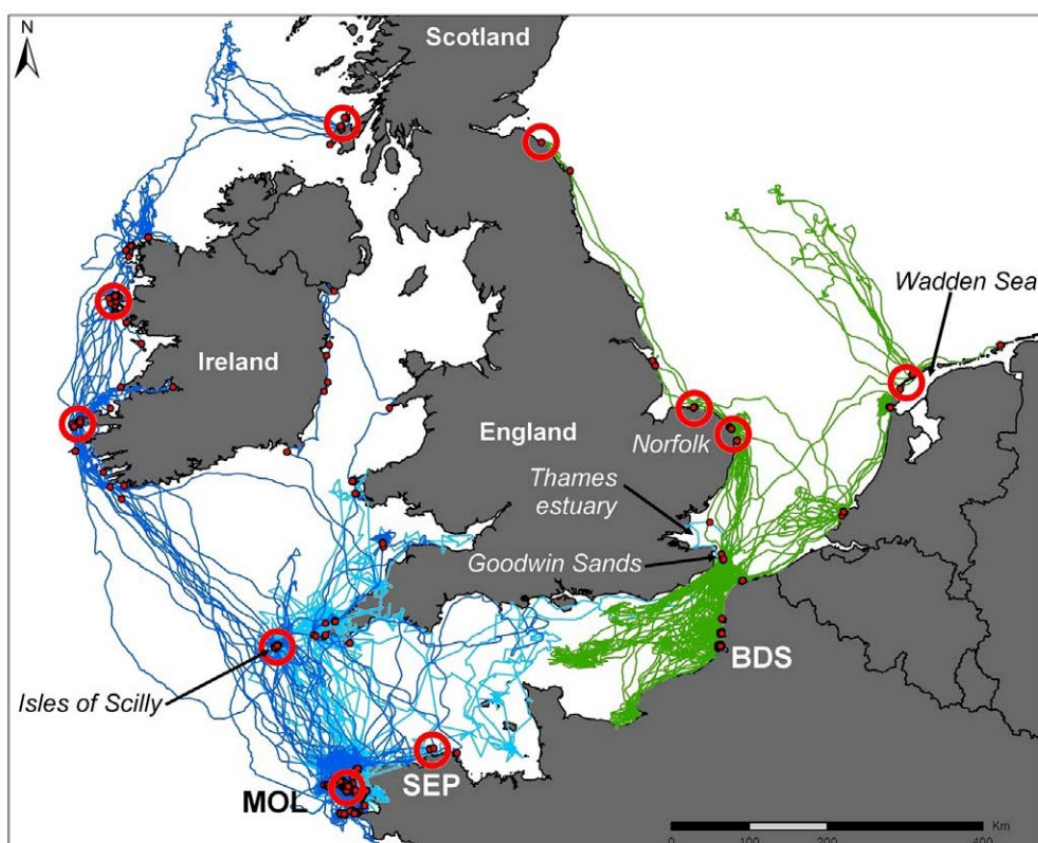
9.6 French seal data

- 9.6.1 Data collected and reported on by Vincent *et al.* (2017) on the abundance of harbour and grey seals along the French coast of the English Channel reported clear evidence that grey seals exhibit wide-ranging movement behaviours. Grey seals tagged in France recorded telemetry data throughout the English Channel, the Wadden Sea and in the vicinity of the Rampion 2 survey area (**Graphic 9-6** and **Graphic 9-7**). Therefore, grey seals will need to be considered in the transboundary assessment of the Environmental Impact Assessment (EIA) for Rampion 2 due to potential impacts that may occur to this species.
- 9.6.2 The fact that the data presented in Vincent *et al.* (2017) show connectivity between French waters, the Wadden Sea and the English Channel highlights a limitation of the current seal habitat preference maps. The current version of the habitat preference maps includes only grey seals tagged in the UK, and therefore does not account for the presence of grey seals from France or the Wadden Sea. Therefore, it is highly likely that the seal habitat preference maps underestimate the true density of grey seals present in the English Channel and in the vicinity of Rampion 2 since these seals from these other populations are not included.

Graphic 9-6 From Vincent *et al.* (2017): Density of grey seal locations (per grid cell) obtained by telemetry from 1999 to 2013, from individuals captured in MOL and BDS



Graphic 9-7 From Vincent *et al.* (2017): Grey seal telemetry tracks



Note: MOL = 15 individuals tracked by Argos tags from 1999 to 2003, in light blue, and 19 individuals tracked by GPS/Global System for Mobile communications (GSM) tags from 2010 to 2013, in dark blue. BDS = 11 individuals tracked in 2012, in green. Red dots indicate haul-out locations of the seals. Thick, red circles indicate breeding locations, as suggested from the activity budget of the seals.

10. Conclusions

- 10.1.1 From the data outlined above it is concluded that Rampion 2 is not an important site for any marine mammal species and predicted densities of all species are relatively low. The main species present during the Rampion 2 site-specific surveys were harbour porpoise with some sightings of common dolphins and seal species. Bottlenose dolphins and minke whales have also been sighted during local and opportunistic surveys and so it is recommended that they are also scoped into the quantitative impact assessment for Rampion 2. Given the lack of white-beaked dolphins sightings during the Rampion 2 surveys, SCANS III, JCP or ORCA surveys, it is recommended that this species is scoped out. The recommended MU and density estimate for each species to be used in the quantitative impact assessment for Rampion 2 are presented in **Table 10-1**.

Table 10-1 Marine mammal reference population and density estimates recommended for use in the Rampion 2 impact assessment.

Species	Density (#/km ²)	Source	Reference Population	Reference Population size	Source
Harbour porpoise	0.213	SCANS III (Hammond <i>et al.</i> , 2017)	North Sea MU	345,373	(Hammond <i>et al.</i> , 2017)
Bottlenose dolphin	0.037	SAMMS surveys (Laran <i>et al.</i> , 2017)	Offshore Channel and SW England	4,856	(IAMMWG, 2015b)
White-beaked dolphin	Scoped out				
Common dolphin	0.171	SAMMS surveys (Laran <i>et al.</i> , 2017)	Celtic and Greater North Seas	56,556	(IAMMWG, 2015b)
Minke whale	0.002	SCANS III (Hammond <i>et al.</i> , 2017)	Celtic and Greater North Seas	23,528	(IAMMWG, 2015b)
Harbour seal	Grid cell specific	Habitat preference (Carter <i>et al.</i> , 2020)	50 percent South & South-east England MUs combined	2,633	2019 counts provided by SMRU

Species	Density (#/km ²)	Source	Reference Population	Reference Population size	Source
Grey seal	Grid cell specific	Habitat preference (Carter <i>et al.</i> , 2020)	South and South-east England MUs combined	36,368	2019 counts provided by SMRU

11. Glossary of terms

Table 11-1 Glossary of terms and abbreviations

Term (acronym)	Definition
Baseline	Refers to existing conditions as represented by latest available survey and other data which is used as a benchmark for making comparisons to assess the impact of development.
BDA	baie d'Authie
BDS	baie de Somme
BDV	baie des Veys
BEIS	Department for Business Energy and Industrial Strategy
BSM	baie du Mont-Saint-Michel
Centre for Environment Fisheries and Aquaculture Science (Cefas)	The Government's marine and freshwater science experts, advising the UK government and overseas partners.
Cetacean	Aquatic mostly marine mammals that includes the whales, dolphins, porpoises.
CI	Confidence Interval
cm	Centimetre
CV	Coefficient of Variation
°	Degree
Environmental Impact Assessment (EIA)	The process of evaluating the likely significant environmental effects of a proposed project or development over and above the existing circumstances (or 'baseline').
Environmental Statement (ES)	The written output presenting the full findings of the Environmental Impact Assessment.
ETG	Expert Topic Group
European Union (EU)	The union of 27 European member states.

Term (acronym)	Definition
Evidence Plan Process (EPP)	A voluntary consultation process with specialist stakeholders to agree the approach and the information required to support the EIA and HRA for certain aspects
FCS	Favourable Conservation Status
GPS	Global Positioning System
GSD	Ground Sampling Distance
GSM	Global System for Mobile communications
IAMMWG	Inter-Agency Marine Mammal Working Group
Impact	The changes resulting from an action.
JCP	Joint Cetacean Protocol
Joint Nature Conservation Committee (JNCC)	JNCC is the public body that advises the UK Government and devolved administrations on UK-wide and international nature conservation.
km	Kilometre
km²	Square Kilometre
Management Unit (MU)	The cetacean MUs have been defined to provide an indication of the spatial scales at which impacts of plans and projects alone, cumulatively and in-combination, need to be assessed for the key cetacean species in UK waters, with consistency across the UK. Seal MUs are geographic areas within which seal populations are considered.
Marine Management Organisation (MMO)	MMO is an executive non-departmental public body, sponsored by the Department for Environment, Food & Rural Affairs. MMO license, regulate and plan marine activities in the seas around England so that they're carried out in a sustainable way.
MERP	Marine Ecosystems Research Programme
MOL	Molene Archipelago
MPA	Marine Protected Areas

Term (acronym)	Definition
n	Number
Natural England	The government advisor for the natural environment in England
NERC	Natural Environment Research Council
Offshore	The sea further than two miles from the coast.
Offshore Wind Farm	An offshore wind farm is a group of wind turbines in the same location (offshore) in the sea which are used to produce electricity
p.a.	Per Annum
/km²	Per Square Kilometre
PDV	Phocine Distemper Virus
Preliminary Environmental Information Report (PEIR)	The written output of the Environmental Impact Assessment undertaken to date for the Proposed Development. It is developed to support formal consultation and presents the preliminary findings of the assessment to allow an informed view to be developed of the Proposed Development, the assessment approach that has been undertaken, and the preliminary conclusions on the likely significant effects of the Proposed Development and environmental measures proposed.
Proposed Development	The development that is subject to the application for development consent, as described in Chapter 4.
Rampion 1	The existing Rampion Offshore Wind Farm located in the English Channel off the south coast of England.
RED	Rampion Extension Development Limited
SAMM	Suivi Aérien de la Mégafaune Marine
SCANS	Small Cetaceans in European Atlantic waters and the North Sea
Scoping Report	A report that presents the findings of an initial stage in the Environmental Impact Assessment process.

Term (acronym)	Definition
SCOS	Special Committee on Seals
SEP	Sept iles archipelago
SMRU	Sea Mammal Research Unit
SNH	Scottish Natural Heritage (now known as NatureScot)
Special Area of Conservation (SAC)	International designation implemented under the Habitats Regulations for the protection of habitats and (non-bird) species. Sites designated to protect habitats and species on Annexes I and II of the Habitats Directive. Sufficient habitat to maintain favourable conservation status of the particular feature in each member state needs to be identified and designated.
Stakeholder	Person or organisation with a specific interest (commercial, professional or personal) in a particular issue.
Study area	Area where potential impacts from the Proposed Development could occur, as defined for each aspect.
TCE	The Crown Estate
The Proposed Development / Rampion 2	The onshore and offshore infrastructure associated with the offshore wind farm comprising of installed capacity of up to 1200 MW, located in the English Channel in off the south coast of England.
Transboundary effects	Assessment of changes to the environment caused by the combined effect of past, present and future human activities and natural processes on other European Economic Area Member States.
TWT	The Wildlife Trust
UK	United Kingdom
WAL	Walde
WWT	Wildfowl & Wetlands Trust

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4.11.2



Volume 4, Appendix 11.2

Marine mammal quantitative underwater noise impact assessment



Executive summary

This report has been produced to provide the quantitative underwater noise impact assessment for marine mammals from pile driving at the Rampion 2 project. The following marine mammal species were included in the quantitative assessment: harbour porpoise, bottlenose dolphins, common dolphins, minke whales, harbour seals and grey seals. For each of these species, the impacts of permanent threshold shift (PTS)-onset, temporary threshold shift (TTS)-onset and behavioural disturbance from pile driving activities at Rampion 2 are assessed. The assessment includes three model locations within the array area to demonstrate differing water depths and propagation conditions, both monopiles and pin-piles and both a worst case and most likely piling profile. The assessment also includes the implementation of embedded mitigation in the form of a Marine Mammal Mitigation Plan (MMMP) to reduce the risk of PTS-onset to negligible levels. This is considered to be sufficient and therefore the quantitative underwater noise impact assessment concludes that there is **no significant impact** predicted to marine mammals from the pile driving activities, and that no additional mitigation outside of the MMMP is considered to be required.

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1. Introduction

- 1.1.1 Rampion Extension Development Limited (RED) is proposing to develop the Rampion 2 Offshore Wind Farm Project (Rampion 2) located adjacent to the existing Rampion Offshore Wind Farm (Rampion 1) located in the English Channel in the south of England.
- 1.1.2 SMRU Consulting was commissioned by the Applicant to undertake a quantitative assessment for the impact of pile driving noise during construction of Rampion 2 on marine mammals. This report focuses only on the pile driving activities during construction, all other impact pathways are presented in the Preliminary Environmental Information Report (PEIR) **Chapter 11: Marine mammals, Volume 2**.
- 1.1.3 This technical report should be read in conjunction with:
- **Appendix 11.1: Marine mammal baseline technical report, Volume 4;**
 - **Appendix 11.3: Underwater noise assessment technical report, Volume 4;** and
 - **PEIR Chapter 11: Marine mammals, Volume 2.**

1.2 Purpose

- 1.2.1 The purpose of this technical report is to provide the full quantitative noise impact assessment for pile driving, which will be used to inform the marine mammal chapter of the PEIR to support the Development Consent Order (DCO) Application for Rampion 2 under the Planning Act 2008 (the 2008 Act).
- 1.2.2 This technical report:
- presents a summary of the results of the baseline characterisation for marine mammals;
 - presents the methodology used to assess the impact of underwater noise from pile driving activities during the construction of Rampion 2 on marine mammals;
 - presents details on the assumptions and limitations of the assessment methodologies; and
 - presents the results for the impact of permanent threshold shift (PTS)-onset, temporary threshold shift (TTS)-onset and behavioural disturbance from pile driving on harbour porpoise, bottlenose dolphins, common dolphins, minke whales, harbour seals and grey seals.

1.3 Baseline summary

- 1.3.1 The marine mammal baseline characterisation is presented in **Appendix 11.1, Volume 4**. The baseline characterisation details the occurrence of marine mammal species present in the Rampion 2 study area, compiled through a

combination of a literature reviews and data obtained from site-specific surveys. The conclusion of the baseline characterisation is a set of recommended density estimates and Management Units (MU) for each species to be used in this quantitative noise impact assessment (**Table 1-1**).

Table 1-1 Marine mammal Management Units (MUs) and density estimates used in the quantitative impact assessment.

	MU	MU size	Density	Density source
Harbour porpoise	North Sea	345,373	0.213	Small Cetaceans in European Atlantic waters and the North Sea (SCANS) III (Hammond <i>et al.</i> , 2017)
Bottlenose dolphin	Offshore Channel and SW England	4,856	0.037	Suivi Aérien de la Mégafaune Marine (SAMMS) surveys (Laran <i>et al.</i> , 2017)
Common dolphin	Celtic and Greater North Seas	56,556	0.171	SAMMS surveys (Laran <i>et al.</i> , 2017)
Minke whale	Celtic and Greater North Seas	23,528	0.002	SCANS III (Hammond <i>et al.</i> , 2017)
Harbour seal	50 percent South and South-east England MUs combined	2,633	Grid cell specific	Habitat preference map (Carter <i>et al.</i> , 2020)
Grey seal	South and Southeast England MUs combined	36,368	Grid cell specific	Habitat preference map (Carter <i>et al.</i> , 2020)

2. Assessment methodology

This section outlines the marine mammal piling noise impact assessment methodology. This includes definitions of magnitude and sensitivity, pile driving parameters, modelling locations, description of the thresholds used for the PTS-onset, TTS-onset and behavioural disturbance assessment and an assessment of the sensitivity of the different species to PTS-onset and behavioural disturbance from pile driving. In addition to this, the assumptions and limitations associated with the assessment methodology is detailed.

2.1 Impact criteria

- 2.1.1 The criteria for determining the significance of effects is a two-stage process that involves defining the sensitivity of the receptors and then predicting the magnitude of the impact. This section describes the criteria applied in this chapter to assign values to the sensitivity of receptors and the magnitude of potential impacts. The criteria for defining marine mammal sensitivity are outlined in **Table 2-1** and the criteria for defining magnitude are outlined in **Table 2-2**. The significance of the impact on marine mammals is determined by a matrix combining the magnitude of the impact and the sensitivity of the receptor. The impact significance matrix is presented in Error! Reference source not found..

Table 2-1 Definition of terms relating to marine mammal sensitivity

Sensitivity	Definition
Very High	<p>No ability to adapt behaviour so that survival and reproduction rates are affected.</p> <p>No tolerance – Effect will cause a change in both reproduction and survival rates.</p> <p>No ability for the animal to recover from any impact on vital rates (reproduction and survival rates).</p>
High	<p>Limited ability to adapt behaviour so that survival and reproduction rates may be affected.</p> <p>Limited tolerance – Effect may cause a change in both reproduction and survival of individuals.</p> <p>Limited ability for the animal to recover from any impact on vital rates (reproduction and survival rates).</p>
Medium	<p>Ability to adapt behaviour so that reproduction rates may be affected but survival rates not likely to be affected.</p> <p>Some tolerance – Effect unlikely to cause a change in both reproduction and survival rates.</p> <p>Ability for the animal to recover from any impact on vital rates (reproduction and survival rates).</p>

Sensitivity	Definition
Low	Receptor is able to adapt behaviour so that survival and reproduction rates are not affected. Receptor is able to tolerate the effect without any impact on reproduction and survival rates. Receptor is able to return to previous behavioural states/activities once the impact has ceased.

Table 2-2 Definition of terms relating to magnitude of impact

Magnitude	Definition
Major	The impact would affect the behaviour and distribution of sufficient numbers of individuals, with sufficient severity, to affect the favourable conservation status and/or the long-term viability of the population at a generational scale (Adverse).
Moderate	Temporary changes in behaviour and/or distribution of individuals at a scale that would result in potential reductions to lifetime reproductive success to some individuals although not enough to affect the population trajectory over a generational scale. Permanent effects on individuals that may influence individual survival but not at a level that would alter population trajectory over a generational scale (Adverse).
Minor	Short-term and/or intermittent and temporary behavioural effects in a small proportion of the population. Reproductive rates of individuals may be impacted in the short term (over a limited number of breeding cycles). Survival and reproductive rates very unlikely to be impacted to the extent that the population trajectory would be altered (Adverse).
Negligible	Very short term, recoverable effect on the behaviour and/or distribution in a very small proportion of the population. No potential for the any changes in the individual reproductive success or survival therefore no changes to the population size or trajectory (Adverse).

Table 2-3 Level of significance of an impact

		Magnitude			
		Major	Moderate	Minor	Negligible
Sensitivity	Very High	Major (Significant)	Major (Significant)	Moderate (Potentially significant)	Minor (Not significant)
	High	Major (Significant)	Moderate (Potentially significant)	Minor (Not significant)	Minor (Not significant)
	Medium	Moderate (Potentially significant)	Minor (Not significant)	Minor (Not significant)	Negligible (Not significant)
	Low	Minor (Not significant)	Minor (Not significant)	Negligible (Not significant)	Negligible (Not significant)

2.2 Piling parameters

- 2.2.1 The noise levels likely to occur as a result of the construction of Rampion 2 were predicted by Subacoustech Environmental Ltd using their INSPIRE (Impulse Noise Sound Propagation and Impact Range Estimator) model. A detailed description of the modelling approach is presented in **Appendix 11.3, Volume 4**.
- 2.2.2 Recent industry operational experience when installing offshore wind farms has shown that the actual hammer energies used during construction have been much lower than the maximum design scenario parameters defined during the Environmental Statement (ES) assessments. In recognition of this, both a worst case scenario and a most likely scenario for both monopiles (**Table 2-4** and **Table 2-5**) and pin-piles (**Table 2-6** and **Table 2-7**) are presented to cover the absolute maximum piling parameters that would ever be required to install a foundation (in terms of maximal hammer energies and longest piling durations) alongside the piling parameters that are considered to be more representative of the majority of the piling activity across the site.
- 2.2.3 For the calculation of cumulative PTS and TTS-onset from monopiles, the assumption has been made that two monopiles can be installed concurrently in a 24-hour period (for example, two vessels piling at the same time: one at the NW location and one at the E location). Given that the capacity of Rampion 2 is for up to 116 Wind Turbine Generator (WTG), this results in a total of 58 piling days assuming two monopiles are concurrently installed in one 24-hour period.
- 2.2.4 For the calculation of cumulative PTS and TTS-onset from pin-piles, the assumption has been made that four pin-piles can be installed at one location in a 24-hour period. Given that the capacity of Rampion 2 is for up to 116 WTGs with 4 pins per jacket, this results in a total number of 116 piling days assuming 4 pin-piles are installed in one 24-hour period.

Table 2-4 Worst case scenario piling parameters for monopiles

Stage	Soft-start	Ramp-up			Full
Percent energy	20	40	60	80	100
Hammer energy (kilojoule (kJ))	880	1,760	2,640	3,520	4,400
# strikes	75	75	113	113	8,400
Duration (min)	7.5	7.5	7.5	7.5	240

Table 2-5 Most likely scenario piling parameters for monopiles

Stage	Soft-start	Ramp-up			Full
Percent energy	20	40	60	80	100
Hammer energy (kJ)	800	1,600	2,400	3,200	4,000
# strikes	75	75	113	113	5,075
Duration (min)	7.5	7.5	7.5	7.5	145

Table 2-6 Worst case scenario piling parameters for pin-piles

Stage	Soft-start	Ramp-up			Full
Percent energy	20	40	60	80	100
Hammer energy (kJ)	500	1,000	1,500	2,000	2,500
# strikes	75	75	113	113	8,400
Duration (min)	7.5	7.5	7.5	7.5	240

Table 2-7 Most likely scenario piling parameters for pin-piles

Stage	Soft-start	Ramp-up			Full
Percent energy	20	40	60	80	100
Hammer energy (kJ)	400	800	1,200	1,600	2,000
# strikes	75	75	113	113	5,075
Duration (min)	7.5	7.5	7.5	7.5	145

2.3 Piling locations

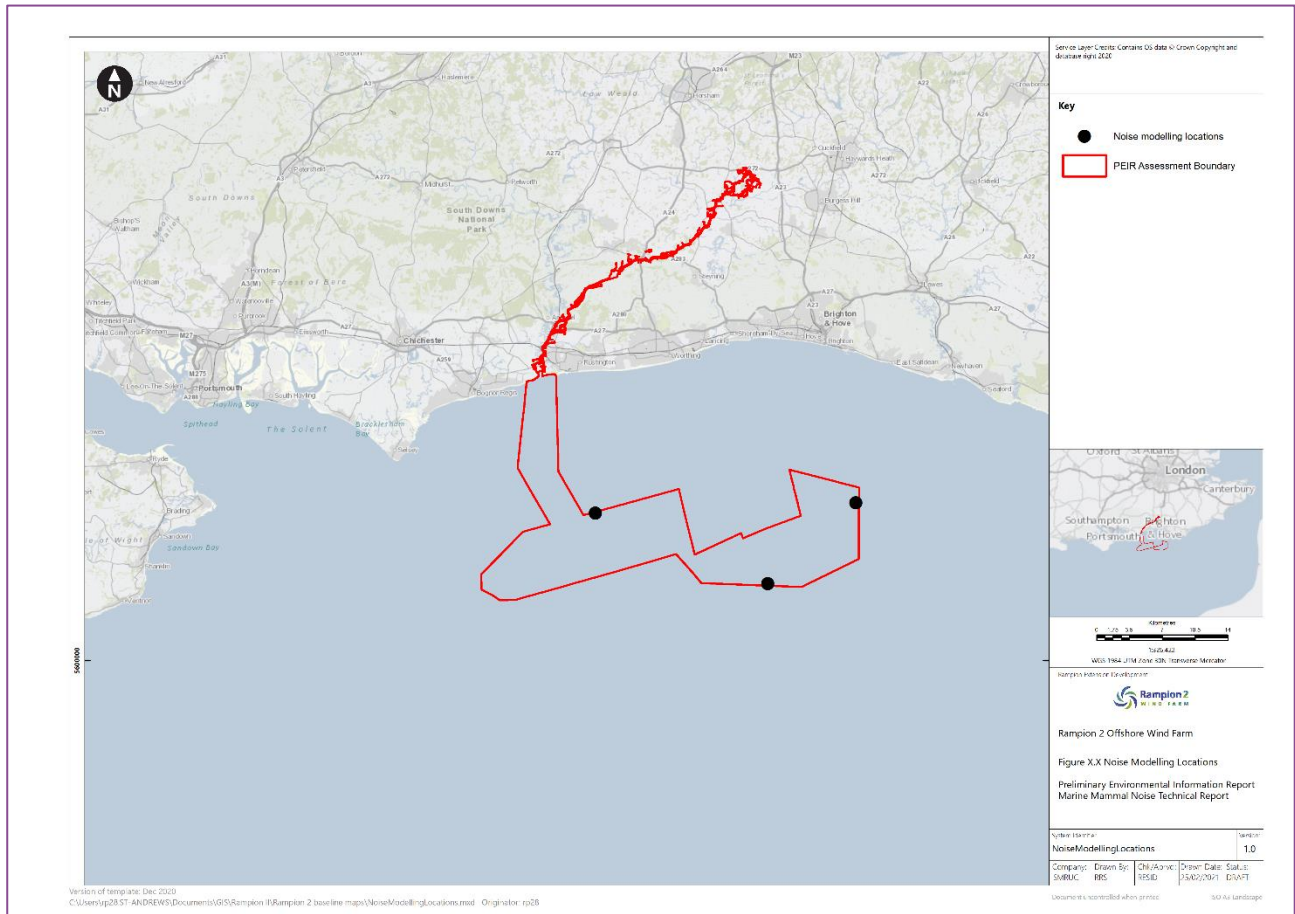
2.3.1

A total of three piling locations have been considered: North west, South and East (**Graphic 2-1**). Both monopiles and pin-piles are considered at the northwest and east locations, but only pin-piles are considered at the south location due to the depth of the water in that corner of the array area. Details of the three piling locations are provided in **Table 2-8**.

Table 2-8 Piling locations included in the underwater noise modelling

Location	Latitude	Longitude	Depth (m)	Pile type
Northwest	50.6659	-0.4924	17.4	Monopiles and pin-piles
South	50.5926	-0.2365	53.4	Pin-piles only
East	50.6667	-0.0993	44.2	Monopiles and pin-piles

Graphic 2-1 Underwater noise modelling locations used for the quantitative impact assessment for pile driving



2.4 Thresholds

Permanent threshold shift (PTS) assessment

2.4.1

For marine mammals, the main impact from Rampion 2 will be as a result of underwater noise produced during construction. Therefore, a detailed assessment has been provided for this impact pathway. Exposure to loud sounds can lead to a reduction in hearing sensitivity (a shift in hearing threshold), which is generally restricted to particular frequencies. This threshold shift results from physical injury to the auditory system and may be temporary (TTS) or permanent (PTS). The PTS and TTS onset thresholds used in this assessment are those presented in Southall *et al.* (2019). The method used to calculate PTS-onset impact ranges for both 'instantaneous' PTS (peak sound pressure level (SPL_{peak})), and 'cumulative' PTS (cumulative sound exposure level (SEL_{cum}), over 24 hours) are detailed in **Appendix 11.3, Volume 4**.

Table 2-9 PTS-onset thresholds for impulsive noise (from Southall *et al* 2019)

Hearing group	Species	Cumulative PTS (SEL _{cum} dB re 1 µPa ² s weighted)	Instantaneous PTS (SPL _{peak} dB re 1 µPa unweighted)
Low-Frequency (LF) cetacean	Minke whale	183	219
High-Frequency (HF) cetacean	Bottlenose dolphin Common dolphin	185	230
Very High-Frequency (VHF) cetacean	Harbour porpoise	155	202
Phocid	Harbour seal Grey seal	185	218

2.4.2 In calculating the received noise level that animals are likely to receive during the whole piling sequence, all animals were assumed to start moving away at a swim speed of 1.5 metres per second (m/s) once the piling has started (based on reported sustained swimming speeds for harbour porpoises) (Otani *et al.*, 2000), except for minke whales which are assumed to swim at a speed of 3.25m/s (Blix and Folkow, 1995). The calculated PTS and TTS-onset impact ranges therefore represent the minimum starting distances from the piling location for animals to escape and prevent them from receiving a dose higher than the threshold.

Table 2-10 Marine mammal swimming speed used in the cumulative PTS-onset assessment

Hearing group	Species	Speed (m/s)
LF cetacean	Minke whale	3.25
HF cetacean	Bottlenose dolphin and Common dolphin	1.5
VHF cetacean	Harbour porpoise	1.5
Phocid	Harbour seal and Grey seal	1.5

Temporary threshold shift (TTS) assessment

2.4.3 SMRU Consulting appreciate that TTS is a temporary impairment of an animal's hearing ability with potential consequences for the animal's ability to escape predation, forage and/or communicate, supporting the statement of Kastelein *et al.* (2012c) that "*the magnitude of the consequence is likely to be related to the duration and magnitude of the TTS*". We would, however, like to point out that an assessment of the impact based on the TTS thresholds as currently given in

Southall *et al.* (2019) (or the former National Marine Fisheries Service (NMFS) (2016) guidelines and Southall *et al.* (2007) guidance) would lead to a substantial overestimate of the potential impact of TTS. Furthermore, SMRU Consulting believe that the prediction of TTS impact ranges, based on the sound exposure level (SEL) thresholds, are subject to the same inherent uncertainties as those for PTS, and in fact the uncertainties may be considered to have a proportionately larger effect on the prediction of TTS. We will explain these points in detail below based on the thresholds detailed by Southall *et al.* (2019), as these are based upon the most up-to-date scientific knowledge.

2.4.4

SMRU Consulting believe that basing any impact assessment on the impact ranges for TTS using current TTS thresholds would overestimate the potential for an ecologically significant effect. This is because the species specific TTS-thresholds in Southall *et al.* (2019) describe those thresholds at which the **onset of TTS** is observed, which is, per their definition, a 6 decibel (dB) shift in the hearing threshold, usually measured four minutes after sound exposure, which is considered as “*the minimum threshold shift clearly larger than any day-to-day or session-to-session variation in a subject’s normal hearing ability*”, and which “*is typically the minimum amount of threshold shift that can be differentiated in most experimental conditions.*” The time hearing recovers back to normal (the recovery time) for such small threshold shifts is expected to be less than an hour, and therefore unlikely to cause any major consequences for an animal. A large shift in the hearing threshold near to values that may cause PTS may however may require multiple days to recover (Finneran, 2015). For TTS induced by steady-state tones or narrowband noise, Finneran (2015) describes a logarithmic relationship between recovery rate and recovery time, expressed in dB/decade (with a decade corresponding to a ratio of 10 between two time intervals, resulting in steps of 10, 100, 1000 minutes and so forth): For an initial shift of 5 to 15dB above hearing threshold, TTS reduced by 4 to 6dB per decade for dolphins, and 4 to 13dB per decade for harbour porpoise and harbour seals. Larger initial TTS tend to result in faster recovery rates, although the total time it takes to recover is usually longer for larger initial shifts (summarised in Finneran, 2015). While the rather simple logarithmic function fits well for exposure to steady-state tones, the relationship between recovery rate and recovery time might be more complex for more complex broadband sound, such as that produced by pile driving noise. For small threshold shifts of 4 to 5dB caused by pulsed noise, Kastelein *et al.* (2016) demonstrated that porpoises recovered within one hour from TTS. While the onset of TTS has been experimentally validated, the determination of a threshold shift that would cause a longer term recovery time and is therefore potentially ecologically significant, is complex and associated with much uncertainty. The degree of TTS and the duration of recovery time that may be considered severe enough to lead to any kind of energetic or fitness consequences for an individual, is currently undetermined, as is how many individuals of a population can suffer this level of TTS before it may lead to population consequences. There is currently no set threshold for the onset of a biologically meaningful TTS, and this threshold is likely to be well above the TTS-onset threshold, leading to smaller impact ranges (and consequently much smaller impact areas, considering a squared relationship between area and range) than those obtained for the TTS-onset threshold. One has to bear in mind that the TTS-onset thresholds as recommended first by Southall *et al.* (2007) and further revised by Southall *et al.* (2019) were determined as a means to be able to determine the PTS-onset

thresholds and represents *the smallest measurable degree of TTS above normal day to day variation*. A direct determination of PTS-onset thresholds would lead to an injury of the experimental animal and is therefore considered as unethical. Guidelines such as National Academies of Sciences Engineering and Medicine (2016) and Southall *et al.* (2007) therefore rely on available data from humans and other terrestrial mammals that indicate that a shift in the hearing threshold of 40dB may lead to the onset of PTS.

2.4.5

For pile driving for offshore wind farm foundations, the TTS and PTS-onset thresholds for impulsive sound are the appropriate thresholds to consider. These consist of a dual metric, a threshold for the peak sound pressure associated with each individual hammer strike, and one for the SEL_{cum} , for which the sound energy over successive strokes is summated. The SEL_{cum} is based on the assumption that each unit of sound energy an animal is exposed to leads to a certain amount of threshold shift once the cumulated energy raises above the TTS-onset threshold. For impulsive sound, the threshold shift that is predicted to occur is 2.3dB per dB noise received; for non-impulsive sound this rate is smaller (1.6dB per dB noise) (Southall *et al.*, 2007). The SEL_{cum} thresholds were determined with the assumption that a) the amount of sound energy an animal is exposed to within 24-hours will have the same effect on its auditory system, regardless of whether it is received all at once or in several smaller units spread over a longer period (called the equal-energy hypothesis), and b) the sound keeps its impulsive character regardless of the distance to the sound source. Both assumptions lead to a conservative determination of the impact ranges, as a) the magnitude of TTS induced might be influenced by the time interval in-between successive pulses, with some time for TTS recovery in-between pulses (for example, Kastelein *et al.*, 2014, Finneran *et al.*, 2010), therefore recovery may be possible in the gaps between individual pile strikes and in any short breaks in piling activity, and b) an impulsive sound will eventually lose its impulsive character while propagating through the water column, therefore becoming non-impulsive (as described in NMFS, 2016, Southall *et al.*, 2019, Hastie *et al.*, 2019), and then causing a smaller rate of threshold shift (see above). Modelling the SEL_{cum} impact ranges of PTS with a 'fleeing animal' model (as is typical during in noise impact assessments) are subject to both of these precautions. Modelling the SEL_{cum} TTS impact ranges will inherit the same uncertainties, however, over a longer period of time, and over greater ranges as the TTS impact ranges are expected to be larger than those of PTS. Therefore, these uncertainties and conservativisms will have a relatively larger effect on predictions of TTS ranges.

2.4.6

It is also important to bear in mind that the quantification of any impact ranges in the environmental assessment process, is done so to inform an assessment of the potential magnitude and significance of an impact. Because the TTS thresholds are not universally used to indicate a level of biologically meaningful impact of concern *per se* but are used to enable the prediction of where PTS might occur, it would be very challenging to use them as the basis of any assessment of impact significance. While SMRU Consulting agree with the conclusion that because all of the data that exists on auditory injury in marine mammals is from studies of TTS, and not PTS, we may be more confident in our prediction of the range at which any TTS may occur, this is not necessarily very useful for the impact assessment process. We accept that scientific understanding of the degree of exposure required to elicit TTS may be more empirically based than our ability to predict the

degree of sound required to elicit PTS, it does not automatically follow that our ability to determine the consequences of a stated level of TTS for individuals is any more certain than our ability to determine the consequences of a stated level of PTS for individuals. It could even be argued that we are more confident in our ability to predict the consequences of a permanent effect than we are to predict the consequences of a temporary effect of variable severity and uncertain duration.

- 2.4.7 It is important to consider that predictions of PTS and TTS are linked to potential changes in hearing sensitivity at particular hearing frequencies, which for piling noise are generally thought to occur in the 2 to 10 kilohertz (kHz) range, and are not considered to occur across the whole frequency spectrum. Studies have shown that exposure to impulsive pile driving noise induces TTS in a relatively narrow frequency band in harbour porpoise and harbour seals (reviewed in Finneran, 2015), with statistically significant TTS occurring at 4 and 8kHz (Kastelein *et al.*, 2016) and centred at 4kHz (Kastelein *et al.*, 2012a, Kastelein *et al.*, 2012b, Kastelein *et al.*, 2013, Kastelein *et al.*, 2017). Our understanding of the consequences of PTS within this frequency range to an individual's survival and fecundity is limited, and therefore our ability to predict and assess the consequences of TTS of variable severity and duration is even more difficult to do.
- 2.4.8 The ranges that indicate TTS-onset were modelled and are presented alongside an estimate of the potential number of animals within these impact ranges. However, as TTS-onset is defined primarily as a means of predicting PTS-onset, there is currently no threshold for TTS-onset that would indicate a biologically significant amount of TTS; therefore it was not possible to carry out a quantitative assessment of the magnitude or significance of the impact of TTS on marine mammals. This approach was agreed with the Centre for Environment Fisheries and Aquaculture Science (Cefas) at the Expert Topic Group (ETG) at the meeting dated 18 September 2020 as part of the Evidence Plan Process (EPP).

Table 2-11 TTS-onset thresholds for impulsive noise (from Southall *et al* 2019)

Hearing group	Species	Cumulative TTS (SEL _{cum} dB re 1 μPa ² s weighted)	Instantaneous TTS (SPL _{peak} dB re 1 μPa unweighted)
LF cetacean	Minke whale	168	213
HF cetacean	Bottlenose dolphin Common dolphin	170	224
VHF cetacean	Harbour porpoise	140	196
Phocid	Harbour seal Grey seal	170	212

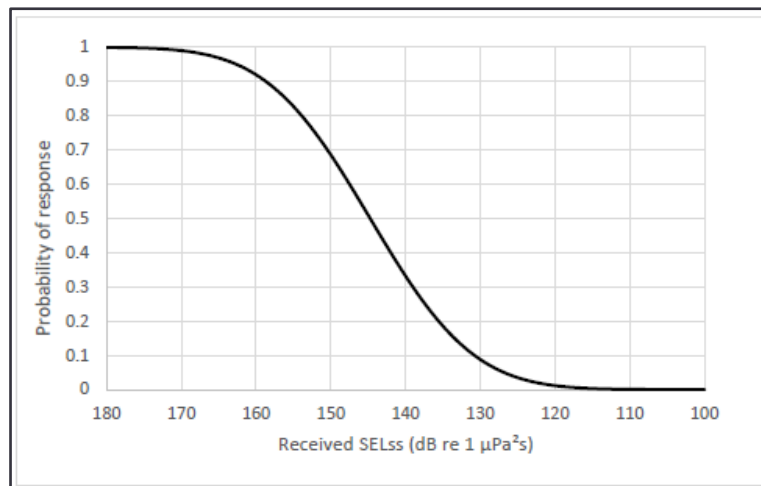
Disturbance assessment

- 2.4.9 The assessment of disturbance was based on the current best practice methodology, making use of the best available scientific evidence. This

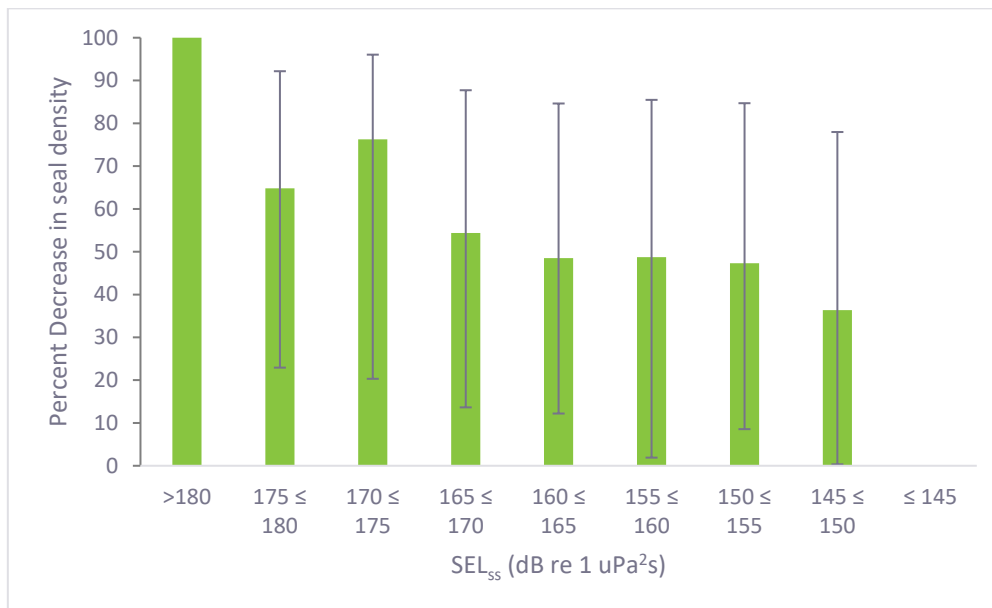
incorporated the application of a species-specific dose-response approach rather than a fixed behavioural threshold approach. Noise contours at 5dB intervals were generated by noise modelling and were overlain on species density surfaces to predict the number of animals potentially disturbed. This allowed for the quantification of the number of animals that will potentially respond.

- 2.4.10 The dose-response curve adopted in this assessment for all harbour porpoise (**Graphic 2-2**) was developed by Graham *et al.* (2017a) and was generated from data on harbour porpoises collected during the first six weeks of piling during Phase 1 of the Beatrice Offshore Wind Farm monitoring program. There is no corresponding data for any other cetacean species, and as such, the same curve was applied to the disturbance assessment for all cetacean species.
- 2.4.11 For both species of seal, the dose-response curve (**Graphic 2-3**) adopted was based on the data presented in Whyte *et al.* (2020), where the percentage change in harbour seal density was predicted at the Linc offshore windfarm. It has been assumed that all seals are displaced at SELs above 180dB re $1\mu\text{Pa}^2\text{s}$, this is a conservative assumption since there was no data presented in the study for harbour seal responses at this level. It is also important to note that the percentage decrease in response in the categories $170 \leq 175$ and $175 \leq 180$ dB re $1\mu\text{Pa}^2\text{s}$ are slightly anomalous (higher response at a lower SEL) due to the small number of spatial cells included in the analysis for these categories ($n=2$ and 3 respectively). There is no corresponding data for grey seals, and as such, the same curve was applied to the grey seal disturbance assessment.

Graphic 2-2 Relationship between the proportion of porpoise responding and the received single strike SEL (SEL_{ss}) (Graham *et al.* 2017a)



Graphic 2-3 Predicted decrease in seal density as a function of estimated sound exposure level (SEL), error bars show 95 percent confidence interval (CI) (from Whyte *et al.*, 2020)



2.5 Sensitivity

Cetacean sensitivity to PTS

- 2.5.1 The ecological consequences of PTS for marine mammals is uncertain. At a Department for Business, Energy and Industrial Strategy (BEIS) funded expert elicitation workshop held at the University of St Andrews (March 2018), experts in marine mammal hearing discussed the nature, extent and potential consequence of PTS to United Kingdom (UK) marine mammal species (Booth and Heinis, 2018). This workshop outlined and collated the best and most recent empirical data available on the effects of PTS on marine mammals. A number of general points came out in discussions as part of the elicitation. These included that PTS did not mean animals were deaf, that the limitations of the ambient noise environment should be considered and that the magnitude and frequency band in which PTS occurs are critical to assessing the effect on vital rates.
- 2.5.2 Southall *et al.* (2007) defined the onset of TTS as “*being a temporary elevation of a hearing threshold by 6dB*” (in which the reference pressure for the dB is 1 micropascal (μPa)). Although 6dB of TTS is a somewhat arbitrary definition of onset, it has been adopted largely because 6dB is a measurable quantity that is typically outside the variability of repeated thresholds measurements. The onset of PTS was defined as a non-recoverable elevation of the hearing threshold of 6dB, for similar reasons. Based upon TTS growth rates obtained from the scientific literature, it has been assumed that the onset of PTS occurs after TTS has grown to 40dB. The growth rate of TTS is dependent on the frequency of exposure, but is nevertheless assumed to occur as a function of an exposure that results in 40dB of TTS, for instance, 40dB of TTS is assumed to equate to 6dB of PTS.

- 2.5.3 To put this magnitude of loss of sensitivity into context, in humans, hearing loss due to aging can lead to reduction in sensitivity at the highest frequency part of the hearing spectrum of ~10dB. By age 40 this increases to 30dB, by age 60, this can be as much as 70dB in the highest frequencies and 3dB in the mid frequencies. 'Mild' hearing loss in humans is defined as a loss of hearing sensitivity of 20 to 40dB.
- 2.5.4 For piling noise, most energy is between ~30 to 500 hertz (Hz), with a peak usually between 100 to 300Hz and energy extending above 2kHz (Kastelein *et al.*, 2015, Kastelein *et al.*, 2016). Studies have shown that exposure to impulsive pile driving noise induces TTS in a relatively narrow frequency band in harbour porpoise and harbour seals (reviewed in Finneran, 2015), with statistically significant TTS occurring at 4 and 8kHz (Kastelein *et al.*, 2016) and centred at 4kHz (Kastelein *et al.*, 2012a, Kastelein *et al.*, 2012b, Kastelein *et al.*, 2013, Kastelein *et al.*, 2017). Therefore, during the expert elicitation, the experts agreed that any threshold shifts as a result of pile driving would manifest themselves in the 2 to 10kHz range (Kastelein *et al.*, 2017) and that a PTS 'notch' of 6 to 18dB in a narrow frequency band in the 2 to 10kHz region is unlikely to significantly affect the fitness of individuals (ability to survive and reproduce).
- 2.5.5 The low frequency noise produced during piling may be more likely to overlap with the hearing range of low frequency cetacean species such as minke whales. For minke whales, Tubelli *et al.* (2012) estimated the most sensitive hearing range as the region with thresholds within 40dB of best sensitivity, to extend from 30 to 100Hz up to 7.5 to 25kHz, depending on the specific model used. Therefore, a 2 to 10kHz notch of 6dB will only affect a small region of minke whale hearing. In addition, minke whale communication signals have been demonstrated to be below 2kHz (Edds-Walton, 2000, Mellinger *et al.*, 2000, Gedamke *et al.*, 2001, Risch *et al.*, 2013, Risch *et al.*, 2014). Like other mysticete whales, minke whales are also thought to be capable of hearing sounds through their skull bones (Cranford and Krysl, 2015).
- 2.5.6 Although the potential for PTS resulting from exposure to pile driving noise to affect the survival and reproduction of individuals is considered low, given the current uncertainty surrounding these effects and how critical sound can be for echolocation, foraging and communication in cetaceans, all cetaceans have been assessed as having a **Medium** sensitivity to PTS.
- 2.5.7 Data collected during wind farm construction have demonstrated that porpoise detections around the pile driving site decline several hours prior to the start of pile driving, and it is assumed that this is due to the increase in other construction related activities and vessel presence in advance of the actual pile driving (Brandt *et al.*, 2018, Graham *et al.*, 2019, Benhemma-Le Gall *et al.*, 2020). Therefore, the presence of construction related vessels prior to the start of piling can act as a local scale deterrent for harbour porpoise and therefore reduce the risk of auditory injury. Assumptions that harbour porpoise are present in the vicinity of the pile driving at the start of the soft start are therefore likely to be overly conservative.

Seal sensitivity to PTS

- 2.5.8 Seals are less dependent on hearing for foraging than cetaceans, but rely on sound for communication and predator avoidance (Deecke *et al.*, 2002). Seals

have very well developed tactile sensory systems that are used for foraging (Dehnhardt *et al.*, 2001) and Hastie *et al.* (2015) reported that, based on calculations of SEL of tagged seals during the Lincs Offshore Windfarm construction, at least half of the tagged seals would have received a dose of sound greater than published thresholds for PTS. A recent update of this analysis using the revised Southall *et al.* (2019) thresholds and weighting reduced this proportion to 25 percent of the seals (Russell and Hastie, 2017). Based on the extent of the offshore wind farm construction in the Wash over the last ten years and the degree of overlap with the foraging ranges of harbour seals in the region (Russell *et al.*, 2016), it would not be unreasonable to suggest that a large number of individuals of the Wash population may have experienced levels of sound with the potential to cause hearing loss.

- 2.5.9 The Wash harbour seal population has been increasing over this period which may provide an indication that either: a) seals are not developing PTS despite predictions of exposure that would indicate that they should; or b) that the survival and fitness of individual seals are not affected by PTS. Point a) would indicate that methods for predicting PTS are perhaps unreliable and/or over precautionary, and b) would suggest a lack of sensitivity to the effects of PTS. At the recent BEIS funded expert elicitation workshop (Booth and Heinis, 2018) experts concluded that the probability of PTS significantly affecting the survival and reproduction of either seal species was very low. As a result of this, and the fact that seals do not generally use hearing as their primary sensory modality for finding prey and navigation in the same way as cetaceans do, the sensitivity of seals to PTS has been assessed as **Low**.

Very High-Frequency (VHF) cetacean sensitivity to pile driving disturbance

- 2.5.10 Previous studies have shown that harbour porpoises are displaced from the vicinity of piling events. For example, studies at wind farms in the German North Sea have recorded large declines in porpoise detections close to the piling (>90 percent decline at noise levels above 170dB) with decreasing effect with increasing distance from the pile (25 percent decline at noise levels between 145 and 150dB) (Brandt *et al.* 2016). The detection rates revealed that porpoise were only displaced from the piling area in the short term (1 to 3 days) (Brandt *et al.*, 2011, Brandt *et al.*, 2016, Brandt *et al.*, 2018, Dähne *et al.*, 2013). Harbour porpoise are small cetaceans which makes them vulnerable to heat loss and requires them to maintain a high metabolic rate with little energy remaining for fat storage (for example, Rojano-Doñate *et al.*, 2018). This makes them vulnerable to starvation if they are unable to obtain sufficient levels of prey intake.
- 2.5.11 Studies using Digital Acoustic Recording Tags (DTAGs) have shown that porpoise tagged after capture in pound nets foraged on small prey nearly continuously during both the day and the night on their release (Wisniewska *et al.*, 2016). However, Hoekendijk *et al.* (2018) point out that this could be an extreme short term response to capture in nets, and may not reflect natural harbour porpoise behaviour. Nevertheless, if the foraging efficiency of harbour porpoise is disturbed or if they are displaced from a high-quality foraging ground, and are unable to find suitable alternative feeding grounds, they could potentially be at risk of changes to

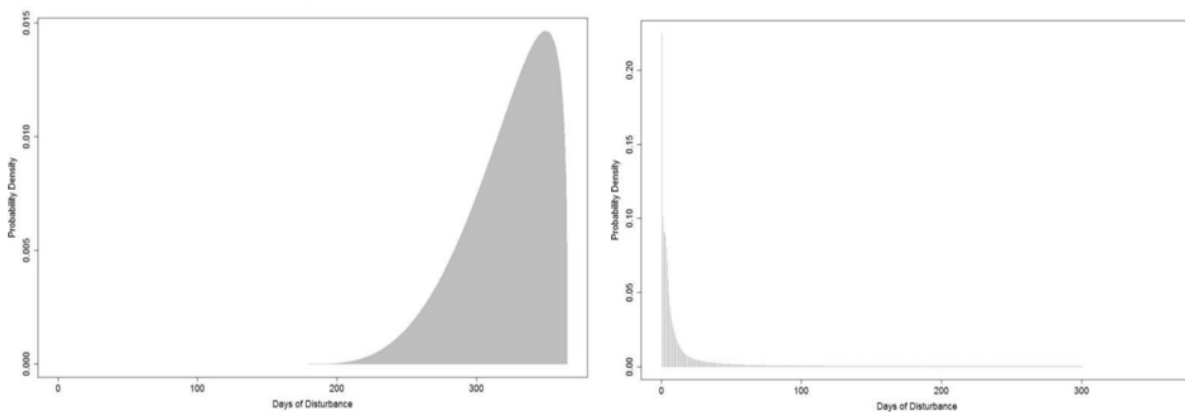
their overall fitness if they are not able to compensate and obtain sufficient food intake in order to meet their metabolic demands.

- 2.5.12 The results from Wisniewska *et al.* (2016) could also suggest that porpoises have an ability to respond to short term reductions in food intake, implying a resilience to disturbance. As Hoekendijk *et al.* (2018) argue, this could help explain why porpoises are such an abundant and successful species. It is important to note that the studies providing evidence for the responsiveness of harbour porpoises to piling noise have not provided any evidence for subsequent individual consequences. In this way, responsiveness to disturbance cannot reliably be equated to sensitivity to disturbance and porpoises may well be able to compensate by moving quickly to alternative areas to feed, while at the same time increasing their feeding rates.
- 2.5.13 Monitoring of harbour porpoise activity at the Beatrice Offshore Wind Farm during pile driving activity has indicated that porpoises were displaced from the immediate vicinity of the pile driving activity – with a 50 percent probability of response occurring at approximately 7 kilometre (km) (Graham *et al.*, 2019). This monitoring also indicated that the response diminished over the construction period, so that eight months into the construction phase, the range at which there was a 50 percent probability of response was only 1.3km. In addition, the study indicated that porpoise activity recovered between pile driving events.
- 2.5.14 A study of tagged harbour porpoises has shown large variability between individual responses to an airgun stimulus (van Beest *et al.*, 2018). Of the five porpoises tagged and exposed to airgun pulses at ranges of 420 to 690 metre (m) (SEL 135 to 147dB re 1 μ Pa²s), one individual showed rapid and directed movements away from the source. Two individuals displayed shorter and shallower dives immediately after exposure and the remaining two animals did not show any quantifiable response. Therefore, there is expected to be a high level of variability in responses from individual harbour porpoises exposed to low frequency broadband pulsed noise (including both airguns and pile-driving).
- 2.5.15 At a BEIS funded expert elicitation workshop held in Amsterdam in June 2018, experts in marine mammal physiology, behaviour and energetics discussed the nature, extent and potential consequences of disturbance to harbour porpoise from exposure to low frequency broadband pulsed noise (for example, pile-driving, airgun pulses) (Booth *et al.*, 2019). Experts were asked to estimate the potential consequences of a six-hour period of zero energy intake, assuming that disturbance from a pile driving event resulted in missed foraging opportunities for this duration. A Dynamic Energy Budget model for harbour porpoise (based on the DEB model in Hin *et al.*, 2019) was used to aid discussions regarding the potential effects of missed foraging opportunities on survival and reproduction. The model described the way in which the life history processes (growth, reproduction and survival) of a female and her calf depend on the way in which assimilated energy is allocated between different processes and was used during the elicitation to model the effects of energy intake and reserves following simulated disturbance. The experts agreed that first year calf survival (post-weaning) and fertility were the most likely vital rates to be affected by disturbance, but that juvenile and adult survival were unlikely to be significantly affected as these life-stages were considered to be more robust. Experts agreed that the final third of the year was the most critical for harbour porpoises as they reach the end of the current

lactation period and the start of new pregnancies, therefore it was thought that significant impacts on fertility would only occur when animals received repeated exposure throughout the whole year. Experts agreed it would likely take high levels of repeated disturbance to an individual before there was any effect on that individual's fertility (**Graphic 2-4 left**), and that it was very unlikely an animal would terminate a pregnancy early. The experts agreed that calf survival could be reduced by only a few days of repeated disturbance to a mother/calf pair during early lactation (**Graphic 2-4 right**); however, it is highly unlikely that the same mother-calf pair would repeatedly return to the area in order to receive these levels of repeated disturbance.

2.5.16 Due to observed responsiveness to piling, their income breeder life history, and the low numbers of days of disturbance expected to effect calf survival, harbour porpoises have been assessed here as having a **Medium** sensitivity to disturbance and resulting displacement from foraging grounds.

Graphic 2-4 Probability distributions showing the consensus of the expert elicitation for harbour porpoise disturbance from piling (Booth *et al.*, 2019)



Note: Left: the number of days of disturbance (for instance, days on which an animal does not feed for six hours) a pregnant female could 'tolerate' before it has any effect on fertility. Right: the number of days of disturbance (of six hours zero energy intake) a mother/calf pair could 'tolerate' before it has any effect on survival.

High-Frequency (HF) cetacean sensitivity to pile driving disturbance

Bottlenose dolphin

2.5.17 Bottlenose dolphins have been shown to be displaced from an area as a result of the noise produced by offshore construction activities; for example, avoidance behaviour in bottlenose dolphins has been shown in relation to dredging activities (Pirodda *et al.*, 2013). In a recent study on bottlenose dolphins in the Moray Firth (in relation to the construction of the Nigg Energy Park in the Cromarty Firth), small effects of pile driving on dolphin presence have been observed, however, dolphins were not excluded from the vicinity of the piling activities (Graham *et al.*, 2017b). In this study the median peak-to-peak source levels recorded during impact piling were estimated to be 240dB re 1µPa (range 8dB) with a single pulse source level of 198dB re 1µPa²s. The pile driving resulted in a slight reduction of the presence,

detection positive hours and the encounter duration for dolphins within the Cromarty Firth, however, this response was only significant for the encounter durations. Encounter durations decreased within the Cromarty Firth (though only by a few minutes) and increased outside of the Cromarty Firth on days of piling activity. These data highlight a small spatial and temporal scale disturbance to bottlenose dolphins as a result of impact piling activities.

2.5.18

According to the opinions of the experts involved in the expert elicitation for PCoD, which forms our best available knowledge on the topic, disturbance would be most likely to affect bottlenose dolphin calf survival, where: *“Experts felt that disturbance could affect calf survival if it exceeded 30 to 50 days, because it could result in mothers becoming separated from their calves and this could affect the amount of milk transferred from the mother to her calf”* (Harwood *et al.*, 2014). There is the potential for behavioural disturbance and displacement to result in disruption in foraging and resting activities and an increase in travel and energetic costs. However, it has been previously shown that bottlenose dolphins have the ability to compensate for behavioural responses as a result of increased commercial vessel activity (New *et al.*, 2013). Therefore, while there remains the potential for disturbance and displacement to affect individual behaviour and therefore vital rates and population level changes, bottlenose dolphins do have some capability to adapt their behaviour and tolerate certain levels of temporary disturbance. Therefore, since bottlenose dolphins are expected to be able to adapt their behaviour, with the impact most likely to result in potential changes in calf survival (but not expected to affect adult survival or future reproductive rates) they are categorised as having a **Medium** sensitivity score to behavioural disturbance from piling.

Common dolphin

2.5.19

The hearing range of common dolphins is currently estimated from their sound production, and has been labelled medium-high frequency, spanning between 150Hz to 160kHz (Finneran, 2016, Houser *et al.*, 2017). There are few studies investigating the effects of pile driving on common dolphins, which could relate to their occupation of deeper waters, contrasting the shallower habitat in which offshore construction frequently occurs. However, an analysis of pile driving activity in Broadhaven bay, Ireland, found construction activity to be associated with a reduction in the presence of minke whales and harbour porpoise, but not with common dolphins (Culloch *et al.*, 2016). Conversely, increased vessel presence during the construction period was associated with a decrease of common dolphins in the surrounding area. While there is little information on the impacts of pile driving on common dolphins, there are a few studies documenting the impacts of seismic activity. Although the noise produced by airguns differs in its duration and cumulative acoustic energy levels, it may be similar in its frequency range to the low-frequency noise produced by pile driving. In general, there is contrasting evidence for the response of common dolphins to seismic surveys. While some research indicates no change in the occurrence or sighting density of common dolphins when exposed to seismic activity (Kavanagh *et al.*, 2019, Stone *et al.*, 2017), Goold (1996) found a reduction in common dolphin presence within 1km of ongoing seismic surveys near Pembrokeshire.

2.5.20

Relatively few studies document the impacts of marine construction or investigation on common dolphins, but there is some evidence of the impacts of vessel traffic and boat noise on common dolphins. While the direct impacts of vessel noise on common dolphins are rather under-researched, the presence of vessel activity has been found to alter their behavioural states and has been linked to disturbance. In New Zealand, Markov chain models were used to assess the impacts of tourism on the behaviour of common dolphins. Foraging and resting bouts were significantly disrupted by boat interactions, with less time spent in these states. In addition, post-disturbance activity indicated a shift from foraging states to milling and socialising and returns to foraging took significantly longer (Stockin *et al.*, 2008, Meissner *et al.*, 2015). While the aforementioned studies relate to short term impacts, a long-term study of common dolphins in the waters around Ischia Island found declines that could have resulted from a combination of habitat degradation and disturbance from increasing traffic. The surrounding area has been listed as one of the noisiest in the Mediterranean due to a range of marine traffic, commercial and seismic surveys, and drilling activity (Mussi *et al.*, 2019). Conversely, some research suggests that common dolphins may be altering their communication to compensate for high levels of anthropogenic noise. It has been suggested that a difference in the frequency of whistles between two populations of common dolphins, one in the Celtic sea, and one in the English Channel, may reflect a shift in acoustic characteristics to counter masking caused by high levels of vessel traffic in the latter location (Ansmann *et al.*, 2007). Recently, for both Atlantic spotted dolphins and short-beaked common dolphins, the presence of high noise levels was associated with an increase in the maximum whistle frequency, indicating vocal compensation for potential masking in a noisy environment (Papale *et al.*, 2015).

2.5.21

The sparse information available for the impacts of construction, seismic activity and vessel noise on common dolphins make it difficult to assess the risk for this species. While there is some evidence of disturbance of animals by seismic activity, and reduced presence in increasingly noisy habitat, this species may adjust its whistle characteristics to account for masking, suggesting some flexibility or tolerance. However, given the high sound pressure level (SPL) and cumulative energy levels produced by pile driving, and our lack of understanding of the sensitivity of this species, it is considered to be more precautionary to assign a **Medium** sensitivity score.

Low-Frequency (LF) cetacean sensitivity to pile driving disturbance

2.5.22

There is little information available on the behavioural responses of minke whales to underwater noise. Minke whales have been shown to change their diving patterns and behavioural state in response to disturbance from whale watching vessels; and it was suggested that a reduction in foraging activity at feeding grounds could result in reduced reproductive success in this capital breeding species (Christiansen *et al.*, 2013). There is only one study showing minke whale reactions to sonar signals (Sivle *et al.*, 2015) with severity scores above 4 for a received SPL of 146dB re 1µPa (score 7) and a received SPL of 158dB re 1µPa (score 8). There is a study detailing minke whale responses to the Lofitech device which has a source level of 204dB re 1µPa @1m, which showed minke whales within 500m and 1,000m of the source exhibiting a behavioural response. Estimated received level at 1,000m was 136.1dB re 1µPa (McGarry *et al.*, 2017).

2.5.23

Since minke whales are known to forage in UK waters in the summer months, there is the potential for displacement to impact on reproductive rates. Therefore, minke whales have been assessed as having a high sensitivity to disturbance and resulting displacement from foraging grounds. Due to their large size and capacity for energy storage, it is expected that minke whales will be able to tolerate temporary displacement from foraging areas much better than harbour porpoise. However, given the lack of empirical data on minke whale responses to pile driving, it is considered to be more precautionary to assign a **Medium** sensitivity score.

Seal sensitivity to pile driving disturbance

Harbour seal

2.5.24

A study of tagged harbour seals in the Wash has shown that they are displaced from the vicinity of piles during pile-driving activities. Russell *et al.* (2016) showed that seal abundance was significantly reduced within an area with a radius of 25km from a pile, during piling activities, with a 19 to 83 percent decline in abundance during pile-driving compared to during breaks in piling. The duration of the displacement was only in the short-term as seals returned to non-piling distributions within two hours after the end of a pile-driving event. Unlike harbour porpoise, both harbour and grey seals store energy in a thick layer of blubber, which means that they are more tolerant of periods of fasting when hauled out and resting between foraging trips, and when hauled out during the breeding and moulting periods. Therefore, they are unlikely to be particularly sensitive to short-term displacement from foraging grounds during periods of active piling.

2.5.25

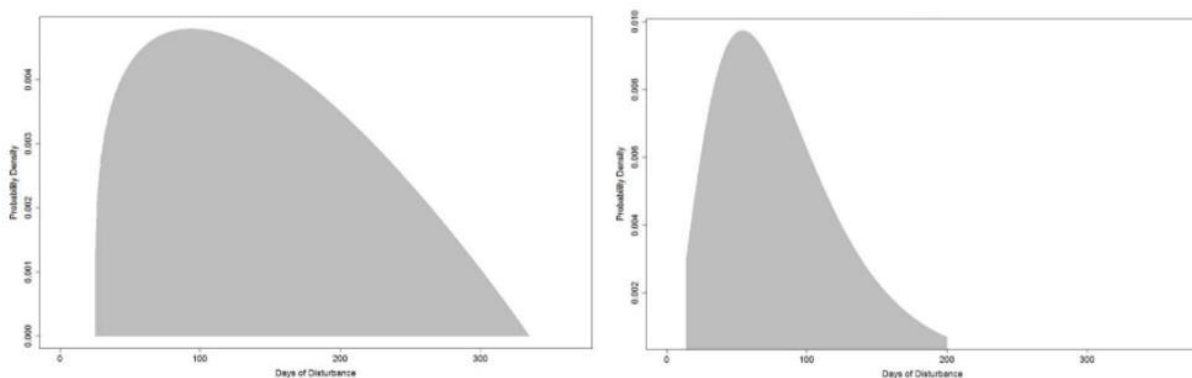
At the expert elicitation workshop in Amsterdam in 2018, (Booth *et al.*, 2019), experts agreed the most likely potential consequences of a six hour period of zero energy intake, assuming that disturbance (from exposure to low frequency broadband pulsed noise (for example, pile-driving, airgun pulses) resulted in missed foraging opportunities. In general, it was agreed that harbour seals were considered to have a reasonable ability to compensate for lost foraging opportunities due to their generalist diet, mobility, life history and adequate fat stores. The survival of 'weaned of the year' animals and fertility were determined to be the most sensitive life history parameters to disturbance (for instance, leading to reduced energy intake). Juvenile harbour seals are typically considered to be coastal foragers (Booth *et al.*, 2019) and so less likely to be exposed to disturbances and similarly pups were thought to be unlikely to be exposed to disturbance due to their proximity to land. Unlike for harbour porpoise, there was no DEB model available to simulate the effects of disturbance on seal energy intake and reserves, therefore the opinions of the experts were less certain. Experts considered that the location of the disturbance would influence the effect of the disturbance, with a greater effect if animals were disturbed at a foraging ground as opposed to when animals were transiting through an area. It was thought that for an animal in bad condition, moderate levels of repeated disturbance might be sufficient to reduce fertility (**Graphic 2-5** left), however there was a large amount of uncertainty in this estimate, with opinions ranging between <50 days and >300 days. The 'weaned of the year' were considered to be most vulnerable following the post-weaning fast, and that during this time, experts felt it

might take ~60 days of repeated disturbance before there was expected to be any effect on the probability of survival (**Graphic 2-5** right), however again, there was a lot of uncertainty surrounding this estimate with estimates ranging between <50 days and >200 days. Similarly to above, it is considered unlikely that individual harbour seals would repeatedly return to a site where they'd been previously displaced from in order to experience this number of days of repeated disturbance.

2.5.26

Due to observed responsiveness to piling, harbour seals have been assessed as having **Medium** sensitivity to disturbance and resulting displacement from foraging grounds during pile-driving events.

Graphic 2-5 Probability distributions showing the consensus of the expert elicitation for harbour seal disturbance from piling (Booth *et al.*, 2019)



Note: Left: the number of days of disturbance (for instance, days on which an animal does not feed for six hours) a pregnant female could 'tolerate' before it has any effect on fertility. Right: the number of days of disturbance (of six hours zero energy intake) a 'weaned of the year' harbour seal could 'tolerate' before it has any effect on survival.

Grey Seal

2.5.27

There are still limited data on grey seal behavioural responses to pile driving. The key dataset on this topic is presented in Aarts *et al.* (2018) where 20 grey seals were tagged in the Wadden Sea to record their responses to pile driving at two offshore wind farms: Luchterduinen in 2014 and Gemini in 2015. The grey seals showed varying responses to the pile driving, including no response, altered surfacing and diving behaviour, and changes in swimming direction. The most common reaction was a decline in descent speed and a reduction in bottom time, which suggests a change in behaviour from foraging to horizontal movement. The distances at which seals responded varied significantly; in one instance a grey seal showed responses at 45km from the pile location, while other grey seals showed no response when within 12km. Differences in responses could be attributed to differences in hearing sensitivity between individuals, differences in sound transmission with environmental conditions or the behaviour and motivation for the seal to be in the area. The telemetry data also showed that seals returned to the pile driving area after pile driving ceased.

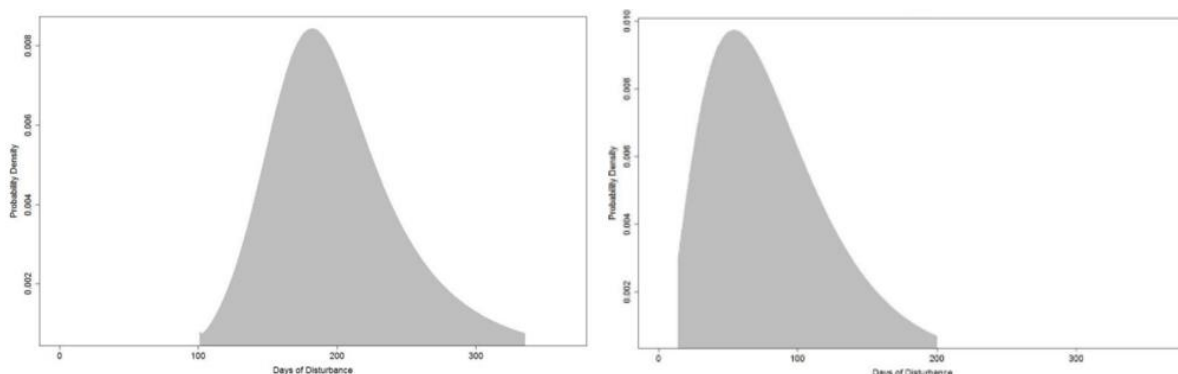
2.5.28

As with harbour seals, the expert elicitation workshop in Amsterdam in 2018, (Booth *et al.*, 2019) concluded that grey seals were considered to have a reasonable ability to compensate for lost foraging opportunities due to their

generalist diet, mobility, life history and adequate fat stores and that the survival of 'weaned of the year' animals and fertility were determined to be most sensitive parameters to disturbance (for instance, reduced energy intake). However, in general, experts agreed that grey seals would be much more robust than harbour seals to the effects of disturbance due to their larger energy stores and more generalist and adaptable foraging strategies. It was agreed that grey seals would require moderate-high levels of repeated disturbance before there was any effect on fertility rates to reduce fertility (**Graphic 2-6** left). As with harbour seals, the 'weaned of the year' were considered to be most vulnerable following the post-weaning fast, and that during this time it might take ~60 days of repeated disturbance before there was expected to be any effect on weaned-of-the-year survival (**Graphic 2-6** right), however there was a lot of uncertainty surrounding this estimate.

- 2.5.29 Grey seals are capital breeders and store energy in a thick layer of blubber, which means that, in combination with their large body size, they are tolerant of periods of fasting as part of their normal life history. Grey seals are also highly adaptable to a changing environment and are capable of adjusting their metabolic rate and foraging tactics, to compensate for different periods of energy demand and supply (Beck *et al.*, 2003, Sparling *et al.*, 2006). Grey seals are also very wide ranging and are capable of moving large distances between different haul out and foraging regions (Russell *et al.*, 2013). Therefore, they are unlikely to be particularly sensitive to displacement from foraging grounds during periods of active piling.
- 2.5.30 Due to observed responsiveness to piling, and their life-history characteristics, grey seals have been assessed as having **Low** sensitivity to disturbance and resulting displacement from foraging grounds during pile-driving events.

Graphic 2-6 Probability distributions showing the consensus of the expert elicitation for grey seal disturbance from piling (Booth *et al.*, 2019)



Noise: Left: the number of days of disturbance (for instance, days on which an animal does not feed for six hours) a pregnant female could 'tolerate' before it has any effect on fertility. Right: the number of days of disturbance (of six hours zero energy intake) a 'weaned of the year' grey seal could 'tolerate' before it has any effect on survival.

Sensitivity summary

- 2.5.31 Through the use of literature reviews on the potential impacts of underwater noise on marine mammals, the sensitivity of each species to PTS-onset and behavioural

disturbance from pile driving has been assessed. Given the definitions of marine mammal sensitivity provided in **Table 2-1**, all marine mammals have been assessed as having either a medium or low sensitivity to PTS-onset and behavioural disturbance from pile driving (**Table 2-12**).

Table 2-12 Summary of key marine mammal sensitivity assessments

Species	PTS-onset from piling	Disturbance from piling
Harbour porpoise	Medium	Medium
Bottlenose dolphin	Medium	Medium
Common dolphin	Medium	Medium
Minke whale	Medium	Medium
Harbour seal	Low	Medium
Grey seal	Low	Low

2.6 Assumptions and limitations

Introduction

- 2.6.1 There are uncertainties relating to the underwater noise modelling and impact assessment for Rampion 2. Broadly, these relate to predicting exposure of animals to underwater noise, predicting the response of animals to underwater noise and predicting potential population consequences of disturbance from underwater noise. Further detail of such uncertainty is set out below.

Swimming speed

- 2.6.2 All marine mammals were modelled to swim away at the onset of piling at a swimming speed of 1.5m/s apart from minke whales which were modelled to flee at 3.25m/s. There are data to suggest that these selected swim speeds are precautionary and that animals are likely to flee at much higher speeds, at least initially. Minke whales have been shown to flee from Acoustic Deterrent Devices (ADDs) at a mean swimming speed of 4.2m/s (McGarry *et al.*, 2017). A recent study by Kastelein *et al.* (2018) showed that a captive harbour porpoise responded to playbacks of pile driving sounds by swimming at speeds significantly higher than baseline mean swimming speeds, with greatest speeds of up to 1.97m/s which were sustained for the 30 minute test period. In another study, van Beest *et al.* (2018) showed that a harbour porpoise responded to an airgun noise exposure with a fleeing speed of 2m/s. These recent studies have demonstrated porpoise and minke whale fleeing swim speeds that are greater than that used in the fleeing model here, which makes the modelled speeds used in this assessment precautionary.

Cumulative exposure – impulsive characteristics

- 2.6.3 There is likely to be much more uncertainty associated with the prediction of levels of cumulative exposure due to the difficulty in predicting the true levels of sound exposure over long periods of time, as a result of uncertainties about responsive movement, the position of animals in the water column, extent of recovery between pulses or in breaks in piling and the extent to which pulsed sound loses its pulse like characteristics over time. As a result of this uncertainty, model parameters are generally highly conservative and therefore the resulting predictions are precautionary and unlikely to be realised.
- 2.6.4 Southall *et al.* (2019) acknowledges that as a result of propagation effects, the sound signal of certain sound sources (for example, pile driving) loses its impulsive characteristics and could potentially be characterised as non-impulsive beyond a certain distance. The changes in noise characteristics with distance generally result in exposures becoming less physiologically damaging with increasing distance as sharp transient peaks become less prominent (Southall *et al.*, 2007). The Southall *et al.* (2019) updated criteria proposed that, while keeping the same source categories, the exposure criteria for impulsive and non-impulsive sound should be applied based on the signal features likely to be perceived by the animal rather than those emitted by the source. Methods to estimate the distance at which the transition from impulsive to non-impulsive noise are currently being developed (Southall *et al.*, 2019).
- 2.6.5 Using the criteria of signal duration, rise time, crest factor and peak pressure divided by signal duration, Hastie *et al.* (2019) estimated the transition from impulsive to non-impulsive characteristics of pile driving noise during the installation of offshore WTG foundations at the Wash and in the Moray Firth. Hastie *et al.* (2019) showed that the noise signal experienced a high degree of change in its impulsive characteristics with increasing distance. Southall *et al.* (2019) state that mammalian hearing is most readily damaged by transient sounds with rapid rise-time, high peak pressures, and sustained duration relative to rise-time. Therefore, of the four criteria used by Hastie *et al.* (2019), the rise-time and peak pressure may be the most appropriate indicators to determine the impulsive/non-impulsive transition. Based on this data it is expected that the probability of a signal being defined as “*impulsive*” (using the criteria of rise time being less than 25ms) reduces to only 20 percent between ~2 and 5km from the source. Predicted PTS impact ranges based on the impulsive noise thresholds may therefore be overestimates in cases where the impact ranges lie beyond this. Any animal present beyond that distance when piling starts will only be exposed to non-impulsive noise, and therefore impact ranges should be based on the non-impulsive thresholds.
- 2.6.6 It is acknowledged that the Hastie *et al.* (2019) study is an initial investigation into this topic, and that further data are required in order to set limits to the range at which impulsive criteria for PTS are applied.

Proportion impacted

- 2.6.7 It is also important to note that it is expected that only 18 to 19 percent of animals are predicted to actually experience PTS at the PTS-onset threshold level. This was the approach adopted by Donovan *et al.* (2017) to develop their dose

response curve implemented into the SAFESIMM (Statistical Algorithms For Estimating the Sonar Influence on Marine Megafauna) model, based on the data presented in Finneran *et al.* (2005). Therefore, where PTS-onset ranges are provided, it is not expected that all individuals within that range will experience PTS. Therefore, the number of animals predicted to be within PTS-onset ranges are precautionary.

Exposure to noise

- 2.6.8 There are uncertainties relating to the ability to predict the exposure of animals to underwater noise, as well as in predicting the response to that exposure. These uncertainties relate to a number of factors: the ability to predict the level of noise that animals are exposed to, particularly over long periods of time; the ability to predict the numbers of animals affected, and the ability to predict the individual and ultimately population consequences of exposure to noise. These are explored in further detail in the paragraphs below.
- 2.6.9 The propagation of underwater noise is relatively well understood and modelled using standard methods. However, there are uncertainties regarding the amount of noise actually produced by each pulse at source and how the pulse characteristics change with range from the source. There are also uncertainties regarding the position of receptors in relation to received levels of noise, particularly over time, and understanding how position in the water column may affect received level. Noise monitoring is not always carried out at distances relevant to the ranges predicted for effects on marine mammals, so effects at greater distances remain un-validated in terms of actual received levels. The extent to which ambient noise and other anthropogenic sources of noise may mask signals from the offshore wind farm construction are not specifically addressed. The dose-response curves for porpoise include behavioural responses at noise levels down to 120dB SEL_{ss} which may be indistinguishable from ambient noise at the ranges these levels are predicted.
- 2.6.10 It is important to note that the SEL_{cum} thresholds were determined with the assumption that:
- the amount of sound energy an animal is exposed to within 24 hours will have the same effect on its auditory system, regardless of whether it is received all at once or in several smaller doses spread over a longer period (called the equal-energy hypothesis);
 - the sound keeps its impulsive character, regardless of the distance to the sound source;
 - the fleeing swim speeds are representative; and
 - that SEL_{cum} levels do not vary within the water column.
- 2.6.11 These assumptions lead to a conservative determination of the impact ranges; and the Proposed Development considers that the calculated SEL_{cum} PTS-onset impact ranges are highly over-precautionary and unrealistic.

Density

- 2.6.12 There are uncertainties relating to the ability to predict the responses of animals to underwater noise and the prediction of the numbers of animals potentially exposed to levels of noise that may cause an impact is uncertain. Given the high spatial and temporal variation in marine mammal abundance and distribution in any particular area of the sea, it is difficult to confidently predict how many animals may be present within the range of noise impacts. All methods for determining at sea abundance and distribution suffer from a range of biases and uncertainties and no single method or data source will provide a complete prediction of future conditions.

Predicting response

- 2.6.13 In addition, there is limited empirical data available to confidently predict the extent to which animals may experience auditory damage or display responses to noise. The current methods for prediction of behavioural responses are based on received sound levels, but it is likely that factors other than noise levels alone will also influence the probability of response and the strength of response (for example, previous experience, behavioural and physiological context, proximity to activities, characteristics of the sound other than level, such as duty cycle and pulse characteristics). However, at present, it is impossible to adequately take these factors into account in a predictive sense. This assessment makes use of the monitoring work that has been carried out during the construction of the Beatrice Offshore Wind Farm and therefore uses the most recent and site-specific information on disturbance to harbour porpoise as a result of pile driving noise.
- 2.6.14 There is also a lack of information on how observed effects (for example, short-term displacement around pile-driving activities) manifest themselves in terms of effects on individual fitness, and ultimately population dynamics (see the section above on marine mammal sensitivity to disturbance and the recent expert elicitation conducted for harbour porpoise and both seal species) in order to attempt to quantify the amount of disturbance required before vital rates are impacted.

Duration of impact

- 2.6.15 The duration of disturbance is another uncertainty. Studies at Horns Rev 2 demonstrated that porpoises returned to the area between one and three days (Brandt *et al.*, 2011) and monitoring at the Dan Tysk Wind Farm as part of the Disturbance Effects on the Harbour Porpoise Population in the North Sea (DEPONS) project found return times of around 12 hours (van Beest *et al.*, 2015). Two studies at Alpha Ventus demonstrated, using aerial surveys, that the return of porpoises was about 18 hours after piling (Dähne *et al.*, 2013). A recent study of porpoise response at the Gemini wind farm in the Netherlands, also part of the DEPONS project, found that local population densities recovered between two and six hours after piling (Nabe-Nielsen *et al.*, 2018). An analysis of data collected at the first seven offshore wind farms in Germany has shown that harbour porpoise detections were reduced between one and two days after piling (Brandt *et al.*, 2018). Analysis of data from monitoring of marine mammal activity during piling of jacket pile foundations at Beatrice Offshore Wind Farm (Graham *et al.*, 2017a,

Graham *et al.*, 2019) provides evidence that harbour porpoise were displaced during pile driving but return after cessation of piling, with a reduced extent of disturbance over the duration of the construction period. This suggests that the assumptions adopted in the current assessment are precautionary as animals are predicted to remain disturbed at the same level for the entire duration of the pile driving phase of construction.

PTS-onset

2.6.16

There are no empirical data on the threshold for auditory injury in the form of PTS-onset for marine mammals, as to test this would be inhumane. Therefore, PTS-onset thresholds are estimated based on extrapolating from TTS-onset thresholds. For pulsed noise, such as piling, National Oceanic and Atmospheric Administration (NOAA) have set the onset of TTS at the lowest level that exceeds natural recorded variation in hearing sensitivity (6dB), and assumes that PTS occurs from exposures resulting in 40dB or more of TTS measured approximately four minutes after exposure (NMFS, 2018).

3. PTS-onset results

This section outlines the marine mammal PTS-onset impact ranges, number of animals potentially within these ranges and the proportion of the MU that may be impacted. This, in combination with the sensitivity assessment presented in **Section 2.5**, provides the magnitude, sensitivity and overall impact significance scores for unmitigated pile driving of both monopiles and pin-piles under both the worst case scenario and most likely scenario.

3.1 VHF Cetacean - Harbour porpoise

- 3.1.1 **Table 3-1** outlines the potential for PTS-onset for harbour porpoise under the worst case scenario for both monopiles and pin-piles. The largest predicted cumulative PTS-onset impact range is 6.1km, resulting in a potential PTS-onset impact to 13 harbour porpoise per piling day which represents 0.004 percent of the North Sea MU.
- 3.1.2 **Table 3-2** outlines the potential for PTS-onset for harbour porpoise under the most likely scenario for both monopiles and pin-piles. The largest predicted cumulative PTS-onset impact range is 5.7km, resulting in a potential PTS-onset impact to 12 harbour porpoise per piling day which represents 0.003 percent of the North Sea MU.
- 3.1.3 Although the numbers of individuals predicted to be at risk per piling day are low and would not be considered significant in Environmental Impact Assessment (EIA) terms, harbour porpoise are an European Protected Species (EPS) and under EPS legislation it is an offence to injure a single individual (this includes PTS auditory injury). Therefore, Rampion 2 has committed to a piling Marine Mammal Mitigation Plan (MMMP) (Commitment C-52 of **Appendix 4.1: Commitment register, Volume 4**) to reduce the risk of PTS to negligible levels. In addition to this embedded mitigation, it is also likely that the presence of novel vessels and associated construction activity will ensure that the vicinity of the pile is free of harbour porpoise by the time that piling begins.
- 3.1.4 The PTS impact is predicted to be of local spatial extent, short term duration and intermittent, however since PTS is a permanent change in the hearing threshold, it is not recoverable. With the use of embedded mitigation methods (**Appendix 4.1 Commitment Register**), it is expected that the risk of PTS will be negligible. As outlined in **Section 2.5**, harbour porpoise have been assessed as having a **Medium** sensitivity to PTS. Therefore, the resulting impact significance for the onset of PTS in harbour porpoise from both the worst case scenario and most likely scenario for both monopiles and pin-piles is **Negligible (Not Significant)**.

Table 3-1 Impact area, maximum range, number of harbour porpoise and percentage of MU predicted to experience PTS-onset for the worst case scenario

	Monopile (4,400kJ)			Pin-pile (2,500kJ)		
	NW	S	E	NW	S	E
Instantaneous PTS: 202dB unweighted SPL_{peak}						
Area (km²)	0.57	NA	1.3	0.34	0.92	0.85
Max range (km)	0.43	NA	0.66	0.34	0.54	0.52
# Porpoise	<1	NA	<1	<1	<1	<1
Percent MU	0.000	NA	0.000	0.000	0.000	0.000
Cumulative PTS: 155dB VHF Weighted SEL_{cum} (2 monopiles / 4 pin-piles in 24 hours)						
Area (km²)	6.9	NA	63	2.7	77	38
Max range (km)	2.20	NA	6.10	1.50	5.9	4.7
# Porpoise	1	NA	13	1	16	8
Percent MU	0.000	NA	0.004	0.000	0.005	0.002

Table 3-2 Impact area, maximum range, number of harbour porpoise and percentage of MU predicted to experience PTS-onset for the most likely scenario

	Monopile (4,000kJ)			Pin-pile (2,000kJ)		
	NW	S	E	NW	S	E
Instantaneous PTS: 202dB unweighted SPL_{peak}						
Area (km²)	0.54	NA	1.3	0.29	0.76	0.71
Max range (km)	0.42	NA	0.65	0.31	0.5	0.48
# Porpoise	<1	NA	<1	<1	<1	<1
Percent MU	0.000	NA	0.000	0.000	0.000	0.000
Cumulative PTS: 155dB VHF Weighted SEL_{cum} (2 monopiles / 4 pin-piles in 24 hours)						
Area (km²)	6.0	NA	57	1.5	57	27
Max range (km)	2.10	NA	5.7	1.1	5.0	4.0
# Porpoise	1	NA	12	<1	12	6
Percent MU	0.000	NA	0.003	0.000	0.003	0.002

3.2 HF Cetacean – Bottlenose and common dolphins

- 3.2.1 **Table 3-3** outlines the potential for PTS-onset for bottlenose and common dolphins under the worst case scenario for both monopiles and pin-piles. The largest predicted cumulative PTS-onset impact range is <0.1km, resulting in a potential PTS-onset impact to <1 individual dolphin per piling day which represents 0.000 percent of the MU for each species. Given the low numbers predicted for the worst case scenario, the most likely scenario numbers were not presented here since they would be lower than those predicted for the worst case scenario.
- 3.2.2 Although the numbers of individuals predicted to be at risk per piling day are minimal and would not be considered significant in EIA terms, bottlenose dolphins and common dolphins are both an EPS and under EPS legislation it is an offence to injure a single individual (this includes PTS auditory injury). Therefore, Rampion 2 has committed to a piling MMMP (Commitment C-52 of **Appendix 4.1, Volume 4**) to reduce the risk of PTS to negligible levels.
- 3.2.3 The PTS-onset impact is predicted to be of local spatial extent, short term duration and intermittent, however since PTS is a permanent change in the hearing threshold, it is not recoverable. With the use of embedded mitigation methods (**Appendix 4.1, Volume 4**), it is expected that the risk of PTS will be negligible. As outlined in **Section 2.5**, both bottlenose and common dolphins have been assessed as having a **Medium** sensitivity to PTS. Therefore, the resulting impact significance for the onset of PTS in bottlenose dolphins and common dolphins from both the worst case scenario and most likely scenario for both monopiles and pin-piles is **Negligible (Not Significant)**.

Table 3-3 Impact area, maximum range and number of bottlenose and common dolphins predicted to experience PTS-onset for the worst case scenario

	Monopile (4,400kJ)			Pin-pile (2,500kJ)		
	NW	S	E	NW	S	E
Instantaneous PTS: 230dB unweighted SPL_{peak}						
Area (km²)	<0.1	NA	<0.1	<0.1	<0.1	<0.1
Max range (km)	<0.05	NA	<0.05	<0.05	<0.05	<0.05
Bottlenose dolphins	<1	NA	<1	<1	<1	<1
Common dolphins	<1	NA	<1	<1	<1	<1
Cumulative PTS: 185dB VHF Weighted SEL_{cum} (2 monopiles / 4 pin-piles in 24 hours)						
Area (km²)	<0.1	NA	<0.1	<0.1	<0.1	<0.1
Max range (km)	<0.10	NA	<0.10	<0.10	<0.10	<0.10

	Monopile (4,400kJ)			Pin-pile (2,500kJ)		
Bottlenose dolphins	<1	NA	<1	<1	<1	<1
Common dolphins	<1	NA	<1	<1	<1	<1

3.3 LF Cetacean – Minke whale

- 3.3.1 **Table 3-4** and **Table 3-5** outline the potential for PTS-onset for minke whales under the worst case scenario and most likely scenario (respectively) for both monopiles and pin-piles. The largest predicted cumulative PTS-onset impact range is 13km under the worst case scenario and 12km under the most likely scenario. Despite these larger PTS-onset impact ranges, the density of minke whales predicted to be in the area is so low (0.002 whales per square kilometre (/km²), SCANS III) that even with impact ranges of this size, this results in a potential PTS-onset impact to <1 individual whale per piling day which represents 0.000 percent of the MU.
- 3.3.2 Although the numbers of individuals predicted to be at risk per piling day are minimal and would not be considered significant in EIA terms, minke whales are an EPS and under EPS legislation it is an offence to injure a single individual (this includes PTS auditory injury). Therefore, Rampion 2 has committed to a piling MMMP (Commitment C-52 of **Appendix 4.1, Volume 4**) to reduce the risk of PTS to negligible levels.
- 3.3.3 The PTS-onset impact is predicted to be of local spatial extent, short term duration and intermittent, however since PTS is a permanent change in the hearing threshold, it is not recoverable. With the use of embedded mitigation methods (**Appendix 4.1, Volume 4**), it is expected that the risk of PTS will be negligible. As outlined in **Section 2.5** minke whales have been assessed as having a **Medium** sensitivity to PTS. Therefore, the resulting impact significance for the onset of PTS in minke whales from both the worst case scenario and most likely scenario for both monopiles and pin-piles is **Negligible (Not Significant)**.

Table 3-4 Impact area, maximum range, number of minke whales predicted to experience PTS-onset for the worst case scenario

	Monopile (4,400kJ)			Pin-pile (2,500kJ)		
	NW	S	E	NW	S	E
Instantaneous PTS: 219dB unweighted SPL_{peak}						
Area (km²)	<0.01	NA	<0.01	<0.01	<0.01	<0.01
Max range (km)	<0.05	NA	<0.05	<0.05	<0.05	<0.05
# whales	<1	NA	<1	<1	<1	<1

	Monopile (4,400kJ)			Pin-pile (2,500kJ)		
Cumulative PTS: 183dB VHF Weighted SEL _{cum} (2 monopiles / 4 pin-piles in 24 hours)						
Area (km ²)	8.6	NA	200	1.3	260	130
Max range (km)	3.20	NA	12.0	1.4	13.0	9.6
# whales	<1	NA	<1	<1	<1	<1

Table 3-5 Impact area, maximum range, number of minke whales predicted to experience PTS-onset for the most likely scenario

	Monopile (4,000kJ)			Pin-pile (2,000kJ)		
	NW	S	E	NW	S	E
Instantaneous PTS: 219dB unweighted SPL_{peak}						
Area (km²)	<0.1	NA	<0.1	<0.1	<0.1	<0.1
Max range (km)	<0.05	NA	<0.05	<0.05	<0.05	<0.05
# whales	<1	NA	<1	<1	<1	<1
Cumulative PTS: 183dB VHF Weighted SEL_{cum} (2 monopiles / 4 pin-piles in 24 hours)						
Area (km²)	7.4	NA	190	0.5	220	100
Max range (km)	3.00	NA	12.0	0.85	11.0	8.6
# whales	<1	NA	<1	<1	<1	<1

3.4 Phocids - Harbour and grey seals

- 3.4.1 **Table 3-6** outlines the potential for PTS-onset for harbour and grey seals under the worst case scenario for both monopiles and pin-piles. The predicted cumulative PTS-onset impact range across all scenarios is <0.1km which represents <1 individual harbour or grey seal. Given the low numbers predicted for the worst case scenario, the most likely scenario numbers were not presented here since they would be lower than those predicted for the worst case scenario.
- 3.4.2 The PTS-onset impact is predicted to be of local spatial extent, short term duration and intermittent, however since PTS is a permanent change in the hearing threshold, it is not recoverable. Given that <1 individual is predicted to experience PTS-onset under any scenario, pile type or location, the magnitude is assessed as **Negligible**. As outlined in **Section 2.5**, both harbour and grey seals have been assessed as having a **Low** sensitivity to PTS. Therefore, the resulting impact significance for the onset of PTS in both harbour and grey seals from both the worst case scenario and most likely scenario for both monopiles and pin-piles is **Negligible (Not Significant)**.

Table 3-6 Impact area, maximum range, number of harbour and grey seals predicted to experience PTS-onset for the worst case scenario

	Monopile (4,400kJ)			Pin-pile (2,500kJ)		
	NW	S	E	NW	S	E
Instantaneous PTS: 218dB unweighted SPL_{peak}						
Area (km²)	<0.01	NA	<0.01	<0.01	<0.01	<0.01
Max range (km)	<0.05	NA	<0.05	<0.05	<0.05	<0.05
Harbour seals	<1	NA	<1	<1	<1	<1
Grey seals	<1	NA	<1	<1	<1	<1
Cumulative PTS: 185dB VHF Weighted SEL_{cum} (2 monopiles / 4 pin-piles in 24 hours)						
Area (km²)	<0.1	NA	<0.1	<0.1	<0.1	<0.1
Max range (km)	<0.1	NA	<0.1	<0.1	<0.1	<0.1
Harbour seals	<1	NA	<1	<1	<1	<1
Grey seals	<1	NA	<1	<1	<1	<1

3.5 PTS-onset summary

- 3.5.1 Given the embedded mitigation of an MMMP to reduce the risk of PTS-onset to negligible levels, the impact of PTS-onset from piling noise under both the worst case scenario and the most likely scenario is not considered to have a significant effect on any marine mammal species considered in this assessment (**Table 3-7**).

Table 3-7 Impact significance for all marine mammals to the impact of PTS-onset from impact piling

Monopiles and Pin-piles (worst case scenario and most likely scenario)			
	Magnitude	Sensitivity	Impact
Harbour porpoise	Negligible	Medium	Negligible (not significant)
Bottlenose dolphin	Negligible	Medium	Negligible (not significant)
Common dolphin	Negligible	Medium	Negligible (not significant)
Minke whale	Negligible	Medium	Negligible (not significant)
Harbour seal	Negligible	Low	Negligible (not significant)
Grey seal	Negligible	Low	Negligible (not significant)

4. TTS-onset results

This section outlines the marine mammal TTS-onset impact ranges and number of animals potentially within these ranges that may be impacted by pile driving of both monopiles and pin-piles under both the worst case scenario and most likely scenario.

4.1 Introduction

4.1.1 The ranges that indicate TTS-onset were modelled and are presented alongside an estimate of the potential number of animals within these impact ranges. However, as TTS-onset is defined primarily as a means of predicting PTS-onset, there is currently no threshold for TTS-onset that would indicate a biologically significant amount of TTS; therefore it was not possible to carry out a quantitative assessment of the magnitude or significance of the impact of TTS on marine mammals. The current set of TTS-onset threshold would result in a significant overestimate of the impact due to the extremely large resulting impact ranges representing the smallest measurable amount of TTS. This approach was agreed with the Cefas at the ETG at the meeting dated 18 September 2020 as part of the EPP.

4.2 VHF Cetacean - Harbour porpoise

4.2.1 **Table 4-1** and **Table 4-2** outline the potential for TTS-onset for harbour porpoise for both monopiles and pin-piles under the worst case scenario and most likely scenario respectively. The largest predicted cumulative TTS-onset impact range is 31km, resulting in a potential TTS-onset impact to 341 harbour porpoise per piling day which represents 0.099 percent of the North Sea MU.

Table 4-1 Impact area, maximum range, number of harbour porpoise and percentage of MU predicted to experience TTS-onset for the worst case scenario

	Monopile (4,400kJ)			Pin-pile (2,500kJ)		
	NW	S	E	NW	S	E
Instantaneous TTS: 196dB unweighted SPL_{peak}						
Area (km²)	2.8	NA	7.3	1.8	5.7	4.9
Max range (km)	0.97	NA	1.6	0.77	1.4	1.3
# Porpoise	1	NA	2	<1	1	1
Percent MU	0.000	NA	0.001	0.000	0.000	0.000
Cumulative TTS: 140dB VHF Weighted SEL_{cum} (2 monopiles / 4 pin-piles in 24 hours)						
Area (km²)	550	NA	1300	440	1600	1100

	Monopile (4,400kJ)			Pin-pile (2,500kJ)		
Max range (km)	21	NA	30	19	31	28
# Porpoise	117	NA	277	94	341	234
Percent MU	0.034	NA	0.080	0.027	0.099	0.068

Table 4-2 Impact area, maximum range, number of harbour porpoise and percentage of MU predicted to experience TTS-onset for the most likely scenario

	Monopile (4,000kJ)			Pin-pile (2,000kJ)		
	NW	S	E	NW	S	E
Instantaneous TTS: 196dB unweighted SPL_{peak}						
Area (km²)	2.7	NA	7	1.5	4.8	4.1
Max range (km)	0.95	NA	1.6	0.71	1.2	1.2
# Porpoise	1	NA	1	<1	1	1
Percent MU	0.000	NA	0.000	0.000	0.000	0.000
Cumulative TTS: 140dB VHF Weighted SEL_{cum} (2 monopiles / 4 pin-piles in 24 hours)						
Area (km²)	510	NA	1300	380	1400	1000
Max range (km)	20	NA	29	17	29	26
# Porpoise	109	NA	277	81	298	213
Percent MU	0.032	NA	0.080	0.023	0.086	0.062

4.3 HF Cetacean – Bottlenose and common dolphins

4.3.1 **Table 4-3** outlines the potential for TTS-onset for bottlenose and common dolphins for both monopiles and pin-piles under the worst case scenario. The largest predicted cumulative TTS-onset impact range is <0.1km, resulting in a potential TTS-onset impact to <1 individual dolphin of each species per piling day which represents 0.000 percent of the relevant MU for each species. Given the low numbers predicted for the worst case scenario, the most likely scenario numbers were not presented here since they would be lower than those predicted for the worst case scenario.

Table 4-3 Impact area, maximum range, number of bottlenose and common dolphins and predicted to experience TTS-onset for the worst case scenario

	Monopile (4,400kJ)			Pin-pile (2,500kJ)		
	NW	S	E	NW	S	E
Instantaneous TTS: 224dB unweighted SPL_{peak}						
Area (km²)	<0.01	NA	<0.01	<0.01	<0.01	<0.01
Max range (km)	<0.05	NA	<0.05	<0.05	<0.05	<0.05
Bottlenose dolphins	<1	NA	<1	<1	<1	<1
Common dolphins	<1	NA	<1	<1	<1	<1
Cumulative TTS: 170dB VHF Weighted SEL_{cum} (2 monopiles / 4 pin-piles in 24 hours)						
Area (km²)	<0.01	NA	<0.01	<0.01	<0.01	<0.01
Max range (km)	<0.1	NA	<0.1	<0.1	<0.1	<0.1
Bottlenose dolphins	<1	NA	<1	<1	<1	<1
Common dolphins	<1	NA	<1	<1	<1	<1

4.4 LF Cetacean – Minke whale

4.4.1 **Table 4-4** and **Table 4-5** outline the potential for TTS-onset for minke whales for both monopiles and pin-piles under the worst case scenario and most likely scenario respectively. The largest predicted cumulative TTS-onset impact range is 42km, resulting in a potential TTS-onset impact to 5 whales per piling day which represents 0.021 percent of the relevant MU.

Table 4-4 Impact area, maximum range, number of minke whales and percentage of MU predicted to experience TTS-onset for the worst case scenario

	Monopile (4,400kJ)			Pin-pile (2,500kJ)		
	NW	S	E	NW	S	E
Instantaneous TTS: 213dB unweighted SPL_{peak}						
Area (km²)	0.02	NA	0.04	<0.01	0.03	0.03
Max range (km)	0.09	NA	0.12	0.07	0.10	0.09

	Monopile (4,400kJ)			Pin-pile (2,500kJ)		
# whales	<1	NA	<1	0	<1	<1
Percent MU	0.000	NA	0.000	0.000	0.000	0.000
Cumulative TTS: 168dB VHF Weighted SEL_{cum} (2 monopiles / 4 pin-piles in 24 hours)						
Area (km ²)	730	NA	2000	530	2400	1700
Max range (km)	26	NA	41	22	42	38
# whales	1	NA	4	1	5	3
Percent MU	0.004	NA	0.017	0.004	0.021	0.013

Table 4-5 Impact area, maximum range, number of minke whales and percentage of MU predicted to experience TTS-onset for the most likely scenario

	Monopile (4,000kJ)			Pin-pile (2,000kJ)		
	NW	S	E	NW	S	E
Instantaneous TTS: 213dB unweighted SPL_{peak}						
Area (km ²)	0.02	NA	0.04	<0.01	0.02	0.02
Max range (km)	0.09	NA	0.12	0.06	0.09	0.09
# whales	<1	NA	<1	<1	<1	<1
Percent MU	0.000	NA	0.000	0.000	0.000	0.000
Cumulative TTS: 168dB VHF Weighted SEL_{cum} (2 monopiles / 4 pin-piles in 24 hours)						
Area (km ²)	710	NA	2000	470	2200	1600
Max range (km)	26	NA	41	21	41	36
# whales	1	NA	4	1	4	3
Percent MU	0.004	NA	0.017	0.004	0.004	0.013

4.5 Phocids - harbour and grey seals

4.5.1 **Table 4-6** and **Table 4-7** outline the potential for TTS-onset for harbour and grey seals for both monopiles and pin-piles under the worst case scenario and most likely scenario respectively. The largest predicted cumulative TTS-onset impact range is 15km, resulting in a potential TTS-onset impact to <1 seal of each species per piling day.

Table 4-6 Impact area, maximum range, number of harbour and grey seals predicted to experience TTS-onset for the worst case scenario

	Monopile (4,400kJ)			Pin-pile (2,500kJ)		
	NW	S	E	NW	S	E
Instantaneous TTS: 212dB unweighted SPL_{peak}						
Area (km²)	0.03	NA	0.06	0.02	0.04	0.04
Max range (km)	0.10	NA	0.14	0.08	0.11	0.11
Harbour seals	<1	NA	<1	<1	<1	<1
Grey seals	<1	NA	<1	<1	<1	<1
Cumulative TTS: 170dB VHF Weighted SEL_{cum} (2 monopiles / 4 pin-piles in 24 hours)						
Area (km²)	35	NA	280	23	400	230
Max range (km)	5.2	NA	13.0	4.3	15.0	12.0
Harbour seals	<1	NA	<1	<1	<1	<1
Grey seals	<1	NA	<1	<1	<1	<1

Table 4-7 Impact area, maximum range, number of harbour and grey seals predicted to experience TTS-onset for the most likely scenario

	Monopile (4,000kJ)			Pin-pile (2,000kJ)		
	NW	S	E	NW	S	E
Instantaneous TTS: 212dB unweighted SPL_{peak}						
Area (km²)	0.03	NA	0.05	0.02	0.03	0.03
Max range (km)	0.10	NA	0.01	0.07	0.10	0.10
Harbour seals	<1	NA	<1	<1	<1	<1
Grey seals	<1	NA	<1	<1	<1	<1
Cumulative TTS: 170dB VHF Weighted SEL_{cum} (2 monopiles / 4 pin-piles in 24 hours)						
Area (km²)	33	NA	260	19	360	200
Max range (km)	5.0	NA	13.0	3.9	14.0	11.0
Harbour seals	<1	NA	<1	<1	<1	<1
Grey seals	<1	NA	<1	<1	<1	<1

5. Disturbance results

This section outlines the marine mammal behavioural disturbance impact ranges, number of animals potentially within these ranges and the proportion of the MU that may be impacted. This, in combination with the sensitivity assessment presented in **Section 2.5**, provides the magnitude, sensitivity and overall impact significance scores for unmitigated pile driving of both monopiles and pin-piles under both the worst case scenario and most likely scenario.

5.1 Harbour porpoise

- 5.1.1 **Table 5-1** outlines the number of harbour porpoise potentially disturbed by pile driving at each modelling location for both monopiles and pin piles under both the worst case scenario and most likely scenario. The highest level of disturbance in spatial terms is predicted to be from the installation of a monopiles, however no monopiles are planned to be installed at the south location which is the deepest location and where noise propagates furthest (an example of the noise contours are shown in **Graphic 5-1¹**).
- 5.1.2 For monopiles, the worst case scenario is the east location, where (using the SCANS III density estimate, 0.213 porpoise/km²) a total of 551 porpoise are predicted to be potentially disturbed once hammer energy reaches its maximum, which represents 0.16 percent of the reference population.
- 5.1.3 For the concurrent piling of monopiles at the northwest and east locations simultaneously, a total of 630 porpoise are predicted to be potentially disturbed once hammer energy reaches its maximum, which represents 0.18 percent of the reference population.
- 5.1.4 For pin-piles, the worst case scenario is the south location, where 633 porpoise are predicted to be potentially disturbed once hammer energy reaches its maximum (0.18 percent of the population), which represents the highest level of disturbance in both spatial and temporal terms.
- 5.1.5 Given the results of the expert elicitation on the likely effects of behavioural disturbance on vital rates (Booth *et al.* 2019) (see **Section 2.5**), a total of 58 days piling for monopiles (assuming two monopiles are installed concurrently) and 116 days piling for pin-piles is unlikely to cause any effect on fertility rates, although there is the potential for calf survival to be affected. However, it is highly unlikely that the same mother-calf pair would repeatedly return to the area in order to receive these levels of repeated disturbance over this many days. Any potential impact on calf survival rates is likely to be temporary and is not expected to result in any changes in the population trajectory or overall size.

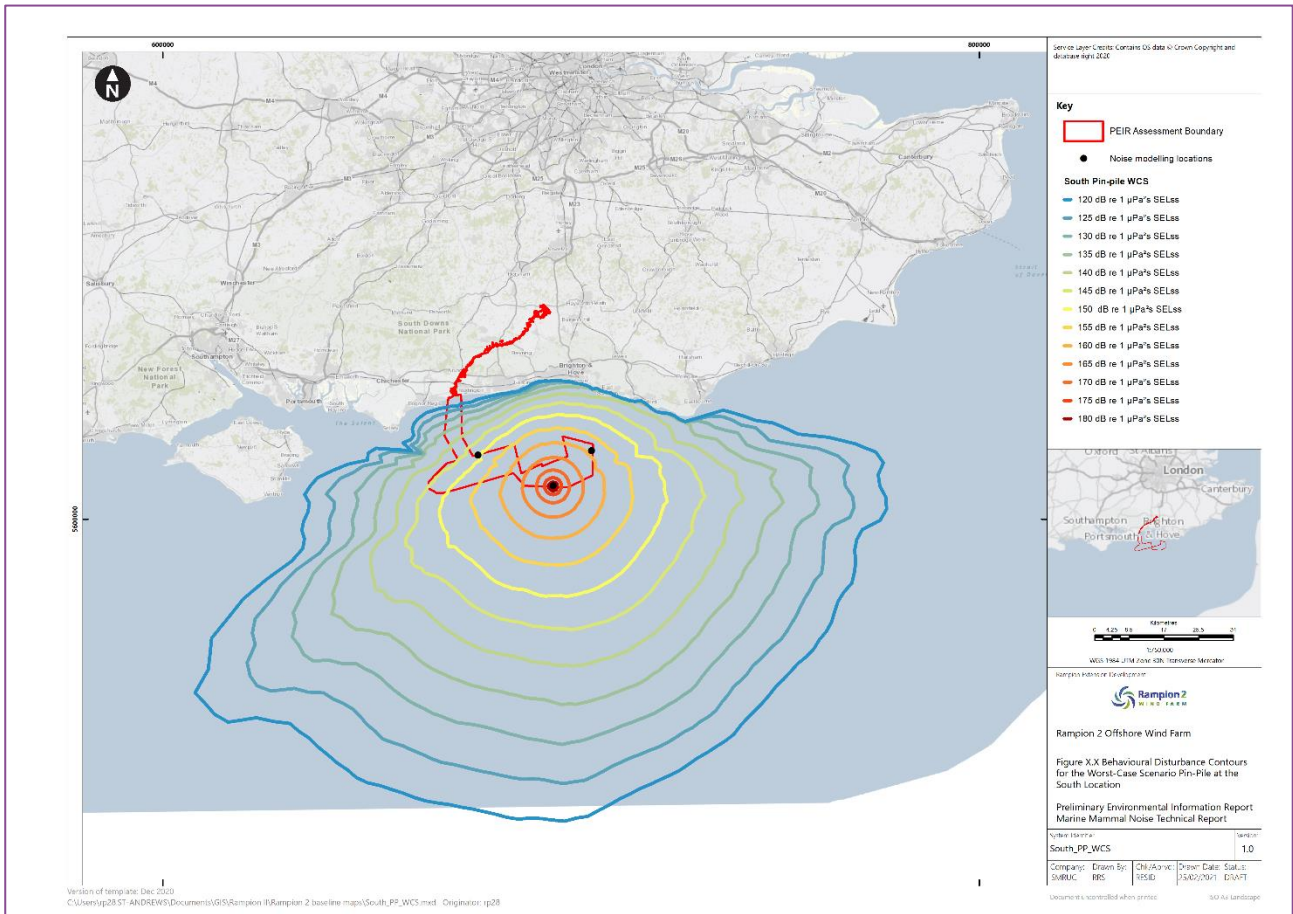
¹ Note: all modelled noise impact contours for both monopiles and pin-piles, for both the worst case scenario and the most likely scenario and all three modelling locations can be found in **Appendix 11.3, Volume 4**.

- 5.1.6 The impact is predicted to be of local spatial extent, short term duration, intermittent and is reversible. The extent of the impact in terms of the number of animals affected, the proportion of the MU affected, and the duration of impact is low. The magnitude is therefore considered to be **Minor**.
- 5.1.7 As outlined in **Section 2.5**, disturbance as result of pile driving may temporarily affect harbour porpoise fertility and the probability of calf survival. Due to observed responsiveness to piling, and their income breeder life history, the sensitivity of harbour porpoise is therefore considered to be **Medium**.
- 5.1.8 Overall, the sensitivity of harbour porpoise to disturbance has been assessed as high and the magnitude is predicted to be minor. Therefore, the resulting impact significance for behavioural disturbance in harbour porpoise from both the worst case scenario and most likely scenario for both monopiles and pin-piles is **Minor (Not Significant)**.

Table 5-1 Number of harbour porpoise and percentage of the MU predicted to experience potential behavioural disturbance for the worst case scenario and most likely scenario

	NW single	S single	E single	NW and E concurrent	NW single	S single	E single
worst case scenario	Monopile (4,400kJ)				Pin-pile (2,500kJ)		
# porpoise	285	NA	551	630	226	633	475
Percent MU	0.08	NA	0.16	0.18	0.07	0.18	0.14
most likely scenario	Monopile (4,000kJ)				Pin-pile (2,000kJ)		
# porpoise	280	NA	543	622	213	604	452
Percent MU	0.08	NA	0.16	0.18	0.06	0.17	0.13

Graphic 5-1 Behavioural disturbance noise contours for the worst-case scenario for pin-piles at the south location



5.2 Bottlenose dolphin

- 5.2.1 **Table 5-2** outlines the number of bottlenose dolphins potentially disturbed by pile driving at each modelling location for both monopiles and pin piles under both the worst case scenario and most likely scenario. The highest level of disturbance in spatial terms is predicted to be from the installation of a monopiles, however no monopiles are planned to be installed at the south location which is the deepest location and where noise propagates furthest.
- 5.2.2 For monopiles, the worst case scenario is the east location, where (using the SAMMS density estimate, 0.037 dolphins/km²) a total of 96 bottlenose dolphins are predicted to be potentially disturbed once hammer energy reaches its maximum, which represents 1.97 percent of the reference population.
- 5.2.3 For the concurrent piling of monopiles at the northwest and east locations simultaneously, a total of 110 dolphins are predicted to be potentially disturbed once hammer energy reaches its maximum, which represents 2.27 percent of the reference population.
- 5.2.4 For pin-piles, the worst case scenario is the south location, where 110 bottlenose dolphins are predicted to be potentially disturbed once hammer energy reaches its

maximum (2.27 percent of the population), which represents the highest level of disturbance in both spatial and temporal terms.

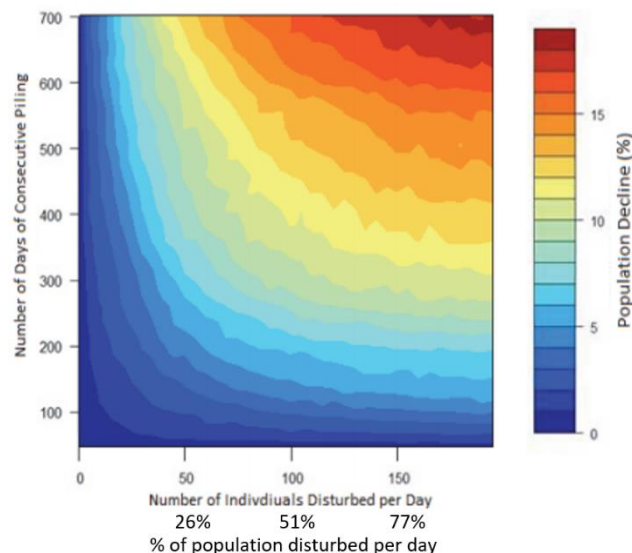
5.2.5

The number of bottlenose dolphins predicted to experience behavioural disturbance as a result of pile-driving is considered to be conservative. This is due to the fact that the density estimate used (0.037 dolphin/km²) is the summer density estimate for the English Channel, however densities are expected to be much lower in the winter (0.010 dolphins/km²) and therefore the numbers presented in **Table 5-2** are highly precautionary for the predicted level of impact in winter months.

5.2.6

Previous iPCoD modelling for bottlenose dolphins has shown that disturbance from piling at the Moray West offshore windfarm to ~5 percent of the population did not result in any significant effect on the long term population size (Moray Offshore Windfarm (West) Limited, 2018). A cumulative impact assessment of Scottish east coast offshore windfarm construction on the east coast bottlenose dolphin population showed that increasing the number of days of consecutive piling and increasing the proportion of the population disturbed per day resulted in an increased risk of population decline (**Graphic 5-2**) (Smith *et al.*, 2019). However, the proportion of the population predicted to be impacted by Rampion 2 (up to 2.27 percent per day) and the number of days of piling expected to occur (116 piling days assuming 4 pin-piles are installed in one 24-hour period) is highly unlikely to result in any decline in the bottlenose dolphin population.

Graphic 5-2 Contour plot showing the effect of increasing the number of days of disturbance and increasing the number of individuals disturbed per day for a population of 195 bottlenose dolphins (residual days of disturbance set to 1) (Smith *et al.*, 2019)



5.2.7

The impact is predicted to be of local spatial extent, short term duration, intermittent and is reversible. However, given the number of dolphins predicted to be impacted and the proportion of the population this represents, the magnitude is conservatively considered to be **Moderate**.

5.2.8

As outlined in **Section 2.5**, disturbance as result of pile driving may result in small spatial and temporal scale disturbance, however direct evidence for this species is generally lacking. There is evidence that pile driving can result in temporary

displacement of bottlenose dolphins, but that this displacement may be limited to small temporal and spatial scales. While there remains the potential for disturbance and displacement to affect individual behaviour and in particular calf survival rates, bottlenose dolphins do have some capability to adapt their behaviour and tolerate certain levels of temporary disturbance. Therefore, the sensitivity of bottlenose dolphins to disturbance from pile driving is considered to be **Medium**.

- 5.2.9 Overall, the sensitivity of bottlenose dolphins to disturbance has been assessed as medium and the magnitude is predicted to be moderate. Therefore, the resulting impact significance for behavioural disturbance in bottlenose dolphins from both the worst case scenario and most likely scenario for both monopiles and pin-piles is **Minor (not significant)**.

Table 5-2 Number of bottlenose dolphins and percentage of the MU predicted to experience potential behavioural disturbance for the worst case scenario and most likely scenario

	NW single	S single	E single	NW and E concurrent	NW single	S single	E single
worst case scenario	Monopile (4,400kJ)				Pin-pile (2,500kJ)		
# dolphins	50	NA	96	110	39	110	83
Percent MU	1.02	NA	1.97	2.27	0.81	2.27	1.70
most likely scenario	Monopile (4,000kJ)				Pin-pile (2,000kJ)		
# dolphins	49	NA	94	108	37	105	79
Percent MU	1.00	NA	1.94	2.23	0.76	2.16	1.62

5.3 Common dolphin

- 5.3.1 **Table 5-3** outlines the number of common dolphins potentially disturbed by pile driving at each modelling location for both monopiles and pin piles under both the worst case scenario and most likely scenario. The highest level of disturbance in spatial terms is predicted to be from the installation of a monopiles, however no monopiles are planned to be installed at the south location which is the deepest location and where noise propagates furthest.
- 5.3.2 For monopiles, the worst case scenario is the east location, where (using the SAMMS density estimate, 0.171 dolphins/km²) a total of 442 common dolphins are predicted to be potentially disturbed once hammer energy reaches its maximum, which represents 0.78 percent of the reference population.
- 5.3.3 For the concurrent piling of monopiles at the northwest and east locations simultaneously, a total of 506 dolphins are predicted to be potentially disturbed

once hammer energy reaches its maximum, which represents 0.89 percent of the reference population.

- 5.3.4 For pin-piles, the worst case scenario is the south location, where 508 common dolphins are predicted to be potentially disturbed once hammer energy reaches its maximum (0.90 percent of the population), which represents the highest level of disturbance in both spatial and temporal terms.
- 5.3.5 Similarly to the situation with bottlenose dolphins, the number of common dolphins predicted to experience behavioural disturbance as a result of pile-driving is considered to be conservative. This is due to the fact that the density estimate used (0.171 dolphin/km²) is the winter density estimate for the English Channel, however the same study predicted densities to be much lower in the summer (0.011 dolphins/km²) (Laran *et al.*, 2017) and therefore the numbers presented in **Table 5-3** are highly precautionary for the predicted level of impact in summer months. In addition to this, the density estimate used is for “*dephinids*” (common and striped dolphins combined) so is likely to be an over-estimate for common dolphins alone.
- 5.3.6 The impact is predicted to be of local spatial extent, short term duration, intermittent and is reversible. However, given the number of dolphins predicted to be impacted and the proportion of the population this represents, the magnitude is considered to be **Moderate**.
- 5.3.7 As outlined in **Section 2.5**, disturbance as result of pile driving may result in small spatial and temporal scale disturbance, however direct evidence for this species is lacking. It is therefore expected that their sensitivity will be similar to bottlenose dolphins, as both species are grouped together as high-frequency cetaceans with similar hearing abilities. While there is the potential for disturbance to affect individual behaviour and therefore vital rates and population level changes, it is expected that like bottlenose dolphins, common dolphins will have some capability to adapt their behaviour and tolerate certain levels of temporary disturbance. Therefore, the sensitivity of common dolphins is considered to be **Medium**.
- 5.3.8 Overall, the sensitivity of common dolphins to disturbance has been assessed as medium and the magnitude is predicted to be moderate. Therefore, the resulting impact significance for behavioural disturbance in common dolphins from both the worst case scenario and most likely scenario for both monopiles and pin-piles is **Minor (not significant)**.

Table 5-3 Number of common dolphins and percentage of the MU predicted to experience potential behavioural disturbance for the worst case scenario and most likely scenario

	NW single	S single	E single	NW and E concurrent	NW single	S single	E single
worst case scenario	Monopile (4,400kJ)				Pin-pile (2,500kJ)		
# dolphins	229	NA	442	506	181	508	382

	NW single	S single	E single	NW and E concurrent	NW single	S single	E single
Percent MU	0.40	NA	0.78	0.89	0.32	0.90	0.67
most likely scenario	Monopile (4,000kJ)				Pin-pile (2,000kJ)		
# dolphins	225	NA	436	499	171	485	363
Percent MU	0.40	NA	0.77	0.88	0.30	0.86	0.64

5.4 Minke whale

- 5.4.1 **Table 5-4** outlines the number of minke whales potentially disturbed by pile driving at each modelling location for both monopiles and pin piles under both the worst case scenario and most likely scenario. The highest level of disturbance in spatial terms is predicted to be from the installation of a monopiles, however no monopiles are planned to be installed at the south location which is the deepest location and where noise propagates furthest.
- 5.4.2 For monopiles, the worst case scenario is the east location, where (using the SCANS III density estimate, 0.002 whales/km²) a total of five minke whales are predicted to be potentially disturbed once hammer energy reaches its maximum, which represents 0.02 percent of the reference population.
- 5.4.3 For the concurrent piling of monopiles at the northwest and east locations simultaneously, a total of 6 whales are predicted to be potentially disturbed once hammer energy reaches its maximum, which represents 0.03 percent of the reference population.
- 5.4.4 For pin-piles, the worst case scenario is the south location, where six minke whales are predicted to be potentially disturbed once hammer energy reaches its maximum (0.03 percent of the population), which represents the highest level of disturbance in both spatial and temporal terms.
- 5.4.5 The impact is predicted to be of local spatial extent, short term duration, intermittent and is reversible. Given the low density of minke whales predicted to be in the area, the resulting number of animals and proportion of the population potentially disturbed by pile driving results in a magnitude score of **Minor**.
- 5.4.6 As outlined in **Section 2.5**, disturbance as result of pile driving may result in small spatial and temporal scale disturbance, however direct evidence for this species is lacking. While there is the potential for disturbance to affect individual behaviour and therefore vital rates and population level changes, it is expected that minke whales will be able to tolerate temporary displacement from foraging areas due to their large size and capacity for energy storage. Therefore, the sensitivity of minke whales is considered to be **Medium**.
- 5.4.7 Overall, the sensitivity of minke whales to disturbance has been assessed as medium and the magnitude is predicted to be minor. Therefore, the resulting impact significance for behavioural disturbance in minke whales from both the

worst case scenario and most likely scenario for both monopiles and pin-piles is **Minor (Not Significant)**.

Table 5-4 Number of minke whales and percentage of the MU predicted to experience potential behavioural disturbance for the worst case scenario and most likely scenario

	NW single	S single	E single	NW and E concurrent	NW single	S single	E single
worst case scenario	Monopile (4,400kJ)				Pin-pile (2,500kJ)		
# whales	3	NA	5	6	2	6	5
Percent MU	0.01	NA	0.02	0.03	0.01	0.03	0.02
most likely scenario	Monopile (4,000kJ)				Pin-pile (2,000kJ)		
# whales	3	NA	5	6	2	6	4
Percent MU	0.01	NA	0.02	0.03	0.01	0.03	0.02

5.5 Harbour seal

- 5.5.1 **Table 5-5** outlines the number of harbour seals potentially disturbed by pile driving at each modelling location for both monopiles and pin piles under the worst case scenario. The highest level of disturbance in spatial terms is predicted to be from the installation of a monopiles, however no monopiles are planned to be installed at the south location which is the deepest location and where noise propagates furthest.
- 5.5.2 For monopiles, the worst case scenario is the east location, where (using the habitat preference maps) a total of <1 harbour seal is predicted to be potentially disturbed once hammer energy reaches its maximum (<0.002 percent of the population), which represents the highest level of disturbance in spatial terms. Likewise, for the concurrent piling of monopiles at the east and northwest locations, a maximum of <1 harbour seal is predicted to be potentially disturbed once hammer energy reaches its maximum.
- 5.5.3 For pin-piles, the worst case scenario is also the east location, where <1 harbour seal is predicted to be potentially disturbed once hammer energy reaches its maximum (<0.002 percent of the population), which represents the highest level of disturbance in temporal terms.
- 5.5.4 Given the low numbers predicted for the worst case scenario, the most likely scenario numbers were not calculated since they would be lower than those predicted for the worst case scenario (as the maximum hammer energy is lower).
- 5.5.5 The impact is predicted to be of local spatial extent, short term duration, intermittent and is reversible. The extent of the impact in terms of the number of

animals affected, the proportion of the MU affected, and the duration of impact is very low. The magnitude is therefore considered to be **Negligible**.

5.5.6 As outlined in **Section 2.5**, disturbance as result of pile driving may temporarily affect harbour seal fertility and survival of “*weaned of the year*”. Due to observed responsiveness to piling, their generalist diet, their life history and their ability to store fat, the sensitivity of harbour seals is therefore considered to be **Medium**.

5.5.7 Overall, the sensitivity of harbour seals to disturbance has been assessed as high and the magnitude is predicted to be negligible. Therefore, the resulting impact significance for behavioural disturbance in harbour seals from both the worst case scenario and most likely scenario for both monopiles and pin-piles is **Negligible (Not Significant)**.

Table 5-5 Number of harbour seals (mean and 95 percent CI) predicted to experience potential behavioural disturbance for the worst case scenario and most likely scenario

	NW single	S single	E single	NW and E concurrent	NW single	S single	E single
worst case scenario	Monopile (4,400kJ)				Pin-pile (2,500kJ)		
# harbour seals	<1 (0 to <1)	NA	<1 (0 to <1)	<1 (0 to <1)	<1 (0 to <1)	<1 (0 to <1)	<1 (0 to <1)

5.6 Grey seal

5.6.1 **Table 5-6** outlines the number of grey seals potentially disturbed by pile driving at each modelling location for both monopiles and pin piles under the worst case scenario. The highest level of disturbance in spatial terms is predicted to be from the installation of a monopiles, however no monopiles are planned to be installed at the south location which is the deepest location and where noise propagates furthest.

5.6.2 For monopiles, the worst case scenario is the east location, where (using the habitat preference maps) a total of two grey seals are predicted to be potentially disturbed once hammer energy reaches its maximum (0.005 percent of the population), which represents the highest level of disturbance in spatial terms. Likewise, for the concurrent piling of monopiles at the east and northwest locations, a maximum of two grey seals are predicted to be potentially disturbed once hammer energy reaches its maximum (0.005 percent of the population).

5.6.3 For pin-piles, the worst case scenario is also the east location, where one grey seal is predicted to be potentially disturbed once hammer energy reaches its maximum (0.004 percent of the population), which represents the highest level of disturbance in temporal terms.

- 5.6.4 Given the low numbers predicted for the worst case scenario, the most likely scenario numbers were not calculated since they would be lower than those predicted for the worst case scenario (as the maximum hammer energy is lower).
- 5.6.5 The impact is predicted to be of local spatial extent, short term duration, intermittent and is reversible. The extent of the impact in terms of the number of animals affected, the proportion of the MU affected, and the duration of impact is very low. The magnitude is therefore considered to be **Negligible**.
- 5.6.6 As outlined in **Section 2.5**, disturbance as result of pile driving may temporarily affect grey seal fertility and survival of “*weaned of the year*”. Due to observed responsiveness to piling, their capital breeder life history and their tolerance of periods of fasting, the sensitivity of grey seals is therefore considered to be **Low**.
- 5.6.7 Overall, the sensitivity of grey seals to disturbance has been assessed as high and the magnitude is predicted to be negligible. Therefore, the resulting impact significance for behavioural disturbance in grey seals from both the worst case scenario and most likely scenario for both monopiles and pin-piles is **Negligible (not significant)**.

Table 5-6 Number of grey seals (mean and 95 percent CI) predicted to experience potential behavioural disturbance for the worst case scenario

	NW single	S single	E single	NW and E concurrent	NW single	S single	E single
worst case scenario	Monopile (4,400kJ)				Pin-pile (2,500kJ)		
# grey seals	<1 (0 to 1)	NA	2 (0 to 3)	2 (0 to 3)	<1 (0 to 1)	<1 (0 to 1)	1 (0 to 2)

5.7 Disturbance summary

- 5.7.1 The impact of behavioural disturbance from piling noise under both the worst case scenario and the most likely scenario is not considered to have a significant effect on any marine mammal species considered in this assessment (**Table 5-7**).

Table 5-7 Impact significance for all marine mammals to the impact of behavioural disturbance from impact piling

Monopiles and Pin-piles (worst case scenario and most likely scenario)			
	Magnitude	Sensitivity	Impact
Harbour porpoise	Minor	Medium	Minor (not significant)
Bottlenose dolphin	Moderate	Medium	Minor (not significant)
Common dolphin	Moderate	Medium	Minor (not significant)

Minke whale	Minor	Medium	Minor (not significant)
Harbour seal	Negligible	Medium	Negligible (not significant)
Grey seal	Negligible	Low	Negligible (not significant)

6. Conclusion

- 6.1.1 This quantitative underwater noise impact assessment has found that there are predicted to be no significant impacts from construction related pile driving at Rampion 2 on marine mammals. The embedded mitigation of an MMMP to reduce the risk of PTS-onset to negligible levels is considered to be sufficient, and no other mitigation measures are required to reduce impacts to marine mammals.

6.2 Glossary of terms and abbreviations

Table 6-1 Glossary of terms and abbreviations

Term (acronym)	Definition
ADD	Acoustic Deterrent Devices
Baseline	Refers to existing conditions as represented by latest available survey and other data which is used as a benchmark for making comparisons to assess the impact of development.
BEIS	Department for Business Energy and Industrial Strategy
Centre for Environment Fisheries and Aquaculture Science (Cefas)	The Government's marine and freshwater science experts, advising the UK government and overseas partners.
Cetacean	Aquatic mostly marine mammals that includes the whales, dolphins, porpoises.
CI	Confidence Interval
dB	Decibel
DEPONS	Disturbance Effects on the Harbour Porpoise Population in the North Sea
DTAGs	Digital Acoustic Recording Tags
Environmental Impact Assessment (EIA)	The process of evaluating the likely significant environmental effects of a proposed project or development over and above the existing circumstances (or 'baseline').
Environmental Statement (ES)	The written output presenting the full findings of the Environmental Impact Assessment.

Term (acronym)	Definition
ETG	Expert Topic Group
EPS	European Protected Species
Evidence Plan Process (EPP)	A voluntary consultation process with specialist stakeholders to agree the approach and the information required to support the EIA and HRA for certain aspects
HF	High-Frequency Cetaceans
Hz	Hertz
Impact	The changes resulting from an action.
INSPIRE	Impulse Noise Sound Propagation and Impact Range Estimator
kHz	Kilohertz
kJ	Kilojoule
km	Kilometre
km²	Square Kilometre
LF	Low-Frequency Cetaceans
m	Metre
Management Unit (MU)	The cetacean MUs have been defined to provide an indication of the spatial scales at which impacts of plans and projects alone, cumulatively and in-combination, need to be assessed for the key cetacean species in UK waters, with consistency across the UK. Seal MUs are geographic areas within which seal populations are considered.
MMMP	Marine Mammal Mitigation Plan
ms⁻¹	Metres per Second
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
Offshore	The sea further than two miles from the coast.

Term (acronym)	Definition
Offshore Wind Farm	An offshore wind farm is a group of wind turbines in the same location (offshore) in the sea which are used to produce electricity
Pa²s	Pascal Squared Seconds
Peak pressure	The highest pressure above or below ambient that is associated with a sound wave.
Peak-to-peak pressure	The sum of the highest positive and negative pressures that are associated with a sound wave.
/km²	Per Square Kilometre
Planning Act 2008	The legislative framework for the process of approving major new infrastructure projects.
Preliminary Environmental Information Report (PEIR)	The written output of the Environmental Impact Assessment undertaken to date for the Proposed Development. It is developed to support formal consultation and presents the preliminary findings of the assessment to allow an informed view to be developed of the Proposed Development, the assessment approach that has been undertaken, and the preliminary conclusions on the likely significant effects of the Proposed Development and environmental measures proposed.
Proposed Development	The development that is subject to the application for development consent, as described in Chapter 4.
Permanent Threshold Shift (PTS)	A permanent total or partial loss of hearing caused by acoustic trauma. PTS results in irreversible damage to the sensory hair cells of the ear, and thus a permanent reduction of hearing acuity
Rampion 1	The existing Rampion Offshore Wind Farm located in the English Channel off the south coast of England.
RED	Rampion Extension Development Limited
SAFESIMM	Statistical Algorithms For Estimating the Sonar Influence on Marine Megafauna
SAMMS	Suivi Aérien de la Mégafaune Marine

Term (acronym)	Definition
Sound Exposure Level (SEL)	The constant sound level acting for one second, which has the same amount of acoustic energy, as indicated by the square of the sound pressure, as the original sound. It is the time-integrated, sound-pressure-squared level. SEL is typically used to compare transient sound events having different time durations, pressure levels, and temporal characteristics.
SEL_{cum}	Cumulative Sound Exposure Level
SEL_{ss}	Single Strike Sound Exposure Level
SCANS	Small Cetaceans in European Atlantic waters and the North Sea
SMRU	Sea Mammal Research Unit
Sound Pressure Level (SPL)	The sound pressure level is an expression of sound pressure using the decibel (dB) scale; the standard frequency pressures of which are 1 µPa for water and 20 µPa for air.
SPL_{peak}	Peak Sound Pressure Level
Study area	Area where potential impacts from the Proposed Development could occur, as defined for each aspect.
The Proposed Development / Rampion 2	The onshore and offshore infrastructure associated with the offshore wind farm comprising of installed capacity of up to 1200 MW, located in the English Channel in off the south coast of England.
Temporary Threshold Shift (TTS)	Temporary reduction of hearing acuity because of exposure to sound over time. Exposure to high levels of sound over relatively short time periods could cause the same amount of TTS as exposure to lower levels of sound over longer time periods. The mechanisms underlying TTS are not well understood, but there may be some temporary damage to the sensory cells. The duration of TTS varies depending on the nature of the stimulus.
UK	United Kingdom

Term (acronym)	Definition
Unweighted sound level	Sound levels which are “raw” or have not been adjusted in any way, for example to account for the hearing ability of a species.
μPa	Micropascal
VHF	Very High-Frequency Cetaceans
Weighted sound level	A sound level which has been adjusted with respect to a “weighting envelope” in the frequency domain, typically to make an unweighted level relevant to a particular species. Examples of this are the dB(A), where the overall sound level has been adjusted to account for the hearing ability of humans in air, or the filters used by Southall <i>et al.</i> (2019) for marine mammals.
WTG	Wind Turbine Generator

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4.11.3



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Underwater Noise Assessment Technical Report



For Issue

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11.3 Underwater Noise Assessment Technical Report

Natalie Hirst

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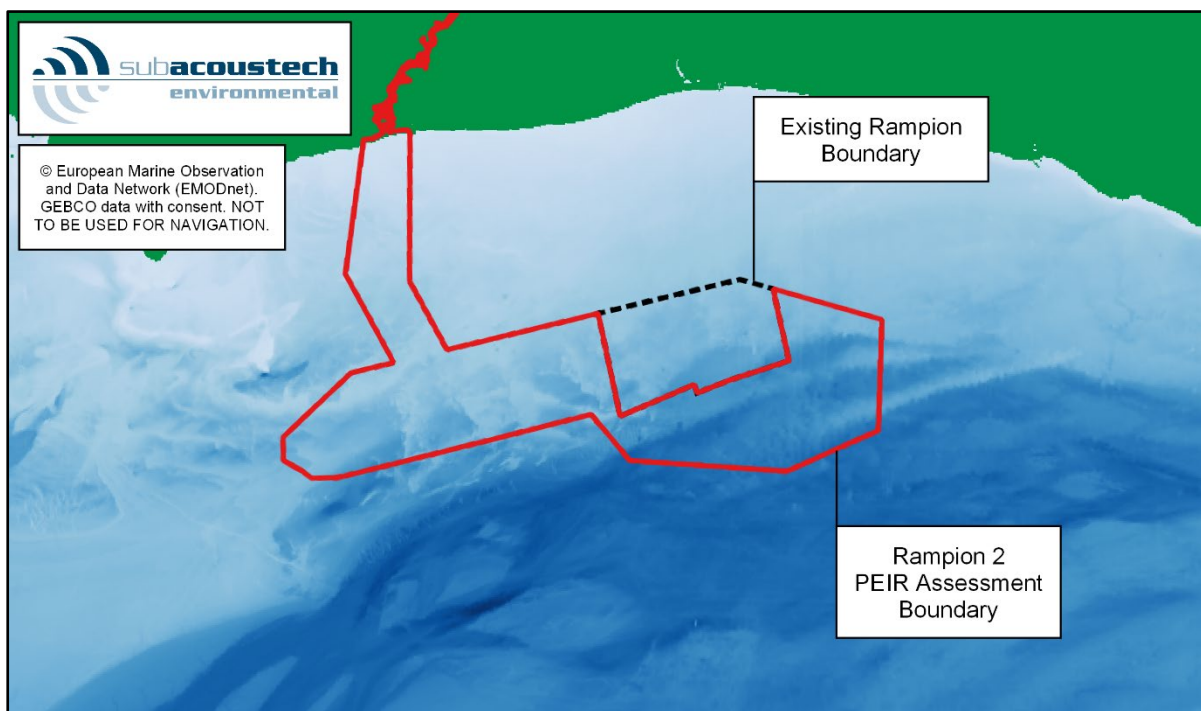
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1 Introduction

- 1.1.1 The Rampion 2 Offshore Wind Farm (hereafter referred to as Rampion 2) is a proposed extension to the existing Rampion Offshore Wind Farm (hereafter referred to as Rampion 1) located off the coast of Sussex. As part of the Environmental Impact Assessment (EIA) process, Subacoustech Environmental Ltd. have undertaken detailed underwater noise modelling and analysis in relation to marine mammals and fish at the proposed wind farm site.
- 1.1.2 The Rampion 2 proposed development is situated 13km from the Sussex coast at its closest point and surrounds the south, east, and west sides of the existing Rampion site and has a proposed capacity of up to 1,200 Megawatts (MW). The location of the wind farm is shown in **Graphic 1-1**.

Graphic 1-1 Overview map showing the Rampion 2 Preliminary Environmental Information Report (PEIR) Assessment Boundary (red line) as well as the existing Rampion offshore wind farm (dotted black line)



- 1.1.3 This report presents a detailed assessment of the potential underwater noise during the construction and operation of Rampion 2 and its effects, and covers the following:
- a review of background information on the units for measuring and assessing underwater noise and a review of the underwater noise metrics and criteria used to assess the possible environmental effects in marine receptors (**Section 2**);

- discussion of the approach, input parameters and assumptions for the noise modelling undertaken (**Section 3**);
- presentation and interpretation of the detailed subsea noise modelling for impact piling with regards to the effects in marine mammals and fish using various metrics and criteria (**Section 4**);
- noise modelling of the other noise sources expected around construction and operation of the wind farm including cable laying, rock placement, dredging, trenching, vessel activity, operational Wind Turbine Generator (WTG) noise and Unexploded Ordnance (UXO) detonation (**Section 5**); and
- summary and conclusions (**Section 6**).

1.1.4 Further modelling of the non-impulsive criteria for impact piling are provided in **Annex A** of this report.

2 Background to underwater noise metrics

2.1 Underwater noise

- 2.1.1 Sound travels much faster in water (approximately $1,500\text{ms}^{-1}$) than in air (340ms^{-1}). Since water is a relatively incompressible, dense medium, the pressure associated with underwater sound tends to be much higher than in air. As an example, background noise levels in the sea of 130dB re 1 μPa for United Kingdom (UK) coastal waters are not uncommon (Nedwell *et al.* 2003; Nedwell *et al.* 2007).
- 2.1.2 It should be noted that stated underwater noise levels should not be confused with noise levels in air, which use a different scale.

Units of measurement

- 2.1.3 Sound measurements underwater are usually expressed using the decibel (dB) scale, which is a logarithmic measure of sound. A logarithmic scale is used because, rather than equal increments of sound having an equal increase in effect, typically each doubling of sound level will cause a roughly equal increase of “loudness.”
- 2.1.4 Any quantity expressed in this scale is termed a “level.” If the unit is sound pressure, expressed on the dB scale, it will be termed a “sound pressure level.”
- 2.1.5 The fundamental definition of the dB scale is given by:

$$\text{Level} = 10 \times \log_{10} \left(\frac{Q}{Q_{\text{ref}}} \right)$$

- 2.1.6 where Q is the quantity being expressed on the scale, and Q_{ref} is the reference quantity.
- 2.1.7 The dB scale represents a ratio. It is therefore used with a reference unit, which expresses the base from which the ratio is expressed. The reference quantity is conventionally smaller than the smallest value to be expressed on the scale so that any level quoted is positive. For example, a reference quantity of $20\mu\text{Pa}$ is used for sound in air since that is the lower threshold of human hearing.
- 2.1.8 When used with sound pressure, the pressure value is squared. So that variations in the units agree, the sound pressure must be specified as units of Root Mean Square (RMS) pressure squared. This is equivalent to expressing the sound as:

$$\text{Sound pressure level} = 20 \times \log_{10} \left(\frac{P_{\text{RMS}}}{P_{\text{ref}}} \right)$$

- 2.1.9 For underwater sound, a unit of 1 μPa is typically used as the reference unit (P_{ref}); a Pascal is equal to the pressure exerted by one Newton over one square metre, one micropascal equals one millionth of this.
- 2.1.10 Unless otherwise defined, all noise levels in this report are referenced to 1 μPa .

Sound pressure level (SPL)

- 2.1.11 The sound pressure level (SPL) is normally used to characterise noise and vibration of a continuous nature, such as drilling, boring, continuous wave sonar, or background sea and river noise levels. To calculate the SPL, the variation in sound pressure is measured over a specific period to determine the RMS level of the time-varying sound. The SPL can therefore be considered a measure of the average unweighted level of sound over the measurement period.
- 2.1.12 Where SPL is used to characterise transient pressure waves, such as that from impact piling, seismic airgun or underwater blasting, it is critical that the period over which the RMS level is calculated is quoted. For instance, in the case of a pile strike lasting a tenth of a second, the mean taken over a tenth of a second will be ten times higher than the mean averaged over one second. Often, transient sounds such as these are quantified using “peak” SPLs or sound exposure levels (SELs).

Peak sound pressure level (SPL_{peak})

- 2.1.13 Peak SPLs are often used to characterise transient sound from impulsive sources, such as percussive impact piling. SPL_{peak} is calculated using the maximum variation of the pressure from positive to zero within the wave. This represents the maximum change in positive pressure (differential pressure from positive to zero) as the transient pressure wave propagates.
- 2.1.14 A further variation of this is the peak-to-peak SPL ($\text{SPL}_{\text{peak-to-peak}}$) where the maximum variation of the pressure from positive to negative is considered. Where the wave is symmetrically distributed in positive and negative pressure, the peak-to-peak pressure will be twice the peak level, or 6dB higher (see **Section 2.1.1**).

Sound exposure level (SEL)

- 2.1.15 When considering the noise from transient sources, the issue of the duration of the pressure wave is often addressed by measuring the total acoustic energy (energy flux density) of the wave. This form of analysis was used by Bebb and Wright (1953, 1954a, 1954b, 1955), and later by Rawlins (1987),

to explain the apparent discrepancies in the biological effect of short and long-range blast waves on human divers. Currently the SEL metric has been used to develop criteria for assessing injury ranges for fish and marine mammals from various noise sources (Popper *et al.*, 2014 and Southall *et al.*, 2019).

- 2.1.16 The SEL sums the acoustic energy over a measurement period, and effectively takes account of both the SPL of the sound and the duration it is present in the acoustic environment. Sound Exposure (SE) is defined by the equation:

$$SE = \int_0^T p^2(t) dt$$

- 2.1.17 where p is the acoustic pressure in Pascals, T is the total duration of the sound in seconds, and t is the time in seconds. The SE is a measurement of acoustic energy and has units of Pascal squared seconds (Pa²s).

- 2.1.18 To express the SE on a logarithmic scale by means of a dB, it has to be compared with a reference acoustic energy level (p_{ref}^2) and a reference time (T_{ref}). The SEL is then defined by:

$$SEL = 10 \times \log_{10} \left(\frac{\int_0^T p^2(t) dt}{p_{ref}^2 T_{ref}} \right)$$

- 2.1.19 By selecting a common reference pressure (p_{ref}) of 1 µPa for assessments of underwater noise, the SEL and SPL can be compared using the expression:

$$SEL = SPL + 10 \times \log_{10} T$$

- 2.1.20 where the SPL is a measure of the average level of broadband noise and the SEL sums the cumulative broadband noise energy.

- 2.1.21 This means that, for continuous sounds of less than one second, the SEL will be lower than the SPL. For periods greater than one second, the SEL will be numerically greater than the SPL (for instance, for a continuous sound of 10 seconds duration, the SEL will be 10dB higher than the SPL; for a sound of 100 seconds duration the SEL will be 20dB higher than the SPL, and so on).

2.2 Analysis of environmental effects

- 2.2.1 Over the last 20 years it has become increasingly evident that noise from human activities in and around underwater environments can have an

impact on the marine species in the area. The extent to which intense underwater sound might cause adverse impacts in species is dependent upon the incident sound level, source frequency, duration of exposure, and/or repetition rate of an impulsive sound (see, for example, Hastings and Popper, 2005). As a result, scientific interest in the hearing abilities of aquatic species has increased. Studies are primarily based on evidence from high level sources of underwater noise such as blasting or impact piling, as these sources are likely to have the greatest immediate environmental impact and therefore the clearest observable effects, although interest in chronic noise exposure is increasing.

2.2.2 The impacts of underwater sound on marine species can be broadly summarised as follows:

- physical traumatic injury and fatality;
- auditory injury (either permanent or temporary); and
- disturbance.

2.2.3 The following sections discuss the underwater noise criteria used in this study with respect to species of marine mammals and fish that may be found within the Rampion 2 survey area.

Criteria to be used

2.2.4 The main metrics and criteria that have been used in this study to aid assessment of environmental effects come from two key papers covering underwater noise and its effects:

- Southall *et al.* (2019) marine mammal noise exposure criteria;
- Popper *et al.* (2014) sound exposure guidelines for fishes; and
- Hawkins *et al.* (2014) observed responses in fish.

2.2.5 At the time of writing these are used as the most up to date and authoritative criteria for assessing environmental effects for use in impact assessments.

Marine mammals

2.2.6 The Southall *et al.* (2019) paper is effectively an update of the previous Southall *et al.* (2007) paper and provides identical thresholds to those from the National Marine Fisheries Service (NMFS) (2018) guidance for marine mammals.

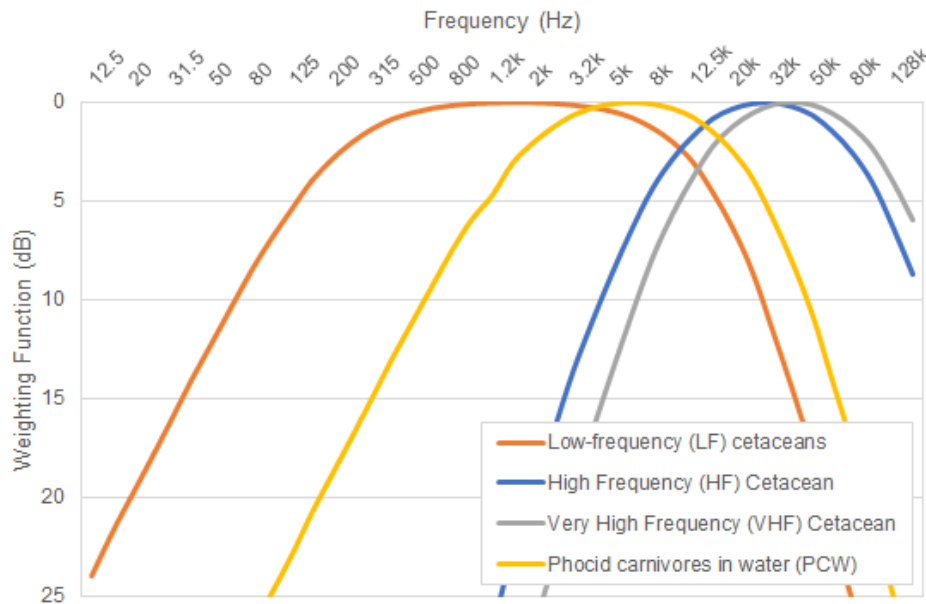
2.2.7 The Southall *et al.* (2019) guidance groups marine mammals into categories of similar species and applies filters to the unweighted noise to approximate the hearing sensitivities of the receptor. The hearing groups given in Southall *et al.* (2019) are summarised in **Table 2-1** and **Graphic 2-1**. Further groups

for sirenians and other marine carnivores in water are also given, but these have not been used for this study as those species are not commonly found in the North Sea.

Table 2-1 Marine mammal hearing groups (from Southall *et al.*, 2019)

Hearing group	Generalised hearing range	Example species
Low-frequency cetaceans (LF)	7Hz to 35kHz	Baleen whales
High-frequency cetaceans (HF)	150Hz to 160kHz	Dolphins, toothed whales, beaked whales, bottlenose whales (including bottlenose dolphin)
Very high-frequency cetaceans (VHF)	275Hz to 160kHz	True porpoises (including harbour porpoise)
Phocid carnivores in water (PCW)	50Hz to 86kHz	True seals (including harbour seal)

Graphic 2-1 Auditory weighting functions for low-frequency cetaceans (LF), high-frequency cetaceans (HF), very high-frequency cetaceans (VHF), and phocid carnivores in water (PCW) (from Southall *et al.*, 2019)



- 2.2.8 Southall *et al.* (2019) also gives individual criteria based on whether the noise source is considered impulsive or non-impulsive. Southall *et al.* categorises impulsive noises as having high peak sound pressure, short duration, fast rise-time and broad frequency content at source, and non-impulsive sources as steady-state noise. Explosives, impact piling and seismic airguns are considered impulsive noise sources and sonars, vibro-piling, drilling and other low-level continuous noises are considered non-impulsive. A non-impulsive noise does not necessarily have to have a long duration.
- 2.2.9 Southall *et al.* (2019) presents single strike, unweighted peak criteria (SPL_{peak}) and cumulative (for instance, more than a single sound impulse) weighted sound exposure criteria (SEL_{cum}) for both permanent threshold shift (PTS), where unrecoverable hearing damage may occur, and temporary threshold shift (TTS), where a temporary reduction in hearing sensitivity may occur in individual receptors.
- 2.2.10 As sound pulses propagate through the environment and dissipate, they also lose their most injurious characteristics (for example, rapid pulse rise time and high peak sound pressure) and become more like a “non-pulse” at greater distances; Southall *et al.* (2019) briefly discusses this. Active research is currently underway into the identification of the distance at which the pulse can be considered effectively non-impulsive, and Hastie *et al.* (2019) have analysed a series of impulsive data to investigate this. Although the situation is complex, the paper reported that most of the signals crossed

their threshold for rapid rise time and high peak sound pressure characteristics associated with impulsive noise at around 3.5km from the source. However, research by Martin *et al.* (2020) casts doubt on these findings, showing that noise in this category should be considered impulsive as long as it is above effective quiet. To provide as much detail as possible, both impulsive and non-impulsive criteria from Southall *et al.* (2019) have been included in this study, with the non-impulsive criteria presented in **Annex A**.

2.2.11 **Table 2-2** and **Table 2-3** present the Southall *et al.* (2019) criteria for the onset of PTS and TTS risk for each of the key marine mammal hearing groups considering impulsive and non-impulsive sources.

Table 2-2 Single strike SPL_{peak} criteria for PTS and TTS in marine mammals (Southall *et al.*, 2019)

Southall <i>et al.</i> (2019)	Unweighted SPL_{peak} (dB re 1 μ Pa)	
	Impulsive	
	PTS	TTS
Low-frequency cetaceans (LF)	219	213
High-frequency cetaceans (HF)	230	224
Very high-frequency cetaceans (VHF)	202	196
Phocid carnivores in water (PCW)	218	212

Table 2-3 Impulsive and non-impulsive SEL_{cum} criteria for PTS and TTS in marine mammals (Southall *et al.*, 2019)

Southall <i>et al.</i> (2019)	Weighted SEL_{cum} (dB re 1 μ Pa ² s)			
	Impulsive		Non-impulsive	
	PTS	TTS	PTS	TTS
Low-frequency cetaceans (LF)	183	168	199	179
High-frequency cetaceans (HF)	185	170	198	178
Very high-frequency cetaceans (VHF)	155	140	173	153
Phocid carnivores in water (PCW)	185	170	201	181

2.2.12 Where SEL_{cum} are required, a fleeing animal model has been used for marine mammals. This assumes that a receptor, when exposed to high noise levels, will swim away from the noise source. For this, a constant

fleeing speed of 3.25ms^{-1} has been assumed for the low-frequency cetaceans (LF) group (Blix and Folkow, 1995), based on data for minke whale, and for other receptors, a constant rate of 1.5ms^{-1} has been assumed for fleeing, which is a cruising speed for a harbour porpoise (Otani *et al.*, 2000). These are considered worst case assumptions as marine mammals are expected to be able to swim much faster under stress conditions. The fleeing animal model and the assumptions related to it are discussed in more detail in **Section 3.2.3**.

- 2.2.13 It is worth noting that, with regards to the criteria from NMFS (2018), although numerically identical to Southall *et al.* (2019), the guidance applies different names to the marine mammal groups and weightings. For example, what Southall *et al.* (2019) calls high-frequency cetaceans (HF), NMFS (2018) calls mid-frequency cetaceans (MF), and what Southall *et al.* (2019) calls very high-frequency cetaceans (VHF), NMFS (2018) refers to as high-frequency cetaceans (HF). As such, care should be taken when comparing results using the Southall *et al.* (2019) and NMFS (2018) criteria, especially as the “HF” groupings and criteria describe different species depending on which study is being used.

Fish

- 2.2.14 The large number of, and variation in, fish species leads to a greater challenge in production of a generic noise criterion, or range of criteria, for the assessment of noise impacts. Whereas previous studies applied broad criteria based on limited studies of fish that are not present in UK waters (for example, McCauley *et al.*, 2000), or measurement data not intended to be used as criteria (Hawkins *et al.*, 2014), the publication of Popper *et al.* (2014) provides an authoritative summary of the latest research and guidelines for fish exposure to sound and uses categories for fish that are representative of the species present in UK waters. However, in the absence of reliable criteria for disturbance in fish, the observed levels presented in Hawkins *et al.* (2014) have been included as part of this study.
- 2.2.15 The Popper *et al.* (2014) study groups species of fish by whether they possess a swim bladder, and whether it is involved in its hearing; a group for fish eggs and larvae is also included. The guidance also gives specific criteria (as both unweighted SPL_{peak} and unweighted SEL_{cum} values) for a variety of noise sources.
- 2.2.16 For this study, criteria for impact piling, continuous noise sources, and explosions have been considered; these are summarised in **Table 2-4** to **Table 2-6**.

Table 2-4 Criteria for mortality and potential mortal injury, recoverable injury and TTS in species of fish from impact piling noise (Popper *et al.*, 2014)

Type of animal	Mortality and potential mortal injury	Impairment	
		Recoverable injury	TTS
<i>Fish: no swim bladder</i>	> 219dB SEL _{cum} > 213dB peak	> 216dB SEL _{cum} > 213dB peak	>> 186dB SEL _{cum}
<i>Fish: swim bladder is not involved in hearing</i>	210dB SEL _{cum} > 207dB peak	203dB SEL _{cum} > 207dB peak	> 186dB SEL _{cum}
<i>Fish: swim bladder involving in hearing</i>	207dB SEL _{cum} > 207dB peak	203dB SEL _{cum} > 207dB peak	186dB SEL _{cum}
<i>Eggs and larvae</i>	> 210dB SEL _{cum} > 207dB peak	See Table 2-7	See Table 2-7

Table 2-5 Criteria for recoverable injury and TTS in species of fish from continuous noise sources (Popper *et al.*, 2014)

Type of animal	Impairment	
	Recoverable injury	TTS
<i>Fish: swim bladder involved in hearing</i>	170dB RMS for 48 hours	158dB RMS For 12 hours

Table 2-6 Criteria for potential mortal injury in species of fish from explosions (Popper *et al.*, 2014)

Type of animal	Mortality and potential mortal injury
<i>Fish: no swim bladder</i>	229 to 234dB peak
<i>Fish: swim bladder is not involved in hearing</i>	229 to 234dB peak
<i>Fish: swim bladder involving in hearing</i>	229 to 234dB peak
<i>Eggs and larvae</i>	> 13mm s ⁻¹ peak velocity

2.2.17 Where insufficient data are available, Popper *et al.* (2014) also gives qualitative criteria that summarise the effect of the noise as having either a high, moderate or low effect on an individual in either the near-field (tens of metres), intermediate-field (hundreds of metres), or far-field (thousands of metres). These qualitative effects are reproduced in **Table 2-7** to **Table 2-9**.

Table 2-7 Summary of the qualitative effects on species of fish from impact piling noise (Popper *et al.*, 2014) (N = Near-field; I = Intermediate-field; F = Far-field)

Type of animal	Impairment			Behaviour
	Recoverable injury	TTS	Masking	
<i>Fish: no swim bladder</i>	See Table 2-4	See Table 2-4	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
<i>Fish: swim bladder is not involved in hearing</i>	See Table 2-4	See Table 2-4	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
<i>Fish: swim bladder involving in hearing</i>	See Table 2-4	See Table 2-4	(N) High (I) High (F) Moderate	(N) High (I) High (F) Moderate
<i>Eggs and larvae</i>	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low

Table 2-8 Summary of the qualitative effects on fish from continuous noise from Popper *et al.* (2014) (N = Near-field; I = Intermediate-field; F = Far-field)

Type of animal	Mortality and potential mortal injury	Impairment			Behaviour
		Recoverable injury	TTS	Masking	
<i>Fish: no swim bladder</i>	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
<i>Fish: swim bladder is not involved in hearing</i>	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
<i>Fish: swim bladder involving in hearing</i>	(N) Low (I) Low (F) Low	See Table 2-5	See Table 2-5	(N) High (I) High (F) High	(N) High (I) Moderate (F) Low
<i>Eggs and larvae</i>	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) High (I) Moderate (F) Low	(N) Moderate (I) Moderate (F) Low

Table 2-9 Summary of the qualitative effects on species of fish from explosions (Popper *et al.*, 2014) (N = Near-field; I = Intermediate-field; F = Far-field)

Type of animal	Impairment			Behaviour
	Recoverable injury	TTS	Masking	
<i>Fish: no swim bladder</i>	(N) High (I) Low (F) Low	(N) High (I) Moderate (F) Low	N/A	(N) High (I) Moderate (F) Low
<i>Fish: swim bladder is not involved in hearing</i>	(N) High (I) High (F) Low	(N) High (I) Moderate (F) Low	N/A	(N) High (I) High (F) Low
<i>Fish: swim bladder involving in hearing</i>	(N) High (I) High (F) Low	(N) High (I) High (F) Low	N/A	(N) High (I) High (F) Low
<i>Eggs and larvae</i>	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	N/A	(N) High (I) Low (F) Low

2.2.19 Both fleeing animal and stationary animal models have been used to cover the SEL_{cum} criteria for fish. It is recognised that there is limited evidence for fish fleeing from high level noise sources in the wild, and it would reasonably be expected that the reaction would differ between species. Most species are likely to move away from a sound that is loud enough to cause harm (Dahl *et al.*, 2015; Popper *et al.*, 2014), some may seek protection in the sediment and others may dive deeper in the water column. For those species that flee, the speed chosen for this study of 1.5ms⁻¹ is relatively slow in relation to data from Hirata (1999) and thus is considered somewhat conservative.

2.2.20 Although it is feasible that some species will not flee, those that are likely to remain are thought more likely to be benthic species or species without a swim bladder; these are the least sensitive species. For example, from Popper *et al.* (2014): “*There is evidence (for example, Goertner et al., 1994; Stephenson et al., 2010; Halvorsen et al., 2012) that little or no damage occurs to fishes without a swim bladder except at very short ranges from an in-water explosive event. Goertner (1978) showed that the range from an explosive event over which damage may occur to a non-swim bladder fish is in the order of 100 times less than that for swim bladder fish.*”

2.2.21 Stationary animal modelling has been included in this study, based on research from Hawkins *et al.* (2014) and other modelling for similar EIA projects. However, basing the modelling on a stationary (zero flee speed) receptor is likely to greatly overestimate the potential risk to fish species, assuming that an individual would remain in the high noise level region of the

water column, especially when considering the precautionary nature of the parameters already built into the cumulative exposure calculations.

- 2.2.22 In the absence of reliable numeric criteria for disturbance in fish, observed levels from Hawkins *et al.* (2014) have been used for this study, although the authors of the paper themselves urge caution with the use of the values as criteria. The study was conducted under conditions, which are unlikely to be equivalent to those around at this wind farm.
- 2.2.23 The report gives unweighted SPL_{peak} , $SPL_{peak-to-peak}$, and SEL_{ss} levels where a 50 percent response level was recorded in sprat and mackerel for an impulsive noise source, simulating pile driving. These levels are summarised in **Table 2-10**.

Table 2-10 Levels for a 50 percent response was observed in fish from Hawkins *et al.* (2014)

Noise metric	Observed noise level for 50 percent response
<i>Unweighted SPL_{peak}</i>	173dB re 1 μ Pa
	168dB re 1 μ Pa
<i>Unweighted $SPL_{peak-to-peak}$</i>	163dB re 1 μ Pa
<i>Unweighted SEL_{ss}</i>	142dB re 1 μPa^2s
	135dB re 1 μPa^2s

Particle motion

- 2.2.24 The criteria defined in the above section all define the noise impacts on fishes in terms of sound pressure or sound pressure-associated functions (for instance, SEL). It has been identified by researchers (for example, Popper and Hawkins (2019), Nedelec *et al.* (2016), Radford *et al.* (2012)) that species of fish, as well as invertebrates, actually detect particle motion rather than pressure. Particle motion describes the back-and-forth movement of a tiny theoretical 'element' of water, substrate or other media as a sound wave passes, rather than the pressure caused by the action of the force created by this movement. Particle motion is usually defined in reference to the velocity of the particle (often a peak particle velocity (PPV)), but sometimes the related acceleration or displacement of the particle is used. Note that species in the "Fish: swim bladder involved in hearing" category, the most sensitive species, are sensitive to sound pressure.
- 2.2.25 Popper and Hawkins (2018) state that in derivation of the sound pressure-based criteria in Popper *et al.* (2014) it may be the unmeasured particle motion detected by the fish, to which the fish were responding: there is a relationship between particle motion and sound pressure in a medium. This relationship is very difficult to define where the sound field is complex, such

as close to the noise source or where there are multiple reflections of the sound wave in shallow water. Even these terms “shallow” and “close” do not have simple definitions.

- 2.2.26 The primary reason for the continuing use of sound pressure as the criteria, despite particle motion appearing to be the physical measure to which the fish react or sense, is a lack of data (Popper and Hawkins, 2018) both in respect of predictions of the particle motion level as a consequence of a noise source such as piling, and a lack of knowledge of the sensitivity of a fish, or a wider category of fish, to a particle motion value. There continue to be calls for additional research on the levels of and effects with respect to levels of particle motion. Until sufficient data are available to enable revised thresholds based on the particle motion metric, Popper *et al.* (2014) continues to be the best source of criteria in respect to fish impacts (Andersson *et al.*, 2016, Popper *et al.*, 2019).

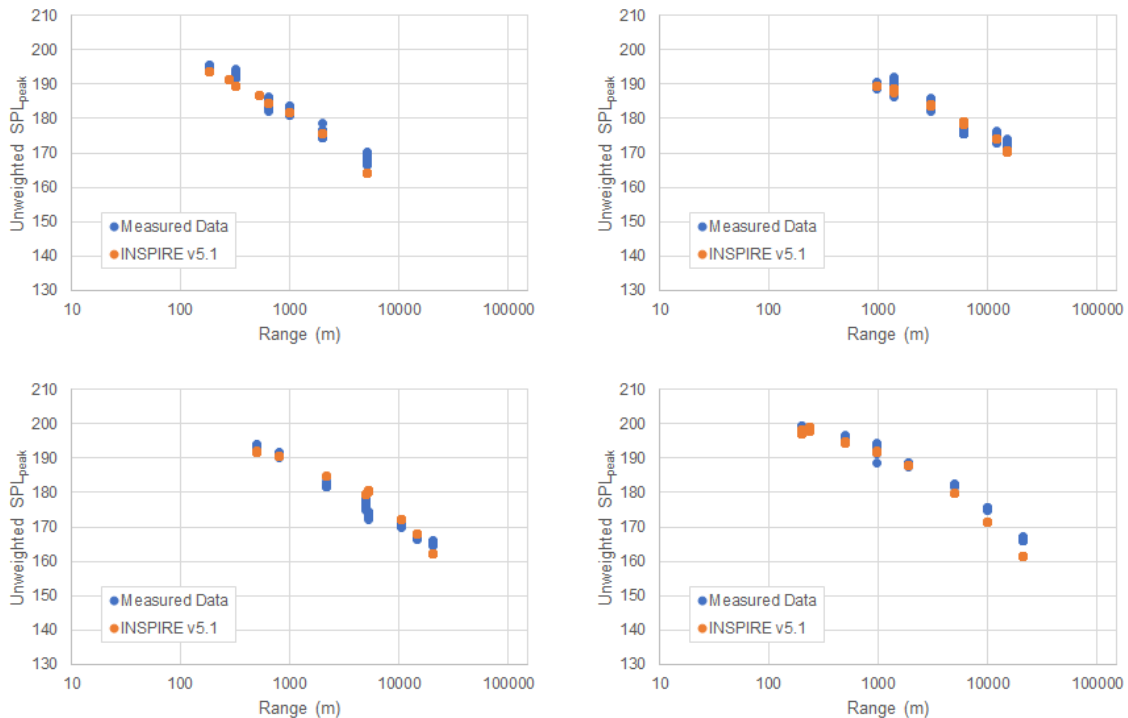
3 Modelling methodology

- 3.1.1 To estimate the underwater noise levels likely to arise during the construction and operation of Rampion 2, predictive noise modelling has been undertaken. The methods described in this section, and utilised within this report, meet the requirements set by the NPL Good Practice Guide 133 for underwater noise measurement (Robinson *et al.*, 2014).
- 3.1.2 The modelling of impact piling has been undertaken using the INSPIRE (Impulse Noise Sound Propagation and Impact Range Estimator) underwater noise model. The INSPIRE model (currently version 5.1) is a semi-empirical underwater noise propagation model based around a combination of numerical modelling and actual measured data. It is designed to calculate the propagation of noise in shallow, mixed water, typical of the conditions around the UK and very well suited to the region around Rampion 2. The model has been tuned for accuracy using over 80 datasets of underwater noise propagation from monitoring around offshore piling activities.
- 3.1.3 The model provides estimates of unweighted SPL_{peak} , SEL_{ss} , and SEL_{cum} noise levels, as well as various other weighted noise metrics. Calculations are made along 180 equally spaced radial transects (one every two degrees). For each modelling run a criterion level can be specified allowing a contour to be drawn, within which a given effect may occur. These results can then be plotted over digital bathymetry data so that impact ranges can be clearly visualised as necessary. INSPIRE also produces these contours as GIS shapefiles.
- 3.1.4 INSPIRE considers a wide array of input parameters, including variations in bathymetry and source frequency content to ensure accurate results are produced specific to the location and nature of the piling operation. It should also be noted that the results should be considered conservative as maximum design parameters and worst-case assumptions have been selected for:
- piling hammer blow energies;
 - soft start, ramp up profile, and strike rate;
 - total duration of piling; and
 - receptor swim speeds.
- 3.1.5 A simple modelling approach has been used for noise sources other than piling that may be present during the lifecycle of Rampion 2; these are discussed in **Section 5**.

3.2 Modelling confidence

- 3.2.1 Previous iterations of the INSPIRE model have endeavoured to give a conservative estimate of underwater noise levels from impact piling. There is always some natural variability with underwater noise measurements, even when considering measurements of pile strikes at the same blow energy taken at the same range. For example, there can be variations in noise level of up to 5 or even 10dB, as seen in Bailey *et al.* (2010) and the data shown in **Graphic 3-1**. When modelling using the upper bounds of this range, along with other worst case parameter selections, conservatism can be compounded and create overcautious predictions, especially when calculating SEL_{cum}. With this in mind, the current version of the INSPIRE model attempts to calculate an average fit to the measured noise levels at all ranges.
- 3.2.2 The current version of INSPIRE (version 5.1) is the product of re-analysing all the impact piling noise measurements in Subacoustech Environmental's measurement database and cross-referencing it with blow energy data from piling logs, giving a database of single strike noise levels referenced to a specific blow energy at a specific range. This analysis showed that the previous versions of INSPIRE could overestimate the change in noise level with higher blow energies and underestimate levels at lower blow energies, which in some cases led to overestimations in predicted levels.
- 3.2.3 As INSPIRE is semi-empirical, a validation process is inherently built into the development process. Whenever a new set of good, reliable impact piling measurement data is gathered through offshore surveys it is compared against the outputted levels from INSPIRE and, if necessary, the model can be adjusted accordingly. Currently over 80 separate impact piling noise datasets from all around the UK have been used as part of the development for the latest version of INSPIRE, and in each case, an average fit is used.
- 3.2.4 In addition, INSPIRE is also validated by comparing the noise levels outputted from the model with measurements and modelling undertaken by third parties.
- 3.2.5 **Graphic 3-1** presents a small selection of measured impact piling noise data plotted against outputs from INSPIRE. The plots show data points from measured data (in blue) plotted alongside modelled data (in orange) using INSPIRE version 5.1, matching the pile size, blow energy and range from the measured data. These show the average fit to the data, with the INSPIRE model data points sitting, more or less, in the middle of the measured noise levels at each range.

Graphic 3-1 Comparison between example measured impact piling data (blue points) and modelled data using INSPIRE version 5.1 (orange points) Top Left: 1.8m pile, Irish Sea, 2010; Top Right: 9.5m pile, North Sea, 2020; Bottom Left: 6.1m pile, Southern North Sea, 2009; Bottom Right: 6m pile, Southern North Sea, 2009.



3.3 Modelling parameters

Modelling locations

3.3.1 Modelling has been undertaken at three representative locations, covering the extents and various water depths at the Rampion 2 site.

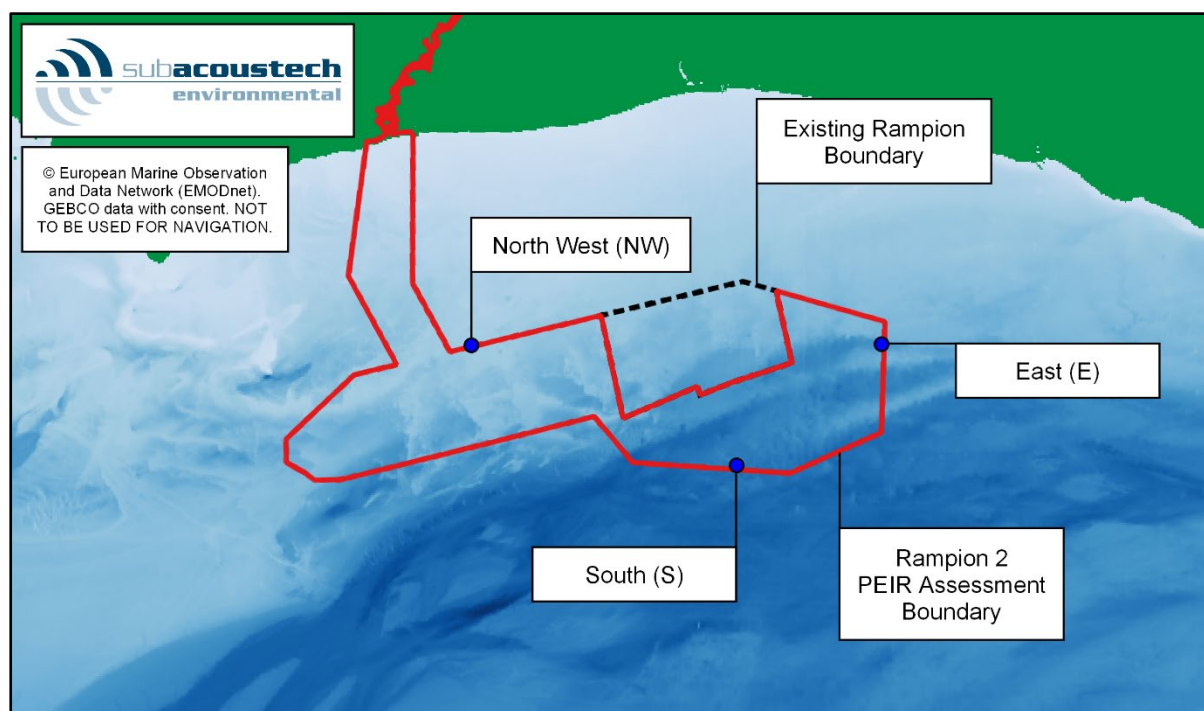
- the North West (NW) location was chosen as it is in shallow water and close to the coast,
- the South (S) location is in the deepest water of the site, however only jacket foundations can be installed at these depths, and
- the East (E) location is representative of the deepest locations at which either monopile or jacket foundations can be installed.

3.3.2 These locations are summarised in **Table 3-1** and illustrated in **Graphic 3-2**.

Table 3-1 Summary of the underwater noise modelling locations at the Rampion site; the South (S) location has only been used for jacket foundations

Modelling locations	North West (NW)	South (S)	East (E)
Latitude	50.6659° N	50.5926° N	50.6667° N
Longitude	0.4924° W	0.2365° W	0.0993° W
Water depth (mean tide)	17.4m	53.4m	44.2m

Graphic 3-2 Approximate positions of the modelling locations at the Rampion 2 PEIR Assessment Boundary



Impact piling parameters

3.3.4 Several piling scenarios have been modelled including monopile and jacket pile foundations for WTGs, covering both worst-case and most likely installation scenarios. The worst-case scenarios consider the maximum possible piling durations and blow energies at the end of ramp up, which may prove to be highly unrealistic due to hammer capacity or pile fatigue, or other on-site practicalities. The most likely scenarios use more realistic blow energies and durations, which have been chosen based on what has been seen at other wind farm installations. The modelled scenarios include:

- worst-case monopile foundations – up to 12m in diameter, installed using a maximum blow energy of 4,400kJ;
- most likely monopile foundations – up to 12m in diameter, installed using a maximum blow energy of 4,000kJ;

- worst-case jacket foundations – up to 3m in diameter, installed using a maximum blow energy of 2,500kJ; and
 - most likely jacket foundations – up to 3m in diameter, installed using a maximum blow energy of 2,000kJ.
- 3.3.5 The monopile foundations are only proposed to be installed at depths of up to 45m; at deeper ranges jacket foundations will be used. On this basis, modelling at the S location only considers jacket foundations.
- 3.3.6 For SEL_{cum} , the soft start and ramp up of blow energies along with the total duration and strike rate must also be considered; these vary for the worst-case and most likely scenarios; these are summarised in **Table 3-2** to **Table 3-5**. The main difference between the worst-case and most likely scenarios are that the most likely scenario uses lower blow energies and has a shorter period at full energy; the soft start and ramp up periods are the same for all scenarios.
- 3.3.7 The modelled scenarios contain a total of 8,776 pile strikes over 4 hours 30 minutes for the worst-case scenarios and 5,451 strikes over 2 hours 55 minutes for the most likely scenarios.
- 3.3.8 In a 24-hour period it is expected that either a maximum of two monopile foundations or four jacket foundations can be installed. This is included as part of the modelling assuming that the foundations are installed consecutively. This increases the overall upper limit of piling durations in a 24-hour period for monopile foundations to 9 hours and 5 hours 50 minutes for worst-case and most likely scenarios, respectively. For jacket foundations this is 18 hours and 11 hours 40 minutes for worst-case and most likely scenarios, respectively.

Table 3-2 Summary of the worst-case ramp up scenario used for calculating SEL_{cum} for monopile foundations

Worst-case monopile foundations	880kJ	1,760kJ	2,640kJ	3,520kJ	4,400kJ
Number of strikes	75	75	113	113	8,400
Duration	7.5 mins	7.5 mins	7.5 mins	7.5 mins	240 mins
Strike rate	10 strikes per minute (1 strike every 6s)		15 strikes per minute (1 strike every 4s)		35 strikes per minute

Table 3-3 Summary of the most likely ramp up scenario used for calculating SEL_{cum} for monopile foundations

Most likely monopile foundations	800kJ	1,600kJ	2,400kJ	3,200kJ	4,000kJ
Number of strikes	75	75	113	113	5,075
Duration	7.5 mins	7.5 mins	7.5 mins	7.5 mins	145 mins
Strike rate	10 strikes per minute (1 strike every 6s)		15 strikes per minute (1 strike every 4s)		35 strikes per minute

Table 3-4 Summary of the worst-case ramp up scenario used for calculating SEL_{cum} for jacket foundations

Worst-case jacket foundations	500kJ	1,000kJ	1,500kJ	2,000kJ	2,500kJ
Number of strikes	75	75	113	113	8,400
Duration	7.5 mins	7.5 mins	7.5 mins	7.5 mins	240 mins
Strike rate	10 strikes per minute (1 strike every 6s)		15 strikes per minute (1 strike every 4s)		35 strikes per minute

Table 3-5 Summary of the most likely ramp up scenario used for calculating SEL_{cum} for jacket foundations

Most likely jacket foundations	400kJ	800kJ	1,200kJ	1,600kJ	2,000kJ
Number of strikes	75	75	113	113	5,075
Duration	7.5 mins	7.5 mins	7.5 mins	7.5 mins	145 mins
Strike rate	10 strikes per minute (1 strike every 6s)		15 strikes per minute (1 strike every 4s)		35 strikes per minute

Source levels

- 3.3.9 Noise modelling requires knowledge of the source level, which is the theoretical noise level at one metre from the noise source. The INSPIRE model assumes that the noise source – the hammer striking the pile – acts as an effective single point, as it will appear at a distance. The source level is estimated based on the pile diameter and the blow energy imparted on the pile by the hammer. This is adjusted depending on the water depth at the modelling location to allow for the length of pile in contact with the water, which can affect the amount of noise that is transmitted from the pile into its surroundings.
- 3.3.10 The unweighted single strike SPL_{peak} and SEL_{ss} source levels estimated for this study are provided in **Table 3-6** and **Table 3-7**.

Table 3-6 Summary of the unweighted SPL_{peak} source levels used for modelling

SPL _{peak} source levels (dB re 1 µPa @ 1m)	Location	Monopile foundations	Jacket foundations
Worst-case Monopile: 12m / 4,400kJ Jacket: 3m / 2,500kJ	NW	242.6	240.8
	S	-	241.1
	E	242.6	241.1
Most likely Monopile: 12m / 4,000kJ Jacket: 3m / 2,000kJ	NW	242.4	240.2
	S	-	240.5
	E	242.4	240.5

Table 3-7 Summary of the unweighted SEL_{ss} source levels used for modelling

SEL _{ss} source levels (dB re 1 µPa ² s @ 1m)	Location	Monopile foundations	Jacket foundations
Worst-case Monopile: 12m / 4,400 kJ Jacket: 3m / 2,500kJ	NW	223.7	221.1
	S	-	221.8
	E	223.7	221.7
Most likely Monopile: 12m / 4,000kJ Jacket: 3m / 2,000kJ	NW	223.5	220.5
	S	-	221.1
	E	223.5	221.1

Environmental conditions

- 3.3.11 With the inclusion of measured data for similar offshore piling operations in UK waters, the INSPIRE model intrinsically accounts for various environmental conditions. This includes the differences that can occur with the temperature and salinity of the water, as well as the sediment type surrounding the site. Data from the British Geological Survey show that the seabed surrounding the Rampion 2 PEIR Assessment Boundary is generally made up of various combinations of gravel and sand.
- 3.3.12 Digital bathymetry, from the European Marine Observation and Data Network (EMODnet), has been used for this modelling; mean tidal depth has been used throughout.

Cumulative SELs and fleeing receptors

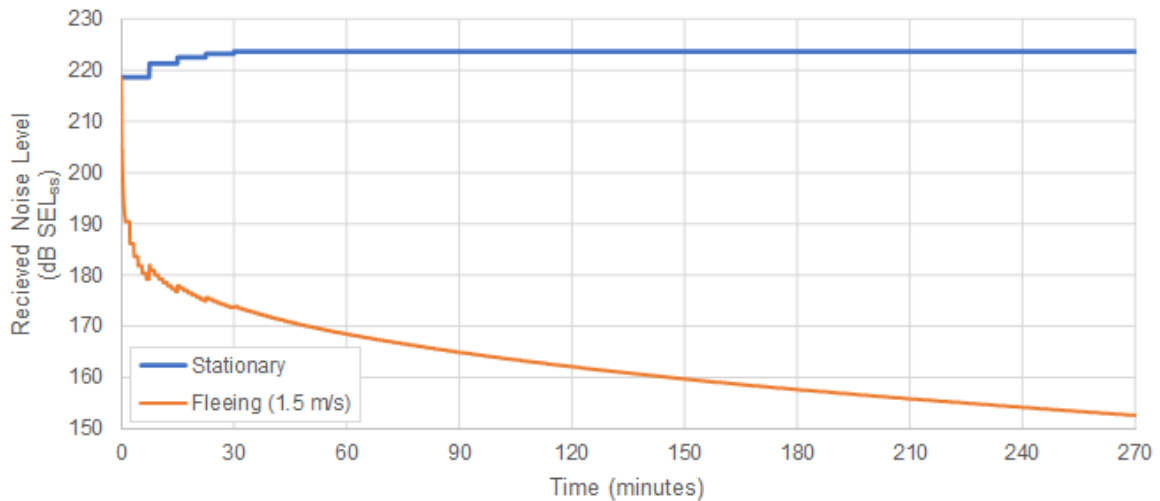
- 3.3.13 Expanding on the information in **Section 2.2.1** regarding SEL_{cum} and the fleeing animal model used for modelling, it is important to understand the meaning of the results presented in the following sections.
- 3.3.14 When an SEL_{cum} impact range is presented for a fleeing animal, this range can essentially be considered a starting position (at commencement of

- piling) for the fleeing animal receptor. For example, if a receptor starting at the position denoted on a PTS contour began to flee, in a straight line away from the noise source, the receptor would receive exactly the noise exposure as per the PTS criterion under consideration.
- 3.3.15 To help explain this, it is helpful to examine how the multiple pulse SEL_{cum} ranges are calculated. As explained in **Section 2.1.1.3**, the SEL_{cum} is a measure of the total received noise over the whole piling operation; in the case of the Southall *et al.* (2019) and Popper *et al.* (2014) criteria this covers any piling in a 24-hour period.
- 3.3.16 When considering a stationary receptor, for instance, one that stays at the same position throughout piling, calculating the SEL_{cum} is relatively straightforward: all the noise levels received at a single point along the transect are aggregated to calculate the SEL_{cum} . If this calculated level is greater than the threshold being modelled, the model steps away from the noise source and the noise levels from that new location are aggregated to calculate the new SEL_{cum} . This continues outward until the threshold is crossed.
- 3.3.17 For a fleeing animal, the receptor's distance from the noise source while moving away needs to be considered. To model this, a starting point close to the source is chosen, and then the received noise level for each pile strike while the receptor is fleeing is noted. For example, if a pile strike occurs every six seconds and an animal is fleeing at a rate of $1.5ms^{-1}$, it is 9m further from the source after each subsequent pile strike, resulting in a slightly reduced received noise level with each strike. These values are then aggregated into an SEL_{cum} over the entire piling period. The faster an animal is fleeing the greater distance travelled between each pile strike. The impact range outputted by the model for this situation is the distance the receptor must be at the start of piling to exactly meet the exposure threshold.
- 3.3.18 The graphs in **Graphic 3-3** and **Graphic 3-4** show the difference in the SELs received by a stationary receptor and a fleeing receptor travelling at a constant speed of $1.5ms^{-1}$, using the worst case monopile foundation parameters (**Table 3-2**). This was carried out at the E location for a single monopile installation as an example.
- 3.3.19 The received SEL_{ss} from the stationary receptor, as illustrated in **Graphic 3-3** shows the noise level gradually increasing as the blow energy increases throughout the piling operation. These step changes are also visible for the fleeing receptor, but as the receptor is further from the source by the time the levels increase, the total received exposure is reduced, resulting in progressively lower received noise levels. For example, after the first 7.5 minutes where the blow energy is 880kJ, the fleeing receptor will have

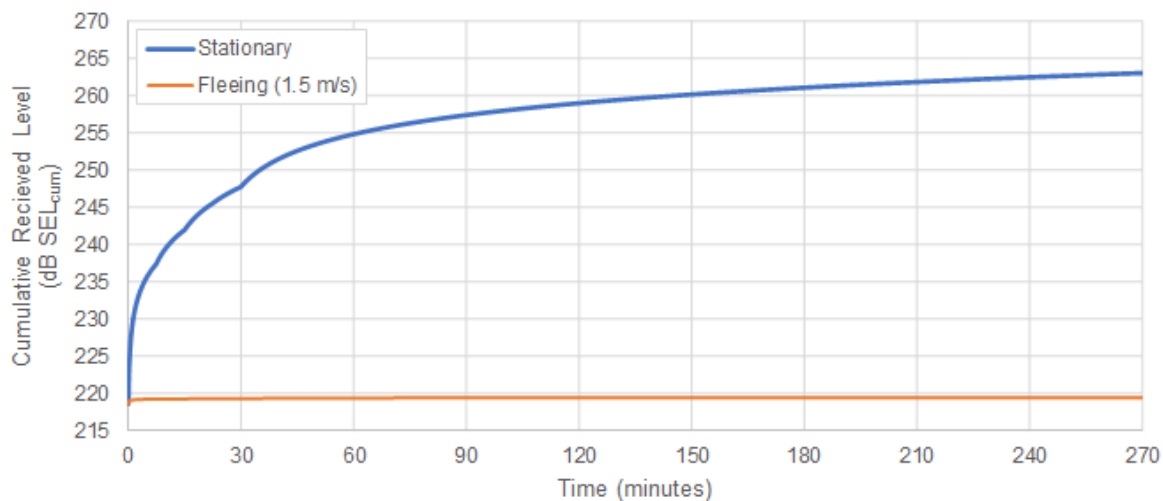
already moved 650m away. After the full piling duration of 4.5 hours, the receptor will be over 24km from the pile.

3.3.20 **Graphic 3-4** shows the effect these different received levels have when calculating the SEL_{cum} . It clearly shows the difference in cumulative effect of the receptor remaining still as opposed to fleeing. To use an extreme example, starting at a range of 1m, the first strike results in a received level of 218.6dB re 1 μPa^2s . If the receptor were to remain stationary throughout the 4.5 hours of piling it would receive a cumulative received level of 263.0dB re 1 μPa^2s , whereas fleeing at $1.5ms^{-1}$ over the same piling scenario would result in a cumulative received level of just 219.4dB re 1 μPa^2s .

Graphic 3-3 Received single-string noise levels (SEL_{ss}) for receptors during the worst case monopile piling parameters at the E location, assuming both a stationary and a fleeing receptor starting at a location 1m from the noise source

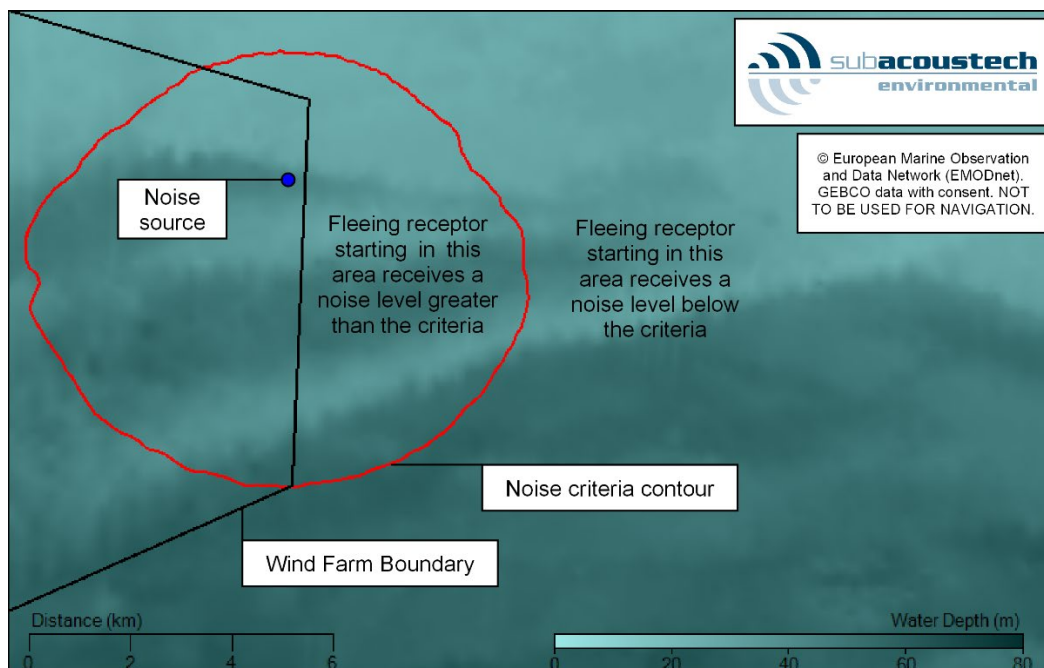


Graphic 3-4 Cumulative received noise levels (SEL_{cum}) for receptors during the worst case monopile piling parameters at the E location, assuming both a stationary and fleeing receptor starting at a location 1m from the noise source



- 3.3.21 The outputted SEL_{cum} values, and ranges presented in **Section 4**, represent the position from where a receptor must begin fleeing at the start of piling in order to exactly receive the noise exposure criterion at the end of the modelled piling event. To summarise, if the receptor were to start fleeing in a straight line from the noise source starting at a range closer than the modelled value it would receive a noise exposure in excess of the criteria, and if the receptor were to start fleeing from a range further than the modelled value it would receive a noise exposure below the criteria. This is illustrated in **Graphic 3-5**.

Graphic 3-5 Example plot showing a fleeing animal SEL_{cum} criteria contour and the areas where the cumulative received noise level will exceed the impact criteria



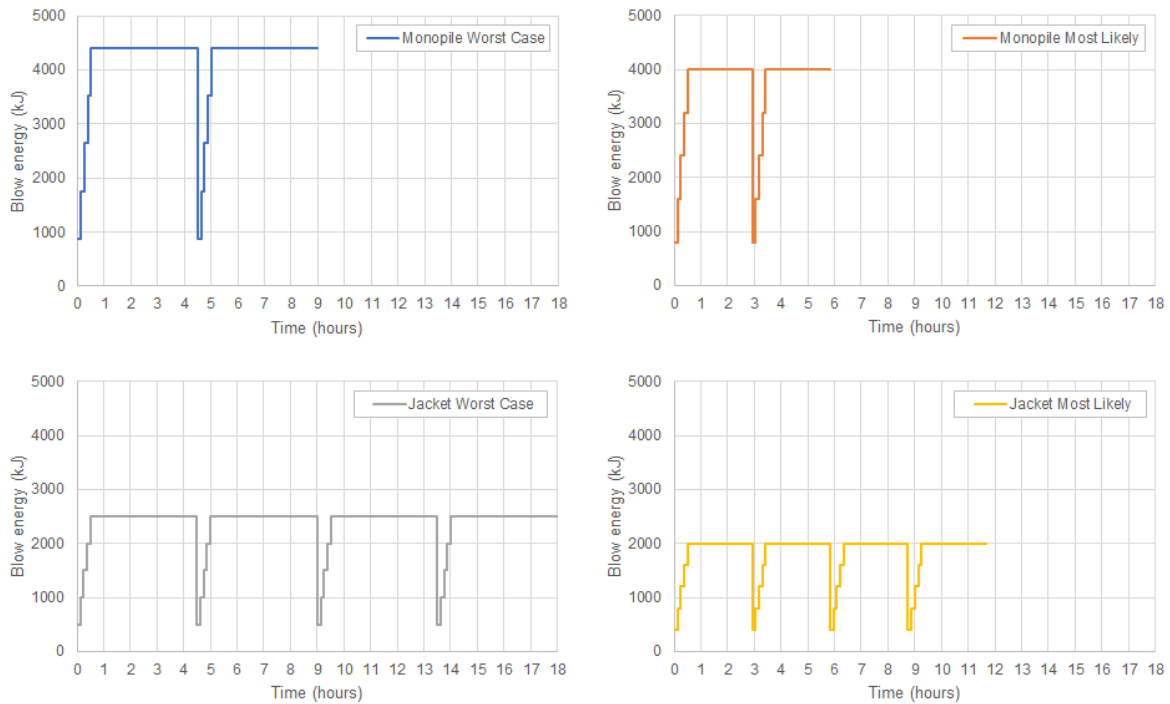
- 3.3.22 Some modelling approaches include the effects of Acoustic Deterrent Devices (ADDs) that cause receptors to flee from the immediate area around the pile before activity commences. Subacoustech's modelling approach does not include this, but the effects of using an ADD can still be inferred from the results. For example, if a receptor were to flee for 20 minutes from an ADD at a rate 1.5ms^{-1} , it would travel 1.8km before piling begins. If a cumulative SEL impact range from INSPIRE was calculated to be below 1.8km, it can safely be assumed that the ADD will be effective in eliminating the risk of injury on the receptor. The noise from an ADD is of a much lower level than impact piling, and as such, the overall effect on the SEL_{cum} exposure on a receptor would be negligible.

The effects of input parameters on cumulative SELs and fleeing receptors

- 3.3.23 As discussed in **Section 3.2.2**, parameters such as water depth, hammer blow energies, piling ramp up, strike rate and duration all have an effect on predicted noise levels. When considering SEL_{cum} and a fleeing animal model, some of these parameters can have a greater influence than others.
- 3.3.24 Parameters like hammer blow energy can have a clear effect on impact ranges, with higher energies resulting in higher source noise levels and therefore larger impact ranges. When considering cumulative noise levels, these higher levels are compounded sometimes thousands of times due to the number of pile strikes. With this in mind, the ramp up from low blow energies to higher ones requires careful consideration for fleeing animals, as

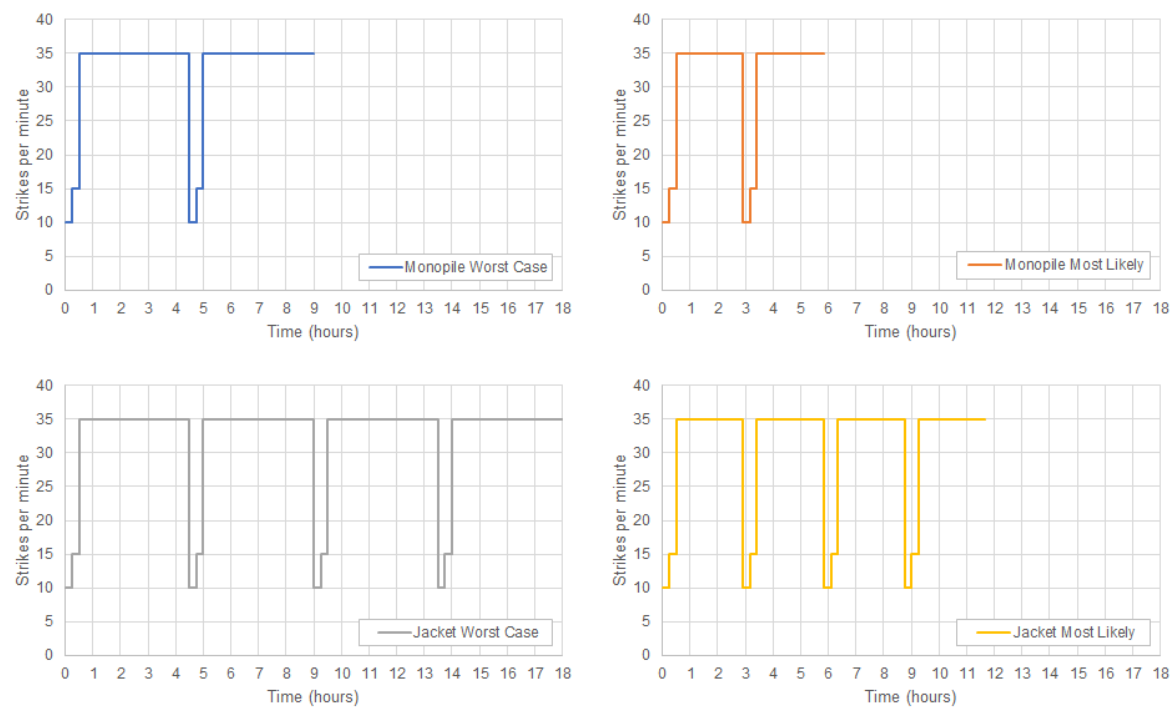
the levels while the receptors are relatively close to the noise source will have a greater effect on the overall cumulative exposure level. **Graphic 3-6** summarises the hammer blow energy ramp up for the four modelled cumulative scenarios, showing how the monopile scenarios reach a higher blow energy over a greater total duration, as well as the effect of multiple consecutive piling operations.

Graphic 3-6 Graphical representation of the blow energy for the three modelled ramp up scenarios



- 3.3.25 Linked to the effect of the ramp up is the strike rate, as the more strikes that occur while the receptor is close to the noise source, the greater the exposure and the greater effect it will have on the SEL_{cum} . The faster the strike rate, the shorter the distance the receptor can flee between each pile strike, which leads to greater exposure. **Graphic 3-7** shows the strike rate against time for the monopile and jacket foundation modelled scenarios. All the scenarios considered for Rampion 2 utilise the same strike rates for the various stages of the installation, with longer periods at full energy for the worst-case parameters.

Graphic 3-7 Graphical representation of the strike rate for the three modelled ramp up scenarios



4 Modelling results

- 4.1.1 The following sections present the modelled impact ranges for the parameters detailed in **Section 3.2** and the criteria outlined in **Section 2.2.1**, split into the Southall *et al.* (2019) marine mammal criteria (**Section 4.1**) and the Popper *et al.* (2014) fish criteria (**Section 4.2**), with subsections covering the worst-case and most likely monopile and jacket foundations. To aid navigation **Table 4-1** contains a list of all the impact range tables in this section. Further modelling has also been completed for non-impulsive noise criteria, these are presented in **Annex A**.
- 4.1.2 For the results presented in this section, predicted ranges smaller than 50m and areas less than 0.01km² for single strike criteria, and ranges smaller than 100m and areas less than 0.1km² for cumulative criteria, have not been presented. This close to the noise source, the modelling processes are unable to model to a sufficient level of accuracy due to acoustic effects near the pile.
- 4.1.3 The largest ranges are predicted for the worst case monopile foundation scenario at the E location and the worst-case jacket foundation scenario at the S location, with smaller ranges predicted for the shallower NW location and most likely scenarios where lower blow energies are utilised.

4.2 Marine mammal criteria

- 4.2.1 **Table 4-2** to **Table 4-9** present the modelling results in terms of the Southall *et al.* (2019) marine mammal criteria covering the worst-case and most likely monopile and jacket foundation parameters.
- 4.2.2 The largest marine mammal impact ranges are predicted for worst-case monopile foundations at the E location and worst-case jacket foundations at the S location, due in part to the water depths at, and surrounding, those locations. Maximum PTS injury ranges are predicted in fleeing LF cetaceans with ranges of up to 12km for worst-case monopile foundations at the E location and 13km for worst-case jacket foundations at the S location. Fleeing VHF cetaceans show maximum PTS ranges of up to 6.1km at the E location for worst-case monopile foundations and 5.9km at the S location for worst-case jacket foundations. Smaller ranges are predicted at the NW location due to the shallower water depths and proximity to the coastline.
- 4.2.3 Further Southall *et al.* (2019) criteria covering non-impulsive in marine mammals are presented in **Annex A**.

Table 4-1 Summary of the results tables presented in this section

Table (page)	Parameters	Criteria	
Table 4-2 (p31)	Worst-case monopile foundations	Southall <i>et al.</i> (2019)	Unweighted SPL _{peak}
Table 4-3 (p31)			Weighted SEL _{cum} (impulsive)
Table 4-4 (p32)	Most likely monopile foundations		Unweighted SPL _{peak}
Table 4-5 (p32)			Weighted SEL _{cum} (impulsive)
Table 4-6 (p33)	Worst-case jacket foundations		Unweighted SPL _{peak}
Table 4-7 (p34)			Weighted SEL _{cum} (impulsive)
Table 4-8 (p35)	Most likely jacket foundations		Unweighted SPL _{peak}
Table 4-9 (p36)			Weighted SEL _{cum} (impulsive)
Table 4-10 (p37)	Worst-case monopile foundations	Popper <i>et al.</i> (2014)	Unweighted SPL _{peak}
Table 4-11 (p38)			Unweighted SEL _{cum} (pile driving)
Table 4-12 (p38)	Most likely monopile foundations		Unweighted SPL _{peak}
Table 4-13 (p39)			Unweighted SEL _{cum} (pile driving)
Table 4-14 (p40)	Worst-case jacket foundations		Unweighted SPL _{peak}
Table 4-15 (p41)			Unweighted SEL _{cum} (pile driving)
Table 4-16 (p42)	Most likely jacket foundations		Unweighted SPL _{peak}
Table 4-17 (p43)			Unweighted SEL _{cum} (pile driving)
Table 4-18 (p44)	Worst-case monopile foundations	Hawkins <i>et al.</i> (2014)	Unweighted SPL _{peak} Unweighted SPL _{peak-to-peak} , Unweighted SEL _{ss}
Table 4-19 (p45)	Most likely monopile foundations		
Table 4-20 (p46)	Worst-case jacket foundations		
Table 4-21 (p47)	Most likely jacket foundations		

Worst-case monopile foundations

Table 4-2 Summary of the impact ranges from the worst-case monopile foundation modelling at Rampion 2 using the Southall *et al.* (2019) unweighted SPL_{peak} criteria for marine mammals

Southall <i>et al.</i> (2019) Unweighted SPL _{peak}		Worst-case monopile foundation							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	< 0.01km ²	< 50m	< 50m	< 50m	0.02km ²	90m	90m	90m
	HF Cetacean	< 0.01km ²	< 50m	< 50m	< 50m	< 0.01km ²	< 50m	< 50m	< 50m
	VHF Cetacean	0.57km ²	430m	420m	430m	2.8km ²	970m	920m	950m
	PCW Pinniped	< 0.01km ²	< 50m	< 50m	< 50m	0.03km ²	100m	100m	100m
E	LF Cetacean	< 0.01km ²	< 50m	< 50m	< 50m	0.04km ²	120m	120m	120m
	HF Cetacean	< 0.01km ²	< 50m	< 50m	< 50m	< 0.01km ²	< 50m	< 50m	< 50m
	VHF Cetacean	1.3km ²	660m	640m	650m	7.3km ²	1.6km	1.5km	1.5km
	PCW Pinniped	< 0.01km ²	50m	50m	50m	0.06km ²	140m	140m	140m

Table 4-3 Summary of the impact ranges from the worst-case monopile foundation modelling at Rampion 2 using the Southall *et al.* (2019) weighted SEL_{cum} impulsive criteria for marine mammals

Southall <i>et al.</i> (2019) Weighted SEL _{cum} (impulsive)		Worst-case monopile foundation							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	8.6km ²	3.2km	500m	1.4km	730km ²	26km	4.6km	13km
	HF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	< 0.1km ²	< 100m	< 100m	< 100m
	VHF Cetacean	6.9km ²	2.2km	800m	1.4km	550km ²	21km	5.6km	12km
	PCW Pinniped	< 0.1km ²	< 100m	< 100m	< 100m	35km ²	5.2km	1.6km	3.1km
E	LF Cetacean	200km ²	12km	2.9km	7.2km	2000km ²	41km	8.8km	22km
	HF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	< 0.1km ²	< 100m	< 100m	< 100m
	VHF Cetacean	63km ²	6.1km	2.6km	4.3km	1300km ²	30km	9.5km	19km
	PCW Pinniped	< 0.1km ²	< 100m	< 100m	< 100m	280km ²	13km	4.8km	8.8km

Most likely monopile foundations

Table 4-4 Summary of the impact ranges from the most likely monopile foundation modelling at Rampion 2 using the Southall *et al.* (2019) unweighted SPL_{peak} criteria for marine mammals

Southall <i>et al.</i> (2019) Unweighted SPL _{peak}		Most likely monopile foundation							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	< 0.01km ²	< 50m	< 50m	< 50m	0.02km ²	90m	90m	90m
	HF Cetacean	< 0.01km ²	< 50m	< 50m	< 50m	< 0.01km ²	< 50m	< 50m	< 50m
	VHF Cetacean	0.54km ²	420m	410m	420m	2.7km ²	950m	910m	930m
	PCW Pinniped	< 0.01km ²	< 50m	< 50m	< 50m	0.03km ²	100m	100m	100m
E	LF Cetacean	< 0.01km ²	50m	< 50m	50m	0.04km ²	120m	120m	120m
	HF Cetacean	< 0.01km ²	< 50m	< 50m	< 50m	< 0.01km ²	< 50m	< 50m	< 50m
	VHF Cetacean	1.3km ²	650m	630m	640m	7.0km ²	1.6km	1.4km	1.5km
	PCW Pinniped	< 0.01km ²	50m	50m	50m	0.06km ²	140m	140m	140m

Table 4-5 Summary of the impact ranges from the most likely monopile foundation modelling at Rampion 2 using the Southall *et al.* (2019) weighted SEL_{cum} impulsive criteria for marine mammals

Southall <i>et al.</i> (2019) Weighted SEL _{cum} (impulsive)		Most likely monopile foundation							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	7.4km ²	3.0km	450m	1.3km	710km ²	26km	4.5km	13km
	HF Cetacean	< 0.1km ²	< 100m	< 100m	< 10m	< 0.1km ²	< 100m	< 100m	< 100m
	VHF Cetacean	6.0km ²	2.1km	750m	1.3km	510km ²	20km	5.5km	12km
	PCW Pinniped	< 0.1km ²	< 100m	< 100m	< 100m	33km ²	5.0km	1.6km	3.1km
E	LF Cetacean	190km ²	12km	2.8km	7.0km	2000km ²	41km	8.8km	22km
	HF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	< 0.1km ²	< 100m	< 100m	< 100m
	VHF Cetacean	57km ²	5.7km	2.5km	4.1km	1300km ²	29km	9.4km	19km
	PCW Pinniped	< 0.1km ²	< 100m	< 100m	< 100m	260km ²	13km	4.8km	8.6km

Worst-case jacket foundations

Table 4-6 Summary of the impact ranges from the worst-case jacket foundation modelling at Rampion 2 using the Southall *et al.* (2019) unweighted SPL_{peak} criteria for marine mammals

Southall <i>et al.</i> (2019) Unweighted SPL _{peak}		Worst-case jacket foundation							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	< 0.01km ²	< 50m	< 50m	< 50m	< 0.01km ²	70m	70m	70m
	HF Cetacean	< 0.01km ²	< 50m	< 50m	< 50m	< 0.01km ²	< 50m	< 50m	< 50m
	VHF Cetacean	0.34km ²	340m	330m	330m	1.8km ²	770m	740m	750m
	PCW Pinniped	< 0.01km ²	< 50m	< 50m	< 50m	0.02km ²	80m	80m	80m
S	LF Cetacean	< 0.01km ²	< 50m	< 50m	< 50m	0.03km ²	100m	100m	100m
	HF Cetacean	< 0.01km ²	< 50m	< 50m	< 50m	< 0.01km ²	< 50m	< 50m	< 50m
	VHF Cetacean	0.92km ²	540m	540m	540m	5.7km ²	1.4km	1.3km	1.4km
	PCW Pinniped	< 0.01km ²	< 50m	< 50m	< 50m	0.04km ²	110m	110m	110m
E	LF Cetacean	< 0.01km ²	< 50m	< 50m	< 50m	0.03km ²	90m	90m	90m
	HF Cetacean	< 0.01km ²	< 50m	< 50m	< 50m	< 0.01km ²	< 50m	< 50m	< 50m
	VHF Cetacean	0.85km ²	520m	510m	520m	4.9km ²	1.3km	1.2km	1.2km
	PCW Pinniped	< 0.01km ²	< 50m	< 50m	< 50m	0.04km ²	110m	110m	110m

Table 4-7 Summary of the impact ranges from the worst-case jacket foundation modelling at Rampion 2 using the Southall *et al.* (2019) weighted SEL_{cum} impulsive criteria for marine mammals

Southall <i>et al.</i> (2019) Weighted SEL _{cum} (impulsive)		Worst-case jacket foundation							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	1.3km ²	1.4km	150m	520m	530km ²	1.5km	450m	870m
	HF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	< 0.1km ²	< 100m	< 100m	< 100m
	VHF Cetacean	2.7km ²	1.5km	450m	870m	440km ²	19km	5.1km	11km
	PCW Pinniped	< 0.1km ²	< 100m	< 100m	< 100m	23km ²	4.3km	1.3km	2.5km
S	LF Cetacean	260km ²	13km	4.8km	8.7km	2400km ²	42km	13km	26km
	HF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	< 0.1km ²	< 100m	< 100m	< 100m
	VHF Cetacean	77km ²	5.9km	3.7km	4.9km	1600km ²	31km	13km	22km
	PCW Pinniped	< 0.1km ²	< 100m	< 100m	< 100m	400km ²	15km	7.3km	11km
E	LF Cetacean	130km ²	9.6km	2.0km	5.5km	1700km ²	38km	8.2km	21km
	HF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	< 0.1km ²	< 100m	< 100m	< 100m
	VHF Cetacean	38km ²	4.7km	2.0km	3.3km	1100km ²	28km	8.9km	18km
	PCW Pinniped	< 0.1km ²	< 100m	< 100m	< 100m	230km ²	12km	4.4km	8.0km

Most likely jacket foundations

Table 4-8 Summary of the impact ranges from the most likely jacket foundation modelling at Rampion 2 using the Southall *et al.* (2019) unweighted SPL_{peak} criteria for marine mammals

Southall <i>et al.</i> (2019) Unweighted SPL _{peak}		Most likely jacket foundation							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	< 0.01km ²	< 50m	< 50m	< 50m	< 0.01km ²	60m	60m	60m
	HF Cetacean	< 0.01km ²	< 50m	< 50m	< 50m	< 0.01km ²	< 50m	< 50m	< 50m
	VHF Cetacean	0.29km ²	310m	300m	310m	1.5km ²	710m	680m	700m
	PCW Pinniped	< 0.01km ²	< 50m	< 50m	< 50m	0.02km ²	70m	70m	70m
S	LF Cetacean	< 0.01km ²	< 50m	< 50m	< 50m	0.02km ²	90m	90m	90m
	HF Cetacean	< 0.01km ²	< 50m	< 50m	< 50m	< 0.01km ²	< 50m	< 50m	< 50m
	VHF Cetacean	0.76km ²	500m	490m	490m	4.8km ²	1.2km	1.2km	1.2km
	PCW Pinniped	< 0.01km ²	< 50m	< 50m	< 50m	0.03km ²	100m	100m	100m
E	LF Cetacean	< 0.01km ²	< 50m	< 50m	< 50m	0.02km ²	90m	80m	90m
	HF Cetacean	< 0.01km ²	< 50m	< 50m	< 50m	< 0.01km ²	< 50m	< 50m	< 50m
	VHF Cetacean	0.71km ²	480m	470m	480m	4.1km ²	1.2km	1.1km	1.1km
	PCW Pinniped	< 0.01km ²	< 50m	< 50m	< 50m	0.03km ²	100m	100m	100m

Table 4-9 Summary of the impact ranges from the most likely jacket foundation modelling at Rampion 2 using the Southall *et al.* (2019) weighted SEL_{cum} impulsive criteria for marine mammals

Southall <i>et al.</i> (2019) Weighted SEL _{cum} (impulsive)		Most likely jacket foundation							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	0.5km ²	850m	100m	320m	470km ²	21km	3.4km	10km
	HF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	< 0.1km ²	< 100m	< 100m	< 100m
	VHF Cetacean	1.5km ²	1.1km	300m	640m	380km ²	17km	4.9km	10km
	PCW Pinniped	< 0.1km ²	< 100m	< 100m	< 100m	19km ²	3.9km	1.2km	2.3km
S	LF Cetacean	220km ²	11km	4.4km	7.9km	2200km ²	41km	13km	25km
	HF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	< 0.1km ²	< 100m	< 100m	< 100m
	VHF Cetacean	57km ²	5.0km	3.3km	4.2km	1400km ²	29km	13km	21km
	PCW Pinniped	< 0.1km ²	< 100m	< 100m	< 100m	360km ²	14km	7.1km	10km
E	LF Cetacean	100km ²	8.6km	1.6km	4.9km	1600km ²	36km	7.9km	20km
	HF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	< 0.1km ²	< 100m	< 100m	< 100m
	VHF Cetacean	27km ²	4.0km	1.7km	2.8km	1000km ²	26km	8.6km	17km
	PCW Pinniped	< 0.1km ²	< 100m	< 100m	< 100m	200km ²	11km	4.2km	7.6km

4.3 Fish criteria

- 4.3.1 **Table 4-10 to Table 4-17** present the impact ranges for the fish criteria for pile driving from Popper *et al.* (2014) covering the worst-case and most likely monopile and jacket foundation parameters as described in section 3.2.
- 4.3.2 The worst-case recoverable injury ranges (203dB SEL_{cum} threshold) in species of fish are 150m in the E position for the worst case monopile, assuming the fish can flee, but up to 13km (S position) for the worst-case jacket foundation if they remain stationary throughout the entire piling operation.
- 4.3.3 Maximum TTS ranges (186dB SEL_{cum} threshold) are predicted of up to 21km for both the worst-case monopile foundations at the E location and the worst-case jacket foundations at the S location when assuming a fleeing animal model. These ranges increase to 37km for the worst-case monopile foundations and 43km for the worst-case jacket foundations when considering a stationary animal, the increase in ranges for the jacket foundations caused by the increased piling duration.
- 4.3.4 **Table 4-18 to Table 4-21** give the predicted ranges for the observed levels given in Hawkins *et al.* (2014) for a 50 percent response in fish from impulsive noise. These show that a disturbance response may occur in fish out to a maximum of 62km from the source using the most precautionary of thresholds.

Worst-case monopile foundations

Table 4-10 Summary of the impact ranges from worst-case monopile foundation modelling at Rampion 2 using the Popper *et al.* (2014) unweighted SPL_{peak} pile driving criteria for pile driving

Popper <i>et al.</i> (2014) Unweighted SPL _{peak}		Worst-case monopile foundation			
		Area	Max	Min	Mean
NW	213dB	0.02km ²	90m	90m	90m
	207dB	0.14km ²	210m	210m	210m
E	213dB	0.04km ²	120m	120m	120m
	207dB	0.29km ²	310m	300m	300m

Table 4-11 Summary of the impact ranges from worst-case monopile foundation modelling at Rampion 2 using the Popper *et al.* (2014) unweighted SEL_{cum} pile driving criteria for fish assuming both a fleeing and a stationary animal model

Popper <i>et al.</i> (2014) Unweighted SEL _{cum}		Worst-case monopile foundation							
		Fleeing animal (1.5ms ⁻¹)				Stationary animal			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	219dB	< 0.1km ²	< 100m	< 100m	< 100m	2.3km ²	900m	800m	860m
	216dB	< 0.1km ²	< 100m	< 100m	< 100m	4.9km ²	1.3km	1.2km	1.2km
	210dB	< 0.1km ²	< 100m	< 100m	< 100m	19km ²	2.7km	2.3km	2.5km
	207dB	< 0.1km ²	< 100m	< 100m	< 100m	36km ²	3.7km	3.1km	3.4km
	203dB	< 0.1km ²	< 100m	< 100m	< 100m	76km ²	5.6km	4.3km	4.9km
	186dB	130km ²	10km	2.8km	5.9km	980km ²	26km	10km	17km
E	219dB	< 0.1km ²	< 100m	< 100m	< 100m	5.7km ²	1.4km	1.3km	1.3km
	216dB	< 0.1km ²	< 100m	< 100m	< 100m	13km ²	2.2km	1.9km	2.0km
	210dB	< 0.1km ²	< 100m	< 100m	< 100m	57km ²	4.8km	3.8km	4.3km
	207dB	< 0.1km ²	< 100m	< 100m	< 100m	110km ²	6.7km	5.1km	5.9km
	203dB	< 0.1km ²	150m	< 100m	100m	240km ²	10km	7.2km	8.7km
	186dB	650km ²	21km	6.8km	13km	2300km ²	37km	15km	26km

Most likely monopile foundations

Table 4-12 Summary of the impact ranges from most likely monopile foundation modelling at Rampion 2 using the Popper *et al.* (2014) unweighted SPL_{peak} pile driving criteria for pile driving

Popper <i>et al.</i> (2014) Unweighted SPL _{peak}		Most likely monopile foundation			
		Area	Max	Min	Mean
NW	213dB	0.02km ²	90m	90m	90m
	207dB	0.13km ²	210m	200m	210m
E	213dB	0.04km ²	120m	120m	120m
	207dB	0.27km	300m	300m	300m

Table 4-13 Summary of the impact ranges from most likely monopile foundation modelling at Rampion 2 using the Popper *et al.* (2014) unweighted SEL_{cum} pile driving criteria for fish assuming both a fleeing and a stationary animal model

Popper <i>et al.</i> (2014) Unweighted SEL _{cum}		Most likely monopile foundation							
		Fleeing animal (1.5ms ⁻¹)				Stationary animal			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	219dB	< 0.1km ²	< 100m	< 100m	< 100m	1.2km ²	650m	600m	630m
	216dB	< 0.1km ²	< 100m	< 100m	< 100m	2.7km ²	950m	850m	920m
	210dB	< 0.1km ²	< 100m	< 100m	< 100m	11km ²	2.1km	1.8km	1.9km
	207dB	< 0.1km ²	< 100m	< 100m	< 100m	22km ²	2.9km	2.5km	2.7km
	203dB	< 0.1km ²	< 100m	< 100m	< 100m	49km ²	4.4km	3.5km	4.0km
	186dB	120km ²	10km	2.8km	5.7km	740km ²	22km	9.3km	15km
E	219dB	< 0.1km ²	< 100m	< 100m	< 100m	3.0km ²	1.0km	900m	970m
	216dB	< 0.1km ²	< 100m	< 100m	< 100m	6.8km ²	1.6km	1.4km	1.5km
	210dB	< 0.1km ²	< 100m	< 100m	< 100m	33km ²	3.6km	3.0km	3.2km
	207dB	< 0.1km ²	< 100m	< 100m	< 100m	66km ²	5.2km	4.1km	4.6km
	203dB	< 0.1km ²	150m	< 100m	< 100m	160km ²	8.0km	5.9km	7.0km
	186dB	610km ²	20km	6.7km	13km	1800km ²	33km	14km	23km

Worst-case jacket foundations

Table 4-14 Summary of the impact ranges from worst-case jacket foundation modelling at Rampion 2 using the Popper *et al.* (2014) unweighted SPL_{peak} pile driving criteria for pile driving

Popper <i>et al.</i> (2014) Unweighted SPL _{peak}		Worst-case jacket foundation			
		Area	Max	Min	Mean
NW	213dB	< 0.01km ²	70m	70m	70m
	207dB	0.08km ²	160m	160m	160m
S	213dB	0.03km ²	100m	100m	100m
	207dB	0.19km ²	250m	250m	250m
E	213dB	0.03km ²	90m	90m	90m
	207dB	0.18km ²	240m	240m	240m

Table 4-15 Summary of the impact ranges from worst-case jacket foundation modelling at Rampion 2 using the Popper *et al.* (2014) unweighted SEL_{cum} pile driving criteria for fish assuming both a fleeing and a stationary animal model

Popper <i>et al.</i> (2014) Unweighted SEL _{cum}		Worst-case jacket foundation							
		Fleeing animal (1.5ms ⁻¹)				Stationary animal			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	219dB	< 0.1km ²	< 100m	< 100m	< 100m	2.6km ²	950m	850m	910m
	216dB	< 0.1km ²	< 100m	< 100m	< 100m	5.4km ²	1.4km	1.3km	1.3km
	210dB	< 0.1km ²	< 100m	< 100m	< 100m	21km ²	2.8km	2.4km	2.6km
	207dB	< 0.1km ²	< 100m	< 100m	< 100m	39km ²	3.9km	3.2km	3.5km
	203dB	< 0.1km ²	< 100m	< 100m	< 100m	83km ²	5.9km	4.4km	5.1km
	186dB	59km ²	7.0km	2.0km	4.0km	1000km ²	26km	10km	17km
S	219dB	< 0.1km ²	< 100m	< 100m	< 100m	9.1km ²	1.8km	1.7km	1.7km
	216dB	< 0.1km ²	< 100m	< 100m	< 100m	21km ²	2.7km	2.6km	2.6km
	210dB	< 0.1km ²	< 100m	< 100m	< 100m	100km ²	5.9km	5.6km	5.8km
	207dB	< 0.1km ²	< 100m	< 100m	< 100m	210km ²	8.5km	7.7km	8.1km
	203dB	< 0.1km ²	< 100m	< 100m	< 100m	450km ²	13km	10km	12km
	186dB	750km ²	21km	9.4km	15km	3300km ²	43km	20km	32km
E	219dB	< 0.1km ²	< 100m	< 100m	< 100m	7.5km ²	1.7km	1.5km	1.6km
	216dB	< 0.1km ²	< 100m	< 100m	< 100m	17km ²	2.5km	2.2km	2.3km
	210dB	< 0.1km ²	< 100m	< 100m	< 100m	72km ²	5.4km	4.3km	4.8km
	207dB	< 0.1km ²	< 100m	< 100m	< 100m	140km ²	7.5km	5.7km	6.6km
	203dB	< 0.1km ²	< 100m	< 100m	< 100m	290km ²	11km	7.7km	9.6km
	186dB	460km ²	17km	5.9km	11km	2500km ²	40km	15km	27km

Most likely jacket foundations

Table 4-16 Summary of the impact ranges from most likely jacket foundation modelling at Rampion 2 using the Popper *et al.* (2014) unweighted SPL_{peak} pile driving criteria for pile driving

Popper <i>et al.</i> (2014) Unweighted SPL _{peak}		Most likely jacket foundation			
		Area	Max	Min	Mean
NW	213dB	< 0.01km ²	60m	60m	60m
	207dB	0.07km ²	150m	150m	150m
S	213dB	0.02km ²	90m	90m	90m
	207dB	0.16km ²	230m	220m	230m
E	213dB	0.02km ²	90m	80m	90m
	207dB	0.15km ²	220m	220m	220m

Table 4-17 Summary of the impact ranges from most likely jacket foundation modelling at Rampion 2 using the Popper *et al.* (2014) unweighted SEL_{cum} pile driving criteria for fish assuming both a fleeing and a stationary animal model

Popper <i>et al.</i> (2014) Unweighted SEL _{cum}		Most likely jacket foundation							
		Fleeing animal (1.5ms ⁻¹)				Stationary animal			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	219dB	< 0.1km ²	< 100m	< 100m	< 100m	1.2km ²	650m	600m	630m
	216dB	< 0.1km ²	< 100m	< 100m	< 100m	2.7km ²	950m	900m	930m
	210dB	< 0.1km ²	< 100m	< 100m	< 100m	11km ²	2.1km	1.8km	1.9km
	207dB	< 0.1km ²	< 100m	< 100m	< 100m	22km ²	2.9km	2.5km	2.7km
	203dB	< 0.1km ²	< 100m	< 100m	< 100m	49km ²	4.4km	3.5km	4.0km
	186dB	45km ²	6.1km	1.7km	3.5km	740km ²	22km	9.3km	15km
S	219dB	< 0.1km ²	< 100m	< 100m	< 100m	4.0km ²	1.2km	1.1km	1.1km
	216dB	< 0.1km ²	< 100m	< 100m	< 100m	9.7km ²	1.8km	1.7km	1.8km
	210dB	< 0.1km ²	< 100m	< 100m	< 100m	51km ²	4.2km	4.0km	4.0km
	207dB	< 0.1km ²	< 100m	< 100m	< 100m	110km ²	6.1km	5.7km	5.9km
	203dB	< 0.1km ²	< 100m	< 100m	< 100m	260km ²	9.7km	8.5km	9.2km
	186dB	650km ²	19km	9.0km	14km	2700km ²	38km	19km	28km
E	219dB	< 0.1km ²	< 100m	< 100m	< 100m	3.5km ²	1.1km	1.0km	1.1km
	216dB	< 0.1km ²	< 100m	< 100m	< 100m	8.0km ²	1.7km	1.5km	1.6km
	210dB	< 0.1km ²	< 100m	< 100m	< 100m	38km ²	3.8km	3.2km	3.5km
	207dB	< 0.1km ²	< 100m	< 100m	< 100m	76km ²	5.5km	4.4km	4.9km
	203dB	< 0.1km ²	< 100m	< 100m	< 100m	170km ²	8.5km	6.2km	7.4km
	186dB	390km ²	16km	5.5km	10km	1900km ²	34km	14km	24km

Hawkins *et al.* (2014) levels

Table 4-18 Summary of the impact ranges from worst-case monopile foundation modelling at Rampion 2 using the Hawkins *et al.* (2014) levels for 50 percent response in fish

Hawkins <i>et al.</i> (2014)		Worst-case monopile foundation			
		Area	Max	Min	Mean
NW	173dB (SPL _{peak})	230km ²	11km	6.6km	8.5km
	168dB (SPL _{peak})	460km ²	17km	8.0km	12km
	163dB (SPL _{peak-to-peak})	1500km ²	33km	11km	20km
	142dB (SEL _{ss})	1500km ²	33km	11km	20km
	135dB (SEL _{ss})	2800km ²	47km	13km	27km
E	173dB (SPL _{peak})	710km ²	19km	11km	15km
	168dB (SPL _{peak})	1200km ²	26km	12km	19km
	163dB (SPL _{peak-to-peak})	3100km ²	46km	15km	29km
	142dB (SEL _{ss})	3100km ²	46km	15km	30km
	135dB (SEL _{ss})	5000km ²	62km	15km	36km

Table 4-19 Summary of the impact ranges from most likely monopile foundation modelling at Rampion 2 using the Hawkins *et al.* (2014) levels for 50 percent response in fish

Hawkins <i>et al.</i> (2014)		Most likely monopile foundation			
		Area	Max	Min	Mean
NW	173dB (SPL _{peak})	230km ²	11km	6.5km	8.4km
	168dB (SPL _{peak})	450km ²	16km	8.0km	12km
	163dB (SPL _{peak-to-peak})	1500km ²	33km	11km	20km
	142dB (SEL _{ss})	1500km ²	32km	11km	20km
	135dB (SEL _{ss})	2700km ²	46km	13km	27km
E	173dB (SPL _{peak})	690km ²	19km	10km	15km
	168dB (SPL _{peak})	1200km ²	26km	12km	19km
	163dB (SPL _{peak-to-peak})	3000km ²	45km	15km	29km
	142dB (SEL _{ss})	3100km ²	46km	15km	29km
	135dB (SEL _{ss})	4900km ²	62km	15km	36km

Table 4-20 Summary of the impact ranges from worst-case jacket foundation modelling at Rampion 2 using the Hawkins *et al.* (2014) levels for 50 percent response in fish

Hawkins <i>et al.</i> (2014)		Worst-case jacket foundation			
		Area	Max	Min	Mean
NW	173dB (SPL _{peak})	180km ²	9.1km	6.0km	7.5km
	168dB (SPL _{peak})	360km ²	14km	7.5km	11km
	163dB (SPL _{peak-to-peak})	1300km ²	30km	11km	19km
	142dB (SEL _{ss})	1100km ²	28km	10km	18km
	135dB (SEL _{ss})	2300km ²	41km	12km	25km
S	173dB (SPL _{peak})	870km ²	19km	13km	17km
	168dB (SPL _{peak})	1500km ²	27km	16km	22km
	163dB (SPL _{peak-to-peak})	3700km ²	47km	21km	33km
	142dB (SEL _{ss})	3600km ²	46km	21km	33km
	135dB (SEL _{ss})	5800km ²	62km	23km	41km
E	173dB (SPL _{peak})	580km ²	17km	9.9km	13km
	168dB (SPL _{peak})	1100km ²	24km	12km	18km
	163dB (SPL _{peak-to-peak})	2700km ²	43km	15km	28km
	142dB (SEL _{ss})	2700km ²	42km	15km	28km
	135dB (SEL _{ss})	4400km ²	57km	15km	34km

Table 4-21 Summary of the impact ranges from most likely jacket foundation modelling at Rampion 2 using the Hawkins *et al.* (2014) levels for 50 percent response in fish

Hawkins <i>et al.</i> (2014)		Most likely jacket foundation			
		Area	Max	Min	Mean
NW	173dB (SPL _{peak})	160km ²	8.7km	5.8km	7.2km
	168dB (SPL _{peak})	330km ²	14km	7.3km	10km
	163dB (SPL _{peak-to-peak})	1200km ²	29km	10km	18km
	142dB (SEL _{ss})	1100km ²	27km	10km	17km
	135dB (SEL _{ss})	21km ²	40km	12km	24km
S	173dB (SPL _{peak})	800km ²	18km	13km	16km
	168dB (SPL _{peak})	1400km ²	26km	16km	21km
	163dB (SPL _{peak-to-peak})	3500km ²	45km	20km	33km
	142dB (SEL _{ss})	3400km ²	44km	21km	32km
	135dB (SEL _{ss})	5600km ²	61km	23km	40km
E	173dB (SPL _{peak})	530km ²	16km	9.6km	13km
	168dB (SPL _{peak})	990km ²	23km	12km	17km
	163dB (SPL _{peak-to-peak})	2700km ²	42km	15km	27km
	142dB (SEL _{ss})	2600km ²	40km	15km	27km
	135dB (SEL _{ss})	4200km ²	56km	15km	34km

5 Other noise sources

- 5.1.1 Although impact piling is expected to be the primary noise source during offshore wind farm construction and development (Bailey *et al.*, 2014), several other anthropogenic noise sources may be present. Each of these has been considered, and relevant biological noise criteria presented, in this section.
- 5.1.2 **Table 5-1** provides a summary of the various noise producing sources, aside from impact piling, that are expected to be present during the construction and operation of Rampion 2.

Table 5-1 Summary of the possible noise making activities at Rampion 2 other than impact piling

Activity	Description
Cable laying	Noise from the cable laying vessel and any other associated noise during the offshore cable installation.
Dredging	Dredging may be required on site for seabed preparation work for certain foundation options, as well as for the export cable, array cable and interconnector cable installation. Suction dredging has been assumed as a worst-case
Trenching	Plough trenching may be required during offshore cable installation.
Rock placement	Potentially required on site for installation of offshore cables (cable crossings and cable protection) and scour protection around foundation structures.
Vessel noise	Jack-up barges for piling substructure and WTG installation. Other large and medium sized vessels on site to carry out other construction tasks, and anchor handling. Other small vessel for crew transport and maintenance on site.
Operational WTG	Noise transmitted through the water from operation WTG. The project design envelope gives turbines with capacities of between 10 and 18MW.
UXO detonation	Unexploded Ordnance (UXO) has been identified with the boundaries of Rampion 2, which need to be cleared before construction can begin.

- 5.1.3 The NPL Good Practice Guide 133 for underwater noise measurements (Robinson *et al.*, 2014) indicates that under certain circumstances, a simple modelling approach may be considered acceptable. Such an approach has been used for these noise sources, which are variously either quiet compared to impact piling (for example, cable laying and dredging), or where detailed modelling would imply unjustified accuracy (for example, where data is limited such as with large operation WTG noise or UXO detonation). The

high-level overview of modelling that has been presented here is considered sufficient and there would be little benefit in using a more detailed model at this stage. The limitations of this approach are noted, including the lack of frequency or bathymetric dependence.

5.2 Noise making activities

- 5.2.1 For the purposes of identifying the greatest noise levels, approximate subsea noise levels have been predicted using a simple modelling approach based on measurement data from Subacoustech Environmental's own underwater noise measurement database, scaled to relevant parameters for the site and to the specific noise sources to be used. The calculation of underwater noise transmission loss for the non-impulsive sources is based on an empirical analysis of the noise measurements taken along transects around these sources by Subacoustech. The predictions use the following principle fitted to the measured data, where R is the range from the source, N is the transmission loss, and α is the absorption loss.

$$\text{Received level} = \text{Source level (SL)} - N \log_{10} R - \alpha R$$

Table 5-2 Summary of the estimated unweighted source levels and transmission losses for the different construction noise sources considered

Source	Estimated unweighted source level	Approximate transmission loss	Comments
Cable laying	171dB re 1 μ Pa @ 1m (RMS)	$13 \log_{10} R$ (no absorption)	Based on 11 datasets from a pipe laying vessel measuring 300m in length; this is considered a worst-case noise source for cable laying operations
Suction Dredging	186dB re 1 μ Pa @ 1m (RMS)	$19 \log_{10} R - 0.0009R$	Based on five datasets from suction and cutter suction dredgers
Trenching	172dB re 1 μ Pa @ 1m (RMS)	$13 \log_{10} R - 0.0004R$	Based on three datasets of measurements from trenching vessels more than 100m in length
Rock placement	172dB re 1 μ Pa @ 1m (RMS)	$12 \log_{10} R - 0.0005R$	Based on four datasets from rock placement vessel 'Rollingstone'
Vessel noise (large)	168dB re 1 μ Pa @ 1m (RMS)	$12 \log_{10} R - 0.0021R$	Based on five datasets of large vessels including container ships, FPSOs and other vessels more than 100m in length.

Source	Estimated unweighted source level	Approximate transmission loss	Comments
			Vessel speed assumed as 10 knots.
Vessel noise (medium)	161dB re 1 μ Pa @ 1m (RMS)	$12 \log_{10} R - 0.0021R$	Based on three datasets of moderate sized vessels less than 100m in length. Vessel speed assumed as 10 knots

- 5.2.2 Predicted source levels and propagation calculations for the construction activities are presented in **Table 5-2** along with a summary of the number of datasets used in each case. As previously, all SEL_{cum} criteria use the same assumptions as presented in **Section 2.2.1**, and ranges smaller than 50m (single strike) and 100m (cumulative) have not been presented. It should be noted that this modelling approach does not take bathymetry or any other environmental conditions into account, and as such can be applied to any location in the Rampion 2 area. Noise from operational WTGs and UXO clearance have been reviewed separately in **Sections 5.2** and **5.3** respectively.
- 5.2.3 For SEL_{cum} calculations, the duration the noise is present also needs to be considered, with all sources operating for a worst-case 12 hours in any given 24-hour period apart from vessel noise which is assumed to be present for 24 hours a day.
- 5.2.4 To account for the weightings required for modelling using the Southall *et al.* (2019) criteria (**Section 2.2.1.1**), reductions in source level have been applied to the various noise sources. **Table 5-1** shows the representative noise measurements used, adjusted for the source levels in **Table 5-2**. **Table 5-3** presents details of the reductions in source levels for each of the weightings used for modelling.

Graphic 5-1 Summary of the 1/3 octave frequency bands used as a basis for the Southall *et al.* (2019) weightings used in the simple modelling

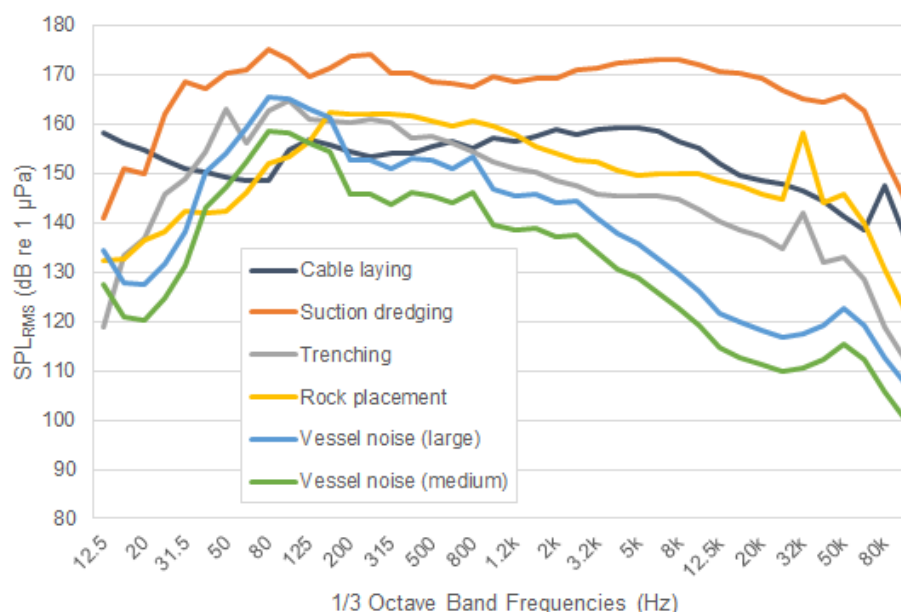


Table 5-3 Reductions in source level for the difference construction noise sources considered when the Southall *et al.* (2019) weightings are applied

Source	Reduction in source level from the unweighted level			
	LF	HF	VHF	PCW
Cable laying	3.6dB	22.9dB	23.9dB	13.2dB
Suction Dredging	2.5dB	7.9dB	9.6dB	4.2dB
Trenching	4.1dB	23.0dB	25.0dB	13.7dB
Rock placement	1.6dB	11.9dB	12.5dB	8.2dB
Vessel noise	5.5dB	34.4dB	38.6dB	17.4dB

5.2.5 **Table 5-4** and **Table 5-5** summarise the predicted impact ranges for these noise sources. It is worth noting that Southall *et al.* (2019) and Popper *et al.* (2014) both give alternative criteria for non-impulsive or continuous noise sources compared to impulsive noise (see **Section 2.2.1**); all sources in this section are considered non-pulse or continuous.

5.2.6 Given the modelled impact ranges, any marine mammal would have to be less than 100m from the continuous noise source at the start of the activity, in most cases, to acquire the necessary exposure to induce PTS as per Southall *et al.* (2019). The exposure calculation assumes the same receptor swim speed as the impact piling modelling in **Section 4**. As explained in **Section 3.2.3**, it should also be noted that this would only mean that the receptor reaches the 'onset' stage, which is the minimum exposure that could potentially lead to the start of an effect and may only be marginal. In

most hearing groups, the noise levels low enough that there is negligible risk.

- 5.2.7 For fish, there is a low to negligible risk of any injury or TTS in line with the SPL_{RMS} guidance for continuous noise sources in Popper *et al.* (2014).
- 5.2.8 All sources presented here are much quieter than those presented for impact piling in **Section 4**.

Table 5-4 Summary of the impact ranges for the different construction noise sources using the non-impulsive criteria from Southall *et al.* (2019) for marine mammals

Southall <i>et al.</i> (2019) Weighted SEL_{cum}		Cable laying	Suction dredging	Trenching	Rock placement	Vessel (large)	Vessel (med)
PTS	199dB (LF)	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m
	198dB (HF)	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m
	173dB (VHF)	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m
	201dB (PCW)	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m
TTS	179dB (LF)	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m
	178dB (HF)	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m
	153dB (VHF)	< 100m	200m	< 100m	1.0km	200m	< 100m
	181dB (PCW)	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m

Table 5-5 Summary of the impact ranges for fish from Popper *et al.* (2014) for shipping and continuous noise, covering the different noise sources

Popper <i>et al.</i> (2014) Unweighted SPL_{RMS}	Cable laying	Suction dredging	Trenching	Rock placement	Vessel (large)	Vessel (med)
Recoverable Injury 170dB (48 hours)	< 50m	< 50m	< 50m	< 50m	< 50m	< 50m
TTS 158dB (12 hours)	< 50m	< 50m	< 50m	< 50m	< 50m	< 50m

5.3 Operational WTG noise

- 5.3.1 The main source of underwater noise from operational WTGs will be mechanically generated vibration from the rotating machinery in the turbines, which is transmitted into the sea through the structure of the turbine tower

and foundations (Nedwell *et al.*, 2003). Noise levels generated above the water surface are low enough that no significant airborne sound will pass from the air to the water.

- 5.3.2 A summary of sites where operational WTG measurements have been collected is given in **Table 5-6**.

Table 5-6 Characteristics of measured operational WTGs used as a basis for modelling

Wind farm	Lynn	Inner Dowsing	Gunfleet Sands 1 & 2	Gunfleet Sands 3
Type of turbine used	Siemens SWT-3.6-107	Siemens SWT-3.6-107	Siemens SWT-3.6-107	Siemens SWT-6.0-120
Number of turbines	27	27	48	2
Power rating	3.6MW	3.6MW	3.6MW	6MW
Rotor diameter	107m	107m	107m	120m
Water depths	6 to 8m	6 to 14m	0 to 15m	5 to 12m
Representative sediment type	Sandy gravel / muddy sandy gravel	Sandy gravel / muddy sandy gravel	Sand / muddy sand / muddy sandy gravel	Sand / muddy sand / muddy sandy gravel
Turbine separation	500m	500m	890m	435m

- 5.3.3 The estimation of the effects of operational WTG noise in these situations has two features that make it harder to predict compared with noise sources such as impact piling. Primarily, the problem is one of level; noise measurements made at many operational wind farms have demonstrated that the operational noise produced was at such a low level that it was difficult to measure relative to background noise at distances of a few hundred metres (Cheesman, 2016). Secondly, the multiple turbines of an offshore wind farm could be considered as an extended, distributed noise source, as opposed to a “point source,” as would be appropriate for piling driving at a single location for example. The measurement techniques used at the sites above have dealt with these issues by considering the operational WTG noise spectra in terms of levels within and on the edge of the wind farm (but relatively close to the turbines, so that some noise above background can be detected).
- 5.3.4 The turbine sizes for modelling at Rampion 2 are larger than those shown in **Table 5-6**, with turbines between 10 and 18MW being considered. The Rampion 2 site is also situated in greater water depths, and as such, estimations of a scaling factor must be conservative to minimise the risk of underestimating the noise. However, it is recognised that the available data

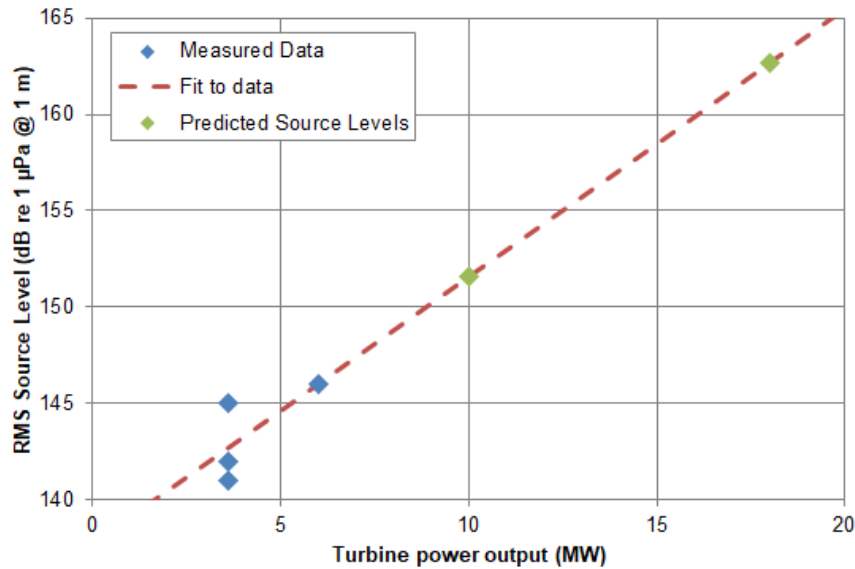
on which to base the scaling factor is limited and the extrapolation that must be made is significant.

- 5.3.5 The operational source levels (as SPL_{RMS}) for the measured sites are given in **Table 5-7** (Cheesman, 2016), with estimated source levels for Rampion 2 at the bottom of the table. To predict operational WTG noise levels at Rampion 2, the extrapolated source level from the measured data at each of the sites has been taken and then a linear correction factor has been included to scale up the source levels (**Graphic 5-2**). A linear fit was applied to the data to keep conservatism in the extrapolation and to take account of the deeper water depths, leading to the highest, and thus worst-case, estimation of sources level noise from the larger turbines. This resulted in estimated source levels of 151.6dB re 1 μPa (SPL_{RMS}) @ 1m for a 10MW WTG and 162.7dB re 1 μPa (SPL_{RMS}) @ 1m for 18MW WTGs; 5.6 and 16.7dB higher, respectively, than the 6MW turbines for which measurements were available.

Table 5-7 Measured operational WTG noise taken at operational wind farms, and the predicted source level for the turbine sizes considered at Rampion 2

Site	Unweighted source level
Lynn (3.6MW)	141dB re 1 μPa (SPL_{RMS}) @ 1m
Inner Dowsing (3.6MW)	142dB re 1 μPa (SPL_{RMS}) @ 1m
Gunfleet Sands 1 & 2 (3.6MW)	145dB re 1 μPa (SPL_{RMS}) @ 1m
Gunfleet Sands 3 (6MW)	146dB re 1 μPa (SPL_{RMS}) @ 1m
Rampion 2 (10MW)	151.6dB re 1 μPa (SPL_{RMS}) @ 1m
Rampion 2 (18MW)	162.7dB re 1 μPa (SPL_{RMS}) @ 1m

Graphic 5-2 Extrapolated source levels from operational WTGs plotted with a linear fit to estimate the source levels for 10 to 18MW WTGs



5.3.6 It is acknowledged that this fit is speculative: the available data is very limited. Newer, larger, direct drive (gearbox-less) designs tend to be more efficient and losses (for example, in energy which produce noise and vibration) are significantly reduced. Preliminary measurements of such direct-drive WTGs have been collected off the east coast of the United States (HDR, 2019), showing extrapolated source levels of 136dB re 1 µPa (SPL_{RMS}) @ 1m for a 6MW turbine. Thus, the linear extrapolation represents a considerably greater noise output and can be considered conservative.

5.3.7 A summary of the predicted impact ranges is given in **Table 5-8** and **Table 5-9**. All SEL_{cum} criteria use the same assumptions as presented in **Section 2.2.1**, and ranges smaller than 50m (single strike) and 100m (cumulative) have not been presented. The operational WTG source is considered a non-impulsive sound by Southall *et al.* (2010) and a continuous source by Popper *et al.* (2014). For SEL_{cum} calculations it has been assumed that the operational WTG noise is present 24 hours a day and a receptor remains stationary in the vicinity for the duration.

Table 5-8 Summary of the impact range for the proposed operational WTGs using the non-impulsive noise criteria from Southall *et al.* (2019) for marine mammals using a stationary animal model

Southall <i>et al.</i> (2019)		Operational WTG (10MW)	Operational WTG (18MW)
PTS Weighted SEL _{cum}	199dB (LF)	< 100m	< 100m
	198dB (HF)	< 100m	< 100m
	173dB (VHF)	< 100m	< 100m
	201dB (PCW)	< 100m	< 100m
TTS Weighted SEL _{cum}	179dB (LF)	< 100m	150m
	178dB (HF)	< 100m	< 100m
	153dB (VHF)	< 100m	440m
	181dB (PCW)	< 100m	< 100m

Table 5-9 Summary of the impact ranges for the proposed operational WTGs using the continuous noise criteria from Popper *et al.* (2014) for fish (swim bladder involved in hearing)

Popper <i>et al.</i> (2014)	Operational WTG (10MW)	Operational WTG (18MW)
Recoverable injury 170dB (48 hours), Unweighted SPL _{RMS}	< 100m	< 100m
TTS 158dB (12 hours), Unweighted SPL _{RMS}	< 100m	< 100m

5.3.8 These results show that, for noise from operational WTGs, injury risk is minimal, with only TTS ranges for LF and VHF cetaceans being calculated above 100m, and importantly this assumes a stationary animal model over a full 24-hour period. This is a highly unlikely scenario; when the animal is able to move, these results are reduced to less than 100m.

5.3.9 Taking the results from this and **Section 5.1**, and comparing them to the impact piling results in **Section 4** and **Annex A**, it is clear that impact piling results in much greater noise levels and impact ranges, and hence should be considered the activity which has the potential to have the greatest effect during the construction and lifecycle of Rampion 2.

5.4 UXO clearance

5.4.1 Several UXO devices with a range of charge weights (or quantity of contained explosive) have been identified within the Rampion 2 PEIR Assessment Boundary. These need to be cleared before any construction can begin. There are expected to be a variety of explosive types, many of which have been subject to degradation and burying over time. Two otherwise identical explosive devices are likely to produce different blasts in

the case where one has spent an extended period on the seabed. A selection of explosive sizes have been considered based on what has been found at similar sites and, in each case, it has been assumed that the maximum explosive charge in each device is present and detonates with the clearance.

Estimation of underwater noise levels

- 5.4.2 The noise produced by the detonation of explosives is affected by several different elements, only one of which can easily be factored into a calculation: the charge weight. In this case, the charge weight is based in the equivalent weight of TNT. Many other elements relating to its situation (for example, its design, composition, age, position, orientation, whether it is covered by sediment) and exactly how it will affect the sound produced by detonation, are usually unknown and cannot be directly considered in this type of assessment. A worst-case estimation has therefore been used for calculations, assuming the UXO to be detonated is not buried, degraded or subject to any other significant attenuation from its “as new” condition.
- 5.4.3 The consequence is that the noise levels produced, particularly by the larger explosives under consideration, are likely to be over-estimated as some degree of degradation would be expected.
- 5.4.4 The range of equivalent charge weights for the potential UXO devices that could be present at Rampion 2 have been estimated as 25, 55, 120, 240, and 525kg. Estimation of the source noise level for each charge weight has been carried out in accordance with the methodology of Soloway and Dahl (2014), which follows Arons (1954) and the Marine Technical Directorate (MTD) (1996).

Estimation of underwater noise propagation

- 5.4.5 For this assessment, the attenuation of the noise from UXO detonation has been accounted for in calculations using geometric spreading and a sound absorption coefficient, primarily using the methodologies cited in Soloway and Dahl (2014), which establishes a trend based on measured data in open water. These are, for SPL_{peak} :

$$SPL_{peak} = 52.4 \times 10^6 \left(\frac{R}{W^{1/3}} \right)^{-1.13}$$

and for SEL_{ss} :

$$SEL_{ss} = 6.14 \times \log_{10} \left(W^{1/3} \left(\frac{R}{W^{1/3}} \right)^{-2.12} \right) + 219$$

where W is the equivalent charge weight for TNT in kilograms and R is the range from the source in metres.

- 5.4.6 These equations give a relatively simple calculation which can be used to give an indication of the range of effect. The equation does not consider variable bathymetry or seabed type, and thus calculation results will be the same regardless where it is used. An attenuation correction can be added to the Soloway and Dahl (2014) equations for the absorption over long ranges (for instance, of the order of thousands of metres), based on measurements of high intensity noise propagation taken in the North and Irish Seas in similar depths to those present at Rampion 2.
- 5.4.7 Despite this attenuation correction, the resulting noise levels still need to be considered carefully. For example, SPL_{peak} noise levels over larger distances are difficult to predict accurately (von Benda-Beckmann *et al.*, 2015). Soloway and Dahl (2014) only verify results from the equations above for small charges at ranges of less than 1km, although the results do agree with measurements presented by von Benda-Beckmann *et al.* (2015). At these larger ranges, greater confidence is expected with the SEL calculations compared to the SPL_{peak} calculations.
- 5.4.8 A further limitation in the Soloway and Dahl (2014) equations that must be considered are that variations in noise levels at different depths are not considered. Where animals are swimming near the surface, the acoustics can cause the noise level, and hence the exposure, to be lower (MTD, 1996). The risk to animals near the surface may therefore be lower than indicated by the impact ranges and therefore the results presented can be considered conservative in respect of the impact at different depths.
- 5.4.9 Additionally, an impulsive wave tends to be smoother (for instance, the pulse becomes longer) over distance (Cudahy and Parvin, 2001), meaning that injurious potential of a wave at greater ranges can be even lower than just a reduction in the absolute noise level. An assessment in respect of SEL is considered preferential at long range as it considers the overall energy, and the smoothing of the peak is less critical.
- 5.4.10 The selection of assessment criteria must also be considered in light of this; as discussed in **Section 2.2.1.1**, the smoothing of the pulse at range means that a pulse may be considered a non-pulse at greater distance. This study has presented impact ranges for both impulsive and non-impulsive criteria, suggesting that, at greater ranges, it may be more appropriate to use the non-pulse criteria.
- 5.4.11 A summary of the unweighted UXO source levels calculated using the equations above are given in **Table 5-10**.

Table 5-10 Summary of the unweighted SPL_{peak} and SEL_{ss} source levels used for UXO modelling

Charge weight	25kg	55kg	120kg	240kg	525kg
SPL _{peak} source level (dB re 1 µPa @ 1m)	284.9	287.4	290.0	292.2	294.8
SEL _{ss} source level (dB re 1 µPa ² s @ 1m)	227.9	230.1	232.3	234.2	236.4

Impact ranges

- 5.4.12 **Table 5-11 to Table 5-14** present the impact ranges for UXO detonation, considering various charge weights and impact criteria. It should be noted that Popper *et al.* (2014) gives specific impact criteria for explosions (**Table 2-9**). A UXO detonation source is defined as a single pulse, and as such the SEL_{cum} criteria from Southall *et al.* (2019) have been given as SEL_{ss} in the tables below. Thus, fleeing animal assumptions do not apply.
- 5.4.13 Although the impact ranges presented in the following tables are large, the duration the noise is present must also be considered. For the detonation of a UXO, each explosion is a single noise event, compared to the multiple pulse nature and longer durations of impact piling.
- 5.4.14 As with the previous sections, ranges smaller than 50m have not been presented.

Table 5-11 Summary of the PTS and TTS impact ranges for UXO detonation using the impulsive, unweighted SPL_{peak} noise criteria from Southall *et al.* (2019) for marine mammals

Southall <i>et al.</i> (2019) Unweighted SPL _{peak}		25kg	55kg	120kg	240kg	525kg
PTS	219dB (LF)	810m	1.0km	1.3km	1.7km	2.2km
	230dB (HF)	260m	340m	450m	560m	730m
	202dB (VHF)	4.6km	6.0km	7.7km	9.8km	13km
	218dB (PCW)	900m	1.1km	1.5km	1.9km	2.5km
TTS	213dB (LF)	1.5km	1.9km	2.5km	3.2km	4.1km
	224dB (HF)	490m	640m	830m	1.0km	1.3km
	196dB (VHF)	8.5km	11km	14km	18km	23km
	212dB (PCW)	1.6km	2.1km	2.8km	3.5km	4.6km

Table 5-12 Summary of the PTS and TTS impact ranges for UXO detonation using the impulsive, weighted SEL_{ss} noise criteria from Southall *et al.* (2019) for marine mammals

Southall <i>et al.</i> (2019) Weighted SEL _{ss}		25kg	55kg	120kg	240kg	525kg
PTS (Impulsive)	183dB (LF)	2.1km	3.2km	4.6km	6.5km	9.5km
	185dB (HF)	< 50m	< 50m	< 50m	< 50m	50m
	155dB (VHF)	560m	740m	950m	1.1km	1.4km
	185dB (PCW)	380m	560m	830m	1.1km	1.6km
TTS (Impulsive)	168dB (LF)	29km	41km	57km	76km	103km
	170dB (HF)	150m	210m	300m	390m	530m
	140dB (VHF)	2.4km	2.8km	3.2km	3.5km	4.0km
	170dB (PCW)	5.2km	7.4km	11km	14km	20km

Table 5-13 Summary of the PTS and TTS impact ranges for UXO detonation using the non-impulsive, weighted SEL_{ss} noise criteria from Southall *et al.* (2019) for marine mammals

Southall <i>et al.</i> (2019) Weighted SEL _{ss}		25kg	55kg	120kg	240kg	525kg
PTS (Non-impulsive)	199dB (LF)	120m	190m	280m	390m	570m
	198dB (HF)	< 50m	< 50m	< 50m	< 50m	< 50m
	173dB (VHF)	< 50m	< 50m	70m	100m	130m
	201dB (PCW)	< 50m	< 50m	< 50m	70m	100m
TTS (Non-impulsive)	179dB (LF)	4.4km	6.4km	9.3km	13km	19km
	178dB (HF)	< 50m	60m	80m	110m	160m
	153dB (VHF)	730m	940m	1.1km	1.4km	1.7km
	181dB (PCW)	780m	1.1km	1.6km	2.3km	3.3km

Table 5-14 Summary of the impact ranges for UXO detonation using the unweighted SPL_{peak} explosion noise criteria from Popper *et al.* (2014) for species of fish.

Popper <i>et al.</i> (2014) Unweighted SPL _{peak}		25kg	55kg	120kg	240kg	525kg
Mortality and potential mortal injury	234dB	170m	230m	290m	370m	490m
	229dB	290m	380m	490m	620m	810m

- 5.4.15 The maximum PTS range calculated her for the largest, 525kg TNT equivalent, UXO is 9.5km for the LF cetacean category, based on the weighted SEL criteria. As explained earlier, this assumes no degradation of the UXO and no smoothing of the pulse over that distance, which is very precautionary. Although an assumption of non-pulse could underestimate

the potential impact (Martin *et al.*, 2020) (the equivalent range based on LF cetacean non-impulsive criteria is 570m), it is likely that the long-range smoothing of the pulse peak would reduce its potential harm and the maximum 'impulsive' range for all species is very precautionary.

6 Summary and conclusions

- 6.1.1 Subacoustech Environmental have undertaken a study on behalf of GoBe Consultants to assess potential underwater noise, and its effects, created during the construction and operation of the proposed Rampion 2 offshore wind farm.
- 6.1.2 The level of underwater noise from the installation of monopile and jacket foundations during construction has been estimated using the INSPIRE semi-empirical underwater noise model. The modelling considers a wide variety of input parameters including bathymetry, hammer blow energy, strike rate and receptor fleeing speed.
- 6.1.3 Three representative modelling locations were chosen to give spatial variation as well as accounting for changes in water depth around the site. At each location worst-case and most likely monopile and jacket foundations were considered. These are listed below. Only jacket foundations were modelled at the deepest location as monopiles are not being considered at these water depths.
- worst-case monopile foundation – a 12m diameter pile installed with a maximum blow energy of 4,400kJ over 4.5 hours, with a maximum of two foundations installed in a single 24-hour period;
 - most likely monopile foundation – a 12m diameter pile installed with a maximum blow energy of 4,000kJ in just under three hours, with a maximum of two foundations installed in a single 24-hour period;
 - worst-case jacket foundation – a 3m diameter pile installed with a maximum blow energy of 2,500kJ over 4.5 hours, with a maximum of four foundations installed in a single 24-hour period; and
 - most likely jacket foundation – a 3m diameter pile installed with a maximum blow energy of 2,000kJ in just under three hours, with a maximum of four foundations installed in a single 24-hour period.
- 6.1.4 The loudest levels of noise and greatest impact ranges have been predicted for worst-case monopile foundations at the East location and worst-case jacket foundations at the deeper South location. Smaller ranges are predicted at the Northwest location due to the shallower water depths and proximity to the coastline, and for the most likely installation scenarios.
- 6.1.5 The modelling results were analysed in terms of relevant noise metrics and criteria to assess the impact of the impact piling noise on marine mammals (Southall *et al.*, 2019) and fish (Popper *et al.*, 2014), which have been used to aid biological assessments.

- 6.1.6 For marine mammals, maximum PTS ranges were predicted for LF cetaceans, with ranges up to 13km when considering the worst-case jacket foundation scenario in the South location. For fish, the largest TTS ranges were predicted to be 21km for a fleeing receptor, increasing to 43km for a stationary receptor. A disturbance response may occur in fish out to a most precautionary 62km from the source, based on reported values from Hawkins *et al.* (2014), although this is from a limited study under different conditions to those that will be present at the wind farm site, and should be treated with caution.
- 6.1.7 Noise sources other than piling were considered using a high-level, simple modelling approach, including cable laying, suction dredging, trenching, rock placement, vessel noise and operational WTG noise. The predicted noise levels for these other construction noise sources and during WTG operation are well below those predicted for impact piling noise. The risk of any potentially injurious effects to fish or marine mammals from these sources are expected to be negligible as the noise emissions from these are close to, or below, the appropriate injury criteria when very close to the source of the noise.
- 6.1.8 UXO detonation has also been considered at the Rampion 2 site, and for the expected UXO detonation noise, there is a risk of PTS up to 9.5km from the largest UXO considered, a 525kg device using the impulsive Southall *et al.* (2019) criteria for LF cetaceans using SEL criteria, or 13km for VHF cetaceans using SPL_{peak} criteria. However, this is likely to be very precautionary as the impact range is based on worst case criteria that do not account for any smoothing of the pulse over long ranges, which reduces the pulse peak and other characteristics of the sound that cause injury.
- 6.1.9 The outputs of this modelling have been used to inform analysis of the impacts of underwater noise on marine mammals and fish in their respective reports.

6.2 Glossary of terms

Table 6-1 Glossary of terms and abbreviations

Term (acronym)	Definition
ADD	Acoustic Deterrent Devices
Cetacean	Aquatic mostly marine mammals that includes the whales, dolphins, porpoises.
°	Degree

Term (acronym)	Definition
Decibel (dB)	A customary scale commonly used (in various ways) for reporting levels of sound. A difference of 10dB corresponds to a factor of 10 in sound power. The actual sound measurement is compared to a fixed reference level and the “decibel” value is defined to be $10 \log_{10}(\text{actual/reference})$ where (actual/reference) is a power ratio. Because sound power is usually proportional to sound pressure squared, the decibel value for sound pressure is $20 \log_{10}(\text{actual pressure/reference pressure})$. The standard reference for underwater sound is 1 micropascal (μPa). The dB symbol is followed by a second symbol identifying the specific reference value (for example, re 1 μPa).
Environmental Impact Assessment (EIA)	The process of evaluating the likely significant environmental effects of a proposed project or development over and above the existing circumstances (or ‘baseline’).
FPSO	Floating Production Storage and Offloading vessel
HF	High-Frequency Cetaceans
Hz	Hertz
Impact	The changes resulting from an action.
INSPIRE	Impulse Noise Sound Propagation and Impact Range Estimator
kHz	Kilohertz
kg	Kilogram
km	Kilometre
km²	Square Kilometre
knot	Knot
LF	Low-Frequency Cetaceans
m	Metre
mm s⁻¹	Millimetre per Second
ms⁻¹	Metres per Second

Term (acronym)	Definition
MTD	Marine Technical Directorate Ltd.
MW	Megawatt
NMFS	National Marine Fisheries Service
NPL	National Physical Laboratory
Offshore	The sea further than two miles from the coast.
Offshore Wind Farm	An offshore wind farm is a group of wind turbines in the same location (offshore) in the sea which are used to produce electricity
Pa²s	Pascal Squared Seconds
PCW	Phocid Carnivores in Water
Peak pressure	The highest pressure above or below ambient that is associated with a sound wave.
Peak-to-peak pressure	The sum of the highest positive and negative pressures that are associated with a sound wave.
PEIR Assessment Boundary	The PEIR Assessment Boundary combines the search areas for the offshore and onshore infrastructure associated with the Proposed Development. It is defined as the area within which the Proposed Development and associated infrastructure will be located, including the temporary and permanent construction and operational work areas.
Preliminary Environmental Information Report (PEIR)	The written output of the Environmental Impact Assessment undertaken to date for the Proposed Development. It is developed to support formal consultation and presents the preliminary findings of the assessment to allow an informed view to be developed of the Proposed Development, the assessment approach that has been undertaken, and the preliminary conclusions on the likely significant effects of the Proposed Development and environmental measures proposed.
Permanent Threshold Shift (PTS)	A permanent total or partial loss of hearing caused by acoustic trauma. PTS results in irreversible damage to the sensory hair cells of the ear, and thus a permanent reduction of hearing acuity

Term (acronym)	Definition
Proposed Development	The development that is subject to the application for development consent, as described in Chapter 4.
Rampion 1	The existing Rampion Offshore Wind Farm located in the English Channel off the south coast of England.
RMS	Root Mean Square
Scoping Report	A report that presents the findings of an initial stage in the Environmental Impact Assessment process.
SE	Sound Exposure
Sound Exposure Level (SEL)	The constant sound level acting for one second, which has the same amount of acoustic energy, as indicated by the square of the sound pressure, as the original sound. It is the time-integrated, sound-pressure-squared level. SEL is typically used to compare transient sound events having different time durations, pressure levels, and temporal characteristics.
SEL_{cum}	Cumulative Sound Exposure Level
SEL_{ss}	Single Strike Sound Exposure Level
Sound Pressure Level (SPL)	The sound pressure level is an expression of sound pressure using the decibel (dB) scale; the standard frequency pressures of which are 1 µPa for water and 20 µPa for air.
SPL_{peak}	Peak Sound Pressure Level
SPL_{peak-to-peak}	Peak-to-peak Sound Pressure Level
SPL_{RMS}	Root Mean Square Sound Pressure Level
The Proposed Development / Rampion 2	The onshore and offshore infrastructure associated with the offshore wind farm comprising of installed capacity of up to 1200MW, located in the English Channel in off the south coast of England.
TNT	Trinitrotoluene
Temporary Threshold Shift (TTS)	Temporary reduction of hearing acuity because of exposure to sound over time. Exposure to high levels of sound over relatively short time periods could cause the same amount of TTS as exposure to lower levels of sound over longer time periods. The

Term (acronym)	Definition
	mechanisms underlying TTS are not well understood, but there may be some temporary damage to the sensory cells. The duration of TTS varies depending on the nature of the stimulus.
UK	United Kingdom
Unweighted sound level	Sound levels which are “raw” or have not been adjusted in any way, for example to account for the hearing ability of a species.
µPa	Micropascal
UXO	Unexploded Ordnance
VHF	Very High-Frequency Cetaceans
Weighted sound level	A sound level which has been adjusted with respect to a “weighting envelope” in the frequency domain, typically to make an unweighted level relevant to a particular species. Examples of this are the dB(A), where the overall sound level has been adjusted to account for the hearing ability of humans in air, or the filters used by Southall <i>et al.</i> (2019) for marine mammals.

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Annex A Non-impulsive impact piling results

Following from the Southall *et al.* (2019) impact ranges presented in **Section 4.1** of the main report, **Table A 1** to **Table A 4** present the modelling results for non-impulsive criteria from impact piling noise at Rampion 2, as discussed in **Section 2.2.1.1**. The predicted ranges are lower than the impulsive criteria presented in the main report.

Table A 1 Summary of the impact ranges from the worst-case monopile foundation modelling at Rampion 2 using the Southall *et al.* (2019) weighted SEL_{cum} non-impulsive criteria for marine mammals

Southall <i>et al.</i> (2019) Weighted SEL _{cum} (non-impulsive)		Worst-case monopile foundation							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	61km ²	8.1km	1.3km	3.8km
	HF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	< 0.1km ²	< 100m	< 100m	< 100m
	VHF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	18km ²	3.6km	1.3km	2.3km
	PCW Pinniped	< 0.1km ²	< 100m	< 100m	< 100m	< 0.1km ²	< 100m	< 100m	< 100m
E	LF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	490km ²	19km	4.6km	11km
	HF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	< 0.1km ²	< 100m	< 100m	< 100m
	VHF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	120km ²	8.4km	3.5km	5.9km
	PCW Pinniped	< 0.1km ²	< 100m	< 100m	< 100m	0.68km ²	700m	150m	420m

Table A 2 Summary of the impact ranges from the most likely monopile foundation modelling at Rampion 2 using the Southall *et al.* (2019) weighted SEL_{cum} non-impulsive criteria for marine mammals

Southall <i>et al.</i> (2019) Weighted SEL _{cum} (non-impulsive)		Most likely monopile foundation							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	56km ²	7.8km	1.2km	3.6km
	HF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	< 0.1km ²	< 100m	< 100m	< 100m
	VHF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	16km	3.4km	1.3km	2.2km
	PCW Pinniped	< 0.1km ²	< 100m	< 100m	< 100m	< 0.1km ²	< 100m	< 100m	< 100m
E	LF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	470km ²	19km	4.5km	11km
	HF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	< 0.1km ²	< 100m	< 100m	< 100m
	VHF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	110km ²	8.0km	3.4km	5.6km
	PCW Pinniped	< 0.1km ²	< 100m	< 100m	< 100m	0.54km ²	600m	150m	380m

Table A 3 Summary of the impact ranges from the worst-case jacket foundation modelling at Rampion 2 using the Southall *et al.* (2019) weighted SEL_{cum} non-impulsive criteria for marine mammals

Southall <i>et al.</i> (2019) Weighted SEL _{cum} (non-impulsive)		Worst-case jacket foundation							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	24km ²	5.3km	650m	2.3km
	HF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	< 0.1km ²	< 100m	< 100m	< 100m
	VHF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	9.5km ²	2.7km	900m	1.7km
	PCW Pinniped	< 0.1km ²	< 100m	< 100m	< 100m	< 0.1km ²	< 100m	< 100m	< 100m
S	LF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	600km ²	20km	7.3km	13km
	HF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	< 0.1km ²	< 100m	< 100m	< 100m
	VHF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	150km ²	8.3km	5.0km	6.8km
	PCW Pinniped	< 0.1km ²	< 100m	< 100m	< 100m	0.9km ²	700m	300m	520m
E	LF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	350km ²	16km	3.8km	9.4km
	HF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	< 0.1km ²	< 100m	< 100m	< 100m
	VHF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	80km ²	6.8km	2.9km	4.8km
	PCW Pinniped	< 0.1km ²	< 100m	< 100m	< 100m	0.15km ²	350m	< 100m	190m

Table A 4 Summary of the impact ranges from the most likely jacket foundation modelling at Rampion 2 using the Southall *et al.* (2019) weighted SEL_{cum} non-impulsive criteria for marine mammals

Southall <i>et al.</i> (2019) Weighted SEL _{cum} (non-impulsive)		Most likely jacket foundation							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	16km ²	4.5km	450m	1.9km
	HF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	< 0.1km ²	< 100m	< 100m	< 100m
	VHF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	6.3km ²	2.2km	700m	1.3km
	PCW Pinniped	< 0.1km ²	< 100m	< 100m	< 100m	< 0.1km ²	< 100m	< 100m	< 100m
S	LF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	530km ²	19km	6.9km	12km
	HF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	< 0.1km ²	< 100m	< 100m	< 100m
	VHF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	120km ²	7.3km	4.5km	6.1km
	PCW Pinniped	< 0.1km ²	< 100m	< 100m	< 100m	0.4km ²	500m	200m	340m
E	LF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	300km ²	15km	3.4km	8.7km
	HF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	< 0.1km ²	< 100m	< 100m	< 100m
	VHF Cetacean	< 0.1km ²	< 100m	< 100m	< 100m	62km ²	6.0km	2.6km	4.2km
	PCW Pinniped	< 0.1km ²	< 100m	< 100m	< 100m	< 0.1km ²	200m	< 100m	120m

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