Hornsea Project Four: Environmental Statement (ES)

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Volume A2, Chapter 4: Marine Mammals

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Table of Contents

List of Tables

List of Figures

Annexes

Annex	Heading
A5.4.1	Marine Mammal Technical Report

Glossary

Term	Definition
Commitment	A term used interchangeably with mitigation and enhancement measures. The purpose of Commitments is to reduce and/or eliminate Likely Significant Effects (LSEs), in EIA terms. Primary (Design) or Tertiary (Inherent) are both embedded within the assessment at the relevant point in the EIA (e.g. at Scoping, Preliminary Environmental Information Report (PEIR) or ES). Secondary commitments are incorporated to reduce LSE to environmentally acceptable levels following initial assessment i.e. so that residual effects are acceptable.
Cumulative effects	The combined effect of Hornsea Four in combination with the effects from a number of different projects, on the same single receptor/resource. Cumulative impacts are those that result from changes caused by other past, present or reasonably foreseeable actions together with Hornsea Project Four.
Development Consent Order (DCO)	An order made under the Planning Act 2008 granting development consent for one or more Nationally Significant Infrastructure Projects (NSIPs).
Effect	Term used to express the consequence of an impact. The significance of an effect is determined by correlating the magnitude of the impact with the importance, or sensitivity of the receptor or resource in accordance with defined significance criteria.
Environmental Impact Assessment (EIA)	A statutory process by which certain planned projects must be assessed before a formal decision to proceed can be made. It involves the collection and consideration of environmental information, which fulfils the assessment requirements of the EIA Directive and EIA Regulations, including the publication of an Environmental Statement.
EIA Directive	European Union Directive 85/337/EEC, as amended by Directives 97/11/EC, 2003/35/EC and 2009/31/EC and then codified by Directive 2011/92/EU of 13 December 2011 (as amended in 2014 by Directive 2014/52/EU).
EIA Regulations	Infrastructure Planning (Environmental Impact Assessment) Regulations 2017.
Export cable corridor (ECC)	The specific corridor of seabed (seaward of Mean High Water Springs (MHWS)) and land (landward of MHWS) from the Hornsea Four array area to the Creyke Beck National Grid substation, within which the export cables will be located.
Habitats Regulations Assessment (HRA)	A process which helps determine likely significant effects and (where appropriate) assesses adverse impacts on the integrity of European conservation sites and Ramsar sites. The process consists of up to four stages of assessment: screening, appropriate assessment, assessment of alternative solutions and assessment of imperative reasons of over-riding public interest (IROPI) and compensatory measures.
High Voltage Alternating Current (HVAC)	High voltage alternating current is the bulk transmission of electricity by alternating current, whereby the flow of electric charge periodically reverses direction.
Hornsea Project Four Offshore Wind Farm	The term covers all elements of the project (i.e. both the offshore and onshore). Hornsea Four infrastructure will include offshore generating stations (wind turbines), electrical export cables to landfall, and connection

Term	Definition
	to the electricity transmission network. Hereafter referred to as Hornsea Four.
Maximum Design Scenario (MDS)	The maximum design parameters of each Hornsea Four asset (both on and offshore) considered to be a worst case for any given assessment.
Mitigation	A term used interchangeably with Commitment(s) by Hornsea Four. Mitigation measures (Commitments) are embedded within the assessment at the relevant point in the EIA (e.g. at Scoping, PEIR or ES).
Permanent Threshold Shift (PTS)	A total or partial permanent loss of hearing at a particular frequency caused by some kind of acoustic trauma. PTS results in irreversible damage to the sensory hair cells of the ear, and thus a permanent reduction of hearing acuity at that frequency.
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.
Sound Pressure Level (SPL)	The sound pressure level or SPL is an expression of the sound pressure using the decibel (dB) scale and the standard reference pressures of 1 μPa for water.
Temporary Threshold Shift (TTS)	Temporary loss of hearing at a particular frequency as a result of exposure to sound over time. 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, but there is generally recovery of full hearing over time.
Threshold	The threshold generally represents the lowest signal level an animal will detect in some statistically predetermined percent of presentations of a signal.
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.
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. The overall sound level has been adjusted to account for the hearing ability of marine mammals.

Acronyms

Acronym	Definition
ADD	Acoustic Deterrent Device
AfL	Agreement for Lease
BAP	Biodiversity Action Plan
BEIS	Department for Business, Energy & Industrial Strategy
BND	Bottlenose dolphin
CEA	Cumulative Effects Assessment
CfD	Contracts for Difference
CFE	Controlled Flow Excavation
CI	Confidence Interval

Acronym	Definition
CPEMMP	Construction Project Environmental Management and Monitoring Plan
CSIP	Cetacean Strandings Investigation Programme
DCO	Development Consent Order
DEB	Dynamic Energy Budget
DEPONS	Disturbance Effects on the Harbour Porpoise Population in the North Sea
DTAG	Digital Acoustic Recording Tag
ECC	Export Cable Corridor
EDR	Effective Deterrence Range
EEA	European Economic Area
EIA	Environmental Impact Assessment
EMF	Electro-Magnetic Fields
EP	Evidence Plan
EPS	European Protected Species
EQT	Effective Quiet Threshold
ES	Environmental Statement
FCS	Favourable Conservation Status
GBS	Gravity Base Structure
GS	Grey seal
HE	High Explosive
HF	High frequency cetaceans
HP	Harbour porpoise
HRGS	High-Resolution Geophysical Surveys
HS	Harbour seal
INSPIRE	Impulse Noise Sound Propagation and Impact Range Estimator
JCP	Joint Cetacean Protocol
JNCC	Joint Nature Conservation Committee
JUV	Jack Up Vessels
LF	Low frequency cetaceans
MDS	Maximum Design Scenario
MHWS	Mean High Water Springs
MMMP	Marine Mammal Mitigation Protocol
MMO	Marine Management Organisation
MPCP	Marine Pollution Contingency Plan
MSFD	Marine Strategy Framework Directive
MU	Management Unit
MW	Minke whale
NEQ	Net Explosive Quantities
NOAA	National Oceanic and Atmospheric Administration
NPS	National Policy Statement
NSIP	Nationally Significant Infrastructure Project
O&M	Operation and Maintenance
OSS	Offshore Substation
OWF	Offshore Wind Farm
PCW	Phocid carnivores in water
PDV	Phocine Distemper Virus
PEIR	Preliminary Environmental Information Report
PINS	Planning Inspectorate

Acronym	Definition
PTS	Permanent Threshold Shift
RIAA	Report to Inform Appropriate Assessment
RMS	Root Mean Square
SAC	Special Area of Conservation
SAFESIMM	Statistical Algorithms For Estimating the Sonar Influence on Marine Megafauna
SCANS	Small Cetaceans in European Atlantic waters and the North Sea
SEL	Sound Exposure Level
SIP	Site Integrity Plan
SMA	Seal Management Area
SNS	Southern North Sea
SNCBs	Statutory Nature Conservation Bodies
SPA	Special Protection Area
SPL	Sound Pressure Level
SSC	Suspended Sediment Concentrations
TTS	Temporary Threshold Shift
TWT	The Wildlife Trusts
UXO	Unexploded Ordnance
VHF	Very high frequency cetaceans
VMP	Vessel Management Plan
WBD	White-beaked dolphin
WDC	Whale and Dolphin Conservation
WTG	Wind Turbine Generator

Units

Unit	Definition
dB	Decibel (sound pressure)
Hz	Hertz (frequency)
kHz	Kilohertz (frequency)
kJ	Kilojoule (energy)
km	Kilometres (distance)
km^2	Kilometres squared (area)
Knot	Knot (speed, at sea)
m	Metres (distance)
m/s	Metres per second (speed)
μPa	Micropascal (pressure)

4.1 Introduction

4.1.1.1 Orsted Hornsea Project Four Limited (hereafter 'the Applicant') is proposing to develop the Hornsea Project Four Offshore Wind Farm (hereafter 'Hornsea Four') which will be located approximately 69 km from the East Riding of Yorkshire in the Southern North Sea and will be the fourth project to be developed in the former Hornsea Zone (please see **Volume A1, Chapter 1: Introduction** for further details on the Hornsea Zone). Hornsea Four will include both offshore and onshore infrastructure including an offshore generating station (wind farm), export cables to landfall, and connection to the electricity transmission network (please see **Volume A1, Chapter 4: Project Description** for full details on the project design).

4.1.1.2 The Hornsea Four Agreement for Lease (AfL) area was 846 km^2 at the Scoping phase of project development. In the spirit of keeping with Hornsea Four's approach to Proportionate Environmental Impact Assessment (EIA), the project has due consideration to the size and location (within the existing AfL area) of the final project that is being taken forward to Development Consent Order (DCO) application. This consideration is captured internally as the "Developable Area Process", which includes Physical, Biological and Human constraints in refining the developable area, balancing consenting and commercial considerations with technical feasibility for construction.

4.1.1.3 The combination of Hornsea Four's Proportionality in EIA and Developable Area process has resulted in a marked reduction in the AfL taken forward at the point of DCO application. Hornsea Four adopted a major site reduction from the AfL presented at Scoping (846 km^2) to the Preliminary Environmental Information Report (PEIR) boundary (600 km^2), with a further reduction adopted for the Environmental Statement (ES) and DCO application (468 km^2) due to the results of the PEIR, technical considerations and stakeholder feedback. The evolution of the Hornsea Four Order Limits is detailed in **Volume A1, Chapter 3: Site Selection and Consideration of Alternatives** and **Volume A4, Annex 3.2: Selection and Refinement of the Offshore Infrastructure**.

4.1.1.4 This chapter of the ES presents the results of the EIA for the potential impacts of Hornsea Four on marine mammals. Specifically, this chapter considers the potential impact of Hornsea Four seaward of Mean High Water Springs (MHWS) during its construction, operation and maintenance, and decommissioning phases.

4.1.1.5 This chapter summarises information contained within technical reports, which are included at **Volume A5, Annex 4.1: Marine Mammal Technical Report** and **Volume A4, Annex 4.5: Subsea Noise Technical Report**. **Volume A5, Annex 4.1: Marine Mammal Technical Report** provides a detailed characterisation of the Hornsea Four marine mammal study area and the wider management units, based on existing literature sources and survey data from across the former Hornsea Zone, including the Hornsea Four array area and offshore export cable corridor (ECC), and includes information on marine mammal species of ecological importance and of commercial and conservation value. **Volume A4, Annex 4.5: Subsea Noise Technical Report** provides detailed methodologies in relation to the subsea noise modelling and presents the results of this modelling.

4.2 Purpose

4.2.1.1 The primary purpose of this ES is to support the DCO application for Hornsea Four under the Planning Act 2008 (the 2008 Act).

4.2.1.2 The ES has been finalised following completion of the pre-application consultation (see **B1.1: Consultation Report** and **Table 4.3**) and will accompany the application to the Planning Inspectorate (PINS) for Development Consent.

4.2.1.3 This ES chapter:

- Summarises the existing environmental baseline established from desk studies, site-specific surveys and consultation;
- Presents the potential environmental effects on marine mammals arising from Hornsea Four, based on the information gathered and the analysis and assessments undertaken;
- Identifies any assumptions and limitations encountered in compiling the environmental information; and
- Highlights any necessary monitoring and/or mitigation measures which could prevent, minimise, reduce or offset the possible environmental effects identified in the EIA process.

4.3 Planning and Policy Context

4.3.1.1 This section outlines the legislation, policy and guidance that is relevant to the assessment of the potential impacts on marine mammals associated with the construction, operation and maintenance (O&M), and decommissioning of Hornsea Four. In addition, other national, regional and local policies are considered within this assessment where they are judged to be relevant. A summary of relevant legislation and policy most relevant to this assessment is described in the following paragraphs.

4.3.1.2 All cetaceans in Northern European waters are listed under Annex IV of the EU Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora (the Habitats Directive) as European Protected Species (EPS) of Community Interest and in need of strict protection. The harbour porpoise (*Phocoena phocoena*), bottlenose dolphin (*Tursiops truncatus*), harbour seal (*Phoca vitulina*) and grey seal (*Halichoerus grypus*) have protection under Annex II as species of Community Interest whose conservation requires the designation of Special Areas of Conservation (SACs).

4.3.1.3 The Habitats Directive was transposed through the Conservation of Habitats and Species Regulations 2017 (in territorial waters out to 12 nautical miles (nm) and the Conservation of Offshore Marine Habitats and Species Regulations 2017 in offshore waters beyond 12nm (together, the Habitats Regulations). The Habitats Regulations provide protection for designated sites, known as the national site network (formerly the Natura 2000 network) which includes SACs and Special Protection Areas (SPAs).

4.3.2 European Protected Species

4.3.2.1 The Habitats Regulations make it an offence to injure or disturb EPS. An incidence of disturbance would be considered an offence if the disturbance impairs the ability of the animals to survive, breed, or rear or nurture their young, to hibernate or migrate (where relevant) or if the disturbance affects significantly the local distribution or abundance of the species to which they belong. A disturbance offence would be committed if either of these elements occurred.

4.3.2.2 If the risk of injury or significant disturbance cannot be reduced to negligible levels with mitigation, then an EPS licence is required. In England, offshore EPS licencing is managed by the Marine Management Organisation (MMO). Licenses are granted if:

- the reason for the license relates to one of the specified purposes listed in Regulation 55 of the Habitats Regulations;
- there is no satisfactory alternative way to reduce injury or disturbance risk; and
- the action authorised must not be detrimental to the maintenance of the population of the species concerned at a Favourable Conservation Status (FCS) in their natural range.

4.3.3 Special Areas of Conservation

4.3.3.1 In order to conserve biodiversity, by maintaining or restoring Annex II species to an FCS, the Habitats Directive requires the designation of SACs for the harbour porpoise, bottlenose dolphins the harbour seal and the grey seal.

Harbour Porpoise

4.3.3.2 The Hornsea Four array area is located entirely within the northern summer part of the Southern North Sea (SNS) SAC designated for harbour porpoise, for which conservation objectives and advice on activities were published in March 2019 (JNCC and Natural England 2019). Full consideration of the potential impact on the conservation objectives of the SNS SAC is presented as part of the Report to Inform Appropriate Assessment (RIAA) (**B2.2 Report to Inform Appropriate Assessment**).

Harbour Seals

4.3.3.3 The closest harbour seal SAC to Hornsea Four is The Wash and North Norfolk Coast SAC where harbour seals are listed as a primary reason for site selection. The Wash and North Norfolk Coast SAC supports the largest breeding colony of harbour seals in the UK. The boundary of The Wash and North Norfolk Coast SAC is approximately a minimum distance of 105 km from the boundary of the Hornsea Four array area and ~100 km from the offshore ECC. Full consideration of the potential impact on the conservation objectives of the SAC is presented as part of the RIAA (**B2.2 Report to Inform Appropriate Assessment**).

Grey Seals

4.3.3.4 The closest grey seal SAC to Hornsea Four is the Humber Estuary SAC where grey seals are listed as a qualifying feature but not the primary reason for site selection. The Humber Estuary SAC is approximately 80 km from the boundary of the Hornsea Four array area and approximately 32 km from the offshore ECC. To the north of that is the Berwickshire and North Northumberland Coast SAC where grey seals are listed as the primary reason for site selection. The boundary of the Berwickshire and North Northumberland Coast SAC is approximately 200 km from the boundary of the Hornsea Four array area. Full consideration of the potential impact on the conservation objectives of the SACs is presented as part of the RIAA (**B2.2 Report to Inform Appropriate Assessment**).

4.3.4 Bonn Convention

4.3.4.1 The Convention on the Conservation of Migratory Species of Wild Animals (the Bonn Convention) requires signatories to conserve migratory species and their habitats by providing strict protection for endangered migratory species (Appendix I of the Convention) and lists migratory species which would benefit from multilateral Agreements for conservation and management (Appendix II). There are 16 cetacean species listed under Appendix I of the Bonn Convention. The UK ratified the Convention in 1985. The legal requirement for the strict protection of Appendix I species is provided by the Wildlife and Countryside Act (1981 as amended).

4.3.5 Bern Convention

4.3.5.1 The Convention on the Conservation of European Wildlife and Natural Habitats (the Bern Convention) aims to ensure conservation and protection of wild plant and animal species and their natural habitats (listed in Appendices I and II of the Convention). There are 19 species of cetacean listed under Annex II of the Bern Convention (strictly protected fauna), including harbour porpoise, bottlenose dolphins, common dolphins, Risso's dolphins, white-beaked dolphins and minke whales. All other cetacean species as well as both grey and harbour seals are listed under Annex III of the Bern Convention (protected fauna). The obligations of the Convention are transposed into national law by means of the Wildlife and Countryside Act (1981 as amended).

4.3.6 Wildlife and Countryside Act, 1981

4.3.6.1 The Wildlife and Countryside Act, 1981 makes it an offence to intentionally (or recklessly) kill, injure or take any wild animal listed on Schedule 5 of the Act, and prohibits interference with places used for shelter or protection, or intentionally disturbing animals occupying such places. All cetacean species are protected within the 12 nm territorial waters under Schedule 5 of the Wildlife and Countryside Act.

4.3.7 Conservation of Seals Act, 1970

4.3.7.1 Both grey and harbour seal species are protected under the Conservation of Seals Act (1970) which provides closed seasons during which it is an offence to take or kill any seal except under licence. Following the Phocine Distemper Virus (PDV) outbreak in 1999, an Order was issued under the Conservation of Seals Act providing year-round protection to both grey and harbour seals on the east and south-east coast of England, from Berwick to Newhaven (under the Conservation of Seals (England) Order 1999).

4.3.8 UK Biodiversity Action Plan and the UK Post-2010 Biodiversity Framework (2012)

4.3.8.1 The UK Biodiversity Action Plan (UK BAP) was published in 1994 as a response to the 1992 Rio de Janeiro Convention on Biological Diversity. The UK BAP identifies biological resources in the UK and plans for their conservation. This was succeeded by the UK Post-2010 Biodiversity Framework in 2012 in response to the Convention on Biological Diversity's Strategic Plan for Biodiversity 2011-2020 (published in 2010) and the EU Biodiversity Strategy (published in 2011). The UK Post-2010 Biodiversity Framework describes how the UK can meet the Aichi Biodiversity Targets. The UK BAP identified priority species that are the most threatened and require conservation. These UK BAP priority species include the cetacean and seal species present in UK waters. This list of priority species is still used to inform statutory lists of priority species in the UK.

4.3.9 National Policy Statements

4.3.9.1 Planning policy on offshore renewable energy Nationally Significant Infrastructure Projects (NSIPs), specifically in relation to marine mammals, is contained in the Overarching National Policy Statement (NPS) for Energy (EN-1) (DECC 2011b) and the NPS for Renewable Energy Infrastructure (EN-3) (DECC 2011a).

4.3.9.2 NPS EN-1 and NPS EN-3 include guidance on what matters are to be considered in the assessment. These are summarised in **Table 4.1** below.

Table 4.1: Summary of NPS EN-1 and EN-3 provision relevant to marine mammals.

Summary of NPS EN-1 and EN-3 provisions	How and where considered in the ES
Biodiversity	
"*Applicants should ensure that the Environmental Statement clearly sets out any effects on internationally, nationally and locally designated sites of ecological or geological conservation importance, on protected species and on habitats and other species identified as being of principal importance for the conservation of biodiversity*" (paragraph 5.3.3 of NPS EN-1).	The potential effects of the construction, operation and decommissioning phases of Hornsea Four on marine mammals have been assessed in the impact assessment (see **Section 4.11: Impact Assessment**). The assessment of impacts on European designated sites is detailed in the RIAA (**B2.2 Report to Inform Appropriate Assessment**).
"*Applicants should assess the effects on the offshore ecology and biodiversity for all stages of the lifespan of the proposed offshore wind farm*" (paragraph 2.6.64 of NPS EN-3).	Construction, operation and decommissioning phases of Hornsea Four have been assessed in the impact assessment (see **Section 4.11: Impact Assessment**).
"*Consultation on the assessment methodologies should be undertaken at early stages with the statutory consultees as appropriate*" (paragraph 2.6.65 of NPS EN-3).	Consultation with relevant statutory and non-statutory stakeholders has been carried out through the Hornsea Four Marine Mammal

Summary of NPS EN-1 and EN-3 provisions	How and where considered in the ES
	Evidence Plan (EP) Technical Panel (see Table 4.3).
"Any relevant data that has been collected as part of post-construction ecological monitoring from existing, operational offshore wind farms should be referred to where appropriate" (paragraph 2.6.66 of NPS EN-3).	Data on marine mammal usage of existing operational offshore wind farms was used to inform the sensitivity assessment for O&M phase impacts (see Section 4.10.4 *et seq.*).
"Applicants should assess the potential for the scheme to have both positive and negative effects on marine ecology and biodiversity" (paragraph 2.6.67 of NPS EN-3).	Both the adverse and beneficial effects of Hornsea Four have been assessed (see Section 4.11: Impact Assessment).
Marine mammals	
"Where necessary the assessment of the effects on marine mammals should include details of: likely feeding areas; known birthing areas/haul out sites; nursery grounds; known migration or commuting routes; duration of potentially disturbing activity including cumulative/in-combination effects; baseline noise levels; predicted noise levels in relation to mortality, Permanent Threshold Shift (PTS) and Temporary Threshold Shift (TTS); soft-start noise levels; and operational noise" (NPS EN-3; paragraph 2.6.92).	All of the specified marine mammal ecology details are included in this chapter. Construction and operational noise impacts and their likely effects on marine mammal behaviour and ecology has been assessed (see Section 4.11: Impact Assessment). This assessment also considers the cumulative impacts of Hornsea Four and other relevant plans or projects (see Section 4.12: Cumulative Effects Assessment (CEA)).
"The Applicant should discuss any proposed piling activities with the relevant body. Where assessment shows that noise from offshore piling may reach noise levels likely to lead to an offence, the Applicant should look at possible alternatives or appropriate mitigation before applying for a EPS licence" (NPS EN-3; paragraph 2.6.93).	Potential mitigation methods will be considered within the piling Marine Mammal Mitigation Protocol (MMMP) (see F2.5: Outline Marine Mammal Mitigation Protocol) in order to reduce the risk of PTS to negligible levels (Co110, Table 4.9). The details of the final MMMP will be agreed once the final project design is known (Co110, Table 4.9).

4.3.9.3 NPS EN-3 also highlights several factors relating to the determination of an application and in relation to mitigation. These are summarised in Table 4.2 below.

Table 4.2: Summary of NPS EN-3 policy on decision making relevant to marine mammals.

Summary of EN-3 provisions	How and where considered in the ES
Biodiversity	
"The Secretary of State should consider the effects of a proposal on marine ecology and biodiversity taking into account all relevant information made available to it" (paragraph 2.6.68 of NPS EN-3).	The potential effects of the construction, operation and decommissioning phases of Hornsea Four on marine mammals have been assessed in the impact assessment (see Section 4.11: Impact Assessment). The assessment of impacts on European designated sites is detailed in the RIAA (B2.2 Report to Inform Appropriate Assessment).
"The designation of an area as a Natura 2000 site does not necessarily restrict the construction or operation of offshore wind farms in or near that area" (paragraph 2.6.69 of NPS EN-3).	Where there is the potential for a significant effect on a SAC or SPA of the national site network (formerly the Natura 2000 network) designated for marine mammal species, this has been

Summary of EN-3 provisions	How and where considered in the ES
	assessed within the RIAA (**B2.2 Report to Inform Appropriate Assessment**).
"Mitigation may be possible in the form of careful design of the development itself and the construction techniques employed" (paragraph 2.6.70 of NPS EN-3).	This was considered when defining the ramp up for piling (ramp up details in **Table 4.14** and **Table 4.15**). In addition, a piling MMMP will be implemented during construction (see **F2.5: Outline Marine Mammal Mitigation Protocol**). The details of the final MMMP will be agreed once the final project design is known (Co110, **Table 4.9**).
"Ecological monitoring is likely to be appropriate during the construction and operational phases to identify the actual impact so that, where appropriate, adverse effects can then be mitigated and to enable further useful information to be published relevant to future projects" (paragraph 2.6.71 of NPS EN-3).	Monitoring will be carried out in order to validate the predictions of the impact assessment (as required). The details of the monitoring will be agreed through consultation with the Statutory Nature Conservation Bodies (SNCBs) (see **F2.7 Outline Marine Monitoring Plan**).
Marine mammals	
"The Secretary of State should be satisfied that the preferred methods of construction, in particular for foundations and the foundation type are designed to reasonably minimise significant disturbance effects. The Secretary of State may refuse the application if suitable noise mitigation measures cannot be imposed by requirements to any development consent" (paragraph 2.6.94 of NPS EN-3).	Hornsea Four has considered different foundation options, hammer energies and ramp-ups. Mitigation methods are considered within the piling MMMP (see **F2.5: Outline Marine Mammal Mitigation Protocol**). The details of the final MMMP will be agreed once the final project design is known (Co110, **Table 4.9**).
"The conservation status of marine European Protected Species, and seals, are of relevance to the Secretary of State. The Secretary of State should take into account the views of the relevant statutory advisors" (paragraph 2.6.95 of NPS EN-3).	The conservation status of EPS and seals is presented in **Volume A5, Annex 4.1: Marine Mammal Technical Report** and **Table 4.7** and is considered within the impact assessment for each species.
"Mitigation: monitoring of a mitigation area for marine mammals surrounding the piling works prior to commencement of, and during, piling activities. During construction, 24 hour working practices may be employed to reduce the total construction programme and the potential for impacts. Soft-start procedures during pile driving may be implemented to avoid significant adverse impacts" (paragraphs 2.6.97 to 2.6.99 of NPS EN-3).	Mitigation methods are considered within the piling MMMP (see **F2.5: Outline Marine Mammal Mitigation Protocol**). The details of the final MMMP will be agreed once the final project design is known (Co110, **Table 4.9**).

4.3.10 Marine Policy Statement

4.3.10.1 The Marine Policy Statement (HM Government 2011) is the framework for preparing Marine Plans and taking decisions affecting the marine environment. The high-level objective *"Living within environmental limits"* includes the following requirements relevant to marine mammals:

- Biodiversity is protected, conserved and, where appropriate, recovered, and loss has been halted;

- Healthy marine and coastal habitats occur across their natural range and are able to support strong, biodiverse biological communities and the functioning of healthy, resilient and adaptable marine ecosystems; and
- Our oceans support viable populations of representative, rare, vulnerable, and valued species.

4.3.11 East Inshore and East Offshore Coast Marine Plans (HM Government 2014)

4.3.11.1 These plans provide objectives and aims that are supported by detailed policies. The East Inshore Marine Plan Area covers the coastline and includes exposed sandy beaches, soft glacial till cliffs and shallow waters (includes the Humber Estuary SAC and the Wash and North Norfolk Coast SAC). The East Offshore Marine Plan Area encompasses the marine area from 12 nautical miles out to the Exclusive Economic Zone (includes the Southern North Sea SAC). The objectives that are relevant to marine mammals include:

- Objective 6: To have a healthy, resilient and adaptable marine ecosystem in the East Marine Plan Areas;
- Objective 7: To protect, conserve and, where appropriate, recover biodiversity that is in or dependent upon the East Marine Plan Areas; and
- Objective 8: To support the objectives of Marine Protected Areas (and other designated sites around the coast that overlap with, or are adjacent to, the East Marine Plan Areas), individually and as part of an ecologically coherent network.

4.3.12 Marine Strategy Framework Directive

4.3.12.1 The Marine Strategy Framework Directive (MSFD) 2008/56/EC provides a legislative framework for an ecosystem-based approach to the management of activities which supports the sustainable use of marine goods and services. The aim of the Directive is to achieve 'Good Environmental Status' by 2020 across Europe's marine environment. The directive was implemented into UK law via the Marine Strategy Regulations 2010. Annex I of the MSFD includes the following requirements that are relevant to marine mammals:

- Biological diversity is maintained;
- The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions;
- All elements of the marine food webs, to the extent that they are known, occur at normal abundance and diversity and levels capable of ensuring the long-term abundance of the species and the retention of their full reproductive capacity;
- Concentrations of contaminants are at levels not giving rise to pollution effects; and
- Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment.

4.4 Consultation

4.4.1.1 Consultation is a key part of the DCO application process. Consultation regarding marine mammals has been conducted through EP Technical Panel meetings, the EIA scoping process (Orsted 2018) and formal consultation on the PEIR. An overview of the project consultation process is presented within **Volume A1, Chapter 6: Consultation**.

4.4.1.2 Agreements made with consultees within the EP process are set out in the topic specific EP Logs which are appendices to the Hornsea Four Evidence Plan (**B1.1.1: Evidence Plan**), an annex of the Hornsea Four Consultation Report (**B1.1: Consultation Report**). All agreements within the EP Logs have unique identifier codes which have been used throughout this document to signpost to the specific agreements made (e.g. OFF-MM-2.1).

4.4.1.3 A summary of the key issues raised during consultation, specific to marine mammals is outlined below in **Table 4.3**, together with how these issues have been considered in the production of this ES.

Table 4.3: Consultation Responses.

Consultee	Date, Document, Forum	Comment	Where addressed in the ES
PINS	November 2018, Scoping Opinion	The Inspectorate considers that significant effects could occur during operation of the wind farm array and the substations and advises that these matters must be assessed in the ES.	The following O&M phase impacts have been assessed: operational noise, vessel collisions, vessel disturbance, reduction in prey, reduction in foraging ability (see **Section 4.11: Impact Assessment**).
PINS	November 2018, Scoping Opinion	The ES should assess the extent to which increases in suspended sediment may affect foraging ability of relevant marine mammal species where significant effects are likely to occur.	**Chapter 1: Marine Geology, Oceanography and Physical Processes** was used to inform the impact of reduced foraging ability (see **Section 4.11 Impact Assessment**, **paragraph 4.11.1.95** and **Chapter 3: Fish and Shellfish Ecology** to inform reduction in prey availability (see **Section 4.11: Impact Assessment**, **paragraph 4.11.1.91**).
PINS	November 2018, Scoping Opinion	Electro-Magnetic Fields (EMF): The Inspectorate agrees that given the nature of the Proposed Development and the referenced literature provided in the Scoping Report, significant effects are unlikely and operational EMF effects on Marine Mammals can be scoped out of the ES.	Impact scoped out (see **Table 4.8** and **Volume A4, Annex 5.1: Impacts Register**).
PINS	November 2018, Scoping Opinion	Disturbance of Haul-Out Sites (construction): The Inspectorate is content that there is unlikely to be significant effects from disturbance during construction to haul out sites the nearest of which is >50 km away from the proposed landfall. The Inspectorate is content that this matter can be scoped out of the ES on that basis.	Impact scoped out (see **Table 4.8** and **Volume A4, Annex 5.1: Impacts Register**).

Consultee	Date, Document, Forum	Comment	Where addressed in the ES
Natural England & MMO/Cefas	November 2018, Scoping Opinion	Sensitivity to PTS: the ES should provide an assessment of low frequency noise on relevant receptors where significant effects are likely	Marine mammal sensitivity to PTS has been fully assessed and has been informed by the latest scientific knowledge on the topic (see **paragraph 4.10.4** *et seq.*).
The Wildlife Trusts (TWT) & Natural England	February 2019, EP Consultee Comments on the Noise Modelling Methodology and Approach	Raised concerns regarding the use of non-impulsive thresholds before scientific information has been published to support their use. If non-impulsive thresholds are used, it should be made clear that they are shown for illustrative purposes only, and the assessment should be against the impulsive thresholds.	Published data are now available on the transition from impulsive to non-impulsive noise characteristics with distance (Hastie et al. 2019). This is discussed in detail in **Appendix A** and the change in signal characteristic from impulsive to non-impulsive has been considered in the assessment of PTS alongside the full impact ranges using the impulsive PTS threshold (OFF-MM-2.4, OFF-MM-2.5 & OFF-MM-2.6).
Whale & Dolphin Conservation (WDC), TWT & Natural England	February 2019, EP Consultee Comments on the Noise Modelling Methodology and Approach	Activities other than development of offshore wind farms need to be considered in the CEA: shipping, oil and gas exploration, Unexploded Ordnance (UXO) clearance, and vessel activity.	Hornsea Four considers that shipping and fisheries are part of the baseline and so are not included in the CEA (see **Volume A4, Annex 5.3: Offshore Cumulative Effects**). The CEA includes impacts from: offshore wind farm and other offshore construction, UXO clearance, operational impacts of offshore wind farms including vessel activity, and oil and gas exploration (seismic surveys) (see **Section 4.12**).
Natural England	30 April 2019, Marine Mammals EP Technical Panel Meeting Four	Prey availability: There needs to be a link between specific prey species and their importance for marine mammals when assessing changes in prey availability.	The key prey species for each marine mammal species has been considered in **Table 4.56.**
Natural England & MMO/Cefas	30 April 2019, Marine Mammals EP Technical Panel Meeting Four	Natural England and MMO/Cefas agreed that for TTS, only ranges will be presented and that TTS impacts will not be carried through to qualitative assessment (OFF-MM-2.2).	TTS impact ranges are presented for construction piling noise, construction non-piling noise, UXO clearance and operational noise (see **Volume A4, Annex 4.5: Subsea Noise Technical Report**).
WDC, TWT, Natural England & MMO/Cefas	26 June 2019, Marine Mammals EP Technical Panel Meeting Five	All consultees agreed that the data collected and the sources being used to define the baseline characterisation for marine mammals in the vicinity of Hornsea Four are fit for the purpose of the Hornsea Four impact assessment (OFF-MM-1.2 & OFF-MM-1.3).	Full details of the baseline characterisation are outlined in **Volume A5, Annex 4.1: Marine Mammal Technical Report**.
WDC, TWT, Natural England & MMO/Cefas	Section 42 consultation and 06 Nov 2019 Marine Mammals	TWT highlighted that recent sighting data has shown an increase in bottlenose dolphin activity along the Yorkshire coast. Agreed to contact the	Sea Watch Foundation sightings data were obtained. Bottlenose dolphins are now included in the baseline (**Volume A5, Annex 4.1: Marine Mammal Technical Report**) and in the impact assessment (**Section 4.11**).

Consultee	Date, Document, Forum	Comment	Where addressed in the ES
	EP Technical Panel Meeting Six	Sea Watch Foundation for sightings data.	
WDC, TWT, Natural England & MMO/Cefas	Section 42 consultation and 06 Nov 2019 Marine Mammals EP Technical Panel Meeting Six	WDC highlighted concerns with the baseline data and methodologies used. Following clarification in discussion, WDC noted that the baseline data is not a concern for this project as two years of aerial data has been collected (OFF-MM-1.2 & OFF-MM-1.3). All confirmed that subject to the addition of bottlenose dolphins, all consultees are happy the baseline was appropriate for DCO application (OFF-MM-1.2).	No further action other than the addition of bottlenose dolphins into the baseline (see **Volume A5, Annex 4.1: Marine Mammal Technical Report**) and in the impact assessment (**Section 4.11**).
WDC, TWT, Natural England & MMO/Cefas	Section 42 consultation and 06 Nov 2019 Marine Mammals EP Technical Panel Meeting Six	All highlighted that the impact assessment should focus on the Maximum Design Scenario (MDS) and not the most likely scenario. In addition, the assessment of simultaneous piling needs to be included.	The MDS has been revised since PEIR and the resulting impact assessment is presented in full for both the MDS and the most likely scenario (**Section 4.11**). The assessment of simultaneous piling (NW and E locations) is now included in the impact assessment for all species (**Section 4.11**).
WDC, TWT, Natural England & MMO/Cefas	Section 42 consultation and 06 Nov 2019 Marine Mammals EP Technical Panel Meeting Six	TWT and Natural England noted that the UXO assessment only included charge sizes up to 263 kg and noted that greater weights have been found in this area of the North Sea. Discussed the ongoing studies to measure UXO noise levels. Unlikely data will be available in time for the Hornsea Four impact assessment. Agreed to use the modelling conducted for Hornsea Project Two for UXOs charge sizes up to 800 kg (OFF-MM-2.9).	The UXO assessment now estimates the impacts on all marine mammals for UXO charge sizes up to 800 kg using the modelling conducted for Hornsea Project Two (see UXO PTS assessment starting at **paragraph 4.4.11.1.96** and UXO disturbance assessment starting at **paragraph 4.4.11.1.100**).
Natural England	Section 42 consultation and 06 Nov 2019 Marine Mammals EP Technical Panel Meeting Six	Natural England did not agree with the use of the (Small Cetaceans in European Atlantic waters and the North Sea) SCANS III density in the UXO assessment and recommended that the same approach is applied as per piling where densities from aerial or acoustic densities are used.	The UXO PTS and disturbance assessment now uses aerial and acoustic densities as requested (see **Table 4.58** and **Table 4.59**) (OFF-MM-2.9).
WDC, TWT, Natural England & MMO/Cefas	Section 42 consultation and 06 Nov 2019 Marine Mammals EP Technical Panel Meeting Six	TWT requested that tables are presented in the cumulative impact assessment.	Tables have been added to the cumulative impact assessment alongside the figures (see **Section 4.12**).

Consultee	Date, Document, Forum	Comment	Where addressed in the ES
WDC, TWT, Natural England & MMO/Cefas	Section 42 consultation and 06 Nov 2019 Marine Mammals EP Technical Panel Meeting Six	Natural England requested that more information is provided on TTS. Agreed that TTS ranges would be presented, but that as per previous agreements, the resulting impacts would not be quantified.	Tables for TTS impacts have been added into the impact assessment (see **Table 4.47** to **Table 4.54**) (OFF-MM-2.1).
WDC, TWT, Natural England & MMO/Cefas	Section 42 consultation and 06 Nov 2019 Marine Mammals EP Technical Panel Meeting Six	Natural England does not agree that sensitivity to PTS is medium for cetaceans. TWT would like to discuss the use of the Expert Elicitation papers. At Meeting Six, SMRU Consulting presented the existing literature and detailed the expert elicitation further. All agreed, with the exception of WDC and TWT, that the assessment will consider the impact of the PTS change rather than the PTS itself, and therefore with additional context added, can be assessed as medium (OFF-MM-2.7).	Details on the literature and the expert elicitation results are presented in **Section 4.10.4** to justify the decision to assess cetacean sensitivity to PTS as medium.
Natural England	Section 42 consultation and 06 Nov 2019 Marine Mammals EP Technical Panel Meeting Six	Natural England believe that the sensitivity of marine mammals to vessel collision should be high, given the fact they will either die, or be seriously injured.	Marine mammal sensitivity to vessel collision has been amended to high (see **paragraph 4.4.11.1.81**).
Natural England	Section 42 consultation	Natural England disagrees that the noise impact of Tiers 3 and 4 are of minor magnitude. Piling is predicted to continue over multiple years, with multiple wind farms, it is not necessarily intermittent in combination with other impulsive noisy activities, and as stated is of medium term and of regional spatial extent. Taking the definitions of minor (short term / intermittent) and moderate, Natural England advise that a moderate magnitude is more appropriate. Raising the magnitude would change the overall significance of the impact. This can be addressed by securing adequate mitigation through the production of a Site Integrity Plan (SIP).	The cumulative impact assessment has been revised in light of the recent Contracts for Difference (CfD) results (see **Section 4.12**). The magnitude definitions for marine mammals do not contain a temporal component, and instead are ranked by the potential to change behaviour, distribution, favourable conservation status and long term population trajectory. The duration of disturbance from impulsive noise across all Tiers will still be considered intermittent (not every day and not for all day everyday) and short term relative to marine mammal generational scales.
Natural England	Section 42 comments, April 2020 comments	Natural England advice is that the Joint Cetacean Protocol (JCP) densities should be taken forward into the	Full details of the limitations of the JCP dataset are presented in **Volume A5, Annex 4.1: Marine Mammal Technical**

Consultee	Date, Document, Forum	Comment	Where addressed in the ES
	on an early draft of **Volume A5, Annex 4.1: Marine Mammal Technical Report**, and 04 Jun 2020 Marine Mammals EP Technical Panel Meeting Eight	assessment. At Meeting Eight, SMRU Consulting outlined the reasons why the JCP dataset was not taken forward to impact assessment. Natural England agreed with the limitations of the dataset presented and all agreed that the limitations should be detailed in both the technical report and the impact assessment to explain why they were not used.	**Report** and are summarised in **paragraph 4.4.7.1.2** (OFF-MM-1.4).
Natural England	Comments on draft ES, February 2021 and 10 May 2021 Marine Mammals EP Technical Panel Meeting Nine	CEA should present figures for simultaneous piling at Hornsea Four together with other piling/UXO/seismic events	Added to CEA section **Table 4.70**.
Natural England	Comments on draft ES, February 2021 and 10 May 2021 Marine Mammals EP Technical Panel Meeting Nine	Seismic surveys should cover a disturbance range of 12 km based on the JNCC underwater noise guidance. In addition, this should not be a point source disturbance, but should be based on an average number of kilometres surveyed per day.	Seismic surveys assessed as per **Figure 4.9**.
Natural England & TWT	Comments on draft ES, January and February 2021 and 10 May 2021 Marine Mammals EP Technical Panel Meeting Nine	Recommendations: Assess bottlenose dolphins as part of the Coastal East Scotland MU. The Marine Mammal Technical Report should also refer to the bottlenose dolphin SAC in the Moray Firth, as per other sections which detail protected areas.	Full details of the bottlenose dolphin MU are presented in **Volume A5, Annex 4.1: Marine Mammal Technical Report.**

4.5 Study area

4.5.1.1 The Hornsea Four marine mammal study area varies depending on the species, considering individual species ecology and behaviour. The marine mammal study area has been defined at two spatial scales (see **Volume A5, Annex 4.1: Marine Mammal Technical Report** for details):

- Regional Scale Study Area: provides a wider geographic context in terms of the species present and their estimated densities and abundance. The regional study area for harbour porpoise is the North Sea Management Unit (MU), for minke whales and white-beaked dolphins is the Celtic and Greater North Sea MU, for harbour seals is the Southeast England Seal Management Area (SMA) and for grey

- seals is the combined Southeast and Northeast England SMAs. Note: there is no defined MU for bottlenose dolphins in this area. This scale defines the appropriate reference population for the assessment;
- Hornsea Four Study Area: includes the Hornsea Four site-specific area survey area and the former Hornsea Zone survey area to provide an indication of the local densities of each species across impact footprints.

4.5.1.2 The marine mammal study areas, reference populations and baseline densities have been agreed with all consultees (EP Technical Panel Meeting Five, 26 June 2019, OFF-MM-1.2 & OFF-MM-1.3).

4.6 Methodology to inform baseline

4.6.1 Desktop Study

4.6.1.1 A desk study was undertaken to obtain information on marine mammals. Data were acquired within the Hornsea Four marine mammal study area through a detailed desktop review of existing studies and datasets. Agreement was reached with all consultees that the data collected and the sources used to define the baseline characterisation for marine mammals in the vicinity of Hornsea Four are fit for the purpose of the Hornsea Four impact assessment (EP Technical Panel Meeting Five, 26 June 2019, OFF-MM-1.2 & OFF-MM-1.3).

4.6.1.2 The following sources of information in **Table 4.4** were consulted. Details of the methodologies, limitations and assumptions of each dataset are detailed in **Volume A5, Annex 4.1: Marine Mammal Technical Report**.

Table 4.4: Key Sources of Marine Mammal Data.

Source	Summary	Coverage of Hornsea Four marine mammal study area
SCANS III	Hornsea Four is located in SCANS III survey block O which was surveyed by visual aerial survey in July 2017 (Hammond et al. 2017).	Broadscale cetacean data with a uniform density estimate for the block containing the Hornsea Four array area and offshore ECC.
SMRU August haul-out counts	August haul-out surveys of harbour and grey seals (data provided by SMRU).	Broadscale data with coverage of the coastline near the offshore ECC landfall.
SMRU grey seal pup counts	Surveys of the main UK grey seal breeding colonies annually between mid-September and late-November to estimate the numbers of pups born at the main breeding colonies (data provided by SMRU).	Broadscale data with coverage of the coastline near the Hornsea Four offshore ECC landfall.
SMRU seal telemetry data	Eighty-six harbour seals tagged in the Southeast England SMA between 2003 and 2016 at the Wash and the Thames. Seventy grey seals tagged in the Southeast and Northeast England SMAs between 1988 and 2015 at Donna Nook, Blakeney and the Farnes.	Broadscale data with telemetry tracks within the Hornsea Four array area and offshore ECC.

Source	Summary	Coverage of Hornsea Four marine mammal study area
Seal habitat preference maps	Telemetry data from 114 grey seals and 239 harbour seals tagged in the UK were combined with haul-out count data and modelled with environmental covariates to provide estimates of the percentage of the British Isles at-sea population per 25 km^2 grid cell (Carter et al. 2020).	Broadscale data with estimated densities within the Hornsea Four array area and offshore ECC.
Joint Nature Conservation Committee (JNCC) Report 544	Analysis of 18 years of survey data on harbour porpoise between 1994 and 2011 held in the JCP database to identify "discrete and persistent areas of high density" that might be considered important for harbour porpoise (Heinänen and Skov 2015).	Broadscale data with estimated densities within the Hornsea Four array area and offshore ECC.
JCP	Thirty-eight data sources between 1994-2010 (Paxton et al. 2016). JCP Phase III Data Analysis Product used to extract abundance estimates averaged for summer 2007-2010 and scaled to the SCANS III estimates for user specified areas.	Broadscale data with estimated densities within the Hornsea Four array area and offshore ECC.
EU seal studies	Telemetry data from various studies on grey (Brasseur et al. 2015, Brasseur and Kirkwood 2015, Vincent et al. 2017, Aarts et al. 2018) and harbour seals (Brasseur et al. 2012, Brasseur and Kirkwood 2015, Vincent et al. 2017) tagged in the Netherlands, France and the Wadden Sea to assess connectivity with European sites.	Broadscale data to assess connectivity between Hornsea Four and European sites.
Sea Watch Foundation	Effort based sightings data for bottlenose dolphins along the Yorkshire coast.	Broadscale data along the Yorkshire coastline.

4.6.2 Site Specific Surveys

4.6.2.1 To inform the EIA, site-specific surveys were undertaken, as agreed with the statutory consultees. A summary of surveys is outlined in **Table 4.5**.

Table 4.5: Summary of site-specific survey data.

Title, year and reference	Summary	Coverage of Hornsea Four development area
Hornsea Four aerial surveys, 2016-2018	HiDef Digital Aerial Surveying Ltd. conducted monthly surveys between April 2016 and March 2018.	Full coverage of the Hornsea Four AfL area plus 4 km buffer.
Former Hornsea Zone surveys 2010-2013	Monthly boat-based visual and towed acoustic surveys conducted between March 2010 and February 2013.	Coverage of the former Hornsea Zone (which included the Hornsea Four array area) plus 10 km buffer.

4.6.2.2 The sea state recorded during all Hornsea Four site-specific aerial surveys was between one and six. Across all seasons, very little survey effort was recorded during sea state one (0.2%), sea state five (4.2%) or sea state six (0.1%). In the summer months (Jun, Jul, Aug) the sea state was predominantly two or three (66%) with the remaining time at sea state four; while in winter (Dec, Jan, Feb) the predominant sea state was four (75%) with only 22% at sea state two and three. HiDef report that the detection probability of marine mammals does not vary within this level of variation in sea state; however, robust analyses have not been carried out to demonstrate this. This is discussed further in **Volume A5, Annex 4.1: Marine Mammal Technical Report.** Agreement was reached with all consultees that the data collected and the sources used to define the baseline characterisation for marine mammals in the vicinity of Hornsea Four are fit for the purpose of the Hornsea Four impact assessment (OFF-MM-1.2 & OFF-MM-1.3).

4.7 Baseline environment

4.7.1 Existing baseline

4.7.1.1 The baseline characterisation information is detailed in **Volume A5, Annex 4.1: Marine Mammal Technical Report**. The following species of marine mammals were as identified most likely to be present at Hornsea Four and were the focus of the baseline characterisation and the impact assessment: Harbour porpoise, minke whale, white-beaked dolphin, bottlenose dolphin, harbour seal and grey seal. The species selected for assessment and the relevant reference population size and density values taken forward for assessment were agreed with all stakeholders (EP Technical Panel Meeting Five, 26 June 2019 (pre-PEIR) and confirmed at EP Technical Panel Meeting Eight, 04 June 2020 (post-PEIR), OFF-MM-1.2 & OFF-MM-1.3). Note: these were then updated to use the new MU information presented in IAMMWG (2021) and the new seal habitat preference maps (Carter et al. 2020).

4.7.1.2 The Hornsea Four site-specific surveys suggested that the area is important for harbour porpoise. This is reflected by a number of other data sets describing harbour porpoise abundance and distribution of harbour porpoise in the North Sea, and the Hornsea Four array area is located within the Southern North Sea SAC designated for harbour porpoise. Harbour porpoise sightings rates are known to vary greatly at fine scale temporal and spatial levels. This is clearly evident in the large difference in sightings rates between consecutive months obtained by the Hornsea Four aerial surveys (see Table 3 in **Volume A5, Annex 4.1: Marine Mammal Technical Report**). There have been several studies that have produced density estimates for harbour porpoise in the vicinity of Hornsea Four, using a variety of survey methods and resulting in a wide range of density estimates from 0.888 (SCANS III survey block O) to 3.80 porpoise/km^2 (Hornsea Four aerial survey summer average). As detailed in **Volume A5, Annex 4.1: Marine Mammal Technical Report**, the use of the JCP Phase III dataset (consisting of aggregated, standardised data from multiple sources) (Paxton et al. 2016) was discussed with the EP Technical Panel (04 June 2020) and was agreed the JCP dataset:

- has a relatively poor spatial and temporal coverage;
- results being indicative rather than an accurate representation of species distribution;
- advice against inferring abundance at a fine scale;
- data are summer only estimates (and therefore inappropriate to use in the quantitative impact assessment as it is not representative of other times of the year); and

- that the site-specific density sources were sufficient to take forward to quantitative impact assessment (OFF-MM-1.4).

4.7.1.3 The densities used in the impact assessment are based on the best available data, with consideration given to the most up to date information together with the necessary precaution applied where there is uncertainty (i.e. where density estimates vary considerably between data sources, a range of estimates are presented in the impact assessment, with the focus being on more recently collected data sets) (**Table 4.6**). The site-specific surveys do not extend far enough to cover the entire potential behavioural impact zones for the noise impact assessment, and as such, broader scale density estimates from SCANS III were incorporated into the assessment. This approach was agreed with all stakeholders (EP Technical Panel Meeting Five, 26 June 2019 (pre-PEIR) and confirmed at EP Technical Panel Meeting Eight, 4 June 2020 (post-PEIR), OFF-MM-1.2).

4.7.1.4 The baseline description provides an accurate reflection of the current state of the existing environment (OFF-MM-1.2 & OFF-MM-1.3). The earliest possible date for the start of construction is August 2026, with an expected operational life of 35 years and therefore there exists the potential for the baseline to evolve between the time of assessment and point of impact. Outside of short-term or seasonal fluctuations, changes to the baseline in relation to marine mammal ecology usually occur over an extended period of time (considered below). Based on current information regarding reasonably foreseeable events over the next six years, the baseline is not anticipated to have fundamentally changed from its current state at the point in time when impacts occur. The baseline environment for operational/decommissioning impacts is expected to evolve as described in the next section, with the additional consideration that any changes during the construction phase will have altered the baseline environment to a degree as set out in this chapter.

Table 4.6: Marine mammal reference populations and densities taken forward for impact assessment for Hornsea Four.

Species	Density Estimate	Density Source	Reference population	Reference Population size
Harbour porpoise	Grid cell specific density (average across array area is 1.6 porpoise/km^2)	Modelled surface density estimates from the boat-based acoustic surveys of former Hornsea Zone plus a 10 km buffer	North Sea MU	345,373
	1.74 porpoise/km^2	Hornsea Four aerial surveys – average across 24 months		
	0.888 porpoise/km^2	SCANS-III Block O		
Minke whale	Grid cell specific density (average across array area is 0.009 whales/km^2)	Modelled surface density estimates from the boat-based visual surveys of former Hornsea Zone plus a 10 km buffer	Celtic and Greater North Sea MU	20,118
	0.010 whales/km^2	SCANS-III Block O		

Species	Density Estimate	Density Source	Reference population	Reference Population size
White-beaked dolphin	Grid cell specific density (average across array area is 0.02 dolphins/km^2)	Modelled surface density estimates from the boat-based visual surveys of former Hornsea Zone plus a 10 km buffer	Celtic and Greater North Sea MU	43,951
	0.002 dolphins/km^2	SCANS-III Block O		
Bottlenose dolphin	0.003 dolphins/km^2	Assuming a uniform density within the Greater North Sea MU	Greater North Sea & Coastal East Scotland MUs	2,211
Harbour seal	Grid cell specific density	Seal habitat preference map	Southeast England MU	5,211
Grey seal	Grid cell specific density	Seal habitat preference map	Southeast & Northeast England MUs	63,464

4.7.2 Evolution of the Baseline

4.7.2.1 The Infrastructure Planning (Environmental Impact Assessment) Regulations 2017 require that "an outline of the likely evolution thereof without implementation of the development as far as natural changes from the baseline scenario can be assessed with reasonable effort on the basis of the availability of environmental information and scientific knowledge" is included within the ES (EIA Regulations, Schedule 4, Paragraph 3). From the point of assessment, over the course of the development and operational lifetime of Hornsea Four (operational lifetime anticipated to be 35 years), long-term trends mean that the condition of the baseline environment is expected to evolve. This section provides a qualitative description of the evolution of the baseline environment, on the assumption that Hornsea Four is not constructed, using available information and scientific knowledge of marine mammal ecology.

4.7.2.2 It is challenging to predict the future trajectories of marine mammal populations. Some UK marine mammal populations have undergone periods of significant change in parts of their range, with a limited understanding of the driving factors responsible. For example, there is uncertainty about whether a reduction in pup mortality or an increase in fecundity that is the cause of the recent exponential growth of grey seals in the North Sea (Russell 2017). Additionally, there is no appropriate monitoring at the right temporal or spatial scales to really understand the baseline dynamics of some marine mammal populations, including all cetacean species included in this assessment.

4.7.2.3 The results of the most recent UK assessment of favourable conservation status for each marine mammal species included in the assessment are outlined in Table 4.7. Grey seals are considered to have a FCS, and all other species apart from harbour seals are considered to have an Unknown conservation status. For harbour seals both the short- and long-term trends in population size were categorised as decreasing and the assessment resulted in a conclusion of the species having Unfavourable - Inadequate future prospects. However, it is important to note that this assessment for harbour seals was conducted at a UK wide level, and that the population estimates for harbour seals in both the Southeast and Northeast England SMAs are increasing.

Table 4.7: Favourable conservation status for each marine mammal species.

Species	Conservation Status	Reference
Harbour porpoise	Unknown	JNCC (2019b)
Minke whale	Unknown	JNCC (2019f)
White-beaked dolphin	Unknown	JNCC (2019e)
Bottlenose dolphin	Unknown	JNCC (2019a)
Harbour seal	Unfavourable - Inadequate	JNCC (2019d)
Grey seal	Favourable	JNCC (2019c)

4.7.2.4 The potential impacts of climate change on marine mammals was reviewed and synthesised by Evans and Bjørge (2013) and they concluded that this topic remains poorly understood. In the UK, changes are predicted to manifest in relation to changes in prey abundance and distribution as a result of warmer sea temperatures. The authors also conclude that species likely to be most affected in the future will be those that have relatively narrow habitat requirements and that shelf sea species like the harbour porpoise, white-beaked dolphin and minke whale may come under increased pressure with reduced available habitat, if they experience range shifts northwards. Although the main cause of widespread declines in UK harbour seal population is not known, the prevalence of domoic acid derived from toxic algae may be a contributory factor, and could be exacerbated by increased sea temperatures (Evans and Bjørge 2013). In addition, sea level rise and an increase in storm frequency and associated wave surges could affect the availability of haul out sites for seals and increased storm frequency and associated conditions could also lead to increased pup and calf mortality (Prime 1985, Gazo et al. 2000, Lea et al. 2009).

4.7.3 Data Limitations

4.7.3.1 The key data limitations with the baseline data and their ability to materially influence the outcome of the EIA are the high spatial and temporal variation in marine mammal abundance and distribution in any particular area of the sea. **Volume A5, Annex 4.1: Marine Mammal Technical Report** details the data sources used in the assessment and their associated assumptions and limitations.

4.8 Project basis for assessment

4.8.1 Impact register and impacts "scoped out"

4.8.1.1 Upon consideration of the baseline environment, the project description outlined in **Volume A1, Chapter 4: Project Description,** the Hornsea Four commitments in **Volume A4, Annex 5.2: Commitments Register** and in response to formal consultation on the PEIR, several impacts have been "not considered in detail" in the ES for marine mammals (agreed with the EP Technical Panel, OFF-MM-2.8). These impacts are outlined, together with appropriate justification for this approach, in **Table 4.8**. Further detail is provided in **Volume A4, Annex 5.1: Impacts Register**.

Table 4.8: Impacts scoped out of the assessment and justification.

Project activity and impact	Likely significance of effect	Approach to assessment	Justification
Construction phase: Toxic contamination (MM-C-8).	No likely significant effect	Scoped Out	Impact not identified at EIA Scoping. Scoped out based on PINS Scoping Opinion (PINS Scoping Opinion, November 2018, ID: 4.5.5). A commitment has been made to a Marine Pollution Contingency Plan (MPCP) which will include measures to be adopted for the prevention of pollution events and outline an emergency plan to be implemented in the unlikely event of any pollution events (see Co111 of **Volume A4, Annex 5.2 Commitments Register**).
Construction phase: Non-piling noise (e.g. cable laying, dredging) (MM-C-9).	No likely significant effect identified at PEIR	Not considered in detail in the ES	Simple assessment at PEIR with conclusion of no likely significant effect (LSE) and confirmed no change to either magnitude or sensitivity of the species. The underwater noise impacts from non-piling noise will be significantly less than that of impact piling and will be very local and short term. Any potential displacement will be temporary and therefore unlikely to significantly affect marine mammal vital rates.
Construction phase: Disturbance to seal haul-outs at landfall (MM-C-10).	No likely significant effect	Scoped Out	Impact not identified at EIA Scoping. Scoped out based on PINS Scoping Opinion (PINS Scoping Opinion, November 2018, ID:4.5.7). There are no grey or harbour seal haul-outs sites in the vicinity of the land-fall site based on the SMRU August haul-out count surveys, and there is no evidence from the at-sea and total usage maps or the available telemetry data that harbour seals use the landfall area in any significant numbers (see **Volume A5, Annex 4.1: Marine Mammal Technical Report**).
Operation phase: Operational noise (MM-O-14).	No likely significant effect identified at PEIR	Not considered in detail in the ES	Simple assessment at PEIR with conclusion of no LSE and confirmed no change to either magnitude or sensitivity of the species. Using the non-impulsive weighted SEL_{cum} PTS and TTS thresholds from Southall et al. (2019) resulted in estimated PTS and TTS impact ranges of <100 m for all marine mammal species. Given the evidence of their presence in and around existing operational offshore wind farms, marine mammals are deemed to be of low vulnerability and have high recoverability to the impact of operational noise. The EP Technical Panel agreed that there is no need for the operational noise assessment to consider anything other than noise related to vessel traffic (OFF-MM-2.2).

Project activity and impact	Likely significance of effect	Approach to assessment	Justification
Operation phase: Disturbance from vessels (MM-O-15).	No likely significant effect identified at PEIR	Not considered in detail in the ES	Simple assessment at PEIR with conclusion of no LSE and confirmed no change to either magnitude or sensitivity of the species. It is not expected that the level of vessel activity during the O&M of Hornsea Four would cause a significant increase in the risk of disturbance by vessels. The adoption of a Vessel Management Plan (VMP) (Co108 of **Volume 4, Annex 5.2 Commitments Register**) that includes preferred transit routes and guidance for vessel operations in the vicinity of marine mammals and around seal haul-outs will minimise the potential for any impact.
Operation phase: Toxic contamination (MM-O-18).	No likely significant effect	Scoped Out	Impact not identified at EIA Scoping. Scoped out based on PINS Scoping Opinion (PINS Scoping Opinion, November 2018, ID: 4.5.5). A commitment has been made to a MPCP which will include measures to be adopted for the prevention of pollution events and outline an emergency plan to be implemented in the unlikely event of any pollution events (see Co111 of **Volume A4, Annex 5.2 Commitments Register**).
Operation phase: EMF (MM-O-19).	No likely significant effect	Scoped Out	Impact not identified at EIA Scoping. Scoped out based on PINS Scoping Opinion (PINS Scoping Opinion, November 2018, ID: 4.5.6). Based on the data available to date, there is no evidence of EMF related to marine renewable devices having any impact (either positive or negative) on marine mammals (Copping 2018).
Decommissioning phase: PTS from underwater noise (MM-O-20).	No likely significant effect identified at PEIR	Not considered in detail in the ES	Simple assessment at PEIR with conclusion of no LSE and confirmed no change to either magnitude or sensitivity of the species. The approach and methodologies employed at decommissioning will be compliant with the legislation and policy requirements at the time of decommissioning. It is assumed that the MDS is to be as per construction (with no pile driving), thus the impact is assumed to be similar to the construction phase (or less). A commitment has been made to a Decommissioning MMMP which will include measures to ensure the risk of permanent threshold shift (PTS) to marine mammals is negligible and will be in line with the latest relevant available guidance (see Co113 of **Volume A4, Annex 5.2 Commitments Register**).
Decommissioning phase: Disturbance from underwater noise (MM-D-21).	No likely significant effect identified at PEIR	Not considered in detail in the ES	
Decommissioning phase: TTS from underwater noise (MM-D-22).	No likely significant effect identified at PEIR	Not considered in detail in the ES	Simple assessment at PEIR with conclusion of no LSE and confirmed no change to either magnitude or sensitivity of the species.

Project activity and impact	Likely significance of effect	Approach to assessment	Justification
			The approach and methodologies employed at decommissioning will be compliant with the legislation and policy requirements at the time of decommissioning (see Co113 of **Volume A4, Annex 5.2 Commitments Register**). Impact assumed to be similar to the construction phase (or less). No assessment of the significance of TTS is provided.
Decommissioning phase: Vessel collision risk (MM-D-23).	No likely significant effect identified at PEIR	Not considered in detail in the ES	Simple assessment at PEIR with conclusion of no LSE and confirmed no change to either magnitude or sensitivity of the species. The level of vessel activity during the decommissioning phase are predicted to be the same as for the construction period. Therefore, the impact is assumed to be similar to construction phase (or less). The adoption of a VMP (Commitment Co108 of **Volume A4, Annex 5.2 Commitments Register**) will minimise the potential for any impact.
Decommissioning phase: Disturbance from vessels (MM-D-24).	No likely significant effect identified at PEIR	Not considered in detail in the ES	Simple assessment at PEIR with conclusion of no LSE and confirmed no change to either magnitude or sensitivity of the species. The level of vessel activity during the decommissioning phase are predicted to be the same as for the construction period. Therefore, the impact is assumed to be similar to construction phase (or less). The adoption of a VMP (Commitment Co108 of **Volume A4, Annex 5.2 Commitments Register**) will minimise the potential for any impact.
Decommissioning phase: Toxic contamination (MM-D-27).	No likely significant effect	Scoped Out	Impact not identified at EIA Scoping. Scoped out based on PINS Scoping Opinion (PINS Scoping Opinion, November 2018, ID: 4.5.5). A commitment has been made to a MPCP which will include measures to be adopted for the prevention of pollution events and outline an emergency plan to be implemented in the unlikely event of any pollution events (see Co111 of **Volume A4, Annex 5.2 Commitments Register**).

Notes:
Grey – Scoped out - Agreement reached between Hornsea Four and the Planning Inspectorate at Scoping.
Purple - Impact not Considered in detail in the ES. No likely significant effect at PEIR.

4.8.2 Commitments

4.8.2.1 Hornsea Four has made several Commitments (primary design principles inherent as part of Hornsea Four, installation techniques and engineering designs/modifications as part of their pre-application phase, to eliminate and/or reduce the LSE arising from a number of impacts. These are outlined in **Volume A4, Annex 5.2: Commitments Register**. Further commitments (adoption of best practice guidance), referred to as tertiary commitments are embedded as an inherent aspect of the EIA process. Secondary commitments are incorporated to reduce LSE to environmentally acceptable levels following initial assessment i.e. so that residual effects are reduced to environmentally acceptable levels.

4.8.2.2 The commitments adopted by Hornsea Four in relation to marine mammals are presented in **Table 4.9**. Full details of commitments are included within the **Volume A4, Annex 5.2: Commitments Register**.

Table 4.9: Relevant marine mammal commitments.

Commitment ID	Measure Proposed	How the measure will be secured
Co85	Primary: No more than a maximum of two foundations are to be installed simultaneously.	DCO Schedule 11, Part 2 - Condition 13(1)(g) and; DCO Schedule 12, Part 2 - Condition 13(1)(g) (Marine mammal mitigation protocol); and DCO Schedule 11, Part 2 - Condition 13(1)(c) and; DCO Schedule 12, Part 2 - Condition 13(1)(c) (Construction Method Statement)
Co108	Tertiary: A Vessel Management Plan (VMP) will be developed pre-construction which will determine vessel routing to and from construction areas and ports to minimise, as far as reasonably practicable, encounters with marine mammals.	DCO Schedule 11, Part 2 - Condition 13(1)(d)(v) and; DCO Schedule 12, Part 2 - Condition 13(1)(d)(v) (Vessel management plan)
Co110	Tertiary: A piling Marine Mammal Mitigation Protocol (MMMP), will be developed in accordance with the Outline MMMP and will be implemented during construction. The piling MMMP will include measures to ensure the risk of instantaneous permanent threshold shift (PTS) to marine mammals is negligible and will be in line with the latest relevant available guidance. The piling MMMP will include details of soft starts to be used during piling operations with lower hammer energies used at the beginning of the piling sequence before increasing energies to the higher levels.	DCO Schedule 11, Part 2 - Condition 13(1)(g) and; DCO Schedule 12, Part 2 - Condition 13(1)(g) (Marine mammal mitigation protocol)
Co111	Tertiary: A Construction Project Environmental Management and Monitoring Plan (CPEMMP) will be developed and will include details of: - a marine pollution contingency plan to address the risks, methods and procedures to deal with any spills and collision incidents of the authorised project in relation to all activities carried out below MHWS;	DCO Schedule 11, Part 2 - Condition 13(1)(d) and; DCO Schedule 12, Part 2 - Condition 13(1)(d) (Construction Project Environmental Management and Monitoring Plan)

Commitment ID	Measure Proposed	How the measure will be secured
	- a chemical risk review to include information regarding how and when chemicals are to be used, stored and transported in accordance with recognised best practice guidance; - a marine biosecurity plan detailing how the risk of introduction and spread of invasive non-native species will be minimised; - waste management and disposal arrangements; - a vessel management plan, to determine vessel routing to and from construction sites and ports, to include a code of conduct for vessel operators; and - the appointment and responsibilities of a company fisheries liaison officer.	
Co113	Tertiary: A Decommissioning Marine Mammal Mitigation Protocol (MMMP), will be implemented during decommissioning. The Decommissioning MMMP will be approved by the Marine Management Organisation (MMO) in consultation with Natural England. The Decommissioning MMMP will include measures to ensure the risk of instantaneous permanent threshold shift (PTS) to marine mammals is negligible and will be in line with the latest relevant available guidance.	A separate Marine Licence will be applied for at the point of decommissioning which will include conditions relevant to minimising impacts on marine mammals where appropriate.
Co181	Tertiary: An Offshore Decommissioning Plan will be developed prior to decommissioning.	DCO Schedule 11, Part 1(6) and; DCO Schedule 12, Part 1(6) (General Provisions)
Co201	Primary: Gravity Base Structure (GBS) foundations (WTG type) will be utilised at a maximum of 110 of the 180 WTG foundation locations. The location of GBS foundations, if used for WTG, will be confirmed through a construction method statement which will include details of foundation installation methodology.	DCO Schedule 11, Part 2 - Condition 13(1(c) (Construction Method Statement)

4.9 Maximum Design Scenario (MDS)

4.9.1.1 This section describes the MDS parameters on which the marine mammals assessment has been based. These are the parameters which are judged to give rise to the maximum levels of effect for the assessment undertaken, as set out in **Volume A1, Chapter 4: Project Description**. Should Hornsea Four be constructed to different parameters within the design envelope, then impacts would not be any greater than those set out in this ES using the MDS presented in **Table 4.10**.

Table 4.10: Maximum design scenario for impacts on marine mammals.

Impact and Phase	Embedded Mitigation Measures	Maximum Design Scenario	Justification
Construction			
PTS (auditory injury) from piling noise (MM-C-1).	Primary: Co85 Tertiary: Co110	**Spatial MDS:**[1] • 180 Wind Turbine Generators (WTGs) on monopile foundations; • Six small and three large Offshore Substations (OSS) on monopile foundations; • One accommodation platform on a monopile foundation; • Three High Voltage Alternating Current (HVAC) Booster Stations (small OSS) on monopile foundations; • Maximum design: 5,000 kJ hammer energy, 4.4 hours piling duration including a 30 min soft start and 22.5 min ramp up; • Most likely: 4,000 kJ hammer energy, 2.1 hours piling duration including a 30 min soft start and 22.5 min ramp up; • Total WTG piling days: 216 assuming 1.2 days per monopile over a 12 month piling period; • Total non-WTG piling days: 16 assuming 1.2 days per monopile over a 12 month piling period; and • Simultaneous piling: only two piles will be piled simultaneously within the Hornsea Four array area. **Temporal MDS:**[2] • 180 WTGs on piled jacket (WTG-type) foundations, three piles per jacket (540 total); • Six small OSS on piled jacket (small OSS) foundations and three large OSS on piled jacket (large OSS) foundations (144 total piles); • One accommodation platform on a piled jacket (small OSS) foundation (16 total piles); • Three HVAC Booster Stations on piled jacket (small OSS) foundations (48 total piles);	The piling scenario with the largest PTS impact ranges represent the maximum design scenario. This differs between species depending on the frequency characteristics emitted during installation of each pile type and the hearing of the species (e.g. for high frequency cetaceans such as harbour porpoise, pin piles have a larger PTS impact range whereas for low frequency cetaceans, monopiles have a larger PTS impact range). The maximum number of piled foundations would represent the temporal maximum design scenario for disturbance. The maximum predicted impact range for underwater noise for piled foundations would represent the spatial maximum design scenario for disturbance. It is important to note that three HVDC converter substations in the array area are mutually exclusive with three HVAC

[1] The spatial MDS is based on all WTGs installed on monopile foundations, as that scenario would result in the maximum spatial effect in terms of underwater noise
[2] The temporal MDS is based on all WTGs installed on piled jacket foundations, as that scenario would result in the longest temporal affect in terms of underwater noise

Impact and Phase	Embedded Mitigation Measures	Maximum Design Scenario	Justification
		• Maximum design: 3,000 kJ hammer energy, 4.4 hours piling duration including a 30 min soft start and 22.5 min ramp up; • Most likely: 1,750 kJ hammer energy, 2.1 hours piling duration including a 30 min soft start and 22.5 min ramp up; • Total WTG piling days: 270 assuming 1.5 days per jacket foundation over a 12 month piling period; • Total non-WTG piling days: 39 assuming 3 days per jacket foundation over a 12 month piling period; and • Simultaneous piling: only two piles will be piled simultaneously within the Hornsea Four array area.	booster stations along the ECC in a single transmission system. As secured by **C1.1 Draft DCO including Draft DML**, a maximum of ten OSS and platforms will be constructed within the Hornsea Four Order Limits, however in order to assess the MDS for both the array and the ECC, the presence of the maximum numbers of OSS and platforms in each area has been considered (ten and three, respectively). As a result, the outcome of the assessment is therefore inherently precautionary.
Disturbance from piling noise (MM-C-2).	Primary: Co85 Tertiary: Co110	The MDS for piling noise is presented in MM-C-1.	
TTS from piling noise (MM-C-3).	Primary: Co85 Tertiary: Co110	The MDS for piling noise is presented in MM-C-1.	
Vessel collision risk (MM-C-4)	Tertiary Co108	**Wind Turbine Foundation Installation:** • Up to 2,880 return trips over a 12-month period. **Wind Turbine Installation:** • Up to 900 return trips over a 24-month period. **OSS Installation (all OSSs and the accommodation platform):** • Up to 270 return trips over a two-month period. **OSS Foundation Installation (all OSSs and the accommodation platform):** • Up to 180 return trips over a two-month period.	The maximum numbers of vessels and associated vessel movements represents the maximum potential for collision risk and disturbance.

Impact and Phase	Embedded Mitigation Measures	Maximum Design Scenario	Justification
		Inter-Array and Interconnector Cable Installation: • Up to 1,488 return trips over a 24-month period. **Offshore Export Cable Installation:** • Up to 408 return trips over a 24-month period. **Total:** • Up to eight vessels in any given 5 km^2 at any one time.	
Disturbance from vessels (MM-C-5).	Tertiary: Co108	The MDS for maximum number of vessels is presented in MM-C-4.	
Reduction in prey availability (MM-C-6).	None	Maximum effect on fish prey species as detailed in the assessment in **Chapter 3: Fish and Shellfish Ecology.**	
Reduction in foraging ability (MM-C-7).	Primary: Co201	**Total volume 12,192,331 m^3** **WTG Foundations:** • 110 turbines on Gravity Base Structure (GBS) (WTG type) foundations requiring seabed preparation, resulting in the suspension of 685,794 m^3 of sediment; and • 70 Suction Caisson Jacket (WTG type) foundations requiring seabed preparation, resulting in the suspension of 359,427 m^3 of sediment. **OSS Foundations (array):** • Six OSS on suction caisson jacket (small OSS) foundations and three OSS on GBS (large OSS) foundations requiring seabed preparation, resulting in the suspension of 737,130 m^3 of sediment. **Offshore Accommodation Platform Foundations:** • One suction caisson jacket (small OSS) foundation requiring seabed preparation, resulting in the suspension of 57,245 m^3 of sediment. **High Voltage Alternating Current (HVAC) Booster Station Foundations:** • Three suction caisson jacket (small OSS) foundations requiring seabed preparation, resulting in the suspension of 171,735 m^3 of sediment. **Sandwave Clearance:**	The MDS for foundation installation results from the largest volume suspended from seabed preparation (GBS and suction caisson jacket foundations). For cable installation, the MDS results from the greatest volume from sandwave clearance and installation using energetic means (CFE). This also assumes the largest number of cables and the greatest burial depth. It is important to note that three HVDC converter substations in the array area are mutually exclusive with three HVAC booster stations along the ECC in a single transmission system. As secured by **C1.1 Draft DCO including Draft DML**, a maximum of ten OSS and platforms will be constructed within the Hornsea Four Order

Impact and Phase	Embedded Mitigation Measures	Maximum Design Scenario	Justification
		• Sandwave clearance for 600 km of array cables resulting in the suspension of 769,000 m^3 of sediment; • Sandwave clearance for 90 km of interconnector cables resulting in the suspension of 115,000 m^3 of sediment; and • Sandwave clearance for 654 km of export cables resulting in the suspension of 834,000 m^3 of sediment. **Cable Trenching:** • Installation of 600 km of array cables by Controlled Flow Excavation (CFE) resulting in the suspension of 3,600,000 m^3 of sediment; • Installation of 90 km of interconnector cables resulting in the suspension of 540,000 m^3 of sediment; • Installation of six export cables by CFE resulting in the suspension of 3,903,000 m^3 of sediment (excluding the part of the export cable within the array); and • Up to 420,000 m^3 of sediment from up to four cable joints per export cable in the ECC.	Limits, however in order to assess the MDS for both the array and the ECC, the presence of the maximum numbers of OSS and platforms in each area has been considered (ten and three, respectively). As a result, the outcome of the assessment is therefore inherently precautionary.
PTS from UXO clearance (MM-C-11).	None	**UXO Clearance:** • Estimated 2,263 targets; • 86 UXOs may require clearance; • up to 5 UXO could be detonated per day.	Estimated maximum design based on data from other projects in the Hornsea Zone. A detailed UXO survey would be completed prior to construction. The type, size (net explosive quantities (NEQ)) and number of possible detonations and duration of UXO clearance operations is therefore not known at this stage.
Disturbance from UXO clearance (MM-C-12).	None	The MDS for maximum UXO disturbance is presented in MM-C-11.	
TTS from UXO Clearance (MM-C-13).	None	The MDS for maximum UXO disturbance is presented in MM-C-11.	
Operation			

Impact and Phase	Embedded Mitigation Measures	Maximum Design Scenario	Justification
Vessel collision risk (MM-O-28)	Tertiary Co108	• Up to 1,205 crew vessel return trips per year • Up to 124 jack-up vessel return trips per year • Up to 104 supply vessel return trips per year **Total Trips:** • Up to 1,433 return trips per year	The maximum numbers of vessels and associated vessel movements represents the maximum potential for collision risk.
Reduction in prey availability (MM-O-16).	None	Maximum effect on fish prey species as detailed in the assessment in **Chapter 3: Fish and Shellfish Ecology**.	
Reduction in foraging ability (MM-O-17).	None	**Array Cable Activities:** • Remedial burial of array cable (42 km total length reburied) by CFE – 252,000 m^3; and • Array cable repairs = 218,258 m^3. **Interconnector Cable Activities:** • Remedial burial of interconnector cables (7 km total length reburied) by CFE = 42,000 m^3; and • Interconnector cable repairs = 11,153 m^3. **Export Cable Activities:** • Remedial burial of export cables (14 km total length reburied) by CFE = 84,000 m^3; and • Export cable repairs = 85,505 m^3. **Total volume: 692,916 m^3**	The maximum impacts from remedial cable burial and cable repairs of array, interconnector and export cables result from the use of CFE. This assumes the largest number of cables, repair events, the greatest burial depth and greatest length/area of maintenance. This results in the maximum sediment volume disturbance.
Decommissioning			
Reduction in prey availability (MM-D-25).	Tertiary: Co181	Maximum effect on fish prey species as detailed in the assessment in **Chapter 3: Fish and Shellfish Ecology**.	
Reduction in foraging ability (MM-D-26).	Tertiary: Co181	MDS is identical (or less) to that of the construction phase (MM-C-7). **Total volume = 12,192,331 m^3**	MDS is assumed to be as per the construction phase, with all infrastructure removed in reverse-construction order. The removal of cables is considered the MDS, however the necessity to remove

Impact and Phase	Embedded Mitigation Measures	Maximum Design Scenario	Justification
			cables will be reviewed at the time of decommissioning.

4.10 Assessment methodology

4.10.1.1 The assessment methodology for marine mammals is consistent with that presented in in **Volume A1, Chapter 5: Environmental Impact Assessment Methodology**. Members of the EP Technical Panel were provided with an outline of the Noise Modelling Methodology and Approach document (February 2019) and all subsequent consultee comments were incorporated into the assessment methodology as appropriate.

4.10.2 Impact assessment criteria

4.10.2.1 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 impacts. This section describes the criteria applied in this chapter to assign values to the sensitivity of receptors and the magnitude of potential impacts. The terms used to define sensitivity and magnitude are based on those used in the DMRB methodology, which is described in further detail in **Volume A1, Chapter 5: Environmental Impact Assessment Methodology**.

4.10.2.2 The criteria for defining marine mammal sensitivity in this chapter are outlined in **Table 4.11** below.

Table 4.11: Definition of terms relating to receptor sensitivity.

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

4.10.2.3 The criteria for defining magnitude in this chapter are outlined in **Table 4.12** below.

Table 4.12: Definition of terms relating to magnitude of an impact.

Magnitude of impact	Definition used in this chapter
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). Long-term, large-scale increase in the population trajectory at a generational scale (Beneficial).
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). Benefit to the habitat influencing foraging efficiency resulting in increased reproductive potential and increased population health and size (Beneficial).
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). Short term (over a limited number of breeding cycles) benefit to the habitat influencing foraging efficiency resulting in increased reproductive potential (Beneficial).
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). Very minor benefit to the habitat influencing foraging efficiency of a limited number of individuals (Beneficial).

4.10.2.4 The significance of the effect upon marine mammals is determined by correlating the magnitude of the impact and the sensitivity of the receptor. The method employed for this assessment is presented in **Table 4.13**. Where a range of significance of effect is presented in **Table 4.13**, the final assessment for each effect is based upon expert judgement.

4.10.2.5 For the purposes of this assessment, any effects with a significance level of minor or less have been concluded to be not significant in terms of the EIA Regulations.

Table 4.13: Matrix used for the assessment of the significance of the effect.

Environmental value (sensitivity)		Magnitude of impact (degree of change)			
		Negligible	*Minor*	*Moderate*	*Major*
	Low	Neutral or Slight (Not Significant)	Neutral or Slight (Not Significant)	Slight (Not Significant)	Slight (Not Significant) or Moderate (Significant)
	Medium	Neutral or Slight (Not Significant)	Slight (Not Significant) or Moderate (Significant)	Moderate or Large (Significant)	Moderate or Large (Significant)
	High	Slight (Not Significant)	Slight (Not Significant) or Moderate (Significant)	Moderate or Large (Significant)	Large or Very Large (Significant)
	Very High	Slight (Not Significant)	Moderate or Large (Significant)	Large or Very Large (Significant)	Very Large (Significant)

4.10.2.6 Where SACs and SPAs of the national site network (formerly the Natura 2000 network) are considered, this chapter summarises the assessments made on the interest features of internationally designated sites as described within **Section 4.3.3** of this chapter (with the assessment on the site itself deferred to **B2.2 Report to Inform Appropriate Assessment, RIAA**). The RIAA Report has been prepared in accordance with PINS Advice Note Ten: Habitats Regulations Assessment Relevant to Nationally Significant Infrastructure Projects (PINS 2017) and is submitted as part of this DCO Application.

4.10.3 Approach to underwater noise assessment

<u>*Noise modelling*</u>

4.10.3.1 The noise levels likely to occur as a result of the construction of Hornsea Four 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 the **Volume A4, Annex 4.5: Subsea Noise Technical Report**. Modelling was undertaken at four representative locations, three within the Hornsea Four array area (northwest, east and south) and the accompanying HVAC booster station search area (see **Volume A4, Annex 4.5: Subsea Noise Technical Report** for details and maps).

4.10.3.2 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 MDS parameters defined during the ES assessments. For example, the noise modelling for the Hornsea Project Two ES (and updated modelling post-ES) covered hammer energies up to a maximum of 4,000 kJ, however, underwater noise monitoring at five of the first seven monopiles showed that the maximum hammer energy used was much lower than this (478 to 2,896 kJ compared to the assessed 4,000 kJ) (Verfuss 2020). In recognition of this, a most likely ramp up scenario is defined to be representative of the majority of the piling activity. The most-likely scenario based on engineering predictions is a maximum of 4,000 kJ hammer energy for monopiles and 1,750 kJ for pin piles (Table 4.14). The most likely piling source levels for each modelling location are detailed in Table 4.16.

4.10.3.3 In addition to this, the MDS is presented for each species at each of the four modelling locations. The MDS is intended 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). The MDS based on engineering predictions is 5,000 kJ hammer energy for monopiles and 3,000 kJ for pin piles (Table 4.15). The MDS piling source levels for each modelling locations are detailed in Table 4.16.

4.10.3.4 The impact assessment provides assessment for both the most-likely scenario and the MDS; while the DCO application seeks consent to cover the MDS, the most likely scenario is presented for context.

Table 4.14: Hornsea Four piling most likely scenario ramp up.

% of maximum hammer capacity	20%	40%	60%	80%	100%
Monopile blow energy (kJ)	800	1,600	2,400	3,200	4,000
Pin pile blow energy (kJ)	350	700	1,050	1,400	1,750
Number of strikes	3	75	112	113	2,250
Strike Rate (strikes/min)	1 strike every 10 min	10	15	15	30
Duration	30 mins	7.5 mins	7.5 mins	7.5 mins	75 mins

Table 4.15: Hornsea Four MDS ramp up.

% of maximum hammer capacity	20%	40%	60%	80%	100%
Monopile blow energy (kJ)	1,000	2,000	3,000	4,000	5,000
Pin pile blow energy (kJ)	600	1,200	1,800	2,400	3,000
Number of strikes	3	75	112	113	6,300
Strike Rate (strikes/min)	1 strike every 10 min	10	15	15	30
Duration	30 mins	7.5 mins	7.5 mins	7.5 mins	210 mins

Table 4.16: Hornsea Four piling noise source levels (SPL_{peak} dB re 1 µPa @ 1 m, SEL_{ss} dB re 1 µPa^{2}s @ 1 m).

Most Likely	Monopile (4,000 kJ)		Pin pile (1,750 kJ)	
	SPL_{peak}	SEL_{ss}	SPL_{peak}	SEL_{ss}
NW	244.0	218.0	240.2	214.2
E	244.0	218.0	240.2	214.2
S	243.0	217.0	239.2	213.2
HVAC	244.0	218.0	240.2	214.2

Most Likely	Monopile (4,000 kJ)		Pin pile (1,750 kJ)	
	SPL_{peak}	SEL_{ss}	SPL_{peak}	SEL_{ss}
MDS	Monopile (5,000 kJ)		Pin pile (3,000kJ)	
	SPL_{peak}	SEL_{ss}	SPL_{peak}	SEL_{ss}
NW	244.8	218.8	242.8	216.8
E	244.8	218.8	242.8	216.8
S	243.9	217.9	241.8	215.8
HVAC	244.8	218.8	242.8	216.8

Permanent and temporary Threshold Shift (PTS and TTS)

4.10.3.5 For marine mammals, the main impact from Hornsea Four 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 (SPL_{peak}), and 'cumulative' PTS (SEL_{cum}, over 24 hours) are detailed in **Volume A4, Annex 4.5: Subsea Noise Technical Report**.

4.10.3.6 It is worth noting that, although measuring the same effect (PTS or TTS), the values given by the SPL_{peak} criteria and SEL_{cum} criteria are describing separate physical processes. The SPL_{peak} measures the instantaneous level at the loudest part of installation when the maximum blow energy is being used. The SEL_{cum} measures the total sound received over the entire piling operation, including soft start and ramp up, and gives a starting range where a receptor fleeing from the noise source would have to be outside to avoid receiving the criterion level. In some cases this can result in a situation where the impact range from the single strike SPL_{peak} criterion is calculated to have greater impact ranges than the multiple strike SEL_{cum} criteria.

Approach to TTS assessment

4.10.3.7 The ranges that indicate TTS-onset were modelled and are presented in this impact assessment. 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 impossible 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. These thresholds were not used to quantify the numbers of animals at risk of any TTS (as agreed with the EP Technical Panel 14 January 2019, OFF-MM-2.1).

Approach to behavioural disturbance

4.10.3.8 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 5 dB 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.

4.10.3.9 The dose-response curve adopted in this assessment for all cetaceans 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 (**Figure 4.1**). In the absence of species-specific data on white-beaked dolphins or minke whales, this dose-response curve has been adopted for all cetaceans, as agreed with statutory consultees (EP Technical Panel Meeting One and EP Note: Noise Modelling Methodology and Approach, February 2019).

4.10.3.10 For both species of seal, the dose-response curve (**Figure 4.2**) adopted was based on the data presented in Whyte et al. (2020), where the percentage change in harbour seal density was predicted at the Lincs offshore windfarm. It has been assumed that all seals are displaced at sound exposure levels above 180 dB re 1 μPa^2s. This is a conservative assumption since there was no data presented in the study for responses at this level. It is also important to note that the percentage decrease in response in the categories 170≤175 and 175≤180 dB re 1 μPa^2s are slightly anomalous (higher response at a lower sound exposure level) 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 harbour seal curve was applied to the grey seal disturbance assessment. This is considered to be an appropriate, but precautionary proxy for grey seals since both species are categorised within the same hearing group while acknowledging that grey seals are considered to be less sensitive to underwater noise than harbour seals (see section 4.10.4 for more detail).

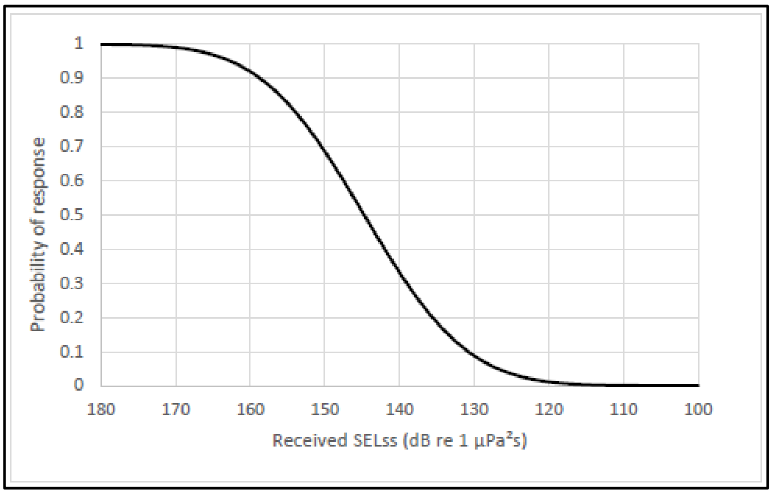


Figure 4.1: Relationship between the proportion of animals responding and the received single strike SEL (SEL_{ss}), based on passive acoustic monitoring results obtained during Phase 1 of the Beatrice Offshore Wind Farm monitoring program (Graham et al. 2017a).

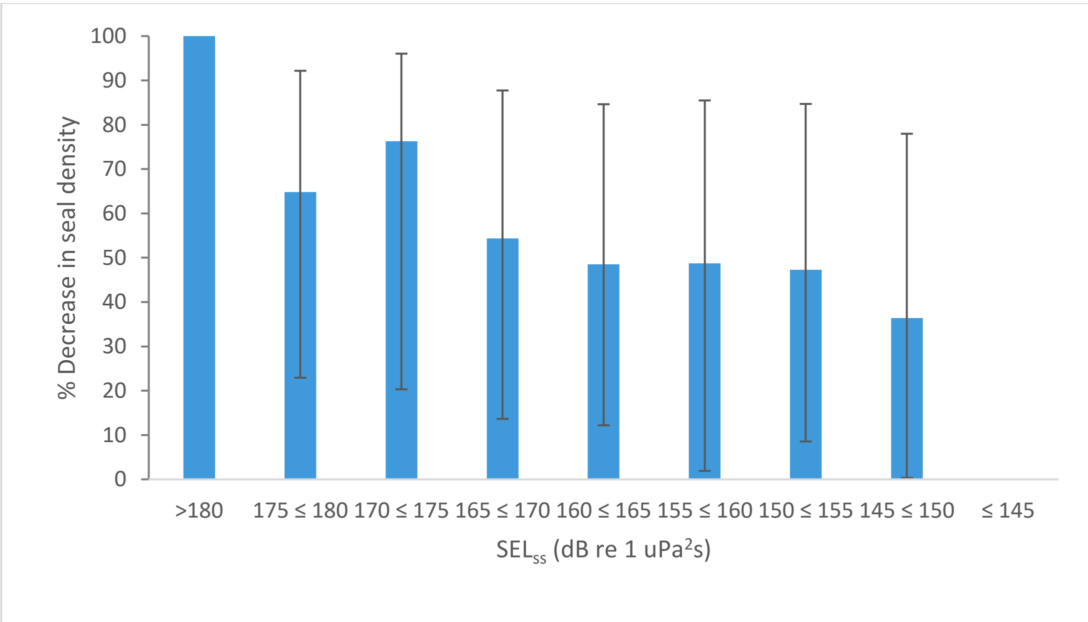


Figure 4.2: Predicted decrease in seal density as a function of estimated sound exposure level, error bars show 95% CI (from Whyte et al 2020).

4.10.4 Marine mammal sensitivity

4.10.4.1 The following paragraphs describe the sensitivity of marine mammal groups and species to PTS, pile driving disturbance and vessel disturbance. A summary of the assessed sensitivity for each species is provided at the end of the section in **Table 4.17**.

<u>*Cetacean sensitivity to PTS*</u>

4.10.4.2 The ecological consequences of PTS for marine mammals is uncertain. At a Department for Business, Energy & 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 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.

4.10.4.3 Southall et al. (2007) defined the onset of TTS as "*being a temporary elevation of a hearing threshold by 6 dB*" (in which the reference pressure for the dB is 1μPa). Although 6 dB of TTS is a somewhat arbitrary definition of onset, it has been adopted largely because 6 dB 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 6 dB, 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 40 dB. 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 40 dB of TTS, i.e. 40 dB of TTS is assumed to equate to 6 dB of PTS.

4.10.4.4 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 ~10 dB. By age 40 this increases to 30 dB, by age 60, this can be as much as 70 dB in the highest frequencies and 30 dB in the mid frequencies. 'Mild' hearing loss in humans is defined as a loss of hearing sensitivity of 20-40 dB.

4.10.4.5 For piling noise, most energy is between ~30 - 500 Hz, with a peak usually between 100 – 300 Hz and energy extending above 2 kHz (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 8 kHz (Kastelein et al. 2016) and centered at 4 kHz (Kastelein et al. 2012a, Kastelein et al. 2012b, Kastelein et al. 2013b, 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 - 10 kHz range (Kastelein et al. 2017), and that a PTS 'notch' of 6 – 18 dB in a narrow frequency band in the 2 - 10 kHz region is unlikely to significantly affect the fitness of individuals (ability to survive and reproduce).

4.10.4.6 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 40 dB of best sensitivity, to extend from 30 to 100 Hz up to 7.5 to 25 kHz, depending on the specific model used. Therefore a 2-10 kHz notch of 6 dB will only affect a small region of minke whale hearing. In addition, minke whale communication signals have been demonstrated to be below 2 kHz (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).

4.10.4.7 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.

4.10.4.8 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. 2018, 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

4.10.4.9 Seals are less dependent on hearing for foraging than cetaceans, but may 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 Wind Farm 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% of the seals (Hastie et al. 2019). 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.

4.10.4.10 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 might; 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 over precautionary, and b) would suggest a lack of sensitivity to the effects of PTS. At the 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.

Harbour porpoise sensitivity to pile-driving disturbance

4.10.4.11 Previous studies have shown that harbour porpoise 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% decline at noise levels above 170 dB) with decreasing effect with increasing distance from the pile (25% decline at noise levels between 145 and 150 dB) (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, Dähne et al. 2013, Brandt et al. 2016, Brandt et al. 2018). 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. This makes them vulnerable to starvation if they are unable to obtain sufficient levels of prey intake.

4.10.4.12 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.

4.10.4.13 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.

4.10.4.14 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% probability of response occurring at approximately 7 km. 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% probability of response was only 1.3 km. In addition, the study indicated that porpoise activity recovered between pile driving events.

4.10.4.15 A study of tagged harbour porpoise 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 – 690 m (SEL 135–147 dB re 1 μPa^{2}s), 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 porpoise exposed to low frequency broadband pulsed noise (including both airguns and pile-driving).

4.10.4.16 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 (e.g. 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 (DEB) 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. The DEB model 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 porpoise 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 (**Figure 4.3** 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 (**Figure 4.3** 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 over this many days.

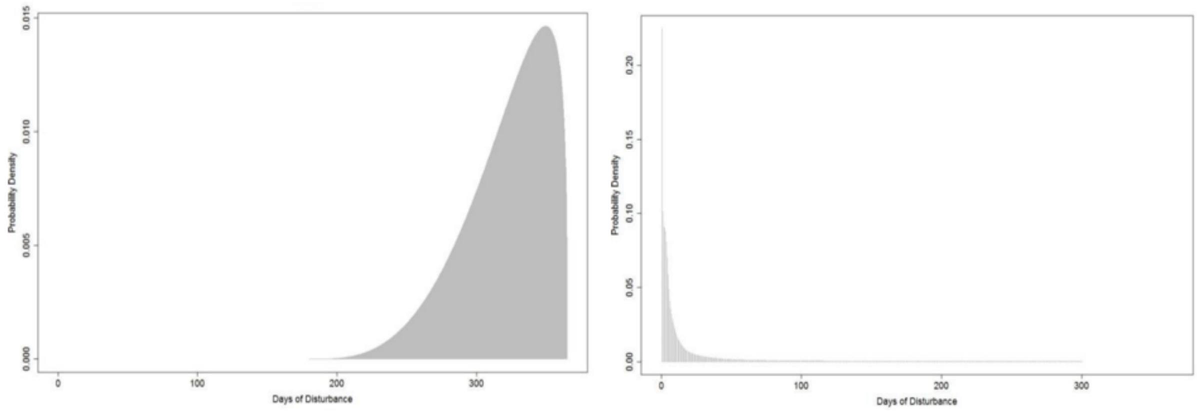


Figure 4.3: Probability distributions showing the consensus of the expert elicitation for harbour porpoise disturbance from piling. Left: the number of days of disturbance (i.e. days on which an animal does not feed for six hours) a pregnant female could 'tolerate' before it has any effect on fertility. 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. Figures obtained from Booth et al. (2019).

4.10.4.17 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.

Minke whale sensitivity to pile-driving disturbance

4.10.4.18 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 146 dB re 1 μPa (score 7) and a received SPL of 158 dB re 1 μPa (score 8). There is a study detailing minke whale responses to the Lofitech device which has a source level of 204 dB re re 1 μPa @1m, which showed minke whales within 500 m and 1,000 m of the source exhibiting a behavioural response. Estimated received level at 1,000 m was 136.1 dB re 1 μPa (McGarry et al. 2017).

4.10.4.19 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 **medium** 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.

White-beaked dolphin sensitivity to pile-driving disturbance

4.10.4.20 There is a single study detailing white beaked dolphin responses to playbacks of amplitude-modulated tones and synthetic pulse-bursts; responses were observed in 90 out of 123 exposures and received levels varied between 153 and 161 dB re 1 µPa for pulse-burst signals (Rasmussen et al. 2016). Due to the limited information on the effects of disturbance on white-beaked dolphins, bottlenose dolphins can be used as a proxy since both species are categorised as high-frequency cetaceans.

Bottlenose dolphin sensitivity to pile-driving disturbance

4.10.4.21 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 (Pirotta 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 240 dB re 1µPa (range 8 dB) with a single pulse source level of 198 dB re 1 $\mu Pa^2 s$. 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. While harbour porpoise are generally considered to be particularly sensitive to underwater noise, Graham et al. (2017b) found that "*Analysis of the effect of impact piling on dolphin and porpoise occurrence at the smaller temporal scale […] gave very similar results*" and therefore the application of the harbour porpoise dose-response curve for bottlenose dolphins is considered to be appropriate, given the lack of species-specific data.

4.10.4.22 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.

4.10.4.23 By using the sensitivity of bottlenose dolphins as a proxy for white-beaked dolphins, both species are assessed as having a **medium** sensitivity to disturbance.

Harbour seal sensitivity to pile-driving disturbance

4.10.4.24 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 25 km from a pile, during piling activities, with a 19 to 83% 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.

4.10.4.25 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 (e.g. 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 (i.e. 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 (**Figure 4.4** left), however there was a large amount of uncertainty in this estimate. 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 (**Figure 4.4** right), however again, there was a lot of uncertainty surrounding this estimate. Similarly to above, it is considered unlikely that individual harbour seals would repeatedly return to a site where they had been previously displaced from in order to experience this number of days of repeated disturbance.

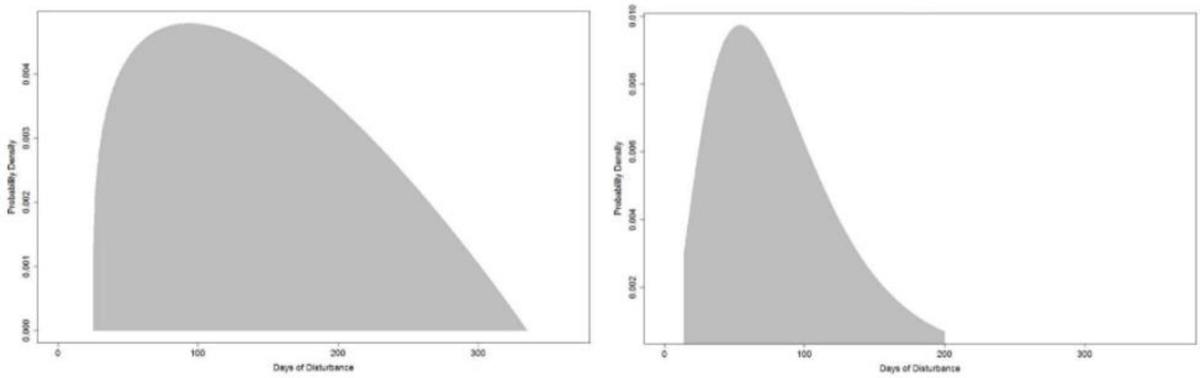


Figure 4.4: Probability distributions showing the consensus of the expert elicitation for harbour seal disturbance from piling. Left: the number of days of disturbance (i.e. days on which an animal does not feed for six hours) a pregnant female could 'tolerate' before it has any effect on fertility. 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. Figures obtained from Booth et al. (2019).

4.10.4.26 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.

Grey seal sensitivity to pile-driving disturbance

4.10.4.27 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 45 km from the pile location, while other grey seals showed no response when within 12 km. 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.

4.10.4.28 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 (i.e. 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 (**Figure 4.5** 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 (**Figure 4.5** right), however there was a lot of uncertainty surrounding this estimate.

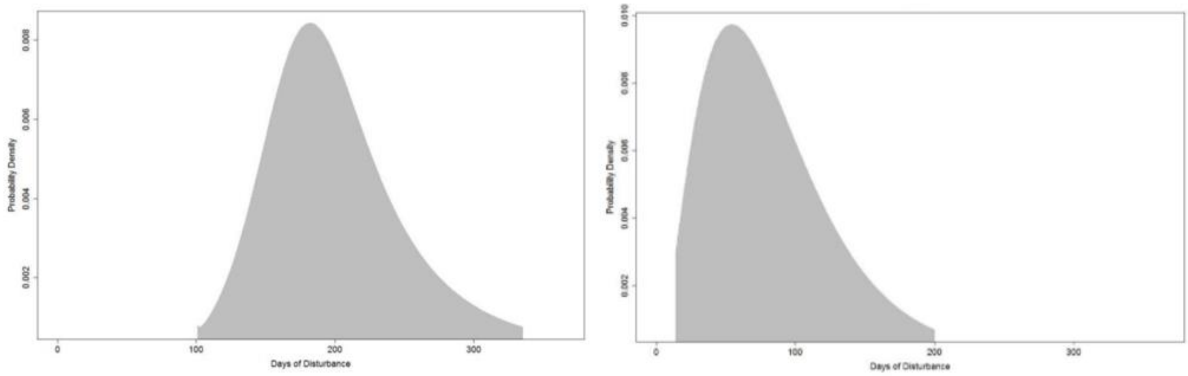


Figure 4.5: Probability distributions showing the consensus of the expert elicitation for grey seal disturbance from piling. Left: the number of days of disturbance (i.e. days on which an animal does not feed for six hours) a pregnant female could 'tolerate' before it has any effect on fertility. Right: 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. Figures obtained from Booth et al. (2019).

4.10.4.29 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. Hastie et al. (2021) found that grey seal avoidance rates in response to pile driving sounds were dependent on the quality of the prey patch, with grey seals continuing to forage at high density prey patches when exposed to pile driving sounds but showing reduced foraging success at low density prey patches when exposed to pile driving sounds. Additionally, the seals showed an initial aversive response to the pile driving playbacks (lower proportion of dives spent foraging) but this diminished during each trial. Therefore, the likelihood of grey seal response is expected to be linked to the quality of the prey patch. The quality of the Hornsea Four array area as a prey patch is unknown, and the importance of this area to grey seals specifically for foraging has not been quantitatively assessed. However, some inference can be made from movement and distribution data. Habitat preference data do not appear to indicate that the Hornsea Four array area itself is an important foraging location, given the predicted moderate to low densities of grey seal relative to elsewhere around the British Isles.

4.10.4.30 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.

Porpoise sensitivity to vessel disturbance

4.10.4.31 Given their high-frequency hearing range, it has been suggested that porpoise are more likely to be sensitive to vessels that produce medium to high frequency noise components (Hermannsen et al. 2014). However, harbour porpoise are known to avoid vessels and behavioural responses have been shown in porpoise exposed to vessel noise that contains low levels of high-frequency components (Dyndo et al. 2015). Thomsen et al. (2006) estimated that porpoise will respond to both small (~2 kHz) and large (~0.25 kHz) vessels at approximately 400 m. Wisniewska et al. (2018) presented data that suggested that porpoises may respond to very close range vessel passes with an interruption in foraging. However, observed responses were short lived, porpoises were observed to resume foraging 10 minutes after a very close-range vessel encounter. Tagged porpoises remained in areas where shipping levels were high. Overall, despite animals remaining in heavily trafficked areas, the incidence of responses to vessels was low, indicating little fitness cost to exposure to vessel noise and any local scale responses taken to avoid vessels.

4.10.4.32 A study on the impacts from construction related activities at the Beatrice and Moray East offshore windfarms in Scotland has shown that harbour porpoise are displaced by offshore windfarm construction vessels (Benhemma-Le Gall et al. 2021). Construction related vessels assessed in this study included key offshore service vessels used for pile-driving and jacket or turbine installation, as well as other construction-related vessel traffic including fishing vessels working as guard vessels, passenger vessels for crew-transfers and some port service craft or unassigned vessels; and across the Moray Firth during the study period, the median construction-related vessel density was 1.4 vessels/km^2. Passive acoustic monitoring at the site showed that porpoise occurrence (hourly occurrence of porpoise detections) declined within 2 km of construction vessels (from 0.37 when vessel intensity was zero, down to 0.02 for a vessel intensity of 9.8 min/km^2), but that responses declined with increasing distance to vessels, out to 4 km where no response was observed. Throughout the study period, buzzing activity (used as a proxy for foraging activity) decreased by up to 24.5% as vessel intensity increased, and by up to 45.9% as the hourly RMS sound pressure levels increased from 104 to 155 dB re 1µPa.

4.10.4.33 It is likely that porpoise may become habituated where vessel movements are regular and predictable whereas they may be expected to show more of a local behavioural response to novel vessel activities related to construction activities. However, because the dose response relationships relating displacement to piling are based on data collected over periods including such vessel activity, these local responses to novel activity such as pile driving vessels have effectively already been included in the assessment of underwater noise related to pile driving above.

4.10.4.34 Heinänen and Skov (2015) suggested that harbour porpoise density was significantly lower in areas with vessel transit rates of greater than 20,000 ships/year (80 per day). Vessel traffic in the Hornsea Four area will be below this figure (see **Volume A1, Chapter 4: Project Description**, the busiest period during construction in terms of vessel traffic would be when up to eight vessels are present in a given 5 km^2 block. This level of activity is unlikely to occur across the entire Hornsea Four array area at any one time, rather this intensity is expected across only approximately three or four 5 km^2 blocks). The sensitivity of harbour porpoise is assessed as **low** since, while it is expected that they will respond to vessel presence, it is expected that they will be able to return to previous behavioural states/activities once the impact has ceased, and it is not expected that the level of vessel activity will result in any changes to reproduction and survival rates (see **Table 4.11**).

Minke whale sensitivity to vessel disturbance

4.10.4.35 There is limited information available on the responses of minke whales to vessels. Whale watching vessels that specifically target minke whales have been shown to cause behavioural responses in minke whales and repeated exposure can result in a decrease in foraging activity (Christiansen et al. 2013). However, these are vessels which specifically target and follow minke whales so it is unknown whether minke whales respond to more general ship traffic. A maximum design is assumed that vessel disturbance could result in temporary displacement of minke whales from the immediate area, however there is no evidence that the Hornsea Four area is an important foraging habitat for minke whales, and given their generalist and varied diet, it is not expected that any temporary displacement resulting from vessel activity in relation to the Hornsea Four will lead to any significant effect on individual energy budgets and subsequently fitness. Therefore, the sensitivity of minke whales to vessel disturbance is assessed as **low**.

White-beaked dolphin sensitivity to vessel disturbance

4.10.4.36 There is limited information available on the responses of white-beaked dolphins to vessels. Due to a lack of data, bottlenose dolphins can be used as a proxy species for white-beaked dolphins as they are both included within the High Frequency cetacean functional hearing group (Southall et al. 2019).

Bottlenose dolphin sensitivity to vessel disturbance

4.10.4.37 Pirotta et al. (2015) found that transit of vessels in the Moray Firth resulted in a reduction (by almost half) of the likelihood of recording bottlenose dolphin prey capture buzzes. They also suggest that vessel presence, not just vessel noise, resulted in disturbance. There is however likely to be rapid recovery from disturbance from vessel presence and vessel noise, as they recorded little pre-emptive disturbance or recovery time following disturbance. There is evidence of bottlenose dolphin habituation to boat traffic, particularly in relation to larger vessel types (Sini et al. 2005). Lusseau et al. (2011) undertook a modelling study which predicted that increased vessel movements associated with offshore wind development in the Moray Firth did not have a negative effect on the local population of bottlenose dolphin, although it did note that foraging may be disrupted by the disturbance from vessels. Therefore, bottlenose dolphins as a proxy for white-beaked dolphins have been assumed to have a **low** sensitivity.

Seal sensitivity to vessel disturbance

4.10.4.38 Jones et al. (2017) presents an analysis of the predicted co-occurrence of ships and seals at sea which demonstrates that UK wide there is a large degree of predicted co-occurrence, particularly within 50 km of the coast close to seal haul-outs. There is no evidence relating decreasing seal populations with high levels of co-occurrence between ships and animals. In fact, in areas where seal populations are showing high levels of growth (e.g. southeast England) ship co-occurrences are highest (Jones et al. 2017). Thomsen et al. (2006) estimated that both harbour and grey seals will respond to both small (~2 kHz) and large (~0.25 kHz) vessels at approximately 400 m. The sensitivity of both seal species is assessed as **low**.

Table 4.17: Summary of key marine mammal sensitivity assessments.

Species	PTS	Behavioural disturbance from pile-driving	Behavioural disturbance from vessels
Harbour porpoise	Medium	Medium	Low
Minke whale	Medium	Medium	Low
White-beaked dolphin	Medium	Medium	Low
Bottlenose dolphin	Medium	Medium	Low
Harbour seal	Low	Medium	Low
Grey seal	Low	Low	Low

4.10.5 Assessment Limitations and Uncertainty

4.10.5.1 There are uncertainties relating to the underwater noise modelling and impact assessment for Hornsea Four. 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.

PTS assessment assumptions

4.10.5.2 All marine mammals were modelled to swim away at the onset of piling at a swimming speed of 1.5 m/s apart from minke whales which were modelled to flee at 3.25 m/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 4.2 m/s (McGarry et al. 2017). A recent study by Kastelein et al. (2018b) 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 1.97 m/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 2 m/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. The modelled swimming speeds were presented to the consultees in the EP Note: Noise Modelling Methodology and Approach and no concerns were raised in subsequent consultee comments (February 2019).

4.10.5.3 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.

4.10.5.4 Southall et al. (2019) acknowledges that as a result of propagation effects, the sound signal of certain sound sources (e.g. 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).

4.10.5.5 Using the criteria of signal duration[3], rise time[4], crest factor[5] and peak pressure[6] divided by signal duration[7], Hastie et al. (2019) estimated the transition from impulsive to non-impulsive characteristics of pile driving noise during the installation of offshore wind turbine 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 (see Appendix A for details). 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 25 ms) reduces to only 20% between ~2 and 5 km from the source. Predicted PTS impact ranges based on the impulsive noise thresholds will therefore be overestimates in cases where the impact ranges lie beyond this. Any

[3] Time interval between the arrival of 5% and 95% of total energy in the signal.
[4] Measured time between the onset (defined as the 5thpercentile of the cumulative pulse energy) and the peak pressure in the signal.
[5] The decibel difference between the peak sound pressure level (i.e. the peak pressure expressed in units of dB re 1 μPa) of the pulse and the root-mean-square sound pressure level calculated over the signal duration.
[6] The greatest absolute instantaneous sound pressure within a specified time interval.
[7] Time interval between the arrival of 5% and 95% of total energy in the signal.

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.

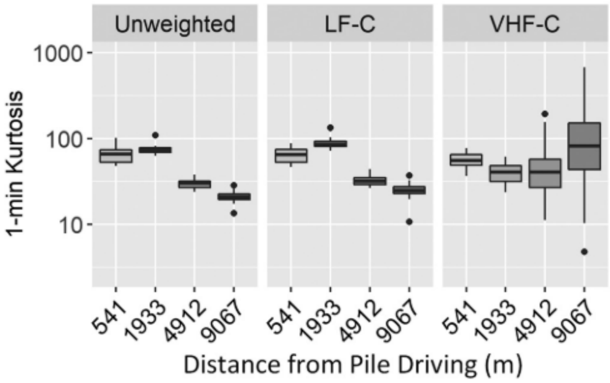
4.10.5.6 It is acknowledged that the Hastie et al. (2019) study is an initial investigation into this topic, and that further data are required in order to set limits to the range at which impulsive criteria for PTS are applied.

4.10.5.7 Since the Hastie et al. (2019) study, Martin et al. (2020) investigated the sound emission of different sound sources to test techniques for distinguishing between the sound being impulsive or non-impulsive. For impulsive sound sources, they included impact pile driving of four 4-legged jacket foundation installed at around 20 m water depth (at the Block Island Wind Farm in the USA). For the pile driving sound they recorded sound at four distances between ~500 m and 9 km, recording the sound of 24 piling events. To investigate the impulsiveness of the sound, they used three different parameters: kurtosis8, crest factor and Harris factor9, which they computed over 1-minute time windows, i.e. integrated over multiple transients (please see Martin et al. (2020) for definitions). As their data showed a strong correlation between the three different factors, the authors argued for the use of kurtosis to further investigate the impulsiveness of sound. Hamernik et al. (2007) showed a positive correlation between the magnitude of PTS and the kurtosis value in chinchillas, with an increase in PTS for a kurtosis value from 3 up to 40. Therefore, Martin et al. (2020) argued that:

- Kurtosis of 0-3 = continuous sinusoidal signal (non-impulsive);
- Kurtosis of 3-40 = transition from non-impulsive to impulsive sound; and
- Kurtosis of 40 = fully impulsive.

4.10.5.8 For the evaluation of their data, Martin et al. (2020) used unweighted as well as LF-Cetacean (C) and VHF-C weighted sound based on the species-specific weighting curves in Southall et al. (2019) to investigate the impulsiveness of sound. Their results for pile driving is shown in **Figure 4.6**. For the unweighted and LF-C weighted sound, the kurtosis value was >40 within 2 km from the piling site. Beyond 2 km, the kurtosis value decreased with increasing distance. For the VHF-C weighted sound, kurtosis factor is more inconclusive with the median value >40 for the 500 m and 9 km measuring stations, and at 40 for the stations in-between. However, the variability of the kurtosis value for the VHF-C weighted sound increased with distance.

[8] Kurtosis is a measure of the asymmetry of a probability distribution of a real-valued variable.
[9] The Harris (1998) impulse factor is the maximum value for each minute of the impulse time-weighted SPL minus the slow time-weighted SPL.



	Median value (1-min kurtosis)		
Distance (km)	Unweighted	LF-C	VHF-C
0.541	65	65	60
1.933	70	85	40
4.912	30	30	40
9.067	20	25	80

Figure 4.6: The range of kurtosis weighted by LF-C and VHF-C Southall et al. (2019) auditory frequency weighting functions for 30 min of impact pile driving data measured in 25 m of water at the Block Island Wind Farm. Unweighted data are 10 Hz and above high pass filtered. For each range and auditory frequency weighting function, the boxes show the interquartile range. The horizontal line in the box is the median value. The vertical lines show the range of values for the 25% of the data above or below the middle half. The dots above or below the line indicate outlier values (From: Martin et al. (2020): Figure 7). Table shows approximate median values extracted from the graph.

4.10.5.9 Martin et al. (2020) used this data to conclude that the change to non-impulsiveness "*is not relevant for assessing hearing injury because sounds retain impulsive character when SPLs are above EQT [effective quiet threshold[10]]*" (i.e. the sounds they recorded retain their impulsive character while being at sound levels that can contribute to auditory injury). The Applicant interprets their results differently. Figure 4.6 clearly shows (for unweighted and LF-C weighted sound) that piling sound loses its impulsiveness with increasing distance from the piling site - the kurtosis value decreases with increasing distance and therefore the sound loses its harmful impulsive characteristics.

4.10.5.10 There are some points that need to be considered before adopting kurtosis as an impulsiveness measure, with the recommended threshold value of 40. Firstly, this value was experimentally obtained for chinchillas that were exposed to noise for a 5-day period. Caution may need to be taken to directly adopt this threshold-value (and the related dose-response of increasing PTS with increasing kurtosis between 3 and 40) to marine mammals, especially given that the PTS guidance considers time periods of up to 24 hours. Secondly, kurtosis is recommended to be computed over at least 30 seconds, which means that it is not a specific measure that can be used for single blows of a piling sequence. Instead, kurtosis has been recommended to evaluate steady-state noise in order to include the risk from embedded impulsive noise (Goley et al. 2011). Metrics used by Hastie et al. (2019) computed for each pile strike (e.g., rise time) may be more suitable to be included in piling impact assessments, as, for each single pile strike, the sound exposure levels received by an animal are considered. Which metric is the most useful and how they correlate with the magnitude of auditory injury in (marine)

[10] From Martin et al. (2020): The proposed effective quiet threshold (EQT) is the 1-min auditory frequency weighted SPL that accumulates to this 1-min SEL, which numerically is 18 dB below the 1-min SEL [because $10 \cdot \log_{10}(1\ \text{min}/1\ \text{s})$ dB¼17.7 dB]. Thus, the proposed level for effective quiet is equivalently a 1-min SPL that is 50 dB below the numeric value of the auditory frequency-weighted Southall et al. (2019) daily SEL TTS threshold for non-impulsive sources.

mammals is still to be investigated. Therefore, for the purpose of presenting a precautionary assessment, the quantitative impact assessment for Hornsea Four is based on fully impulsive thresholds, but the potential for overestimation should be considered.

4.10.5.11 It is also important to note that it is expected that only 18-19% 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 of marine mammals to noise

4.10.5.12 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.

4.10.5.13 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 120 dB SEL_{ss} which may be indistinguishable from ambient noise at the ranges these levels are predicted (see **Volume A4, Annex 4.5: Subsea Noise Technical Report**, ambient noise levels in the Hornsea Zone are between 112 - 122 dB re 1μPa Root Mean Square (RMS).

4.10.5.14 It is important to note that 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 doses spread over a longer period (called the equal-energy hypothesis), b) the sound keeps its impulsive character, regardless of the distance to the sound source, c) the fleeing swim speeds are representative and d) that SEL_{cum} levels do not vary within the water column. These assumptions lead to a conservative determination of the impact ranges; and the Project considers that the calculated SEL_{cum} PTS-onset impact ranges are highly over-precautionary and unrealistic (see **Appendix B** for full details).

4.10.5.15 There is also a lack of data on the underwater noise produced by the clearance of various different types and sizes of UXO, and the current models to predict the noise propagation have not been validated at ranges relevant to the predictions and there is a possibility that models significantly overestimate ranges for large charge masses. Therefore, where there are empirical and modelled data available on impact ranges from UXO clearance, these have been presented to provide an estimate for the potential impacts at Hornsea Four. Until a UXO survey has been completed at Hornsea Four, it is unknown how many or what size UXO will require clearance. To define a design scenario for consideration in the EIA, a review of recent publicly available information on UXO disposal was undertaken, along with experience from previous Hornsea projects. Hornsea Project One identified 23 large NEQ items of UXO that required *in-situ* detonation and 30 incendiary units. These large NEQ items comprised 12 Allied 1000lb High Explosive (H*E*) bombs, two German 500 kg HE bombs and nine Allied 500 lb HE bombs. Based on the recent report conducted by Ordtek for Hornsea Three, the number of UXO requiring inspection and detonation has been scaled for Hornsea Four. The numbers are scaled for the array area and offshore ECC. It is assumed that there will be 86 targets that will require high order disposal (detonation) and that one UXO will be cleared in any 24 hour period. Note: UXO clearance will not be included in the application at this stage since the number, location and size of any potential UXOs is unknown; however, a high-level assessment is provided on the basis of assumptions about the expected level of risk. A detailed assessment of UXO clearance will be developed for a separate marine licence at a later stage (this approach was agreed with the MMO 26 November 2018 – see **Volume A1, Chapter 4: Project Description**).

Predicting the Response of Animals to Underwater Noise

4.10.5.16 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. The marine mammal baseline (**Volume A5, Annex 4.1: Marine Mammal Technical Report**) details the data sources used in the assessment and the most robust estimates of density have been agreed with the EP Technical Panel (Meeting 30 April 2019 and 26 June 2019, OFF-MM-1.2).

4.10.5.17 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 (e.g. 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.

4.10.5.18 There is also a lack of information on how observed effects (e.g. 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.

4.10.5.19 The duration of disturbance is another uncertainty. Studies at Horns Rev 2 demonstrated that porpoises returned to the area between 1 and 3 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. 2018, 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.

4.10.5.20 There are no empirical data on the responses of minke whales to pile driving noise, but a recent study of responses to ADDs demonstrated that minke whales responded to ADD signals by swimming directly away from the noise source at speeds increased above baseline, and some individuals were found to return to the deployment site after the ADD playback ceased, suggesting possible recovery after 10 - 15 minutes (McGarry et al. 2017).

4.10.5.21 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 Association (NOAA) have set the onset of TTS at the lowest level that exceeds natural recorded variation in hearing sensitivity (6 dB), and assumes that PTS occurs from exposures resulting in 40 dB or more of TTS measured approximately four minutes after exposure (NMFS 2018).

4.11 Impact assessment

4.11.1 Construction

4.11.1.1 The impacts of the offshore construction of Hornsea Four have been assessed on marine mammals. The environmental impacts arising from the construction of Hornsea Four are listed in **Table 4.10** along with the MDS against which each construction phase impact has been assessed.

4.11.1.2 A description of the potential effect on marine mammal receptors caused by each identified impact is given below.

PTS (auditory injury) from piling noise (MM-C-1)

Harbour porpoise

4.11.1.3 **Table 4.18** indicates the areas and maximum ranges within which there is any risk of PTS-onset occurring to harbour porpoise (very high frequency cetaceans (VHF)) at each of the four modelling locations under the MDS, and how many animals are estimated to be within the PTS-onset impact area based on survey derived density estimates. The number of animals predicted to experience PTS-onset was calculated using either the Hornsea Four aerial survey density (1.74 porpoise/km^2) or the acoustic density surface for the Former Hornsea Zone. Where impact areas extended beyond the aerial survey area or the extent of the acoustic density surface, the density applied to the remaining area was the SCANS III density of 0.888 porpoise/km^2.

4.11.1.4 The largest predicted instantaneous (SPL_{peak}) PTS-onset impact range is 2.9 km for monopiles (maximum 55 animals, 0.02% MU) and 2.1 km for pin piles (maximum 29 animals, 0.01% MU). The largest predicted cumulative (SEL_{cum}) PTS-onset impact range is 12 km for pin piles and 450 m for monopiles. As detailed in **Appendix A** and **paragraphs 4.10.5.4** *et seq.*, this maximum impact range of 12 km is likely to be an overestimate (though potential mitigation measures for this precautionary range are detailed in **F2.5: Outline Marine Mammal Mitigation Protocol**). The maximum number of porpoise predicted to experience cumulative PTS-onset from pin piles is 352 porpoise (0.10% MU). The SPL_{peak} PTS-onset impact ranges at the beginning of the soft start are a maximum of 740 m for monopiles and 380 m for pin piles.

Table 4.18: Impact area, maximum range, number of harbour porpoise and percentage of MU predicted to experience PTS-onset for the MDS. Shaded cells denote the maximum instantaneous and cumulative PTS-onset impact ranges for both monopiles and pin piles.

Full hammer energy	Monopile (5,000 kJ)				Pin pile (3,000 kJ)			
PTS Threshold	NW	E	S	HVAC	NW	E	S	HVAC
Instantaneous PTS at full hammer energy: 202 dB Unweighted SPL_{peak}								
Area (km²)	25	25	16	25	13	13	8.6	13
Max Range (m)	2,900	2,900	2,300	2,800	2,100	2,100	1,700	2,100
# Porpoise (aerial + SCANS III)	43 <0.01%	43 <0.01%	28 <0.01%	22 <0.01%	23 <0.01%	23 <0.00%	15 <0.00%	12 <0.00%
# Porpoise (acoustic + SCANS III)	55 0.02%	38 0.01%	23 0.01%	51 0.01%	29 0.01%	20 0.01%	12 0.00%	28 0.01%
Cumulative PTS: 155 dB VHF Weighted SEL_{cum}								
Area (km²)	<0.01	0.09	<0.01	<1.01	160	170	51	160
Max Range (m)	<100	450	<100	<100	8,800	12,000	5,000	7,900
# Porpoise (aerial + SCANS III)	<1	<1	<1	<1	260 0.08%	265 0.08%	90 0.03%	142 0.04%
# Porpoise (acoustic + SCANS III)	<1	<1	<1	<1	352 0.10%	235 0.07%	72 0.02%	283 0.08%
Soft start	**Monopile (1,000 kJ)**				**Pin pile (600 kJ)**			
Instantaneous PTS at commencement of soft-start: 202 dB Unweighted SPL_{peak}								
Area (km²)	1.7	1.7	1.1	1.7	0.45	0.45	0.29	0.45
Max Range (m)	740	740	600	740	380	380	310	380

4.11.1.5 **Table 4.19** indicates the areas and maximum ranges within which there is any risk of PTS-onset occurring to harbour porpoise at each of the four modelling locations under the most likely scenario and how many animals are estimated to be within the PTS impact area based on survey derived average density estimates. The largest predicted PTS-onset impact ranges reach a maximum of 4.6 km at the east modelling location for pin piles (SEL_{cum}) and 2.6 km at the east location for monopiles (SPL_{peak}). The SPL_{peak} PTS-onset impact ranges at the beginning of the soft start are a maximum of 560 m for monopiles and 170 m for pin piles.

Table 4.19: Impact area, maximum range, number of harbour porpoise and percentage of MU predicted to experience PTS-onset for the most likely piling scenarios. Shaded cells denote the maximum instantaneous and cumulative PTS-onset impact ranges for both monopiles and pin piles.

Full hammer energy	Monopile (4,000 kJ)				Pin pile (1,750 kJ)			
PTS Threshold	**NW**	**E**	**S**	**HVAC**	**NW**	**E**	**S**	**HVAC**
Instantaneous PTS at full hammer energy: 202 dB Unweighted SPL_{peak}								
Area (km^2)	19	19	13	19	5.6	5.5	3.6	5.6
Max Range (m)	2,500	2,600	2,000	2,500	1,300	1,300	1,100	1,300
# Porpoise (aerial + SCANS III)	33 (0.01%)	33 (0.01%)	22 (0.01%)	17 (0.00%)	10 (0.00%)	10 (0.00%)	6 (0.00%)	5 (0.00%)
# Porpoise (acoustic + SCANS III)	43 (0.01%)	29 (0.01%)	18 (0.01%)	40 (0.01%)	12 (0.00%)	8 (0.00%)	5 (0.00%)	12 (0.00%)
Cumulative PTS: 155 dB VHF Weighted SEL_{cum}								
Area (km^2)	<0.01	<0.01	<0.01	<0.01	31	36	4.4	30
Max Range (m)	<100	<100	<100	<100	3,600	4,600	1,200	3,200
# Porpoise (aerial + SCANS III)	<1	<1	<1	<1	54 (0.02%)	63 (0.02%)	5 (0.00%)	27 (0.01%)
# Porpoise (acoustic + SCANS III)	<1	<1	<1	<1	69 (0.02%)	54 (0.02%)	4 (0.00%)	61 (0.02%)
Soft start	**Monopile (800 kJ)**				**Pin pile (350 kJ)**			
Instantaneous PTS at commencement of soft-start: 202 dB Unweighted SPL_{peak}								
Area (km^2)	0.99	0.98	0.64	0.99	0.08	0.08	0.06	0.08
Max Range (m)	560	50	450	560	170	170	130	170

4.11.1.6 Although the numbers of individuals predicted to be at risk under both the MDS and the most likely scenario are low and would be considered negligible in EIA terms, harbour porpoise are an EPS and under EPS legislation it is an offence to injure a single individual (this includes PTS auditory injury). Therefore, Hornsea Four has committed to a piling MMMP (Commitment Co110) to reduce the risk of PTS-onset to negligible levels (see **F2.5: Outline Marine Mammal Mitigation Protocol**). 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.

Magnitude of impact

4.11.1.7 The generation of noise of sufficient amplitude to result in the onset of PTS is predicted to be of local spatial extent, short-term duration and intermittent. While PTS is a permanent change in the hearing threshold, and is not recoverable, such an effect is not expected to impact the vital rates of the affected individuals (see **paragraph 4.10.4.2** *et seq.*). With the use of embedded mitigation methods (Commitment Co110 and outlined in **F2.5: Outline Marine Mammal Mitigation Protocol**), it is expected that the risk of PTS will be negligible. The magnitude of this impact is therefore considered to be **negligible** under both the MDS and the most likely scenario. Irrespective of the sensitivity of the receptor, the significance of the impact on harbour porpoise is **not significant** as defined in the assessment of significance matrix (**Table 4.13**) and is therefore not considered further in this assessment.

Minke whale

4.11.1.8 **Table 4.20** indicates the areas and maximum ranges within which there is any risk of PTS-onset occurring to minke whales (low frequency (LF) cetaceans) at each of the four modelling locations under the MDS and how many animals are estimated to be within the PTS-onset impact area. While the largest SEL_{cum} PTS-onset impact ranges are reasonably large (up to 11 km for monopiles at the east location), the density of minke whales in the area is low and so the number of individual whales expected to experience PTS-onset at each modelling location is very low (<1 for all scenarios). The SPL_{peak} PTS-onset impact ranges at the beginning of the soft start are <50 m for both monopiles and pin piles.

Table 4.20: Impact area, maximum range, number of minke whales and percentage of MU predicted to experience PTS-onset for the MDS. Shaded cells denote the maximum instantaneous and cumulative PTS-onset impact ranges for both monopiles and pin piles.

Full hammer energy	Monopile (5,000 kJ)				Pin pile (3,000 kJ)			
	NW	E	S	HVAC	NW	E	S	HVAC
Instantaneous PTS at full hammer energy 219: dB Unweighted SPL_{peak}								
Area (km^2)	0.06	0.06	0.04	0.06	0.03	0.03	0.02	0.03
Max Range (m)	140	140	120	140	100	100	80	100
# Whales	<1	<1	<1	<1	<1	<1	<1	<1
% of MU	<0.5%	<0.5%	<0.5%	<0.5%	<0.5%	<0.5%	<0.5%	<0.5%
Cumulative PTS: 183 dB LF Weighted SEL_{cum}								
Area (km^2)	66	76	5.6	65	42	53	1.5	41
Max Range (m)	6,900	11,000	2,500	5,800	5,800	9,200	1,500	4,700
# Whales	<1	<1	<1	<1	<1	<1	<1	<1
% of MU	<0.5%	<0.5%	<0.5%	<0.5%	<0.5%	<0.5%	<0.5%	<0.5%
Soft start	**Monopile (1,000 kJ)**				**Pin pile (600 kJ)**			
Unweighted Instantaneous PTS at commencement of soft-start: 219 dB SPL_{peak}								
Area (km^2)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Max Range (m)	<50	<50	<50	<50	<50	<50	<50	<50

4.11.1.9 **Table 4.21** indicates the areas and maximum ranges within which there is any risk of PTS-onset occurring to minke whales at each of the four modelling locations under the most likely scenario and how many animals are estimated to be within the PTS-onset impact area. While the largest SEL_{cum} PTS-onset impact ranges are reasonably large (up to 7.7 km for monopiles at the east location), the density of minke whales in the area is very low and so the number of individual whales expected to experience PTS-onset at each modelling location is very low (<1 for all scenarios). The SPL_{peak} PTS-onset impact ranges at the beginning of the soft start are <50 m for both monopiles and pin piles.

Table 4.21: Impact area, maximum range, number of minke whales and percentage of MU predicted to experience PTS-onset for the most likely piling scenarios. Shaded cells denote the maximum instantaneous and cumulative PTS-onset impact ranges for both monopiles and pin piles.

Full hammer energy	Monopile (4,000 kJ)				Pin pile (1,750 kJ)			
	NW	E	S	HVAC	NW	E	S	HVAC
Instantaneous PTS at full hammer energy 219: dB Unweighted SPL_{peak}								
Area (km^2)	0.04	0.04	0.03	0.04	<0.01	<0.01	<0.01	<0.01
Max Range (m)	120	120	100	120	60	60	50	60
# Whales % of MU	<1 <0.5%	<1 <0.5%	<1 <0.5%	<1 <0.5%	<1 <0.5%	<1 <0.5%	<1 <0.5%	<1 <0.5%
Cumulative PTS: 183 dB LF Weighted SEL_{cum}								
Area (km^2)	31	41	0.59	32	0.43	4.8	<0.01	0.21
Max Range (m)	4,800	7,700	1,000	3,900	1,200	3,200	<100	550
# Whales % of MU	<1 <0.5%	<1 <0.5%	<1 <0.5%	<1 <0.5%	<1 <0.5%	<1 <0.5%	<1 <0.5%	<1 <0.5%
Soft start	**Monopile (800 kJ)**				**Pin pile (350 kJ)**			
Unweighted Instantaneous PTS at commencement of soft-start: 219 dB SPL_{peak}								
Area (km^2)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Max Range (m)	<50	<50	<50	<50	<50	<50	<50	<50

4.11.1.10 Although the numbers of individuals predicted to be at risk are very low under both the MDS and the most likely scenario and would be considered negligible in EIA terms, minke whales are an EPS and under EPS legislation it is an offence to injure a single individual. Therefore, Hornsea Four has committed to a piling MMMP (Commitment Co110) to reduce the risk of PTS to negligible levels (see **F2.5: Outline Marine Mammal Mitigation Protocol**). In addition to the embedded mitigation, there is also the potential that the presence of vessels and associated activity will serve to displace minke whales from the immediate vicinity of the piling location prior to the start of piling.

4.11.1.11 Consideration needs to be given to the fact that impulsive sounds from pile driving have been shown to lose their impulsive characteristics (such as rise time) within 2 - 5 km from the source (Hastie et al. 2019) (detailed in **Appendix A** and **paragraphs 4.10.5.4** *et seq.*). Therefore, the PTS-onset impact range of 11 km under the MDS using an impulsive threshold is likely to be an overestimate.

4.11.1.12 It should be noted that the baseline characterisation data confirmed that minke whales are only present in the Hornsea Four area in the summer months (see **Volume A5, Annex 4.1: Marine Mammal Technical Report**), and therefore it is expected that they will only potentially be present over a few months each year.

Magnitude of impact

4.11.1.13 Although the numbers of individuals predicted to be at risk are very low under both the MDS and the most likely scenario and would be considered negligible in EIA terms, minke whales are an EPS and under EPS legislation it is an offence to injure a single individual. Therefore, Hornsea Four has committed to a piling MMMP (Commitment Co110 and outlined in **F2.5: Outline Marine Mammal Mitigation Protocol**) to reduce the risk of PTS to negligible levels, therefore it is expected that the risk of PTS will be negligible. The magnitude of this impact is therefore considered to be **negligible** under both the MDS and the most likely scenario. Irrespective of the sensitivity of the receptor, the significance of the impact on minke whale is **not significant** as defined in the assessment of significance matrix (**Table 4.13**) and is therefore not considered further in this assessment.

White-beaked and bottlenose dolphin

4.11.1.14 **Table 4.22** indicates the areas and maximum ranges within which there is any risk of PTS-onset occurring to white-beaked and bottlenose dolphins (high frequency (HF) cetaceans) at each of the four modelling locations under the MDS. All modelling locations have very small PTS-onset impact areas (<0.01 km^2) and less than one single dolphin of either species is predicted to be within the PTS-onset impact area at any one time. The SPL_{peak} PTS-onset impact ranges at the beginning of the soft start are <100 m for both monopiles and pin piles, with the exception of the northwest monopile which was <50 m.

Table 4.22: Impact area, maximum range and number of white-beaked and bottlenose dolphins predicted to experience PTS-onset for the MDS.

Full hammer energy	Monopile (5,000 kJ)				Pin pile (3,000 kJ)			
	NW	E	S	HVAC	NW	E	S	HVAC
Instantaneous PTS at full hammer energy: 230 dB Unweighted SPL_{peak}								
Area (km^2)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Max Range (m)	<50	<50	<50	<50	<50	<50	<50	<50
# White-beaked	<1	<1	<1	<1	<1	<1	<1	<1
# Bottlenose	<1	<1	<1	<1	<1	<1	<1	<1
Cumulative PTS: 185 dB HF Weighted SEL_{cum}								
Area (km^2)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Max Range (m)	<100	<100	<100	<100	<100	<100	<100	<100
# White-beaked	<1	<1	<1	<1	<1	<1	<1	<1
# Bottlenose	<1	<1	<1	<1	<1	<1	<1	<1
Soft start	**Monopile (1,000 kJ)**				**Pin pile (600 kJ)**			
Instantaneous PTS at commencement of soft-start: 230 dB Unweighted SPL_{peak}								
Area (km^2)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Max Range (m)	<50	<100	<100	<100	<100	<100	<100	<100

4.11.1.15 **Table 4.23** indicates the areas and maximum ranges within which there is any risk of PTS-onset occurring to white-beaked and bottlenose dolphins at each of the four modelling locations under the most likely scenario and how many animals estimated to be are within the PTS-onset impact area. The results of the number of dolphins of either species impacted during the most likely scenario are the same as for the maximum design scenario (<1 animal at risk of PTS-onset for all locations). The SPL_{peak} PTS-onset impact ranges at the beginning of the soft start are <50 m for both monopiles and pin piles.

Table 4.23: Impact area, maximum range and number of white-beaked and bottlenose dolphins predicted to experience PTS-onset for the most likely piling scenarios.

Full hammer energy	Monopile (4,000 kJ)				Pin pile (1,750 kJ)			
	NW	E	S	HVAC	NW	E	S	HVAC
Instantaneous PTS at full hammer energy: 230 dB Unweighted SPL_{peak}								
Area (km^2)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Max Range (m)	<50	<50	<50	<50	<50	<50	<50	<50
# White-beaked	<1	<1	<1	<1	<1	<1	<1	<1
# Bottlenose	<1	<1	<1	<1	<1	<1	<1	<1
Cumulative PTS: 185 dB HF Weighted SEL_{cum}								
Area (km^2)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Max Range (m)	<100	<100	<100	<100	<100	<100	<100	<100
# White-beaked	<1	<1	<1	<1	<1	<1	<1	<1
# Bottlenose	<1	<1	<1	<1	<1	<1	<1	<1
Soft start	**Monopile (800 kJ most likely)**				**Pin pile (350 kJ)**			
Instantaneous PTS at commencement of soft-start: 230 dB Unweighted SPL_{peak}								
Area (km^2)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Max Range (m)	<50	<50	<50	<50	<50	<50	<50	<50

4.11.1.16 Although the numbers of individuals predicted to be at risk are very low under both the MDS and the most likely scenario and would be considered negligible in EIA terms, white-beaked and bottlenose dolphins are an EPS and under EPS legislation it is an offence to injure a single individual. Therefore, Hornsea Four has committed to a piling MMMP (Commitment Co110) to reduce the risk of PTS to negligible levels (see **F2.5: Outline Marine Mammal Mitigation Protocol**). It should also be noted that the baseline characterisation data confirmed that white-beaked dolphins are only present in the area in the winter months, and therefore it is expected that they will only potentially be present during a few months of the construction period.

Magnitude of impact

4.11.1.17 The 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 (Commitment Co110 and outlined in **F2.5: Outline Marine Mammal Mitigation Protocol**), it is expected that the risk of PTS will be negligible for both species. The magnitude of this impact is therefore considered to be **negligible** under both the MDS and the most likely scenario for both species. Irrespective of the sensitivity of the receptor, the significance of the impact on white-beaked and bottlenose dolphins is **not significant** as defined in the assessment of significance matrix (**Table 4.13**) and is therefore not considered further in this assessment.

Seal species

4.11.1.18 **Table 4.24** indicates the areas and maximum ranges within which there is any risk of PTS-onset occurring to seals (phocid carnivores in water (PCW)) at each of the four modelling locations under the most MDS and how many animals estimated to be are within the PTS impact area. The maximum PTS-onset impact range is for monopiles at the northwest, east or HVAC locations where impact ranges reach a maximum of 170 m. However, seal density estimates are low in the area and so less than one single seal of each species is predicted to be within the PTS-onset impact areas at any one time.

Table 4.24: Impact area, maximum range and number of harbour and grey seals predicted to experience PTS-onset for the MDS. Shaded cells denote the maximum instantaneous and cumulative PTS-onset impact ranges for both monopiles and pin piles.

Full hammer energy	Monopile (5,000 kJ)				Pin pile (3,000 kJ)			
	NW	E	S	HVAC	NW	E	S	HVAC
Instantaneous PTS at full hammer energy: 218 dB Unweighted SPL_{peak}								
Area (km^2)	0.09	0.09	0.06	0.09	0.04	0.04	0.03	0.04
Max Range (m)	170	170	140	170	120	120	100	120
# Harbour Seals	<1	<1	<1	<1	<1	<1	<1	<1
# Grey Seals	<1	<1	<1	<1	<1	<1	<1	<1
Cumulative PTS: 185 dB PCW Weighted SEL_{cum}								
Area (km^2)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Max Range (m)	<100	<100	<100	<100	<100	<100	<100	<100
# Harbour Seals	<1	<1	<1	<1	<1	<1	<1	<1
# Grey Seals	<1	<1	<1	<1	<1	<1	<1	<1
Soft-start	**Monopile (1,000 kJ)**				**Pin pile (600 kJ)**			
Instantaneous PTS at commencement of soft-start: 218 dB Unweighted SPL_{peak}								
Area (km^2)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Max Range (m)	<50	<50	<50	<50	<50	<50	<50	<50

4.11.1.19 **Table 4.25** indicates the areas and maximum ranges within which there is any risk of PTS-onset occurring to seals at each of the four modelling locations under the most likely scenario and how many animals estimated to be are within the PTS-onset impact area. In terms of the number of seals predicted to experience PTS, the results of the most-likely scenario modelling are the same as for the MDS (<1 animal at risk of PTS-onset for all locations).

Table 4.25: Impact area, maximum range and number of harbour and grey seals predicted to experience PTS-onset for the most likely piling scenarios. Shaded cells denote the maximum instantaneous and cumulative PTS-onset impact ranges for both monopiles and pin piles.

Full hammer energy	Monopile (4,000 kJ)				Pin pile (1,750 kJ)			
	NW	E	S	HVAC	NW	E	S	HVAC
Instantaneous PTS at full hammer energy: 218 dB Unweighted SPL_{peak}								
Area (km²)	0.07	0.07	0.04	0.07	0.02	0.02	<0.01	0.02
Max Range (m)	150	150	120	150	70	70	60	70
# Harbour Seals	<1	<1	<1	<1	<1	<1	<1	<1
# Grey Seals	<1	<1	<1	<1	<1	<1	<1	<1
Cumulative PTS: 185 dB PCW Weighted SEL_{cum}								
Area (km²)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Max Range (m)	<100	<100	<100	<100	<100	<100	<100	<100
# Harbour Seals	<1	<1	<1	<1	<1	<1	<1	<1
# Grey Seals	<1	<1	<1	<1	<1	<1	<1	<1
Soft-start	**Monopile (800 kJ)**				**Pin pile (350 kJ)**			
Instantaneous PTS at commencement of soft-start: 218 dB Unweighted SPL_{peak}								
Area (km²)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Max Range (m)	<50	<50	<50	<50	<50	<50	<50	<50

Magnitude of impact

4.11.1.20 The impact is predicted to be of local spatial extent, short term duration and intermittent, and less than one seal is predicted to experience PTS-onset at all modelling locations and as such, the risk is negligible. However, since PTS is a permanent change in the hearing threshold, it is not recoverable. Given that <1 animal is predicted to experience PTS-onset and given the use of embedded mitigation methods (Commitment Co110 and outlined in **F2.5: Outline Marine Mammal Mitigation Protocol**), it is expected that the risk of PTS will be negligible. The magnitude of this impact is therefore considered to be **negligible** under both the MDS and the most likely scenario. Irrespective of the sensitivity of the receptor, the significance of the impact on seal species is **not significant** as defined in the assessment of significance matrix (**Table 4.13**) and is therefore not considered further in this assessment.

Multiple pin-piles in 24 hours

4.11.1.21 In addition to the PTS-onset impact assessment provided above, a further cumulative modelling scenario has been included where three pin piles are installed one after the other, in a single 24-hour period, using the MDS at the NW location. As shown in **Table 4.26**, the installation of three consecutive pin piles does not significantly change the predicted SEL_{cum} PTS-onset impact ranges for any species. The maximum impact range increases by up to 300 m; this is not significantly different to the impact ranges presented above for the installation of one pin pile, and therefore the magnitude scores and assessment conclusions remain the same.

Table 4.26: Comparison in SEL_{cum} PTS-onset ranges for one single pin pile and for three consecutive pin piles installed at the NW modelling location considering the MDS pin pile parameters.

Southall *et al.* (2019) – Cumulative PTS *Weighted SEL_{cum}*		Maximum design (3,000 kJ)				
		Scenario	*Area (km²)*	*Max range*	*Min range*	*Mean range*
LF (minke whale)	183 dB	1x pin pile	42	5.8 km	2.9 km	3.6 km
		3x pin piles	43	5.8 km	2.9 km	3.7 km
HF (white-beaked and bottlenose dolphins)	185 dB	1x pin pile	< 0.01	< 100 m	< 100 m	< 100 m
		3x pin piles	< 0.01	< 100 m	< 100 m	< 100 m
VHF (harbour porpoise)	155 dB	1x pin pile	160	8.8 km	6.6 km	7.2 km
		3x pin piles	170	9.1 km	6.7 km	7.3 km
PCW (harbour and grey seals)	185 dB	1x pin pile	< 0.01	< 100 m	< 100 m	< 100 m
		3x pin piles	< 0.01	< 100 m	< 100 m	< 100 m

<u>*Summary of marine mammal PTS-onset from piling noise*</u>

4.11.1.22 The impact of PTS-onset from piling noise under both the most likely and the MDS is not considered to have a significant effect on any marine mammal species considered in this assessment.

Behavioural disturbance from piling noise (MM-C-2)

4.11.1.23 Full details of the underwater noise modelling conducted to obtain the disturbance impact ranges are detailed in **Volume A4, Annex 4.5: Subsea Noise Technical Report**. The noise impact contours for the simultaneous piling assessment were obtained by merging the contours from the northwest and the east modelling locations, selected because they were the furthest apart and therefore represented the largest spatial footprint which could be experienced.

<u>*Harbour porpoise*</u>

4.11.1.24 **Table 4.27** indicates the number of harbour porpoise potentially disturbed by pile driving at each modelling location for both monopiles and pin piles under the MDS. The highest level of disturbance in spatial terms for a single piling event is predicted to be from the installation of a monopile at the NW location resulting in 6,417 porpoise predicted to be potentially disturbed once hammer energy reaches its maximum, which represents 1.86% of the reference population. The equivalent number during pin pile installation at the same location is 5,618 animals (1.63% of the population) which represents the highest level of disturbance in temporal terms. The method used to calculate the number of porpoise predicted to experience behavioural disturbance is shown in **Table 4.28** for the installation of a monopile at the NW location, using the JCP III density estimate and the Graham et al. (2017a) dose-response curve.

Table 4.27: Number of harbour porpoise and percentage of the MU predicted to experience behavioural disturbance for the maximum design piling scenarios. Shaded cells denote the maximum number of animals potentially disturbed for both monopiles and pin piles.

Full hammer energy - MDS	Monopile (5,000 kJ)				Pin pile (3,000 kJ)			
	NW	E	S	HVAC	NW	E	S	HVAC
# Porpoise (acoustic + SCANS III)	6,417 1.86%	6,176 1.79%	5,441 1.58%	5,408 1.57%	5,618 1.63%	5,369 1.55%	4,690 1.36%	4,784 1.39%
# Porpoise (aerial + SCANS III)	4,793 1.39%	4,459 1.29%	3,805 1.10%	3,694 1.07%	4,187 1.21%	3,949 1.14%	3,343 0.97%	3,215 0.93%

Table 4.28: Calculation of the number of harbour porpoise predicted to experience behavioural disturbance for the installation of a monopile at the NW location, using the aerial + SCANS III density estimate and the Graham et al. (2017a) dose-response curve.

Received level (SEL_{ss} dB re 1μPa²s)	Area (km²)	# Porpoise	Proportion of porpoise predicted to respond	# Porpoise predicted to respond
180+	7.6	13	0.9994	13.1
175<180	28.5	50	0.9973	49.5
170<175	99.4	157	0.9898	155.1
165<170	248.3	317	0.9685	306.9
160<165	471.3	544	0.9192	499.9
155<160	779.9	838	0.8266	692.6
150<155	1181.9	1199	0.6849	821.5
145<150	1619.9	1606	0.509	817.3
140<145	2045.9	2004	0.3312	663.9
135<140	2410.0	2313	0.1852	428.4
130<135	2726.8	2529	0.0878	222.0
125<130	2921.0	2626	0.0349	91.6
120<125	3070.7	2727	0.0115	31.4
Total number of porpoise predicted to respond				**4,793**

4.11.1.25 Table 4.29 indicates the number of harbour porpoise potentially disturbed by pile driving at each modelling location for both monopiles and pin piles under the most likely scenario. The highest level of disturbance in spatial terms is predicted to be from the installation of a monopile at the northwest location. Using the former Hornsea Zone acoustic density surface and SCANS III beyond that, a total of 6,080 porpoise are predicted to be potentially disturbed once hammer energy reaches its maximum, which represents 1.76% of the reference population. The equivalent number during pin pile installation at the same location is 4,665 animals (1.35% of the population) which represents the highest level of disturbance in temporal terms.

Table 4.29: Number of harbour porpoise and percentage of the MU predicted to experience potential behavioural disturbance for the most likely piling scenarios. Shaded cells denote the maximum number of animals potentially disturbed for both monopiles and pin piles.

Full hammer energy – most likely	Monopile (4,000 kJ)				Pin pile (1,750 kJ)			
	NW	E	S	HVAC	NW	E	S	HVAC
Former Hornsea Zone acoustic density surface + SCANS III								
Number of porpoise	6,080	5,839	5,126	5,138	4,665	4,408	3,802	3,977
% of MU	1.76%	1.69%	1.48%	1.49%	1.35%	1.28%	1.10%	1.15%
Hornsea Four aerial survey average density + SCANS III								
Number of porpoise	4,540	4247	3612	3477	3463	3325	2793	2632
% of MU	1.31%	1.23%	1.05%	1.01%	1.00%	0.96%	0.81%	0.76%

4.11.1.26 **Table 4.30** indicates the number of harbour porpoise potentially disturbed by simultaneous pile driving for both monopiles and pin piles under the maximum design scenario. The highest potential disturbance levels were for the simultaneous installation of two monopiles where 9,686 porpoise are predicted to be disturbed (2.80% of the reference population) which represents the highest level of disturbance in spatial terms. The equivalent number for simultaneous pin piles is 8,507 porpoise (2.46% of the population) which represents the highest level of disturbance in temporal terms.

Table 4.30: Number of harbour porpoise and percentage of the MU predicted to experience behavioural disturbance for the simultaneous MDS.

Full hammer energy - MDS	Monopile (5,000 kJ)	Pin pile (3,000 kJ)
	NW & E	NW & E
Former Hornsea Zone acoustic density surface + SCANS III		
Number of porpoise	9,686	8,507
% of MU	2.80%	2.46%
Hornsea Four aerial survey average density + SCANS III		
Number of porpoise	6,886	6,158
% of MU	1.99	1.78

4.11.1.27 As outlined in **Table 4.10**, all disturbance will occur intermittently over a maximum period of 12 months foundation installation, with monopiles requiring fewer total piling days than pin piles and simultaneous piling requiring fewer days than single piling. Given the results of the recent expert elicitation on the likely effects of behavioural disturbance on vital rates (Booth et al. 2019) (see **paragraph 4.10.4.16**), the number of days of repeated disturbance under the maximum design scenarios (approximately 200-300 days for single piling) 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 multiple 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.

4.11.1.28 It is important to consider that the conclusions of the expert elicitation were based on the assumption that "disturbance" equated to 6 hours of no feeding which would have resulting energetic consequences to the individual. However, a recent study has shown that this assumption may not be valid. Benhemma-Le Gall et al. (2021) provided two key findings in relation to harbour porpoise response to pile driving: 1) Porpoise were not completely displaced from the piling site: detections of clicks (echolocation) and buzzing (associated with prey capture) in the short-range did not cease in response to pile driving, and 2) porpoise appeared to compensate: detections of both clicks (echolocation) and buzzing (associated with prey capture) increased above baseline levels with increasing distance from the pile, which suggests that those porpoise that are displaced from the near-field, compensate by increasing foraging activities beyond the impact range (**Figure 4.7**). Therefore, porpoise that experience displacement are expected to be able to compensate for the lost foraging opportunities and the increased energy expenditure of fleeing. As such, it is not expected that disturbance (displacement from the piling site) will have any significant effect on energetics since the individuals are expected to be able to compensate.

4.11.1.29 Since the impact is expected to result in short-term, intermittent and temporary behavioural effects in a small proportion of the population, and the fact that new evidence suggests that harbour porpoise can compensate for any resulting loss in energy intake, it is considered unlikely that there would be any significant effect on survival and reproductive rates, and thus the population trajectory would not be altered. This results in a minor magnitude for the impact.

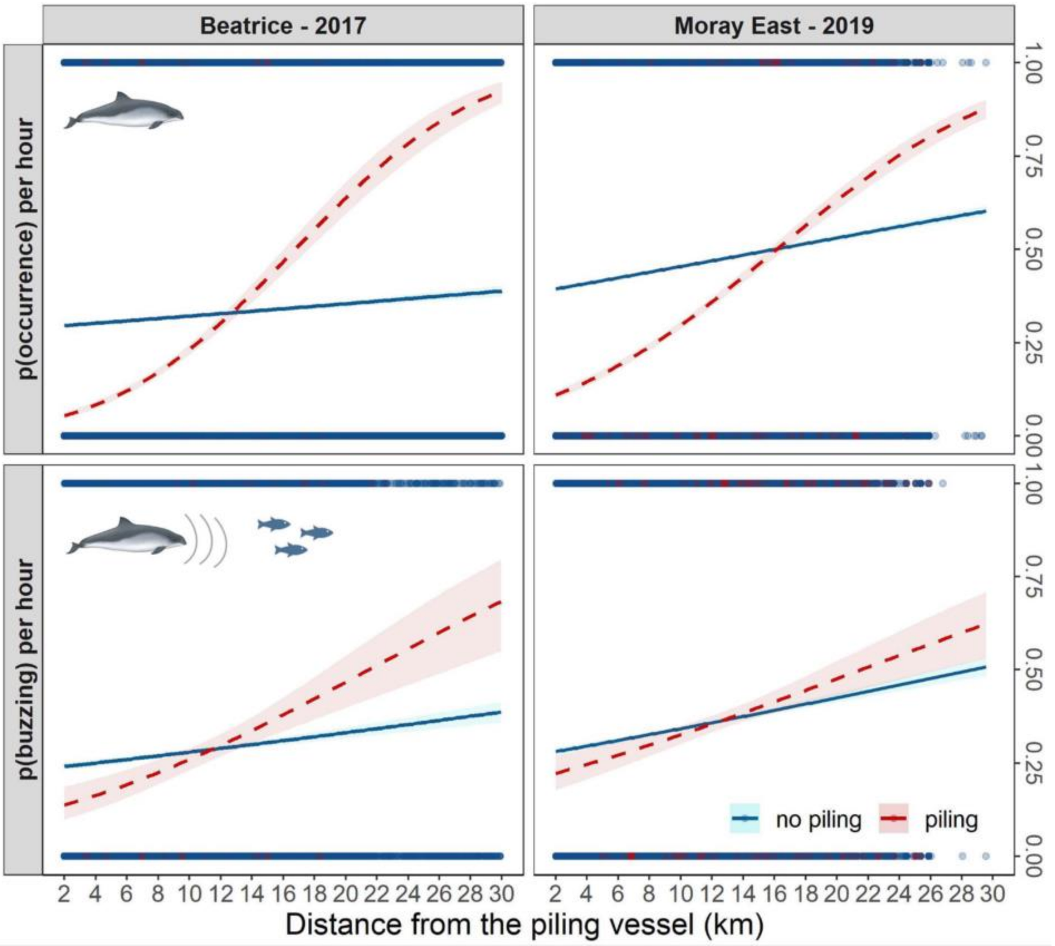


Figure 4.7: The probability of harbour porpoise occurrence and buzzing activity per hour during (dashed red line) and out with (blue line) pile-driving hours, in relation to distance from the pile-driving vessel at Beatrice (left) and Moray East (right). Obtained from Benhemma-Le Gall et al. (2021).

Magnitude of impact

4.11.1.30 Piling activities for the project alone assessment are considered to be short-term impacts given the likely number of piling days within the construction period and the fact that piling will not be constant on or between piling days. In addition, there is evidence that marine mammals return to the vicinity of the construction site and that any disturbance effect is short lived. For example, Brandt et al. (2018) showed that porpoise detections returned to normal within 24-48 hours after piling ceased, therefore disturbance from pile driving is not considered to be a long-term impact.

4.11.1.31 The impact is predicted to be of local spatial extent, short term duration (only over one breeding cycle), 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 minor. The magnitude is therefore considered to be **minor** in line with the definition provided in Table 4.12.

Sensitivity of the receptor

4.11.1.32 As outlined in **paragraph 4.10.4.16** onwards, 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**.

Significance of the effect

4.11.1.33 Overall, the sensitivity of harbour porpoise to disturbance has been assessed as **medium** and the magnitude is predicted to be **minor** under both the most likely and the maximum design single piling scenarios and the maximum design simultaneous piling scenario. This can result in either a slight or a moderate significance based on the assessment of significance matrix (**Table 4.13**). Given the fact that it is highly unlikely that porpoise would remain in the area on consecutive days of impact, and that new evidence suggests that they are capable of compensating for any loss in energy intake from disturbance, there is very little chance of disturbance from pile driving resulting in any effect on vital rates or population level changes, and thus the impact is considered to be **slight**, which is not significant in EIA terms.

Further mitigation

4.11.1.34 None proposed beyond existing commitments (Co110).

Minke whale

4.11.1.35 **Table 4.31** indicates the number of minke whales potentially disturbed by pile driving at each modelling location for both monopiles and pin piles under the MDS. The highest level of disturbance in spatial terms is predicted to be from the installation of a monopile at the northwest location resulting in 46 minke whales predicted to be potentially disturbed once hammer energy reaches its maximum, which represents 0.23% of the reference population. The equivalent number during pin pile installation at the same location is 40 whales (0.20% of the population) which represents the highest level of disturbance in temporal terms.

Table 4.31: Number of minke whales predicted to experience behavioural disturbance for the MDS. Shaded cells denote the maximum number of animals potentially disturbed for both monopiles and pin piles.

Full hammer energy - MDS	Monopile (5,000 kJ)				Pin pile (3,000 kJ)			
	NW	E	S	HVAC	NW	E	S	HVAC
# Whales	46	32	25	40	40	28	21	36
% of MU	0.23%	0.16%	0.12%	0.20%	0.20%	0.14%	0.10%	0.18%

4.11.1.36 **Table 4.32** indicates the number of minke whales potentially disturbed by pile driving at each modelling location for both monopiles and pin piles under the most likely scenario. The highest level of disturbance in spatial terms is predicted from the installation of a monopile at the northwest location, where a total of 44 minke whales are predicted to be potentially disturbed as a result of the installation of a monopile, which represents 0.22% of the reference population. The equivalent number for pin piles is 33 animals (0.16% of the MU) which represents the highest level of disturbance in temporal terms.

Table 4.32: Number of minke whales predicted to experience potential behavioural disturbance for the most likely piling scenarios. Shaded cells denote the maximum number of animals potentially disturbed for both monopiles and pin piles.

Full hammer energy – most likely	Monopile (4,000 kJ)				Pin pile (1,750 kJ)			
	NW	E	S	HVAC	NW	E	S	HVAC
Number of whales	44	30	23	38	33	23	17	30
% of MU	0.22%	0.15%	0.11%	0.19%	0.16%	0.11%	0.08%	0.15%

4.11.1.37 **Table 4.33** indicates the number of minke whales potentially disturbed by simultaneous pile driving for both monopiles and pin piles under the MDS. The highest potential disturbance levels were for the simultaneous installation of two monopiles where 60 whales are predicted to be disturbed (0.30% of the reference population) which represents the highest level of disturbance in spatial terms. The equivalent number for simultaneous pin piles is 53 whales (0.26% of the population) which represents the highest level of disturbance in temporal terms.

Table 4.33: Number of minke whales predicted to experience behavioural disturbance for simultaneous pile driving for monopiles and pin piles under the MDS.

Full hammer energy, MDS	Monopile (5,000 kJ)	Pin pile (3,000 kJ)
	NW & E	NW & E
Number of Whales	60	53
% of MU	0.30%	0.26%

4.11.1.38 As outlined in **Table 4.10**, all piling related disturbance will occur over a maximum of 12 months, with monopiles requiring fewer total piling days than pin piles. According to the best available knowledge on the topic, as provided in an expert elicitation: "*Experts felt disturbance may result in reduced feeding and an increase in energetic costs of movement and therefore a reduction in body condition and elevated stress levels*" which the experts agreed could in turn affect fertility rates (Harwood et al. 2014); although expert opinion varied quite considerably on the duration of disturbance required to result in a reduction in fertility. A total of up to 44 individuals may be affected during piling (60 individuals for simultaneous piling), therefore the most conservative assumption would be that individuals are repeatedly disturbed and that the total disturbance results in a failure of a small proportion of the MU to breed in the year of disturbance. However, this is considered highly unlikely as disturbed animals would probably move away from the area and not be subject to repeated disturbance. This level of disturbance is not expected to have a lasting effect on the overall population trajectory.

4.11.1.39 It should also be noted that the baseline characterisation data confirmed that minke whales are only present in the area in the summer months (May-Aug during the site-specific aerial surveys), and therefore it is expected that they will only be disturbed during the summer months.

Magnitude of impact

4.11.1.40 The impact is predicted to be of local spatial extent, short term duration, intermittent and high reversibility. The extent of the impact in terms of the number of animals, the proportion of the MU affected, and the duration of the impact is negligible. The magnitude is therefore considered to be **negligible** for minke whales under both the most likely and the maximum design single piling scenarios and the maximum design simultaneous piling scenario. Irrespective of the sensitivity of the receptor, the significance of the impact on minke whale is **not significant** as defined in the assessment of significance matrix (**Table 4.13**) and is therefore not considered further in this assessment.

White-beaked dolphin

4.11.1.41 **Table 4.34** indicates the number of white-beaked dolphins potentially disturbed by pile driving at each modelling location for both monopiles and pin piles under the MDS. The highest level of disturbance in spatial terms is predicted to be from the installation of a monopile at the northwest location resulting in 85 dolphins predicted to be potentially disturbed once hammer energy reaches its maximum, which represents 0.19% of the reference population. The equivalent number during pin pile installation at the same location is 74 dolphins (0.17% of the population) which represents the highest level of disturbance in temporal terms.

Table 4.34: Number of white-beaked dolphins predicted to experience behavioural disturbance for the MDS. Shaded cells denote the maximum number of animals potentially disturbed for both monopiles and pin piles.

Full hammer energy - MDS	Monopile (5,000 kJ)				Pin pile (3,000 kJ)			
	NW	E	S	HVAC	NW	E	S	HVAC
# Dolphins	85	40	43	77	74	35	37	67
% MU	0.19%	0.09%	0.10%	0.18%	0.17%	0.08%	0.08%	0.15%

4.11.1.42 **Table 4.35** indicates the number of white-beaked dolphins potentially disturbed by pile driving at each modelling location for both monopiles and pin piles under the most likely scenario. The highest level of disturbance in spatial terms is predicted from the installation of a monopile at the northwest location, where a total of 78 white-beaked dolphins are predicted to be disturbed, which represents 0.18% of the reference population. The equivalent number for pin piles at the same location is 64 animals (0.15% of the population) which represents the highest level of disturbance in temporal terms.

Table 4.35: Number of white-beaked dolphins predicted to experience potential behavioural disturbance for the most likely piling scenarios. Shaded cells denote the maximum number of animals potentially disturbed for both monopiles and pin piles.

Full hammer energy – most likely	Monopile (4,000 kJ)				Pin pile (1,750 kJ)			
	NW	E	S	HVAC	NW	E	S	HVAC
Number of animals	78	38	40	74	64	29	30	62
% of MU	0.18%	0.09%	0.09%	0.17%	0.15%	0.07%	0.07%	0.14%

4.11.1.43 **Table 4.36** indicates the number of white-beaked dolphins potentially disturbed by simultaneous pile driving for both monopiles and pin piles under the maximum design scenario. The highest potential disturbance levels were for the simultaneous installation of two monopiles where 91 dolphins are predicted to be disturbed (0.21% of the reference population) which represents the highest level of disturbance in spatial terms. The equivalent number for simultaneous pin piles is 88 dolphins (0.20% of the population) which represents the highest level of disturbance in temporal terms.

Table 4.36: Number of white-beaked dolphins predicted to experience behavioural disturbance for the maximum design simultaneous scenario.

Full hammer energy - MDS	Monopile (5,000 kJ)	Pin pile (3,000 kJ)
	NW & E	NW & E
Number of dolphins	91	88
% of MU	0.21%	0.20%

4.11.1.44 As outlined in **Table 4.10**, all disturbance will occur intermittently over a maximum period of 12 months, with monopiles requiring fewer total piling days than pin piles. White-beaked dolphins were not included as part of the expert elicitation process; therefore, it is not possible to present equivalent expert elicitation findings for this species. However, given that there is information for bottlenose dolphins, and that both species are grouped together as high-frequency cetaceans, the results of a previous bottlenose dolphin expert explication (Harwood et al. 2014) can be used as a proxy for white-beaked dolphins. The experts agreed that disturbance could (depending on the levels) result in some reduction in fecundity, calf and juvenile survival rates. However, as outlined in the harbour porpoise section (**paragraph 4.10.4.16**), it is highly likely that white-beaked dolphins, like harbour porpoise, will be able to compensate for any disturbance by increasing foraging beyond the impact range. There is no indication that the area is a key foraging area for white-beaked dolphins and therefore it is considered to be unlikely that animals would remain in the impacted area on repeated days of impact, and thus unlikely that they would receive the repeated levels of disturbance that would result in changes to vital rates. Given the low numbers of white-beaked dolphins predicted to experience behavioural disturbance from pile driving, there is expected to be no impact on the population size or trajectory and therefore the impact of disturbance from piling driving is considered to be of negligible magnitude.

4.11.1.45 It should also be noted that the baseline characterisation data confirmed that white-beaked dolphin sightings were are only predominant in the area in the winter months

(Nov-Jan during the site-specific aerial surveys) (see **Volume A5, Annex 4.1: Marine Mammal Technical Report**), and therefore it is expected that they will only potentially be present over a few months of construction.

Magnitude of impact

4.11.1.46 The impact is predicted to be of local spatial extent, short term duration, intermittent and high reversibility. 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 negligible. The magnitude is therefore, considered to be **negligible** for white-beaked dolphins under both the most likely and the maximum design single piling scenarios and the maximum design simultaneous piling scenario. Irrespective of the sensitivity of the receptor, the significance of the impact on white-beaked dolphin is **not significant** as defined in the assessment of significance matrix (**Table 4.13**) and is therefore not considered further in this assessment.

Bottlenose dolphin

4.11.1.47 **Table 4.37** indicates the number of bottlenose dolphins potentially disturbed by pile driving at each modelling location for both monopiles and pin piles under the MDS. The highest level of disturbance in spatial terms is predicted from the installation of a monopile at the NW location, where a total of 14 bottlenose dolphins are predicted to be disturbed, which represents 0.63% of the reference population. The equivalent number for pin piles at the same location is 12 animals (0.54% of the population) which represents the highest level of disturbance in temporal terms.

Table 4.37: Number of bottlenose dolphins predicted to experience behavioural disturbance for the MDS. Shaded cells denote the maximum number of animals potentially disturbed for both monopiles and pin piles.

Full hammer energy - MDS	Monopile (5,000 kJ)				Pin pile (3,000 kJ)			
	NW	E	S	HVAC	NW	E	S	HVAC
# Dolphins	14	12	9	12	12	10	8	11
% MU	0.63%	0.54%	0.41%	0.54%	0.54%	0.45%	0.36%	0.50%

4.11.1.48 **Table 4.38** indicates the number of bottlenose dolphins potentially disturbed by pile driving at each modelling location for both monopiles and pin piles under the most likely scenario. The highest level of disturbance in spatial terms is predicted from the installation of a monopile at the northwest location, where a total of 13 dolphins are predicted to be disturbed, which represents 0.59% of the reference population. The equivalent number for pin piles at the same location is 10 animals (0.45% of the population) which represents the highest level of disturbance in temporal terms.

Table 4.38: Number of bottlenose dolphins predicted to experience potential behavioural disturbance for the most likely piling scenarios. Shaded cells denote the maximum number of animals potentially disturbed for both monopiles and pin piles.

Full hammer energy – most likely	Monopile (4,000 kJ)				Pin pile (1,750 kJ)			
	NW	E	S	HVAC	NW	E	S	HVAC
Number of animals	13	11	9	11	10	9	7	9
% of MU	0.59%	0.50%	0.41%	0.50%	0.45%	0.41%	0.32%	0.43%

4.11.1.49 Table 4.39 indicates the number of bottlenose dolphins potentially disturbed by simultaneous pile driving for both monopiles and pin piles under the maximum design scenario. The highest potential disturbance levels were for the simultaneous installation of two monopiles where 20 dolphins are predicted to be disturbed (0.90% of the reference population) which represents the highest level of disturbance in spatial terms. The equivalent number for simultaneous pin piles is 17 dolphins (0.77% of the population) which represents the highest level of disturbance in temporal terms.

Table 4.39: Number of bottlenose dolphins predicted to experience behavioural disturbance for the maximum design simultaneous scenario.

Full hammer energy - MDS	Monopile (5,000 kJ)	Pin pile (3,000 kJ)
	NW & E	NW & E
Number of dolphins	20	17
% of MU	0.90%	0.77%

Magnitude of impact

4.11.1.50 When assessing the magnitude of impact, it is important to consider the level of precaution built into the assessment. A key source of precaution in this assessment is that the harbour porpoise dose-response curve and harbour porpoise EDRs have been used for bottlenose dolphins, as there is no bottlenose dolphin-specific equivalent. Harbour porpoise have a lower auditory injury threshold (i.e. higher hearing sensitivity) than bottlenose dolphins (Southall et al. 2019) and are considered to be particularly responsive to anthropogenic disturbance, with playback experiments showing avoidance reactions to very low levels of sound (Tyack 2009) and multiple studies showing that porpoise respond (avoidance and reduced vocalisation) to a variety of anthropogenic noise sources to distances of multiple kilometres (e.g., Brandt et al. 2013, Thompson et al. 2013, Tougaard et al. 2013, Brandt et al. 2018, Sarnocinska et al. 2019, Thompson et al. 2020, Benhemma-Le Gall et al. 2021). Studies have shown that dolphin species show comparatively less of a disturbance response from underwater noise compared to harbour porpoise. For example, through an analysis of 16 years of marine mammal observer data from seismic survey vessels, Stone et al. (2017) found a significant reduction in porpoise detection rates when large seismic airgun arrays were actively firing, but not for bottlenose dolphins. While the strength and significance of responses varied between porpoise and other dolphin species for different measures of effect, the study emphasised the sensitivity of the harbour porpoise (Stone et al. 2017) In the Moray Firth, bottlenose dolphins have been shown to remain in the impacted area during both seismic activities and pile installation activities (Fernandez-Betelu et al.

2021) which highlights a lack of complete displacement response. Likewise, other high-frequency cetacean species such as striped and common dolphins have been shown to display less of a response to underwater noise signals and construction-related activities compared to harbour porpoise (e.g. Kastelein et al. 2006, Culloch et al. 2016). Noise modelling in support of UXO clearance impact assessments consistently estimate that, based on differences in hearing sensitivity alone, the anticipated range to the onset of temporary hearing loss (TTS, sometimes used as a proxy for behavioural responses to a single impulse) for harbour porpoise is c. 10-20 times greater than that for dolphins (e.g. Mason and Barnham 2018, Neart na Gaoithe Offshore Wind Farm 2019). Considering the above, it can be concluded that using porpoise response data as a proxy for bottlenose dolphins is likely to result in an over-estimate of the response for bottlenose dolphins.

4.11.1.51 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 negligible. The magnitude is therefore considered to be **negligible** in line with the definition provided in **Table 4.12.**

Sensitivity of the receptor

4.11.1.52 As outlined in **paragraph 4.10.4.21** onwards, disturbance as result of pile driving may temporarily result in disruption in foraging and resting activities and an increase in travel and energetic costs. Due to observed responsiveness to piling, and their ability to compensate for behavioural responses, the sensitivity of bottlenose dolphins is therefore considered to be **medium**.

Significance of the effect

4.11.1.53 Overall, the sensitivity of bottlenose dolphins to disturbance has been assessed as **medium** and given the precautionary use of the porpoise dose-response curve, and the fact that it is highly unlikely that bottlenose dolphins would remain in the area on consecutive days and therefore very little chance of repeated disturbance resulting in any effect on vital rates or population level changes, the impact is considered to be **slight**, which is not significant in EIA terms (**Table 4.13**).

Further mitigation

4.11.1.54 None proposed beyond existing commitments (Co110).

Harbour seal

4.11.1.55 **Table 4.40** indicates the number of harbour seals potentially disturbed by pile driving at each modelling location for both monopiles and pin piles under the MDS. The highest level of disturbance in spatial terms is predicted to be from the installation of a monopile at the HVAC location resulting in five harbour seals predicted to be potentially disturbed once hammer energy reaches its maximum, which represents 0.10% of the reference population. The equivalent number during pin pile installation at the same location is four seals (0.08% of the population) which represents the highest level of disturbance in temporal terms.

Table 4.40: Number of harbour seals predicted to experience behavioural disturbance for the MDS. Shaded cells denote the maximum number of animals potentially disturbed for both monopiles and pin piles.

Full hammer energy - MDS	Monopile (5,000 kJ)				Pin pile (3,000 kJ)			
	NW	E	S	HVAC	NW	E	S	HVAC
Habitat preference map (Carter et al. 2020)								
# Harbour Seals	1 (0 – 2)	1 (0 – 2)	2 (0 – 4)	5 (1 – 9)	1 (0 – 2)	1 (0 – 2)	2 (0 – 3)	4 (0 – 7)
% MU	0.02% (0.00 – 0.04)	0.02% (0.00 – 0.04)	0.04% (0.00 – 0.08)	0.10% (0.02 – 0.17)	0.02% (0.00 – 0.04)	0.02% (0.00 – 0.04)	0.04% (0.00 – 0.06)	0.08% (0.00 – 0.13)

4.11.1.56 Table 4.41 indicates the number of harbour seals potentially disturbed by pile driving at each modelling location for both monopiles and pin piles under the most likely scenario. The highest disturbance levels were predicted for the HVAC location, where a total of 4 harbour seals are predicted to be disturbed for the installation of a monopile, which represents 0.08% of the reference population. The equivalent number for pin piles at the same location is 3 animals (0.06% of the population) which represents the highest level of disturbance in temporal terms.

Table 4.41: Number of harbour seals predicted to experience behavioural disturbance for the most likely piling scenarios. Shaded cells denote the maximum number of animals potentially disturbed for both monopiles and pin piles.

Full hammer energy – most likely	Monopile (4,000 kJ)				Pin pile (1,750 kJ)			
	NW	E	S	HVAC	NW	E	S	HVAC
Number of harbour seals	1 (0 – 2)	1 (0 – 2)	2 (0 – 3)	4 (0 – 8)	1 (0 – 1)	1 (0 – 1)	1 (0 – 2)	3 (0 – 6)
% of MU	0.02% (0.00 – 0.04)	0.02% (0.00 – 0.04)	0.04% (0.00 – 0.06)	0.08% (0.00 – 0.15)	0.02% (0.00 – 0.02)	0.02% (0.00 – 0.02)	0.02% (0.00 – 0.04)	0.06% (0.00 – 0.12)

4.11.1.57 Table 4.42 indicates the number of harbour seals potentially disturbed by simultaneous pile driving for both monopiles and pin piles under the MDS. The highest potential disturbance levels were for the simultaneous installation of two monopiles where two harbour seals are predicted to be disturbed (0.04% of the reference population) which represents the highest level of disturbance in spatial terms. The equivalent number for simultaneous pin piles is two animals (0.04% of the population) which represents the highest level of disturbance in temporal terms.

Table 4.42: Number of harbour seals predicted to experience behavioural disturbance for the maximum design simultaneous scenario.

Full hammer energy - MDS	Monopile (5,000 kJ)	Pin pile (3,000 kJ)
	NW & E	NW & E
Number of harbour seals	2 (0 – 4)	2 (0 – 3)
% of MU	0.04% (0.00 – 0.08)	0.04% (0.00 – 0.06)

4.11.1.58 As outlined in **Table 4.10**, all disturbance will occur intermittently over a maximum period of 12 months, with monopiles requiring fewer total piling days than pin piles. Given the results of the recent expert elicitation on the likely effects of behavioural disturbance on vital rates (Booth et al. 2019) (see **Section 4.10.4**), there is the potential for this level of disturbance to cause an effect on fertility rates and survival of 'weaned of the year' animals, however expert opinions varied greatly on the number of days of repeated disturbance that this would require. The area has an estimated low density of harbour seals, and as such, it is not considered to be an important foraging area for the species. Therefore, any disturbance and displacement is unlikely to result in a significant reduction in energy intake and thus unlikely to result in changes to individual vital rates. In addition, data collated during wind farm construction has shown that harbour seal density quickly recovers once piling has ceased, and so any disturbance is likely to be short lived and temporary in nature. Given the extremely low numbers of harbour seals predicted to experience behavioural disturbance from pile driving, there is expected to be no impact on the population size or trajectory and therefore the impact of disturbance from piling driving is considered to be of negligible magnitude.

Magnitude of impact

4.11.1.59 The impact is predicted to be of local spatial extent, short term duration, intermittent and high reversibility. 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 negligible. The magnitude is therefore, considered to be **negligible** for harbour seals under both the most likely and the maximum design single piling scenarios and the maximum design simultaneous piling scenario. Irrespective of the sensitivity of the receptor, the significance of the impact on harbour seal is **not significant** as defined in the assessment of significance matrix (**Table 4.13**) and is therefore not considered further in this assessment.

Grey seal

4.11.1.60 **Table 4.43** indicates the number of grey seals potentially disturbed by pile driving at each modelling location for both monopiles and pin piles under the MDS. The highest level of disturbance in spatial terms is predicted to be from the installation of a monopile at the HVAC location resulting in 1,489 grey seals predicted to be potentially disturbed once hammer energy reaches its maximum, which represents 2.3% of the reference population. The equivalent number during pin pile installation at the same location is 1,291 seals (2.0% of the population) which represents the highest level of disturbance in temporal terms.

Table 4.43: Number of grey seals predicted to experience behavioural disturbance for the MDS. Shaded cells denote the maximum number of animals potentially disturbed for both monopiles and pin piles.

Full hammer energy - MDS	Monopile (5,000 kJ)				Pin pile (3,000 kJ)			
	NW	E	S	HVAC	NW	E	S	HVAC
# Grey Seals	864 (102 – 1606)	809 (109 – 1473)	703 (89 – 1295)	1,489 (199 – 2703)	708 (80 – 1328)	692 (87 – 1272)	585 (69 – 1090)	1,291 (161 – 2371)
% MU	1.4% (0.2 – 2.5)	1.3% (0.2 – 2.3)	1.1% (0.1 – 2.0)	2.3% (0.3 – 4.3)	1.1% (0.1 – 2.1)	1.1% (0.1 – 2.0)	0.9% (0.1 – 1.7)	2.0% (0.3 – 3.7)

4.11.1.61 **Table 4.44**: indicates the number of grey seals potentially disturbed by pile driving at each modelling location for both monopiles and pin piles under the most likely scenario. The highest potential disturbance levels on a spatial basis were predicted for the HVAC location where a total of 1,399 grey seals are predicted to be disturbed for the installation of a monopile, which represents 2.2% of the reference population. The equivalent number for pin piles at the same location is 1,038 animals (1.6% of the population), though noting that the piling duration at the HVAC location is of very short duration.

Table 4.44: Number of grey seals predicted to experience behavioural disturbance for the most likely piling scenarios. Shaded cells denote the maximum number of animals potentially disturbed for both monopiles and pin piles.

Full hammer energy – most likely	Monopile (4,000 kJ)				Pin pile (1,750 kJ)			
	NW	E	S	HVAC	NW	E	S	HVAC
# Grey seals	797 (92 – 1487)	760 (100 – 1388)	653 (81 – 1208)	1,399 (181 – 2553)	536 (56 – 1016)	558 (64 – 1038)	449 (47 – 849)	1,038 (118 – 1937)
% of MU	1.3% (0.1 – 2.3)	1.2% (0.2 – 2.2)	1.0% (0.1 – 1.9)	2.2% (0.3 – 4.0)	0.8% (0.1 – 1.6)	0.9% (0.1 – 1.6)	0.7% (0.1 – 1.3)	1.6% (0.2 – 3.1)

4.11.1.62 Table 4.45 indicates the number of grey seals potentially disturbed by simultaneous pile driving for both monopiles and pin piles under the MDS. The highest potential disturbance levels were for the simultaneous installation of two monopiles where 1,371 grey seals are predicted to be disturbed (2.2% of the reference population) which represents the highest level of disturbance in spatial terms. The equivalent number for simultaneous pin piles is 1,177 animals (1.9% of the population) which represents the highest level of disturbance in temporal terms.

Table 4.45: Number of grey seals predicted to experience behavioural disturbance for the maximum design simultaneous scenario.

Full hammer energy, MDS	Monopile (5,000 kJ)	Pin pile (3,000 kJ)
	NW & E	NW & E
Number of grey seals	1,371 (187 – 2488)	1,177 (150 – 2156)
% of MU	2.2% (0.3 – 3.9)	1.9% (0.2 – 3.4)

4.11.1.63 As outlined in Table 4.10, all disturbance will occur intermittently over a maximum period of 12 months, with monopiles requiring fewer total piling days than pin piles and concurrent piling requiring few piling days than single vessel piling. Given the results of the expert elicitation on the likely effects of behavioural disturbance on vital rates (Booth et al. 2019) (see Section 4.10.4), there is the potential for this level of disturbance to cause an effect on fertility rates and survival of 'weaned of the year' animals if repeated disturbance were to result in a significant reduction in foraging and therefore energy intake; however expert opinions varied greatly on the number of days of repeated disturbance that this would require. Data collated during wind farm construction has shown that seals quickly return to the area once piling has ceased, and so any disturbance is likely to be short lived and temporary in nature (Russell et al. 2016). In addition, telemetry data have shown that not all grey seals respond to pile driving (Aarts et al. 2018), and so may not be disturbed and displaced out of an area that they are motivated to stay in for foraging. Overall, there is the potential for a risk of a decline in fertility and survival of 'weaned of the year' for a very small proportion of the population if animals are repeatedly displaced from foraging areas over the 12 month construction period, though this is highly unlikely and would be limited to one breeding cycle. This risk is discussed further below in the context of Hornsea Four.

4.11.1.64 The dose-response curve used for grey seal behavioural responses was produced from data obtained from tagged harbour seals only, and there is currently no grey seal dose-response curve available. Grey seals are considered to be less sensitive to behavioural disturbance than harbour seals (see Section 4.10.4), and recent studies of tagged grey seals have shown that there is vast individual variation is responses to pile driving, with some animals not showing any evidence of a behavioural response when within 12 km of the pile driving location (Aarts et al. 2018). Therefore, the adoption of the harbour seal dose-response curve for grey seals is likely to over-estimate the potential for impact on grey seals.

4.11.1.65 Based on the data presented in Aarts et al. (2018) and Hastie et al. (2021) it is possible that some grey seals may show no behavioural response at all, given their motivation to remain in the area for foraging (if the area contains a high quality prey patch). The quality of the Hornsea Four array area as a prey patch is unknown, and the importance of this area to grey seals specifically for foraging has not been quantitatively assessed. However, some inference can be made from movement and distribution data. Habitat preference data do not appear to indicate that the Hornsea Four array area itself is an important foraging location, given the predicted moderate to low densities of grey seal relative to elsewhere around the British Isles. Furthermore, telemetry data show low density of tracks through the array area, with the majority of these tracks suggestive of transit to other areas, rather than area-restricted search patterns (more sinuous tracks) indicative of foraging (Boyd 1996) which are observed to the west/north-west of the Hornsea Four array area and in multiple discrete areas elsewhere in the wider region. Given the wide ranging behaviour of grey seals, travelling up to 448 km from a haul-out site (Carter et al. 2020), it is highly likely that any grey seals displaced from lower quality prey patches will be able to compensate by travelling to a different foraging patch, and thus it is expected that any displacement would result in minimal energetic cost and thus is unlikely to result in any changes in vital rates for the individual. Should the seals choose to remain in the area during piling then this indicates that the energetic benefit outweighs the perceived risk from piling.

4.11.1.66 Similarly, it is expected that some grey seals may be displaced around the HVAC location at the time of piling, however pile driving will be temporary in nature (maximum three HVAC stations, taking 1.2 days each to install) and since not all seals are predicted to respond they will still be expected to transit through and around this area from the Humber Estuary SAC in order to reach foraging sites. This very short-term disturbance at the HVAC site is not considered to be sufficient to result in changes to individual vital rates.

4.11.1.67 This type of short-term, intermittent and temporary behavioural response will affect only a very small proportion of the population and it is highly likely that any grey seals displaced will be able to compensate by travelling to a different foraging patch, and thus it is expected that any displacement would result in minimal energetic cost and thus is unlikely to result in any changes in vital rates for the individual. Therefore survival and reproductive rates are very unlikely to be impacted to the extent that the population trajectory would be altered, and as such, the impact is considered to be of minor magnitude at most.

Magnitude of impact

4.11.1.68 The impact is predicted to be of local spatial extent, short term duration, intermittent and high reversibility. 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 minor. The magnitude is therefore considered to be **minor** for grey seals.

Sensitivity of the receptor

4.11.1.69 As outlined in **paragraph 4.10.4.22** onwards, the sensitivity of grey seals is considered to be **low**.

Significance of the effect

4.11.1.70 Overall, the sensitivity of grey seals to disturbance has been assessed as **low** and the magnitude is predicted to be **minor** under both the most likely and the maximum design single piling scenarios and the maximum design simultaneous piling scenario. The effect is of **slight** significance, which is not significant in EIA terms.

Further mitigation

4.11.1.71 None proposed beyond existing commitments.

Summary of potential behavioural disturbance from piling noise

4.11.1.72 The impact of behavioural disturbance from piling noise under both the MDS and the most likely scenario is not considered to have a significant effect on any marine mammal species considered in this assessment.

Table 4.46: Summary of predicted significance of impacts to marine mammals resulting from behavioural disturbance under both the MDS and the most likely scenario and the maximum design simultaneous piling scenario.

Species	Magnitude	Sensitivity	Significance
Harbour porpoise	**Minor**	**Medium**	**Slight** (not significant in EIA terms)
Minke whale	**Negligible**	**Medium**	**Slight** (not significant in EIA terms)
White-beaked dolphin	**Negligible**	**Medium**	**Slight** (not significant in EIA terms)
Bottlenose dolphin	**Negligible**	**Medium**	**Slight** (not significant in EIA terms)
Harbour seal	**Negligible**	**Medium**	**Slight** (not significant in EIA terms)
Grey seal	**Minor**	**Low**	**Slight** (not significant in EIA terms)

TTS-onset from piling noise (MM-C-3)

4.11.1.73 Full details of the underwater noise modelling and the resulting TTS-onset impact areas and ranges are detailed in **Volume A4, Annex 4.5: Subsea Noise Technical Report**. As outlined in **Section 4.10.3**, there are no thresholds to determine a biologically significant effect from TTS-onset, therefore the predicted ranges and area for the onset of TTS are presented in **Table 4.47** to **Table 4.50** for the most likely scenario, and **Table 4.51** to **Table 4.54** for the MDS, but no assessment of the number of animals, magnitude, sensitivity or significance of effect is given. This approach was agreed with members of EP Technical Panel at EP Technical Panel Meeting Four (30 April 2019, OFF-MM-2.1).

Most likely scenario

Table 4.47: Predicted harbour porpoise TTS-onset impact ranges for the most likely scenario.

	Monopile (4,000 kJ)				Pin pile (1,750 kJ)			
TTS Threshold	NW	E	S	HVAC	NW	E	S	HVAC
196 dB Unweighted SPL_{peak}								
Area (km^2)	110	80	71	100	38	27	26	37
Max Range (m)	6,000	5,700	4,800	5,800	3,500	3,200	2,900	3,500
140 dB VHF Weighted SEL_{cum}								
Area (km^2)	570	450	290	580	1500	1,100	830	1,400
Max Range (m)	16,000	18,000	12,000	15,000	26,000	29,000	21,000	24,000

Table 4.48: Predicted minke whale TTS-onset impact ranges for the most likely scenario.

	Monopile (4,000 kJ)				Pin pile (1,750 kJ)			
TTS Threshold	NW	E	S	HVAC	NW	E	S	HVAC
213 dB Unweighted SPL_{peak}								
Area (km^2)	0.42	0.32	0.34	0.42	0.1	0.08	0.08	0.1
Max Range (m)	370	320	330	370	180	160	160	180
168 dB LF Weighted SEL_{cum}								
Area (km^2)	1,800	1,300	920	1,600	1,300	870	600	1,100
Max Range (m)	32,000	35,000	24,000	29,000	26,000	30,000	20,000	24,000

Table 4.49: Predicted white-beaked dolphin and bottlenose dolphin TTS-onset impact ranges for the most likely scenario.

	Monopile (4,000 kJ)				Pin pile (1,750 kJ)			
TTS Threshold	NW	E	S	HVAC	NW	E	S	HVAC
224 dB Unweighted SPL_{peak}								
Area (km^2)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Max Range (m)	50	50	50	50	<50	<50	<50	<50
170 dB HF Weighted SEL_{cum}								
Area (km^2)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Max Range (m)	<100	<100	<100	<100	<100	<100	<100	<100

Table 4.50: Predicted harbour and grey seal TTS-onset impact ranges for the most likely scenario.

	Monopile (4,000 kJ)				Pin pile (1,750 kJ)			
TTS Threshold	NW	E	S	HVAC	NW	E	S	HVAC
212 dB Unweighted SPL_{peak}								
Area (km^2)	0.61	0.47	0.48	0.61	0.15	0.11	0.12	0.15
Max Range (m)	440	390	390	440	220	190	190	220
170 dB PCW Weighted SEL_{cum}								
Area (km^2)	430	340	200	440	180	140	68	180
Max Range (m)	14,000	15,000	9,800	13,000	8,900	9,600	5,300	8,100

Maximum design scenario

Table 4.51: Predicted harbour porpoise TTS-onset impact ranges for the MDS.

	Monopile (5,000 kJ)				Pin pile (3,000 kJ)			
TTS Threshold	NW	E	S	HVAC	NW	E	S	HVAC
196 dB Unweighted SPL_{peak}								
Area (km²)	130	99	86	130	79	58	53	76
Max Range (m)	6,600	6,400	5,300	6,400	5,100	4,800	4,200	5,000
140 dB VHF Weighted SEL_{cum}								
Area (km²)	880	650	440	840	2,500	1,800	1,400	2,200
Max Range (m)	20,000	23,000	15,000	19,000	36,000	39,000	28,000	33,000

Table 4.52: Predicted minke whale TTS-onset impact ranges for the MDS.

	Monopile (5,000 kJ)				Pin pile (3,000 kJ)			
TTS Threshold	NW	E	S	HVAC	NW	E	S	HVAC
213 dB Unweighted SPL_{peak}								
Area (km²)	0.57	0.44	0.45	0.57	0.27	0.21	0.22	0.27
Max Range (m)	430	380	380	430	300	260	260	300
168 dB LF Weighted SEL_{cum}								
Area (km²)	2,200	1,500	1,100	1,800	2,000	1,300	970	1,700
Max Range (m)	36,000	39,000	26,000	32,000	35,000	37,000	25,000	31,000

Table 4.53: Predicted white-beaked dolphin and bottlenose dolphin TTS-onset impact ranges for the MDS.

	Monopile (5,000 kJ)				Pin pile (3,000 kJ)			
TTS Threshold	NW	E	S	HVAC	NW	E	S	HVAC
224 dB Unweighted SPL_{peak}								
Area (km²)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Max Range (m)	60	50	50	60	<50	50	50	50
170 dB HF Weighted SEL_{cum}								
Area (km²)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Max Range (m)	<100	<100	<100	<100	<100	<100	<100	<100

Table 4.54: Predicted harbour and grey seal TTS-onset impact ranges for the MDS.

	Monopile (5,000 kJ)				Pin pile (3,000 kJ)			
TTS Threshold	NW	E	S	HVAC	NW	E	S	HVAC
212 dB Unweighted SPL_{peak}								
Area (km²)	0.82	0.63	0.65	0.82	0.39	0.3	0.31	0.4
Max Range (m)	510	450	460	510	360	310	320	360
170 dB NOAA PCW Weighted SEL_{cum}								
Area (km²)	670	510	330	660	480	370	220	480
Max Range (m)	18,000	20,000	13,000	17,000	15,000	17,000	11,000	14,000

Vessel collision risk (MM-C-4)

4.11.1.74 The area surrounding Hornsea Four already experiences a reasonable amount of vessel traffic throughout the year, with an average of 26 or 27 vessels per day passing through the array area (in summer and winter, respectively - see **Chapter 7: Shipping and Navigation**). Therefore, the introduction of additional vessels during construction is not a novel impact for marine mammals present in the area.

4.11.1.75 During construction of the wind farm, a potential source of impact from increased vessel activity is physical trauma from collision with a boat or ship. These injuries include blunt trauma to the body or injuries consistent with propeller strikes. The risk of collision of marine mammals with vessels would be directly influenced by the type of vessel and the speed with which it is travelling (Laist et al. 2001) and indirectly by ambient noise levels underwater and the behaviour the marine mammal is engaged in.

4.11.1.76 There is currently a lack of information on the frequency of occurrence of vessel collisions as a source of marine mammal mortality. There is little evidence from marine mammals stranded in the UK that injury from vessel collisions is an important source of mortality. The UK Cetacean Strandings Investigation Programme (CSIP) documents the annual number of reported strandings and the cause of death for those individuals examined at post-mortem. **Table 4.55** outlines the number of strandings for each species, how many were examined at post-mortem and how many concluded vessel collisions as the cause of death between 2005 and 2015. The CSIP data shows that very few strandings have been attributed to vessel collisions, therefore, while there is evidence that mortality from vessel collisions can and does occur, it is not considered to be a key source of mortality highlighted from post-mortem examinations. However, it is important to note that the strandings data are biased to those carcasses that wash ashore for collection and therefore may not be representative.

Table 4.55: Data from the UK CSIP[11] on the number of cetacean strandings and identified causes of death.

Species	Period	# Stranded	# Post-mortems	Vessel collision	Unknown physical trauma
Harbour Porpoise	2011-2015	1676	371	13	23
	2005-2010	1922	478	4	22
Minke Whale	2011-2015	75	16	2	0
	2005-2010	87	11	1	0
White-beaked dolphin	2011-2015	79	33	0	1
	2005-2010	70	23	0	0

4.11.1.77 There are very few studies that indicate a critical level of activity in relation to risk of collisions but an analysis presented in Heinänen and Skov (2015) suggested that harbour porpoise density was significantly lower in areas with vessel transit rates of greater than

[11] (CSIP 2011, 2012, 2013, 2014, 2015, 2016)

80 per day within a 5 km grid. As outlined in **Volume A1, Chapter 4: Project Description**, the busiest period during construction in terms of vessel traffic would be when up to eight vessels are present in a given 5 km^2 block. This level of activity is unlikely to occur across the entire Hornsea Four array area at any one time, rather this intensity is expected across approximately three or four 5 km^2 blocks. Vessel traffic in the Hornsea Four area, even considering the addition of construction traffic, will still be below 80 per day within a 5 km grid.

4.11.1.78 Harbour porpoises, dolphins and seals are relatively small and highly mobile, and given observed responses to noise, are expected to detect vessels in close proximity and largely avoid collision. Predictability of vessel movement by marine mammals is known to be a key aspect in minimising the potential risks imposed by vessel traffic (e.g. Nowacek et al. 2001, Lusseau 2003, 2006). The VMP (Commitment Co108) will ensure that vessel traffic moves along predictable routes and will define how vessels should behave in the presence of marine mammals.

4.11.1.79 It is highly likely that a proportion of vessels will be stationary or slow moving throughout construction activities for significant periods of time. Therefore, the actual increase in vessel traffic (see **Table 4.10**) moving around the site and to/from port to the site will occur over short periods of the offshore construction activity.

Magnitude of impact

4.11.1.80 It is not expected that the level of vessel activity during construction would cause an increase in the risk of mortality from collisions. The adoption of a vessel management plan during construction (Commitment Co108) will minimise the potential for any impact. The impact is therefore predicted to be of local spatial extent, short term duration and intermittent. The magnitude is therefore considered to be **minor**.

Sensitivity of the receptor

4.11.1.81 All marine mammal receptors are deemed to be of low vulnerability given that vessel collision is not considered to be a key source of mortality highlighted from post-mortem examinations of stranded animals. However, should a collision event occur, this is likely to kill or injure the animal. As a result of the low vulnerability to a strike but the serious consequences of a strike, the sensitivity of the marine mammal receptors to collisions is considered to be **high**.

Significance of the effect

4.11.1.82 Overall, the sensitivity of all marine mammals to vessel collisions has been assessed as **high** and the magnitude is predicted to be **minor**. This can result in either a slight or a moderate significance based on the assessment of significance matrix (**Table 4.13**). Given that there have been no reported instances of offshore wind farm construction vessel collisions with harbour porpoise, this impact is more likely to be of **slight** significance, which is not significant in EIA terms.

Further mitigation

4.11.1.83 None proposed beyond existing commitments (see of **Volume A4, Annex 5.2 Commitment Register)**.

Disturbance from vessels (MM-C-5)

4.11.1.84 Increased vessel traffic during construction has the potential to result in disturbance of marine mammals. Disturbance from vessel noise is only likely to occur where increased noise from vessel movements associated with the construction of the Development is greater than the background ambient noise. The maximum design scenario (**Table 4.10**) lists the maximum number of vessels that will be involved in construction. As outlined in **Volume A1, Chapter 4: Project Description**, the busiest period during construction in terms of vessel traffic would be when up to eight vessels are present in a given 5 km^2 block. This level of activity is unlikely to occur across the entire Hornsea Four array area at any one time, rather this intensity is expected across approximately three or four 5 km^2 blocks. The total duration of the installation campaign for turbines is expected to be a maximum of 12 months.

4.11.1.85 During the period of piling operations, it is considered unlikely that vessel noise will impact marine mammal receptors at levels additional to the piling activity itself. It is difficult to separate out the effect of vessel presence and activity from the effect of pile driving in isolation, since the data collected to date on the response of animals to pile driving, will have included a degree of vessel activity in combination with the piling, therefore it could be considered that the typical vessel activity related to pile driving, may be already assessed to some extent under the pile driving assessment. Individuals have more potential to be impacted by increased vessel movements during periods when piling is not taking place.

4.11.1.86 The magnitude and characteristics of vessel noise varies depending on ship type, ship size, mode of propulsion, operational factors and speed. Vessels of varying size produce different frequencies, generally becoming lower frequency with increasing size. The distance at which animals may react is difficult to predict and behavioural responses can vary a great deal depending on context.

Magnitude of impact

4.11.1.87 It is not expected that the level of vessel activity during the construction of Hornsea Four would cause a significant increase in the risk of disturbance by vessels. The adoption of a vessel management plan (Commitment Co108) that includes preferred transit routes and guidance for vessel operations in the vicinity of marine mammals and around seal haul-outs will minimise the potential for any impact. The impact is predicted to be of local, short-term duration and intermittent. It is expected that any marine mammals that are disturbed as a result of vessel presence will return to the area once the vessel disturbance has ended. The magnitude is therefore considered to be **minor**.

Sensitivity of the receptor

4.11.1.88 All marine mammal receptors are deemed to be of low vulnerability given the existing evidence behavioural responses to vessels (see **paragraph 4.10.4.31** onwards). The sensitivity of the marine mammal receptors is therefore considered to be **low**.

Significance of the effect

4.11.1.89 Overall, the sensitivity of marine mammals to vessel disturbance has been assessed as **low** and the magnitude is predicted to be **minor**. The effect is of **slight** significance, which is not significant in EIA terms.

Further mitigation

4.11.1.90 None proposed beyond existing commitments.

Reduction in prey availability (MM-C-6)

4.11.1.91 Given that marine mammals are dependent on fish prey, there is the potential for indirect effects on marine mammals as a result of impacts upon fish species or the habitats that support them. The key prey species for each marine mammal receptor are listed in **Table 4.56**.

Table 4.56: Common prey species for each of the marine mammal receptors. Key species are in bold.

Receptor	Prey species	References
Harbour porpoise	**Whiting, sandeel** herring, haddock, saith, pollock, bobtail squid	Pierce et al. (2007)
Minke whale	**Sandeel, herring, sprat** mackerel, goby, Norway pout/poor cod	Pierce et al. (2004)
White-beaked dolphin	**Haddock, whiting** cod, herring, mackerel	Canning et al. (2008)
Bottlenose dolphin	**Cod, saithe, whiting** salmon, mackerel, haddock, pout, squid sp.	Santos et al. (2001) De Pierrepont et al. (2005)
Harbour seal	**Sandeel**, **whiting**, **dragonet** cod, herring, sprat, dover sole, plaice, lemon sole, dab, flounder, goby, bullrout, sea scorpion, octopus, squid	Wilson and Hammond (2016) SCOS (2018)
Grey seal	**Sandeel** cod, whiting, haddock, ling, plaice, sole, flounder, dab	SCOS (2018)

4.11.1.92 **Chapter 3: Fish and Shellfish Ecology** concluded no significant impacts on all fish species, given embedded mitigation measures. Piling at the HVAC site would have the greatest potential impact on spawning herring, however, the implementation of a seasonal restriction for piling at the HVAC booster station location during the peak spawning period of the Banks herring stock of the central North Sea (01 September to 16 October) will mitigate against these impacts (see Co109). With the seasonal restrictions, the impact of noise on spawning herring was assessed as slight significance which is not significant in EIA terms.

4.11.1.93 While there may be certain fish species that comprise the main part of their diet, all marine mammals in this assessment are considered to be generalist feeders and are thus not reliant on a single prey species. Given that no significant impact has been identified for any fish species, the magnitude of this impact on marine mammals is therefore considered to be **negligible**. Irrespective of the sensitivity of the receptor, the significance of the impact on marine mammals is **not significant** as defined in the assessment of significance matrix (**Table 4.13**) and is therefore not considered further in this assessment.

Reduction in foraging ability (MM-C-7)

4.11.1.94 Disturbance to water quality as a result of construction activities can have both direct and indirect impacts on marine mammals. Indirect impacts would include effects on prey species which have already been covered in the previous section. Direct impacts include the impairment of visibility and therefore foraging ability which might be expected to reduce foraging success. Marine mammals are well known to forage in tidal areas where water conditions are turbid and visibility conditions poor. For example, harbour porpoise and harbour seals in the UK have been documented foraging in areas with high tidal flows (e.g. Pierpoint 2008, Marubini et al. 2009, Hastie et al. 2016); therefore, low light levels, turbid waters and suspended sediments are unlikely to negatively impact marine mammal foraging success. It is important to note that it is hearing, not vision that is the primary sensory modality for most marine mammals. When the visual sensory systems of marine mammals are compromised, they are able to sense the environment in other ways, for example, seals can detect water movements and hydrodynamic trails with their mystacial vibrissae; while odontocetes primarily use echolocation to navigate and find food in darkness.

4.11.1.95 **Chapter 1: Marine Geology, Oceanography and Physical Processes** concluded that the magnitude of the maximum potential increase in Suspended Sediment Concentrations (SSC) resulting from construction activities is negligible and the impact will be short-term, intermittent and of localised extent and reversible. Therefore, there is expected to be no significant increase in the level of SSC from the construction of Hornsea Four. The magnitude of this impact is therefore considered to be **negligible**. Irrespective of the sensitivity of the receptor, the significance of the impact on marine mammals is **not significant** as defined in the assessment of significance matrix (**Table 4.13**) and is therefore not considered further in this assessment.

PTS from UXO clearance (MM-C-11)

4.11.1.96 There is the potential requirement for underwater UXO clearance prior to construction. However, since a UXO survey has not yet been conducted, it is not possible at this time to define an accurate prediction of the number of UXO which may require detonation. As a result, a separate Marine Licence application will be submitted pre-construction for the detonation of any UXO. However, the detonation of UXO is a source of additional noise in the marine environment and hence is considered in the assessment for marine mammals. For this assessment, it has been assumed that a total of 86 targets will require detonation over a period of 150 to 324 days (depending on the number of targets per day)[12]. UXO clearance for the purposes of this assessment is considered to involve the high-order detonation of the UXO in situ to make it safe to undertake construction works in the surrounding area.

4.11.1.97 Current advice from the statutory nature conservation bodies (SNCBs) is that the recent NOAA/Southall injury thresholds (NMFS 2018, Southall et al. 2019) should be used for assessing the impacts from UXO detonation on marine mammals. However, the suitability of the NOAA criteria for UXO is under discussion due to the lack of empirical evidence from UXO detonations using the NOAA metrics, in particular the range dependent characteristics of the peak sounds, and whether current propagation models can accurately predict the range at which these thresholds are reached. No noise modelling has been conducted for UXO clearance for Hornsea Four. For Hornsea Project Two, an estimation of the source level and predicted PTS-onset impact ranges were calculated for a range of expected UXO sizes (Orsted 2018). The source level of each UXO charge weight was calculated in accordance with Soloway and Dahl (2014), Arons (1954) and Barett (1996), using conservative calculation parameters that result in the upper estimate of the source level for each charge size. This is therefore considered to be an indication of the potential maximum noise output from each charge size and, as such, likely results in an overestimate of PTS-onset impact ranges, especially for larger charge sizes (Orsted 2018). The predicted PTS-onset impact ranges calculated for Hornsea Project Two were used to inform the assessment of PTS-onset for Hornsea Four (**Table 4.57**).

Table 4.57: Sound pressure levels (SPL) for a range of potential UXO charge sizes (dB SPL_{peak} re 1 µPa) and associated PTS-onset impact ranges (m).

Charge size (kg)		10	50	145	227	500	700	800
Source level (SPL_{peak})		281.9	287.1	290.6	292.1	294.7	295.8	296.2
Species Group	PTS SPL_{peak} threshold	PTS-onset impact range (m)						
VHF (porpoise)	202 dB re 1µPa	3,210	5,200	7,220	8,210	10,200	11,240	11,610
HF (dolphin)	230 dB re 1µPa	195	330	475	550	710	800	830
LF (minke whale)	219 dB re 1µPa	595	1,000	1,430	1,660	2,100	2,380	2,470
PCW (seal)	218 dB re 1µPa	600	1,100	1,580	1,830	2,300	2,620	2,720

4.11.1.98 For each species, the number of individuals that could potentially be affected by PTS-onset from UXO clearance for a range of charge sizes is presented in **Table 4.58**. This was quantified by calculating the numbers of animals likely to be within each of the stated impact ranges by multiplying the area of the impact range by the appropriate density estimate. For the assessment of harbour porpoise, white-beaked dolphins and

[12] Numbers are scaled and are from the report: "HOW03 Estimation of Potential UXO – Main Array and Export Cable (V1.0)".

minke whales, which were expected to be present within the array area and have a species specific density surface available, it was assumed that the UXO was located in the centre of the array area. For bottlenose dolphins, which were assessed using a uniform density surface, it made no difference where the UXO was located. For both seal species, both the centre of the array area and a location ~1/3 of the way along the ECC was assumed to allow consideration of the higher densities near the coast.

Table 4.58: Estimated number of marine mammals potentially at risk of PTS-onset during UXO clearance.

Species		Charge Size (kg)						
		10	50	145	227	500	700	800
UXO located in centre of array								
Harbour porpoise	Impact range (m)	3,210	5,200	7,220	8,210	10,200	11,240	11,610
	Number (visual)	34	90	176	230	360	441	472
	Number (acoustic)	43	116	229	299	469	573	613
	% MU (visual)	0.01%	0.03%	0.05%	0.07%	0.10%	0.13%	0.14%
	% MU (acoustic)	0.01%	0.03%	0.07%	0.09%	0.14%	0.17%	0.18%
	Magnitude	**Negligible**						
White-beaked dolphin	Impact range (m)	195	330	475	550	710	800	830
	Number	<1	<1	<1	<1	<1	<1	<1
	% MU	<0.01%	<0.01%	<0.01%	<0.01%	<0.01%	<0.01%	<0.01%
	Magnitude	**Negligible**						
Minke whale	Impact range (m)	595	1,000	1,430	1,660	2,100	2,380	2,470
	Number	<1	<1	<1	<1	<1	<1	<1
	% MU	<0.01%	<0.01%	<0.01%	<0.01%	<0.01%	<0.01%	<0.01%
	Magnitude	**Negligible**						
Harbour seal	Impact range (m)	600	1,100	1,580	1,830	2,300	2,620	2,720
	Number	<1	<1	<1	<1	<1	<1	<1
	% MU	<0.01%	<0.01%	<0.01%	<0.01%	<0.01%	<0.01%	<0.01%
	Magnitude	**Negligible**						
Grey seal	Impact range (m)	600	1,100	1,580	1,830	2,300	2,620	2,720
	Number	1	1	3	4	7	9	9
	% MU	<0.01%	<0.01%	<0.01%	<0.01%	0.01%	0.01%	0.01%
	Magnitude	**Negligible**						
UXO located anywhere (uniform density surface assumed)								
Bottlenose dolphin	Impact range (m)	195	330	475	550	710	800	830
	Number	<1	<1	<1	<1	<1	<1	<1
	% MU	<0.01%	<0.01%	<0.01%	<0.01%	<0.01%	<0.01%	<0.01%
	Magnitude	**Negligible**						
UXO located in ECC (worst-case for seals)								
Harbour seal	Impact range (m)	600	1,100	1,580	1,830	2,300	2,620	2,720
	Number	<1	<1	<1	<1	<1	<1	<1
	% MU	<0.01%	<0.01%	<0.01%	<0.01%	<0.01%	<0.01%	<0.01%
	Magnitude	**Negligible**						
Grey seal	Impact range (m)	600	1,100	1,580	1,830	2,300	2,620	2,720
	Number	1	4	9	12	19	25	27
	% MU	<0.01%	<0.01%	0.01%	0.02%	0.03%	0.04%	0.04%

Species		Charge Size (kg)						
		10	50	145	227	500	700	800
	Magnitude	**Negligible**						

Magnitude of impact

4.11.1.99 The 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. As part of subsequent EPS and marine licence conditions, Hornsea Four will be required to implement a UXO specific MMMP to ensure that the risk of PTS is reduced to negligible. The exact mitigation measures contained with the UXO MMMP are yet to be determined and will be agreed with Natural England and the MMO; however, multiple measures are available and have been implemented elsewhere for UXO clearance, such as the use of ADDs and scarer charges to displace animals to beyond the PTS impact range, noise abatement techniques such as bubble curtains where appropriate, or alternative detonation methods such as deflagration (low-order detonation) or low-yield methods. The magnitude of this impact is therefore considered to be **negligible**. Irrespective of the sensitivity of the receptor, the significance of the impact on marine mammals is **not significant** as defined in the assessment of significance matrix (**Table 4.13**) and is therefore not considered further in this assessment.

Disturbance from UXO clearance (MM-C-12)

4.11.1.100 Natural England and JNCC advise that a buffer of 26 km around the source location is used to determine the impact area from UXO clearance with respect to disturbance of harbour porpoise in the Southern North Sea SAC (JNCC 2020). In the absence of agreed metrics for the use of other marine mammal species for disturbance and given a lack of empirical data on the likelihood of response to explosives, this 26 km radius (area of 2,124 km^2) has been applied for all species. The resulting number of animals, proportion of the reference population and impact magnitude is detailed in Table 4.59. This is quantified by calculating the numbers of animals likely to be within each of the stated impact ranges by multiplying the area of the impact range by the appropriate density estimate. For the assessment of harbour porpoise, white-beaked dolphins and minke whales, which were expected to be present within the array area and have a species specific density surface available, it was assumed that the UXO was located in the centre of the array area. For bottlenose dolphins, which were assessed using a uniform density surface, it made no difference where the UXO was located. For both seal species, a location ~1/3 of the way along the ECC was assumed to allow consideration of the higher densities near the coast.

Magnitude of impact

4.11.1.101 The impact is predicted to be of local spatial extent, very short-term duration, intermittent and high reversibility. Given the proportion of the grey seal population that is expected to experience behavioural disturbance (3.2%), and the proximity of the ECC to the Humber Estuary SAC, this has been assessed as a **minor** magnitude. For harbour porpoise, bottlenose dolphins, white-beaked dolphins, minke whales and harbour seals, the lower proportion of the MU expected to be impacted (0.21-0.98%) results in a magnitude score of **negligible**.

Table 4.59: Estimated number of marine mammals potentially at risk of disturbance during UXO clearance.

Species	Density Source	# Impacted	% Ref Pop	Magnitude
Harbour porpoise (UXO in array area)	Acoustic + SCANS III	3,394	0.98%	**Negligible**
	Visual + SCANS III	2,941	0.85%	**Negligible**
Minke whale (UXO in array area)	Visual + SCANS III	18	0.09%	**Negligible**
White-beaked dolphin (UXO in array area)	Visual + SCANS III	37	0.08%	**Negligible**
Bottlenose dolphin (UXO anywhere)	Average across GNS MU	6	0.30%	**Negligible**
Harbour seal (coastal UXO)	Habitat preference map	11	0.21%	**Negligible**
Grey seal (coastal UXO)	Habitat preference map	2,028	3.2%	**Minor**

Sensitivity of the receptor

4.11.1.102 As outlined in **paragraph 4.10.4.16** *et seq.,* disturbance may temporarily affect harbour porpoise fertility and the probability of calf survival. The sensitivity of harbour porpoise is therefore considered to be **medium**.

4.11.1.103 As outlined in **paragraph 4.10.4.21** *et seq.*, disturbance may temporarily affect individual behaviour and therefore vital rates. The sensitivity of bottlenose dolphins is therefore considered to be **medium**.

4.11.1.104 As outlined in **paragraph 4.10.4.24** *et seq.*, harbour seals have been assessed as having **medium** sensitivity to disturbance and resulting displacement from foraging grounds.

4.11.1.105 As outlined in **paragraph 4.10.4.22** *et seq.*, the sensitivity of grey seals is considered to be **low**.

Significance of the effect

4.11.1.106 Overall, the sensitivity of harbour porpoise, bottlenose dolphins, white-beaked dolphins, minke whales and harbour seals to disturbance from UXO clearance has been assessed as **medium** and the magnitude is predicted to be **negligible**. This results in a **slight** significance based on the assessment of significance matrix (**Table 4.13**).

4.11.1.107 Overall, the sensitivity of grey seals to disturbance from UXO clearance has been assessed as **low** and the magnitude is predicted to be **minor**. This results in a **slight** significance based on the assessment of significance matrix (**Table 4.13**), which is not significant in EIA terms.

Further mitigation

4.11.1.108 None proposed beyond the adoption of a UXO MMMP. The exact mitigation measures contained with the UXO MMMP are yet to be determined and will be agreed with Natural England and the MMO through the separate Marine Licencing process.

TTS from UXO clearance (MM-C-13)

4.11.1.109 As outlined in **Section 4.10.3**, there are no thresholds to determine a biologically significant effect from TTS-onset, therefore the predicted ranges for the onset of TTS from UXO clearance are presented in **Table 4.57**, but no assessment of the number of animals, magnitude, sensitivity or significance of effect is given. This approach was agreed with members of EP Technical Panel at EP Technical Panel Meeting Four (30 April 2019, OFF-MM-2.1).

Table 4.60: Sound pressure levels (SPL) for a range of potential UXO charge sizes (dB SPL_{peak} re 1 µPa) and associated TTS-onset impact ranges (m).

Charge size (kg)		10	50	145	227	500	700	800
Source level (SPL_{peak})		281.9	287.1	290.6	292.1	294.7	295.8	296.2
Species Group	TTS SPL_{peak} threshold	TTS-onset impact range (m)						
VHF (porpoise)	196 dB re 1µPa	5,610	8,960	12,010	13,520	16,540	17,970	18,560
HF (dolphin)	224 dB re 1µPa	360	610	860	1,000	1,300	1,450	1,510
LF (minke whale)	213 dB re 1µPa	1,080	1,830	2,570	2,960	3,790	4,210	4,380
PCW (seal)	212 dB re 1µPa	1,200	2,020	2,830	3,260	4,170	4,620	4,810

Further mitigation

4.11.1.110 None proposed beyond the adoption of a UXO MMMP. The exact mitigation measures contained with the UXO MMMP are yet to be determined and will be agreed with Natural England and the MMO through the separate Marine Licencing process.

4.11.2 Operation and Maintenance

4.11.2.1 The potential impacts of the offshore operation and maintenance of Hornsea Four have been assessed on marine mammals. The potential environmental impacts arising from the operation and maintenance of Hornsea Four are listed in **Table 4.10** along with the MDS against which each operation and maintenance phase impact has been assessed.

4.11.2.2 A description of the potential effect on marine mammals caused by each identified impact is given below.

Vessel collision risk (MM-O-28)

4.11.2.3 The MDS states that there will be a maximum of 1,433 return visits per year during the operation and maintenance of Hornsea Four. This equates to an average of approximately 10 return trips per day; however, it is expected that a currently unknown portion of these will be by helicopter rather than by vessel, and therefore the assessment presented here is precautionary. Vessel types may include crew transport vessels (CTVs), service operation vessels (SOVs), supply vessels, cable and remedial protection vessels and jack-up vessels (JUVs).

4.11.2.4 There are very few studies that indicate a critical level of activity in relation to risk of collisions but an analysis presented in Heinänen and Skov (2015) suggested that harbour porpoise density was significantly lower in areas with vessel transit rates of greater than 80 per day. Vessel traffic in the Hornsea Four area, even considering the addition of operation and maintenance traffic will still be well below this figure.

Magnitude of impact

4.11.2.5 It is not expected that the level of vessel activity during the operation and maintenance of Hornsea Four would cause an increase in the risk of mortality from collisions. The adoption of a vessel management plan (Co108, **Table 4.9** and **Volume 4, Annex 5.2: Commitments Register**) that includes preferred transit routes and guidance for vessel operations in the vicinity of marine mammals and around seal haul-outs will minimise the potential for any impact. The impact is predicted to be of local, short-term duration and intermittent. The magnitude is therefore considered to be **minor**.

Sensitivity of the receptor

4.11.2.6 All marine mammal receptors are deemed to be of low vulnerability given that vessel collision is not considered to be a key source of mortality highlighted from post-mortem examinations of stranded animals. However, should a collision event occur, this is likely to kill or injure the animal. As a result of the low vulnerability to a strike but the serious consequences of a strike, the sensitivity of the marine mammal receptors to collisions is considered to be **high**.

Significance of the effect

4.11.2.7 Overall, the sensitivity of marine mammals to vessel collision risk has been assessed as **high** and the magnitude is predicted to be **minor**. This can result in either a slight or a moderate significance based on the assessment of significance matrix (**Table 4.13**). Given the fact that marine mammals have been shown to be displaced by vessels (e.g. Brandt et al. 2018, Benhemma-Le Gall et al. 2020), the risk of collision is low, especially given the implementation of a vessel management plan (Co108), thus an assessment of slight is more appropriate. The effect is of **slight** significance, which is not significant in EIA terms.

Further mitigation

4.11.2.8 None proposed beyond existing commitments.

Reduction in prey availability (MM-O-16)

4.11.2.9 It is possible that operational wind farms may actually increase prey availability. Tagged seals have shown targeted foraging behaviour around operational offshore wind farms which suggests that they act as fish aggregating devices, providing enhanced or novel foraging opportunities (Russell et al. 2014). In addition, studies have shown that porpoise are detected regularly within operational offshore wind farms (Diederichs et al. 2008, Scheidat et al. 2011) and may be attracted to offshore wind farms for increased foraging opportunities (Lindeboom et al. 2011). Therefore, it is possible that the underwater structures associated with Hornsea Four could provide an ecological benefit by providing new foraging opportunities to marine mammals in the area. Any potential habitat change as a result of fish aggregation or artificial reefs is expected to positively affect marine mammals by providing novel foraging opportunities.

4.11.2.10 **Chapter 3: Fish and Shellfish Ecology** concluded no significant impacts on any fish species during the operational phase of Hornsea Four. The magnitude of this impact is therefore considered to be **negligible**. Irrespective of the sensitivity of the receptor, the significance of the impact on marine mammals is **not significant** as defined in the assessment of significance matrix (**Table 4.13**) and is therefore not considered further in this assessment.

Reduction in foraging ability (MM-O-17)

4.11.2.11 Disturbance to water quality as a result of operation and maintenance activities can have both direct and indirect impacts on marine mammals. Indirect impacts would include effects on prey species which have already been covered in the previous section. Direct impacts include the impairment of visibility and therefore foraging ability which might be expected to reduce foraging success. As outlined above, marine mammals are known to frequent operational wind farms with evidence for potential feeding within arrays. The magnitude of this impact is therefore considered to be **negligible**. Irrespective of the sensitivity of the receptor, the significance of the impact on marine mammals is **not significant** as defined in the assessment of significance matrix (**Table 4.13**) and is therefore not considered further in this assessment.

4.11.3 Decommissioning

4.11.3.1 The potential impacts of the offshore decommissioning of Hornsea Four have been assessed on marine mammals. The potential environmental impacts arising from the decommissioning of Hornsea Four are listed in **Table 4.10** along with the MDS against which each decommissioning phase impact has been assessed. Decommissioning would involve the dismantling of structures and removal of offshore structures above the seabed, in reverse order to the construction sequence. The effects of these activities on marine mammals are considered to be similar to or less (as a result of there being no piling) than those occurring as a result of construction. Therefore, the effects of decommissioning are considered to be no greater than those described for the construction phase.

Reduction in prey availability (MM-D-25)

4.11.3.2 **Volume 2, Chapter 3: Fish and Shellfish Ecology** concluded no significant impacts on any fish species during the decommissioning phase of Hornsea Four. The magnitude is therefore considered to be **negligible** adverse for marine mammals. Irrespective of the sensitivity of the receptor, the significance of the impact on marine mammals is **not significant** as defined in the assessment of significance matrix (**Table 4.13**) and is therefore not considered further in this assessment.,

Reduction in foraging ability (MM-D-26)

4.11.3.3 Increases in SSC and sediment deposition from the decommissioning works will be similar to that for construction and are of a similar magnitude. There is expected to be no significant increase in the level of SSC from the construction of Hornsea Four, thus there is also expected to be no significant increase in the level of suspended sediment concentration from the decommissioning of Hornsea Four. The magnitude is therefore considered to be **negligible**. Irrespective of the sensitivity of the receptor, the significance of the impact on marine mammals is **not significant** as defined in the assessment of significance matrix (**Table 4.13**) and is therefore not considered further in this assessment.

4.12 Cumulative effect assessment (CEA)

4.12.1.1 Cumulative effects can be defined as effects upon a single receptor from Hornsea Four when considered alongside other proposed and reasonably foreseeable projects and developments. This includes all projects that result in a comparative effect that is not intrinsically considered as part of the existing environment and is not limited to offshore wind projects.

4.12.1.2 A screening process has identified a number of reasonably foreseeable projects and developments which may act cumulatively with Hornsea Four. The full list of such projects that have been identified in relation to the offshore environment are set out in **Volume A4, Annex 5.3: Offshore Cumulative Effects** and are presented in a series of maps within **Volume A4, Annex 5.4: Location of Offshore Cumulative Schemes**.

4.12.1.3 In assessing the potential cumulative impacts for Hornsea Four, it is important to bear in mind that some projects, predominantly those 'proposed' or identified in development plans, may not actually be taken forward, or fully built out as described within their MDS. There is therefore a need to build in some consideration of certainty (or uncertainty) with respect to the potential impacts which might arise from such proposals. For example, those projects under construction are likely to contribute to cumulative impacts (providing effect or spatial pathways exist), whereas those proposals not yet approved are less likely to contribute to such an impact, as some may not achieve approval or may not ultimately be built due to other factors.

4.12.1.4 With this in mind, all projects and plans considered alongside Hornsea Four have been allocated into 'tiers' reflecting their current stage within the planning and development process. This allows the cumulative impact assessment to present several future development scenarios, each with a differing potential for being ultimately built out. This approach also allows appropriate weight to be given to each scenario (tier) when considering the potential cumulative impact. The proposed tier structure is intended to ensure that there is a clear understanding of the level of confidence in the cumulative assessments provided in the Hornsea Four ES. An explanation of each tier is included in **Table 4.61.**

4.12.1.5 The proposed tier structure for marine mammals is different to that presented for other receptors. This is due to the need to take into account greater levels of uncertainty in the degree and timing of overlap of activities which will generate significant levels of underwater noise during the construction phase of projects.

Table 4.61: Description of tiers of other developments considered for CEA (adapted from PINS Advice Note 17).

Tier	Description
Tier 1	Operational and under construction projects which were not in place when baseline data was collected. Projects with a legally secure consent that have been awarded a CfD but have not yet been implemented. All Tier 1 offshore wind farm projects that are operational have been scoped out of the assessment.
Tier 2	Tier 2 includes all projects/plans that have a legally secure consent, but have no CfD; therefore, there is uncertainty about the timeline for construction of these projects. The potential for cumulative construction phase impacts have been considered where there is a reasonable chance of overlap of pile driving with Hornsea Four.
Tier 3	Tier 3 projects are projects for which an application has been submitted, but not yet determined. There is therefore information on which to base a quantitative assessment of cumulative impact but there is a degree of uncertainty as to the final approved design of the project and the timeline for construction. Tier 3 offshore wind farm projects have the potential for cumulative construction impacts.
Tier 4	Tier 4 projects are relevant marine infrastructure projects that the regulatory body are expecting to be submitted for determination and projects for which PEIR has been submitted, but not yet a full ES. There is therefore some information on which to base a quantitative assessment of cumulative impact but there is a large degree of uncertainty as to the final design of the project and the timeline for construction. Tier 4 offshore wind farm projects have the potential for cumulative construction impacts.
Tier 5	Tier 5 projects are relevant marine infrastructure projects that the regulatory body are expecting to be submitted for determination (e.g. projects listed under the Planning Inspectorate programme of projects). For Tier 5 projects there is a lot of uncertainty and not enough information to allow a robust assessment. However, as a very precautionary approach, the Tier 5 UK offshore wind farm projects that we are currently aware of have been included in the CEA.

4.12.1.6 The plans and projects selected as relevant to the CEA of impacts to marine mammals are based on an initial screening exercise undertaken on a long list (see **Volume A4, Annex 5.3: Offshore Cumulative Effects**). A consideration of effect-receptor-pathways, data confidence and temporal and spatial scales has been given to select projects for a topic-specific short-list. For the majority of potential effects for marine mammals, planned projects were screened into the assessment based on the extent of the relevant marine mammal reference population area for harbour porpoise (all cetaceans were based on the North Sea as the largest area over which cumulative effects could be realistically expected to overlap) and the grey seal (the combined Northeast and Southeast SMAs). Harbour seals have been scoped out of the CEA due to the extremely low levels of impact on this species from the project alone assessment. In addition, the CEA does not include construction related impacts on minke whales or white-beaked dolphins due to the project alone assessment of magnitude being negligible.

4.12.1.7 Therefore, only three species of were scoped into the CEA for marine mammals due to non-negligible magnitudes predicted by the project alone:

- Harbour porpoise;
- Bottlenose dolphin; and
- Grey seal.

4.12.1.8 The specific projects scoped into the CEA for marine mammals, as well as the Tiers into which they have been allocated are presented in **Table 4.62** below. For the full list of projects considered, including those screened-out, please see the Cumulative Effects Annex (**Volume A4, Annex 5.3: Offshore Cumulative Effects**). The list of projects screened into the CEA for marine mammals was then further refined to exclude projects where impact pathways were deemed to be negligible.

4.12.1.9 Certain impacts assessed for Hornsea Four alone are not considered further in the cumulative assessment due to:

- The highly localised nature of the impacts (i.e. they occur entirely within the Hornsea Four boundary only);
- Management and mitigation measures in place for Hornsea Four will also be in place on other projects reducing their risk of occurring; and/or
- Where the potential significance of the impact from Hornsea Four alone has been assessed as negligible.

4.12.1.10 The impacts excluded from the CEA for the above reasons are:

- Auditory injury (PTS): where PTS may result from activities such as pile driving and UXO clearance, suitable mitigation will be put in place to reduce injury risk to marine mammals to negligible levels (as a requirement of EPS legislation);
- Disturbance from underwater noise during construction to minke whale, white-beaked dolphin and harbour seals due to the negligible levels predicted for these species in the project alone assessment;
- Changes in prey availability during construction and operation;
- Changes in foraging ability during construction and operation;
- Collision risk from vessels during construction and operation as it is expected that all offshore energy projects will employ a vessel management plan to reduce the already low risk of collisions with marine mammals to negligible; and

- Operational noise: not included for any species due to localised effects and an assessment of negligible significance in the project alone assessment.

4.12.1.11 Therefore, the impacts that are considered in the CEA are as follows:

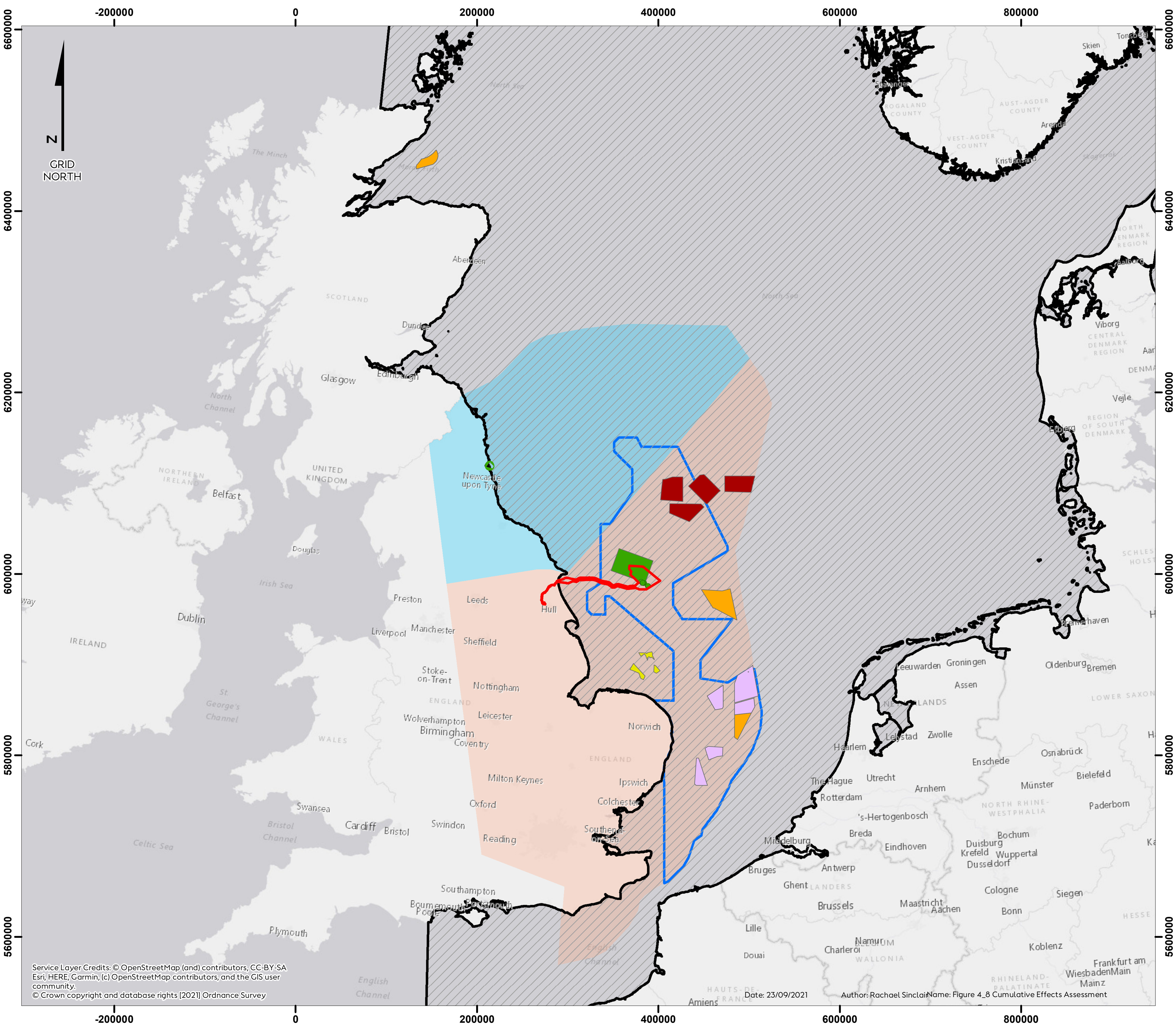
- The potential for disturbance to harbour porpoise, bottlenose dolphin and grey seals from underwater noise during construction activity (pile driving, UXO, seismic survey and vessels);and
- The potential for disturbance from vessel activity during construction, operation and maintenance and decommissioning of developments.

4.12.1.12 The cumulative MDS described in **Table 4.63** have been selected as those having the potential to result in the greatest cumulative effect on an identified receptor group. The cumulative impacts presented and assessed in this section have been selected from the details provided in the project description for Hornsea Four (summarised for marine mammals in **Table 4.10**), as well as the information available on other projects and plans in order to inform a cumulative maximum design scenario. Effects of greater adverse significance are not predicted to arise should any other development scenario, based on details within the project design envelope to that assessed here, be taken forward in the final design scheme.

Table 4.62: Projects screened-in to the marine mammal cumulative assessment (see paragraph 4.12.1.10) (HP = harbour porpoise, BND = bottlenose dolphin, GS = grey seal).

Tier	Project/ plan	Details/ relevant dates	Distance to Hornsea Four array (km)	Distance to Hornsea Four ECC (km)	Distance to Hornsea Four HVAC (km)	Reason for inclusion in CEA
Offshore energy						
1	Dogger Bank A	Consented: Construction expected 2021-2024	65.86	83.83	108.33	Construction cumulative impacts (HP, BND & GS)
1	Dogger Bank B	Consented: Construction expected 2021-2024	76.14	94.18	111.26	Construction cumulative impacts (HP, BND & GS)
1	Sofia	Consented: Construction expected 2024	97.75	114.01	144.05	Construction cumulative impacts (HP, BND & GS)
1	Dogger Bank C	Consented: Construction expected 2023-2026	120.86	136.85	171.02	Construction cumulative impacts (HP, BND & GS)
2	East Anglia Three	Consented: Construction expected 2020-2023	168.48	169.31	212.86	Construction cumulative impacts (HP, BND & GS)
2	Moray West	Consented: Construction expected 2022-2024	490.62	478.40	486.94	Construction cumulative impacts (HP & BND)
2	Hornsea Project Three	Consented Construction expected 2027-2028	46.47	60.28	116.91	Construction cumulative impacts (HP, BND & GS)
3	Norfolk Vanguard	Being re-determined: Construction expected 2024-2028	134.40	135.41	176.99	Construction cumulative impacts (HP, BND & GS)
3	Norfolk Boreas	Application submitted: Construction expected 2025-2027	134.88	138.68	188.41	Construction cumulative impacts (HP, BND & GS)
3	East Anglia One North	Application submitted: Construction expected 2025-2028	186.20	186.60	220.74	Construction cumulative impacts (HP, BND & GS)
3	East Anglia Two	Application submitted: Construction expected 2025-2027	194.20	194.48	225.13	Construction cumulative impacts (HP, BND & GS)
4	Dudgeon Extension	PEIR submitted: Construction expected 2026	69.5	69.5	92.8	Construction cumulative impacts (HP, BND & GS)
4	Sheringham Shoal Extension	PEIR submitted: Construction expected 2026	83.6	82.3	100.7	Construction cumulative impacts (HP, BND & GS)

Tier	Project/ plan	Details/ relevant dates	Distance to Hornsea Four array (km)	Distance to Hornsea Four ECC (km)	Distance to Hornsea Four HVAC (km)	Reason for inclusion in CEA
5	Blyth	Decommissioning expected 2026-2027	185.59	147.34	165.41	Decommissioning cumulative impacts (HP, BND & GS)
5	Endurance Carbon Capture & Storage Area	Construction expected 2023-2026	0.00	2.15	18.78	Construction cumulative impacts (HP, BND & GS)
Oil and Gas						
5	Johnston WHPS	Decommissioning expected: 2021-2031(onwards)	0.00	2.83	57.79	Decommissioning cumulative impacts (HP, BND & GS)
5	Johnston template/manifold	Decommissioning expected 2021-2031(onwards)	0.00	2.86	51.65	Decommissioning cumulative impacts (HP, BND & GS)
Other Activities						
5	Seismic Surveys across various Oil and Gas development blocks in the North Sea	Assumed to be ongoing, however there is no information on any planned or upcoming surveys to indicate frequency, location or type. Therefore, it has been assumed that up to four seismic (airgun) surveys could occur in the north Sea at any one time.				Construction and Operational cumulative impacts (HP, BND & GS)



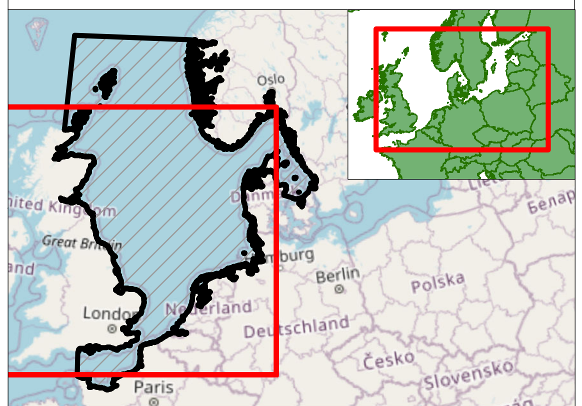
Hornsea Four

Figure 4.8

Cumulative Effects Assessment

Marine Mammals

- Tier 1
- Tier 2
- Tier 3
- Tier 4
- Tier 5
- Northeast England Seal Management Area
- Southeast England Seal Management Area
- North Sea Management Unit
- Southern North Sea SAC



Coordinate system: ETRS 1989 UTM Zone 31N

Scale@A3: 1:4,000,000

0 100 200 Kilometres

0 45 90 Nautical Miles

REV	REMARK	DATE
....	First Issue	18/06/2019
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Cumulative Effects Assessment
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Created by: RRS
Checked by: BPHB
Approved by: LK

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Table 4.63: Cumulative MDS for marine mammals.

Project Phase	Potential Impact	Maximum Design Scenario	Justification
Construction	Cumulative effect of underwater noise from Hornsea Four construction operations alongside other underwater noise generating activities (construction activities including vessel activity, piling operations, UXO clearance and seismic survey activity).	MDS for Hornsea Four plus the cumulative construction activities of the following projects (piling and UXO clearance activities): **Tier 1:** Construction and UXO clearance activities at offshore wind farm projects consented but not yet under construction (Sofia; Dogger Bank A, B & C) **Tier 2:** Construction and UXO clearance activities at offshore wind farm projects consented, with no CfD and not yet under construction (Moray West, Hornsea Three and East Anglia Three) **Tier 3:** Construction and UXO clearance activities at offshore wind farm projects that have been submitted but not yet determined (Norfolk Vanguard, East Anglia One North, East Anglia Two) **Tier 4:** Construction and UXO clearance activities at offshore wind farm projects that have been submitted PEIR, but are not yet determined (Dudgeon Extension and Sheringham Shoal Extension) **Tier 5:** Decommissioning activities at Blyth Offshore Wind Farm and Johnston WHPS and Johnston template/manifold. Construction of Endurance Carbon Capture and Storage Area. In addition to underwater noise generated by seismic surveys.	Maximum potential for cumulative effects from underwater noise associated with offshore wind farm construction and other noisy activities is considered within the relevant management unit/area for each species. This spatial scale was chosen as a result of the spatial extent of noise related impacts as well as the high mobility of marine mammal receptors. Only projects where the construction periods are expected to overlap with, or occurring the year immediately prior to or after, the construction activity at Hornsea Four have been included (NB. Hornsea Four construction window runs from Aug 2024 to Q1 2029).
Construction	Cumulative effect of increased disturbance risk from an increase in vessel activity across construction of Hornsea Four alongside other operations requiring an increase in vessel activity.	**Tier 1:** Vessels associated with offshore wind farm projects under construction or not yet constructed (Sofia; Dogger Bank A, B & C) **Tier 2:** Vessels associated with offshore wind farm projects consented but not yet under construction, but which are expected to be overlapping in construction with Hornsea Four (Moray West, Hornsea Three and East Anglia Three) **Tier 3:** Vessel activity associated with construction activities at offshore wind farm projects that have been submitted but not yet determined (Norfolk Vanguard, East Anglia One North, East Anglia Two) **Tier 4:** Vessel activity associated with construction activities at offshore wind farm projects that have submitted PEIR but not yet determined (Dudgeon Extension and Sheringham Shoal Extension) **Tier 5:** Decommissioning activities at Blyth Offshore Wind Farm and Johnston WHPS and Johnston template/manifold. Construction of Endurance Carbon Capture and Storage Area.	Maximum potential for cumulative effects from the increased risk of disturbance from an increase in vessel activity is considered within the relevant management unit/area for each species. This spatial scale was chosen as a result of the high mobility of marine mammal receptors.

4.12.1.13 A description of the significance of cumulative effects upon marine mammals arising from each identified impact is given below. The cumulative effects assessment has been based on information available in ESs and it is noted that the project parameters quoted within ESs are often refined during the determination period and in the post-consent phase. The assessment presented here is therefore considered to be conservative, with the level of impacts in the as built projects expected to be reduced compared to those presented here.

4.12.2 Underwater noise during the construction of Hornsea Four cumulatively with other plans and projects.

4.12.2.1 The methodology for assessing the impact of UXO clearance, pile driving construction and seismic surveys is described below.

UXOs and Pile driving

4.12.2.2 Different offshore windfarm (OWF) EIAs have assessed disturbance using a variety of thresholds and methods, including effective deterrence ranges, fixed noise thresholds and dose-response curves. This means that the predicted number of animals disturbed is not necessarily comparable between projects. In order to account for this, three methods are presented in this CEA:

- In order to standardise the CEA approach, the assessment of disturbance from construction activities at OWF sites follows the advice provided in JNCC (2020) where unabated pile driving of a monopile and clearance of a UXO are both predicted to have an effective deterrence range of 26 km for harbour porpoise;
- In order to take account of project specific parameters such as hammer energy, the number of animals predicted to experience disturbance from the installation of a single monopile was obtained from project specific EIAs; and
- In order to account for the fact that the worst case spatially is the installation of concurrent monopiles (two monopiles at the same time within a site), the number of animals predicted to experience disturbance from the installation of concurrent monopiles was also obtained from project specific EIAs (where available).

Seismic surveys

4.12.2.3 The potential number of seismic surveys that could be undertaken is unknown. Therefore, it has been assumed that four seismic surveys are conducted within the North Sea at any one time (to account for concurrent surveys in the northern and southern North Sea in both UK waters and those of neighbouring North Sea nations). It has been assumed that the Effective Deterrence range (EDR) for seismic (airgun) surveys is 12 km as per the advice provided in JNCC (2020). It is considered that this approach is sufficiently precautionary (i.e. it is unlikely that this number of seismic surveys will be occurring concurrently, less so concurrently with Hornsea Four construction) to also account for any behavioural disturbance resulting from high-resolution geophysical site surveys (HRGS) within relevant regions (e.g. to support wind farm development). While the potential for behavioural disturbance from HRGS is poorly understood, it is acknowledged to be of a considerably lower magnitude than that of seismic survey (e.g. precautionary 5 km EDR suggested in JNCC 2020).

4.12.2.4 It is acknowledged that seismic surveys are a moving sound source and not a point source. Therefore, the approach presented in BEIS (2020) has been adopted here. Therefore, it has been assumed that a seismic survey vessel travelling at 4.5 knots (8.3 km/h) could, in theory, survey a total of 199 km of survey line in a single 24 hr period and therefore impact an area of 4,294 km^2/day (**Figure 4.9**). This approach was agreed at an Evidence Plan meeting on 10th May 2021 (OFF-MM-4.1).

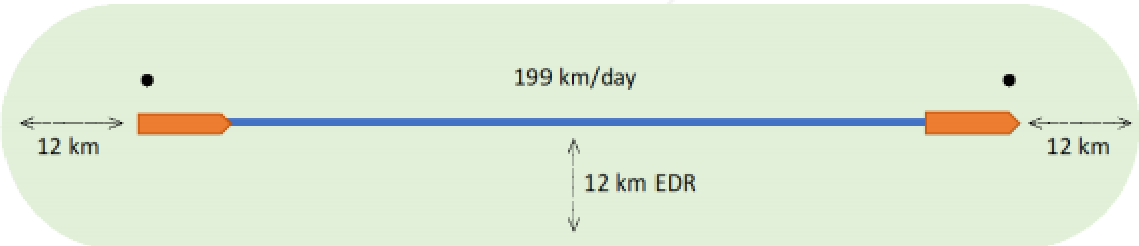

Figure 4.9: Maximum worst-case theoretical area of impact over a single day from a seismic survey travelling at 4.5 knots using 12 km EDR (BEIS 2020).

Projects screened in

4.12.2.5 The projects screened into the cumulative assessment of underwater noise during the construction of Hornsea Four cumulatively with other plans and projects are listed in **Table 4.64**. This details the offshore construction period for each project, within which piling operations may take place, as well as the pre-construction period, within which UXO clearance may take place. The timeline information is based on data available in ES and PEIR chapters that are available in the public domain.

Table 4.64: Projects screened into the cumulative impact assessment for underwater noise during offshore construction.

	Hornsea Four	Dogger Bank A	Dogger Bank B	Sofia	Dogger Bank C	East Anglia 3	Moray West	Hornsea Three	Norfolk Vanguard	Norfolk Boreas	East Anglia One North	East Anglia Two	Dudgeon Ext	Sheringham Shoal Ext	Seismic survey 1	Seismic survey 2	Seismic survey 3	Seismic survey 4
Tier		T1	T1	T1	T1	T2	T2	T2	T3	T3	T3	T3	T4	T4	T5	T5	T5	T5
Q4 2023		Piling	Piling	UXO	Piling	Piling	Piling		UXO						Seismic	Seismic	Seismic	Seismic
Q1 2024		Piling	Piling	Piling	Piling		Piling	UXO	UXO			UXO			Seismic	Seismic	Seismic	Seismic
Q2 2024		Piling	Piling	Piling	Piling		Piling	UXO	Piling			UXO			Seismic	Seismic	Seismic	Seismic
Q3 2024		Piling	Piling	Piling	Piling		Piling	UXO	Piling			UXO			Seismic	Seismic	Seismic	Seismic
Q4 2024		Piling	Piling	Piling	Piling		Piling	UXO	Piling			UXO			Seismic	Seismic	Seismic	Seismic
Q1 2025					Piling			UXO	Piling		UXO	Piling			Seismic	Seismic	Seismic	Seismic
Q2 2025					Piling			UXO			UXO	Piling	UXO	UXO	Seismic	Seismic	Seismic	Seismic
Q3 2025					Piling			UXO		UXO	UXO	Piling	UXO	UXO	Seismic	Seismic	Seismic	Seismic
Q4 2025					Piling			UXO		UXO	UXO	Piling	UXO	UXO	Seismic	Seismic	Seismic	Seismic
Q1 2026	UXO				Piling					UXO	Piling	Piling	UXO	UXO	Seismic	Seismic	Seismic	Seismic
Q2 2026	UXO				Piling					Piling	Piling	Piling	Piling	Piling	Seismic	Seismic	Seismic	Seismic

	Hornsea Four	Dogger Bank A	Dogger Bank B	Sofia	Dogger Bank C	East Anglia 3	Moray West	Hornsea Three	Norfolk Vanguard	Norfolk Boreas	East Anglia One North	East Anglia Two	Dudgeon Ext	Sheringham Shoal Ext	Seismic survey 1	Seismic survey 2	Seismic survey 3	Seismic survey 4
Q3 2026	UXO				Piling					Piling	Piling	Piling	Piling	Piling	Seismic	Seismic	Seismic	Seismic
Q4 2026	Piling				Piling					Piling	Piling	Piling	Piling	Piling	Seismic	Seismic	Seismic	Seismic
Q1 2027	Piling							Piling		Piling	Piling	Piling			Seismic	Seismic	Seismic	Seismic
Q2 2027	Piling							Piling	Piling	Piling	Piling	Piling			Seismic	Seismic	Seismic	Seismic
Q3 2027	Piling							Piling	Piling	Piling	Piling	Piling			Seismic	Seismic	Seismic	Seismic
Q4 2027								Piling	Piling	Piling	Piling	Piling			Seismic	Seismic	Seismic	Seismic
Q1 2028								Piling	Piling		Piling				Seismic	Seismic	Seismic	Seismic
Q2 2028								Piling			Piling				Seismic	Seismic	Seismic	Seismic
Q3 2028											Piling				Seismic	Seismic	Seismic	Seismic

Assumes UXO clearance occurs within the year prior to piling – unless otherwise stated in project specific ES/PEIR chapters

Precaution in the assessment

4.12.2.6 There are significant levels of precaution / conservatism within this CEA, resulting in the estimated effects being highly precautionary and unrealistic. The main areas of precaution / conservatism in the assessment include:

- The approach of summing across concurrent activities assumes that there is no spatial overlap in the impact footprints between individual activities, which is highly unrealistic considering the close proximity of many of the OWF projects to each other;
- The inclusion of lower tier developments. In reality, the best information in terms of construction timeline is available for Tier 1 projects which have consent and have secured a CfD. By including projects that have either: no consent, no ES, no PEIR or no submitted information at all (Tiers 3-5), then worst-case scenarios have to be assumed in the absence of other information;
- The exact timing of UXO clearance and piling driving for each development is unknown, therefore it has been assumed that these activities could occur at any point throughout the construction window. This has resulted in UXO and piling activities occurring over multiple consecutive years with associated estimated disturbance levels far greater than would occur in reality;
- The 26 km EDR for UXO clearance is based on the high order detonation of UXOs, however, there is no empirical evidence of harbour porpoise avoidance from such events. It is expected that the detonation of a UXO would elicit a startle response and potentially very short duration behavioural responses, and are therefore not expected to cause widespread and prolonged displacement (JNCC 2020);
- The timelines presented in PEIR and ES chapters are worst case scenarios and the true period of piling activity will likely be shorter than this;
- The approach to the impact from seismic surveys was highlighted by BEIS (2020) as being highly precautionary and should be considered as an unrealistic worst-case scenario. This is mainly due to the fact that the approach does not take into consideration time when the seismic airguns are not firing within a survey day, or the overlap of impact areas within a day from a single vessel due to the survey line pattern. Airguns are required to be turned off at the end of every survey line as the vessel turns, which can take 2-3 hours per turn and several turns can occur each day. For example, a review of six seismic surveys undertaken across UK waters during 2018 indicated that out of a total of 171 potential survey days airguns were operated for 52% of the time (BEIS 2020). The inclusion of seismic surveys in the cumulative impact assessment at all is highly speculative, since there are no such surveys known to be in planning during the Hornsea Four offshore construction period (the potential for and possible number of seismic airgun surveys to occur in relation to the Endurance project is unknown);
- The assumption that all developments will install pile driven monopile foundations. The project envelope for most of these developments includes options for pin-piles or monopiles, alongside options for non-piled foundations. As a worst case assumption monopiles have been assumed; however, a portion of these projects may instead use jacket foundations with pin-piles, which have a much lower recommended effective deterrence range (15 km instead of 26 km, equating to a 66% smaller area) (JNCC 2020), and will therefore disturb far fewer

porpoise (e.g. assuming a density of 0.888 porpoise/km^2 a 26 km radius impacts 1,886 porpoise, while a 15 km radius impacts 628 porpoise); and

- The assumption that all porpoise within a 26 km range are disturbed and that this extent of disturbance remains constant throughout the construction of each wind farm. While it is acknowledged that 26 km represents an overall average temporary loss of habitat estimated by Tougaard et al. (2013) (more noise-tolerant animals will lose less than this mean area, while less noise-tolerant animals would lose more), there is now considerable evidence that exclusion of animals to 26 km is a significant over-estimate. For example, pile driving at the first seven large scale offshore windfarms in the German Bight (including monopiles and piling without noise abatement) found declines in porpoise out to only 17 km (Brandt et al. 2018), while acoustic monitoring during piling at the Gemini wind farm in the Netherlands (7.5 m monopiles) showed that the avoidance distance of harbour porpoises was in the range of 10-20 km (Geelhoed et al. 2018). Furthermore, passive acoustic monitoring during pin piling at the Beatrice wind farm in the Moray Firth showed a 50% probability of porpoise response (a significant reduction in detection relative to baseline) within 7.4 km at the first location piled, with decreasing response levels over the construction period to a 50% probability of response within 1.3 km by the final piling location (**Figure 4.10**) (Graham et al. 2019).

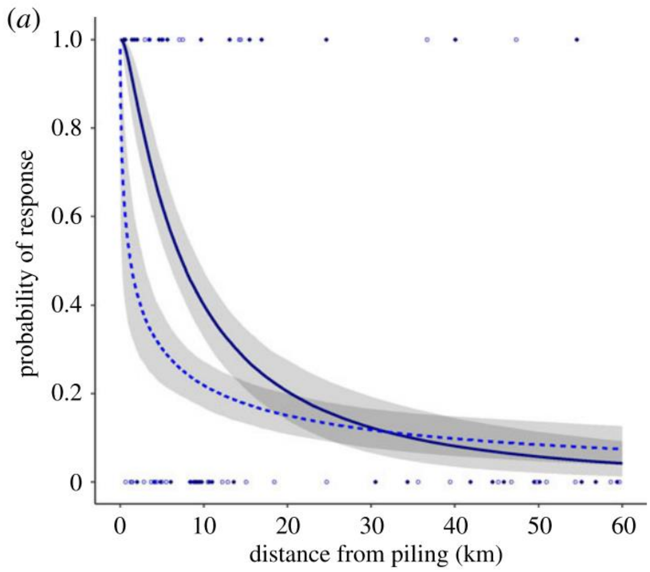

Figure 4.10: The probability of a harbour porpoise response (24 h) in relation to the partial contribution of distance from piling for the first location piled (solid navy line) and the final location piled (dashed blue line) (Graham et al. 2019).

4.12.3 CEA Construction Noise - Harbour porpoise

Tiers 1-2

4.12.3.1 The assessment of Tier 1 and 2 projects is the most realistic as this includes the projects which are consented (with or without CfD). This means that full environmental impact assessments are available and there is reasonable confidence in the timelines for the construction of these projects.

4.12.3.2 The highest predicted impact across T1-2 projects occurs between Q4 2023 and Q4 2024 inclusive, where offshore construction activity occurs concurrently across Dogger Bank A, Dogger Bank B, Sofia, Dogger Bank C, East Anglia 3, Moray West and Hornsea Three (**Table 4.65**). This is predicted to occur prior to the start of offshore construction work at Hornsea Four, and thus is predicted to occur even in the absence of Hornsea Four.

4.12.3.3 The highest predicted impact across T1-2 projects during the offshore construction period for Hornsea Four (Q2-3 2027 inclusive) is outlined in **Table 4.65** and summarised as:

- Maximum predicted impact across T1-2 during the Hornsea Four pre-piling and piling period assuming SCANS III density and 26 km EDR for a single monopile is 1.1% MU;
- Maximum predicted impact across T1-2 during the Hornsea Four pre-piling and piling period using numbers obtained from project EIAs for a single monopile is 3.3% MU; and
- Maximum predicted impact across T1-2 during the Hornsea Four pre-piling and piling period using numbers obtained from project EIAs for concurrent monopiles is 4.9% MU.

4.12.3.4 This maximum predicted impact across T1-2 during the Hornsea Four pre-piling and piling period (4.9%) occurs when concurrent piling at Hornsea Four occurs at the same time as concurrent piling at Hornsea Three. It is expected that this level of impact may result in reproductive rates of individuals being impacted in the short term (over 1 breeding cycle), although survival and reproductive rates are very unlikely to be impacted to the extent that the population trajectory would be altered. Under this assumption the magnitude would be assessed as **Minor** and the resulting impact significance would be **Slight** (not significant in EIA terms).

4.12.3.5 It must be emphasised when viewing these results, that the numbers obtained from project EIAs are based on the Project MDS which represents the worst-case construction parameters within the project design envelope. In reality, these parameters are refined and reduced post consent, and re-assessment of the likely impacts based on the actual constructed project will be presented in the final MMMP.

Tiers 1-5

4.12.3.6 The assessment of Tiers 3, 4 and 5 is very uncertain as these projects are not yet consented, are at the PEIR stage or are in initial planning stages. **Table 4.65** outlines the maximum percentage of the MU that is predicted to be impacted should all Tier 1 to Tier 5 projects construct at the same time as the Hornsea Four pre-piling and piling construction period. This is summarised as:

- Maximum predicted impact across T1-5 during the Hornsea Four pre-piling and piling period assuming SCANS III density and 26 km EDR for a single monopile is 6.3% MU;
- Maximum predicted impact across T1-5 during the Hornsea Four pre-piling and piling period using numbers obtained from project EIAs for a single monopile is 8.2% MU; and
- Maximum predicted impact across T1-5 during the Hornsea Four pre-piling and piling period using numbers obtained from project EIAs for concurrent monopiles is 11.4% MU.

4.12.3.7 The likelihood of all T1-5 projects piling at the same time is extremely unlikely. The highest predicted impact occurs in Q2-3 2027, when six OWFs may be pile driving (concurrent piling within a site) and four seismic surveys may be occurring. Logistically, this scenario is improbable as this would require a total of 12 piling vessels to be active at the same time in the North Sea and this number of piling vessels are not currently available and are unlikely to be available in the near future.

4.12.3.8 Compared to the impact caused by the other Tier 1-5 projects considered in this assessment, the relative contribution of Hornsea Four is low. For example, the maximum predicted impact across T1-5 during the Hornsea Four pre-piling and piling period (using numbers obtained from project EIAs for concurrent monopiles) is 11.4% MU (in Q2-3 2027), but in the absence of Hornsea Four, the impact to the MU is still 8.6%. Therefore, the impact to the harbour porpoise population is considered to be of moderate magnitude even in the absence of Hornsea Four.

4.12.3.9 When considering the assessment of all Tier 1-5 projects, it is important to note that all the projects (with the exception of Moray West) will be required to implement a SIP in order to ensure that the potential for disturbance from underwater noise within the Southern North Sea (SNS) SAC does not exceed the limits of 20% of the area over a day or 10% of the area on average over a season (see **F2.11: Outline Southern North Sea Special Area of Conservation Site Integrity Plan**).

4.12.3.10 The summer portion of the SAC is ~27,000 km^2. If the maximum 10% SAC area is allowed to be impacted on average across the summer season, then that equates to 2,700 km^2 being impacted. This means that a maximum of 2,398 porpoise could be disturbed on average across a summer season within the summer portion of the SAC (using the SCANS III density of 0.888 porpoise/km^2).

4.12.3.11 If the maximum 20% SAC area is allowed to be impacted in a single day, then that equates to 5,400 km^2 being impacted. This means that a maximum of 4,795 porpoise could be disturbed in a single day within the summer portion of the SAC (using the SCANS III density of 0.888 porpoise/km^2).

4.12.3.12 According to the Hornsea Four RIAA (**B2.2 Report to Inform Appropriate Assessment**), if all the OWFs with disturbance impact contours overlapping the SNS SAC were to construct at the same time, then this would result in a maximum of 13,967 km^2 of the summer portion of the SAC being impacted in summer 2027, which represents 51.7% of the summer portion of the SAC area. Legally this cannot be allowed to occur, and thus the various OWF projects will be required to implement a SIP. The purpose of the SIP is to manage the uncertainty presented by future construction scenarios in-combination (cumulatively) with respect to underwater noise within the SNS SAC, to provide mitigation measures to be applied if required, and to provide certainty that adherence to the threshold values are not exceeded. Therefore, to avoid the thresholds being exceeded (20% in a 24 hour period, 10% on average across a six month season), mitigation measure(s) would be required across the various OWFs (with these provided for within the SIP). Thus, the constraint offered by the SIP to ensure compliance with the SNS SAC conservation objectives will ensure that considerably fewer porpoise will be disturbed than the worst-case unmitigated numbers presented in this cumulative impact assessment.

4.12.3.13 While the exact mitigation measures that may be employed though project specific SIPs is unknown at this stage, an illustrative scenario can be presented, where at source noise mitigation is assumed for monopiles and low order detonation is assumed for UXO clearance. Current advice is that the EDR for monopiles with noise abatement is 15 km (JNCC 2020). Current risk assessments conducted to support UXO Marine License Applications are including deflagration as the preferred method, assuming an EDR of 5 km (e.g. GoBe 2021). This significantly reduces the number of porpoise predicted to experience behavioural disturbance from 1,886 (assuming a 26 km EDR) to 70 (assuming a 5 km EDR) (**Table 4.72** and **Table 4.73**). Under this mitigated scenario, a maximum of 4% of the porpoise MU is predicted to be impacted on any single day. This would result in a Minor magnitude at most, and overall **slight** impact significance, which is not significant in EIA terms.

4.12.3.14 The estimated number of porpoise predicted to experience behavioural disturbance from seismic surveys is also a source of precaution. While larger 2D and 3D seismic surveys used in oil and gas exploration can produce large impact ranges (a 12 km EDR is recommended for porpoise), the disturbance impact is short-lived, and porpoise have been shown to return to the impacted area within 19 hours after the cessation of activities (Thompson et al. 2013). In addition, the duration of the activity is limited; for example, the majority of seismic surveys occurring within the Southern North Sea SAC between 2008 and 2017 have lasted less than 30 days (BEIS 2020). Therefore, both the duration of the activity and the duration of the disturbance is limited as is thus not expected to result in any changes in the individual reproductive success or survival, making the magnitude of effect from seismic surveys more likely to be Negligible.

Conclusion

4.12.3.15 Overall, the construction of Tier 1 and Tier 2 projects at the same time as Hornsea Four may result in reproductive rates of individuals being impacted in the short term (over a limited number of breeding cycles – 2 breeding cycles within the Hornsea Four offshore construction period), resulting in a **minor** magnitude assessment and overall **slight** impact significance, which is not significant in EIA terms.

4.12.3.16 While there is the potential for a **moderate** magnitude and thus **moderate** impact significance to occur if Tier 1-4 and T1-5 projects are included prior to the application of any mitigation measures, it is highly unlikely that these projects would all occur on this schedule at the same time. Additionally, the implementation of management measures at each project, through the SIP for the Southern North Sea SAC, means that the impact would be managed and considerably reduced and is therefore unlikely to be significant.

Table 4.65: Harbour porpoise CEA Construction noise significance assessment for both unmitigated and mitigated impact - results during the HOW4 pre-piling and piling construction period (between Q1 2026 and Q3 2027 inclusive).

	SCANS III density & 26 km EDR (piling & UXO) = Unmitigated			SCANS III density, 26 km EDR (piling), 5 km EDR (UXO) = MITIGATED			Project ES - single monopile Unmitigated			Project ES – concurrent monopiles Unmitigated		
	Max % MU	Mag	Unmitigated Significance	Max % MU	Mag	Mitigated Significance	Max % MU	Mag	Unmitigated Significance	Max % MU	Mag	Unmitigated Significance
CEA for only the offshore construction period for Hornsea Four (Q4 2024 – Q3 2027 inclusive)												
T1	1.1	Minor	Slight (Not Significant)	0.2	Negligible	Slight (Not Significant)	2.4	Minor	Slight (Not Significant)	3.9	Minor	Slight (Not Significant)
T1-2	1.1	Minor		0.4	Negligible		3.3	Minor		4.9	Minor	
T1-3	2.9	Minor		1.0	Minor		5.6	Moderate	Moderate (Significant)*	8.8	Moderate	Moderate (Significant)*
T1-4	3.4	Minor		1.1	Minor		5.6	Moderate		8.8	Moderate	
T1-5	6.0	Moderate	Moderate (Significant)*	3.7	Minor		8.2	Moderate		11.4	Moderate	

* these scenarios are highly unlikely to occur as they: a) include lower Tier projects for which there is considerably less confidence in the prediction of the number of porpoise impacted and the timelines for these projects and b) assume unmitigated piling and UXO clearance which is unlikely to occur given the proximity of the projects to the Southern North Sea SAC and the requirement for a SIP to ensure compliance with the SNS SAC conservation objectives.

Table 4.66: Number of porpoise disturbed per project assuming a 26 km EDR for UXO clearance and monopile pile driving and using SCANS III density estimates (UXO clearance, pile driving, seismic survey).

	Hornsea Four	Dogger Bank A	Dogger Bank B	Sofia	Dogger Bank C	East Anglia 3	Moray West	Hornsea Three	Norfolk Vanguard	Norfolk Boreas	East Anglia One North	East Anglia Two	Dudgeon Ext	Sheringham Shoal Extension	Seismic survey 1	Seismic survey 2	Seismic survey 3	Seismic survey 4
Tier		**T1**	**T1**	**T1**	**T1**	**T2**	**T2**	**T2**	**T3**	**T3**	**T3**	**T3**	**T4**	**T4**	**T5**	**T5**	**T5**	**T5**
Block	O	O	O	O	N	L	S	O	O/L	O/L	L	L	O	O	Average North Sea			
Density	0.888	0.888	0.888	0.888	0.837	0.607	0.152	0.888	0.888	0.888	0.607	0.607	0.888	0.888	0.52			
Q4 2023		1886	1886	1886	1778	1289	323		1886						2,233	2,233	2,233	2,233
Q1 2024		1886	1886	1886	1778		323	1886	1886			1289			2,233	2,233	2,233	2,233
Q2 2024		1886	1886	1886	1778		323	1886	1886			1289			2,233	2,233	2,233	2,233
Q3 2024		1886	1886	1886	1778		323	1886	1886			1289			2,233	2,233	2,233	2,233
Q4 2024		1886	1886	1886	1778		323	1886	1886			1289			2,233	2,233	2,233	2,233
Q1 2025					1778			1886	1886		1289	1289			2,233	2,233	2,233	2,233
Q2 2025					1778			1886			1289	1289	1886	1886	2,233	2,233	2,233	2,233
Q3 2025					1778			1886		1886	1289	1289	1886	1886	2,233	2,233	2,233	2,233
Q4 2025					1778			1886		1886	1289	1289	1886	1886	2,233	2,233	2,233	2,233

	Hornsea Four	Dogger Bank A	Dogger Bank B	Sofia	Dogger Bank C	East Anglia 3	Moray West	Hornsea Three	Norfolk Vanguard	Norfolk Boreas	East Anglia One North	East Anglia Two	Dudgeon Ext	Sheringham Shoal Extension	Seismic survey 1	Seismic survey 2	Seismic survey 3	Seismic survey 4
Tier		T1	T1	T1	T1	T2	T2	T2	T3	T3	T3	T3	T4	T4	T5	T5	T5	T5
Q1 2026	**1886**				**1778**					**1886**	**1289**	**1289**	**1886**	**1886**	**2,233**	**2,233**	**2,233**	**2,233**
Q2 2026	**1886**				**1778**					**1886**	**1289**	**1289**	**1886**	**1886**	**2,233**	**2,233**	**2,233**	**2,233**
Q3 2026	**1886**				**1778**					**1886**	**1289**	**1289**	**1886**	**1886**	**2,233**	**2,233**	**2,233**	**2,233**
Q4 2026	**1886**				**1778**					**1886**	**1289**	**1289**	**1886**	**1886**	**2,233**	**2,233**	**2,233**	**2,233**
Q1 2027	**1886**							**1886**		**1886**	**1289**	**1289**			**2,233**	**2,233**	**2,233**	**2,233**
Q2 2027	**1886**							**1886**	**1886**	**1886**	**1289**	**1289**			**2,233**	**2,233**	**2,233**	**2,233**
Q3 2027	**1886**							**1886**	**1886**	**1886**	**1289**	**1289**			**2,233**	**2,233**	**2,233**	**2,233**
Q4 2027								1886	1886	1886	1289	1289			2,233	2,233	2,233	2,233
Q1 2028								1886	1886		1289				2,233	2,233	2,233	2,233
Q2 2028								1886			1289				2,233	2,233	2,233	2,233
Q3 2028											1289				2,233	2,233	2,233	2,233

Table 4.67: Number of porpoise disturbed across the different Tiers - assuming a 26 km EDR for UXO clearance and monopile pile driving and using SCANS III density estimates.

	Tier 1		Tier 1-2		Tier 1-3		Tier 1-4		Tier 1-5	
	Total	% MU	Total	% MU	Total	% MU	Total	% MU	Total	% MU
Q4 2023	7436	2.2%	9048	2.6%	10934	3.2%	10934	3.2%	19866	5.8%
Q1 2024	7436	2.2%	9645	2.8%	12820	3.7%	12820	3.7%	21752	6.3%
Q2 2024	7436	2.2%	9645	2.8%	12820	3.7%	12820	3.7%	21752	6.3%
Q3 2024	7436	2.2%	9645	2.8%	12820	3.7%	12820	3.7%	21752	6.3%
Q4 2024	7436	2.2%	9645	2.8%	12820	3.7%	12820	3.7%	21752	6.3%
Q1 2025	1778	0.5%	3664	1.1%	8128	2.4%	8128	2.4%	17060	4.9%
Q2 2025	1778	0.5%	3664	1.1%	6242	1.8%	10014	2.9%	18946	5.5%
Q3 2025	1778	0.5%	3664	1.1%	8128	2.4%	11900	3.4%	20832	6.0%
Q4 2025	1778	0.5%	3664	1.1%	8128	2.4%	11900	3.4%	20832	6.0%
Q1 2026	**3664**	**1.1%**	**3664**	**1.1%**	**8128**	**2.4%**	**11900**	**3.4%**	**20832**	**6.0%**
Q2 2026	**3664**	**1.1%**	**3664**	**1.1%**	**8128**	**2.4%**	**11900**	**3.4%**	**20832**	**6.0%**
Q3 2026	**3664**	**1.1%**	**3664**	**1.1%**	**8128**	**2.4%**	**11900**	**3.4%**	**20832**	**6.0%**
Q4 2026	**3664**	**1.1%**	**3664**	**1.1%**	**8128**	**2.4%**	**11900**	**3.4%**	**20832**	**6.0%**
Q1 2027	**1886**	**0.5%**	**3772**	**1.1%**	**8236**	**2.4%**	**8236**	**2.4%**	**17168**	**5.0%**
Q2 2027	**1886**	**0.5%**	**3772**	**1.1%**	**10122**	**2.9%**	**10122**	**2.9%**	**19054**	**5.5%**
Q3 2027	**1886**	**0.5%**	**3772**	**1.1%**	**10122**	**2.9%**	**10122**	**2.9%**	**19054**	**5.5%**
Q4 2027	0	0.0%	1886	0.5%	8236	2.4%	8236	2.4%	17168	5.0%
Q1 2028	0	0.0%	1886	0.5%	5061	1.5%	5061	1.5%	13993	4.1%
Q2 2028	0	0.0%	1886	0.5%	3175	0.9%	3175	0.9%	12107	3.5%
Q3 2028	0	0.0%	0	0.0%	1289	0.4%	1289	0.4%	10221	3.0%
Overall Min	**0**	**0.0%**	**0**	**0.0%**	**1289**	**0.4%**	**1289**	**0.4%**	**10221**	**3.0%**
Overall Mean	**3230**	**0.9%**	**4696**	**1.4%**	**8580**	**2.5%**	**9900**	**2.9%**	**18832**	**5.5%**
Overall Max	**7436**	**2.2%**	**9645**	**2.8%**	**12820**	**3.7%**	**12820**	**3.7%**	**21752**	**6.3%**

Table 4.68: Number of porpoise disturbed per project using predictions from project specific OWF EIAs for installation of a single monopile (UXO clearance, pile driving, seismic survey).

	Hornsea Four	Dogger Bank A	Dogger Bank B	Sofia	Dogger Bank C	East Anglia 3	Moray West	Hornsea Three	Norfolk Vanguard	Norfolk Boreas	East Anglia One North	East Anglia Two	Dudgeon Ext	Sheringham Shoal Extension	Seismic survey 1	Seismic survey 2	Seismic survey 3	Seismic survey 4
Tier		**T1**	**T1**	**T1**	**T1**	**T2**	**T2**	**T2**	**T3**	**T3**	**T3**	**T3**	**T4**	**T4**	**T5**	**T5**	**T5**	**T5**
Q4 2023		1311	2317	1886	1717	1875	1432		2676						2,233	2,233	2,233	2,233
Q1 2024		1311	2317	1820	1717		1432	1869	2676			1551			2,233	2,233	2,233	2,233
Q2 2024		1311	2317	1820	1717		1432	1869	2676			1551			2,233	2,233	2,233	2,233
Q3 2024		1311	2317	1820	1717		1432	1869	2676			1551			2,233	2,233	2,233	2,233
Q4 2024		1311	2317	1820	1717		1432	1869	2676			1551			2,233	2,233	2,233	2,233
Q1 2025					1717			1869	2676		1289	1551			2,233	2,233	2,233	2,233
Q2 2025					1717			1869			1289	1551	3483	1886	2,233	2,233	2,233	2,233
Q3 2025					1717			1869		2251	1289	1551	3483	1886	2,233	2,233	2,233	2,233
Q4 2025					1717			1869		2251	1289	1551	3483	1886	2,233	2,233	2,233	2,233
Q1 2026	3394				1717					2251	2974	1551	3483	1886	**2,233**	**2,233**	**2,233**	**2,233**

	Hornsea Four	Dogger Bank A	Dogger Bank B	Sofia	Dogger Bank C	East Anglia 3	Moray West	Hornsea Three	Norfolk Vanguard	Norfolk Boreas	East Anglia One North	East Anglia Two	Dudgeon Ext	Sheringham Shoal Extension	Seismic survey 1	Seismic survey 2	Seismic survey 3	Seismic survey 4
Tier		**T1**	**T1**	**T1**	**T1**	**T2**	**T2**	**T2**	**T3**	**T3**	**T3**	**T3**	**T4**	**T4**	**T5**	**T5**	**T5**	**T5**
Q2 2026	3394				1717					2251	2974	1551	2,296	1242	**2,233**	**2,233**	**2,233**	**2,233**
Q3 2026	3394				1717					2251	2974	1551	2,296	1242	**2,233**	**2,233**	**2,233**	**2,233**
Q4 2026	6417				1717					2251	2974	1551	2,296	1242	**2,233**	**2,233**	**2,233**	**2,233**
Q1 2027	6417							4999		2251	2974				**2,233**	**2,233**	**2,233**	**2,233**
Q2 2027	6417							4999	2676	2251	2974				**2,233**	**2,233**	**2,233**	**2,233**
Q3 2027	6417							4999	2676	2251	2974				**2,233**	**2,233**	**2,233**	**2,233**
Q4 2027								4999	2676	2251	2974				2,233	2,233	2,233	2,233
Q1 2028								4999	2676		2974				2,233	2,233	2,233	2,233
Q2 2028								4999			2974				2,233	2,233	2,233	2,233
Q3 2028											2974				2,233	2,233	2,233	2,233

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Table 4.69: Number of porpoise disturbed across the different Tiers using predictions from project specific OWF EIAs for installation of a single monopile.

	Tier 1		Tier 1-2		Tier 1-3		Tier 1-4		Tier 1-5	
	Total	% MU	Total	% MU	Total	% MU	Total	% MU	Total	% MU
Q4 2023	7231	2.1%	10538	3.1%	13214	3.8%	13214	3.8%	22146	6.4%
Q1 2024	7165	2.1%	10466	3.0%	14693	4.3%	14693	4.3%	23625	6.8%
Q2 2024	7165	2.1%	10466	3.0%	14693	4.3%	14693	4.3%	23625	6.8%
Q3 2024	7165	2.1%	10466	3.0%	14693	4.3%	14693	4.3%	23625	6.8%
Q4 2024	7165	2.1%	10466	3.0%	14693	4.3%	14693	4.3%	23625	6.8%
Q1 2025	1717	0.5%	3586	1.0%	9102	2.6%	9102	2.6%	18034	5.2%
Q2 2025	1717	0.5%	3586	1.0%	6426	1.9%	11795	3.4%	20727	6.0%
Q3 2025	1717	0.5%	3586	1.0%	8677	2.5%	14046	4.1%	22978	6.7%
Q4 2025	1717	0.5%	3586	1.0%	8677	2.5%	14046	4.1%	22978	6.7%
Q1 2026	**5111**	**1.5%**	**5111**	**1.5%**	**11887**	**3.4%**	**17256**	**5.0%**	**26188**	**7.6%**
Q2 2026	**5111**	**1.5%**	**5111**	**1.5%**	**11887**	**3.4%**	**15425**	**4.5%**	**24357**	**7.1%**
Q3 2026	**5111**	**1.5%**	**5111**	**1.5%**	**11887**	**3.4%**	**15425**	**4.5%**	**24357**	**7.1%**
Q4 2026	**8134**	**2.4%**	**8134**	**2.4%**	**14910**	**4.3%**	**18448**	**5.3%**	**27380**	**7.9%**
Q1 2027	**6417**	**1.9%**	**11416**	**3.3%**	**16641**	**4.8%**	**16641**	**4.8%**	**25573**	**7.4%**
Q2 2027	**6417**	**1.9%**	**11416**	**3.3%**	**19317**	**5.6%**	**19317**	**5.6%**	**28249**	**8.2%**
Q3 2027	**6417**	**1.9%**	**11416**	**3.3%**	**19317**	**5.6%**	**19317**	**5.6%**	**28249**	**8.2%**
Q4 2027	0	0.0%	4999	1.4%	12900	3.7%	12900	3.7%	21832	6.3%
Q1 2028	0	0.0%	4999	1.4%	10649	3.1%	10649	3.1%	19581	5.7%
Q2 2028	0	0.0%	4999	1.4%	7973	2.3%	7973	2.3%	16905	4.9%
Q3 2028	0	0.0%	0	0.0%	2974	0.9%	2974	0.9%	11906	3.4%
Min	**0**	**0.0%**	**0**	**0.0%**	**2974**	**0.9%**	**2974**	**0.9%**	**11906**	**3.4%**
Mean	**4274**	**1.2%**	**6973**	**2.0%**	**12261**	**3.5%**	**13865**	**4.0%**	**22797**	**6.6%**
Max	**8134**	**2.4%**	**11416**	**3.3%**	**19317**	**5.6%**	**19317**	**5.6%**	**28249**	**8.2%**

Table 4.70: Number of porpoise disturbed per project using predictions from project specific OWF EIAs for installation of concurrent monopiles (UXO clearance, pile driving, seismic survey).

	Hornsea Four	Dogger Bank A	Dogger Bank B	Sofia	Dogger Bank C	East Anglia 3	Moray West	Hornsea Three	Norfolk Vanguard	Norfolk Boreas	East Anglia One North*	East Anglia Two*	Dudgeon Ext*	Sheringham Shoal Extension *	Seismic survey 1	Seismic survey 2	Seismic survey 3	Seismic survey 4
Tier		**T1**	**T1**	**T1**	**T1**	**T2**	**T2**	**T2**	**T2**	**T3**	**T3**	**T3**	**T4**	**T4**	**T5**	**T5**	**T5**	**T5**
Q4 2023		3176	4473	1886	3848	2519	2207		2676						2,233	2,233	2,233	2,233
Q1 2024		3176	4473	3516	3848		2207	1869	2676			1551			2,233	2,233	2,233	2,233
Q2 2024		3176	4473	3516	3848		2207	1869	4420			1551			2,233	2,233	2,233	2,233
Q3 2024		3176	4473	3516	3848		2207	1869	4420			1551			2,233	2,233	2,233	2,233
Q4 2024		3176	4473	3516	3848		2207	1869	4420			1551			2,233	2,233	2,233	2,233
Q1 2025					3848			1869	4420		1289	1551			2,233	2,233	2,233	2,233
Q2 2025					3848			1869			1289	1551	3483	1886	2,233	2,233	2,233	2,233
Q3 2025					3848			1869		2251	1289	1551	3483	1886	2,233	2,233	2,233	2,233
Q4 2025					3848			1869		2251	1289	1551	3483	1886	2,233	2,233	2,233	2,233
Q1 2026	**3394**				**3848**					**2251**	**2974**	**1551**	**3483**	**1886**	**2,233**	**2,233**	**2,233**	**2,233**
Q2 2026	**3394**				**3848**					**4396**	**2974**	**1551**	**3094**		**2,233**	**2,233**	**2,233**	**2,233**

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	Hornsea Four	Dogger Bank A	Dogger Bank B	Sofia	Dogger Bank C	East Anglia 3	Moray West	Hornsea Three	Norfolk Vanguard	Norfolk Boreas	East Anglia One North*	East Anglia Two*	Dudgeon Ext*	Sheringham Shoal Extension *	Seismic survey 1	Seismic survey 2	Seismic survey 3	Seismic survey 4
Tier		T1	T1	T1	T1	T2	T2	T2	T2	T3	T3	T3	T4	T4	T5	T5	T5	T5
Q3 2026	3394				3848					4396	2974	1551	3094		2,233	2,233	2,233	2,233
Q4 2026	9686				3848					4396	2974	1551	3094		2,233	2,233	2,233	2,233
Q1 2027	9686							7330		4396	2974	1551			2,233	2,233	2,233	2,233
Q2 2027	9686							7330	4420	4396	2974	1551			2,233	2,233	2,233	2,233
Q3 2027	9686							7330	4420	4396	2974	1551			2,233	2,233	2,233	2,233
Q4 2027								7330	4420	4396	2974	1551			2,233	2,233	2,233	2,233
Q1 2028								7330	4420		2974				2,233	2,233	2,233	2,233
Q2 2028								7330			2974				2,233	2,233	2,233	2,233
Q3 2028											2974				2,233	2,233	2,233	2,233

* Concurrent pile driving is not expected within East Anglia One North, East Anglia Two, Dudgeon Extension or Sheringham Shoal Extension. Concurrent piling could occur between Dudgeon Extension or Sheringham Shoal Extension

Table 4.71: Number of porpoise disturbed across the different Tiers using predictions from project specific OWF EIAs for installation of concurrent monopiles.

	Tier 1		Tier 1-2		Tier 1-3		Tier 1-4		Tier 1-5	
	Total	% MU	Total	% MU	Total	% MU	Total	% MU	Total	% MU
Q4 2023	13383	3.9%	18109	5.2%	20785	6.0%	20785	6.0%	29717	8.6%
Q1 2024	15013	4.3%	19089	5.5%	23316	6.8%	23316	6.8%	32248	9.3%
Q2 2024	15013	4.3%	19089	5.5%	25060	7.3%	25060	7.3%	33992	9.8%
Q3 2024	15013	4.3%	19089	5.5%	25060	7.3%	25060	7.3%	33992	9.8%
Q4 2024	15013	4.3%	19089	5.5%	25060	7.3%	25060	7.3%	33992	9.8%
Q1 2025	3848	1.1%	5717	1.7%	12977	3.8%	12977	3.8%	21909	6.3%
Q2 2025	3848	1.1%	5717	1.7%	8557	2.5%	13926	4.0%	22858	6.6%
Q3 2025	3848	1.1%	5717	1.7%	10808	3.1%	16177	4.7%	25109	7.3%
Q4 2025	3848	1.1%	5717	1.7%	10808	3.1%	16177	4.7%	25109	7.3%
Q1 2026	**7242**	**2.1%**	**7242**	**2.1%**	**14018**	**4.1%**	**19387**	**5.6%**	**28319**	**8.2%**
Q2 2026	**7242**	**2.1%**	**7242**	**2.1%**	**16163**	**4.7%**	**19257**	**5.6%**	**28189**	**8.2%**
Q3 2026	**7242**	**2.1%**	**7242**	**2.1%**	**16163**	**4.7%**	**19257**	**5.6%**	**28189**	**8.2%**
Q4 2026	**13534**	**3.9%**	**13534**	**3.9%**	**22455**	**6.5%**	**25549**	**7.4%**	**34481**	**10.0%**
Q1 2027	**9686**	**2.8%**	**17016**	**4.9%**	**25937**	**7.5%**	**25937**	**7.5%**	**34869**	**10.1%**
Q2 2027	**9686**	**2.8%**	**17016**	**4.9%**	**30357**	**8.8%**	**30357**	**8.8%**	**39289**	**11.4%**
Q3 2027	**9686**	**2.8%**	**17016**	**4.9%**	**30357**	**8.8%**	**30357**	**8.8%**	**39289**	**11.4%**
Q4 2027	0	0.0%	7330	2.1%	20671	6.0%	20671	6.0%	29603	8.6%
Q1 2028	0	0.0%	7330	2.1%	14724	4.3%	14724	4.3%	23656	6.8%
Q2 2028	0	0.0%	7330	2.1%	10304	3.0%	10304	3.0%	19236	5.6%
Q3 2028	0	0.0%	0	0.0%	2974	0.9%	2974	0.9%	11906	3.4%
Min	**0**	**0.0%**	**0**	**0.0%**	**2974**	**0.9%**	**2974**	**0.9%**	**11906**	**3.4%**
Mean	**7657**	**2.2%**	**11282**	**3.3%**	**18328**	**5.3%**	**19866**	**5.8%**	**28798**	**8.3%**
Max	**15013**	**4.3%**	**19089**	**5.5%**	**30357**	**8.8%**	**30357**	**8.8%**	**39289**	**11.4%**

Table 4.72: Number of porpoise disturbed per project assuming a 15 km EDR for piling with noise abatement and 5 km EDR for low order UXO clearance and using SCANS III density estimates (UXO clearance, pile driving, seismic survey).

	Hornsea Four	Dogger Bank A	Dogger Bank B	Sofia	Dogger Bank C	East Anglia 3	Moray West	Hornsea Three	Norfolk Vanguard	Norfolk Boreas	East Anglia One North	East Anglia Two	Dudgeon Ext	Sheringham Shoal Extension	Seismic survey 1	Seismic survey 2	Seismic survey 3	Seismic survey 4
Tier		**T1**	**T1**	**T1**	**T1**	**T2**	**T2**	**T2**	**T3**	**T3**	**T3**	**T3**	**T4**	**T4**	**T5**	**T5**	**T5**	**T5**
Block	O	O	O	O	N	L	S	O	O/L	O/L	L	L	O	O	Average North Sea			
Density	0.888	0.888	0.888	0.888	0.837	0.607	0.152	0.888	0.888	0.888	0.607	0.607	0.888	0.888	0.52			
Q4 2023		628	628	70	592	429	323		70						2,233	2,233	2,233	2,233
Q1 2024		628	628	628	592		323	70	70			48			2,233	2,233	2,233	2,233
Q2 2024		628	628	628	592		323	70	1886			48			2,233	2,233	2,233	2,233
Q3 2024		628	628	628	592		323	70	1886			48			2,233	2,233	2,233	2,233
Q4 2024		628	628	628	592		323	70	1886			48			2,233	2,233	2,233	2,233
Q1 2025					592			70	1886		48	429			2,233	2,233	2,233	2,233
Q2 2025					592			70			48	429	70	70	2,233	2,233	2,233	2,233
Q3 2025					592			70		70	48	429	70	70	2,233	2,233	2,233	2,233
Q4 2025					592			70		70	48	429	70	70	2,233	2,233	2,233	2,233

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	Hornsea Four	Dogger Bank A	Dogger Bank B	Sofia	Dogger Bank C	East Anglia 3	Moray West	Hornsea Three	Norfolk Vanguard	Norfolk Boreas	East Anglia One North	East Anglia Two	Dudgeon Ext	Sheringham Shoal Extension	Seismic survey 1	Seismic survey 2	Seismic survey 3	Seismic survey 4
Tier		**T1**	**T1**	**T1**	**T1**	**T2**	**T2**	**T2**	**T3**	**T3**	**T3**	**T3**	**T4**	**T4**	**T5**	**T5**	**T5**	**T5**
Q1 2026	**70**				**592**					**70**	**429**	**429**	**70**	**70**	**2,233**	**2,233**	**2,233**	**2,233**
Q2 2026	**70**				**592**					**628**	**429**	**429**	**628**	**628**	**2,233**	**2,233**	**2,233**	**2,233**
Q3 2026	**70**				**592**					**628**	**429**	**429**	**628**	**628**	**2,233**	**2,233**	**2,233**	**2,233**
Q4 2026	**628**				**592**					**628**	**429**	**429**	**628**	**628**	**2,233**	**2,233**	**2,233**	**2,233**
Q1 2027	**628**							**628**		**628**	**429**	**429**			**2,233**	**2,233**	**2,233**	**2,233**
Q2 2027	**628**							**628**	**628**	**628**	**429**	**429**			**2,233**	**2,233**	**2,233**	**2,233**
Q3 2027	**628**							**628**	**628**	**628**	**429**	**429**			**2,233**	**2,233**	**2,233**	**2,233**
Q4 2027								628	628	628	429	429			2,233	2,233	2,233	2,233
Q1 2028								628	628		429				2,233	2,233	2,233	2,233
Q2 2028								628			429				2,233	2,233	2,233	2,233
Q3 2028											429				2,233	2,233	2,233	2,233

Table 4.73: Number of porpoise disturbed across the different Tiers assuming a 15 km EDR for piling with noise abatement and 5 km EDR for low order UXO clearance and using SCANS III density estimates.

	Tier 1		Tier 1-2		Tier 1-3		Tier 1-4		Tier 1-5	
	Total	% MU	Total	% MU	Total	% MU	Total	% MU	Total	% MU
Q4 2023	1918	0.6%	2670	0.8%	2740	0.8%	2740	0.8%	11672	3.4%
Q1 2024	2476	0.7%	2869	0.8%	2987	0.9%	2987	0.9%	11919	3.5%
Q2 2024	2476	0.7%	2869	0.8%	4803	1.4%	4803	1.4%	13735	4.0%
Q3 2024	2476	0.7%	2869	0.8%	4803	1.4%	4803	1.4%	13735	4.0%
Q4 2024	2476	0.7%	2869	0.8%	4803	1.4%	4803	1.4%	13735	4.0%
Q1 2025	592	0.2%	662	0.2%	3025	0.9%	3025	0.9%	11957	3.5%
Q2 2025	592	0.2%	662	0.2%	1139	0.3%	1279	0.4%	10211	3.0%
Q3 2025	592	0.2%	662	0.2%	1209	0.4%	1349	0.4%	10281	3.0%
Q4 2025	592	0.2%	662	0.2%	1209	0.4%	1349	0.4%	10281	3.0%
Q1 2026	**662**	**0.2%**	**662**	**0.2%**	**1590**	**0.5%**	**1730**	**0.5%**	**10662**	**3.1%**
Q2 2026	**662**	**0.2%**	**662**	**0.2%**	**2148**	**0.6%**	**3404**	**1.0%**	**12336**	**3.6%**
Q3 2026	**662**	**0.2%**	**662**	**0.2%**	**2148**	**0.6%**	**3404**	**1.0%**	**12336**	**3.6%**
Q4 2026	**1220**	**0.4%**	**1220**	**0.4%**	**2706**	**0.8%**	**3962**	**1.1%**	**12894**	**3.7%**
Q1 2027	**628**	**0.2%**	**1256**	**0.4%**	**2742**	**0.8%**	**2742**	**0.8%**	**11674**	**3.4%**
Q2 2027	**628**	**0.2%**	**1256**	**0.4%**	**3370**	**1.0%**	**3370**	**1.0%**	**12302**	**3.6%**
Q3 2027	**628**	**0.2%**	**1256**	**0.4%**	**3370**	**1.0%**	**3370**	**1.0%**	**12302**	**3.6%**
Q4 2027	0	0.0%	628	0.2%	2742	0.8%	2742	0.8%	11674	3.4%
Q1 2028	0	0.0%	628	0.2%	1685	0.5%	1685	0.5%	10617	3.1%
Q2 2028	0	0.0%	628	0.2%	1057	0.3%	1057	0.3%	9989	2.9%
Q3 2028	0	0.0%	0	0.0%	429	0.1%	429	0.1%	9361	2.7%
Min	**0**	**0.0%**	**0**	**0.0%**	**429**	**0.1%**	**429**	**0.1%**	**9361**	**2.7%**
Mean	**964**	**0.3%**	**1283**	**0.4%**	**2535**	**0.7%**	**2752**	**0.8%**	**11684**	**3.4%**
Max	**2476**	**0.7%**	**2869**	**0.8%**	**4803**	**1.4%**	**4803**	**1.4%**	**13735**	**4.0%**

4.12.4 CEA Construction Noise - Bottlenose dolphin

4.12.4.1 Only the Moray West ES Chapter and the Dudgeon and Sheringham Shoal Extension PEIR chapters included an assessment for bottlenose dolphins. The Dudgeon and Sheringham Shoal Extension PEIR did not present behavioural disturbance for bottlenose dolphins, instead TTS-onset impact ranges were provided (<1 individual impacted). Therefore, the lack of project specific impact assessments for bottlenose dolphins meant that only a broad scale assessment using the average Greater North Sea MU density estimate and assumed 26 km EDRs (for UXO and piling) and 12 km EDR (for seismic) was possible.

4.12.4.2 As highlighted above for harbour porpoise, the assessment of Tiers 3, 4 and 5 is very uncertain as these projects are not yet consented, are at the PEIR stage or are in initial planning stages and thus there is little information available on the predicted level of impact or the project construction timelines. In particular, the offshore construction timelines for some of these projects are gross over-estimates. Overall, the predicted magnitude of impact is **minor** across all Tier 1-5 projects (**Table 4.74**). Even under the improbable worst-case scenario of all Tier 1-5 projects occurring as outlined in **Table 4.75**, a maximum of 100 bottlenose dolphins are predicted to be disturbed on any one day, which equates to 4.5% of the MU.

4.12.4.3 A key source of precaution in this assessment is that the harbour porpoise dose-response curve and harbour porpoise EDRs have been used for bottlenose dolphins, as there is no bottlenose dolphin-specific equivalent. Harbour porpoise have a lower auditory injury threshold (i.e. higher hearing sensitivity) than bottlenose dolphins (Southall et al. 2019) and are considered to be particularly responsive to anthropogenic disturbance, with playback experiments showing avoidance reactions to very low levels of sound (Tyack 2009) and multiple studies showing that porpoise respond (avoidance and reduced vocalisation) to a variety of anthropogenic noise sources to distances of multiple kilometres (e.g., Brandt et al. 2013, Thompson et al. 2013, Tougaard et al. 2013, Brandt et al. 2018, Sarnocinska et al. 2019, Thompson et al. 2020, Benhemma-Le Gall et al. 2021).

4.12.4.4 Studies have shown that dolphin species show comparatively less of a disturbance response from underwater noise compared to harbour porpoise. For example, through an analysis of 16 years of marine mammal observer data from seismic survey vessels, Stone et al. (2017) found a significant reduction in porpoise detection rates when large seismic airgun arrays were actively firing, but not for bottlenose dolphins. While the strength and significance of responses varied between porpoise and other dolphin species for different measures of effect, the study emphasised the sensitivity of the harbour porpoise (Stone et al. 2017). In the Moray Firth, bottlenose dolphins have been shown to remain in the impacted area during both seismic activities and pile installation activities (Fernandez-Betelu et al. 2021) which highlights a lack of complete displacement response. Likewise, other high-frequency cetacean species such as striped and common dolphins have been shown to display less of a response to underwater noise signals and construction-related activities compared to harbour porpoise (e.g. Kastelein et al. 2006, Culloch et al. 2016). Noise modelling in support of UXO clearance impact assessments consistently estimate that, based on differences in hearing sensitivity alone, the anticipated range to the onset of temporary hearing loss (TTS, sometimes used as a proxy for behavioural responses to a single impulse) for harbour porpoise is c. 10-20 times greater than that for dolphins (e.g. Mason and Barnham 2018, Neart na Gaoithe Offshore Wind Farm 2019). Considering the above, it can be concluded that using porpoise response data as a proxy for bottlenose dolphins is likely to result in an over-estimate of the response for bottlenose dolphins.

4.12.4.5 It is also important to consider that any mitigation measures put in place by each of the OWFs as part of their SIP to prevent significant impacts to the Southern North Sea SAC for porpoise, would also serve to mitigate and reduce impacts to bottlenose dolphins at the same time. Therefore, accepting that there are high levels of precaution in the assessment, the cumulative assessment for construction noise on bottlenose dolphins is considered to be **Slight**, which is not significant in EIA terms.

Table 4.74: Bottlenose dolphin CEA Construction noise significance assessment.

	Average Greater North Sea MU density & 26 km EDR			
	Max % MU	Unmitigated Magnitude	Sensitivity	Unmitigated Significance
T1	1.1	**Minor**: Reproductive rates of individuals may be impacted in the short term (over a limited number of breeding cycles).	**Medium**	**Slight** (Not Significant)
T1-2	1.6			
T1-3	2.3			
T1-4	2.2			
T1-5	4.5			

Table 4.75: Number of bottlenose dolphins disturbed per project assuming a 26 km EDR for UXO clearance and monopile pile driving (UXO clearance, pile driving, seismic survey).

	Hornsea Four	Dogger Bank A	Dogger Bank B	Sofia	Dogger Bank C	East Anglia 3	Moray West	Hornsea Three	Norfolk Vanguard	Norfolk Boreas	East Anglia One North	East Anglia Two	Dudgeon Ext	Sheringham Shoal Extension	Seismic survey 1	Seismic survey 2	Seismic survey 3	Seismic survey 4
Tier		T1	T1	T1	T1	T2	T2	T2	T3	T3	T3	T3	T4	T4	T5	T5	T5	T5
Density	Average across Greater North Sea MU = 0.003 dolphins/km^2																	
Q4 2023		6	6	6	6	6	6		6						13	13	13	13
Q1 2024		6	6	6	6		6	6	6			6			13	13	13	13
Q2 2024		6	6	6	6		6	6	6			6			13	13	13	13
Q3 2024		6	6	6	6		6	6	6			6			13	13	13	13
Q4 2024		6	6	6	6		6	6	6			6			13	13	13	13
Q1 2025					6			6	6		6	6			13	13	13	13
Q2 2025					6			6			6	6	6	6	13	13	13	13
Q3 2025					6			6		6	6	6	6	6	13	13	13	13
Q4 2025					6			6		6	6	6	6	6	13	13	13	13
Q1 2026	**6**				**6**					**6**	**6**	**6**	**6**	**6**	**13**	**13**	**13**	**13**
Q2 2026	**6**				**6**					**6**	**6**	**6**	**6**	**6**	**13**	**13**	**13**	**13**
Q3 2026	**6**				**6**					**6**	**6**	**6**	**6**	**6**	**13**	**13**	**13**	**13**
Q4 2026	**6**				**6**					**6**	**6**	**6**	**6**	**6**	**13**	**13**	**13**	**13**
Q1 2027	**6**							**6**		**6**	**6**	**6**			**13**	**13**	**13**	**13**
Q2 2027	**6**							**6**	**6**	**6**	**6**	**6**			**13**	**13**	**13**	**13**
Q3 2027	**6**							**6**	**6**	**6**	**6**	**6**			**13**	**13**	**13**	**13**
Q4 2027								6	6	6	6	6			13	13	13	13
Q1 2028								6	6		6				13	13	13	13
Q2 2028								6			6				13	13	13	13
Q3 2028											6				13	13	13	13

Table 4.76: Number of dolphins disturbed across the different Tiers - assuming an unmitigated 26 km EDR for UXO clearance and monopile pile driving.

	Tier 1		Tier 1-2		Tier 1-3		Tier 1-4		Tier 1-5	
	Total	% MU	Total	% MU	Total	% MU	Total	% MU	Total	% MU
Q4 2023	24	1.1%	36	1.6%	42	1.9%	42	1.9%	94	4.3%
Q1 2024	24	1.1%	36	1.6%	48	2.2%	48	2.2%	100	4.5%
Q2 2024	24	1.1%	36	1.6%	48	2.2%	48	2.2%	100	4.5%
Q3 2024	24	1.1%	36	1.6%	48	2.2%	48	2.2%	100	4.5%
Q4 2024	24	1.1%	36	1.6%	48	2.2%	48	2.2%	100	4.5%
Q1 2025	6	0.3%	12	0.5%	30	1.4%	30	1.4%	82	3.7%
Q2 2025	6	0.3%	12	0.5%	24	1.1%	36	1.6%	88	4.0%
Q3 2025	6	0.3%	12	0.5%	30	1.4%	42	1.9%	94	4.3%
Q4 2025	6	0.3%	12	0.5%	30	1.4%	42	1.9%	94	4.3%
Q1 2026	**12**	**0.5%**	**12**	**0.5%**	**30**	**1.4%**	**42**	**1.9%**	**94**	**4.3%**
Q2 2026	**12**	**0.5%**	**12**	**0.5%**	**30**	**1.4%**	**42**	**1.9%**	**94**	**4.3%**
Q3 2026	**12**	**0.5%**	**12**	**0.5%**	**30**	**1.4%**	**42**	**1.9%**	**94**	**4.3%**
Q4 2026	**12**	**0.5%**	**12**	**0.5%**	**30**	**1.4%**	**42**	**1.9%**	**94**	**4.3%**
Q1 2027	**6**	**0.3%**	**12**	**0.5%**	**30**	**1.4%**	**30**	**1.4%**	**82**	**3.7%**
Q2 2027	**6**	**0.3%**	**12**	**0.5%**	**36**	**1.6%**	**36**	**1.6%**	**88**	**4.0%**
Q3 2027	**6**	**0.3%**	**12**	**0.5%**	**36**	**1.6%**	**36**	**1.6%**	**88**	**4.0%**
Q4 2027	0	0.0%	6	0.3%	30	1.4%	30	1.4%	82	3.7%
Q1 2028	0	0.0%	6	0.3%	18	0.8%	18	0.8%	70	3.2%
Q2 2028	0	0.0%	6	0.3%	12	0.5%	12	0.5%	64	2.9%
Q3 2028	0	0.0%	0	0.0%	6	0.3%	6	0.3%	58	2.6%
Min	**0**	**0.0%**	**0**	**0.0%**	**6**	**0.3%**	**6**	**0.3%**	**58**	**2.6%**
Mean	**11**	**0.5%**	**17**	**0.7%**	**32**	**1.4%**	**36**	**1.6%**	**88**	**4.0%**
Max	**24**	**1.1%**	**36**	**1.6%**	**48**	**2.2%**	**48**	**2.2%**	**100**	**4.5%**

4.12.5 CEA Construction Noise - Grey seal

4.12.5.1 There were substantial differences in the approach taken to disturbance impact assessment across the different project EIAs, with varying density estimates (including site-specific densities and at-sea usage estimates), as well as various thresholds used to assess disturbance (including TTS-onset, dose-response and fixed EDR). Given the fact that grey seal numbers have significantly increased in the last decade, it was considered inappropriate to base the cumulative impact assessment for grey seals on old density estimates used in the EIAs or the old at-sea usage maps. Therefore, in order to be conservative in the estimate of cumulative impact, the assessment was conducted using the new seal habitat preference map as the density source, the 26 km EDR for both UXO and piling and a 12 km EDR for a moving seismic source. Moray West was not included in the CEA for grey seals as it is outside of the combined Southeast and Northeast England MUs.

4.12.5.2 Table 4.77 outlines the maximum percentage of the MU that is predicted to be impacted should all Tier 1 to Tier 5 projects construct at the same time as the Hornsea Four pre-piling and piling construction period. This is summarised as:

- Maximum predicted impact across T1 during the Hornsea Four pre-piling and piling period assuming a 26 km EDR for a single monopile and UXO clearance is 1.9% MU;
- Maximum predicted impact across T1-2 during the Hornsea Four pre-piling and piling period assuming a 26 km EDR for a single monopile and UXO clearance is 2.3% MU;
- Maximum predicted impact across T1-3 during the Hornsea Four pre-piling and piling period assuming a 26 km EDR for a single monopile and UXO clearance is 4.1% MU;
- Maximum predicted impact across T1-4 during the Hornsea Four pre-piling and piling period assuming a 26 km EDR for a single monopile and UXO clearance is 8.2% MU; and
- Maximum predicted impact across T1-5 during the Hornsea Four pre-piling and piling period assuming a 26 km EDR for a single monopile and UXO clearance is 13.4% MU.

4.12.5.3 The likelihood of all T1-5 projects occurring within this time period is extremely unlikely. The highest predicted impact occurs in Q1-Q4 2026, when seven OWFs may be constructing, and four seismic (airgun) surveys may be occurring on the same day. The likelihood that all these projects conduct noise generating activity (UXO, piling or seismic airgun surveys) on the same day is minimal.

4.12.5.4 The number of animals predicted to be impacted is driven primarily by Hornsea Four, in combination with Dudgeon Extension and Sheringham Shoal Extension, since these are the sites closest to land and therefore closest to higher densities of grey seals (though it should be noted that the numbers presented here are higher than those assessed in the Dudgeon and Sheringham Shoal Extension PEIR as it assessed TTS not disturbance).

4.12.5.5 When considering this assessment for grey seals, it is important to consider that a key source of precaution in the assessment is the fact that the harbour porpoise EDRs have been used for grey seals, as there is no grey seal-specific equivalent. Harbour porpoise have a lower auditory injury threshold (i.e. higher hearing sensitivity) than grey seals (Southall et al. 2019) and are considered to be particularly responsive to anthropogenic disturbance, with playback experiments showing avoidance reactions to very low levels of sound (Tyack 2009) and multiple studies showing that porpoise respond (avoidance and reduced vocalisation) to a variety of anthropogenic noise sources to distances of multiple kilometres (e.g., Brandt et al. 2013, Thompson et al. 2013, Tougaard et al. 2013, Brandt et al. 2018, Sarnocinska et al. 2019, Thompson et al. 2020, Benhemma-Le Gall et al. 2021).

4.12.5.6 Studies have shown that seal species show comparatively less of a disturbance response from underwater noise compared to harbour porpoise. Based on data presented in Aarts et al. (2018) and more recently in Hastie et al. (2021) it is possible that grey seals may show no behavioural response at all, if they are motivated to remain in the area for foraging, with foraging decisions and the decision to remain or respond being consistent with a risk/profit balancing approach. Given the wide ranging behaviour of grey seals, travelling over 100 km between haul-out sites and with foraging trips lasting up to 30 days (SCOS 2021), it is highly likely that if any grey seals are displaced from this area, they will be able to compensate by travelling to a different foraging patch.

4.12.5.7 In addition to the grey seal information, studies have shown that harbour seals are also less sensitive than harbour porpoise. Harbour seals (which are considered to be more sensitive to underwear noise disturbance than grey seals) are less likely to experience TTS due to exposure to pile-driving sounds than harbour porpoises, which may be related to the difference in the dynamic range of hearing between the two species (Kastelein et al. 2018a). Additionally, displacement of harbour porpoise resulting from pile driving has been shown to last 1-2 days after piling ends (Brandt et al. 2016, Brandt et al. 2018), whereas harbour seals have been shown to return to the impacted area within two hours after the end of piling events (Russell et al. 2016). Species specific dose-response curves for pile driving have shown large differences between the two species, with the harbour porpoise dose-response curve predicting responses above 120 dB re 1 $\mu Pa^2 s$ SEL_{ss} (Graham et al. 2017a), whereas the harbour seal dose-response curve predicts responses above 145 dB re 1 $\mu Pa^2 s$ SEL_{ss} (Whyte et al. 2020).

4.12.5.8 Given that harbour porpoise are expected to respond to lower noise levels than grey seals, and that seals return to the impacted area much quicker than harbour porpoise, it can be concluded that using porpoise EDRs as a proxy for grey seals is likely to result in an over-estimate of the response for grey seals. With this in mind, the magnitude of impact to grey seals is considered to be Minor to Moderate at most, whereby temporary changes in behaviour and/or distribution of individuals is predicted to be at a scale that could result in potential reductions to lifetime reproductive success to some individuals although not enough to affect the population trajectory over a generational scale.

4.12.5.9 It is also important to consider that any mitigation measures put in place by each of the OWFs as part of their SIP to prevent significant impacts to the Southern North Sea SAC for porpoise, would also serve to mitigate and reduce impacts to grey seals at the same time.

4.12.5.10 In conclusion, as outlined in **paragraph 4.10.4.27** *et seq.*, the sensitivity of grey seals to disturbance from underwater noise is considered to be **low**. Therefore, even in the highly unlikely scenario that all Tier 1-5 projects occur as shown in **Table 4.78**, the magnitude of the impact is **minor** to **moderate**, and therefore this impact is assessed as **Slight** significance, which is not significant in EIA terms.

Table 4.77: Grey seal CEA Construction noise significance assessment.

	Average Greater North Sea MU density & 26 km EDR			
	Max % MU	Unmitigated Magnitude	Sensitivity	Unmitigated Significance
T1	1.9	**Minor:** Reproductive rates of individuals may be impacted in the short term (over a limited number of breeding cycles).	**Low**	**Slight** (Not Significant)
T1-2	2.3			
T1-3	4.1			
T1-4	8.2	**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).		
T1-5	13.4			

Table 4.78: Number of grey seals disturbed per project assuming a 26 km EDR for UXO clearance and monopile pile driving (UXO clearance, pile driving, seismic survey).

	Hornsea Four	Dogger Bank A	Dogger Bank B	Sofia	Dogger Bank C	East Anglia 3	Hornsea Three	Norfolk Vanguard	Norfolk Boreas	East Anglia One North	East Anglia Two	Dudgeon Ext	Sheringham Shoal Ext	Seismic survey 1	Seismic survey 2	Seismic survey 3	Seismic survey 4
Tier		T1	T1	T1	T1	T2	T2	T3	T3	T3	T3	T4	T4	T5	T5	T5	T5
Density*	0.476	0.168	0.175	0.129	0.093	0.089	0.224	0.142	0.103	0.133	0.136	0.737	0.759	0.194**	0.194	0.194	0.194
Q4 2023		356	371	274	196	190		302						831	831	831	831
Q1 2024		356	371	274	196		475	302			288			831	831	831	831
Q2 2024		356	371	274	196		475	302			288			831	831	831	831
Q3 2024		356	371	274	196		475	302			288			831	831	831	831
Q4 2024		356	371	274	196		475	302			288			831	831	831	831
Q1 2025					196		475	302		283	288			831	831	831	831
Q2 2025					196		475			283	288	1565	1612	831	831	831	831
Q3 2025					196		475		218	283	288	1565	1612	831	831	831	831
Q4 2025					196		475		218	283	288	1565	1612	831	831	831	831
Q1 2026	**1011**				**196**				**218**	**283**	**288**	**1565**	**1612**	**831**	**831**	**831**	**831**
Q2 2026	**1011**				**196**				**218**	**283**	**288**	**1565**	**1612**	**831**	**831**	**831**	**831**
Q3 2026	**1011**				**196**				**218**	**283**	**288**	**1565**	**1612**	**831**	**831**	**831**	**831**
Q4 2026	**1011**				**196**				**218**	**283**	**288**	**1565**	**1612**	**831**	**831**	**831**	**831**
Q1 2027	**1011**						**475**		**218**	**283**	**288**			**831**	**831**	**831**	**831**
Q2 2027	**1011**						**475**	**302**	**218**	**283**	**288**			**831**	**831**	**831**	**831**
Q3 2027	**1011**						**475**	**302**	**218**	**283**	**288**			**831**	**831**	**831**	**831**
Q4 2027							475	302	218	283	288			831	831	831	831
Q1 2028							475	302		283				831	831	831	831
Q2 2028							475			283				831	831	831	831
Q3 2028										283				831	831	831	831

* Average density estimate across the wind farm array area + 26 km buffer, calculated using the seal habitat preference map (Carter et al. 2020)

** Average density across the combined SE and NE England MUs, calculated using the seal habitat preference map (Carter et al. 2020)

Table 4.79: Number of grey seals across the different Tiers - assuming an unmitigated 26 km EDR for UXO clearance and monopile pile driving.

	Tier 1		Tier 1-2		Tier 1-3		Tier 1-4		Tier 1-5	
	Total	% MU	Total	% MU	Total	% MU	Total	% MU	Total	% MU
Q4 2023	1197	1.9%	1387	2.2%	1689	2.7%	1689	2.7%	5013	7.9%
Q1 2024	1197	1.9%	1672	2.6%	2262	3.6%	2262	3.6%	5586	8.8%
Q2 2024	1197	1.9%	1672	2.6%	2262	3.6%	2262	3.6%	5586	8.8%
Q3 2024	1197	1.9%	1672	2.6%	2262	3.6%	2262	3.6%	5586	8.8%
Q4 2024	1197	1.9%	1672	2.6%	2262	3.6%	2262	3.6%	5586	8.8%
Q1 2025	196	0.3%	671	1.1%	1544	2.4%	1544	2.4%	4868	7.7%
Q2 2025	196	0.3%	671	1.1%	1242	2.0%	4419	7.0%	7743	12.2%
Q3 2025	196	0.3%	671	1.1%	1460	2.3%	4637	7.3%	7961	12.5%
Q4 2025	196	0.3%	671	1.1%	1460	2.3%	4637	7.3%	7961	12.5%
Q1 2026	**1207**	**1.9%**	**1207**	**1.9%**	**1996**	**3.1%**	**5173**	**8.2%**	**8497**	**13.4%**
Q2 2026	**1207**	**1.9%**	**1207**	**1.9%**	**1996**	**3.1%**	**5173**	**8.2%**	**8497**	**13.4%**
Q3 2026	**1207**	**1.9%**	**1207**	**1.9%**	**1996**	**3.1%**	**5173**	**8.2%**	**8497**	**13.4%**
Q4 2026	**1207**	**1.9%**	**1207**	**1.9%**	**1996**	**3.1%**	**5173**	**8.2%**	**8497**	**13.4%**
Q1 2027	**1011**	**1.6%**	**1486**	**2.3%**	**2275**	**3.6%**	**2275**	**3.6%**	**5599**	**8.8%**
Q2 2027	**1011**	**1.6%**	**1486**	**2.3%**	**2577**	**4.1%**	**2577**	**4.1%**	**5901**	**9.3%**
Q3 2027	**1011**	**1.6%**	**1486**	**2.3%**	**2577**	**4.1%**	**2577**	**4.1%**	**5901**	**9.3%**
Q4 2027	0	0.0%	475	0.7%	1566	2.5%	1566	2.5%	4890	7.7%
Q1 2028	0	0.0%	475	0.7%	1060	1.7%	1060	1.7%	4384	6.9%
Q2 2028	0	0.0%	475	0.7%	758	1.2%	758	1.2%	4082	6.4%
Q3 2028	0	0.0%	0	0.0%	283	0.4%	283	0.4%	3607	5.7%
Min	**0**	**0.0%**	**0**	**0.0%**	**283**	**0.4%**	**283**	**0.4%**	**3607**	**5.7%**
Mean	**732**	**1.2%**	**1074**	**1.7%**	**1776**	**2.8%**	**2888**	**4.6%**	**6212**	**9.8%**
Max	**1207**	**1.9%**	**1672**	**2.6%**	**2577**	**4.1%**	**5173**	**8.2%**	**8497**	**13.4%**

4.12.6 Vessel disturbance during construction of Hornsea Four cumulatively with other plans and projects

4.12.6.1 It is extremely difficult to reliably quantify the increased disturbance risk to marine mammals resulting from increased vessel activity on a cumulative basis given the large degree of temporal and spatial variation in vessel movements between projects and regions, coupled with the spatial and temporal variation in marine mammal movements across the region. This cumulative assessment considers the increased potential for disturbance to marine mammals, due to the potential increase in vessel movements from the construction of the Hornsea Four offshore wind farm with other planned or existing projects, plans and activities.

4.12.6.2 The activities that were considered are:

- Offshore wind farms where construction and operational and maintenance phases overlap with the construction phase of Hornsea Four; and
- Cable and pipeline projects that have not yet commenced construction but where construction is expected to overlap with construction activities at Hornsea Four.

4.12.6.3 **Table 4.80** presents the quantitative information that is available for all projects screened into the CEA for vessel disturbance, covering the construction and operation phase vessel movements expected for each project. Vessel routes to and from offshore wind farms and other projects will use existing vessel routes where marine mammals will be accustomed to, and potentially habituated to regular vessel movements and therefore the additional risk is confined mainly to construction sites. Vessel movements within construction areas are likely to be limited and relatively slow. In addition, most projects are likely to adopt vessel management plans in order to minimise any potential effects on marine mammals. The impact is predicted to be of local, long-term duration but intermittent. It is expected that any marine mammals that are disturbed as a result of vessel presence will return to the area once the vessel disturbance has ended. The magnitude is therefore considered to be **minor**.

4.12.6.4 All marine mammal receptors are deemed to be of low vulnerability given the existing evidence behavioural responses to vessels (see **paragraph 4.10.4.31** *et seq.*). The sensitivity of the marine mammal receptors is therefore considered to be **low**.

4.12.6.5 Overall, the sensitivity of marine mammals to vessel disturbance has been assessed as **low** and the magnitude is predicted to be **minor**. The effect is of **slight** significance, which is not significant in EIA terms.

Table 4.80: CEA projects – predicted additional vessel activity during the Hornsea Four construction period.

Tier	Project	Construction	Operation
	Hornsea Four	Foundation Installation: 2,880 return trips over 1 yr. Wind Turbine Installation: 900 return trips over 1 yr. OSS Installation: 270 return trips over 2 months. OSS Foundation Installation: 180 return trips over 2 months. Inter-Array and Interconnector Cable Installation: 1,488 return trips over 1 yr. Offshore Export Cable Installation:408 return trips over 1 yr. Up to 8 vessels in any given 5 km^2 at any one time.	NA
1	Dogger Bank A	Not constructing while Hornsea Four is constructing.	683 round trips. Max 28 vessels on site at any time.
1	Dogger Bank B		683 round trips. Max 28 vessels on site at any time.
1	Dogger Bank C	396 vessels (cumulative for 6 concurrent projects). Max 66 vessels offshore/project. Total round trips: Construction = 5150, Materials transport = 660. Dogger Bank C and Sofia not assessed separately.	4,797 round trips. Max 26 vessels on site at any time. Dogger Bank C and Sofia not assessed separately.
1	Sofia	Not constructing while Hornsea Four is constructing.	
2	East Anglia Three	Indicative # movements: 5,695 total. Max 45 vessels on site at any one time.	Service vessels: 52 round trips. WTG support vessels: 4,015 round trips
2	Moray West	Not constructing while Hornsea Four is constructing.	150-200 return trips per year.
3	Norfolk Vanguard	1,180 round trips total (590 x 2 phase). Max 57 vessels on site at any time.	440 round trips.
3	Norfolk Boreas	1,296 round trips total. Max 57 vessels on site at any time.	Not operational while Hornsea Four is constructing.
3	East Anglia One North	3,335 round trips total. Max 74 vessels on site at any one time.	Not operational while Hornsea Four is constructing.
3	Hornsea Three	Up to 126 construction vessels in the vicinity (up to 10,774 return trips). Up to eight vessels in a 5 km^2 area at any one time	2,885 round trips per year.
3	East Anglia Two	3,672 vessel trips total. 74 vessels on site at any one time.	Not operational while Hornsea Four is constructing.
4	Dudgeon Extension	603 round trips over 2 years. Max 16 vessels on site at any one time.	Up to 7 vessels on site at any one time. Up to 690 round trips per year.
4	Sheringham Shoal Extension	603 round trips over 2 years. Max 16 vessels on site at any one time.	Up to 7 vessels on site at any one time. Up to 690 round trips per year.
5	Blyth	Unknown	Unknown
5	Endurance CCS Area	Unknown	Unknown
5	Johnston WHPS	Unknown	Unknown

Tier	Project	Construction	Operation
5	Johnston template/ manifold	Unknown	Unknown

4.13 Transboundary effects

4.13.1.1 Transboundary effects are defined as those effects upon the receiving environment of other European Economic Area (EEA) states, whether occurring from Hornsea Four alone, or cumulatively with other projects in the wider area. A transboundary screening exercise was undertaken at Scoping (Annex L of the Scoping Report, (Orsted, 2018)), which identified that there was the potential for transboundary effects to occur in relation to marine mammals. The potential transboundary impacts screened into the assessment for marine mammals were:

- Underwater noise generated during construction and decommissioning, particularly piling during the installation of foundations; and
- Disturbance to prey (fish) species from loss of fish spawning and nursery habitat and suspended sediments and deposition.

4.13.1.2 Behavioural disturbance resulting from underwater noise during construction could occur over large ranges (tens of kilometres) and therefore there is the potential for transboundary effects to occur where subsea noise arising from Hornsea Four could extend into waters of other EEA states (such as the Netherlands whose marine border is located approximately 87 km from Hornsea Four). For Hornsea Four, these impacts were predicted to be short term and intermittent, with recovery of marine mammal populations to affected areas following completion of all piling activities. Overall, the sensitivity of marine mammal receptors to behavioural disturbance was assessed as **medium** to **low** and the magnitude predicted to be **negligible** to **minor** adverse. The effect was therefore considered to be a maximum of **slight**, which is not considered significant in EIA terms.

4.13.1.3 No significant effects of reduction in prey availability are predicted to extend into the waters of other EEA states. **Chapter 3: Fish and Shellfish Ecology** concluded no significant impacts on all fish species. Therefore, the impact of a reduction in prey ability will not lead to a significant effect.

4.14 Inter-related effects

4.14.1.1 Inter-related effects consider impacts from the construction, operation or decommissioning of Hornsea Four on the same receptor (or group). The potential inter-related effects that could arise in relation to marine mammals are presented in **Table 4.81**. Such inter-related effects include both:

- Project lifetime effects: i.e. those arising throughout more than one phase of the project (construction, operation, and decommissioning) to interact to potentially create a more significant effect on a receptor than if just one phase were assessed in isolation; and
- Receptor led effects: Assessment of the scope for all effects to interact, spatially and temporally, to create inter-related effects on a receptor (or group). Receptor-led effects might be short term, temporary or transient effects, or incorporate longer term effects.

4.14.1.2 A description of the process to identify and assess these effects is presented in **Section 5.8** of **Volume A1, Chapter 5: Environmental Impact Assessment Methodology**.

Table 4.81: Inter-related effects assessment for marine mammals.

Project phase(s)	Nature of inter-related effect	Assessment alone	Inter-related effects assessment
Project-lifetime effects			
Construction and decommissioning	Disturbance from underwater noise	Disturbance from piling in the construction phase was assessed as minor and similar (or lesser) effects are expected for decommissioning.	Disturbance to marine mammals will be mainly caused by underwater noise from piling in the construction phase and removal of structures in the decommissioning phase. The construction and decommissioning phases are significantly temporally separate such that there will be no interaction between the two. Disturbance from underwater noise was assessed as not significant in EIA terms. Therefore, across the project lifetime, the effects on marine mammal receptors are not anticipated to interact in such a way as to result in combined effects of greater significance than the assessments presented for each individual phase.
Construction, operation and, decommissioning	Collisions and disturbance from vessels	Both collisions and disturbance from vessels were assessed as minor significance across all three project phases.	The potential for disturbance and/or collision effects will arise at all stages of the project, resulting in a potential project lifetime effect. However, it is not predicted that the significance of any potential effects will increase due to the interaction of this impact across all project stages, rather be maintained at the same level throughout the project. With the implementation of a VMP, impacts from vessel activity is assessed as minor and therefore not significant across all three phases. Therefore, across the project lifetime, the effects on marine mammals are not anticipated to interact in such a way as to result in combined effects of greater significance than the assessments presented for each individual phase.
Receptor-led effects			
Inter-related effect from the combination of disturbance from underwater noise, the presence of vessels and loss of prey resources on marine mammals.		The greatest potential for spatial and temporal interactions is likely to occur with underwater construction noise impacts (i.e. during the construction phase). The individual impacts were assigned significance of negligible to minor. It is noted that some of these interactions are mutually exclusive (i.e. disturbance/displacement resulting from underwater noise will mean reduced potential for vessel interactions). It is therefore not anticipated that any inter-related effects will be produced that are of greater significance than the assessments presented for each individual phase.	

4.15 Conclusion and summary

4.15.1.1 This chapter has investigated the potential effects on marine mammal receptors arising from Hornsea Four. The range of potential impacts and associated effects considered has been informed by the Scoping Opinion, consultation on the PEIR, and agreed through EP Technical Meetings, as well as reference to existing policy and guidance. The impacts considered include those brought about directly (e.g. underwater noise from construction activities), as well as indirectly (e.g. a reduction in prey availability).

4.15.1.2 Characterisation of the baseline environment through both survey data from the former Hornsea Zone and within the Hornsea Four study area and a desk-based literature review found that the key marine mammal receptors were harbour porpoise, minke whales, white-beaked dolphins, bottlenose dolphins, harbour seals and grey seals.

4.15.1.3 **Table 4.82** presents a summary of the impacts assessed within this ES chapter, any commitments made, and mitigation required and the residual effects. The project-alone impact assessment has not identified any significant impacts on any marine mammal receptors.

4.15.1.4 The assessment of cumulative impacts from Hornsea Four and other developments and activities, including offshore wind farms, seismic surveys and aggregate extraction, concluded that the effects of any cumulative impacts would generally be of **slight** significance, and not significant in EIA terms.

4.15.1.5 The screening of transboundary impacts identified that there was potential for transboundary effects for marine mammals from Hornsea Four upon the interests of other EEA States. However, following consideration of the relevant impact assessments, these impacts were not predicted to have significant effects on marine mammal populations of other EEA States.

Table 4.82: Summary of potential impacts assessed for marine mammals from Hornsea Four alone. HP= harbour porpoise, MW = minke whale, WBD = white-beaked dolphin, BND = bottlenose dolphin, HS = harbour seal, GS = grey seal.

Impact and Phase	Receptor	Magnitude	Sensitivity	Impact significance	Mitigation	Residual impact
Construction						
PTS from piling noise (MM-C-1)	All	Negligible	Not Significant		Co85 & Co110	Negligible
Disturbance from piling noise (MM-C-2)	HP & BND	Minor	Medium	Slight	Co85 & Co110	Slight
	GS	Minor	Low	Slight	Co110	Slight
	MW, WBD, HS	Negligible	Not Significant			
TTS from piling noise (MM-C-3)	All	Impact magnitude, species sensitivity and overall impact significance is not quantified				
Vessel collision risk (MM-C-4)	All	Minor	High	Slight	Co108	Slight
Disturbance from vessels (MM-C-5)	All	Minor	Low	Slight	Co108	Slight
Reduction in prey availability (MM-C-6)	All	Negligible	Not Significant			
Reduction in foraging ability (MM-C-7)	All	Negligible	Not Significant			
PTS from UXO clearance (MM-C-11)	All	Negligible	Not significant		UXO MMMP	Negligible
Disturbance from UXO clearance (MM-C-12)	HP, BND & HS	Minor	Medium	Slight	UXO MMMP	Slight
	GS	Moderate	Low	Slight	UXO MMMP	Slight
	MW, WBD	Negligible	Not Significant			
TTS from UXO clearance (MM-C-13)	All	Impact magnitude, species sensitivity and overall impact significance is not quantified				
Operation						
Vessel collision risk (MM-O-28)	All	Minor	High	Slight	Co108	Slight
Reduction in prey availability (MM-O-16)	All	Negligible	Not Significant			
Reduction in foraging ability (MM-O-17)	All	Negligible	Not Significant			
Decommissioning						
Reduction in prey availability (MM-D-25)	All	Negligible	Not Significant			
Reduction in foraging ability (MM-D-26)	All	Negligible	Not Significant			

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Appendix A - Range dependent characteristics of impulsive sounds

Exposure to loud, brief, transient sounds (impulsive sounds, such as explosions, airgun shots or pile strikes) is more damaging to the mammalian ear as it increases the hearing threshold faster than exposure to non-impulsive sound (such as from drilling and shipping), i.e. less sound energy is needed to induce TTS or PTS. Therefore, Southall et al. (2019) presents two different sets of noise thresholds, one for impulsive and one for non-impulsive sound.

Southall et al. (2019) acknowledges that, as a result of propagation effects, the signal of certain sound sources (e.g. pile driving) loses its impulsive characteristics and could potentially be characterised as a 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. 2019). 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).

In the draft version of the National Marine Fisheries Service (2018) guidance (NOAA guidance) that was released in 2015 for public consultation, four criteria were proposed to determine whether a signal is impulsive or non-impulsive in nature. These criteria were based on signal duration[13], rise time[14], crest factor[15] and peak pressure[16] divided by signal duration. Hastie et al. (2019) used these criteria to estimate the transition from impulsive to non-impulsive characteristics of pile driving noise during the installation of offshore wind turbine foundations at The Wash and in the Moray Firth based on sound recorded at increasing distances from the piling site. 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. Signal duration alone may not be sufficient as it does not describe the signal's impulsiveness. Peak pressure/signal duration was used by Hastie et al. (2019) as a proxy for rise-time, therefore, rise-time should be the preferred criteria where the information is available.

Based on the rise-time criterion (rise time <25 ms defines a signal as impulsive), Hastie et al. (2019) showed that the noise signal experienced a high degree of change in its impulsive characteristics within three to nine km from the source (**Table A 1**). For pile driving at the Moray Firth (1.8 m diameter pin-piles in 42 m water depth in 2006), the probability of the piling noise being impulsive reduced from 70% at ~0.7 km down to 1% at ~3.1 km (**Figure A 1**). For pile driving at The Wash (5.2 m diameter

[13] Time interval between the arrival of 5% and 95% of total energy in the signal.
[14] Measured time between the onset (defined as the 5th percentile of the cumulative pulse energy) and the peak pressure in the signal.
[15] The decibel difference between the peak sound pressure level (i.e. the peak pressure expressed in units of dB re 1 μPa) of the pulse and the root-mean-square sound pressure level calculated over the signal duration.
[16] The greatest absolute instantaneous sound pressure within a specified time interval.

monopiles in water depths of 8-20 m in 2006 and 2012), this probability reduced from 70% at ~1.4 km down to 1% at ~8.6 km.

Table A 1: Relationship between probability of a signal being defined as "impulsive" and range from the pile site, using the criteria of rise time being less than 25 ms. Values obtained from the supplementary data from Hastie et al. (2019) and as shown in Figure A 1.

Probability	Range to Pile Site (km)					
	Moray Firth			The Wash		
	Mean	95% Confidence Interval (CI)		Mean	95% CI	
0.9						1.7
0.8	0.6		0.8			2.3
0.7	0.9	0.7	1.0	1.4		2.8
0.6	1.0	0.9	1.1	2.0		3.2
0.5	1.2	1.1	1.3	2.5		3.6
0.4	1.4	1.3	1.5	3.1		4.1
0.3	1.6	1.5	1.7	3.7	1.5	5.0
0.2	1.8	1.7	1.9	4.4	3.2	6.9
0.1	2.1	2.0	2.3	5.4	4.4	
0.09	2.2	2.0	2.4	5.6	4.5	
0.08	2.2	2.1	2.4	5.8	4.6	
0.07	2.3	2.1	2.5	6.0	4.8	
0.06	2.4	2.2	2.6	6.2	4.9	
0.05	2.4	2.2	2.7	6.4	5.1	
0.04	2.5	2.3	2.8	6.7	5.3	
0.03	2.7	2.4	2.9	7.1	5.5	
0.02	2.8	2.6	3.2	7.7	5.9	
0.01	3.1	2.8	3.5	8.6	6.4	
0.005	3.4	3.1	3.8	9.5	7.0	

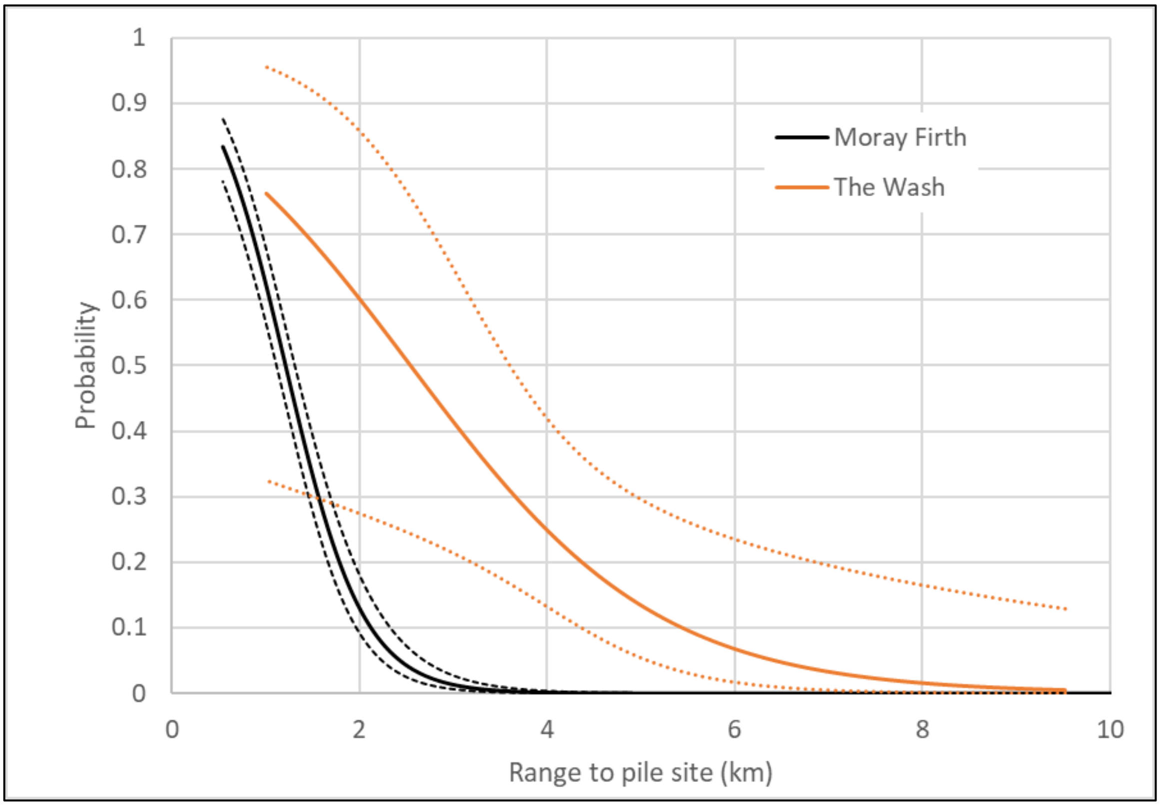

Figure A 1: Modelled functions describing the probability of a signal being defined as "impulsive" based on the rise time being less than 25 ms. The lines represent the modelled fits (solid lines) and their 95% confidence intervals (dashed lines) for Moray Firth (black) and The Wash (orange). Figure adapted from Hastie et al. (2019).

Predicted PTS impact ranges based on the impulsive noise thresholds will therefore overestimate the risk of PTS in cases and at ranges where the likelihood increases that an animal is exposed to non-impulsive sound. The data presented in Hastie et al. (2019) suggests that there is not a specific distance at which sounds lose their impulsiveness and therefore it is not possible to define a 'transition point' at which sounds switch from impulsive to non-impulsive. It is more likely that there is a 'transition zone' over which the probability of a sound being considered impulsive reduces. Beyond this zone, the probability of a sound being considered impulsive should be zero. Any animal present beyond this transition zone when piling starts will only be exposed to non-impulsive noise. For these ranges, non-impulsive thresholds should be applied. An animal present within the transition zone may be exposed to both impulsive and non-impulsive sound while moving through the transition zone during a sequence of pulses. How to evaluate the risk of PTS within the transition zone requires further consideration. One approach would be to define a level of acceptable probability beyond which all sounds are considered non-impulsive (e.g. 95% probability that sounds are non-impulsive). Whilst this approach may be acceptable for single exposures to sounds, exposure to multiple pulses is more complex and the cumulative probability of exposure to pulses must be considered. It is important to consider each of the noise threshold criteria (SPL_{peak} and SEL_{cum}) of the dual-criterion separately. This is explored further below.

Hastie et al. (2019) state that the relationship between noise characteristics and the change from impulsive to non-impulsive and the distance to the sound source is likely to depend on both static (e.g. seabed characteristics, water depth) and dynamic (e.g. sea state, tidal height) environmental parameters as well as source characteristics (e.g. hammer energy), and that further studies are needed to quantify this relationship. With reference to water depth and substrate type, the Hornsea Four site is more similar to the Moray Firth site than to The Wash. It could therefore be assumed that the range within which the transition zone can be expected at Hornsea Four is closer to that found at the Moray Firth than that found at The Wash. Currently, the best available data to estimate the transition zone range for Hornsea Four would be the sound recordings obtained during pile driving at Hornsea Project One, which could be analysed in a similar way to Hastie et al. (2019). In the absence of this analysis, all further discussions here are based on the Moray Firth data, with the assumption that these are most representative of the Hornsea Four area.

Instantaneous PTS (SPL_{peak})

It only takes one single impulsive sound above the SPL_{peak} PTS threshold to induce instantaneous PTS. However, an animal swimming through the transition zone may be exposed to a series of pile strikes, each with an associated probability of being impulsive (single strike probability), and with this probability decreasing as the animal moves away from the source. Although this probability decreases on a per strike basis, the likelihood that the animal is exposed to at least one impulsive strike increases with each pile strike (multiple strike probability or cumulative probability) (**Figure A 2**). While the multiple strike probability shown in **Figure A 2** is based on the animal being stationary for simplicity, this probability will likely be less for a moving animal and will depend on the animal speed and the strike rate of the piling. With a speed of 1.5 m/s and a strike rate of 30 strikes per minute, the animal moves 3 m between each strike, i.e. moving 30 m during 10 strikes. The multiple strike probability will, in this case, only be slightly below that of a stationary animal. For 100 strikes, at strike rate of 30 strikes per minute, the animal moves 300 m, and the multiple strike probability will be between that of a stationary animal at the starting position and that of a stationary animal at the starting position + 300 m. **Figure A 2** illustrates that even at a distance at which the probability of a strike sound being impulsive is reduced to 1% (for the Moray Firth: 3.1 km), the likelihood that an animal is exposed to an impulsive sound during the exposure of multiple pile strikes with a sound level above the PTS threshold, is several times higher. The multiple strike probability can be estimated based on swim speed and strike rate, which may be a useful tool in cases where the PTS impact range for impulsive sound is longer than the ranges at which the single strike probability near 0. For Hornsea Four however, the instantaneous PTS ranges are within the transition ranges discussed here, and therefore these calculations are not needed for this particular project.

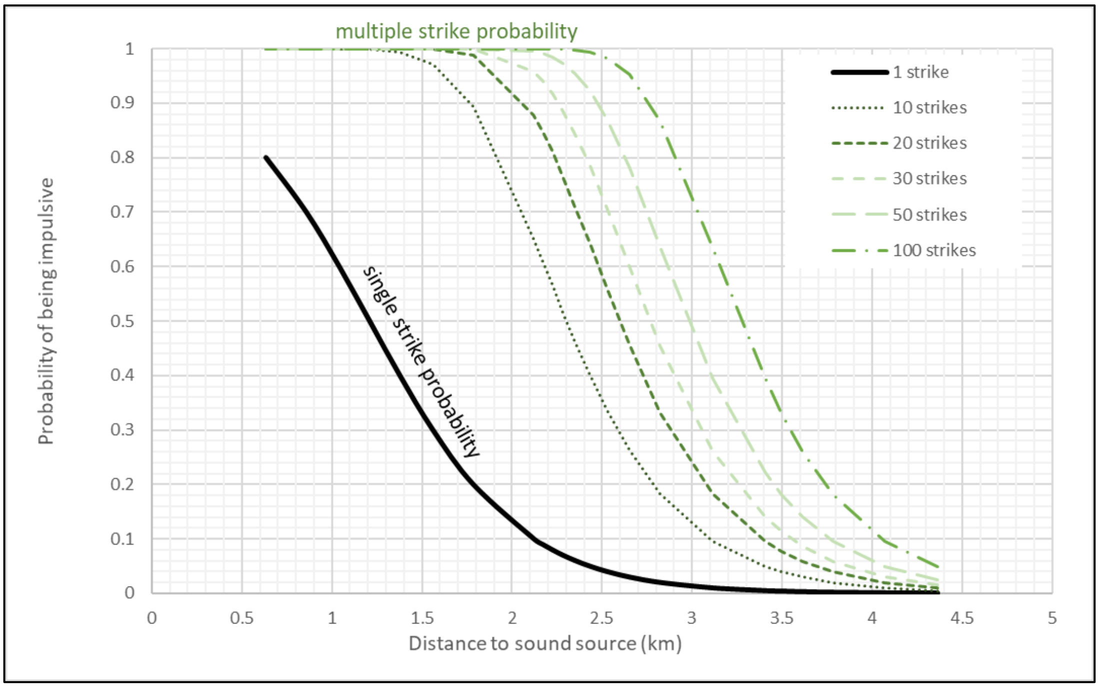

Figure A 2: Single strike (black) and multiple strike (green) probability of an animal being exposed to an "impulsive" strike based on the rise time (see Figure 1, Moray Firth). The figure shows the probability that at least one out of a series of strikes is impulsive (multiple strike probability - given are different examples from 10 to 100 strikes) based on the probability of each individual strike to be impulsive (single strike probability). This example is for stationary animals.

PTS from cumulative exposure (SEL_{cum})

For cumulative SEL PTS impact ranges, all strikes within a piling sequence are considered in the calculations. As the animal moves away from the pile site, the energy of each strike the animal is exposed to is summed to calculate the SEL_{cum}. With each doubling of the sound energy, the SEL_{cum} increases by 3 dB (see **Figure A 3**). This means that for a 3 dB increase in SEL_{cum}, it needs twice as much energy as for the preceding 3 dB rise. This logarithmic relationship between energy and SEL leads to a fast increase in SEL_{cum} during the first strikes of a piling sequence, which flattens with increasing number of strikes. This in turn explains why the energy and characteristics of the initial strikes an animal is exposed to are highly influential on the risk of an animal experiencing PTS. The SEL_{cum} PTS impact range is a measure of the minimum distance (safe distance) at which an animal can start at, at the onset of piling, while the energy it is exposed to adds up to an SEL_{cum} value below the PTS threshold. If the resulting safe distance is within or beyond the transition zone, the impulsive PTS impact ranges are likely to be overestimated. This is because each sound that is non-impulsive leads to a smaller hearing threshold shift than would be the case for impulsive sound. Where an animal is exposed to both impulsive and non-impulsive sounds neither threshold is particularly appropriate, and a different approach is required.

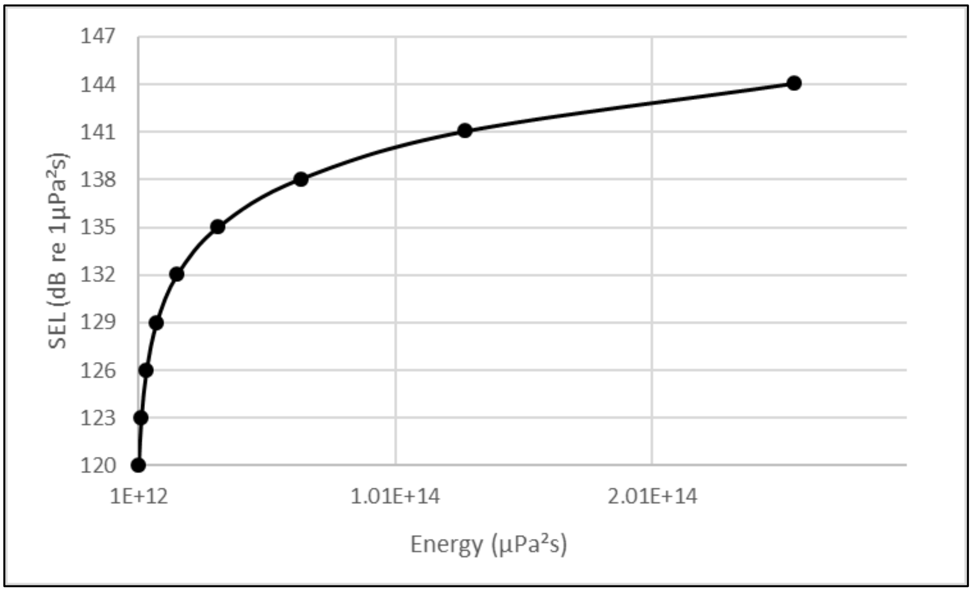

Figure A 3: Relationship between Energy and SEL. Each successive dot on the black line indicates a doubling of energy and an increase in SEL of 3 dB.

The exposure at which PTS may occur is likely to lie between the impulsive PTS threshold and the non-impulsive threshold, and its value needs to be determined on a case-by-case basis. The resulting "mixed threshold" is not only influenced by the ratio between impulsive and non-impulsive sounds, but also and especially on the characteristics and energy of the first sounds an animal is exposed to (as explained above). As the sound characteristics are expressed in a range dependent probability function, the mixed threshold can be determined with a modelling exercise combined with the safe distance analysis.

The data presented in Hastie et al. (2019) provide a good starting point with which to evaluate the potential consequences of the change in impulsiveness of pile driving sounds with range. Based on the data presented therein, it is clear that the probability of pile strike sounds being characterised as impulsive reduced as range increased. For predicting PTS from SEL_{cum} in the ES, adopting a benchmark of 80% probability of strikes being non-impulsive (single strike probability) results in a distance of ~1.8 km based on the Moray Firth and 4.4 km based on The Wash data.

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 PTS impact ranges. Therefore, Natural England have recommended a precautionary approach of setting a PTS limit of 10 km until more data are available to refine this limit further (Section 42 comments - see **Table 4.3** for further information).

Appendix B – Limitations of SEL_{cum} predictions

Introduction

Exposure to loud sounds can lead to a reduction in hearing sensitivity (a shift in hearing threshold), which is generally restricted to particular frequencies (e.g. Kastelein et al. 2017). This threshold shift results from physical injury to the auditory system and may be temporary (TTS) or permanent (PTS). The Hornsea Four impact assessment for marine mammals presents PTS impact ranges for piling events, using the Southall et al. (2019) thresholds for all species. The thresholds are based on a dual criteria approach whereby both should be evaluated and that predicting the largest range of impact, should be considered for the impact assessment. The first metric is pressure based, taken as zero-to-peak sound pressure level (SPL_{zp}) or as peak-to-peak sound pressure level (SPL_{pp}). Any single exposure at or above this pressure-based metric is considered to have the potential to cause PTS, regardless of the exposure duration. The second metric is energy based and is a measure for the accumulated sound energy an animal is exposed to over an exposure period, referred to as sound exposure level (SEL) when considering single pulses, or cumulative sound exposure levels (SEL_{cum}) when considering exposure periods with multiple pulses.

The sound exposure level metric is based on the 'equal-energy assumption', having its origin in human research, and stating that sounds of equivalent energy will have generally similar effects on the auditory systems of exposed human subjects, even if they differ in SPL, duration, and /or temporal exposure pattern (Southall et al. 2007). While the sound pressure levels are analysed unweighted, NMFS (2018) and Southall et al. (2019) describe species specific frequency filters to be applied before the sound exposure level is calculated.

The SEL-thresholds for PTS take into account the received level and the duration of exposure, accounting for the accumulated exposure over the duration of an activity within a 24-hour period. NMFS (2018) recommends the application of SEL_{cum} for the individual activity within 24 hours (e.g. one piling event with multiple strikes) rather than for multiple activities occurring within the same area or over the same time (e.g. concurrent piling).

The method used to calculate PTS impact ranges for 'instantaneous' PTS (SPL_{pk}), and PTS induced by cumulative sound exposure (SEL_{cum}, over 24 hours) are detailed in **Volume A4, Annex 4.5: Subsea Noise Technical Report**.

Precaution in cumulative PTS (SEL_{cum}) calculations

There is 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 impulsive characteristics over time. As a result of this uncertainty, model parameters are generally highly conservative and when considered across multiple parameters this precaution is compounded therefore the resulting predictions are very precautionary and very unlikely to be realised.

It is important to note that 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 doses 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. Modelling the SEL_{cum} impact ranges of PTS with a 'fleeing animal' model, as is typical in noise impact assessments, are subject to both of these uncertainties and the result is a highly precautionary prediction of impact ranges.

Equal energy hypothesis

The equal energy hypothesis assumes that "exposures of equal energy are assumed to produce equal amounts of noise-induced threshold shift, regardless of how the energy is distributed over time". However, in a review on noise induced threshold shifts in marine mammals, Finneran (2015) showed that several marine mammal studies have demonstrated that the temporal pattern of the exposure does in fact affect the resulting threshold shift (e.g. Kastak et al. 2005, Mooney et al. 2009, Finneran et al. 2010, Kastelein et al. 2013a). Intermittent noise allows for some recovery of the threshold shift in between exposures, and therefore recovery can occur in the gaps between individual pile strikes and in the breaks in piling activity, resulting in a lower overall threshold shift compared to continuous exposure at the same SEL. The study by Kastelein et al. (2013a) showed that for seals, the threshold shifts observed did not follow the assumptions made in the guidance regarding the equal energy hypothesis, and that instead, the threshold shifts observed were more similar to the hypothesis presented in Henderson et al. (1991): hearing loss induced due to noise does not solely depend upon the total amount of energy, but on the interaction of several factors such as the level and duration of the exposure, the rate of repetition, and the susceptibility of the animal. Therefore, the equal energy hypothesis assumption behind the SEL_{cum} threshold is not valid, and as such, models will overestimate the level of threshold shift experienced from intermittent noise exposures.

Impulsive characteristics

Southall et al. (2019) acknowledges that, as a result of propagation effects, the signal of certain sound sources (e.g., pile driving) loses its impulsive characteristics and could potentially be characterised as a 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. 2019). In the draft version of the NMFS (2018) guidance that was released in 2015 for public consultation, four criteria were proposed to determine whether a signal is impulsive or non-impulsive in nature. These criteria were based on signal duration, rise time, crest factor and peak pressure divided by signal duration. Hastie et al. (2019) used these criteria to estimate the transition from impulsive to non-impulsive characteristics of pile driving noise during the installation of offshore wind turbine foundations at The Wash and in the Moray Firth based on sound recorded at increasing distances from the piling site. 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 the rise-time criterion (rise time <25 ms defines a signal as impulsive), Hastie et al. (2019) showed that the noise signal experienced a high degree of change in its impulsive characteristics within 3 - 9 km from the source. For pile driving at the Moray Firth (1.8 m diameter pin-piles in 42 m water depth), the probability of the piling noise being impulsive reduced from 70% at ~0.7 km down to 1% at ~3.1 km. For pile driving at The Wash (5.2 m diameter monopiles in water depths of 8-20 m), this probability reduced from 70% at ~1.4 km down to 1% at ~8.6 km. Therefore, predicted PTS-onset impact ranges based on the impulsive noise thresholds will overestimate the risk of PTS-onset in cases and at ranges where the likelihood increases that an animal is exposed to non-impulsive sound.

Swimming speed

To determine the number of animals experiencing energy-induced PTS, one has to calculate the accumulated energy over the course of the series of pile strikes. To do this, assumptions have to be made regarding swimming speed and direction of movement, which introduces a degree of uncertainty in the range within which animals are at risk of PTS-onset. All marine mammals were modelled to swim away at the onset of piling at a swimming speed of 1.5 m/s apart from minke whales which were modelled to flee at 3.25 m/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 ADDs at a mean swimming speed of 4.2 m/s (McGarry et al. 2017). A recent study by Kastelein et al. (2018b) 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 1.97 m/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 2 m/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.

Animal depth

Empirical data on SEL_{ss} levels recorded during piling construction at the Lincs offshore wind farm have been compared to estimates obtained using the Aquarius pile driving model[17] (Whyte et al. 2020). This has demonstrated that measured recordings of SEL_{ss} levels made at 1 m depth were all lower than the model predicted single-strike sound exposure levels for the shallowest depth bin (2.5 m). In contrast, measurements made at 9 m depth were much closer to the model predicted single-strike sound exposure levels. This highlights the limitations of modelling exposure using depth averaged sound levels, as the acoustic model can overpredict exposure at the surface. This is important to note since animals may conduct shorter and shallower dives when fleeing (e.g. van Beest et al. 2018).

4.16.1 Conclusion

Given the above, the Applicant considers that the calculated SEL_{cum} PTS-onset impact ranges are highly precautionary and that the true extent of effects (impact ranges and numbers of animals experiencing PTS) will likely be considerably less than that assessed here.

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[17] From more information on the Aquarius model see: de Jong, C., Binnerts, B., Prior, M., Colin, M., Ainslie, M., Mulder, I., and Hartstra, I. (2019). "Wozep – WP2: update of the Aquarius models for marine pile driving sound predictions," TNO Rep. (2018), number R11671, The Hague, Netherlands, p. 94. Retrieved from https://www.noordzeeloket.nl/publish/pages/160801/update_aquarius_models_pile_driving_sound_predeictions_tno_2019.pdf