Project Title	Dogger Bank A & B
Date:	17th December 2021

Dogger Bank A & B

Non-Material Change application for increase in pin-pile and monopile hammer energy: Environmental report

LF500013-CST-RHD-REP-0002 / LF600013-CST-RHD-REP-0002

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Glossary of Acronyms

µPa	Micro pascal
ADD	Acoustic Deterrent Device
BEIS	Department for Business, Energy and Industrial Strategy
CGNS	Celtic and Greater North Seas
dB	Decibel
DBA	Dogger Bank A
DBB	Dogger Bank B
DBC	Dogger Bank C
DCLG	Department for Communities and Local Government
DCO	Development Consent Order
DECC	Department of Energy and Climate Change
dML	deemed Marine Licence
EDR	Effective Deterrent Radius
EPS	European Protected Species
ES	Environmental Statement
GNS	Greater North Sea
HRA	Habitats Regulations Assessment
IAMMWG	Inter-Agency Marine Mammal Working Group
JNCC	Joint Nature Conservation Committee
kJ	Kilojoules
km	Kilometre
km^2	Kilometre squared
LSE	Likely Significant Effect
m	Meter
MMMP	Marine Mammal Mitigation Protocol
MMO	Marine Management Organisation
MU	Management Unit
NMC	Non-Material Change
NPL	National Physical Laboratory
NS	North Sea
OSP	Offshore substation platform
OWF	Offshore Wind Farm
pSAC	Potential Special Area of Conservation
pSPA	Potential Special Protection Area
PTS	Permanent Threshold Shift
RoC	Review of Consents
SAC	Special Area of Conservation
SCANS	Small Cetaceans in the European Atlantic and North Sea
SCOS	Special Committee on Seals
SE	South East
SEL	Sound Exposure Level
SEL_{ss}	Sound Exposure Level for single strike
SEL_{cum}	Cumulative Sound Exposure Level
SIP	Site Integrity Plan
SMRU	Sea Mammal Research Unit
SNCBs	Statutory Nature Conservation Bodies

SPL	Sound Pressure Level
TTS	Temporary Threshold Shift
TWT	The Wildlife Trusts
WDC	Whale and Dolphin Conservation
WTG	Wind Turbine Generator

1 Introduction

1.1 Project Background

Dogger Bank Offshore Wind Farm Project 1 Projco Limited, Dogger Bank Offshore Wind Farm Project 2 Projco Limited, and Dogger Bank Offshore Wind Farm Project 3 Projco Limited are a Joint Venture between SSE, Equinor and ENI, which have been set up to take forward the development of the Dogger Bank Offshore Wind Farm.

The Dogger Bank Offshore Wind Farm is to be constructed in three phases, namely Dogger Bank A (DBA), Dogger Bank B (DBB) and Dogger Bank C (DBC).

The DBA and DBB phases are located 131 kilometres (km) from shore at their closest point and cover areas of 515 square kilometres (km^2) and 599 km^2, respectively (**Figure 1**).

The offshore export cables, which run from the offshore substation platforms to the landfall, are 175 km in length. These cables come ashore to the north of Ulrome on the Holderness Coast and run approximately 30 km inland to two new converter stations, situated north of the A1079 between Beverley and Cottingham. DBA and DBB will each have 95 wind turbine generators (WTGs), which will be installed on monopiles, and one Offshore Substation Platform (OSP), which will be installed on pin-piles.

Figure 1: Location of DBA and DBB

1.2 Consents and Licences

DBA and DBB were granted consent by the Secretary of State for Energy and Climate Change in February 2015 under the Dogger Bank Creyke Beck Offshore Wind Farm Development

Consent Order (DCO). Dogger Bank Offshore Wind Farm Project 1 Projco Limited and Dogger Bank Offshore Wind Farm Project 2 Projco Limited are a Joint Venture between SSE, Equinor and ENI, which have been set up to take forward the development of DBA and DBB.

Under the DCO, separate deemed Marine Licences (dMLs) have been granted for each Project for the generation assets and the transmission assets. Licences for DBA and DBB generation assets form Schedules 8 and 9 of the DCO (dMLs 1 and 2). DBA and DBB transmission asset licences form Schedules 10 and 11 of the DCO (dMLs 3 and 4).

1.3 Purpose of this Report

This Non-Material Change (NMC) application is to allow for an increase in the hammer energy required to install the pin-piles for the OSPs and the monopiles for the WTG foundations. The increase in hammer energy is required as a contingency measure for potential pile-refusal (see **Section 2** for further details). As this would require a change to the consented parameters (**Section 2**), Dogger Bank Wind Farm is looking to make a NMC to the DCO to enable the Projects to be constructed in the most efficient manner.

The purpose of this report is to:

1. Provide information on the nature of the proposed changes;
2. Describe the predicted effects of the changes alongside the outcome of the original assessments that informed the DCO;
3. Set out why it is considered appropriate for the Application to be determined as an NMC to the DCO; and
4. Ensure compliance with relevant nature conservation legislation, in particular the Conservation of Habitats and Species Regulations 2017 (as amended).

An application to vary the dMLs has been made to the Marine Management Organisation (MMO) in parallel to the NMC application. Details of these changes are set out in the covering letter provided to the MMO separately. This report is also intended to support that application.

The report is structured as follows:

- **Section 2 Details of Proposed Change** – Overview of the proposed change;
- **Section 3 Consultation** – Consultation undertaken prior to submitting the NMC application and the proposals for consultation on the application once submitted;
- **Section 4 Approach to the assessment** – Approach to considering the effects of the proposed change;
- **Section 5 Screening**– Screens in/out all receptors based on the effects that may result from the proposed change;
- **Section 6 Assessment** – Assessment of receptors screened in;
- **Section 7 Assessment of Materiality** – Test of materiality of the proposed change; and
- **Section 8 Conclusions** – Clear account of assessment outcomes.

2 Details of Proposed Change

This NMC application is for an increase to the consented parameters for the maximum hammer energy that can be used for the installation of pin-piles for the OSPs and the monopiles for the WTG foundations. All other DCO parameters remain unchanged.

An increase in the maximum hammer energy is required as the pile driveability assessment for the pin-piles for the OSPs indicated that if 1,900kJ hammer energy was used, there was the potential for hard driving and when encoutering the harde soils approaching design penetrationr. Therefore, an increase in the pin-pile hammer energy is required in order to ensure that the piles can be driven to target.. Similarly for monopile installation, driveability assessment has indicated a number of locations with risk of refusal and therefore the increased hammer energy is required as a contingency measure to ensure piles can be driven to target penetration.

Table 1 summarises the currently consented parameters relevant to the NMC and the parameters where an amendment to the DCO is being sought.

To support the NMC application, a review of the proposed amendment has been undertaken to confirm that the proposed changes would not give rise to new or materially different likely significant effects or invoke the need for a new Habitats Regulations Assessment (HRA). To inform this review a comparison has been being undertaken with the Environmental Statement (ES) (Forewind, 2013) and the HRA (Department of Energy and Climate Change (DECC), 2015) that informed the DCO. In addition, the Department for Business, Energy and Industrial Strategy (BEIS) Review of Consents (RoC) of Offshore Wind Farms (OWFs) in the Southern North Sea harbour porpoise Special Area of Conservation (SAC) has also been considered to ensure the outcomes would remain the same.

Table 1: Proposed consent amendment

Parameter	Consented Envelope	Proposed Amendment
Maximum hammer energy – monopile	Up to 3,000kJ	Up to 4,000kJ
Monopile diameter	Up to 10m	No change
Maximum hammer energy – pin-pile for OSPs	Up to 1,900kJ	Up to 3,000kJ
Pin-pile diameter for OSPs	Up to 2.744m	No change

3 Consultation

This section provides a summary of the consultation that has been carried out on the proposed amendment prior to submission of the NMC application. Further details will be provided within the Consultation and Publicity Statement that will be submitted following submission of the application.

Stakeholders were identified as either being key to agreeing procedure and approach for the NMC application (BEIS, MMO and the Planning Inspectorate) or having a key interest in relation to the topics which may be affected by the proposed amendment (e.g., Natural England, The Wildlife Trusts (TWT) and Whale and Dolphin Conservation (WDC)).

A reduced and focused scope of consultation from that carried out with respect to the DCO application was agreed with BEIS through a request in accordance with Regulation 7(3) of the

Infrastructure Planning (Changes to, and Revocation of, Development Consent Orders) Regulations 2011 (the 2011 Regulations). This provided a targeted list of consultees that will be consulted for this NMC application (see List of Consultees attached to this application).

An introductory email was sent to all those organisations identified on the List of Consultees providing an update on the Projects and the proposed amendment. Furthermore, letters to inform consultees that the NMC application has been made will be sent following the submission of this NMC application. This will include a link to the application documents and will explain how such consultees can make a representation. In addition, the application will be publicised in accordance with the 2011 Regulations, at the following locations:

- Fishing News (online and hard copy newspaper)
- The Holderness Gazette (online and hard copy newspaper)
- Bridlington Free Press (online and hard copy newspaper)

4 Approach to Assessment

A screening exercise has been undertaken of all of the topic areas that were considered in the ES which supported the grant of the DCO to determine if there could be any potential for new or materially different likely significant effects as a result of the proposed DCO amendment. This approach has enabled this report to focus on the receptors that could be affected by the proposed DCO amendment, alongside providing a clear rationale for those receptors where no effects are predicted.

For the receptors that were not screened out of this assessment, a review of the proposed amendment has been undertaken to confirm that the proposed changes will not give rise to new or materially different likely significant effects. This has been undertaken by carrying out a comparison with the ES which informed the grant of the DCO.

Alongside this, consideration is also given to the HRA undertaken by the Secretary of State to inform the grant of the DCO in order to determine whether the proposed DCO amendments have the potential to impact designated sites. This includes all the sites that were considered at the time of the granting of the DCO and the Southern North Sea SAC which was not proposed at the time of consent. Following designation of the Southern North Sea SAC, BEIS undertook a RoCs to consider the impacts of projects on the newly designated SAC. A comparison with the BEIS (2020) RoC HRA has been included in the Marine Mammal Technical Report to determine whether the proposed DCO amendments could have additional impacts on the SAC (**Appendix 1 paragraph 5.4**).

The original assessment referred to throughout this report (and **Appendix 1**) is the assessment conducted for the ES, HRA and everything that led to consent, including examination.

5 Screening

This section sets out the environmental topics (receptors) as they were assessed in the ES and considers whether the proposed amendments will lead to any new or materially different likely significant effects (**Table 2**). Where it could not be immediately ruled out that a receptor would not be impacted by the proposed amendments this topic is 'screened in' and further assessed in **Section 6**.

Table 2: Screening of potential receptors for increase in maximum hammer energy for OSP pin-piles and monopiles for WTG foundations

Topic area from ES	Potential change in effect	Screened In/Out
Chapter 8 – Designated Sites	Potential effects of the increase in maximum hammer energy for OSP pin-piles and monopiles for WTG foundations on marine mammals is considered under Section 6.1 Marine Mammals.	In (Section 6.1)
Chapter 9 – Marine Physical Processes	No effect on this topic from an increase in maximum hammer energy for OSP pin-piles and monopiles for WTG foundations as there is no impact pathway.	Out
Chapter 10 – Marine Water and Sediment Quality	No effect on this topic from an increase in maximum hammer energy for OSP pin-piles and monopiles for WTG foundations as there is no impact pathway.	Out
Chapter 11 – Marine and Coastal Ornithology	No direct effect on Marine and Coastal Ornithology from an increase in maximum hammer energy for OSP pin-piles and monopiles for WTG foundations. Consideration of the effects on the prey species of birds due to the increase in maximum hammer energy for OSP pin-piles and monopiles for WTG foundations is provided under Section 6.2 Fish and Shellfish.	Out
Chapter 12 – Marine and Intertidal Ecology	No effect on this topic from an increase in maximum hammer energy for OSP pin-piles and monopiles for WTG foundations as there is no impact pathway.	Out
Chapter 13 – Fish and Shellfish	Potential change in effect due to an increase in underwater noise from increase in maximum hammer energy for OSP pin-piles and monopiles for WTG foundations on fish species is considered further in Section 6.2.	In (Section 6.2)
Chapter 14 – Marine Mammals	Potential change in effect due to an increase in underwater noise from increase in maximum hammer energy for OSP pin-piles and monopiles for WTG foundations is considered further in Section 6.1.	In (Section 6.1)
Chapter 15 – Commercial Fisheries	Potential changes in impacts on fish receptors from underwater noise caused by the increase in maximum hammer energy for OSP pin-piles and monopiles for WTG foundations is considered further in Section 6.2. No effects on commercial fisheries are anticipated, therefore this topic is screened out.	Out
Chapter 16 – Shipping and Navigation Chapter 17 – Other Marine Users	No effect on this topic from an increase in maximum hammer energy for OSP pin-piles and monopiles for WTG foundations as there is no impact pathway.	Out

Topic area from ES	Potential change in effect	Screened In/Out
Chapter 18 – Marine and Coastal Archaeology Chapter 19 – Military Activities and Civil Aviation Chapter 20 – Seascape and Visual Character Chapter 21 – Landscape and Visual Chapter 22 – Socio-economics Chapter 23 – Tourism and Recreation Chapter 24 – Geology, water resources and land quality Chapter 25 – Terrestrial Ecology Chapter 26 – Land Use and Agriculture Chapter 27 – Onshore Cultural Chapter 28 – Traffic and Access Chapter 29 – Noise and Vibration Chapter 30 – Air Quality Chapter 32 – Transboundary Effects		

6 Assessment

6.1 Marine Mammals

The ES assessed the potential impact on marine mammals from permanent auditory injury, temporary auditory injury and likely or possible avoidance of an area in respect of the relevant receptors, which were:

- Harbour porpoise *Phocoena phocoena*;
- White-beaked dolphin *Lagenorhynchus albirostris*;
- Minke whale *Balaenoptera acutorostrata*;
- Grey seal *Halichoerus grypus*; and
- Harbour seal *Phoca vitulina*.

A review of the distribution of marine mammals throughout the North Sea confirms that these are the species of marine mammals most likely to be present in and around the DBA and DBB array sites (Hammond *et al*., 2021; Paxton *et al*., 2016; Waggitt *et al*., 2019; Special Committee on Seals (SCOS), 2020). However, in recent years an increase in bottlenose dolphins in the north-east of England has been reported (Aynsley, 2017). Although bottlenose dolphin are most likely to be in coastal waters, as a precautionary approach, the updated assessments have also included:

- Bottlenose dolphin *Tursiops truncatus*

Since the ES was completed, updated information on the density estimates and reference populations for marine mammals in the Dogger Bank area has become available (see **Appendix 1 paragraph 4.1 and Table 2**). Therefore, the most recent and relevant density estimates have been used for the updated assessment based on the SCANS-III survey for cetaceans (Hammond *et al*., 2021) and the Sea Mammal Research Unit (SMRU) seal at-sea usage maps (Russell *et al*., 2017). The assessments are also based on the most recent reference populations for cetaceans (Inter-Agency Marine Mammal Working Group (IAMMWG), 2021) and seals (SCOS, 2020). Further details are provided in the Marine Mammal Technical Report (**Appendix 1 paragraph 4.1 and Table 3**).

6.1.1 *Outcome of the Assessments*

To assess what the effects of the proposed increase in maximum hammer energy for OSP pin-piles and monopiles for WTG foundations would be, updated underwater noise modelling was carried out and compared with the maximum hammer energy assessments in the ES that informed the DCO.

It should be noted that the underwater noise propagation modelling for the original assessments in the ES was carried out by the National Physical Laboratory (NPL) (Theobald *et al.*, 2012) to assess the effects of noise from the construction of the Projects. Since the NPL modelling was completed for the ES, NPL no longer conduct noise modelling for individual projects. The updated noise modelling has therefore been undertaken by Subacoustech Environmental Ltd.

In addition, since the underwater noise modelling was completed for the ES, new noise thresholds and criteria have been published by Southall *et al*. (2019) for both Permanent Threshold Shift (PTS) where unrecoverable changes to hearing sensitivity may occur, and Temporary Threshold Shift (TTS) where a temporary reduction in hearing sensitivity may occur.

Therefore, the assessments are based on:

(i) The updated underwater noise modelling for the previous maximum hammer energy of 1,900kJ and the proposed increase to 3,000kJ for OSP pin-piles and for the previous maximum hammer energy of 3,000kJ and the proposed increase to 4,000kJ for monopiles, using the latest thresholds and criteria for PTS and TTS (Southall *et al*.,

2019) (details of the underwater noise modelling are provided in **Appendix 1 paragraph 4.2,** and the full underwater noise modelling report is provided in **Appendix 2**).

(ii) Comparison with assessments in the ES (Forewind, 2013) that informed the DCO, including cumulative impact assessment.

(iii) Comparison with assessments in the HRA, including in-combination assessment.

(iv) Comparison with BEIS (2020) RoC for OWFs in the Southern North Sea harbour porpoise SAC.

The aim of the updated assessments is to determine whether there are any new or materially different significant effects in relation to marine mammals between using the proposed maximum hammer energies compared to the currently consented maximum hammer energies.

The results presented in this section provide a summary of the information provided in the Marine Mammal Technical Report (**Appendix 1**) where details of the underwater noise modeling, results and assessments are provided.

6.1.1.1 Updated underwater noise modelling and assessments

Each assessment, based on the updated noise modelling, considers:

- The increase in impact range; and
- The number of individuals and percentage of the reference population (relevant Management Unit (MU)) that could be impacted.

A summary of the updated underwater noise modelling results is provided in **Table 3** for OSP pin-piles and **Table 4** for WTG monopiles, further details is provided in **Appendix 1** and the underwater noise modelling report is provided in **Appendix 2**. The summaries are based on the worst-case for the risk of instantaneous PTS (SPL_{peak}) or TTS from cumulative exposure (SEL_{cum}) during piling, with the greatest impact range for the two DBA and DBB sites (further details are provided in **Appendix 1 section 5.1**).

6.1.1.1.1 Pin piles

In relation to the potential impacts for each species, the updated modelling and assessments demonstrate that there is no significant difference in the impact significance for a maximum hammer energy of 1,900kJ or 3,000kJ for the OSP pin-piles, for marine mammals (i.e. there is no difference with an increase in the maximum hammer energy).

The assessments within the original ES are also provided as a comparison. However, it should be noted that there are significant differences in the method of the modelling undertaken for the original ES, and the updated modelling, due to updated threshold criterion for marine mammal species. See **Appendix 1 paragraph 4.2.5** for more information.

The Marine Mammal Mitigation Protocols (MMMP) for the projects will include a marine mammal monitoring zone, the activation of Acoustic Deterrent Devices (ADDs), soft start and ramp-up to reduce the risk of PTS from the maximum hammer energy. The mitigation would be the same for both the OSP pin-piles as consented and the proposed hammer energies.

There is no significant difference in the percentage of the harbour porpoise reference population that could temporarily have possible avoidance / behavioural reaction as a result of a maximum hammer energy of 1,900kJ or 3,000kJ for OSP pin-piles (**Table 3**) at DBA and DBB.

The impact significance for harbour porpoise for possible avoidance / behavioural reaction from maximum hammer energies of 1,900kJ or 3,000kJ for OSP pin-piles is negligible (negligible magnitude (less than 1% of the reference population anticipated to be exposed to effect) and low sensitivity; see **Appendix 1 Table 16**) (i.e. there is no difference with an increase in the maximum hammer energy for OSP pin-piles).

It is important to note that not all harbour porpoise would be disturbed in the maximum area for possible avoidance / behavioural reaction.

Table 3: Summary of the maximum PTS SPL_{peak} and TTS SEL_{cum} predicted impact ranges, number of marine mammals, % of reference population and impact assessment for updated modelling and assessment of maximum hammer energies of 1,900kJ or 3,000kJ for OSP pin-piles, based on the worst-case for DBA and DBB

Species	PTS (instantaneous)			TTS / fleeing response (cumulative)			Behavioural response (cumulative)		
	1,900kJ in ES	**1,900kJ**	**3,000kJ**	**3,000kJ in ES**	**1,900kJ**	**3,000kJ**	**3,000kJ in ES**	**1,900kJ**	**3,000kJ**
Harbour porpoise[1]	<550m	360m 0.36 harbour porpoise (0.0001%)	430m 0.5 harbour porpoise (0.00014%)	4.4km	12.0km 275 harbour porpoise (0.079%)	13.0km 302 harbour porpoise (0.087%)	34.4km	24km 1,155 harbour porpoise (0.33%)	26km 1,332 harbour porpoise (0.38%)
	No significant difference in impact ranges			**No significant difference in updated modelling results**			**No significant difference in updated modelling results**		
Bottlenose dolphin[2]	<50m (for mid-frequency cetaceans) Bottlenose dolphin not assessed	<50m 0.0003 bottlenose dolphin (0.000015%)	<50m 0.0003 bottlenose dolphin (0.000015%)	<100m (for mid-frequency cetaceans) Bottlenose dolphin not assessed	<100m 0.003 bottlenose dolphin (0.00015%)	<100m 0.003 bottlenose dolphin (0.00015%)	7.5km (for mid-frequency cetaceans) Bottlenose dolphin not assessed	As for TTS	
	No difference in impact ranges			**No difference in impact ranges**			**As for TTS**		

[1] *based on harbour porpoise density of 0.88/km² (Hammond et al., 2021) and reference population (NS MU) of 346,601 (IAMMWG, 2021); updated modelling based on Southall et al. (2019) unweighted criteria for instantaneous PTS (SPL_{peak} 202 dB re 1 µPa) and weighted criteria for TTS from cumulative exposure (SEL_{cum} 140 dB re 1 µPa²s); and Lucke et al. (2009) unweighted criteria for possible avoidance (SEL_{ss} 145 dB re 1 µPa²s)*

[2] *based on bottlenose dolphin density of 0.0298/km² (Hammond et al., 2021) and reference population (GNS MU) of 2,022 (IAMMWG, 2021); updated modelling based on Southall et al. (2019) unweighted criteria for instantaneous PTS (SPL_{peak} 230 dB re 1 µPa) and weighted criteria for TTS from cumulative exposure (SEL_{cum} 170 dB re 1 µPa²s)*

Species	PTS (instantaneous)			TTS / fleeing response (cumulative)			Behavioural response (cumulative)		
	1,900kJ in ES	**1,900kJ**	**3,000kJ**	**3,000kJ in ES**	**1,900kJ**	**3,000kJ**	**3,000kJ in ES**	**1,900kJ**	**3,000kJ**
White-beaked dolphin[3]	<50m	<50m 0.00002 white-beaked dolphin (0.00000005%)	<50m 0.00002 white-beaked dolphin (0.00000005%)	<100m	<100m 0.0002 white-beaked dolphin (0.0000005%)	<100m 0.0002 white-beaked dolphin (0.0000005%)	7.5km	As for TTS	
	No difference in impact ranges			**No difference in impact ranges**			**As for TTS**		
Minke whale[4]	<50m	<50m 0.0001 minke whale (0.0000005%)	<50m 0.0001 minke whale (0.0000005%)	<250m	17km 5.2 minke whale (0.026%)	17km 5.3 minke whale (0.026%)	49km	As for TTS	
	No difference in impact ranges			**No difference in updated modelling results**			**As for TTS**		
Grey seal[5]	<100m	50m 0.002 grey seal (0.000023%)	50m 0.002 grey seal (0.000023%)	<1.5km	3km 4.4 grey seal (0.05%)	3.1km 4.6 grey seal (0.05%)	As for TTS		
	No difference in updated modelling results			**No significant difference in updated modelling results**			**As for TTS**		

[3] *based on white-beaked dolphin density of 0.002/km^2 (Hammond et al., 2021) and reference population (CGNS MU) of 43,951 (IAMMWG, 2021); updated modelling based on Southall et al. (2019) unweighted criteria for instantaneous PTS (SPL_{peak} 230 dB re 1 µPa) and weighted criteria for TTS from cumulative exposure (SEL_{cum} 170 dB re 1 µPa^{2}s)*

[4] *based on minke whale density of 0.010/km^2 (Hammond et al., 2021) and reference population (CGNS MU) of 20,118 (IAMMWG, 2021); updated modelling based on Southall et al. (2019) unweighted criteria for instantaneous PTS (SPL_{peak} 219 dB re 1 µPa) and weighted criteria for TTS from cumulaltive exposure (SEL_{cum} 168 dB re 1 µPa^{2}s)*

[5] *based on grey seal density of 0.20/km^2 (Russell et al., 2017) and reference population (SE England MU) of 8,667 (SCOS, 2020); updated modelling based on Southall et al. (2019) unweighted criteria for instantaneous PTS (SPL_{peak} 218 dB re 1 µPa) and weighted criteria for TTS from cumulative exposure (SEL_{cum} 170 dB re 1 µPa^{2}s)*

Species	PTS (instantaneous)			TTS / fleeing response (cumulative)			Behavioural response (cumulative)		
	1,900kJ in ES	1,900kJ	3,000kJ	3,000kJ in ES	1,900kJ	3,000kJ	3,000kJ in ES	1,900kJ	3,000kJ
Harbour seal[6]	<100m (for pinnipeds) Harbour seal not assessed	50m 0.000098 harbour seal (0.0000026%)	50m 0.000098 harbour seal (0.0000026%)	<1.5km (for pinnipeds)	3km 0.22 harbour seal (0.006%)	3.1km 0.23 harbour seal (0.006%)	As for TTS		
	No difference in updated modelling results			**No difference in updated modelling results**			**As for TTS**		

[6] *based on harbour seal density of 0.0098/km^2 (Russell et al., 2017) and reference population (SE England MU) of 3,752 (SCOS, 2020); updated modelling based on Southall et al. (2019) unweighted criteria for instantaneous PTS (SPL_{peak} 218 dB re 1 µPa) and weighted criteria for TTS from cumulative exposure (SEL_{cum} 170 dB re 1 µPa^{2}s)*

6.1.1.1.2 Monopiles

In relation to the potential impacts for each species, the updated assessments demonstrate that there is no significant difference in the impact significance between the impacts as assessed for a maximum hammer energy of 3,000kJ or 4,000kJ for WTG monopiles, for marine mammals (i.e. there is no difference with an increase in the maximum hammer energy).

The MMMP for the projects will include a marine mammal monitoring zone, the activation of ADDs, soft start and ramp-up to reduce the risk of PTS from the maximum hammer energy. The mitigation in the MMMPs would be the same for both WTG monopiles as consented and the proposed hammer energies.

There is no significant difference in the percentage of the harbour porpoise reference population that could temporarily have possible avoidance / behavioural reaction as a result of a maximum hammer energy of 3,000kJ or 4,000kJ for WTG monopiles at DBA and DBB.

The impact significance for harbour porpoise for possible avoidance / behavioural reaction from maximum hammer energies of 3,000kJ or 4,000kJ for WTG monopiles is negligible (negligible magnitude (less than 1% of the reference population anticipated to be exposed to effect) and low sensitivity; see **Appendix 1 Table 22**) (i.e. there is no difference with an increase in the maximum hammer energy for WTG monopiles).

It is important to note that not all harbour porpoise would be disturbed in the maximum area for possible avoidance / behavioural reaction.

Table 4: Summary of the maximum PTS SPL_{peak} and TTS SEL_{cum} predicted impact ranges, number of marine mammals, % of reference population and impact assessment for updated modelling and assessment of maximum hammer energies of 3,000kJ or 4,000kJ for WTG monopiles, based on the worst-case for DBA and DBB

Species[7]	PTS (instantaneous)			TTS / fleeing response (cumulative)			Behavioural response (cumulative)		
	3,000kJ in ES	**3,000kJ**	**4,000kJ**	**3,000kJ in ES**	**3,000kJ**	**4,000kJ**	**3,000kJ in ES**	**3,000kJ**	**4,000kJ**
Harbour porpoise	<700m 1 harbour porpoise (0.0004%)	480m 0.63 harbour porpoise (0.00018%)	520m 0.74 harbour porpoise (0.00021%)	5.5km 62 harbour porpoise (0.03%)	20.0km 649 harbour porpoise (0.19%)	20.0km 666 harbour porpoise (0.19%)	43km 2,276 harbour porpoise (0.98%)	29km 1,598 harbour porpoise (0.5%)	30km 1,687 harbour porpoise (0.5%)
	No significant difference in impact ranges			**No significant difference in updated modelling results**			**No significant difference in updated modelling results**		
Bottlenose dolphin	<50m (for mid-frequency cetaceans) Bottlenose dolphin not assessed	<50m 0.0003 bottlenose dolphin (0.000015%)	<50m 0.0003 bottlenose dolphin (0.000015%)	<150m (for mid-frequency cetaceans) Bottlenose dolphin not assessed	<100m 0.003 bottlenose dolphin (0.00015%)	<100m 0.003 bottlenose dolphin (0.00015%)	9km (for mid-frequency cetaceans) Bottlenose dolphin not assessed	As for TTS	
	No difference in updated modelling results			**No difference in updated modelling results**			**As for TTS**		
White-beaked dolphin	<50m 0.00006 white-beaked dolphin (<0.00001%)	<50m 0.00002 white-beaked dolphin (0.00000005%)	<50m 0.00002 white-beaked dolphin (0.00000005%)	<150m 0.0004 white-beaked dolphin (<0.00001%)	<100m 0.0002 white-beaked dolphin (0.0000005%)	<100m 0.0002 white-beaked dolphin (0.0000005%)	9km 1.1 white-beaked dolphin (0.006%)	As for TTS	

[7] See footnotes for Table 3

Species[7]	PTS (instantaneous)			TTS / fleeing response (cumulative)			Behavioural response (cumulative)		
	3,000kJ in ES	**3,000kJ**	**4,000kJ**	**3,000kJ in ES**	**3,000kJ**	**4,000kJ**	**3,000kJ in ES**	**3,000kJ**	**4,000kJ**
	No difference in impact ranges			**No difference in updated modelling results**			**As for TTS**		
Minke whale	<50m 0.00002 minke whale (<0.00001%)	<50m 0.0001 minke whale (0.0000005%)	<50m 0.0001 minke whale (0.0000005%)	<350m 0.0009 minke whale (<0.00001%)	28km 12 minke whale (0.06%)	28km 12 minke whale (0.06%)	56km 13 minke whale (0.05%)	As for TTS	
	No difference in impact ranges			**No difference in updated modelling results**			**As for TTS**		
Grey seal	<150m 0.06 grey seal (<0.0003%)	50m 0.002 grey seal (0.000023%)	50m 0.002 grey seal (0.000023%)	<1.9km 8.5 grey seal (0.04%)	7.1km 22 grey seal (0.25%)	7.1km 24 grey seal (0.28%)	As for TTS		
	No difference in updated modelling results			**No difference in updated modelling results**			**As for TTS**		
Harbour seal	<150m (for pinnipeds) Harbour seal not assessed	50m 0.000098 harbour seal (0.0000026%)	50m 0.000098 harbour seal (0.0000026%)	<1.9km (for pinnipeds) Harbour seal not assessed	7.1km 1 harbour seal (0.027%)	7.1km 1 harbour seal (0.027%)	As for TTS		
	No difference in updated modelling results			**No difference in updated modelling results**			**As for TTS**		

6.1.1.2 Comparison with ES assessments

It is important to note that this is not a 'like for like' comparison. As previously outlined, there have been changes to the modelling, threshold criteria, species density estimates and reference populations since the ES (see **Appendix 1 paragraph 5.2** for further details).

It is more relevant, especially in determining whether there are any new or materially different significant effects in relation to marine mammals between the proposed maximum hammer energy and the currently consented maximum hammer energy, for the NMC, to provide a comparison of the impact significance and overall outcomes of the original assessments in the ES (Forewind, 2013), on which the DCO was based, with the impact significance and overall outcomes of the updated assessments for the increase in hammer energy, as presented in **Table 5**.

The comparison with the impact significance (without mitigation) based on assessments for the consented maximum hammer energies with the updated assessments for the proposed increases in maximum hammer energies, indicate that for harbour porpoise the impact significance for PTS is the same or less than assessment in ES. For minke whale, the updated assessments for PTS, have a worst-case of moderate to minor which reflects updates to modelling, density estimates and reference population (**Table 5**). However, as previously outlined, the MMMP would be implemented to reduce the risk of PTS in marine mammals, based on the greatest potential impact range for PTS. Therefore, the residual impacts for PTS (with mitigation) would be the same as assessed in the ES, no impact.

Therefore, there are no new or materially different significant effects in relation to marine mammals between using the proposed maximum hammer energy of 3,000kJ for OSP pin-piles and 4,000kJ for monopiles compared to the currently consented maximum hammer energy of 1,900kJ for OSP pin-piles and 3,000kJ for monopiles.

Table 5: Comparison of assessment of impact significance in ES and updated assessments for piling at DBA and DBB

Location	**DBA and DBB - Impact significance (without mitigation)**					
Hammer energy	**Assessments for 3,000kJ in ES**	Updated noise modelling for 1,900kJ OSP pin-piles	Updated noise modelling for 3,000kJ OSP pin-piles	Updated noise modelling for 3,000kJ WTG monopiles	Updated noise modelling for 4,000kJ WTG monopiles	**Difference**
Potential impact for harbour porpoise						
PTS	Moderate	Minor (not significant)	Minor (not significant)	Minor (not significant) to Moderate	Minor (not significant) to Moderate	**Same or less than assessment in ES**
TTS	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	**No change**
Possible avoidance	Negligible	Negligible	Negligible	Negligible	Negligible	**No change**
Potential impact for dolphin species						
PTS	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	**No change**
TTS	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	**No change**
Potential impact for minke whale						
PTS	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant) to Moderate	Minor (not significant) to Moderate	**Precautionary update to moderate reflects updates to modelling, density estimates and reference population**.
TTS	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	**No change**
Potential impact for grey and harbour seal						
PTS	Moderate	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	**No change**
TTS	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	**No change**
Residual impact (with mitigation) for PTS in all marine mammal species is minor adverse (not significant) / no impact						

6.1.1.2.1 Cumulative Impact Assessment

As demonstrated in **Section 6.1.1.1**, there is no significant difference in the potential impacts on marine mammals from increasing the OSP pin-pile maximum hammer energy from 1,900kJ to 3,000kJ, or increasing the maximum monopile hammer energy of 3,000kJ to 4,000kJ compared to the ES assessment. Therefore, there will be no significant difference to the outcome of the cumulative impact assessment in the ES assessment.

The CIA has been updated to take into account activities and noise sources that could have cumulative impacts during piling at DBA and DBB, and if the proposed increase in hammer energy would result in any significant differences (see **Appendix 1 paragraph 5.2.1** for more information).

Piling at DBA is scheduled to commence in June 2022 and end in March 2023. There is the potential for cumulative impacts with:

- DBC unexploded ordnance (UXO) (in 2022)
- Sofia UXO (April to June 2022)
- East Anglia hub piling (2023-2026)
- East Anglia hub UXO (2023-2026, assume not at the same time as piling)
- Hornsea Project Three piling (2023 – 2025)
- Hornsea Project Three UXO (2023 -2025, assume not at the same time as piling)
- Dredging projects (very small area so unlikely to contribute to cumulative impacts and have not been included in CIA)
    - Lowestoft Eastern Energy Facility
    - Berths 6 and 7, Trinity Terminal, Port of Felixstowe
- Geophysical surveys with sub bottom profiler (SBP) (assume up to two)

Piling at Dogger Bank B is scheduled to commence in April 2023 and end in November 2023. There is the potential for cumulative impacts with:

- East Anglia hub piling (2023-2026)
- East Anglia hub UXO (2023-2026, assume not at the same time as piling)
- Hornsea Project Three piling (2023 – 2025)
- Hornsea Project Three UXO (2023 -2025, assume not at the same time as piling)
- Hornsea Project Four UXO (2023-2024)
- Port of Ramsgate Replacement of Berth 4/5 (very small area so unlikely to contribute to cumulative impacts and have not been included in CIA)
- Geophysical surveys with SBP (assume up to two)

The CIA has been updated to take into account activities and noise sources that could have cumulative impacts during piling at DBA and DBB (**Table 6** and **Table 7**), and if the proposed increase in hammer energy would result in any significant differences.

The updated CIA indicates that, with mitigation, the proposed increase in maximum hammer energy for OSP pin-piles and monopiles for WTG foundations would be the same or less than CIA assessments in the ES that informed the DCO.

Table 6: The potential for increased risk of PTS and / or disturbance from cumulative impacts of underwater noise during piling at DBA (for each cumulative impact assessment scenario)

Project and activity	DBA: Maximum number of marine mammals potentially at increased risk of PTS and disturbance (and overall impact significance)					
	Harbour porpoise	**Bottlenose dolphin**	**White-beaked dolphin**	**Minke whale**	**Grey seal**	**Harbour seal**
Total number of individuals and % of reference population for OSP pin-piles at DBA, with DBC & Sofia UXO without mitigation and piling at EA HUB & HP3 *[or with bubble curtain at Sofia & DBC for UXO clearance]*						
PTS	1,192 (0.34%) *[154 (0.04%)]*	0.15 (0.007%) *[0.02 (0.001%)]*	0.008 (0.00002%) *[0.002 (0.000005%)]*	8 (0.04%) *[0.2 (0.001%)]*	(0.06%) *[0.7 (0.008%)]*	0.3 (0.008%) *[0.04 (0.001%)]*
	Major [Major]	**Moderate [Moderate]**	**Minor [Minor]**	**Major [Moderate]**	**Major [Moderate]**	**Moderate [Moderate]**
Disturbance	7,932.7 (2.29%) *[4,450.3 (1.28%)]*	0.59 (0.03%) *[0.19 (0.09%)]*	0.03 (0.00007%) *[0.016 (0.00004%)]*	939.8 (4.67%) *[65.2 (0.32%)]*	189.2 (2.18%) *[34.1 (0.39%)]*	6.9 (0.18%) *[2.5 (0.07%)]*
	Minor [Minor]	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**
Total number of individuals and % of reference population for OSP pin-piles at DBA, with DBC, Sofia EA HUB & HP3 UXO without mitigation *[or with bubble curtain for UXO clearance]*						
PTS	2,192 (0.6%) *[279 (0.08%)]*	0.2 (0.01%) *[0.3 (0.02%)]*	0.01 (0.00002%) *[0.002 (0.000005%)]*	12 (0.06%) *[0.3 (0.0015%)]*	7.5 (0.09%) *[1 (0.01%)]*	0.6 (0.02%) *[0.07 (0.002%)]*
	Major *[Major]*	**Major *[Major]***	**Minor *[Minor]***	**Major *[Moderate]***	**Major *[Major]***	**Major *[Moderate]***
Disturbance	8,465.5 (2.44%) *[2,051.7 (0.59%)]*	0.78 (0.04%) *[0.22 (0.01%)]*	0.04 (0.0001%) *[0.018 (0.00004%)]*	1,387.8 (6.90%) *[75.9 (0.38%)]*	328.6 (3.79%) *[29.9 (0.34%)]*	25.8 (0.69%) *[1.9 (0.05%)]*
	Minor [Minor]	**Minor [Minor]**	**Minor [Minor]**	**Moderate [Minor]**	**Minor [Minor]**	**Minor [Minor]**

Project and activity	**DBA: Maximum number of marine mammals potentially at increased risk of PTS and disturbance (and overall impact significance)**					
	Harbour porpoise	**Bottlenose dolphin**	**White-beaked dolphin**	**Minke whale**	**Grey seal**	**Harbour seal**
Total number of individuals and % of reference population for WTG monopiles at DBA, with DBC & Sofia UXO without mitigation and piling at EA HUB & HP3 ***[or with bubble curtain at Sofia & DBC]***						
PTS	1,195 (0.35%) *[157 (0.05%)]*	0.15 (0.007%) *[0.02 (0.001%)]*	0.008 (0.00002%) *[0.002 (0.000005%)]*	8 (0.04%) *[0.25 or 0.6 (0.001% or 0.003%)]*	5.3 (0.06%) *[0.7 (0.008%)]*	0.3 (0.008%) *[0.04 (0.001%)]*
	Major [Major]	**Moderate [Moderate]**	**Minor [Minor]**	**Major [Moderate]**	**Major [Moderate]**	**Moderate [Moderate]**
Disturbance	8,092.7 (2.33%) *[4,610.3 (1.33%)]*	0.59 (0.03%) *[0.19 (0.009%)]*	0.03 (0.00007%) *[0.016 (0.00004%)]*	943.9 (4.69%) *[69.3 (0.34%)]*	190.8 (2.20%) *[35.6 (0.41%)]*	6.9 (0.18%) *[2.5 (0.07%)]*
	Minor [Minor]	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**
Total number of individuals and % of reference population for WTG monopiles at DBA, with DBC, Sofia EA HUB & HP3 UXO without mitigation ***[or with bubble curtain]***						
PTS	2,196 (0.6%) *[283 (0.08%)]*	0.2 (0.01%) *[0.3 (0.02%)]*	0.01 (0.00002%) *[0.002 (0.000005%)]*	12 or 13 (0.06 or 0.065%) *[0.4 or 0.7 (0.002 or 0.0035%)]*	7.5 (0.09%) *[1 (0.01%)]*	0.6 (0.02%) *[0.07 (0.002%)]*
	Major [Major]	**Major [Major]**	**Minor [Minor]**	**Major [Moderate]**	**Major [Major]**	**Major [Moderate]**
Disturbance	8,625.5 (2.49%) *[2,211.7 (0.64%)]*	0.78 (0.04%) *[0.2 (0.01%)]*	0.04 (0.0001%) *[0.018 (0.00004%)]*	1,391.9 (6.92%) *[80.0 (0.40%)]*	330.2 (3.81%) *[31.5 (0.36%)]*	25.8 (0.69%) *[1.9 (0.08%)]*
	Minor	**Minor**	**Minor**	**Moderate**	**Minor**	**Minor**

Project and activity	DBA: Maximum number of marine mammals potentially at increased risk of PTS and disturbance (and overall impact significance)					
	Harbour porpoise	Bottlenose dolphin	White-beaked dolphin	Minke whale	Grey seal	Harbour seal
	[Minor]	**[Minor]**	**[Minor]**	**[Minor]**	**[Minor]**	**[Minor]**
Overall cumulative assessment for DBA						
PTS: with MMMPs for piling and UXO, including low-order detonations	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**
Disturbance: with MMMPs for piling and UXO, including low-order detonations	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**

Table 7: The potential for increased risk of PTS from cumulative impacts of underwater noise during piling at Dogger Bank B

Project and activity	Maximum number of marine mammals potentially at increased risk of PTS					
	Harbour porpoise	Bottlenose dolphin	White-beaked dolphin	Minke whale	Grey seal	Harbour seal
Total number of individuals and % of reference population for OSP pin-piles at DBB, with HP4 UXO without mitigation and piling at EA HUB & HP3 *[or with bubble curtain at HP4]*						
PTS	597 (0.2%) *[77.5, 78.3 or 78.4 (0.02%)]*	0.08 (0.004%) *[0.01 (0.0005%)]*	0.004 (0.00002%) *[0.001 (0.000002%)]*	4.3 (0.02%) *[0.2 (0.001%)]*	3.4 (0.04%) *[0.5 (0.006%)]*	1 (0.03%) *[0.13 (0.004%)]*
	Major [Major]	**Moderate [Moderate]**	**Minor [Minor]**	**Major [Moderate]**	**Major [Moderate]**	**Moderate [Moderate]**
Disturbance	6,631 (1.9%) *[4,889.8 (1.4%)]*	0.4 (0.02%) *[0.2 (0.01%)]*	0.02 (0.00005%) *[0.01 (0.00003%)]*	483.6 (2.4%) *[46.3 (0.2%)]*	270.2 (3.11%) *[41.5 (0.48%)]*	19.2 (0.5%) *[3.2 (0.09%)]*
	Minor	**Minor**	**Minor**	**Minor**	**Minor**	**Minor**

Project and activity	Maximum number of marine mammals potentially at increased risk of PTS					
	Harbour porpoise	Bottlenose dolphin	White-beaked dolphin	Minke whale	Grey seal	Harbour seal
	[Minor]	**[Minor]**	**[Minor]**	**[Minor]**	**[Minor]**	**[Minor]**
Total number of individuals and % of reference population for OSP pin-piles at DBB, with HP4, EA HUB & HP3 UXO without mitigation *[or with bubble curtain]*						
PTS	1,598 (0.5%) *[205 (0.06%)]*	0.14 (0.007%) *[0.02 (0.001%)]*	0.008 (0.00002%) *[0.001 (0.000002%)]*	8.6 (0.04%) *[0.3 (0.0015%)]*	5.6 (0.065%) *[0.74 (0.0085%)]*	1.3 (0.035%) *[0.2 (0.005%)]*
	Major ***[Major]***	**Moderate** ***[Moderate]***	**Minor** ***[Minor]***	**Major** ***[Moderate]***	**Major** ***[Moderate]***	**Major** ***[Moderate]***
Disturbance	7,163.8 (2.07%) *[2,491.2 (0.72%)]*	0.6 (0.03%) *[0.2 (0.01%)]*	0.03 (0.00007%) *[0.02 (0.00004%)]*	931.6 (4.6%) *[57 (0.3%)]*	409.6 (4.73%) *[37.3 (0.43%)]*	38.2 (1.02%) *[2.7 (0.07%)]*
	Minor **[Minor]**	**Minor** **[Minor]**	**Minor** **[Minor]**	**Minor** **[Minor]**	**Minor** **[Minor]**	**Minor** **[Minor]**
Total number of individuals and % of reference population for WTG monopiles at DBB, with HP4 UXO without mitigation and piling at EA HUB & HP3 *[or with bubble curtain at HP4]*						
PTS	602 (0.2%) *[83 (0.024%)]*	0.08 (0.004%) *[0.01 (0.0005%)]*	0.004 (0.00002%) *[0.001 (0.000002%)]*	4.7 (0.02%) *[0.48 (0.002%)]*	3.4 (0.04%) *[0.5 (0.006%)]*	1 (0.03%) *[0.13 (0.004%)]*
	Major **[Major]**	**Moderate** **[Moderate]**	**Minor** **[Minor]**	**Major** **[Moderate]**	**Major** **[Moderate]**	**Moderate** **[Moderate]**
Disturbance	6,986 (2.02%) *[5,244.8 (1.51%)]*	0.4 (0.02%) *[0.2 (0.01%)]*	0.02 (0.00005%) *[0.01 (0.00003%)]*	490.3 (2.4%) *[53 (0.3%)]*	289.6 (3.34%) *[60.9 (0.7%)]*	20.0 (0.5%) *[4.0 (0.1%)]*
	Minor **[Minor]**	**Minor** **[Minor]**	**Minor** **[Minor]**	**Minor** **[Minor]**	**Minor** **[Minor]**	**Minor** **[Minor]**
Total number of individuals and % of reference population for WTG monopiles at DBB, with HP4, EA HUB & HP3 UXO without mitigation *[or with bubble curtain]*						

Project and activity	Maximum number of marine mammals potentially at increased risk of PTS					
	Harbour porpoise	**Bottlenose dolphin**	**White-beaked dolphin**	**Minke whale**	**Grey seal**	**Harbour seal**
PTS	1,602 (0.5%) *[209 (0.06%)]*	0.14 (0.007%) *[0.02 (0.001%)]*	0.008 (0.00002%) *[0.001 (0.000002%)]*	9 (0.045) *[0.6 (0.003%)]*	5.6 (0.065%) *[0.74 (0.0085%)]*	1.3 (0.035%) *[0.2 (0.005%)]*
	Major [Major]	**Moderate [Moderate]**	**Minor [Minor]**	**Major [Moderate]**	**Major [Moderate]**	**Major [Moderate]**
Disturbance	7,518.8 (2.17%) *[2,846.2 (0.82%)]*	0.6 (0.03%) *[0.2 (0.01%)]*	0.03 (0.00007%) *[0.02 (0.00004%)]*	938.3 (4.7%) *[63.7 (0.3%)]*	429.0 (4.95%) *[56.7 (0.65%)]*	38.9 (1.04%) *[3.4 (0.09%)]*
	Minor [Minor]	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**
Overall cumulative assessment for DBB						
PTS: with MMMPs for piling and UXO, including low-order detonations	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**
Disturbance: with MMMPs for piling and UXO, including low-order detonations	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**

6.1.1.3 Comparison with HRA

As demonstrated, there is no significant difference in the potential impacts on marine mammals from increasing the maximum hammer energy for the OSP pin-piles from 1,900kJ to 3,000kJ or the maximum hammer energy for the WTG monopiles from 3,000kJ to 4,000kJ. As a result, the conclusions of the HRA (DECC, 2015) which underpin the DCO are not affected and the proposed changes themselves would not have the potential to give rise to likely significant effects on any designated sites with marine mammals as a qualifying feature.

6.1.1.3.1 Updated Assessment for the Southern North Sea SAC

The Southern North Sea SAC was designated for harbour porpoise in February 2019, after DBA and DBB were consented. DBA and DBB are located within the Southern North Sea SAC summer area.

6.1.1.3.1.1 Assessment of the Potential for PTS

For PTS from cumulative exposure the maximum difference between OSP pin-pile hammer energy of 1,900kJ compared to 3,000kJ difference is 0.08 harbour porpoise (0.000023% of North Sea MU; see **Appendix 1 Table 13**). Therefore, there is no significant difference (i.e. the additional difference is less than 0.001% of the North Sea MU reference population) between the consented hammer energy of 1,900kJ and the proposed increase to a maximum hammer energy of 3,000kJ for OSP pin-piles.

For the WTG monopiles, the difference in PTS ranges from the cumulative exposure for hammer energies of 3,000kJ compared to 4,000kJ difference is 0.15 harbour porpoise (0.000043% of North Sea MU; see **Appendix 1 Table 19**). Therefore, there is no significant difference (i.e. the additional difference is less than 0.001% of the North Sea MU reference population) between the consented hammer energy of 3,000kJ and the proposed increase to a maximum hammer energy of 4,000kJ for WTG monopiles.

The potential for PTS associated with underwater noise will be mitigated through the MMMP, based on the maximum potential range for PTS. The MMMP, as secured through the existing deemed Marine Licences, will reduce the risk of PTS in harbour porpoise in the Southern North Sea SAC. As such, the proposed NMC would not result in a likely significant effect or an adverse effect on integrity for either the Projects alone or in-combination with other plans, projects or proposals.

6.1.1.3.1.2 Assessment of the Potential for Disturbance

Disturbance is considered to be significant if it leads to the exclusion of harbour porpoise from a significant portion of the site for a significant period of time. Draft Statutory Nature Conservation Bodies (SNCBs) guidance for assessing the significance of noise disturbance to a site suggests:

> *"Noise disturbance within an SAC from a plan/project individually or in combination is significant if it excludes harbour porpoise from more than:*
>
> *1. 20% of the relevant area of the site in any given day, and*
>
> *2. an average of 10% of the relevant area of the site over a season".*

The current SNCB advice, which is also considered within the BEIS (2020) RoC HRA, is that the assessments for potential disturbance of harbour porpoise in the Southern North Sea SAC is based on an area of Effective Deterrence Radius (EDR) of 26km for monopiles, and 15km for pin-piles, irrespective of hammer energy or pile size. Therefore, based on current SNCB advice there is no alteration in the disturbance range from the proposed amendments compared to the consented projects.

The approach to the assessments, and in the Site Integrity Plan for the potential disturbance of harbour porpoise in the Southern North Sea SAC summer area from underwater noise follows the current advice from the SNCBs (JNCC *et al.,* 2020), that:

- Displacement of harbour porpoise should not exceed 20% of the relevant area of the site in any given day or on average exceed 10% of the relevant area of the site over a season.
- The effect of the project should be considered in the context of the seasonal components of the SAC area, rather than the SAC area as a whole.
- A distance of 26km (EDR) from an individual percussive piling location (for monopiles) should be used to assess the area of SAC habitat that harbour porpoise may be disturbed from during piling operations for monopiles, with a potential disturbance area of 2,124km^2.
- For pin-pile piles, the recommended EDR is 15km, with a potential disturbance area of up to 707km^2.

The increase in maximum hammer energy compared to the consented DBA and DBB have been considered in relation to the Southern North Sea SAC. This demonstrates that there is no difference in the impacts due to the increase in hammer energy for the OSP pin-piles and the WTG monopiles, as the recommended EDRs of 26km for monopiles and 15km for pin-piles (JNCC *et al.,* 2020) is irrespective of the hammer energy.

The assessment therefore supports a conclusion that the proposed changes would not give rise to a likely significant effect or an adverse effect on the Southern North Sea SAC. See **Appendix 1 paragraph 5.4** for more detailed assessments for the Southern North Sea SAC.

6.1.1.3.1.3 Potential for In-Combination Effects

As demonstrated, there is no significant difference in the potential impacts on harbour porpoise from increasing the maximum monopile hammer energy to 4,000kJ compared to the maximum monopile hammer energy of 3,000kJ in the original assessment, therefore there will be no significant difference to the outcome of any in-combination effect scenarios. In addition, the assessment of disturbance to harbour porpoise from piling activities are based on standard disturbance ranges, and do not take account of hammer energies used in piling events. Therefore, potential effects to harbour porpoise would be the same for piling, regardless of the hammer energy required.

6.1.1.4 Comparison with BEIS (2020) RoC for OWFs in the Southern North Sea harbour porpoise SAC

Since the Project was granted consent, the Southern North Sea SAC was designated for the protection of harbour porpoise. The Southern North Sea SAC was therefore not considered during the determination of the original DCO application; however, impacts on harbour porpoises, including the reference population, were considered.

The May 2016 BEIS "Guidance on when new marine Natura 2000 sites should be taken into account in offshore renewable energy consents and licences" (DECC, 2016) states that as a matter of government policy where an amendment is sought to a DCO, potential Special Protection Areas (SPA) and pSACs should be considered as if they are designated/classified and *"any possible likely significant effects (and adverse effects on integrity) of the proposed changes in the variation or amendment would need to be considered."* It is clear from the Guidance that it is the Likely Significant Effect (LSE) of the variation or amendment to the DCO that needs to be considered and not the LSE of the DCO as amended. Based on the updated assessment using the latest criteria, it is concluded that the proposed change would not give rise to LSE on the Southern North Sea SAC, no more than the consented impacts (either alone or in-combination). The implications of the Projects on the Southern North Sea SAC have been considered as part of the BEIS (2020) RoC.

The modelling for the BEIS (2020) RoC HRA did not include the OSP pin-piles with a maximum hammer energy of 1,900kJ. A comparison with the BEIS (2020) RoC HRA indicates that the maximum predicted PTS impact ranges for the updated noise modelling for a maximum hammer energy of 4,000kJ for the WTG monopiles are within the maximum predicted PTS ranges in the BEIS (2020) RoC HRA (**Table 8**). Differences in the maximum predicted impact ranges of possible avoidance of harbour porpoise reflect differences in the noise modelling conducted for the RoC HRA and the Dogger Bank projects (see **Appendix 1 paragraph 5.4.1**).

Table 8: Comparison of maximum predicted impact ranges (and areas) for PTS from a single strike (SPL_{peak}) and from cumulative exposure (SEL_{cum}) in non-material changes assessment compared to BEIS (2020) RoC HRA modelling for harbour porpoise

Receptor	Threshold	Maximum predicted impact range and area			
		Maximum hammer energy of 3,000kJ for monopile	Maximum hammer energy of 4,000kJ for monopile	RoC HRA 3,000kJ for monopile at Creyke Beck A	RoC HRA 3,000kJ for monopile at Creyke Beck B
SPL_{peak} single strike					
Harbour porpoise	unweighted SPL_{peak} 202 dB re 1 µPa	480m (0.71km^2)	520m (0.83km^2)	819m (1.72km^2)	806m (1.8km^2)
Cumulative SEL					
Harbour porpoise	SEL_{cum} Weighted 155 dB re 1 µPa^{2}s	2,200m (13km^2)	2,300m (13km^2)	2,499m (15.55km^2)	2,718m (17.65km^2)
Harbour porpoise – possible avoidance	unweighted SEL_{ss} 145 dB re 1 µPa^{2}a	29km (1,800km^2)	30km (1,900km^2)	19.87km (791km^2)	27.05km (1,498km^2)

It is important to note that, irrespective of the maximum hammer energy required to install the pin-piles for the OSP or the monopiles for the WTG, the mitigation measures in the MMMPs would reduce the potential risk of PTS in all marine mammal species. In addition, the DBA and DBB Southern North Sea SAC SIP will reduce the potential for significant disturbance of harbour porpoise from the Projects alone and in-combination with other projects and activities.

6.1.2 *Conclusion of the Marine Mammal Assessments*

The assessments undertaken demonstrate that there is no difference in the impact significance between the impacts as assessed in the ES and the updated assessment. Therefore, the assessments demonstrate that an increase in maximum hammer energy of 1,900kJ to 3,000kJ for the OSP pin-piles, or from 3,000kJ to 4,000kJ for the WTG monopiles, does not affect impact significance on any of the assessed receptors.

It is therefore concluded that as there is no material difference between the impacts consented, as assessed in the ES, and those resulting from the proposed amendment to the Projects. The conclusions of the ES and its associated documents are not affected by the proposed change and the recommendations of the Examining Authority and the conclusions of the HRA which underpin the DCO are similarly not affected. The proposed change does not have the potential to give rise to LSE on any designated sites. Therefore, the proposed amendment to the DCO will not give rise to any new or materially different LSE in relation to marine mammals and no further assessment is required for marine mammals in support of the proposed amendment to the DCO. In light of this, no new or additional mitigation will be required in relation to marine mammals other than that which is already secured through the DCO.

6.2 Fish and Shellfish

For the proposed amendments of increases in hammer energies, as set out in **Section 5**, fish and shellfish have been screened in for further consideration. The assessment for fish and shellfish is set out below.

6.2.1 *Outcomes of Assessment*

6.2.1.1 Updated assessments

The underwater noise modelling for this assessment was undertaken based on the latest inputs and scenarios for maximum hammer energies of 1,900kJ and 3,000kJ to install the OSP pin-piles and of 3,000kJ and 4,000 kJ to install the monopiles for the WTG foundations, using the Popper *et al*. (2014) thresholds and criteria to determine the maximum impact ranges for fish.

In relation to the potential impacts for each receptor, the updated assessments demonstrate that there is no significant difference in the impact ranges for a maximum hammer energy of 1,900kJ or 3,000kJ for the OSP pin-piles and of 3,000kJ and 4,000 kJ for the monopiles of the WTG foundations for any of the assessed receptors. The results are provided in **Table 9 to Table 14**. The impact ranges for fleeing fish in **Table 10** and **Table 13** have assumed a conservative fleeing speed of 1.5 m/s (Hirata, 1999). Underwater noise modelling was also carried out for stationary fish (

Table 11 and **Table 14**). The assessment in this section is based on the worst-case with the greatest impact range for the two DBA and DBB sites.

The results demonstrate that the difference in impact ranges for a 1,900kJ and 3,000kJ hammer energy for the pin-piles, and 3,000kJ and 4,000 kJ hammer energies for the monopiles, is negligible.

Table 9: Maximum predicted unweighted SPL_{peak} impact ranges for fish using criteria from Popper *et al*. (2014) (taken from Section 4.4.4 and 4.4.6 of the Underwater Noise Modelling Report in Appendix 2)

Fish - impact criterion	Maximum hammer energy of 1,900kJ for pin-pile	Maximum hammer energy of 3,000kJ for pin-pile
Injury (fish: no swim bladder) unweighted SPL_{peak} (213 dB re 1 μPa)	Area: 0.02km^2 Max range: 80 m	Area: 0.02km^2 Max range: 80 m
Injury (fish: with swim bladder) unweighted SPL_{peak} (207 dB re 1 μPa)	Area: 0.11km^2 Max range: 190 m	Area: 0.12km^2 Max range: 200 m

Table 10: Maximum predicted unweighted SEL_{cum} impact ranges for fish using criteria from Popper *et al*. (2014) assuming a fleeing speed of 1.5 m/s (Hirata, 1999) (taken from Section 4.4.4 and 4.4.6 of the Underwater Noise Modelling Report in Appendix 2)

Fish – impact criterion	Maximum hammer energy of 1,900kJ for pin-pile	Maximum hammer energy of 3,000kJ for pin-pile
Mortality (fish: no swim bladder) SEL_{cum} (> 219 dB re 1 μPa^{2}s)	Area: <0.1km^2 Max range: <100 m	Area: <0.1km^2 Max range: <100 m
Recoverable injury (fish: no swim bladder) SEL_{cum} (> 216 dB re 1 μPa^{2}s)	Area: <0.1km^2 Max range: <100 m	Area: <0.1km^2 Max range: <100 m
Mortality (fish: swim bladder not involved in hearing) SEL_{cum} (210 dB re 1 μPa^{2}s)	Area: <0.1km^2 Max range: <100 m	Area: <0.1km^2 Max range: <100 m
Mortality (fish: swim bladder involved in hearing) SEL_{cum} (207 dB re 1 μPa^{2}s)	Area: <0.1km^2 Max range: <100 m	Area: <0.1km^2 Max range: <100 m
Recoverable injury (fish: swim bladder not involved in hearing and fish: swim bladder involved in hearing) SEL_{cum} (203 dB re 1 μPa^{2}s)	Area: <0.1km^2 Max range: <100 m	Area: <0.1km^2 Max range: <100 m
TTS (all fish) SEL_{cum} (186 dB re 1 μPa^{2}s)	Area: 95km^2 Max range: 6.7km	Area: 42km^2 Max range: 4.2km

Table 11: Maximum predicted unweighted SEL_{cum} impact ranges for stationary fish using criteria from Popper *et al*. (2014) (taken from Section 4.4.4 and 4.4.6 of the Underwater Noise Modelling Report in Appendix 2)

Fish – impact criterion	Maximum hammer energy of 1,900kJ for pin-pile	Maximum hammer energy of 3,000kJ for pin-pile
Mortality (fish: no swim bladder) SEL_{cum} (> 219 dB re 1 μPa²s)	Area: 0.94km² Max range: 560 m	Area: 1.1km² Max range: 600 m
Recoverable injury (fish: no swim bladder) SEL_{cum} (> 216 dB re 1 μPa²s)	Area: 2.2km² Max range: 870 m	Area: 2.5km² Max range: 930 m
Mortality (fish: swim bladder not involved in hearing) SEL_{cum} (210 dB re 1 μPa²s)	Area: 13km² Max range: 2.1km	Area: 14km² Max range: 2.2km
Mortality (fish: swim bladder involved in hearing) SEL_{cum} (207 dB re 1 μPa²s)	Area: 26km² Max range: 3km	Area: 29km² Max range: 3.2km
Recoverable injury (fish: swim bladder not involved in hearing and fish: swim bladder involved in hearing) SEL_{cum} (203 dB re 1 μPa²s)	Area: 65km² Max range: 4.8km	Area: 72km² Max range: 5km
TTS (all fish) SEL_{cum} (186 dB re 1 μPa²s)	Area: 1000km² Max range: 21km	Area: 1100km² Max range: 21km

Table 12: Maximum predicted unweighted SPL_{peak} impact ranges for fish using criteria from Popper *et al*. (2014) (taken from Section 4.4.1 and 4.4.2 of the Underwater Noise Modelling Report in Appendix 2)

Fish - impact criterion	Maximum hammer energy of 3,000kJ for monopiles	Maximum hammer energy of 4,000kJ for monopiles
Injury (fish: no swim bladder) unweighted SPL_{peak} (213 dB re 1 μPa)	Area: 0.03km² Max range: 90m	Area: 0.03km² Max range: 100m
Injury (fish: with swim bladder) unweighted SPL_{peak} (207 dB re 1 μPa)	Area: 0.16km² Max range: 230m	Area: 0.19km² Max range: 250m

Table 13: Maximum predicted unweighted SEL_{cum} impact ranges for fish using criteria from Popper *et al*. (2014) assuming a fleeing speed of 1.5 m/s (Hirata, 1999) (taken from Section 4.4.1 and 4.4.2 of the Underwater Noise Modelling Report in Appendix 2)

Fish – impact criterion	Maximum hammer energy of 3,000kJ for monopiles	Maximum hammer energy of 4,000kJ for monopiles
Mortality (fish: no swim bladder) SEL_{cum} (> 219 dB re 1 μPa²s)	Area: <0.1km² Max range: <100 m	Area: <0.1km² Max range: <100 m
Recoverable injury (fish: no swim bladder) SEL_{cum} (> 216 dB re 1 μPa²s)	Area: <0.1km² Max range: <100 m	Area: <0.1km² Max range: <100 m
Mortality (fish: swim bladder not involved in hearing) SEL_{cum} (210 dB re 1 μPa²s)	Area: <0.1km² Max range: <100 m	Area: <0.1km² Max range: <100 m
Mortality (fish: swim bladder involved in hearing) SEL_{cum} (207 dB re 1 μPa²s)	Area: <0.1km² Max range: <100 m	Area: <0.1km² Max range: <100 m
Recoverable injury (fish: swim bladder not involved in hearing and fish: swim bladder involved in hearing) SEL_{cum} (203 dB re 1 μPa²s)	Area: <0.1km² Max range: <100 m	Area: <0.1km² Max range: <100 m
TTS (all fish) SEL_{cum} (186 dB re 1 μPa²s)	Area: 220km² Max range: 10km	Area: 230km² Max range: 10km

Table 14: Maximum predicted unweighted SEL_{cum} impact ranges for stationary fish using criteria from Popper *et al*. (2014) (taken from Section 4.4.1 and 4.4.2 of the Underwater Noise Modelling Report in Appendix 2)

Fish – impact criterion	Maximum hammer energy of 3,000kJ for monopiles	Maximum hammer energy of 4,000kJ for monopiles
Mortality (fish: no swim bladder) SEL_{cum} (> 219 dB re 1 μPa²s)	Area: 1.2km² Max range: 630m	Area: 1.3km² Max range: 660m
Recoverable injury (fish: no swim bladder) SEL_{cum} (> 216 dB re 1 μPa²s)	Area: 2.8km² Max range: 980m	Area: 3.1km² Max range: 1km
Mortality (fish: swim bladder not involved in hearing) SEL_{cum} (210 dB re 1 μPa²s)	Area: 15km² Max range: 2.3km	Area: 17km² Max range: 2.4km

Fish – impact criterion	Maximum hammer energy of 3,000kJ for monopiles	Maximum hammer energy of 4,000kJ for monopiles
Mortality (fish: swim bladder involved in hearing) SEL_{cum} (207 dB re 1 μPa²s)	Area: 32km² Max range: 3.4km	Area: 34km² Max range: 4.7km
Recoverable injury (fish: swim bladder not involved in hearing and fish: swim bladder involved in hearing) SEL_{cum} (203 dB re 1 μPa²s)	Area: 78km² Max range: 5.3km	Area: 83km² Max range: 5.4km
TTS (all fish) SEL_{cum} (186 dB re 1 μPa²s)	Area: 1100km² Max range: 22km	Area: 1200km² Max range: 23km

6.2.1.2 Comparison with ES assessments

It is important to note that this is not a 'like for like' comparison, as there have been changes to the modelling and threshold criteria since the ES. However, it does provide an indicative comparison of the impact significance for construction noise assessed in the ES and the updated assessments for a maximum hammer energy of 3,000kJ for the OSP pin-piles and 4,000kJ for the WTG foundation monopiles.

The maximum impact range for disturbance within the ES assessments was 19km for pin-piles, and 21.5km for monopiles (Forewind, 2013). These are slightly less than the updated modelled impact ranges for TTS / fleeing response for both pin-piles and monopiles. For pin-piles at 3,000kJ, the updated modelling range was for 21km compared to 19km in the original assessments (for 1,900kJ). For monopiles at 4,000kJ, the TTS / fleeing response range is 23km, compared to 21.5km as modelled for 3,000kJ within the original ES.

The updated modelling results show slightly higher impact ranges in some cases (i.e. for TTS / fleeing response), but they are not significant changes, and are not considered to alter the conclusions of the original assessments. Therefore, the assessments made within the ES are considered valid for the proposed change to hammer energies for both OSP pin-piles and WTG monopiles.

Table 15: Comparison of the impact significance assessed in the ES for construction noise with the updated assessment of maximum hammer energy of 3,000kJ for OSP pin-piles

Impact	Receptor	ES assessment	Updated assessment for maximum hammer energy of 3,000kJ
Lethal / injury	Adult and juvenile fish	Negligible	Negligible
	Larvae	Minor adverse	Minor adverse
Disturbance to spawning fish and	Majority of fish	Minor adverse	Minor adverse

Impact	Receptor	ES assessment	Updated assessment for maximum hammer energy of 3,000kJ
nursery grounds	species		
	Herring	Minor adverse	Minor adverse
	Sandeel	Minor adverse	Minor adverse
Disturbance to migration	Diadromous species and elasmobranchs	Minor adverse	Minor adverse
	Other fish species	Minor adverse	Minor adverse
Effects on prey species/feeding	All fish species	Minor adverse	Minor adverse

Table 16: Comparison of the impact significance assessed in the ES for construction noise with the updated assessment of maximum hammer energy of 4,000kJ for the WTG foundation monopiles

Impact	Receptor	ES assessment	Updated assessment for maximum hammer energy of 4,000kJ
Lethal / injury	Adult and juvenile fish	Negligible	Negligible
	Larvae	Minor adverse	Minor adverse
Disturbance to spawning fish and nursery grounds	Majority of fish species	Minor adverse	Minor adverse
	Herring	Minor adverse	Minor adverse
	Sandeel	Minor adverse	Minor adverse
Disturbance to migration	Diadromous species and elasmobranchs	Minor adverse	Minor adverse
	Other fish species	Minor adverse	Minor adverse
Effects on prey species/feeding	All fish species	Minor adverse	Minor adverse

6.2.2 *Conclusion of the fish assessments*

The assessments demonstrate that the potential impact ranges have only slightly increased due to the increase in maximum hammer energy for the OSP pin-piles and monopiles for the WTG foundations. Within the ES and DCO examination, no issues were raised regarding piling noise and potential impacts on the Flamborough Head herring spawning ground, due to the distance between the wind farm array site and the inshore spawning grounds. The Statement of Common Ground with the MMO (Forewind, 2014) demonstrated agreement that impacts on fish and shellfish during construction would not be significant. The NMC application does not alter this conclusion.

In relation to the Flamborough Head herring spawning grounds, the offshore wind farm areas for both Projects are not within this area. The Projects are located approximately 80km from the high-density spawning grounds. The modelled maximum ranges of impact, for both fleeing and stationary fish, indicate these ranges do not overlap the herring spawning grounds. As such, the proposed change does not present a risk to herring eggs or larvae.

There is no pathway for effect on the Flamborough Head spawning ground resulting from piling activities. Additionally, the ES describes a minor adverse impact given the relatively small area around each pile driving operation where larval mortality may potentially occur and the short-term intermittent nature of the activity. As such, it is concluded that there will be no impact on eggs and larvae as a result of the proposed increase in hammer energy for the OSP pin-piles and monopiles for the WTG foundations.

Based on the information above, and the fact that the worst-case scenario in relation to construction noise has not altered due to the proposed amendments, it is concluded that there will be no new or materially different LSEs compared to the existing consented scheme. The conclusions of the original assessment in the ES that fish impacts are not significant for the Project alone and cumulatively with other projects are not affected. Consequently, this is also the conclusion drawn for effects on prey species for marine ornithological receptors, as the impacts on fish are not significant. The proposed changes do not have the potential to give rise to LSE on any designated sites. The worst-case position remains the same and no further assessment is required for fish (or ornithological prey) in support of the proposed changes to the DCO.

7 Assessment of Materiality

There is no statutory definition of what constitutes a material or non-material amendment for the purposes of Schedule 6 of the Planning Act 2008 and Part 1 of the 2011 Regulations.

However, criteria for determining whether an amendment should be material or non-material is outlined in the Department for Communities and Local Government (DCLG) guidance "Planning Act 2008: Guidance on Changes to Development Consent Orders" (December 2015) (the Guidance). Paragraphs 9-16 of the Guidance sets out the four characteristics which act to provide an indication on whether a proposed change is material or non-material. The following characteristics are stated to indicate that an amendment is more likely to be considered material.

1. A change should be treated as material if it would require an updated ES (from that at the time the original DCO was made) to take account of new, or materially different, likely significant effects on the environment.
2. A change is likely to be material if it would invoke a need for a Habitats Regulations Assessment. Similarly, the need for a new or additional licence in respect of European Protected Species (EPS) is also likely to be indicative of a material change.
3. A change should be treated as material that would authorise the compulsory acquisition of any land, or an interest in or rights over land that was not authorised through the existing DCO.

4. The potential impact of the proposed changes on local people will also be a consideration in determining whether a change is material.

The proposed amendment to the DCO in relation to the hammer energy for the OSP pin-piles and monopiles for the WTG foundations has been considered in light of these four characteristics as presented in the following sections.

7.1 EIA considerations

The information provided in **Sections 5** and **6** demonstrates that the proposed amendments will not give rise to new or materially different likely significant effects on the environment. As such, the proposed amendments can be viewed as non-material changes to the DCO.

7.2 HRA and EPS considerations

The information presented in **Section 6** demonstrates that the conclusions of the HRA which underpin the DCO are not affected by the proposed amendments and the proposed changes do not have the potential to give rise to likely significant effects on any designated sites. As such there will be no new HRA required.

In relation to the Southern North Sea SAC, it is noted that the proposed amendment to hammer energy for the OSP pin-piles and monopiles for the WTG foundations does not have the potential to give rise to any likely significant effects, so do not invoke the need for HRA (see **Section 6.1.1**). The SAC designation invoked the need for BEIS (as the competent authority) to undertake a review of existing licences and consents that are likely to have a significant effect, either alone or in combination with other plans and projects, on harbour porpoise in accordance with the Habitats Regulations (see **Section 6.1.1.4**). This concluded that for DBA and DBB there would be no adverse effect on the Southern North Sea SAC with the implementation of a Site Integrity Plan for the Projects.

A comparison with the BEIS (2020) RoC HRA indicates that the maximum predicted PTS and TTS impact ranges for the updated noise modelling for a maximum hammer energy of 3,000kJ for the OSP pin-piles and 4,000kJ for the monopiles of the WTG foundations are within the maximum predicted ranges in the BEIS (2020) RoC HRA (see **Appendix 1**).

In addition, the current guidelines for the assessment of disturbance from piling of monopiles and pin-piles is to use a 26km or 15km EDR respectively for all hammer energies and pile sizes. Therefore, increasing the hammer energy for either OSP pin-piles or WTG monopiles will have no difference to the outcomes of any HRA assessment in relation to disturbance on the Southern North Sea SAC, based on current SNCB guidance (JNCC *et al*., 2020).

In relation to in-combination assessments, whilst new projects have entered the consenting process, these projects would have had to consider the Dogger Bank projects as part of their own in-combination assessments.

As the conclusions of the ES and HRA remain unchanged, it is not considered that there is a need for any new or additional licences in respect of EPS, therefore in accordance with the non-materiality of the proposed amendments.

7.3 Compulsory acquisition of land

The proposed change applies to activities being undertaken within the existing DCO Order limits, and are only relevant to the marine environment. As such, the possible requirement for compulsory acquisition does not arise.

7.4 Implications on local people

The proposed amendments will have no effect on the local population, given the distance of the Projects from shore.

7.5 Summary

The above sections assess the materiality of the proposed amendments to the DCO, with respect to the four characteristics set out by the DCLG Guidance, and set out that:

- The proposed amendments will not give rise to new or materially different likely significant effects on the environment;
- The conclusions of the ES and HRA remain unchanged, it is not considered that there is a need for any new or additional licences in respect of EPS;
- There is no requirement for the compulsory acquisition of land; and
- There is no effect on the local population.

Based on these outcomes, the assessment of materiality in this section demonstrates that the proposed amendments are non-material changes to the DCO.

8 Conclusions

This Environmental Report has reviewed the potential effects of the proposed NMC on all the topics considered in the ES and the HRA. A screening exercise was undertaken which identified the following topics as requiring more detailed consideration:

- Designated sites;
- Marine Mammals; and
- Fish and shellfish.

With respect to marine mammals, consideration of the impact of the proposed change in maximum hammer energy for OSP pin-piles and monopiles for the WTG foundations for permanent auditory injury (PTS), temporary auditory injury (TTS) and possible avoidance were assessed. The updated underwater noise modelling and assessments have been compared to the assessments in the ES and HRA that informed the DCO.

The assessments demonstrate that there is no difference in the impact significance assessed under the original assessment and the updated assessment. The assessments demonstrate that an increase in maximum hammer energy from 1,900kJ to 3,000kJ for the OSP pin-piles and from 3,000kJ to 4,000kJ for the monopiles of the WTG foundations does not give rise to new or materially different likely significant effects in relation to any of the assessed receptors.

With respect to fish, the worst-case scenario assessed for construction noise in the ES would not alter due to the increase in hammer energies for the OSP pin-piles or WTG monopiles. The updated noise modelling indicates there is no significant difference to the impact range for maximum hammer energy from 1,900kJ to 3,000kJ for the OSP pin-piles and from 3,000kJ to 4,000kJ for the monopiles of the WTG foundation. Therefore, the proposed amendment does not give rise to any new or materially different likely significant effects in relation to fish.

In relation to potential effects on designated sites the assessments demonstrate that the HRA conclusions are not affected by the proposed change. The potential effects of the proposed change do not have the potential to give rise to likely significant effects on any designated sites, including the Southern North Sea SAC. Therefore, no further assessments are required in relation to designated sites.

It is concluded that the proposed changes would not give rise to any new or materially different likely significant effects on any receptor and that the conclusions of the ES and the HRA are not affected and no new HRA is required. The proposed change also has no impact on Compulsory Acquisition Powers or local people. It is therefore appropriate for the application to be consented as an NMC to the DCO.

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Appendix 1 - Marine Mammal Technical Report

Dogger Bank A&B Projects

Non-Material Change Application: Appendix 1 Marine Mammal Technical Report

LF500013-CST-RHD-REP-0006 / LF600013-CST-RHD-REP-0007

17th December 2021

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Glossary of Acronyms

µPa	Micro pascal
ADD	Acoustic Deterrent Device
BEIS	Department for Business, Energy and Industrial Strategy
BND	Bottlenose dolphin
BGS	British Geological Survey
CGNS	Celtic and Greater North Seas
CI	Confidence Interval
CIA	Cumulative Impact Assessment
cu. in.	Cubic inches
CV	Confidence Variation
dB	Decibel
DBA	Dogger Bank A
DBB	Dogger Bank B
DCO	Development Consent Order
DECC	Department of Energy and Climate Change
dML	deemed Marine Licence
EDR	Effective Deterrent Radius
EMODnet	European Marine Observation and Data Network
EPS	European Protected Species
ES	Environmental Statement
GNS	Greater North Sea
GS	Grey seal
HF	High-frequency
HP	Harbour porpoise
HRA	Habitats Regulations Assessment
HS	Harbour seal
IAMMWG	Inter-Agency Marine Mammal Working Group
INSPIRE	Impulse Noise Sound Propagation and Range Estimator (Subacoustech's noise model for estimating impact piling noise)
kHz	Kilohertz
kJ	Kilojoules
km	Kilometre
km^2	Kilometre squared
LF	Low-frequency
m/s	Meter per second

m	Meter
MF	Mid-frequency
MMMP	Marine Mammal Mitigation Protocol
MMO	Marine Management Organisation
MU	Management Unit
MW	Minke whale
N/A	Not Applicable
NMC	Non-Material Change
NPL	National Physical Laboratory
NS	North Sea
OSPs	Offshore Substation Platforms
OWF	Offshore Wind Farm
PCW	Pinnipeds in water
PE	Parabolic equation
PTS	Permanent Threshold Shift
RoC	Review of Consents
SAC	Special Area of Conservation
SBP	Sub bottom profiler
SCANS	Small Cetaceans in the European Atlantic and North Sea
SCOS	Special Committee on Seals
SE	South East
SEL	Sound Exposure Level
SEL_{ss}	Sound Exposure Level for single strike
SEL_{cum}	Cumulative Sound Exposure Level
SIP	Site Integrity Plan
SMRU	Sea Mammal Research Unit
SNCBs	Statutory Nature Conservation Bodies
SPL	Sound Pressure Level
SPL_{peak}	Peak Sound Pressure Level
TTS	Temporary Threshold Shift
UXO	Unexploded ordnance
VHF	Very high frequency
WBD	White-beaked dolphin
WTGs	Wind Turbine Generators

Executive Summary

Dogger Bank A (previously Creyke Beck A) and Dogger Bank B (previously Creyke Beck B) Offshore Wind Farms (OWFs) were consented in 2015 under the Dogger Bank Creyke Beck Offshore Wind Farm Development Consent Order (DCO).

This technical report supports the Non-Material Change (NMC) application for increasing the hammer energy required to install the pin-piles for the Offshore Substation Platforms (OSPs) and the monopiles for the Wind Turbine Generators (WTGs).

An increase in the maximum hammer energy is required as the pile driveability assessment for the pin piles for the OSPs indicated that if 1,900kJ hammer energy was used, there was the potential for hard driving and refusal risk when encountering the harder soils when approaching design penetration.. Therefore, an increase in the pin-pile hammer energy is required in order to ensure that the piles can be driven to target.Similarly for monopile installation, driveability assessment has indicated a number of locations with risk of refusal and therefore the increased energy is required as a contingency measure to ensure piles can be successfully driven to target penetration.

As the increase in hammer energy would require a change to the consented parameters, this NMC application is required to the DCO to enable the Projects to be constructed in the most efficient manner.

This report considers the potential for changes to the outcomes of the marine mammal assessment provided in the Environmental Statement (ES) (Forewind, 2013) and Habitats Regulations Assessment (HRA) (Department of Energy and Climate Change (DECC), 2015; now Department for Business, Energy and Industrial Strategy (BEIS)) for the Dogger Bank A & B projects. To assess what the effects of the proposed increase in maximum hammer energy for OSP pin-piles and monopiles for WTG foundations would be, updated underwater noise modelling was carried out and compared with the maximum hammer energy assessments in the ES that informed the DCO.

The assessments determine the potential for permanent change in hearing sensitivity (Permanent Threshold Shift (PTS)) and temporary change in hearing sensitivity (Temporary Threshold Shift (TTS)) in harbour porpoise, bottlenose dolphin, white-beaked dolphin, minke whale, grey seal and harbour seal and the possible avoidance / behavioural reaction of harbour porpoise.

The updated assessments in this report demonstrate that in each case, the previous assessment outcomes in the ES would not be significantly affected by the proposed increase in maximum hammer energy for OSP pin-piles and WTG monopiles.

As there is no significant difference in the potential impacts on marine mammals from increasing the maximum monopile hammer energy from 3,000kJ to 4,000kJ and maximum OSP pin-pile hammer energy from 1,900kJ to 3,000kJ, there will be no significant difference to the outcome of the cumulative impact assessment in the ES assessment or to the outcome of the HRA as a result of the proposed changes.

This report confirms that there are no new or materially different significant effects compared to the original assessments. Therefore, the conclusions of the ES, that marine mammal impacts are not significant for the project alone and cumulatively with other projects, are not affected. Similarly, the conclusions of the HRA of no adverse effect on the integrity of any European site arising from the project alone and in-combination with all other sites are also not affected. The proposed changes do not have the potential to give rise to likely significant effects on any European sites (including the Southern North Sea Special Area of Conservation (SAC)). The worst-case position remains the same and no further assessment is required for marine mammals in support of the proposed changes to the DCO.

A comparison with the BEIS (2020) Review of Consented (RoC) OWFs in the Southern North Sea harbour porpoise SAC indicates that the maximum predicted PTS impact ranges for the updated noise modelling for a maximum hammer energy for monopiles and pin-piles are within the maximum predicted PTS ranges in the BEIS (2020) RoC HRA. Differences in the maximum predicted impact ranges of possible avoidance of harbour porpoise reflect differences in the noise modelling conducted for the RoC HRA and the Dogger Bank A&B projects.

It is concluded that the proposed changes would not give rise to any new or materially different significant effects on any marine mammal receptor and that the conclusions of the ES, the DECC HRA and BEIS (2020) RoC HRA are not affected and no further assessments or new HRA is required. Therefore, it is appropriate for the application to amend the maximum hammer energy for OSP pin-piles and WTG monopiles to be considered as a NMC to the DCO.

1 Introduction

This technical report assesses how the proposed amendments outlined in **Section 2** would affect the marine mammal assessments presented in the original assessments in the ES and the HRA.

The report is structured as follows:

- **Section 2: Proposed Amendment**
- **Section 3: Purpose of Assessment**
- **Section 4: Methodology for Assessment**
- **Section 5: Outcome of Assessment**
  - **Section 5.1: Results of updated noise modelling and assessments**
  - **Section 5.2: Comparison with ES assessment**
  - **Section 5.3: Comparison with HRA**
  - **Section 5.4: Comparison with BEIS (2020) RoC HRA**
- **Section 6 Conclusions**

2 Proposed amendment

The proposed amendment requires an increase to the consented maximum hammer energy for OSP pin-piles and WTG monopiles, whilst leaving all other DCO parameters unchanged (**Table 1**).

Increasing the maximum hammer energy for OSP pin-piles and WTG monopiles has the potential to affect the original marine mammal assessments for the ES and HRA, that informed the DCO. Reassessments have therefore been undertaken using the updated parameters shown in **Table 1**. A screening exercise was undertaken in Section 5 of the Environmental Report to assess potential for impacts on receptors.

There are no proposed changes to the pile diameter in relation to OSP pin-piles or monopiles.

Table 1: Proposed consent amendments relevant to marine mammals

Parameter	Consented Envelope	Proposed Amendment
Maximum hammer energy – monopiles	Up to 3,000kJ	Up to 4,000kJ
Maximum hammer energy – pin piles for OSPs	Up to 1,900kJ	Up to 3,000kJ
Monopile diameter	Up to 10m	No change
OSP pin-pile diameter	Up to 2.744m	No change

3 Purpose of assessment

The purpose of the updated assessment is to determine the potential impacts on marine mammals associated with the proposed increase in hammer energy for OSP pin-piles and WTG monopiles. This report provides a comparison of the original assessment for the ES and the HRA with the updated assessment for the increased hammer energies. The original assessment referred to throughout this report is the assessment conducted for the ES, HRA and everything that led to consent, including examination.

Underwater noise propagation modelling for the original assessment was carried out by the National Physical Laboratory (NPL) (Theobald *et al*., 2012) to assess the effects of noise from the construction of the Dogger Bank Creyke Beck (now Dogger Bank A&B) offshore wind farms.

Since the NPL modelling was completed for the ES, NPL no longer conduct noise modelling for individual projects. In addition, new noise thresholds and criteria (Southall *et al*., 2019) have been developed for both PTS and TTS in marine mammals.

To assess what the effects of the proposed increase in maximum hammer energy for OSP pin-piles and monopiles for WTG foundations would be, updated underwater noise modelling was carried out for the proposed hammer energies and compared with the maximum hammer energy assessments in the ES that informed the DCO. The noise modelling was undertaken by Subacoustech (details provided in **Section 4.2**) for:

(i) Maximum hammer energy for OSP pin-piles of up to 1,900kJ or 3,000kJ for marine mammal species using Southall *et al*. (2019) thresholds and criteria for PTS and TTS.

(ii) Maximum hammer energy for monopiles of up to 3,000kJ and 4,000kJ for marine mammal species using Southall *et al*. (2019) thresholds and criteria for PTS and TTS.

The updated assessments in this report are based on:

(i) The updated underwater noise modelling for the previous maximum hammer energies and the proposed increases to maximum hammer energies (as detailed above), using the Southall *et al*. (2019) thresholds and criteria for permanent threshold shift (PTS) where unrecoverable changes to hearing sensitivity may occur, and temporary threshold shift (TTS) where a temporary reduction in hearing sensitivity may occur.

(ii) Comparison with assessments in the ES (Forewind, 2013) that informed the DCO, including comparison and updated cumulative impact assessment.

(iii) Comparison and updated HRA, including in-combination assessment.

(iv) Comparison with BEIS (2020) RoC for OWFs in the Southern North Sea harbour porpoise SAC.

In addition, since the original assessments for the ES there have been updates to marine mammal density estimates and reference populations (see **Section 4.1**). Therefore, the most recent and relevant density estimates have been used for the updated assessment.

Due to the differences in the underwater modelling, thresholds and criteria it is not possible to make a direct comparison of impact ranges with the original assessments in the ES. However, the updated noise modelling includes the previous, consented maximum hammer energy for OSP pin-piles and monopiles of 1,900kJ and 3,000kJ respectively. Comparison with the impact significance and overall outcomes of the original assessments for the ES (Forewind, 2013) and HRA (DECC, 2015) have also been made in relation the impact significance and overall outcomes of the updated assessments for the increase in hammer energy.

The aim of the updated assessments and comparisons is to determine whether there are any new or materially different likely significant effects in relation to marine mammals between using the proposed maximum hammer energy of 3,000kJ compared to the currently consented maximum hammer energy of 1,900 for OSP pin-piles and using the proposed maximum hammer energy of 4,000kJ compared to the currently consented maximum hammer energy of 3,000kJ for monopiles.

4 Methodology for assessment

The ES assessed the potential impacts on the following marine mammal species:

- Harbour porpoise *Phocoena phocoena*
- White-beaked dolphin *Lagenorhynchus albirostris*
- Minke whale *Balaenoptera acutorostrata*
- Grey seal *Halichoerus grypus*
- Harbour seal *Phoca vitulina*

A review of the distribution of marine mammals throughout the North Sea confirms that these are the species of marine mammals most likely to be present in and around the Dogger Bank A and B offshore wind farm areas (Hammond *et al*., 2021; Paxton *et al*., 2016; Waggitt *et al*., 2019; Special Committee on Seals (SCOS), 2020). However, in recent years an increase in bottlenose dolphins in the north-east of England has been reported (Aynsley, 2017). Although bottlenose dolphin are most likely to be in coastal waters, as a precautionary approach, the updated assessments have also included:

- Bottlenose dolphin *Tursiops truncatus*

4.1 Density estimates and reference populations

Since the ES was completed, updated information on the density estimates (Hammond *et al*., 2021; Russell *et al*., 2017; Carter *et al*., 2020) and reference populations (Inter-Agency Marine Mammal Working Group (IAMMWG), 2021; SCOS, 2020) for marine mammals in the Dogger Bank area has become available. **Table 2** and **Table 3** provide the density estimates and reference populations, respectively, used in the original assessments in the ES and the updated assessments in this report.

The most recent density estimates have been based on the SCANS-III survey for cetaceans (Hammond *et al*., 2021) and the Sea Mammal Research Unit (SMRU) seal at-sea usage maps (Russell *et al*., 2017) have been used for the updated assessments. It is important to note that Carter *et al*. (2020) provides *relative density* (i.e. percentage of at-sea population within each 5 km x 5 km grid square), whereas Russel *et al*. (2017) present *absolute density* (i.e. number of animals). Therefore, Russel *et al*. (2017) has been used for the grey and harbour seal density estimates.

Table 2: Marine mammal density estimates used in the ES and updated assessments

Species	Original assessment		Updated assessment	
	Density estimate used in ES	ES data source	Updated density estimate (number of individuals per km^2)	Updated data source
Harbour porpoise	0.6536/km^2 (95% Confidence Interval (CI) = 0.4445-0.9409/km^2)	Site specific surveys; ES (Forewind, 2013)	0.888/km^2 (Coefficient of Variation (CV) = 0.209)	SCANS-III survey block O* (Hammond *et al*., 2021)
Bottlenose dolphin	N/A	N/A	0.0298/km^2 (CV = 0.861)	SCANS-III survey block R* (Hammond *et al*., 2021)
White-beaked dolphin	0.0071/km^2 (95% CI = 0.0064-0.0948/km^2)	Site specific surveys; ES (Forewind, 2013)	0.002/km^2 (CV = 0.970)	SCANS-III survey block O* (Hammond *et al*., 2021)
Minke whale	0.0023/km^2 (95% CI = 0.0015-0.0048/km^2).	Site specific surveys; ES (Forewind, 2013)	0.010/km^2 (CV = 0.621)	SCANS-III survey block O* (Hammond *et al*., 2021)
Grey seal	Maximum mean density of 0.84 seals per km^2	SMRU (2013)	DBA array site = 0.055/km^2 DBB array site = 0.20/km^2	SMRU seal at-sea usage maps (Russell *et al*., 2017)
Harbour seal	N/A	N/A	DBA array site = 0.0003/km^2 DBB array site = 0.0098/km^2	SMRU seal at-sea usage maps (Russell *et al*., 2017)

**Dogger Bank A and B array sites are both located in SCANS-III survey block O; there is no density estimate for bottlenose dolphin in block O, therefore SCANS-III density estimate for bottlenose dolphin in the adjacent survey block R has been used.*

Table 3: Marine mammal reference populations used in the ES and updated assessments

Species	Reference populations	
	ES Assessments	Updated Assessments
Harbour porpoise	North Sea (NS) Management Unit (MU) = 232,450 (95% CI = 154,451 – 310,449; Hammond *et al.*, 2013)	NS MU = 346,601 (95% CI = 289,498 – 419,967; IAMMWG, 2021)
Bottlenose dolphin	N/A	Greater North Sea (GNS) MU = 2,022 (95% CI= 548 – 7,453; IAMMWG, 2021)
White-beaked dolphin	16,536 (95% CI=9,245 - 29,586; Hammond *et al*., 2013)	Celtic and Greater North Seas (CGNS) MU = 43,951 (95% CI=28,439 – 67,924; IAMMWG, 2021)
Minke whale	25,723 (95% CI=11,037-73,605; Hammond *et al*., 2013; Macleod *et al*., 2009)	CGNS MU = 20,118 (95% CI=14,061 – 28,786; IAMMWG, 2021)
Grey seal	North Sea = 22,412 (19,100 (14,000 - 26,500) + 3,312; UK North Sea (SCOS) and Mainland Europe (Waddensea Secretariat))	South-east (SE) England MU = 8,667 grey seal (SCOS, 2020)
Harbour seal	England east coast = 4,221 (minimum population size; SCOS)	SE England MU = 3,752 harbour seal (SCOS, 2020)

4.2 Underwater noise modelling

The updated underwater noise modelling was undertaken by Subacoustech (2021) using the INSPIRE v5.1 model. The full modelling report is provided in **Appendix 2** of the Environmental Report, however a summary is provided below.

The underwater noise modelling for marine mammals was undertaken using the Southall *et al*. (2019) threshold and criteria (see **Section 4.2.5**) for impulsive sources from a single strike (unweighted peak sound pressure level (SPL_{peak})) and from cumulative exposure (weighted cumulative sound exposure level (SEL_{cum})) for both PTS, where a permanent shift in hearing sensitivity may occur, and TTS, where a temporary reduction in hearing sensitivity may occur in individual receptors:

- Very high-frequency cetaceans (harbour porpoise)
- High-frequency cetaceans (dolphin species)
- Low-frequency cetaceans (minke whale)
- Pinnipeds in water (grey and harbour seal)

In addition, the criteria from Lucke *et al*. (2009) have been used to determine in the possible avoidance / behavioural reaction of harbour porpoise.

4.2.1 Modelling locations

Dogger Bank A and B are both located approximately 131km from the shore, at their closest point, with Dogger Bank A having an array area of 515km^2 and Dogger Bank B an array area of 599km^2.

Modelling was undertaken at four representative locations across the two sites (two locations at each site) covering the site extents and various water depths (

Table 4 and **Figure 1**).

Table 4: Summary of the underwater noise modelling locations at Dogger Bank A and B

Modelling locations	Dogger Bank A North (N)	Dogger Bank A South West (SW)	Dogger Bank B North West (NW)	Dogger Bank B South East (SE)
Latitude	54.8279° N	54.7405° N	55.0733° N	54.8902° N
Longitude	001.7932° E	001.7430° E	1.5056° E	1.8157° E
Water depth (mean tide)	20.1m	22.7m	24.1m	22.9m

Data from the British Geological Survey (BGS) show that the seabed surrounding the Dogger Bank sites is generally made up predominantly of sand and some areas of gravel and gravelly sand. Digital bathymetry, from the European Marine Observation and Data Network (EMODnet), has been used for this modelling. Mean tidal depth has been used throughout.

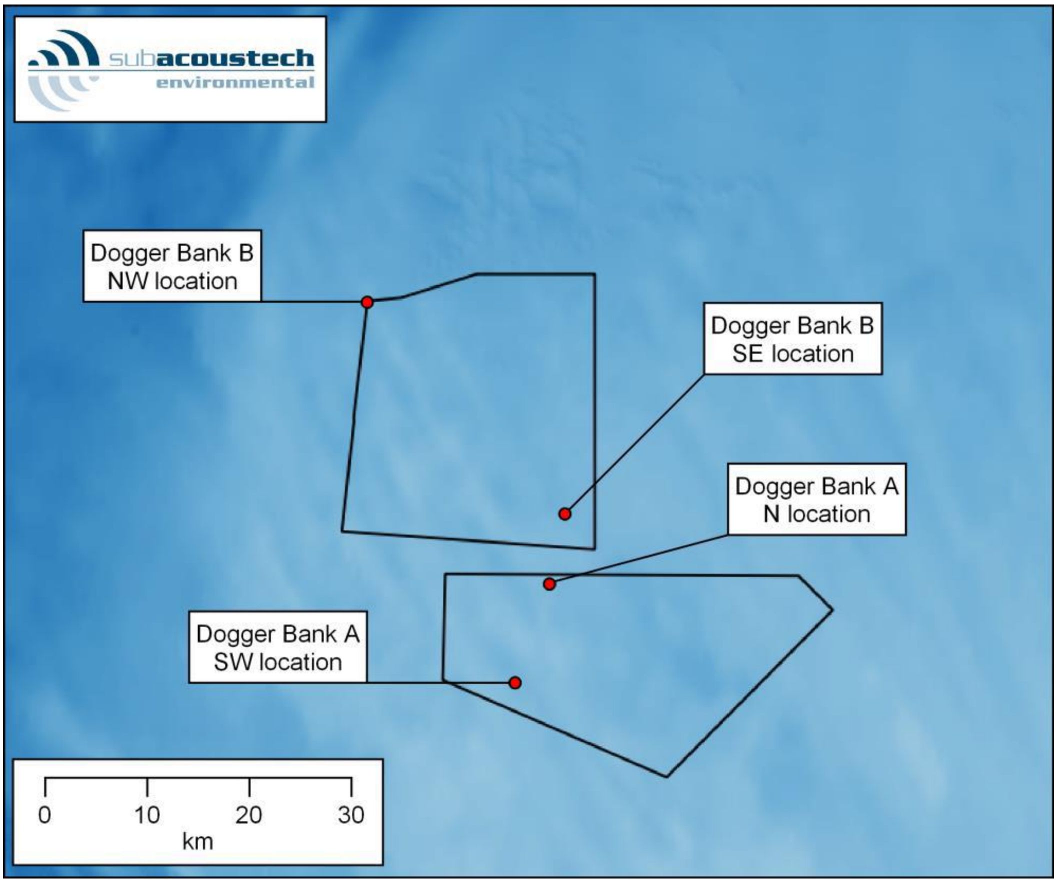

Figure 1: Approximate locations of the modelling locations at Dogger Bank A and B

4.2.2 Modelling parameters

The maximum hammer energies and pile diameters for OSP pin-piles and WTG monopiles used in the updated underwater noise modelling are presented in **Table 5**.

The OSP pin-pile diameter could be up to 2.744m (**Table 1**), however, the minimum diameter could be 2.438m, therefore as a worst case for pin-piles, the minimum diameter was modelled (**Table 5**).

Table 5: Hammer energies and pile diameters assessed in the updated underwater noise modelling

Assessment	Pile diameter	Maximum hammer energy
OSP Pin-piles	2.438m (minimum)	Previous = 1,900kJ Proposed increase = 3,000kJ
WTG monopiles	Up to 10m	Previous = 3,000kJ Proposed increase = 4,000kJ

4.2.3 Soft-start, ramp-up, strike rate and piling duration

For cumulative Sound Exposure Level (SEL_{cum}), the soft start and ramp up of hammer energy along with the total duration and strike rate is taken into account in the modelling (**Table 6** for OSP pin-piles and

Table 7 for WTG monopiles).

In a 24-hour period it is possible that up to two monopiles or four pin-pile foundations could be installed, therefore, as a worst-case scenario, this is included in the modelling, assuming that the foundation piles are installed consecutively.

Table 6: Soft-start and ramp-up parameters for OSP pin-piles with maximum hammer energy of 1,900kJ or 3,000kJ

Piling parameters	Hammer energy at each piling stage				Total for full piling event
OSP pin-piles 1,900kJ	**300kJ**	**850kJ**	**1,500kJ**	**1,900kJ**	Total of 5,820 strikes over 4 hours 20 minutes (increased to 11,640 strikes and 17 hours 20 minutes when considering four piles installed in 24 hours)
Number of strikes	60	1,800	400	3,560	
Duration	10 minutes	78 minutes	17 minutes	155 minutes	
Strike rate (strikes / minute)	6	~23	~23	~23	
OSP pin-piles 3,000kJ	**320kJ**	**850KJ**	**1,500kJ**	**3,000kJ**	Total of 5,820 strikes over 4 hours 20 minutes (increased to 11,640 strikes and 17 hours 20 minutes when considering four piles installed in 24 hours)
Number of strikes	60	1,800	400	3,560	
Duration	10 minutes	78 minutes	17 minutes	155 minutes	
Strike rate (strikes / minute)	6	~23	~23	~23	

Table 7: Soft-start and ramp-up parameters for WTG monopiles with maximum hammer energy of 3,000kJ and 4,000kJ

Piling parameters	Hammer energy at each piling stage					Total for full piling event
WTG monopiles 3,000kJ	300kJ	880kJ	1,320kJ	2,640kJ	3,000kJ	Total of 6,047 strikes over 2 hours 44 minutes (increased to 12,094 strikes and 5 hours 28 minutes when considering two piles installed in 24 hours)
Number of strikes	110	804	3,472	90	1,571	
Duration	11 minutes	27 minutes	87 minutes	2 minutes	37 minutes	
Strike rate (strikes / minute)	10	~30	~40	45	~42	
WTG monopiles 4,000kJ	400kJ	880kJ	1,320kJ	2,640kJ	4,000kJ	Total of 6,047 strikes over 2 hours 44 minutes (increased to 12,094 strikes and 5 hours 28 minutes when considering two piles installed in 24 hours)
Number of strikes	110	804	3,472	90	1,571	
Duration	11 minutes	27 minutes	87 minutes	2 minutes	37 minutes	
Strike rate (strikes / minute)	10	~30	~40	45	~42	

The cumulative SEL modelling uses a fleeing animal model for marine mammals. This assumes that the animal exposed to the noise levels will swim away from the source as it occurs. For this assessment, a constant speed of 3.25 m/s has been assumed for minke whale (Blix and Folkow, 1995). All other marine mammals are assumed to swim at a constant speed of 1.5 m/s (Otani *et al*. 2000). These are considered worst-case (i.e. relatively slow, leading to greater calculated exposures) as marine mammals are expected to swim much faster under stress conditions.

The SEL_{cum} impact range indicates that if the receptor were to start fleeing in a straight line from the noise source starting at a range closer than the modelled value, it would receive a noise exposure above the criteria threshold, and if the receptor were to start fleeing from a range further than the modelled value it would receive a noise exposure below the criteria threshold. Therefore, marine mammals within the impact range limit at the start of piling could receive noise levels greater than the criteria threshold. Although, within the impact area, receptors closer to the noise source will have a greater overall cumulative exposure level than those further away.

4.2.4 Source levels

The unweighted single strike SPL_{peak} and SEL_{ss} source levels used in the underwater noise modelling are presented in

Table 8.

The source level is estimated based on the pile diameter and the blow energy imparted on the pile by the hammer. This is adjusted depending on the water depth at the modelling location to allow for the length of pile in contact with the water, which can affect the amount of noise that is transmitted from the pile into its surroundings.

Table 8: Unweighted single strike SPL_{peak} and SEL_{ss} source levels used for modelling

Source level	DBA N	DBA SW	DBB NW	DBB SE
SPL_{peak} source level (dB re 1 μPa @ 1m)				
OSP pin-pile 1,900kJ	239.8	239.9	239.9	239.9
OSP pin-pile 3,000kJ	240.9	241.0	241.0	241.0
WTG monopile 3,000kJ	241.9	241.9	241.9	241.9
WTG monopile 4,000kJ	242.4	242.4	242.4	242.2
SEL_{ss} source level (dB re 1 μPa²s @ 1m)				
OSP pin-pile 1,900kJ	219.8	219.9	220.0	219.9
OSP pin-pile 3,000kJ	221.1	221.2	221.3	221.2
WTG monopile 3,000kJ	222.8	222.8	222.8	222.8
WTG monopile 4,000kJ	223.4	223.5	223.5	223.5

4.2.5 Thresholds and criteria

The marine mammal thresholds and criteria from Southall *et al*. (2019) for single strike unweighted peak criteria (SPL_{peak}) and cumulative weighted sound exposure criteria (SEL_{cum}) for PTS and TTS were used in the underwater noise modelling (**Table 9**).

Table 9: PTS and TTS thresholds and criteria for marine mammals for impulsive noise (Southall et al., 2019)

Marine mammal hearing group	PTS threshold		TTS threshold	
	SPL_{peak} (unweighted) dB re 1 μPa	SEL_{cum} (weighted) dB re 1 μPa²s	SPL_{peak} (unweighted) dB re 1 μPa	SEL_{cum} (weighted) dB re 1 μPa²s
Very high frequency (VHF) cetaceans (harbour porpoise)	202	155	196	140
High frequency (HF) cetaceans (dolphin species)	230	185	224	170
Low frequency (LF) cetaceans (minke whale)	219	183	213	168
Pinnipeds in water (PCW) (grey and harbour seal)	218	185	212	170

In addition, the criteria from Lucke *et al*. (2009) have been used to determine in the possible avoidance / behavioural reaction of harbour porpoise (**Table 10**). However, it is important to note that not all harbour porpoise would be disturbed in the maximum area for possible avoidance / behavioural reaction.

Table 10: Possible avoidance / behavioural reaction of harbour porpoise criteria (Lucke et al., 2009)

Lucke *et al*. (2009)	Possible avoidance / behavioural reaction of harbour porpoise
Unweighted SEL_{ss} (dB re 1 μPa^2s)	145

5 Outcome of assessment

5.1 Results of updated underwater noise modelling and assessments

5.1.1 OSP pin-piles increased hammer energy

5.1.1.1 PTS from first strike of soft-start for OSP pin-piles

The updated underwater noise modelling results (**Appendix 2** of the Environmental Report) indicate there are very small differences only in the maximum PTS ranges and areas for single strike of the starting hammer energy for OSP pin-piles at Dogger Bank A and B for the starting hammer energy of 300kJ for maximum hammer energy of 1,900kJ or starting hammer energy of 320kJ for maximum hammer energy of 3,000kJ (**Table 11**). All PTS ranges for soft-start hammer energies are the same for either 300kJ or 320kJ, with the exception of harbour porpoise, where at most locations, there is a slight increase from a range of 80m for a 300kJ starting energy, to 90m for a 320kJ starting hammer energy.

There is no significant difference in the maximum number of marine mammals or percentage of the reference population that could be impacted (PTS) as a result of a starting hammer energy of 300kJ or 320kJ for OSP pin-piles at Dogger Bank A and B (**Table 11**).

The impact significance for all marine mammal species for potential PTS from first strike of the soft-start, 300kJ or 320kJ for OSP pin-piles is minor (not significant) (i.e. there is no difference with an increase in the maximum hammer energy; **Table 11**). The assessment indicates that the magnitude is negligible with less than 0.001% of the reference population anticipated to be exposed to permanent effect, with high sensitivity for all marine mammals to PTS; see **Annex A**.

The Marine Mammal Mitigation Protocols (MMMP) include the activation of Acoustic Deterrent Devices (ADDs) prior to the soft start to reduce the risk of instantaneous PTS from the first strike of the starting hammer energy. The duration of the ADD activation would be the same for starting hammer energy of 300kJ or 320kJ. Therefore, there would be no difference to the ADD activation if the maximum hammer energy for the OSP pin-piles at Dogger Bank A and B was increased from 1,900kJ to 3,000kJ.

Table 11: Maximum PTS* ranges and areas for single strike of the starting hammer energy of 300kJ (for a maximum hammer energy of 1,900kJ as consented) or 320kJ (for a maximum hammer energy of 3,000kJ) for OSP pin-piles at Dogger Bank A&B and number of marine mammals (% of reference population) that could be impacted (without mitigation)

Species	DBA N		DBA SW		DBB NW		DBB SE	
	300kJ	320kJ	300kJ	320kJ	300kJ	320kJ	300kJ	320kJ
Harbour porpoise (HP)	**80m (0.02km^2)**	**80m (0.02km^2)**	**80m (0.02km^2)**	**90m (0.02km^2)**	**80m (0.02km^2)**	**90m (0.02km^2)**	**80m (0.02km^2)**	**90m (0.02km^2)**
	0.018 HP (0.000005% NS MU)	0.018 HP (0.000005% NS MU)	0.018 HP (0.000005% NS MU)	0.018 HP (0.000005% NS MU)	0.018 HP (0.000005% NS MU)	0.018 HP (0.000005% NS MU)	0.018 HP (0.000005% NS MU)	0.018 HP (0.000005% NS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
Dolphin species	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**
Bottlenose dolphin (BND)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
White-beaked dolphin (WBD)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
	<50m	**<50m**	**<50m**	**50m**	**<50m**	**50m**	**<50m**	**50m**

Species	DBA N		DBA SW		DBB NW		DBB SE	
	300kJ	320kJ	300kJ	320kJ	300kJ	320kJ	300kJ	320kJ
Minke whale (MW)	**(<0.01km^2)**	**(0.01km^2)**	**(0.01km^2)**	**(0.01km^2)**	**(0.01km^2)**	**(0.01km^2)**	**(0.01km^2)**	**(0.01km^2)**
	0.0001 MW (0.0000005% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
Grey seal and harbour seal	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**
Grey seal (GS) (using DBA or DBB project specific density estimates)	0.00055 GS (0.000006% SE MU)	0.00055 GS (0.000006% SE MU)	0.00055 GS (0.000006% SE MU)	0.00055 GS (0.000006% SE MU)	0.002 GS (0.000023% SE MU)	0.002 GS (0.000023% SE MU)	0.002 GS (0.000023% SE MU)	0.002 GS (0.000023% SE MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
Harbour seal (HS) (using DBA or DBB project specific density estimates)	0.000003 HS (0.00000008% SE MU)	0.000003 HS (0.00000008% SE MU)	0.000003 HS (0.00000008% SE MU)	0.000003 HS (0.00000008% SE MU)	0.000098 HS (0.0000026% SE MU)	0.000098 HS (0.0000026% SE MU)	0.000098 HS (0.0000026% SE MU)	0.000098 HS (0.0000026% SE MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)

*based on unweighted SPL_{peak} *for HP, BND, WBD, GS & HS and* weighted SEL_{ss} *for MW*

5.1.1.2 PTS from single strike of maximum hammer energy for OSP pin-piles

The updated underwater noise modelling results (**Appendix 2** of the Environmental Report) indicate there is no difference in the maximum PTS ranges and areas for single strike of the maximum hammer energy for OSP pin-piles of 1,900kJ or 3,000kJ at Dogger Bank A and B for bottlenose dolphin, white-beaked dolphin, minke whale, grey seal and harbour seal, all being less than 50m (**Table 12**).

There are slight, but not significant differences in the maximum PTS ranges for harbour porpoise for single strike of the maximum hammer energy for OSP pin-piles, ranging from a maximum of up to 360m for 1,900kJ, and up to 430m for 3,000kJ (**Table 12**). However, the maximum number of harbour porpoise that could be impacted, without mitigation, is less than 0.5, for all locations and for both maximum OSP pin-pile hammer energies (**Table 12**).

There is no significant difference in the maximum number of marine mammals or percentage of the reference population that could be impacted (PTS) as a result of a maximum hammer energy of 1,900kJ or 3,000kJ for OSP pin-piles at Dogger Bank A and B (**Table 12**).

The impact significance for all marine mammal species for potential PTS from single strike of the maximum hammer energies of 1,900kJ or 3,000kJ for OSP pin-piles is **minor (not significant)** (with a negligible magnitude for all species and hammer energies, and a high sensitivity; see **Annex A**) (i.e. there is no difference with an increase in the maximum hammer energy from 1,900kJ as currently consented, to 3,000kJ; **Table 12**).

The MMMPs include a marine mammal monitoring zone, the activation of ADDs, soft start and ramp-up to reduce the risk of PTS from the maximum hammer energy. The mitigation would be the same for OSP pin-pile maximum hammer energy of either 1,900kJ or 3,000kJ.

Table 12: Maximum PTS ranges and areas for single strike of the maximum hammer energy of 1,900kJ (currently consented) or 3,000kJ for OSP pin-piles at Dogger Bank A&B and number of marine mammals (% of reference population) that could be impacted (without mitigation)*

Species	DBA N		DBA SW		DBB NW		DBB SE	
	1,900kJ	3,000kJ	1,900kJ	3,000kJ	1,900kJ	3,000kJ	1,900kJ	3,000kJ
HP	**320m ($0.31km^2$)**	**380m ($0.44km^2$)**	**340m ($0.37km^2$)**	**410m ($0.5km^2$)**	**360m ($0.4km^2$)**	**430m ($0.56km^2$)**	**350m ($0.37km^2$)**	**410m ($0.52km^2$)**
	0.28 HP (0.00008% NS MU)	0.39 HP (0.00011% NS MU)	0.33 HP (0.000095% NS MU)	0.44 HP (0.00013% NS MU)	0.36 HP (0.0001% NS MU)	0.5 HP (0.00014% NS MU)	0.33 HP (0.000095% NS MU)	0.46 HP (0.00013% NS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
Dolphin species	**<50m (<$0.01km^2$)**	**<50m (<$0.01km^2$)**	**<50m (<$0.01km^2$)**	**<50m (<$0.01km^2$)**	**<50m (<$0.01km^2$)**	**<50m (<$0.01km^2$)**	**<50m (<$0.01km^2$)**	**<50m (<$0.01km^2$)**
BND	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
WBD	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005 % CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
MW	**<50m**	**<50m**	**<50m**	**<50m**	**<50m**	**<50m**	**<50m**	**<50m**

Species	DBA N		DBA SW		DBB NW		DBB SE	
	1,900kJ	3,000kJ	1,900kJ	3,000kJ	1,900kJ	3,000kJ	1,900kJ	3,000kJ
	(<0.01km²)	**(0.01km²)**	**(<0.01km²)**	**(<0.01km²)**	**(<0.01km²)**	**(<0.01km²)**	**(<0.01km²)**	**(<0.01km²)**
	0.0001 MW (0.0000005% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
Grey seal and harbour seal	**<50m (<0.01km²)**	**<50m (<0.01km²)**	**<50m (<0.01km²)**	**<50m (<0.01km²)**	**<50m (<0.01km²)**	**<50m (<0.01km²)**	**<50m (<0.01km²)**	**<50m (<0.01km²)**
GS (using DBA or DBB project specific density estimates)	0.00055 GS (0.000006% SE MU)	0.00055 GS (0.000006% SE MU)	0.00055 GS (0.000006% SE MU)	0.00055 GS (0.000006% SE MU)	0.002 GS (0.000023% SE MU)	0.002 GS (0.000023% SE MU)	0.002 GS (0.000023% SE MU)	0.002 GS (0.000023% SE MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
HS (using DBA or DBB project specific density estimates)	0.000003 HS (0.00000008% SE MU)	0.000003 HS (0.00000008% SE MU)	0.000003 HS (0.00000008% SE MU)	0.000003 HS (0.00000008% SE MU)	0.000098 HS (0.0000026% SE MU)	0.000098 HS (0.0000026% SE MU)	0.000098 HS (0.0000026% SE MU)	0.000098 HS (0.0000026% SE MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)

**based on unweighted SPL_{peak} for HP, BND, WBD, MW, GS & HS*

5.1.1.3 PTS from cumulative exposure for OSP pin-piles

As outlined in **Section 4.2.3**, PTS from cumulative exposure (SEL_{cum}) takes into account the soft start and ramp up of hammer energy along with the total duration and strike rate. As a worst-case, the installation of four pin-piles, sequentially, in the same 24-hour period has been assessed.

The updated underwater noise modelling results (**Appendix 2** of the Environmental Report) indicate there is no difference in the maximum cumulative PTS ranges and areas for the maximum hammer energy of 1,900kJ or 3,000kJ for OSP pin-piles at Dogger Bank A and B for bottlenose dolphin, white-beaked dolphin, grey seal and harbour seal, with a range of 100m for both hammer energies at all locations (**Table 13**).

There are slight, but not significant, differences in the maximum cumulative PTS ranges for harbour porpoise for the maximum hammer energy for OSP pin-piles, ranging from maximum of up to 600m for 1,900kJ and maximum of up to 650m for 3,000kJ (**Table 13**). The maximum number of harbour porpoise that could be impacted, without mitigation, is less than one, for all locations and all both maximum OSP pin-pile hammer energies (**Table 13**).

The maximum cumulative PTS impact range also varied with location for minke whale, however, the maximum was up to 900m for both 1,900kJ and 3,000kJ maximum hammer energy for OSP pin-piles (**Table 13**). Therefore, there is no difference in assessment as a result of increasing the maximum hammer energy from 1,900kJ to 3,000kJ.

There is no significant difference in the maximum number of marine mammals or percentage of the reference population that could be impacted (cumulative PTS) as a result of a maximum hammer energy of 1,900kJ or 3,000kJ for OSP pin-piles at Dogger Bank A and B (**Table 13**).

The impact significance for all marine mammal species for potential cumulative PTS is **minor (not significant)** (with a negligible magnitude for all hammer energies, locations, and species, and a high sensitivity; see **Annex A**) for the maximum hammer energies of 1,900kJ or 3,000kJ for OSP pin-piles (i.e. there is no difference with an increase in the maximum hammer energy; **Table 13**).

The MMMPs include marine mammal monitoring zone, the activation of ADDs, soft start and ramp-up to reduce the risk of PTS from the maximum hammer energy. The mitigation would be the same for OSP pin-pile with maximum hammer energy of either 1,900kJ or 3,000kJ.

Table 13: Maximum cumulative exposure PTS ranges and areas for maximum hammer energy of 1,900kJ (currently consented) or 3,000kJ for OSP pin-piles at Dogger Bank A&B and number of marine mammals (% of reference population) that could be impacted (without mitigation)

Species	DBA N		DBA SW		DBB NW		DBB SE	
	1,900kJ	3,000kJ	1,900kJ	3,000kJ	1,900kJ	3,000kJ	1,900kJ	3,000kJ
HP	**300m ($0.19km^2$)**	**300m ($0.21km^2$)**	**350m ($0.29km^2$)**	**350m ($0.25km^2$)**	**600m ($0.89km^2$)**	**650m ($0.98km^2$)**	**400m ($0.4km^2$)**	**400m ($0.38km^2$)**
	0.17 HP (0.00005% NS MU)	0.19 HP (0.000054% NS MU)	0.26 HP (0.000075% NS MU)	0.22 HP (0.000064% NS MU)	0.79 HP (0.00023% NS MU)	0.87 HP (0.00025% NS MU)	0.36 HP (0.0001% NS MU)	0.34 HP (0.0001% NS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
Dolphin species	**<100m (<$0.1km^2$)**	**<100m (<$0.1km^2$)**	**<100m (<$0.1km^2$)**	**<100m (<$0.1km^2$)**	**<100m (<$0.1km^2$)**	**<100m (<$0.1km^2$)**	**<100m (<$0.1km^2$)**	**<100m (<$0.1km^2$)**
BND	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
WBD	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
MW	**<100m (<$0.1km^2$)**	**<100m (<$0.1km^2$)**	**110m (<$0.1km^2$)**	**230m ($0.05km^2$)**	**900m ($1.6km^2$)**	**900m ($1.7km^2$)**	**350m ($0.17km^2$)**	**330m ($0.15km^2$)**

Species	DBA N		DBA SW		DBB NW		DBB SE	
	1,900kJ	3,000kJ	1,900kJ	3,000kJ	1,900kJ	3,000kJ	1,900kJ	3,000kJ
	0.001 MW (0.000005% CGNS MU)	0.001 MW (0.000005% CGNS MU)	0.001 MW (0.000005% CGNS MU)	0.0005 MW (0.0000025% CGNS MU)	0.016 MW (0.00008% CGNS MU)	0.017 MW (0.000085% CGNS MU)	0.0017 MW (0.0000085% CGNS MU)	0.0015 MW (0.0000075% CGNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
Grey seal and harbour seal	**<100m (<0.1km²)**	**<100m (<0.1km²)**	**<100m (<0.1km²)**	**<100m (<0.1km²)**	**<100m (<0.1km²)**	**<100m (<0.1km²)**	**<100m (<0.1km²)**	**<100m (<0.1km²)**
GS (using DBA or DBB project specific density estimates)	0.0055 GS (0.00006% SE MU)	0.0055 GS (0.00006% SE MU)	0.0055 GS (0.00006% SE MU)	0.0055 GS (0.00006% SE MU)	0.02 GS (0.00023% SE MU)	0.02 GS (0.00023% SE MU)	0.02 GS (0.00023% SE MU)	0.02 GS (0.00023% SE MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
HS (using DBA or DBB project specific density estimates)	0.00003 HS (0.0000008% SE MU)	0.00003 HS (0.0000008% SE MU)	0.00003 HS (0.0000008% SE MU)	0.00003 HS (0.0000008% SE MU)	0.00098 HS (0.000026% SE MU)	0.00098 HS (0.000026% SE MU)	0.00098 HS (0.000026% SE MU)	0.00098 HS (0.000026% SE MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)

5.1.1.4 TTS from single strike of maximum hammer energy for OSP pin-piles

The updated underwater noise modelling results (**Appendix 2** of the Environmental Report) indicate there are no major differences in the maximum TTS ranges for single strike of the maximum hammer energy for OSP pin-piles of 1,900kJ or 3,000kJ at Dogger Bank A and B for bottlenose dolphin (0m difference), white-beaked dolphin (0m difference), minke whale (10m difference), grey seal and harbour seal (10-20m difference) (**Table 14**).

There are differences in the maximum TTS ranges for harbour porpoise for single strike of the maximum hammer energy for OSP pin-piles, ranging from maximum of up to 860m for 1,900kJ or up to 1km for 3,000kJ; a difference of 140m, respectively (**Table 14**). However, these differences in maximum impact ranges and areas do not result in any significant difference to the number of harbour porpoise or percentage of the reference population that could be temporary impacted (**Table 14**).

There is no significant difference in the maximum number of marine mammals or percentage of the reference population that could be temporarily impacted as a result of a maximum hammer energy of 1,900kJ or 3,000kJ for OSP pin-piles at Dogger Bank A and B (**Table 14**).

The impact significance for all marine mammal species for potential TTS from single strike of the maximum hammer energies of 1,900kJ or 3,000kJ for OSP pin-piles is minor (not significant) (negligible magnitude for all species, locations, and hammer energies, and a medium sensitivity; see **Annex A**) (i.e. there is no difference with an increase in the maximum hammer energy; **Table 14**).

The MMMPs to reduce the risk of PTS would also reduce the risk of TTS. The mitigation would be the same for OSP pin-pile maximum hammer energy of 1,900kJ or 3,000kJ.

Table 14: Maximum TTS ranges and areas for single strike of the maximum hammer energy of 1,900kJ (currently consented) and 2,400kJ for OSP pin-piles at Dogger Bank A&B and number of marine mammals (% of reference population) that could be impacted (without mitigation)*

Species	DBA N		DBA SW		DBB NW		DBB SE	
	1,900kJ	3,000kJ	1,900kJ	3,000kJ	1,900kJ	3,000kJ	1,900kJ	3,000kJ
HP	**740m (1.7km^2)**	**870m (2.3km^2)**	**810m (2km^2)**	**950m (2.7km^2)**	**860m (2.3km^2)**	**1km (3.1km^2)**	**820m (2.1km^2)**	**960m (2.8km^2)**
	1.5 HP (0.0004% NS MU)	2.04 HP (0.0006% NS MU)	1.78 HP (0.0005% NS MU)	2.4 HP (0.0007% NS MU)	2.04 HP (0.00059% NS MU)	2.75 HP (0.0008% NS MU)	1.86 HP (0.0005% NS MU)	2.49 HP (0.00072% NS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
Dolphin species	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**
BND	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
WBD	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
MW	**60m (<0.01km^2)**	**70m (0.02km^2)**	**70m (<0.01km^2)**	**80m (0.02km^2)**	**70m (<0.01km^2)**	**80m (0.02km^2)**	**70m (<0.01km^2)**	**80m (0.02km^2)**

Species	DBA N		DBA SW		DBB NW		DBB SE	
	1,900kJ	3,000kJ	1,900kJ	3,000kJ	1,900kJ	3,000kJ	1,900kJ	3,000kJ
	0.0001 MW (0.0000005% CGNS MU)	0.0002 MW (0.000001% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)	0.0002 MW (0.000001% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)	0.0002 MW (0.000001% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)	0.0002 MW (0.000001% CGNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
Grey seal and harbour seal	**70m ($0.02km^2$)**	**90m ($0.02km^2$)**	**80m ($0.02km^2$)**	**90m ($0.03km^2$)**	**80m ($0.02km^2$)**	**90m ($0.03km^2$)**	**80m ($0.02km^2$)**	**90m ($0.03km^2$)**
GS (using DBA or DBB project specific density estimates)	0.0011 GS (0.000013% SE MU)	0.0011 GS (0.000013% SE MU)	0.0011 GS (0.000013% SE MU)	0.0017 GS (0.00002% SE MU)	0.004 GS (0.00005% SE MU)	0.006 GS (0.00007% SE MU)	0.004 GS (0.00005% SE MU)	0.006 GS (0.00007% SE MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
HS (using DBA or DBB project specific density estimates)	0.000006 HS (0.00000016% SE MU)	0.000006 HS (0.00000016% SE MU)	0.000006 HS (0.00000016% SE MU)	0.000009 HS (0.00000024% SE MU)	0.0002 HS (0.000005% SE MU)	0.0003 HS (0.000008% SE MU)	0.0002 HS (0.000005% SE MU)	0.0003 HS (0.000008% SE MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)

**based on unweighted SPL_{peak} for HP, BND, WBD, MW, GS & HS*

5.1.1.5 TTS from cumulative exposure for OSP pin-piles

As outlined in **Section 4.2.3**, TTS from cumulative exposure (SEL_{cum}) takes into account the soft start and ramp up of hammer energy along with the total duration and strike rate. As a worst-case, the installation of four pin-piles, sequentially, in the same 24-hour period has been assessed.

The updated underwater noise modelling results (**Appendix 2** of the Environmental Report) indicate there is no differences in the maximum cumulative TTS ranges and areas for the maximum hammer energy of 1,900kJ or 3,000kJ for OSP pin-piles at Dogger Bank A and B for bottlenose dolphin and white-beaked dolphin, with a range of 100m. For minke whale there are difference between locations, but no difference in increasing the maximum hammer energy from 1,900kJ to 3,000kJ at the same location, with a maximum impact range of 8.3km for Dogger Bank A and 17km for Dogger Bank B. For grey and harbour seal, there is no difference in increasing the maximum hammer energy at the Dogger Bank A locations, and only slight difference at the Dogger Bank B locations (0.1km) (**Table 15**).

There are differences in the maximum cumulative TTS ranges for harbour porpoise for the maximum hammer energy for OSP pin-piles, ranging from a maximum of up to 12km for 1,900kJ and maximum of up to 13km for 3,000kJ (**Table 15**). However, these differences in maximum impact ranges and areas do not result in any significant difference to the maximum number of harbour porpoise or percentage of the reference population that could be temporary impacted (**Table 15**).

There is no significant difference in the maximum number of marine mammals or percentage of the reference population that could be impacted as a result of a maximum hammer energy of 1,900kJ or 3,000kJ for OSP pin-piles at Dogger Bank A and B (**Table 15**).

The impact significance for all marine mammal species for potential cumulative TTS from maximum hammer energies of 1,900kJ or 3,000kJ for OSP pin-piles is **minor (not significant)** (negligible magnitude for all species, locations, and hammer energies, and a medium sensitivity; see **Annex A**) (i.e. there is no difference with an increase in the maximum hammer energy; **Table 15**).

The MMMPs to reduce the risk of PTS would also reduce the risk of TTS. The mitigation would be the same for OSP pin-pile maximum hammer energy of 1,900kJ or 3,000kJ.

Table 15: Maximum cumulative exposure TTS ranges and areas for maximum hammer energy of 1,900kJ (currently consented) or 3,000kJ for OSP pin-piles at Dogger Bank A&B and number of marine mammals (% of reference population) that could be impacted (without mitigation)

Species	DBA N		DBA SW		DBB NW		DBB SE	
	1,900kJ	3,000kJ	1,900kJ	3,000kJ	1,900kJ	3,000kJ	1,900kJ	3,000kJ
HP	**7.4km ($130km^2$)**	**7.6km ($140km^2$)**	**6.9km ($120km^2$)**	**6.9km ($120km^2$)**	**12km ($310km^2$)**	**13km ($340km^2$)**	**8.3km ($160km^2$)**	**8.5km ($160km^2$)**
	115 HP (0.033% NS MU)	124 HP (0.036% NS MU)	107 HP (0.031% NS MU)	107 HP (0.031% NS MU)	275 HP (0.079% NS MU)	302 HP (0.087% NS MU)	142 HP (0.041% NS MU)	142 HP (0.041% NS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
Dolphin species	**<100m (<$0.1km^2$)**	**<100m (<$0.1km^2$)**	**<100m (<$0.1km^2$)**	**<100m (<$0.1km^2$)**	**<100m (<$0.1km^2$)**	**<100m (<$0.1km^2$)**	**<100m (<$0.1km^2$)**	**<100m (<$0.1km^2$)**
BND	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
WBD	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
MW	**8.3km ($150km^2$)**	**8.3km ($150km^2$)**	**7.7km ($140km^2$)**	**7.7km ($140km^2$)**	**17km ($520km^2$)**	**17km ($530km^2$)**	**9.9km ($200km^2$)**	**9.9km ($200km^2$)**

Species	DBA N		DBA SW		DBB NW		DBB SE	
	1,900kJ	3,000kJ	1,900kJ	3,000kJ	1,900kJ	3,000kJ	1,900kJ	3,000kJ
	1.5 MW (0.0075% CGNS MU)	1.5 MW (0.0075% CGNS MU)	1.4 MW (0.007% CGNS MU)	1.4 MW (0.007% CGNS MU)	5.2 MW (0.026% CGNS MU)	5.3 MW (0.026% CGNS MU)	2 MW (0.01% CGNS MU)	2 MW (0.01% CGNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
Grey seal and harbour seal	**1.7km ($6.6km^2$)**	**1.7km ($6.8km^2$)**	**1.9km ($7.7km^2$)**	**1.9km ($7.6km^2$)**	**3km ($22km^2$)**	**3.1km ($23km^2$)**	**2.1km ($11km^2$)**	**2.1km ($11km^2$)**
GS (using DBA or DBB project specific density estimates)	0.36 GS (0.0042% SE MU)	0.37 GS (0.0043% SE MU)	0.42 GS (0.005% SE MU)	0.42 GS (0.005% SE MU)	4.4 GS (0.05% SE MU)	4.6 GS (0.05% SE MU)	2.2 GS (0.025% SE MU)	2.2 GS (0.025% SE MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
HS (using DBA or DBB project specific density estimates)	0.002 HS (0.00005% SE MU)	0.002 HS (0.00005% SE MU)	0.0023 HS (0.00006% SE MU)	0.0023 HS (0.00006% SE MU)	0.22 HS (0.006% SE MU)	0.23 HS (0.006% SE MU)	0.11 HS (0.003% SE MU)	0.11 HS (0.003% SE MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)

5.1.1.6 Possible avoidance / behavioural reaction in harbour porpoise

The maximum impact range and area for the possible avoidance / behavioural reaction in harbour porpoise varies with location, however the difference for a maximum OSP pin-pile hammer energy of 1,900kJ or 3,000kJ are relatively small (1-2km), with a maximum range of 26km at Dogger Bank B (**Table 16**).

There is no significant difference in the percentage of the harbour porpoise reference population that could temporarily have possible avoidance / behavioural reaction as a result of a maximum hammer energy of 1,900kJ or 3,000kJ for OSP pin-piles at Dogger Bank A and B, with less than 0.4% of the population for all locations (**Table 16**).

The impact significance for harbour porpoise for possible avoidance / behavioural reaction from maximum hammer energies of 1,900kJ or 3,000kJ for OSP pin-piles is negligible (negligible magnitude (less than 1% of the reference population anticipated to be exposed to impact) and low sensitivity; see **Annex A**) (i.e. there is no difference with an increase in the maximum hammer energy; **Table 16**).

It is important to note that not all harbour porpoise would be disturbed in the maximum area for possible avoidance / behavioural reaction.

Table 16: Maximum possible avoidance / behavioural response in harbour porpoise ranges and areas for single strike of the maximum hammer energy of 1,900kJ (currently consented) or 3,000kJ for OSP pin-piles at Dogger Bank A&B and number of animals (% of reference population) that could be impacted

Species	DBA N		DBA SW		DBB NW		DBB SE	
	1,900kJ	3,000kJ	1,900kJ	3,000kJ	1,900kJ	3,000kJ	1,900kJ	3,000kJ
HP	**16km (630km^2)**	**17km (710km^2)**	**15km (580km^2)**	**16km (660km^2)**	**25km (1,400km^2)**	**26km (1,500km^2)**	**17km (740km^2)**	**19km (830km^2)**
	559 HP (0.16% NS MU)	630 HP (0.18% NS MU)	515 HP (0.15% NS MU)	586 HP (0.17% NS MU)	1,243 HP (0.36% NS MU)	1,332 HP (0.38% NS MU)	657 HP (0.19% NS MU)	737 HP (0.2% NS MU)
	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible

5.1.2 WTG monopiles increased hammer energy

5.1.2.1 PTS from first strike of soft-start for WTG monopiles

The updated underwater noise modelling results (**Appendix 2** of the Environmental Report) indicate there is no significant difference in the maximum PTS ranges and areas for single strike of the starting hammer energy for WTG monopiles at Dogger Bank A and B. With maximum impact ranges of up to 90m and 130m for harbour porpoise and 50m and 80m for minke whale for the starting hammer energy of 300kJ for maximum hammer energy of 3,000kJ or starting hammer energy of 400kJ for maximum hammer energy of 4,000kJ, respectively (**Table 17**). For dolphin and seal species, PTS ranges are less than 50m for all locations, and for both 300kJ and 400kJ starting hammer energies.

There is also no significant difference in the maximum number of marine mammals or percentage of the reference population that could be impacted (PTS) as a result of a starting hammer energy of 300kJ or 400kJ for WTG monopiles at Dogger Bank A and B (**Table 17**).

The impact significance for all marine mammal species for potential PTS from first strike of the soft-start, 300kJ or 400kJ for WTG monopiles is **minor (not significant)** (**Table 17**). The assessment indicates that the magnitude is negligible with less than 0.001% of the reference population anticipated to be exposed to permanent effect and all marine mammals have high sensitivity to PTS; see **Annex A**.

The MMMP includes the activation of ADDs prior to the soft start to reduce the risk of instantaneous PTS from the first strike of the starting hammer energy. The duration of the ADD activation would be the same for starting hammer energy of 300kJ and 400kJ.

5.1.2.2 PTS from single strike of maximum hammer energy for WTG monopiles

The updated underwater noise modelling results (**Appendix 2** of the Environmental Report) indicate there is no difference in the maximum PTS ranges and areas for single strike of the maximum hammer energy for WTG monopiles of 3,000kJ or 4,000kJ at Dogger Bank A and B for bottlenose dolphin, white-beaked dolphin, minke whale, grey seal and harbour seal, with PTS ranges of less than 50m for both hammer energies, at all locations (**Table 18**).

There are slight, but not significant differences in the maximum PTS ranges for harbour porpoise for single strike of the maximum hammer energy for WTG monopiles, ranging from maximum of up to 480m for 3,000kJ and up to 520m for 4,000kJ (**Table 18**). However, the maximum number of harbour porpoise that could be impacted, without mitigation, is less than one, for all locations and both maximum WTG monopile hammer energies (**Table 18**).

There is no significant difference in the maximum number of marine mammals or percentage of the reference population that could be impacted (PTS) as a result of a maximum hammer energy of 3,000kJ or 4,000kJ for WTG monopiles at Dogger Bank A and B (**Table 18**).

The impact significance for all marine mammal species for potential PTS from single strike of the maximum hammer energies of 3,000kJ or 4,000kJ for WTG monopiles is **minor (not significant)**. The assessment indicates that the magnitude is negligible with less than 0.001% of the reference population anticipated to be exposed to permanent effect and all marine mammals have high sensitivity to PTS; see **Annex A** (**Table 18**).

The MMMP includes marine mammal monitoring zone, the activation of ADDs, soft start and ramp-up to reduce the risk of PTS from the maximum hammer energy. The mitigation would be the same for both WTG monopiles consented and proposed hammer energies.

5.1.2.3 PTS from cumulative exposure for WTG monopiles

As outlined in **Section 4.2.3**, PTS from cumulative exposure (SEL_{cum}) takes into account the soft start and ramp up of hammer energy along with the total duration and strike rate. As a worst-case, the installation of two monopiles, sequentially, in the same 24-hour period has been assessed.

The updated underwater noise modelling results (**Appendix 2** of the Environmental Report) indicate there is no difference in the maximum cumulative PTS ranges and areas for the maximum hammer energy of 3,000kJ or 4,000kJ for WTG monopiles at Dogger Bank A and B for bottlenose dolphin, white-beaked dolphin, grey seal and harbour seal, with a PTS range of less than 100m (**Table 19**).

There are slight differences in the maximum cumulative PTS ranges for harbour porpoise at different locations, with PTS ranges of between 1.3km and 2.3km. There is no difference in the maximum impact ranges for 3,000kJ or 4,000kJ at the same location, with the exception of Dogger Bank B (NW location), with a range of 2.2km for 3,000kJ and 2.3km for 4,000kJ (**Table 19**).

There are differences in the maximum cumulative PTS ranges for minke whale between all locations (**Table 19**), due to the variations in the bathymetry within range of these locations. For a hammer energy of 3,000kJ, the maximum impact range is 4.0km, and for 4,000kJ, the maximum range is 4.1km (both at Dogger Bank B NW location). There is a maximum difference of 2.6km between hammer energies at Dogger Bank A (SW location). However, less than 0.4 minke whale would be at risk of PTS at all locations and hammer energies.

The impact significance for bottlenose dolphin, white beaked dolphin, grey seal and harbour seal for potential cumulative PTS is **minor (not significant)** for the maximum hammer energies of 3,000kJ or 4,000kJ for WTG monopiles (**Table 19**). The assessment indicates that the magnitude is negligible with less than 0.001% of the reference population anticipated to be exposed to permanent effect and all marine mammals have high sensitivity to PTS; see **Annex A**.

The PTS cumulative impact significance for harbour porpoise is **moderate (without mitigation)** at all locations for WTG monopiles with maximum hammer energies of 3,000kJ or 4,000kJ (i.e. there is no difference with an increase in the maximum hammer energy; **Table 19**). The assessment indicates that the magnitude is low with between 0.001% and 0.01% of the reference population anticipated to be exposed to permanent effect and all marine mammals have high sensitivity to PTS; see **Annex A**.

The PTS cumulative impact significance for minke whale is **minor to moderate (without mitigation)** for maximum hammer energies of 3,000kJ or 4,000kJ, depending on location (i.e. there is no difference with an increase in the maximum hammer energy; **Table 19**).

The MMMP includes marine mammal monitoring zone, the activation of ADDs, soft start and ramp-up to reduce the risk of PTS. The mitigation would be the same for both WTG monopiles consented and proposed hammer energies.

Table 17: Maximum PTS* ranges and areas for single strike of the starting hammer energy of 300kJ (for the currently consented hammer energy of 3,000kJ) or 400kJ (for a hammer energy of 4,000kJ) for WTG monopiles at Dogger Bank A&B and number of marine mammals (% of reference population) that could be impacted (without mitigation)

Species	DBA N		DBA SW		DBB NW		DBB SE	
	300kJ	400kJ	300kJ	400kJ	300kJ	400kJ	300kJ	400kJ
HP	**90m (0.02km²)**	**120m (0.04km²)**	**90m (0.03km²)**	**130m (0.05km²)**	**90m (0.03km²)**	**130m (0.05km²)**	**90m (0.02km²)**	**130m (0.05km²)**
	0.018 HP (0.000005% NS MU)	0.036 HP (0.00001 % NS MU)	0.027 HP (0.0000078 % NS MU)	0.044 HP (0.00001% NS MU)	0.027 HP (0.0000078 % NS MU)	0.044 HP (0.00001% NS MU)	0.018 HP (0.000005% NS MU)	0.044 HP (0.00001% NS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
Dolphin species	**<50m (<0.01km²)**	**<50m (<0.01km²)**	**<50m (<0.01km²)**	**<50m (<0.01km²)**	**<50m (<0.01km²)**	**<50m (<0.01km²)**	**<50m (<0.01km²)**	**<50m (<0.01km²)**
BND	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
WBD	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
MW	**50m**	**70m**	**60m**	**80m**	**60m**	**80m**	**50m**	**80m**

Species	DBA N		DBA SW		DBB NW		DBB SE	
	300kJ	400kJ	300kJ	400kJ	300kJ	400kJ	300kJ	400kJ
	(0.01km^2)	**(0.02km^2)**	**(0.01km^2)**	**(0.02km^2)**	**(0.01km^2)**	**(0.02km^2)**	**(0.01km^2)**	**(0.02km^2)**
	0.0001 MW (0.0000005% CGNS MU)	0.0002 MW (0.000001% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)	0.0002 MW (0.000001% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)	0.0002 MW (0.000001% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)	0.0002 MW (0.000001% CGNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
Grey seal and harbour seal	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**
GS (using DBA or DBB project specific density estimates)	0.00055 GS (0.000006% SE MU)	0.00055 GS (0.000006% SE MU)	0.00055 GS (0.000006% SE MU)	0.00055 GS (0.000006% SE MU)	0.002 GS (0.000023% SE MU)	0.002 GS (0.000023% SE MU)	0.002 GS (0.000023% SE MU)	0.002 GS (0.000023% SE MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
HS (using DBA or DBB project specific density estimates)	0.000003 HS (0.00000008% SE MU)	0.000003 HS (0.00000008% SE MU)	0.000003 HS (0.00000008% SE MU)	0.000003 HS (0.00000008% SE MU)	0.000098 HS (0.0000026% SE MU)	0.000098 HS (0.0000026% SE MU)	0.000098 HS (0.0000026% SE MU)	0.000098 HS (0.0000026% SE MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)

based on unweighted SPL_{peak} for HP, BND, WBD, GS & HS and weighted SEL_{ss} for MW

Table 18: Maximum PTS* ranges and areas for single strike of the maximum hammer energy of 3,000kJ or 4,000kJ for WTG monopiles at Dogger Bank A&B and number of marine mammals (% of reference population) that could be impacted (without mitigation)

Species	DBA N		DBA SW		DBB NW		DBB SE	
	3,000kJ	4,000kJ	3,000kJ	4,000kJ	3,000kJ	4,000kJ	3,000kJ	4,000kJ
HP	**430m ($0.57km^2$)**	**460m ($0.66km^2$)**	**460m ($0.66km^2$)**	**500m ($0.8km^2$)**	**480m ($0.71km^2$)**	**520m ($0.83km^2$)**	**460m ($0.67km^2$)**	**500m ($0.78km^2$)**
	0.51 HP (0.00015% NS MU)	0.59 HP (0.00017% NS MU)	0.59 HP (0.00017% NS MU)	0.71 HP (0.0002% NS MU)	0.63 HP (0.00018% NS MU)	0.74 HP (0.00021% NS MU)	0.59 HP (0.00017% NS MU)	0.69 HP (0.0002% NS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
Dolphin species	**<50m (<$0.01km^2$)**	**<50m (<$0.01km^2$)**	**<50m (<$0.01km^2$)**	**<50m (<$0.01km^2$)**	**<50m (<$0.01km^2$)**	**<50m (<$0.01km^2$)**	**<50m (<$0.01km^2$)**	**<50m (<$0.01km^2$)**
BND	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
WBD	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)

Species	DBA N		DBA SW		DBB NW		DBB SE	
	3,000kJ	4,000kJ	3,000kJ	4,000kJ	3,000kJ	4,000kJ	3,000kJ	4,000kJ
MW	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**
	0.0001 MW (0.0000005% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)	0.0001 MW (0.0000005% CGNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
Grey seal and harbour seal	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**	**<50m (<0.01km^2)**
GS (using DBA or DBB project specific density estimates)	0.00055 GS (0.000006% SE MU)	0.00055 GS (0.000006% SE MU)	0.00055 GS (0.000006% SE MU)	0.00055 GS (0.000006% SE MU)	0.002 GS (0.000023% SE MU)	0.002 GS (0.000023% SE MU)	0.002 GS (0.000023% SE MU)	0.002 GS (0.000023% SE MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
HS (using DBA or DBB project specific density estimates)	0.000003 HS (0.00000008% SE MU)	0.000003 HS (0.00000008% SE MU)	0.000003 HS (0.00000008% SE MU)	0.000003 HS (0.00000008% SE MU)	0.000098 HS (0.0000026% SE MU)	0.000098 HS (0.0000026% SE MU)	0.000098 HS (0.0000026% SE MU)	0.000098 HS (0.0000026% SE MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)

**based on unweighted* SPL_{peak} *for HP, BND, WBD, MW, GS & HS*

Table 19: Maximum cumulative exposure PTS ranges and areas for maximum hammer energy of 3,000kJ (currently consented) or 4,000kJ for WTG monopiles at Dogger Bank A&B and number of marine mammals (% of reference population) that could be impacted (without mitigation)

Species	DBA N		DBA SW		DBB NW		DBB SE	
	3,000kJ	4,000kJ	3,000kJ	4,000kJ	3,000kJ	4,000kJ	3,000kJ	4,000kJ
HP	**1.3km (3.8km^2)**	**1.3km (4km^2)**	**1.4km (3.9km^2)**	**1.4km (4km^2)**	**2.2km (13km^2)**	**2.3km (13km^2)**	**1.6km (5.8km^2)**	**1.6km (5.8km^2)**
	3.4 HP (0.001% NS MU)	3.55 HP (0.001% NS MU)	3.5 HP (0.001% NS MU)	3.55 HP (0.001% NS MU)	11.5 HP (0.003% NS MU)	11.5 HP (0.003% NS MU)	5.15 HP (0.0015% NS MU)	5.15 HP (0.0015% NS MU)
	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Dolphin species	**<100m (<0.1km^2)**	**<100m (<0.1km^2)**	**<100m (<0.1km^2)**	**<100m (<0.1km^2)**	**<100m (<0.1km^2)**	**<100m (<0.1km^2)**	**<100m (<0.1km^2)**	**<100m (<0.1km^2)**
BND	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
WBD	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
MW	**1.4km (3.5km^2)**	**1.5km (4km^2)**	**1.6km (3.7km^2)**	**4.2km (34km^2)**	**4.0km (32km^2)**	**4.1km (33km^2)**	**410m (0.31km^2)**	**2.2km (8.7km^2)**

Species	DBA N		DBA SW		DBB NW		DBB SE	
	3,000kJ	4,000kJ	3,000kJ	4,000kJ	3,000kJ	4,000kJ	3,000kJ	4,000kJ
	0.035 MW (0.00017% CGNS MU)	0.04 MW (0.0002% CGNS MU)	0.037 MW (0.00018% CGNS MU)	0.34 MW (0.0017% CGNS MU)	0.32 MW (0.0016% CGNS MU)	0.33 MW (0.0016% CGNS MU)	0.0031 MW (0.000015% CGNS MU)	0.087 MW (0.000435% CGNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Moderate	Moderate	Moderate	Minor (not significant)	Minor (not significant)
Grey seal and harbour seal	**<100m (<0.1km²)**	**<100m (<0.1km²)**	**<100m (<0.1km²)**	**<100m (<0.1km²)**	**<100m (<0.1km²)**	**<100m (<0.1km²)**	**<100m (<0.1km²)**	**<100m (<0.1km²)**
GS (using DBA or DBB project specific density estimates)	0.0055 GS (0.00006% SE MU)	0.0055 GS (0.00006% SE MU)	0.0055 GS (0.00006% SE MU)	0.0055 GS (0.00006% SE MU)	0.02 GS (0.00023% SE MU)	0.02 GS (0.00023% SE MU)	0.02 GS (0.00023% SE MU)	0.02 GS (0.00023% SE MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
HS (using DBA or DBB project specific density estimates)	0.00003 HS (0.0000008% SE MU)	0.00003 HS (0.0000008% SE MU)	0.00003 HS (0.0000008% SE MU)	0.00003 HS (0.0000008% SE MU)	0.00098 HS (0.000026% SE MU)	0.00098 HS (0.000026% SE MU)	0.00098 HS (0.000026% SE MU)	0.00098 HS (0.000026% SE MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)

5.1.2.4 TTS from single strike of maximum hammer energy for WTG monopiles

The updated underwater noise modelling results (**Appendix 2** of the Environmental Report) indicate that there are no major differences in the maximum TTS ranges and areas for single strike of the maximum hammer energy for WTG monopiles of 3,000kJ or 4,000kJ at Dogger Bank A and B for bottlenose dolphin (0m), white-beaked dolphin (0m), minke whale (10m), grey seal and harbour seal (10m) (**Table 20**).

There are some differences in the maximum TTS ranges for harbour porpoise for single strike of the maximum hammer energy for WTG monopiles, ranging from a maximum of up to 1.1km for 3,000kJ and up to 1.2km for 4,000kJ (**Table 20**). However, these differences in maximum impact ranges and areas do not result in any significant difference to the number of harbour porpoise or percentage of the reference population that could be temporarily impacted (**Table 20**).

There is no significant difference in the maximum number of marine mammals or percentage of the reference population that could be temporarily impacted as a result of a maximum hammer energy of 3,000kJ or 4,000kJ for WTG monopiles at Dogger Bank A and B (**Table 20**).

The impact significance for all marine mammal species for potential TTS from single strike of the maximum hammer energies of 3,000kJ or 4,000kJ for WTG monopiles is minor (not significant). The assessment indicates that the magnitude is negligible with less than 1% of the reference population anticipated to be exposed to temporary effect and all marine mammals have medium sensitivity to TTS; see **Annex A**) (i.e. there is no difference with an increase in the maximum hammer energy; **Table 20**).

The MMMP to reduce the risk of PTS would also reduce the risk of TTS. The mitigation would be the same for both WTG monopiles consented and proposed hammer energies.

5.1.2.5 TTS from cumulative exposure for WTG monopiles

As outlined in **Section 4.2.3**, TTS from cumulative exposure (SEL_{cum}) takes into account the soft start and ramp up of hammer energy along with the total duration and strike rate. As a worst-case, the installation of two monopiles, sequentially, in the same 24-hour period has been assessed.

The updated underwater noise modelling results (**Appendix 2** of the Environmental Report) indicate there is no difference in the maximum cumulative PTS ranges and areas for the maximum hammer energy of 3,000kJ or 4,000kJ for WTG monopiles at Dogger Bank A and B for bottlenose dolphin and white-beaked dolphin, with ranges of less than 100m. For grey seal and harbour seal there are only slight differences in the impact range and area, depending on location, however, these differences are not significant for increasing the maximum hammer energy from 3,000kJ to 4,000kJ (with a maximum increase of 100m at Dogger Bank A) (**Table 21**).

For minke whale there are no differences in the cumulative TTS impact range or area for maximum hammer energy of 3,000kJ or 4,000kJ at Dogger Bank A N or Dogger Bank B NW locations. Although there are differences at the Dogger Bank A SW location (increase of 11km) and Dogger Bank B SE location (increase of 4.4km), with the increased hammer energy (**Table 21**). However, the maximum cumulative TTS impact range is the same, 28km for 3,000kJ and 4,000kJ at the Dogger Bank B NW location. Less than 0.06% of the reference population could be temporarily impacted, at any location and for either hammer energy (**Table 21**).

For harbour porpoise there are differences between locations, but no difference in the cumulative TTS impact range for increasing the maximum hammer energy from 3,000kJ to 4,000kJ at the same location, with a maximum TTS range of 20km at Dogger Bank B (NW location) (**Table 21**).

There is no significant difference in the maximum number of marine mammals or percentage of the reference population that could impacted as a result of a maximum hammer energy of 3,000kJ or 4,000kJ for WTG monopiles at Dogger Bank A and B (**Table 21**).

The impact significance for all marine mammal species for potential cumulative TTS from maximum hammer energies of 3,000kJ or 4,000kJ for WTG monopiles is **minor (not significant)** (negligible magnitude and medium sensitivity; see **Annex A**) (i.e. there is no difference with an increase in the maximum hammer energy; **Table 21**).

The MMMPs to reduce the risk of PTS would also reduce the risk of TTS. The mitigation would be the same for both WTG monopiles consented and proposed hammer energies.

5.1.2.6 Possible avoidance / behavioural reaction in harbour porpoise

The maximum impact range and area for the possible avoidance / behavioural reaction in harbour porpoise varies with location, however the differences for a maximum WTG monopile hammer energy of 3,000kJ or 4,000kJ are relatively small (1km) (**Table 22**).

There is no significant difference in the percentage of the harbour porpoise reference population that could temporarily have possible avoidance / behavioural reaction as a result of a maximum hammer energy of 3,000kJ or 4,000kJ for WTG monopiles at Dogger Bank A and B (**Table 22**).

The impact significance for harbour porpoise for possible avoidance / behavioural reaction from maximum hammer energies of 3,000kJ or 4,000kJ for WTG monopiles is **negligible** (negligible magnitude (less than 1% of the reference population anticipated to be exposed to impact) and low sensitivity; see **Annex A**) (i.e. there is no difference with an increase in the maximum hammer energy; **Table 22**).

It is important to note that not all harbour porpoise would be disturbed in the maximum area for possible avoidance / behavioural reaction.

It is also important to note that these are maximum impact ranges, based on worst-case scenarios. There is also variation between locations and in the maximum, minimum and mean ranges at the same location for the same hammer energy. For example, at Dogger Bank A SW for 4,000kJ the maximum, minimum and mean ranges were 18km, 13km and 16km, respectively and at Dogger Bank B NW for 4,000kJ the maximum, minimum and mean ranges were 30km, 18km and 24km, respectively.

Table 20: Maximum TTS* ranges and areas for single strike of the maximum hammer energy of 3,000kJ (currently consented) or 4,000kJ for WTG monopiles at Dogger Bank A&B and number of marine mammals (% of reference population) that could be impacted (without mitigation)

Species	DBA N		DBA SW		DBB NW		DBB SE	
	3,000kJ	4,000kJ	3,000kJ	4,000kJ	3,000kJ	4,000kJ	3,000kJ	4,000kJ
HP	**980m ($3km^2$)**	**1.1km ($3.4km^2$)**	**1.1km ($3.4km^2$)**	**1.1km ($4km^2$)**	**1.1km ($3.9km^2$)**	**1.2km ($4.5km^2$)**	**1.1km ($3.6km^2$)**	**1.2km ($4.1km^2$)**
	2.7 HP (0.0008% NS MU)	3.0 HP (0.0009% NS MU)	3.0 HP (0.0009% NS MU)	3.6 HP (0.001% NS MU)	3.5 HP (0.001% NS MU)	4 HP (0.001% NS MU)	3.2 HP (0.0009% NS MU)	3.6 HP (0.001% NS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
Dolphin species	**<50m (<$0.01km^2$)**	**<50m (<$0.01km^2$)**	**<50m (<$0.01km^2$)**	**<50m (<$0.01km^2$)**	**<50m (<$0.01km^2$)**	**<50m (<$0.01km^2$)**	**<50m (<$0.01km^2$)**	**<50m (<$0.01km^2$)**
BND	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)	0.0003 BND (0.000015% GNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
WBD	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)	0.00002 WBD (0.00000005% CGNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
MW	**90m ($0.02km^2$)**	**90m ($0.03km^2$)**	**90m ($0.02km^2$)**	**100m ($0.03km^2$)**	**90m ($0.03km^2$)**	**100m ($0.03km^2$)**	**90m ($0.03km^2$)**	**100m ($0.03km^2$)**

Species	DBA N		DBA SW		DBB NW		DBB SE	
	3,000kJ	4,000kJ	3,000kJ	4,000kJ	3,000kJ	4,000kJ	3,000kJ	4,000kJ
	0.0002 MW (0.000001% CGNS MU)	0.0003 MW (0.0000015% CGNS MU)	0.0002 MW (0.000001% CGNS MU)	0.0003 MW (0.0000015% CGNS MU)	0.0003 MW (0.0000015% CGNS MU)	0.0003 MW (0.0000015% CGNS MU)	0.0003 MW (0.0000015% CGNS MU)	0.0003 MW (0.0000015% CGNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
Grey seal and harbour seal	**100m ($0.03km^2$)**	**110m ($0.04km^2$)**	**100m ($0.03km^2$)**	**110m ($0.04km^2$)**	**110m ($0.04km^2$)**	**120m ($0.04km^2$)**	**110m ($0.03km^2$)**	**110m ($0.04km^2$)**
GS (using DBA or DBB project specific density estimates)	0.0017 GS (0.00002% SE MU)	0.0022 GS (0.000025% SE MU)	0.0017 GS (0.00002% SE MU)	0.0022 GS (0.000025% SE MU)	0.008 GS (0.000092% SE MU)	0.008 GS (0.000092% SE MU)	0.006 GS (0.00007% SE MU)	0.008 GS (0.000092% SE MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
HS (using DBA or DBB project specific density estimates)	0.000009 HS (0.00000024% SE MU)	0.000012 HS (0.00000032% SE MU)	0.000009 HS (0.00000024% SE MU)	0.000012 HS (0.00000032% SE MU)	0.0004 HS (0.000012% SE MU)	0.0004 HS (0.000012% SE MU)	0.0004 HS (0.000012% SE MU)	0.0004 HS (0.000012% SE MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)

**based on unweighted SPL_{peak} for HP, BND, WBD, MW, GS & HS*

Table 21: Maximum cumulative exposure TTS ranges and areas for maximum hammer energy of 3,000kJ (currently consented) or 4,000kJ for WTG monopiles at Dogger Bank A&B and number of marine mammals (% of reference population) that could be impacted (without mitigation)

Species	DBA N		DBA SW		DBB NW		DBB SE	
	3,000kJ	4,000kJ	3,000kJ	4,000kJ	3,000kJ	4,000kJ	3,000kJ	4,000kJ
HP	**11km (280km²)**	**11km (280km²)**	**10km (240km²)**	**10km (240km²)**	**20km (730km²)**	**20km (750km²)**	**12km (330km²)**	**12km (330km²)**
	249 HP (0.072% NS MU)	249 HP (0.072% NS MU)	213 HP (0.061% NS MU)	213 HP (0.061% NS MU)	649 HP (0.19% NS MU)	666 HP (0.19% NS MU)	293 HP (0.085% NS MU)	293 HP (0.085% NS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
Dolphin species	**<100m (<0.1km²)**	**<100m (<0.1km²)**	**<100m (<0.1km²)**	**<100m (<0.1km²)**	**<100m (<0.1km²)**	**<100m (<0.1km²)**	**<100m (<0.1km²)**	**<100m (<0.1km²)**
BND	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)	0.003 BND (0.00015% GNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
WBD	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)	0.0002 WBD (0.0000005% CGNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
MW	**12km (310km²)**	**12km (310km²)**	**11km (270km²)**	**17km (560km²)**	**28km (1,200km²)**	**28km (1,200km²)**	**9.6km (190km²)**	**14km (400km²)**

Species	DBA N		DBA SW		DBB NW		DBB SE	
	3,000kJ	4,000kJ	3,000kJ	4,000kJ	3,000kJ	4,000kJ	3,000kJ	4,000kJ
	3.1 MW (0.015% CGNS MU)	3.1 MW (0.015% CGNS MU)	2.7 MW (0.013% CGNS MU)	5.6 MW (0.028% CGNS MU)	12 MW (0.06% CGNS MU)	12 MW (0.06% CGNS MU)	1.9 MW (0.01% CGNS MU)	4 MW (0.02% CGNS MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
Grey seal and harbour seal	**4.0km ($38km^2$)**	**4.1km ($38km^2$)**	**4.0km ($36km^2$)**	**4.0km ($38km^2$)**	**7.1km ($110km^2$)**	**7.1km ($120km^2$)**	**4.9km ($53km^2$)**	**4.9km ($52km^2$)**
GS (using DBA or DBB project specific density estimates)	2 GS (0.023% SE MU)	2 GS (0.023% SE MU)	2 GS (0.023% SE MU)	2 GS (0.023% SE MU)	22 GS (0.25% SE MU)	24 GS (0.28% SE MU)	11 GS (0.13% SE MU)	10 GS (0.12% SE MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)
HS (using DBA or DBB project specific density estimates)	0.01 HS (0.0003% SE MU)	0.01 HS (0.0003% SE MU)	0.01 HS (0.0003% SE MU)	0.01 HS (0.0003% SE MU)	1 HS (0.027% SE MU)	1 HS (0.027% SE MU)	0.5 HS (0.013% SE MU)	0.5 HS (0.013% SE MU)
	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)

Table 22: Maximum possible avoidance / behavioural response in harbour porpoise ranges and areas for single strike of the maximum hammer energy of 3,000kJ or 4,000kJ for WTG monopiles at Dogger Bank A&B and number of animals (% of reference population) that could be impacted

Species	DBA N		DBA SW		DBB NW		DBB SE	
	3,000kJ	4,000kJ	3,000kJ	4,000kJ	3,000kJ	4,000kJ	3,000kJ	4,000kJ
HP	**19km (840km²)**	**19km (890km²)**	**18km (770km²)**	**18km (810km²)**	**29km (1,800km²)**	**30km (1,900km²)**	**20km (970km²)**	**21km (1,000km²)**
	746 HP (0.22% NS MU)	790 HP (0.23% NS MU)	684 HP (0.2% NS MU)	719 HP (0.2% NS MU)	1,598 HP (0.5% NS MU)	1,687 HP (0.5% NS MU)	862 HP (0.25% NS MU)	888 HP (0.26% NS MU)
	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible

5.2 Comparison with ES assessment

As outlined in **Section 3**, due to the differences in the underwater modelling, thresholds and criteria it is not possible to make a direct comparison of impact ranges with the original assessments in the ES. However, a summary of the assessments in the ES (Forewind, 2013), have been provided in **Table 24**.

It is more relevant, especially in determining whether there are any new or materially different significant impacts in relation to marine mammals between using the proposed maximum hammer energy of 3,000kJ for OSP pin-piles and 4,000kJ for monopiles compared to the currently consented maximum hammer energy of 1,900kJ for OSP pin-piles and 3,000kJ for monopiles, for the NMC, to provide a comparison of the impact significance and overall outcomes of the original assessments in the ES (Forewind, 2013), on which the DCO was based, with the impact significance and overall outcomes of the updated assessments for the increase in hammer energy, as presented in **Table 23**.

The following comparison with the impact significance (without mitigation) is based on the assessments for maximum hammer energy of 3,000kJ in the ES, with the updated assessments for maximum hammer energy of 1,900kJ or 3,000kJ for OSP pin-piles and 3,000kJ or 4,000kJ for WTG monopiles. This indicates that for harbour porpoise, the impact significance for PTS is the same or less than assessment in ES. For minke whale, the updated assessments for PTS, have a worst-case of moderate to minor which reflects updates to modelling, density estimates and reference population (**Table 23**). This is same or less than the assessment in the ES, as can be seen in **Table 23**. However, as previously outlined, the MMMP would be implemented to reduce the risk of PTS in marine mammals, based on the greatest potential impact range for PTS. Therefore, the residual impacts for PTS (with mitigation) would be the same as assessed in the ES: no impact.

Therefore, there are no new or materially different significant effects in relation to marine mammals between using the proposed maximum hammer energy of 3,000kJ for OSP pin-piles and 4,000kJ for monopiles compared to the currently consented maximum hammer energy of 1,900kJ for OSP pin-piles and 3,000kJ for monopiles.

Table 23: Comparison of assessment of impact significance in ES and updated assessments for piling at Dogger Bank A and B

Potential impact	**Impact significances (without mitigation)**					
Hammer energy	**Assessment for 3,000kJ in ES (Table 24)**	**Updated noise modelling for 1,900kJ OSP pin-piles (Table 11-Table 16)**	**Updated noise modelling for 3,000kJ OSP pin-piles (Table 11-Table 16)**	**Updated noise modelling for 3,000kJ WTG monopiles (Table 17 - Table 22)**	**Updated noise modelling for 4,000kJ WTG monopiles (Table 17 - Table 22)**	**Difference in overall assessments**
Potential impact for harbour porpoise						
PTS	Moderate	Minor (not significant)	Minor (not significant)	Minor (not significant) to Moderate	Minor (not significant) to Moderate	**Same or less than assessment in ES**
TTS	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	**No change**
Possible avoidance	Negligible	Negligible	Negligible	Negligible	Negligible	**No change**

Potential impact	Impact significances (without mitigation)					
Hammer energy	**Assessment for 3,000kJ in ES (Table 24)**	**Updated noise modelling for 1,900kJ OSP pin-piles (Table 11-Table 16)**	**Updated noise modelling for 3,000kJ OSP pin-piles (Table 11-Table 16)**	**Updated noise modelling for 3,000kJ WTG monopiles (Table 17 - Table 22)**	**Updated noise modelling for 4,000kJ WTG monopiles (Table 17 - Table 22)**	**Difference in overall assessments**
Potential impact for dolphin species						
PTS	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	**No change**
TTS	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	**No change**
Potential impact for minke whale						
PTS	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant) to Moderate	Minor (not significant) to Moderate	**Precautionary update to moderate reflects updates to modelling, density estimates and reference population**
TTS	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	**No change**
Potential impact for grey and harbour seal						
PTS	Moderate	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	**No change**
TTS	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	Minor (not significant)	**No change**

Table 24: Summary of marine mammal ES impact ranges for piling at Dogger Bank A and B (Tables 6.4-6.9, 6.14-6.18 in ES Chapter 14, Forewind, 2013)

Location	Dogger Bank A				Dogger Bank B				Magnitude of effect for 3,000kJ maximum hammer energy from ES	Impact significance (without mitigation – see Annex A)
Hammer energy	300kJ	1,900kJ	2,300kJ	3,000kJ	300kJ	1,900kJ	2,300kJ	3,000kJ		
Impact criterion for harbour porpoise (Lucke *et al*., 2009)	**Harbour porpoise impact ranges**									
Instantaneous PTS (pulse SEL 179dB re 1 µPa²·s)	<100m	<550m	<600m	<700m	<100m	<550m	<600m	<700m	Low	**Moderate**
TTS/fleeing response (pulse SEL 164dB re 1 µPa²·s)	<1.5km	3.5 - 4.0km	4.0 - 4.5km	4.5 - 5.0km	1.2 - 0.5km	3.2 - 4.4km	4.0 - 5km	4.5 - 5.5km	Negligible	**Minor (not significant)**
Possible avoidance (pulse SEL 145dB re 1 µPa²·s)	10.5 - 13.0km	17.5 - 23.5km	18.0 - 26.0km	19.5 - 28.5km	10.5 - 14.5km	20.5 - 34.5km	22 - 38km	24 - 43km	Negligible	**Negligible**
Impact criterion (Southall *et al*., 2007)	**Dolphin species impact ranges**									
Instantaneous PTS (Mmf weighted 198dB re 1 µPa²·s)	<50m	<50m	<50m	<50m	<50m	<50m	<50m	<50m	Negligible (WBD)	**Minor (not significant)**
TTS/fleeing response (Mmf weighted 183dB re 1 µPa²·s)	<50m	<100m	<100m	<150m	<50m	<100m	<100m	<150m	Negligible (WBD)	**Minor (not significant)**

Location Hammer energy	Dogger Bank A				Dogger Bank B				Magnitude of effect for 3,000kJ maximum hammer energy from ES	Impact significance (without mitigation – see Annex A)
	300kJ	1,900kJ	2,300kJ	3,000kJ	300kJ	1,900kJ	2,300kJ	3,000kJ		
Impact criterion for harbour porpoise (Lucke *et al*., 2009)	**Harbour porpoise impact ranges**									
Impact criterion (Southall *et al*., 2007)	**Minke whale impact ranges**									
Instantaneous PTS (Mlf weighted 198dB re 1 µPa^2·s)	<50m	<50m	<50m	<50m	<50m	<50m	<50m	<50m	Negligible	**Minor (not significant)**
TTS/fleeing response (Mlf weighted 183dB re 1 µPa^2·s)	<50m	<250m	<300m	<350m	<50m	<250m	<300m	<350m	Negligible	**Minor (not significant)**
Impact criterion (Southall *et al*., 2007)	**Grey and harbour seal impact ranges**									
Instantaneous PTS (Mpw weighted 186dB re 1 µPa^2·s)	<50m	<100m	<100m	<150m	<50m	<100m	<100m	<150m	Low (GS)	**Moderate**
TTS/Fleeing response (Mpw weighted 171dB re 1 µPa^2·s)	<400m	<1.4km	<1.6km	<1.8km	<350m	<1.5km	<1.6km	<1.9km	Negligible (GS)	**Minor (not significant)**

5.2.1 Cumulative impact assessment

5.2.1.1 ES assessment

As demonstrated, there is no significant difference in the potential impacts on marine mammals from increasing the OSP pin-pile maximum hammer energy from 1,900kJ to 3,000kJ, or increasing the maximum monopile hammer energy of 3,000kJ to 4,000kJ compared to the ES assessment. Therefore, there will be no significant difference to the outcome of the cumulative impact assessment in the ES assessment.

In the ES, the cumulative impact assessment (CIA) for Dogger Bank A and B (previously Creyke Beck A and B) considered (where relevant) the potential for cumulative impacts in the following sequence:

- With the second phase of development in the Dogger Bank Zone, known as Dogger Bank Teesside A & B (now Dogger Bank C and Sofia);
- With the above, plus any other activities, projects and plans in the Dogger Bank Zone; and
- With all of the above, in addition to any other activities, projects and plans outwith the Dogger Bank Zone.

For cumulative impacts in the Dogger Bank Zone from piling the assessment in the ES was undertaken based on eight piling vessels across the four Dogger Bank projects (now Dogger Bank A, B and C and Sofia). The assessment determined that with mitigation there would be no residual impact for PTS for all marine mammal species, with the exception of grey seal which was assessed as minor adverse. For behavioural response, the overall residual impact to pile driving noise was predicted to be **minor adverse** for all species. Additionally, it is worth noting that there will now not be eight piling vessels across the four Dogger Bank projects, as was assessed in the ES.

For harbour porpoise, in the ES CIA in the Dogger Bank Zone the potential possible avoidance of the area could impact less than 5% of the reference population. Harbour porpoise have low sensitivity to possible avoidance; therefore, the overall impact in the ES was considered minor adverse. Based on a medium sensitivity to likely avoidance, the magnitude of effect remains low, and therefore the overall residual impact was also **minor adverse**.

Table 25 summarises the CIA in the ES, including projects outwith the Dogger Bank Zone.

The CIA in the ES determined that with mitigation there would be no residual impact for PTS for all cetacean species. For grey seal the cumulative impact significance for PTS was assessed as **moderate adverse**.

In the CIA in the ES, it was predicted that it was possible that more than 10% of the reference population for harbour porpoise could be disturbed (as a worst-case), which would be a high magnitude of effect. This combined with the low sensitivity to possible avoidance gives a moderate adverse impact (**Table 25**). For minke whale and white-beaked dolphin, impact magnitudes were considered medium, the overall impact was minor adverse, based on low sensitivity (**Table 25**). For grey and harbour seal, impact magnitudes were considered high and medium, respectively, with the overall impact assessed as moderate and minor adverse, respectively, based on low sensitivity (**Table 25**).

Table 25: Summary of predicted cumulative impacts in ES (Table 12.4 in Chapter 14 of ES)

Impact	Receptor	Residual Impact significance
All phases		
Underwater noise – behavioural response (all sources)	Harbour porpoise Minke whale White-beaked dolphin Grey seal	Moderate Minor Minor Moderate

Impact	Receptor	Residual Impact significance
	Harbour seal	Minor

5.2.1.2 Updated CIA

Piling at Dogger Bank A is scheduled to commence in June 2022 and end in March 2023. There is the potential for cumulative impacts with:

- Dogger Bank C unexploded ordnance (UXO) clearance (in 2022)
- Sofia UXO clearance (April to June 2022)
- East Anglia hub piling (2023-2026)
- East Anglia hub UXO clearance (2023-2026, assume not at the same time as piling)
- Hornsea Project Three piling (2023 – 2025)
- Hornsea Project Three UXO clearance (2023 -2025, assume not at the same time as piling)
- Dredging projects (very small area so unlikely to contribute to cumulative impacts and have not been included in CIA)
    - Lowestoft Eastern Energy Facility
    - Berths 6 and 7, Trinity Terminal, Port of Felixstowe
- Geophysical surveys with sub bottom profiler (SBP) (assume up to two)

Piling at Dogger Bank B is scheduled to commence in April 2023 and end in November 2023. There is the potential for cumulative impacts with:

- East Anglia hub piling (2023-2026)
- East Anglia hub UXO clearance (2023-2026, assume not at the same time as piling)
- Hornsea Project Three piling (2023 – 2025)
- Hornsea Project Three UXO clearance (2023 -2025, assume not at the same time as piling)
- Hornsea Project Four UXO clearance (2023-2024)
- Port of Ramsgate Replacement of Berth 4/5 (very small area so unlikely to contribute to cumulative impacts and have not been included in CIA)
- Geophysical surveys with SBP (assume up to two)

The CIA has been updated to take into account activities and noise sources that could have cumulative impacts during piling at Dogger Bank A and B, and if the proposed increase in hammer energy would result in any significant differences.

5.2.1.2.1 PTS

There would be no potential for any PTS cumulative impacts as each project listed above would be required to ensure adequate mitigation in their MMMP to reduce the risk of PTS to marine mammals. However, as a precautionary approach, the potential for any cumulative impacts for any PTS has been assessed.

The activities that have the potential to cause PTS in marine mammals (without mitigation) are:

- UXO detonation; and
- Piling,

All other activities, including underwater noise from seismic surveys, geophysical surveys (including SBP) and vessels would not result in the risk of PTS. Therefore, these activities are not included in the CIA for PTS.

For example, as assessed in the ION Southern North Sea Seismic Survey HRA (BEIS, 2020b), the noise modelling indicated that, based on the weighted SEL threshold, there is potential for sound levels to cause the onset of PTS to harbour porpoise out to 320m. However, the estimated area of potential impact from PTS is within 500m of the airgun array and therefore within the radius which, if marine mammals are detected during a pre-shooting search, the commencement of the firing of the airguns must be delayed by a minimum of 20 minutes, as per the JNCC guidance (JNCC, 2017).

The Dogger Bank A and Dogger Bank B projects have committed to no piling and UXO detonations on the same day at either, or between, the Dogger Bank A and Dogger Bank B projects. Therefore, there is no PTS cumulative impacts for the proposed UXO clearance and piling at the Dogger Bank A and Dogger Bank B projects.

The PTS impact ranges and areas for UXO clearance and piling at other offshore wind farm sites has been based on the maximum impact areas from the latest modelling for Dogger Bank A and Dogger Bank B.

The potential for PTS from UXO clearance has been based on a worst-case assessment, using the maximum impact area for high-order detonation, with and without bubble curtain[1]. The potential for PTS from piling is based on a worst-case, maximum impact area, without mitigation (**Table 26**).

Table 26: Maximum PTS impact areas used in CIA

Maximum impact area used in CIA	Harbour porpoise	Bottlenose dolphin	White-beaked dolphin	Minke whale	Grey seal	Harbour seal
PTS – piling (SEL_{cum})	0.98km^2	0.1km^2	0.1km^2	1.7km^2	0.1km^2	0.1km^2
PTS – UXO (high-order detonation with and without bubble curtain)	670km^2 (85km^2)	2.2km^2 (0.28km^2)	2.2km^2 (0.28km^2)	422.7km^2 (12.6km^2)	24.6km^2 (3.14km^2)	24.6km^2 (3.14km^2)

The number of marine mammals at potential risk of PTS has been calculated based on the relative density estimates for the locations of the other offshore wind farm sites (**Table 27**). Density estimates for harbour porpoise, bottlenose dolphin, white-beaked dolphin, and minke whale, are based on the relevant density estimate from the SCAS-III survey (Hammond *et al*., 2021). The density estimates for grey seal and harbour seal are based on the calculated density from the at-sea total (mean) seal usage maps (Russell *et al.,* 2017) for the relevant project site.

Table 27: Marine Mammal density estimates used in CIA

Maximum impact area used in CIA	Harbour porpoise	Bottlenose dolphin	White-beaked dolphin	Minke whale	Grey seal	Harbour seal
Dogger Bank A	0.888/km^2	0.0298/km^2	0.002/km^2	0.010/km^2	0.055/km^2	0.0003/km^2
Dogger Bank B	0.888/km^2	0.0298/km^2	0.002/km^2	0.010/km^2	0.20/km^2	0.0098/km^2
Dogger Bank C	0.888/km^2	0.0298/km^2	0.002/km^2	0.010/km^2	0.001/km^2	0.0007/km^2
Sofia	0.888/km^2	0.0298/km^2	0.002/km^2	0.010/km^2	0.094/km^2	0.002/km^2

[1] *Using the underwater noise modelling undertaken for UXO clearance at the Dogger Bank A and B projects (Subacoustech, 2020)*

Maximum impact area used in CIA	Harbour porpoise	Bottlenose dolphin	White-beaked dolphin	Minke whale	Grey seal	Harbour seal
East Anglia HUB	0.607/km^2	N/A	N/A	N/A	0.008/km^2	0.004/km^2
Hornsea Project Three	0.888/km^2	0.0298/km^2	0.002/km^2	0.010/km^2	0.08/km^2	0.008/km^2
Hornsea Project Four	0.888/km^2	0.0298/km^2	0.002/km^2	0.010/km^2	0.14/km^2	0.04/km^2
Geophysical survey	0.888/km^2	0.0298/km^2	0.002/km^2	0.010/km^2	0.1/km^2	0.01/km^2

Table 28 provides an assessment of the potential worst-case for cumulative PTS impacts from underwater noise during piling at Dogger Bank A, including the proposed increase in hammer energy for OSP pin-piles and WTG monopiles.

There is no difference in the CIA assessments (number of marine mammals that could be impacted) for OSP pin-piles with a maximum hammer energy of 1,900kJ or 3,000kJ, or for WTG monopiles with a maximum hammer energy of 3,000kJ or 4,000kJ at Dogger Bank A (

Table 28).

Table 29 provides an assessment of the potential worst-case for cumulative PTS impacts from underwater noise during piling at Dogger Bank B, including increase in hammer energy for OSP pin-piles and WTG monopiles.

There is no difference in the CIA assessments (number of marine mammals that could be impacted) for OSP pin-piles with a maximum hammer energy of 1,900kJ or 3,000kJ, or for WTG monopiles with a maximum hammer energy of 3,000kJ or 4,000kJ at Dogger Bank B (**Table 29**).

With MMMPs for piling to reduce risk of PTS and MMMPs for UXO, including low-order detonations, the residual impact significance for all marine mammals would be **minor (not significant)**.

As outlined in **Section 5.2.1.1**, the CIA in the ES determined that with mitigation there would be no residual impact for PTS for all cetacean species. For grey seal the cumulative impact significance for PTS was assessed as moderate adverse.

The updated CIA indicates, that, with mitigation, the proposed increase in maximum hammer energy for OSP pin-piles and monopiles for WTG foundations would be the same or less than CIA assessments in the ES that informed the DCO.

Table 28: The potential for increased risk of PTS from cumulative impacts of underwater noise during piling at Dogger Bank A

Project and activity	Maximum number of marine mammals potentially at increased risk of PTS					
	Harbour porpoise	Bottlenose dolphin	White-beaked dolphin	Minke whale	Grey seal	Harbour seal
Summary of assessments for piling at DBA						
DBA piling of OSP pin-piles with maximum hammer energy of 1,900kJ or 3,000kJ (SEL_{cum})	0.26 or **0.27**	0.003 or **0.003**	0.0002 or **0.0002**	0.001 or **0.001**	0.0055 or **0.0055**	0.00003 or **0.00003**
DBA piling of WTG monopiles with maximum hammer energy of 3,000kJ or 4,000kJ (SEL_{cum})	3.5 or **3.55**	0.003 or **0.003**	0.0002 or **0.0002**	0.037 or **0.34**	0.0055 or **0.0055**	0.00003 or **0.00003**
Cumulative projects screened in for assessment						
Dogger Bank C (DBC) – UXO ***(high-order detonation with bubble curtain)***	595 *(76)*	0.07 *(0.008)*	0.004 *(0.0006)*	4 *(0.1)*	3 *(0.4)*	0.25 *(0.03)*
Sofia – UXO ***(high-order detonation with bubble curtain)***	595 *(76)*	0.07 *(0.008)*	0.004 *(0.0006)*	4 *(0.1)*	2.3 *(0.3)*	0.05 *(0.006)*
East Anglia (EA) HUB -Piling or UXO ***(UXO with mitigation)***	Piling: 0.6 UXO: 407 *(51)*	N/A	N/A	N/A	Piling: 0.0008 UXO: 0.2 *(0.025)*	Piling: 0.0004 UXO: 0.1 *(0.01)*
Hornsea Project Three (HP3) -	Piling: 0.9	Piling: 0.003	Piling: 0.0002	Piling: 0.017	Piling: 0.008	Piling: 0.0008

Project and activity	**Maximum number of marine mammals potentially at increased risk of PTS**					
	Harbour porpoise	**Bottlenose dolphin**	**White-beaked dolphin**	**Minke whale**	**Grey seal**	**Harbour seal**
Piling or UXO ***(UXO with mitigation)***	UXO: 595 *(76)*	UXO: 0.07 *(0.008)*	UXO: 0.004 *(0.0006)*	UXO: 4.3 *(0.13)*	UXO: 2 *(0.25)*	UXO: 0.2 *(0.025)*
Cumulative assessment of DBA piling of OSP pin-piles with maximum hammer energy of 1,900kJ or 3,000kJ – UXO clearance at DBC & Sofia, and piling at EA HUB & HP3						
Total number of individuals and % of reference population for OSP pin-piles at DBA, with DBC & Sofia UXO without mitigation and piling at EA HUB & HP3 ***[or with bubble curtain at Sofia & DBC]***	1,192 (0.34%) *[154 (0.04%)]*	0.15 (0.007%) *[0.02 (0.001%)]*	0.008 (0.00002%) *[0.002 (0.000005%)]*	8 (0.04%) *[0.2 (0.001%)]*	(0.06%) *[0.7 (0.008%)]*	0.3 (0.008%) *[0.04 (0.001%)]*
Magnitude of impact	Medium *[Medium]*	Low *[Low]*	Negligible *[Negligible]*	Medium *[Low]*	Medium *[Low]*	Low *[Low]*
Sensitivity	High	High	High	High	High	High
Impact significance	**Major** **[Major]**	**Moderate** **[Moderate]**	**Minor** **[Minor]**	**Major** **[Moderate]**	**Major** **[Moderate]**	**Moderate** **[Moderate]**
Cumulative assessment of DBA piling of OSP pin-piles with maximum hammer energy of 1,900kJ or 3,000kJ – UXO clearance at DBC, Sofia, EA HUB & HP3						
Total number of individuals and % of reference population for	2,192 (0.6%)	0.2 (0.01%)	0.01 (0.00002%)	12 (0.06%)	7.5 (0.09%)	0.6 (0.02%)

Project and activity	Maximum number of marine mammals potentially at increased risk of PTS					
	Harbour porpoise	Bottlenose dolphin	White-beaked dolphin	Minke whale	Grey seal	Harbour seal
OSP pin-piles at DBA, with DBC, Sofia EA HUB & HP3 UXO without mitigation ***[or with bubble curtain]***	*[279 (0.08%)]*	*[0.3 (0.02%)]*	*[0.002 (0.000005%)]*	*[0.3 (0.0015%)]*	*[1 (0.01%)]*	*[0.07 (0.002%)]*
Magnitude of impact	Medium *[Medium]*	Medium *[Medium]*	Negligible *[Negligible]*	Medium *[Low]*	Medium *[Medium]*	Medium *[Low]*
Sensitivity	High	High	High	High	High	High
Impact significance	Major *[Major]*	Major *[Major]*	Minor *[Minor]*	Major *[Moderate]*	Major *[Major]*	Major *[Moderate]*
Cumulative assessment of DBA piling of WTG monopiles with maximum hammer energy of 3,000kJ or 4,000kJ – UXO clearance at DBC & Sofia, and piling at EA HUB & HP3						
Total number of individuals and % of reference population for WTG monopiles at DBA, with DBC & Sofia UXO without mitigation and piling at EA HUB & HP3 ***[or with bubble curtain at Sofia & DBC]***	1,195 (0.35%) *[157 (0.05%)]*	0.15 (0.007%) *[0.02 (0.001%)]*	0.008 (0.00002%) *[0.002 (0.000005%)]*	8 (0.04%) *[0.25 or 0.6 (0.001% or 0.003%)]*	5.3 (0.06%) *[0.7 (0.008%)]*	0.3 (0.008%) *[0.04 (0.001%)]*
Magnitude of impact	Medium [Medium]	Low [Low]	Negligible [Negligible]	Medium [Low]	Medium [Low]	Low [Low]

Project and activity	Maximum number of marine mammals potentially at increased risk of PTS					
	Harbour porpoise	**Bottlenose dolphin**	**White-beaked dolphin**	**Minke whale**	**Grey seal**	**Harbour seal**
Sensitivity	High	High	High	High	High	High
Impact significance	Major [Major]	Moderate [Moderate]	Minor [Minor]	Major [Moderate]	Major [Moderate]	Moderate [Moderate]
Cumulative assessment of DBA piling of WTG monopiles with maximum hammer energy of 3,000kJ or 4,000kJ – UXO clearance at DBC, Sofia, EA HUB & HP3						
Total number of individuals and % of reference population for WTG monopiles at DBA, with DBC, Sofia EA HUB & HP3 UXO without mitigation ***[or with bubble curtain]***	2,196 (0.6%) *[283 (0.08%)]*	0.2 (0.01%) *[0.3 (0.02%)]*	0.01 (0.00002%) *[0.002 (0.000005%)]*	12 or 13 (0.06 or 0.065%) *[0.4 or 0.7 (0.002 or 0.0035%)]*	7.5 (0.09%) *[1 (0.01%)]*	0.6 (0.02%) *[0.07 (0.002%)]*
Magnitude of impact	Medium [Medium]	Medium [Medium]	Negligible [Negligible]	Medium [Low]	Medium [Medium]	Medium [Low]
Sensitivity	High	High	High	High	High	High
Impact significance	Major [Major]	Major [Major]	Minor [Minor]	Major [Moderate]	Major [Major]	Major [Moderate]
Overall cumulative assessment for DBA						
With MMMPs for piling and UXO,	**Minor (not**	**Minor (not**	**Minor (not**	**Minor (not**	**Minor (not**	**Minor (not**

Project and activity	Maximum number of marine mammals potentially at increased risk of PTS					
	Harbour porpoise	Bottlenose dolphin	White-beaked dolphin	Minke whale	Grey seal	Harbour seal
including low-order detonations	**significant)**	**significant)**	**significant)**	**significant)**	**significant)**	**significant)**

Table 29: The potential for increased risk of PTS from cumulative impacts of underwater noise during piling at Dogger Bank B

Project and activity	Maximum number of marine mammals potentially at increased risk of PTS					
	Harbour porpoise	Bottlenose dolphin	White-beaked dolphin	Minke whale	Grey seal	Harbour seal
Summary of assessments for piling at DBB						
DBB piling of OSP pin-piles with maximum hammer energy of 1,900kJ or 3,000kJ (SEL_{cum})	0.79 or **0.87**	0.003 or **0.003**	0.0002 or **0.0002**	0.016 or **0.017**	0.02 or **0.02**	0.00098 or **0.00098**
DBB piling of WTG monopiles with maximum hammer energy of 3,000kJ or 4,000kJ (SEL_{cum})	5.15 or **5.15**	0.003 or **0.003**	0.0002 or **0.0002**	0.32 or **0.33**	0.02 or **0.02**	0.00098 or **0.00098**
Cumulative projects screened in for assessment						
East Anglia (EA) HUB - Piling or UXO ***(UXO with mitigation)***	Piling: 0.6 UXO: 407 *(51)*	N/A	N/A	N/A	Piling: 0.0008 UXO: 0.2 *(0.025)*	Piling: 0.0004 UXO: 0.1 *(0.01)*
Hornsea Project Three (HP3) - Piling or	Piling: 0.9	Piling: 0.003	Piling: 0.0002	Piling: 0.017	Piling: 0.008	Piling: 0.0008

Project and activity	Maximum number of marine mammals potentially at increased risk of PTS					
	Harbour porpoise	Bottlenose dolphin	White-beaked dolphin	Minke whale	Grey seal	Harbour seal
UXO ***(UXO with mitigation)***	UXO: 595 *(76)*	UXO: 0.07 *(0.008)*	UXO: 0.004 *(0.0006)*	UXO: 4.3 *(0.13)*	UXO: 2 *(0.25)*	UXO: 0.2 *(0.025)*
Hornsea Project Four (HP4) - UXO ***(with mitigation)***	595 *(76)*	0.07 *(0.008)*	0.004 *(0.0006)*	4.3 *(0.13)*	3.4 *(0.44)*	1 *(0.13)*
Cumulative assessment of DBB piling of OSP pin-piles with maximum hammer energy of 1,900kJ or 3,000kJ – UXO clearance at HP4, and piling at EA HUB & HP3						
Total number of individuals and % of reference population for OSP pin-piles at DBB, with HP4 UXO without mitigation and piling at EA HUB & HP3 ***[or with bubble curtain at HP4]***	597 (0.2%) *[77.5, 78.3 or 78.4 (0.02%)]*	0.08 (0.004%) *[0.01 (0.0005%)]*	0.004 (0.00002%) *[0.001 (0.000002%)]*	4.3 (0.02%) *[0.2 (0.001%)]*	3.4 (0.04%) *[0.5 (0.006%)]*	1 (0.03%) *[0.13 (0.004%)]*
Magnitude of impact	Medium *[Medium]*	Low *[Low]*	Negligible *[Negligible]*	Medium *[Low]*	Medium *[Low]*	Low *[Low]*
Sensitivity	High	High	High	High	High	High
Impact significance	**Major** **[Major]**	**Moderate** **[Moderate]**	**Minor** **[Minor]**	**Major** **[Moderate]**	**Major** **[Moderate]**	**Moderate** **[Moderate]**
Cumulative assessment of DBB piling of OSP pin-piles with maximum hammer energy of 1,900kJ or 3,000kJ – UXO clearance at HP4, EA HUB & HP3						

Project and activity	Maximum number of marine mammals potentially at increased risk of PTS					
	Harbour porpoise	Bottlenose dolphin	White-beaked dolphin	Minke whale	Grey seal	Harbour seal
Total number of individuals and % of reference population for OSP pin-piles at DBB, with HP4, EA HUB & HP3 UXO without mitigation **_[or with bubble curtain]_**	1,598 (0.5%) *[205 (0.06%)]*	0.14 (0.007%) *[0.02 (0.001%)]*	0.008 (0.00002%) *[0.001 (0.000002%)]*	8.6 (0.04%) *[0.3 (0.0015%)]*	5.6 (0.065%) *[0.74 (0.0085%)]*	1.3 (0.035%) *[0.2 (0.005%)]*
Magnitude of impact	Medium *[Medium]*	Low *[Low]*	Negligible *[Negligible]*	Medium *[Low]*	Medium *[Low]*	Medium *[Low]*
Sensitivity	High	High	High	High	High	High
Impact significance	Major *[Major]*	Moderate *[Moderate]*	Minor *[Minor]*	Major *[Moderate]*	Major *[Moderate]*	Major *[Moderate]*
Cumulative assessment of DBB piling of WTG monopiles with maximum hammer energy of 3,000kJ or 4,000kJ – UXO clearance at HP4, and piling at EA HUB & HP3						
Total number of individuals and % of reference population for WTG monopiles at DBB, with HP4 UXO without mitigation and piling at EA HUB & HP3 **_[or with bubble curtain at HP4]_**	602 (0.2%) *[83 (0.024%)]*	0.08 (0.004%) *[0.01 (0.0005%)]*	0.004 (0.00002%) *[0.001 (0.000002%)]*	4.7 (0.02%) *[0.48 (0.002%)]*	3.4 (0.04%) *[0.5 (0.006%)]*	1 (0.03%) *[0.13 (0.004%)]*
Magnitude of impact	Medium [Medium]	Low [Low]	Negligible [Negligible]	Medium [Low]	Medium [Low]	Medium [Low]

Project and activity	Maximum number of marine mammals potentially at increased risk of PTS					
	Harbour porpoise	Bottlenose dolphin	White-beaked dolphin	Minke whale	Grey seal	Harbour seal
Sensitivity	High	High	High	High	High	High
Impact significance	Major [Major]	Moderate [Moderate]	Minor [Minor]	Major [Moderate]	Major [Moderate]	Moderate [Moderate]
Cumulative assessment of DBB piling of WTG monopiles with maximum hammer energy of 3,000kJ or 4,000kJ – UXO clearance at HP4, EA HUB & HP3						
Total number of individuals and % of reference population for WTG monopiles at DBB, with HP4, EA HUB & HP3 UXO without mitigation ***[or with bubble curtain]***	1,602 (0.5%) *[209 (0.06%)]*	0.14 (0.007%) *[0.02 (0.001%)]*	0.008 (0.00002%) *[0.001 (0.000002%)]*	9 (0.045) *[0.6 (0.003%)]*	5.6 (0.065%) *[0.74 (0.0085%)]*	1.3 (0.035%) *[0.2 (0.005%)]*
Magnitude of impact	Medium [Medium]	Low [Low]	Negligible [Negligible]	Medium [Low]	Medium [Low]	Medium [Low]
Sensitivity	High	High	High	High	High	High
Impact significance	Major [Major]	Moderate [Moderate]	Minor [Minor]	Major [Moderate]	Major [Moderate]	Major [Moderate]
Overall cumulative assessment for DBB						
With MMMPs for piling and UXO, including low-order detonations	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**

5.2.1.2.2 Possible avoidance / behavioral reaction

The activities (as described in **Section 5.2.1.2**) that have the potential to cause possible avoidance or behavioural reactions in marine mammals (without mitigation) are:

- UXO detonation;
- Piling; and
- Geophysical surveys .

As noted above, the Dogger Bank A and Dogger Bank B projects have committed to no piling and UXO detonations on the same day at either, or between, the Dogger Bank A and Dogger Bank B projects. Therefore, there is no avoidance or behavioural cumulative impacts for the proposed UXO clearance and piling at the Dogger Bank A and Dogger Bank B projects.

The impact ranges and areas for UXO clearance and piling for possible avoidance (for harbour porpoise only) or disturbance (using TTS / fleeing response for species other than harbour porpoise) at other offshore wind farm sites has been based on the maximum impact areas from the latest modelling for Dogger Bank A and Dogger Bank B.

This assessment has been based on the potential for disturbance due to geophysical surveys undertaken at the same time as the construction of Dogger Bank A and B. The magnitude of the potential disturbance from these surveys has been estimated based on the following disturbance ranges for each marine mammal species:

- Harbour porpoise
    - The potential impact area during geophysical surveys, based on a radius of 5km from the survey vessel (256.1km^2)[2], following the current Statutory Nature Conservation Body (SNCB) guidance (JNCC *et al*., 2020) for the assessment of impact to harbour porpoise in the Southern North Sea SAC.
- Bottlenose dolphin and white-beaked dolphin
    - There is little available information on the potential for disturbance from seismic (or geophysical) surveys, however, observations of behavioural changes in common dolphins in the Irish Sea show a reduced vocalisation rate and / or exclusion within 1km of a 2D seismic survey (of 2,120 cubic inches (cu. in.)) (Goold, 1996); a potential disturbance range of 1km (disturbance area of 3.1km^2) will therefore be applied to both white-beaked dolphin and bottlenose dolphin due to a lack of species-specific information.
- Minke whale
    - As for dolphin species, there is little available information on the potential for disturbance from seismic (or geophysical) surveys for minke whale, however, observations of behavioural changes in other baleen whale species have shown avoidance reactions in up to 10km (for a seismic survey of 1,600 cu. in.) (Macdonald *et al.,* 1995); a potential disturbance range of 10km (disturbance area of 314.1km^2) will therefore be applied to minke whale due to a lack of species-specific information.
- Grey seal and harbour seal
    - As for both dolphin species and minke whale, there is little available information on the potential for disturbance from seismic (or geophysical) surveys for either grey seal or harbour seal, however, observations of behavioural changes in other seal species have shown avoidance reactions up to 3.6km from the source (for a seismic survey of 1,600 cu. in.) (Harris *et al.,* 2001); a potential disturbance range of 3.6km (disturbance area of

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[2] *As used within the BEIS RoC HRA (BEIS, 2020), taking into account the survey line length that could be undertaken in a day for any generic geophysical survey*

40.7km²) will therefore be applied to both grey seal and harbour seal due to a lack of species-specific information.

It should be noted that this assessment is based on the potential impacts for seismic surveys required by the oil and gas industry. The higher frequencies typically used for geophysical surveys for offshore windfarms generally fall outside the hearing frequencies of cetaceans and the sounds produced are likely to attenuate more quickly than the lower frequencies used in deeper waters (JNCC, 2017). Therefore, the use of reported disturbance ranges for seismic surveys for the assessment of disturbance due to geophysical surveys is considered to be a worst-case and precautionary approach.

The potential for disturbance from UXO clearance has been based on a worst-case assessment, using the maximum impact area for high-order detonation, with and without bubble curtains[3]. The potential for disturbance from piling is based on a worst-case, maximum impact area, without mitigation (**Table 26**).

Table 30: Maximum PTS impact areas used in CIA

Maximum impact area used in CIA	Harbour porpoise	Bottlenose dolphin	White-beaked dolphin	Minke whale	Grey seal	Harbour seal
Possible avoidance of harbour porpoise due to piling	1,900km²	N/A	N/A	N/A	N/A	N/A
Disturbance from piling based on TTS / fleeing response	N/A	<0.1km²	<0.1km²	1,200km²	120km²	120km²
Disturbance from UXO based on TTS / fleeing response (without bubble curtain)	2,256.4km²	7.1km²	7.1km²	45,996.1km²	1,705.5km²	1,705.5km²
Disturbance from UXO based on TTS / fleeing response (with bubble curtain)	295.6km²	1.0km²	1.0km²	2,273.3km²	72.4km²	72.4km²
Disturbance from geophysical surveys	256.1km²	3.1km²	3.1km²	314.1km²	40.7km²	40.7km²

The number of marine mammals at potential risk of avoidance or disturbance has been calculated based on the relative density estimates for the locations of the other offshore wind farm sites (**Table 27**). Density estimates for harbour porpoise, bottlenose dolphin, white-beaked dolphin, and minke whale, are based on the relevant density estimate from the SCANS-III survey (Hammond *et al*., 2021). The density estimates for grey seal and harbour seal are based on the calculated density from the at-sea total (mean) seal usage maps (Russell *et al.,* 2017) for the relevant project site. Due to the unknown location of geophysical surveys, the highest density estimate for each species has been used in the assessment.

Table 31: Marine Mammal density estimates used in CIA

Maximum impact area used in CIA	Harbour porpoise	Bottlenose dolphin	White-beaked dolphin	Minke whale	Grey seal	Harbour seal
Dogger Bank A	0.888/km²	0.0298/km²	0.002/km²	0.010/km²	0.055/km²	0.0003/km²

[3] *Using the underwater noise modelling undertaken for UXO clearance at the Dogger Bank A and B projects (SubAcoustech, 2020)*

Maximum impact area used in CIA	Harbour porpoise	Bottlenose dolphin	White-beaked dolphin	Minke whale	Grey seal	Harbour seal
Dogger Bank B	0.888/km^2	0.0298/km^2	0.002/km^2	0.010/km^2	0.20/km^2	0.0098/km^2
Dogger Bank C	0.888/km^2	0.0298/km^2	0.002/km^2	0.010/km^2	0.001/km^2	0.0007/km^2
Sofia	0.888/km^2	0.0298/km^2	0.002/km^2	0.010/km^2	0.094/km^2	0.002/km^2
East Anglia HUB	0.607/km^2	N/A	N/A	N/A	0.008/km^2	0.004/km^2
Hornsea Project Three	0.888/km^2	0.0298/km^2	0.002/km^2	0.010/km^2	0.08/km^2	0.008/km^2
Hornsea Project Four	0.888/km^2	0.0298/km^2	0.002/km^2	0.010/km^2	0.14/km^2	0.0098/km^2
Geophysical survey	0.888/km^2	0.0298/km^2	0.002/km^2	0.010/km^2	0.2/km^2	0.01/km^2

Table 32

Table 28 provides an assessment of the potential worst-case for cumulative potential avoidance / disturbance impacts from underwater noise during piling at Dogger Bank A, including the proposed increase in hammer energy for OSP pin-piles and WTG monopiles.

For bottlenose dolphin, white-beaked dolphin, grey seal, and harbour seal, there is no difference in the CIA assessments (number of marine mammals that could be impacted) for OSP pin-piles with a maximum hammer energy of 1,900kJ or 3,000kJ, or for WTG monopiles with a maximum hammer energy of 3,000kJ or 4,000kJ at Dogger Bank A (

Table 28). For minke whale, there is no difference in the CIA assessment for OSP pin-piles with a hammer energy of either 1,900kJ or 3,000kJ.

For harbour porpoise, there is a slight change in the number of individuals at risk of potential avoidance for the OSPs pin-pile with a hammer energy of 1,900kJ or 3,000kJ, and in the number of individuals for a monopile with a hammer energy of 3,000kJ or 4,000kJ. However, the difference between the number of harbour porpoise is small (with an increase of 71; or 0.02% of the reference population for OSP pin-piles, and an increase of 44 for monopiles; or 0.01% of the reference population). This does not therefore represent a significant difference in the assessment and does not alter the overall magnitude of impacts for harbour porpoise, with an assessment of minor adverse. For minke whale, there is an increase of 2.5 individuals at risk of disturbance for a hammer energy of 4,000kJ compared to 3,000kJ (or 0.01% of the reference population). As for harbour porpoise, this does not alter the overall magnitude of impact for minke whale, with an assessment of minor to moderate adverse (dependent on the cumulative scenario).

Table 33 provides an assessment of the potential worst-case for cumulative potential avoidance / disturbance impacts from underwater noise during piling at Dogger Bank B, including increase in hammer energy for OSP pin-piles and WTG monopiles.

For bottlenose dolphin, white-beaked dolphin, minke whale, and harbour seal, there is no difference, or very insignificant differences, in the CIA assessments (number of marine mammals that could be impacted) for OSP pin-piles with a maximum hammer energy of 1,900kJ or 3,000kJ, or for WTG monopiles with a maximum hammer energy of 3,000kJ or 4,000kJ at Dogger Bank B (

Table 28). For minke whale, there is no difference in the CIA assessment for monopiles with a hammer energy of either 3,000kJ or 4,000kJ.

For harbour porpoise, there is a slight change in the number of individuals at risk of potential avoidance for the OSPs pin-pile with a hammer energy of 1,900kJ or 3,000kJ, and in the number of individuals for a monopile with a hammer energy of 3,000kJ or 4,000kJ. However, the difference between the number of harbour porpoise is small (with an increase of 89 for both pile types; or 0.03% of the reference population). This does not therefore represent a significant difference in the assessment and does not alter the overall magnitude of impacts for harbour porpoise, with an assessment of minor adverse. For grey seal, there is an increase of 2 individuals at risk of disturbance for a monopile hammer energy of 4,000kJ compared to 3,000kJ (or 0.02% of the reference population). As for harbour porpoise, this does not alter the overall magnitude of impact, with an assessment of minor adverse (dependent on the cumulative scenario).

With MMMPs for piling to reduce risk of PTS and MMMPs for UXO, including low-order detonations, the residual impact significance for all marine mammals would be **minor (not significant)**.

As outlined in **Section 5.2.1.1**, the CIA in the ES determined that with mitigation there would be no residual impact for PTS for all cetacean species. For grey seal the cumulative impact significance for PTS was assessed as moderate adverse.

The updated CIA indicates, that, with mitigation, the proposed increase in maximum hammer energy for OSP pin-piles and monopiles for WTG foundations would be the same or less than CIA assessments in the ES that informed the DCO.

Table 32: The potential for avoidance or disturbance cumulative impacts of underwater noise during piling at Dogger Bank A

Project and activity	Maximum number of marine mammals with the potential for avoidance / disturbance impacts					
	Harbour porpoise	Bottlenose dolphin	White-beaked dolphin	Minke whale	Grey seal	Harbour seal
Summary of assessments for piling at DBA						
DBA piling of OSP pin-piles with maximum hammer energy of 1,900kJ or 3,000kJ (SEL_{cum})	559 or **630**	0.003 or **0.003**	0.0002 or **0.0002**	1.5 or **1.5**	0.42 or **0.42**	0.0023 or **0.0023**
DBA piling of WTG monopiles with maximum hammer energy of 3,000kJ or 4,000kJ (SEL_{cum})	746 or **790**	0.003 or **0.003**	0.0002 or **0.0002**	3.1 or **5.6**	2 or **2**	0.01 or **0.01**
Cumulative projects screened in for assessment						
Dogger Bank C (DBC) – UXO ***(high-order detonation with bubble curtain)***	2,003.7 *(262.5)*	0.2 *(0.03)*	0.01 *(0.002)*	460.0 *(22.7)*	1.7 *(0.07)*	1.2 *(0.05)*
Sofia – UXO ***(high-order detonation with bubble curtain)***	2,003.7 *(262.5)*	0.2 *(0.03)*	0.01 *(0.002)*	460.0 *(22.7)*	160.3 *(6.8)*	3.4 *(0.14)*
East Anglia (EA) HUB - Piling or UXO ***(UXO with mitigation)***	Piling: 1,153.3 UXO: 1,369.6 *(179.4)*	N/A	N/A	N/A	Piling: 0.96 UXO: 13.6 *(0.6)*	Piling: 0.48 UXO: 6.8 *(0.3)*
Hornsea Project Three (HP3) - Piling	Piling: 1,687.2	Piling: 0.003	Piling: 0.0002	Piling: 12.0	Piling: 9.6	Piling: 0.96

Project and activity	Maximum number of marine mammals with the potential for avoidance / disturbance impacts					
	Harbour porpoise	Bottlenose dolphin	White-beaked dolphin	Minke whale	Grey seal	Harbour seal
or UXO **_(UXO with mitigation)_**	UXO: 2,003.7 *(262.5)*	UXO: 0.2 *(0.03)*	UXO: 0.01 *(0.002)*	UXO: 460.0 *(22.7)*	UXO: 136.4 *(5.8)*	UXO: 13.6 *(0.6)*
Geophysical surveys (assume two as a worst-case)	454.8 (227.4 per survey)	0.18 (0.09 per survey)	0.012 (0.006 per survey)	6.3 (3.14 per survey)	16.2 (8.1 per survey)	0.82 (0.41 per survey)
Cumulative assessment of DBA piling of OSP pin-piles with maximum hammer energy of 1,900kJ or 3,000kJ – UXO clearance at DBC & Sofia, piling at EA HUB & HP3, and geophysical surveys						
Total number of individuals and % of reference population for OSP pin-piles at DBA, with DBC & Sofia UXO without mitigation, piling at EA HUB & HP3, and geophysical surveys **_[or with bubble curtain at Sofia & DBC]_**	7,932.7 (2.29%) *[4,450.3 (1.28%)]*	0.59 (0.03%) *[0.19 (0.09%)]*	0.03 (0.00007%) *[0.016 (0.00004%)]*	939.8 (4.67%) *[65.2 (0.32%)]*	189.2 (2.18%) *[34.1 (0.39%)]*	6.9 (0.18%) *[2.5 (0.07%)]*
Magnitude of impact	Low *[Low]*	Negligible *[Negligible]*	Negligible *[Negligible]*	Low *[Negligible]*	Low *[Negligible]*	Negligible *[Negligible]*
Sensitivity	Medium	Medium	Medium	Medium	Medium	Medium
Impact significance	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**

Project and activity	Maximum number of marine mammals with the potential for avoidance / disturbance impacts					
	Harbour porpoise	**Bottlenose dolphin**	**White-beaked dolphin**	**Minke whale**	**Grey seal**	**Harbour seal**
Cumulative assessment of DBA piling of OSP pin-piles with maximum hammer energy of 1,900kJ or 3,000kJ – UXO clearance at DBC, Sofia, EA HUB & HP3 and geophysical surveys						
Total number of individuals and % of reference population for OSP pin-piles at DBA, with DBC, Sofia EA HUB & HP3 UXO without mitigation and geophysical surveys ***[or with bubble curtain]***	8,465.5 (2.44%) *[2,051.7 (0.59%)]*	0.78 (0.04%) *[0.22 (0.01%)]*	0.04 (0.0001%) *[0.018 (0.00004%)]*	1,387.8 (6.90%) *[75.9 (0.38%)]*	328.6 (3.79%) *[29.9 (0.34%)]*	25.8 (0.69%) *[1.9 (0.05%)]*
Magnitude of impact	Low *[Negligible]*	Negligible *[Negligible]*	Negligible *[Negligible]*	Medium *[Negligible]*	Low *[Negligible]*	Negligible *[Negligible]*
Sensitivity	Medium	Medium	Medium	Medium	Medium	Medium
Impact significance	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**	**Moderate [Minor]**	**Minor [Minor]**	**Minor [Minor]**
Cumulative assessment of DBA piling of WTG monopiles with maximum hammer energy of 3,000kJ or 4,000kJ – UXO clearance at DBC & Sofia, piling at EA HUB & HP3 and geophysical surveys						
Total number of individuals and % of reference population for WTG monopiles at DBA, with DBC & Sofia UXO without mitigation piling at EA HUB & HP3, and geophysical surveys ***[or with bubble curtain at Sofia &***	8,092.7 (2.33%) *[4,610.3 (1.33%)]*	0.59 (0.03%) *[0.19 (0.009%)]*	0.03 (0.00007%) *[0.016 (0.00004%)]*	943.9 (4.69%) *[69.3 (0.34%)]*	190.8 (2.20%) *[35.6 (0.41%)]*	6.9 (0.18%) *[2.5 (0.07%)]*

Project and activity	Maximum number of marine mammals with the potential for avoidance / disturbance impacts					
	Harbour porpoise	Bottlenose dolphin	White-beaked dolphin	Minke whale	Grey seal	Harbour seal
DBC]						
Magnitude of impact	Low *[Low]*	Negligible *[Negligible]*	Negligible *[Negligible]*	Low *[Negligible]*	Low *[Negligible]*	Negligible *[Negligible]*
Sensitivity	Medium	Medium	Medium	Medium	Medium	Medium
Impact significance	**Minor** **[Minor]**	**Minor** **[Minor]**	**Minor** **[Minor]**	**Minor** **[Minor]**	**Minor** **[Minor]**	**Minor** **[Minor]**
Cumulative assessment of DBA piling of WTG monopiles with maximum hammer energy of 3,000kJ or 4,000kJ – UXO clearance at DBC, Sofia, EA HUB & HP3, and geophysical surveys						
Total number of individuals and % of reference population for WTG monopiles at DBA, with DBC, Sofia EA HUB & HP3 UXO without mitigation, and geophysical surveys ***[or with bubble curtain]***	8,625.5 (2.49%) *[2,211.7 (0.64%)]*	0.78 (0.04%) *[0.2 (0.01%)]*	0.04 (0.0001%) *[0.018 (0.00004%)]*	1,391.9 (6.92%) *[80.0 (0.40%)]*	330.2 (3.81%) *[31.5 (0.36%)]*	25.8 (0.69%) *[1.9 (0.08%)]*
Magnitude of impact	Low *[Negligible]*	Negligible *[Negligible]*	Negligible *[Negligible]*	Medium *[Negligible]*	Low *[Negligible]*	Negligible *[Negligible]*
Sensitivity	Medium	Medium	Medium	Medium	Medium	Medium
Impact significance	**Minor**	**Minor**	**Minor**	**Moderate**	**Minor**	**Minor**

Project and activity	Maximum number of marine mammals with the potential for avoidance / disturbance impacts					
	Harbour porpoise	Bottlenose dolphin	White-beaked dolphin	Minke whale	Grey seal	Harbour seal
	[Minor]	[Minor]	[Minor]	[Minor]	[Minor]	[Minor]
Overall cumulative assessment for DBA						
With MMMPs for piling and UXO, including low-order detonations	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**

Table 33: The potential for increased risk of PTS from cumulative impacts of underwater noise during piling at Dogger Bank B

Project and activity	Maximum number of marine mammals potentially at increased risk of PTS					
	Harbour porpoise	Bottlenose dolphin	White-beaked dolphin	Minke whale	Grey seal	Harbour seal
Summary of assessments for piling at DBB						
DBB piling of OSP pin-piles with maximum hammer energy of 1,900kJ or 3,000kJ (SEL_{cum})	1,243 or **1,332**	0.003 or **0.003**	0.0002 or **0.0002**	5.2 or **5.3**	4.4 or **4.6**	0.22 or **0.23**
DBB piling of WTG monopiles with maximum hammer energy of 3,000kJ or 4,000kJ (SEL_{cum})	1,598 or **1,687**	0.003 or **0.003**	0.0002 or **0.0002**	12 or **12**	22 or **24**	1 or **1**
Cumulative projects screened in for assessment						
East Anglia (EA) HUB - Piling or UXO	Piling: 1,153.3	N/A	N/A	N/A	Piling: 0.96	Piling: 0.48

Project and activity	Maximum number of marine mammals potentially at increased risk of PTS					
	Harbour porpoise	Bottlenose dolphin	White-beaked dolphin	Minke whale	Grey seal	Harbour seal
(UXO with mitigation)	UXO: 1,369.6 *(179.4)*				UXO: 13.6 *(0.6)*	UXO: 6.8 *(0.3)*
Hornsea Project Three (HP3) - Piling or UXO ***(UXO with mitigation)***	Piling: 1,687.2 UXO: 2,003.7 *(262.5)*	Piling: 0.003 UXO: 0.2 *(0.03)*	Piling: 0.0002 UXO: 0.01 *(0.002)*	Piling: 12.0 UXO: 460.0 *(22.7)*	Piling: 9.6 UXO: 136.4 *(5.8)*	Piling: 0.96 UXO: 13.6 *(0.6)*
Hornsea Project Four (HP4) – UXO ***(with mitigation)***	2,003.7 *(262.5)*	0.2 *(0.03)*	0.01 *(0.002)*	460.0 *(22.7)*	238.8 *(10.1)*	16.7 *(0.71)*
Geophysical surveys (assume two as a worst-case)	454.8 (227.4 per survey)	0.18 (0.09 per survey)	0.012 (0.006 per survey)	6.3 (3.14 per survey)	16.2 (8.1 per survey)	0.82 (0.41 per survey)
Cumulative assessment of DBB piling of OSP pin-piles with maximum hammer energy of 1,900kJ or 3,000kJ – UXO clearance at HP4, and piling at EA HUB & HP3						
Total number of individuals and % of reference population for OSP pin-piles at DBB, with HP4 UXO without mitigation and piling at EA HUB & HP3 ***[or with bubble curtain at HP4]***	6,631 (1.9%) *[4,889.8 (1.4%)]*	0.4 (0.02%) *[0.2 (0.01%)]*	0.02 (0.00005%) *[0.01 (0.00003%)]*	483.6 (2.4%) *[46.3 (0.2%)]*	270.2 (3.11%) *[41.5 (0.48%)]*	19.2 (0.5%) *[3.2 (0.09%)]*
Magnitude of impact	Low *[Low]*	Negligible *[Negligible]*	Negligible *[Negligible]*	Low *[Negligible]*	Low *[Negligible]*	Negligible *[Negligible]*

Project and activity	Maximum number of marine mammals potentially at increased risk of PTS					
	Harbour porpoise	Bottlenose dolphin	White-beaked dolphin	Minke whale	Grey seal	Harbour seal
Sensitivity	Medium	Medium	Medium	Medium	Medium	Medium
Impact significance	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**
Cumulative assessment of DBB piling of OSP pin-piles with maximum hammer energy of 1,900kJ or 3,000kJ – UXO clearance at HP4, EA HUB & HP3						
Total number of individuals and % of reference population for OSP pin-piles at DBB, with HP4, EA HUB & HP3 UXO without mitigation ***[or with bubble curtain]***	7,163.8 (2.07%) *[2,491.2 (0.72%)]*	0.6 (0.03%) *[0.2 (0.01%)]*	0.03 (0.00007%) *[0.02 (0.00004%)]*	931.6 (4.6%) *[57 (0.3%)]*	409.6 (4.73%) *[37.3 (0.43%)]*	38.2 (1.02%) *[2.7 (0.07%)]*
Magnitude of impact	Low *[Negligible]*	Negligible *[Negligible]*	Negligible *[Negligible]*	Low *[Negligible]*	Low *[Negligible]*	Low *[Negligible]*
Sensitivity	Medium	Medium	Medium	Medium	Medium	Medium
Impact significance	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**
Cumulative assessment of DBB piling of WTG monopiles with maximum hammer energy of 3,000kJ or 4,000kJ – UXO clearance at HP4, and piling at EA HUB & HP3						
Total number of individuals and % of reference population for WTG	6,986 (2.02%) *[5,244.8*	0.4 (0.02%)	0.02 (0.00005%)	490.3 (2.4%)	289.6 (3.34%)	20.0 (0.5%)

Project and activity	Maximum number of marine mammals potentially at increased risk of PTS					
	Harbour porpoise	Bottlenose dolphin	White-beaked dolphin	Minke whale	Grey seal	Harbour seal
monopiles at DBB, with HP4 UXO without mitigation and piling at EA HUB & HP3 ***[or with bubble curtain at HP4]***	*(1.51%)]*	*[0.2 (0.01%)]*	*[0.01 (0.00003%)]*	*[53 (0.3%)]*	*[60.9 (0.7%)]*	*[4.0 (0.1%)]*
Magnitude of impact	Low *[Low]*	Negligible *[Negligible]*	Negligible *[Negligible]*	Low *[Negligible]*	Low *[Negligible]*	Negligible *[Negligible]*
Sensitivity	Medium	Medium	Medium	Medium	Medium	Medium
Impact significance	**Minor** **[Minor]**	**Minor** **[Minor]**	**Minor** **[Minor]**	**Minor** **[Minor]**	**Minor** **[Minor]**	**Minor** **[Minor]**
Cumulative assessment of DBB piling of WTG monopiles with maximum hammer energy of 3,000kJ or 4,000kJ – UXO clearance at HP4, EA HUB & HP3						
Total number of individuals and % of reference population for WTG monopiles at DBB, with HP4, EA HUB & HP3 UXO without mitigation ***[or with bubble curtain]***	7,518.8 (2.17%) *[2,846.2 (0.82%)]*	0.6 (0.03%) *[0.2 (0.01%)]*	0.03 (0.00007%) *[0.02 (0.00004%)]*	938.3 (4.7%) *[63.7 (0.3%)]*	429.0 (4.95%) *[56.7 (0.65%)]*	38.9 (1.04%) *[3.4 (0.09%)]*
Magnitude of impact	Low *[Negligible]*	Negligible *[Negligible]*	Negligible *[Negligible]*	Low *[Negligible]*	Low *[Negligible]*	Low *[Negligible]*
Sensitivity	Medium	Medium	Medium	Medium	Medium	Medium

Project and activity	Maximum number of marine mammals potentially at increased risk of PTS					
	Harbour porpoise	Bottlenose dolphin	White-beaked dolphin	Minke whale	Grey seal	Harbour seal
Impact significance	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**	**Minor [Minor]**
Overall cumulative assessment for DBB						
With MMMPs for piling and UXO, including low-order detonations	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**	**Minor (not significant)**

5.3 Comparison with HRA

As demonstrated, there is no significant difference in the potential impacts on marine mammals from increasing the maximum hammer energy for the OSP pin-piles from 1,900kJ to 3,000kJ or the maximum hammer energy for the WTG monopiles from 3,000kJ to 4,000kJ. As a result, the conclusions of the HRA (DECC, 2015) which underpin the DCO are not affected and the proposed changes themselves would not have the potential to give rise to likely significant effects on any designated sites with marine mammals as a qualifying feature.

5.4 Comparison with BEIS (2020) RoC HRA

The RoC HRA (BEIS, 2020) reviewed seven OWF consents, including Dogger Bank A and B (formerly Dogger Bank Creyke Beck A and B). The conclusion of the RoC HRA is that the consented offshore wind farms considered will not have an adverse effect on the Southern North Sea SAC either alone or in combination with other plans and projects, provided that the parameters of each wind farm as assessed by the HRA are not exceeded, and that both a MMMP and SIP is a requirement of each project. As this NMC application would alter the parameters assessed within that HRA, a comparison is provided in **Table 34** below, between the outcomes of the BEIS HRA and the updated modelling.

The maximum predicted PTS impact ranges for the updated noise modelling for a maximum hammer energy of 4,000kJ are within the maximum predicted PTS ranges in the BEIS (2020) RoC HRA.

Table 34 Comparison of maximum predicted impact ranges (and areas) for PTS from a single strike (SPL_{peak}) and from cumulative exposure (SEL_{cum}) for updated noise modelling and BEIS (2020) RoC HRA modelling

Receptor	Threshold	Maximum predicted impact range and area			
		Maximum hammer energy of 3,000kJ for monopile	Maximum hammer energy of 4,000kJ for monopile	RoC HRA 3,000kJ for monopile at Creyke Beck A	RoC HRA 3,000kJ for monopile at Creyke Beck B
SPL_{peak} single strike					
Harbour porpoise	unweighted SPL_{peak} 202 dB re 1 µPa	480m (0.71km^2)	520m (0.83km^2)	819m (1.72km^2)	806m (1.8km^2)
Cumulative SEL					
Harbour porpoise	SEL_{cum} Weighted 155 dB re 1 µPa^{2}s	2,200m (13km^2)	2,300m (13km^2)	2,499m (15.55km^2)	2,718m (17.65km^2)

The maximum predicted impact ranges of possible avoidance for the updated noise modelling for a maximum hammer energy of 4,000kJ are greater than the maximum predicted ranges in the BEIS (2020) RoC HRA. However, the maximum impact ranges of possible avoidance for the updated noise modelling for a maximum hammer energy of 3,000kJ are also greater than the maximum predicted ranges in the BEIS (2020) RoC HRA (**Table 35**). These differences reflect differences in the noise modelling as outlined below.

It should be noted that, the current advice from the SNCBs is that:

- A distance of 26km (EDR for monopiles) or 15km (EDR for pin-piles) from an individual percussive piling location should be used to assess the area of SAC habitat harbour porpoise may be disturbed from during piling operations. Therefore, based on current SNCB advice, there is no effect from increasing the hammer energy on the disturbance of harbour porpoise.

Table 35 Comparison of maximum predicted impact ranges (and areas) for possible behavioural response in harbour porpoise for updated noise modelling and (BEIS, 2020) RoC HRA modelling

Receptor	Threshold	Maximum predicted impact range and area			
		Maximum hammer energy of 3,000kJ for monopiles	Maximum hammer energy of 4,000kJ for monopiles	RoC HRA 3,000kJ for monopiles at Creyke Beck A	RoC HRA 3,000kJ for monopiles at Creyke Beck B
Harbour porpoise – possible avoidance	unweighted SEL_{ss} 145 dB re 1 $\mu Pa^2 a$	29km ($1,800km^2$)	30km ($1,900km^2$)	19.87km ($791km^2$)	27.05km ($1,498km^2$)

5.4.1 Overview of differences in the modelling conducted for the RoC HRA and modelling conducted for the Creyke Beck projects

There are several differences in the modelling conducted for the RoC HRA (BEIS, 2020) and modelling conducted for the Dogger Bank A and B projects, these are summarised in **Table 36**.

Table 36 Comparison of the modelling conducted for the RoC HRA and modelling conducted for Dogger Bank A and B

Parameter	BEIS (2020) modelling	Dogger Bank A and B modelling
Propagation Model	Parabolic equation (PE) using RAM for low frequencies. Ray Tracing using Bellhop for high frequencies	INSPIRE semi-empirical model, based on combination of numerical modelling and actual measured data for piling
Noise source	Source spectrum from Ainslie *et al*. (2012) (up to ~25 kHz)	Source spectrum from Subacoustech noise database (up to 100 kHz)
Source levels for 3,000 kJ hammer	247.3 dB re 1 µPa @ 1 m (SPL_{peak}) 221.3 dB re 1 $\mu Pa^2 s$ @ 1 m (SEL_{ss})	241.9 dB re 1 µPa @ 1 m (SPL_{peak}) 222.8 dB re 1 $\mu Pa^2 s$ @ 1 m (SEL_{ss})
Locations	The underwater noise modelling used in the RoC HRA are slightly different from those used in the Subacoustech modelling for Dogger Bank A and B	
Flee speed (cumulative)	1.5 m/s for all species of marine mammal and fish Also includes a consideration for a receptors changes in depth while fleeing	3.25 m/s for LF cetaceans 1.5 m/s for all other species of marine mammal and fish[4]
Piling parameters	Both sets of modelling assume the same pile sizes / blow energies / durations / soft start and ramp up scenarios.	

It should be noted that neither of these methods or assumptions used for modelling are necessarily wrong. Rather, they are different ways to approach the same problem – each have benefits and compromises. The differences in the predicted impact ranges are down to some of the assumptions, in particular the source levels and the type of model used, these are discussed in more detail below.

Source levels

The Genesis modelling used in the RoC HRA predicts source levels that are higher for the SPL_{peak}, and slightly lower than the SEL_{ss} to those used in Subacoustech modelling for the project. This is significant,

[4] The swimming speeds used here reflect what has been used and agreed for other recent assessments.

but it does not always mean that the results are going to always be higher with higher source levels, as the levels at range depend on the prediction of the noise's propagation and absorption as it travels through the water, which is predicated by the model.

Propagation model

The Genesis modelling uses the models RAM and Bellhop for PE and Ray-Tracing solvers. These methods are purely mathematical; for comparison, INSPIRE is a semi-empirical model wherein measured data is used alongside mathematical methods to calculate noise levels.

All the modelling methods mentioned are considered reliable and are often used in the acoustics community; however, they are all different and some may overestimate levels at close range whilst some may underestimate absorption at long ranges.

Summary

To summarise, the single pulse results are likely to be different simply from the use of different models and input parameters. Cumulative results magnify any variations.

In addition, the locations for the underwater noise modelling used in the RoC HRA are slightly different from those used in the Subacoustech modelling for Dogger Bank A and B. This could result in differences in the modelling results, therefore not providing a direct like-for-like comparison.

5.5 European Protected Species (EPS)

All cetaceans (including harbour porpoise) are fully protected in UK waters under the EU Habitats Directive, irrespective of whether they are likely to be present within or outside a SAC. The level of protection is high, and enforced by law, and includes the prevention of disturbance that could have an adverse effect on the population and its conservation status.

The Applicant will obtain a Marine Wildlife Licence from the Marine Management Organisation (MMO) in order to gain licence for the unmitigated disturbance of harbour porpoise (or any other EPS). MMMP

A MMMP is required under Condition 9(e) of the dMLs 1&2 which relate to the generation assets of Dogger Bank A and B, respectively; and Condition 8(e) of dMLs 3&4 which relate to the transmission assets of Dogger Bank A and B, respectively. This is required to ensure that the potential for auditory injury is reduced as far as is possible for marine mammal species. There will be one MMMP covering each project (two MMMPs in total).

As piling at DBA is planned to commence in June 2022, the current version of the DBA MMMP (which was submitted for approval in December 2021), is based on the existing consented maximum hammer energies of 3,000kJ for the monopiles and 1,900kJ for the pin piles. As the proposed increased hammer energies that are being applied for are not yet consented, these will not be reflected in the current version of the DBA MMMP. Therefore, once the NMC is determined by BEIS and if approved, the Projects propose that an addendum to the DBA MMMP is submitted, if required, which will outline any changes in the mitigation measures first included in the MMMP and seek approval of the revised MMMP. Any increase in hammer energies would not be utilised on the Project until the NMC and the updated MMMP has been approved.

The DBB MMMP will be submitted separately at a later date, closer to the time of construction commencing at DBB. The MMMP for DBB will ensure that the injury ranges for the proposed hammer energy increases are considered, and the mitigations designed to mitigate for the impact ranges of the increased hammer energies (of 3,000kJ for OSP pin-piles, and 4,000kJ for monopiles) for all species. In the case that the DBB MMMP is submitted prior to approval being secured on the proposed increase in hammer energy, the same approach will be followed as for DBA MMMP above, and no increase in hammer energy would be utilised on DBB until the NMC and (if required) the revised MMMP, to take account of the increased hammer energies, is approved by the regulator.

5.6 Site Integrity Plan

The Site Integrity Plan (SIP) (Document reference: RE-PM575-RHDHV-00057_03) for the Southern North Sea SAC was produced to discharge Condition 9(h) of dMLs 1 & 2 and Condition 8(h) of dMLs 3 & 4, granted under the Dogger Bank Creyke Beck Offshore Wind Farm Order 2015 (as amended) (the DCO).

The SIP was agreed with the regulators and statutory consultees and was approved by the MMO on 13th September 2021. It sets out the approach to deliver measures for Dogger Bank A and B to ensure the avoidance of significant disturbance of harbour porpoise during piling works in the summer period, in relation to the Southern North Sea SAC Conservation Objectives.

As per guidance from SNCBs and set out above, the SIP is based on EDRs, rather than modelling impact ranges for the consented hammer energy. As such, it is based on an EDR of 26km for monopiles and 15km for pin-piles, regardless of the consented and actual hammer energies to be used. Therefore, the proposed increase in hammer energies would not result in any updates being required to the impact ranges and subsequent assessments in the SIP; and the calculations and conclusions in the approved SIP would remain valid. Consequently, no updates to the SIP will be provided or reapprovals sought, should the NMC be granted.

6 Conclusions

This marine mammal technical report has reviewed and re-modelled the impacts on marine mammals which could arise from the proposed amendments to Dogger Bank A and B on a like for like basis with the currently consented hammer energies. In addition, due to the change in noise thresholds and criteria that have occurred since the projects were consented, an assessment of the potential impacts based on these has also been undertaken

The modelling carried out on a ‘like for like’ basis with the original consent showed that there was no significant difference between the potential impact for a pin-pile maximum hammer energy of 1,900kJ compared to 3,000kJ, and for a monopile maximum hammer energy of 3,000kJ compared to 4,000kJ for permanent auditory injury (PTS), temporary auditory injury (TTS) and likely or possible avoidance for all species, as summarised in **Table 37**. Therefore, the proposed increase in maximum hammer energies for pin-piles and monopiles would not alter the outcomes of the original assessment made within the ES, including the cumulative impact assessment and, where relevant, the HRA.

In addition, the updated underwater noise modelling (provided in **Appendix 2** of the Environmental Report), based on the Southall *et al.* (2019) thresholds and criteria for PTS and TTS and updated density estimates and reference populations, also showed that there is no predicted difference in the potential impacts on marine mammals from increasing the maximum monopile hammer energies to 3,000kJ and 4,000kJ compared to the consented hammer energies of 1,900kJ and 3,000kJ, for pin-piles and monopiles, respectively, as summarised in **Table 38**.

It is therefore concluded that as there is no material difference between the impacts assessed in the ES and those resulting from the proposed amendments to the Projects, the conclusions of the ES and its associated documents are not materially affected by the proposed changes and that the recommendations of the Examining Authority and the conclusions of the HRA which underpin the DCO or the BEIS (2020) RoC HRA, are similarly not affected. The proposed changes do not have the potential to give rise to likely significant effects on any European sites (including the Southern North Sea SAC). Therefore, the proposed amendments to the DCO will not give rise to any new or materially different likely significant effects in relation to marine mammals and no further assessment is required for marine mammals in support of the proposed amendment to the DCO.

Therefore, it is appropriate for the application to amend the maximum hammer energies of pin-piles and monopiles as an NMC to the DCO.

Table 37 Summary of the comparison of the predicted impact ranges, number of marine mammals and % of reference population and impact assessment for maximum hammer energy of 1,900kJ and 3,000kJ for OSP pin-piles, and original ES assessment (note only impact ranges provided in ES)

Species	PTS (instantaneous)			TTS / fleeing response (cumulative)			Behavioural response (cumulative)		
	1,900kJ in ES	1,900kJ	3,000kJ	3,000kJ in ES	1,900kJ	3,000kJ	3,000kJ in ES	1,900kJ	3,000kJ
Harbour porpoise[5]	<550m	360m 0.36 harbour porpoise (0.0001%) Minor adverse No impact with mitigation	430m 0.5 harbour porpoise (0.00014%) Minor adverse No impact with mitigation	4.4km	12.0km 275 harbour porpoise (0.079%) Minor adverse	13.0km 302 harbour porpoise (0.087%) Minor adverse	34.4km	24km 1,155 harbour porpoise (0.33%) Negligible	26km 1,332 harbour porpoise (0.38%) Negligible
	No significant difference in impact ranges			**No significant difference in updated modelling results**			**No significant difference in updated modelling results**		
Bottlenose dolphin[6]	<50m (for mid-frequency cetaceans) Bottlenose dolphin not assessed	<50m 0.0003 bottlenose dolphin (0.000015%) Minor adverse	<50m 0.0003 bottlenose dolphin (0.000015%) Minor adverse No impact with mitigation	<100m (for mid-frequency cetaceans) Bottlenose dolphin not assessed	<100m 0.003 bottlenose dolphin (0.00015%) Minor adverse	<100m 0.003 bottlenose dolphin (0.00015%) Minor adverse	7.5km (for mid-frequency cetaceans) Bottlenose dolphin not assessed	As for TTS	

[5] *based on harbour porpoise density of 0.88/km^2 (Hammond et al., 2021) and reference population (NS MU) of 346,601 (IAMMWG, 2021); updated modelling based on Southall et al. (2019) unweighted criteria for instantaneous PTS (SPL_{peak} 202 dB re 1 µPa) and weighted criteria for TTS from cumulative exposure (SEL_{cum} 140 dB re 1 µPa^{2}s); and Lucke et al. (2009) unweighted criteria for possible avoidance (SEL_{ss} 145 dB re 1 µPa^{2}s)*

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[6] *based on bottlenose dolphin density of 0.0298/km^2 (Hammond et al., 2021) and reference population (GNS MU) of 2,022 (IAMMWG, 2021); updated modelling based on Southall et al. (2019) unweighted criteria for instantaneous PTS (SPL_{peak} 230 dB re 1 µPa) and weighted criteria for TTS from cumulative exposure (SEL_{cum} 170 dB re 1 µPa^{2}s)*

Species	PTS (instantaneous)			TTS / fleeing response (cumulative)			Behavioural response (cumulative)		
	1,900kJ in ES	1,900kJ	3,000kJ	3,000kJ in ES	1,900kJ	3,000kJ	3,000kJ in ES	1,900kJ	3,000kJ
		No impact with mitigation							
	No difference in impact ranges			No difference in impact ranges			As for TTS		
White-beaked dolphin[7]	<50m	<50m 0.00002 white-beaked dolphin (0.00000005%) Minor adverse No impact with mitigation	<50m 0.00002 white-beaked dolphin (0.00000005%) Minor adverse No impact with mitigation	<100m	<100m 0.0002 white-beaked dolphin (0.0000005%) Minor adverse	<100m 0.0002 white-beaked dolphin (0.0000005%) Minor adverse	7.5km	As for TTS	
	No difference in impact ranges			No difference in impact ranges			As for TTS		
Minke whale[8]	<50m	<50m 0.0001 minke whale (0.0000005%) Minor adverse No impact with mitigation	<50m 0.0001 minke whale (0.0000005%) Minor adverse No impact with mitigation	<250m	17km 5.2 minke whale (0.026%) Minor adverse	17km 5.3 minke whale (0.026%) Minor adverse	49km	As for TTS	

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[7] *based on white-beaked dolphin density of 0.002/km^2 (Hammond et al., 2021) and reference population (CGNS MU) of 43,951 (IAMMWG, 2021); updated modelling based on Southall et al. (2019) unweighted criteria for instantaneous PTS (SPL_{peak} 230 dB re 1 µPa) and weighted criteria for TTS from cumulative exposure (SEL_{cum} 170 dB re 1 µPa^{2}s)*

[8] *based on minke whale density of 0.010/km^2 (Hammond et al., 2021) and reference population (CGNS MU) of 20,118 (IAMMWG, 2021); updated modelling based on Southall et al. (2019) unweighted criteria for instantaneous PTS (SPL_{peak} 219 dB re 1 µPa) and weighted criteria for TTS from cumulative exposure (SEL_{cum} 168 dB re 1 µPa^{2}s)*

Species	PTS (instantaneous)			TTS / fleeing response (cumulative)			Behavioural response (cumulative)		
	1,900kJ in ES	1,900kJ	3,000kJ	3,000kJ in ES	1,900kJ	3,000kJ	3,000kJ in ES	1,900kJ	3,000kJ
	No difference in impact ranges			**No difference in updated modelling results**			**As for TTS**		
Grey seal[9]	<100m	50m 0.002 grey seal (0.000023%) Minor adverse No impact with mitigation	50m 0.002 grey seal (0.000023%) Minor adverse No impact with mitigation	<1.5km	3km 4.4 grey seal (0.05%) Minor adverse	3.1km 4.6 grey seal (0.05%) Minor adverse	As for TTS		
	No difference in updated modelling results			**No significant difference in updated modelling results**			**As for TTS**		
Harbour seal[10]	<100m (for pinnipeds) Harbour seal not assessed	50m 0.000098 harbour seal (0.0000026%) Minor adverse No impact with mitigation	50m 0.000098 harbour seal (0.0000026%) Minor adverse No impact with mitigation	<1.5km (for pinnipeds) Harbour seal not assessed	3km 0.22 harbour seal (0.006%) Minor adverse	3.1km 0.23 harbour seal (0.006%) Minor adverse	As for TTS		
	No difference in updated modelling results			**No difference in updated modelling results**			**As for TTS**		

[9] *based on grey seal density of 0.20/km^2 (Russell et al., 2017) and reference population (SE England MU) of 8,667 (SCOS, 2020); updated modelling based on Southall et al. (2019) unweighted criteria for instantaneous PTS (SPL_{peak} 218 dB re 1 µPa) and weighted criteria for TTS from cumulative exposure (SEL_{cum} 170 dB re 1 µPa^{2}s)*

[10] *based on harbour seal density of 0.0098/km^2 (Russell et al., 2017) and reference population (SE England MU) of 3,752 (SCOS, 2020); updated modelling based on Southall et al. (2019) unweighted criteria for instantaneous PTS (SPL_{peak} 218 dB re 1 µPa) and weighted criteria for TTS from cumulative exposure (SEL_{cum} 170 dB re 1 µPa^{2}s)*

Table 38: Summary of the predicted impact ranges, number of marine mammals and % of reference population (based on updated values) and impact assessment for updated assessment of maximum hammer energy of 3,000kJ and 4,000kJ for WTG monopiles, and original ES assessments

Species[11]	PTS (instantaneous)			TTS / fleeing response (cumulative)			Behavioural response (cumulative)		
	3,000kJ in ES	**3,000kJ**	**4,000kJ**	**3,000kJ in ES**	**3,000kJ**	**4,000kJ**	**3,000kJ in ES**	**3,000kJ**	**4,000kJ**
Harbour porpoise	<700m 1 harbour porpoise (0.0004%) No impact with mitigation	480m 0.63 harbour porpoise (0.00018%) Minor adverse No impact with mitigation	520m 0.74 harbour porpoise (0.00021%) Minor adverse No impact with mitigation	5.5km 62 harbour porpoise (0.03%) Negligible	20.0km 649 harbour porpoise (0.19%) Negligible	20.0km 666 harbour porpoise (0.19%) Negligible	43km 2,276 harbour porpoise (0.98%) Negligible	29km 1,598 harbour porpoise (0.5%) Negligible	30km 1,687 harbour porpoise (0.5%) Negligible
	No significant difference in impact ranges			**No significant difference in updated modelling results**			**No significant difference in updated modelling results**		
Bottlenose dolphin	<50m (for mid-frequency cetaceans) Bottlenose dolphin not assessed	<50m 0.0003 bottlenose dolphin (0.000015%) Minor adverse No impact with mitigation	<50m 0.0003 bottlenose dolphin (0.000015%) Minor adverse No impact with mitigation	<150m (for mid-frequency cetaceans) Bottlenose dolphin not assessed	<100m 0.003 bottlenose dolphin (0.00015%) Minor adverse	<100m 0.003 bottlenose dolphin (0.00015%) Minor adverse	9km (for mid-frequency cetaceans) Bottlenose dolphin not assessed	As for TTS	
	No difference in updated modelling results			**No difference in updated modelling results**			**As for TTS**		

[11] See footnotes for Table 37

Species[11]	PTS (instantaneous)			TTS / fleeing response (cumulative)			Behavioural response (cumulative)		
	3,000kJ in ES	3,000kJ	4,000kJ	3,000kJ in ES	3,000kJ	4,000kJ	3,000kJ in ES	3,000kJ	4,000kJ
White-beaked dolphin	<50m 0.00006 white-beaked dolphin (<0.00001%) No impact with mitigation	<50m 0.00002 white-beaked dolphin (0.00000005%) Minor adverse No impact with mitigation	<50m 0.00002 white-beaked dolphin (0.00000005%) Minor adverse No impact with mitigation	<150m 0.0004 white-beaked dolphin (<0.00001%) No impact with mitigation	<100m 0.0002 white-beaked dolphin (0.0000005%) Minor adverse	<100m 0.0002 white-beaked dolphin (0.0000005%) Minor adverse	9km 1.1 white-beaked dolphin (0.006%) Negligible	As for TTS	
	No difference in impact ranges			**No difference in updated modelling results**			**As for TTS**		
Minke whale	<50m 0.00002 minke whale (<0.00001%) No impact with mitigation	<50m 0.0001 minke whale (0.0000005%) Minor adverse No impact with mitigation	<50m 0.0001 minke whale (0.0000005%) Minor adverse No impact with mitigation	<350m 0.0009 minke whale (<0.00001%) No impact with mitigation	28km 12 minke whale (0.06%) Minor adverse	28km 12 minke whale (0.06%) Minor adverse	56km 13 minke whale (0.05%) Negligible	As for TTS	
	No difference in impact ranges			**No difference in updated modelling results**			**As for TTS**		
Grey seal	<150m 0.06 grey seal (<0.0003%) Minor adverse	50m 0.002 grey seal (0.000023%) Minor adverse No impact with mitigation	50m 0.002 grey seal (0.000023%) Minor adverse No impact with mitigation	<1.9km 8.5 grey seal (0.04%) Negligible	7.1km 22 grey seal (0.25%) Minor adverse	7.1km 24 grey seal (0.28%) Minor adverse	As for TTS		

Species[11]	PTS (instantaneous)			TTS / fleeing response (cumulative)			Behavioural response (cumulative)		
	3,000kJ in ES	3,000kJ	4,000kJ	3,000kJ in ES	3,000kJ	4,000kJ	3,000kJ in ES	3,000kJ	4,000kJ
	No difference in updated modelling results			**No difference in updated modelling results**			**As for TTS**		
Harbour seal	<150m (for pinnipeds) Harbour seal not assessed	50m 0.000098 harbour seal (0.0000026%) Minor adverse No impact with mitigation	50m 0.000098 harbour seal (0.0000026%) Minor adverse No impact with mitigation	<1.9km (for pinnipeds) Harbour seal not assessed	7.1km 1 harbour seal (0.027%) Minor adverse	7.1km 1 harbour seal (0.027%) Minor adverse	As for TTS		
	No difference in updated modelling results			**No difference in updated modelling results**			**As for TTS**		

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Annex A – Impact Assessment Methodology

A.1 Value

All marine mammals are considered to have high value in the assessments.

A1.2 Sensitivity

Table A.1: Sensitivity of marine mammals to noise impacts from pile driving

Species	PTS	TTS	Disturbance / fleeing response	Possible avoidance / behavioural reaction
Harbour porpoise	High	Medium	Medium	Low
Bottlenose dolphin	High	Medium	Medium	N/A
White-beaked dolphin	High	Medium	Medium	N/A
Minke whale	High	Medium	Medium	N/A
Grey seal	High	Medium	Medium	N/A
Harbour seal	High	Medium	Medium	N/A

Table A.2: Definition of sensitivity for a marine mammal receptor

Sensitivity	Definition
High	Individual receptor has very limited capacity to avoid, adapt to, tolerate or recover from the anticipated impact.
Medium	Individual receptor has limited capacity to avoid, adapt to, tolerate or recover from the anticipated impact.
Low	Individual receptor has some tolerance to avoid, adapt to, tolerate or recover from the anticipated impact.
Negligible	Individual receptor is generally tolerant to and can tolerate or recover from the anticipated impact.

A1.3 Magnitude

Table A.3: Definitions of magnitude levels for marine mammals

Magnitude	Definition
High	Permanent irreversible change to exposed receptors or feature(s) of the habitat which are of particular importance to the receptor. Assessment indicates that more than 1% of the reference population are anticipated to be exposed to the effect. OR Temporary effect (e.g. limited to the construction phase of development) to the exposed receptors or feature(s) of the habitat which are of particular importance to the receptor.

Magnitude	Definition
	Assessment indicates that more than 10% of the reference population are anticipated to be exposed to the effect.
Medium	Permanent irreversible change to exposed receptors or feature(s) of the habitat of particular importance to the receptor. Assessment indicates that between 0.01% and 1% of the reference population anticipated to be exposed to effect. OR Temporary effect (e.g. limited to the construction phase of development) to the exposed receptors or feature(s) of the habitat which are of particular importance to the receptor. Assessment indicates that between 5% and 10% of the reference population anticipated to be exposed to effect.
Low	Permanent irreversible change to exposed receptors or feature(s) of the habitat of particular importance to the receptor. Assessment indicates that between 0.001% and 0.01% of the reference population anticipated to be exposed to effect. OR Intermittent and temporary effect (e.g. limited to the construction phase of development) to the exposed receptors or feature(s) of the habitat which are of particular importance to the receptor.
Negligible	Permanent irreversible change to exposed receptors or feature(s) of the habitat of particular importance to the receptor. Assessment indicates that less than 0.001% of the reference population anticipated to be exposed to effect. OR Intermittent and temporary effect (limited to the construction phase of development or Project timeframe) to the exposed receptors or feature(s) of the habitat which are of particular importance to the receptor. Assessment indicates that less than 1% of the reference population anticipated to be exposed to effect.

A1.4 Impact significance

Table A.4: Impact significance matrix

Impact significance		Sensitivity			
		High	Medium	Low	Negligible
Magnitude	High	*Major*	*Major*	*Moderate*	*Minor*
	Medium	*Major*	*Moderate*	*Minor*	*Negligible*
	Low	*Moderate*	*Minor*	*Minor*	*Negligible*
	Negligible	*Minor*	*Minor*	*Negligible*	*Negligible*

Potential impacts identified within the assessment as **major or moderate** are regarded as significant in terms of the EIA regulations.

Appendix 2 – Underwater Noise Modelling Report

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Dogger Bank A & B: Underwater noise assessment

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16 December 2021

Subacoustech Environmental Report No. P278R0302

Document No.	*Date*	*Written*	*Approved*	*Distribution*
P278R0301	*30/09/2021*	*R Barham*	*T Mason*	*J Learmonth (HaskoningDHV)*
P278R0302	*16/12/2021*	*R Barham*	*T Mason*	*J Learmonth (HaskoningDHV)*

This report is a controlled document. The report documentation page lists the version number, record of changes, referencing information, abstract and other documentation details.

List of contents

Glossary

Term	Definition
Decibel (dB)	A customary scale commonly used (in various ways) for reporting levels of sound. A difference of 10 dB corresponds to a factor of 10 in sound power. The actual sound measurement is compared to a fixed reference level and the "decibel" value is defined to be $10\log_{10}(actual/reference)$ where $(actual/reference)$ is a power ratio. Because sound power is usually proportional to sound pressure squared, the decibel value for sound pressure is $20\log_{10}(actual\ pressure/reference\ pressure)$. The standard reference for underwater sound is 1 micropascal (µPa). The dB symbol is followed by a second symbol identifying the specific reference value (e.g., re 1 µPa).
Peak pressure	The highest pressure above or below ambient that is associated with a sound wave.
Peak-to-peak pressure	The sum of the highest positive and negative pressures that are associated with a sound wave.
Permanent Threshold Shift (PTS)	A permanent total or partial loss of hearing caused by acoustic trauma. PTS results in irreversible damage to the sensory hair cells of the air, and thus a permanent reduction of hearing acuity
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 is an expression of sound pressure using the decibel (dB) scale; the standard frequency pressures of which are 1 µPa for water and 20 µPa for air.
Temporary Threshold Shift (TTS)	Temporary reduction of hearing acuity because of exposure to sound over time. Exposure to high levels of sound over relatively short time periods could cause the same amount of TTS as exposure to lower levels of sound over longer time periods. The mechanisms underlying TTS are not well understood, but there may be some temporary damage to the sensory cells. The duration of TTS varies depending on the nature of the stimulus.
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. Examples of this are the dB(A), where the overall sound level has been adjusted to account for the hearing ability of humans in air, or the filters used by Southall *et al*. (2019) for marine mammals.

Acronyms

Acronym	Definition
ADD	Acoustic Deterrent Device
HF	High-Frequency Cetaceans (Marine mammal hearing group from Southall *et al*., 2019)
INSPIRE	Impulse Noise Sound Propagation and Range Estimator (Subacoustech's noise model for estimating impact piling noise)
LF	Low-Frequency Cetaceans (Marine mammal hearing group from Southall *et al*., 2019)
NPL	National Physical Laboratory
OWF	Offshore Wind Farm
PCW	Phocid Carnivores in Water (Marine mammal hearing group from Southall *et al*., 2019)
PTS	Permanent Threshold Shift
RMS	Root Mean Square
SE	Sound Exposure
SEL	Sound Exposure Level
SEL_{cum}	Cumulative Sound Exposure Level
SEL_{ss}	Single Strike Sound Exposure Level
SPL	Sound Pressure Level
SPL_{peak}	Peak Sound Pressure Level
$SPL_{pk\text{-}to\text{-}pk}$	Peak-to-peak Sound Pressure Level
SPL_{RMS}	Root Mean Square Sound Pressure Level
TTS	Temporary Threshold Shift
VHF	Very High-Frequency Cetaceans (Marine mammal hearing group from Southall *et al*., 2019)
WTG	Wind Turbine Generator

Units

Unit	Definition
dB	Decibel (sound pressure)
GW	Gigawatt (power)
Hz	Hertz (frequency)
kHz	Kilohertz (frequency)
km	Kilometre (distance)
m	Metre (distance)
ms^{-1}	Metres per second (speed)
Pa^2s	Pascal squared seconds (acoustic energy)
µPa	Micropascal (pressure)

1 Introduction

Dogger Bank A and Dogger Bank B are proposed offshore wind projects in the North Sea and consist of the first two phases of the Dogger Bank Round 3 Offshore Development Zone. As part of the development process, Subacoustech Environmental Ltd. have undertaken detailed underwater noise modelling and analysis using the latest modelling methods, covering the noise from impact piling operations in relation to the marine mammals and fish at Dogger Bank A and B.

Dogger Bank A and B are both located around 131 km from the shore, at its closest point, with Dogger Bank A having a development area of around 515 km^2 and Dogger Bank B having a slightly larger development area of around 599 km^2. Upon completion both sites will each have an installed generation capacity of up to 1.2 GW. The locations of the two sites are shown in Figure 1-1.

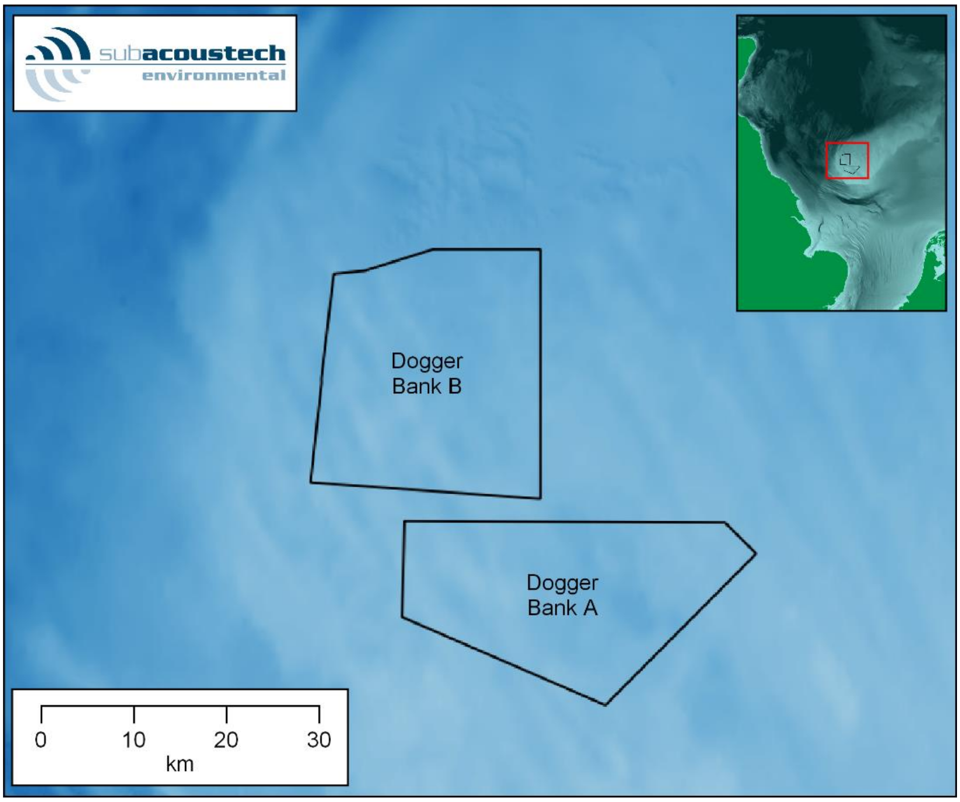

Figure 1-1 Overview map showing the Dogger Bank A and B site boundaries and their location in the North Sea

This report presents a detailed assessment of the potential underwater noise during the impact piling operations at Dogger Bank A and B and its effects, and covers the following:

- A review of background information on the units for measuring and assessing underwater noise and a review of the underwater noise metrics and criteria used to assess the possible environmental effects in marine receptors (Section 2);
- Discussion of the approach, input parameters and assumptions for the detailed noise modelling undertaken (Section 3);
- Presentation and interpretation of the detailed subsea noise modelling for impact piling with regards to the effects on marine mammals and fish using relevant metrics and criteria (Section 4); and
- Summary and conclusions (Section 5)

In addition, further modelling results, covering the noise from the first hammer strike of the piling operations are provided in Appendix A.

2 Background to underwater noise metrics

2.1 Underwater noise

Sound travels much faster in water (approximately 1,500 ms^{-1}) than in air (340 ms^{-1}). Since water is a relatively incompressible, dense medium, the pressure associated with underwater sound tends to be much higher than in air. As an example, background noise levels in the sea of 130 dB re 1 µPa for UK coastal waters are not uncommon (Nedwell *et al*. 2003; Nedwell *et al.* 2007).

It should be noted that stated underwater noise levels should not be confused with noise levels in air, which use a different scale.

2.1.1 Units of measurement

Sound measurements underwater are usually expressed using the decibel (dB) scale, which is a logarithmic measure of sound. A logarithmic scale is used because, rather than equal increments of sound having an equal increase in effect, typically each doubling of sound level will cause a roughly equal increase of "loudness."

Any quantity expressed in this scale is termed a "level." If the unit is sound pressure, expressed on the dB scale, it will be termed a "sound pressure level."

The fundamental definition of the dB scale is given by:

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

where Q is the quantity being expressed on the scale, and Q_{ref} is the reference quantity.

The dB scale represents a ratio. It is therefore used with a reference unit, which expresses the base from which the ratio is expressed. The reference quantity is conventionally smaller than the smallest value to be expressed on the scale so that any level quoted is positive. For example, a reference quantity of 20 µPa is used for sound in air since that is the lower threshold of human hearing.

When used with sound pressure, the pressure value is squared. This is equivalent to expressing the sound as:

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

A doubling in the RMS pressure is therefore equivalent to an increase in sound pressure level of approximately 6 dB.

For underwater sound, a unit of 1 µPa is typically used as the reference unit (P_{ref}); a Pascal is equal to the pressure exerted by one Newton over one square metre, one micropascal equals one millionth of this.

2.1.2 Sound Pressure Level (SPL)

The Sound Pressure Level (SPL) is normally used to characterise noise and vibration of a continuous nature, such as drilling, boring, continuous wave sonar, or background sea and river noise levels. To calculate the SPL, the variation in sound pressure is measured over a specific period to determine the RMS level of the time-varying sound. The SPL can therefore be considered a measure of the average unweighted level of sound over the measurement period.

Where SPL is used to characterise transient pressure waves, such as that from impact piling, seismic airgun or underwater blasting, it is critical that the period over which the RMS level is calculated is quoted. For instance, in the case of a pile strike lasting a tenth of a second, the mean taken over a tenth of a second will be ten times higher than the mean averaged over one second. Often, transient sounds such as these are quantified using "peak" SPLs or Sound Exposure Levels (SELs).

Unless otherwise defined, all SPL noise levels in this report are referenced to 1 µPa.

2.1.3 *Peak Sound Pressure Level (SPL_{peak})*

Peak SPLs are often used to characterise transient sound from impulsive sources, such as percussive impact piling. SPL_{peak} is calculated using the maximum variation of the pressure from positive to zero within the wave. This represents the maximum change in positive pressure (differential pressure from positive to zero) as the transient pressure wave propagates.

A further variation of this is the peak-to-peak SPL ($SPL_{peak\text{-}to\text{-}peak}$) where the maximum variation of the pressure from positive to negative is considered. Where the wave is symmetrically distributed in positive and negative pressure, the peak-to-peak pressure will be twice the peak level, or 6 dB higher (see section 2.1.1).

2.1.4 *Sound Exposure Level (SEL)*

When considering the noise from transient sources, the issue of the duration of the pressure wave is often addressed by measuring the total acoustic energy (energy flux density) of the wave. This form of analysis was used by Bebb and Wright (1953, 1954a, 1954b, 1955), and later by Rawlins (1987), to explain the apparent discrepancies in the biological effect of short and long-range blast waves on human divers. More recently, this form of analysis has been used to develop criteria for assessing injury ranges for fish and marine mammals from various noise sources (Popper *et al*., 2014 and Southall *et al*., 2019).

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

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

where p is the acoustic pressure in Pascals, T is the total duration of the sound in seconds, and t is the time in seconds. The SE is a measurement of acoustic energy and has units of Pascal squared seconds (Pa^2s).

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

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

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

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

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

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

2.2 Analysis of environmental effects

Over the last 20 years there has been increasing interest in noise from human activities in and around underwater environments and how it can have an impact on the marine species in the area. The extent to which intense underwater sound might cause adverse impacts in species is dependent upon the incident sound level, sound frequency, duration of exposure, and/or repetition rate of an impulsive sound (see, for example, Hastings and Popper, 2005). As a result, scientific interest in the hearing abilities of aquatic species has increased. Studies are primarily based on evidence from high level sources of underwater noise such as blasting or impact piling, as these sources are likely to have the greatest immediate environmental impact and therefore the clearest observable effects, although interest in chronic noise exposure is increasing.

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

- Physical traumatic injury and fatality;
- Auditory injury (either permanent (PTS) or temporary (TTS)); and
- Disturbance.

The following sections discuss the underwater noise criteria used in this study with respect to species of marine mammals and fish that may be present at the Dogger Bank A and B sites.

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

- Southall *et al*. (2019) marine mammal noise exposure injury criteria;
- Popper *et al*. (2014) sound exposure guidelines for fishes.

At the time of writing these are the most up to date and authoritative criteria for assessing environmental effects for use in impact assessments. Also included are thresholds presented in Lucke *et al*. (2009) for harbour porpoise TTS and behavioural reaction.

2.2.1 Marine mammals

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

The Southall *et al*. (2019) guidance groups marine mammals into categories of similar species and applies filters to the unweighted noise to approximate the hearing sensitivities of the receptor. The hearing groups given in Southall *et al*. (2019) are summarised in Table 2-1 and Figure 2-1. Further groups for sirenians and other marine carnivores in water are also given, but these have not been used for this study as those species are not commonly found in the North Sea.

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

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

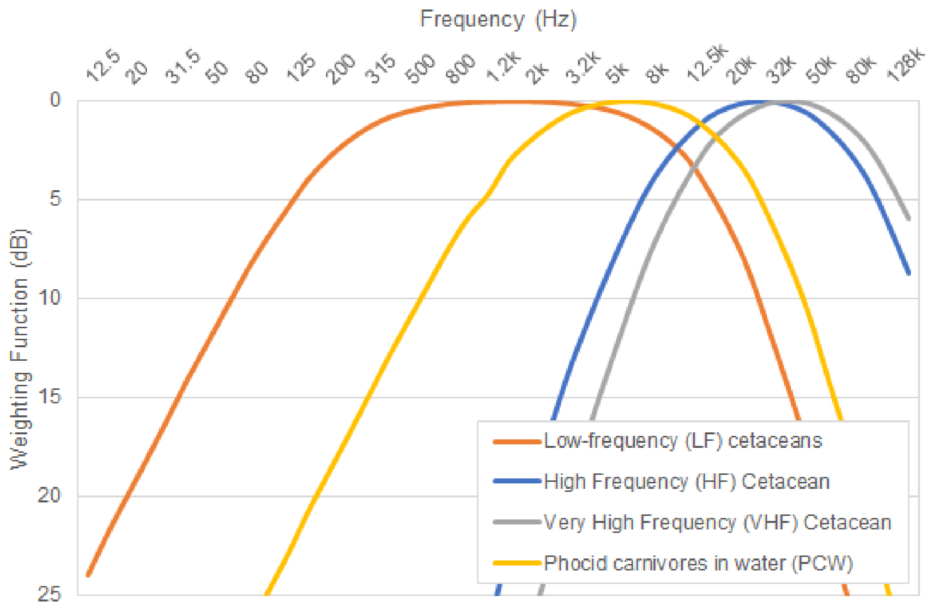

Figure 2-1 Auditory weighting functions for low-frequency cetaceans (LF), high-frequency cetaceans (HD), very high-frequency cetaceans (VHF), and phocid carnivores in water (PCW) (from Southall et al., 2019)

Southall *et al*. (2019) presents single strike, unweighted peak criteria (SPL_{peak}) and cumulative (i.e., more than a single sound impulse) weighted sound exposure criteria (SEL_{cum}) for both permanent threshold shift (PTS), where unrecoverable hearing damage may occur, and temporary threshold shift (TTS), where a temporary reduction in hearing sensitivity may occur in individual receptors.

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

Southall *et al.* (2019)	**Impulsive**			
	Unweighted SPL_{peak} (dB re 1 µPa)		**Weighted SEL_{cum} (dB re 1 µPa²s)**	
	PTS	**TTS**	**PTS**	**TTS**
Low-frequency cetaceans (LF)	219	213	183	168
High-frequency cetaceans (HF)	230	224	185	170
Very high-frequency cetaceans (VHF)	202	196	155	140
Phocid carnivores in water (PCW)	218	212	185	170

Table 2-2 Impulsive criteria for PTS and TTS in marine mammals (Southall et al., 2019)

Where SEL_{cum} are required, a fleeing animal model has been used for marine mammals. This assumes that a receptor, when exposed to high noise levels, will swim away from the noise source. For this, a constant fleeing speed of 3.25 ms^{-1} has been assumed for the low-frequency cetaceans (LF) group (Blix and Folkow, 1995), based on data for minke whale, and for other receptors, a constant rate of 1.5 ms^{-1} has been assumed for fleeing, which is a cruising speed for a harbour porpoise (Otani *et al*., 2000). These are considered worst case assumptions as marine mammals are expected to be able to swim much faster under stress conditions. The fleeing animal model and the assumptions related to it are discussed in more detail in section 3.4.

In addition, values from Lucke *et al*. (2009) have been included to cover aversive behavioural reactions and TTS impacts on harbour porpoises from impulsive noise. The Lucke *et al*. (2009) study exposed harbour porpoises to seismic airgun stimuli and derived noise levels where TTS and an aversive behavioural reaction were documented. These levels have been used for this study in the absence of dedicated behavioural effect data or criteria from impact piling noise and are summarised in Table 2-3.

Lucke *et al*. (2009)	**TTS**	**Aversive behavioural reaction**
Unweighted SPL_{peak} (dB re 1 µPa)	199.7	174
Unweighted SEL_{ss} (dB re 1 µPa^{2}s)	164.3	145

Table 2-3 Unweighted single strike noise levels used for assessments based on data from Lucke et al (2009)

2.2.2 Fish

The large number of, and variation in, fish species leads to a greater challenge in production of a generic noise criterion, or range of criteria, for the assessment of noise impacts. Whereas previous studies applied broad criteria based on limited studies of fish that are not present in UK waters (e.g., McCauley *et al*., 2000) or measurement data not intended to be used as criteria (Hawkins *et al*., 2014), the publication of Popper *et al*. (2014) provides an authoritative summary of the latest research and guidelines for fish exposure to sound and uses categories for fish that are representative of the species present in UK waters.

The Popper *et al*. (2014) study groups species of fish by whether they possess a swim bladder, and whether it is involved in its hearing; a group for fish eggs and larvae is also included. The guidance also gives specific criteria (as both unweighted SPL_{peak} and unweighted SEL_{cum} values) for a variety of noise sources. For this study, criteria for impact piling have been considered. These are summarised in Table 2-4.

Type of animal	**Mortality and potential mortal injury**	**Impairment**	
		Recoverable injury	**TTS**
Fish: no swim bladder	> 219 dB SEL_{cum} > 213 dB peak	> 216 dB SEL_{cum} > 213 dB peak	>> 186 dB SEL_{cum}
Fish: swim bladder is not involved in hearing	210 dB SEL_{cum} > 207 dB peak	203 dB SEL_{cum} > 207 dB peak	> 186 dB SEL_{cum}
Fish: swim bladder involved in hearing	207 dB SEL_{cum} > 207 dB peak	203 dB SEL_{cum} > 207 dB peak	186 dB SEL_{cum}
Sea turtles	> 210 dB SEL_{cum} > 207 dB peak	See Table 2-5	See Table 2-5
Eggs and larvae	> 210 dB SEL_{cum} > 207 dB peak	See Table 2-5	See Table 2-5

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

Where insufficient data are available, especially for lower-level impacts such as behavioural effects, Popper *et al*. (2014) also gives qualitative criteria that summarise the effect of noise as having either a high, moderate or low effect on an individual in either the near-field (tens of metres), intermediate-field (hundreds of metres), or far-field (thousands of metres). These qualitative effects are reproduced in Table 2-5.

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

Table 2-5 Summary of the qualitative effects on species of fish from impact piling noise (Popper et al., 2014) (N = Near-field; I = Intermediate-field; F = Far-field)

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

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

Stationary animal modelling has been included in this study, based on research from Hawkins *et al*. (2014) and other modelling for similar EIA projects. However, basing the modelling on a stationary (zero flee speed) receptor is likely to greatly overestimate the potential risk to fish species, assuming that an individual would remain in the high noise level region of the water column, especially when considering the precautionary nature of the parameters already built into the cumulative exposure calculations.

2.2.2.1 Particle motion

The criteria defined in the above section all define the noise impacts on fishes in terms of sound pressure or sound pressure-associated functions (i.e., SEL). It has been identified by researchers (e.g., Popper and Hawkins (2019), Nedelec *et al*. (2016), Radford *et al.* (2012)) that species of fish, as well as invertebrates, actually detect particle motion rather than pressure. Particle motion describes the back-and-forth movement of a tiny theoretical ‘element’ of water, substrate or other media as a sound wave passes, rather than the pressure caused by the action of the force created by this movement. Particle motion is usually defined in reference to the velocity of the particle (often a peak particle velocity, PPV), but sometimes the related acceleration or displacement of the particle is used. Note that species in the “Fish: swim bladder involved in hearing” category, the most sensitive species in the tables above, are sensitive to sound pressure.

Popper and Hawkins (2018) state that in derivation of the sound pressure-based criteria in Popper *et al.* (2014) it may be the unmeasured particle motion detected by the fish, to which the fish were responding: there is a relationship between particle motion and sound pressure in a medium. This relationship is very difficult to define where the sound field is complex, such as close to the noise source or where there are multiple reflections of the sound wave in shallow water. Even these terms “shallow” and “close” do not have simple definitions.

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

3 Modelling methodology

3.1 Introduction

To estimate the underwater noise levels likely to arise during impact piling operations at Dogger Bank A and B, predictive noise modelling has been undertaken. The methods described in this section, and utilised within this report, meet the requirements set by the NPL Good Practice Guide 133 for underwater noise measurement (Robinson *et al*., 2014).

The modelling of impact piling has been undertaken using the INSPIRE underwater noise model. The INSPIRE model (currently version 5.1) is a semi-empirical underwater noise propagation model based around a combination of numerical modelling, based around a combined geometric and energy flow/hysteresis loss method, and actual measured data. It is designed to calculate the propagation of noise in shallow, mixed water, typical of the conditions around the UK and very well suited to the region around AyM. The model has been tuned for accuracy using over 80 datasets of underwater noise propagation from monitoring around offshore piling activities.

The model provides estimates of unweighted SPL_{peak}, SEL_{ss}, and SEL_{cum} noise levels, as well as various other weighted noise metrics. Calculations are made along 180 equally spaced radial transects (one every two degrees). For each modelling run a criterion level can be specified allowing a contour to drawn, within which a given effect may occur. These results can then be plotted over digital bathymetry data so that impact ranges can be clearly visualised, as necessary. INSPIRE also produces these contours as GIS shapefiles.

INSPIRE considers a wide array of input parameters, including variations in bathymetry and source frequency to ensure accurate results are produced specific to the location and nature of the piling operation. It should also be noted that the results should be considered conservative as maximum design parameters and worst-case assumptions have been selected for:

- Piling hammer blow energies;
- Soft start, ramp up profile, and strike rate;
- Total duration of piling; and
- Receptor swim speeds.

3.2 Modelling confidence

INSPIRE is semi-empirical and thus a validation process is inherently built into the development process. Whenever a new set of good, reliable impact piling measurement data is gathered through offshore surveys it is compared against the outputted levels from INSPIRE and, if necessary, the model can be adjusted accordingly. Currently over 80 separate impact piling noise datasets from all around the UK have been used as part of the development for the latest version of INSPIRE, and in each case, an average fit is used.

In addition, INSPIRE is also validated by comparing the noise levels outputted from the model with measurements and modelling undertaken by third parties, as well as in Thompson *et al.* (2013).

The current version of INSPIRE (version 5.1) is the product of re-analysing all the impact piling noise measurements in Subacoustech Environmental's measurement database and cross-referencing it with blow energy data from piling logs. This gave a database of single strike noise levels referenced to a specific blow energy at a specific range. This analysis showed that, based on the most up to date measurement data for large piles at high blow energies, the previous versions of INSPIRE tended to overestimate the predicted noise levels at these blow energies.

Previous iterations of the INSPIRE model have endeavoured to give a worst-case estimate of underwater noise levels produced by impact piling. There is always some natural variability with underwater noise measurements, even when considering measurements of pile strikes under the same conditions, i.e., at the same blow energy, taken at the same range. For example, there can be variations in noise level of up to five or even 10 dB, as seen in Bailey *et al*. (2010) and the data shown in Figure 3-1. When modelling using the upper bounds of this range, in combination with other worst case parameter selections, conservatism can be compounded and create excessively overcautious predictions, especially when calculating SEL_{cum}. With this in mind, the current version of the INSPIRE model attempts to calculate closer to the average fit of the measured noise levels at all ranges.

Figure 3-1 presents a small selection of measured impact piling noise data plotted against outputs from INSPIRE. The plots show data points from measured data (in blue) plotted alongside modelled data (in orange) using INSPIRE version 5.1, matching the pile size, blow energy and range from the measured data. These show the fit to the data, with the INSPIRE model data points sitting, more or less, in the middle of the measured noise levels at each range. When combined with the worst-case assumptions in parameter selection, modelled results will remain precautionary.

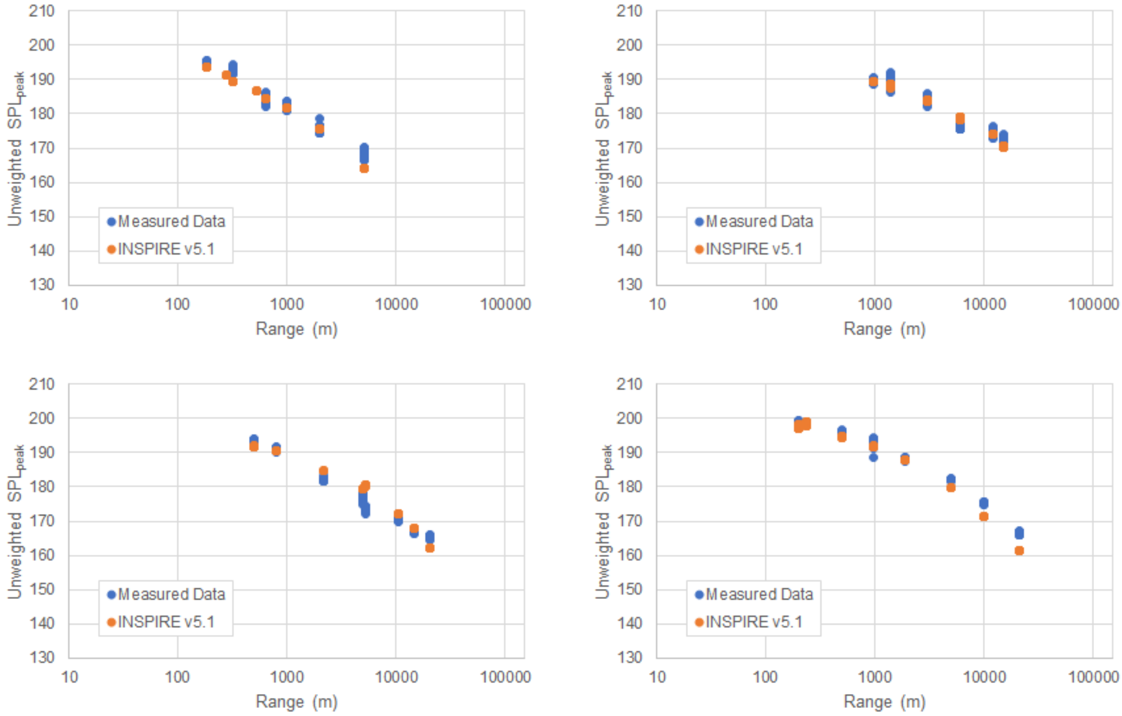

Figure 3-1 Comparison between example measured impact piling data (blue points) and modelled data using INSPIRE version 5.1 (orange points)

Top Left: 1.8 m pile, Irish Sea, 2010; Top Right: 9.5 m pile, North Sea, 2020; Bottom Left: 6.1 m pile, Southern North Sea, 2009; Bottom Right: 6 m pile, Southern North Sea, 2009.

3.3 Modelling parameters

3.3.1 Modelling locations

Modelling for WTG foundation impact piling has been undertaken at four representative locations across the two sites (two locations at each site) covering the site extents and various water depths. The modelling locations are:

- Dogger Bank A – North (N) location;
- Dogger Bank A – South West (SW) location;
- Dogger Bank B – North West (NW) location; and
- Dogger Bank B – South East (SE) location.

These locations are summarised in Table 3-1 and illustrated in Figure 3-2.

Modelling locations	Dogger Bank A		Dogger Bank B	
	North (N)	South West (SW)	North West (NW)	South East (SE)
Latitude	54.8279° N	54.7405° N	55.0733° N	54.8902° N
Longitude	001.7932° E	001.7430° E	1.5056° E	1.8157° E
Water depth (mean tide)	20.1 m	22.7 m	24.1 m	22.9 m

Table 3-1 Summary of the underwater noise modelling locations at Dogger Bank A and B.

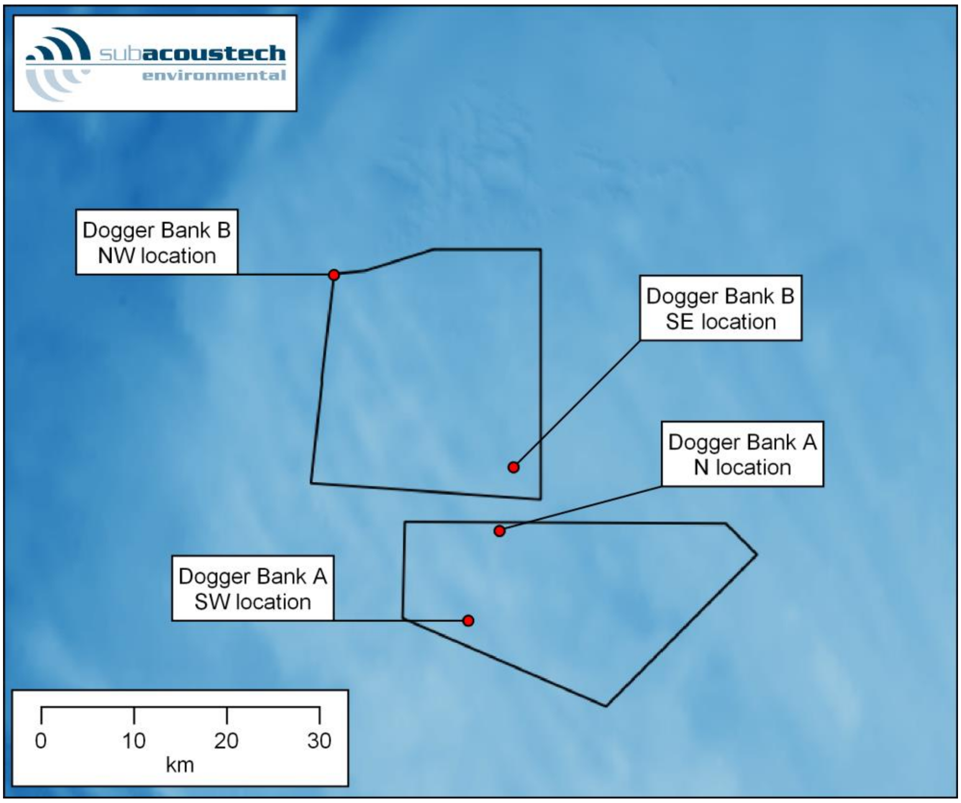

Figure 3-2 Approximate locations of the modelling locations at Dogger Bank A and B

3.3.2 WTG foundation impact piling parameters

Six piling scenarios covering both monopile and multi-leg (pin pile) foundations for WTGs have been considered, the modelled scenarios are as follows:

- Scenario 1 – Absolute worst-case monopile – up to 10 m in diameter, using a maximum blow energy of 4,000 kJ, with a maximum of two foundations installed in a 24-hour period;
- Scenario 2 – Worst-case monopile – up to 10 m in diameter, using a maximum blow energy of 3,000 kJ, with a maximum of two foundations installed in a 24-hour period;
- Scenario 3 – Most likely monopile – up to 10 m in diameter, using a maximum blow energy of 880 kJ, with a maximum of two foundations installed in a 24-hour period;
- Scenario 4 – Absolute worst-case pin pile – up to 2.438 m in diameter, using a maximum blow energy of 3,000 kJ, with a maximum of four foundations installed in a 24-hour period;
- Scenario 5 – Worst-case pin pile – up to 2.438 m in diameter, using a maximum blow energy of 2,400 kJ, with a maximum of four foundations installed in a 24-hour period; and
- Scenario 6 – Most likely pin pile – up to 2.438 m in diameter, using a maximum blow energy of 1,900 kJ, with a maximum of four foundations installed in a 24-hour period.

The worst-case and absolute worst-case scenarios consider the maximum possible piling durations and blow energies at the end of the ramp up, which may prove to be unrealistic due to hammer capacity, pile fatigue, or other on-site practicalities.

For SEL_{cum}, the soft start and ramp up of blow energies along with the total duration and strike rate must also be considered; these are summarised in Table 3-2 to Table 3-7.

In a 24-hour period it is expected that up to two monopiles or four pin pile foundations can be installed; this is included as part of the modelling, assuming that the foundation piles are installed consecutively.

Scenario 1: Absolute worst-case monopile	400 kJ	880 kJ	1,320 kJ	2,640 kJ	4,000 kJ	Maximum 2 piles installed in 24 hours
Number of strikes	110	804	3,472	90	1,571	
Duration	11 mins	27 mins	87 mins	2 mins	37 mins	
Strike rate (str/min)	10	~30	~40	45	~42	

Table 3-2 Soft start and ramp up parameters used for scenario 1, absolute worst-case monopile, including a total of 6,047 strikes over 2 hours 44 minutes (increased to 12,094 strikes and 5 hours 28 minutes when considering two piles installed in 24 hours)

Scenario 2: Worst-case monopile	300 kJ	880 kJ	1,320 kJ	2,640 kJ	3,000 kJ	Maximum 2 piles installed in 24 hours
Number of strikes	110	804	3,472	90	1,571	
Duration	11 mins	27 mins	87 mins	2 mins	37 mins	
Strike rate (str/min)	10	~30	~40	45	~42	

Table 3-3 Soft start and ramp up parameters used for scenario 2, worst-case monopile, including a total of 6,047 strikes over 2 hours 44 minutes (increased to 12,094 strikes and 5 hours 28 minutes when considering two piles installed in 24 hours)

Scenario 3: Most likely monopile	300 kJ	400 kJ	880 kJ	Maximum 2 piles installed in 24 hours
Number of strikes	102	2,179	1,046	
Duration	10 mins	73 mins	35 mins	
Strike rate (str/min)	~10	~30	~30	

Table 3-4 Soft start and ramp up parameters used for scenario 3, most likely monopile, including a total of 3,327 strikes over 1 hour 58 minutes (increased to 6,654 strikes and 3 hours 56 minutes when considering two piles installed in 24 hours)

Scenario 4: Absolute worst-case pin pile	320 kJ	850 kJ	1,500 kJ	3,000 kJ	Maximum 4 piles installed in 24 hours
Number of strikes	60	1,800	400	3,560	
Duration	10 mins	78 mins	17 mins	155 mins	
Strike rate (str/min)	6	~23	~23	~23	

Table 3-5 Soft start and ramp up parameters used for scenario 4, absolute worst-case pin pile, including a total of 5,820 strikes over 4 hours 20 minutes (increased to 11,640 strikes and 17 hours 20 minutes when considering four piles installed in 24 hours)

Scenario 5: Worst-case pin pile	320 kJ	850 kJ	1,500 kJ	2,400 kJ	Maximum 4 piles installed in 24 hours
Number of strikes	60	1,800	400	3,560	
Duration	10 mins	78 mins	17 mins	155 mins	
Strike rate (str/min)	6	~23	~23	~23	

Table 3-6 Soft start and ramp up parameters used for scenario 5, worst-case pin pile, including a total of 5,820 strikes over 4 hours 20 minutes (increased to 11,640 strikes and 17 hours 20 minutes when considering four piles installed in 24 hours)

Scenario 6: Most likely pin pile	300 kJ	850 kJ	1,500 kJ	1,900 kJ	Maximum 4 piles installed in 24 hours
Number of strikes	60	1800	400	3,560	
Duration	10 mins	78 mins	17 mins	155 mins	
Strike rate (str/min)	6	~23	~23	~23	

Table 3-7 Soft start and ramp up parameters used for scenario 6, most likely pin pile, including a total of 5,820 strikes over 4 hours 20 minutes (increased to 11,640 strikes and 17 hours 20 minutes when considering four piles installed in 24 hours)

3.3.3 Source levels

Noise modelling requires knowledge of the source level, which is the theoretical noise level at one metre from the noise source. The INSPIRE model assumes that the noise source – the hammer striking the pile – acts as an effective single point, as it will appear at a distance. The source level is estimated based on the pile diameter and the blow energy imparted on the pile by the hammer. This is adjusted depending on the water depth at the modelling location to allow for the length of pile in contact with the water, which can affect the amount of noise that is transmitted from the pile into its surroundings.

It is worth noting that the 'source level' technically does not exist in the context of many shallow water noise sources (Heaney *et al*. 2020). In practice, in underwater noise modelling such as this, it is effectively an 'apparent source level' and simply a value that can be used to produce correct noise levels at range (for a specific model), as required in impact assessments.

The estimated unweighted, single strike SPL_{peak} and SEL_{ss} source levels used for this study are provided in Table 3-8 and Table 3-9. These figures are presented in accordance with typical requests by regulatory authorities, although as indicated above they are not necessarily compatible or comparable with any other model or source levels predicted under different contexts or techniques.

SPL_{peak} source levels (dB re 1 µPa @ 1 m)		Dogger Bank A		Dogger Bank B	
		N	SW	NW	SE
Monopile	Scenario 1	242.4	242.4	242.4	242.4
	Scenario 2	241.9	241.9	241.9	241.9
	Scenario 3	237.8	237.8	237.8	237.8
Pin pile	Scenario 4	240.9	241.0	241.0	241.0
	Scenario 5	240.4	240.5	240.5	240.5
	Scenario 6	239.8	239.9	239.9	239.9

Table 3-8 Summary of the unweighted SPL_{peak} source levels used for modelling

SEL_{ss} source levels (dB re 1 µPa^{2}s @ 1 m)		Dogger Bank A		Dogger Bank B	
		N	SW	NW	SE
Monopile	Scenario 1	223.4	223.5	223.5	223.5
	Scenario 2	222.8	222.8	222.8	222.8
	Scenario 3	218.6	218.6	218.6	218.6
Pin pile	Scenario 4	221.1	221.2	221.3	221.2
	Scenario 5	220.5	220.6	220.7	220.6
	Scenario 6	219.8	219.9	220.0	219.9

Table 3-9 Summary of the unweighted single strike SEL source levels used for modelling

3.3.4 Environmental conditions

With the inclusion of measured noise propagation data for similar offshore piling operations in UK waters, the INSPIRE model intrinsically accounts for various environmental conditions. This includes the differences that can occur with the temperature and salinity of the water, as well as the sediment type surrounding the site. Data from the British Geological Survey show that the seabed surrounding the Dogger Bank sites is generally made up predominantly of sand and some areas of gravel and gravelly sand.

Digital bathymetry, from the European Marine Observation and Data Network (EMODnet), has been used for this modelling. Mean tidal depth has been used throughout.

3.4 Cumulative SELs and fleeing receptors

Expanding on the information in section 2.2 regarding SEL_{cum} and the fleeing animal model used for modelling, it is important to understand the meaning of the results presented in the following sections.

When an SEL_{cum} impact range is presented for a fleeing animal, this range can essentially be considered a starting position (at commencement of piling) for the fleeing animal receptor. For example, if a receptor starting at the position denoted on a modelled PTS contour began to flee, in a straight line away from the noise source, the receptor would receive exactly the noise exposure as per the PTS criterion under consideration.

To help explain this, it is helpful to examine how the multiple pulse SEL_{cum} ranges are calculated. As described in section 2.1.4, the SEL_{cum} is a measure of the total received noise over the whole piling operation: in the case of the Southall *et al*. (2019) and Popper *et al*. (2014) criteria this covers any piling in a 24-hour period.

When considering a stationary receptor (i.e., a receptor that stays at the same position throughout piling) calculating the SEL_{cum} is relatively straightforward: all the noise pulses produced during the piling event and received at a single point along the transect are aggregated to calculate the SEL_{cum}. If this calculated level is greater than the threshold being modelled, the model steps away from the noise source and the noise levels from that new location are aggregated to calculate the new SEL_{cum}. This continues outward until the threshold is met.

For a fleeing animal, the receptor's distance from the noise source while moving away also needs to be considered. To model this, a starting point close to the source is chosen, and then the received noise level for each pile strike while the receptor is fleeing is noted. For example, if a pile strike occurs every six seconds and an animal is fleeing at a rate of 1.5 ms^{-1}, it is 9 m further from the source after each subsequent pile strike, resulting in a slightly reduced received noise level with each strike. These values are then aggregated into an SEL_{cum} over the entire piling period. The faster an animal is fleeing the greater the distance travelled between each pile strike. The impact range outputted by the model for this situation is the distance the receptor must be at the start of piling to exactly meet the exposure threshold.

The graphs in Figure 3-3 and Figure 3-4 show the difference in the SEL received by a stationary receptor and a fleeing receptor travelling at a constant speed of 1.5 ms^{-1}, using the Scenario 1 parameters for the absolute worst case monopile (Table 3-2). This was carried out for a single deep water monopile installation at the N location of Dogger Bank A, as an example.

The received SEL_{ss} from the stationary receptor, as illustrated in Figure 3-3, shows the noise level gradually increasing as the blow energy increases throughout the piling operation. These step changes are also visible for the fleeing receptor, but as the receptor is further from the source by the time the levels increase, the total received exposure is reduced, resulting in progressively lower received noise levels. For example, after the first 11 minutes where the blow energy is 400 kJ, the receptor fleeing at 1.5 ms^{-1} will have already moved 990 m from the start position. After the full piling duration of 2 hours 44 minutes, the receptor will be over 14 km from the pile.

Figure 3-4 shows the effect these different received levels have when calculating the SEL_{cum}. It clearly shows the difference in cumulative effect of the receptor remaining still as opposed to fleeing. To use an extreme example, starting at a range of 1 m, the first strike results in a received level of 214.4 dB re 1 μPa^2s. If the receptor were to remain stationary throughout the 2 hours 44 minutes of piling it would receive a cumulative received level of 259.0 dB re 1 μPa^2s, whereas fleeing at 1.5 ms^{-1} over the same piling scenario would result in a cumulative received level of just 215.0 dB re 1 μPa^2s.

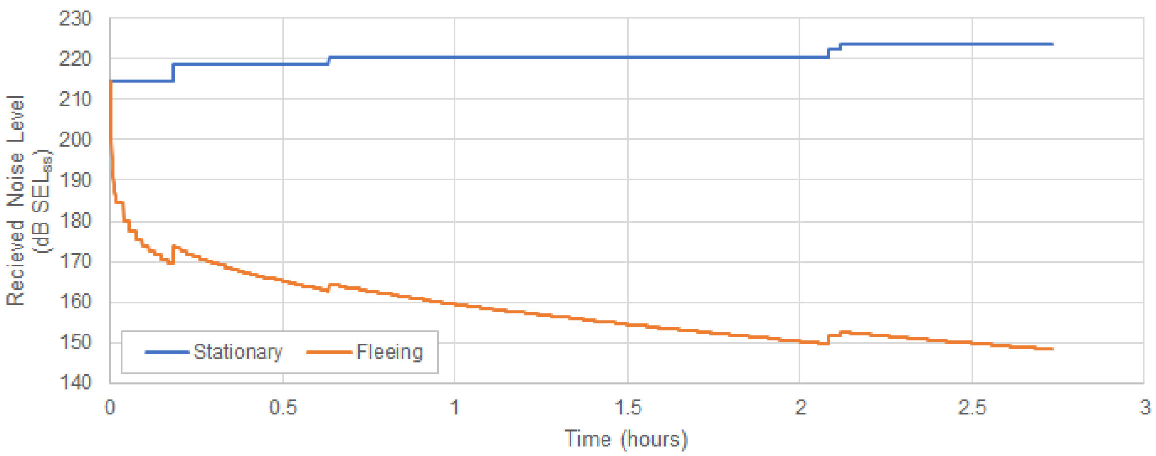

Figure 3-3 Received single strike noise levels (SEL_{ss}) for receptors during Scenario 1 (absolute worst-case monopile parameters) at the N location in Dogger Bank A, assuming both a stationary and fleeing receptor starting at a location 1 m from the noise source

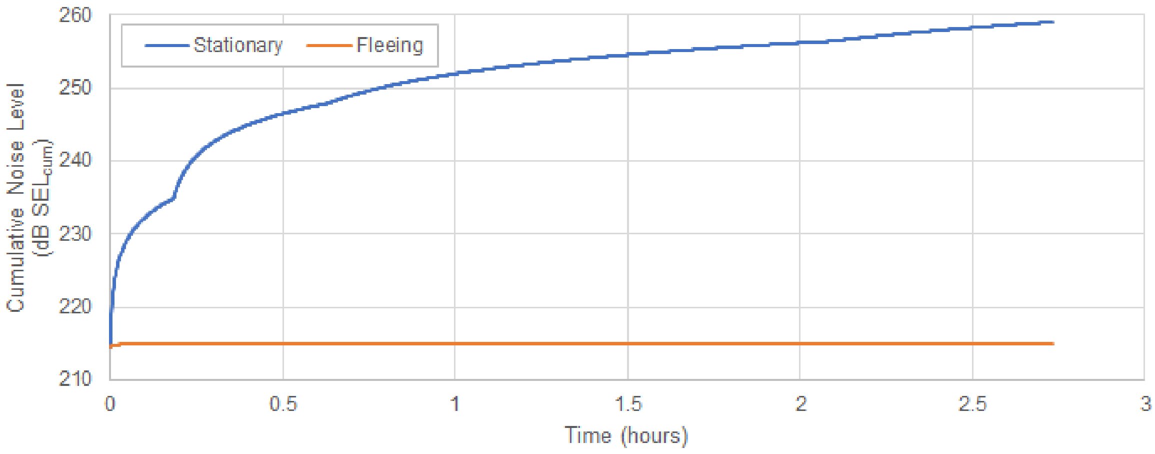

Figure 3-4 Cumulative received noise levels (SEL_{cum}) for receptors during Scenario 1 (absolute worst-case monopile parameters) at the N location in Dogger Bank A, assuming both a stationary and fleeing receptor starting at a location 1 m from the noise source

In summary, if the receptor were to start fleeing in a straight line from the noise source starting at a range closer than the modelled value, it would receive a noise exposure above the criteria, and if the receptor were to start fleeing from a range further than the modelled value it would receive a noise exposure below the criteria. This is illustrated in Figure 3-5.

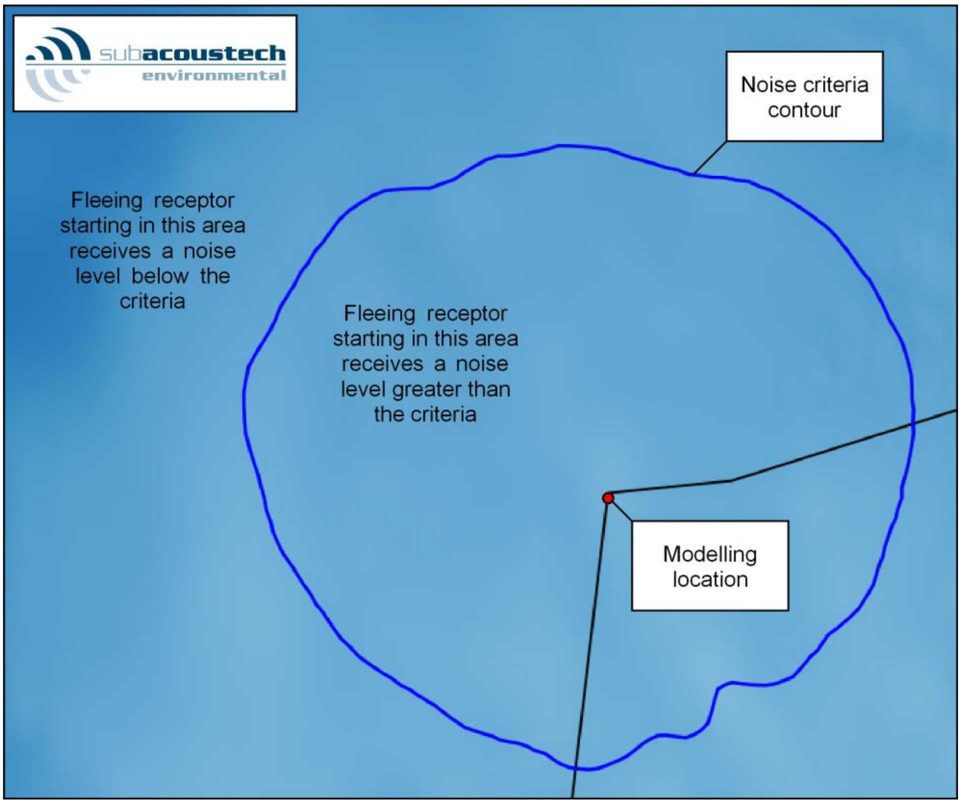

Figure 3-5 Example plot showing a fleeing animal SEL_{cum} criteria contour and the areas where the cumulative noise level will exceed the impact criteria

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

3.4.1 The effects of impact parameters on cumulative SELs and fleeing receptors

As discussed in section 3.3, parameters such as water depth, hammer blow energies, piling ramp up, strike rate and duration all influence predicted noise levels. When considering SEL_{cum} and a fleeing animal model, some of these parameters can have a greater influence than others.

Parameters like hammer blow energy can have a clear effect on impact ranges, with higher energies resulting in higher source noise levels and therefore larger impact ranges. When considering cumulative noise levels, these higher levels are compounded sometimes thousands of times due to the number of pile strikes. With this in mind, the ramp up in piling energy requires careful consideration for fleeing animals, as the levels while the receptors are relatively close to the noise source will have a greater effect on the overall cumulative exposure level than those occurring later.

Figure 3-6 summarises the hammer blow energy ramp up for the six modelled cumulative scenarios, showing how the monopile scenarios reach a higher blow energy over a greater total duration, as well as the effect of multiple consecutive piling operations. For a precautionary modelling prediction, it is assumed that subsequent piles follow on directly from the previous pile with no pause.

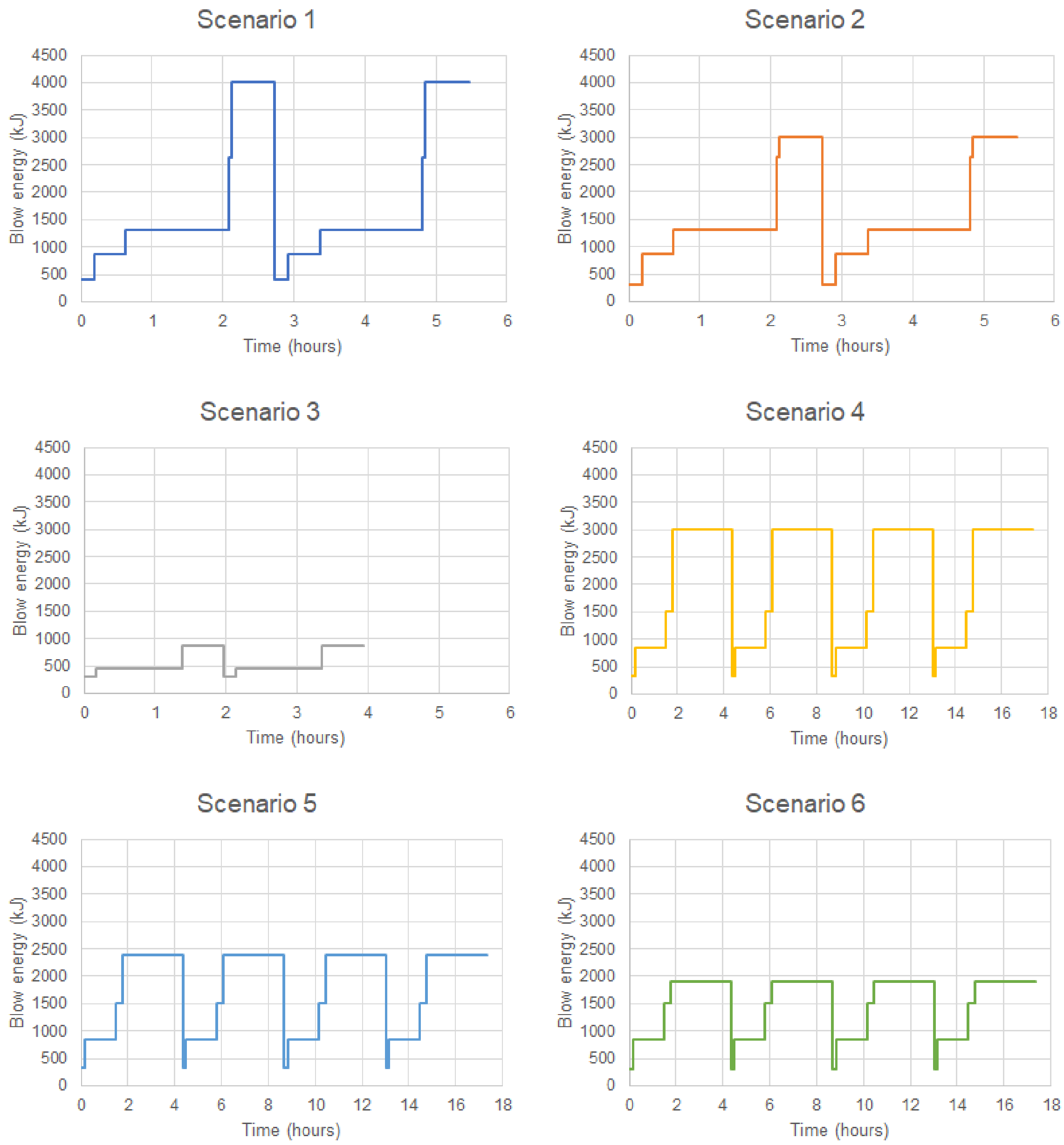

Figure 3-6 Graphical representation of the blow energies for the modelling scenarios

Linked to the effect of the ramp up is the strike rate, as the more strikes that occur while the receptor is close to the noise source, the greater the exposure and the greater effect it will have on the SEL_{cum}. The faster the strike rate, the shorter the distance the receptor can flee between each pile strike, which leads to greater exposure. Figure 3-7 shows the strike rate against time for the modelling scenarios. Two of the monopile scenarios (Scenarios 1 and 2) utilise the same strike rate parameters, as do all the pin pile scenarios (Scenarios 4, 5 and 6). Scenario 3 maintains a constant 30 strikes per minute outside of soft start.

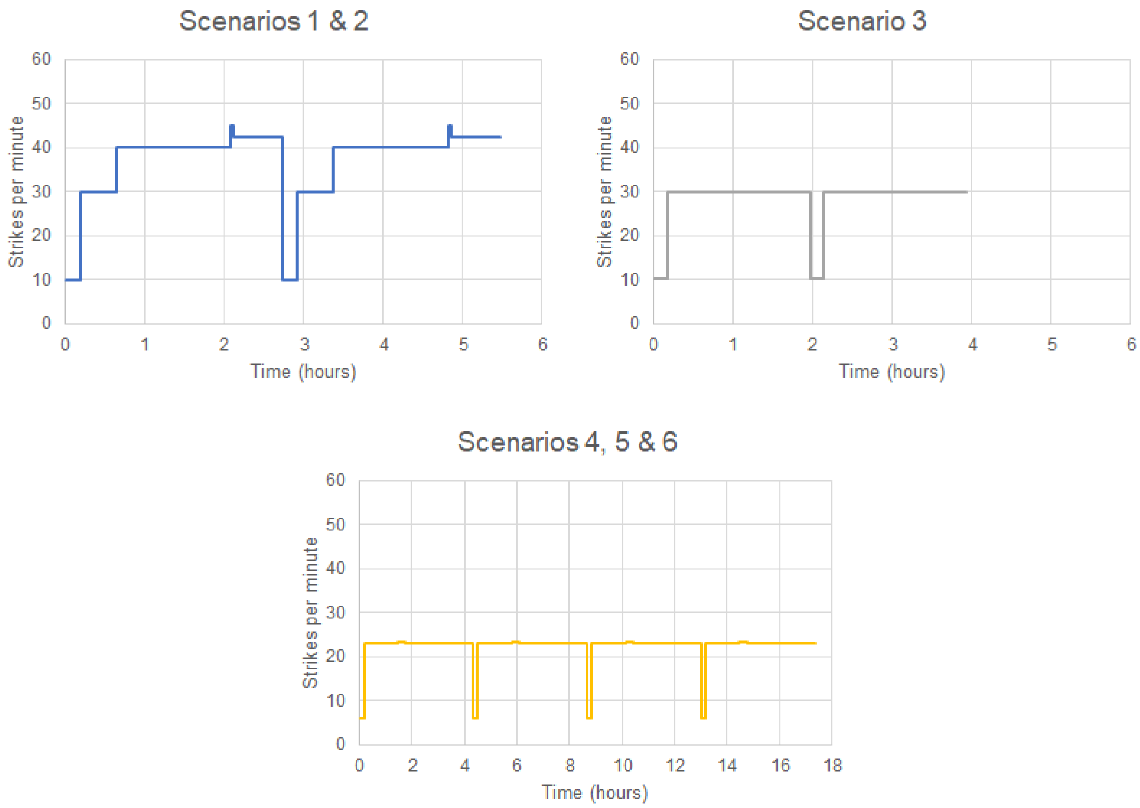

Figure 3-7 Graphical representation of the strike rate for the modelling scenarios

4 Modelling results

The following sections present the modelled impact ranges for impact piling noise as unweighted contour plots (section 4.1), and impact ranges. The impact ranges are split into the Southall *et al*. (2019) and Lucke *et al*. (2009) marine mammal criteria (sections 4.2 and 4.3), and the Popper *et al*. (2014) fish criteria (section 4.4), with subsections covering the six sets of parameters.

Further modelling covering the calculated impact ranges following only the first strike of the piling operation are presented in Appendix A (section A.1) of this report.

To aid navigation, Table 4-1 and Table 4-2 contain a complete list of the modelling figures and impact range tables. Section 4.1 only contains the unweighted SPL_{peak} noise plots for the N modelling location at Dogger Bank A; figures for the other locations and unweighted SEL_{ss} noise are presented in Appendix A (section A.1).

For the results presented throughout this section, any predicted ranges smaller than 50 m and areas less than 0.01 km^2 for single strike criteria and ranges smaller than 100 m and areas less than 0.1 km^2 for cumulative criteria, have not been presented. At ranges this close to the noise source, the modelling processes are unable to model to a sufficient level of accuracy due to acoustic effects near the pile. In these circumstances, ranges are given as "less than" this limit.

The largest ranges are predicted for the Scenario 1 (absolute worst-case monopile) parameters at the NW modelling location in Dogger Bank B due to the louder source levels predicted for Scenario 1 and the deeper water present to the north and west of Dogger Bank B boundary.

Figure (section; page)	Location		Parameters	Metric
Figure 4-1 (4.1; p24)	Dogger Bank A	N	Scenario 1 (Absolute worst-case monopile)	SPL_{peak}
Figure A 1 (A.1; p61)				SEL_{ss}
Figure A 2 (A.1; p62)		SW		SPL_{peak}
Figure A 3 (A.1; p62)				SEL_{ss}
Figure A 4 (A.1; p63)	Dogger Bank B	NW		SPL_{peak}
Figure A 5 (A.1; p63)				SEL_{ss}
Figure A 6 (A.1; p64)		SE		SPL_{peak}
Figure A 7 (A.1; p64)				SEL_{ss}
Figure 4-2 (4.1; p25)	Dogger Bank A	N	Scenario 2 (Worst-case monopile)	SPL_{peak}
Figure A 8 (A.1; p65)				SEL_{ss}
Figure A 9 (A.1; p65)		SW		SPL_{peak}
Figure A 10 (A.1; p66)				SEL_{ss}
Figure A 11 (A.1; p66)	Dogger Bank B	NW		SPL_{peak}
Figure A 12 (A.1; p67)				SEL_{ss}
Figure A 13 (A.1; p67)		SE		SPL_{peak}
Figure A 14 (A.1; p68)				SEL_{ss}
Figure 4-3 (4.1; p25)	Dogger Bank A	N	Scenario 3 (Most likely monopile)	SPL_{peak}
Figure A 15 (A.1; p68)				SEL_{ss}
Figure A 16 (A.1; p69)		SW		SPL_{peak}
Figure A 17 (A.1; p69)				SEL_{ss}
Figure A 18 (A.1; p70)	Dogger Bank B	NW		SPL_{peak}
Figure A 19 (A.1; p70)				SEL_{ss}
Figure A 20 (A.1; p71)		SE		SPL_{peak}
Figure A 21 (A.1; p71)				SEL_{ss}
Figure 4-4 (4.1; p26)	Dogger Bank A	N	Scenario 4 (Absolute worst-case pin pile)	SPL_{peak}
Figure A 22 (A.1; p72)				SEL_{ss}
Figure A 23 (A.1; p72)		SW		SPL_{peak}
Figure A 24 (A.1; p73)				SEL_{ss}
Figure A 25 (A.1; p73)	Dogger Bank B	NW		SPL_{peak}
Figure A 26 (A.1; p74)				SEL_{ss}

Figure (section; page)	Location		Parameters	Metric
Figure A 27 (A.1; p74)		SE		SPL_{peak}
Figure A 28 (A.1; p75)				SEL_{ss}
Figure 4-5 (4.1; p26)	Dogger Bank A	N	Scenario 5 (Worst-case pin pile)	SPL_{peak}
Figure A 29 (A.1; p75)				SEL_{ss}
Figure A 30 (A.1; p76)		SW		SPL_{peak}
Figure A 31 (A.1; p76)				SEL_{ss}
Figure A 32 (A.1; p77)	Dogger Bank B	NW		SPL_{peak}
Figure A 33 (A.1; p77)				SEL_{ss}
Figure A 34 (A.1; p78)		SE		SPL_{peak}
Figure A 35 (A.1; p78)				SEL_{ss}
Figure 4-6 (4.1; p27)	Dogger Bank A	N	Scenario 6 (Most likely pin pile)	SPL_{peak}
Figure A 36 (A.1; p79)				SEL_{ss}
Figure A 37 (A.1; p79)		SW		SPL_{peak}
Figure A 38 (A.1; p80)				SEL_{ss}
Figure A 39 (A.1; p80)	Dogger Bank B	NW		SPL_{peak}
Figure A 40 (A.1; p81)				SEL_{ss}
Figure A 41 (A.1; p81)		SE		SPL_{peak}
Figure A 42 (A.1; p82)				SEL_{ss}

Table 4-1 Summary of the impact range results tables presented in section 4.1 and Appendix A (section A.1)

Table (section; page)	Location		Parameters	Criteria
Table 4-3 (4.2.1; p28)	Dogger Bank A	N	Scenario 1 (Absolute worst-case monopile)	Southall *et al.* (2019)
Table 4-4 (4.2.1; p28)		SW		
Table 4-5 (4.2.1; p29)	Dogger Bank B	NW		
Table 4-6 (4.2.1; p29)		SE		
Table 4-7 (4.2.2; p30)	Dogger Bank A	N	Scenario 2 (Worst-case monopile)	
Table 4-8 (4.2.2; p30)		SW		
Table 4-9 (4.2.2; p31)	Dogger Bank B	NW		
Table 4-10 (4.2.2; p31)		SE		
Table 4-11 (4.2.3; p32)	Dogger Bank A	N	Scenario 3 (Most likely monopile)	
Table 4-12 (4.2.3; p32)		SW		
Table 4-13 (4.2.3; p33)	Dogger Bank B	NW		
Table 4-14 (4.2.3; p33)		SE		
Table 4-15 (4.2.4; p34)	Dogger Bank A	N	Scenario 4 (Absolute worst-case pin pile)	
Table 4-16 (4.2.4; p34)		SW		
Table 4-17 (4.2.4; p35)	Dogger Bank B	NW		
Table 4-18 (4.2.4; p35)		SE		
Table 4-19 (4.2.5; p36)	Dogger Bank A	N	Scenario 5 (Worst-case pin pile)	
Table 4-20 (4.2.5; p36)		SW		
Table 4-21 (4.2.5; p37)	Dogger Bank B	NW		
Table 4-22 (4.2.5; p37)		SE		
Table 4-23 (4.2.6; p38)	Dogger Bank A	N	Scenario 6 (Most likely pin pile)	
Table 4-24 (4.2.6; p38)		SW		
Table 4-25 (4.2.6; p39)	Dogger Bank B	NW		
Table 4-26 (4.2.6; p39)		SE		
Table 4-27 (4.3.1; p40)	Dogger Bank A	N	Scenario 1 (Absolute worst-case monopile)	Lucke *et al.* (2009)
Table 4-28 (4.3.1; p40)		SW		
Table 4-29 (4.3.1; p40)	Dogger Bank B	NW		
Table 4-30 (4.3.1; p40)		SE		
Table 4-31 (4.3.2; p40)	Dogger Bank A	N	Scenario 2 (Worst-case monopile)	
Table 4-32 (4.3.2; p41)		SW		
Table 4-33 (4.3.2; p41)	Dogger Bank B	NW		
Table 4-34 (4.3.2; p41)		SE		
Table 4-35 (4.3.3; p41)	Dogger Bank A	N	Scenario 3	

Table (section; page)	Location		Parameters	Criteria
Table 4-36 (4.3.3; p41)		SW	(Most likely monopile)	
Table 4-37 (4.3.3; p42)	Dogger Bank B	NW		
Table 4-38 (4.3.3; p42)		SE		
Table 4-39 (4.3.4; p42)	Dogger Bank A	N	Scenario 4 (Absolute worst-case pin pile)	
Table 4-40 (4.3.4; p42)		SW		
Table 4-41 (4.3.4; p42)	Dogger Bank B	NW		
Table 4-42 (4.3.4; p43)		SE		
Table 4-43 (4.3.5; p43)	Dogger Bank A	N	Scenario 5 (Worst-case pin pile)	
Table 4-44 (4.3.5; p43)		SW		
Table 4-45 (4.3.5; p43)	Dogger Bank B	NW		
Table 4-46 (4.3.5; p43)		SE		
Table 4-47 (4.3.6; p44)	Dogger Bank A	N	Scenario 6 (Most likely pin pile)	
Table 4-48 (4.3.6; p44)		SW		
Table 4-49 (4.3.6; p44)	Dogger Bank B	NW		
Table 4-50 (4.3.6; p44)		SE		
Table 4-51 (4.4.1; p45)	Dogger Bank A	N	Scenario 1 (Absolute worst-case monopile)	Popper *et al*. (2014)
Table 4-52 (4.4.1; p45)		SW		
Table 4-53 (4.4.1; p46)	Dogger Bank B	NW		
Table 4-54 (4.4.10; p46)		SE		
Table 4-55 (4.4.2; p47)	Dogger Bank A	N	Scenario 2 (Worst-case monopile)	
Table 4-56 (4.4.2; p47)		SW		
Table 4-57 (4.4.2; p48)	Dogger Bank B	NW		
Table 4-58 (4.4.2; p48)		SE		
Table 4-59 (4.4.3; p49)	Dogger Bank A	N	Scenario 3 (Most likely monopile)	
Table 4-60 (4.4.3; p49)		SW		
Table 4-61 (4.4.3; p50)	Dogger Bank B	NW		
Table 4-62 (4.4.3; p50)		SE		
Table 4-63 (4.4.4; p51)	Dogger Bank A	N	Scenario 4 (Absolute worst-case pin pile)	
Table 4-64 (4.4.4; p51)		SW		
Table 4-65 (4.4.4; p52)	Dogger Bank B	NW		
Table 4-66 (4.4.4; p52)		SE		
Table 4-67 (4.4.5; p53)	Dogger Bank A	N	Scenario 5 (Worst-case pin pile)	
Table 4-68 (4.4.5; p53)		SW		
Table 4-69 (4.4.5; p54)	Dogger Bank B	NW		
Table 4-70 (4.4.5; p54)		SE		
Table 4-71 (4.4.6; p55)	Dogger Bank A	N	Scenario 6 (Most likely pin pile)	
Table 4-72 (4.4.6; p55)		SW		
Table 4-73 (4.4.6; p56)	Dogger Bank B	NW		
Table 4-74 (4.4.6; p56)		SE		

Table 4-2 Summary of the impact range results tables presented in sections 4.2, 4.3 and 4.4

4.1 Unweighted noise levels

The figures presented in Figure 4-1 to Figure 4-6 present single strike, unweighted SPL_{peak} noise levels in 5 dB increments for each of the six impact piling scenarios at the N modelling location at Dogger Bank A. These contour plots help visualise the transmission of the impact piling noise through the water, with deeper waters resulting in reduced attenuation and therefore larger impact ranges.

Contour plots for the other three modelling locations as well as unweighted SEL_{ss} noise are presented in Appendix A (section A.1); these are summarised in Table 4-1.

The noise levels presented in these figures have been used to calculate biologically significant impact ranges using the noise metrics and criteria from section 2.2.

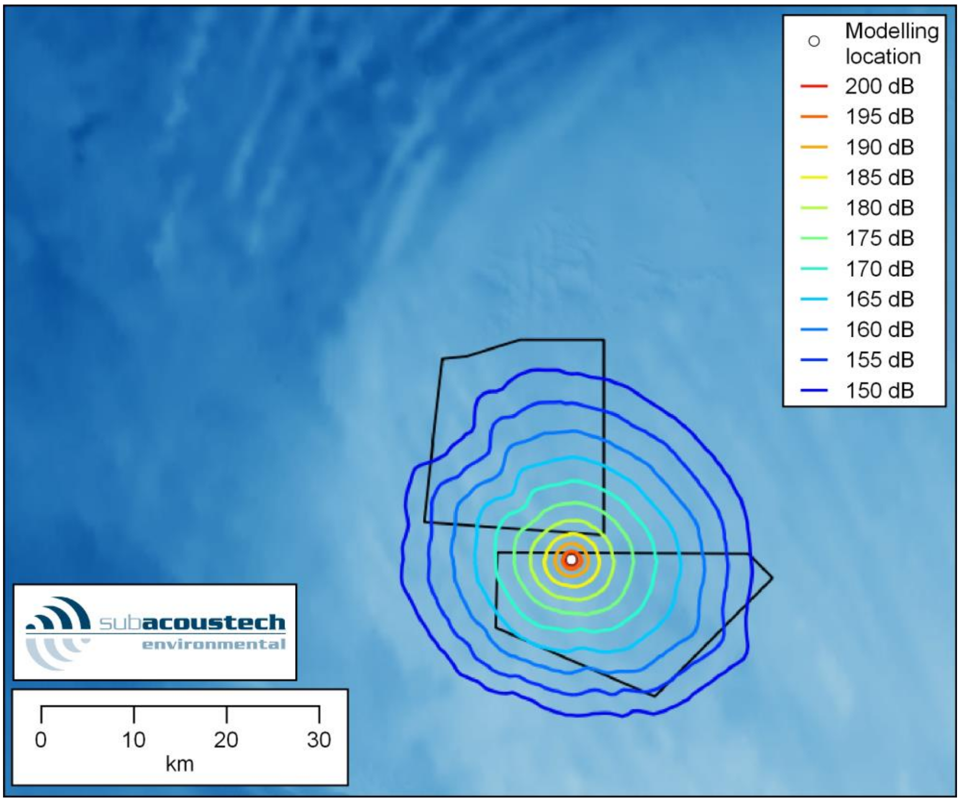

Figure 4-1 Contour plot showing the unweighted SPL_{peak} noise levels at Dogger Bank A, N location using the scenario 1 parameters (absolute worst-case monopile)

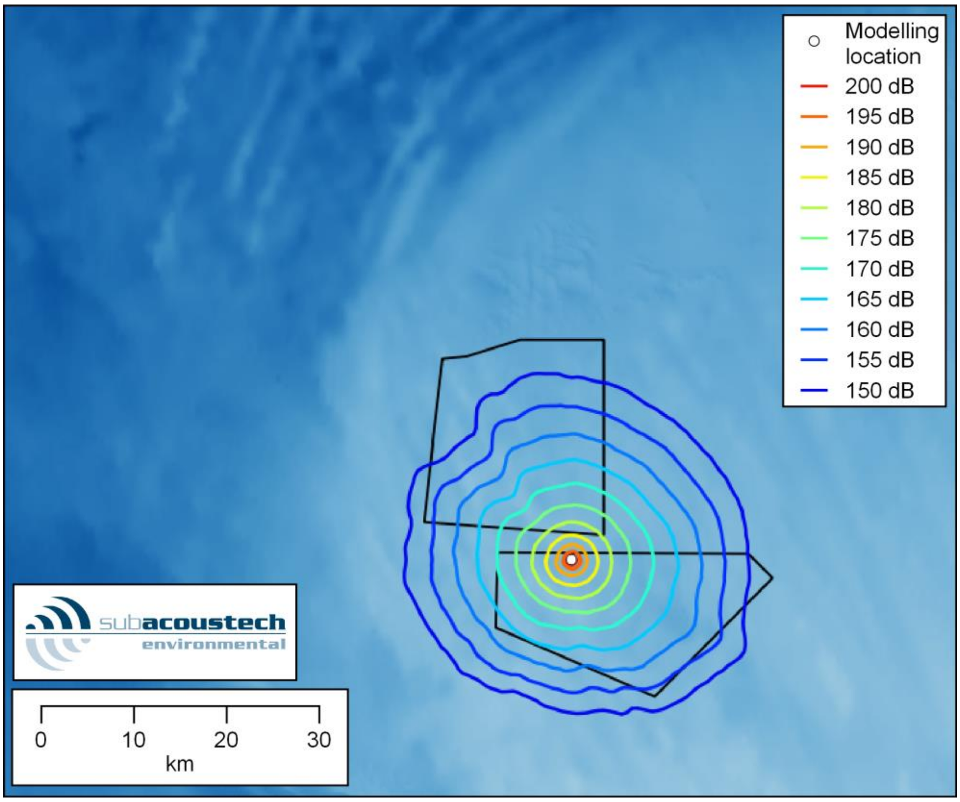

Figure 4-2 Contour plot showing the unweighted SPL_{peak} noise levels at Dogger Bank A, N location using the scenario 2 parameters (worst-case monopile)

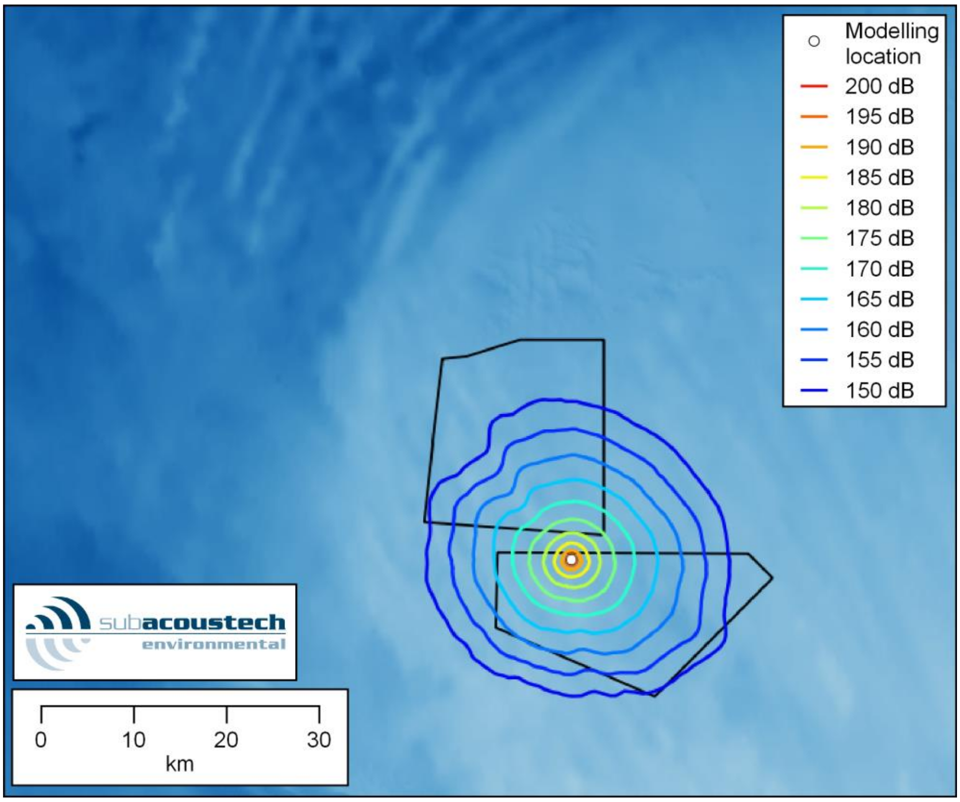

Figure 4-3 Contour plot showing the unweighted SPL_{peak} noise levels at Dogger Bank A, N location using the scenario 3 parameters (most likely monopile)

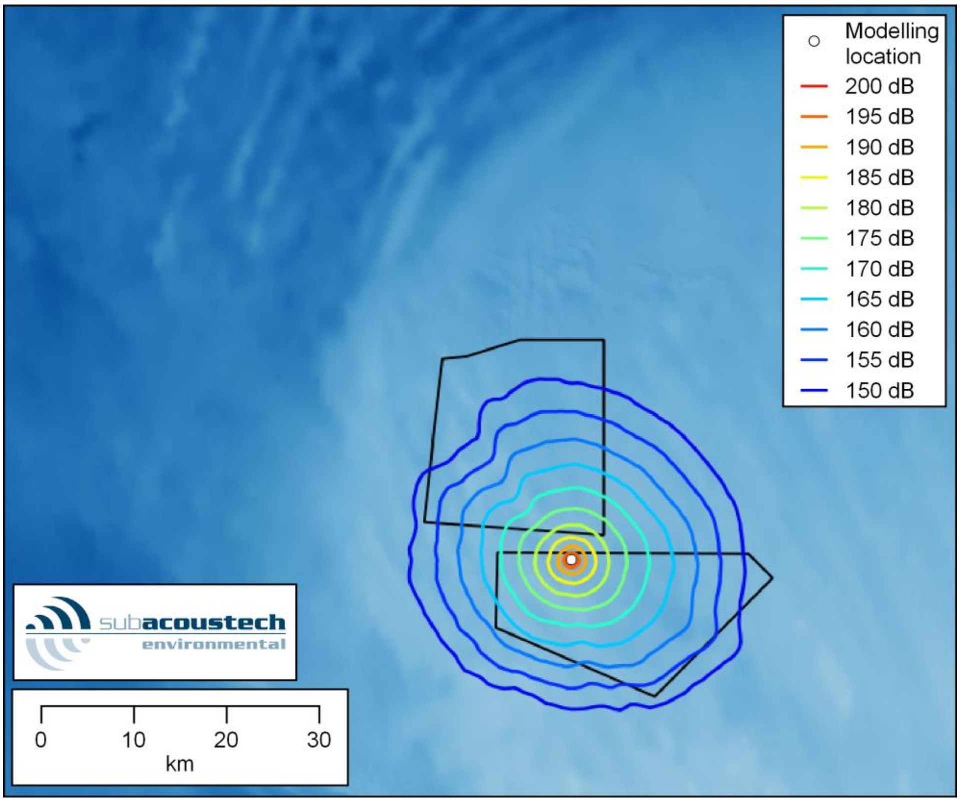

Figure 4-4 Contour plot showing the unweighted SPL_{peak} noise levels at Dogger Bank A, N location using the scenario 4 parameters (absolute worst-case pin pile)

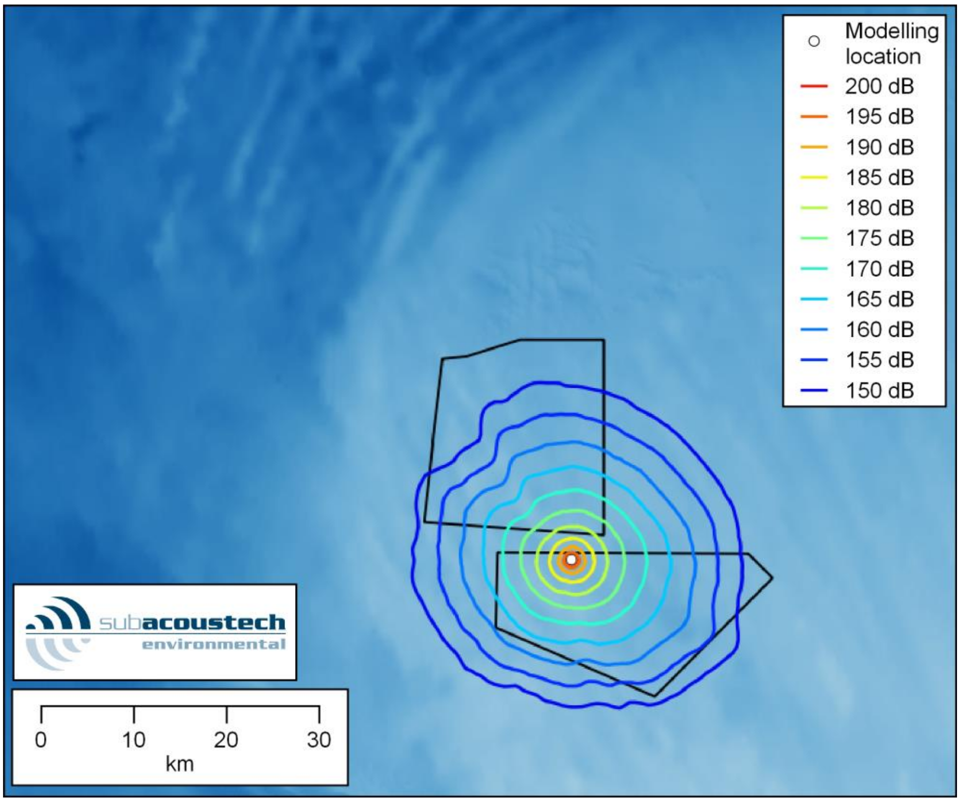

Figure 4-5 Contour plot showing the unweighted SPL_{peak} noise levels at Dogger Bank A, N location using the scenario 5 parameters (worst-case pin pile)

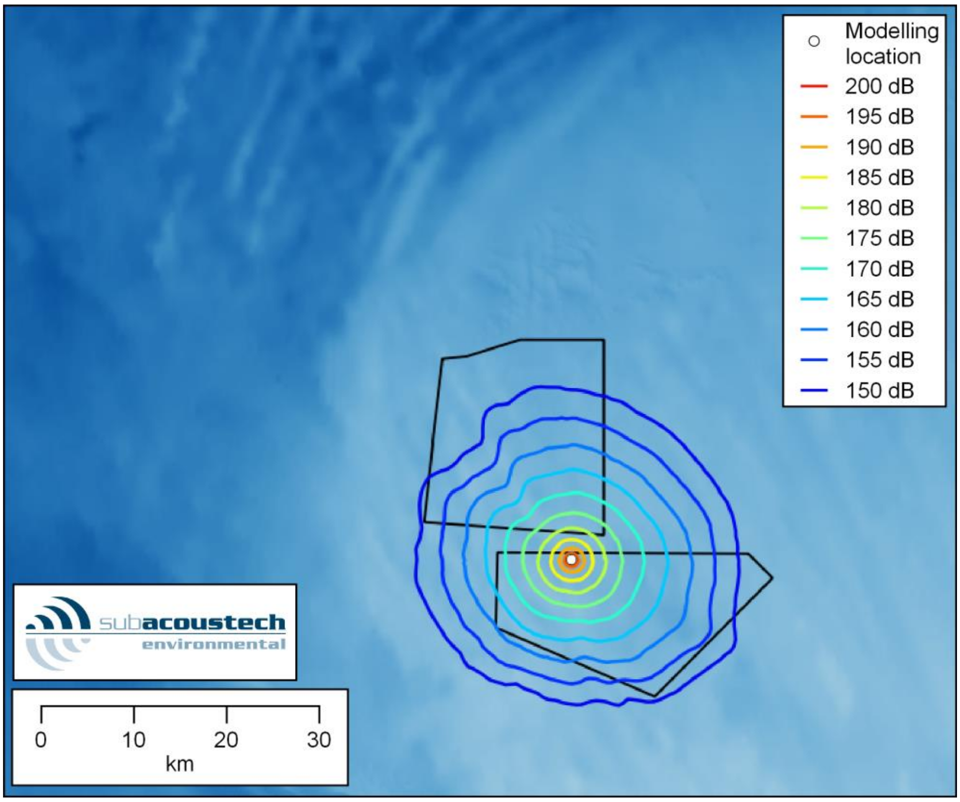

Figure 4-6 Contour plot showing the unweighted SPL_{peak} noise levels at Dogger Bank A, N location using the scenario 1 parameters (most likely pin pile)

4.2 Southall *et al*. (2019) criteria

Table 4-3 to Table 4-26 present the modelling results in terms of the Southall *et al*. (2019) marine mammal criteria covering the six scenarios.

The largest impact ranges using the Southall *et al.* (2019) criteria are predicted to be for the LF cetaceans group, with maximum PTS SEL_{cum} ranges of up to 4.1 km for Scenario 1 (absolute worst-case monopile) at the NW location of Dogger Bank B. Significant PTS ranges are also predicted for VHF cetaceans with maximum ranges of up to 2.3 km predicted for the same location and piling scenario.

Larger ranges of up to 28 km for LF cetaceans and 20 km for VHF cetaceans are predicted for TTS injury using the SEL_{cum} criteria, assuming fleeing receptors.

Additional Southall *et al*. (2019) criteria covering the calculated impact ranges following the first strike of the piling scenarios are presented in Appendix A.

4.2.1 Scenario 1

Southall *et al*. (2019)			**Scenario 1: Dogger Bank A – N location**			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.66 km^2	460 m	460 m	460 m
		PCW (218 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	0.03 km^2	90 m	90 m	90 m
		HF (224 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	3.4 km^2	1.1 km	1.0 km	1.0 km
		PCW (212 dB)	0.04 km^2	110 m	110 m	110
Weighted SEL_{cum} (Fleeing)	PTS	**LF** (183 dB)	4.0 km^2	1.5 km	870 m	1.1 km
		HF (185 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	4.0 km^2	1.3 km	950 m	1.1 km
		PCW (185 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	TTS	**LF** (168 dB)	310 km^2	12 km	8.3 km	10 km
		HF (170 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	280 km^2	11 km	8.1 km	9.4 km
		PCW (170 dB)	38 km^2	4.1 km	3.1 km	3.5 km

Table 4-3 Summary of the modelled impact ranges for Scenario 1 (absolute worst-case monopile) at the N location of Dogger Bank A using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			**Scenario 1: Dogger Bank A – SW location**			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.8 km^2	500 m	500 m	500 m
		PCW (218 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	0.03 km^2	100 m	100 m	100 m
		HF (224 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	4.0 km^2	1.1 km	1.1 km	1.1 km
		PCW (212 dB)	0.04 km^2	110 m	110 m	110 m
Weighted SEL_{cum} (Fleeing)	PTS	**LF** (183 dB)	34 km^2	4.2 km	1.9 km	3.2 km
		HF (185 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	4.0 km^2	1.4 km	950 m	1.1 km
		PCW (185 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	TTS	**LF** (168 dB)	560 km^2	17 km	8.9 km	13 km
		HF (170 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	240 km^2	10 km	6.9 km	8.8 km
		PCW (170 dB)	36 km^2	4.0 km	2.8 km	3.4 km

Table 4-4 Summary of the modelled impact ranges for Scenario 1 (absolute worst-case monopile) at the SW location of Dogger Bank A using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			**Scenario 1: Dogger Bank B – NW location**			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.83 km²	520 m	510 m	520 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	0.03 km²	100 m	100 m	100 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	4.5 km²	1.2 km	1.2 km	1.2 km
		PCW (212 dB)	0.04 km²	120 m	120 m	120 m
Weighted SEL_{cum} (Fleeing)	PTS	**LF** (183 dB)	33 km²	4.1 km	2.0 km	3.2 km
		HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	13 km²	2.3 km	1.6 km	2.0 km
		PCW (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	TTS	**LF** (168 dB)	1200 km²	28 km	11 km	19 km
		HF (170 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	750 km²	20 km	10 km	15 km
		PCW (170 dB)	120 km²	7.1 km	4.5 km	6.1 km

Table 4-5 Summary of the modelled impact ranges for Scenario 1 (absolute worst-case monopile) at the NW location of Dogger Bank B using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			**Scenario 1: Dogger Bank B – SE location**			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.78 km²	500 m	500 m	500 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	0.03 km²	100 m	100 m	100 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	4.1 km²	1.2 km	1.1 km	1.1 km
		PCW (212 dB)	0.04 km²	110 m	110 m	110 m
Weighted SEL_{cum} (Fleeing)	PTS	**LF** (183 dB)	8.7 km²	2.2 km	1.3 km	1.7 km
		HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	5.8 km²	1.6 km	1.2 km	1.4 km
		PCW (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	TTS	**LF** (168 dB)	400 km²	14 km	9.3 km	11 km
		HF (170 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	330 km²	12 km	8.9 km	10 km
		PCW (170 dB)	52 km²	4.9 km	3.6 km	4.1 km

Table 4-6 Summary of the modelled impact ranges for Scenario 1 (absolute worst-case monopile) at the SE location of Dogger Bank B using the Southall et al. (2019) injury criteria for marine mammals

4.2.2 Scenario 2

Southall *et al*. (2019)			Scenario 2: Dogger Bank A – N location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.57 km²	430 m	420 m	430 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	0.02 km²	90 m	80 m	90 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	3.0 km²	980 m	970 m	970 m
		PCW (212 dB)	0.03 km²	100 m	100 m	100 m
Weighted SEL_{cum} (Fleeing)	PTS	**LF** (183 dB)	3.5 km²	1.4 km	780 m	1.1 km
		HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	3.8 km²	1.3 km	950 m	1.1 km
		PCW (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	TTS	**LF** (168 dB)	310 km²	12 km	8.3 km	9.9 km
		HF (170 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	280 km²	11 km	8.1 km	9.4 km
		PCW (170 dB)	38 km²	4.0 km	3.0 km	3.5 km

Table 4-7 Summary of the modelled impact ranges for Scenario 2 (worst-case monopile) at the N location of Dogger Bank A using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			Scenario 2: Dogger Bank A – SW location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.66 km²	460 m	460 m	460 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	0.02 km²	90 m	90 m	90 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	3.4 km²	1.1 km	1.0 km	1.0 km
		PCW (212 dB)	0.03 km²	100 m	100 m	100 m
Weighted SEL_{cum} (Fleeing)	PTS	**LF** (183 dB)	3.7 km²	1.6 km	770 m	1.1 km
		HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	3.9 km²	1.4 km²	950 m	1.1 km
		PCW (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	TTS	**LF** (168 dB)	270 km²	11 km	6.9 km	9.3 km
		HF (170 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	240 km²	10 km	7.0 km	8.8 km
		PCW (170 dB)	36 km²	4.0 km	2.8 km	3.4 km

Table 4-8 Summary of the modelled impact ranges for Scenario 2 (worst-case monopile) at the SW location of Dogger Bank A using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			Scenario 2: Dogger Bank B – NW location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.71 km²	480 m	480 m	480 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	0.03 km²	90 m	90 m	90 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	3.9 km²	1.1 km	1.1 km	1.1 km
		PCW (212 dB)	0.04 km²	110 m	110 m	110 m
Weighted SEL_{cum} (Fleeing)	PTS	**LF** (183 dB)	32 km²	4.0 km	2.0 km	3.2 km
		HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	13 km²	2.2 km	1.6 km	2.0 km
		PCW (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	TTS	**LF** (168 dB)	1200 km²	28 km	11 km	19 km
		HF (170 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	730 km²	20 km	10 km	15 km
		PCW (170 dB)	110 km²	7.1 km	4.5 km	6.0 km

Table 4-9 Summary of the modelled impact ranges for Scenario 2 (worst-case monopile) at the NW location of Dogger Bank B using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			Scenario 2: Dogger Bank B – SE location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	0.67 km²	460 m	460 m	460 m
		VHF (202 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	0.03 km²	90 m	90 m	90 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	3.6 km²	1.1 km	1.1 km	1.1 km
		PCW (212 dB)	0.03 km²	110 m	100 m	100 m
Weighted SEL_{cum} (Fleeing)	PTS	**LF** (183 dB)	0.31 km²	410 m	260 m	320 m
		HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	5.8 km²	1.6 km	1.2 km	1.4 km
		PCW (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	TTS	**LF** (168 dB)	190 km²	9.6 km	6.8 km	7.9 km
		HF (170 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	330 km²	12 km	8.9 km	10 km
		PCW (170 dB)	53 km²	4.9 km	3.6 km	4.1 km

Table 4-10 Summary of the modelled impact ranges for Scenario 2 (worst-case monopile) at the SE location of Dogger Bank B using the Southall et al. (2019) injury criteria for marine mammals

4.2.3 Scenario 3

Southall *et al*. (2019)			Scenario 3: Dogger Bank A – N location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.17 km²	240 m	240 m	240 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	< 0.01 km²	50 m	50 m	50 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	0.97 km²	560 m	560 m	560 m
		PCW (212 dB)	< 0.01 km²	50 m	50 m	50 m
Weighted SEL_{cum} (Fleeing)	PTS	**LF** (183 dB)	< 0.1 km²	220 m	150 m	180 m
		HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	< 0.1 km²	170 m	140 m	150 m
		PCW (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	TTS	**LF** (168 dB)	150 km²	8.2 km	5.9 km	6.9 km
		HF (170 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	100 km²	6.4 km	5.1 km	5.7 km
		PCW (170 dB)	8.2 km²	1.8 km	1.5 km	1.6 km

Table 4-11 Summary of the modelled impact ranges for Scenario 3 (most likely monopile) at the N location of Dogger Bank A using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			Scenario 3: Dogger Bank A – SW location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.2 km²	250 m	250 m	250 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	< 0.01 km²	50 m	50 m	50 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	1.1 km²	610 m	600 m	600 m
		PCW (212 dB)	< 0.01 km²	60 m	60 m	60 m
Weighted SEL_{cum} (Fleeing)	PTS	**LF** (183 dB)	0.17 km²	330 m	190 m	230 m
		HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	< 0.1 km²	210 m	170 m	180 m
		PCW (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	TTS	**LF** (168 dB)	130 km²	7.5 km	5.2 km	6.5 km
		HF (170 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	92 km²	6.1 km	4.7 km	5.4 km
		PCW (170 dB)	9.0 km²	2.0 km	1.5 km	1.7 km

Table 4-12 Summary of the modelled impact ranges for Scenario 3 (most likely monopile) at the SW location of Dogger Bank A using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			Scenario 3: Dogger Bank B – NW location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.21 km²	260 m	260 m	260 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	< 0.01 km²	50 m	50 m	50 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	1.2 km²	640 m	630 m	630 m
		PCW (212 dB)	< 0.01 km²	60 m	60 m	60 m
Weighted SEL_{cum} (Fleeing)	PTS	**LF** (183 dB)	1.4 km²	830 m	450 m	680 m
		HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	0.26 km²	320 m	250 m	290 m
		PCW (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	TTS	**LF** (168 dB)	480 km²	16 km	8.3 km	12 km
		HF (170 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	220 km²	9.7 km	6.6 km	8.4 km
		PCW (170 dB)	24 km²	3.0 km	2.3 km	2.8 km

Table 4-13 Summary of the modelled impact ranges for Scenario 3 (most likely monopile) at the NW location of Dogger Bank B using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			Scenario 3: Dogger Bank B – SE location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.2 km²	260 m	250 m	250 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	< 0.01 km²	50 m	50 m	50 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	1.2 km²	610 m	610 m	610 m
		PCW (212 dB)	< 0.01 km²	60 m	60 m	60 m
Weighted SEL_{cum} (Fleeing)	PTS	**LF** (183 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	0.13 km²	230 m	190 m	210 m
		PCW (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	TTS	**LF** (168 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		HF (170 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	120 km²	7.2 km	5.7 km	6.2 km
		PCW (170 dB)	12 km²	2.3 km	1.8 km	2.0 km

Table 4-14 Summary of the modelled impact ranges for Scenario 3 (most likely monopile) at the SE location of Dogger Bank B using the Southall et al. (2019) injury criteria for marine mammals

4.2.4 Scenario 4

Southall *et al*. (2019)			Scenario 4: Dogger Bank A – N location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.44 km^2	380 m	370 m	370 m
		PCW (218 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	0.02 km^2	70 m	70 m	70 m
		HF (224 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	2.3 km^2	870 m	850 m	860 m
		PCW (212 dB)	0.02 km^2	90 m	90 m	90 m
Weighted SEL_{cum} (Fleeing)	PTS	**LF** (183 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		HF (185 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	0.21 km^2	300 m	200 m	260 m
		PCW (185 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	TTS	**LF** (168 dB)	150 km^2	8.3 km	5.9 km	7.0 km
		HF (170 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	140 km^2	7.6 km	5.8 km	6.6 km
		PCW (170 dB)	6.8 km^2	1.7 km	1.3 km	1.5 km

Table 4-15 Summary of the modelled impact ranges for Scenario 4 (absolute worst-case pin pile) at the N location of Dogger Bank A using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			Scenario 4: Dogger Bank A – SW location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.5 km^2	410 m	400 m	410 m
		PCW (218 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	0.02 km^2	80 m	80 m	80 m
		HF (224 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	2.7 km^2	950 m	930 m	940 m
		PCW (212 dB)	0.03 km^2	90 m	90 m	90 m
Weighted SEL_{cum} (Fleeing)	PTS	**LF** (183 dB)	< 0.1 km^2	230 m	< 100 m	120 m
		HF (185 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	0.25 km^2	350 m	250 m	280 m
		PCW (185 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	TTS	**LF** (168 dB)	140 km^2	7.7 km	5.2 km	6.6 km
		HF (170 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	120 km^2	6.9 km	5.2 km	6.2 km
		PCW (170 dB)	7.6 km^2	1.9 km	1.4 km	1.6 km

Table 4-16 Summary of the modelled impact ranges for Scenario 4 (absolute worst-case pin pile) at the SW location of Dogger Bank A using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			Scenario 4: Dogger Bank B – NW location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.56 km^2	430 m	420 m	420 m
		PCW (218 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	0.02 km^2	80 m	80 m	80 m
		HF (224 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	3.1 km^2	1.0 km	990 m	1.0 km
		PCW (212 dB)	0.03 km^2	90 m	90 m	90 m
Weighted SEL_{cum} (Fleeing)	PTS	**LF** (183 dB)	1.7 km^2	900 m	400 m	720 m
		HF (185 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	0.98 km^2	650 m	450 m	560 m
		PCW (185 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	TTS	**LF** (168 dB)	530 km^2	17 km	8.5 km	13 km
		HF (170 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	340 km^2	13 km	7.5 km	10 km
		PCW (170 dB)	23 km^2	3.1 km	2.2 km	2.7 km

Table 4-17 Summary of the modelled impact ranges for Scenario 4 (absolute worst-case pin pile) at the NW location of Dogger Bank B using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			Scenario 4: Dogger Bank B – SE location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.52 km^2	410 m	410 m	410 m
		PCW (218 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	0.02 km^2	80 m	80 m	80 m
		HF (224 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	2.8 km^2	960 m	940 m	950 m
		PCW (212 dB)	0.03 km^2	90 m	90 m	90 m
Weighted SEL_{cum} (Fleeing)	PTS	**LF** (183 dB)	0.2 km^2	330 m	150 m	210 m
		HF (185 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	0.38 km^2	400 m	300 m	350 m
		PCW (185 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	TTS	**LF** (168 dB)	200 km^2	9.9 km	6.9 km	8.0 km
		HF (170 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	160 km^2	8.5 km	6.4 km	7.2 km
		PCW (170 dB)	11 km^2	2.1 km	1.7 km	1.8 km

Table 4-18 Summary of the modelled impact ranges for Scenario 4 (absolute worst-case pin pile) at the SE location of Dogger Bank B using the Southall et al. (2019) injury criteria for marine mammals

4.2.5 Scenario 5

Southall *et al*. (2019)			Scenario 5: Dogger Bank A – N location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.38 km²	350 m	350 m	350 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	< 0.01 km²	70 m	70 m	70 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	2.0 km²	810 m	800 m	800 m
		PCW (212 dB)	0.02 km²	80 m	80 m	80 m
Weighted SEL_{cum} (Fleeing)	PTS	**LF** (183 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	0.2 km²	300 m	200 m	250 m
		PCW (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	TTS	**LF** (168 dB)	150 km²	8.3 km	5.9 km	7.0 km
		HF (170 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	130 km²	7.5 km	5.7 km	6.5 km
		PCW (170 dB)	6.7 km²	1.7 km	1.3 km	1.5 km

Table 4-19 Summary of the modelled impact ranges for Scenario 5 (worst-case pin pile) at the N location of Dogger Bank A using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			Scenario 5: Dogger Bank A – SW location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.44 km²	380 m	380 m	380 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	0.02 km²	70 m	70 m	70 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	2.4 km²	880 m	870 m	870 m
		PCW (212 dB)	0.02 km²	90 m	90 m	90 m
Weighted SEL_{cum} (Fleeing)	PTS	**LF** (183 dB)	< 0.1 km²	130 m	< 100 m	100 m
		HF (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (155 dB)	0.3 km²	350 m	250 m	310 m
		PCW (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (168 dB)	140 km²	7.7 km	5.3 km	6.6 km
		HF (170 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (140 dB)	120 km²	6.9 km	5.2 km	6.1 m
		PCW (170 dB)	7.8 km²	1.9 km	1.4 km	1.6 km

Table 4-20 Summary of the modelled impact ranges for Scenario 5 (worst-case pin pile) at the SW location of Dogger Bank A using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			Scenario 5: Dogger Bank B – NW location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.48 km²	390 m	390 m	390 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	0.02 km²	80 m	70 m	80 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	2.7 km²	940 m	920 m	930 m
		PCW (212 dB)	0.02 km²	90 m	90 m	90 m
Weighted SEL_{cum} (Fleeing)	PTS	**LF** (183 dB)	1.7 km²	900 m	400 m	720 m
		HF (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (155 dB)	0.95 km²	650 m	450 m	550 m
		PCW (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (168 dB)	520 km²	17 km	8.5 km	13 km
		HF (170 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (140 dB)	330 km²	13 km	7.5 km	10 km
		PCW (170 dB)	23 km²	3.0 km	2.1 km	2.7 km

Table 4-21 Summary of the modelled impact ranges for Scenario 5 (worst-case pin pile) at the NW location of Dogger Bank B using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			Scenario 5: Dogger Bank B – SE location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.45 km²	380 m	380 m	380 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	0.02 km²	70 m	70 m	70 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	2.5 km²	890 m	880 m	890 m
		PCW (212 dB)	0.02 km²	90 m	80 m	90 m
Weighted SEL_{cum} (Fleeing)	PTS	**LF** (183 dB)	0.19 km²	350 m	200 m	240 m
		HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	0.43 km²	400 m	350 m	370 m
		PCW (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	TTS	**LF** (168 dB)	200 km²	9.9 km	7.0 km	8.1 km
		HF (170 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	160 km²	8.4 km	6.4 km	7.2 km
		PCW (170 dB)	11 km²	2.2 km	1.7 km	1.9 km

Table 4-22 Summary of the modelled impact ranges for Scenario 5 (worst-case pin pile) at the SE location of Dogger Bank B using the Southall et al. (2019) injury criteria for marine mammals

4.2.6 Scenario 6

Southall *et al*. (2019)			Scenario 6: Dogger Bank A – N location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.31 km²	320 m	320 m	320 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	< 0.01 km²	60 m	60 m	60 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	1.7 km²	740 m	730 m	740 m
		PCW (212 dB)	0.02 km²	70 m	70 m	70 m
Weighted SEL_{cum} (Fleeing)	PTS	**LF** (183 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	0.19 km²	300 m	200 m	240 m
		PCW (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	TTS	**LF** (168 dB)	150 km²	8.3 km	5.9 km	7.0 km
		HF (170 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	130 km²	7.4 km	5.7 km	6.5 km
		PCW (170 dB)	6.6 km²	1.7 km	1.3 km	1.5 km

Table 4-23 Summary of the modelled impact ranges for Scenario 6 (most likely pin pile) at the N location of Dogger Bank A using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			Scenario 6: Dogger Bank A – SW location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.37 km²	340 m	340 m	340 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	< 0.01 km²	70 m	70 m	70 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	2.0 km²	810 m	800 m	800 m
		PCW (212 dB)	0.02 km²	80 m	80 m	80 m
Weighted SEL_{cum} (Fleeing)	PTS	**LF** (183 dB)	< 0.1 km²	110 m	< 100 m	< 100 m
		HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	0.29 km²	350 m	250 m	300 m
		PCW (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	TTS	**LF** (168 dB)	140 km²	7.7 km	5.3 km	6.6 km
		HF (170 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	120 km²	6.9 km	5.2 km	6.1 km
		PCW (170 dB)	7.7 km²	1.9 km	1.4 km	1.6 km

Table 4-24 Summary of the modelled impact ranges for Scenario 6 (most likely pin pile) at the SW location of Dogger Bank A using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			**Scenario 6: Dogger Bank B – NW location**			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.4 km²	360 m	360 m	360 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	< 0.01 km²	70 m	70 m	70 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	2.3 km²	860 m	840 m	850 m
		PCW (212 dB)	0.02 km²	80 m	80 m	80 m
Weighted SEL_{cum} (Fleeing)	PTS	**LF** (183 dB)	1.6 km²	900 m	400 m	700 m
		HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	0.89 km²	600 m	450 m	530 m
		PCW (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	TTS	**LF** (168 dB)	520 km²	17 km	8.5 km	13 km
		HF (170 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	310 km²	12 km	7.4 km	9.9 km
		PCW (170 dB)	22 km²	3.0 km	2.1 km	2.7 km

Table 4-25 Summary of the modelled impact ranges for Scenario 6 (most likely pin pile) at the NW location of Dogger Bank B using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			**Scenario 6: Dogger Bank B – SE location**			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.37 km²	350 m	340 m	350 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	< 0.01 km²	70 m	70 m	70 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	2.1 km²	820 m	810 m	810 m
		PCW (212 dB)	0.02 km²	80 m	80 m	80 m
Weighted SEL_{cum} (Fleeing)	PTS	**LF** (183 dB)	0.17 km²	350 m	150 m	230 m
		HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	0.4 km²	400 m	300 m	360 m
		PCW (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	TTS	**LF** (168 dB)	200 km²	9.9 km	7.0 km	8.0 km
		HF (170 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	160 km²	8.3 km	6.4 km	7.1 km
		PCW (170 dB)	11 km²	2.1 km	1.7 km	1.8 km

Table 4-26 Summary of the modelled impact ranges for Scenario 6 (most likely pin pile) at the SE location of Dogger Bank B using the Southall et al. (2019) injury criteria for marine mammals

4.3 Lucke *et al*. (2009) criteria

Table 4-27 to Table 4-50 present the predicted TTS and behavioural reaction ranges using the noise levels from Lucke *et al*. (2009) for harbour porpoises. Using the unweighted $SPL_{pk\text{-}to\text{-}pk}$ criteria, maximum ranges of 1.7 km for TTS and 20 km for behavioural response are predicted for Scenario 1 (absolute worst-case monopile) at the NW location of Dogger Bank B. When considering the SEL_{ss} levels, maximum ranges of 6.4 km for TTS and 30 km for behavioural response are predicted for the same location and piling scenario.

4.3.1 Scenario 1

Lucke *et al.* (2009)		Scenario 1: Dogger Bank A – N location			
		Area	Max range	Min range	Mean range
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	6.2 km^2	1.4 km	1.4 km	1.4 km
	Behavioural (173 dB)	480 km^2	14 km	11 km	12 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	72 km^2	5.1 km	4.6 km	4.8 km
	Behavioural (145 dB)	890 km^2	19 km	15 km	17 km

Table 4-27 Summary of the modelled impact ranges for Scenario 1 (absolute worst-case monopile) at the N location of Dogger Bank A using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al.* (2009)		Scenario 1: Dogger Bank A – SW location			
		Area	Max range	Min range	Mean range
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	7.1 km^2	1.6 km	1.5 km	1.5 km
	Behavioural (173 dB)	440 km^2	13 km	10 km	12 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	75 km^2	5.4 km	4.6 km	4.9 km
	Behavioural (145 dB)	810 km^2	18 km	13 km	16 km

Table 4-28 Summary of the modelled impact ranges for Scenario 1 (absolute worst-case monopile) at the SW location of Dogger Bank A using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al.* (2009)		Scenario 1: Dogger Bank B – NW location			
		Area	Max range	Min range	Mean range
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	8.5 km^2	1.7 km	1.6 km	1.6 km
	Behavioural (173 dB)	910 km^2	20 km	14 km	17 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	120 km^2	6.4 km	5.6 km	6.1 km
	Behavioural (145 dB)	1900 km^2	30 km	18 km	24 km

Table 4-29 Summary of the modelled impact ranges for Scenario 1 (absolute worst-case monopile) at the NW location of Dogger Bank B using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al.* (2009)		Scenario 1: Dogger Bank B – SE location			
		Area	Max range	Min range	Mean range
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	7.4 km^2	1.6 km	1.5 km	1.5 km
	Behavioural (173 dB)	560 km^2	15 km	12 km	13 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	87 km^2	5.6 km	5.0 km	5.3 km
	Behavioural (145 dB)	1000 km^2	21 km	16 km	18 km

Table 4-30 Summary of the modelled impact ranges for Scenario 1 (absolute worst-case monopile) at the SE location of Dogger Bank B using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

4.3.2 Scenario 2

Lucke *et al.* (2009)		Scenario 2: Dogger Bank A – N location			
		Area	Max range	Min range	Mean range
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	5.3 km^2	1.3 km	1.3 km	1.3 km
	Behavioural (173 dB)	460 km^2	13 km	11 km	12 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	65 km^2	4.8 km	4.3 km	4.5 km
	Behavioural (145 dB)	840 km^2	19 km	15 km	16 km

Table 4-31 Summary of the modelled impact ranges for Scenario 2 (worst-case monopile) at the N location of Dogger Bank A using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al.* (2009)		Scenario 2: Dogger Bank A – SW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	6.2 km^2	1.4 km	1.4 km	1.4 km
	Behavioural (173 dB)	420 km^2	13 km	10 km	12 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	67 km^2	5.1 km	4.4 km	4.6 km
	Behavioural (145 dB)	770 km^2	18 km	13 km	16 km

Table 4-32 Summary of the modelled impact ranges for Scenario 2 (worst-case monopile) at the SW location of Dogger Bank A using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al.* (2009)		Scenario 2: Dogger Bank B – NW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	7.4 km^2	1.6 km	1.5 km	1.5 km
	Behavioural (173 dB)	860 km^2	19 km	14 km	17 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	100 km^2	6.0 km	5.3 km	5.8 km
	Behavioural (145 dB)	1800 km^2	29 km	18 km	23 km

Table 4-33 Summary of the modelled impact ranges for Scenario 2 (worst-case monopile) at the NW location of Dogger Bank B using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al.* (2009)		Scenario 2: Dogger Bank B – SE location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	6.5 km^2	1.5 km	1.4 km	1.4 km
	Behavioural (173 dB)	530 km^2	15 km	12 km	13 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	78 km^2	5.3 km	4.7 km	5.0 km
	Behavioural (145 dB)	970 km^2	20 km	16 km	18 km

Table 4-34 Summary of the modelled impact ranges for Scenario 2 (worst-case monopile) at the SE location of Dogger Bank B using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

4.3.3 Scenario 3

Lucke *et al.* (2009)		Scenario 3: Dogger Bank A – N location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	1.9 km^2	790 m	770 m	780 m
	Behavioural (173 dB)	290 km^2	11 km	8.8 km	9.7 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	28 km^2	3.1 km	2.9 km	3.0 km
	Behavioural (145 dB)	550 km^2	15 km	12 km	13 km

Table 4-35 Summary of the modelled impact ranges for Scenario 3 (most likely monopile) at the N location of Dogger Bank A using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al.* (2009)		Scenario 3: Dogger Bank A – SW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	2.2 km^2	840 m	830 m	840 m
	Behavioural (173 dB)	270 km^2	10 km	8.3 km	9.4 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	31 km^2	3.4 km	3.0 km	3.1 km
	Behavioural (145 dB)	510 km^2	14 km	11 km	13 km

Table 4-36 Summary of the modelled impact ranges for Scenario 3 (most likely monopile) at the SW location of Dogger Bank A using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al.* (2009)		Scenario 3: Dogger Bank B – NW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	2.4 km^2	900 m	870 m	880 m
	Behavioural (173 dB)	520 km^2	14 km	11 km	13 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	42 km^2	3.8 km	3.5 km	3.7 km
	Behavioural (145 dB)	1100 km^2	21 km	15 km	18 km

Table 4-37 Summary of the modelled impact ranges for Scenario 3 (most likely monopile) at the NW location of Dogger Bank B using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al.* (2009)		Scenario 3: Dogger Bank B – SE location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	2.3 km^2	860 m	840 m	850 m
	Behavioural (173 dB)	340 km^2	12 km	9.8 km	10 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	34 km^2	3.4 km	3.2 km	3.3 km
	Behavioural (145 dB)	640 km^2	16 km	13 km	14 km

Table 4-38 Summary of the modelled impact ranges for Scenario 3 (most likely monopile) at the SE location of Dogger Bank B using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

4.3.4 Scenario 4

Lucke *et al.* (2009)		Scenario 4: Dogger Bank A – N location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	4.3 km^2	1.2 km	1.2 km	1.2 km
	Behavioural (173 dB)	420 km^2	13 km	10 km	12 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	46 km^2	4.0 km	3.7 km	3.8 km
	Behavioural (145 dB)	710 km^2	17 km	13 km	15 km

Table 4-39 Summary of the modelled impact ranges for Scenario 4 (absolute worst-case pin pile) at the N location of Dogger Bank A using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al.* (2009)		Scenario 4: Dogger Bank A – SW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	5.0 km^2	1.3 km	1.3 km	1.3 km
	Behavioural (173 dB)	380 km^2	12 km	9.6 km	11 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	51 km^2	4.4 km	3.8 km	4.0 km
	Behavioural (145 dB)	660 km^2	16 km	12 km	14 km

Table 4-40 Summary of the modelled impact ranges for Scenario 4 (absolute worst-case pin pile) at the SW location of Dogger Bank A using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al.* (2009)		Scenario 4: Dogger Bank B – NW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	5.9 km^2	1.4 km	1.4 km	1.4 km
	Behavioural (173 dB)	780 km^2	18 km	13 km	16 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	76 km^2	5.1 km	4.6 km	4.9 km
	Behavioural (145 dB)	1500 km^2	26 km	17 km	22 km

Table 4-41 Summary of the modelled impact ranges for Scenario 4 (absolute worst-case pin pile) at the NW location of Dogger Bank B using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al.* (2009)		Scenario 4: Dogger Bank B – SE location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	5.2 km²	1.3 km	1.3 km	1.3 km
	Behavioural (173 dB)	480 km²	14 km	11 km	12 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	57 km²	4.5 km	4.1 km	4.3 km
	Behavioural (145 dB)	830 km²	19 km	15 km	16 km

Table 4-42 Summary of the modelled impact ranges for Scenario 4 (absolute worst-case pin pile) at the SE location of Dogger Bank B using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

4.3.5 Scenario 5

Lucke *et al.* (2009)		Scenario 5: Dogger Bank A – N location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	3.7 km²	1.1 km	1.1 km	1.1 km
	Behavioural (173 dB)	390 km²	12 km	10 km	11 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	41 km²	3.8 km	3.5 km	3.6 km
	Behavioural (145 dB)	670 km²	17 km	13 km	15 km

Table 4-43 Summary of the modelled impact ranges for Scenario 5 (worst-case pin pile) at the N location of Dogger Bank A using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al.* (2009)		Scenario 5: Dogger Bank A – SW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	4.4 km²	1.2 km	1.2 km	1.2 km
	Behavioural (173 dB)	370 km²	12 km	9.4 km	11 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	46 km²	4.1 km	3.6 km	3.8 km
	Behavioural (145 dB)	620 km²	16 km	12 km	14 km

Table 4-44 Summary of the modelled impact ranges for Scenario 5 (worst-case pin pile) at the SW location of Dogger Bank A using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al.* (2009)		Scenario 5: Dogger Bank B – NW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	5.9 km²	1.4 km	1.4 km	1.4 km
	Behavioural (173 dB)	780 km²	18 km	13 km	16 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	76 km²	5.1 km	4.6 km	4.9 km
	Behavioural (145 dB)	1500 km²	26 km	17 km	22 km

Table 4-45 Summary of the modelled impact ranges for Scenario 5 (worst-case pin pile) at the NW location of Dogger Bank B using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al.* (2009)		Scenario 5: Dogger Bank B – SE location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	4.6 km²	4.3 km	3.9 km	4.1 km
	Behavioural (173 dB)	460 km²	14 km	11 km	12 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	51 km²	4.3 km	3.9 km	4.1 km
	Behavioural (145 dB)	790 km²	18 km	14 km	16 km

Table 4-46 Summary of the modelled impact ranges for Scenario 5 (worst-case pin pile) at the SE location of Dogger Bank B using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

4.3.6 Scenario 6

Lucke *et al*. (2009)		Scenario 6: Dogger Bank A – N location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted $SPL_{pk\text{-}pk}$	**TTS** (199.7 dB)	3.2 km²	1.0 km	1.0 km	1.0 km
	Behavioural (173 dB)	370 km²	12 km	9.8 km	11 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	36 km²	3.5 km	3.3 km	3.4 km
	Behavioural (145 dB)	630 km²	16 km	13 km	14 km

Table 4-47 Summary of the modelled impact ranges for Scenario 6 (most likely pin pile) at the N location of Dogger Bank A using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al*. (2009)		Scenario 6: Dogger Bank A – SW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted $SPL_{pk\text{-}pk}$	**TTS** (199.7 dB)	3.8 km²	1.1 km	1.1 km	1.1 km
	Behavioural (173 dB)	340 km²	11 km	9.1 km	10 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	40 km²	3.9 km	3.4 km	3.6 km
	Behavioural (145 dB)	580 km²	15 km	12 km	14 km

Table 4-48 Summary of the modelled impact ranges for Scenario 6 (most likely pin pile) at the SW location of Dogger Bank A using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al*. (2009)		Scenario 6: Dogger Bank B – NW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted $SPL_{pk\text{-}pk}$	**TTS** (199.7 dB)	5.1 km²	1.3 km	1.3 km	1.3 km
	Behavioural (173 dB)	730 km²	17 km	13 km	15 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	67 km²	4.8 km	4.3 km	4.6 km
	Behavioural (145 dB)	1400 km²	25 km	16 km	21 km

Table 4-49 Summary of the modelled impact ranges for Scenario 6 (most likely pin pile) at the NW location of Dogger Bank B using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al*. (2009)		Scenario 6: Dogger Bank B – SE location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted $SPL_{pk\text{-}pk}$	**TTS** (199.7 dB)	3.9 km²	1.1 km	1.1 km	1.1 km
	Behavioural (173 dB)	430 km²	13 km	11 km	12 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	45 km²	4.0 km	3.7 km	3.8 km
	Behavioural (145 dB)	740 km²	17 km	14 km	15 km

Table 4-50 Summary of the modelled impact ranges for Scenario 6 (most likely pin pile) at the SE location of Dogger Bank B using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

4.4 Popper *et al*. (2014) criteria

Injury ranges for fish using the Popper *et al*. (2014) criteria are presented in Table 4-51 to Table 4-74, covering unweighted SPL_{peak}, and both fleeing and stationary unweighted SEL_{cum} criteria.

Recoverable injury ranges for fish (203 dB SEL_{cum}) are predicted to be less than 100 m for all scenarios when considering a fleeing receptor, increasing to a maximum of 5.4 km for a stationary receptor at the NW location of Dogger Bank B for piling scenario 1 (absolute worst-case monopile). Larger ranges are predicted for TTS in fish (186 dB SEL_{cum}), with maximum ranges of up to 10 km for fleeing receptors and 23 km for stationary receptors.

4.4.1 Scenario 1

Popper *et al*. (2014)			Scenario 1: Dogger Bank A – N location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB		0.03 km²	90 m	90 m	90 m
	207 dB		0.16 km²	220 m	220 m	220 m
Unweighted SEL_{cum}	Fleeing (1.5 ms^{-1})	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		186 dB	71 km²	5.6 km	4.1 km	4.7 km
	Stationary	219 dB	1.0 km²	580 m	570 m	580 m
		216 dB	2.3 km²	880 m	860 m	870 m
		210 dB	12 km²	2.0 km	1.9 km	1.9 km
		207 dB	23 km²	2.8 km	2.6 km	2.7 km
		203 dB	52 km²	4.3 km	3.9 km	4.1 km
		186 dB	600 km²	15 km	12 km	14 km

Table 4-51 Summary of the modelled impact ranges for Scenario 1 (absolute worst-case monopile) at the N location of Dogger Bank A using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)			Scenario 1: Dogger Bank A – SW location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB		0.03 km²	100 m	100 m	100 m
	207 dB		0.18 km²	240 m	240 m	240 m
Unweighted SEL_{cum}	Fleeing (1.5 ms^{-1})	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		186 dB	64 km²	5.3 km	3.7 km	4.5 km
	Stationary	219 dB	1.3 km²	650 m	630 m	640 m
		216 dB	2.9 km²	980 m	950 m	960 m
		210 dB	13 km²	2.1 km	2.0 km	2.0 km
		207 dB	25 km²	3.0 km	2.7 km	2.8 km
		203 dB	55 km²	4.6 km	4.0 km	4.2 km
		186 dB	550 km²	15 km	11 km	13 km

Table 4-52 Summary of the modelled impact ranges for Scenario 1 (absolute worst-case monopile) at the SW location of Dogger Bank A using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)			Scenario 1: Dogger Bank B – NW location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB		0.03 km²	100 m	100 m	100 m
	207 dB		0.19 km²	250 m	250 m	250 m
Unweighted SEL_{cum}	Fleeing (1.5 ms⁻¹)	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		186 dB	230 km²	10 km	6.0 km	8.4 km
	Stationary	219 dB	1.3 km²	660 m	640 m	650 m
		216 dB	3.1 km²	1.0 km	980 m	1.0 km
		210 dB	17 km²	2.4 km	2.3 km	2.3 km
		207 dB	34 km²	3.5 km	3.2 km	3.3 km
		203 dB	83 km²	5.4 km	4.8 km	5.1 km
		186 dB	1200 km²	23 km	15 km	19 km

Table 4-53 Summary of the modelled impact ranges for Scenario 1 (absolute worst-case monopile) at the NW location of Dogger Bank B using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)			Scenario 1: Dogger Bank B – SE location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB		0.03 km²	100 m	100 m	100 m
	207 dB		0.18 km²	240 m	240 m	240 m
Unweighted SEL_{cum}	Fleeing (1.5 ms⁻¹)	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		186 dB	96 km²	6.7 km	4.8 km	5.5 km
	Stationary	219 dB	1.3 km²	650 m	630 m	640 m
		216 dB	2.9 km²	1.0 km	950 m	970 m
		210 dB	14 km²	2.2 km	2.1 km	2.1 km
		207 dB	28 km²	4.7 km	4.3 km	4.5 km
		203 dB	62 km²	4.7 km	4.3 km	4.5 km
		186 dB	690 km²	17 km	13 km	15 km

Table 4-54 Summary of the modelled impact ranges for Scenario 1 (absolute worst-case monopile) at the SE location of Dogger Bank B using the Popper et al. (2014) injury criteria for fish

4.4.2 Scenario 2

Popper *et al*. (2014)			Scenario 2: Dogger Bank A – N location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB		0.02 km²	90 m	80 m	90 m
	207 dB		0.13 km²	210 m	210 m	210 m
Unweighted SEL_{cum}	Fleeing (1.5 ms^{-1})	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		186 dB	70 km²	5.6 km	4.1 km	4.7 km
	Stationary	219 dB	0.89 km²	560 m	540 m	550 m
		216 dB	2.1 km²	850 m	830 m	840 m
		210 dB	11 km²	2.0 km	1.8 km	1.9 km
		207 dB	22 km²	2.8 km	2.6 km	2.6 km
		203 dB	50 km²	4.2 km	3.8 km	4.0 km
		186 dB	580 km²	15 km	12 km	14 km

Table 4-55 Summary of the modelled impact ranges for Scenario 2 (worst-case monopile) at the N location of Dogger Bank A using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)			Scenario 2: Dogger Bank A – SW location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB		0.02 km²	90 m	90 m	90 m
	207 dB		0.15 km²	220 m	220 m	220 m
Unweighted SEL_{cum}	Fleeing (1.5 ms^{-1})	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		186 dB	63 km²	5.3 km	3.7 km	4.5 km
	Stationary	219 dB	1.1 km²	600 m	590 m	600 m
		216 dB	2.5 km²	910 m	900 m	910 m
		210 dB	13 km²	2.1 km	2.0 km	2.0 km
		207 dB	24 km²	3.0 km	2.7 km	2.8 km
		203 dB	53 km²	4.5 km	3.9 km	4.1 km
		186 dB	530 km²	14 km	11 km	13 km

Table 4-56 Summary of the modelled impact ranges for Scenario 2 (worst-case monopile) at the SW location of Dogger Bank A using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)			Scenario 2: Dogger Bank B – NW location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB		0.03 km²	90 m	90 m	90 m
	207 dB		0.16 km²	230 m	230 m	230 m
Unweighted SEL_{cum}	Fleeing (1.5 ms^{-1})	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		186 dB	220 km²	10 km	5.9 km	8.3 km
	Stationary	219 dB	1.2 km²	630 m	610 m	620 m
		216 dB	2.8 km²	980 m	950 m	960 m
		210 dB	15 km²	2.3 km	2.2 km	2.2 km
		207 dB	32 km²	3.4 km	3.1 km	3.2 km
		203 dB	78 km²	5.3 km	4.7 km	5.0 km
		186 dB	1100 km²	22 km	15 km	19 km

Table 4-57 Summary of the modelled impact ranges for Scenario 2 (worst-case monopile) at the NW location of Dogger Bank B using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)			Scenario 2: Dogger Bank B – SE location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB		0.03 km²	90 m	90 m	90 m
	207 dB		0.15 km²	220 m	220 m	220 m
Unweighted SEL_{cum}	Fleeing (1.5 ms^{-1})	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		186 dB	95 km²	6.7 km	4.8 km	5.5 km
	Stationary	219 dB	1.1 km²	610 m	590 m	600 m
		216 dB	2.6 km²	930 m	910 m	920 m
		210 dB	13 km²	2.1 km	2.0 km	2.1 km
		207 dB	26 km²	3.0 km	2.9 km	2.9 km
		203 dB	60 km²	4.6 km	4.2 km	4.4 km
		186 dB	670 km²	17 km	13 km	15 km

Table 4-58 Summary of the modelled impact ranges for Scenario 2 (worst-case monopile) at the SE location of Dogger Bank B using the Popper et al. (2014) injury criteria for fish

4.4.3 Scenario 3

Popper *et al*. (2014)			Scenario 3: Dogger Bank A – N location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB		< 0.01 km^2	50 m	50 m	50 m
	207 dB		0.04 km^2	110 m	110 m	110 m
Unweighted SEL_{cum}	Fleeing (1.5 ms^{-1})	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		186 dB	13 km^2	2.4 km	1.8 km	2.1 km
	Stationary	219 dB	< 0.1 km^2	170 m	160 m	170 m
		216 dB	0.2 km^2	260 m	250 m	260 m
		210 dB	1.1 km^2	610 m	590 m	600 m
		207 dB	2.5 km^2	920 m	900 m	910 m
		203 dB	7.8 km^2	1.7 km	1.6 km	1.6 km
		186 dB	210 km^2	8.7 km	7.5 km	8.1 km

Table 4-59 Summary of the modelled impact ranges for Scenario 3 (most likely monopile) at the N location of Dogger Bank A using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)			Scenario 3: Dogger Bank A – SW location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB		< 0.01 km^2	50 m	50 m	50 m
	207 dB		0.04 km^2	120 m	120 m	120 m
Unweighted SEL_{cum}	Fleeing (1.5 ms^{-1})	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		186 dB	14 km^2	2.6 km	1.9 km	2.1 km
	Stationary	219 dB	< 0.1 km^2	180 m	170 m	180 m
		216 dB	0.2 km^2	280 m	270 m	280 m
		210 dB	1.3 km^2	650 m	640 m	650 m
		207 dB	3.0 km^2	990 m	970 m	980 m
		203 dB	8.9 km^2	1.7 km	1.7 km	1.7 km
		186 dB	200 km^2	8.8 km	7.3 km	8.0 km

Table 4-60 Summary of the modelled impact ranges for Scenario 3 (most likely monopile) at the SW location of Dogger Bank A using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)			Scenario 3: Dogger Bank B – NW location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB		< 0.01 km^2	50 m	50 m	50 m
	207 dB		0.05 km^2	120 m	120 m	120 m
Unweighted SEL_{cum}	Fleeing (1.5 ms^{-1})	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		186 dB	41 km^2	4.0 km	2.9 km	3.6 km
	Stationary	219 dB	< 0.1 km^2	190 m	180 m	190 m
		216 dB	0.3 km^2	290 m	280 m	290 m
		210 dB	1.4 km^2	690 m	670 m	680 m
		207 dB	3.6 km^2	1.2 km	1.1 km	1.1 km
		203 dB	11 km^2	1.9 km	1.8 km	1.9 km
		186 dB	360 km^2	11 km	9.3 km	11 km

Table 4-61 Summary of the modelled impact ranges for Scenario 3 (most likely monopile) at the NW location of Dogger Bank B using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)			Scenario 3: Dogger Bank B – SE location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB		< 0.01 km^2	50 m	50 m	50 m
	207 dB		0.04 km^2	120 m	120 m	120 m
Unweighted SEL_{cum}	Fleeing (1.5 ms^{-1})	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		186 dB	20 km^2	2.9 km	2.3 km	2.5 km
	Stationary	219 dB	< 0.1 km^2	180 m	170 m	180 m
		216 dB	0.23 km^2	280 m	270 m	280 m
		210 dB	1.3 km^2	660 m	650 m	650 m
		207 dB	3.0 km^2	1.0 km	990 m	1.0 km
		203 dB	9.4 km^2	1.8 km	1.7 km	1.7 km
		186 dB	240 km^2	9.6 km	8.3 km	8.8 km

Table 4-62 Summary of the modelled impact ranges for Scenario 3 (most likely monopile) at the SE location of Dogger Bank B using the Popper et al. (2014) injury criteria for fish

4.4.4 Scenario 4

Popper *et al*. (2014)			Scenario 4: Dogger Bank A – N location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB		0.02 km^2	70 m	70 m	70 m
	207 dB		0.1 km^2	180 m	180 m	180 m
Unweighted SEL_{cum}	Fleeing (1.5 ms^{-1})	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		186 dB	11 km^2	2.2 km	1.6 km	1.9 km
	Stationary	219 dB	0.79 km^2	520 m	500 m	510 m
		216 dB	1.8 km^2	790 m	770 m	780 m
		210 dB	9.5 km^2	1.8 km	1.7 km	1.7 km
		207 dB	19 km^2	2.6 km	2.4 km	2.5 km
		203 dB	44 km^2	3.9 km	3.6 km	3.8 km
		186 dB	540 km^2	15 km	12 km	13 km

Table 4-63 Summary of the modelled impact ranges for Scenario 4 (absolute worst-case pin pile) at the N location of Dogger Bank A using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)			Scenario 4: Dogger Bank A – SW location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB		0.02 km^2	80 m	80 m	80 m
	207 dB		0.12 km^2	190 m	190 m	190 m
Unweighted SEL_{cum}	Fleeing (1.5 ms^{-1})	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		186 dB	12 km^2	2.4 km	1.7 km	2.0 km
	Stationary	219 dB	1.0 km^2	580 m	550 m	570 m
		216 dB	2.4 km^2	880 m	850 m	870 m
		210 dB	11 km^2	1.9 km	1.8 km	1.9 km
		207 dB	22 km^2	2.8 km	2.5 km	2.6 km
		203 dB	48 km^2	4.3 km	3.7 km	3.9 km
		186 dB	510 km^2	14 km	11 km	13 km

Table 4-64 Summary of the modelled impact ranges for Scenario 4 (absolute worst-case pin pile) at the SW location of Dogger Bank A using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)			Scenario 4: Dogger Bank B – NW location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB		0.02 km^2	80 m	80 m	80 m
	207 dB		0.12 km^2	200 m	200 m	200 m
Unweighted SEL_{cum}	Fleeing (1.5 ms^{-1})	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		186 dB	42 km^2	4.2 km	2.7 km	3.6 km
	Stationary	219 dB	1.1 km^2	600 m	580 m	590 m
		216 dB	2.5 km^2	930 m	900 m	910 m
		210 dB	14 km^2	2.2 km	2.1 km	2.1 km
		207 dB	29 km^2	3.2 km	3.0 km	3.1 km
		203 dB	72 km^2	5.0 km	4.5 km	4.8 km
		186 dB	1100 km^2	21 km	15 km	18 km

Table 4-65 Summary of the modelled impact ranges for Scenario 4 (absolute worst-case pin pile) at the NW location of Dogger Bank B using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)			Scenario 4: Dogger Bank B – SE location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB		0.02 km^2	80 m	80 m	80 m
	207 dB		0.12 km^2	200 m	190 m	200 m
Unweighted SEL_{cum}	Fleeing (1.5 ms^{-1})	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		186 dB	18 km^2	2.8 km	2.1 km	2.4 km
	Stationary	219 dB	1.1 km^2	600 m	580 m	590 m
		216 dB	2.4 km^2	900 m	880 m	880 m
		210 dB	12 km^2	2.0 km	1.9 km	1.9 km
		207 dB	23 km^2	2.8 km	2.7 km	2.7 km
		203 dB	54 km^2	4.4 km	4.0 km	4.2 km
		186 dB	640 km^2	16 km	13 km	14 km

Table 4-66 Summary of the modelled impact ranges for Scenario 4 (absolute worst-case pin pile) at the SE location of Dogger Bank B using the Popper et al. (2014) injury criteria for fish

4.4.5 Scenario 5

Popper *et al*. (2014)			Scenario 5: Dogger Bank A – N location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB		< 0.01 km²	70 m	70 m	70 m
	207 dB		0.09 km²	170 m	170 m	170 m
Unweighted SEL_{cum}	Fleeing (1.5 ms^{-1})	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		186 dB	11 km²	2.2 km	1.6 km	1.8 km
	Stationary	219 dB	0.7 km²	480 m	470 m	480 m
		216 dB	1.6 km²	740 m	720 m	730 m
		210 dB	8.5 km²	1.7 km	1.6 km	1.6 km
		207 dB	17 km²	2.5 km	2.3 km	2.3 km
		203 dB	40 km²	3.8 km	3.5 km	3.6 km
		186 dB	520 km²	14 km	12 km	13 km

Table 4-67 Summary of the modelled impact ranges for Scenario 5 (worst-case pin pile) at the N location of Dogger Bank A using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)			Scenario 5: Dogger Bank A – SW location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB		0.02 km²	70 m	70 m	70 m
	207 dB		0.1 km²	180 m	180 m	180 m
Unweighted SEL_{cum}	Fleeing (1.5 ms^{-1})	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		186 dB	12 km²	2.5 km	1.7 km	2.0 km
	Stationary	219 dB	0.84 km²	530 m	520 m	530 m
		216 dB	2.0 km²	810 m	800 m	800 m
		210 dB	10 km²	1.9 km	1.8 km	1.8 km
		207 dB	20 km²	2.7 km	2.5 km	2.5 km
		203 dB	45 km²	4.1 km	3.6 km	3.8 km
		186 dB	490 km²	14 km	11 km	12 km

Table 4-68 Summary of the modelled impact ranges for Scenario 5 (worst-case pin pile) at the SW location of Dogger Bank A using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)			Scenario 5: Dogger Bank B – NW location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB		0.02 km²	80 m	70 m	80 m
	207 dB		0.11 km²	190 m	180 m	190 m
Unweighted SEL_{cum}	Fleeing (1.5 ms⁻¹)	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		186 dB	40 km²	4.1 km	2.7 km	3.6 km
	Stationary	219 dB	0.94 km²	560 m	540 m	550 m
		216 dB	2.2 km²	870 m	840 m	850 m
		210 dB	12 km²	2.1 km	2.0 km	2.0 km
		207 dB	26 km²	3.0 km	2.8 km	2.9 km
		203 dB	65 km²	4.8 km	4.3 km	4.6 km
		186 dB	1000 km²	21 km	15 km	18 km

Table 4-69 Summary of the modelled impact ranges for Scenario 5 (worst-case pin pile) at the NW location of Dogger Bank B using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)			Scenario 5: Dogger Bank B – SE location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB		0.02 km²	70 m	70 m	70 m
	207 dB		0.1 km²	180 m	180 m	180 m
Unweighted SEL_{cum}	Fleeing (1.5 ms⁻¹)	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		186 dB	17 km²	2.8 km	2.1 km	2.4 km
	Stationary	219 dB	0.86 km²	540 m	520 m	530 m
		216 dB	2.0 km²	820 m	800 m	810 m
		210 dB	11 km²	1.9 km	1.8 km	1.8 km
		207 dB	22 km²	2.7 km	2.6 km	2.6 km
		203 dB	50 km²	4.2 km	3.9 km	4.0 km
		186 dB	610 km²	16 km	13 km	14 km

Table 4-70 Summary of the modelled impact ranges for Scenario 5 (worst-case pin pile) at the SE location of Dogger Bank B using the Popper et al. (2014) injury criteria for fish

4.4.6 Scenario 6

Popper *et al*. (2014)			Scenario 6: Dogger Bank A – N location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB		< 0.01 km^2	60 m	60 m	60 m
	207 dB		0.07 km^2	150 m	150 m	150 m
Unweighted SEL_{cum}	Fleeing (1.5 ms^{-1})	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		186 dB	10 km^2	2.1 km	1.6 km	1.8 km
	Stationary	219 dB	0.61 km^2	450 m	440 m	450 m
		216 dB	1.4 km^2	690 m	670 m	680 m
		210 dB	7.5 km^2	1.6 km	1.5 km	1.5 km
		207 dB	15 km^2	2.3 km	2.2 km	2.2 km
		203 dB	36 km^2	3.6 km	3.3 km	3.4 km
		186 dB	490 km^2	14 km	11 km	13 km

Table 4-71 Summary of the modelled impact ranges for Scenario 6 (most likely pin pile) at the N location of Dogger Bank A using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)			Scenario 6: Dogger Bank A – SW location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB		< 0.01 km^2	70 m	70 m	70 m
	207 dB		0.08 km^2	160 m	160 m	160 m
Unweighted SEL_{cum}	Fleeing (1.5 ms^{-1})	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
		186 dB	12 km^2	2.4 km	1.7 km	1.9 km
	Stationary	219 dB	0.72 km^2	490 m	480 m	490 m
		216 dB	1.7 km^2	750 m	740 m	750 m
		210 dB	8.9 km^2	1.7 km	1.7 km	1.7 km
		207 dB	18 km^2	2.5 km	2.3 km	2.4 km
		203 dB	41 km^2	3.9 km	3.5 km	3.6 km
		186 dB	460 km^2	13 km	10 km	12 km

Table 4-72 Summary of the modelled impact ranges for Scenario 6 (most likely pin pile) at the SW location of Dogger Bank A using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)			Scenario 6: Dogger Bank B – NW location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB		0.02 km²	80 m	70 m	80 m
	207 dB		0.11 km²	190 m	180 m	190 m
Unweighted SEL_{cum}	Fleeing (1.5 ms^{-1})	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		186 dB	40 km²	4.1 km	2.7 km	3.6 km
	Stationary	219 dB	0.94 km²	560 m	540 m	550 m
		216 dB	2.2 km²	870 m	840 m	850 m
		210 dB	12 km²	2.1 km	2.0 km	2.0 km
		207 dB	26 km²	3.0 km	2.8 km	2.9 km
		203 dB	65 km²	4.8 km	4.3 km	4.6 km
		186 dB	1000 km²	21 km	15 km	18 km

Table 4-73 Summary of the modelled impact ranges for Scenario 6 (most likely pin pile) at the NW location of Dogger Bank B using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)			Scenario 6: Dogger Bank B – SE location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB		< 0.01 km²	70 m	70 m	70 m
	207 dB		0.08 km²	160 m	160 m	160 m
Unweighted SEL_{cum}	Fleeing (1.5 ms^{-1})	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		186 dB	95 km²	6.7 km	4.8 km	5.5 km
	Stationary	219 dB	0.74 km²	500 m	490 m	490 m
		216 dB	1.8 km²	760 m	750 m	760 m
		210 dB	13 km²	2.1 km	2.0 km	2.1 km
		207 dB	26 km²	3.0 km	2.9 km	2.9 km
		203 dB	60 km²	4.6 km	4.2 km	4.4 km
		186 dB	670 km²	17 km	13 km	15 km

Table 4-74 Summary of the modelled impact ranges for Scenario 6 (most likely pin pile) at the SE location of Dogger Bank B using the Popper et al. (2014) injury criteria for fish

5 Summary and conclusions

Subacoustech Environmental have undertaken a study on behalf of HaskoningDHV UK Ltd to assess the potential underwater noise, and its effects during impact piling operations at Dogger Bank A and B.

The level of underwater noise from the installation of monopile and pin pile foundations during construction has been estimated using the INSPIRE semi-empirical underwater noise model. The modelling considers a wide variety of input parameters including bathymetry, hammer blow energy, strike rate and receptor flee speed.

Four representative modelling locations were chosen for the WTG foundations, two in Dogger Bank A and two in Dogger Bank B, to give spatial variation as well as accounting for changes in water depth around the sites, which affects noise propagation. Six piling scenarios were considered, three monopile and three pin pile, consisting of absolute worst-case, worst-case and most likely scenarios at each location.

The loudest levels of noise, and greatest impact ranges have been predicted for the absolute worst-case monopile scenarios at the NW corner of Dogger Bank B, due to the deep water, and hence reduced attenuation of sound, to the north and west of this location.

The modelling results were analysed in terms of relevant noise metrics and criteria to assess the impact piling noise on marine mammals (Southall *et al*., 2019 and Lucke *et al*., 2009) and fish (Popper *et al*., 2014). For marine mammals, maximum PTS ranges were predicted for the LF cetaceans and VHF cetacean species group, with ranges of up to 4.1 km and 2.3 km respectively for the absolute worst-case monopile results at the NW corner of Dogger Bank B. For fish, the largest TTS ranges were also at Dogger Bank B, NW, and were predicted to be 10 km for a fleeing receptor, increasing to 23 km for a stationary receptor.

The outputs of this modelling have been used to inform analysis of the impacts of underwater noise on marine mammals and fish for the Dogger Bank A and B projects.

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Appendix A Additional results

The following sections contain additional modelling results to supplement and expand upon the information provided in section 4 in the main body of the report.

A.1 Additional unweighted noise contour plots

Figure A 1 to Figure A 42 show the remaining contour plots in 5 dB increments as referenced in Table 4-1. These cover the SW modelling location at Dogger Bank A and the NW and SE modelling locations at Dogger Bank B for unweighted SPL_{peak} and all four modelling locations for unweighted SEL_{ss}.

Scenario 1

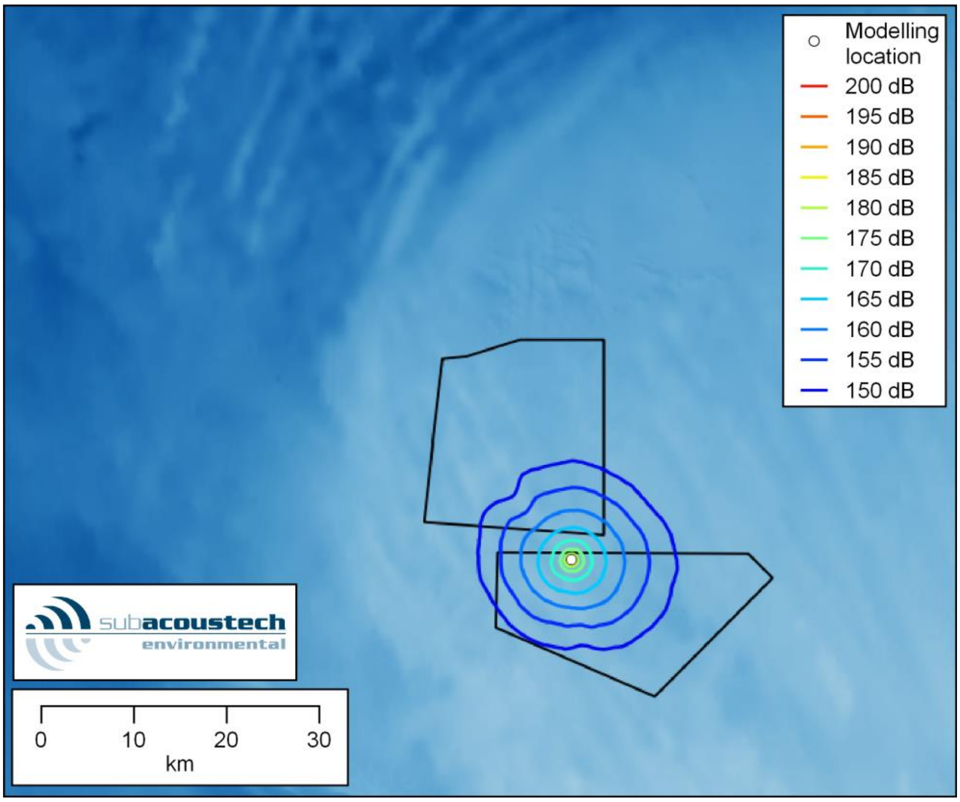

Figure A 1 Contour plot showing the unweighted SEL_{ss} noise levels at Dogger Bank A, N location using the scenario 1 parameters (absolute worst-case monopile)

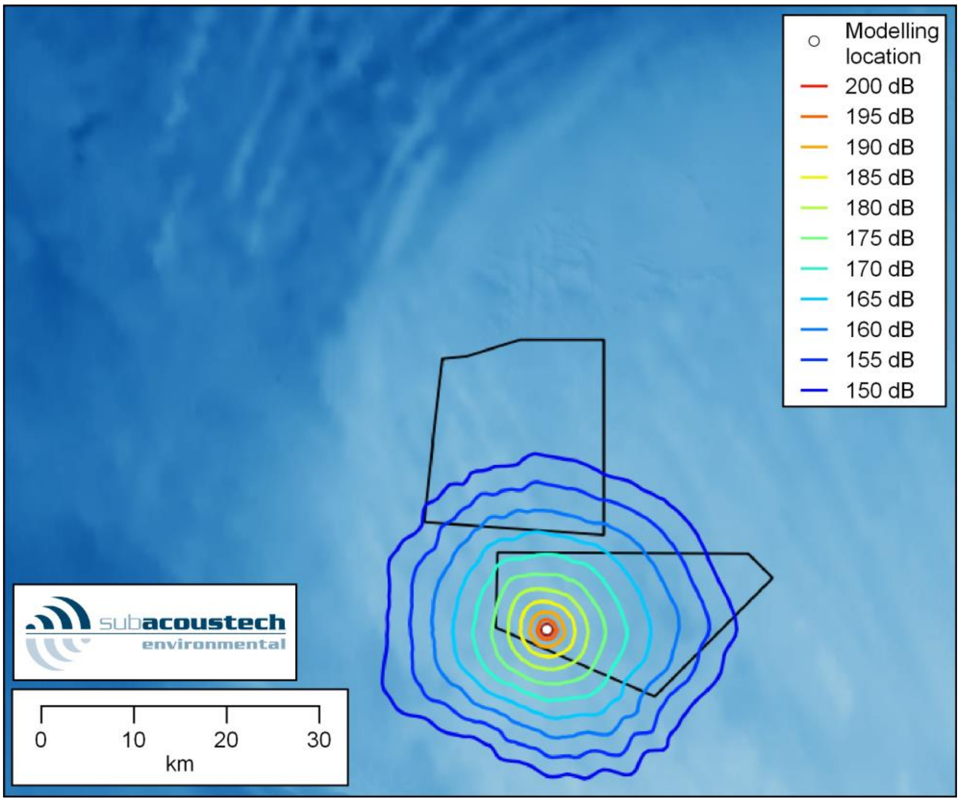

Figure A 2 Contour plot showing the unweighted SPL_{peak} noise levels at Dogger Bank A, SW location using the scenario 1 parameters (absolute worst-case monopile)

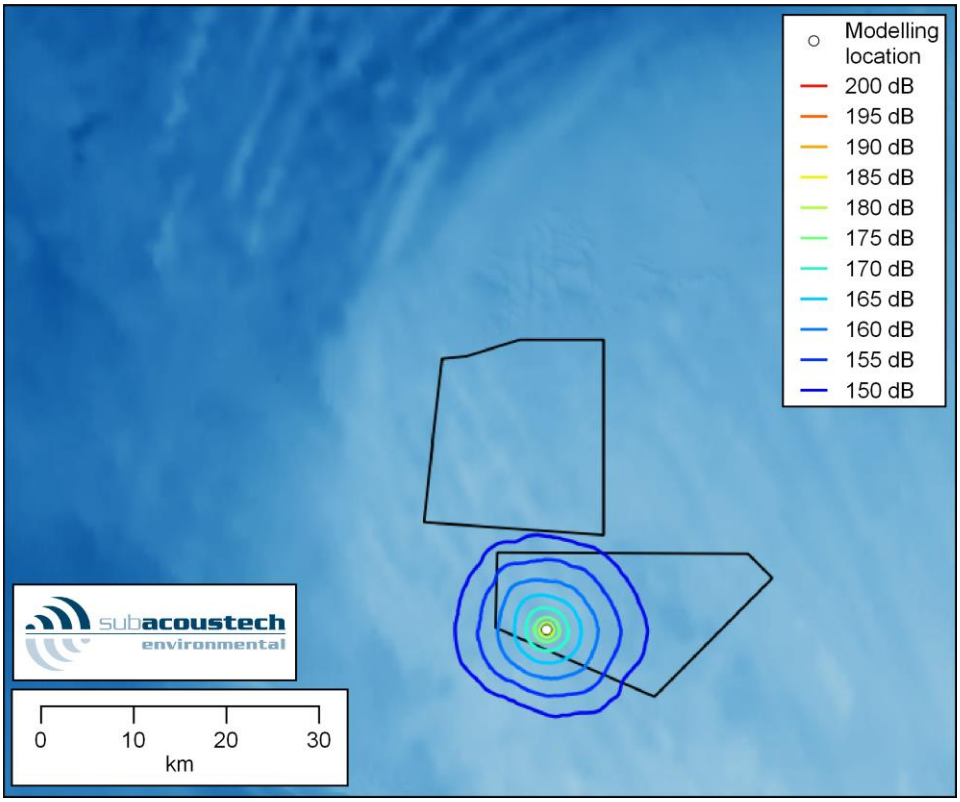

Figure A 3 Contour plot showing the unweighted SEL_{ss} noise levels at Dogger Bank A, SW location using the scenario 1 parameters (absolute worst-case monopile)

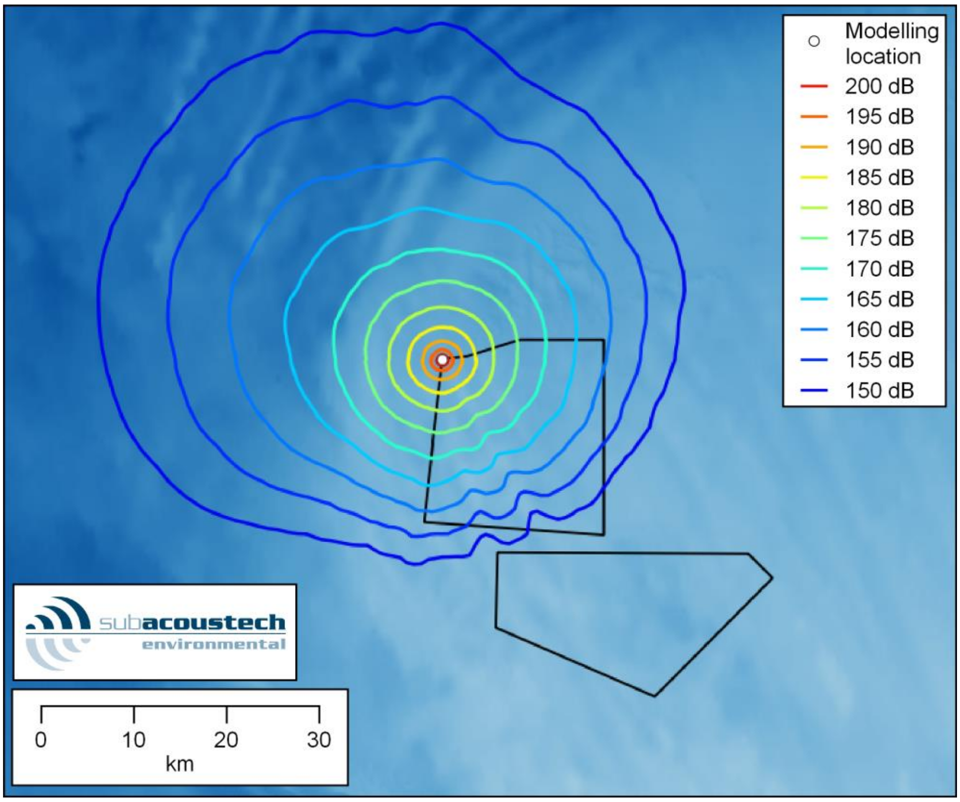

Figure A 4 Contour plot showing the unweighted SPL_{peak} noise levels at Dogger Bank B, NW location using the scenario 1 parameters (absolute worst-case monopile)

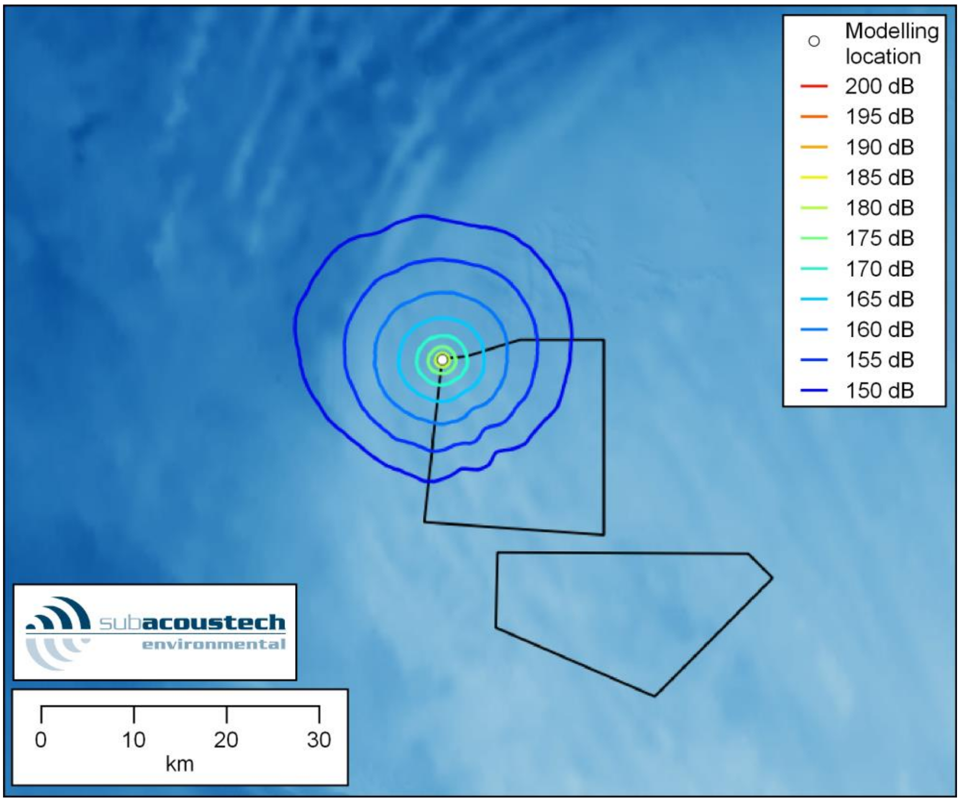

Figure A 5 Contour plot showing the unweighted SEL_{ss} noise levels at Dogger Bank B, NW location using the scenario 1 parameters (absolute worst-case monopile)

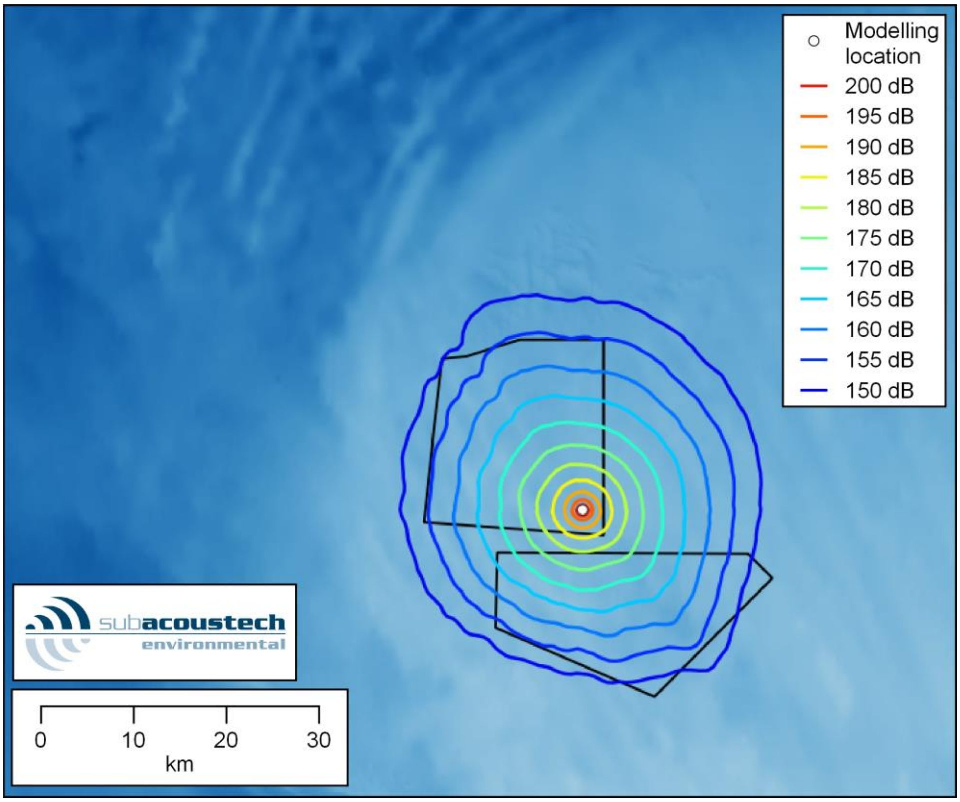

Figure A 6 Contour plot showing the unweighted SPL_{peak} noise levels at Dogger Bank B, SE location using the scenario 1 parameters (absolute worst-case monopile)

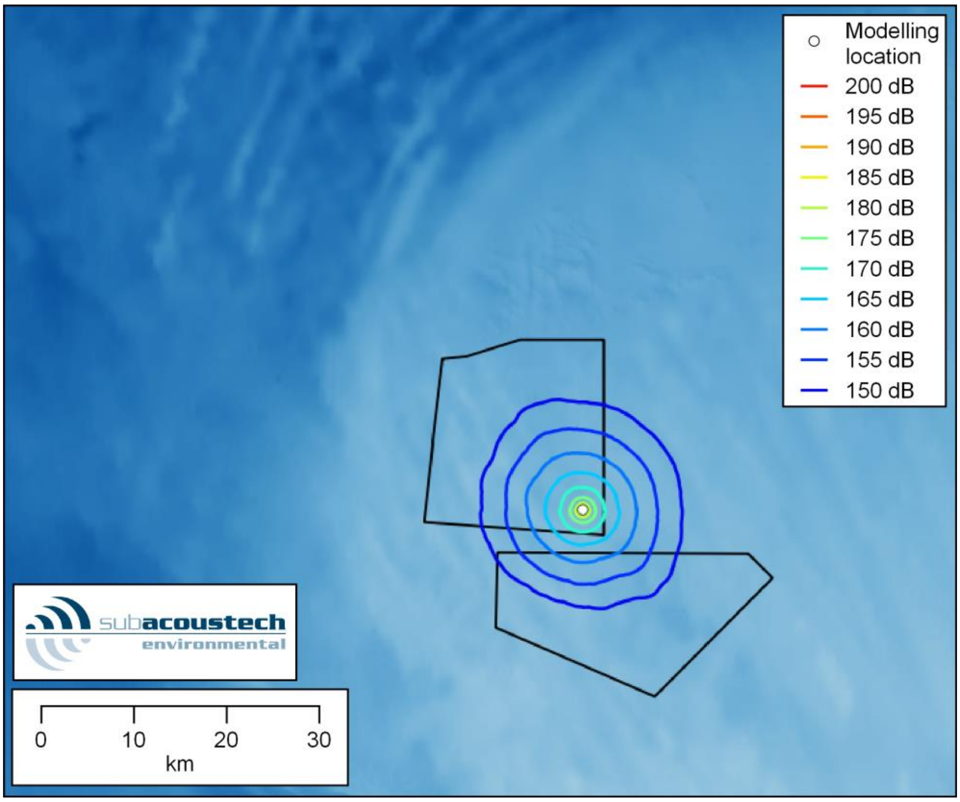

Figure A 7 Contour plot showing the unweighted SEL_{ss} noise levels at Dogger Bank B, SE location using the scenario 1 parameters (absolute worst-case monopile)

Scenario 2

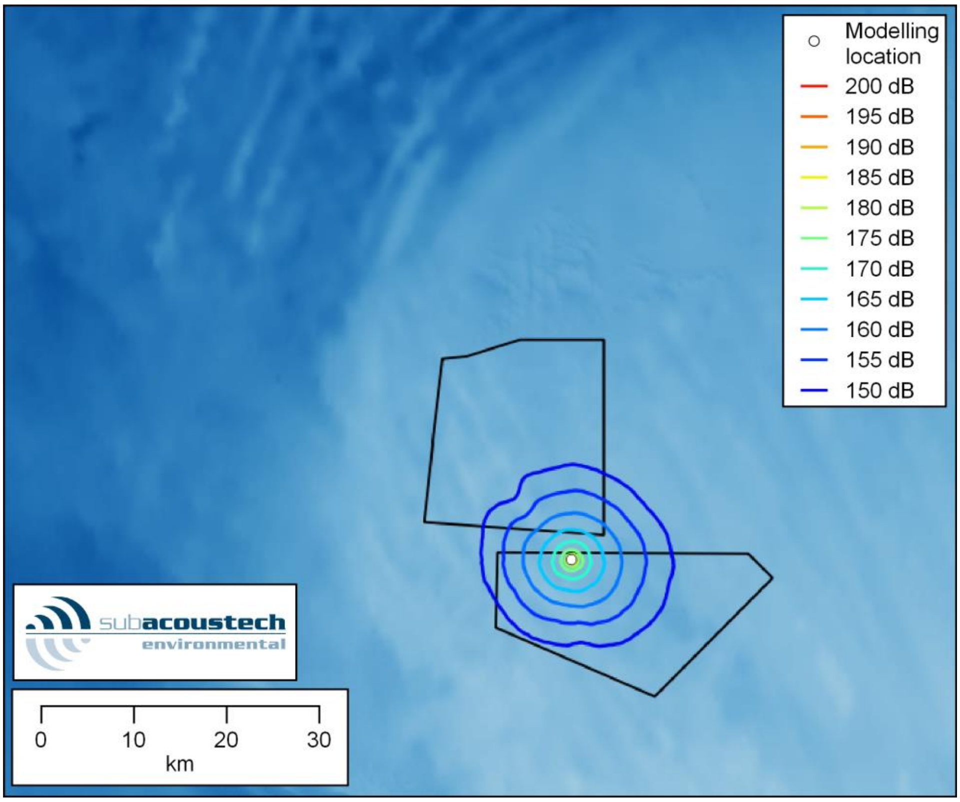

Figure A 8 Contour plot showing the unweighted SEL_{ss} noise levels at Dogger Bank A, N location using the scenario 2 parameters (worst-case monopile)

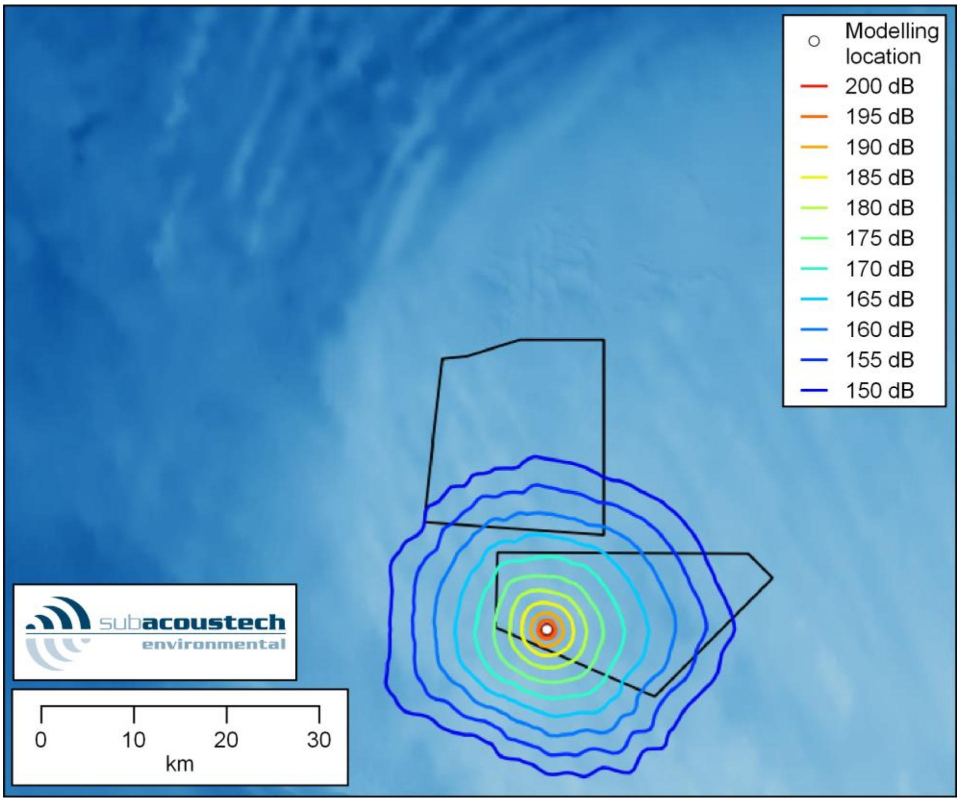

Figure A 9 Contour plot showing the unweighted SPL_{peak} noise levels at Dogger Bank A, SW location using the scenario 2 parameters (worst-case monopile)

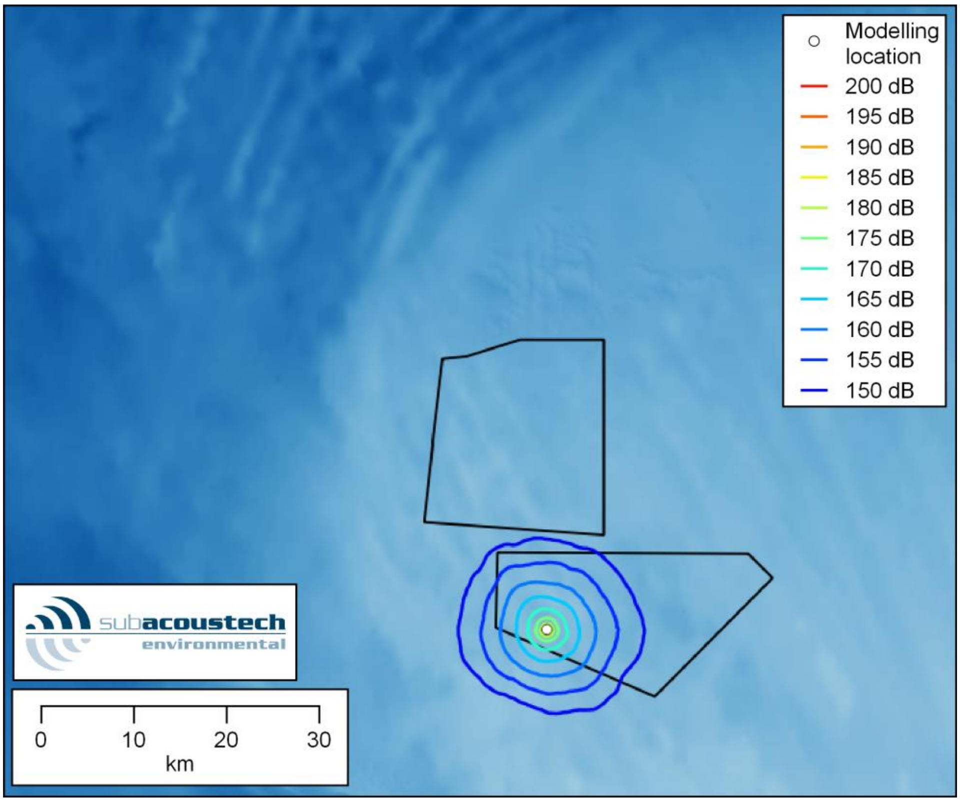

Figure A 10 Contour plot showing the unweighted SEL_{ss} noise levels at Dogger Bank A, SW location using the scenario 2 parameters (worst-case monopile)

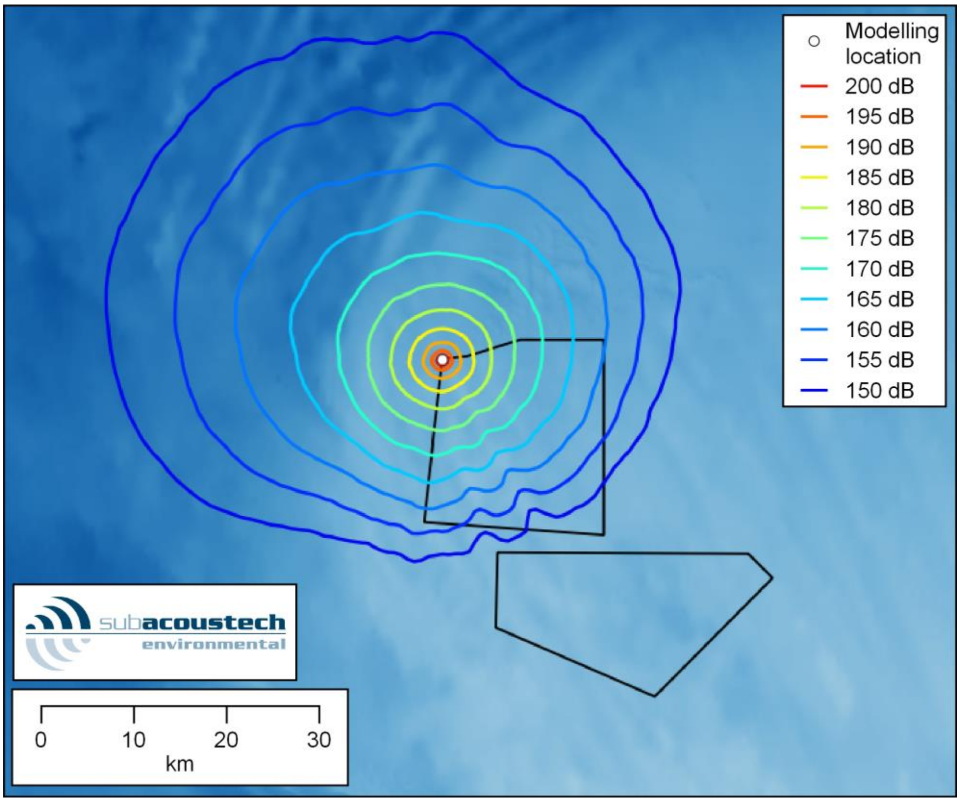

Figure A 11 Contour plot showing the unweighted SPL_{peak} noise levels at Dogger Bank B, NW location using the scenario 2 parameters (worst-case monopile)

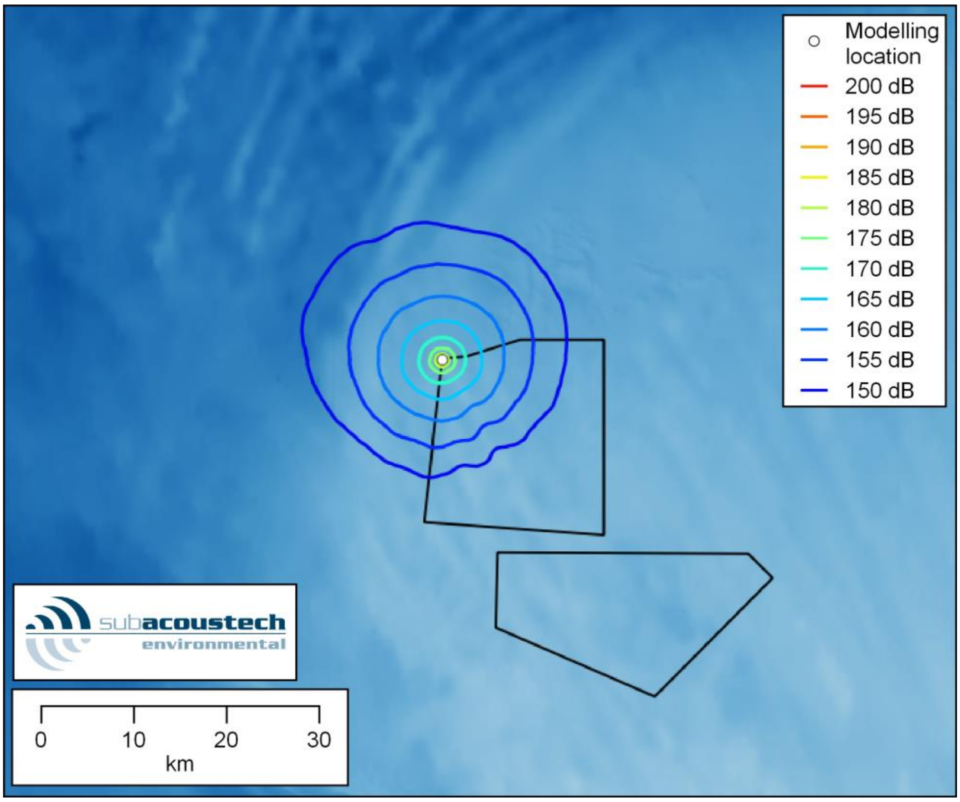

Figure A 12 Contour plot showing the unweighted SEL_{ss} noise levels at Dogger Bank B, NW location using the scenario 2 parameters (worst-case monopile)

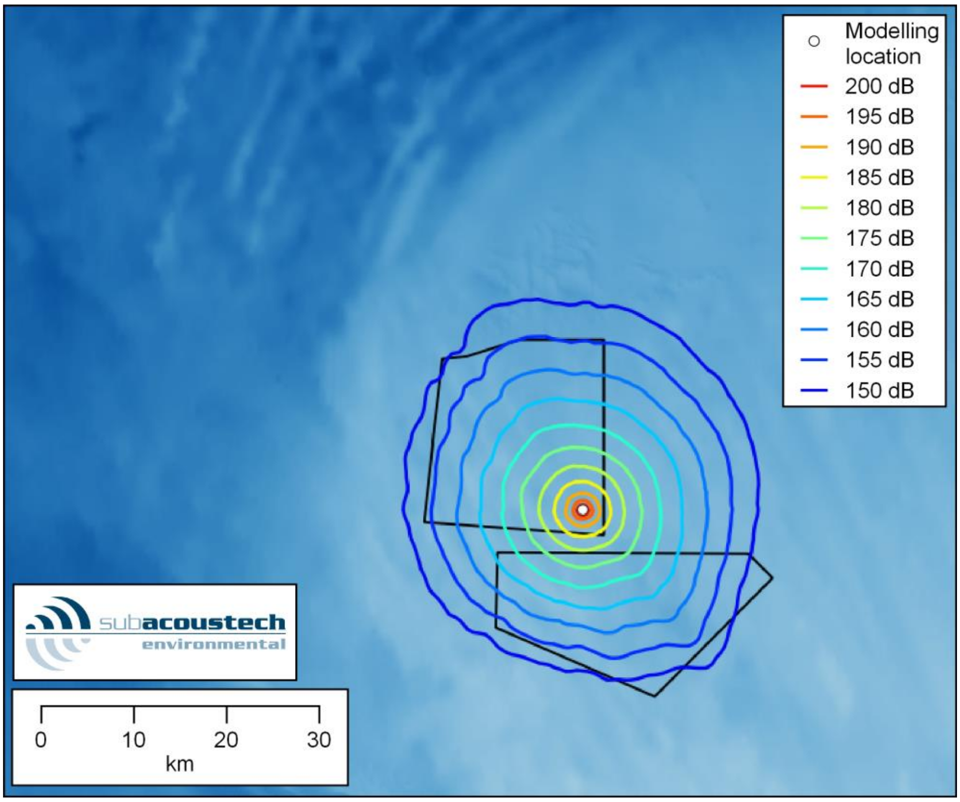

Figure A 13 Contour plot showing the unweighted SPL_{peak} noise levels at Dogger Bank B, SE location using the scenario 2 parameters (worst-case monopile)

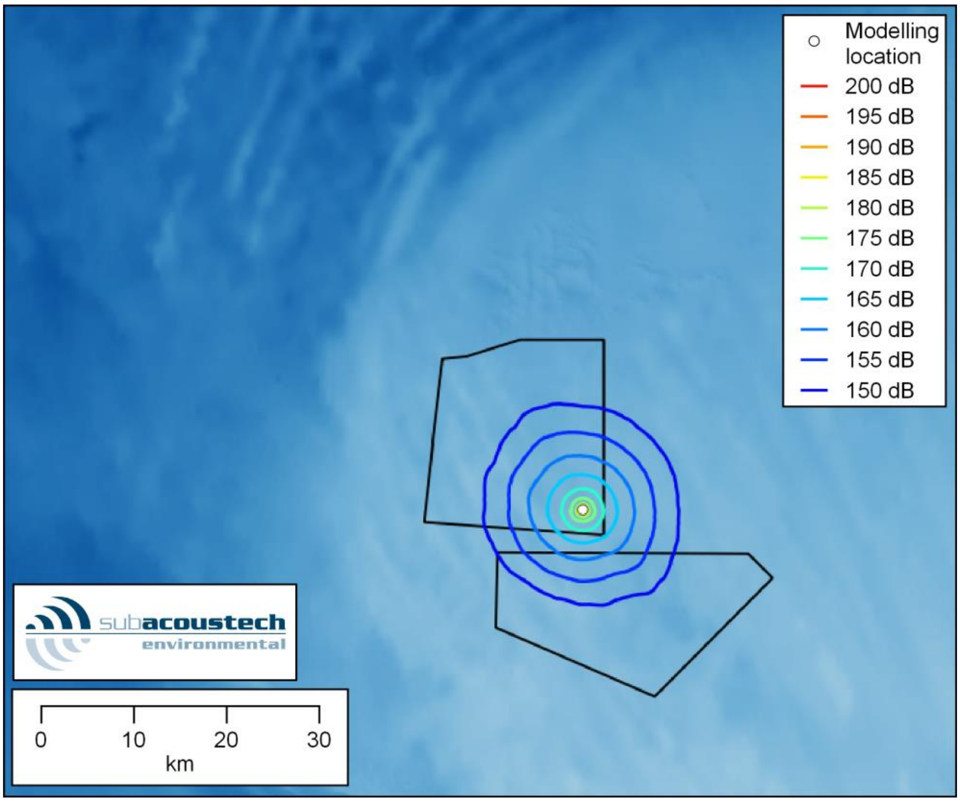

Figure A 14 Contour plot showing the unweighted SEL_{ss} noise levels at Dogger Bank B, SE location using the scenario 2 parameters (worst-case monopile)

Scenario 3

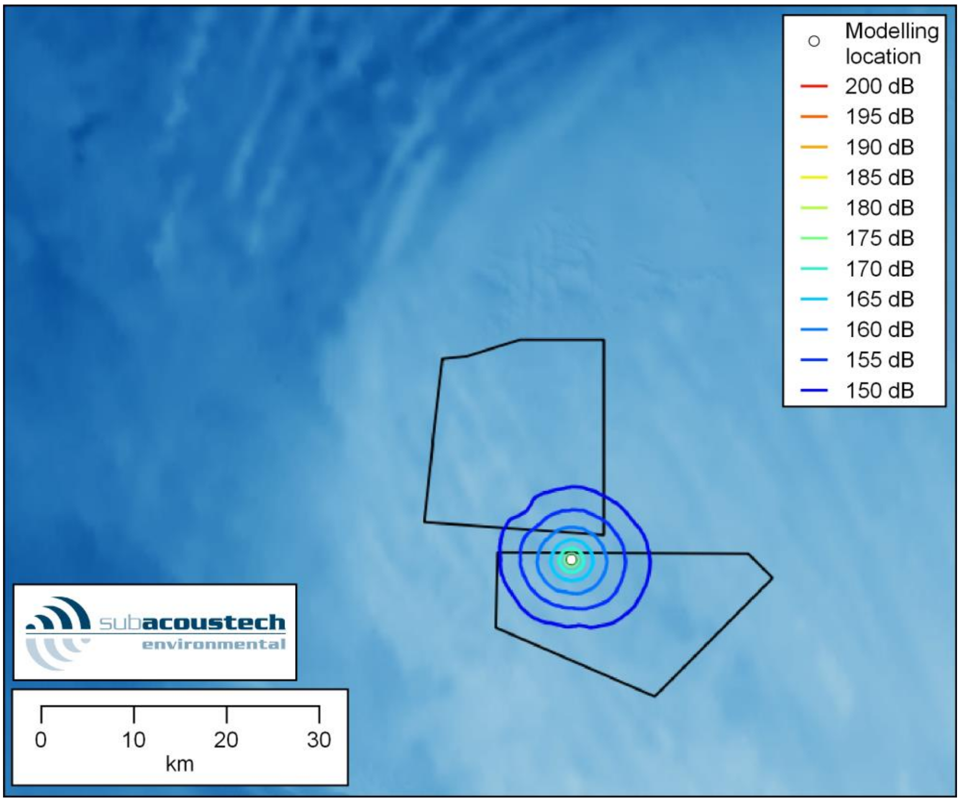

Figure A 15 Contour plot showing the unweighted SEL_{ss} noise levels at Dogger Bank A, N location using the scenario 3 parameters (most likely monopile)

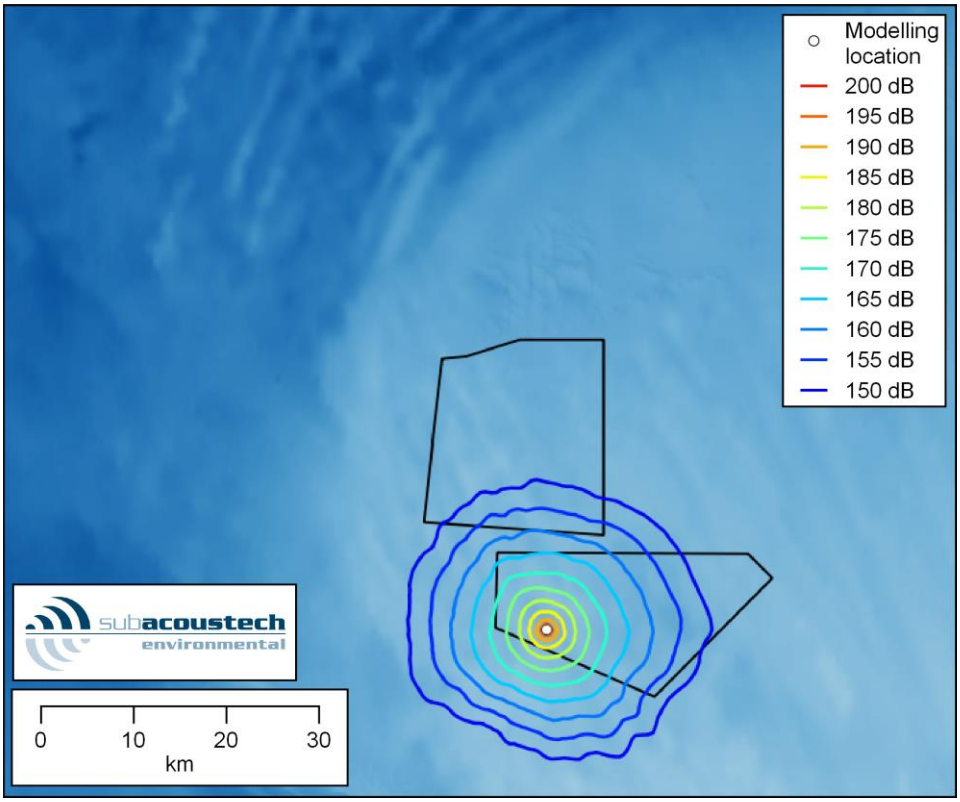

Figure A 16 Contour plot showing the unweighted SPL_{peak} noise levels at Dogger Bank A, SW location using the scenario 3 parameters (most likely monopile)

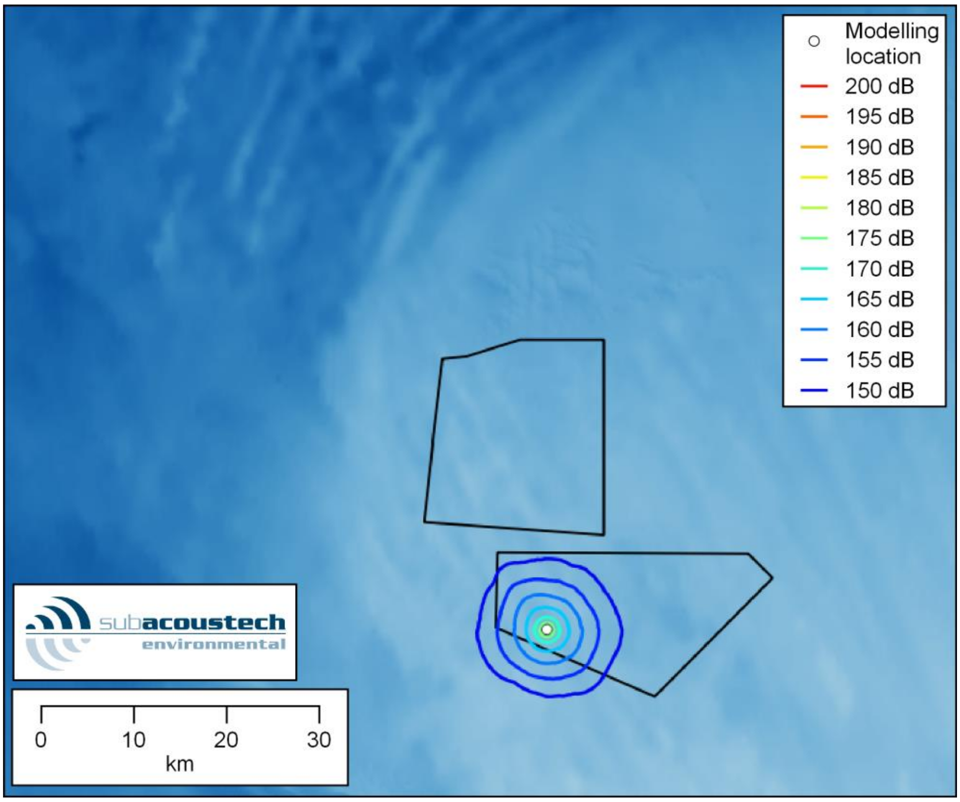

Figure A 17 Contour plot showing the unweighted SEL_{ss} noise levels at Dogger Bank A, SW location using the scenario 3 parameters (most likely monopile)

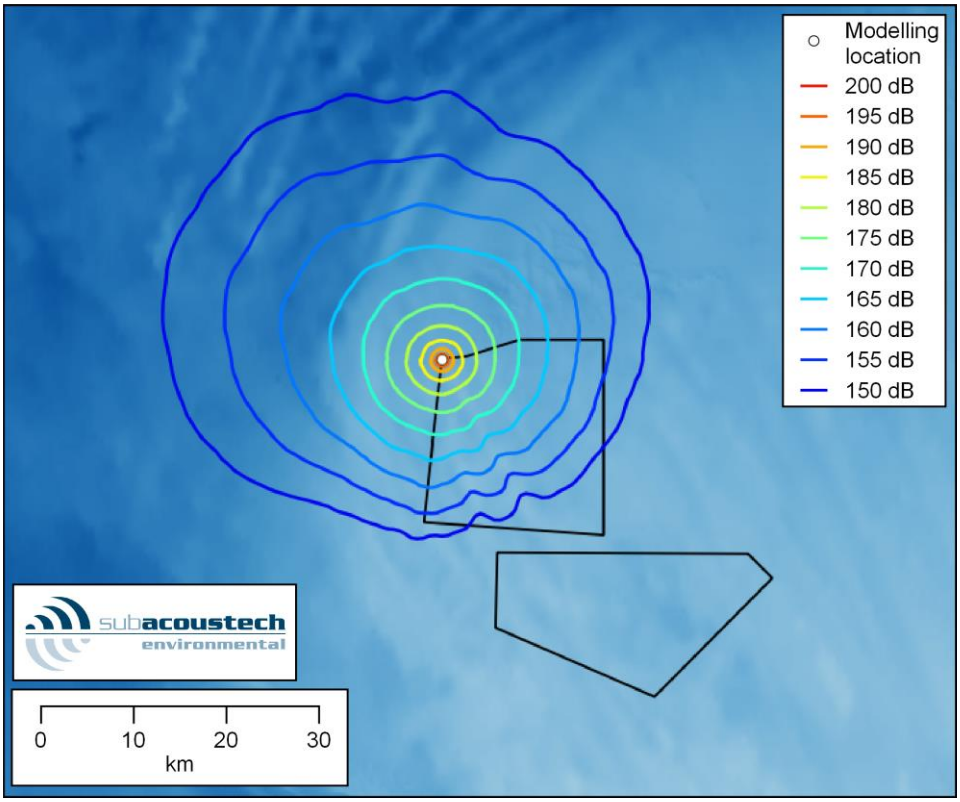

Figure A 18 Contour plot showing the unweighted SPL_{peak} noise levels at Dogger Bank B, NW location using the scenario 3 parameters (most likely monopile)

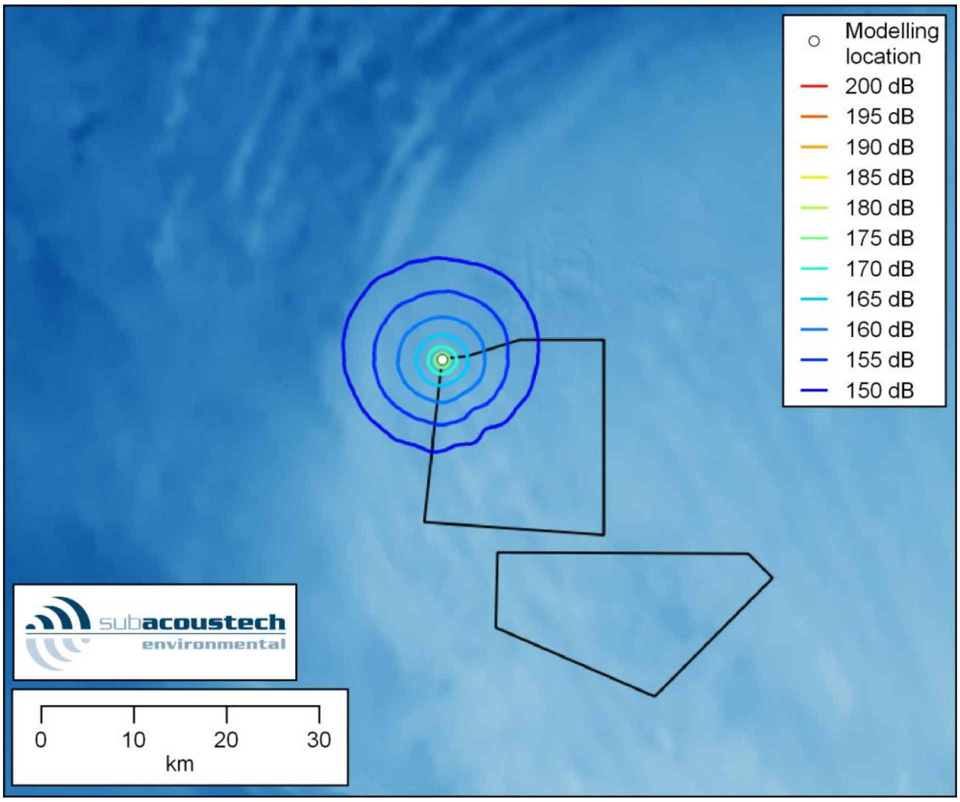

Figure A 19 Contour plot showing the unweighted SEL_{ss} noise levels at Dogger Bank B, NW location using the scenario 3 parameters (most likely monopile)

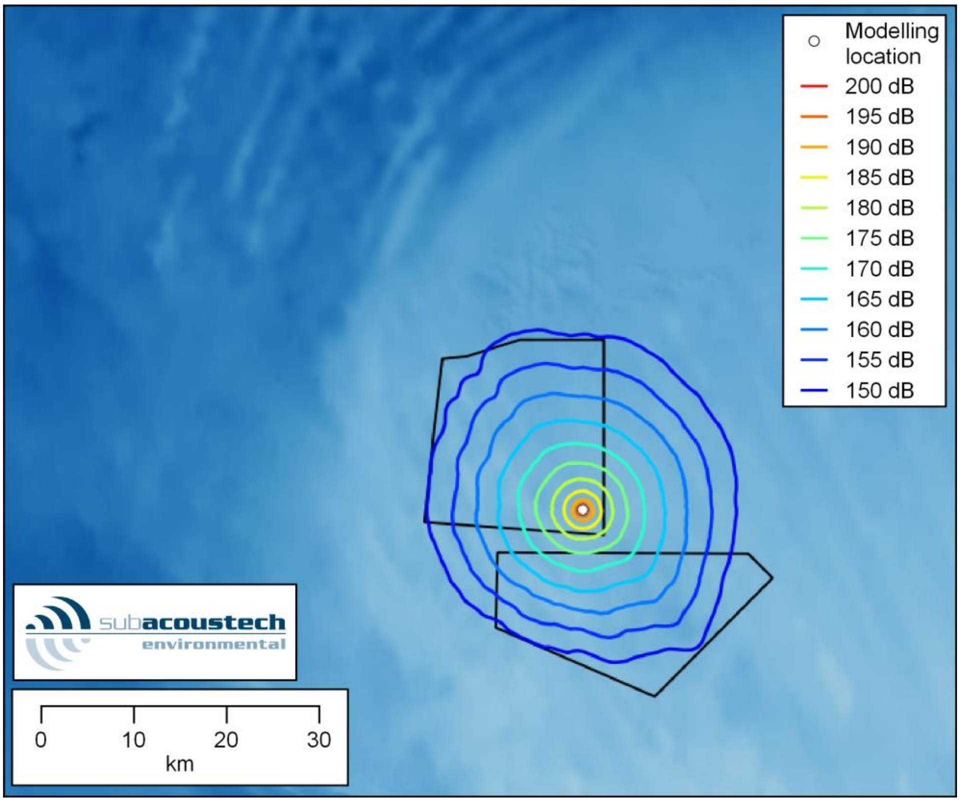

Figure A 20 Contour plot showing the unweighted SPL_{peak} noise levels at Dogger Bank B, SE location using the scenario 3 parameters (most likely monopile)

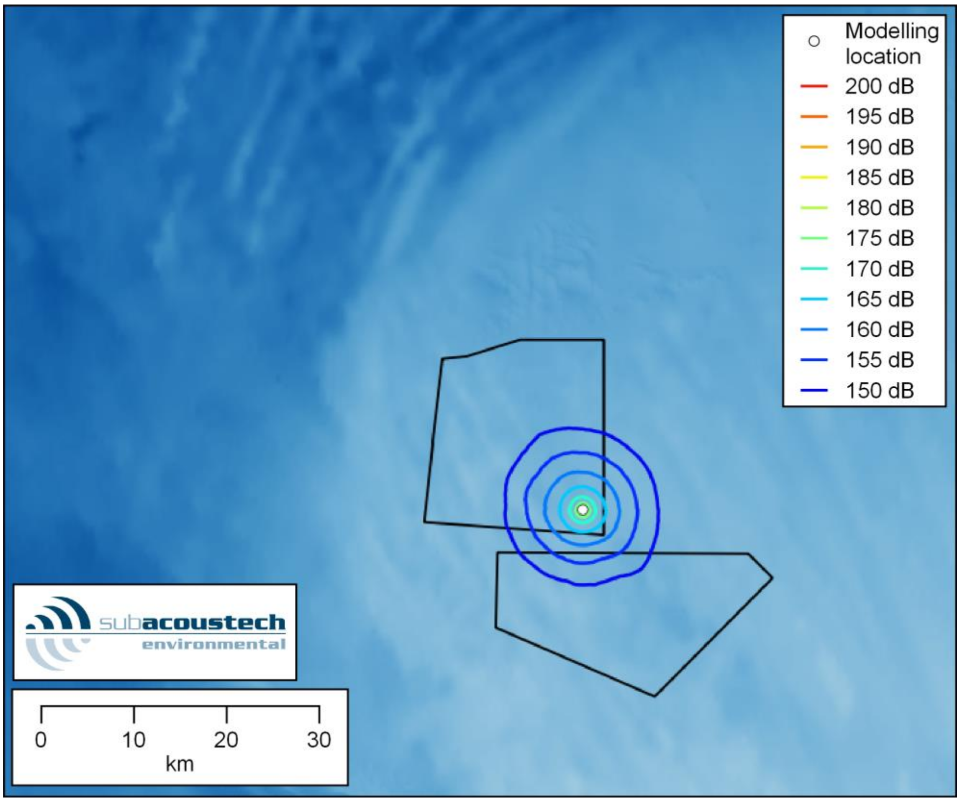

Figure A 21 Contour plot showing the unweighted SEL_{ss} noise levels at Dogger Bank B, SE location using the scenario 3 parameters (most likely monopile)

Scenario 4

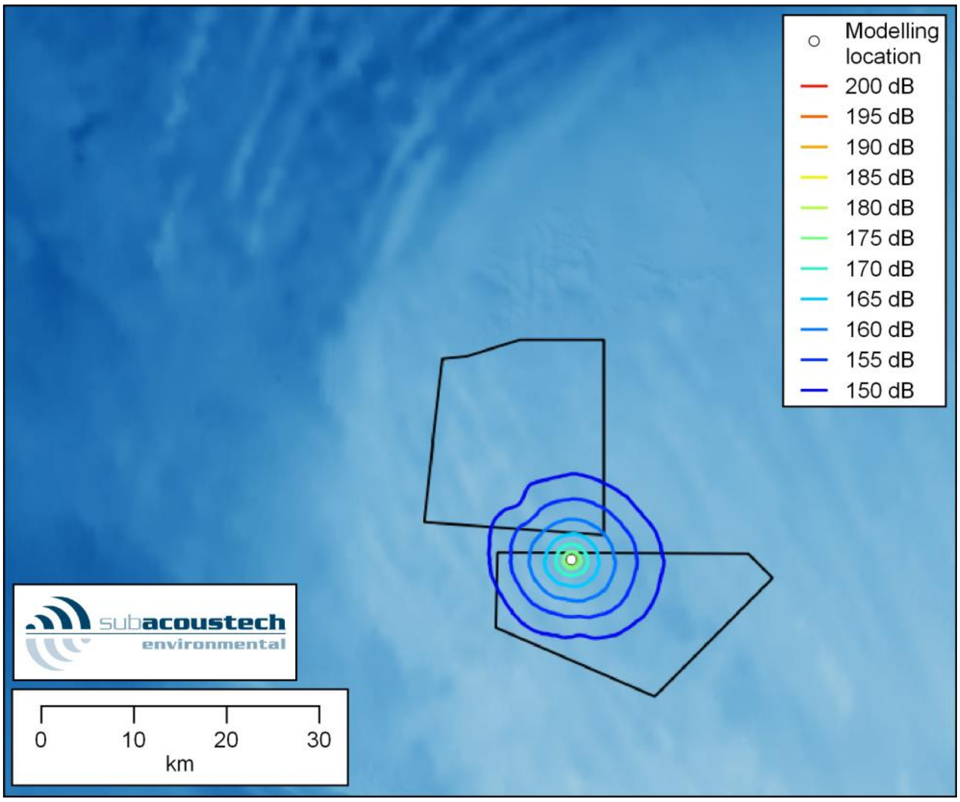

Figure A 22 Contour plot showing the unweighted SEL_{ss} noise levels at Dogger Bank A, N location using the scenario 4 parameters (absolute worst-case pin pile)

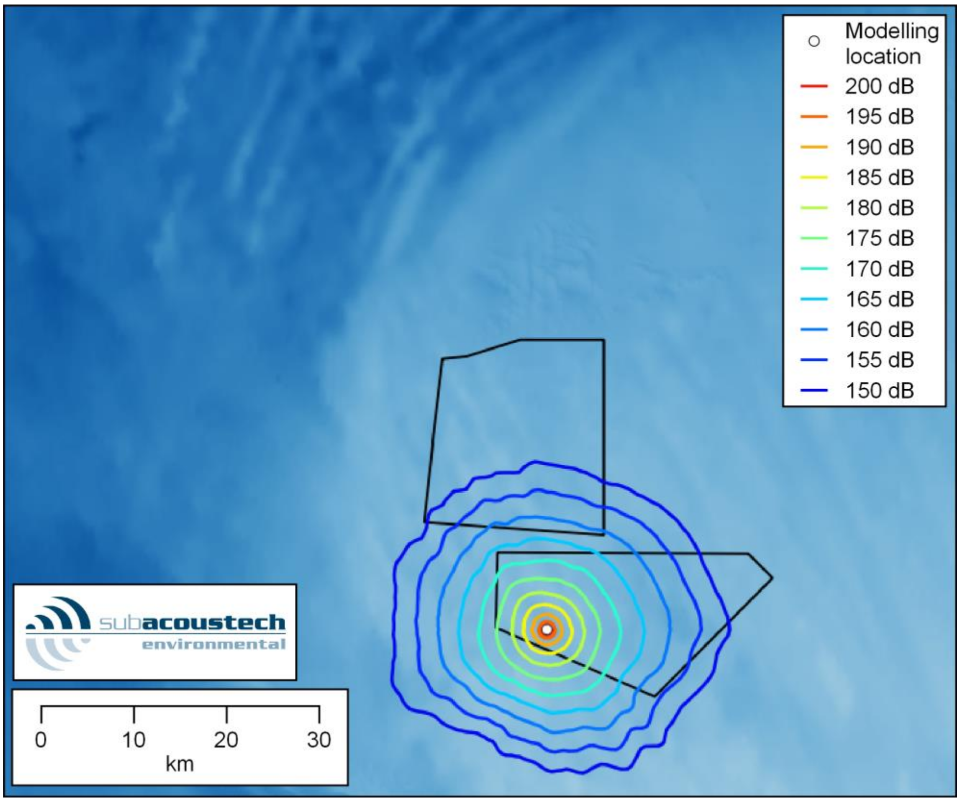

Figure A 23 Contour plot showing the unweighted SPL_{peak} noise levels at Dogger Bank A, SW location using the scenario 4 parameters (absolute worst-case pin pile)

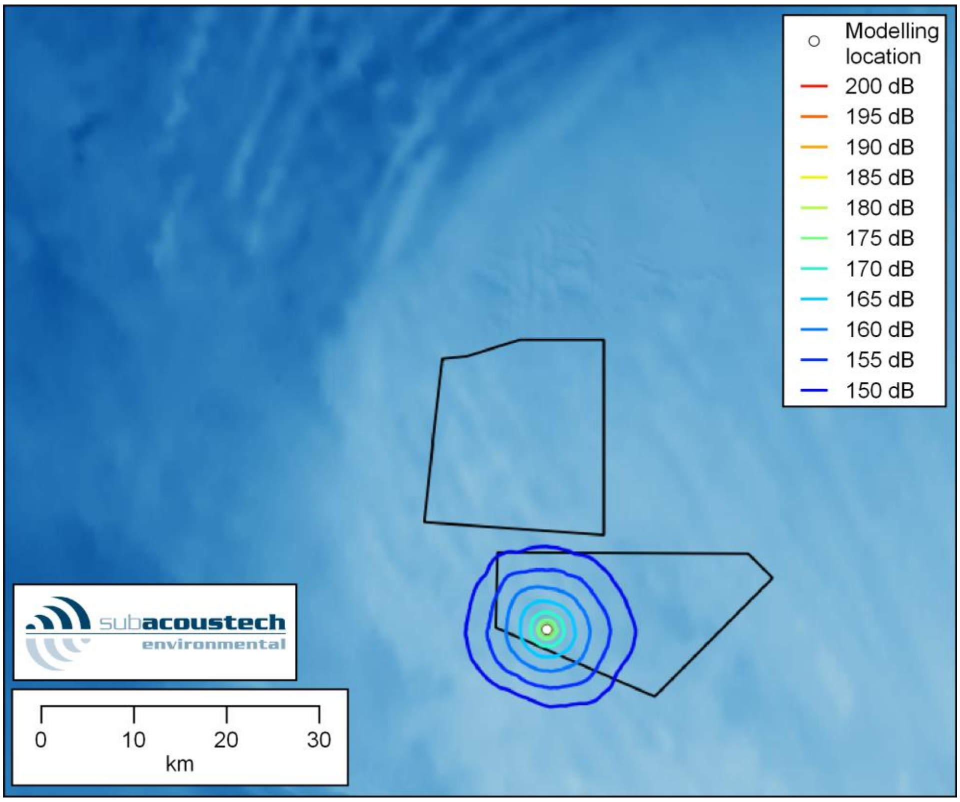

Figure A 24 Contour plot showing the unweighted SEL_{ss} noise levels at Dogger Bank A, SW location using the scenario 4 parameters (absolute worst-case pin pile)

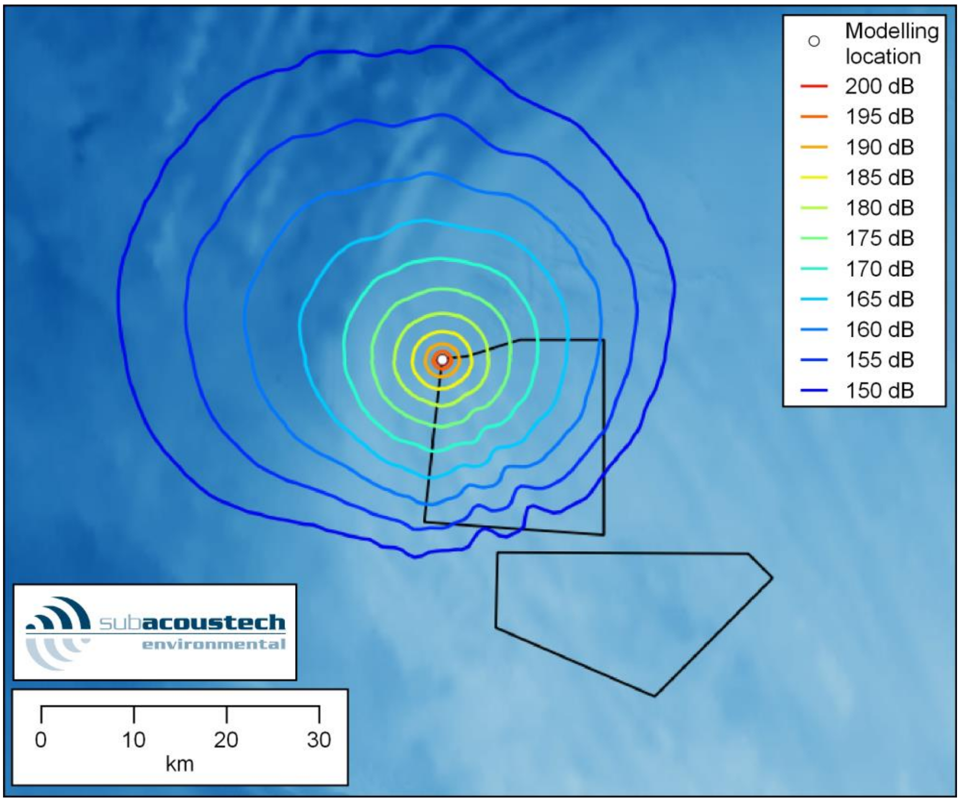

Figure A 25 Contour plot showing the unweighted SPL_{peak} noise levels at Dogger Bank B, NW location using the scenario 4 parameters (absolute worst-case pin pile)

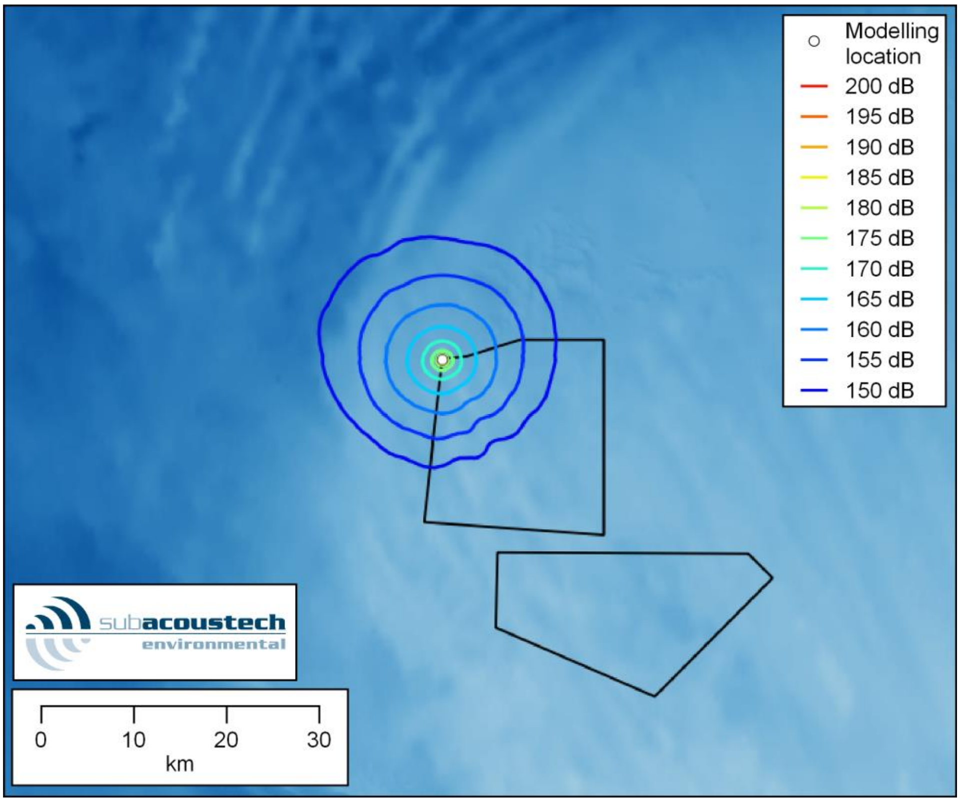

Figure A 26 Contour plot showing the unweighted SEL_{ss} noise levels at Dogger Bank B, NW location using the scenario 4 parameters (absolute worst-case pin pile)

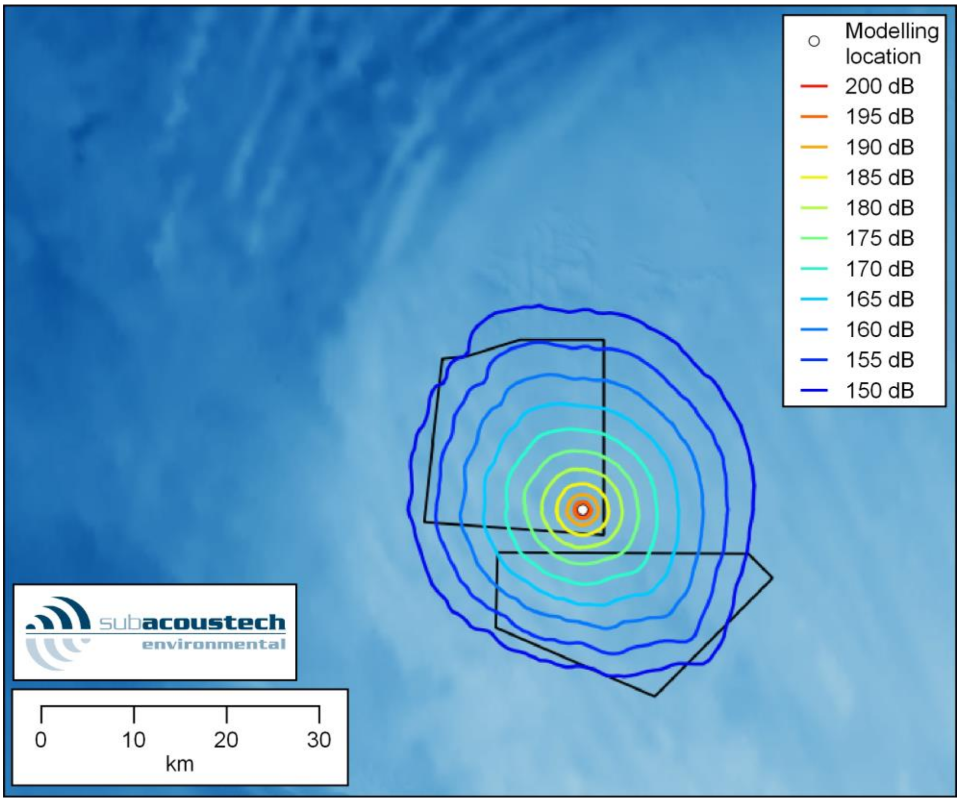

Figure A 27 Contour plot showing the unweighted SPL_{peak} noise levels at Dogger Bank B, SE location using the scenario 4 parameters (absolute worst-case pin pile)

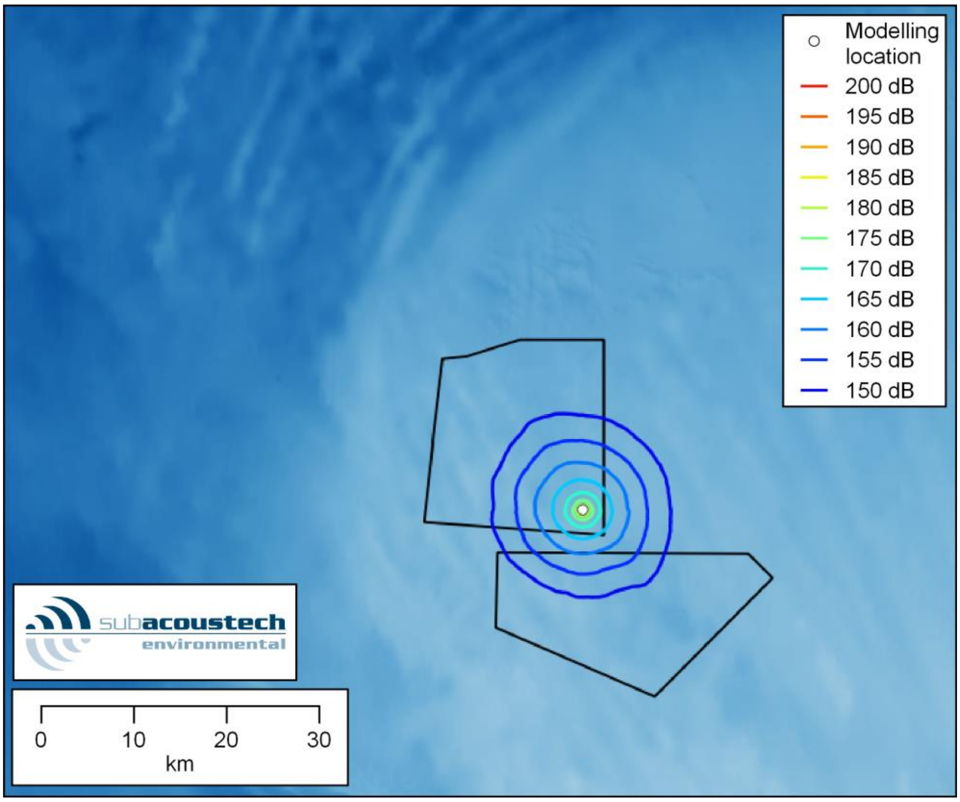

Figure A 28 Contour plot showing the unweighted SEL_{ss} noise levels at Dogger Bank B, SE location using the scenario 4 parameters (absolute worst-case pin pile)

<u>*Scenario 5*</u>

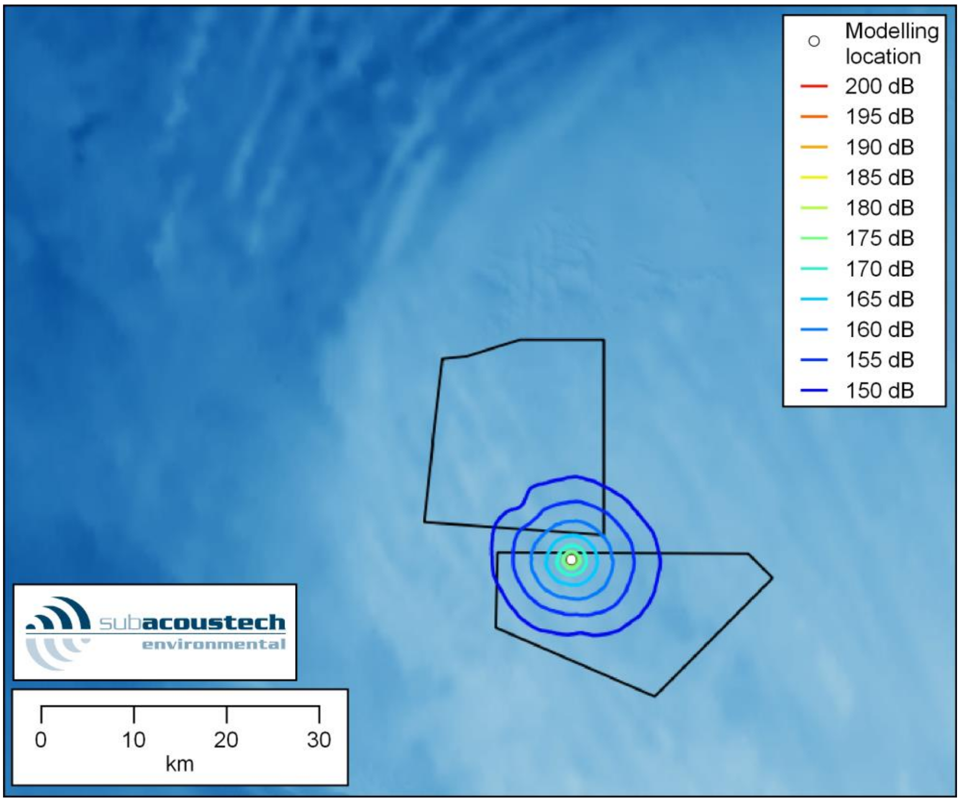

Figure A 29 Contour plot showing the unweighted SEL_{ss} noise levels at Dogger Bank A, N location using the scenario 5 parameters (worst-case pin pile)

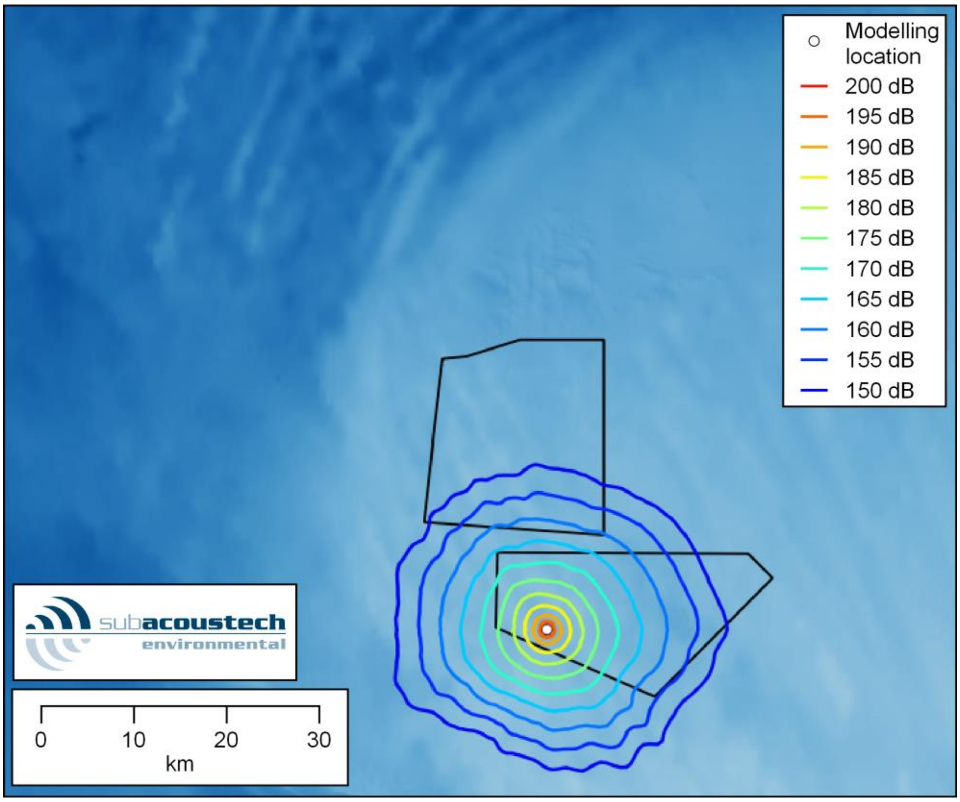

Figure A 30 Contour plot showing the unweighted SPL_{peak} noise levels at Dogger Bank A, SW location using the scenario 5 parameters (worst-case pin pile)

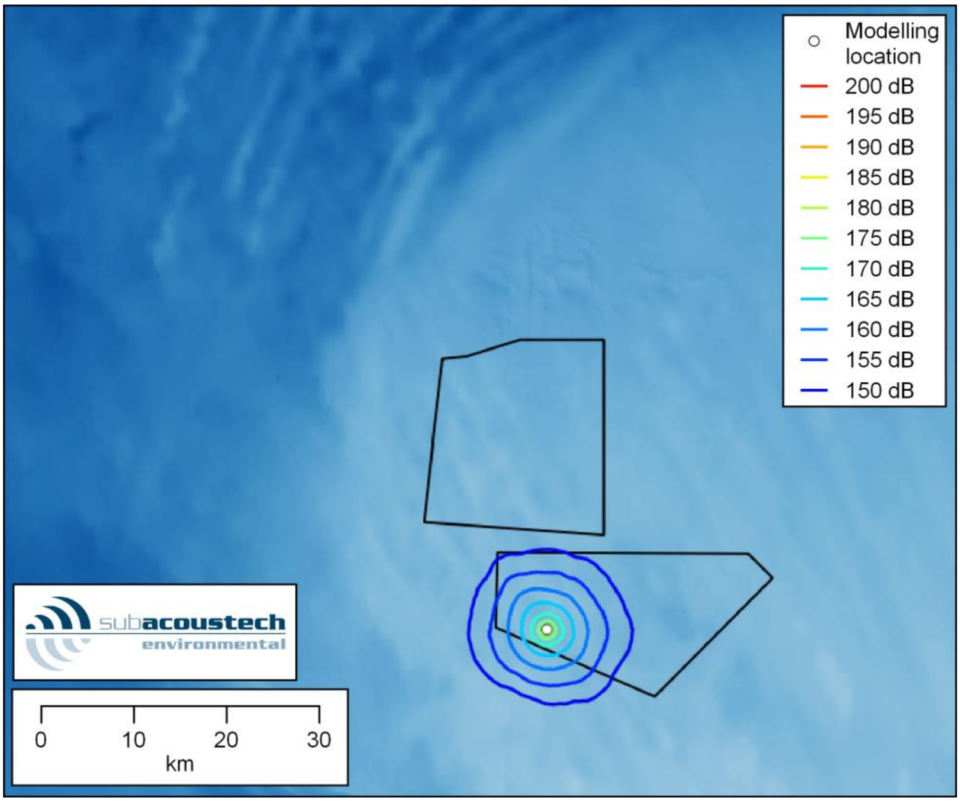

Figure A 31 Contour plot showing the unweighted SEL_{ss} noise levels at Dogger Bank A, SW location using the scenario 5 parameters (worst-case pin pile)

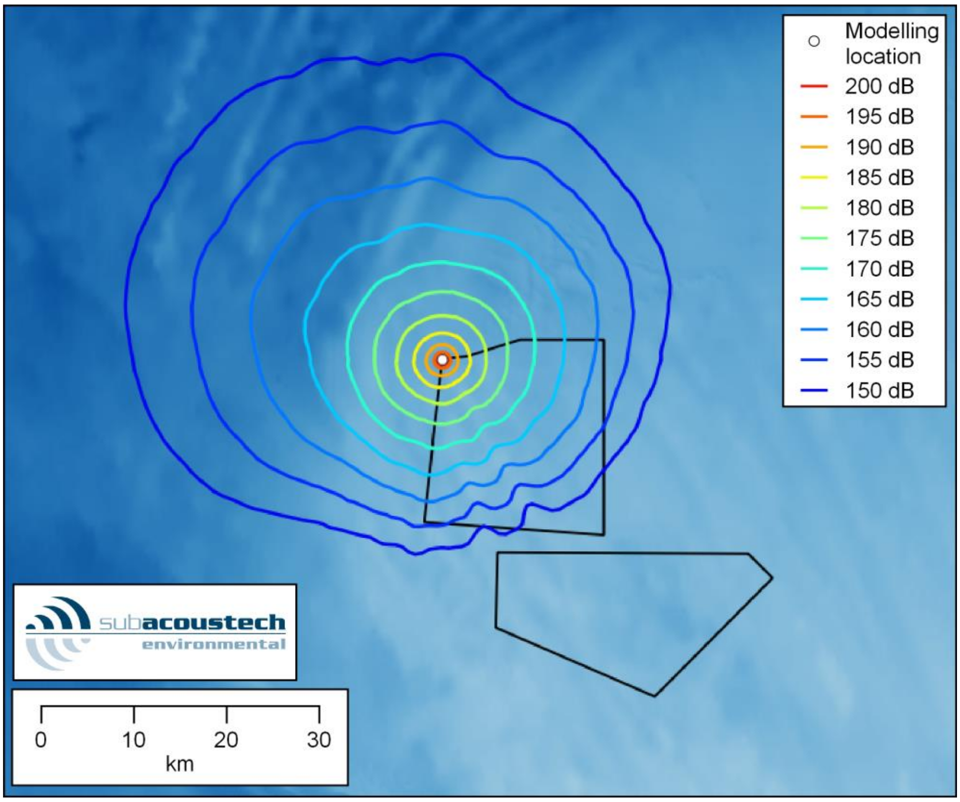

Figure A 32 Contour plot showing the unweighted SPL_{peak} noise levels at Dogger Bank B, NW location using the scenario 5 parameters (worst-case pin pile)

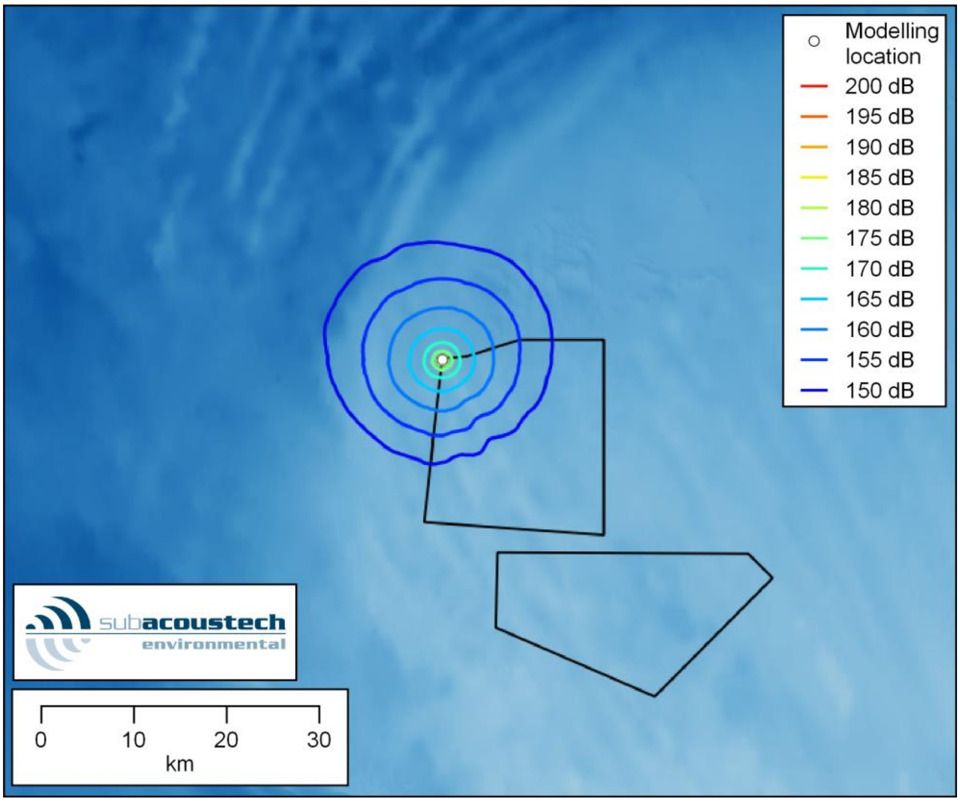

Figure A 33 Contour plot showing the unweighted SEL_{ss} noise levels at Dogger Bank B, NW location using the scenario 5 parameters (worst-case pin pile)

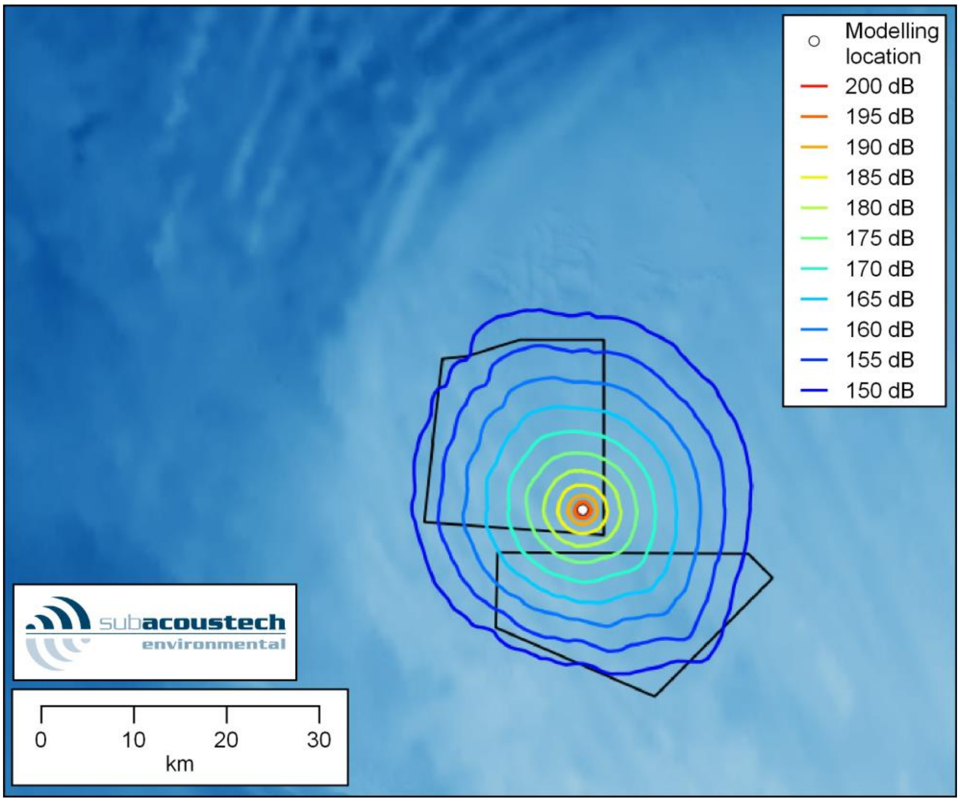

Figure A 34 Contour plot showing the unweighted SPL_{peak} noise levels at Dogger Bank B, SE location using the scenario 5 parameters (worst-case pin pile)

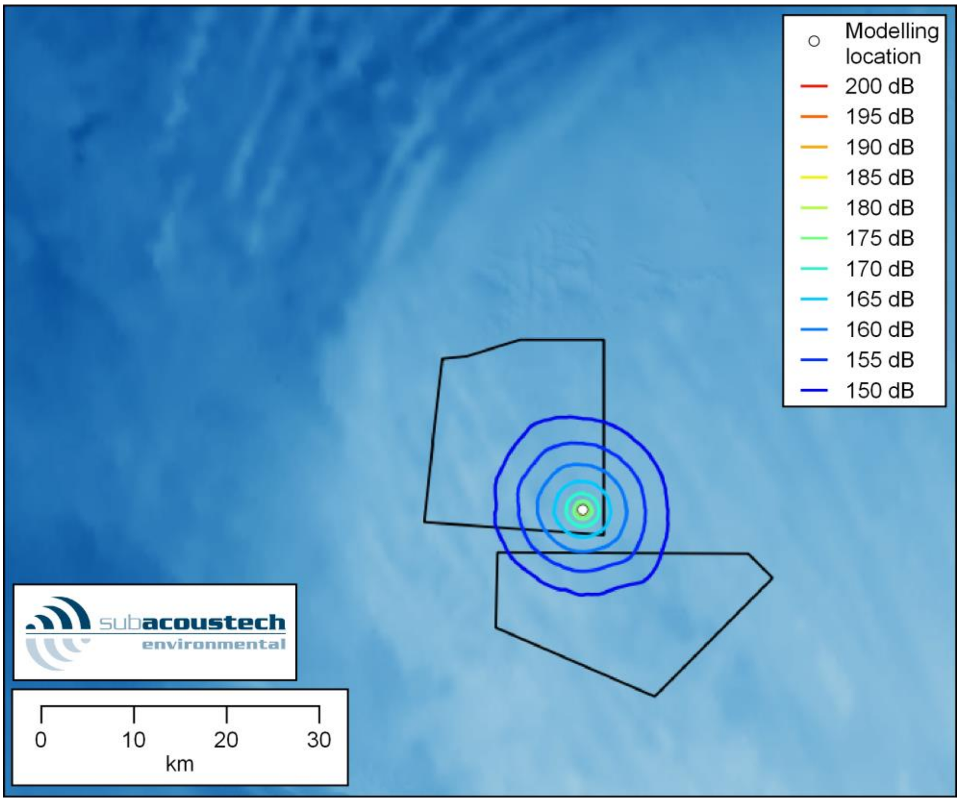

Figure A 35 Contour plot showing the unweighted SEL_{ss} noise levels at Dogger Bank B, SE location using the scenario 5 parameters (worst-case pin pile)

Scenario 6

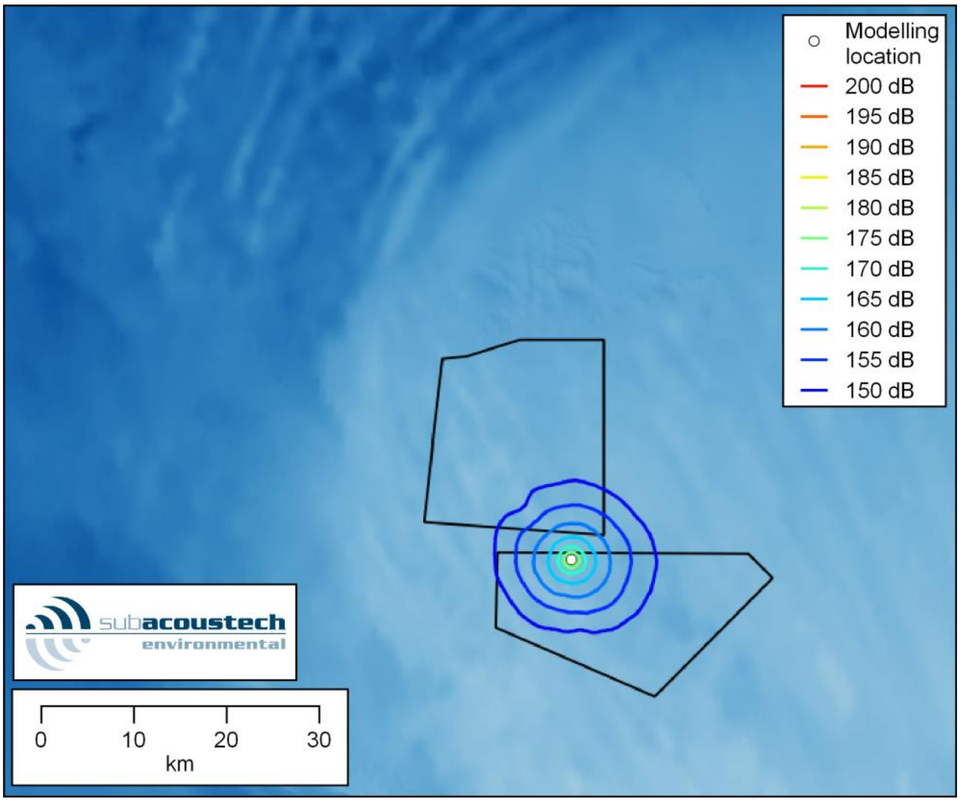

Figure A 36 Contour plot showing the unweighted SEL_{ss} noise levels at Dogger Bank A, N location using the scenario 6 parameters (most likely pin pile)

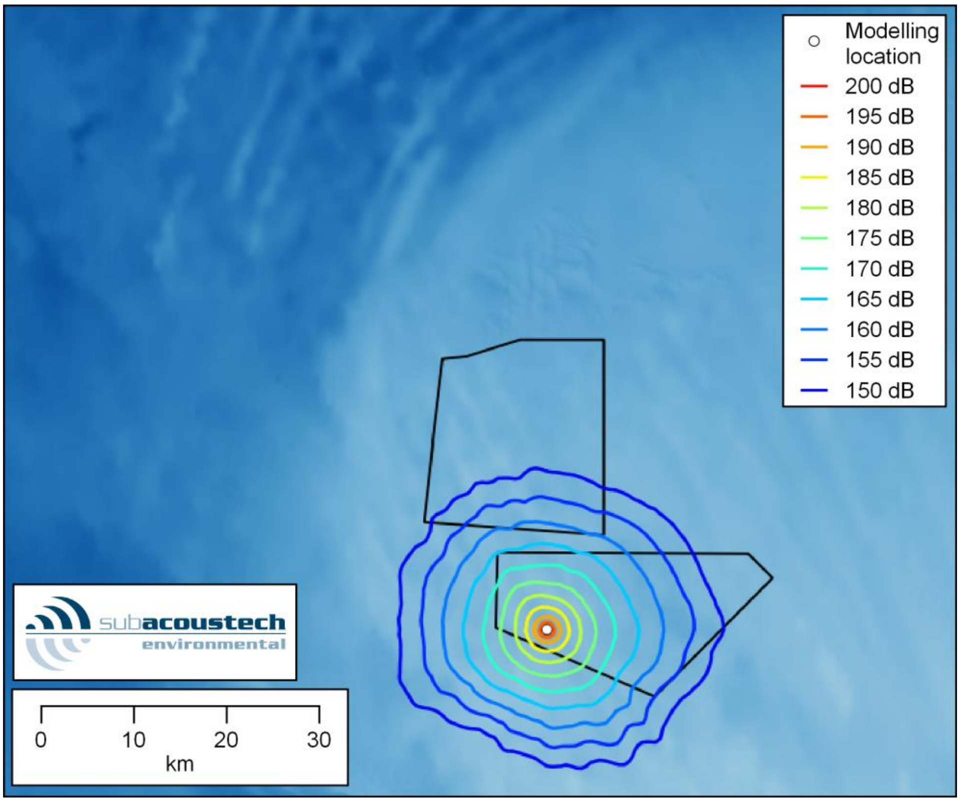

Figure A 37 Contour plot showing the unweighted SPL_{peak} noise levels at Dogger Bank A, SW location using the scenario 6 parameters (most likely pin pile)

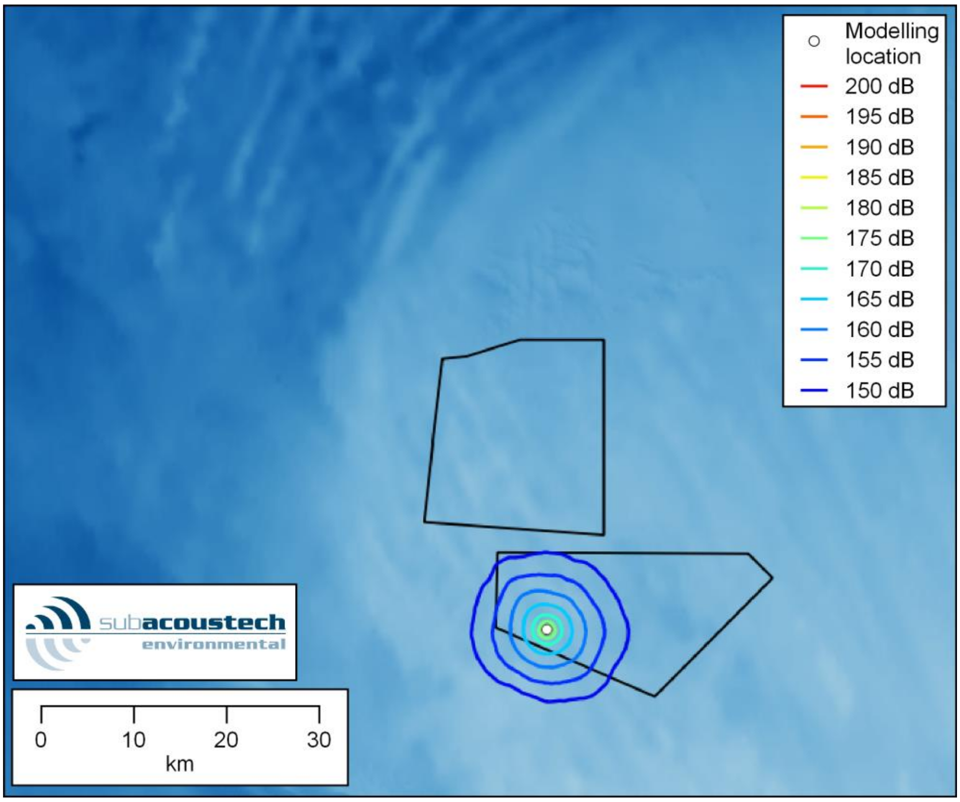

Figure A 38 Contour plot showing the unweighted SEL_{ss} noise levels at Dogger Bank A, SW location using the scenario 6 parameters (most likely pin pile)

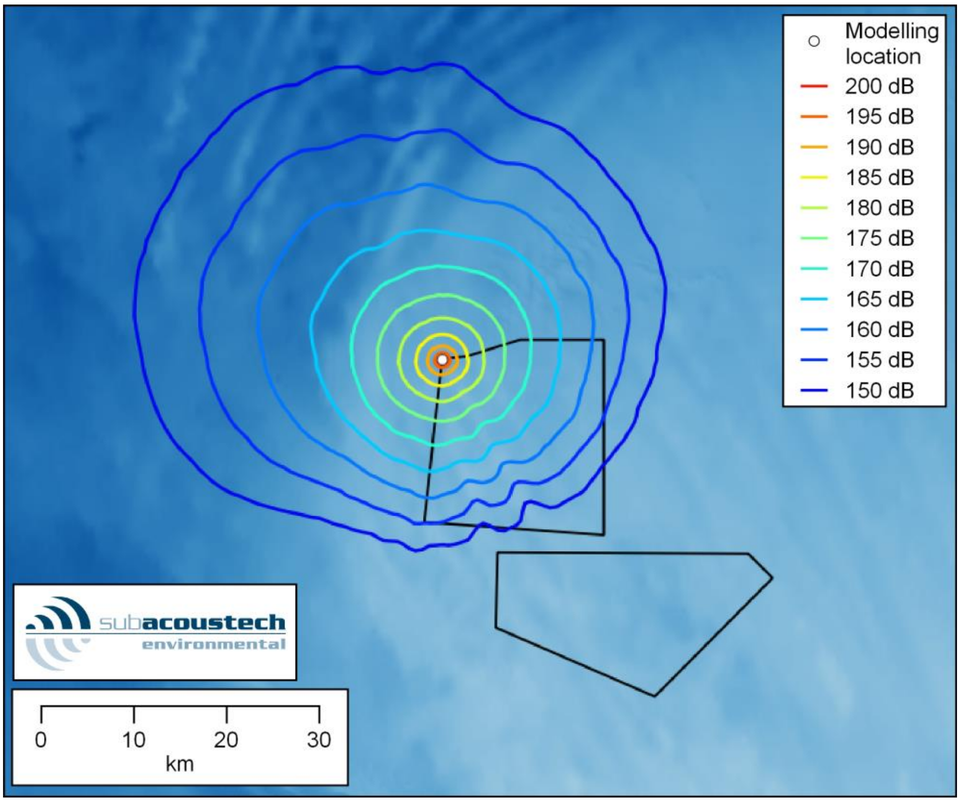

Figure A 39 Contour plot showing the unweighted SPL_{peak} noise levels at Dogger Bank B, NW location using the scenario 6 parameters (most likely pin pile)

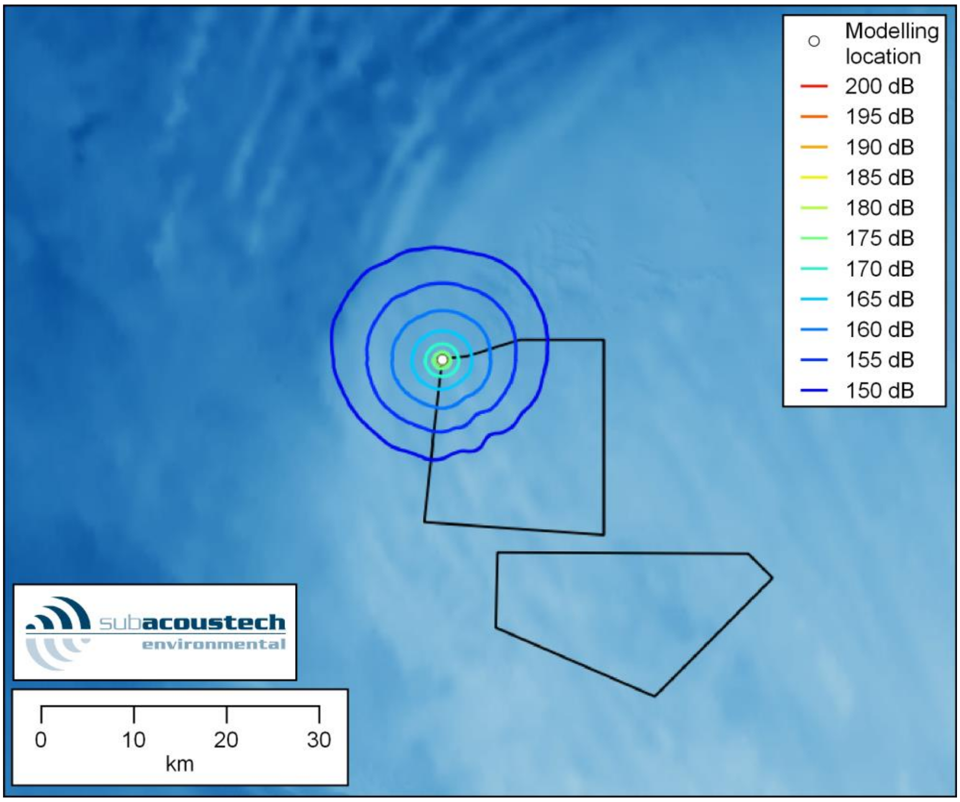

Figure A 40 Contour plot showing the unweighted SEL_{ss} noise levels at Dogger Bank B, NW location using the scenario 6 parameters (most likely pin pile)

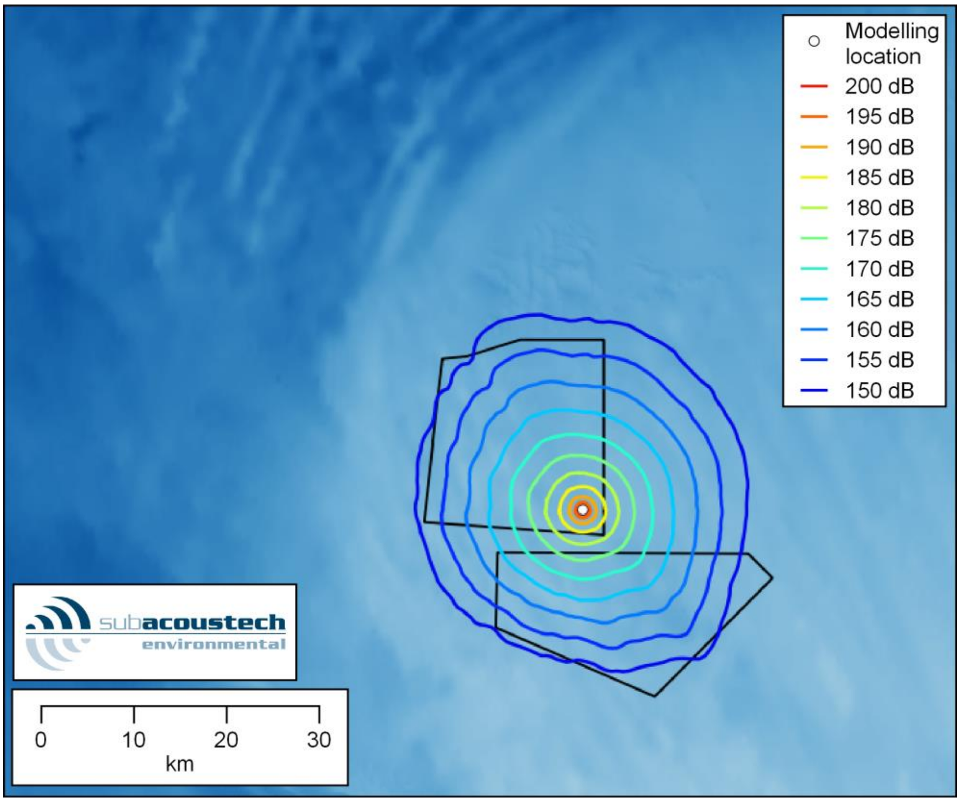

Figure A 41 Contour plot showing the unweighted SPL_{peak} noise levels at Dogger Bank B, SE location using the scenario 6 parameters (most likely pin pile)

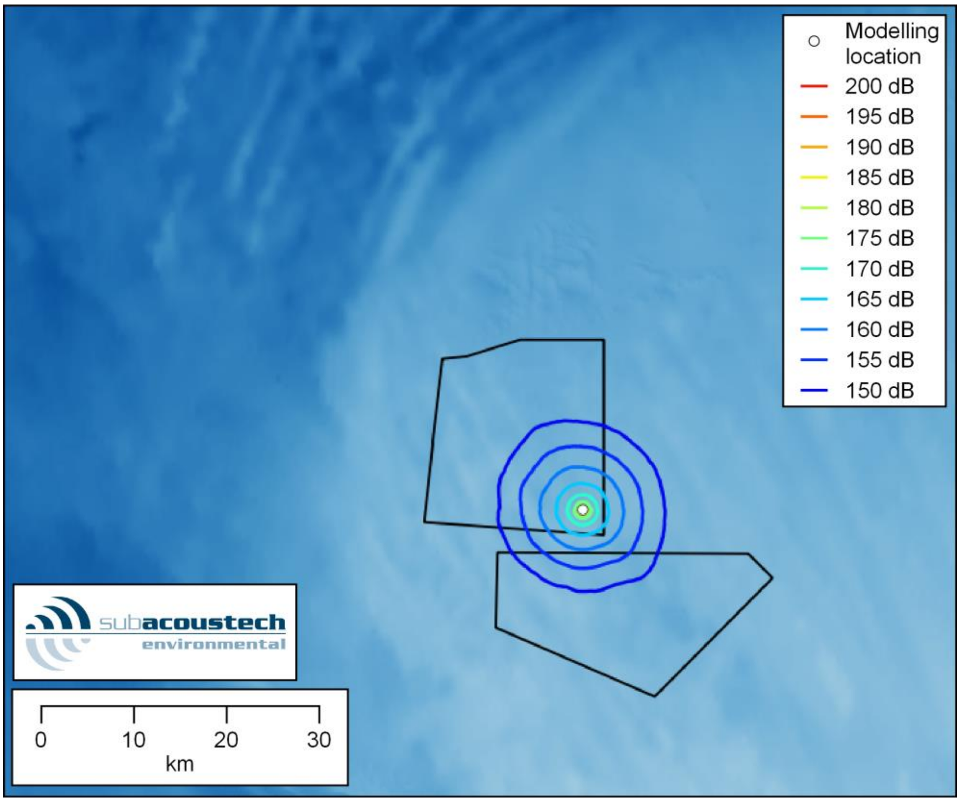

Figure A 42 Contour plot showing the unweighted SEL_{ss} noise levels at Dogger Bank B, SE location using the scenario 6 parameters (most likely pin pile)

A.2 First strike results

Additional modelling was carried out to investigate the impact ranges for marine mammals and fish after only the first pile strike in soft start; these are summarised in Table A 2 to Table A 49.

As the first strikes of some of the piling scenarios (section 3.3.2) share the same parameters, only four sets of results need to be presented for the first pile strike, these are:

- Scenario 1: 10 m diameter pile with a 400 kJ first strike;
- Scenarios 2 and 3: 10 m diameter pile with a 300 kJ first strike;
- Scenarios 4 and 5: 2.438 m diameter pile with a 320 kJ first strike; and
- Scenario 6: 2.438 m diameter pile with a 300 kJ first strike.

All the modelling has been run for the same Southall *et al*. (2019), Lucke *et al*. (2009) and Popper *et al*. (2014) criteria as the main modelling in section 4, and the results tables are summarised, to aid navigation, in Table A 1.

Table (page)	Location		Parameters	Criteria
Table A 2 (p84)	Dogger Bank A	N	Scenario 1 (Absolute worst-case monopile)	Southall *et al*. (2019)
Table A 3 (p85)		SW		
Table A 4 (p85)	Dogger Bank B	NW		
Table A 5 (p86)		SE		
Table A 6 (p86)	Dogger Bank A	N	Scenarios 2 and 3 (Worst-case / most likely monopile)	
Table A 7 (p87)		SW		
Table A 8 (p87)	Dogger Bank B	NW		
Table A 9 (p88)		SE		
Table A 10 (p88)	Dogger Bank A	N	Scenario 4 and 5 (Absolute worst-case / worst-case pin pile)	
Table A 11 (p89)		SW		
Table A 12 (p89)	Dogger Bank B	NW		
Table A 13 (p90)		SE		
Table A 14 (p90)	Dogger Bank A	N	Scenario 6 (Most likely pin pile)	
Table A 15 (p91)		SW		
Table A 16 (p91)	Dogger Bank B	NW		
Table A 17 (p92)		SE		
Table A 18 (p92)	Dogger Bank A	N	Scenario 1 (Absolute worst-case monopile)	Lucke *et al*. (2009)
Table A 19 (p92)		SW		
Table A 20 (p92)	Dogger Bank B	NW		
Table A 21 (p93)		SE		
Table A 22 (p93)	Dogger Bank A	N	Scenarios 2 and 3 (Worst-case / most likely monopile)	
Table A 23 (p93)		SW		
Table A 24 (p93)	Dogger Bank B	NW		
Table A 25 (p93)		SE		
Table A 26 (p94)	Dogger Bank A	N	Scenario 4 and 5 (Absolute worst-case / worst-case pin pile)	
Table A 27 (p94)		SW		
Table A 28 (p94)	Dogger Bank B	NW		
Table A 29 (p94)		SE		
Table A 30 (p94)	Dogger Bank A	N	Scenario 6 (Most likely pin pile)	
Table A 31 (p95)		SW		
Table A 32 (p95)	Dogger Bank B	NW		
Table A 33 (p95)		SE		
Table A 34 (p95)	Dogger Bank A	N	Scenario 1 (Absolute worst-case monopile)	Popper *et al*. (2014)
Table A 35 (p96)		SW		
Table A 36 (p96)	Dogger Bank B	NW		
Table A 37 (p96)		SE		
Table A 38 (p96)	Dogger Bank A	N	Scenarios 2 and 3	

Table (page)	Location		Parameters	Criteria
Table A 39 (p97)		SW	(Worst-case / most likely monopile)	
Table A 40 (p97)	Dogger Bank B	NW		
Table A 41 (p97)		SE		
Table A 42 (p97)	Dogger Bank A	N	Scenario 4 and 5 (Absolute worst-case / worst-case pin pile)	
Table A 43 (p98)		SW		
Table A 44 (p98)	Dogger Bank B	NW		
Table A 45 (p98)		SE		
Table A 46 (p98)	Dogger Bank A	N	Scenario 6 (Most likely pin pile)	
Table A 47 (p99)		SW		
Table A 48 (p99)	Dogger Bank B	NW		
Table A 49 (p99)		SE		

Table A 1 Summary of the first strike results presented in this section

Southall et al. (2019) criteria

Scenario 1

Southall *et al*. (2019)			Scenario 1: Dogger Bank A – N location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.04 km²	120 m	120 m	120 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	0.26 km²	290 m	290 m	290 m
		PCW (212 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
Weighted SEL_{ss}	PTS	**LF** (183 dB)	0.02 km²	70 m	70 m	70 m
		HF (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (155 dB)	0.01 km²	< 50 m	< 50 m	< 50 m
		PCW (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (168 dB)	1.6 km²	720 m	710 m	710 m
		HF (170 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (140 dB)	0.39 km²	350 m	350 m	350 m
		PCW (170 dB)	0.02 km²	80 m	70 m	80 m

Table A 2 Summary of the modelled first strike impact ranges for Scenario 1 (absolute worst-case monopile) at the N location of Dogger Bank A using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			**Scenario 1: Dogger Bank A – SW location**			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL$_{peak}$	PTS	**LF** (219 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.05 km^2	130 m	130 m	130 m
		PCW (218 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF (224 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	0.3 km^2	310 m	310 m	310 m
		PCW (212 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
Weighted SEL$_{ss}$	PTS	**LF** (183 dB)	0.02 km^2	80 m	80 m	80 m
		HF (185 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		VHF (155 dB)	0.01 km^2	50 m	< 50 m	50 m
		PCW (185 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	TTS	**LF** (168 dB)	1.9 km^2	790 m	770 m	780 m
		HF (170 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		VHF (140 dB)	0.42 km^2	370 m	370 m	370 m
		PCW (170 dB)	0.02 km^2	80 m	80 m	80 m

Table A 3 Summary of the modelled first strike impact ranges for Scenario 1 (absolute worst-case monopile) at the SW location of Dogger Bank A using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			**Scenario 1: Dogger Bank B – NW location**			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL$_{peak}$	PTS	**LF** (219 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.05 km^2	130 m	130 m	130 m
		PCW (218 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF (224 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	0.32 km^2	320 m	320 m	320 m
		PCW (212 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
Weighted SEL$_{ss}$	PTS	**LF** (183 dB)	0.02 km^2	80 m	80 m	80 m
		HF (185 dB)	2.1 km^2	830 m	820 m	820 m
		VHF (155 dB)	0.01 km^2	50 m	50 m	50 m
		PCW (185 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	TTS	**LF** (168 dB)	2.1 km^2	830 m	820 m	820 m
		HF (170 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		VHF (140 dB)	0.44 km^2	380 m	370 m	370 m
		PCW (170 dB)	0.02 km^2	80 m	80 m	80 m

Table A 4 Summary of the modelled first strike impact ranges for Scenario 1 (absolute worst-case monopile) at the NW location of Dogger Bank B using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			Scenario 1: Dogger Bank B – SE location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.05 km²	130 m	130 m	130 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	0.3 km²	310 m	310 m	310 m
		PCW (212 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
Weighted SEL_{ss}	PTS	**LF** (183 dB)	0.02 km²	80 m	80 m	80 m
		HF (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (155 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PCW (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (168 dB)	1.9 km²	790 m	780 m	790 m
		HF (170 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (140 dB)	0.42 km²	370 m	370 m	370 m
		PCW (170 dB)	0.02 km²	80 m	80 m	80 m

Table A 5 Summary of the modelled first strike impact ranges for Scenario 1 (absolute worst-case monopile) at the SE location of Dogger Bank B using the Southall et al. (2019) injury criteria for marine mammals

Scenarios 2 and 3

Southall *et al*. (2019)			Scenarios 2 and 3: Dogger Bank A – N location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.02 km²	90 m	90 m	90 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	0.14 km²	210 m	210 m	210 m
		PCW (212 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
Weighted SEL_{ss}	PTS	**LF** (183 dB)	0.01 km²	50 m	50 m	50 m
		HF (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (155 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PCW (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (168 dB)	0.86 km²	530 m	520 m	530 m
		HF (170 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (140 dB)	0.23 km²	270 m	270 m	270 m
		PCW (170 dB)	0.01 km²	60 m	60 m	60 m

Table A 6 Summary of the modelled first strike impact ranges for Scenarios 2 and 3 (worst-case / most likely monopile) at the N location of Dogger Bank A using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			**Scenarios 2 and 3: Dogger Bank A – SW location**			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.03 km²	90 m	90 m	90 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	0.16 km²	220 m	220 m	220 m
		PCW (212 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
Weighted SEL_{ss}	PTS	**LF** (183 dB)	0.01 km²	60 m	60 m	60 m
		HF (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (155 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PCW (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (168 dB)	1.0 km²	580 m	570 m	570 m
		HF (170 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (140 dB)	0.25 km²	280 m	280 m	280 m
		PCW (170 dB)	0.01 km²	60 m	60 m	60 m

Table A 7 Summary of the modelled first strike impact ranges for Scenarios 2 and 3 (worst-case / most likely monopile) at the SW location of Dogger Bank A using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			**Scenarios 2 and 3: Dogger Bank B – NW location**			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.03 km²	90 m	90 m	90 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	0.17 km²	230 m	230 m	230 m
		PCW (212 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
Weighted SEL_{ss}	PTS	**LF** (183 dB)	0.01 km²	60 m	60 m	60 m
		HF (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (155 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PCW (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (168 dB)	1.1 km²	610 m	600 m	600 m
		HF (170 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (140 dB)	0.26 km²	290 m	290 m	290 m
		PCW (170 dB)	0.01 km²	60 m	60 m	60 m

Table A 8 Summary of the modelled first strike impact ranges for Scenarios 2 and 3 (worst-case / most likely monopile) at the NW location of Dogger Bank B using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			Scenarios 2 and 3: Dogger Bank B – SE location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.03 km²	90 m	90 m	90 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	0.16 km²	230 m	220 m	220 m
		PCW (212 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
Weighted SEL_{ss}	PTS	**LF** (183 dB)	0.01 km²	50 m	50 m	50 m
		HF (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (155 dB)	0.01 km²	< 50 m	< 50 m	< 50 m
		PCW (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (168 dB)	0.89 km²	540 m	530 m	540 m
		HF (170 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (140 dB)	0.28 km²	300 m	300 m	300 m
		PCW (170 dB)	0.01 km²	60 m	60 m	60 m

Table A 9 Summary of the modelled first strike impact ranges for Scenarios 2 and 3 (worst-case / most likely monopile) at the SE location of Dogger Bank B using the Southall et al. (2019) injury criteria for marine mammals

<u>*Scenarios 4 and 5*</u>

Southall *et al*. (2019)			Scenarios 4 and 5: Dogger Bank A – N location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.02 km²	80 m	80 m	80 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	0.12 km²	200 m	200 m	200 m
		PCW (212 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
Weighted SEL_{ss}	PTS	**LF** (183 dB)	0.01 km²	< 50 m	< 50 m	< 50 m
		HF (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (155 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PCW (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (168 dB)	0.72 km²	480 m	480 m	480 m
		HF (170 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (140 dB)	0.26 km²	290 m	290 m	290 m
		PCW (170 dB)	0.01 km²	60 m	60 m	60 m

Table A 10 Summary of the modelled first strike impact ranges for Scenarios 4 and 5 (absolute worst-case / worst-case pin pile) at the N location of Dogger Bank A using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			**Scenarios 4 and 5: Dogger Bank A – SW location**			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.02 km²	90 m	90 m	90 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	0.14 km²	210 m	210 m	210 m
		PCW (212 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
Weighted SEL_{ss}	PTS	**LF** (183 dB)	0.01 km²	50 m	50 m	50 m
		HF (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (155 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PCW (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (168 dB)	0.88 km²	530 m	530 m	530 m
		HF (170 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (140 dB)	0.28 km²	300 m	300 m	300 m
		PCW (170 dB)	0.01 km²	60 m	60 m	60 m

Table A 11 Summary of the modelled first strike impact ranges for Scenarios 4 and 5 (absolute worst-case / worst-case pin pile) at the SW location of Dogger Bank A using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			**Scenarios 4 and 5: Dogger Bank B – NW location**			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.02 km²	90 m	90 m	90 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	0.15 km²	220 m	220 m	220 m
		PCW (212 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
Weighted SEL_{ss}	PTS	**LF** (183 dB)	0.01 km²	50 m	50 m	50 m
		HF (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (155 dB)	0.01 km²	< 50 m	< 50 m	< 50 m
		PCW (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (168 dB)	0.98 km²	560 m	560 m	560 m
		HF (170 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (140 dB)	0.29 km²	310 m	300 m	310 m
		PCW (170 dB)	0.01 km²	60 m	60 m	60 m

Table A 12 Summary of the modelled first strike impact ranges for Scenarios 4 and 5 (absolute worst-case / worst-case pin pile) at the NW location of Dogger Bank B using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			Scenarios 4 and 5: Dogger Bank B – SE location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.02 km²	90 m	90 m	90 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	0.14 km²	220 m	210 m	220 m
		PCW (212 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
Weighted SEL_{ss}	PTS	**LF** (183 dB)	0.01 km²	50 m	50 m	50 m
		HF (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (155 dB)	0.01 km²	< 50 m	< 50 m	< 50 m
		PCW (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (168 dB)	0.89 km²	540 m	530 m	540 m
		HF (170 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (140 dB)	0.28 km²	300 m	300 m	300 m
		PCW (170 dB)	0.01 km²	60 m	60 m	60 m

Table A 13 Summary of the modelled first strike impact ranges for Scenarios 4 and 5 (absolute worst-case / worst-case pin pile) at the SE location of Dogger Bank B using the Southall et al. (2019) injury criteria for marine mammals

Scenario 6

Southall *et al*. (2019)			Scenario 6: Dogger Bank A – N location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.02 km²	80 m	80 m	80 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	0.11 km²	190 m	180 m	180 m
		PCW (212 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
Weighted SEL_{ss}	PTS	**LF** (183 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (155 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PCW (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (168 dB)	0.62 km²	450 m	440 m	450 m
		HF (170 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (140 dB)	0.23 km²	270 m	270 m	270 m
		PCW (170 dB)	0.01 km²	50 m	50 m	50 m

Table A 14 Summary of the modelled first strike impact ranges for Scenario 6 (most likely pin pile) at the N location of Dogger Bank A using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			**Scenario 6: Dogger Bank A – SW location**			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.02 km²	80 m	80 m	80 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	0.12 km²	200 m	200 m	200 m
		PCW (212 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
Weighted SEL_{ss}	PTS	**LF** (183 dB)	0.01 km²	< 50 m	< 50 m	< 50 m
		HF (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (155 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PCW (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (168 dB)	0.76 km²	500 m	490 m	490 m
		HF (170 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (140 dB)	0.25 km²	280 m	280 m	280 m
		PCW (170 dB)	0.01 km²	60 m	60 m	60 m

Table A 15 Summary of the modelled first strike impact ranges for Scenario 6 (most likely pin pile) at the SW location of Dogger Bank A using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			**Scenario 6: Dogger Bank B – NW location**			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.02 km²	80 m	80 m	80 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	0.13 km²	210 m	200 m	210 m
		PCW (212 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
Weighted SEL_{ss}	PTS	**LF** (183 dB)	0.01 km²	< 50 m	< 50 m	< 50 m
		HF (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (155 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PCW (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (168 dB)	0.84 km²	520 m	520 m	520 m
		HF (170 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (140 dB)	0.26 km²	290 m	290 m	290 m
		PCW (170 dB)	0.01 km²	60 m	60 m	60 m

Table A 16 Summary of the modelled first strike impact ranges for Scenario 6 (most likely pin pile) at the NW location of Dogger Bank B using the Southall et al. (2019) injury criteria for marine mammals

Southall *et al*. (2019)			Scenario 6: Dogger Bank B – SE location			
			Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	PTS	**LF** (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (202 dB)	0.02 km²	80 m	80 m	80 m
		PCW (218 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (213 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (196 dB)	0.12 km²	200 m	200 m	200 m
		PCW (212 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
Weighted SEL_{ss}	PTS	**LF** (183 dB)	0.01 km²	< 50 m	< 50 m	< 50 m
		HF (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (155 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PCW (185 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	TTS	**LF** (168 dB)	0.77 km²	500 m	500 m	500 m
		HF (170 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
		VHF (140 dB)	0.25 km²	280 m	280 m	280 m
		PCW (170 dB)	0.01 km²	60 m	60 m	60 m

Table A 17 Summary of the modelled first strike impact ranges for Scenario 6 (most likely pin pile) at the SE location of Dogger Bank B using the Southall et al. (2019) injury criteria for marine mammals

Lucke et al. (2009) criteria

Scenario 1

Lucke *et al*. (2009)		Scenario 1: Dogger Bank A – N location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted $SPL_{pk\text{-}pk}$	**TTS** (199.7 dB)	0.01 km²	70 m	70 m	70 m
	Behavioural (173 dB)	21 km²	2.7 km	2.5 km	2.6 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	11 km²	1.9 km	1.8 km	1.8 km
	Behavioural (145 dB)	340 km²	11 km	9.4 km	10 km

Table A 18 Summary of the modelled first strike impact ranges for Scenario 1 (absolute worst-case monopile) at the N location of Dogger Bank A using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al*. (2009)		Scenario 1: Dogger Bank A – SW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted $SPL_{pk\text{-}pk}$	**TTS** (199.7 dB)	0.06 km²	430 m	430 m	430 m
	Behavioural (173 dB)	160 km²	7.9 km	6.6 km	7.1 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	12 km²	2.1 km	1.9 km	2.0 km
	Behavioural (145 dB)	320 km²	11 km	8.9 km	10 km

Table A 19 Summary of the modelled first strike impact ranges for Scenario 1 (absolute worst-case monopile) at the SW location of Dogger Bank A using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al*. (2009)		Scenario 1: Dogger Bank B – NW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted $SPL_{pk\text{-}pk}$	**TTS** (199.7 dB)	0.02 km²	70 m	70 m	70 m
	Behavioural (173 dB)	32 km²	3.3 km	3.0 km	3.2 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	15 km²	2.3 km	2.2 km	2.2 km
	Behavioural (145 dB)	610 km²	15 km	12 km	14 km

Table A 20 Summary of the modelled first strike impact ranges for Scenario 1 (absolute worst-case monopile) at the NW location of Dogger Bank B using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al.* (2009)		Scenario 1: Dogger Bank B – SE location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted $SPL_{pk\text{-}pk}$	**TTS** (199.7 dB)	0.6 km²	440 m	430 m	430 m
	Behavioural (173 dB)	190 km²	8.5 km	7.3 km	7.8 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	13 km²	2.1 km	2.0 km	2.0 km
	Behavioural (145 dB)	400 km²	13 km	10 km	11 km

Table A 21 Summary of the modelled first strike impact ranges for Scenario 1 (absolute worst-case monopile) at the SE location of Dogger Bank B using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Scenarios 2 and 3

Lucke *et al.* (2009)		Scenarios 2 and 3: Dogger Bank A – N location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted $SPL_{pk\text{-}pk}$	**TTS** (199.7 dB)	0.01 km²	50 m	< 50 m	50 m
	Behavioural (173 dB)	13 km²	2.1 km	2.0 km	2.1 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	6.7 km²	1.5 km	1.4 km	1.5 km
	Behavioural (145 dB)	270 km²	10 km	8.4 km	9.2 km

Table A 22 Summary of the modelled first strike impact ranges for Scenarios 2 and 3 (worst-case / most likely monopile) at the N location of Dogger Bank A using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al.* (2009)		Scenarios 2 and 3: Dogger Bank A – SW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted $SPL_{pk\text{-}pk}$	**TTS** (199.7 dB)	0.01 km²	50 m	50 m	50 m
	Behavioural (173 dB)	15 km²	2.3 km	2.1 km	2.2 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	7.8 km²	1.6 km	1.5 km	1.6 km
	Behavioural (145 dB)	250 km²	9.9 km	8.0 km	9.0 km

Table A 23 Summary of the modelled first strike impact ranges for Scenarios 2 and 3 (worst-case / most likely monopile) at the SW location of Dogger Bank A using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al.* (2009)		Scenarios 2 and 3: Dogger Bank B – NW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted $SPL_{pk\text{-}pk}$	**TTS** (199.7 dB)	0.01 km²	50 m	50 m	50 m
	Behavioural (173 dB)	19 km²	2.5 km	2.4 km	2.5 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	9.3 km²	1.8 km	1.7 km	1.7 km
	Behavioural (145 dB)	470 km²	13 km	10 km	12 km

Table A 24 Summary of the modelled first strike impact ranges for Scenarios 2 and 3 (worst-case / most likely monopile) at the NW location of Dogger Bank B using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al.* (2009)		Scenarios 2 and 3: Dogger Bank B – SE location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted $SPL_{pk\text{-}pk}$	**TTS** (199.7 dB)	0.01 km²	50 m	50 m	50 m
	Behavioural (173 dB)	16 km²	2.3 km	2.2 km	2.3 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	8.1 km²	1.6 km	1.6 km	1.6 km
	Behavioural (145 dB)	310 km²	11 km	9.4 km	10 km

Table A 25 Summary of the modelled first strike impact ranges for Scenarios 2 and 3 (worst-case / most likely monopile) at the SE location of Dogger Bank B using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Scenarios 4 and 5

Lucke *et al.* (2009)		Scenarios 4 and 5: Dogger Bank A – N location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	0.01 km^2	< 50 m	< 50 m	< 50 m
	Behavioural (173 dB)	12 km^2	2.0 km	1.9 km	2.0 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	4.9 km^2	1.3 km	1.2 km	1.3 km
	Behavioural (145 dB)	220 km^2	9.1 km	7.8 km	8.5 km

Table A 26 Summary of the modelled first strike impact ranges for Scenarios 4 and 5 (absolute worst-case / worst-case pin pile) at the N location of Dogger Bank A using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al.* (2009)		Scenarios 4 and 5: Dogger Bank A – SW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	0.01 km^2	50 m	< 50 m	50 m
	Behavioural (173 dB)	14 km^2	2.2 km	2.1 km	2.1 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	5.9 km^2	1.4 km	1.4 km	1.4 km
	Behavioural (145 dB)	220 km^2	9.3 km	7.6 km	8.4 km

Table A 27 Summary of the modelled first strike impact ranges for Scenarios 4 and 5 (absolute worst-case / worst-case pin pile) at the SW location of Dogger Bank A using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al.* (2009)		Scenarios 4 and 5: Dogger Bank B – NW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	0.01 km^2	50 m	50 m	50 m
	Behavioural (173 dB)	18 km^2	2.5 km	2.3 km	2.4 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	7.0 km^2	1.5 km	1.5 km	1.5 km
	Behavioural (145 dB)	400 km^2	12 km	9.8 km	11 km

Table A 28 Summary of the modelled first strike impact ranges for Scenarios 4 and 5 (absolute worst-case / worst-case pin pile) at the NW location of Dogger Bank B using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al.* (2009)		Scenarios 4 and 5: Dogger Bank B – SE location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	0.01 km^2	50 m	< 50 m	50 m
	Behavioural (173 dB)	15 km^2	2.3 km	2.1 km	2.2 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	6.1 km^2	1.4 km	1.4 km	1.4 km
	Behavioural (145 dB)	270 km^2	10 km	8.7 km	9.3 km

Table A 29 Summary of the modelled first strike impact ranges for Scenarios 4 and 5 (absolute worst-case / worst-case pin pile) at the SE location of Dogger Bank B using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Scenario 6

Lucke *et al.* (2009)		Scenario 6: Dogger Bank A – N location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	0.01 km^2	< 50 m	< 50 m	< 50 m
	Behavioural (173 dB)	11 km^2	1.9 km^2	18 km^2	19 km^2
Unweighted SEL_{ss}	**TTS** (164.3 dB)	4.4 km^2	1.2 km^2	1.2 km^2	1.2 km^2
	Behavioural (145 dB)	210 km^2	8.8 km^2	7.5 km^2	8.2 km^2

Table A 30 Summary of the modelled first strike impact ranges for Scenario 6 (most likely pin pile) at the N location of Dogger Bank A using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al.* (2009)		Scenario 6: Dogger Bank A – SW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	0.01 km^2	< 50 m	< 50 m	< 50 m
	Behavioural (173 dB)	13 km^2	2.1 km	1.9 km	2.0 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	5.3 km^2	1.3 km	1.3 km	1.3 km
	Behavioural (145 dB)	210 km^2	9.0 km	7.4 km	8.1 km

Table A 31 Summary of the modelled first strike impact ranges for Scenario 6 (most likely pin pile) at the SW location of Dogger Bank A using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al.* (2009)		Scenario 6: Dogger Bank B – NW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	0.01 km^2	< 50 m	< 50 m	< 50 m
	Behavioural (173 dB)	16 km^2	2.3 km	2.2 km	2.3 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	6.2 km^2	1.4 km	1.4 km	1.4 km
	Behavioural (145 dB)	380 km^2	12 km	9.5 km	11 km

Table A 32 Summary of the modelled first strike impact ranges for Scenario 6 (most likely pin pile) at the NW location of Dogger Bank B using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Lucke *et al.* (2009)		Scenario 6: Dogger Bank B – SE location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{pk-pk}	**TTS** (199.7 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	Behavioural (173 dB)	13 km^2	2.1 km	2.0 km	2.1 km
Unweighted SEL_{ss}	**TTS** (164.3 dB)	5.5 km^2	1.3 km	1.3 km	1.3 km
	Behavioural (145 dB)	250 km^2	9.9 km^2	8.4 km^2	9.0 km^2

Table A 33 Summary of the modelled first strike impact ranges for Scenario 6 (most likely pin pile) at the SE location of Dogger Bank B using the Lucke et al. (2009) TTS and behavioural criteria for harbour porpoises

Popper et al. (2014) criteria

Scenario 1

Popper *et al.* (2014)		Scenario 1: Dogger Bank A – N location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	207 dB	0.01 km^2	60 m	60 m	60 m
Unweighted SEL_{ss}	219 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	186 dB	0.02 km^2	80 m	80 m	80 m

Table A 34 Summary of the modelled first strike impact ranges for Scenario 1 (absolute worst-case monopile) at the N location of Dogger Bank A using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)		Scenario 1: Dogger Bank A – SW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	207 dB	0.01 km²	60 m	60 m	60 m
Unweighted SEL_{ss}	219 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	186 dB	0.02 km²	90 m	90 m	90 m

Table A 35 Summary of the modelled first strike impact ranges for Scenario 1 (absolute worst-case monopile) at the SW location of Dogger Bank A using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)		Scenario 1: Dogger Bank B – NW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	207 dB	0.01 km²	60 m	60 m	60 m
Unweighted SEL_{ss}	219 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	186 dB	0.03 km²	90 m	90 m	90 m

Table A 36 Summary of the modelled first strike impact ranges for Scenario 1 (absolute worst-case monopile) at the NW location of Dogger Bank B using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)		Scenario 1: Dogger Bank B – SE location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	207 dB	0.01 km²	60 m	60 m	60 m
Unweighted SEL_{ss}	219 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	186 dB	0.02 km²	90 m	90 m	90 m

Table A 37 Summary of the modelled first strike impact ranges for Scenario 1 (absolute worst-case monopile) at the SE location of Dogger Bank B using the Popper et al. (2014) injury criteria for fish

<u>Scenarios 2 and 3</u>

Popper *et al*. (2014)		Scenario 2 and 3: Dogger Bank A – N location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	207 dB	0.01 km²	< 50 m	< 50 m	< 50 m
Unweighted SEL_{ss}	219 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	186 dB	0.01 km²	60 m	60 m	60 m

Table A 38 Summary of the modelled first strike impact ranges for Scenarios 2 and 3 (worst-case / most likely monopile) at the N location of Dogger Bank A using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)		Scenario 2 and 3: Dogger Bank A – SW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	207 dB	0.01 km^2	< 50 m	< 50 m	< 50 m
Unweighted SEL_{ss}	219 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	186 dB	0.01 km^2	70 m	70 m	70 m

Table A 39 Summary of the modelled first strike impact ranges for Scenarios 2 and 3 (worst-case / most likely monopile) at the SW location of Dogger Bank A using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)		Scenario 2 and 3: Dogger Bank B – NW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	207 dB	0.01 km^2	< 50 m	< 50 m	< 50 m
Unweighted SEL_{ss}	219 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	186 dB	0.01 km^2	70 m	70 m	70 m

Table A 40 Summary of the modelled first strike impact ranges for Scenarios 2 and 3 (worst-case / most likely monopile) at the NW location of Dogger Bank B using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)		Scenario 2 and 3: Dogger Bank B – SE location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	207 dB	0.01 km^2	< 50 m	< 50 m	< 50 m
Unweighted SEL_{ss}	219 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	186 dB	0.01 km^2	70 m	70 m	70 m

Table A 41 Summary of the modelled first strike impact ranges for Scenarios 2 and 3 (worst-case / most likely monopile) at the SE location of Dogger Bank B using the Popper et al. (2014) injury criteria for fish

<u>Scenarios 4 and 5</u>

Popper *et al*. (2014)		Scenario 4 and 5: Dogger Bank A – N location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
Unweighted SEL_{ss}	219 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	186 dB	0.01 km^2	50 m	50 m	50 m

Table A 42 Summary of the modelled first strike impact ranges for Scenarios 4 and 5 (absolute worst-case / worst-case pin pile) at the N location of Dogger Bank A using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)		Scenario 4 and 5: Dogger Bank A – SW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	207 dB	0.01 km²	< 50 m	< 50 m	< 50 m
Unweighted SEL_{ss}	219 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	186 dB	0.01 km²	60 m	60 m	60 m

Table A 43 Summary of the modelled first strike impact ranges for Scenarios 4 and 5 (absolute worst-case / worst-case pin pile) at the SW location of Dogger Bank A using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)		Scenario 4 and 5: Dogger Bank B – NW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	207 dB	0.01 km²	< 50 m	< 50 m	< 50 m
Unweighted SEL_{ss}	219 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	186 dB	0.01 km²	60 m	60 m	60 m

Table A 44 Summary of the modelled first strike impact ranges for Scenarios 4 and 5 (absolute worst-case / worst-case pin pile) at the NW location of Dogger Bank B using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)		Scenario 4 and 5: Dogger Bank B – SE location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	207 dB	0.01 km²	< 50 m	< 50 m	< 50 m
Unweighted SEL_{ss}	219 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	186 dB	0.01 km²	60 m	60 m	60 m

Table A 45 Summary of the modelled first strike impact ranges for Scenarios 4 and 5 (absolute worst-case / worst-case pin pile) at the SE location of Dogger Bank B using the Popper et al. (2014) injury criteria for fish

Scenario 6

Popper *et al*. (2014)		Scenario 6: Dogger Bank A – N location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
Unweighted SEL_{ss}	219 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	186 dB	0.01 km²	< 50 m	< 50 m	< 50 m

Table A 46 Summary of the modelled first strike impact ranges for Scenario 6 (most likely pin pile) at the N location of Dogger Bank A using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)		Scenario 6: Dogger Bank A – SW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
Unweighted SEL_{ss}	219 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	186 dB	0.01 km^2	50 m	50 m	50 m

Table A 47 Summary of the modelled first strike impact ranges for Scenario 6 (most likely pin pile) at the SW location of Dogger Bank A using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)		Scenario 6: Dogger Bank B – NW location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
Unweighted SEL_{ss}	219 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	186 dB	0.01 km^2	50 m	50 m	50 m

Table A 48 Summary of the modelled first strike impact ranges for Scenario 6 (most likely pin pile) at the NW location of Dogger Bank B using the Popper et al. (2014) injury criteria for fish

Popper *et al*. (2014)		Scenario 6: Dogger Bank B – SE location			
		Area	**Max range**	**Min range**	**Mean range**
Unweighted SPL_{peak}	213 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
Unweighted SEL_{ss}	219 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	186 dB	0.01 km^2	50 m	50 m	50 m

Table A 49 Summary of the modelled first strike impact ranges for Scenario 6 (most likely pin pile) at the SE location of Dogger Bank B using the Popper et al. (2014) injury criteria for fish

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Document No.	Draft	Date	Details of change
P278R0300	02	15/09/2021	Initial writing and internal review
P278R0301	01	30/09/2021	Minor amendments
P278R0302	-	16/12/2021	Issue to client

Originator’s current report number	P278R0302
Originator’s name and location	R Barham; Subacoustech Environmental Ltd.
Contract number and period covered	P278; July 2021 – December 2021
Sponsor’s name and location	Jen Learmonth; HaskoningDHV UK Ltd
Report classification and caveats in use	COMMERCIAL IN CONFIDENCE
Date written	September-December 2021
Pagination	Cover + iv + 100
References	32
Report title	Dogger Bank A & B: Underwater noise assessment
Translation/Conference details (if translation, give foreign title/if part of a conference, give conference particulars)	
Title classification	Unclassified
Author(s)	Richard Barham, Tim Mason
Descriptors/keywords	
Abstract	
Abstract classification	Unclassified; Unlimited distribution