Dogger Bank Project –PB9446-RHD-ZZ-OF-RP-YE-0003

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

Validity area: Dogger Bank Teesside A Project / Offshore

ASSURANCE OF CONTENT

Role for assurance*	Role in organisation	Name	Date
Prepared by	Marine Mammal Lead	Jennifer Learmonth	14/05/2020
Process Control by	QRM	Kerrie Craig	19/05/2020
Approved by	Project Director	Adam Pharaoh	20/05/2020
Recommender	Offshore Consent Manager	Peter Moore	21/05/2020
Recommender	Lead Consent Manager	Jonathan Wilson	21/05/2020

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Role for assurance	Responsibility
Prepared by	The person who is regarded as the author of the document
Process Control by	The person who has made sure that a sufficient process for quality assurance and quality control has been followed, and has the authority to recommend implementation
Approved by	The person who has the authority to accept the document and release it for implementation

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Glossary of Acronyms

µPa	Micro pascal
ADD	Acoustic Deterrent Device
BEIS	Department for Business, Energy and Industrial Strategy
BGS	British Geological Survey
CI	Confidence Interval
CODA	Cetacean Offshore Distribution and Abundance in the European Atlantic
CV	Confidence Variation
dB	Decibels
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
ES	Environmental Statement
FCS	Favourable Conservation Status
GW	Gigawatts
HF	High-frequency
HRA	Habitats Regulations Assessment
Hz	Hertz
IAMMWG	Inter-Agency Marine Mammal Working Group
INSPIRE	Impulsive Noise Propagation and Impact Estimator
JNCC	Joint Nature Conservation Committee
kJ	Kilojoules
km	Kilometre
km^2	Kilometre squared
LF	Low-frequency
m	meter
MAREMAP	Marine Environmental Mapping Programme
MF	Mid-frequency
MMMP	Marine Mammal Mitigation Protocol
MMO	Marine Management Organisation
MU	Management Unit
N/A	Not Applicable
NMC	Non-Material Change
NMFS	National Marine Fisheries Services
NOAA	National Oceanic and Atmospheric Administration
NPL	National Physical Laboratory
NS	North Sea
OWF	Offshore Wind Farm
PCW	Phocid Carnivores in Water
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
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
SNS	Southern North Sea
SPL	Sound Pressure Level
TSEG	Trilateral Seal Expert Group
TTS	Temporary Threshold Shift
US	United States
VHF	Very High Frequency

Executive Summary

Dogger Bank Teesside A offshore wind farm was consented in 2015 under the Dogger Bank Teesside Offshore Wind Farm Order 2015 (the Development Consent Order (DCO)). In respect of the Dogger Bank Teesside A project, the DCO prescribes a number of parameters including the maximum hammer energy.

Since the DCO was granted, advancements in technology mean that larger turbines have become available which would require a limited number of changes to the consented parameters. As a result, the Project Team is seeking to make a non-material change (NMC) to the DCO. In relation to potential effects on marine mammals, the key change is an increase in the maximum hammer energy from 3,000kJ to 4,000kJ for monopiles.

This report considers the potential for changes to the outcomes of the assessment provided in the Environmental Statement (ES) (Forewind, 2014a) and Habitats Regulations Assessment (HRA) (DECC, 2015) for the consented Teesside A project. A like for like comparison for a hammer energy of 3,000kJ is undertaken for the previous and updated noise modelling to determine if there are any significant differences. Updated assessments are conducted based on updated modelling for maximum hammer energy of 3,000kJ or 4,000kJ. These updated assessments consider the potential impacts on marine mammals from permanent auditory injury, temporary auditory injury and likely or possible avoidance of an area in respect of the relevant receptors (harbour porpoise, white-beaked dolphin, minke whale, grey seal and harbour seal). This report demonstrates that in each case, the assessment outcomes would not be affected by proposed increase in hammer energy.

The assessments undertaken demonstrate that there is no difference in the impact significance between the impacts as assessed under the original assessment and the updated assessment. Therefore, the assessments demonstrate that an increase in maximum hammer energy to 4,000kJ for monopiles does not affect impact significance on any of the assessed receptors.

As there is no significant difference in the potential impacts on marine mammals from increasing the maximum monopile hammer energy to 4,000kJ compared to the maximum monopile hammer energy of 3,000kJ in the original assessment, there will be no significant difference to the outcome of the cumulative impact assessment in the ES assessment (Forewind, 2014a) or to the outcome of the Department of Energy and Climate Change (DECC; now Department for Business, Energy and Industrial Strategy (BEIS)) HRA (DECC, 2015) as a result of the proposed change.

Therefore, this report confirms that there are no new or materially different likely significant effects compared to the existing scheme. The conclusions of the existing 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 designated site arising from the project alone and in-combination with all other sites are not affected. The proposed change does not have the potential to give rise to likely significant effects on any European designated 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 change to the DCO.

A comparison with the BEIS (2018) draft HRA for the Review of Consented (RoC) Offshore Wind Farms (OWFs) in the Southern North Sea (SNS) harbour porpoise Special Area of Conservation (SAC) indicates that the maximum predicted permanent auditory injury (Permanent Threshold Shift; 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 (2018) draft 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 Teesside A project. The draft RoC HRA assumes a worst case hammer energy for the Project of 5,500kJ and concludes that Teesside A alone and in combination with Sofia would not have an adverse effect on site integrity.

It is therefore concluded that the proposed change 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 DECC HRA are not

affected and no new HRA is required. Therefore, it is appropriate for the application to amend the maximum hammer energy to be consented as a NMC to the DCO.

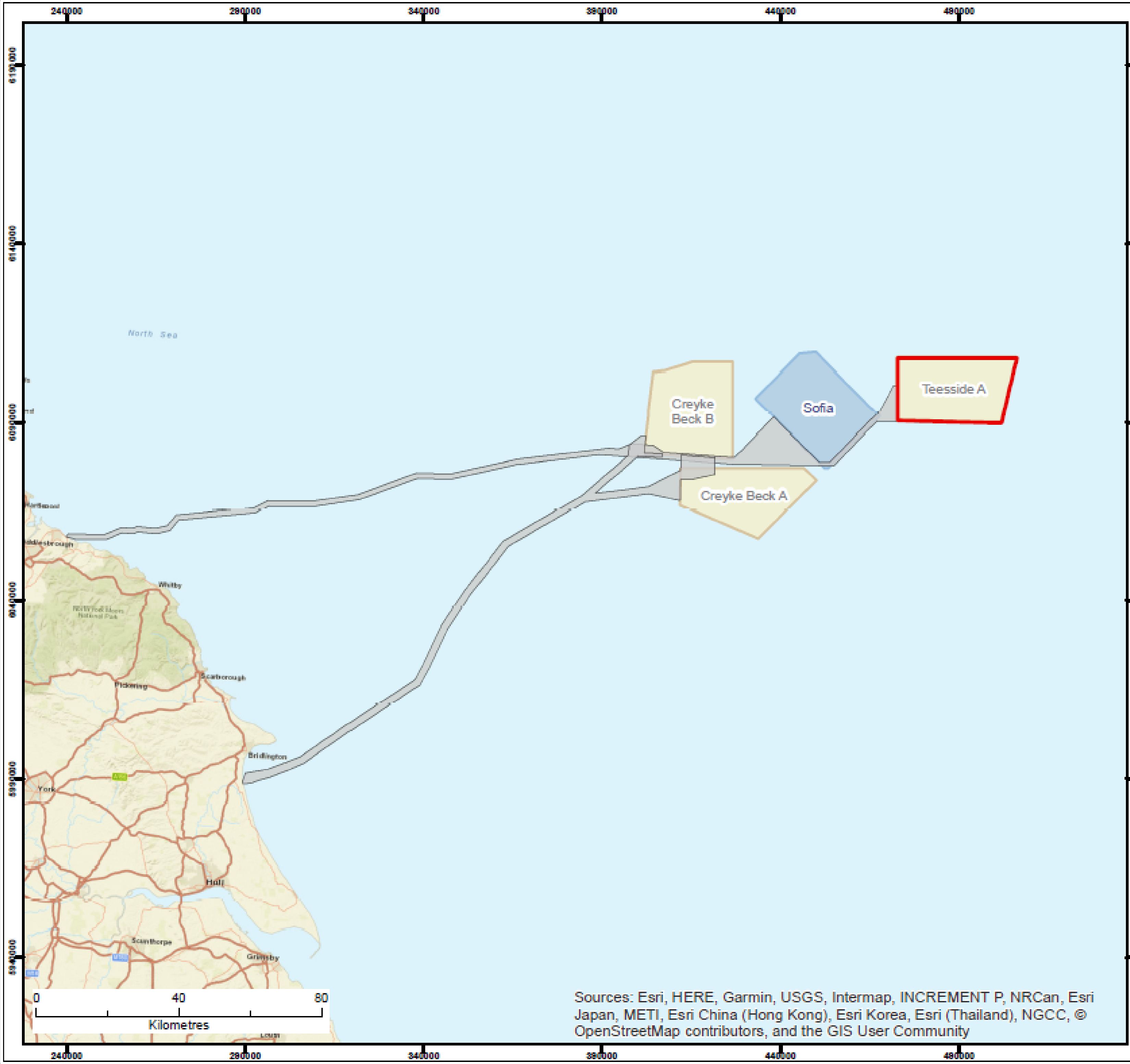
1 Introduction

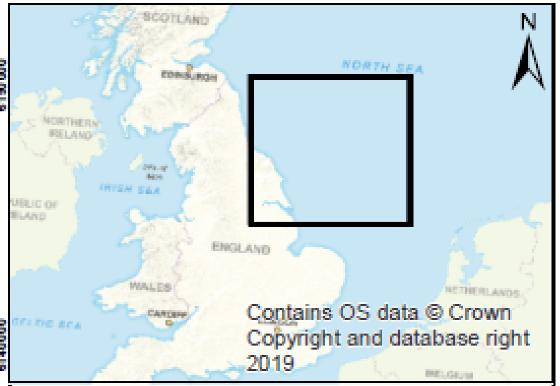
Since the DCO was granted there have been a number of advancements in technology that would make the wind farm more efficient and cost effective. These advances are based on the size of wind turbine generators that are available, or that are likely to become available during the course of the development programme. As some of these would require a limited number of changes to the consented parameters (Section 2), the Project Team is looking to make a non-material change (NMC) to the DCO as amended to enable the Project to be constructed in the most efficient and cost-effective manner.

This technical report describes how the proposed amendment could affect the marine mammal assessment presented in the ES and the HRA undertaken by DECC (now BEIS).

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**; and
- **Section 6 Conclusions**.





Legend:

- Dogger Bank Teesside A
- Dogger Bank Wind Farms
- Sofia Offshore Wind Farm
- Export Cable Corridor

Client:	Project:
SSE & Equinor	Dogger Bank Teesside A

Title:

Location of Dogger Bank Teesside A Offshore Wind Farm

Figure: 1 Drawing No: PB8446-RHD-ZZ-OF-DR-Z-0001

Revision:	Date:	Drawn:	Checked:	Size:	Scale:
01	26/09/2019	GC	GC	A4	1:1,500,000

Co-ordinate system: WGS84 UTM 31N

Royal HaskoningDHV Enhancing Society Together

DOGGER BANK WIND FARMS BY sse equinor

2 Proposed Amendment

The proposed amendment requires an increase to the consented parameter for hammer energy, whilst leaving all other DCO parameters unchanged (**Table 1**). There are no proposed changes to the maximum hammer energy in relation to pin-piles.

An increase in hammer energy has the potential to affect the marine mammal assessment. Review and reassessment has been undertaken using the updated parameters shown in **Table 1**.

Table 1 Proposed consent amendments relevant to marine mammals

Parameter	Consented Envelope	Proposed Amendment
Maximum hammer energy – monopile	3,000kJ	Up to 4,000kJ
Maximum hammer energy – pin pile	2,300kJ	No change
Monopile diameter	Up to 12m	No change
Pin-pile diameter	3.5m	No change

3 Purpose of Assessment

As set out in **Section 2**, the proposed change is an increase in the maximum hammer energy for single monopile structures from 3,000kJ to up to 4,000kJ.

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

Underwater noise propagation modelling for the original assessment was carried out by the National Physical Laboratory (NPL) (Forewind, 2014b) to assess the effects of noise from the construction of the Dogger Bank Teesside A offshore wind farm.

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 have been developed by the United States (US) National Marine Fisheries Service (NMFS, 2018) and published by Southall *et al*. (2019) for both permanent threshold shift (PTS) where unrecoverable hearing damage may occur, as well as temporary threshold shift (TTS) where a temporary reduction in hearing sensitivity may occur in marine mammals. The thresholds and criteria published by Southall *et al*. (2019) use identical thresholds to those from the NMFS (2018) guidance for marine mammals, although there are some differences in the category names, which is presented in Annex 1 Subacoustech Report. As outlined in Annex 1, the Southall *et al*. (2019) criteria has been used for this study as it is a peer-reviewed and published paper, whereas NMFS (2018) is a guidance document.

Therefore, for the proposed increase in hammer energy, underwater noise modelling has been undertaken by Subacoustech to:

(i) Compare the NPL model used in the original assessment and Subacoustech's INSPIRE model used in this assessment to ensure the models are comparable. This is presented in **Annex 1**[1].

(ii) Replicate underwater noise modelling undertaken for the original assessment, for equivalent inputs and scenarios to enable a like for like comparison to be made between the consented hammer energy of 3,000kJ.

(iii) Update the underwater noise modelling based on the latest inputs and scenarios for increased hammer energy using the latest (Southall *et al*., 2019) thresholds and criteria for PTS and TTS.

This aim of the assessment 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 4,000kJ compared to the currently consented maximum hammer energy of 3,000kJ.

[1] The Subacoustech modelling presented in Annex 1 was also undertaken for a hammer energy of 5,400kJ. This was originally a consideration, but a Project decision was taken not to progress this hammer energy, therefore this assessment, and the NMC application is only for 4,000kJ.

4 Methodology for Assessment

The ES identified the following species as requiring assessment:

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

4.1 Underwater noise modelling

The original model used by NPL is not openly available. As such, Subacoustech have used the INSPIRE model to produce comparable modelling methodology.

As outlined in **Section 5.1** and **Annex 1**, on a like for like basis the Subacoustech modelling using the INSPIRE model provides comparable results to the previous NPL modelling used in the ES and is therefore considered to be suitable to conduct the updated noise modelling and to allow a comparison with the original assessment.

4.1.1 Modelling locations and environmental conditions

The same modelling locations and environmental conditions that were used in the original assessment were also used in the updated assessment as outlined in **Annex 1**.

The results from location ID1 at Teesside A was chosen as a representative worst case modelling location with the greatest potential impact ranges (location shown on Figure 1-1 in **Annex 1**; modelling for the other location within the Teesside A site (location ID5) is presented in **Annex 1**). The locations encompass the worst-case scenario and include a wide area of the Teesside A site including both deep and shallow water areas.

4.1.2 Increased hammer energy

The maximum hammer energies for monopiles in the original assessment and updated assessment for the increased hammer energy are presented in **Table 2**.

Table 2: Maximum hammer energies assessed in the original assessment and updated assessment

Assessment	Maximum hammer energy
Original assessment	3,000kJ
Updated assessment	4,000kJ

4.1.3 Source levels

The unweighted source level for maximum hammer energies of 3,000kJ and 4,000kJ for monopiles used in the original assessment and updated assessment are presented in **Table 3**, these are in line with those seen at other, similar scale offshore wind farm (OWF) projects.

It is important to note that the source level value is theoretical and does not necessarily, nor is intended to, represent the actual noise level at 1m from the piling operation, which is highly complex close to a large distributed source. Its purpose is for the accurate calculation of noise levels at greater distances from the source, to correspond with relevant thresholds, and crucially in this case, to agree with the original NPL modelling (see **Annex 1** for further details).

Table 3 Unweighted, single strike, source levels used for modelling in the assessment

Source level	SPLpeak source level	SEL_{ss} source level
Monopile 300kJ (starting hammer energy)	233.2 dB re 1 µPa @ 1 m	208.0 dB re 1 µPa^{2}s @ 1 m
Monopile 400kJ (starting hammer energy)	234.8 dB re 1 µPa @ 1 m	209.4 dB re 1 µPa^{2}s @ 1 m
Monopile 3,000kJ (maximum hammer energy)	245.2 dB re 1 µPa @ 1 m	219.0 dB re 1 µPa^{2}s @ 1 m
Monopile 4,000kJ (maximum hammer energy)	247.0 dB re 1 µPa @ 1 m	220.5 dB re 1 µPa^{2}s @ 1 m

4.1.4 Soft-start, strike rate, piling duration and swim speeds

The soft-start, strike rate and piling duration scenarios used in the in the original assessment and for increased hammer energy for monopiles used in the updated assessment are presented in **Table 4**.

For cumulative SELs (SEL_{cum}), which accounts for the total exposure of a receptor to the noise of the complete piling period, the soft start, strike rate and duration of the piling events have also been considered. The two worst cases of these sequences (sequence 2 and 3) were used in the Subacoustech modelling (see Annex 1). Assessments have been based on the worst-case scenario for piling duration, sequence 3 (as referred to in the original assessment (Forewind, 2014b)), which assumes 12,600 strikes over 330 minutes.

The soft-start (the use of lower hammer energy for an initial period) takes place over the first half-hour of piling, with a starting hammer energy of 10% of the maximum energy, then for the remaining number of strikes the hammer energy is 100%. This is a worst-case scenario, as it is likely that following the soft start the hammer energy will ramp-up gradually from 10% to 100% rather than go straight to 100%, and for engineering reasons piling would not be at 100% for this extended period (and may not operate at 100%). However, information on a ramp-up was unavailable in the NPL report and ES (Forewind, 2014b), and thus these worst-case assumptions have been made and have informed the basis for this assessment.

Table 4 Summary of the multiple pulse scenarios used for cumulative SEL modelling used in the original assessment and updated assessment

Soft-start, strike rate and piling duration scenarios for SEL_{cum}	Percentage of maximum hammer energy	
	10% (soft-start)	100%
3,000kJ (monopile)	300kJ	3,000kJ
4,000kJ (monopile)	400kJ	4,000kJ
Strike rate	1 strike every 3 seconds	1 strike every 1.5 seconds
Duration	30 minutes	110 minutes (sequence 2) 300 minutes (sequence 3)
Number of strikes	600 strikes	4,400 strikes (sequence 2) 12,000 strikes (sequence 3)

The cumulative SEL modelling uses a fleeing animal model. 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 receptors are assumed to swim at a constant speed of 1.5 m/s (Otani *et al*. 2000; Hirata, 1999). These are the same swim speeds used in the original assessment.

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 (for example, Kastelein *et al*. (2018) recorded harbour porpoise swimming speeds of 1.97m/s during playbacks of pile driving sounds).

4.1.5 Thresholds and criteria

4.1.5.1 Original assessment

The following criteria were used in the NPL modelling (Forewind, 2014b) for the original assessment:

- Lucke *et al*. (2009) for harbour porpoise (e.g. high-frequency cetaceans); and
- Southall *et al*. (2007) for mid-frequency cetaceans (e.g. dolphin species); low-frequency cetaceans (e.g. minke whale) and pinnipeds in water (e.g. grey and harbour seal).

The criteria used in the original assessment are summarised in **Table 5** to **Table** 8. It should be noted that the Southall *et al*. (2007) and Lucke *et al*. (2007) criteria presented in the NPL modelling, and here as a comparison, are only for single strike SEL (SEL_{ss}).

Table 5 Criteria for assessing impacts on harbour porpoise in the original assessment and modelled by NPL, based on Lucke et al. (2009)

Potential Impact	Criteria
Instantaneous injury / PTS	SPL_{peak} 200 dB re 1 μPa
	Unweighted SEL_{ss} 179 dB re 1 μPa²s
TTS / fleeing response	SPL_{peak} 194 dB re 1 μPa
	Unweighted SEL_{ss} 164 dB re 1 μPa²s
Possible avoidance	SPL_{peak} 168 dB re 1 μPa
	Unweighted SEL_{ss} 145 dB re 1 μPa²s

Table 6 Criteria for assessing impacts on mid-frequency (MF) cetaceans (e.g. dolphin species) in the original assessment and modelled by NPL, based on Southall et al. (2007)

Potential Impact	Criteria
Instantaneous injury / PTS	SPL_{peak} 230 dB re 1 μPa
	M_{mf} weighted SEL_{ss} 198 dB re 1 μPa²s
TTS / fleeing response	SPL_{peak} 224 dB re 1 μPa
	M_{mf} weighted SEL_{ss} 183 dB re 1 μPa²s

Potential Impact	Criteria
Likely avoidance from area	Unweighted SEL_{ss} 170 dB re 1 μPa^2s
Possible avoidance from area	Unweighted SEL_{ss} 160 dB re 1 μPa^2s

Table 7 Criteria for assessing impacts on low-frequency (LF) cetaceans (e.g. minke whale) in the original assessment and modelled by NPL, based on Southall et al. (2007)

Potential Impact	Criteria
Instantaneous injury / PTS	SPL_{peak} 230 dB re 1 μPa
	M_{lf} weighted SEL_{ss} 198 dB re 1 μPa^2s
TTS / fleeing response	SPL_{peak} 224 dB re 1 μPa
	M_{lf} weighted SEL_{ss} 183 dB re 1 μPa^2s
Likely avoidance from area	Unweighted SEL_{ss} 152 dB re 1 μPa^2s
Possible avoidance from area	Unweighted SEL_{ss} 142 dB re 1 μPa^2s

Table 8 Criteria for assessing impacts on pinnipeds in water (e.g. grey and harbour seal) in the original assessment and modelled by NPL, based on Southall et al. (2007)

Potential Impact	Criteria
Instantaneous injury / PTS	SPL_{peak} 218 dB re 1 μPa
	M_{pw} weighted SEL_{ss} 186 dB re 1 μPa^2s
TTS / fleeing response	SPL_{peak} 212 dB re 1 μPa
	M_{pw} weighted SEL_{ss} 171 dB re 1 μPa^2s

4.1.5.2 Latest criteria

The latest criteria (Southall *et al*., 2019) for single strike unweighted peak Sound Pressure Level criteria (SPL_{peak}), single strike weighted Sound Exposure Level (SEL_{ss}) and cumulative (i.e. more than a single impulsive sound) weighted sound exposure criteria (SEL_{cum}) for PTS and TTS were used in the updated assessment (**Table 9**).

It should be noted that these cannot be compared like-for-like with criteria in the original assessment as cumulative SELs were not considered for marine mammals (cumulative SELs are the risk of PTS or TTS during the duration of the pile installation including the soft-start and ramp-up and the total maximum duration, as opposed to risk from a single strike).

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

Marine Mammal hearing group	PTS threshold			TTS threshold		
	SPL_{peak} (unweighted) dB re 1 µPa	SEL_{ss} (weighted) dB re 1 μPa^2s	SEL_{cum} (weighted) dB re 1 μPa^2s	SPL_{peak} (unweighted) dB re 1 µPa	SEL_{ss} (weighted) dB re 1 μPa^2s	SEL_{cum} (weighted) dB re 1 μPa^2s
Low-frequency cetaceans (e.g. minke whale)	219	183	183	213	168	168
High-frequency cetaceans (e.g. dolphin species)	230	185	185	224	170	170
Very high-frequency cetaceans (e.g. harbour porpoise)	202	155	155	196	140	140
Pinnipeds in water (e.g. grey and harbour seal)	218	185	185	212	170	170

4.2 Density estimates and reference populations

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. **Table 10** and **Table 11** provide the density estimates and reference populations, respectively, used in the original assessment and the updated assessment.

The same density estimates and reference populations used in the original assessment have been used in the like for like comparison (**Section 5.1**).

The most recent density estimates have been based on the SCANS-III survey for cetaceans (Hammond *et al*., 2017) and the latest Sea Mammal Research Unit (SMRU) seal at-sea usage maps (Russell *et al*., 2017) have been used for the updated assessment (**Section 5.3**).

Since the original assessment, the density estimates for:

1. Harbour porpoise has increased from 0.716 to 0.837 harbour porpoise per km^2, based on the latest SCANS-III survey. This increased density estimate has been used as a worst-case scenario, e.g. highest density estimate, in the updated assessment.
2. White-beaked dolphin has lowered from 0.015 to 0.002 individuals per km^2, based on the latest SCANS-III survey. However, for the wider area of likely or possible avoidance the SCANS-III density estimate was more appropriate to use.
3. Minke whale has increased from 0.009 to 0.020 individuals per km^2, based on the latest SCANS-III survey. This increased density estimate has been used as a worst-case scenario, e.g. highest density estimate, in the updated assessment.
4. Grey seal has remained virtually the same, with only a slight change from 0.213 to 0.02 individuals per km^2. The most recent SMRU data is the most appropriate density estimate to use in the updated assessment.

Since the original assessment, the reference population for:

1. Harbour porpoise in the North Sea Management Unit (MU) has increased by an estimated 118,075 harbour porpoise. The estimates cover the same area and reflect a change in harbour porpoise number between the SCANS-II survey in 2005 and the latest SCANS-III survey in 2016.
2. White-beaked dolphin has remained the same.
3. Minke whale has increased slightly by 359 individuals. The estimates cover the same area and reflect a refinement of the estimate from the SCANS-II publication (Hammond *et al*., 2013) and Cetacean Offshore Distribution and Abundance in the European Atlantic (CODA) survey publication (Macleod *et al*., 2009) to the Inter-Agency Marine Mammal Working Group (IAMMWG, 2015) publication.
4. Grey seal has decreased by 3,473 individuals. The estimates are based, as closely as possible, on counts from the same areas and reflect an increase in the number of grey seal in these areas.

Harbour seal were not assessed in the original assessment, but the reference population for the south-east coast of England has increased by approximately 1,398 individuals, compared to the previous reference population for the east coast of England, reflecting an increase in the number of harbour seal in this area (SCOS, 2018).

Table 10 Marine mammal density estimates used in the original assessment 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	0.7161/km^2 (95% CI = 0.52284-0.97333/km^2)	Site specific surveys; ES (Forewind, 2014a)	0.837/km^2 (CV = 0.26)	SCANS-III survey block N (Hammond *et al*., 2017)
White-beaked dolphin	0.01487/km^2 (95% CI = 0.00663-0.02813/km^2)	Site specific surveys; ES (Forewind, 2014a)	0.002/km^2 (CV = 0.97)	SCANS-III survey block O* (Hammond *et al*., 2017)
Minke whale	0.00866/km^2 (95% CI = 0-0.02391/km^2).	Site specific surveys; ES (Forewind, 2014a)	0.020/km^2 (CV = 0.50)	SCANS-III survey block N (Hammond *et al*., 2017)
Grey seal	0.02131/km^2 (95% CI = 0.01571-0.03257)	SMRU (2013); ES (Forewind, 2014a)	0.02/km^2	SMRU seal at-sea usage maps (Russell *et al*., 2017)

Species	Original assessment		Updated assessment	
	Density estimate used in ES	ES data source	Updated density estimate (number of individuals per km²)	Updated data source
Harbour seal	N/A	N/A	0.00004/km²	SMRU seal at-sea usage maps (Russell *et al*., 2017)

* No white-beaked dolphin density estimate is available for SCANS-III survey block N, therefore the density estimate for nearby survey block O has been used.

Table 11 Marine mammal reference populations used in the original assessment and updated assessments

Species	Reference population		
	Extent	Size	Year of estimate and data source
Harbour porpoise	North Sea MU	345,373 (CV = 0.18; 95% CI = 246,526-495,752) *[used in updated assessment*]	2016 based SCANS-III (Hammond *et al*., 2017)
		227,298 (95% CI = 176,360-292,948) [*used in original assessment*]	2005; IAMMWG (2013) based on SCANS-II (Hammond *et al*., 2013)
White-beaked dolphin	Celtic and Greater North Seas (CGNS) MU	15,895 (CV=0.29; 95% CI=9,107-27,743) [*used in updated assessment*]	2005; IAMMWG (2015) based on SCANS-II (Hammond *et al*., 2013)
	All UK waters (British Isles; BI) MU	15,895 (95% CI=9,107-27,743) [*used in original assessment*]	2005; IAMMWG (2013) based on SCANS-II (Hammond *et al*., 2013)
Minke whale	Celtic and Greater North Seas (CGNS) MU	23,528 (CV=0.27; 95% CI=13,989-39,572) [*used in updated assessment*]	2005 & 2007; IAMMWG (2015) based on SCANS-II (Hammond *et al*., 2013) and CODA (Macleod *et al*., 2009)
	All UK waters (BI) MU	23,169 (95% CI=13,772-38,958) [*used in original assessment*]	2005 & 2007; IAMMWG (2013) based on SCANS-II (Hammond *et al*., 2013) and CODA (Macleod *et al*., 2009)
Grey seal	South-east England MU; North-east England MU; East coast of Scotland MU; & Waddenzee region	25,516 = 8,716 + 7,004 + 3,652 + 6,144 [*used in updated assessment*]	2008-2017; SCOS (2018) and Brauseur *et al*. (2018)
	South-east England MU	8,716 [*used in updated assessment*]	2008- 2017; SCOS (2018)
	North Sea (South-east England, North east England and East coast MU + Waddenzee)	28,989 = 24,950 + 4,039 [*used in original assessment*]	2007, 2008, 2010, 2011 & 2012; UK North Sea (IAMMWG, 2013) and Mainland Europe (Waddenzee Secretariat)

Species	Reference population		
	Extent	Size	Year of estimate and data source
Harbour seal	South-east England MU; and Waddenzee region	44,965 = 4,965 + 40,000 [*used in updated assessment*]	2013-2017; SCOS (2018) and Galatius *et al*. (2018)
	South-east England MU	4,965 [*used in updated assessment*]	2013-2017; SCOS (2018)
		3,567 (minimum population size) [*used in original assessment*]	2011 (IAMMWG, 2013)

5 Outcome of Assessments

5.1 Model comparison

In order to obtain modelling results representative of those produced by NPL, modelling was carried out using the INSPIRE model and the parameters detailed in the previous section to acquire a transmission loss over multiple transects. These transmission losses were then compared against the results of the NPL modelling (Forewind, 2014b). Location ID1 at Teesside A was chosen as a representative modelling location due to its location in the deeper water to the north west of the site.

As outlined in Annex 1, there was good correlation between the two resultant data sets. Figures 3-2 and 3-3 in Annex 1 compare the unweighted noise level plots from the NPL report and the new Subacoustech modelling at the same scale. It should be noted that although the noise levels do not line up perfectly, the figures do show many of the same features, such as a largely uniform distribution in all directions for the highest noise levels, with larger ranges into the deeper water to the north and northwest and some effects of shallower areas and sandbanks to the south, which reduce noise transmission.

Table 12 summarises the maximum modelled SPL_{peak} values for the NPL modelling and worst-case for the Subacoustech modelling for a maximum hammer energy of 3,000kJ (see Annex 1 for further details).

Table 12 Summary of the maximum modelled SPL_{peak} values for the NPL modelling and worst-case for the Subacoustech modelling for a maximum hammer energy of 3,000kJ

SPL_{peak} Criteria	NPL modelling	INSPIRE worst-case	Difference
206 dB re 1 µPa	200m	280m	+80m (+40%)
200 dB re 1 µPa	600m	640m	+40m (+6.7%)
173 dB re 1 µPa	7.5-10km	13km	+3km (+30%)
168 dB re 1 µPa	17-21km	19km	-2km (+9.5%)

5.2 Like for like comparison

The results presented in this section summarise the like for like comparison of the NPL modelling in the ES and the Subacoustech modelling (**Annex 1**) for the predicted maximum impact ranges for a hammer energy of 3,000kJ, using the same parameters as used in the original ES assessment for a range of thresholds and criteria.

It should be noted that whilst the percentage increase from the original ES assessment is provided for context purposes, the outcome of the comparison and conclusion that follows is based on the number of individuals and percentage of the reference population at risk, and how this compares to the original assessment.

The like for like comparison has been based on the density estimates (**Table 10**) and reference populations (**Table 11**) used in the original ES assessment.

In relation to each of the potential impacts for each of the receptors, the like for like comparison demonstrates that there are no significant differences in the predicted impacts (i.e. magnitude of effect) based on the underwater noise modelling under the original ES assessment by NPL and by Subacoustech for a hammer energy of 3,000kJ.

The like for like comparison indicates that the modelling undertaken by Subacoustech generally has greater impact ranges and areas compared to the previous NPL modelling in the ES and is therefore more precautionary in assessing the potential impacts. The idiosyncrasies of any model mean that another model emulating it will have variations, as can be seen in the differences presented in **Table 12**. Overall, there is a good level of correlation between the two datasets and the results from the INSPIRE model, with the INSPIRE model having a slightly smaller spread of ranges and the NPL model having a greater variability along the transect than INSPIRE, which produces a smoother curve. This does lead to larger calculated effect ranges in some locations for INSPIRE's worst case. Small ranges of the order of hundreds of metres or less, will always produce significant variability as all models are designed for long-range accuracy, as this is where the majority of thresholds are reached and where receptors are present. The chosen approach provides a good substitute for the NPL modelling in calculating the Southall *et al.* (2019) criteria.

The assessment for the proposed increase in hammer energy has been based on the more appropriate updated noise modelling using the latest thresholds and criteria in **Section 5.3.**

Table 13 Like for like comparison of predicted impact ranges (and areas) modelled by NPL and Subacoustech for a maximum hammer energy of 3,000kJ and predicted impacts (number of marine mammals and % of reference population) in the original ES assessment and like for like comparison*

Threshold and Criteria	Predicted impact for NPL modelling and ES assessment	Predicted impact for Subacoustech modelling and like for like assessment	Difference
Unweighted SEL_{ss} 179 dB re 1 μPa²s Instantaneous PTS of harbour porpoise (Lucke *et al.*, 2009)	700m (1.5km²)	690m (1.5km²)	-10m (difference = -1.4%) No difference in area
	1.1 harbour porpoise (0.005% of reference population)	1.1 harbour porpoise (0.005% of reference population)	No difference
	Magnitude of effect = negligible	Magnitude of effect = negligible	No difference
Unweighted SEL_{ss} 164 dB re 1 μPa²s TTS / fleeing response	4.0-5.5km (82.3km²)	5.8km (105.43km²)	+300m (difference = 5.5%) +23.13km² (difference = 28%)

Threshold and Criteria	Predicted impact for NPL modelling and ES assessment	Predicted impact for Subacoustech modelling and like for like assessment	Difference
of harbour porpoise (Lucke *et al*., 2009)	59 harbour porpoise (0.03% of reference population)	75.5 harbour porpoise (0.03% of reference population)	+16.5 harbour porpoise (0.007% of reference population)
	Magnitude of effect = negligible	Magnitude of effect = negligible	No difference
Unweighted SEL_{ss} 145 dB re 1 μPa^2s Possible avoidance of harbour porpoise (Lucke *et al*., 2009)	22-33km (2,681km^2)	31km (3,500.9km^2)	Within range (difference = -6%) +819.9km^2 (difference = +30.6%)
	1,920 harbour porpoise (0.84% of reference population)	2,507 harbour porpoise (1% of reference population)	587 harbour porpoise (0.3% of reference population)
	Magnitude of effect = negligible	Magnitude of effect = negligible	No difference
Unweighted SEL_{ss} 170 dB re 1 μPa^2s Likely avoidance of white-beaked dolphin (mid-frequency cetaceans) (Southall *et al*., 2007)	2.5km (16km^2)	2.7km (22.15km^2)	+200m (difference = +8%) +6.15km^2 (difference = +38%)
	0.2 white-beaked dolphin (0.001% of reference population)	0.3 white-beaked dolphin (0.002% of reference population)	0.1 white-beaked dolphin (0.0006% of reference population)
	Magnitude of effect = negligible	Magnitude of effect = negligible	No difference
Unweighted SEL_{ss} 160 dB re 1 μPa^2s Possible avoidance of white-beaked dolphin (mid-frequency cetaceans) (Southall *et al*., 2007)	6.0-8.5km (209km^2)	9.2km (255.12km^2)	+700m (difference = +8%) +46.12km^2 (difference = +22%)
	3 white-beaked dolphin (0.02% of reference population)	3.8 white-beaked dolphin (0.02% of reference population)	0.8 white-beaked dolphin (0.005% of reference population)
	Magnitude of effect = negligible	Magnitude of effect = negligible	No difference
Unweighted SEL_{ss} 152 dB re 1 μPa^2s Likely avoidance of minke whale (low-frequency cetacean) (Southall *et al*., 2007)	13.5-18km (918km^2)	19km (1,026.5km^2)	+1km (difference = +5.5%) +108.5km^2 (difference = +11.8%)
	8 minke whale (0.03% of reference population)	9 minke whale (0.04% of reference population)	1 minke whale (0.004% of reference population)

Threshold and Criteria	Predicted impact for NPL modelling and ES assessment	Predicted impact for Subacoustech modelling and like for like assessment	Difference
	Magnitude of effect = negligible	Magnitude of effect = negligible	No difference
Unweighted SEL_{ss} 142 dB re 1 μPa^2s Possible avoidance of minke whale (low-frequency cetacean) (Southall *et al*., 2007)	26.5-41km (3,940km²)	38km (3,500.9km²)	Within range (difference = -7%) -439.1km² (difference = -11%)
	34 minke whale (0.1% of reference population)	30 minke whale (0.1% of reference population)	4 minke whale (0.02% of reference population)
	Magnitude of effect = negligible	Magnitude of effect = negligible	No difference

* based on the density estimates (**Table 10**) and reference populations (**Table 11**) used in the original ES assessment

5.3 Updated assessments

Each assessment is based on the latest Southall *et al*. (2019) criteria (see **Section 4.1.5.2**) and considers:

- The increase in predicted impact range and area; and
- The maximum number of individuals and percentage of the reference population that could potentially be impacted.

It should be noted that whilst the percentage increase in impact range and area is provided for context purposes, the assessment outcome and conclusion that follows is based on the number of individuals and percentage of the reference population, and how this compares to the original assessment.

In relation to each of the potential impacts for each of the receptors, the updated assessments based on the latest criteria demonstrates that there is no difference in the impact significance between the impacts as assessed for a maximum hammer energy from 3,000kJ or 4,000kJ for any of the assessed receptors.

A summary of the updated assessment is provided in **Table 33**.

5.3.1 Harbour porpoise

5.3.1.1 PTS

5.3.1.1.1 PTS from single strike

In the original ES assessment, the NPL modelling of instantaneous auditory injury (PTS) in harbour porpoise for a single strike of the maximum monopile hammer energy of 3,000kJ, based on the unweighted Lucke *et al*. (2009) criteria (pulse SEL 179 dB re 1 μPa²s), predicted a potential impact range of <700m (1.5km²). The maximum number of harbour porpoise that could be at risk of PTS in the ES assessment was 1.1 harbour porpoise, based on a density of 0.7161 harbour porpoise per km². The ES assessment determined that 0.005% of the 227,298 reference population could be impacted and that the magnitude of effect was negligible, with less than 0.001% of the reference population anticipated to be exposed to effect. The impact significance, without mitigation, was assessed as minor adverse (high sensitivity x permanent impact with negligible magnitude).

In the updated assessment, the potential for any permanent auditory injury (PTS), the Southall *et al*. (2019) criteria for unweighted SPL_{peak} for single strike, weighted SEL for single strike and PTS from cumulative exposure (SEL_{cum}) have been modelled for the proposed increased monopile hammer energy (up to 4,000kJ), as well as the 3,000kJ hammer energy for monopiles. Cumulative SEL assessments have been based on the worst-case soft-start and ramp-up scenario, sequence 3, which assumes 12,600 strikes over 330 minutes.

In the updated assessment, for the 3,000kJ hammer energy the maximum predicted impact range is 480m (0.73km^2) for the unweighted SPL_{peak} criteria for a single strike. The maximum number of harbour porpoise that could be at risk of PTS is 0.61 harbour porpoise, based on a density of 0.837 harbour porpoise per km^2 (**Table 14**). This represents 0.0002% of the current North Sea MU reference population, therefore, without mitigation, the magnitude of effect would negligible, with less than 0.001% of the reference population anticipated to be exposed to effect. The impact significance, without mitigation, is assessed as minor adverse (high sensitivity x permanent impact with negligible magnitude). See **Annex 2** for assessment of impacts methodology.

In the updated assessment, for the 4,000kJ hammer energy the maximum predicted impact range is 610m (1.2km^2) for the unweighted SPL_{peak} criteria for a single strike. The maximum number of harbour porpoise that could be at risk of PTS is 1 harbour porpoise, based on a density of 0.837 harbour porpoise per km^2 (**Table 14**). This represents 0.0003% of the current North Sea MU reference population, therefore, without mitigation, the magnitude of effect would negligible, with less than 0.001% of the reference population anticipated to be exposed to effect. The impact significance, without mitigation, is assessed as minor adverse (high sensitivity x permanent impact with negligible magnitude).

The maximum difference between the predicted PTS range for the 3,000kJ and 4,000kJ maximum hammer energies, based on the Southall *et al*. (2019) unweighted SPL_{peak} criteria for single strike, is up to 130m (0.47km^2). The difference in the number of harbour porpoise that could be impacted by the 4,000kJ compared to the 3,000kJ hammer energy is 0.39 (0.0001% of the North Sea MU) (**Table 14**).

For harbour porpoise there is no difference between the maximum predicted PTS SEL single strike ranges for the maximum hammer energy of 3,000kJ or 4,000kJ (**Table 14**).

There is no significant difference in the potential impacts assessed in the ES for the risk of PTS to harbour porpoise from a single strike at a maximum hammer energy of 3,000kJ compared to the potential risk from a single strike at a maximum hammer energy of 4,000kJ , without any mitigation. The magnitude of effect is assessed as negligible for all three hammer energies, which is the same as in the original ES assessment for the consented maximum hammer energy of 3,000kJ.

As outlined in **Section 5.3.1.1.3**, effective mitigation will be put in place to reduce the risk of any physical or permanent auditory injury (PTS) from underwater noise during piling.

Table 14 Maximum predicted impact ranges (areas) and maximum number of harbour porpoise (% of reference population) that could be at risk of permanent auditory injury (PTS) from a single strike (SPL_{peak} and SEL_{ss}) and from cumulative exposure (SEL_{cum}), based on Southall et al. (2019) impulsive criteria for harbour porpoise (very high frequency cetacean)

PTS threshold	Maximum predicted impact ranges (areas) and Maximum number of individuals (% reference population)*		
	Maximum hammer energy of 3,000kJ for monopiles	Maximum hammer energy of 4,000kJ for monopiles	Difference between 3,000kJ and 4,000kJ
Single strike			
Unweighted SPL_{peak} Single strike 202 dB re 1 µPa (very high frequency cetacean)	480m ($0.73km^2$)	610m ($1.2km^2$)	130m = +27% ($0.47km^2$ = +64%)
	0.61 harbour porpoise (0.0002% NS MU)	1.0 harbour porpoise (0.0003% NS MU)	0.4 harbour porpoise (0.0001% NS MU)
	Magnitude of effect = negligible	Magnitude of effect = negligible	No difference in magnitude of effect
Weighted SEL_{ss} Single strike 155 dB re 1 µPa²s (very high frequency cetacean)	<50m (<$0.01km^2$)	<50m (<$0.01km^2$)	No difference
	0.01 harbour porpoise (0.000002% NS MU)	0.01 harbour porpoise (0.000002% NS MU)	No difference
	Magnitude of effect = negligible	Magnitude of effect = negligible	No difference in magnitude of effect
Cumulative SEL			
Weighted SEL_{cum} Cumulative 155 dB re 1 µPa²s (very high frequency cetacean)	<100m (<$0.01km^2$)	<100m (<$0.01km^2$)	No difference
	0.008 harbour porpoise (0.000002% NS MU)	0.008 harbour porpoise (0.000002% NS MU)	No difference
	Magnitude of effect = negligible	Magnitude of effect = negligible	No difference in magnitude of effect

*SCANS-III harbour porpoise density = 0.837/km^2 (CV = 0.26); SCANS-III harbour porpoise North Sea MU reference population = 345,373 (CV = 0.18; 95% CI = 246,526-495,752)

5.3.1.1.2 PTS from cumulative exposure

The potential cumulative impacts were not assessed in the original ES assessment.

For harbour porpoise there is no difference between the maximum predicted PTS cumulative SEL ranges for the maximum hammer energy of 3,000kJ and 4,000kJ (**Table 14**).

In the updated assessment, for the 4,000kJ hammer energy the maximum predicted impact range is less than 100m (less than 0.01km^2) for the weighted SEL_{cum} criteria. The maximum number of harbour porpoise that could be at risk of PTS is 0.008 harbour porpoise, based on a density of 0.837 harbour porpoise per km^2 (**Table 14**). This represents 0.000002% of the current North Sea MU reference population, therefore, without mitigation, the magnitude of effect would negligible, with less than 0.001% of the reference population anticipated to be exposed to effect. The impact significance, without mitigation, is assessed as minor adverse (high sensitivity x permanent impact with negligible magnitude).

The maximum difference between the predicted PTS range for the 3,000kJ and 4,000kJ maximum hammer energies, based on the Southall *et al*. (2019) weighted SEL_{cum} criteria, is up to 130m (0.47km^2). The difference in the number of harbour porpoise that could be impacted by the 4,000kJ compared to the 3,000kJ hammer energy is 0.4 harbour porpoise (0.0001% North Sea MU) (**Table 14**).

There is no significant difference in the potential risk of PTS to harbour porpoise from cumulative exposure for a maximum hammer energy of 3,000kJ compared to the potential risk from a maximum hammer energy of 4,000kJ, without any mitigation.

As outlined in **Section 5.3.1.1.3**, effective mitigation will be put in place to reduce the risk of any physical or permanent auditory injury (PTS) from underwater noise during piling.

5.3.1.1.3 Mitigation

The MMMP will detail the proposed mitigation measures to reduce the risk of any permanent auditory injury (PTS) to marine mammals as a result of underwater noise during piling.

During the 30 minute soft-start and ramp-up (**Table 4**) and based on a precautionary average swimming speed of 1.5m/s (Otani *et al*. 2000), harbour porpoise would move at least 2.7km from the pile location, which is considerably greater than the maximum predicted impact range for a maximum hammer energy of 4,000kJ (**Table 14**Error! Reference source not found.). Therefore, there should be no harbour porpoise in the potential impact area and at risk of instantaneous PTS from a single strike of the maximum hammer energy of 4,000kJ after the soft-start and ramp-up.

5.3.1.1.4 Impact significance

There is no difference in the impact significance for PTS in harbour porpoise (with or without mitigation) for the proposed increased maximum hammer energy to 4,000kJ compared to the consented maximum hammer energy of 3,000kJ (**Table 15**).

Table 15 Impact significance for PTS in harbour porpoise from maximum hammer energy of 3,000kJ and 4,000kJ*

Impact significance for PTS in harbour porpoise	Maximum hammer energy of 3,000kJ	Maximum hammer energy of 4,000kJ
Without mitigation	Minor adverse (high sensitivity x permanent impact with negligible magnitude (<0.001% ref. pop.))	Minor adverse (high sensitivity x permanent impact with negligible magnitude (<0.001% ref. pop.))

Impact significance for PTS in harbour porpoise	Maximum hammer energy of 3,000kJ	Maximum hammer energy of 4,000kJ
With mitigation (residual impact)	No impact / negligible	No impact / negligible

*see Annex 2 for definitions of sensitivity, magnitude and impact significance matrix

5.3.1.2 TTS / fleeing response

5.3.1.2.1 TTS / fleeing response from single strike

In the original ES assessment, the NPL modelling of instantaneous temporary auditory injury (TTS) / fleeing response in harbour porpoise for a single strike of the maximum monopile hammer energy of 3,000kJ, based on the unweighted Lucke *et al*. (2009) criteria (pulse SEL 164 dB re 1 $\mu Pa^2 s$), predicted a potential impact range of 4.0-5.5km (82.3km^2). The maximum number of harbour porpoise that could be at risk of TTS / fleeing response in the ES assessment was 59 harbour porpoise, based on a density of 0.7161 harbour porpoise per km^2. The ES assessment determined that 0.03% of the 227,298 reference population could be impacted and that the magnitude of effect was negligible, with less than 1% of the reference population anticipated to be temporarily exposed to effect. The impact significance, without mitigation, was assessed as negligible (medium sensitivity x temporary impact with negligible magnitude).

In the updated assessment, the potential for any temporary auditory injury (TTS) / fleeing response, the Southall *et al*. (2019) criteria for unweighted SPL_{peak} for single strike, weighted SEL for single strike and TTS from cumulative exposure (SEL_{cum}) have been modelled for the proposed increased monopile hammer energy (up to 4,000kJ), as well as the 3,000kJ hammer energy for monopiles. Cumulative SEL assessments have been based on the worst-case soft-start and ramp-up scenario, sequence 3, which assumes 12,600 strikes over 330 minutes.

The maximum difference between the predicted TTS range for the 3,000kJ and 4,000kJ maximum hammer energies, based on the Southall *et al*. (2019) unweighted SPL_{peak} criteria for single strike, is up to 300m (2.2km^2). The difference in the number of harbour porpoise that could be temporarily impacted by the 4,000kJ compared to the 3,000kJ hammer energy is 1.8 (0.0005% of the North Sea MU) (**Table 16**).

For harbour porpoise the impact ranges and areas for the weighted SEL for single strike are less than those predicted based on the unweighted SPL_{peak} criteria for a single strike for the maximum hammer energy of 4,000kJ (**Table 16**).

There is no significant difference in the potential temporary impacts assessed in the ES for the risk of TTS to harbour porpoise from a single strike at a maximum hammer energy of 3,000kJ compared to the potential risk from a single strike at a maximum hammer energy of 4,000kJ, without any mitigation. The magnitude of effect is assessed as negligible for all three hammer energies, which is the same as in the original ES assessment for the consented maximum hammer energy of 3,000kJ.

5.3.1.2.2 TTS from cumulative exposure

The potential cumulative impacts were not assessed in the original ES assessment.

The maximum difference between the predicted TTS range for the 3,000kJ and 4,000kJ maximum hammer energies, based on the Southall *et al*. (2019) weighted SEL_{cum} criteria, is up to 3km (200km^2). The difference in the number of harbour porpoise that could be temporarily impacted by the 4,000kJ compared to the 3,000kJ hammer energy is up to 167 (0.05% of the North Sea MU) (**Table 16**).

There is no significant difference in the potential temporary risk of TTS to harbour porpoise from cumulative exposure for a maximum hammer energy of 3,000kJ compared to the potential risk from a maximum hammer energy of 4,000kJ without any mitigation. The magnitude of effect is assessed as negligible for all three hammer energies, which is the same as in the original ES assessment for the consented maximum hammer energy of 3,000kJ.

Table 16 Maximum predicted impact ranges (areas) and maximum number of harbour porpoise (% of reference population) that could be at risk of temporary auditory injury (TTS) / fleeing response from a single strike (SPL_{peak} and SEL_{ss}) and from cumulative exposure (SEL_{cum}), based on Southall et al. (2019) impulsive criteria for harbour porpoise (very high frequency cetacean)

TTS threshold	Maximum predicted impact ranges (areas) and Maximum number of individuals (% reference population)*		
	Maximum hammer energy of 3,000kJ for monopiles	**Maximum hammer energy of 4,000kJ for monopiles**	**Difference between 3,000kJ and 4,000kJ**
Single strike			
Unweighted SPL_{peak} Single strike 196 dB re 1 µPa (very high frequency cetacean)	1.1km ($3.7km^2$)	1.4km ($5.9km^2$)	0.3km = +27% ($2.2km^2$ = +59%)
	3.1 harbour porpoise (0.0009% NS MU)	4.9 harbour porpoise (0.0014% NS MU)	1.8 harbour porpoise (0.0005% NS MU)
	Magnitude of effect = negligible	Magnitude of effect = negligible	No difference in magnitude of effect
Weighted SEL_{ss} Single strike 140 dB re 1 µPa²s (very high frequency cetacean)	220m ($0.15km^2$)	280m ($0.25km^2$)	60m = +27% ($0.1km^2$ = +67%)
	0.13 harbour porpoise (0.00004% NS MU)	0.21 harbour porpoise (0.0001% NS MU)	0.8 harbour porpoise (0.00002% NS MU)
	Magnitude of effect = negligible	Magnitude of effect = negligible	No difference in magnitude of effect
Cumulative SEL			
Weighted SEL_{cum} Cumulative 140 dB re 1 µPa²s (very high frequency cetacean)	15km ($570km^2$)	18km ($770km^2$)	3km = +20% ($200km^2$ = +35%)
	477 harbour porpoise (0.14% NS MU)	644.5 harbour porpoise (0.19% NS MU)	167 harbour porpoise (0.05% NS MU)
	Magnitude of effect = negligible	Magnitude of effect = negligible	No difference in magnitude of effect

*SCANS-III harbour porpoise density = $0.837/km^2$ (CV = 0.26); SCANS-III harbour porpoise North Sea MU reference population = 345,373 (CV = 0.18; 95% CI = 246,526-495,752)

5.3.1.2.3 Impact significance

There is no difference in the impact significance for TTS / fleeing response in harbour porpoise for the proposed increased maximum hammer energy to 4,000kJ compared to the maximum hammer energy of 3,000kJ (**Table 17**).

Table 17 Impact significance for TTS / fleeing response in harbour porpoise from maximum hammer energy of 3,000kJ and 4,000kJ*

Updated modelling for maximum hammer energy of 3,000kJ	Updated modelling for maximum hammer energy of 4,000kJ
Negligible (medium sensitivity x temporary impact with negligible magnitude (≤1% ref. pop.))	Negligible (medium sensitivity x temporary impact with negligible magnitude (≤1% ref. pop.))

*see Annex 2 for definitions of sensitivity, magnitude and impact significance matrix

5.3.1.3 Disturbance

The latest Southall *et al*. (2019) criteria do not currently provide any thresholds for any behavioural response or disturbance. However, the current Statutory Nature Conservation Bodies (SNCBs) advice, which is also considered within the BEIS (2018) draft RoC HRA, is that the assessments for potential disturbance of harbour porpoise in the Southern North Sea Special Area of Conservation (SAC) is based on an area of effective deterrence radius (EDR) of 26km irrespective of hammer energy or pile size. Therefore, using this approach there is no alteration in the disturbance range from the proposed amendment compared to the consented project.

5.3.2 White-beaked dolphin

5.3.2.1 PTS

There is no difference between the predicted PTS ranges for the 3,000kJ and 4,000kJ maximum hammer energies, based on the Southall *et al*. (2019) criteria for high-frequency cetaceans (dolphin species) (**Table 18**). There is no difference in the impact significance for PTS in dolphin species for the proposed increased maximum hammer energy to 4,000kJ compared to the consented maximum hammer energy of 3,000kJ.

Table 18 Maximum predicted impact ranges (and areas) for PTS from a single strike (SPL_{peak} and SEL_{ss}) and from cumulative exposure (SEL_{cum}) based on Southall et al. (2019) impulsive criteria for high-frequency cetaceans (dolphin species)

Receptor	Threshold	Maximum predicted impact range and area		Difference
		Maximum hammer energy of 3,000kJ for monopiles	Maximum hammer energy of 4,000kJ for monopiles	Difference between 3,000kJ and 4,000kJ
Single strike				
Dolphin species (high frequency cetacean)	Unweighted SPL_{peak} 230 dB re 1 µPa	<50m (<0.1km²)	<50m (<0.1km²)	No difference
	Weighted SEL_{ss} 185 dB re 1 µPa²s	<50m (<0.1km²)	<50m (<0.1km²)	No difference
Cumulative SEL				
Dolphin species (high frequency cetacean)	SEL_{cum} Weighted 185 dB re 1 µPa²s	<100m (<0.1km²)	<100m (<0.1km²)	No difference

5.3.2.2 TTS / fleeing response

There is no difference between the predicted TTS ranges for the 3,000kJ and 4,000kJ maximum hammer energies, based on Southall *et al*. (2019) criteria for high-frequency cetaceans (dolphin species) (**Table 19**).

Table 19 Maximum predicted impact ranges (and areas) for TTS from a single strike (SPL_{peak} and SEL_{ss}) and from cumulative exposure (SEL_{cum}) based on Southall et al. (2019) impulsive criteria for high-frequency cetaceans (dolphin species)

Receptor	Threshold	Maximum predicted impact range and area		Difference
		Maximum hammer energy of 3,000kJ for monopiles	Maximum hammer energy of 4,000kJ for monopiles	Difference between 3,000kJ and 4,000kJ
Single strike				
Dolphin species (high frequency cetacean)	Unweighted SPL_{peak} 224 dB re 1 µPa	<50m (<0.1km²)	<50m (<0.1km²)	No difference
	Weighted SEL_{ss} 170 dB re 1 µPa²s	<50m (<0.1km²)	<50m (<0.1km²)	No difference

Receptor	Threshold	Maximum predicted impact range and area		Difference
		Maximum hammer energy of 3,000kJ for monopiles	Maximum hammer energy of 4,000kJ for monopiles	Difference between 3,000kJ and 4,000kJ
Cumulative SEL				
Dolphin species (high frequency cetacean)	SEL_{cum} Weighted 170 dB re 1 µPa²s	<100m (<0.1km²)	<100m (<0.1km²)	No difference

5.3.3 Minke whale

5.3.3.1 PTS

The difference between the predicted PTS range for the 3,000kJ and 4,000kJ hammer energies, based on the SPL_{peak} criteria for single strike, is relatively small (up to 10m) for minke whale (**Table 20**).

The difference between the predicted PTS range for the 3,000kJ and 4,000kJ hammer energies, based on the SEL_{ss} criteria for single strike, is up to 40m for minke whale (**Table 20**).

Up to an additional 0.001 minke whale (0.000004% CGNS MU) could be at increased risk of PTS from a single strike for the proposed increased hammer energy of 4,000kJ compared to 3,000kJ hammer energy, based on Southall *et al*. (2019) impulsive criteria (**Table 21**).

Without mitigation, the magnitude of effect for PTS from a single strike would be negligible for a maximum hammer energy of 4,000kJ with less than 0.001% of the reference population anticipated to be exposed to any permanent effect (see Annex 2). The impact significance, without mitigation, is assessed as minor adverse (high sensitivity x permanent impact with negligible magnitude; see **Annex 2**).

The original assessment in the ES (Forewind, 2014a) determined the potential magnitude of effect for minke whale for a single strike of the maximum hammer energy of 3,000kJ to be negligible.

There is no significant difference in the potential impacts assessed in the ES for the risk of PTS to minke whale from a single strike at a maximum hammer energy of 3,000kJ compared to the potential risk from a single strike at a maximum hammer energy of 4,000kJ, without any mitigation. The magnitude of effect is assessed as negligible for all three hammer energies, which is the same as in the original ES assessment for the consented maximum hammer energy of 3,000kJ.

As outlined in **Section 5.3.3.1.1**, effective mitigation will be put in place to reduce the risk of any physical or permanent auditory injury (PTS) from underwater noise during piling.

Table 20 Maximum predicted impact ranges (and areas) for PTS from a single strike (SPL_{peak}) and from cumulative exposure (SEL_{cum}) based on Southall et al. (2019) impulsive criteria for low-frequency cetaceans (minke whale)

Threshold	Maximum predicted impact range and area		Difference
	Maximum hammer energy of 3,000kJ for monopiles	Maximum hammer energy of 4,000kJ for monopiles	Difference between 3,000kJ and 4,000kJ
Single strike			
Unweighted SPL_{peak} 219 dB re 1 µPa (low frequency cetacean)	<50m (0.1km²)	60m (0.1km²)	+10m = +20% (no difference in area)
Weighted SEL_{ss} 183 dB re 1 µPa²s (low frequency cetacean)	160m (0.07km²)	200m (0.12km²)	+40m = +25% (+0.05km² = +71%)
Cumulative SEL			
SEL_{cum} Weighted 183 dB re 1 µPa²s (low frequency cetacean)	4.2km (39km²)	6.2km (87km²)	2km = +48% (48km² = +123%)

For the PTS SEL_{cum} criteria, larger ranges are predicted for minke whale up to 6.2km for 4,000kJ and worst-case ramp-up sequence, compared to 4.2km for the 3,000kJ hammer energy. This relates to their sensitivity to low-frequency noise. This is a difference of up to 2km (48km²) between the predicted PTS cumulative SEL ranges for the maximum hammer energy of 3,000kJ and 4,000kJ (**Table 20**).

Up to an additional 0.96 minke whale (0.004% CGNS MU) could be at increased risk of PTS from cumulative exposure for the proposed increased hammer energy of 4,000kJ compared to 3,000kJ hammer energy, based on Southall *et al*. (2019) impulsive criteria (**Table 21**).

Without mitigation, the magnitude of effect for PTS from cumulative exposure would be low for a maximum hammer energy of 4,000kJ, with 0.01% or less of the reference population anticipated to be exposed to any permanent effect (see Annex 2). The impact significance, without mitigation, is assessed as moderate adverse (high sensitivity x permanent impact with low magnitude; see **Annex 2**).

PTS from cumulative exposure was not assessed in the original assessment in the ES (Forewind, 2014a).

There is no significant difference in the potential risk of PTS to minke whale from cumulative exposure for a maximum hammer energy of 3,000kJ compared to the potential risk from a maximum hammer energy of 4,000kJ, without any mitigation.

As outlined in **Section 5.3.3.1.1**, effective mitigation will be put in place to reduce the risk of any physical or permanent auditory injury (PTS) from underwater noise during piling.

Table 21 The maximum number of minke whale and % of reference population that could be at risk of PTS from cumulative exposure (SEL_{cum}) based on Southall et al. (2019) impulsive criteria when the proposed maximum hammer energy is increased from 3,000kJ to 4,000kJ

Threshold	Maximum number of individuals (% reference population)*		Difference
	Maximum hammer energy of 3,000kJ for monopiles	Maximum hammer energy of 4,000kJ for monopiles	Difference between 3,000kJ and 4,000kJ
Single strike			
SEL_{ss} Weighted 183 dB re 1 µPa²s (low frequency cetacean)	0.001 minke whale (0.000004% CGNS MU)	0.002 minke whale (0.000009% CGNS MU)	0.001 minke whale (0.000004% CGNS MU)
	Magnitude of effect = negligible	Magnitude of effect = negligible	No difference in magnitude of effect
Cumulative SEL			
SEL_{cum} Weighted 183 dB re 1 µPa²s (low frequency cetacean)	0.78 minke whale (0.003% CGNS MU)	1.74 minke whale (0.007% CGNS MU)	0.96 minke whale (0.004% CGNS MU)
	Magnitude of effect = low	Magnitude of effect = low	No difference in magnitude of effect

*SCANS-III minke whale density = 0.020/km² (CV = 0.62); minke whale reference population = 23,528

5.3.3.1.1 Mitigation

The MMMP will detail the proposed mitigation measures to reduce the risk of any permanent auditory injury (PTS) to marine mammals as a result of underwater noise during piling.

During the 30 minute soft-start and ramp-up (**Table 4**) and based on a constant speed of 3.25m/s for minke whale (Blix and Folkow, 1995), minke whale would move at least 5.85km from the pile location. If acoustic deterrent devices (ADDs) were activated, for example, for up to 20 minutes before the soft-start, minke whale would move an additional 3.6km. Therefore, there should be no minke whale in the potential impact area and at risk of instantaneous or cumulative PTS from the maximum hammer energy of 4,000kJ.

5.3.3.1.2 Impact significance

There is no difference in the impact significance for PTS in minke whale (with or without mitigation) for the proposed increased maximum hammer energy to 4,000kJ compared to the consented hammer energy of 3,000kJ (**Table 22**).

Table 22 Impact significance for PTS in minke whale from maximum hammer energy of 3,000kJ, 4,000kJ*

Impact significance for PTS in minke whale	Maximum hammer energy of 3,000kJ	Maximum hammer energy of 4,000kJ
PTS from single strike without mitigation	Minor adverse (high sensitivity x permanent impact with negligible magnitude (<0.001% ref. pop.))	Minor adverse (high sensitivity x permanent impact with negligible magnitude (<0.001% ref. pop.))
PTS from single strike with mitigation	No impact / negligible	No impact / negligible
PTS from cumulative exposure without mitigation	Moderate adverse (high sensitivity x permanent impact with low magnitude (<0.01% ref. pop.))	Moderate adverse (high sensitivity x permanent impact with low magnitude (<0.01% ref. pop.))
PTS from cumulative exposure with mitigation	No impact / negligible	No impact / negligible

*see Annex 2 for definitions of sensitivity, magnitude and impact significance matrix

5.3.3.2 TTS / fleeing response

The difference between the predicted TTS / fleeing response range for the maximum hammer energy of 3,000kJ and 4,000kJ, based on the SPL_{peak} criteria for single strike, is up to 30m, for minke whale (**Table 23**).

For the TTS SEL_{cum} criteria, the difference between the maximum predicted range for hammer energies of 3,000kJ and 4,000kJ is up to 5.1km for minke whale (**Table 23**).

Table 23 Maximum predicted impact ranges (and areas) for TTS from a single strike (SPL_{peak}) and from cumulative exposure (SEL_{cum}) based on Southall et al. (2019) criteria for minke whale

Receptor	Threshold	Maximum predicted impact range and area		Difference
		Maximum hammer energy of 3,000kJ for monopiles	Maximum hammer energy of 4,000kJ for monopiles	Difference between 3,000kJ and 4,000kJ
Single strike				
Minke whale	Unweighted SPL_{peak} 213 dB re 1 µPa	100m (<0.03km^2)	130m (0.05km^2)	30m = +30% (0.02km^2 = +67%)
Minke whale	SEL_{ss} Weighted 168 dB re 1 µPa^{2}s	1.7km (8.5km^2)	2.1km (13km^2)	400m = +23% (4.5km^2 = +53%)
Cumulative SEL				
Minke whale	SEL_{cum} Weighted 168 dB re 1 µPa^{2}s	35km (2,200km^2)	41km (2,800km^2)	6km = +17% (600km^2 = +27%)

Up to an additional 12 minke whale (0.00051% CGNS MU) could temporarily be impacted by cumulative TTS from the maximum hammer energy of 4,000kJ compared to a 3,000kJ hammer energy, based on Southall *et al*. (2019) criteria. There is no significant difference (i.e. the additional difference is less than 1% of the reference population could be temporarily affected) as a result of increasing the maximum hammer energy from 3,000kJ to the proposed 4,000kJ (**Table 24**).

Table 24 The maximum number of minke whale and % of reference population that could be at risk of TTS from cumulative exposure (SEL_{cum}) based on Southall et al. (2019) criteria for minke whale

Receptor	Threshold	Maximum number of individuals (% reference population)		Difference
		Maximum hammer energy of 3,000kJ for monopiles	Maximum hammer energy of 4,000kJ for monopiles	Difference between 3,000kJ and 4,000kJ
Single strike				
Minke whale	Unweighted SPL_{peak} 213 dB re 1 µPa	0.0006 minke whale (0.000003% CGNS MU)	0.001 minke whale (0.000004% CGNS MU)	0.0004 minke whale (0.000002% CGNS MU) *No significant difference*
Minke whale	SEL_{ss} Weighted 168 dB re 1 µPa²s	0.17 minke whale (0.0007% CGNS MU)	0.26 minke whale (0.001% CGNS MU)	0.09 minke whale (0.0004% CGNS MU) *No significant difference*
Cumulative SEL				
Minke whale	SEL_{cum} Weighted 168 dB re 1 µPa²s	44 minke whale (0.2% CGNS MU)	56 minke whale (0.2% CGNS MU)	12 minke whale (0.05% CGNS MU) *No significant difference*

*SCANS-III minke whale density = 0.020/km² (CV = 0.62); minke whale reference population = 23,528

There is no difference in the impact significance for TTS in minke whale for the proposed increased maximum hammer energy to 4,000kJ compared to the maximum hammer energy of 3,000kJ (**Table 25**).

Table 25 Impact significance for TTS in minke whale from maximum hammer energy of 3,000kJ and 4,000kJ*

Updated modelling for maximum hammer energy of 3,000kJ	Updated modelling for maximum hammer energy of 4,000kJ
Negligible (medium sensitivity x temporary impact with negligible magnitude (≤1% ref. pop.))	Negligible (medium sensitivity x temporary impact with negligible magnitude (≤1% ref. pop.))

*see Annex 2 for definitions of sensitivity, magnitude and impact significance matrix

5.3.4 Grey and harbour seal

5.3.4.1 PTS

The difference between the predicted PTS range for the 3,000kJ and 4,000kJ hammer energies, based on the SPL_{peak} criteria for single strike, is very small (up to 20m) for seals with no predicted difference in the potential impact area (**Table 26**).

For seals there is no difference between the maximum predicted PTS cumulative SEL ranges or areas for the maximum hammer energy of 3,000kJ and 4,000kJ (**Table 26**).

Table 26 Maximum predicted impact ranges (and areas) for PTS from a single strike (SPL_{peak}) and from cumulative exposure (SEL_{cum}) based on Southall et al. (2019) criteria for seals

Receptor	Threshold	Maximum predicted impact range and area		Difference
		Maximum hammer energy of 3,000kJ for monopiles	Maximum hammer energy of 4,000kJ for monopiles	Difference between 3,000kJ and 4,000kJ
Single strike				
Grey seal and harbour seal	Unweighted SPL_{peak} 218 dB re 1 µPa	50m (<0.1km²)	70m (<0.1km²)	20m = +40% (no difference in area)
Grey seal and harbour seal	SEL_{ss} Weighted 185 dB re 1 µPa²s	50m (<0.1km²)	50m (<0.1km²)	No difference
Cumulative SEL				
Grey seal and harbour seal	SEL_{cum} Weighted 185 dB re 1 µPa²s	<100m (<0.1km²)	<100m (<0.1km²)	No difference

There is no difference in the number of grey seal or harbour seal that could be at risk of PTS for the consented hammer energy of 3,000kJ and proposed 4,000kJ maximum hammer energy, based on Southall *et al*. (2019) criteria for a single strike and for cumulative exposure, due to there being no difference in the predicted impact areas (**Table 26**).

There is no difference in the impact significance for PTS in grey and harbour seal for the proposed increased maximum hammer energy to 4,000kJ compared to the consented maximum hammer energy of 3,000kJ.

The MMMP will detail the proposed mitigation measures to reduce the risk of any permanent auditory injury (PTS) to marine mammals as a result of underwater noise during piling.

5.3.4.2 TTS

The difference between the predicted TTS range for the maximum hammer energies of 3,000kJ and 4,000kJ, based on the SPL_{peak} criteria for single strike, is up to 30m for seals with no predicted difference in the potential impact area (**Table 27**).

For the TTS SEL_{cum} criteria, the difference between the maximum predicted range for hammer energies of 3,000kJ and 4,000kJ is up to 2km for seals (**Table 27**).

Table 27 Maximum predicted impact ranges (and areas) for TTS from a single strike (SPL_{peak}) and from cumulative exposure (SEL_{cum}) based on Southall et al. (2019) criteria for seals

Receptor	Threshold	Maximum predicted impact range and area		Difference
		Maximum hammer energy of 3,000kJ for monopiles	Maximum hammer energy of 4,000kJ for monopiles	Difference between 3,000kJ and 4,000kJ
Single strike				
Grey seal and harbour seal	Unweighted SPL_{peak} 212 dB re 1 µPa	120m (0.04km²)	150m (0.07km²)	30m = +25% (0.03km² = +75%)
Grey seal and harbour seal	SEL_{ss} Weighted 170 dB re 1 µPa²s	180m (0.1km²)	230m (0.16km²)	50m = +28% (0.06km² = +60%)
Cumulative SEL				
Grey seal and harbour seal	SEL_{cum} Weighted 170 dB re 1 µPa²s	13km (420km²)	15km (580km²)	2km = +15% (160km² = +38%)

Up to an additional 3.2 grey seal could be temporarily impacted by cumulative TTS from the maximum hammer energy of 4,000kJ compared to 3,000kJ hammer energy. There is no significant difference (i.e. the additional difference is less than 1% of the reference population could be temporarily affected) as a result of increasing the maximum hammer energy from 3,000kJ to the proposed 4,000kJ (**Table 28**).

Table 28 The maximum number of grey and harbour seal (and % of reference population) that could be at risk of TTS from a single strike (SPL_{peak}) and from cumulative exposure (SEL_{cum}) based on Southall et al. (2019) criteria

Receptor	Threshold	Maximum number of individuals (% reference population)		Difference
		Maximum hammer energy of 3,000kJ for monopiles	Maximum hammer energy of 4,000kJ for monopiles	Difference between 3,000kJ and 4,000kJ
Single strike				
Grey seal	Unweighted SPL_{peak} 212 dB re 1 µPa	0.0008 grey seal (0.000003% of ref. pop.; 0.000009% of SE MU)	0.001 grey seal (0.000006% of ref. pop.; 0.00001% of SE MU)	0.0002 grey seal (0.000008% of ref. pop.; 0.000002% of SE MU) *No significant difference*
Harbour seal	Unweighted SPL_{peak} 212 dB re 1 µPa	0.0000016 harbour seal (0.000000003% of ref. pop.; 0.00000003% of SE MU)	0.0000028 harbour seal (0.00000032% of ref. pop.; 0.00000006% of SE MU)	0.0000012 harbour seal (0.000000002% of ref. pop.; 0.00000002% of SE MU)

Receptor	Threshold	Maximum number of individuals (% reference population)		Difference
		Maximum hammer energy of 3,000kJ for monopiles	Maximum hammer energy of 4,000kJ for monopiles	Difference between 3,000kJ and 4,000kJ
				No significant difference
Grey seal	SEL_{ss} Weighted 170 dB re 1 µPa²s	0.002 grey seal (0.000008% of ref. pop.; 0.00002% of SE MU)	0.003 grey seal (0.00001% of ref. pop.; 0.00003% of SE MU)	0.001 grey seal (0.000004% of ref. pop.; 0.00001% of SE MU) *No significant difference*
Harbour seal	SEL_{ss} Weighted 170 dB re 1 µPa²s	0.000004 harbour seal (0.000000008% of ref. pop.; 0.00000008% of SE MU)	0.000006 harbour seal (0.00000001% of ref. pop.; 0.0000001% of SE MU)	0.000002 harbour seal (0.000000004% of ref. pop.; 0.00000004% of SE MU) *No significant difference*
Cumulative SEL				
Grey seal	SEL_{cum} Weighted 170 dB re 1 µPa²s	8.4 grey seal (0.03% of ref. pop.; 0.1% of SE MU)	11.6 grey seal (0.05% of ref. pop.; 0.1% of SE MU)	3.2 grey seal (0.01% of ref. pop.; 0.04% of SE MU) *No significant difference*
Harbour seal	SEL_{cum} Weighted 170 dB re 1 µPa²s	0.02 harbour seal (0.00004% of ref. pop.; 0.0004% of SE MU)	0.02 harbour seal (0.00004% of ref. pop.; 0.0004% of SE MU)	*No difference*

*Grey seal density = 0.02/km² and harbour seal density = 0.00004/km², based on SMRU seal at-sea usage maps (Russell *et al.*, 2017). Grey seal reference population = 25,516; grey seal south-east England MU = 8,716; harbour seal reference population = 44,965; and harbour seal south-east England MU = 4,965

There is no difference in the impact significance for TTS in grey and harbour seal for the proposed increased maximum hammer energy to 4,000kJ compared to the maximum hammer energy of 3,000kJ (**Table 29**).

It should be noted that these cannot be compared like-for-like with criteria in the ES as cumulative SELs were not considered for marine mammals.

Table 29 Impact significance for TTS in grey and harbour seal from maximum hammer energy of 3,000kJ and 4,000kJ*

Updated modelling for maximum hammer energy of 3,000kJ	Updated modelling for maximum hammer energy of 4,000kJ
Negligible (medium sensitivity x temporary impact with negligible magnitude (≤1% ref. pop.))	Negligible (medium sensitivity x temporary impact with negligible magnitude (≤1% ref. pop.))

*see Annex 2 for definitions of sensitivity, magnitude and impact significance matrix

5.4 Comparison with cumulative impact assessment

As demonstrated, there is no significant difference in the potential impacts on marine mammals 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 the cumulative impact assessment in the original assessment.

5.5 Comparison with HRA

As demonstrated, there is no significant difference in the potential impacts on marine mammals from increasing the maximum monopile hammer energy to 4,000kJ compared to the maximum monopile hammer energy of 3,000kJ in the original assessment. As a result, the conclusions of the HRA which underpin the DCO (DECC, 2015) are not affected and the proposed change itself does not have the potential to give rise to likely significant effects on any European site (including the Southern North Sea Special Area of Conservation (SAC)).

It is important to note that it is the impacts of the proposed change that should be assessed rather than the Project as a whole. The increase in hammer energy compared to the consented Project has been considered in relation to the Southern North Sea SAC. This has been undertaken by considering the impacts on harbour porpoise as predicted in the ES and the additional impacts that may be caused by the increase in hammer energy. This has been done by considering the potential increase in impact ranges on both a like for like basis with the assessments in the ES and for the latest Southall *et al*. (2019) criteria. For the latest criteria, the potential change in impacts has then been considered in relation to the effects on the North Sea Management Unit (MU) population of harbour porpoise. This demonstrates that there is no significant difference in the impacts due to the increase in hammer energy and therefore supports a conclusion that the proposed change would not give rise to likely significant effects on the Southern North Sea SAC.

5.5.1 PTS and MMMP

As outlined in **Section 5.3.1.1**, up to an additional 0.4 harbour porpoise (0.0001% North Sea MU), based on the SCANS-III density estimate, could be at increased risk of PTS from a single strike of the maximum hammer energy of 4,000kJ compared to 3,000kJ hammer energy, based on Southall *et al*. (2019) unweighted criteria for SPL_{peak}. 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 4,000kJError! Reference source not found..

The potential for any auditory injury (PTS), associated with underwater noise will be mitigated through the MMMP (such as establishing mitigation zone based on the maximum potential range for PTS, soft-start and ramp-up, activation of Acoustic Deterrent Devices (ADDs) prior to soft-start) will ensure this is not a risk for harbour porpoise in the Southern North Sea SAC. The overriding purpose of the MMMP is to provide mitigation for the potential to kill or injure harbour porpoise during construction.

5.5.2 Disturbance and SIP

An In Principle Teesside A SNS SAC Site Integrity Plan (SIP) will be prepared to set out the approach to deliver any potential mitigation measures for Teesside A, to ensure the avoidance of significant disturbance of harbour porpoise in relation to the SNS SAC site Conservation Objectives.

This In-Principle SIP will reflect the commitment of the Teesside A project to undertake required measures to reduce the potential for any significant disturbance of harbour porpoise in the SNS SAC, whilst allowing scope for refinement of the measures through consultation once the final management measures are available for the SNS SAC, and once final construction methods for the Teesside A project have been confirmed. This will enable the use of the most appropriate project related measures to be confirmed based on best knowledge, evidence and proven available technology at the time of construction.

5.5.3 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, this includes the BEIS (2018) draft RoC HRA, as outlined in **Section 5.6**.

5.5.4 Southern North Sea Conservation Objectives

The Conservation Objectives for the site are (JNCC and Natural England, 2019):

To ensure that the integrity of the site is maintained and that it makes the best possible contribution to maintaining Favourable Conservation Status (FCS) for the harbour porpoise in UK waters.

In the context of natural change, this will be achieved by ensuring that:

1. *Harbour porpoise is a viable component of the site;*
2. *There is no significant disturbance of the species; and*
3. *The condition of supporting habitats and processes, and the availability of prey is maintained*.

The specific conversation objectives are considered below in relation to the proposed non-material amendment to the DCO.

Conservation Objective 1: Harbour porpoise is a viable component of the site

The intent of this Conservation Objective is to minimise the risk of injury and killing or other factors that could restrict the survivability and reproductive potential of harbour porpoise within the site. Specifically, this objective is concerned with operations within the site that would result in unacceptable levels of impact upon individuals using the site. Unacceptable levels are defined as those that would have an impact upon the Favourable Conservation Status (FCS) of the population. The Conservation Objectives state that, with regard to assessing impacts, '*the reference population for assessments against this objective is the MU population in which the SAC is situated (IAMMWG, 2015)".*

Harbour porpoise are considered to a *viable component of the site* if they are able to live successfully within it. PTS has been used to determine the area where harbour porpoise could be at increased risk of any physical or permanent auditory injury. The assessment indicates a potential increase in range of 130m (from 480m to 610m), based on the latest Southall *et al*. (2019) criteria. In relation to the proposed amendment, this equates to 0.0001% North Sea MU population that could be at increased risk of any physical injury or permanent auditory injury. As outlined above, any impact at these ranges would be mitigated by the MMMP, as secured through the existing deemed Marine Licences. As such, the proposed NMC would not result in an adverse effect on integrity for either the Project alone or in-combination with other plans, projects or proposals.

Conservation Objective 2: There is no significant disturbance of the species

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 SNCB guidance (JNCC *et al*. 2020) for assessing the significance of noise disturbance is:

> "*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 (JNCC *et al*., 2020) is that the assessments for potential disturbance of harbour porpoise in the Southern North Sea SAC is based on an area of EDR of 26km (or an area of 2,124km^2), irrespective of hammer energy or pile size. It is acknowledged that draft guidance has a precautionary EDR for monopiles with noise abatement of 15km (JNCC *et al*., 2020), however the assessment has been based on the potential worst-case of monopiles with 26 km EDR.

Teesside A is not located within the Southern North Sea SAC, but it is within the disturbance range of 26km (24km at closest point to the summer area). Based on the 26km EDR, there would be no difference in the disturbance to harbour porpoise within the Southern North Sea SAC, as a result of piling at Teesside A, for any hammer energy used, and given the distance of the Teesside A project to the SAC, there would no potential for any adverse effect on the Southern North Sea SAC.

Conservation Objective 3: The condition of supporting habitats and processes, and the availability of prey is maintained.

Within this Conservation Objective, supporting habitats relates to the characteristics of the seabed and water column, and supporting processes encompass the movements and physical properties of the habitat. The maintenance of supporting habitats and processes contributes to ensuring that prey is maintained and available to individuals within the site. Harbour porpoise are strongly reliant on the availability of prey species due to their high energy demands, and are highly dependent on being able to access prey species year-round. The densities of harbour porpoise within a site are therefore highly dependent on the availability of key prey species.

This Conservation Objective is designed to ensure that harbour porpoise are able to access food resources year round, and that activities occurring in the SNS SAC will not affect this. As set out in the Environmental Report submitted in support of the NMC application, the proposed increase in hammer energy does not alter the worst case assessed for fish and will not result in a physical change in habitat in addition to that already considered for the consented Project. In addition, there would be no additional displacement of harbour porpoise as a result of any changes in prey resources during piling, as harbour porpoise would already be potentially disturbed as a result of underwater noise during piling and the potential area of any disturbance of prey species would be the same or less as those assessed for directly for harbour porpoise. Therefore, the proposed amendment would not give rise to any additional impacts in relation to this Conservation Objective compared to the consented Project.

In considering the Conservation Objectives of the Southern North Sea SAC it can be concluded that the increase in hammer energy would not result in an adverse effect on the integrity of the site for either the project alone or in-combination with other projects.

5.6 Comparison with BEIS (2018) draft RoC HRA

The draft RoC HRA (BEIS, 2018) reviewed six offshore wind farm consents, including Teesside A. The conclusion of the draft 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. The draft RoC HRA assumes a worst case hammer energy for the Project of 5,500kJ and concludes that Teesside A alone and in combination with Sofia would not have an adverse effect on site integrity.

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 (2018) draft RoC HRA (**Table 30**).

Table 30 Maximum predicted impact ranges (and areas) for PTS from a single strike (SPL_{peak}) and from cumulative exposure (SEL_{cum}) based on Southall et al. (2019) criteria at worst-case location in Teesside A in non-material change assessment compared to BEIS (2018) RoC HRA modelling for Teesside A

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 Teesside A	RoC HRA 5,500kJ for monopile at Teesside A
Harbour porpoise	Single strike unweighted SPL_{peak} 202 dB re 1 µPa	480m ($0.73km^2$)	610m ($1.2km^2$)	716m ($1.46km^2$)	1,128m ($3.53km^2$)
Harbour porpoise	Cumulative SEL_{cum} Weighted 155 dB re 1 $µPa^2s$	<100m (<$0.1km^2$)	<100m (<$0.1km^2$)	2,401m ($14.82km^2$)	4,777m ($62.52km^2$)

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 (2018) draft 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 (2018) draft RoC HRA (**Table 31**). These differences reflect differences in the noise modelling as outlined in **Section 5.6.1**.

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

- A distance of 26km (EDR) 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.

Table 31 Maximum predicted impact ranges (and areas) for possible behavioural response in harbour porpoise from a single strike of maximum hammer energy of 3,000kJ and 4,000kJ based on Lucke et al. (2009) unweighted criteria at worst-case location in Teesside A in non-material change assessment compared to RoC HRA modelling for Teesside A

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 Teesside A	RoC HRA 5,500kJ for monopiles at Teesside A
Harbour porpoise – possible avoidance	unweighted SPL_{peak} 168 dB re 1 µPa	19km ($1,000km^2$)	21km ($1,200km^2$)	N/A	N/A
	unweighted SEL_{ss} 145 dB re 1 $µPa^2a$	9.3km ($250km^2$)	34km ($3,000km^2$)	22.9km ($1,226km^2$)	29.3km ($1,964km^2$)

5.6.1 Overview of differences in the modelling conducted for the RoC HRA and modelling conducted for Teesside A

There are several differences in the modelling conducted for the RoC HRA and modelling conducted for the Teesside A, these are summarised in **Table 32**.

Table 32 Comparison of the modelling conducted for the RoC HRA and modelling conducted for Teesside A

Parameter	Genesis (2018) modelling	Subacoustech modelling
Propagation Model	Parabolic equation (PE) using RAM for low frequencies. Ray Tracing using Bellhop for high frequencies.	A modified version of the INSPIRE model to fit data from the original NPL modelling report, which used an energy flux solution by Weston (1976).
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 3000 kJ hammer	247.3 dB re 1 µPa @ 1 m (SPL_{peak}) 221.3 dB re 1 $µPa^2s$ @ 1 m (SEL_{ss})	233.2 dB re 1 µPa @ 1 m (SPL_{peak}) 208.0 dB re 1 $µPa^2s$ @ 1 m (SEL_{ss})
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
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 wrong. 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 approximately 2dB higher than those used in Subacoustech modelling for the project. This is significant, but it does not always mean that the results are going to always be higher 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.

Essentially, 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, some may underestimate absorption at long ranges.

Comparisons

The results are not too different from each other, for example, the single strike criteria are all of the same order of magnitude, except for the harbour porpoise cumulative SEL. A feature of the SEL_{cum} results is that as soon as the receptor reaches the required exposure, the ranges will step up rapidly and this is very noticeable when the calculated range is close to the source.

One other potential consideration is what the "range at PTS/TTS threshold" actually means. With single strike thresholds it is fairly easy: it is the distance at which the noise travelling out reaches the appropriate noise level. It is much more complicated for SEL_{cum} thresholds because the noise pulse changes, speeds up, and the receptor moves. Subacoustech define the "range at PTS/TTS" to be the distance from the pile that the receptor must be at the start of piling for it to have just received the exposure defined exposure threshold at the end of piling. The Genesis report does not define exactly what their range means.

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 Teesside A. This could result in differences in the modelling results, therefore not a direct like-for-like comparison.

6 Conclusions

This marine mammal technical report has reviewed and re-modelled the impacts on marine mammals which could arise from the proposed amendment to Teesside A on a like for like basis with the modelling that informed the ES and HRA which underpin the DCO. In addition, due to the change in noise thresholds and criteria that have occurred since the project was 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 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 33**. Therefore, the proposed increase in maximum hammer energy from 3,000kJ to 4,000kJ 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, based on 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 energy to 4,000kJ compared to the consented maximum monopile hammer energy of 3,000kJ, as summarised in **Table 34**.

The assessments undertaken demonstrate that there is no difference in the impact significance between the impacts as assessed under the original assessment and the updated assessment. Therefore, the assessments demonstrate that an increase in maximum hammer energy from 3,000kJ to 4,000kJ 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 assessed in the ES and those resulting from the proposed amendment to the Project, the conclusions of the ES and its associated documents are not affected by the proposed change and that 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 likely significant effects on any European sites (including the Southern North Sea SAC). Therefore, the proposed amendment 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.

As such, it is appropriate for the application to amend the maximum hammer energy to be consented as an NMC to the DCO.

It is also important to note that although an increase in maximum hammer is being applied for it will not be required for all pile locations, and if used would only be a very small proportion of the total piling time. For example, at the Beatrice Offshore Wind Farm, it was estimated in the ES that the maximum hammer energy would be 2,300kJ (Beatrice Offshore Wind Farm Ltd, 2018). However, during construction, the maximum hammer energy actually used ranged between 435kJ and 2,299kJ, with an average across the site of 1,088kJ (Beatrice Offshore Wind Farm Ltd, 2018).

Table 33 Summary of the comparison of the predicted impact ranges, number of marine mammals and % of reference population (based on values used in ES) and impact assessment for maximum hammer energy of 3,000kJ in ES and proposed increased maximum hammer energy of 4,000kJ

Species	**PTS**		**TTS / fleeing response**		**Behavioural response**	
	3,000kJ in ES	**4,000kJ**	**3,000kJ in ES**	**4,000kJ**	**3,000kJ in ES**	**4,000kJ**
Harbour porpoise[1]	<700m 1.1 harbour porpoise (0.0005%) Negligible	880m 1.7 harbour porpoise (0.0008%) Negligible	5.5km 59 harbour porpoise (0.03%) Negligible	7km 107 harbour porpoise (0.05%) Negligible	33km 1,920harbour porpoise (0.84%) Negligible	34km 2,148 harbour porpoise (0.95%) Negligible
	No significant difference		**No significant difference**		**No significant difference**	
White-beaked dolphin[2]	<100m 0.0005 white-beaked dolphin (<0.00001%) Negligible	<50m 0.00015 white-beaked dolphin (0.0000009%) Negligible	<200m 0.002 white-beaked dolphin (<0.0001%) Negligible	170m 0.001 white-beaked dolphin (0.000008%) Negligible	8.5km 3 white-beaked dolphin (0.02%) Negligible	11km 5 white-beaked dolphin (0.03%) Negligible
	No significant difference		**No significant difference**		**No significant difference**	
Minke whale[3]	<100m 0.0003 minke whale (<0.00001%) Negligible	60m 0.00009 minke whale (0.0000004%) Negligible	<400m 0.004 minke whale (<0.0001%) Negligible	480m 0.006 minke whale (0.00003%) Negligible	41km 34 minke whale (0.15%) Negligible	41km 35 minke whale (0.1517%) Negligible
	No significant difference		**No significant difference**		**No difference**	
Grey seal[4]	<200m 0.01 grey seal (<0.00001%) Negligible	180m 0.002 grey seal (0.000007%) Negligible	<1.7km 0.8 grey seal (<0.003%) Negligible	1.7km 0.2 grey seal (0.0007%) Negligible	N/A	
	No significant difference		**No significant difference**			

[1]based on Lucke *et al*. (2009) unweighted criteria for instantaneous PTS (SEL$_{ss}$ 179 dB re 1 μPa^{2}s); TTS / fleeing response (SEL$_{ss}$ 164 dB re 1 μPa^{2}s); and possible avoidance (SEL$_{ss}$ 145 dB re 1 μPa^{2}s). ES harbour porpoise density = 0.7161/km^2; ES harbour porpoise reference population = 227,298.
[2]based on Southall *et al*. (2007) M-weighted criteria for instantaneous PTS (SEL$_{ss}$ 198 dB re 1 μPa^{2}s); TTS / fleeing response (SEL$_{ss}$ 183 dB re 1 μPa^{2}s); and possible avoidance (SEL$_{ss}$ 160 dB re 1 μPa^{2}s). ES white-beaked dolphin density = 0.01487/km^2; ES white-beaked dolphin reference population = 15,895.
[3]based on Southall *et al*. (2007) M-weighted criteria for instantaneous PTS (SEL$_{ss}$ 198 dB re 1 μPa^{2}s); TTS / fleeing response (SEL$_{ss}$ 183 dB re 1 μPa^{2}s); and possible avoidance (SEL$_{ss}$ 142 dB re 1 μPa^{2}s). ES minke whale density = 0.00866/km^2; ES minke whale reference population = 223,168

[4]based on Southall *et al*. (2007) M-weighted criteria for instantaneous PTS (SEL_{ss} 186 dB re 1 μPa^{2}s); TTS / fleeing response (SEL_{ss} 171 dB re 1 μPa^{2}s); and possible avoidance ES grey seal density = 0.02131/km^2; ES grey seal reference population = 28,989.

Table 34 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

Species	PTS		TTS / fleeing response	
	3,000kJ	**4,000kJ**	**3,000kJ**	**4,000kJ**
Harbour porpoise[1]	480m (0.73km^2) 0.61 harbour porpoise (0.0002% NS MU) Negligible	610m (1.2km^2) 1.0 harbour porpoise (0.0003% NS MU) Negligible	1.1km (3.7km^2) 3.1 harbour porpoise (0.0009% NS MU) Negligible	1.4km (5.9km^2) 4.9 harbour porpoise (0.0014% MS MU) Negligible
	No significant difference		**No significant difference**	
White-beaked dolphin[2]	<50m	<50m	<50m	<50m
	No difference		**No difference**	
Minke whale[3]	160m (0.07km^2) 0.001 minke whale (0.000004% CGNS MU) Negligible	200m (0.12km^2) 0.002 minke whale (0.000009% CGNS MU) Negligible	1.7km (8.5km^2) 0.17 minke whale (0.0007% CGNS MU) Negligible	2.1km (13km^2) 0.26 minke whale (0.001% CGNS MU) Negligible
	No significant difference		**No significant difference**	
Grey seal[4]	50m (<0.1km^2)	70m (<0.1km^2)	180m (0.1km^2) 0.002 grey seal (0.000008% of ref. pop.; 0.00002% of SE MU)	230m (0.16km^2) 0.003 grey seal (0.00001% of ref. pop.; 0.00003% of SE MU)
	No difference in impact area		**No significant difference**	
Harbour seal[4]	50m (<0.1km^2)	70m (<0.1km^2)	180m (0.1km^2) 0.000004 harbour seal (0.000000008% of ref. pop.; 0.00000008% of SE MU)	230m (0.16km^2) 0.000006 harbour seal (0.00000001% of ref. pop.; 0.0000001% of SE MU)
	No difference in impact area		**No significant difference**	

[1]based on the Southall *et al*. (2019) unweighted SPL_{peak} criteria for PTS (202 dB re 1 μPa) and TTS (196 dB re 1 μPa). SCANS-III harbour porpoise density = 0.837/km^2; SCANS-III harbour porpoise reference population = 345,373.
[2]based on the Southall *et al*. (2019) unweighted SPL_{peak} criteria for PTS (230 dB re 1 μPa) and TTS (224 dB re 1 μPa). SCANS-III white-beaked dolphin density = 0.002/km^2; white-beaked dolphin reference population = 15,895.

[3]based on the Southall *et al*. (2019) weighted SEL_{ss} criteria for PTS (183 dB re 1 µPa^2s) and TTS (168 dB re 1 µPa^2s). SCANS-III minke whale density = 0.02/km^2; minke whale reference population = 23,528.

[4]based on the Southall *et al*. (2019) unweighted SPL_{peak} criteria for PTS (218 dB re 1 µPa) and weighted SEL_{ss} criteria for TTS (170 dB re 1 µPa^2s).

7 References

Beatrice Offshore Wind Farm Ltd (2018). Beatrice Offshore Wind Farm Piling Strategy Implementation Report. Available from: http://marine.gov.scot/sites/default/files/lf000005-rep-2397_bowlpilingstrategyimplementationreport_rev1_redacted.pdf

BEIS (2018). Record of the Habitats Regulations Assessment undertaken under Regulation 36 of the Conservation of Habitats and Species (2017), and Regulation 33 of the Conservation of Offshore Marine Habitats and Species Regulations (2017). Review of Consented Offshore Wind Farms in the Southern North Sea Harbour Porpoise SCI. October 2018. Department for Business, Energy and Industrial Strategy.

Blix, A.S. and Folkow, L.P. (1995). Daily energy expenditure in free living minke whales. Acta Physiol. Scand., 153:61-66.

Brandt, M., Diederichs, A., Betke, K., and Nehls, G. (2011). Responses of harbour porpoises to pile driving at the Horns Rev II offshore windfarm in the Danish North Sea. Marine Ecology Progress Series, 421; 205-215.

Brasseur S., Cremer J., Czeck R., Galatius A., Jeß A., Körber P., Pund R., Siebert U., Teilmann J. and Klöpper S. (2018). TSEG grey seal surveys in the Wadden Sea and Helgoland in 2017-2018. Common Wadden Sea Secretariat, Wilhelmshaven, Germany.

Carlson, T., Hastings, M. and Popper, A.N. (2007). Memorandum – Update on recommendations for revised interim sound exposure criteria for fish during pile driving activities. Sent to California Dept. of Trans. And Washington Dept. of Trans.

DECC (2015). Dogger Bank Teesside A & B Offshore Wind Farm: Record of the Habitats Regulations Assessment undertaken under Regulation 61 of the Conservation of Habitats and Species Regulation 2010 (as amended) and Regulation 25 of the Offshore Habitats Regulation for an application under the Planning Act 2008 (as amended).

Forewind (2014a). Dogger Bank Teesside A & B Environmental Statement Chapter 14 Marine Mammals. March 2014. Application Reference: 6.14.

Forewind (2014b). Dogger Bank Teesside A & B Environmental Statement Chapter 5 Appendix A Underwater Noise Modelling. March 2014. Application Reference: 6.5.1.

Galatius, A., Brasseur, S., Cremer, J., Czeck, R., Jeß, A., Körber, P., Pund, R., Siebert, U., Teilmann, J. and Klöpper, S. (2018). Aerial surveys of Harbour Seals in the Wadden Sea in 2018. Common Wadden Sea Secretariat, Wilhelmshaven, Germany.

Halvorsen, M.B., Casper, B.M., Woodley, C.M., Carlson, T.J. and Popper, A.N. (2011). Predicting and mitigating hydroacoustic impacts on fish from pile installations. NCHRP Research Results Digest 363, Project 25-28, National cooperative Highway Research Program, Transportation Research Board, National Academy of Sciences, Washington D.C.

Hammond P.S., Macleod K., Berggren P., Borchers D.L., Burt L., Cañadas A., Desportes G., Donovan G.P., Gilles A., Gillespie D., Gordon J., Hiby L., Kuklik I., Leaper R., Lehnert K, Leopold M., Lovell P., Øien N., Paxton C.G.M., Ridoux V., Rogano E., Samarraa F., Scheidatg M., Sequeirap M., Siebertg U., Skovq H., Swifta R., Tasker M.L., Teilmann J., Canneyt O.V. and Vázquez J.A. (2013). Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management. Biological Conservation 164, 107-122.

Hammond, P.S., Lacey, C., Gilles, A., Viquerat, S., Boerjesson, P., Herr, H., Macleod, K., Ridoux, V., Santos, M., Scheidat, M. and Teilmann, J. (2017). Estimates of cetacean abundance in European Atlantic waters in summer 2016 from the SCANS-III aerial and shipboard surveys. Wageningen Marine Research.

Hirata K (1999). Swimming speeds of some common fish. National Maritime Research Institute (Japan). Data sourced from Iwai T, Hisada M (1998). Fishes – Illustrated Book of Gakken (in Japanese). Accessed on 9th April 2020 at https://www.nmri.go.jp/oldpages/eng/khirata/fish/general/speed/speede.htm

IAMMWG (2013). Management Units for cetaceans in UK waters (June 2013).

IAMMWG (2015). Management Units for cetaceans in UK waters (January 2015). JNCC Report No. 547, JNCC Peterborough.

JNCC and Natural England (2019). Harbour Porpoise (*Phocoena phocoena*) Special Area of Conservation: Southern North Sea Conservation Objectives and Advice on Operations. Advice under Regulation 21 of The Conservation of Offshore Marine Habitats and Species Regulation 2017 and Regulation 37(3) of the Conservation of Habitats and Species Regulations 2017. March 2019.

JNCC, Natural England and Department of Agriculture, Environment and Rural Affairs (DAERA) (2020). Draft guidance for assessing the significance of noise disturbance against Conservation Objectives of harbour porpoise SACs (England, Wales & Northern Ireland). 30.01.20.

Kastelein, R.A., Van de Voorde, S, and Jennings, N. (2018). Swimming Speed of a Harbour Porpoise (*Phocoena phocoena*) During Playbacks of Offshore Pile Driving Sounds. Aquatic Mammals: 44(1):92-99.

Lucke, K., Siebert, U., Lepper, P. A. and Blanchet, M. A. (2009). Temporary shift in masked hearing thresholds in a harbor porpoise (*Phocoena phocoena*) after exposure to seismic airgun stimuli, J. Acoust. Soc. Am., 125 (6), pp. 4060-4070.

Macleod, K., Burt, M.L., Cañadas, A., Rogan, E., Santos, B., Uriarte, A., Van Canneyt, O., Vázquez, J.A. and Hammond, P.S. (2009). Design-based estimates of cetacean abundance in offshore European Atlantic waters. Appendix I in the Final Report of the Cetacean Offshore Distribution and Abundance in the European Atlantic. 16pp.

McCauley, R.D., Fewtrell, K., Duncan, A.J., Jenner C., Jenner, M-N., Penrose, J.D., Prince, R.I.T, Adhitya, A., Murdoch, J. and McCabe, K. (2000). Marine seismic surveys – A study of environmental implications. Appea Journal, pp 692-708.

NMFS (National Marine Fisheries Service) (2018). Revisions to: Technical guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept of Commer., NOAA. NOAA Technical Memorandum NMFS-OPR-59.

Otani, S., Naito, T., Kato, A. and Kawamura, A. (2000). Diving behaviour and swimming speed of a free-ranging harbour porpoise *(Phocoena phocoena).* Marine mammal science, Volume 16, Issue 4, pp 811-814, October 2000.

Pearson W.H., Skalski, J.R. and Malme, C.I. (1992). Effects of sounds from a geophysical survey device on behaviour of captive rockfish *(Sebastes spp.)*. Can. J. Fish. Aquat. Sci., 49, pp. 1343-1355.

Popper, A.N., Carlson, T.J., Hawkins, A.D., Southall, B.D. and Gentry, R.L. (2006). Interim criteria for injury in fish exposed to a pile driving operation*.* A white paper, available from http://www.wsdot.wa.gov/NR/rdonlyres/84A6313A-9297-42C9-BFA6-750A691E1DB3/0/BA_ PileDrivingInterimCriteria.pdf 2005.

Popper, A.N., Hawkins, A.D., Fay, R.R., Mann, D.A., Bartol, S., Carlson, T.J., Coombs, S., Ellison, W.T., Gentry, R.L., Halvorsen, M.B., Løkkeborg, S., Rogers, P.H., Southall, B.L., Zeddies, D.G. and Tavolga, W.N. (2014). Sound Exposure Guidelines for Fishes and Sea Turtles. Springer Briefs in Oceanography, DOI 10. 1007/978-3-319-06659-2.

RHDHV 2018. Minutes of meeting held 11th April 2018 to discuss scope of non-material change application environmental assessment (dated 16th April 2018).

Robinson, S.P., Lepper, P.A. and Hazelwood, R.A. (2014). Good practice guide for underwater noise measurement. National Measurement Office, Marine Scotland, The Crown Estate. NPL Good Practice Guide No. 133, ISSN: 1368-6550.

Russell, D.J.F, Jones, E.L. and Morris, C.D. (2017) Updated Seal Usage Maps: The Estimated at-sea Distribution of Grey and Harbour Seals. Scottish Marine and Freshwater Science Vol 8 No 25, 25pp. DOI: 10.7489/2027-1.

SCOS (2018). Scientific Advice on Matters Related to the Management of Seal Populations: 2018. Available at: http://www.smru.st-andrews.ac.uk.

SMRU (2013) Grey and harbour seal density maps. Marine Mammal Scientific Support Research Programme MMSS/001/11.

Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J., Gentry, R.L., Greene Jr., C.R., Kastak, D., Ketten, D.R., Miller, J.H., Nachtigall, P.E., Richardson, W.J., Thomas, J.A., and Tyack, P.L. (2007). Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. Aquatic Mammals, 33 (4), pp. 411-509.

Southall, B.L., Finneran, J.J., Reichmuth, C., Nachtigall, P.E., Ketten, D.R., Bowles, A.E., Ellison, W.T., Nowacek, D.P. and Tyack, P.L. (2019). Marine mammal noise exposure criteria: updated scientific recommendations for residual hearing effects. Aquatic Mammals, 45(2), pp.125-232.

Subacoustech Environmental (2019) Underwater noise modelling at the Teesside A offshore wind farm, Dogger Bank. 28 October 2019. Subacoustech Environmental Report No. P260R0102.

Weston D (1976). Propagation in water with uniform sound velocity by variable-depth lossy bottom. Journal of Sound and Vibration, 49, pp. 473-483.

Annex 1 – Subacoustech Underwater Noise Modelling Report

[See standalone document]

Annex 2 – Impact Methodology

A2.1 Assessment of impacts methodology

This section contains a copy of the assessment of impacts methodology from ES (Forewind, 2014a).

A2.1.1 Value

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

A2.1.2 Sensitivity

Table A2.1 Sensitivity of individuals in the reference population to the different impacts of noise from pile driving

Species	Auditory injury (PTS)	TTS	Likely avoidance	Possible avoidance
Harbour porpoise	High	Medium	Medium	Low
White-beaked dolphin	High	Medium	Medium	Low
Minke whale	High	Medium	Medium	Low
Grey seal	Medium	Medium	N/A	N/A
Harbour seal	Medium	Medium	N/A	N/A

A2.1.3 Magnitude

Table A2.2 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 >1% of the reference population are anticipated to be exposed to the effect. OR Temporary effect (limited to 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 >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

Magnitude	Definition
	Temporary effect (limited to 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 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 (limited to 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 between >1% and <=5% of the reference population anticipated to be exposed to effect.
Negligible	Permanent irreversible change to exposed receptors or feature(s) of the habitat of particular importance to the receptor. Assessment indicates that <=0.001% of the reference population anticipated to be exposed to effect. OR Intermittent and temporary effect (limited to 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 <=1% of the reference population anticipated to be exposed to effect.

A2.4 Impact significance

Table A2.3 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*	*Negligible*	*Negligible*	*Negligible*