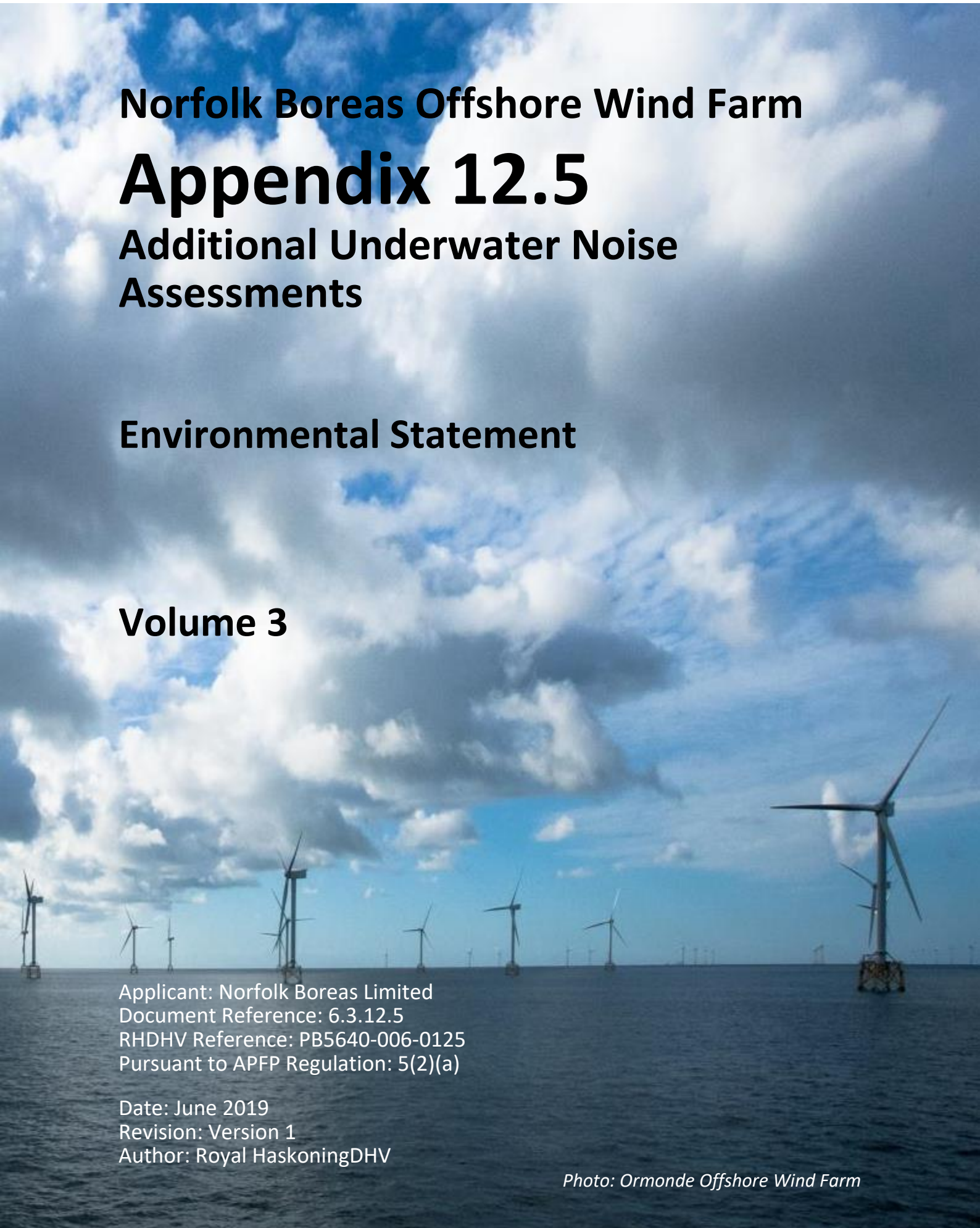
Norfolk Boreas Offshore Wind Farm

Appendix 12.5

Additional Underwater Noise Assessments

Environmental Statement

Volume 3



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Glossary of Acronyms

cum	Cumulative
ETG	Expert Topic Group
HF	High Frequency Cetaceans
MU	Management Unit
NMFS	National Marine Fisheries Service
NOAA	National Oceanographic and Atmospheric Association
NPL	National Physical Laboratory
PEIR	Preliminary Environmental Information Report
PTS	Permanent Threshold Shift
PW	Pinnipeds in water
SAC	Special Area of Conservation
SEL	Sound Exposure Level
SPL	Sound Pressure Level
SS	Single strike
TTS	Temporary Threshold Shift

Glossary of Terminology

Norfolk Boreas site	The Norfolk Boreas wind farm boundary. Located offshore, this will contain all the wind farm array.
Norfolk Vanguard	Norfolk Vanguard offshore wind farm, sister project of Norfolk Boreas.
Norfolk Vanguard OWF sites	Term used exclusively to refer to the two distinct offshore wind farm areas, Norfolk Vanguard East and Norfolk Vanguard West (also termed NV East and NV West) which will contain the Norfolk Vanguard arrays.
The project	Norfolk Boreas Wind Farm including the onshore and offshore infrastructure.

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1 Introduction

1.1 Purpose of this Document

1. Subacoustech Environmental Ltd has undertaken predictive underwater noise modelling to estimate the noise levels likely to arise during construction of Norfolk Boreas, and to determine the potential impacts on marine mammals (Appendix 5.4 and Chapter 12 Marine Mammals of the Environmental Statement (ES)).

2. This Appendix presents additional assessments based on the underwater noise modelling using the Southall et al. (2007) and Lucke et al. (2009) thresholds and criteria. This is presented for information only and to provide continuity with the assessments of previous projects which have used these models for their assessments. It was agreed with Expert Topic Group (ETG) on 8th December 2017 for Norfolk Vanguard that it would be useful context to include this information further to the agreed thresholds used in the ES Chapter.

2 Underwater Noise Modelling

3. Underwater noise modelling was carried out using the INSPIRE subsea noise propagation model. The INSPIRE model is a semi-empirical noise propagation model based on the use of a combination of numerical modelling and actual measured underwater noise data. It was designed to calculate the propagation of noise in shallow, mixed water, typical of both conditions around the UK and therefore the Norfolk Boreas site. The same parameters presented in Chapter 12 Marine Mammals of the ES for piling location, pile size, hammer energies, environmental conditions, source levels, soft-start and ramp-up were used in the assessments presented in this Appendix.

2.1 Thresholds and Criteria

4. Southall et al. (2007) proposed criteria for the levels of underwater noise that may impact marine mammals based on M-Weighted SELs, which are generalised frequency weighting functions to filter underwater noise data to better represent the levels of underwater noise various marine species are likely to be able to hear, and the known or estimated auditory sensitivity at different frequencies for marine mammal groups. The Southall et al. (2007) metrics and criteria used in the underwater noise modelling for auditory injury (Permanent Threshold Shift (PTS)) and Temporary Threshold Shift (TTS); a short-term reduction in hearing acuity and onset of fleeing response) are summarised in Table 2.1. The Southall et al. (2007) TTS criteria are only for single pulses and not multiple pulses like piling; therefore, cannot be modelled for SEL cumulative.

Table 2.1 Southall et al. (2007) metrics and criteria used in the underwater noise modelling

Species or species group	Impact	Southall et al. (2007)		
		SPL_{peak} Unweighted (dB re 1 µPa)	SEL_{ss} Weighted (dB re 1 µPa²s)	SEL_{cum} Weighted (dB re 1 µPa²s)
Harbour porpoise	Auditory Injury - PTS	230	198	198
High Frequency Cetaceans (HF)	TTS and fleeing response	224	183	N/A
Grey seal and harbour seal	Auditory Injury - PTS	218	186	186
Pinnipeds in water (PW)	TTS and fleeing response	212	171	N/A

SS = single strike; cum = cumulative; N/A = not applicable

5. In addition, a more precautionary approach has also been proposed for harbour porpoise by Lucke et al. (2009) using unweighted SELs. The Lucke et al. (2009) metrics and criteria used in the underwater noise modelling are summarised in Table 2.2. These criteria are derived from testing harbour porpoise hearing thresholds before and after being exposed to seismic airgun stimuli (a pulsed noise like impact piling). The generic high frequency cetacean group criteria by Southall et al. (2007) may not be suitable for harbour porpoise, since both injury and behavioural response may occur at greater distances from the sound source. Harbour porpoise injury ranges have therefore been derived based on a TTS to PTS extrapolation of data published by Lucke et al. (2009). The TTS to PTS extrapolation following the methodology outlined by Southall et al. (2007).

6. The Lucke et al. (2009) threshold and criteria for possible behavioural response (unweighted SEL_{ss} 145 dB re 1 µPa²s) has been assessed in Chapter 12 Marine Mammals of the ES

Table 2.2 Lucke et al. (2009) metrics and criteria used in the underwater noise modelling

Species or species group	Impact	Lucke et al. (2007) SEL_{ss} Unweighted (dB re 1 µPa²s)
Harbour porpoise	Auditory Injury – PTS	179
	TTS and fleeing response	164

SS = single strike

7. The National Oceanographic and Atmospheric Association (NOAA) (National Marine Fisheries Service (NMFS), 2018) groups marine mammals into functional hearing groups and applies filters to the unweighted noise to approximate the hearing

sensitivity of the receptor. However, these weightings are different to the "M-weightings" used in Southall et al. (2007)

8. The weightings applied for NMFS (201o) and Southall et al. (2007) for the same species groups are not identical and so comparisons between the stated thresholds for SEL_{cum} guideline values should only be made once noise levels have been weighted in accordance with the relevant criteria.

9. A weighting applies a filter to the frequency spectrum of the sound under consideration. Table 2.3 shows an example of the reduction to the unweighted noise level for a pile strike spectrum caused by the weightings.

10. For example, the pinniped PTS SEL_{cum} threshold using Southall et al. (2007) criteria is 186 dB re 1 μPa^2s and the NMFS (2018) threshold is 185 dB re 1 μPa^2s. However, the weighting applied to each is very different.

Table 2.3 Example of the effects of weighting a sound source spectrum from a nominal pile strike using Southall et al. (2007) and NMFS (2018) weighting

Species or species group	Southall et al. (2007) weighting	NMFS (2018) weighting
High frequency cetaceans	-8.4dB	-45dB
Pinnipeds in water	-3.6dB	-18dB

3 Permanent Auditory Injury (PTS)

11. The underwater noise modelling results for the maximum predicted ranges (and areas) for permanent auditory injury (PTS) in harbour porpoise, grey seal and harbour seal are presented for the following:

- Single strike SEL of maximum starting hammer energy of 500kJ for monopiles;
- Single strike SEL of maximum starting hammer energy of 270kJ for pin-piles;
- Single strike SEL of monopile with maximum hammer energy of 5,000kJ;
- Single strike SEL of pin-pile with a maximum hammer energy of 2,700kJ; and
- Cumulative SEL taking into account maximum soft start and ramp-up plus maximum duration to install pile at maximum hammer energy. For the pin-piles the SEL_{cum}, is based on the duration to install four pin-piles for each foundation (not per individual pin-pile).

12. Based on:

- Southall et al. (2007) criteria for unweighted SPL_{peak}, PTS from single strike (SEL_{ss}) and PTS from cumulative exposure (SEL_{cum}) for harbour porpoise and seals; and
- Lucke et al. (2009) criteria for PTS from single strike (SELss) for harbour porpoise.

Table 3.1 Maximum predicted impact ranges (and areas) for PTS from a single strike and from cumulative exposure based on thresholds and criteria from Southall et al. (2007) and Lucke et al. (2009)

Potential Impact	Receptor	Criteria and threshold	Maximum predicted impact range (km) and area (km^2)			
			Monopile with maximum hammer energy of 5,000kJ	Pin-pile with maximum hammer energy of 2,700kJ	Starting hammer energy of 500kJ	Starting hammer energy of 270kJ
PTS without mitigation – single strike	Harbour porpoise	Southall et al. (2007) unweighted SPL_{peak} 230 dB re 1 µPa	<0.05km (0.0008km^2)	<0.05km (0.0008km^2)	<0.05km (0.00002km^2)	<0.05km (0.00002km^2)
	Harbour porpoise	Southall et al. (2007) SEL_{ss} Weighted 198 dB re 1 μPa^2s	<0.05km (0.002km^2)	<0.05km (0.0008km^2)	<0.05km (0.00004km^2)	<0.05km (0.00002km^2)
	Harbour porpoise	Lucke et al. (2009) SEL_{ss} Unweighted 179 dB re 1 μPa^2s	0.61km (1.15km^2)	0.44km (0.60km^2)	0.12km (0.05km^2)	0.07km (0.02km^2)
	Grey seal and harbour seal	Southall et al. (2007) unweighted SPL_{peak} 218 dB re 1 µPa	<0.05km (0.006km^2)	<0.05km (0.006km^2)	<0.05km (0.0002km^2)	<0.05km (0.0001km^2)
	Grey seal and harbour seal	Southall et al. (2007) SEL_{ss} Weighted 186 dB re 1 μPa^2s	0.15km (0.07km^2)	0.13km (0.05km^2)	<0.05km (0.002km^2)	<0.05km (0.001km^2)
PTS from cumulative SEL (including soft-start and ramp-up)	Harbour porpoise	Southall et al. (2007) SEL_{cum} Weighted 198 dB re 1 μPa^2s	<0.10km (0.03km^2)	<0.10km (0.08km^2)	N/A	N/A
	Grey seal and harbour seal	Southall et al. (2007) SEL_{cum} Weighted 186 dB re 1 μPa^2s	3.1km (18.6km^2)	2.0km (11.2km^2)	N/A	N/A

Table 3.2 Maximum number of individuals (and % of reference population) that could be at risk of PTS from a single strike and from cumulative exposure based on thresholds and criteria from Southall et al. (2007) and Lucke et al. (2009)

			Monopile with maximum hammer energy of 5,000kJ		Pin-pile with maximum hammer energy of 2,700kJ		Starting hammer energy of 500kJ	
Potential Impact	**Receptor**	**Criteria and threshold**	**Maximum number of individuals (% of reference population)[1]** (no mitigation)	**Magnitude[2]**	**Maximum number of individuals (% of reference population)[1]** (no mitigation)	**Magnitude[2]**	**Maximum number of individuals (% of reference population)[1]**	**Magnitude[2]**
PTS – single strike	Harbour porpoise	Southall et al. (2007) unweighted SPL_{peak} 230 dB re 1 µPa	0.0007 harbour porpoise (0.0000002% NS MU; 0.000002% SNS SAC) based on SCANS-III survey block O density (0.888/km^2). 0.0008 harbour porpoise (0.0000002% NS MU; 0.000003% SNS SAC) based on the Norfolk Boreas site specific survey density (1.06/km^2).	Permanent impact with **negligible** magnitude (i.e. <0.001% of reference population). The embedded mitigation will ensure that the magnitude remains **negligible.**	0.0007 harbour porpoise (0.0000002% NS MU; 0.000002% SNS SAC) based on SCANS-III survey block O density (0.888/km^2). 0.0008 harbour porpoise (0.0000002% NS MU; 0.000003% SNS SAC) based on the Norfolk Boreas site specific survey density (1.06/km^2).	Permanent impact with **negligible** magnitude (i.e. <0.001% of reference population). The embedded mitigation will ensure that the magnitude remains **negligible.**	0.00002 harbour porpoise (<0.0000001% NS MU; <0.0000001% SNS SAC) based on SCANS-III survey block O density (0.888/km^2). 0.00002 harbour porpoise (<0.0000001% NS MU; <0.0000001% SNS SAC) based on the Norfolk Boreas site specific survey density (1.06/km^2).	Permanent impact with **negligible** magnitude (i.e. <0.001% of reference population).
	Harbour porpoise	Southall et al. (2007) SEL_{ss} Weighted 198 dB re 1	0.002 harbour porpoise (0.0000006% NS MU; 0.000007% SNS SAC) based on SCANS-III survey block O	Permanent impact with **negligible** magnitude (i.e. <0.001% of reference	0.0007 harbour porpoise (0.0000002% NS MU; 0.000002% SNS SAC) based on SCANS-III survey block O	Permanent impact with **negligible** magnitude (e.g. <0.001% of reference	0.00004 harbour porpoise (<0.0000001% NS MU; 0.0000001% SNS SAC) based on SCANS-III survey	Permanent impact with **negligible** magnitude (i.e. <0.001% of reference

Potential Impact	Receptor	Criteria and threshold	Monopile with maximum hammer energy of 5,000kJ		Pin-pile with maximum hammer energy of 2,700kJ		Starting hammer energy of 500kJ	
			Maximum number of individuals (% of reference population)[1] (no mitigation)	Magnitude[2]	Maximum number of individuals (% of reference population)[1] (no mitigation)	Magnitude[2]	Maximum number of individuals (% of reference population)[1]	Magnitude[2]
		μPa^2s	density (0.888/km^2). 0.002 harbour porpoise (0.0000006% NS MU; 0.000007% SNS SAC) based on the Norfolk Boreas site specific survey density (1.06/km^2).	population). The embedded mitigation will ensure that the magnitude remains **negligible.**	density (0.888/km^2). 0.0008 harbour porpoise (0.0000002% NS MU; 0.000003% SNS SAC) based on the Norfolk Boreas site specific survey density (1.06/km^2).	population). The embedded mitigation will ensure that the magnitude remains **negligible.**	block O density (0.888/km^2). 0.00004 harbour porpoise (<0.0000001% NS MU; 0.0000001% SNS SAC) based on the Norfolk Boreas site specific survey density (1.06/km^2).	population).
	Harbour porpoise	Lucke et al. (2009) SEL_{ss} Unweighted 179 dB re 1 μPa^2s	1 harbour porpoise (0.0003% NS MU; 0.003% SNS SAC) based on SCANS-III survey block O density (0.888/km^2). 1.2 harbour porpoise (0.0004% NS MU; 0.004% SNS SAC) based on the Norfolk Boreas site specific survey density (1.06/km^2).	Permanent effect with **low** magnitude (i.e. between 0.001% and 0.01% of the reference population anticipated to be exposed to effect without mitigation). This will be reduced with the mitigation to a	0.5 harbour porpoise (0.0002% NS MU; 0.002% SNS SAC) based on SCANS-III survey block O density (0.888/km^2). 0.6 harbour porpoise (0.0002% NS MU; 0.002% SNS SAC) based on the Norfolk Boreas site specific survey density (1.06/km^2).	Permanent effect with **low** magnitude (i.e. between 0.001% and 0.01% of the reference population anticipated to be exposed to effect without mitigation). This will be	0.04 harbour porpoise (0.00001% NS MU; 0.0001% SNS SAC) based on SCANS-III survey block O density (0.888/km^2). 0.05 harbour porpoise (0.00001% NS MU; 0.0002% SNS SAC) based on the Norfolk Boreas site specific survey density (1.06/km^2).	Permanent effect with **negligible** magnitude (i.e. between 0.001% and 0.01% of the reference population anticipated to be exposed to effect without mitigation).

Potential Impact	Receptor	Criteria and threshold	Monopile with maximum hammer energy of 5,000kJ		Pin-pile with maximum hammer energy of 2,700kJ		Starting hammer energy of 500kJ	
			Maximum number of individuals (% of reference population)[1] (no mitigation)	Magnitude[2]	Maximum number of individuals (% of reference population)[1] (no mitigation)	Magnitude[2]	Maximum number of individuals (% of reference population)[1]	Magnitude[2]
				negligible magnitude (as all animals will be beyond PTS range).		reduced with the mitigation to a **negligible** magnitude (as all animals will be beyond PTS range).		
	Grey seal	Southall et al. (2007) unweighted SPL_{peak} 218 dB re 1 µPa	0.000006 grey seal (<0.0000001% ref pop; 0.0000001% SE England MU) based on Norfolk Boreas site density (0.001/km^2).	Permanent impact with **negligible** magnitude (i.e. <0.001% of reference population). The embedded mitigation will ensure that the magnitude remains **negligible.**	0.000006 grey seal (<0.0000001% ref pop; 0.0000001% SE England MU) based on Norfolk Boreas site density (0.001/km^2).	Permanent impact with **negligible** magnitude (i.e. <0.001% of reference population). The embedded mitigation will ensure that the magnitude remains **negligible.**	0.0000002 grey seal (<0.0000001% ref pop; <0.0000001% SE England MU) based on Norfolk Boreas site density (0.001/km^2).	Permanent impact with **negligible** magnitude (i.e. <0.001% of reference population).
	Grey seal	Southall et al. (2007) SEL_{ss}	0.00007 grey seal (0.0000003% ref pop; 0.000001% SE England MU) based	Permanent impact with **negligible** magnitude (i.e.	0.00005 grey seal (0.0000002% ref pop; 0.0000008% SE England MU) based	Permanent impact with **negligible** magnitude	0.000002 grey seal (<0.0000001% ref pop; <0.0000001% SE England MU) based	Permanent impact with **negligible** magnitude (i.e.

Potential Impact	Receptor	Criteria and threshold	Monopile with maximum hammer energy of 5,000kJ		Pin-pile with maximum hammer energy of 2,700kJ		Starting hammer energy of 500kJ	
			Maximum number of individuals (% of reference population)[1] (no mitigation)	Magnitude[2]	Maximum number of individuals (% of reference population)[1] (no mitigation)	Magnitude[2]	Maximum number of individuals (% of reference population)[1]	Magnitude[2]
		Weighted 186 dB re 1 μPa^2s	on Norfolk Boreas site density (0.001/km^2).	<0.001% of reference population). The embedded mitigation will ensure that the magnitude remains **negligible.**	on Norfolk Boreas site density (0.001/km^2).	(i.e. <0.001% of reference population). The embedded mitigation will ensure that the magnitude remains **negligible.**	on Norfolk Boreas site density (0.001/km^2).	<0.001% of reference population).
	Harbour seal	Southall et al. (2007) unweighted SPL_{peak} 218 dB re 1 µPa	0.0000006 harbour seal (<0.0000001% ref pop; <0.0000001% SE England MU) based on Norfolk Boreas site density (0.0001/km^2).	Permanent impact with **negligible** magnitude (i.e. <0.001% of reference population). The embedded mitigation will ensure that the magnitude remains **negligible.**	0.0000006 harbour seal (<0.0000001% ref pop; <0.0000001% SE England MU) based on Norfolk Boreas site density (0.0001/km^2).	Permanent impact with **negligible** magnitude (i.e. <0.001% of reference population). The embedded mitigation will ensure that the magnitude remains **negligible.**	0.00000002 harbour seal (<0.0000001% ref pop; <0.0000001% SE England MU) based on Norfolk Boreas site density (0.0001/km^2).	Permanent impact with **negligible** magnitude (i.e. <0.001% of reference population).
	Harbour	Southall et al.	0.000007 harbour seal (<0.0000001%	Permanent impact with	0.000005 harbour seal (<0.0000001%	Permanent impact with	0.0000002 harbour seal (<0.0000001%	Permanent impact with

Potential Impact	Receptor	Criteria and threshold	Monopile with maximum hammer energy of 5,000kJ		Pin-pile with maximum hammer energy of 2,700kJ		Starting hammer energy of 500kJ	
			Maximum number of individuals (% of reference population)[1] (no mitigation)	Magnitude[2]	Maximum number of individuals (% of reference population)[1] (no mitigation)	Magnitude[2]	Maximum number of individuals (% of reference population)[1]	Magnitude[2]
	seal	(2007) SEL_{ss} Weighted 186 dB re 1 μPa^2s	ref pop; 0.0000001% SE England MU) based on Norfolk Boreas site density (0.0001/km^2).	**negligible** magnitude (i.e. <0.001% of reference population). The embedded mitigation will ensure that the magnitude remains **negligible.**	ref pop; 0.0000001% SE England MU) based on Norfolk Boreas site density (0.0001/km^2).	**negligible** magnitude (i.e. <0.001% of reference population). The embedded mitigation will ensure that the magnitude remains **negligible.**	ref pop; <0.0000001% SE England MU) based on Norfolk Boreas site density (0.0001/km^2).	**negligible** magnitude (i.e. <0.001% of reference population).
PTS – cumulative exposure (based on maximum energy)	Harbour porpoise	Southall et al. (2007) SEL_{cum} Weighted 198 dB re 1 μPa^2s	0.03 harbour porpoise (0.000009% NS MU; 0.0001% SNS SAC) based on SCANS-III survey block O density (0.888/km^2). 0.03 harbour porpoise (0.000009% NS MU; 0.0001% SNS SAC) based on the Norfolk Boreas site specific survey	Permanent impact with **negligible** magnitude (i.e. <0.001% of reference population). The embedded mitigation will ensure that the magnitude remains **negligible.**	0.07 harbour porpoise (0.00002% NS MU; 0.0002% SNS SAC) based on SCANS-III survey block O density (0.888/km^2). 0.08 harbour porpoise (0.00002% NS MU; 0.0003% SNS SAC) based on the Norfolk Boreas site specific survey	Permanent impact with **negligible** magnitude (i.e. <0.001% of reference population). The embedded mitigation will ensure that the magnitude remains **negligible.**	N/A	N/A

Potential Impact	Receptor	Criteria and threshold	Monopile with maximum hammer energy of 5,000kJ		Pin-pile with maximum hammer energy of 2,700kJ		Starting hammer energy of 500kJ	
			Maximum number of individuals (% of reference population)[1] (no mitigation)	Magnitude[2]	Maximum number of individuals (% of reference population)[1] (no mitigation)	Magnitude[2]	Maximum number of individuals (% of reference population)[1]	Magnitude[2]
			density (1.06/km^2).		density (1.06/km^2).			
PTS – cumulative exposure (including maximum soft-start and ramp-up)	Grey seal	Southall et al. (2007) SEL_{cum} Weighted 186 dB re 1 µPa^{2}s	0.02 grey seal (0.00009% ref pop; 0.0003% SE England MU) based on Norfolk Boreas site density (0.001/km^2).	Permanent effect with **negligible** magnitude (i.e. between 0.001% and 0.01% of the reference population anticipated to be exposed to effect). The embedded mitigation will ensure that the magnitude remains **negligible.**	0.01 grey seal (0.00005% ref pop; 0.002% SE England MU) based on Norfolk Boreas site density (0.001/km^2).	Permanent effect with **negligible** magnitude (i.e. between 0.001% and 0.01% of the reference population anticipated to be exposed to effect). The embedded mitigation will ensure that the magnitude remains **negligible.**	N/A	N/A
PTS – cumulative exposure (including maximum	Harbour seal	Southall et al. (2007) SEL_{cum} Weighted	0.002 harbour seal (0.000005% ref pop; 0.00004% SE England MU) based on Norfolk Boreas site	Permanent effect with **negligible** magnitude (i.e. between 0.001% and 0.01% of the	0.001 harbour seal (0.000002% ref pop; 0.00002% SE England MU) based on Norfolk Boreas site	Permanent effect with **negligible** magnitude (i.e. between	N/A	N/A

Potential Impact	Receptor	Criteria and threshold	Monopile with maximum hammer energy of 5,000kJ		Pin-pile with maximum hammer energy of 2,700kJ		Starting hammer energy of 500kJ	
			Maximum number of individuals (% of reference population)[1] (no mitigation)	Magnitude[2]	Maximum number of individuals (% of reference population)[1] (no mitigation)	Magnitude[2]	Maximum number of individuals (% of reference population)[1]	Magnitude[2]
soft-start and ramp-up)		186 dB re 1 μPa^2s	density (0.0001/km^2).	reference population anticipated to be exposed to effect). The embedded mitigation will ensure that the magnitude remains **negligible.**	density (0.0001/km^2).	0.001% and 0.01% of the reference population anticipated to be exposed to effect). The embedded mitigation will ensure that the magnitude remains **negligible.**		

[1]Based on density estimate and reference population (see Table 12.14 and Table 12.15 in Chapter 12 of the ES for the North Sea Management Unit (MU) and based on Appendix 12.4 for the SAC); [2]See Table 12.7 in Chapter 12 Marine Mammals of the ES for definitions.

4 Temporary Auditory Injury (based on TTS)

13. The underwater noise modelling results for the maximum predicted ranges (and areas) for temporary auditory injury (based on TTS) and fleeing response in harbour porpoise, grey seal and harbour seal are presented in (Table 4.1) for:

- Monopile with maximum hammer energy of 5,000kJ; and
- Pin-pile with maximum hammer energy of 2,700kJ.

14. Based on:

- The Southall et al. (2007) criteria for unweighted SPL_{peak} and single strike TTS (SEL_{ss}); and
- Lucke et al. (2009) for single strike TTS (SEL_{ss}) in harbour porpoise.

Table 4.1 Maximum predicted impact ranges (and areas) for TTS / fleeing response from a single strike and for TTS from cumulative exposure based on thresholds and criteria from Southall et al. (2007) and Lucke et al. (2009)

Potential Impact	Receptor	Criteria and threshold	Maximum predicted impact range (km) and area (km^2)	
			Monopile with maximum hammer energy of 5,000kJ	Pin-pile with maximum hammer energy of 2,700kJ
TTS without mitigation and fleeing response – single strike	Harbour porpoise	Southall et al. (2007) unweighted SPL_{peak} 224 dB re 1 µPa	0.05km (0.002km^2)	0.05km (0.002km^2)
	Harbour porpoise	Southall et al. (2007) SEL_{ss} Weighted 183 dB re 1 μPa^2s	0.12km (0.04km^2)	0.10km (0.03km^2)
	Harbour porpoise	Lucke et al. (2009) SEL_{ss} Unweighted 164 dB re 1 μPa^2s	4.20km (54.74km^2)	3.20km (31.53km^2)
	Grey seal and harbour seal	Southall et al. (2007) unweighted SPL_{peak} 212 dB re 1 µPa	0.08km (0.03km^2)	0.06km (0.02km^2)
	Grey seal and harbour seal	Southall et al. (2007) SEL_{ss} Weighted 171 dB re 1 μPa^2s	1.10km (3.76km^2)	0.97km (2.92km^2)

Table 4.2 Maximum number of individuals (and % of reference population) that could be at risk of TTS / fleeing response from a single strike based on thresholds and criteria from Southall et al. (2007) and Lucke et al. (2009)

Potential Impact	Receptor	Criteria and threshold	Maximum number of individuals (% of reference population)[1]			
			Monopile with maximum hammer energy of 5,000kJ	Magnitude[2]	Pin-pile with maximum hammer energy of 2,700kJ	Magnitude[2]
TTS / fleeing response – single strike	Harbour porpoise	Southall et al. (2007) unweighted SPL_{peak} 224 dB re 1 µPa	0.002 harbour porpoise (0.0000006% NS MU; 0.000007% SNS SAC) based on SCANS-III survey block O density (0.888/km^2). 0.002 harbour porpoise (0.0000006% NS MU; 0.000007% SNS SAC) based on the Norfolk Boreas site specific survey density (1.06/km^2).	Temporary impact with '**negligible**' magnitude (i.e. <1% of reference population).	0.002 harbour porpoise (0.0000006% NS MU; 0.000007% SNS SAC) based on SCANS-III survey block O density (0.888/km^2). 0.002 harbour porpoise (0.0000006% NS MU; 0.000007% SNS SAC) based on the Norfolk Boreas site specific survey density (1.06/km^2).	Temporary impact with '**negligible**' magnitude (i.e. <1% of reference population).
	Harbour porpoise	Southall et al. (2007) SEL_{ss} Weighted 183 dB re 1 µPa^{2}s	0.04 harbour porpoise (0.00001% NS MU; 0.0001% SNS SAC) based on SCANS-III survey block O density (0.888/km^2). 0.04 harbour porpoise (0.00001% NS MU; 0.0001% SNS SAC) based on the Norfolk Boreas site specific survey density (1.06/km^2).	Temporary impact with '**negligible**' magnitude (i.e. <1% of reference population).	0.03 harbour porpoise (0.000009% NS MU; 0.0001% SNS SAC) based on SCANS-III survey block O density (0.888/km^2). 0.03 harbour porpoise (0.000009% NS MU; 0.0001% SNS SAC) based on the Norfolk Boreas site specific survey density (1.06/km^2).	Temporary impact with '**negligible**' magnitude (i.e. <1% of reference population).
	Harbour porpoise	Lucke et al. (2009) SEL_{ss} Unweighted 164 dB re 1 µPa^{2}s	49 harbour porpoise (0.01% NS MU; 0.2% SNS SAC) based on SCANS-III survey block O density (0.888/km^2). 58 harbour porpoise (0.02% NS MU; 0.2% SNS SAC) based on the Norfolk Boreas site specific survey	Temporary impact with '**negligible**' magnitude (i.e. <1% of reference population).	28 harbour porpoise (0.008% NS MU; 0.1% SNS SAC) based on SCANS-III survey block O density (0.888/km^2). 33 harbour porpoise (0.01% NS MU; 0.1% SNS SAC) based on the Norfolk Boreas site specific survey	Temporary impact with '**negligible**' magnitude (i.e. <1% of reference population).

Potential Impact	Receptor	Criteria and threshold	Maximum number of individuals (% of reference population)[1] Monopile with maximum hammer energy of 5,000kJ	Magnitude[2]	Pin-pile with maximum hammer energy of 2,700kJ	Magnitude[2]
			density (1.06/km^2).		density (1.06/km^2).	
	Grey seal	Southall et al. (2007) unweighted SPL_{peak} 212 dB re 1 µPa	0.00003 grey seal (0.0000001% ref pop; 0.0000005% SE England MU) based on Norfolk Boreas site density (0.001/km^2).	Temporary impact with '**negligible**' magnitude (i.e. <1% of reference population).	0.00002 grey seal (<0.0000001% ref pop; 0.0000003% SE England MU) based on Norfolk Boreas site density (0.001/km^2).	Temporary impact with '**negligible**' magnitude (i.e. <1% of reference population).
	Grey seal	Southall et al. (2007) SEL_{ss} Weighted 171 dB re 1 µPa^{2}s	0.004 grey seal (0.00002% ref pop; 0.00007% SE England MU) based on Norfolk Boreas site density (0.001/km^2).	Temporary impact with '**negligible**' magnitude (i.e. <1% of reference population).	0.003 grey seal (0.00001% ref pop; 0.00005% SE England MU) based on Norfolk Boreas site density (0.001/km^2).	Temporary impact with '**negligible**' magnitude (i.e. <1% of reference population).
	Harbour seal	Southall et al. (2007) unweighted SPL_{peak} 212 dB re 1 µPa	0.000003 harbour seal (<0.0000001% ref pop; <0.0000001% SE England MU) based on Norfolk Boreas site density (0.0001/km^2).	Temporary impact with '**negligible**' magnitude (i.e. <1% of reference population).	0.000002 harbour seal (<0.0000001% ref pop; <0.0000001% SE England MU) based on Norfolk Boreas site density (0.0001/km^2).	Temporary impact with '**negligible**' magnitude (i.e. <1% of reference population).
	Harbour seal	Southall et al. (2007) SEL_{ss} Weighted 171 dB re 1 µPa^{2}s	0.0004 harbour seal (0.0000009% ref pop; 0.000008% SE England MU) based on Norfolk Boreas site density (0.0001/km^2).	Temporary impact with '**negligible**' magnitude (i.e. <1% of reference population).	0.0003 harbour seal (0.0000007% ref pop; 0.000006% of SE England MU) based on Norfolk Boreas site density (0.0001/km^2).	Temporary impact with '**negligible**' magnitude (i.e. <1% of reference population).

[1]Based on density estimate and reference population (see Table 12.14 and Table 12.15 in Chapter 12 of the ES for the North Sea Management Unit (MU) and based on Appendix 12.4 for the SAC); [2]See Table 12.7 in Chapter 12 of the ES for definitions.

5 References

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