Appendix B: Inch Cape Pile Driving Noise Assessment: Potential Effects of Use of Greater Hammer Energies on Marine Mammals and Fish

Inch Cape Pile Driving Noise Assessment

Potential Effects of Use of Greater Hammer Energies on Marine Mammals and Fish

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Executive Summary

The use of monopile foundations at Inch Cape Offshore Wind Farm (OWF) has been identified as a key factor in ensuring Inch Cape Offshore Limited's (ICOL's) competitiveness in the next Contracts for Difference (CfD) round. Site investigation work conducted since the Inch Cape OWF was awarded consent in 2019 has identified difficult ground conditions within the Development Area and raised the likelihood that greater hammer energies than those described in the 2018 Environmental Impact Assessment Report (EIAR) (ICOL, 2018) will be required to install monopile foundations.

Several new scenarios have been modelled using the INSPIRE underwater noise propagation software to explore how use of greater hammer energies, with maximums of 5,500 kJ and 3,500 kJ for monopiles and pin piles respectively, may affect the size of potential impact zones (and numbers of marine mammals which have the potential to be exposed to received noise levels sufficient to induce either the onset of permanent threshold shift (PTS) or displacement).

Key findings for marine mammals

Instantaneous PTS: Although the maximum impact ranges were up to 710 m for monopiles and 600 m for pin piles for very high frequency cetaceans (harbour porpoise, *Phocoena phocoena*), they were ≤60 m for the other hearing groups (low frequency cetaceans, high frequency cetaceans, phocid seals in water). Appropriate use of mitigation (i.e., activation of an acoustic deterrent device) will ensure that no animals are present within the zone of potential impact. The potential impact (with mitigation) is therefore considered to be zero, i.e., no effect (and not significant; see Table 2.8).

Cumulative PTS and displacement: The numbers of individuals of the different species estimated to have the potential to be exposed to noise levels sufficient to induce the onset of cumulative PTS or a behavioural response (displacement) were greater than those presented in the 2018 EIAR. This is the result of a combination of factors; use of a different noise modelling approach (Subacoustech's INSPIRE as opposed to Cefas' model), use of different species density surfaces, use of different noise dose-behavioural response relationships, and use of greater hammer energies. However, when expressed as percentages of the relevant reference populations and used to predict the significance of the potential effects, the potential impacts arising were considered to result in nil, minor, or moderate effects. Using the same criteria (for predicting significance of effects) as the 2013 ES and 2018 EIAR, these potential effects were considered to be not significant.

Key findings for fish

The modelled zones of effect for peak sound pressure level (SPL) and cumulative sound exposure level (SEL) were greater than the 2018 EIAR. However, this is only likely to affect a small number of individuals (at all effect levels) due to a lack of large aggregations predicted in the area. Some interaction with spawning and nursery habitats is expected, however such interactions are considered not to affect key/high intensity areas of those habitats, or will only affect a small proportion. The magnitude of the effect on the fish receptor group is considered to be low and is not significant.

1. Introduction

The Inch Cape Offshore Wind Farm (OWF) will see up to 72 wind turbine generators (WTGs) located 15 km off the Angus coast. Inch Cape OWF is currently undergoing a process of design optimisation in order to be competitive in the next Contracts for Difference (CfD) auction round (Allocation Round (AR) 4). Site investigations and design engineering undertaken since the project was awarded consent in 2019 have identified monopiles as the preferred design solution, but difficult ground conditions mean that greater hammer energies than those described in the 2018 Environmental Impact Report (EIAR) (ICOL, 2018) will be required at some installation locations. Similarly, results of the site investigations have indicated that a 2,400 kJ hammer may be insufficient for pin piles if jacket foundations are progressed.

This document describes the underwater noise propagation and subsequent modelling work which has been undertaken to determine whether any increase in noise caused by the use of greater hammer energies leads to the potential for significant effects on marine mammals and fish receptors when using greater hammer energies. Due to differences in assessment methodology, the marine mammal assessment is presented in the main report with the fish assessment presented separately in Appendix A.

2. Methodology

The methodology used to estimate the numbers of marine mammals which have the potential to be impacted by underwater noise follows that used in both the 2013 ES (section 14B.3; ICOL, 2013) and 2018 EIAR (section 10.7.1) and can be summarised as follows:

- Description of the spatial distribution/density of marine mammals;
- Assessment of the spatial distribution of piling noise under different scenarios (noise modelling);
- Integration of the marine mammal spatial distribution/density and piling noise spatial distribution (including use of a dose-response curve for displacement) to estimate the numbers of animals which have the potential to be impacted by noise; and
- Prediction of the significance of the potential effects.

Following advice from Marine Scotland (MS) and NatureScot (NS), the marine mammal spatial distribution/density information used for the different species was updated (see section 2.1). Dose-response relationships (see section 2.3.3) and reference population abundance estimates (Appendix B) were also updated.

2.1. Spatial distribution/density of marine mammals

The density of animals at the site for each of six species (minke whale (*Balaenoptera acutorostrata*), white-beaked dolphin (*Lagenorhynchus albirostris*), bottlenose dolphin (*Tursiops truncatus*), harbour porpoise (*Phocoena phocoena*), grey seal (*Halichoerus grypus*), harbour seal (*Phoca vitulina*)) was calculated based on updated data available in the public domain or provided by experts through personal communication.

For harbour seal and grey seal, two density surfaces were applied for each species. The first were the updated estimated at-sea distribution maps produced by the Sea Mammal Research Unit (SMRU) (Russell *et al*., 2017). The second were calculated by scaling the UK-wide density surfaces provided by Carter *et al.* (2020) to predict the number of seals at sea within each cell of a 5 km x 5 km grid such that the combined total number of animals added up to the total of at sea animals estimated by Carter *et al*. (2020) (150,700 for grey seal and 42,800 for harbour seal).

Similarly, two surfaces each were applied for harbour porpoise, minke whale and white-beaked dolphin. The most recent SCANS-III density estimates for the block containing the site of the proposed development (Block R, 0.599 harbour porpoise per km^2, 0.039 minke whale per km^2 and 0.243 white-beaked dolphin per km^2; Hammond *et al*., 2021) were used to generate a flat surface on a 5 km x 5 km grid as an input density surface. Since confidence intervals around the density estimate are not provided, confidence intervals were calculated by dividing the confidence limits presented alongside the abundance estimate for the block by the area of the block as calculated from the shapefile available on the SCANS website[1] (giving confidence limits of 0.319 – 1.031 harbour porpoise per km^2, 0.009 – 0.105 minke whale per km^2 and 0.050 – 0.517 white-beaked dolphin per km^2). These are therefore subject to rounding error. The second set of surfaces were distribution surfaces from the SCANS-III project provided by C. Lacey on 04/11/2021 (Lacey *et al*., 2021 – in prep). Densities per 10,000 m x 10,000 m grid cell were not provided with confidence intervals and it was noted that the key aim of the surfaces were to accurately reflect the distribution, rather than density, across the surface.

For bottlenose dolphin, the five-year weighted average for the East Coast population (224, CIs: 214 – 234, Arso Civil *et al*. 2021) was assumed to be split 50:50 between the east coast (from Rattray Head south) and the Moray Firth (Cape Wrath to Rattray Head). The 20 m depth contour was used to differentiate between the 'coastal strip' (where bottlenose dolphins tend to be encountered) and the 'non-coastal strip' (where bottlenose dolphins tend not to be encountered). The choice of the 20 m depth contour was informed by data from the south side of the Moray Firth

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[1] https://synergy.st-andrews.ac.uk/scans3/category/researchoutput

where greater than 95 per cent of sightings made were within the 20 m depth contour (Culloch and Robinson, 2008; Robinson *et al*., 2007). The 112 individuals assumed to be present on the east coast (i.e., 50 per cent of the population of 224 individuals) were distributed evenly across the area inside the 20 m depth contour on a 5 km x 5 km grid. Zero density was used beyond the 20 m depth contour and within the Forth and Inner Tay (where bottlenose dolphins are known not to regularly be present).

2.2. Noise modelling

Detailed subsea noise modelling for impact piling (with regards to the effect on marine mammals and fish) was carried out by Subacoustech using their INSPIRE underwater noise propagation model (version 5.1). Their full report (Subacoustech Environmental Report No. P271R0501) has been provided as Annex 1. It should be noted that outputs from Subacoustech's INSPIRE model are more conservative than those from Cefas (at least for PTS), i.e., the noise impact contours are generally larger, but are validated against field measurements.

In summary, the main metrics and criteria used came from two key papers covering underwater noise and its effects:

- Southall *et al*. (2019) marine mammal noise exposure criteria (see Appendix C); and
- Popper *et al*. (2014) sound exposure guidelines for fish.

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

Six scenarios were modelled, representing pile driving for monopile (scenarios 1 – 3) versus pin pile (scenarios 4 – 6) foundations using different hammer energies and strike regimes (see Tables 2.1 to 2.6 below). Models were run for two different piling locations: F3 at the northwest edge of the development area, and F4 at the southwest edge of the development area. It is expected that one monopile foundation or up to four multi-leg foundation (pin) piles can be installed in a 24-hour period; this was included as part of the modelling.

For each of the six scenarios, the following ranges (for impact piling noise) were modelled:

- Estimates of unweighted SPL_{peak} noise levels, i.e., instantaneous permanent threshold shift (PTS) ranges;
- Estimates of weighted SEL_{cum} noise levels, i.e., cumulative PTS ranges; and
- Estimates of SEL_{ss} noise levels, i.e., displacement contours (at a 1 dB resolution).

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

Table 2.1: Piling scenario 1: 11 m monopile installed with a maximum hammer capacity of 4,500 kJ

Scenario 1	**% of hammer capacity**			
	10%	**20%**	**30%**	**90%**
Blow energy	450 kJ	900 kJ	1350 kJ	4050 kJ
No. of strikes	522	696	348	10440
Duration	30 mins	20 mins	10 mins	5 hours
Strike rate	17 blows/min	35 blows/min		

Table 2.2: Piling scenario 2: 11 m monopile installed with a maximum hammer capacity of 5,500 kJ

Scenario 2	**% of hammer capacity**			
	10%	**20%**	**30%**	**90%**
Blow energy	550 kJ	1100 kJ	1650 kJ	4950 kJ
No. of strikes	522	696	348	10440
Duration	30 mins	20 mins	10 mins	5 hours
Strike rate (blows per minute)	17 blows/min	35 blows/min		

Table 2.3: Piling scenario 3: 11 m monopile installed with a maximum hammer capacity of 5,500 kJ

Scenario 3	**% of hammer capacity**					
	10%		**15%**	**20%**	**25%**	**100%**
Blow energy	600 kJ		825 kJ	1100 kJ	1375 kJ	5500 kJ
No. of strikes	6	90	90	90	90	12240
Duration	1 min	5 mins	5 mins	5 mins	5 mins	6 hours 58 mins
Strike rate	6 blows/min	18 blows/min				25 blows/min

Table 2.4: Piling scenario 4: 2.4 m pin piles installed with a maximum hammer capacity of 2,160 kJ with 4 piles being installed sequentially

Scenario 4	**% of hammer capacity**			
	12%	**20%**	**30%**	**90%**
Blow energy	264 kJ	432 kJ	648 kJ	1944 kJ
No. of strikes	348	696	348	3689
Duration	20 mins	20 mins	10 mins	1 hour 46 mins
Strike rate	17 blows/min		35 blows/min	

Table 2.5: Piling scenario 5: 3 m pin piles installed with a maximum hammer capacity of 3,500 kJ with 4 piles being installed sequentially

Scenario 5	% of hammer capacity			
	10%	20%	30%	90%
Blow energy	350 kJ	700 kJ	1050 kJ	3150 kJ
No. of strikes	348	696	348	3689
Duration	20 mins	20 mins	10 mins	1 hour 46 mins
Strike rate	17 blows/min		35 blows/min	

Table 2.6: Piling scenario 6: 3 m pin piles installed with a maximum hammer capacity of 3,500 kJ with 4 piles being installed sequentially

Scenario 6	% of hammer capacity					
	10%		15%	20%	25%	100%
Blow energy	350 kJ		525 kJ	700 kJ	875 kJ	3500 kJ
No. of strikes	6	90	90	90	90	4896
Duration	1 min	5 mins	5 mins	5 mins	5 mins	2 hours 16 mins
Strike rate	6 blows/min	18 blows/min				36 blows/min

2.3. Estimating the number of individuals which have the potential to be impacted

2.3.1. Cumulative PTS

The species-specific density surfaces (section 2.1) and cumulative PTS (SEL_{cum}) contours (section 2.2) were used to estimate the number of individuals of each species which have the potential to be exposed to levels of noise sufficient to induce the onset of PTS. For each density surface grid cell overlapped by the PTS contour, the proportion of the grid cell within the contour was calculated and multiplied by the number of animals for that grid cell. These were then summed to provide the total number of individuals with the potential to be exposed to levels of noise sufficient to induce the onset of PTS.

2.3.2. Displacement

The mean unweighted SEL single strike (SEL_{ss}) noise levels were calculated for each scenario within each grid cell of the species-specific density surfaces. A noise dose-behavioural response (dose-response) relationship was then used to convert the noise level into a probability of animals within that cell responding to the level received. The number of animals in each cell was then multiplied by the probability of response to estimate the number displaced, and these were summed across the density surface to derive the total number of animals predicted to be displaced.

In the 2018 EIAR, an interim dose-response curve based on harbour porpoise data and derived by Thompson (2017) was applied across all species.

In this new round of modelling, an updated version of this curve (presented in the supplementary material of Graham *et al*. (2019)) was used for all cetacean species (minke whale, bottlenose dolphin, white-beaked dolphin, harbour porpoise). The updated curve includes piling order as a covariate and reflects the finding that naïve animals have a greater probability of responding to pile driving noise than individuals that have previously been exposed to such noise. We consider that animals within the vicinity of the Inch Cape Offshore Wind Farm will not be naïve to pile driving noise, as they will have been exposed to such noise from other wind farms (e.g., in the Moray Firth and, to a lesser extent, the Forth and Tay) which lie within their ranges. We therefore used the realisation of the Graham curve that is based on the final (86th) piling location. However, we also analysed the data using the first piling location to illustrate the effect this assumption has on the predictions. Parameter estimates and standardisation values for reconstructing the Graham curves were not presented in their paper but were kindly provided via personal communication with I. Graham. The Graham dose-response curves, along with the original/interim Thompson curve, are presented in Figure 2.1.

Source: Thompson (2017); Graham et al. (2019)

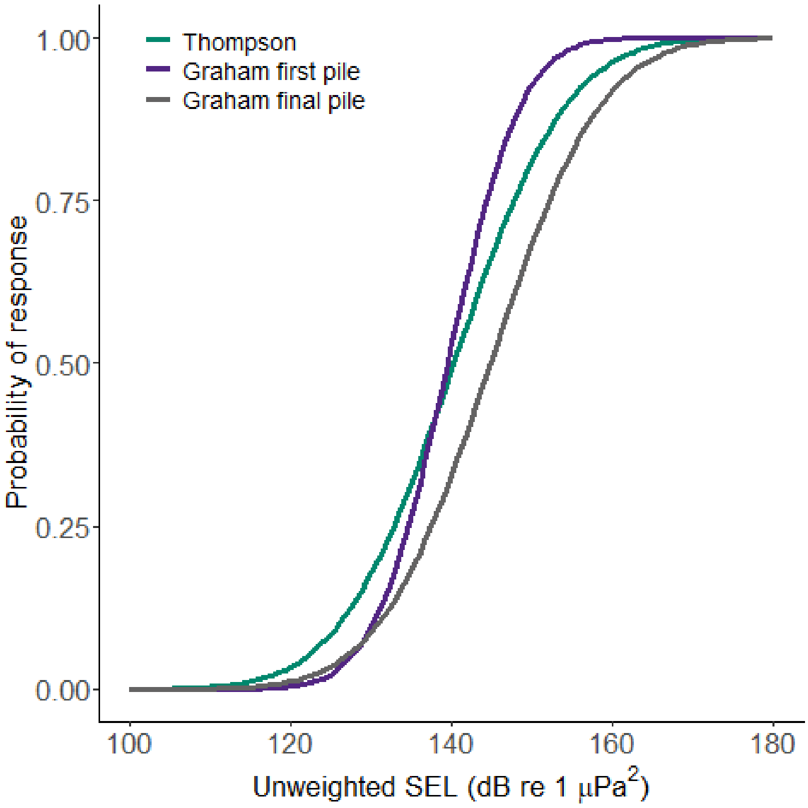

Figure 2.1: Dose-response curves used for cetacean displacement analysis. The Thompson curve was used in the 2018 EIAR. The Graham curves for both the first piling location and the final (86th) piling location are presented

For seals, the dose-response relationship presented in Whyte *et al*. (2020) was used to estimate the probability of response and this was applied across the surfaces as described above. Probability of displacement at given noise levels was taken from Table V in Whyte *et al*. (2020; see Table 2.7). However, it was noted that while the probability of response increased with increasing noise levels up until 170 dB, animals experiencing noise levels of 175 dB were predicted to have a lower probability of response. Whilst this could be a genuine effect, we consider that it is likely that sample sizes for higher noise levels were smaller and therefore more susceptible to sampling error. We therefore took a precautionary approach of assuming that all animals experiencing noise levels of 170 dB or greater would respond at the greatest probability presented in the table (0.7927 for 170 dB – 175 dB). The modified Whyte dose-response relationship, along with the original/interim Thompson curve, is presented in Figure 2.2.

Source: Thompson (2017); Whyte et al. (2020)

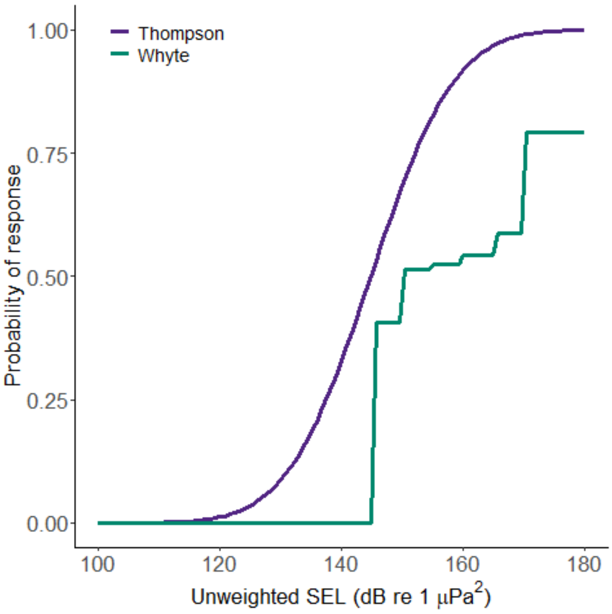

Figure 2.2: Dose-response relationships used for seal displacement analysis. The Thompson curve was used in the 2018 EIAR. The Whyte relationship was constructed using data from Table V in Whyte *et al*. (2020; see Table 2.7), and modified such that all animals experiencing 170 dB or more responded with the greatest (median) probability presented

Table 2.7: Table V in Whyte *et al*. (2020) reproduced here for ease of reference

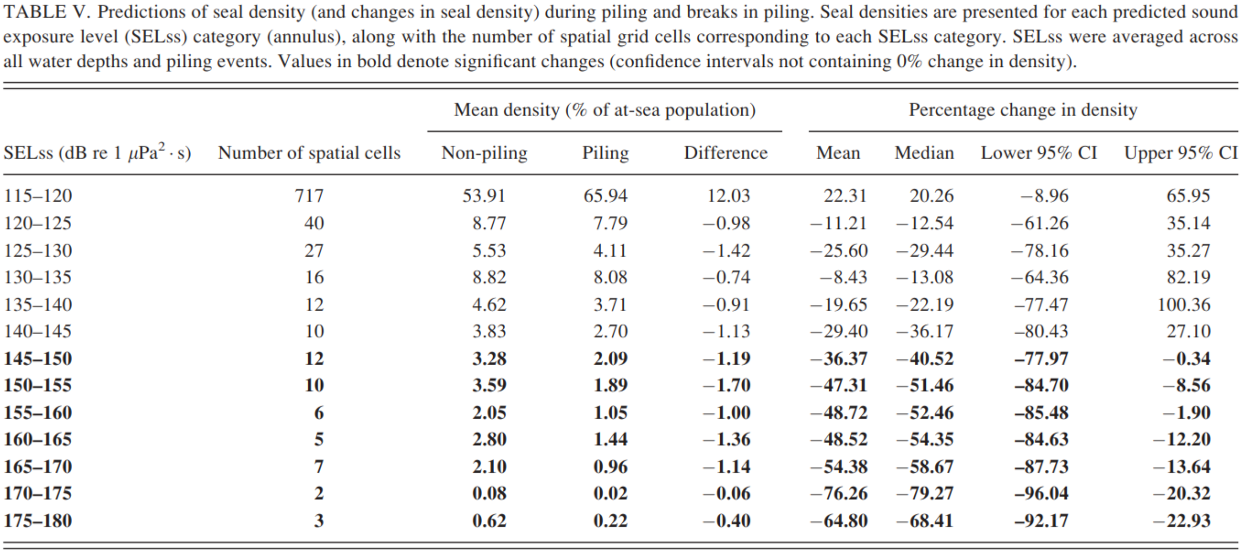

TABLE V. Predictions of seal density (and changes in seal density) during piling and breaks in piling. Seal densities are presented for each predicted sound exposure level (SELss) category (annulus), along with the number of spatial grid cells corresponding to each SELss category. SELss were averaged across all water depths and piling events. Values in bold denote significant changes (confidence intervals not containing 0% change in density).

		Mean density (% of at-sea population)			Percentage change in density			
SELss (dB re 1 $\mu Pa^2 \cdot s$)	Number of spatial cells	Non-piling	Piling	Difference	Mean	Median	Lower 95% CI	Upper 95% CI
115–120	717	53.91	65.94	12.03	22.31	20.26	−8.96	65.95
120–125	40	8.77	7.79	−0.98	−11.21	−12.54	−61.26	35.14
125–130	27	5.53	4.11	−1.42	−25.60	−29.44	−78.16	35.27
130–135	16	8.82	8.08	−0.74	−8.43	−13.08	−64.36	82.19
135–140	12	4.62	3.71	−0.91	−19.65	−22.19	−77.47	100.36
140–145	10	3.83	2.70	−1.13	−29.40	−36.17	−80.43	27.10
145–150	**12**	**3.28**	**2.09**	**−1.19**	**−36.37**	**−40.52**	**−77.97**	**−0.34**
150–155	**10**	**3.59**	**1.89**	**−1.70**	**−47.31**	**−51.46**	**−84.70**	**−8.56**
155–160	**6**	**2.05**	**1.05**	**−1.00**	**−48.72**	**−52.46**	**−85.48**	**−1.90**
160–165	**5**	**2.80**	**1.44**	**−1.36**	**−48.52**	**−54.35**	**−84.63**	**−12.20**
165–170	**7**	**2.10**	**0.96**	**−1.14**	**−54.38**	**−58.67**	**−87.73**	**−13.64**
170–175	**2**	**0.08**	**0.02**	**−0.06**	**−76.26**	**−79.27**	**−96.04**	**−20.32**
175–180	**3**	**0.62**	**0.22**	**−0.40**	**−64.80**	**−68.41**	**−92.17**	**−22.93**

2.4. Predicting of the significance of the potential effects

To provide context, and in order to be able to predict the significance of the potential effects, the number of individuals of each species estimated to have the potential to be exposed to noise levels sufficient to induce the onset of cumulative PTS and/or a behavioural response (displacement) under the different scenarios were expressed as a percentage of the relevant reference population (see Appendix B). These percentages (or magnitudes) were used to predict the significance of the potential effects using the criteria presented in Table 2.8. In line with the 2013 ES and 2018 EIAR, major and moderate/major effects were considered significant (in EIA terms).

Table 2.8: Criteria used for predicting significance of effects

Magnitude	Duration of impact		
	Short term (days)	Medium term (construction years)	Long term (detectable after 25 years)
High (>20% of population)	Moderate/Major	Major	Major
Medium (10-20% of population)	Minor	Moderate	Moderate
Low (<10% of population)	Negligible	Minor	Minor

Source: 2013 ES (ICOL, 2013); 2018 EIAR (ICOL, 2018)

3. Results

3.1. Instantaneous PTS

Using the Southall *et al*. (2019) SPL_{peak} criteria (Table A.1, Appendix C), maximum impact ranges were generally predicted to be ≤50 m[2] at both noise modelling locations (F3 and F4). They exceeded 50 m for very high frequency cetaceans and phocid seals in water in some cases (Table 3.1).

For very high frequency cetaceans, the maximum range varied from 660 m (scenario 1) to 710 m (scenario 3) for monopiles and 470 m (scenario 4) to 600 m (scenario 6) for pin piles.

These ranges are sufficiently small that mitigation (use of an acoustic deterrent device) will reduce the potential for effect to zero, i.e., no effect (and not significant; see Table 2.8).

Table 3.1: Maximum instantaneous PTS (unweighted SPL_{peak}) ranges

Hearing group	Example species	Greatest maximum range (m)	Scenario
Low frequency cetaceans	Minke whale	50	1, 2, 3
High frequency cetaceans	Bottlenose dolphin White-beaked dolphin	<50	1, 2, 3, 4, 5, 6
Very high frequency cetaceans	Harbour porpoise	710	3
Phocid seals in water	Grey seal Harbour seal	60	2, 3

Source: Barham and Mason (2021; see Annex 1)

3.2. Cumulative PTS

The total number of individuals which have the potential to be exposed to noise levels sufficient to induce the onset of (cumulative) PTS has been presented for the different scenarios by species in the following sections. Where the number of individuals was ≥1, they have also been expressed as a percentage of the relevant reference population (see Appendix B) and assessed.

3.2.1. Minke whale

When the SCANS point estimate was used to describe their spatial distribution/density, the number of minke whales estimated to have the potential to be exposed to noise levels sufficient to induce the onset of cumulative PTS varied from 18 to 24 for monopiles and 9 to 17 for pin piles (Table 3.2). When expressed as a percentage of the reference population, these numbers represented ≤0.1% (Table 3.3), i.e., minor effect and not significant (Table 2.8).

The numbers of individuals (and therefore percentage of the reference population) were much lower (50 to 56% of the SCANS point estimate values) when the SCANS density surface was used (Table 3.2).

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[2] 50 m is the smallest resolution of the model (see section 2.2).

Table 3.2: **Number of minke whale predicted to be impacted by PTS onset under different scenarios – PTS threshold 183 dB, Low Frequency weighted (and 95% CIs)**

Pile type	Scenario	SCANS point estimate		SCANS density surface	
		Location F3	Location F4	Location F3	Location F4
Monopile	Scenario 1	18 (4 – 49)	18 (4 – 49)	9	10
	Scenario 2	20 (5 – 54)	20 (5 – 55)	10	11
	Scenario 3	24 (6 – 66)	24 (6 – 66)	13	13
Pin pile	Scenario 4	11 (3 – 29)	11 (3 – 29)	6	6
	Scenario 5	17 (4 – 45)	17 (4 – 45)	9	9
	Scenario 6[3]	9 (2 – 25)	9 (2 – 24)	5	5

Note: The SCANS point estimate numbers are the same or similar for the different noise modelling locations because, although the noise contours for F3 and F4 are different, the SCANS point estimate surface is flat.

Table 3.3: **Percentage of minke whale reference population predicted to be impacted by PTS onset under different scenarios (current WC location used)**

Pile type	Scenario	% of minke whale reference population	
		SCANS point estimate	SCANS density surface
Monopile	Scenario 1	0.1	<0.1
	Scenario 2	0.1	0.1
	Scenario 3	0.1	0.1
Pin pile	Scenario 4	0.1	<0.1
	Scenario 5	0.1	<0.1
	Scenario 6	<0.1	<0.1

3.2.2. Bottlenose dolphin

The number of bottlenose dolphins estimated to have the potential to be exposed to noise levels sufficient to induce the onset of cumulative PTS was zero for both monopiles and pin piles (Table 3.4), i.e., no effect and not significant.

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[3] Even though the overall maximum energy is the highest, scenario 6 creates the lowest SEL_{cum} ranges for fleeing animals due to the soft start used. In general, when considering SEL_{cum} calculations the most important part is where the receptor is closest to the noise source; in this case it is during the piling soft start. Scenario 6 utilised a minute of slow piling before reaching similar speeds to Scenario 5. This means that the receptor was able to flee further between each pile strike, reaching greater ranges before the louder pile strikes occur.

Table 3.4: Number of bottlenose dolphin predicted to be impacted by PTS onset under different scenarios – PTS threshold 185 dB, High Frequency weighted

Pile type	Scenario	Inferred 'coastal strip' surface	
		Location F3	Location F4
Monopile	Scenario 1	0	0
	Scenario 2	0	0
	Scenario 3	0	0
Pin pile	Scenario 4	0	0
	Scenario 5	0	0
	Scenario 6	0	0

3.2.3. White-beaked dolphin

The number of white-beaked dolphins estimated to have the potential to be exposed to noise levels sufficient to induce the onset of cumulative PTS was less than 0.1 for both monopiles and pin piles (Table 3.5), i.e., minor effect[4] and not significant.

Table 3.5: Number of white-beaked dolphin predicted to be impacted by PTS onset under different scenarios – PTS threshold 185 dB, High Frequency weighted (and 95% CIs)

Pile type	Scenario	SCANS point estimate		SCANS density surface	
		Location F3	Location F4	Location F3	Location F4
Monopile	Scenario 1	<0.1 (<0.1 - <0.1)	<0.1 (<0.1 - <0.1)	<0.1	<0.1
	Scenario 2	<0.1 (<0.1 - <0.1)	<0.1 (<0.1 - <0.1)	<0.1	<0.1
	Scenario 3	<0.1 (<0.1 - <0.1)	<0.1 (<0.1 - <0.1)	<0.1	<0.1
Pin pile	Scenario 4	<0.1 (<0.1 - <0.1)	<0.1 (<0.1 - <0.1)	<0.1	<0.1
	Scenario 5	<0.1 (<0.1 - <0.1)	<0.1 (<0.1 - <0.1)	<0.1	<0.1
	Scenario 6	<0.1 (<0.1 - <0.1)	<0.1 (<0.1 - <0.1)	<0.1	<0.1

3.2.4. Harbour porpoise

When the SCANS point estimate was used to describe their spatial distribution/density, the number of harbour porpoises estimated to have the potential to be exposed to noise levels sufficient to induce the onset of cumulative PTS varied from 39 to 67 for monopiles and 11 to 39 for pin piles (Table 3.6). When expressed as a percentage of the reference population, these numbers represented less than 0.1% (Table 3.7), i.e., minor effect and not significant.

The numbers of individuals (and therefore percentage of the reference population) were lower (generally around 90% of the SCANS point estimate values) when the SCANS density surface was used (Table 3.6).

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[4] Although the percentage of the reference population these numbers represent has not been calculated it can be assumed that, at less than 1 individual, they represent a minor effect.

Table 3.6: Number of harbour porpoise predicted to be impacted by PTS onset under different scenarios – PTS threshold 155 dB, Very High Frequency weighted (and 95% CIs)

Pile type	Scenario	SCANS point estimate		SCANS density surface	
		Location F3	Location F4	Location F3	Location F4
Monopile	Scenario 1	42 (22 – 71)	39 (21 – 67)	37	36
	Scenario 2	51 (27 – 87)	48 (26 – 83)	45	44
	Scenario 3	67 (35 – 115)	64 (34 – 109)	59	59
Pin pile	Scenario 4	19 (10 – 33)	18 (9 – 30)	17	16
	Scenario 5	39 (21 – 68)	37 (20 – 64)	35	34
	Scenario 6[5]	12 (6 – 21)	11 (6 – 20)	10	11

Table 3.7: Percentage of harbour porpoise population predicted to be impacted by PTS onset under different scenarios (current WC location used)

Pile type	Scenario	% of harbour porpoise reference population	
		SCANS point estimate	SCANS density surface
Monopile	Scenario 1	<0.1	<0.1
	Scenario 2	<0.1	<0.1
	Scenario 3	<0.1	<0.1
Pin pile	Scenario 4	<0.1	<0.1
	Scenario 5	<0.1	<0.1
	Scenario 6	<0.1	<0.1

3.2.5. Grey seal

The number of grey seals estimated to have the potential to be exposed to noise levels sufficient to induce the onset of cumulative PTS was ≤0.02 for both monopiles and pin piles (Table 3.8), i.e., minor effect[6] and not significant.

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[5] Even though the overall maximum energy is the highest, scenario 6 creates the lowest SEL_{cum} ranges for fleeing animals due to the soft start used. In general, when considering SEL_{cum} calculations the most important part is where the receptor is closest to the noise source; in this case it is during the piling soft start. Scenario 6 utilised a minute of slow piling before reaching similar speeds to Scenario 5. This means that the receptor was able to flee further between each pile strike, reaching greater ranges before the louder pile strikes occur.

[6] Although the percentage of the reference population these numbers represent has not been calculated it can be assumed that, at less than 1 individual, they represent a minor effect.

Table 3.8: **Number of grey seal predicted to be impacted by PTS onset under different scenarios – PTS threshold 185 dB, PCW frequency weighted (and 95% CIs)**

Pile type	Scenario	Carter scaled surface		SMRU usage	
		Location F3	Location F4	Location F3	Location F4
Monopile	Scenario 1	0.01 (<0.01 – 0.01)	0.02 (0.01 – 0.03)	<0.01 (<0.01 – 0.01)	<0.01 (<0.01 – 0.01)
	Scenario 2	0.01 (<0.01 – 0.01)	0.02 (0.01 – 0.03)	<0.01 (<0.01 – 0.01)	<0.01 (<0.01 – 0.01)
	Scenario 3	0.01 (<0.01 – 0.01)	0.02 (0.01 – 0.03)	<0.01 (<0.01 – 0.01)	<0.01 (<0.01 – 0.01)
Pin pile	Scenario 4	0.01 (<0.01 – 0.01)	0.02 (0.01 – 0.03)	<0.01 (<0.01 – 0.01)	<0.01 (<0.01 – 0.01)
	Scenario 5	0.01 (<0.01 – 0.01)	0.02 (0.01 – 0.03)	<0.01 (<0.01 – 0.01)	<0.01 (<0.01 – 0.01)
	Scenario 6	0.01 (<0.01 – 0.01)	0.02 (0.01 – 0.03)	<0.01 (<0.01 – 0.01)	<0.01 (<0.01 – 0.01)

3.2.6. Harbour seal

The number of harbour seals estimated to have the potential to be exposed to noise levels sufficient to induce the onset of cumulative PTS was less than 0.01 for both monopiles and pin piles (Table 3.9), i.e., minor effect[7] and not significant.

Table 3.9: **Number of harbour seal predicted to be impacted by PTS onset under different scenarios – PTS threshold 185 dB, PCW frequency weighted (and 95% CIs)**

Pile type	Scenario	Carter scaled surface		SMRU usage	
		Location F3	Location F4	Location F3	Location F4
Monopile	Scenario 1	<0.01 (<0.01 – <0.01)	<0.01 (<0.01 – <0.01)	<0.01 (<0.01 – 0.01)	<0.01 (<0.01 – <0.01)
	Scenario 2	<0.01 (<0.01 – <0.01)	<0.01 (<0.01 – <0.01)	<0.01 (<0.01 – 0.01)	<0.01 (<0.01 – <0.01)
	Scenario 3	<0.01 (<0.01 – <0.01)	<0.01 (<0.01 – <0.01)	<0.01 (<0.01 – 0.01)	<0.01 (<0.01 – <0.01)
Pin pile	Scenario 4	<0.01 (<0.01 – <0.01)	<0.01 (<0.01 – <0.01)	<0.01 (<0.01 – 0.01)	<0.01 (<0.01 – <0.01)
	Scenario 5	<0.01 (<0.01 – <0.01)	<0.01 (<0.01 – <0.01)	<0.01 (<0.01 – 0.01)	<0.01 (<0.01 – <0.01)
	Scenario 6	<0.01 (<0.01 – <0.01)	<0.01 (<0.01 – <0.01)	<0.01 (<0.01 – 0.01)	<0.01 (<0.01 – <0.01)

3.3. Displacement

The total number of individuals which have the potential to be exposed to noise levels sufficient to induce a behavioural response (displacement) has been presented by species for the different scenarios in the following sections.

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[7] Although the percentage of the reference population these numbers represent has not been calculated it can be assumed that, at less than 1 individual, they represent a minor effect.

The outputs from the analysis using the realisation of the Graham curve (used for the cetacean species) that is based on the final (86th) piling location have been expressed as a percentage of the relevant reference population (see Appendix B) and assessed. However, as described in section 2.3.3, outputs from the analysis using the curve based on the first piling location have also been presented to illustrate the effect this assumption (that animals within the vicinity of the Inch Cape Offshore Wind Farm will not be naïve to pile driving noise) has on the predictions.

3.3.1. Minke whale

When the SCANS point estimate was used to describe their spatial distribution/density, the number of minke whales estimated to have the potential to be exposed to noise levels sufficient to induce a behavioural response (displacement) varied from 173 to 183 for monopiles and 140 to 165 for pin piles (Table 3.10). When expressed as a percentage of the reference population (Table 3.11), these numbers represented less than 1%, i.e., minor effect and not significant (Table 2.8). For comparison, the numbers of animals affected are only slightly elevated if they are considered to be naïve to piling noise (Table 3.12), though this is considered to be an unrealistic scenario.

The numbers of individuals (and therefore percentage of the reference population) predicted to be displaced were much lower (52 to 53% of the SCANS point estimate values) when the SCANS density surface was used (Table 3.10).

Table 3.10: Number of minke whale predicted to be displaced under different scenarios (and 95% CIs) – Graham final pile

Pile type	Scenario	SCANS point estimate		SCANS density surface	
		Location F3	Location F4	Location F3	Location F4
Monopile	Scenario 1	173 (42 – 471)	176 (43 – 477)	91	92
	Scenario 2	178 (43 – 484)	180 (44 – 490)	94	94
	Scenario 3	180 (44 – 490)	183 (45 – 496)	95	96
Pin pile	Scenario 4	140 (34 – 380)	143 (35 – 388)	73	74
	Scenario 5	159 (39 – 433)	162 (40 – 440)	83	85
	Scenario 6	162 (40 – 440)	165 (40 – 447)	85	86

Table 3.11: Percentage of minke whale population predicted to be displaced under different scenarios (current WC location used) – Graham final pile

Pile type	Scenario	% of minke whale reference population	
		SCANS point estimate	SCANS density surface
Monopile	Scenario 1	0.9	0.5
	Scenario 2	0.9	0.5
	Scenario 3	0.9	0.5
Pin pile	Scenario 4	0.7	0.4
	Scenario 5	0.8	0.4
	Scenario 6	0.8	0.4

Table 3.12: Number of minke whale predicted to be displaced under different scenarios (and 95% CIs) – Graham first pile

Pile type	Scenario	SCANS point estimate		SCANS density surface	
		Location F3	Location F4	Location F3	Location F4
Monopile	Scenario 1	213 (52 – 579)	217 (53 – 589)	112	113
	Scenario 2	219 (53 – 594)	222 (54 – 604)	116	116
	Scenario 3	221 (54 – 602)	225 (55 – 611)	117	118
Pin pile	Scenario 4	173 (42 – 469)	178 (43 – 482)	90	92
	Scenario 5	196 (48 – 533)	201 (49 – 545)	103	105
	Scenario 6	199 (49 – 542)	204 (50 – 554)	105	106

3.3.2. Bottlenose dolphin

The number of bottlenose dolphins estimated to have the potential to be exposed to noise levels sufficient to induce a behavioural response (displacement) varied from 15 to 18 for monopiles and 12 to 17 for pin piles (Table 3.13). When expressed as a percentage of the reference population (Table 3.14), these numbers represented 8% for monopiles and 6.7 to 7.6% for pin piles, i.e., minor effect and not significant. For comparison, the numbers of animals affected are only slightly elevated if they are considered to be naïve to piling noise (Table 3.15), though this is considered to be an unrealistic scenario.

Table 3.13: Number of bottlenose dolphin predicted to be displaced under different scenarios (and 95% CIs) – Graham dose-response, final pile

Pile type	Scenario	Inferred ‘coastal strip’ surface	
		Location F3	Location F4
Monopile	Scenario 1	18 (17 - 18)	15 (14 - 16)
	Scenario 2	18 (17 - 19)	15 (15 - 16)
	Scenario 3	18 (17 - 19)	16 (15 - 16)
Pin pile	Scenario 4	15 (14 - 16)	12 (12 - 13)
	Scenario 5	17 (16 - 17)	14 (13 - 14)
	Scenario 6	17 (16 - 18)	14 (13 - 15)

Table 3.14: Percentage of bottlenose population predicted to be displaced under different scenarios (current WC location used) – Graham final pile

Pile type	Scenario	% of bottlenose dolphin reference population
		Inferred 'coastal strip' surface
Monopile	Scenario 1	8
	Scenario 2	8
	Scenario 3	8
Pin pile	Scenario 4	6.7
	Scenario 5	7.6
	Scenario 6	7.6

Table 3.15: Number of bottlenose dolphin predicted to be displaced under different scenarios (and 95% CIs) – Graham dose-response, first pile

Pile type	Scenario	Inferred 'coastal strip' surface	
		Location F3	Location F4
Monopile	Scenario 1	23 (22 - 24)	20 (19 - 20)
	Scenario 2	23 (22 - 24)	20 (19 - 21)
	Scenario 3	23 (22 - 24)	20 (19 - 21)
Pin pile	Scenario 4	20 (19 - 21)	16 (16 - 17)
	Scenario 5	21 (21 - 22)	18 (17 - 19)
	Scenario 6	22 (21 - 23)	19 (18 - 19)

3.3.3. White-beaked dolphin

When the SCANS point estimate was used to describe their spatial distribution/density, the number of white-beaked dolphins estimated to have the potential to be exposed to noise levels sufficient to induce a behavioural response (displacement) varied from 1086 to 1144 for monopiles and 876 to 1032 for pin piles (Table 3.16). When expressed as a percentage of the reference population (Table 3.17), these numbers represented 2.5 to 2.6% for monopiles and 2 to 2.3% for pin piles, i.e., minor effect and not significant. For comparison, the numbers of animals affected are elevated if they are considered to be naïve to piling noise (Table 3.18), though this is considered to be an unrealistic scenario.

The numbers of individuals (and therefore percentage of the reference population) predicted to be displaced were much lower (23 to 31% of the SCANS point estimate values) when the SCANS density surface was used (Table 3.16).

Table 3.16: Number of white-beaked dolphin predicted to be displaced under different scenarios (and 95% CIs) – Graham final pile dose-response

Pile type	Scenario	SCANS point estimate		SCANS density surface	
		Location F3	Location F4	Location F3	Location F4
Monopile	Scenario 1	1086 (222 - 2309)	1101 (225 - 2340)	339	261
	Scenario 2	1116 (228 - 2372)	1130 (231 - 2402)	350	269
	Scenario 3	1130 (231 - 2403)	1144 (234 - 2432)	355	273
Pin pile	Scenario 4	876 (179 - 1862)	895 (183 - 1902)	266	207
	Scenario 5	998 (204 - 2122)	1015 (208 - 2158)	308	238
	Scenario 6	1016 (208 - 2159)	1032 (211 - 2195)	315	243

Table 3.17: Percentage of white-beaked dolphin reference population predicted to be displaced under different scenarios (current WC location used) – Graham final pile

Pile type	Scenario	% of white-beaked dolphin reference population	
		SCANS point estimate	SCANS density surface
Monopile	Scenario 1	2.5	0.8
	Scenario 2	2.6	0.8
	Scenario 3	2.6	0.8
Pin pile	Scenario 4	2.0	0.6
	Scenario 5	2.3	0.7
	Scenario 6	2.3	0.7

Table 3.18: Number of white-beaked dolphin predicted to be displaced under different scenarios (and 95% CIs) – Graham first pile dose-response

Pile type	Scenario	SCANS point estimate		SCANS density surface	
		Location F3	Location F4	Location F3	Location F4
Monopile	Scenario 1	1335 (273 - 2839)	1359 (278 - 2890)	413	319
	Scenario 2	1371 (280 - 2915)	1394 (285 - 2963)	426	328
	Scenario 3	1388 (284 - 2951)	1410 (288 - 2999)	432	333
Pin pile	Scenario 4	1081 (221 - 2298)	1112 (227 - 2365)	325	254
	Scenario 5	1229 (251 - 2613)	1257 (257 - 2672)	376	292
	Scenario 6	1250 (256 - 2658)	1278 (261 - 2717)	384	297

3.3.4. Harbour porpoise

When the SCANS point estimate was used to describe their spatial distribution/density, the number of harbour porpoises estimated to potentially be exposed to noise sufficient to induce a behavioural response (displacement) varied from 2677 to 2819 for monopiles and 2158 to 2544 for pin piles (Table 3.19). When expressed as a percentage of the reference population (Table 3.20), these numbers represented 0.8% for monopiles and 0.6 to 0.7% for pin piles, i.e., minor effect and not significant. For comparison, the numbers of animals affected are elevated if they are considered to be naïve to piling noise (Table 3.21), though this is considered to be an unrealistic scenario.

The numbers of individuals (and therefore percentage of the reference population) predicted to be displaced were lower (generally around 90% of the SCANS point estimate values) when the SCANS density surface was used (Table 3.19).

Table 3.19: Number of harbour porpoise predicted to be displaced under different scenarios (and 95% CIs) – Graham final pile

Pile type	Scenario	SCANS point estimate		SCANS density surface	
		Location F3	Location F4	Location F3	Location F4
Monopile	Scenario 1	2677 (1426 - 4607)	2712 (1445 - 4669)	2363	2445
	Scenario 2	2750 (1465 - 4733)	2785 (1483 - 4793)	2430	2511
	Scenario 3	2785 (1484 - 4794)	2819 (1502 - 4852)	2463	2543
Pin pile	Scenario 4	2158 (1150 - 3715)	2204 (1174 - 3794)	1885	1971
	Scenario 5	2460 (1310 - 4234)	2501 (1332 - 4304)	2167	2245
	Scenario 6	2503 (1333 – 4308)	2544 (1355 - 4379)	2208	2287

Table 3.20: Percentage of harbour porpoise population predicted to be displaced under different scenarios (current WC location used) – Graham final pile

Pile type	Scenario	% of harbour porpoise reference population	
		SCANS point estimate	SCANS density surface
Monopile	Scenario 1	0.8	0.7
	Scenario 2	0.8	0.7
	Scenario 3	0.8	0.7
Pin pile	Scenario 4	0.6	0.6
	Scenario 5	0.7	0.6
	Scenario 6	0.7	0.7

Table 3.21: Number of harbour porpoise predicted to be displaced under different scenarios (and 95% CIs) – Graham first pile

Pile type	Scenario	SCANS point estimate		SCANS density surface	
		Location F3	Location F4	Location F3	Location F4
Monopile	Scenario 1	3290 (1753 - 5663)	3349 (1784 - 5765)	2920	3017
	Scenario 2	3378 (1800 - 5815)	3435 (1830 - 5912)	3002	3097
	Scenario 3	3421 (1822 - 5888)	3476 (1852 - 5983)	3042	3135
Pin pile	Scenario 4	2664 (1419 - 4585)	2741 (1460 - 4719)	2338	2449
	Scenario 5	3028 (1613 - 5213)	3098 (1650 - 5332)	2678	2779
	Scenario 6	3081 (1641 - 5302)	3149 (1677 - 5420)	2728	2828

3.3.5. Grey seal

When the Carter scaled surface was used to describe their spatial distribution/density, the number of grey seals estimated to have the potential to be exposed to noise levels sufficient to induce a behavioural response (displacement) varied from 1669 to 2138 for monopiles and 1239 to 1901 for pin piles (Table 3.22). When expressed as a percentage of the reference population (Table 3.23), these numbers represented 13.3 to 13.9% for monopiles and 9.9 to 12.3% for pin piles, i.e., minor to moderate effect and not significant.

The numbers of individuals (and therefore percentage of the reference population) predicted to be displaced were much lower (27 to 35% of the Carter scaled surface values) when the SMRU usage density surface was used (Table 3.22). When expressed as a percentage of the reference population these (SMRU usage density surface-derived) numbers represented 3.6 to 3.8% for monopiles and 2.8 to 3.4% for pin piles i.e., minor effect (and not significant).

Table 3.22: Number of grey seal predicted to be displaced under different scenarios (and 95% CIs) – Whyte dose-response relationship (highest displacement rate assumed from 170 dB up)

Pile type	Scenario	Carter scaled surface		SMRU usage	
		Location F3	Location F4	Location F3	Location F4
Monopile	Scenario 1	1669 (835 - 2526)	2045 (1025 - 3161)	534 (190 - 877)	562 (208 - 917)
	Scenario 2	1752 (874 - 2665)	2119 (1062 - 3273)	561 (199 - 924)	575 (214 - 935)
	Scenario 3	1793 (896 - 2723)	2138 (1072 - 3301)	569 (202 - 935)	579 (216 - 942)
Pin pile	Scenario 4	1239 (616 - 1884)	1524 (777 - 2270)	428 (147 - 708)	426 (157 - 694)
	Scenario 5	1429 (711 - 2171)	1882 (943 - 2901)	479 (168 - 790)	517 (192 - 843)
	Scenario 6	1462 (728 - 2223)	1901 (953 - 2928)	486 (171 – 801)	523 (194 - 852)

Table 3.23: Percentage of grey seal population predicted to be displaced under different scenarios (current WC location used) – Whyte dose-response relationship (highest displacement rate assumed from 170 dB up)

Pile type	Scenario	% of grey seal reference population	
		Carter scaled surface	SMRU usage
Monopile	Scenario 1	13.3	3.6
	Scenario 2	13.8	3.7
	Scenario 3	13.9	3.8
Pin pile	Scenario 4	9.9	2.8
	Scenario 5	12.2	3.4
	Scenario 6	12.3	3.4

3.3.6. Harbour seal

When the SMRU usage density surface was used to describe their spatial distribution/density, the number of harbour seals estimated to have the potential to be exposed to noise levels sufficient to induce a behavioural response (displacement) varied from 14 to 16 for monopiles and 13 to 16 for pin piles (Table 3.24). When expressed as a percentage of the reference population (Table 3.25), these numbers represented 3.4% for monopiles and 3.2 to 3.4% for pin piles i.e., minor effect (and not significant).

The numbers of individuals (and therefore percentage of the reference population) predicted to be displaced were lower (54 to 88% of the SMRU usage density surface values) when the Carter scaled surface was used (Table 3.24).

Table 3.24: Number of harbour seal predicted to be displaced under different scenarios (and 95% CIs) – Whyte dose-response relationship (highest displacement rate assumed from 170 dB up)

Pile type	Scenario	Carter scaled surface		SMRU usage	
		Location F3	Location F4	Location F3	Location F4
Monopile	Scenario 1	11 (2 - 37)	12 (3 - 39)	16 (2 - 30)	14 (2 - 25)
	Scenario 2	14 (3 - 41)	12 (3 - 39)	16 (2 - 30)	14 (2 - 26)
	Scenario 3	14 (3 - 42)	12 (3 - 40)	16 (2 - 30)	14 (2 - 26)
Pin pile	Scenario 4	9 (2 - 31)	7 (1 - 28)	15 (2 - 28)	13 (2 - 23)
	Scenario 5	10 (2 - 34)	11 (2 - 37)	16 (2 - 29)	13 (2 - 25)
	Scenario 6	10 (2 - 35)	11 (2 - 37)	16 (2 - 29)	13 (2 - 25)

Table 3.25: Percentage of harbour seal population predicted to be displaced under different scenarios (current WC location used) – Whyte dose-response relationship (highest displacement rate assumed from 170 dB up)

Pile type	Scenario	% of harbour seal reference population	
		Carter scaled surface	SMRU usage
Monopile	Scenario 1	2.3	3.4
	Scenario 2	2.9	3.4
	Scenario 3	2.9	3.4
Pin pile	Scenario 4	1.9	3.2
	Scenario 5	2.1	3.4
	Scenario 6	2.1	3.4

4. Conclusions

Instantaneous PTS: Although the maximum impact ranges were up to 710 m for monopiles and 600 m for pin piles for very high frequency cetaceans, they were ≤60 m for the other hearing groups (low frequency cetaceans, high frequency cetaceans, phocid seals in water). Appropriate use of mitigation (i.e., activation of an acoustic deterrent device) will ensure that no animals are present within the zone of potential impact. The potential impact (with mitigation) of instantaneous PTS is therefore considered to be zero, i.e., no effect (and not significant; see Table 2.8).

Cumulative PTS and displacement: The numbers of individuals (of the different species) estimated to have the potential to be exposed to noise levels sufficient to induce the onset of cumulative PTS or a behavioural response (displacement) were greater than those presented in the 2018 EIAR. This is the result of a combination of factors; use of a different noise modelling approach (Subacoustech's INSPIRE as opposed to Cefas' model[8]), use of different species density surfaces, use of different noise dose-behavioural response relationships, and use of greater hammer energies. However, when expressed as percentages of the relevant reference populations and used to predict the significance of the potential effects, these potential impacts were considered to result in nil, minor, or moderate effects only. Using the same criteria (for predicting significance of effects) as the 2013 ES and 2018 EIAR, these potential effects were not significant.

The findings of this exercise are in line with those from the 2018 EIAR, i.e., no significant effects. As such, use of greater hammer energies can be considered acceptable.

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[8] Subacoustech note that contours from their INSPIRE model are consistent with what is observed in the field (see section 2.2).

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Appendices

A. Fish assessment

A.1. Introduction

This Appendix describes the underwater noise propagation and subsequent modelling work which has been undertaken to determine whether there is potential for significant effects on fish when using greater hammer energies. In line with the 2018 EIAR (ICOL, 2018), the assessment scope covers any impacts of barrier effects, disturbance or physical injury associated with construction noise from piling on species of fish with particular sensitivity to noise. As such the same species (fish receptor group) have also been included in this assessment: cod (*Gadus morhua*), herring (*Clupea harengus*), allis shad (*Alosa alosa*), twaite shad (*Alosa fallax*) and sprat (*Sprattus sprattus*).

To allow for comparison, the 2018 EIAR assessment scenario and conclusions are summarised below, followed by the new model parameters, outputs, and updated conclusions.

A.2. Previous assessment scenario and conclusions

2018 EIAR Worst Case Scenarios

The design envelope parameters for the worst-case scenario from piling impacts in the 2018 EIAR are detailed in Table A.1 and A.2 below.

Table 5.1: Worst case scenario pin piles: 2.4 m pile diameter installed with a maximum hammer capacity of 2400 kJ

	% of hammer capacity			
	10%	**20%**	**30%**	**90%**
Blow energy	240 kJ	480 kJ	720 kJ	2160 kJ
Duration	20 mins	20 mins	10 mins	106 mins
Strike rate	During soft start: ~ 18 blows/min After soft start: ~ 120 blows/min			

Source: ICOL (2018)

Table A5.2: Worst case scenario monopiles: 12 m monopile installed with a maximum hammer capacity of 5000 kJ

	% of hammer capacity			
	10%	**20%**	**30%**	**90%**
Blow energy	500 kJ	1000 kJ	1500 kJ	4500 kJ
Duration	30 mins	20 mins	10 mins	5 hours
Strike rate	17 blows/min	35 blows/min		

Source: ICOL (2018)

2018 Assessment Summary

The assessment methodology for the fish receptor group (as defined above) is outlined in ICOL (2018) in line with *Chartered Institute of Ecology and Environmental Management (CIEEM) Guidelines for Ecological Assessment in the UK and Ireland* (CIEEM, 2016). It evaluates how the baseline conditions will change for each ecological feature scoped into the assessment, the extent of the impacts and their magnitude, duration, timing, frequency, and reversibility. Whether an impact is deemed significant is determined by evaluating the magnitude of the change arising from the Development with the sensitivity (value and vulnerability) of the particular receptor under consideration (ICOL, 2018).

In 2018, the fish receptor group was considered to be of 'moderate' sensitivity. Based on this conclusion it was determined that any effects with a magnitude of moderate or high would result in an ecologically significant effect. Thresholds against which to assess impacts on fish from piling, using the cumulative Sound Exposure Level (SEL_{cum}) metric, have been established in the literature (Popper *et al*., 2014). For the purposes of the assessment thresholds for the most sensitive fish category in terms of hearing effects, i.e., "fish with a swim bladder (or other gas volume) involved in hearing" were used and are summarised below. Peak Sound Pressure Level (SPL) criteria are also included in Popper *et al*. (2014), although the lack of data has led to these generally being defined as "greater than" rather than a specific value and so the focus in this assessment is on SEL_{cum} thresholds, which tend to be more precautionary than Peak SPL.

- Mortality and potential mortal injury – immediate or potentially delayed death (SEL_{cum} – 207 dB re.1 μPa^2s);
- Recoverable injury – injuries, including hair cell damage, minor internal or external hematoma, etc. None of these injuries are likely to result in mortality (SEL_{cum} – 203 dB re.1 μPa^2s); and
- Temporary Threshold Shift (TTS) – short recoverable changes in hearing sensitivity that may or may not reduce fitness (SEL_{cum} – 186 dB re.1 μPa^2s)

No fleeing behaviour was assumed due to uncertainties in specific fish behaviours. Therefore, all ranges calculated for fish are expected to be precautionary, as they assume that an individual would remain static in a high noise area of the water column and make no attempt to seek shelter or a quieter position.

Effect zones for mortality and recoverable injury under the peak SPL criterion for the fish receptor group did not exceed 50 m at the initial hammer energy (areas of 0.01 km^2 and 0.04 km^2 for pin piles and monopiles respectively). Under the cumulative SEL criterion, there were no mortal effects found until the third pin pile in any successive sequence. After all successive pin piles, the following areas of impact were calculated based on the predicted SELs:

- Mortality and mortal injury: 5 km^2
- Recoverable injury: 16.95 km^2
- TTS: 1,738.31 km^2

For monopiles, the impact areas were slightly reduced as the overall cumulative energy was found to be lower for monopile installation compared with piled jackets:

- Mortality and mortal injury: 4.15 km^2
- Recoverable injury: 15.42 km^2
- TTS: 1,655.98 km^2

2018 Conclusions

Overall, the areas affected at the level deemed able to cause mortal or injury effects to the fish receptor group (i.e., species most sensitive to noise) were concluded to be very small. Some interaction with spawning and nursery habitats was expected, however such interactions were considered not to affect key areas of those habitats, or to affect such a small proportion that any effects were considered negligible. For these reasons the magnitude of effect was considered to be low and was not deemed to represent a significant effect.

A.3. New assessment scenarios and conclusions

New Worst Case Scenarios

Under the new model scenarios, the worst-case for peak SPL criterion and cumulative SEL criterion differed slightly. This is due to different ramp up regimes in the piling, which yield different initial blow energies, number of strikes and durations. For this reason, the worst-case scenarios for peak SPL and cumulative SEL are listed separately below.

The design envelope parameters for the new worst-case scenario from peak/instantaneous piling impacts for both sites (F3 and F4) are detailed in Table A.3 and A.4.

Table A5.3: Worst case scenario (scenario 6) pin piles: 3 m pile diameter installed with a maximum hammer capacity of 3500 kJ, 4 piles installed sequentially

	% of hammer capacity					
	10%		15%	20%	25%	100%
Blow energy	350 kJ		525 kJ	700 kJ	875 kJ	3500 kJ
No. of strikes	6	90	90	90	90	4896
Duration	1 min	5 mins	5 mins	5 mins	5 mins	2 hours 16 mins
Strike rate	6 blows/min	18 blows/min				36 blows/min

Table 5.4: Worst case scenario (scenario 3) monopiles: 11 m pile diameter installed with a maximum hammer capacity of 5500 kJ

	% of hammer capacity					
	10%		15%	20%	25%	100%
Blow energy	600 kJ		825 kJ	1100 kJ	1375 kJ	5500 kJ
No. of strikes	6	90	90	90	90	12240
Duration	1 min	5 mins	5 mins	5 mins	5 mins	6 hours 58 mins
Strike rate	6 blows/min	18 blows/min				25 blows/min

The design envelope parameters for the new worst-case scenario from cumulative piling impacts for both sites (F3 and F4) in the 2021 assessment are detailed in Table A.5 and A.6.

Table 5.5: Worst case scenario (scenario 5) pin piles: 3 m pile diameter installed with a maximum hammer capacity of 3500 kJ, 4 piles installed sequentially

	% of hammer capacity			
	10%	20%	30%	90%
Blow energy	350 kJ	700 kJ	1050 kJ	3150 kJ
No. of strikes	348	696	348	3689
Duration	20 mins	20 mins	10 mins	1 hour 46 mins
Strike rate	17 blows/min	35 blows/min		

Table 5.6: Worst case scenario (scenario 2) monopiles: 11 m monopile installed with a maximum hammer capacity of 5500 kJ

	% of hammer capacity			
	10%	**20%**	**30%**	**90%**
Blow energy	550 kJ	1100 kJ	1650 kJ	4950 kJ
No. of strikes	522	696	348	10440
Duration	30 mins	20 mins	10 mins	5 hours
Strike rate	17 blows/min	35 blows/min		

Assessment

The baseline conditions, data sources and receptor sensitivities outlined in ICOL (2018) are deemed to provide a suitable picture of receptor distribution and abundance to allow a robust assessment to be undertaken. The magnitude of impact has been reassessed with the updated model outputs based on professional judgement, expert opinion and the use of the INSPIRE model (v5.1). As in 2018, based on the moderate sensitivity of the fish receptor group, effects with a magnitude of moderate or high are considered to result in an ecologically significant effect. The Popper *et al.* (2014) SELs have also been used.

The maximum effect zones for mortality and recoverable injury under the peak SPL criterion for fish were 0.23 km^2 and 0.33 km^2 for pin piles and monopiles respectively.

Under the cumulative SEL criterion for pin piles, the following maximum areas of impact were calculated based on the predicted SELs (across both sites):

- Mortality and mortal injury: 100 km^2
- Recoverable injury: 260 km^2
- TTS: 2700 km^2

For monopiles the impact areas were slightly reduced for mortality/mortal injury and recoverable injury as the overall cumulative energy was found to be lower for monopile installation compared with piled jackets:

- Mortality and mortal injury: 99 km^2
- Recoverable injury: 250 km^2
- TTS: 2700 km^2

Conclusions - herring

Based on the cumulative SELs, the noise from piling operations could potentially impact herring from the Buchan population off the Aberdeenshire coast when within (or migrating to) their spawning grounds. There remains no potential connectivity with the Banks population off the Berwickshire coast (Figure A1 and A2). Despite the increase in area at all effect levels compared to 2018, the region affected by the piling noise still represents a small proportion of the total available Buchan spawning ground, with a maximum of ~6% overlap for TTS at location F3 (Table A7). TTS is considered as short, recoverable changes in hearing sensitivity that may or may not reduce fitness. The recoverable injury and mortality noise contours overlap a maximum of 0.45% and 0.06% of the spawning ground at location F3 respectively (Table A7). Furthermore, the 2018 spawning study (ICOL, 2018) demonstrated that the southern limits of the Buchan population spawning ground (i.e., that affected by the piling noise) is rarely utilised for spawning activity, with aggregations of spawning fish concentrated in the north.

It is concluded that the assessment detailed in ICOL (2018) for nursery ground impacts remains valid for this updated assessment. Interaction with herring larvae is a possibility due to the southerly direction of travel of this life stage. However only limited effects of piling noise are predicted due to the evidence of limited impacts of noise on larval populations, the small proportion of available nursery grounds impacted by piling noise, and the use of Popper *et al.* (2014) estimates (which are assumed conservative for larval stages).

In summary, although limited injury and mortality effects are possible, it remains that only a small area of the defined spawning grounds will be affected by piling noise from the Development, and the area predicted to be affected is not thought to represent key spawning habitat. Therefore, no loss of key habitat (or barriers to migration to it) is expected. Furthermore, only limited effects of piling noise on herring larvae are predicted. As such, it is considered the effect on herring will be of low magnitude and therefore the effect is not significant.

Table A.7: Area (Km^2) of the noise contours at all effect levels (Popper *et al*. 2014) which overlap with the Buchan herring spawning ground, along with percentage overlap of total spawning ground.

	F3		F4	
	Area (Km^2)	% of spawning ground	Area (km^2)	% of spawning ground
TTS (186 dB)	734.89	6.28	343.12	2.93
Recoverable injury (203 dB)	52.95	0.45	NA	NA
Mortality (207 dB)	7.04	0.06	NA	NA

Conclusions - other species (sprat, cod, and shad)

Although limited injury or mortality effects are possible for these species, these are only likely to affect a small number of individuals due to the lack of large aggregations predicted in the area. Some interaction with spawning and nursery habitats is expected, however such interactions are considered not to affect key/high intensity areas of those habitats or affect such a small proportion that any effects are considered negligible. For these reasons the magnitude of effect is considered to be low and is not deemed to represent a significant effect.

In summary, based on the above assessment the conclusions of the 2018 EIAR for fish remain valid. The magnitude of the effect ‘Barrier effects, disturbance, or physical injury associated with construction noise’ on the fish receptor group is low and not significant.

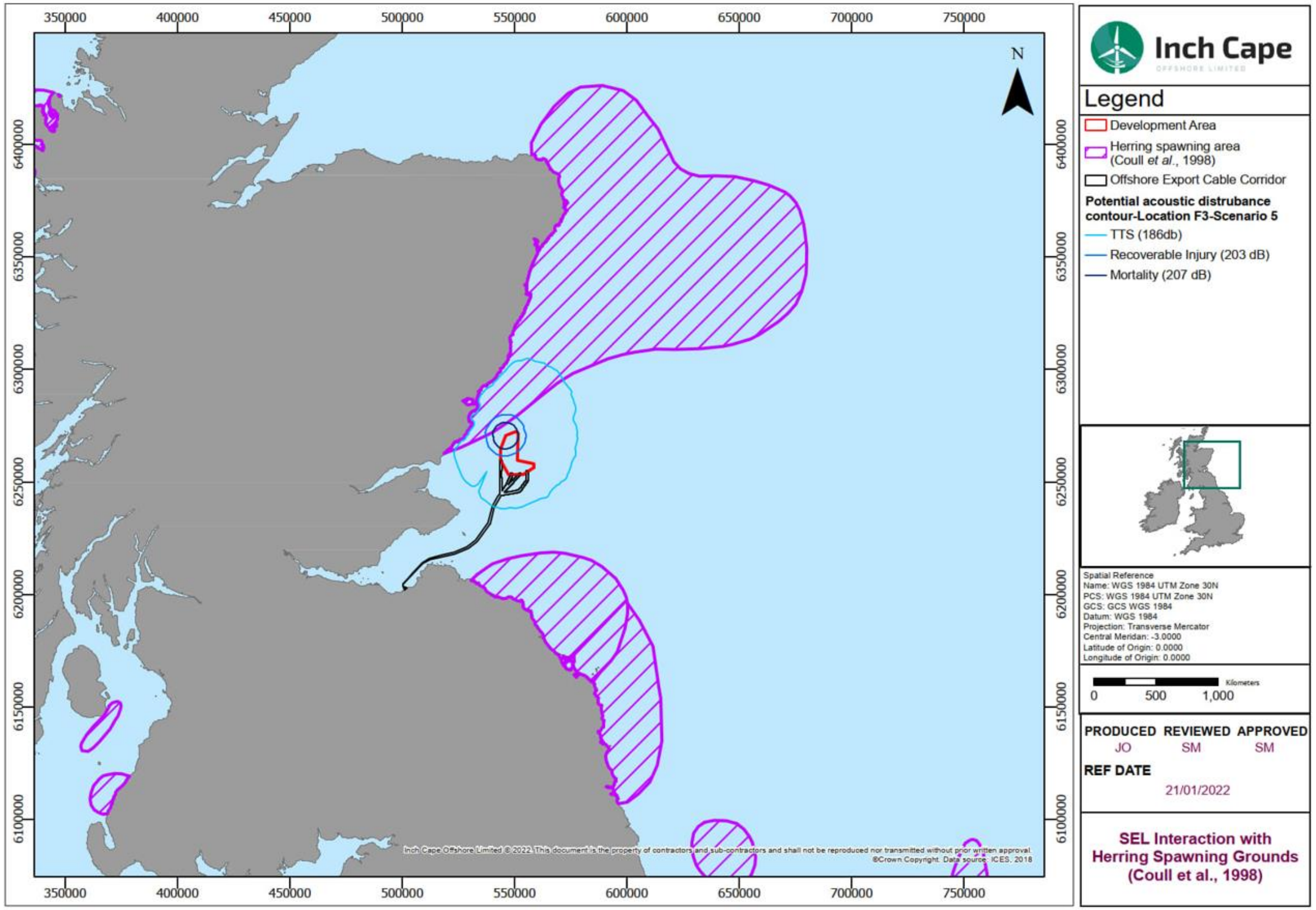

Figure A5.1: Maximum SEL interaction with herring spawning grounds – pin piles at location F3

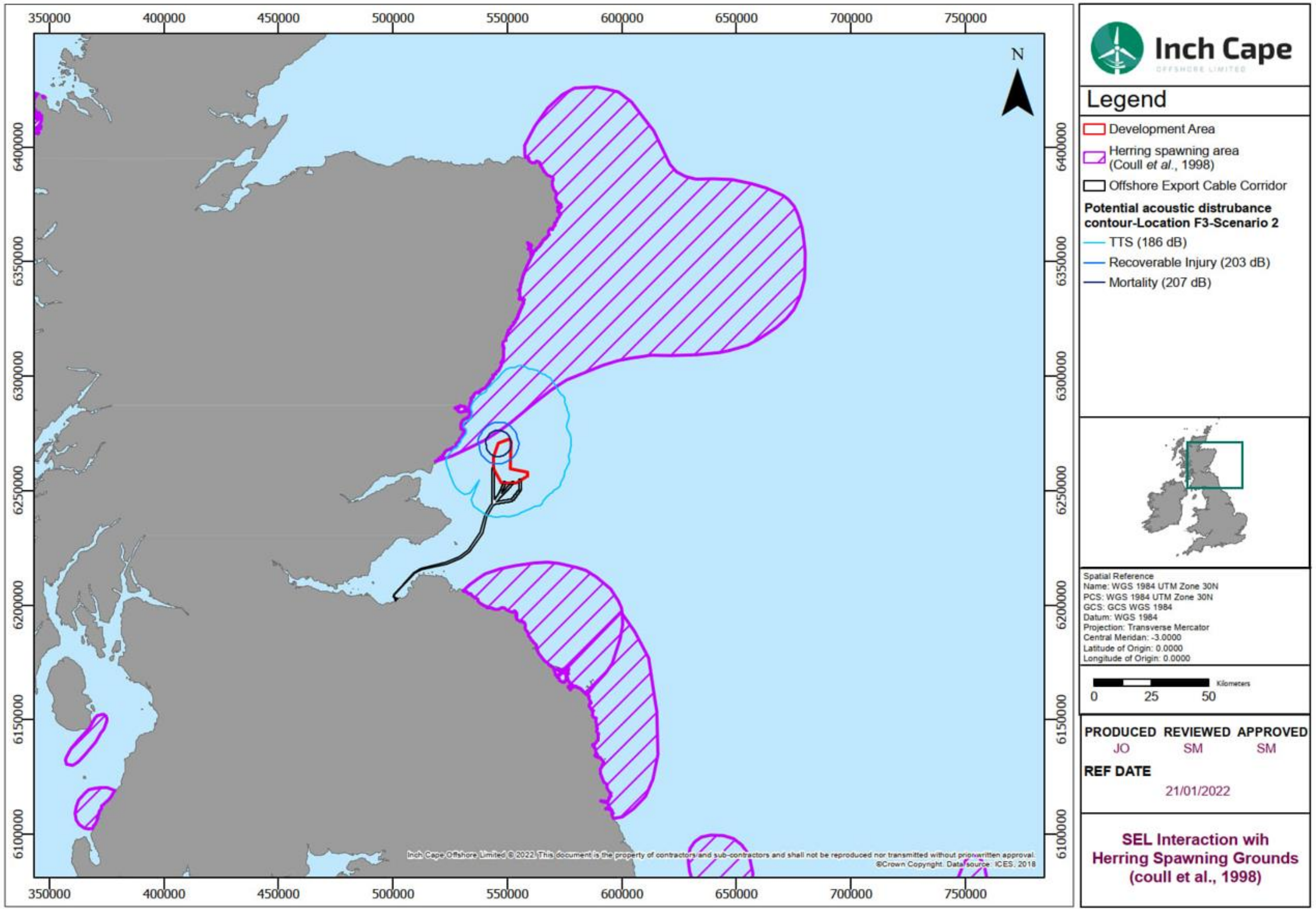

Figure 5.2: Maximum SEL interaction with herring spawning grounds – monopiles at location F3

B. Reference populations for marine mammals

Table B.1: Cetacean reference population abundance estimates. Estimates in **bold** are considered most biologically appropriate and were used in our calculations

Species	Reference population	Abundance		Reference
		Estimate	95% CI	
Minke whale	Celtic and Greater North Seas Management Unit	20,136	11,498-35,264	IAMMWG (2015) revised (Appendix 1 of IAMMWG, 2021)
		20,118	14,061-28,786	IAMMWG (2021)[9]
	UK portion of Celtic and Greater North Seas Management Unit	10,288	6,210-17,042	IAMMWG (2021)
Bottlenose dolphin	East coast population	**224**	214 – 234	This is a five-year weighted average of the estimates presented in Arso Civil *et al*. (2021)
White-beaked dolphin	Celtic and Greater North Seas Management Unit	37,309	21,464-64,852	IAMMWG (2015) revised (Appendix 1 of IAMMWG, 2021)
		43,951	28,439-67,924	IAMMWG (2021)
	UK portion of Celtic and Greater North Seas Management Unit	34,025	20,026-57,807	IAMMWG (2021)
Harbour porpoise	North Sea Management Unit	369,560	241,338-565,906	IAMMWG (2015) revised (Appendix 1 of IAMMWG, 2021)
		346,601	289,498 – 419,967	IAMMWG (2021)
	UK portion of North Sea Management Unit	159,632	127,442-199,954	IAMMWG (2021)
	North Sea ICES Assessment Unit	345,373	246,526-495,752	Hammond *et al*. (2021)[10]

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[9] JNCC has confirmed that this report takes into account the revised SCANS-III estimates (08/10/2021 e-mail to Natural Power).

[10] SCANS-III ICES Assessment Unit abundance estimate provided for harbour porpoise only (by Hammond *et al*., 2021).

Table B.2: Seal reference population abundance estimates. **Bold** estimates are those used in our calculations

Species	Reference population	Abundance		Reference
		Estimate	95% CI	
Grey seal	East Scotland	**15,410**	12,878-19,182	Estimated using the 2016-2019 summer count of 3,683 (SCOS, 2020) and a scalar of 0.239 (0.192-0.286; Russell *et al*., 2016) to correct for the proportion of seals hauled out when the count was made
	North Sea	46,500	35,800-61,600	Thomas (2020), i.e., based on pup production
Harbour seal	East Scotland	**476**	390-635	Estimated using the 2016-2019 summer count of 343 (SCOS, 2020) and a scalar of 0.72 (0.54-0.88; Lonergan *et al*., 2011; Lonergan, 2013) to correct for the proportion of seals hauled out when the count was made

C. Underwater noise criteria (impulsive noise e.g., from pile driving) for marine mammals

Table C.1: Single strike SPL_{peak} criteria (for instantaneous PTS; dB re 1 μPa)

Hearing group	SPL_{peak} criteria
Low frequency cetaceans	219 dB
High frequency cetaceans	230 dB
Very high frequency cetaceans	202 dB
Phocid seals in water	218 dB

Source: Southall et al. (2019)

Note: SPL_{peak} criteria are unweighted.

Table C.2: SEL_{cum} criteria (for cumulative PTS; dB re 1 μPa^{2}s)

Hearing group	SEL_{cum} criteria
Low frequency cetaceans	183 dB
High frequency cetaceans	185 dB
Very high frequency cetaceans	155 dB
Phocid seals in water	185 dB

Source: Southall et al. (2019)

Note: SEL_{cum} criteria are weighted for the hearing sensitivity of their respective species group.

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