Project title	Modelling outputs of piling and dredging off the Isle of Skye
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Author(s)	Richard Barham, Tim Mason
Company	Subacoustech Environmental Ltd.
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Introduction

Piling and dredging activities have been modelled in support of construction work for a new pier near Kyleakin, Isle of Skye, Scotland. This note gives a summary of the modelling outputs.

Source levels

Noise source	Unweighted noise level at 1 m
Impact piling (Tubular piles, 1225 mm diameter, and sheet piles, 1220 – 1300 mm)	227 dB re 1 µPa @ 1 m (Peak)
Impact piling (Sheet piles, 365 x 356 x 133 mm)	208 dB re 1 µPa @ 1 m (Peak)
Vibropiling (Tubular piles, 1225 mm diameter)	193 dB re 1 µPa @ 1 m (RMS)
Vibropiling (Sheet piles, 365 x 356 x 133 mm)	183 dB re 1 µPa @ 1 m (RMS)
Trailer Suction Hopper (TSH) dredging	186 dB re 1 µPa @ 1 m (RMS)
Backhoe dredging	165 dB re 1 µPa @ 1 m (RMS)

Source levels are given as unweighted peak levels for impulsive sounds and unweighted RMS levels for continuous noises. All the source levels have been extrapolated from real measurements taken from Subacoustech's substantial database of underwater noise measurements of piling and dredging.

Impact piling results

Impact piling has been modelled using the INSPIRE model, this model is based upon a large database of measured data and takes differences in bathymetry into account when calculating noise propagation through water. The tables below summarise the maximum unweighted levels predicted at various ranges and the maximum ranges to various noise criteria. A high tide of 5.7 m has been assumed for this modelling based on spring tides for the area. For multiple pulse criteria, a worst case 24 hour period of operation has been assumed, with a blow rate of 1 strike per second, and the receptor fleeing at a rate of 1.5 ms^{-1}.

Where the contours are of a large enough size, they have been presented as contour plots in Figure 1 to Figure 3. Results for small ranges (i.e. less than 100 m) are provided are presented in tables only.

Impact piling	Tubular piles (1225 mm diameter) and Sheet piles (1220 – 1300 mm)	Steel H-piles (365 x 356 x 133 mm)
Max level at 250 m range	186.8 dB re 1 µPa (Peak)	167.4 dB re 1 µPa (Peak)
Max level at 500 m range	181.7 dB re 1 µPa (Peak)	162.3 dB re 1 µPa (Peak)
Max level at 750 m range	178.7 dB re 1 µPa (Peak)	159.3 dB re 1 µPa (Peak)

Southall *et al* (2007)	**Tubular piles (1225 mm diameter) and Sheet piles (1220 – 1300 mm)**	**Steel H-piles (365 x 356 x 133 mm)**
230 dB re 1 µPa^{2}s (SPL_{peak}) (PTS in harbour porpoise)	< 1 m	< 1 m
218 dB re 1 µPa^{2}s (SPL_{peak}) (TTS in harbour porpoise)	3 m	< 1 m
224 dB re 1 µPa^{2}s (SPL_{peak}) (PTS in harbour seal)	1 m	< 1 m
212 dB re 1 µPa^{2}s (SPL_{peak}) (TTS in harbour seal)	6 m	< 1 m
198 dB re 1 µPa^{2}s(M_{hf}) (M-Wtd SEL) (PTS in harbour porpoise, multiple pulse)	3 m	< 1 m
186 dB re 1 µPa^{2}s(M_{pw}) (M-Wtd SEL) (PTS in harbour seal, multiple pulse)	340 m	< 1 m

Nehls *et al* (2014), Tougaard (2013), Lucke *et al* (2009)	**Tubular piles (1225 mm diameter) and Sheet piles (1220 – 1300 mm)**	**Steel H-piles (365 x 356 x 133 mm)**
180 dB re 1 µPa^{2}s (SEL_{ss}) (PTS in harbour porpoise)	21 m	< 1 m
165 dB re 1 µPa^{2}s (SEL_{ss}) (TTS in harbour porpoise)	224 m	7 m
145 dB re 1 µPa^{2}s (SEL_{ss}) (Minor behavioural avoidance in harbour porpoise)	4.8 km	145 m

NOAA Interim Sound Thresholds (Level B behavioural disruption)	**Tubular piles (1225 mm diameter) and Sheet piles (1220 – 1300 mm)**	**Steel H-piles (365 x 356 x 133 mm)**
160 dB re 1 µPa (RMS) (Impulsive noises)	490 m	14 m

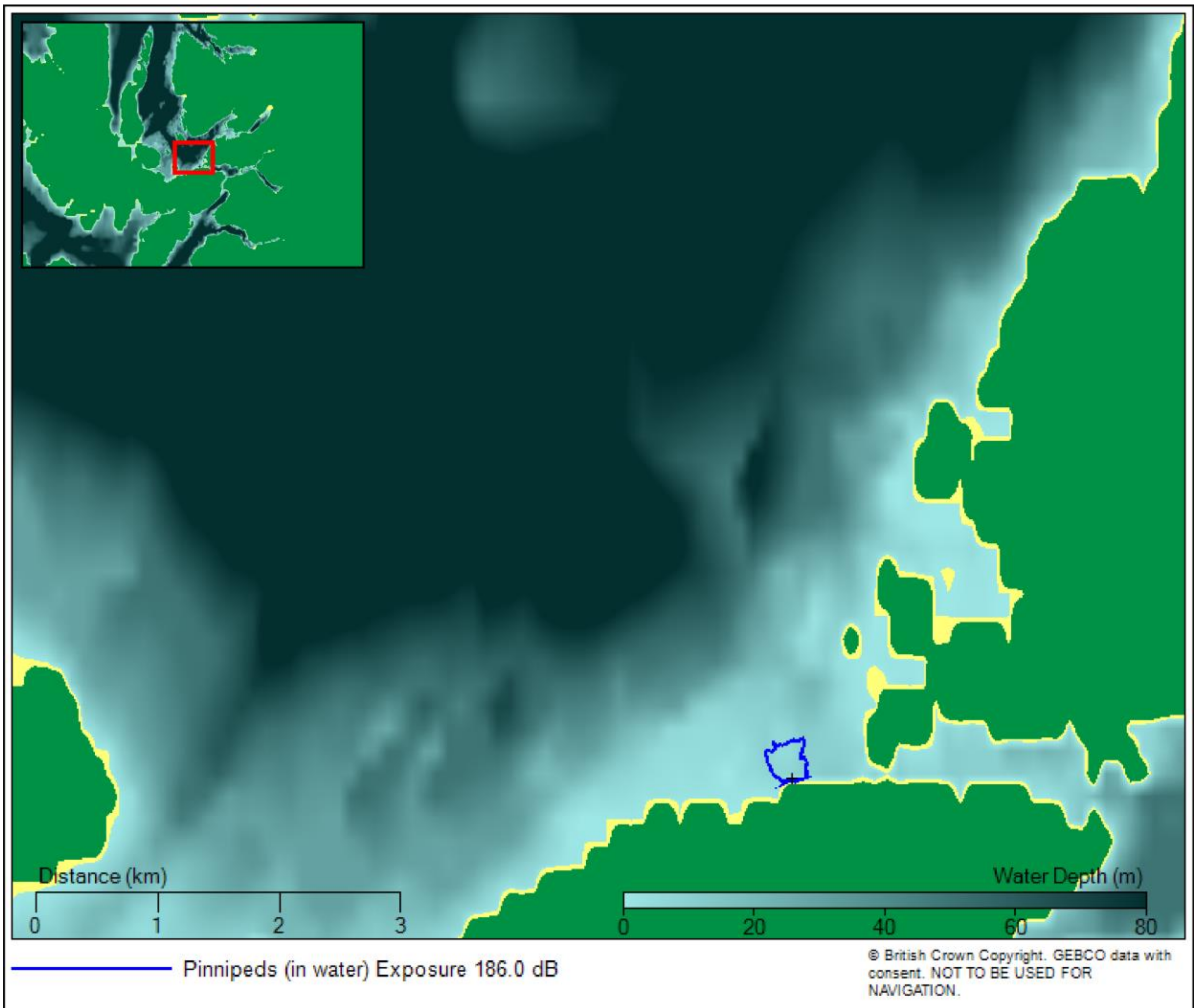

Figure 1 Contour plot showing PTS in harbour seal using the Southall et al (2007) multiple pulse criteria assuming 24 hours exposure and a fleeing animal for impact piling of tubular or sheet piles

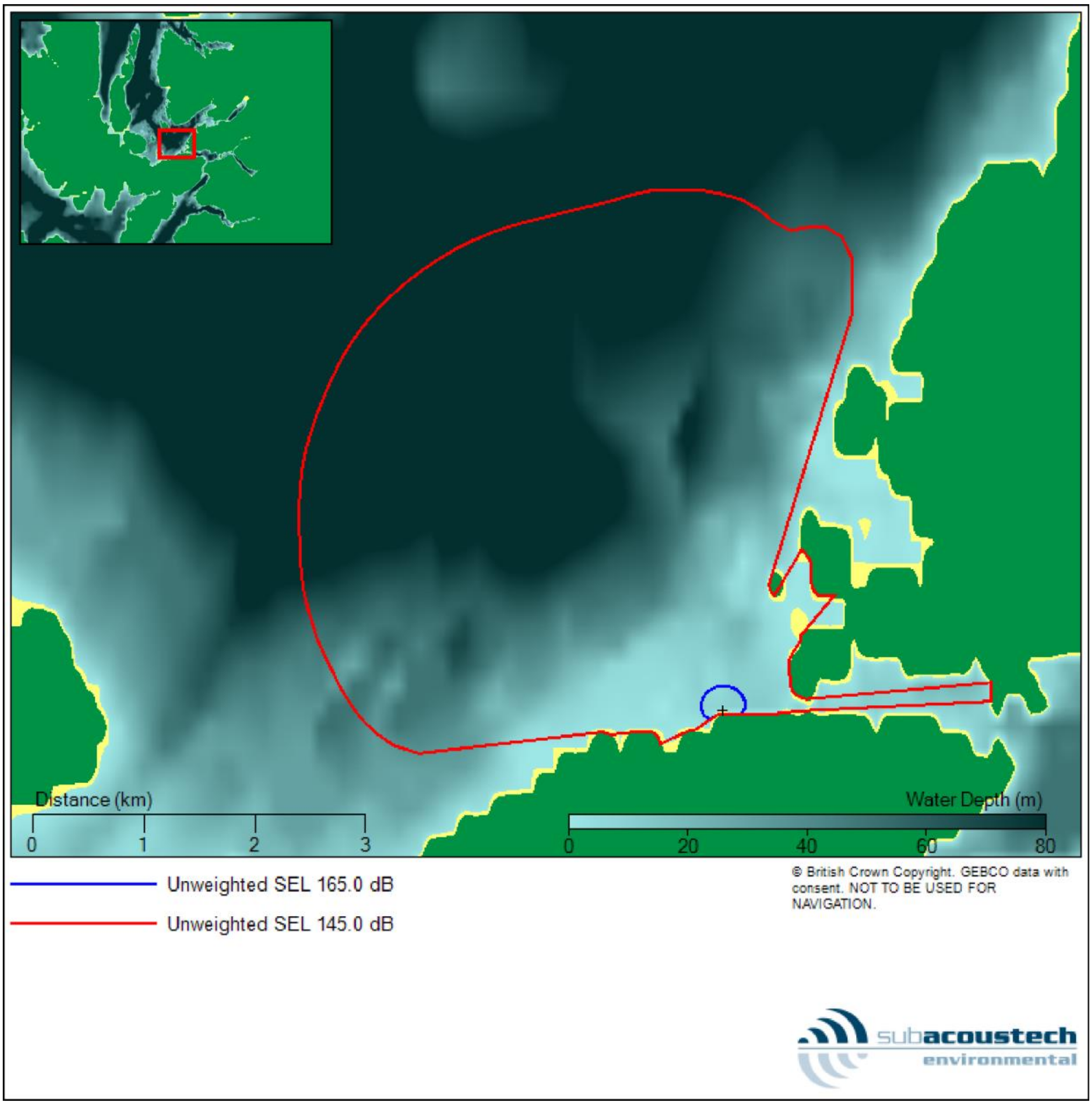

Figure 2 Contour plot showing TTS and minor behavioural avoidance in harbour porpoise using the Nehls et al (2014) and Lucke et al (2009) criteria for impact piling of tubular or sheet piles

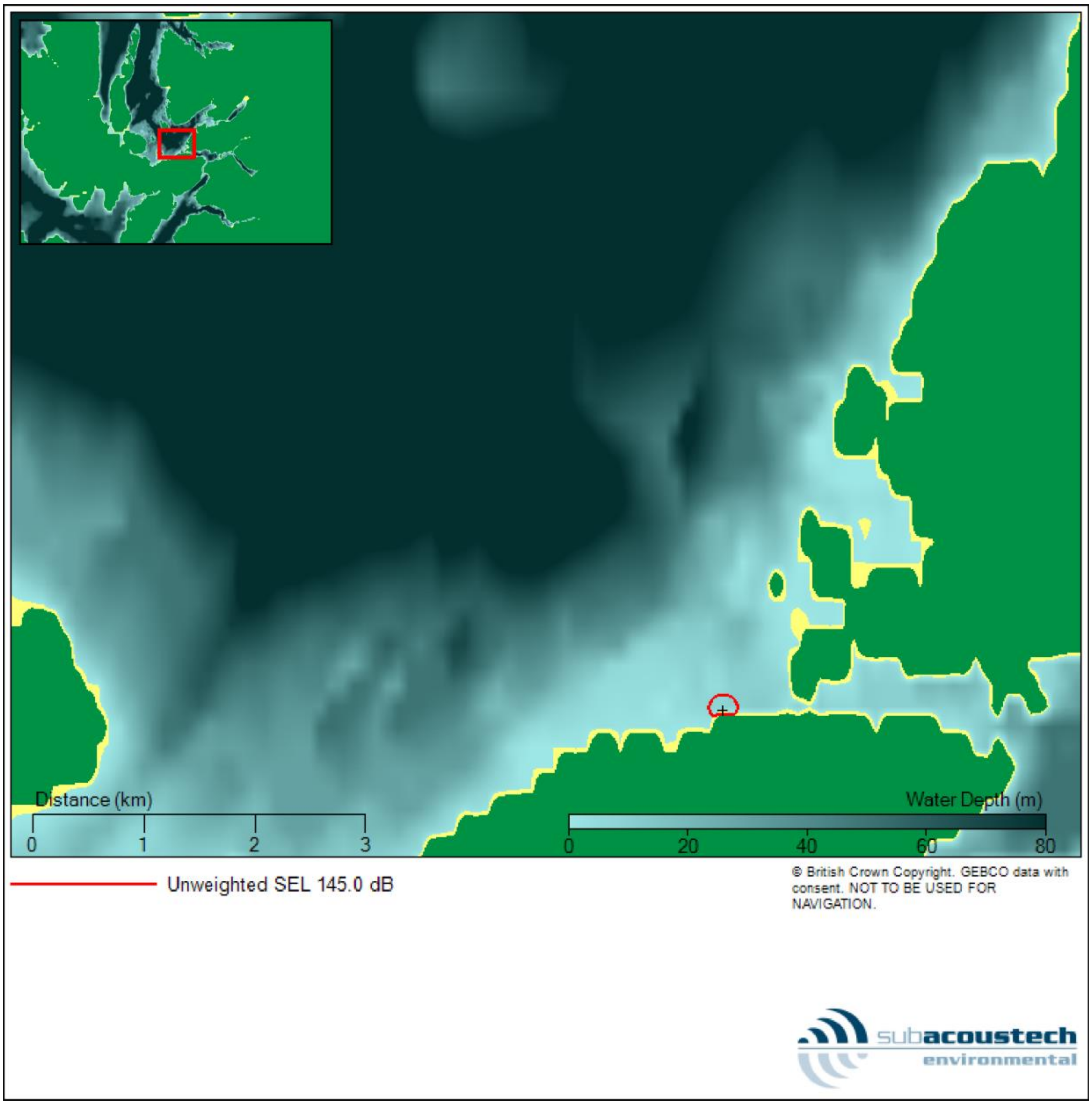

Figure 3 Contour plot showing minor behavioural avoidance in harbour porpoise using the Lucke et al (2009) criteria for impact piling of steel H-Piles

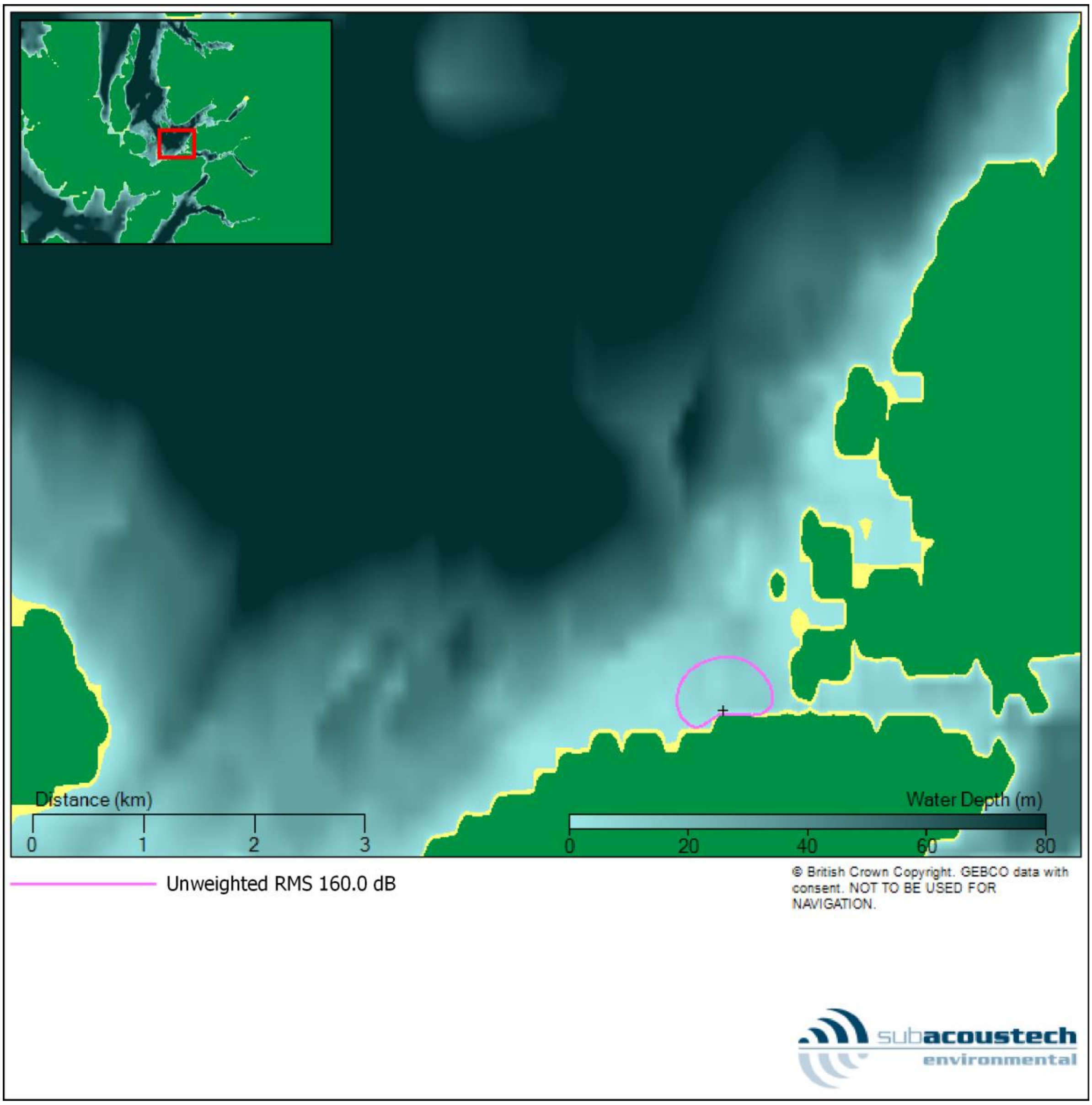

Figure 4 Contour plot showing Level B behavioural disruption in marine mammals using the NOAA interim criteria for impulsive noise for impact piling of tubular or sheet piles

Shapefiles for these contours have also been supplied.

Vibropiling results

The SPEAR model has been used to estimate noise levels from vibropiling activities. The SPEAR model is a SL-TL model based on Subacoustech's measurement database. It does not take local bathymetry into account, although this will have a negligible impact due to the relatively short distances involved. These modelling results have also been compared against recent measurements of vibropiling made by Subacoustech and have shown to give a good estimate of levels for piles of these sizes. The tables below summarise the predicted levels at various ranges and the ranges at which impact criteria are met. A 24 hour worst case assumption has been used to estimate cumulative impacts, with the receptor fleeing at a rate of 1.5 ms^{-1}.

It is worth noting that the NOAA interim criteria used for behavioural disruption gives much larger impact ranges than anything else for vibropiling and the NOAA interim criteria for impact piling from the previous section. The main impact is the use of different criteria; each 3 dB difference represents a doubling (or halving) of sound pressure, meaning the difference between 145 dB and 120 dB is very large and the difference between 160 dB and 120 dB is greater still. By the time distances for noise levels of the order of 120 dB are reached then the noise is decaying very slowly relative to how it attenuates closer to the source. It is also important to note that in terms of a specific noise source, 120 dB is low, and approaching the order of background noise.

Vibropiling	**Tubular piles (1225 mm diameter) and Sheet piles (1220 – 1300 mm)**	**Steel H-Piles (365 x 356 x 133 mm)**
Level at 250 m range	140.7 dB re 1 µPa (RMS)	139.8 dB re 1 µPa (RMS)
Level at 500 m range	136.7 dB re 1 µPa (RMS)	134.4 dB re 1 µPa (RMS)
Level at 750 m range	134.3 dB re 1 µPa (RMS)	131.2 dB re 1 µPa (RMS)

Southall *et al* (2007)	**Tubular piles (1225 mm diameter) and Sheet piles (1220 – 1300 mm)**	**Steel H-Piles (365 x 356 x 133 mm)**
230 dB re 1 µPa^2s (SPL_{peak}) (PTS in harbour porpoise)	< 1 m	< 1 m
218 dB re 1 µPa^2s (SPL_{peak}) (TTS in harbour porpoise)	< 1 m	< 1 m
224 dB re 1 µPa^2s (SPL_{peak}) (PTS in harbour seal)	< 1 m	< 1 m
212 dB re 1 µPa^2s (SPL_{peak}) (TTS in harbour seal)	< 1 m	< 1 m
215 dB re 1 µPa^2s(M_{hf}) (M-Wtd SEL) (PTS in harbour porpoise, cumulative)	< 1 m	< 1 m
203 dB re 1 µPa^2s(M_{pw}) (M-Wtd SEL) (PTS in harbour seal, cumulative)	< 1 m	< 1 m

Nehls *et al* (2014), Tougaard (2013), Lucke *et al* (2009)	**Tubular piles (1225 mm diameter) and Sheet piles (1220 – 1300 mm)**	**Steel H-Piles (365 x 356 x 133 mm)**
180 dB re 1 µPa^2s (SEL_{ss}) (PTS in harbour porpoise)	< 1 m	< 1 m
165 dB re 1 µPa^2s (SEL_{ss}) (TTS in harbour porpoise)	19 m	5 m
145 dB re 1 µPa^2s (SEL_{ss}) (Minor behavioural avoidance in harbour porpoise)	250 m	68 m

NOAA Interim Sound Thresholds (Level B behavioural disruption)	**Tubular piles (1225 mm diameter) and Sheet piles (1220 – 1300 mm)**	**Steel H-Piles (365 x 356 x 133 mm)**
120 dB re 1 µPa (RMS) (Non-pulse noise)	11 km	3.1 km

Dredging results

Underwater noise levels from dredging activities have also been predicted using the SPEAR model. The tables below summarise the predicted levels of dredging noise at various ranges and the ranges at which impact criteria are met. A 24 hour constant activity worst case assumption has been used to estimate cumulative impacts, with the receptor fleeing at a rate of 1.5 ms^{-1}.

Dredging	**Trailer Suction Hopper (TSH) dredging**	**Backhoe dredging**
Level at 250 m range	140.2 dB re 1 µPa (RMS)	119.2 dB re 1 µPa (RMS)
Level at 500 m range	134.3 dB re 1 µPa (RMS)	113.3 dB re 1 µPa (RMS)
Level at 750 m range	130.7 dB re 1 µPa (RMS)	109.7 dB re 1 µPa (RMS)

Southall *et al* (2007)	**Trailer Suction Hopper (TSH) dredging**	**Backhoe dredging**
230 dB re 1 $\mu Pa^2 s$ (SPL_{peak}) (PTS in harbour porpoise)	< 1 m	< 1 m
218 dB re 1 $\mu Pa^2 s$ (SPL_{peak}) (TTS in harbour porpoise)	< 1 m	< 1 m
224 dB re 1 $\mu Pa^2 s$ (SPL_{peak}) (PTS in harbour seal)	< 1 m	< 1 m
212 dB re 1 $\mu Pa^2 s$ (SPL_{peak}) (TTS in harbour seal)	< 1 m	< 1 m
215 dB re 1 $\mu Pa^2 s(M_{hf})$ (M-Wtd SEL) (PTS in harbour porpoise, cumulative)	< 1 m	< 1 m
203 dB re 1 $\mu Pa^2 s(M_{pw})$ (M-Wtd SEL) (PTS in harbour seal, cumulative)	< 1 m	< 1 m

Nehls *et al* (2014), Tougaard (2013), Lucke *et al* (2009)	**Trailer Suction Hopper (TSH) dredging**	**Backhoe dredging**
180 dB re 1 $\mu Pa^2 s$ (SEL_{ss}) (PTS in harbour porpoise)	5 m	< 1 m
165 dB re 1 $\mu Pa^2 s$ (SEL_{ss}) (TTS in harbour porpoise)	23 m	2 m
145 dB re 1 $\mu Pa^2 s$ (SEL_{ss}) (Minor behavioural avoidance in harbour porpoise)	190 m	14 m

NOAA Interim Sound Thresholds (Level B behavioural disruption)	**Trailer Suction Hopper (TSH) dredging**	**Backhoe dredging**
120 dB re 1 µPa (RMS) (Non-pulse noise)	2.3 km	220 m