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East Anglia TWO and East Anglia ONE North Offshore Wind Farms: Underwater noise assessment

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East Anglia TWO Offshore Windfarm

Appendix 11.3

Underwater Noise Assessment

Preliminary Environmental Information
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1 Introduction

This report has been prepared by Subacoustech Environmental Ltd for HaskoningDHV UK Ltd. and presents the underwater noise modelling results for impact piling and other noise sources relating to the construction and lifecycle of the proposed East Anglia TWO (EA2) and East Anglia ONE North (EA1N) offshore wind farm projects.

1.1 EA2 and EA1N Offshore Wind Farm overview

EA2 and EA1N are proposed offshore wind farms in development in the North Sea off the coast of Suffolk. EA2 is located approximately 31 km from the coast and EA1N is located approximately 36 km off the coast at the nearest point to shore. The locations of the wind farms are shown in Figure 1-1. The proposed projects would have a potential capacity of up to 900 MW (EA2) and 800 MW (EA1N).

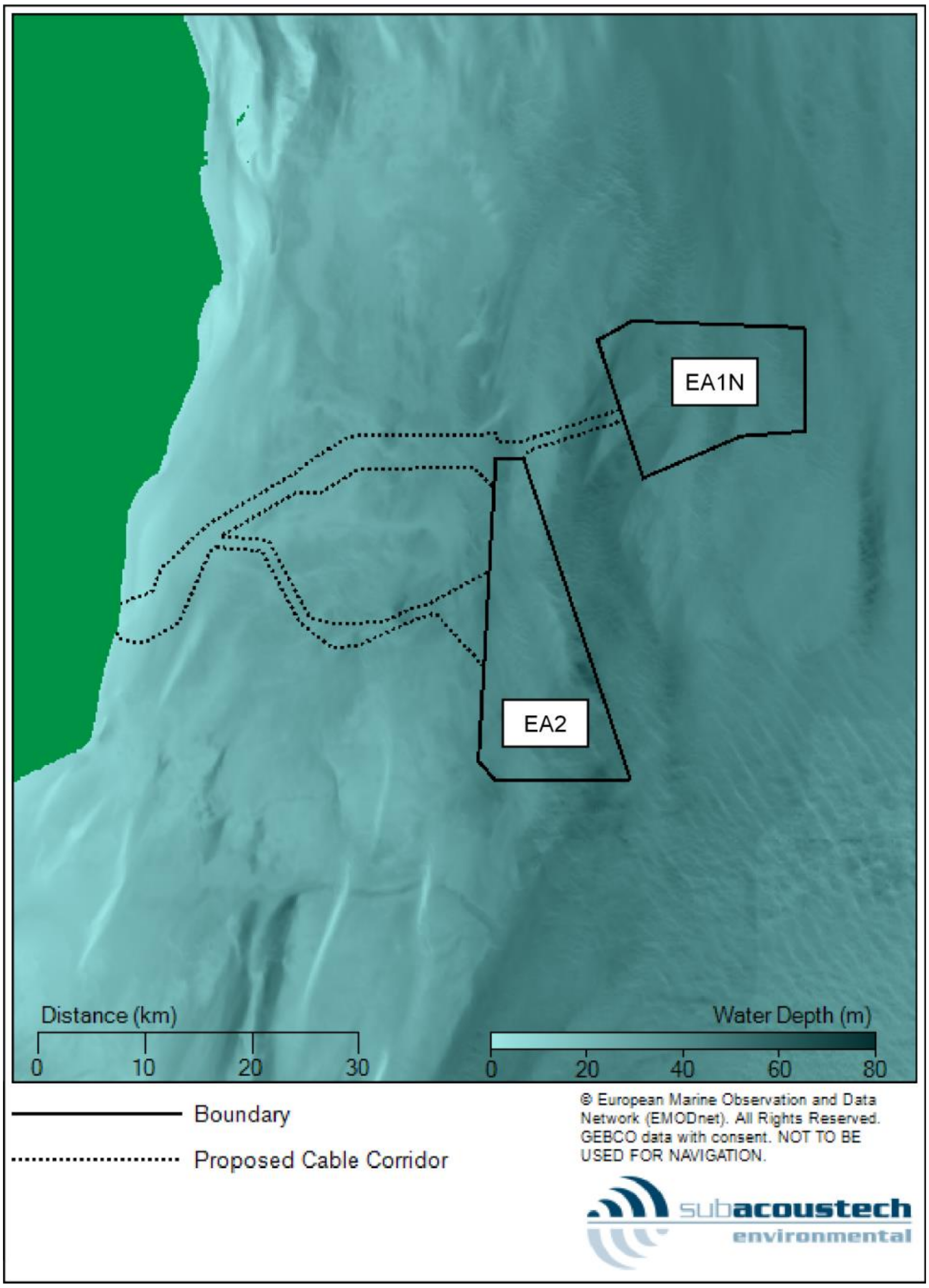

Figure 1-1 Map showing the boundaries of the EA2 and EA1N Offshore Wind Farm projects

1.2 Noise assessment

This report focuses on pile driving activities during construction at the EA2 and EA1N sites, and also considers other noise sources that are likely to be present during the development. Underwater noise modelling has been carried out in two parts. Impact piling has been considered using Subacoustech's INSPIRE (Impulse Noise Sound Propagation and Impact Range Estimator) subsea noise propagation and prediction software. Other noise sources have been considered using a high-level, simple modelling approach.

1.2.1 Impact piling

Impact piling has been proposed as a method for installing foundation piles for wind turbines into the seabed. It could be used to install either monopile or pin pile (jacket) foundation options.

The impact piling technique involves a large weight or "ram" being dropped or driven onto the top of the pile, forcing it into the seabed. Usually, double-acting hammers are used in which a downward force on the ram is applied, exerting a larger force than would be the case if it were only dropped under the action of gravity. Impact piling has been established as a source of high-level underwater noise (Würsig *et al.*, 2000; Caltrans, 2001; Nedwell *et al.*, 2003b and 2007; Parvin *et al.*, 2006; and Thomsen *et al.*, 2006).

Noise is created in air by the hammer as a direct result of the impact of the hammer with the pile and some of this airborne noise is transmitted into the water. Of more significance to the underwater noise is the direct radiation of noise from the pile into the water because of the compressional, flexural or other complex structural waves that travel down the pile following the impact of the hammer on the top. Structural pressure waves in the submerged section of the pile transmit sound efficiently into the surrounding water. These waterborne pressure waves will radiate outwards, usually providing the greatest contribution to the underwater noise.

1.2.2 Other source of noise

Although impact piling is expected to be the greatest noise source of noise during construction (Bailey *et al.* 2014, Bergström *et al.* 2014), several other noise sources associated with the wind farm development may also be present. These include UXO (unexploded ordnance) detonation, dredging, drilling, cable laying, rock placement, trenching, vessel noise and noise from operational wind turbines. These noise sources have been considered using a simple modelling approach due to the relative levels of noise and available information from these activities.

1.3 Scope of work

This report presents a detailed assessment of the potential underwater noise from impact piling at EA2 and EA1N and covers the following:

- A review of information on the units for measuring and assessing underwater noise and a review of underwater noise metrics and criteria that have been used to assess possible environmental effects in marine receptors (Section 2);
- A brief discussion of baseline ambient noise (Section 3);
- Discussion of the approach, input parameters and assumptions for the impact piling noise modelling undertaken (Section 4);
- Presentation of detailed subsea noise modelling using unweighted metrics (Section 5.1) and interpretation of the subsea noise modelling results with regards to injury and behavioural effects in marine mammals and fish using various noise metrics and criteria (Section 5.2);

- Summary of the predicted noise levels from the simple modelling approach for UXO detonation, dredging, drilling, cable laying, rock placement, trenching, vessel noise and noise from operational wind turbines (Section 6); and
- Summary and conclusions (Section 7).

An appendix of additional impact piling noise modelling, covering 75% and 50% of the full piling hammer energy, has also been included as Appendix A.

2 Measurement of noise

2.1 Underwater noise

Sound travels much faster in water (approximately 1,500 ms^{-1}) than in air (340 ms^{-1}). Since water is a relatively incompressible, dense medium, the pressures associated with underwater sound tend to be much higher than in air. As an example, background noise levels in the sea of 130 dB re 1 µPa for UK coastal waters are not uncommon (Nedwell *et al.*, 2003a and 2007). It should be noted that stated underwater noise levels should not be confused with the noise levels in air, which use a different scale.

2.1.1 Units of measurement

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

Any quantity expressed in this scale is termed a "level". If the unit is sound pressure, expressed on the dB scale, it will be termed a "Sound Pressure Level". The fundamental definition of the dB scale is given by:

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

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

The dB scale represents a ratio and, for instance, 6 dB really means "twice as much as…". It is, therefore, used with a reference unit, which expresses the base from which the ratio is expressed. The reference quantity is conventionally smaller than the smallest value to be expressed on the scale, so that any level quoted is positive. For instance, a reference quantity of 20 µPa is used for sound in air, since this is the threshold of human hearing.

A refinement is that the scale, when used with sound pressure, is applied to the pressure squared rather than the pressure. If this were not the case, when the acoustic power level of a source rose by 10 dB the Sound Pressure Level would rise by 20 dB. So that variations in the units agree, the sound pressure must be specified in units of root mean square (RMS) pressure squared. This is equivalent to expressing the sound as:

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

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

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

2.1.2 Sound pressure level (SPL)

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

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

2.1.3 Peak sound pressure level (SPL_{peak})

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

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

2.1.4 Sound exposure level (SEL)

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

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

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

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

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

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

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

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

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

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

Weighted metrics for marine mammals have been proposed by the National Marine Fisheries Service (NMFS) (2018) and Southall *et al.* (2007). These assign a frequency response to groups of marine mammals and are discussed in detail in the following section.

2.2 Analysis of environmental effects

2.2.1 Background

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

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

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

The following sections discuss the agreed criteria for assessing these impacts in species of marine mammal and fish at EA2 and EA1N.

2.2.2 Criteria to be used

The main metrics and criteria that have been used in this study to assess environmental effect come from several key papers covering underwater noise and its effects:

- The National Marine Fisheries Service guidance (NMFS, 2018) for marine mammals;
- The Southall *et al.* (2007) marine mammal noise exposure criteria;
- Data from Lucke *et al.* (2009) regarding harbour porpoise response to underwater noise;
- Sound exposure guidelines for fishes by Popper *et al.* (2014).

At the time of writing, these include the most up to date and authoritative criteria for assessing environmental effects for use in impact assessments. The NMFS (2018) document effectively updates Southall *et al.* (2007) but for completeness, both sets of criteria have been used. These are described in the following section.

2.2.2.1 Marine mammals

This assessment considers three sets of criteria to assess the effects of impact piling noise on marine mammals: NMFS (2018), Southall *et al.* (2007) and Lucke *et al.* (2009).

NMFS (2018) was co-authored by many of the same authors from the Southall *et al.* (2007) paper, and effectively updates its criteria for assessing the risk of auditory injury.

The NMFS (2018) guidance groups marine mammals into groups of similar species and applies filters to the unweighted noise to approximate the hearing sensitivity of the receptor. The hearing groups given in the NMFS (2018) are summarised in Table 2-1 and Figure 2-1. A further group for Otariid Pinnipeds is also given in the guidance for sea lions and fur seals but this has not been used in this study as those species of pinnipeds are not found in the North Sea.

Hearing group	Generalised hearing range	Example species
Low Frequency (LF) Cetaceans	7 Hz to 35 kHz	Baleen Whales
Mid Frequency (MF) Cetaceans	150 Hz to 160 kHz	Dolphins, Toothed Whales, Beaked Whales, Bottlenose Whales (including Bottlenose Dolphin)
High Frequency (HF) Cetaceans	275 Hz to 160 kHz	True Porpoises (including Harbour Porpoise
Phocid Pinnipeds (PW) (underwater)	50 Hz to 86 kHz	True Seals (including Harbour Seal)

Table 2-1 Marine mammal hearing groups (from NMFS, 2018)

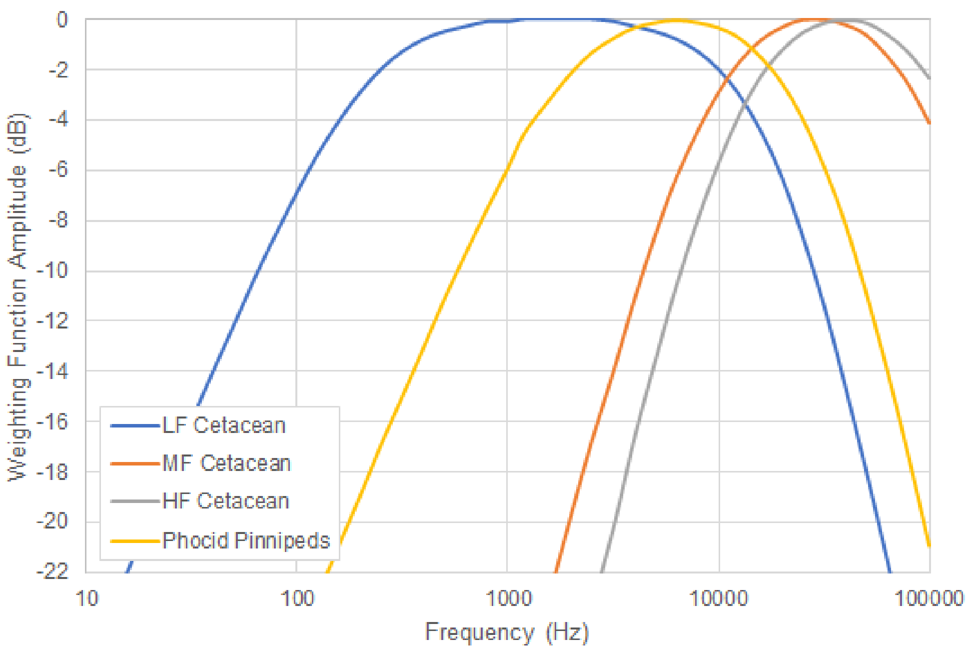

Figure 2-1 Auditory weighting functions for low frequency (LF) cetaceans, mid frequency (MF) cetaceans, high frequency (HF) cetaceans and phocid pinnipeds (PW) (underwater) (from NMFS, 2018)

NMFS (2018) also gives individual criteria based on whether the noise source is considered impulsive or non-impulsive. NMFS (2018) categorises impulsive noise as having high peak sound pressure, short duration, fast rise-time and broad frequency content at source, and non-impulsive sources as steady-state noise. Explosives, impact piling and seismic airguns are considered impulsive sources and sonars, vibropiling and other low-level continuous noises are considered non-impulsive. A non-impulsive sound does not necessarily have to have long duration.

NMFS (2018) presents single strike, unweighted peak criteria (SPL_{peak}) and cumulative (i.e. more than a single sound impulse), weighted sound exposure criteria (SEL_{cum}) for both permanent threshold shift (PTS) where unrecoverable hearing damage may occur and temporary threshold shift (TTS) where a temporary reduction in hearing sensitivity may occur in individual receptors. In addition, this study also includes weighted single strike sound exposure levels (SEL_{ss}).

Table 2-2 and Table 2-3 presents the NMFS (2018) criteria for onset of risk of PTS and TTS for each of the key marine mammal hearing groups considering impulsive and non-impulsive noise sources.

NMFS (2018)	Unweighted SPL_{peak} (dB re 1 µPa)	
	Impulsive	
	PTS	**TTS**
Low Frequency (LF) Cetaceans	219	213
Mid Frequency (MF) Cetaceans	230	224
High Frequency (HF) Cetaceans	202	196
Phocid Pinnipeds (PW) (underwater)	218	212

Table 2-2 SPL_{peak} criteria for assessment of PTS and TTS in marine mammals (NMFS, 2018)

NMFS (2018)	Weighted SEL_{cum} and SEL_{ss} (dB re 1 µPa²s)			
	Impulsive		**Non-impulsive**	
	PTS	**TTS**	**PTS**	**TTS**
Low Frequency (LF) Cetaceans	183	168	199	179
Mid Frequency (MF) Cetaceans	185	170	198	178
High Frequency (HF) Cetaceans	155	140	173	153
Phocid Pinnipeds (PW) (underwater)	185	170	201	181

Table 2-3 SEL_{cum} and SEL_{ss} criteria for assessment of PTS and TTS in marine mammals (NMFS, 2018)

Southall *et al.* (2007) has been the source of the most widely used criteria to assess the effects of noise on marine mammals since it was published, although has largely been superseded by NMFS (2018). The criteria from Southall *et al.* (2007) are based on M-Weighted SELs, which are generalised frequency weighting functions to adjust underwater noise data to better represent the levels of underwater noise that various marine species are likely to be able to hear; it is worth noting that M-Weightings differ from the weightings used in NMFS (2018). The authors group marine mammals into five groups, four of which are relevant to underwater noise (the fifth is for pinnipeds in air). For each group, an approximate frequency range of hearing is proposed based on known audiogram data, where available, or inferred from other information such as auditory morphology. The M-Weighting filters are summarised in in Table 2-4 and Figure 2-2.

Functional hearing group	Established auditory bandwidth	Genera represented	Example species
Low frequency (LF) cetaceans	7 Hz to 22 kHz	*Balaena, Caperea, Eschrichtius, Megaptera, Balaenoptera* (13 species/subspecies)	Humpback whale, minke whale
Mid frequency (MF) cetaceans	150 Hz to 160 kHz	*Steno, Sousa, Sotalia, Tursiops, Stenella, Delphinus, Lagenodelphis, Lagenorhynchus, Lissodelphis, Grampus, Peponocephala, Feresa, Pseudorca, Orcinus, Globicephala, Orcaella, Physeter, Delphinapterus, Monodon, Ziphius, Berardius, Tasmacetus, Hyperoodon, Mesoplodon* (57 species/subspecies)	Bottlenose dolphin, white-beaked dolphin, killer whale, sperm whale
High frequency (HF) cetaceans	200 Hz to 180 kHz	*Phocoena, Neophocaena, Phocoenoides, Platanista, Inia, Kogia, Lipotes, Pontoporia, Cephalorhynchus* (20 species/subspecies)	Harbour porpoise
Pinnipeds (in water)	75 Hz to 75 kHz	*Arctocephalus, Callorhinus, Zalophus, Eumetopias, Neophoca, Phocarctos, Otaria, Erignathus, Phoca, Pusa, Halichoerus, Histriophoca, Pagophilus, Cystophora, Monachus, Mirounga, Leptonychotes, Ommatophoca, Lobodon, Hydrurga*, *Odobenus* (41 species/subspecies)	Harbour (common) seal, grey seal

Table 2-4 Functional marine mammal groups, their assumed auditory bandwidth of hearing and genera presented in each group (from Southall et al., 2007)

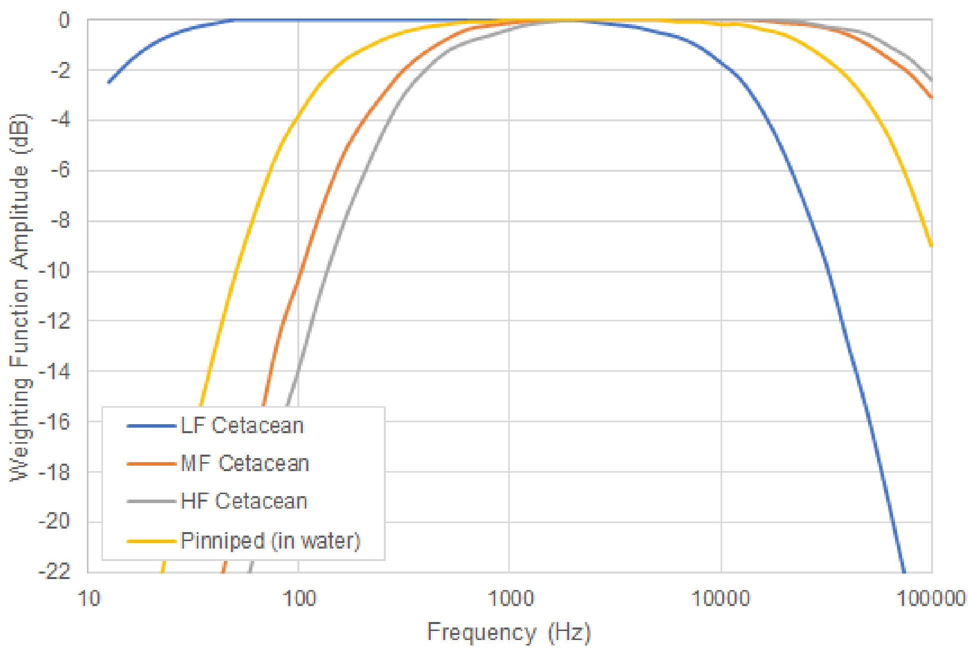

Figure 2-2 Auditory M-weighting functions for low frequency (LF) cetacean, mid frequency (MF) cetacean, high frequency (HF) cetacean and pinniped (in water) (underwater) (from Southall et al. 2007)

The unweighted SPL_{peak} and M-Weighted SEL criteria used in this study are summarised in Table 2-5 to Table 2-7, covering auditory injury, TTS and behavioural avoidance for both impulsive and non-impulsive noise sources. It should be noted that for this study the SEL criteria for both multiple pulse (SEL_{cum}) and single pulse (SEL_{ss}) have been used.

Southall *et al.* (2007)	Unweighted SPL_{peak} (dB re 1 µPa)	
	Impulsive	
	Auditory Injury	**TTS**
Low Frequency (LF) Cetaceans	230	224
Mid Frequency (MF) Cetaceans	230	224
High Frequency (HF) Cetaceans	230	224
Pinnipeds (in water) (PW)	218	212

Table 2-5 SPL_{peak} criteria for assessment of auditory injury and TTS in marine mammals (Southall et al, 2007)

Southall *et al.* (2007)	M-Weighted SEL_{cum} and SEL_{ss} (dB re 1 µPa²s)		
	Impulsive		**Non-impulsive**
	Auditory injury	**TTS (SEL_{ss} only)**	**Auditory injury**
Low Frequency (LF) Cetaceans	198	183	215
Mid Frequency (MF) Cetaceans	198	183	215
High Frequency (HF) Cetaceans	198	183	215
Pinnipeds (in water) (PW)	186	171	203

Table 2-6 SEL_{cum} and SEL_{ss} criteria for assessment of auditory injury and TTS in marine mammals (Southall et al, 2007)

Southall *et al.* (2007)	Unweighted SEL_{ss} (dB re 1 µPa²s)	
	Likely Avoidance	**Possible Avoidance**
Low Frequency (LF) Cetaceans	152	142
Mid Frequency (MF) Cetaceans	170	160

Table 2-7 Criteria for assessment of behavioural avoidance in marine mammals (Southall et al, 2007)

In addition to Southall *et al.* (2007), criteria from Lucke *et al.* (2009) have been used to further assess the effects of noise on harbour porpoise. The criteria from Lucke *et al.* (2009) are derived from testing harbour porpoise hearing thresholds before and after being exposed to seismic airgun stimuli (a pulsed noise like impact piling). All the criteria used are unweighted single strike (SEL_{ss}). These are summarised in Table 2-8. These are included for completeness; use of the NMFS (2018) criteria is recommended as a preference.

Lucke *et al.* (2009)	Unweighted SEL_{ss} (dB re 1 µPa²s)		
	Impulsive		
	Auditory Injury	**TTS**	**Behavioural**
Harbour Porpoise	179	164	145

Table 2-8 Criteria for assessment of auditory injury, TTS and behavioural response in harbour porpoise (Lucke et al, 2009)

Where SEL_{cum} are required, a fleeing animal model has been used. This assumes that the animal exposed to high noise levels will swim away from the noise source. For this a constant fleeing speed of 3.25 ms^{-1} has been assumed for the low frequency (LF) cetaceans group (Blix and Folkow, 1995), based on data for minke whale, and for other receptors a constant rate of 1.5 ms^{-1} has been assumed, which is a cruising speed for a harbour porpoise (Otani *et al.*, 2000). These are considered ‘worst case’ as marine mammals are expected to be able to swim much faster under stress conditions. The model assumes that when a fleeing receptor reaches the coast it receives no more noise, as it is likely that the receptor will flee along the coast, and at this distance from EA2 and EA1N sites the receptor will be far enough from the piling that it will have received the majority of its noise exposure.

This assessment is comprehensive in its inclusion of the criteria from NMFS (2018) as well as the older Southall *et al.* and Lucke *et al.* (2009) criteria.

2.2.2.2 Fish

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

The Popper *et al.* (2014) study groups species of fish into whether they possess a swim bladder, and whether it is involved in its hearing. The guidance also gives specific criteria (as both SPL_{peak} and SEL_{cum} values) for a variety of noise sources; in this case impact piling, explosions (for UXO) and continuous noise have been considered. As with the marine mammal criteria, SEL_{ss} values have been considered alongside the SEL_{cum} criteria.

The criteria used for modelling are summarised in Table 2-9 to Table 2-11. In a similar fashion to marine mammals for SEL_{cum} results, a fleeing animal model has been used assuming a fish flees from the source at a constant rate of 1.5 ms^{-1}, based on data from Hirata (1999). This speed is the slowest of all species identified. This is discussed further, below.

Impact piling	Mortality and potential mortal injury	Impairment	
		Recoverable injury	TTS
Fish: no swim bladder	>219 dB SEL_{cum} or >213 dB SPL_{peak}	>216 dB SEL_{cum} or >213 dB SPL_{peak}	>>186 dB SEL_{cum}
Fish: swim bladder is not involved in hearing	210 dB SEL_{cum} or >207 dB SPL_{peak}	203 dB SEL_{cum} or >207 dB SPL_{peak}	>186 dB SEL_{cum}
Fish: swim bladder involved in hearing	207 dB SEL_{cum} or >207 dB SPL_{peak}	203 dB SEL_{cum} or >207 dB SPL_{peak}	186 dB SEL_{cum}

Table 2-9 Criteria for assessment of mortality and potential mortal injury, recoverable injury and TTS in species of fish from impact piling noise (Popper et al, 2014)

Explosions	Mortality and potential mortal injury
Fish: no swim bladder	229 – 234 dB SPL_{peak}
Fish: swim bladder is not involved in hearing	229 – 234 dB SPL_{peak}
Fish: swim bladder involved in hearing	229 – 234 dB SPL_{peak}

Table 2-10 Criteria for assessment of mortality and potential mortal injury in species of fish from explosion noise, for UXO detonation (Popper et al, 2014)

Shipping and continuous sounds	Impairment	
	Recoverable injury	**TTS**
Fish: swim bladder involved in hearing	170 dB RMS for 48 h	158 dB RMS for 12 h

Table 2-11 Criteria for assessment of recoverable injury and TTS in species of fish from continuous noise sources (Popper et al, 2014)

A further set of criteria also exists for turtles and fish eggs and larvae; however, these have not been considered as part of this study. Where insufficient data is available, Popper *et al.* (2014) give qualitative criteria that summarise the effect of the noise as having either a high, moderate or low effect on an individual in either the near-filed (tens of metres), intermediate-field (hundreds of metres), or far-field (thousands of metres). These qualitative effects are reproduced in Table 2-12 to Table 2-14.

Impact piling	**Mortality & potential mortal injury**	**Impairment**			**Behaviour**
		Recoverable injury	**TTS**	**Masking**	
Fish: no swim bladder	See Table 2-9	See Table 2-9	See Table 2-9	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder is not involved in hearing	See Table 2-9	See Table 2-9	See Table 2-9	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder involved in hearing	See Table 2-9	See Table 2-9	See Table 2-9	(N) High (I) High (F) Moderate	(N) High (I) High (F) Moderate

Table 2-12 Summary of the qualitative effects on fish from impact piling from Popper et al. (2014) (N=Near-field, I=Intermediate-field, F=Far-field)

Explosions	**Mortality & potential mortal injury**	**Impairment**			**Behaviour**
		Recoverable injury	**TTS**	**Masking**	
Fish: no swim bladder	See Table 2-10	(N) High (I) Low (F) Low	(N) High (I) Moderate (F) Low	N/A	(N) High (I) Moderate (F) Low
Fish: swim bladder is not involved in hearing	See Table 2-10	(N) High (I) High (F) Low	(N) High (I) Moderate (F) Low	N/A	(N) High (I) High (F) Low
Fish: swim bladder involved in hearing	See Table 2-10	(N) High (I) High (F) Low	(N) High (I) High (F) Low	N/A	(N) High (I) High (F) Low

Table 2-13 Summary of the qualitative effects on fish from explosions, for UXO detonation, from Popper et al. (2014) (N=Near-field, I=Intermediate-field, F=Far-field)

Shipping and continuous sounds	**Mortality & potential mortal injury**	**Impairment**			**Behaviour**
		Recoverable injury	**TTS**	**Masking**	
Fish: no swim bladder	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
Fish: swim bladder is not involved in hearing	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
Fish: swim bladder involved in hearing	(N) Low (I) Low (F) Low	See Table 2-11	See Table 2-11	(N) High (I) High (F) High	(N) High (I) Moderate (F) Low

Table 2-14 Summary of the qualitative effects on fish from continuous noise from Popper et al. (2014) (N=Near-field, I=Intermediate-field, F=Far-field)

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

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

Therefore, basing the assessment on a stationary (zero flee speed) receptor is likely to greatly overestimate the potential risk to fish species, especially when considering the precautionary nature of the parameters already built into the cumulative exposure model.

3 Baseline Ambient Noise

The baseline noise level in open water, in the absence of any specific anthropogenic noise source, is generally dependent on a mix of the movement of the water and sediment, weather conditions and shipping. There is a component of biological noise from marine mammal and fish vocalisation, as well as an element from invertebrates.

Outside of the naturally occurring ambient noise, man-made noise dominates the background. The North Sea is heavily shipped by fishing, cargo and passenger vessels, which contribute to the ambient noise in the water. The larger vessels are not only louder but the noise tends to have a lower frequency, which travels more readily, especially in the deeper open water. Other vessels such as dredgers and small fishing boats have a lower overall contribution. There are no dredging areas, Active Dredge Zones or Dredging Application Option and Prospecting Areas within the EA2 and EA1N offshore project area.

Other sources of anthropogenic noise include oil and gas platforms and other drilling activity, clearance of unexploded ordnance (UXO) and military exercises. Drilling may contribute some low frequency noise in the wind farm site, although due to its low-level nature (see section 6) this is unlikely to contribute to the overall ambient noise. Clearance of UXO contributes high but infrequent noise. Little information is available on the scope and timing of military exercises, but they are not expected to last for an extended period, and so would have little contribution to the long-term ambient noise in the area.

The Marine Strategy Framework Directive requires European Union members to ascertain baseline noise levels by 2020, and monitoring processes are being put into place for this around Europe. Good quality, long-term underwater noise data for the region is not currently available.

Typical underwater noise levels show a frequency dependency in relation to different noise sources; the classic curves are given in Wenz (1962) and are reproduced in Figure 3-1 below. Figure 3-1 shows that any unweighted overall (i.e. single-figure non-frequency-dependent) noise level is typically dependent on the very low frequency element of the noise. The introduction of a nearby anthropogenic noise source (such as piling or sources involving engines) will tend to increase the noise levels in the 100-1000 Hz region, but to a lesser extent will also extend into higher and lower frequencies.

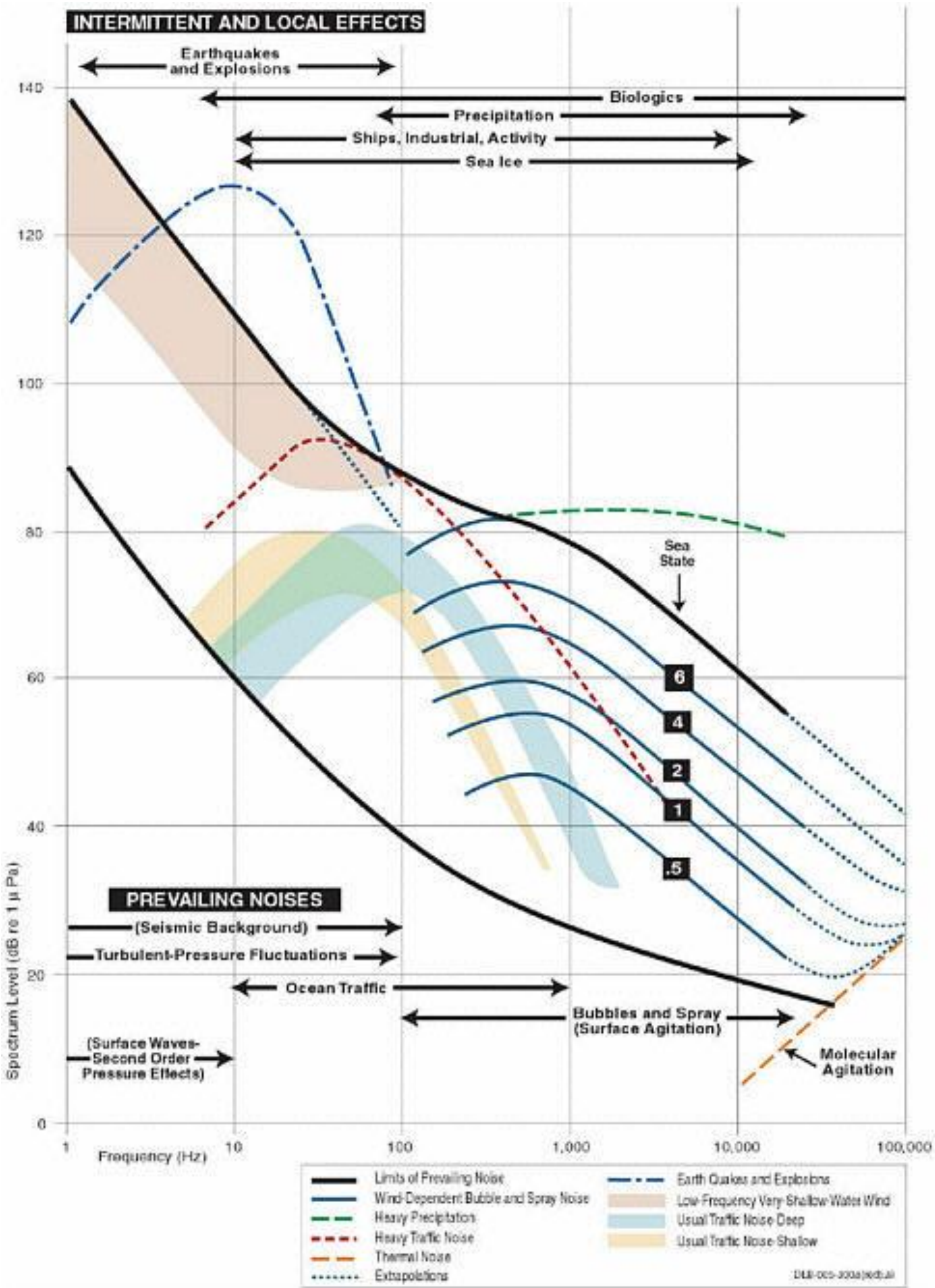

Figure 3-1 Ambient underwater noise following Wenz (1962) showing frequency dependency from different noise sources.

In 2011, around the time of the met-mast installation in the former Hornsea zone, also in the North Sea, snapshot baseline underwater noise levels were sampled as part of the met-mast installation noise survey (Nedwell and Cheesman, 2011). Measurements were taken outside of the installation activity and in the absence of any nearby vessel noise. This survey sampled noise levels of 112 to 122 dB re 1 µPa RMS over two days and were described as not unusual for the area. The higher figure was due to higher sea state on that day. Unweighted overall noise levels of this type should be used with caution without access to more detail regarding the duration, frequency content and conditions under which the sound was recorded, although they do demonstrate an indication of the natural variation in background noise levels.

There is little additional, documented ambient noise data publicly available for the region. Merchant *et al*. (2014) measured underwater ambient noise in the Moray Firth, acquiring measurements of a similar order to the baseline snapshot levels noted above, and which showed significant variation (i.e. a 60 dB spread) in daily average noise levels. Although this is outside of the region and in a much more coastal and heavily shipped location, it demonstrates that the snapshot noted above gives only limited information as the average daily noise levels are so dependent on weather and local activity. However, the snapshot measurements taken do show noise levels that are of the same order as baseline noise levels sampled elsewhere in the North Sea (Nedwell *et al*., 2003a) and so are considered to be realistic.

In principle, when noise introduced by anthropogenic sources propagates far enough it will reduce to the level of ambient noise, at which point it can be considered negligible. In practice, as the underwater noise thresholds defined in section 2.2.2 are all considerably above the level of background noise, any noise baseline would not feature in an assessment to these criteria.

4 Impact piling modelling methodology

4.1 Modelling introduction

To estimate the underwater noise levels likely to arise during construction of EA2 and EA1N, predictive noise modelling has been undertaken. The methods described in this section, and utilised within this report, meet the requirements set by the NPL Good Practice Guide 133 for underwater noise measurement (Robinson *et al.*, 2014).

The modelling has been undertaken using the INSPIRE noise model. The INSPIRE model (currently version 4.0) is a semi-empirical underwater noise propagation model based around a combination of numerical modelling and actual measured data. It is designed to calculate the propagation of noise in shallow, mixed water, typical of the conditions around the UK and very well suited to the EA2 and EA1N sites. The model has been tuned for accuracy using over 50 datasets of underwater noise propagation around offshore piling.

The model provides estimates of unweighted SPL_{peak}, SEL_{ss}, and SEL_{cum} noise levels as well as various other weighted noise metrics. Calculations are made along 180 equally spaced radial transects (one every 2°). For each modelling run a criterion level can be specified allowing a contour to be drawn, within which a given effect may occur. These results are then plotted over digital bathymetry data so that impact ranges can be clearly visualised and assessed as necessary.

INSPIRE considers a wide array of input parameters, including variations in bathymetry and source frequency content to ensure accurate results for the circumstances. It should also be noted that the results presented in this study should be considered conservative as worst-case parameters have been selected for:

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

The input parameters for the modelling are detailed in the following section.

4.2 Locations

Modelling has been undertaken at two representative locations at each wind farm site, covering the worst-case (WC) position (i.e. the deepest location where piling can take place, which tends to give the greatest noise propagation), and an average water depth (AV) location located in slightly shallower water. The chosen locations are shown in Figure 4-1 and summarised in Table 4-1, below.

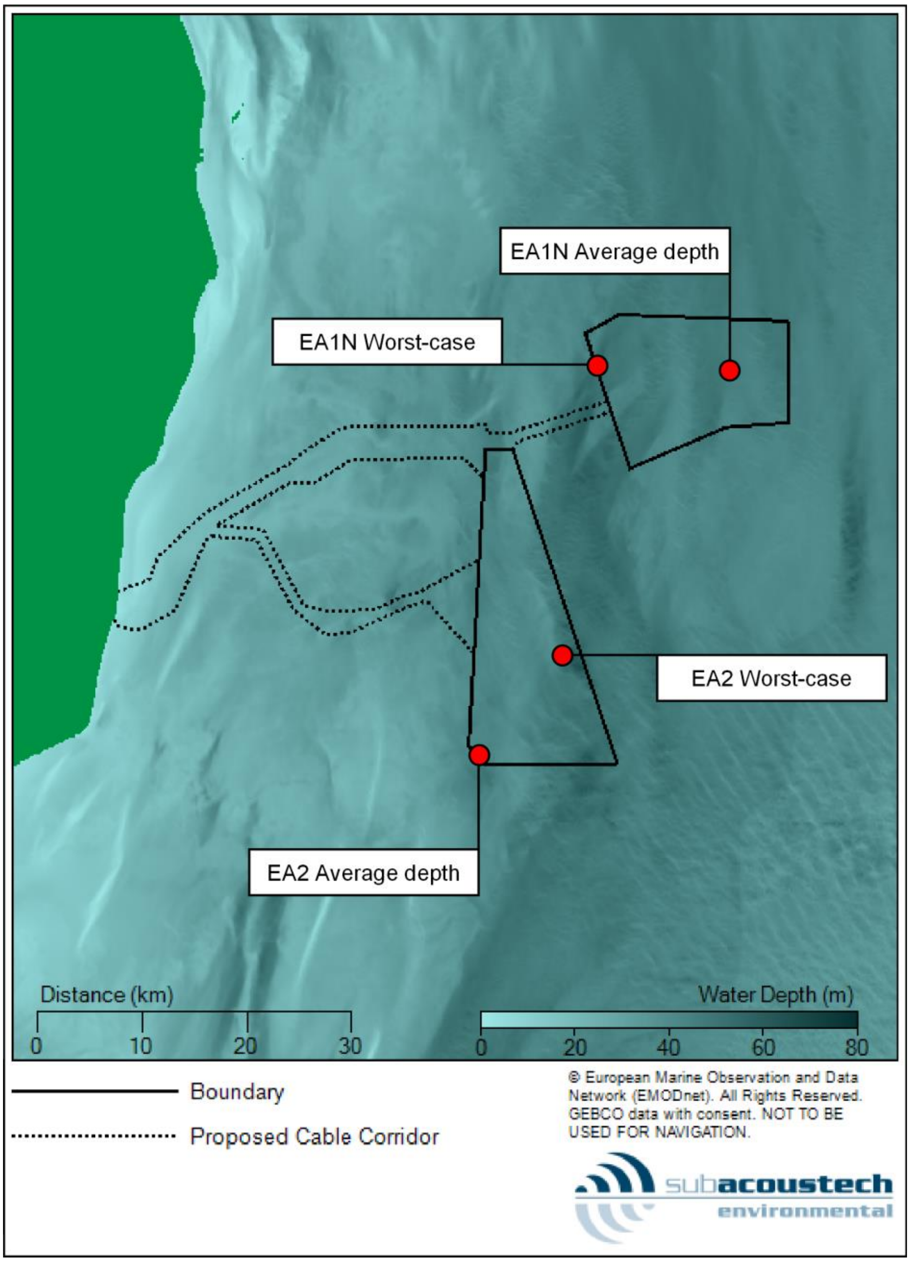

Figure 4-1 Map showing the underwater noise modelling locations in the EA2 and EA1N OWF sites

	EA2		EA1N	
	Worst-case	Average depth	Worst-case	Average depth
Latitude	52.1423°N	52.0564°N	52.3916°N	52.3864°N
Longitude	002.2541°E	002.1369°E	002.3023°E	002.4882°E
Water depth	55 m	47.5 m	55 m	45 m

Table 4-1 Summary of the underwater noise modelling locations and associated water depths (mean tide)

4.3 Input parameters

The modelling takes full account of the environmental parameters within the study area and the characteristics of the noise source. The following parameters have been assumed for modelling.

4.3.1 Impact piling parameters

Two piling source scenarios have been modelled to include monopile and pin pile (jacket) WTG (wind turbine generator) foundations across the EA2 and EA1N OWF farm sites. These are:

- Monopiles, up to 15 m in diameter, installed using a maximum hammer blow energy of 4000 kJ; and
- Pin piles, up to 4.6 m in diameter installed using a maximum hammer blow energy of 2400 kJ.

For cumulative SELs, the soft start and ramp up of blow energies along with total duration and strike rate of the piling have also been considered. These are summarised in Table 4-2 to Table 4-3, below. The soft start and ramp ups take place over the first half-hour of piling, starting at ten percent of maximum and gradually increasing in blow energy to 80% before reaching the maximum energy and strike rate, where it stays for the remaining time.

The monopile scenario contains 9,300 pile strikes over 325 minutes (5 hours 25 minutes, inclusive of soft start and ramp up), the pin pile scenario contains 7210 pile strikes over 199 minutes (3 hours 19 minutes).

	Soft start (10%)	Ramp up to 80%	Main piling (100%)
Monopile blow energy	400 kJ	Gradual increase	4000 kJ
Number of strikes	150 strikes	300 strikes	8850 strikes
Duration	10 minutes	20 minutes	295 minutes
Strike rate	15 strikes per minute		30 strikes per minute

Table 4-2 Summary of the ramp up scenario used for calculating cumulative SELs for monopiles

	Soft start (10%)	Ramp up to 80%	Main piling (100%)
Pin pile blow energy	240 kJ	Gradual increase	2400 kJ
Number of strikes	150 strikes	300 strikes	6760 strikes
Duration	10 minutes	20 minutes	169 minutes
Strike rate	15 strikes per minute		40 strikes per minute

Table 4-3 Summary of the ramp up scenario used for calculating cumulative SELs for a single pin pile

At the time of reporting a driveability study has not been completed, and as such additional modelling runs have been undertaken to assess noise levels assuming the blow energy only reaches 75% and 50% of the maximum hammer blow energy during the main piling. Not reaching full power is a frequent occurrence during piling on site. The results of this modelling are presented in Appendix A along with a comparison to the 100% maximum hammer blow energy results.

4.3.2 Source levels

Noise modelling requires knowledge of the source level, which is the theoretical noise level at 1 m from the noise source.

The INSPIRE noise propagation model assumes that the noise source, the hammer striking the pile, acts as a single point, as it will appear at a distance. This is then adjusted to take into account the water depth at the modelled source location to allow for the length of pile in contact with the water, which can affect the amount of noise that is transmitted from the pile into its surroundings. However, as the water depths for the modelling locations considered for this study are all in excess of 45 m, the source levels do not alter with location.

The unweighted single strike SPL_{peak} and SEL_{ss} source levels estimated for this project are provided in Table 4-4 and Table 4-5.

		SPL_{peak} source level	SEL_{ss} source level
Monopile	10% (400kJ)	235.4 dB re 1 µPa @ 1 m	219.0 dB re 1 µPa²s @ 1 m
	100% (4000kJ)	239.6 dB re 1 µPa @ 1 m	223.3 dB re 1 µPa²s @ 1 m

Table 4-4 Summary of the unweighted single strike source levels used for modelling monopiles in this study

		SPL_{peak} source level	SEL_{ss} source level
Pin pile	10% (240kJ)	233.1 dB re 1 µPa @ 1 m	216.8 dB re 1 µPa²s @ 1 m
	100% (2400kJ)	239.2 dB re 1 µPa @ 1 m	222.9 dB re 1 µPa²s @ 1 m

Table 4-5 Summary of the unweighted single strike source levels used for modelling pin piles in this study

4.3.3 Frequency content

The size of the pile being installed affects the frequency content of the noise it produces. For this modelling, frequency data has been sourced from Subacoustech's noise measurement database and an average taken to obtain representative 1/3-octave band frequency spectrum levels (i.e. the frequency break-down of a noise level) for installing monopiles and pin piles. The 1/3-octave band levels for maximum hammer energy used for modelling are illustrated in Figure 4-2; the shape of each spectrum is the same for all the other locations and blow energies, with the overall source levels adjusted depending on these parameters. This is particularly important when considering marine mammal species that are more sensitive to a particular frequency of sound than others.

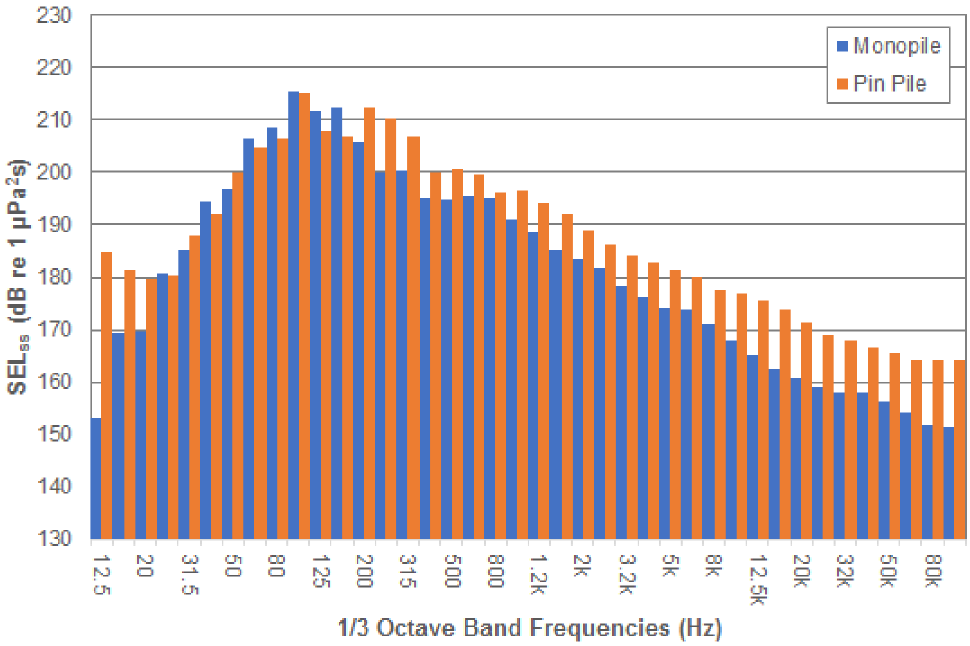

Figure 4-2 1/3-octave source level frequency spectra for the maximum hammer blow energy

Frequency spectra for piles of 7 m in diameter, the largest with measured data available, has been used for the monopile modelling and piles of approximately 4 m in diameter (near the top end of the pin pile options being considered) have been used for pin pile modelling. It is worth noting that the monopiles contain more low frequency content and the pin piles contain more high frequency content, due to the acoustics related to the dimensions of the pile. This trend would be expected to continue to larger piles under consideration for the monopiles at EA2 and EA1N. A larger diameter would be expected to move the dominant frequency of the sound (i.e. the frequency where the highest levels are present) produced lower, further below the frequencies of greatest hearing sensitivity of marine mammals. Thus, the sound would appear slightly quieter to a receptor more sensitive to higher frequencies, such as dolphins and porpoises (MF and HF cetaceans) and the spectrum used is likely to be worst case. Marine mammal hearing sensitivity is covered in section 2.2.

4.3.4 Environmental conditions

Accurate modelling of underwater noise propagation requires knowledge of the sea and seabed conditions. The semi-empirical nature of the INSPIRE model considers the seabed type and speed of sound in water for the mixed conditions around the EA2 and EA1N site as it is based on over 50 datasets taken of impact piling noise in coastal and offshore waters surrounding the UK.

Mean tidal depth has been used for the depth of water across the site as the tidal state will fluctuate throughout installation of foundations.

4.4 Modelling confidence

Modelling has been undertaken using the latest iteration (version 4.0) of the INSPIRE modelling software.

As discussed in section 4.1, INSPIRE is a semi-empirical model based around a combination of numerical modelling and actual measured data. The INSPIRE model has always endeavoured to give a conservative estimate of underwater noise levels from impact piling noise. There is always some variability with underwater noise measurements, even when considering measurements of pile strikes at the same blow energy taken at the same range, there can still be big variations in noise level (sometimes up to 5 or even 10 dB) (for example, Bailey *et al*. (2010) and the data shown in Figure 4-3). The INSPIRE model is always compared to the highest of these measured noise levels at any range.

INSPIRE version 4.0 is the product of going back and re-analysing all the impact piling noise measurements in Subacoustech's measurement database and cross-referencing it with blow energy data from piling logs, giving a database of single strike noise levels referenced to a specific blow energy at various ranges. This re-analysis showed that the previous version of INSPIRE overestimated the change in noise level with blow energy, which in most cases lead to overestimations in predicted noise levels.

As the INSPIRE model is semi-empirical, a validation process is inherently built into the development process. Whenever a new set of good, reliable, impact piling measurement data is gathered through offshore surveys, it is compared against the outputted levels from INSPIRE. Currently, over 50 separate impact piling noise datasets from all around the UK have been used as part of development for the latest version of INSPIRE, and in each case, a conservative fit is used. This is the same process that has been used for the previous iterations of INSPIRE, however with each new version more measurement data is used.

In addition to this, INSPIRE is also validated by comparing the noise levels from the model with measurements and modelling undertaken by third parties.

Figure 4-3 presents a selection of example measured impact piling noise data plotted against outputs from INSPIRE version 4.0. The plots show data points from measured data (red points) plotted alongside modelled data (green points) using the INSPIRE version 4.0 model matching the pile size, blow energy and range of the measured data. These show the conservative fit to data with the data points from INSPIRE sitting at the upper end of the measured noise level at each range.

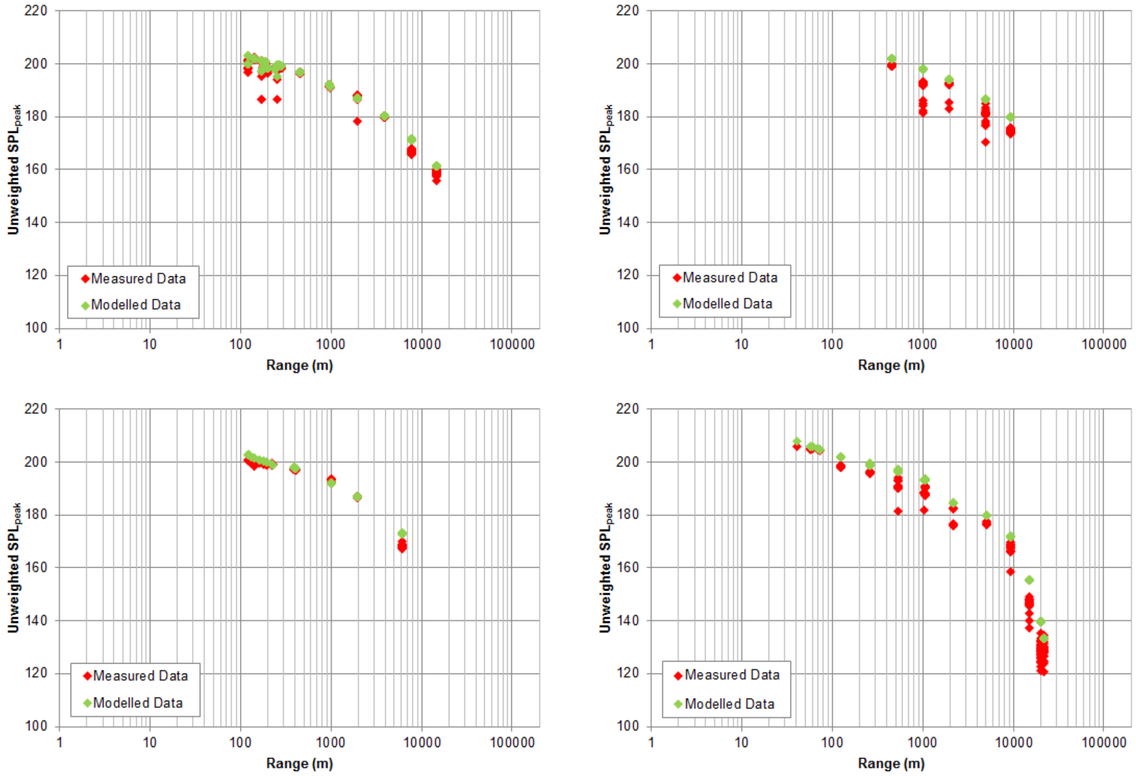

Figure 4-3 Comparison between example measured data (red points) and modelled data using INSPIRE version 4.0 (green points)

5 Impact piling noise modelling outputs

5.1 Unweighted subsea noise modelling

This section presents the unweighted noise level results (i.e. in the absence of any weighting applied for marine mammal hearing sensitivity) from the modelling undertaken for impact piling operations using the modelling parameters detailed in section 2.2.2.

The following figures present unweighted SPL_{peak} noise levels from impact piling operations at the EA2 and EA1N modelling locations shown in Figure 4-1.

Figure 5-1 to Figure 5-8 show the unweighted SPL_{peak} noise levels for monopiles (installed using a maximum blow energy of 4000 kJ) and the unweighted SPL_{peak} noise levels for pin piles (installed using a maximum blow energy of 2400 kJ).

Comparing these plots shows that, in general, the increased noise levels with no weighting applied, are expected to occur in deeper water. The effect of the deep water on noise transmission is also shown when considering the ridges to the southwest and northwest of the site, where a more ‘jagged’ contour occurs between the ridges on the seabed.

Due to the transient nature of impact piling noise, the impulsive noise introduced to the water will return to background levels within seconds of the impulse passing.

The noise levels on these plots, denoted in dB SPL_{peak}, should not be confused with background or ambient noise levels, which are typically described in terms of dB SPL_{RMS}. The two metrics are not directly comparable.

As discussed in section 4.3.1, results for the 75% and 50% maximum blow energy scenarios are presented as part of Appendix A.

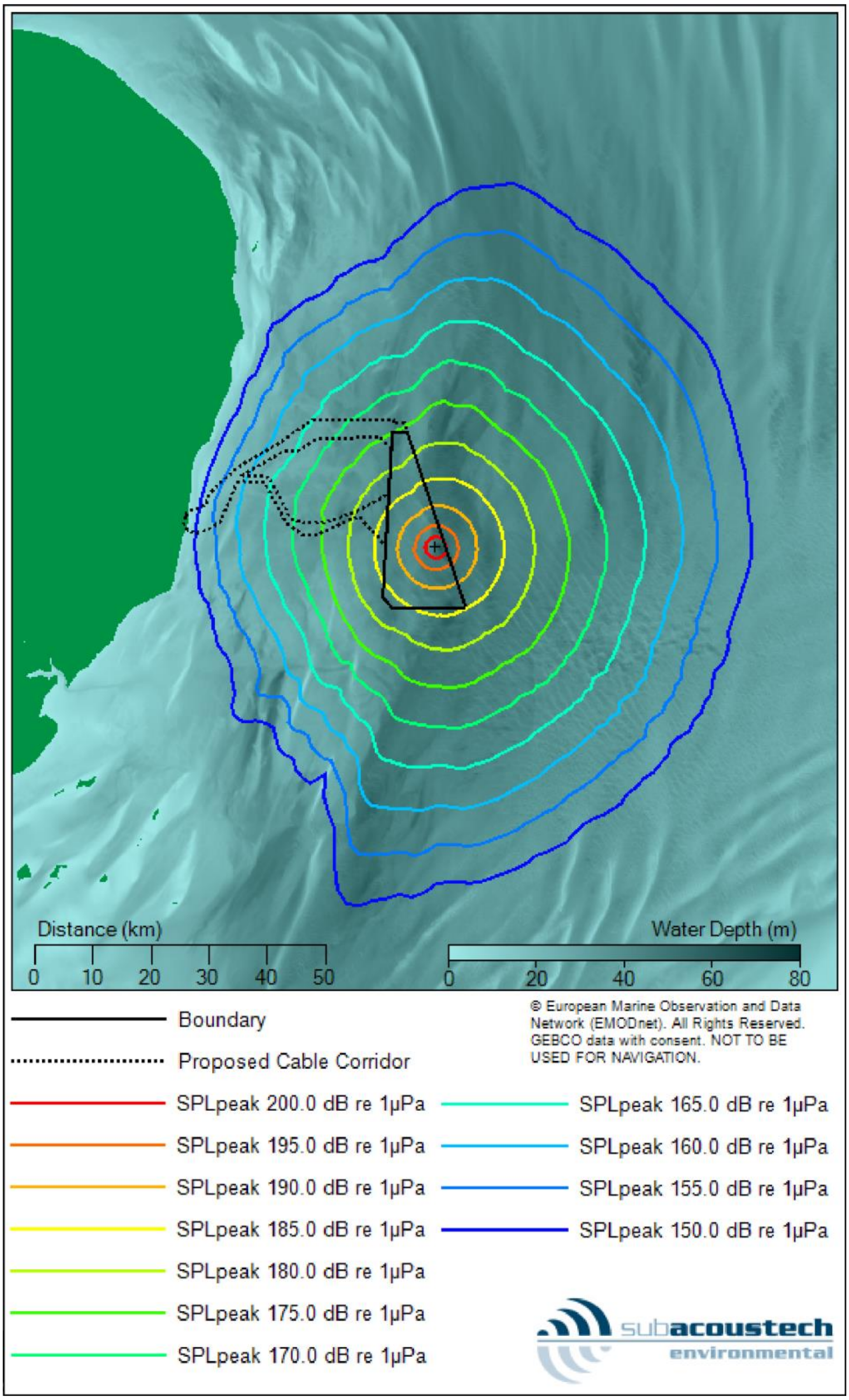

Figure 5-1 Noise level plot showing the predicted SPL_{peak} noise levels predicted for installing a monopile using a maximum blow energy of 4000 kJ at the worst-case location in EA2

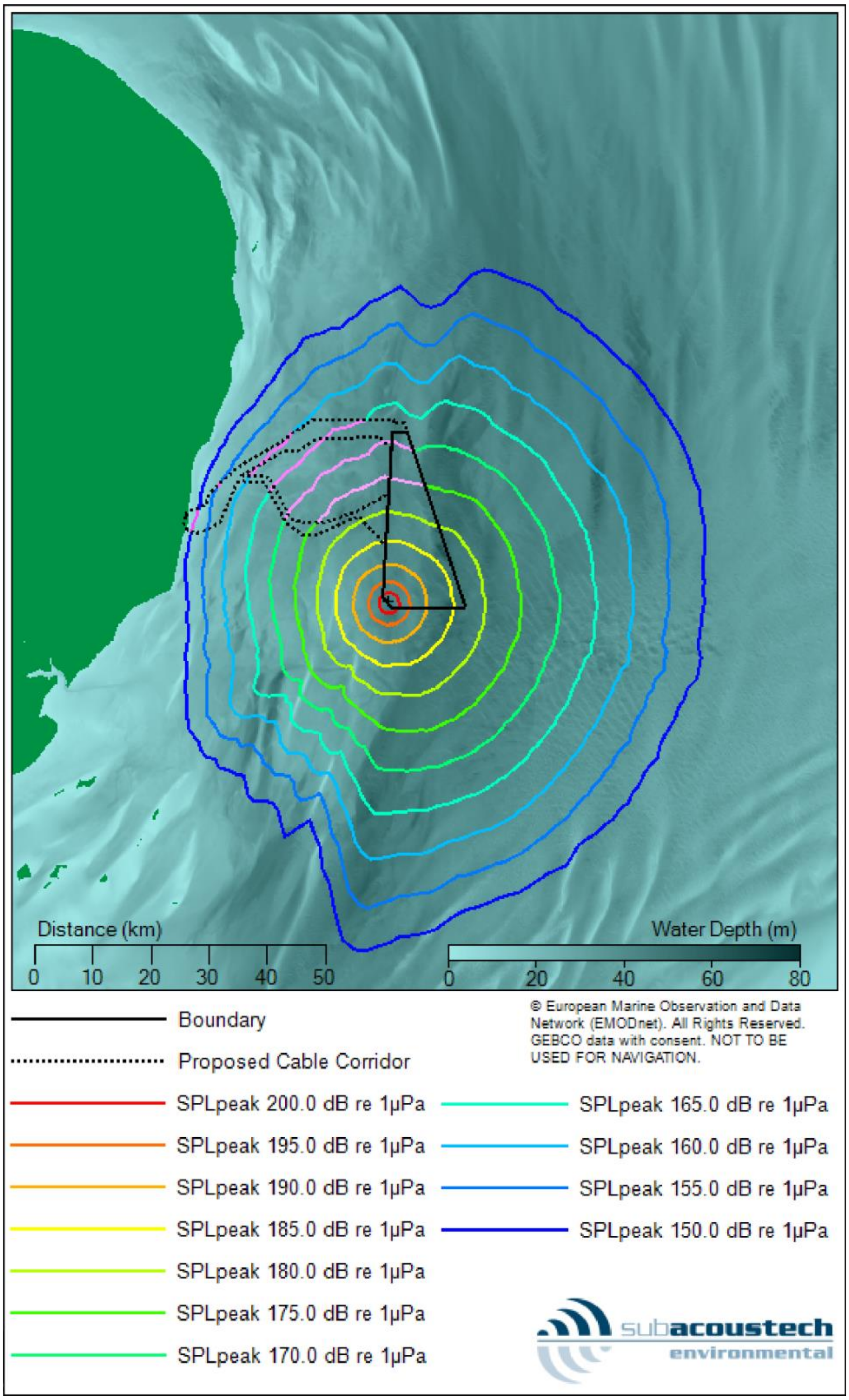

Figure 5-2 Noise level plot showing the predicted SPL_{peak} noise levels predicted for installing a monopile using a maximum blow energy of 4000 kJ at the average depth location in EA2

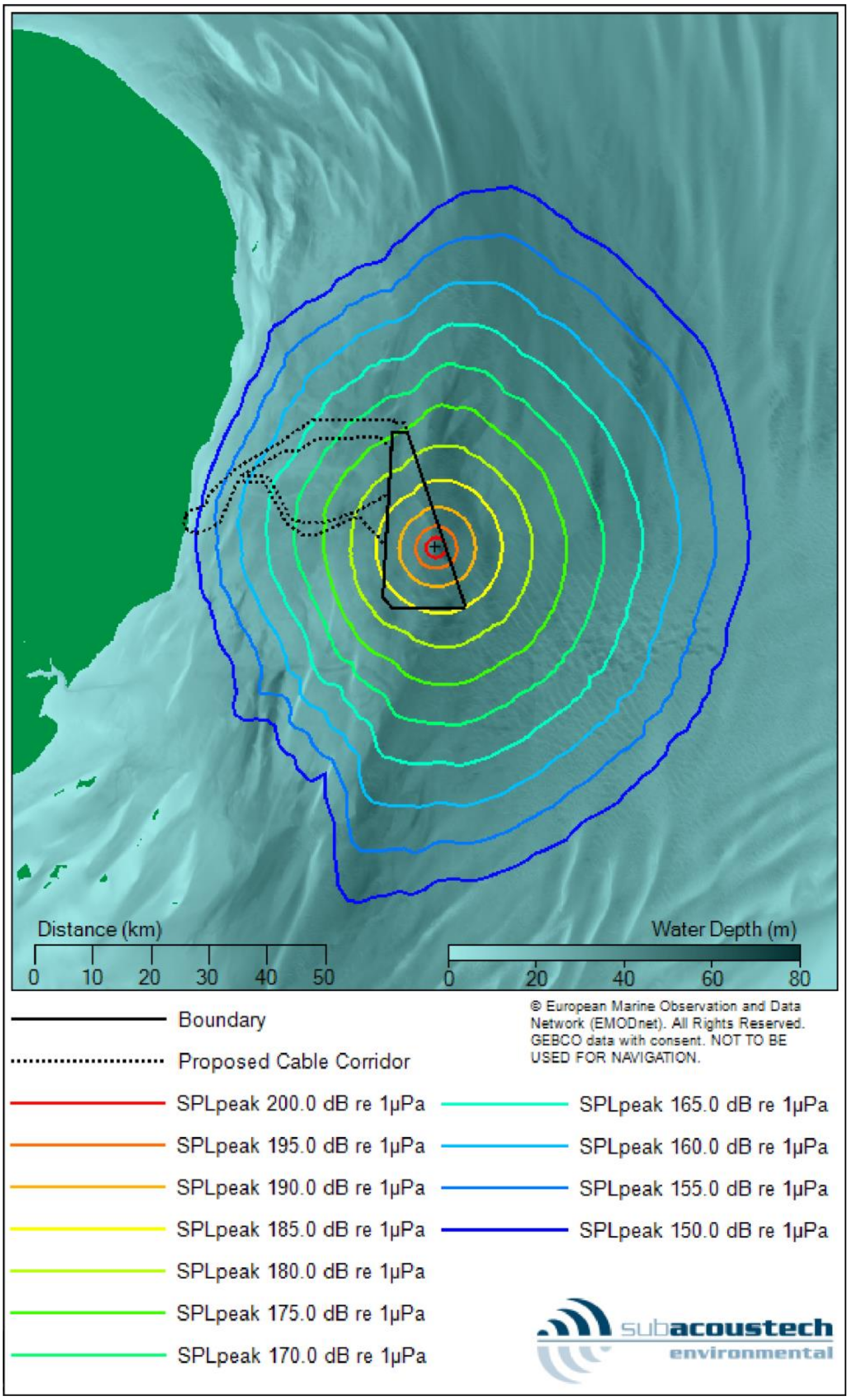

Figure 5-3 Noise level plot showing the predicted SPL_{peak} noise levels predicted for installing a pin pile using a maximum blow energy of 2400 kJ at the worst-case location in EA2

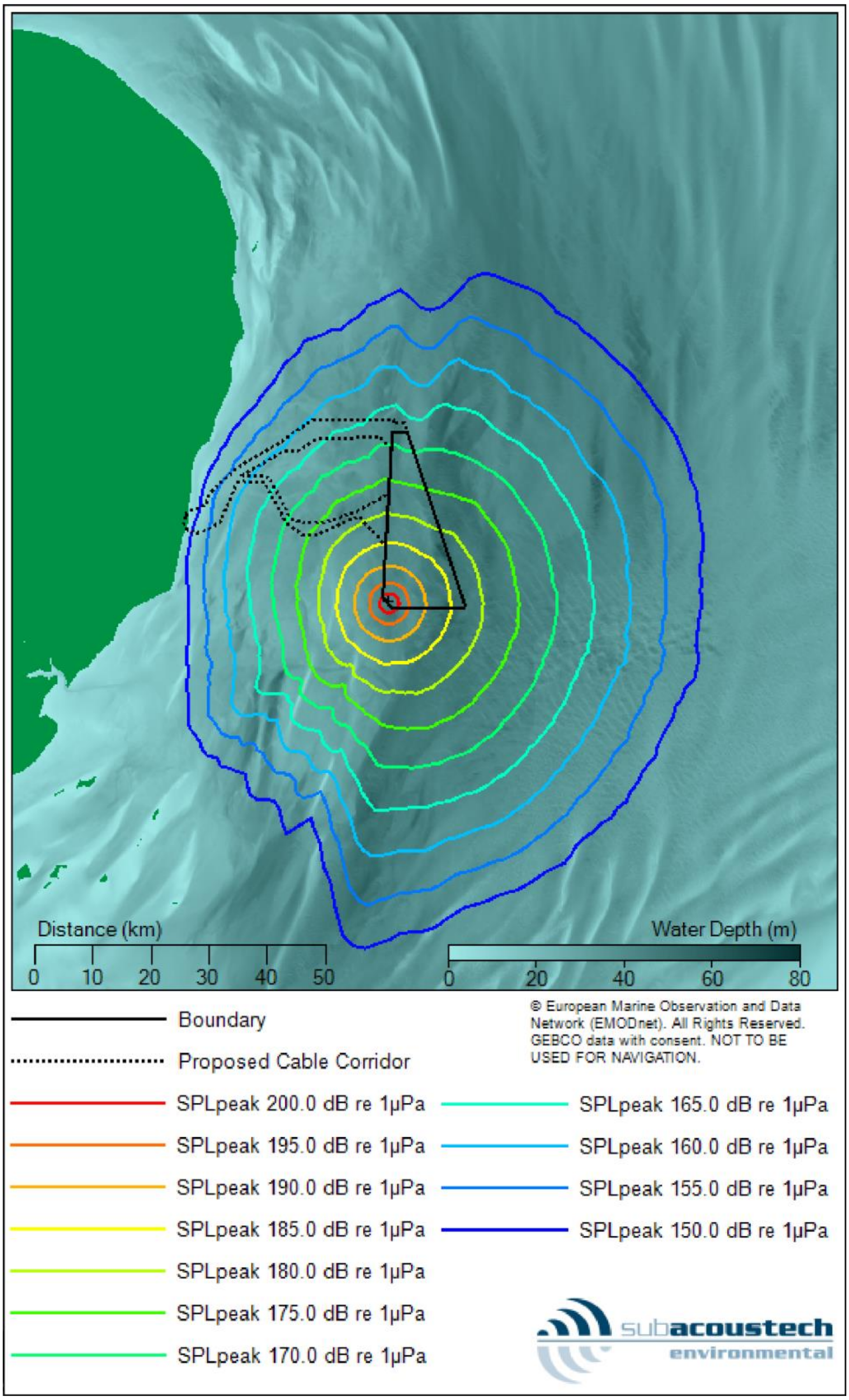

Figure 5-4 Noise level plot showing the predicted SPL_{peak} noise levels predicted for installing a pin pile using a maximum blow energy of 2400 kJ at the average depth location in EA2

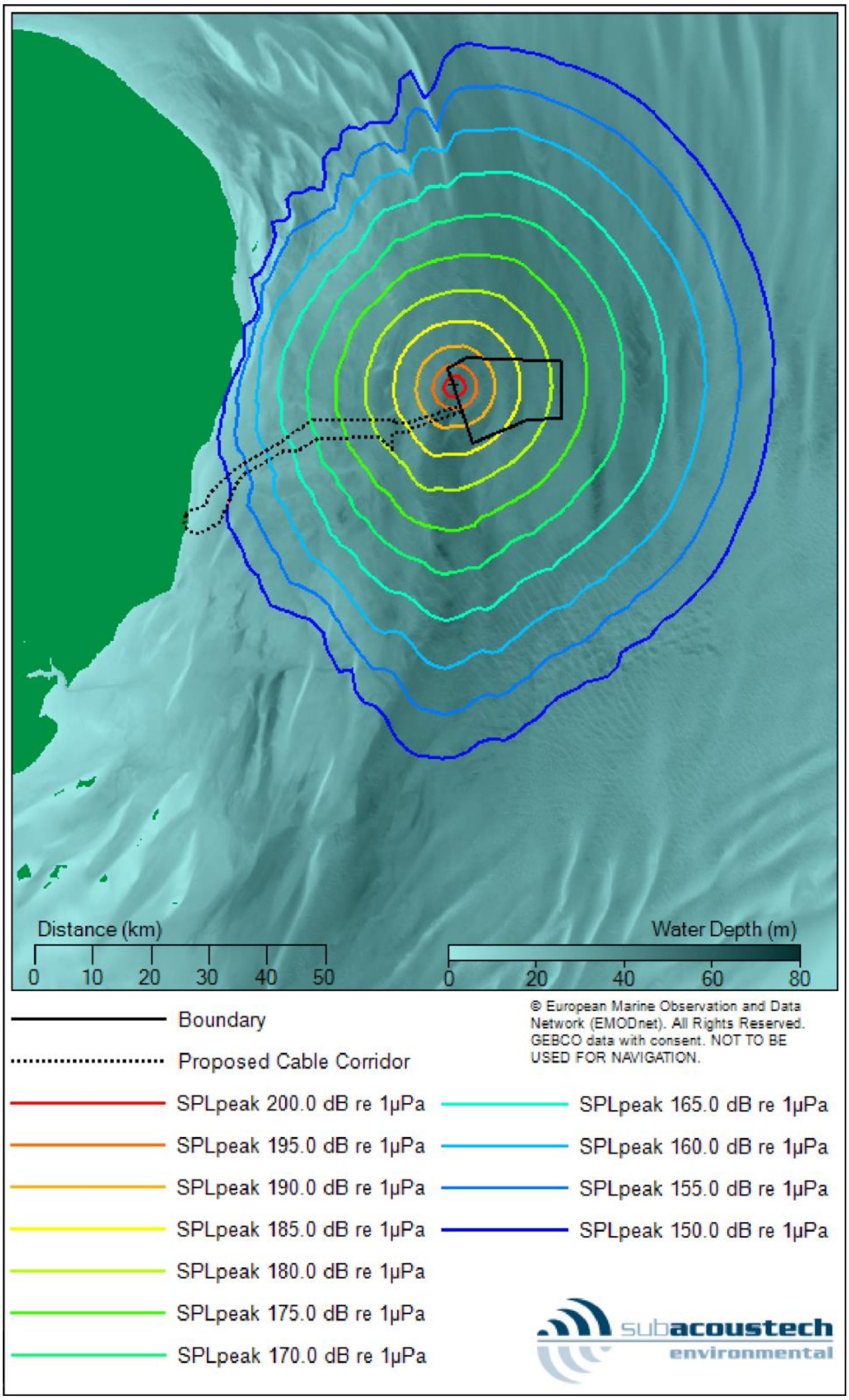

Figure 5-5 Noise level plot showing the predicted SPL_{peak} noise levels predicted for installing a monopile using a maximum blow energy of 4000 kJ at the worst-case location in EA1N

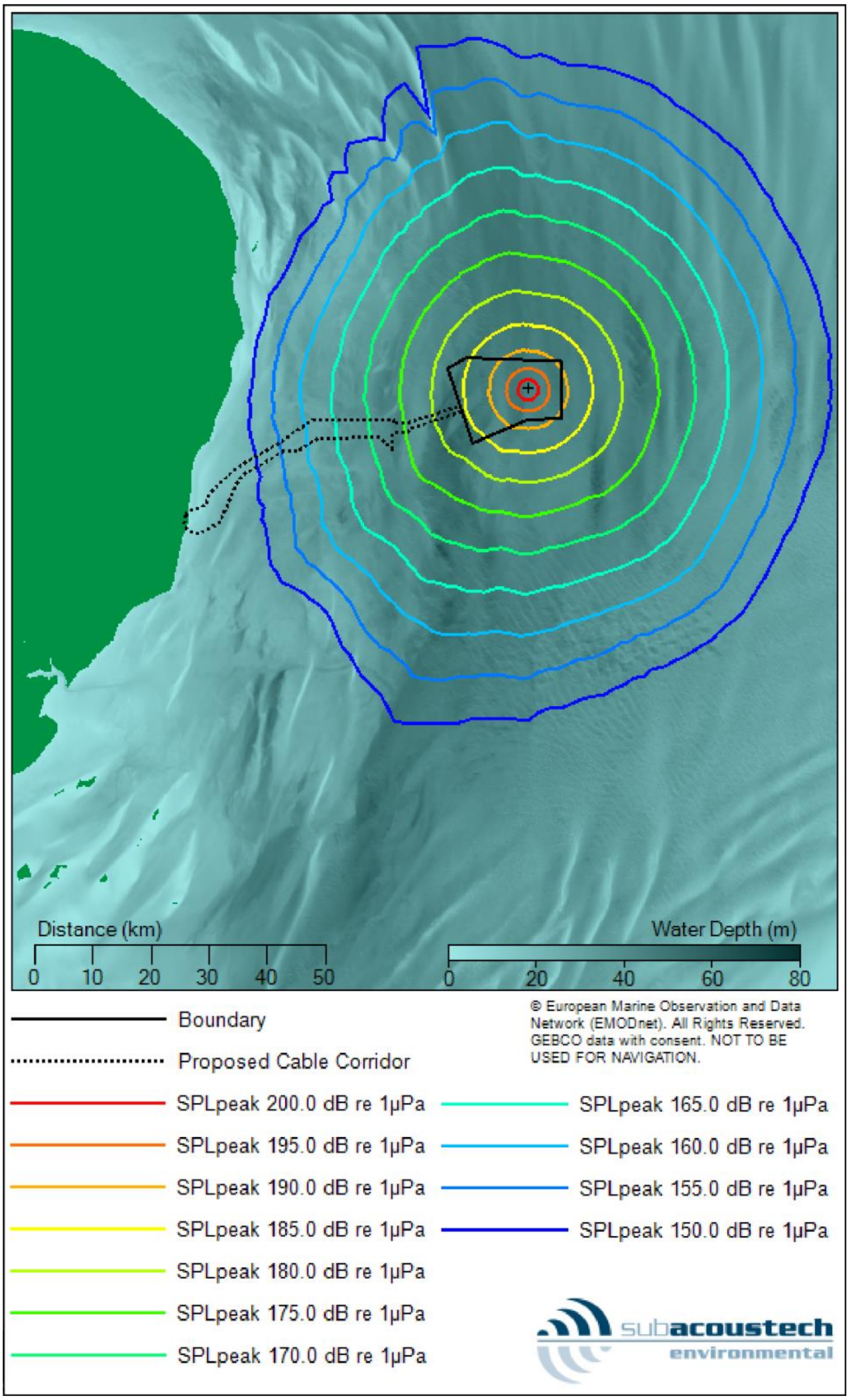

Figure 5-6 Noise level plot showing the predicted SPL_{peak} noise levels predicted for installing a monopile using a maximum blow energy of 4000 kJ at the average depth location in EA1N

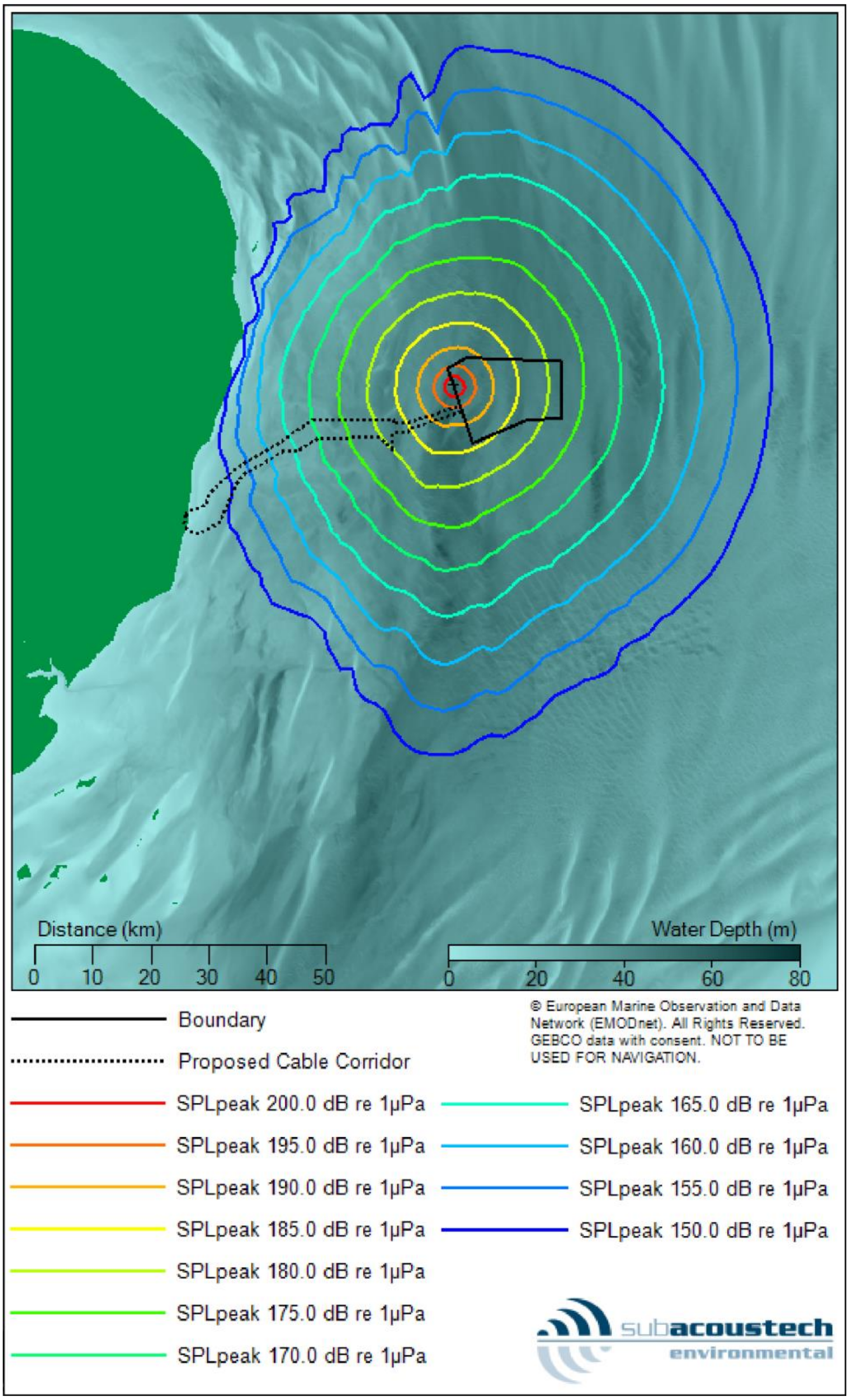

Figure 5-7 Noise level plot showing the predicted SPL_{peak} noise levels predicted for installing a pin pile using a maximum blow energy of 2400 kJ at the worst-case location in EA1N

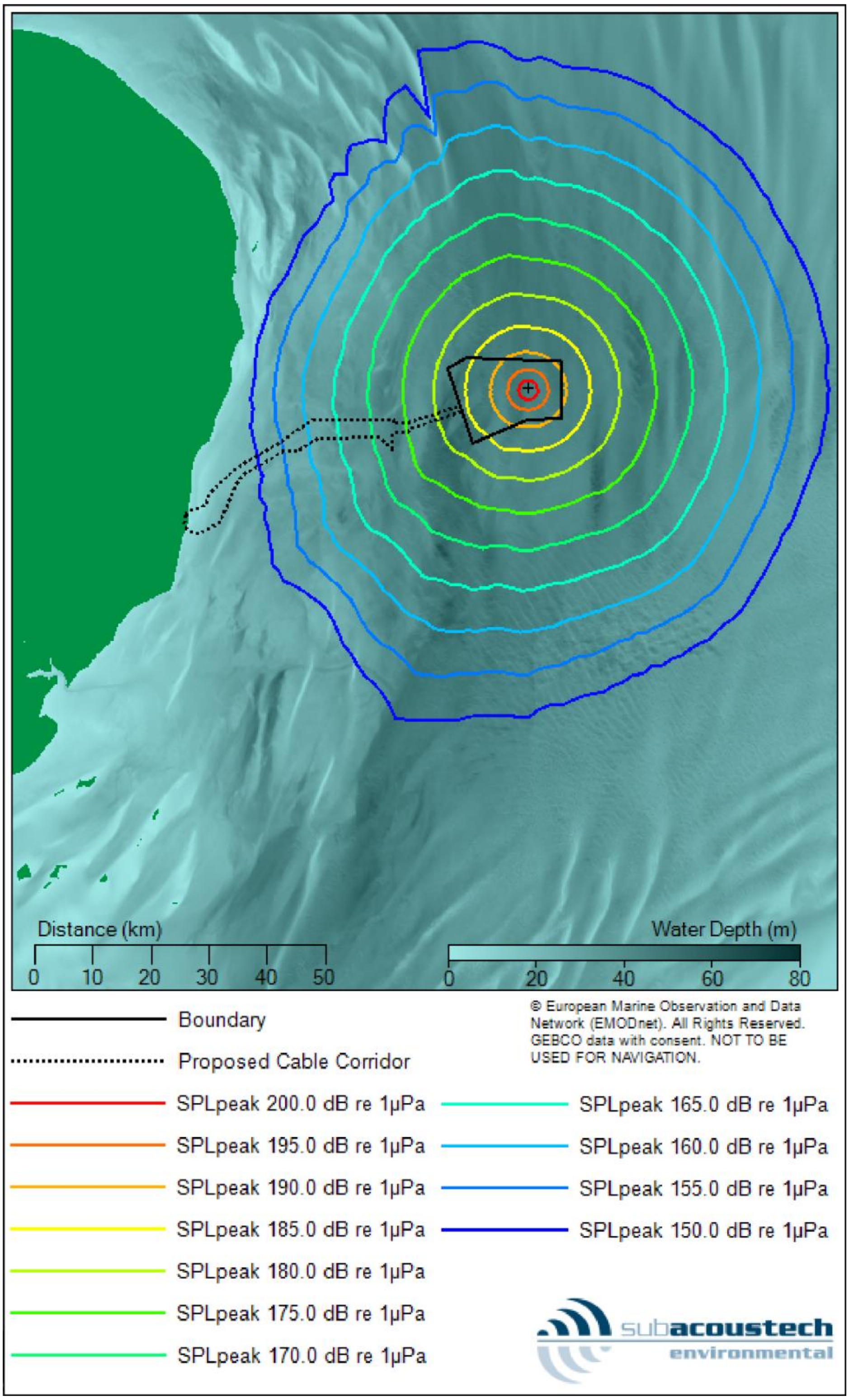

Figure 5-8 Noise level plot showing the predicted SPL_{peak} noise levels predicted for installing a pin pile using a maximum blow energy of 2400 kJ at the average depth location in EA1N

5.2 Interpretation of results

This section presents the modelling results in terms of the noise metrics and criteria covered in section 2.2. This discussion will guide the assessment of environmental impact to marine species from the predicted impact piling noise. For all the results given in the following sections, ranges calculated to be less than 50 m for single strike criteria and 100 m for cumulative criteria have not been included as due to the uncertainty in the accuracy of the results at such close range. In this case the ranges are given as “<50m” or “<100m”, in that the impact range will be closer to the pile than this distance.

5.2.1 Impacts on marine mammals

The following sections present the modelling results in biological terms for various species of marine mammal, separated by the guidance: NMFS (2018), Southall *et al.* (2007) and Lucke *et al.* (2009). As discussed in section 2.2.2.1, for the SEL_{cum} criteria, fleeing animal speeds of 3.25 ms^{-1} (Blix and Folkow, 1995) for LF cetaceans and 1.5 ms^{-1} (Otani *et al.* 2000) for other species of marine mammal have been used.

5.2.1.1 NMFS (2018) results

Table 5-1 to Table 5-16 present the predicted PTS and TTS impact ranges for the different marine mammal hearing groups using the NMFS (2018) thresholds. The criteria are given as unweighted SPL_{peak} or weighted SELs, of which both single strike (SEL_{ss}) and cumulative (SEL_{cum}) have been presented. Multiple pulse results include the noise exposure to a fleeing animal receptor over the entire installation period. SEL_{cum} are not calculated for the soft start, as this represents only the first strike of the piling process.

In line with the unweighted results shown in section 5.1, maximum SEL_{cum} ranges of 21 km predicted for PTS and 45 km predicted for TTS in LF and HF cetaceans at the worst-case modelling location for the EA1N site. It is worth noting that the SEL_{cum} results for pin piles are consistently larger than those for monopiles. This is primarily because of the faster strike rate assumed for installing pin piles (Table 4-2 and Table 4-3). The larger impact ranges for pin piles for MF and HF cetaceans are also caused by the frequencies filtered by the NMFS (2018) species group weightings (Table 2-1 and Figure 2-1). This is discussed further in section 5.2.1.1.3.

Results for the initial impact ranges for the first strike of the soft start (400 kJ for monopile and 240 kJ for pin pile) and for the maximum energy, including exposure over the entire piling sequence, are given in separate tables.

5.2.1.1.1 *EA2*

EA2	NMFS (2018) - PTS			Monopile (400kJ – soft start, 10%)			
				Area	Maximum	Minimum	Mean
Worst case	Unweighted SPL_{peak}	LF Cetacean	219 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		MF Cetacean	230 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	1.0 km^2	580 m	570 m	580 m
		PW Pinniped	218 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	Weighted SEL_{ss}	LF Cetacean	183 dB	0.39 km^2	360 m	350 m	350 m
		MF Cetacean	185 dB	< 0.01 km^2	< 50 m	< 50m	< 50 m
		HF Cetacean	155 dB	< 0.01 km^2	< 50 m	< 50m	< 50 m
		PW Pinniped	185 dB	< 0.01 km^2	< 50 m	< 50m	< 50 m
Average depth	Unweighted SPL_{peak}	LF Cetacean	219 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		MF Cetacean	230 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	1.0 km^2	570 m	570 m	570 m
		PW Pinniped	218 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	Weighted SEL_{ss}	LF Cetacean	183 dB	0.38 km^2	350 m	350 m	350 m
		MF Cetacean	185 dB	< 0.01 km^2	< 50 m	< 50m	< 50 m
		HF Cetacean	155 dB	< 0.01 km^2	< 50 m	< 50m	< 50 m
		PW Pinniped	185 dB	< 0.01 km^2	< 50 m	< 50m	< 50 m

Table 5-1 Summary of the single strike impact ranges for PTS from NMFS (2018) for installation of a monopile at EA2 using the 10% soft start hammer blow energy of 400 kJ

EA2	NMFS (2018) - PTS			Monopile (4000kJ – main piling, 100%)			
				Area	Maximum	Minimum	Mean
Worst case location	Unweighted SPL_{peak}	LF Cetacean	219 dB	0.01 km^2	50 m	50 m	50 m
		MF Cetacean	230 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	4.6 km^2	1.2 km	1.2 km	1.2 km
		PW Pinniped	218 dB	0.01 km^2	60 m	60 m	60 m
	Weighted SEL_{cum}	LF Cetacean	183 dB	580 km^2	17 km	11 km	14 km
		MF Cetacean	185 dB	< 0.01 km^2	< 100 m	< 100 m	< 100 m
		HF Cetacean	155 dB	96 km^2	6.4 km	4.6 km	5.5 km
		PW Pinniped	185 dB	57 km^2	4.9 km	3.5 km	4.2 km
	Weighted SEL_{ss}	LF Cetacean	183 dB	1.8 km^2	770 m	760 m	760 m
		MF Cetacean	185 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	155 dB	0.02 km^2	70 m	70 m	70 m
		PW Pinniped	185 dB	0.01 km^2	50 m	50 m	50 m
Average depth location	Unweighted SPL_{peak}	LF Cetacean	219 dB	0.01 km^2	50 m	50 m	50 m
		MF Cetacean	230 dB	< 0.01 km^2	< 50 m	< 50m	< 50 m
		HF Cetacean	202 dB	4.5 km^2	1.2 km	1.2 km	1.2 km
		PW Pinniped	218 dB	0.01 km^2	60 m	60 m	60 m
	Weighted SEL_{cum}	LF Cetacean	183 dB	450 km^2	14 km	7.9 km	12 km
		MF Cetacean	185 dB	< 0.01 km^2	< 100 m	< 100 m	< 100 m
		HF Cetacean	155 dB	68 km^2	5.4 km	3.5 km	4.6 km
		PW Pinniped	185 dB	39 km^2	4.1 km	2.7 km	3.5 km
	Weighted SEL_{ss}	LF Cetacean	183 dB	1.8 km^2	760 m	750 m	750 m
		MF Cetacean	185 dB	< 0.01 km^2	< 50 m	< 50m	< 50 m
		HF Cetacean	155 dB	0.02 km^2	70 m	70 m	70 m
		PW Pinniped	185 dB	0.01 km^2	50 m	50 m	50 m

Table 5-2 Summary of the single strike and cumulative impact ranges for PTS from NMFS (2018) for installation of a monopile at EA2 using the 100% maximum hammer blow energy of 4000 kJ

<table>
<tr><th rowspan="2">EA2</th><th colspan="3" rowspan="2">NMFS (2018) - PTS</th><th colspan="4">Pin Pile (240kJ – soft start, 10%)</th></tr>
<tr><th>Area</th><th>Maximum</th><th>Minimum</th><th>Mean</th></tr>
<tr><td rowspan="8">Worst case</td><td rowspan="4">Unweighted SPL_{peak}</td><td>LF Cetacean</td><td>219 dB</td><td>< 0.01 km²</td><td>< 50 m</td><td>< 50 m</td><td>< 50 m</td></tr>
<tr><td>MF Cetacean</td><td>230 dB</td><td>< 0.01 km²</td><td>< 50 m</td><td>< 50 m</td><td>< 50 m</td></tr>
<tr><td>HF Cetacean</td><td>202 dB</td><td>0.45 km²</td><td>380 m</td><td>380 m</td><td>380 m</td></tr>
<tr><td>PW Pinniped</td><td>218 dB</td><td>< 0.01 km²</td><td>< 50 m</td><td>< 50 m</td><td>< 50 m</td></tr>
<tr><td rowspan="4">Weighted SEL_{ss}</td><td>LF Cetacean</td><td>183 dB</td><td>0.27 km²</td><td>300 m</td><td>290 m</td><td>290 m</td></tr>
<tr><td>MF Cetacean</td><td>185 dB</td><td>< 0.01 km²</td><td>< 50 m</td><td>< 50 m</td><td>< 50 m</td></tr>
<tr><td>HF Cetacean</td><td>155 dB</td><td>0.05 km²</td><td>130 m</td><td>130 m</td><td>130 m</td></tr>
<tr><td>PW Pinniped</td><td>185 dB</td><td>< 0.01 km²</td><td>< 50 m</td><td>< 50 m</td><td>< 50 m</td></tr>
<tr><td rowspan="8">Average depth</td><td rowspan="4">Unweighted SPL_{peak}</td><td>LF Cetacean</td><td>219 dB</td><td>< 0.01 km²</td><td>< 50 m</td><td>< 50 m</td><td>< 50 m</td></tr>
<tr><td>MF Cetacean</td><td>230 dB</td><td>< 0.01 km²</td><td>< 50 m</td><td>< 50 m</td><td>< 50 m</td></tr>
<tr><td>HF Cetacean</td><td>202 dB</td><td>0.44 km²</td><td>380 m</td><td>380 m</td><td>380 m</td></tr>
<tr><td>PW Pinniped</td><td>218 dB</td><td>< 0.01 km²</td><td>< 50 m</td><td>< 50 m</td><td>< 50 m</td></tr>
<tr><td rowspan="4">Weighted SEL_{ss}</td><td>LF Cetacean</td><td>183 dB</td><td>0.27 km²</td><td>290 m</td><td>290 m</td><td>290 m</td></tr>
<tr><td>MF Cetacean</td><td>185 dB</td><td>< 0.01 km²</td><td>< 50 m</td><td>< 50 m</td><td>< 50 m</td></tr>
<tr><td>HF Cetacean</td><td>155 dB</td><td>0.05 km²</td><td>130 m</td><td>130 m</td><td>130 m</td></tr>
<tr><td>PW Pinniped</td><td>185 dB</td><td>< 0.01 km²</td><td>< 50 m</td><td>< 50 m</td><td>< 50 m</td></tr>
</table>

Table 5-3 Summary of the single strike impact ranges for PTS from NMFS (2018) for installation of a pin pile at EA2 using the 10% soft start hammer blow energy of 240 kJ

<table>
<tr><th rowspan="2">EA2</th><th colspan="3" rowspan="2">NMFS (2018) - PTS</th><th colspan="4">Pin Pile (2400kJ – main piling, 100%)</th></tr>
<tr><th>Area</th><th>Maximum</th><th>Minimum</th><th>Mean</th></tr>
<tr><td rowspan="12">Worst case location</td><td rowspan="4">Unweighted SPL_{peak}</td><td>LF Cetacean</td><td>219 dB</td><td>0.01 km²</td><td>50 m</td><td>50 m</td><td>50 m</td></tr>
<tr><td>MF Cetacean</td><td>230 dB</td><td>< 0.01 km²</td><td>< 50 m</td><td>< 50 m</td><td>< 50 m</td></tr>
<tr><td>HF Cetacean</td><td>202 dB</td><td>4.1 km²</td><td>1.2 km</td><td>1.1 km</td><td>1.1 km</td></tr>
<tr><td>PW Pinniped</td><td>218 dB</td><td>0.01 km²</td><td>60 m</td><td>60 mm</td><td>60 m</td></tr>
<tr><td rowspan="4">Weighted SEL_{cum}</td><td>LF Cetacean</td><td>183 dB</td><td>860 km²</td><td>20 km</td><td>13 km</td><td>16 km</td></tr>
<tr><td>MF Cetacean</td><td>185 dB</td><td>< 0.01 km²</td><td>< 100 m</td><td>< 100 m</td><td>< 100 m</td></tr>
<tr><td>HF Cetacean</td><td>155 dB</td><td>970 km²</td><td>21 km</td><td>14 km</td><td>18 km</td></tr>
<tr><td>PW Pinniped</td><td>185 dB</td><td>110 km²</td><td>6.8 km</td><td>4.9 km</td><td>5.9 km</td></tr>
<tr><td rowspan="4">Weighted SEL_{ss}</td><td>LF Cetacean</td><td>183 dB</td><td>2.5 km²</td><td>910 m</td><td>890 m</td><td>900 m</td></tr>
<tr><td>MF Cetacean</td><td>185 dB</td><td>< 0.01 km²</td><td>< 50 m</td><td>< 50 m</td><td>< 50 m</td></tr>
<tr><td>HF Cetacean</td><td>155 dB</td><td>0.5 km²</td><td>400 m</td><td>400 m</td><td>400 m</td></tr>
<tr><td>PW Pinniped</td><td>185 dB</td><td>0.01 km²</td><td>50 m</td><td>50 m</td><td>50 m</td></tr>
<tr><td rowspan="12">Average depth location</td><td rowspan="4">Unweighted SPL_{peak}</td><td>LF Cetacean</td><td>219 dB</td><td>0.01 km²</td><td>50 m</td><td>50 m</td><td>50 m</td></tr>
<tr><td>MF Cetacean</td><td>230 dB</td><td>< 0.01 km²</td><td>< 50 m</td><td>< 50 m</td><td>< 50 m</td></tr>
<tr><td>HF Cetacean</td><td>202 dB</td><td>3.9 km²</td><td>1.1 km</td><td>1.1 km</td><td>1.1 km</td></tr>
<tr><td>PW Pinniped</td><td>218 dB</td><td>0.01 km²</td><td>60 m</td><td>60 m</td><td>60 m</td></tr>
<tr><td rowspan="4">Weighted SEL_{cum}</td><td>LF Cetacean</td><td>183 dB</td><td>690 km²</td><td>18 km</td><td>9.4 km</td><td>15 km</td></tr>
<tr><td>MF Cetacean</td><td>185 dB</td><td>< 0.01 km²</td><td>< 100 m</td><td>< 100 m</td><td>< 100 m</td></tr>
<tr><td>HF Cetacean</td><td>155 dB</td><td>790 km²</td><td>19 km</td><td>11 km</td><td>16 km</td></tr>
<tr><td>PW Pinniped</td><td>185 dB</td><td>78 km²</td><td>5.8 km</td><td>3.7 km</td><td>4.9 km</td></tr>
<tr><td rowspan="4">Weighted SEL_{ss}</td><td>LF Cetacean</td><td>183 dB</td><td>2.5 km²</td><td>890 m</td><td>880 m</td><td>890 m</td></tr>
<tr><td>MF Cetacean</td><td>185 dB</td><td>< 0.01 km²</td><td>< 50 m</td><td>< 50 m</td><td>< 50 m</td></tr>
<tr><td>HF Cetacean</td><td>155 dB</td><td>0.49 km²</td><td>400 m</td><td>400 m</td><td>400 m</td></tr>
<tr><td>PW Pinniped</td><td>185 dB</td><td>0.01 km²</td><td>50m</td><td>50 m</td><td>50 m</td></tr>
</table>

Table 5-4 Summary of the single strike and cumulative impact ranges for PTS from NMFS (2018) for installation of a pin pile at EA2 using the 100% maximum hammer blow energy of 2400 kJ

EA2		NMFS (2018) - TTS		**Monopile (400kJ – soft start, 10%)**			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	**Unweighted SPL$_{peak}$**	LF Cetacean	213 dB	0.02 km^2	70 m	70 m	70 m
		MF Cetacean	224 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	8.5 km^2	1.7 km	1.6 km	1.6 km
		PW Pinniped	212 dB	0.03 km^2	90 m	90 m	90 m
	Weighted SEL$_{ss}$	LF Cetacean	168 dB	59 km^2	4.6 km	4.1 km	4.3 km
		MF Cetacean	170 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	0.86 km^2	530 m	520 m	530 m
		PW Pinniped	170 dB	0.51 km^2	410 m	400 m	410 m
Average depth	**Unweighted SPL$_{peak}$**	LF Cetacean	213 dB	0.02 km^2	70 m	70 m	70 m
		MF Cetacean	224 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	8.1 km^2	1.6 km	1.6 km	1.6 km
		PW Pinniped	212 dB	0.03 km^2	90 m	90 m	90 m
	Weighted SEL$_{ss}$	LF Cetacean	168 dB	54 km^2	4.3 km	4.0 km	4.2 km
		MF Cetacean	170 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	0.85 km^2	520 m	520 m	520 m
		PW Pinniped	170 dB	0.51 km^2	400 m	400 m	400 m

Table 5-5 Summary of the single strike impact ranges for TTS from NMFS (2018) for installation of a monopile at EA2 using the 10% soft start hammer blow energy of 400 kJ

EA2		NMFS (2018) - TTS		**Monopile (4000kJ – main piling, 100%)**			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case location	**Unweighted SPL$_{peak}$**	LF Cetacean	213 dB	0.08 km^2	160 m	160 m	160 m
		MF Cetacean	224 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	31 km^2	3.3 km	3.0 km	3.2 km
		PW Pinniped	212 dB	0.12 km^2	200 m	200 m	200 m
	Weighted SEL$_{cum}$	LF Cetacean	168 dB	3100 km^2	39 km	23 km	31 km
		MF Cetacean	170 dB	< 0.01 km^2	< 100 m	< 100 m	< 100 m
		HF Cetacean	140 dB	1500 km^2	27 km	17 km	22 km
		PW Pinniped	170 dB	1300 km^2	25 km	16 km	20 km
	Weighted SEL$_{ss}$	LF Cetacean	168 dB	160 km^2	7.6 km	6.6 km	7.2 km
		MF Cetacean	170 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	3.9 km^2	1.1 km	1.1 km	1.1 km
		PW Pinniped	170 dB	2.4 km^2	880 m	860 m	870 m
Average depth location	**Unweighted SPL$_{peak}$**	LF Cetacean	213 dB	0.08 km^2	160 m	160 m	160 m
		MF Cetacean	224 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	29 km^2	3.1 km	3.1 km	3.1 km
		PW Pinniped	212 dB	0.12 km^2	200 m	200 m	200 m
	Weighted SEL$_{cum}$	LF Cetacean	168 dB	2700 km^2	36 km	19 km	29 km
		MF Cetacean	170 dB	< 0.01 km^2	< 100 m	< 100 m	< 100 m
		HF Cetacean	140 dB	1300 km^2	24 km	14 km	20 km
		PW Pinniped	170 dB	1100 km^2	22 km	13 km	18 km
	Weighted SEL$_{ss}$	LF Cetacean	168 dB	140 km^2	7.1 km	6.3 km	6.7 km
		MF Cetacean	170 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	3.7 km^2	1.1 km	1.1 km	1.1 km
		PW Pinniped	170 dB	2.3 km^2	860 m	860 m	860 m

Table 5-6 Summary of the single strike and cumulative impact ranges for TTS from NMFS (2018) for installation of a monopile at EA2 using the 100% maximum hammer blow energy of 4000 kJ

EA2	NMFS (2018) - TTS			Pin Pile (240kJ – soft start, 10%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	**Unweighted SPL_{peak}**	LF Cetacean	213 dB	0.01 km²	60 m	60 m	60 m
		MF Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	3.9 km²	1.1 km	1.1 km	1.1 km
		PW Pinniped	212 dB	0.01 km²	60 m	60 m	60 m
	Weighted SEL_{ss}	LF Cetacean	168 dB	46 km²	4.0 km	3.6 km	3.8 km
		MF Cetacean	170 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	13 km²	2.1 km	1.9 km	2.0 km
		PW Pinniped	170 dB	0.25 km²	290 m	280 m	280 m
Average depth	**Unweighted SPL_{peak}**	LF Cetacean	213 dB	0.01 km²	50 m	50 m	50 m
		MF Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	3.8 km²	1.1 km	1.1 km	1.1 km
		PW Pinniped	212 dB	0.01 km²	60 m	60 m	60 m
	Weighted SEL_{ss}	LF Cetacean	168 dB	42 km²	3.8 km	3.5 km	3.7 km
		MF Cetacean	170 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	12 km²	2.0 km	1.9 km	2.0 km
		PW Pinniped	170 dB	0.25 km²	280 m	280 m	280 m

Table 5-7 Summary of the single strike impact ranges for TTS from NMFS (2018) for installation of a pin pile at EA2 using the 10% soft start hammer blow energy of 240 kJ

EA2	NMFS (2018) - TTS			Pin Pile (2400kJ – main piling, 100%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case location	**Unweighted SPL_{peak}**	LF Cetacean	213 dB	0.07 km²	150 m	150 m	150 m
		MF Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	28 km²	3.1 km	2.9 km	3.0 km
		PW Pinniped	212 dB	0.11 km²	190 m	180 m	190 m
	Weighted SEL_{cum}	LF Cetacean	168 dB	3700 km²	44 km	25 km	34 km
		MF Cetacean	170 dB	72 km²	5.5 km	3.9 km	4.8 km
		HF Cetacean	140 dB	4000 km²	44 km	27 km	35 km
		PW Pinniped	170 dB	1600 km²	27 km	18 km	23 km
	Weighted SEL_{ss}	LF Cetacean	168 dB	200 km²	8.4 km	7.3 km	7.9 km
		MF Cetacean	170 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	70 km²	5.0 km	4.4 km	4.7 km
		PW Pinniped	170 dB	2.4 km²	880 m	860 m	870 m
Average depth location	**Unweighted SPL_{peak}**	LF Cetacean	213 dB	0.07 km²	150 m	150 m	150 m
		MF Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	26 km²	3.0 km	2.8 km	2.9 km
		PW Pinniped	212 dB	0.11 km²	180 m	180 m	180 m
	Weighted SEL_{cum}	LF Cetacean	168 dB	3200 km²	18 km	9.4 km	15 km
		MF Cetacean	170 dB	50 km²	4.7 km	3.0 km	4.0 km
		HF Cetacean	140 dB	3500 km²	41 km	23 km	33 km
		PW Pinniped	170 dB	1300 km²	24 km	14 km	20 km
	Weighted SEL_{ss}	LF Cetacean	168 dB	170 km²	7.8 km	6.9 km	7.4 km
		MF Cetacean	170 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	64 km²	4.7 km	4.4 km	4.5 km
		PW Pinniped	170 dB	2.3 km²	860 m	850 m	860 m

Table 5-8 Summary of the single strike and cumulative impact ranges for TTS from NMFS (2018) for installation of a pin pile at EA2 using the 100% maximum hammer blow energy of 2400 kJ

5.2.1.1.2 EA1N

EA1N	NMFS (2018) - PTS			Monopile (400kJ – soft start, 10%)			
				Area	Maximum	Minimum	Mean
Worst case	**Unweighted SPL_{peak}**	LF Cetacean	219 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		MF Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	1.0 km²	580 m	540 m	580 m
		PW Pinniped	218 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	Weighted SEL_{ss}	LF Cetacean	183 dB	0.39 km²	360 m	350 m	350 m
		MF Cetacean	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	155 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PW Pinniped	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
Average depth	**Unweighted SPL_{peak}**	LF Cetacean	219 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		MF Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	1.0 km²	570 m	570 m	570 m
		PW Pinniped	218 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	Weighted SEL_{ss}	LF Cetacean	183 dB	0.38 km²	350 m	350 m	350 m
		MF Cetacean	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	155 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PW Pinniped	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m

Table 5-9 Summary of the single strike impact ranges for PTS from NMFS (2018) for installation of a monopile at EA1N using the 10% soft start hammer blow energy of 400 kJ

EA1N	NMFS (2018) - PTS			Monopile (4000kJ – main piling, 100%)			
				Area	Maximum	Minimum	Mean
Worst case location	**Unweighted SPL_{peak}**	LF Cetacean	219 dB	0.01 km²	50 m	50 m	50 m
		MF Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	4.6 km²	1.2 km	1.2 km	1.2 km
		PW Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	Weighted SEL_{cum}	LF Cetacean	183 dB	570 km²	17 km	11 km	13 km
		MF Cetacean	185 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		HF Cetacean	155 dB	92 km²	6.6 km	4.6 km	5.4 km
		PW Pinniped	185 dB	54 km²	5.2 km	3.6 km	4.2 km
	Weighted SEL_{ss}	LF Cetacean	183 dB	1.8 km²	770 m	760 m	760 m
		MF Cetacean	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	155 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PW Pinniped	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
Average depth location	**Unweighted SPL_{peak}**	LF Cetacean	219 dB	0.01 km²	50 m	50 m	50 m
		MF Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	4.4 km²	1.2 km	1.2 km	1.2 km
		PW Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	Weighted SEL_{cum}	LF Cetacean	183 dB	600 km²	15 km	13 km	14 km
		MF Cetacean	185 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		HF Cetacean	155 dB	90 km²	5.7 km	5.1 km	5.4 km
		PW Pinniped	185 dB	53 km²	4.3 km	3.9 km	4.1 km
	Weighted SEL_{ss}	LF Cetacean	183 dB	1.8 km²	750 m	750 m	750 m
		MF Cetacean	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	155 dB	0.02 km²	70 m	70 m	70 m
		PW Pinniped	185 dB	0.01 km²	50 m	50 m	50 m

Table 5-10 Summary of the single strike and cumulative impact ranges for PTS from NMFS (2018) for installation of a monopile at EA1N using the 100% maximum hammer blow energy of 4000 kJ

EA1N	NMFS (2018) - PTS			Pin Pile (240kJ – soft start, 10%)			
				Area	Maximum	Minimum	Mean
Worst case	Unweighted SPL_{peak}	LF Cetacean	219 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		MF Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	0.45 km²	380 m	380 m	380 m
		PW Pinniped	218 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	Weighted SEL_{ss}	LF Cetacean	183 dB	0.27 km²	300 m	290 m	290 m
		MF Cetacean	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	155 dB	0.05 km²	130 m	130 m	130 m
		PW Pinniped	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
Average depth	Unweighted SPL_{peak}	LF Cetacean	219 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		MF Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	0.44 km²	380 m	380 m	380 m
		PW Pinniped	218 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	Weighted SEL_{ss}	LF Cetacean	183 dB	0.27 km²	290 m	290 m	290 m
		MF Cetacean	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	155 dB	0.05 km²	130 m	130 m	130 m
		PW Pinniped	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m

Table 5-11 Summary of the single strike impact ranges for PTS from NMFS (2018) for installation of a pin pile at EA1N using the 10% soft start hammer blow energy of 240 kJ

EA1N	NMFS (2018) - PTS			Pin Pile (2400kJ – main piling, 100%)			
				Area	Maximum	Minimum	Mean
Worst case location	Unweighted SPL_{peak}	LF Cetacean	219 dB	0.01 km²	50 m	50 m	50 m
		MF Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	4.1 km²	1.2 km	1.1 km	1.1 km
		PW Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	Weighted SEL_{cum}	LF Cetacean	183 dB	870 km²	21 km	13 km	17 km
		MF Cetacean	185 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		HF Cetacean	155 dB	980 km²	21 km	15 km	18 km
		PW Pinniped	185 dB	100 km²	7.1 km	5.0 km	5.8 km
	Weighted SEL_{ss}	LF Cetacean	183 dB	2.5	900 m	890 m	900 m
		MF Cetacean	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	155 dB	0.5	400 m	400 m	400 m
		PW Pinniped	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
Average depth location	Unweighted SPL_{peak}	LF Cetacean	219 dB	0.01 km²	50 m	50 m	50 m
		MF Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	3.9 km²	1.1 km	1.1 km	1.1 km
		PW Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	Weighted SEL_{cum}	LF Cetacean	183 dB	910 km²	19 km	16 km	17 km
		MF Cetacean	185 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		HF Cetacean	155 dB	1000 km²	20 km	17 km	18 km
		PW Pinniped	185 dB	100 km²	6.1 km	5.4 km	5.7 km
	Weighted SEL_{ss}	LF Cetacean	183 dB	2.4 km²	890 m	880 m	880 m
		MF Cetacean	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	155 dB	0.49 km²	400 m	400 m	400 m
		PW Pinniped	185 dB	0.01 km²	50	50	50

Table 5-12 Summary of the single strike and cumulative impact ranges for PTS from NMFS (2018) for installation of a pin pile at EA1N using the 100% maximum hammer blow energy of 2400 kJ

EA1N		NMFS (2018) - TTS		Monopile (400kJ – soft start, 10%)			
				Area	Maximum	Minimum	Mean
Worst case	Unweighted SPL_{peak}	LF Cetacean	213 dB	0.02 km²	70 m	70 m	70 m
		MF Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	8.5 km²	1.7 km	1.6 km	1.6 km
		PW Pinniped	212 dB	0.03 km²	90 m	90 m	90 m
	Weighted SEL_{ss}	LF Cetacean	168 dB	59 km²	4.5 km	4.2 km	4.3 km
		MF Cetacean	170 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	0.86 km²	530 m	520 m	530 m
		PW Pinniped	170 dB	0.51 km²	410 m	400 m	410 m
Average depth	Unweighted SPL_{peak}	LF Cetacean	213 dB	0.02 km²	70 m	70 m	70 m
		MF Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	8.1 km²	1.6 km	1.6 km	1.6 km
		PW Pinniped	212 dB	0.02 km²	90 m	90 m	90 m
	Weighted SEL_{ss}	LF Cetacean	168 dB	57 km²	4.4 km	4.2 km	4.3 km
		MF Cetacean	170 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	0.84 km²	520 m	520 m	520 m
		PW Pinniped	170 dB	0.5 km²	400 m	400 m	400 m

Table 5-13 Summary of the single strike impact ranges for TTS from NMFS (2018) for installation of a monopile at EA1N using the 10% soft start hammer blow energy of 400 kJ

EA1N		NMFS (2018) - TTS		Monopile (4000kJ – main piling, 100%)			
				Area	Maximum	Minimum	Mean
Worst case location	Unweighted SPL_{peak}	LF Cetacean	213 dB	0.08 km²	160 m	160 m	160 m
		MF Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	31 km²	3.2 km	3.1 km	3.2 km
		PW Pinniped	212 dB	0.12 km²	200 m	200m	200 m
	Weighted SEL_{cum}	LF Cetacean	168 dB	3200 km²	40 km	24 km	31 km
		MF Cetacean	170 dB	0.01 km²	< 100 m	< 100 m	< 100 m
		HF Cetacean	140 dB	1600 km²	27 km	18 km	22 km
		PW Pinniped	170 dB	1300 km²	25 km	17 km	21 km
	Weighted SEL_{ss}	LF Cetacean	168 dB	160 km²	7.7 km	6.8 km	7.1 km
		MF Cetacean	170 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	3.9 km²	1.1 km	1.1 km	1.1 km
		PW Pinniped	170 dB	2.4 km²	870 m	870 m	870 m
Average depth location	Unweighted SPL_{peak}	LF Cetacean	213 dB	0.08 km²	160 m	160 m	160 m
		MF Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	30 km²	3.1 km	3.0 km	3.1 km
		PW Pinniped	212 dB	0.12 km²	200 m	200 m	200 m
	Weighted SEL_{cum}	LF Cetacean	168 dB	3300 km²	38 km	29 km	32 km
		MF Cetacean	170 dB	0.01 km²	< 100 m	< 100 m	< 100 m
		HF Cetacean	140 dB	1600 km²	26 km	22 km	23 km
		PW Pinniped	170 dB	1400 km²	24 km	20 km	21 km
	Weighted SEL_{ss}	LF Cetacean	168 dB	150 km²	7.3 km	6.9 km	7.0 km
		MF Cetacean	170 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	3.7 km²	1.1 km	1.1 km	1.1 km
		PW Pinniped	170 dB	2.3 km²	860 m	860 m	860 m

Table 5-14 Summary of the single strike and cumulative impact ranges for TTS from NMFS (2018) for installation of a monopile at EA1N using the 100% maximum hammer blow energy of 4000 kJ

EA1N	NMFS (2018) - TTS			Pin Pile (240kJ – soft start, 10%)			
				Area	Maximum	Minimum	Mean
Worst case	Unweighted SPL_{peak}	LF Cetacean	213 dB	0.01 km²	50 m	50 m	50 m
		MF Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	3.9 km²	1.1 km	1.1 km	1.1 km
		PW Pinniped	212 dB	0.01 km²	60 m	60 m	60 m
	Weighted SEL_{ss}	LF Cetacean	168 dB	45 km²	4.0 km	3.7 km	3.8 km
		MF Cetacean	170 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	12 km²	2.1 km	1.9 km	2.0 km
		PW Pinniped	170 dB	0.25 km²	290 m	280 m	280 m
Average depth	Unweighted SPL_{peak}	LF Cetacean	213 dB	0.01 km²	50 m	50 m	50 m
		MF Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	3.8 km²	1.1 km	1.1 km	1.1 km
		PW Pinniped	212 dB	0.01 km²	60 m	60 m	60 m
	Weighted SEL_{ss}	LF Cetacean	168 dB	43 km²	3.8 km	3.6 km	3.7 km
		MF Cetacean	170 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	12 km²	2.0 km	1.9 km	2.0 km
		PW Pinniped	170 dB	0.25 km²	280 m	280 m	280 m

Table 5-15 Summary of the single strike impact ranges for TTS from NMFS (2018) for installation of a pin pile at EA1N using the 10% soft start hammer blow energy of 240 kJ

EA1N	NMFS (2018) - TTS			Pin Pile (2400kJ – main piling, 100%)			
				Area	Maximum	Minimum	Mean
Worst case location	Unweighted SPL_{peak}	LF Cetacean	213 dB	0.07 km²	150 m	150 m	150 m
		MF Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	28 km²	3.1 km	3.0 km	3.0 km
		PW Pinniped	212 dB	0.11 km²	190 m	180 m	190 m
	Weighted SEL_{cum}	LF Cetacean	168 dB	3800 km²	45 km	26 km	34 km
		MF Cetacean	170 dB	69 km²	5.8 km	4.0 km	4.7 km
		HF Cetacean	140 dB	4000 km²	45 km	28 km	36 km
		PW Pinniped	170 dB	1600 km²	28 km	19 km	23 km
	Weighted SEL_{ss}	LF Cetacean	168 dB	190 km²	8.6 km	7.4 km	7.9 km
		MF Cetacean	170 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	70 km²	5.0 km	4.6 km	4.7 km
		PW Pinniped	170 dB	2.4 km²	870 m	870 m	870 m
Average depth location	Unweighted SPL_{peak}	LF Cetacean	213 dB	0.07 km²	150 m	150 m	150 m
		MF Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	27 km²	3.0 km	2.9 km	2.9 km
		PW Pinniped	212 dB	0.1 km²	180 m	180 m	180 m
	Weighted SEL_{cum}	LF Cetacean	168 dB	4000 km²	42 km	31 km	36 km
		MF Cetacean	170 dB	67 km²	4.9 km	4.4 km	4.6 km
		HF Cetacean	140 dB	4200 km²	43 km	33 km	37 km
		PW Pinniped	170 dB	1700 km²	26 km	22 km	23 km
	Weighted SEL_{ss}	LF Cetacean	168 dB	190 km²	8.0 km	7.6 km	7.8 km
		MF Cetacean	170 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	67 km²	4.8 km	4.5 km	4.6 km
		PW Pinniped	170 dB	2.3 km²	860 m	850 m	860 m

Table 5-16 Summary of the single strike and cumulative impact ranges for TTS from NMFS (2018) for installation of a pin pile at EA1N using the 100% maximum hammer blow energy of 2400 kJ

5.2.1.1.3 Discussion

The ranges of impact vary depending on the hearing (species) group and severity of impact. Looking at the monopile results from the worst-case modelling location at EA2 as an example (Table 5-2 and Table 5-6), the SEL results using the LF weighting lead to the greatest ranges as the MF and HF cetacean and pinniped weightings filter out much of the piling energy at lower frequencies. It is also worth noting that greater ranges are created for the transects travelling through the deepest water. This is shown clearly in section 5.1.

This also explains why some of the ranges for the “worst case” piling locations are actually shorter than the “average depth” location. Although the source is in a slightly deeper position, the “average depth” location is closer to areas of deeper water, and so this can lead to more of the overall area around this location being at a slightly higher noise level, and thus the noise exposure being slightly greater overall.

The SEL_{cum} results show that larger ranges are expected for pin piles than for monopiles due to the faster strike rate assumed for those scenarios. Another factor that adds to this is the difference between the marine mammal hearing groups and the sound frequencies produced by the different piles.

The frequency spectra used as inputs to the model (Figure 4-2) show that the noise from pin piles contains more high frequency components than the noise from monopiles. The overall unweighted noise level is higher for the monopile due to the low frequency components of piling noise (i.e. most of the pile strike energy is in the lower frequencies). The MF and HF cetacean filters (Figure 2-1) both remove the low frequency components of the noise, as species in these marine mammal groups are much less sensitive to noise at these frequencies. This leaves the higher frequency noise, which, in the case of the pin piles, is higher than that for the monopiles.

To illustrate this, Figure 5-9 shows the sound frequency spectra for monopiles and pin piles, adjusted (weighted) to account for the sensitivities of MF and HF cetaceans. These can be compared to the original unweighted frequency spectra in Figure 4-2 (shown faintly in Figure 5-9). Overall, higher levels are present in the weighted pin pile spectrum.

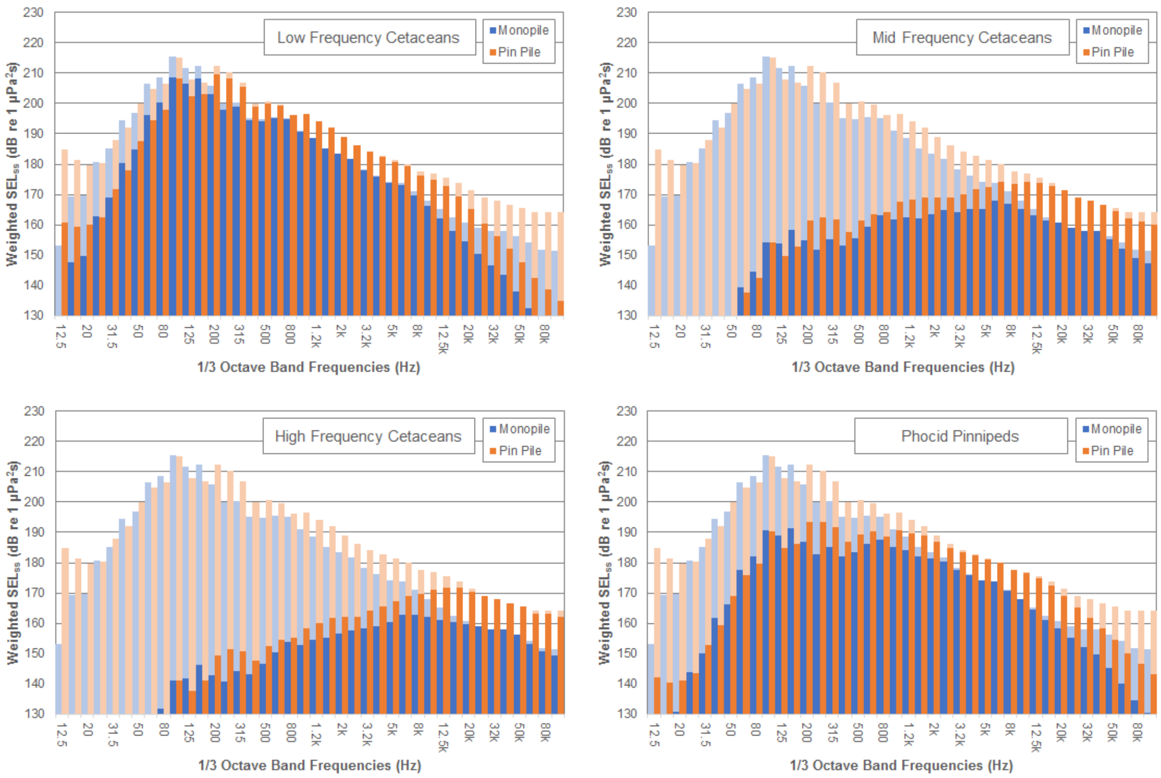

Figure 5-9 Filtered noise inputs for monopiles and pin piles using the NMFS (2018) filters. The lighter coloured bars show the unweighted third octave levels

5.2.1.2 Southall et al. (2007) results

Table 5-17 to Table 5-24 (EA2) and Table 5-29 to Table 5-36 (EA1N) present the predicted PTS and TTS impact ranges for various cetaceans and pinniped hearing groups based on the Southall *et al.*

(2007) thresholds for soft start and maximum energy including exposure over the entire installation of a pile. Behavioural avoidance results for low and mid frequency cetaceans are given in Table 5-25 to Table 5-28 (EA2) and Table 5-37 to Table 5-40 (EA1N). The behavioural response ranges for high frequency cetaceans are given using the Lucke *et al*. (2009) criteria in section 5.2.1.3.

Maximum PTS ranges for any species are predicted for pinnipeds (in water) of 7.5 km using the SEL_{cum} criteria from Southall *et al*. (2007) due to the more conservative criteria for pinnipeds compared to the cetacean hearing groups. Ranges out to a maximum of 51 km are also predicted for behavioural avoidance in LF cetaceans.

5.2.1.2.1 *EA2*

EA2	Southall *et al.* (2007) - PTS			**Monopile (400kJ – soft start, 10%)**			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	**Unweighted SPL_{peak}**	Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	M-Weighted SEL_{ss}	LF Cetacean	198 dB	0.01 km²	60 m	60 m	60 m
		MF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	0.24 km²	280 m	280 m	280 m
Av. depth	**Unweighted SPL_{peak}**	Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	M-Weighted SEL_{ss}	LF Cetacean	198 dB	0.01 km²	60 m	60 m	60 m
		MF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	0.24 km²	280 m	280 m	280 m

Table 5-17 Summary of the single strike impact ranges for PTS from Southall et al. (2007) for installation of a monopile at EA2 using the 10% soft start hammer blow energy of 400 kJ

EA2	Southall *et al.* (2007) - PTS			**Monopile (4000kJ – main piling, 100%)**			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	**Unweighted SPL_{peak}**	Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	M-Weighted SEL_{cum}	LF Cetacean	198 dB	37 km²	4.2 km	2.6 km	3.4 km
		MF Cetacean	198 dB	19 km²	2.8 km	1.9 km	2.4 km
		HF Cetacean	198 dB	6.1 km²	1.7 km	1.0 km	1.4 km
		PW Pinniped	186 dB	1000 km²	22 km	15 km	18 km
	M-Weighted SEL_{ss}	LF Cetacean	198 dB	0.05 km²	130 m	130 m	130 m
		MF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	1.2 km²	610 m	600 m	610 m
Average depth	**Unweighted SPL_{peak}**	Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	M-Weighted SEL_{cum}	LF Cetacean	198 dB	23 km²	3.4 km	1.8 km	2.7 km
		MF Cetacean	198 dB	12 km²	2.3 km	1.5 km	2.0 km
		HF Cetacean	198 dB	3.7 km²	1.3 km	800 m	1.1 km
		PW Pinniped	186 dB	840 km²	19 km	11 km	16 km
	M-Weighted SEL_{ss}	LF Cetacean	198 dB	0.05 km²	130 m	130 m	130 m
		MF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	1.1 km²	600 m	600 m	600 m

Table 5-18 Summary of the single strike and cumulative impact ranges for PTS from Southall et al. (2007) for installation of a monopile at EA2 using the 100% maximum hammer blow energy of 4000 kJ

EA2	Southall *et al.* (2007) - PTS			**Pin Pile (240kJ – soft start, 10%)**			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	**Unweighted SPL$_{peak}$**	Cetacean	230 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	M-Weighted SEL$_{ss}$	LF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		MF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	0.18 km^2	240 m	240 m	240 m
Av. depth	**Unweighted SPL$_{peak}$**	Cetacean	230 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	M-Weighted SEL$_{ss}$	LF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		MF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	0.18 km^2	240 m	240 m	240 m

Table 5-19 Summary of the single strike impact ranges for PTS from Southall et al. (2007) for installation of a pin pile at EA2 using the 10% soft start hammer blow energy of 240 kJ

EA2	Southall *et al.* (2007) - PTS			**Pin Pile (2400kJ – main piling, 100%)**			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	**Unweighted SPL$_{peak}$**	Cetacean	230 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	0.01 km^2	60 m	60 m	60 m
	M-Weighted SEL$_{cum}$	LF Cetacean	198 dB	62 km^2	5.6 km	3.3 km	4.4 km
		MF Cetacean	198 dB	73 km^2	5.6 km	4.0 km	4.8 km
		HF Cetacean	198 dB	30 km^2	3.5 km	2.4 km	3.1 km
		PW Pinniped	186 dB	1500 km^2	26 km	17 km	21 km
	M-Weighted SEL$_{ss}$	LF Cetacean	198 dB	0.04 km^2	120 m	120 m	120 m
		MF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	1.7 km^2	740	730 m	740 m
Average depth	**Unweighted SPL$_{peak}$**	Cetacean	230 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	0.01 km^2	60 m	60 m	60 m
	M-Weighted SEL$_{cum}$	LF Cetacean	198 dB	38 km^2	4.4 km	2.0 km	3.4 km
		MF Cetacean	198 dB	50 km^2	4.7 km	3.0 km	4.0 km
		HF Cetacean	198 dB	19 km^2	2.9 km	1.8 km	2.5 km
		PW Pinniped	186 dB	1200 km^2	23 km	14 km	19 km
	M-Weighted SEL$_{ss}$	LF Cetacean	198 dB	0.04 km^2	120 m	120 m	120 m
		MF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	1.7 km^2	730 m	730 m	730 m

Table 5-20 Summary of the single strike and cumulative impact ranges for PTS from Southall et al. (2007) for installation of a pin pile at EA2 using the 100% maximum hammer blow energy of 2400 kJ

EA2		Southall *et al.* (2007) - TTS		Monopile (400kJ – soft start, 10%)			
				Area	Maximum	Minimum	Mean
Worst case	Unweighted SPL_{peak}	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.03 km²	90 m	90 m	90 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	2.7 km²	940 m	910 m	930 m
		MF Cetacean	183 dB	0.22 km²	270 m	270 m	270 m
		HF Cetacean	183 dB	0.12 km²	200 m	200 m	200 m
		PW Pinniped	171 dB	42 km²	3.9 km	3.4 km	3.7 km
Av. depth	Unweighted SPL_{peak}	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.03 km²	90 m	90 m	90 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	2.6 km²	910 m	910 m	910 m
		MF Cetacean	183 dB	0.22 km²	270 m	260 m	270 m
		HF Cetacean	183 dB	0.12 km²	200 m	200 m	200 m
		PW Pinniped	171 dB	39 km²	3.7 km	3.4 km	3.5 km

Table 5-21 Summary of the single strike impact ranges for TTS from Southall et al. (2007) for installation of a monopile at EA2 using the 10% soft start hammer blow energy of 400 kJ

EA2		Southall *et al.* (2007) - TTS		Monopile (4000kJ – main piling, 100%)			
				Area	Maximum	Minimum	Mean
Worst case	Unweighted SPL_{peak}	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.12 km²	200 m	200 m	200 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	12 km²	2.1 km	1.9 km	2.0 km
		MF Cetacean	183 dB	1.1 km²	590 m	580 m	580 m
		HF Cetacean	183 dB	0.59 km²	440 m	430 m	440 m
		PW Pinniped	171 dB	120 km²	6.6 km	5.8 km	6.2 km
Av. depth	Unweighted SPL_{peak}	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.12 km²	200 m	200 m	200 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	12 km²	2.0 km	1.9 km	2.0 km
		MF Cetacean	183 dB	1.0 km²	580 m	570 m	570 m
		HF Cetacean	183 dB	0.58 km²	430 m	430 m	430 m
		PW Pinniped	171 dB	110 km²	6.2 km	5.6 km	5.9 km

Table 5-22 Summary of the single strike impact ranges for TTS from Southall et al. (2007) for installation of a monopile at EA2 using the 100% maximum hammer blow energy of 4000 kJ

EA2		Southall *et al.* (2007) - TTS		Pin Pile (240kJ – soft start, 10%)			
				Area	Maximum	Minimum	Mean
Worst case	Unweighted SPL_{peak}	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.01 km²	60 m	60 m	60 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	1.2 km²	620 m	610 m	620 m
		MF Cetacean	183 dB	0.16 km²	230 m	230 m	230 m
		HF Cetacean	183 dB	0.08 km²	160 m	160 m	160 m
		PW Pinniped	171 dB	33 km²	3.5 km	3.1 km	3.3 km
Av. depth	Unweighted SPL_{peak}	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.01 km²	60 m	60 m	60 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	1.2 km²	610 m	610 m	610 m
		MF Cetacean	183 dB	0.16 km²	230 m	230 m	230 m
		HF Cetacean	183 dB	0.08 km²	160 m	160 m	160 m
		PW Pinniped	171 dB	31 km²	3.3 km	3.0 km	3.2 km

Table 5-23 Summary of the single strike impact ranges for TTS from Southall et al. (2007) for installation of a pin pile at EA2 using the 10% soft start hammer blow energy of 240 kJ

EA2	Southall *et al.* (2007) - TTS			Pin Pile (2400kJ – main piling, 100%)			
				Area	Maximum	Minimum	Mean
Worst case	Unweighted SPL_{peak}	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.11 km²	190 m	180 m	190 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	11 km²	2.0 km	1.8 km	1.9 km
		MF Cetacean	183 dB	1.6 km²	710 m	700 m	710 m
		HF Cetacean	183 dB	0.75 km²	490 m	490 m	490 m
		PW Pinniped	171 dB	150 km²	7.4 km	6.5 km	7.0 km
Av. depth	Unweighted SPL_{peak}	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.11 km²	180 m	180 m	180 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	11 km²	1.9 km	1.8 km	1.9 km
		MF Cetacean	183 dB	1.5 km²	700 m	690 m	700 m
		HF Cetacean	183 dB	0.73 km²	490 m	480 m	480 m
		PW Pinniped	171 dB	130 km²	6.9 km	6.2 km	6.6 km

Table 5-24 Summary of the single strike impact ranges for TTS from Southall et al. (2007) for installation of a pin pile at EA2 using the 100% maximum hammer blow energy of 2400 kJ

EA2	Southall *et al.* (2007) – Behavioural (Unweighted SEL_{ss})			Monopile (400kJ – soft start, 10%)			
				Area	Maximum	Minimum	Mean
WC	Likely avoidance	LF Cetacean	152 dB	1900 km²	29 km	21 km	25 km
		MF Cetacean	170 dB	130 km²	6.9 km	6.0 km	6.5 km
	Possible Avoidance	LF Cetacean	142 dB	4300 km²	43 km	29 km	37 km
		MF Cetacean	160 dB	790 km²	18 km	14 km	16 km
AV	Likely avoidance	LF Cetacean	152 dB	1700 km²	26 km	18 km	23 km
		MF Cetacean	170 dB	120 km²	6.4 km	5.8 km	6.1 km
	Possible Avoidance	LF Cetacean	142 dB	3800 km²	40 km	26 km	34 km
		MF Cetacean	160 dB	650 km²	16 km	12 km	14 km

Table 5-25 Summary of the single strike impact ranges for behavioural response from Southall et al. (2007) for installation of a monopile at EA2 using the 10% soft start hammer blow energy of 400 kJ

EA2	Southall *et al.* (2007) – Behavioural (Unweighted SEL_{ss})			Monopile (400kJ – main piling, 100%)			
				Area	Maximum	Minimum	Mean
WC	Likely avoidance	LF Cetacean	152 dB	2800 km²	34 km	24 km	30 km
		MF Cetacean	170 dB	310 km²	11 km	9.1 km	10 km
	Possible Avoidance	LF Cetacean	142 dB	5500 km²	50 km	33 km	42 km
		MF Cetacean	160 dB	1300 km²	23 km	18 km	21 km
AV	Likely avoidance	LF Cetacean	152 dB	2400 km²	32 km	21 km	28 km
		MF Cetacean	170 dB	260 km²	9.8 km	8.3 km	9.2 km
	Possible Avoidance	LF Cetacean	142 dB	4900 km²	47 km	29 km	39 km
		MF Cetacean	160 dB	1100 km²	21 km	15 km	19 km

Table 5-26 Summary of the single strike impact ranges for behavioural response from Southall et al. (2007) for installation of a monopile at EA2 using the 100% maximum hammer blow energy of 4000 kJ

EA2	Southall *et al.* (2007) – Behavioural (Unweighted SEL_{ss})			Pin Pile (240kJ – soft start, 10%)			
				Area	Maximum	Minimum	Mean
WC	Likely avoidance	LF Cetacean	152 dB	1600 km²	25 km	19 km	22 km
		MF Cetacean	170 dB	77 km²	5.3 km	4.6 km	5.0 km
	Possible Avoidance	LF Cetacean	142 dB	3700 km²	40 km	27 km	34 km
		MF Cetacean	160 dB	570 km²	15 km	12 km	13 km
AV	Likely avoidance	LF Cetacean	152 dB	1300 km²	23 km	16 km	20 km
		MF Cetacean	170 dB	70 km²	4.9 km	4.6 km	4.7 km
	Possible Avoidance	LF Cetacean	142 dB	3200 km²	37 km	24 km	32 km
		MF Cetacean	160 dB	470 km²	14 km	10 km	12 km

Table 5-27 Summary of the single strike impact ranges for behavioural response from Southall et al. (2007) for installation of a pin pile at EA2 using the 10% soft start hammer blow energy of 240 kJ

EA2		Southall *et al.* (2007) – Behavioural (Unweighted SEL_{ss})		Pin Pile (2400kJ – main piling, 100%)			
				Area	**Maximum**	**Minimum**	**Mean**
WC	**Likely avoidance**	LF Cetacean	152 dB	2700 km²	34 km	24 km	29 km
		MF Cetacean	170 dB	290 km²	10 km	8.8 km	9.7 km
	Possible Avoidance	LF Cetacean	142 dB	5400 km²	49 km	33 km	41 km
		MF Cetacean	160 dB	1300 km²	23 km	18 km	20 km
AV	**Likely avoidance**	LF Cetacean	152 dB	2400 km²	31 km	21 km	27 km
		MF Cetacean	170 dB	250 km²	9.4 km	8.1 km	8.9 km
	Possible Avoidance	LF Cetacean	142 dB	4800 km²	47 km	29 km	39 km
		MF Cetacean	160 dB	1100 km²	21 km	15 km	18 km

Table 5-28 Summary of the single strike impact ranges for behavioural response from Southall et al. (2007) for installation of a pin pile at EA2 using the 100% maximum hammer blow energy of 2400 kJ

5.2.1.2.2 EA1N

EA1N		Southall *et al.* (2007) - PTS		Monopile (400kJ – soft start, 10%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	**Unweighted SPL_{peak}**	Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	M-Weighted SEL_{ss}	LF Cetacean	198 dB	0.01 km²	60 m	60 m	60 m
		MF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	0.24 km²	280 m	280 m	280 m
Av. depth	**Unweighted SPL_{peak}**	Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
	M-Weighted SEL_{ss}	LF Cetacean	198 dB	0.01 km²	60 m	60 m	60 m
		MF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	0.24 km²	280 m	280 m	280 m

Table 5-29 Summary of the single strike impact ranges for PTS from Southall et al. (2007) for installation of a monopile at EA1N using the 10% soft start hammer blow energy of 400 kJ

EA1N		Southall *et al.* (2007) - PTS		Monopile (4000kJ – main piling, 100%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	**Unweighted SPL_{peak}**	Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	M-Weighted SEL_{cum}	LF Cetacean	198 dB	35 km²	4.4 km	2.7 km	3.3 km
		MF Cetacean	198 dB	18 km²	3.0 km	2.0 km	2.4 km
		HF Cetacean	198 dB	5.7 km²	1.8 km	1.1 km	1.3 km
		PW Pinniped	186 dB	1000 km²	22 km	15 km	18 km
	M-Weighted SEL_{ss}	LF Cetacean	198 dB	0.05 km²	130 m	130 m	130 m
		MF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	1.2 km²	610 m	610 m	610 m
Average depth	**Unweighted SPL_{peak}**	Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	M-Weighted SEL_{cum}	LF Cetacean	198 dB	34 km²	3.6 km	3.0 km	3.3 km
		MF Cetacean	198 dB	17 km²	2.5 km	2.2 km	2.3 km
		HF Cetacean	198 dB	5.1 km²	1.4 km	1.2 km	1.3 km
		PW Pinniped	186 dB	1100 km²	21 km	17 km	19 km
	M-Weighted SEL_{ss}	LF Cetacean	198 dB	0.05	130 m	130 m	130 m
		MF Cetacean	198 dB	0.01 km²	60 m	60 m	60 m
		HF Cetacean	198 dB	0.01 km²	60 m	60 m	60 m
		PW Pinniped	186 dB	1.1	600 m	600 m	600 m

Table 5-30 Summary of the single strike and cumulative impact ranges for PTS from Southall et al. (2007) for installation of a monopile at EA1N using the 100% maximum hammer blow energy of 4000 kJ

EA1N		Southall *et al.* (2007) - PTS		**Pin Pile (240kJ – soft start, 10%)**			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	**Unweighted SPL$_{peak}$**	Cetacean	230 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	M-Weighted SEL$_{ss}$	LF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		MF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	0.18 km^2	240 m	240 m	240 m
Av. depth	**Unweighted SPL$_{peak}$**	Cetacean	230 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	M-Weighted SEL$_{ss}$	LF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		MF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	0.17 km^2	240 m	240 m	240 m

Table 5-31 Summary of the single strike impact ranges for PTS from Southall et al. (2007) for installation of a pin pile at EA1N using the 10% soft start hammer blow energy of 240 kJ

EA1N		Southall *et al.* (2007) - PTS		**Pin Pile (2400kJ – main piling, 100%)**			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	**Unweighted SPL$_{peak}$**	Cetacean	230 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	0.01 km^2	60 m	60 m	60 m
	M-Weighted SEL$_{cum}$	LF Cetacean	198 dB	58 km^2	5.7 km	3.4 km	4.3 km
		MF Cetacean	198 dB	69 km^2	5.8 km	4.0 km	4.7 km
		HF Cetacean	198 dB	28 km^2	3.8 km	2.5 km	3.0 km
		PW Pinniped	186 dB	1500 km^2	26 km	18 km	22 km
	M-Weighted SEL$_{ss}$	LF Cetacean	198 dB	0.04 km^2	120 m	120 m	120 m
		MF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	1.7 km^2	740 m	730 m	740 m
Average depth	**Unweighted SPL$_{peak}$**	Cetacean	230 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	0.01 km^2	60 m	60 m	60 m
	M-Weighted SEL$_{cum}$	LF Cetacean	198 dB	58 km^2	4.8 km	3.9 km	4.3 km
		MF Cetacean	198 dB	67 km^2	4.9 km	4.4 km	4.6 km
		HF Cetacean	198 dB	26 km^2	3.1 km	2.7 km	2.9 km
		PW Pinniped	186 dB	1600 km^2	25 km	21 km	22 km
	M-Weighted SEL$_{ss}$	LF Cetacean	198 dB	11 km^2	1.9 km	1.8 km	1.9 km
		MF Cetacean	198 dB	1.5 km^2	700 m	690 m	700 m
		HF Cetacean	198 dB	0.73 km^2	480 m	480 m	480 m
		PW Pinniped	186 dB	150 km^2	7.1 km	6.8 km	6.9 km

Table 5-32 Summary of the single strike and cumulative impact ranges for PTS from Southall et al. (2007) for installation of a pin pile at EA1N using the 100% maximum hammer blow energy of 2400 kJ

EA1N		Southall *et al.* (2007) - TTS		Monopile (400kJ – soft start, 10%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	**Unweighted SPL_{peak}**	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.03 km²	90 m	90 m	90 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	2.7 km²	930 m	920 m	920 m
		MF Cetacean	183 dB	0.22 km²	270 m	270 m	270 m
		HF Cetacean	183 dB	0.12 km²	200 m	200 m	200 m
		PW Pinniped	171 dB	42 km²	3.8 km	3.6 km	3.7 km
Av. depth	**Unweighted SPL_{peak}**	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.02 km²	90 m	90 m	90 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	2.6 km²	910 m	910 m	910 m
		MF Cetacean	183 dB	0.22 km²	270 m	260 m	270 m
		HF Cetacean	183 dB	0.12 km²	200 m	200 m	200 m
		PW Pinniped	171 dB	40 km²	3.7 km	3.5 km	3.6 km

Table 5-33 Summary of the single strike impact ranges for TTS from Southall et al. (2007) for installation of a monopile at EA1N using the 10% soft start hammer blow energy of 400 kJ

EA1N		Southall *et al.* (2007) - TTS		Monopile (4000kJ – main piling, 100%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	**Unweighted SPL_{peak}**	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.12 km²	200 m	200 m	200 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	12 km²	2.1 km	1.9 km	2.0 km
		MF Cetacean	183 dB	1.1 km²	580 m	580 m	580 m
		HF Cetacean	183 dB	0.59 km²	440 m	430 m	440 m
		PW Pinniped	171 dB	120 km²	6.6 km	5.9 km	6.2 km
Av. depth	**Unweighted SPL_{peak}**	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.12 km²	200 m	200 m	200 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	12 km²	2.0 km	1.9 km	2.0 km
		MF Cetacean	183 dB	1.0 km²	570 m	570 m	570 m
		HF Cetacean	183 dB	0.58 km²	430 m	430 m	430 m
		PW Pinniped	171 dB	120 km²	6.3 km	6.0 km	6.1 km

Table 5-34 Summary of the single strike impact ranges for TTS from Southall et al. (2007) for installation of a monopile at EA1N using the 100% maximum hammer blow energy of 4000 kJ

EA1N		Southall *et al.* (2007) - TTS		Pin Pile (240kJ – soft start, 10%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	**Unweighted SPL_{peak}**	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.01 km²	60 m	60 m	60 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	1.2 km²	620 m	610 m	620 m
		MF Cetacean	183 dB	0.16 km²	230 m	230 m	230 m
		HF Cetacean	183 dB	0.08 km²	160 m	160 m	160 m
		PW Pinniped	171 dB	33 km²	3.4 km	3.2 km	3.3 km
Av. depth	**Unweighted SPL_{peak}**	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.01 km²	60 m	60 m	60 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	1.2 km²	610 m	610 m	610 m
		MF Cetacean	183 dB	0.16 km²	230 m	230 m	230 m
		HF Cetacean	183 dB	0.08 km²	160 m	160 m	160 m
		PW Pinniped	171 dB	32 km²	3.3 km	3.1 km	3.2 km

Table 5-35 Summary of the single strike impact ranges for TTS from Southall et al. (2007) for installation of a pin pile at EA1N using the 10% soft start hammer blow energy of 240 kJ

EA1N	Southall *et al.* (2007) - TTS			Pin Pile (2400kJ – main piling, 100%)			
				Area	Maximum	Minimum	Mean
Worst case	Unweighted SPL_{peak}	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.11 km²	190 m	180 m	190 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	11 km²	1.9 km	1.8 km	1.9 km
		MF Cetacean	183 dB	1.6 km²	710 m	700 m	710 m
		HF Cetacean	183 dB	0.75 km²	490 m	490 m	490 m
		PW Pinniped	171 dB	150 km²	7.5 km	6.6 km	7.0 km
Av. depth	Unweighted SPL_{peak}	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.1 km²	180 m	180 m	180 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	11 km²	1.9 km	1.8 km	1.9 km
		MF Cetacean	183 dB	1.5 km²	700 m	690 m	700 m
		HF Cetacean	183 dB	0.73 km²	480 m	480 m	480 m
		PW Pinniped	171 dB	150 km²	7.1 km	6.8 km	6.9 km

Table 5-36 Summary of the single strike impact ranges for TTS from Southall et al. (2007) for installation of a pin pile at EA1N using the 100% maximum hammer blow energy of 2400 kJ

EA1N	Southall *et al.* (2007) – Behavioural (Unweighted SEL_{ss})			Monopile (400kJ – soft start, 10%)			
				Area	Maximum	Minimum	Mean
WC	Likely avoidance	LF Cetacean	152 dB	2000 km²	28 km	22 km	25 km
		MF Cetacean	170 dB	130 km²	6.9 km	6.2 km	6.5 km
	Possible Avoidance	LF Cetacean	142 dB	4400 km²	45 km	31 km	37 km
		MF Cetacean	160 dB	770 km²	18 km	15 km	16 km
AV	Likely avoidance	LF Cetacean	152 dB	2000 km²	27 km	24 km	25 km
		MF Cetacean	170 dB	130 km²	6.6 km	6.3 km	6.4 km
	Possible Avoidance	LF Cetacean	142 dB	4500 km²	42 km	35 km	38 km
		MF Cetacean	160 dB	780 km²	16 km	15 km	16 km

Table 5-37 Summary of the single strike impact ranges for behavioural response from Southall et al. (2007) for installation of a monopile at EA1N using the 10% soft start hammer blow energy of 400 kJ

EA1N	Southall *et al.* (2007) – Behavioural (Unweighted SEL_{ss})			Monopile (4000kJ – main piling, 100%)			
				Area	Maximum	Minimum	Mean
WC	Likely avoidance	LF Cetacean	152 dB	2800 km²	35 km	26 km	30 km
		MF Cetacean	170 dB	310 km²	11 km	9.3 km	9.9 km
	Possible Avoidance	LF Cetacean	142 dB	5600 km²	51 km	34 km	42 km
		MF Cetacean	160 dB	1300 km²	23 km	19 km	20 km
AV	Likely avoidance	LF Cetacean	152 dB	3000 km²	34 km	29 km	31 km
		MF Cetacean	170 dB	300 km²	10 km	9.6 km	9.8 km
	Possible Avoidance	LF Cetacean	142 dB	5800 km²	49 km	39 km	43 km
		MF Cetacean	160 dB	1300 km²	22 km	20 km	21 km

Table 5-38 Summary of the single strike impact ranges for behavioural response from Southall et al. (2007) for installation of a monopile at EA1N using the 100% maximum hammer blow energy of 4000 kJ

EA1N	Southall *et al.* (2007) – Behavioural (Unweighted SEL_{ss})			Pin Pile (240kJ – soft start, 10%)			
				Area	Maximum	Minimum	Mean
WC	Likely avoidance	LF Cetacean	152 dB	1600 km²	25 km	20 km	22 km
		MF Cetacean	170 dB	77 km²	5.2 km	4.7 km	5.0 km
	Possible Avoidance	LF Cetacean	142 dB	3700 km²	41 km	29 km	34 km
		MF Cetacean	160 dB	550 km²	15 km	13 km	13 km
AV	Likely avoidance	LF Cetacean	152 dB	1600 km²	24 km	22 km	23 km
		MF Cetacean	170 dB	74 km²	5.0 km	4.8 km	4.9 km
	Possible Avoidance	LF Cetacean	142 dB	3900 km²	39 km	33 km	35 km
		MF Cetacean	160 dB	550 km²	14 km	13 km	13 km

Table 5-39 Summary of the single strike impact ranges for behavioural response from Southall et al. (2007) for installation of a pin pile at EA1N using the 10% soft start hammer blow energy of 240 kJ

EA1N	Southall *et al.* (2007) – Behavioural (Unweighted SEL_{ss})			Pin Pile (2400kJ – main piling, 100%)			
				Area	Maximum	Minimum	Mean
WC	**Likely avoidance**	LF Cetacean	152 dB	2800 km²	34 km	26 km	30 km
		MF Cetacean	170 dB	290 km²	11 km	9.0 km	9.6 km
	Possible Avoidance	LF Cetacean	142 dB	5500 km²	51 km	34 km	42 km
		MF Cetacean	160 dB	1300 km²	22 km	18 km	20 km
AV. D	**Likely avoidance**	LF Cetacean	152 dB	2900 km²	33 km	29 km	30 km
		MF Cetacean	170 dB	280 km²	9.8 km	9.3 km	9.5 km
	Possible Avoidance	LF Cetacean	142 dB	5700 km²	48 km	39 km	43 km
		MF Cetacean	160 dB	1300 km²	22 km	19 km	20 km

Table 5-40 Summary of the single strike impact ranges for behavioural response from Southall et al. (2007) for installation of a pin pile at EA1N using the 100% maximum hammer blow energy of 2400 kJ

5.2.1.3 Lucke et al. (2009) results

Table 5-41 to Table 5-48 present the predicted impact ranges in terms of the criteria from Lucke *et al.* (2009), covering auditory injury, TTS and behavioural reaction in harbour porpoise. These criteria are defined in section 2.2.2.1. The criteria from Lucke *et al.* (2009) are all unweighted single strike SELs.

5.2.1.3.1 EA2

EA2	Lucke *et al.* (2009) (Unweighted SEL_{ss})		Monopile (400kJ – soft start, 10%)			
			Area	Maximum	Minimum	Mean
WC	Auditory injury	179 dB	12 km²	2.0 km	1.8 km	1.9 km
	TTS	164 dB	430 km²	13 km	11 km	12 km
	Behavioural	145 dB	3500 km²	39 km	27 km	33 km
AV	Auditory injury	179 dB	11 km²	2.0 km	1.8 km	1.9 km
	TTS	164 dB	360 km²	12 km	9.5 km	11 km
	Behavioural	145 dB	3000 km²	36 km	23 km	31 km

Table 5-41 Summary of the single strike impact ranges for criteria from Lucke et al. (2009) for installation of a monopile at EA2 using the 10% soft start hammer blow energy of 400 kJ

EA2	Lucke *et al.* (2009) (Unweighted SEL_{ss})		Monopile (4000kJ – main piling, 100%)			
			Area	Maximum	Minimum	Mean
WC	Auditory injury	179 dB	40 km²	3.8 km	3.3 km	3.6 km
	TTS	164 dB	810 km²	18 km	15 km	16 km
	Behavioural	145 dB	4600 km²	45 km	30 km	38 km
AV	Auditory injury	179 dB	37 km²	3.6 km	3.3 km	3.4 km
	TTS	164 dB	670 km²	16 km	12 km	15 km
	Behavioural	145 dB	4100 km²	42 km	27 km	36 km

Table 5-42 Summary of the single strike impact ranges for criteria from Lucke et al. (2009) for installation of a monopile at EA2 using the 100% maximum hammer blow energy of 4000 kJ

EA2	Lucke *et al.* (2009) (Unweighted SEL_{ss})		Pin Pile (240kJ – soft start, 10%)			
			Area	Maximum	Minimum	Mean
WC	Auditory injury	179 dB	4.9 km²	1.3 km	1.2 km	1.3 km
	TTS	164 dB	290 km²	10 km	8.7 km	9.6 km
	Behavioural	145 dB	2900 km²	35 km	25 km	30 km
AV	Auditory injury	179 dB	4.7 km²	1.2 km	1.2 km	1.2 km
	TTS	164 dB	240 km²	9.3 km	8.0 km	8.8 km
	Behavioural	145 dB	2500 km²	32 km	21 km	28 km

Table 5-43 Summary of the single strike impact ranges for criteria from Lucke et al. (2009) for installation of a pin pile at EA2 using the 10% soft start hammer blow energy of 240 kJ

EA2	Lucke *et al.* (2009) (Unweighted SEL_{ss})		Pin Pile (2400kJ – main piling, 100%)			
			Area	Maximum	Minimum	Mean
WC	Auditory injury	179 dB	36 km²	3.6 km	3.2 km	3.4 km
	TTS	164 dB	770 km²	17 km	14 km	16 km
	Behavioural	145 dB	4500 km²	45 km	30 km	38 km
AV	Auditory injury	179 dB	33 km²	3.4 km	3.2 km	3.3 km
	TTS	164 dB	640 km²	16 km	12 km	14 km
	Behavioural	145 dB	4000 km²	42 km	27 km	35 km

Table 5-44 Summary of the single strike impact ranges for criteria from Lucke et al. (2009) for installation of a pin pile at EA2 using the 100% maximum hammer blow energy of 2400 kJ

5.2.1.3.2 EA1N

EA1N	Lucke *et al.* (2009) (Unweighted SEL_{ss})		Monopile (400kJ – soft start, 10%)			
			Area	Maximum	Minimum	Mean
WC	Auditory injury	179 dB	12 km²	2.0 km	1.9 km	2.0 km
	TTS	164 dB	420 km²	13 km	11 km	12 km
	Behavioural	145 dB	3500 km²	39 km	28 km	34 km
AV	Auditory injury	179 dB	11 km²	1.9 km	1.8 km	1.9 km
	TTS	164 dB	420 km²	12 km	11 km	12 km
	Behavioural	145 dB	3700 km²	38 km	32 km	34 km

Table 5-45 Summary of the single strike impact ranges for criteria from Lucke et al. (2009) for installation of a monopile at EA1N using the 10% soft start hammer blow energy of 400 kJ

EA1N	Lucke *et al.* (2009) (Unweighted SEL_{ss})		Monopile (4000kJ – main piling, 100%)			
			Area	Maximum	Minimum	Mean
WC	Auditory injury	179 dB	40 km²	3.7 km	3.4 km	3.6 km
	TTS	164 dB	800 km²	18 km	15 km	16 km
	Behavioural	145 dB	4700 km²	46 km	32 km	39 km
AV	Auditory injury	179 dB	38 km²	3.6 km	3.4 km	3.5 km
	TTS	164 dB	800 km²	17 km	15 km	16 km
	Behavioural	145 dB	4900 km²	44 km	36 km	40 km

Table 5-46 Summary of the single strike impact ranges for criteria from Lucke et al. (2009) for installation of a monopile at EA1N using the 100% maximum hammer blow energy of 4000 kJ

EA1N	Lucke *et al.* (2009) (Unweighted SEL_{ss})		Pin Pile (240kJ – soft start, 10%)			
			Area	Maximum	Minimum	Mean
WC	Auditory injury	179 dB	4.9 km²	1.3 km	1.2 km	1.2 km
	TTS	164 dB	280 km²	10 km	8.9 km	9.5 km
	Behavioural	145 dB	3000 km²	36 km	26 km	31 km
AV	Auditory injury	179 dB	4.7 km²	1.2 km	1.2 km	1.2 km
	TTS	164 dB	270 km²	9.7 km	9.2 km	9.4 km
	Behavioural	145 dB	3100 km²	34 km	30 km	32 km

Table 5-47 Summary of the single strike impact ranges for criteria from Lucke et al. (2009) for installation of a pin pile at EA1N using the 10% soft start hammer blow energy of 240 kJ

EA1N	Lucke *et al.* (2009) (Unweighted SEL_{ss})		Pin Pile (2400kJ – main piling, 100%)			
			Area	Maximum	Minimum	Mean
WC	Auditory injury	179 dB	36 km²	3.5 km	3.3 km	3.4 km
	TTS	164 dB	760 km²	18 km	14 km	16 km
	Behavioural	145 dB	4600 km²	46 km	32 km	38 km
AV	Auditory injury	179 dB	34 km²	3.4 km	3.2 km	3.3 km
	TTS	164 dB	760 km²	16 km	15 km	16 km
	Behavioural	145 dB	4800 km²	44 km	36 km	39 km

Table 5-48 Summary of the single strike impact ranges for criteria from Lucke et al. (2009) for installation of a pin pile at EA1N using the 100% maximum hammer blow energy of 2400 kJ

5.2.2 Impacts on fish

Table 5-49 to Table 5-72 give the maximum, minimum, and mean impact ranges for species of fish based on the injury criteria found in the Popper *et al.* (2014) guidance.

As discussed in section 2.2.2.2, for the SEL_{cum} criteria, a fleeing animal speed of 1.5 ms^{-1} has been used (Hirata, 1999). All the impact thresholds from the Popper *et al.* (2014) guidance are unweighted. It should be noted that some of the same noise levels are used as criteria for multiple effects. This is as per the Popper *et al.* (2014) guidelines (shown in Table 2-9), which is based on a comprehensive literature review. The data available to create the criteria are very limited and most criteria are "greater than", with a precise threshold not identified. All ranges associated with criteria defined as ">" are therefore conservative and in practice the actual range at which an effect could occur will be somewhat lower. As with the marine mammal criteria, where impact ranges are less than 50 m (SPL_{peak}) and 100 m (SEL_{cum}); these are denoted < 50 m and < 100 m, without attempting to define ranges any more accurately.

The results show that fish with swim bladders involved in hearing are the most sensitive to the impact piling noise with ranges of up to a maximum of 500 m for the SPL_{peak} recoverable injury criteria and ranges up to 29 km for TTS (SEL_{cum}) for the pin pile scenarios. As with the modelling results presented in the previous sections, the largest SEL_{cum} ranges are predicted for pin piles due to the more rapid assumed strike rate.

5.2.2.1.1 EA2

EA2		Popper *et al.* (2014) – Fish (no swim bladder)		**Monopile (400kJ – soft start, 10%)**			
				Area	**Maximum**	**Minimum**	**Mean**
WC	SPL_{peak}	Mortal and potential mortal injury	> 213 dB	0.02 km²	70 m	70 m	70 m
		Recoverable injury	> 213 dB	0.02 km²	70 m	70 m	70 m
AV	SPL_{peak}	Mortal and potential mortal injury	> 213 dB	0.02 km²	70 m	70 m	70 m
		Recoverable injury	> 213 dB	0.02 km²	70 m	70 m	70 m

Table 5-49 Summary of the unweighted single strike impact ranges for fish (no swim bladder) using the impact piling criteria from Popper et al. (2014) for installation of a monopile at EA2 using the 10% soft start hammer blow energy of 400 kJ

EA2		Popper *et al.* (2014) – Fish (no swim bladder)		**Monopile (4000kJ – main piling, 100%)**			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 213 dB	0.08 km²	160 m	160 m	160 m
		Recoverable injury	> 213 dB	0.08 km²	160 m	160 m	160 m
	SEL_{cum}	Mortal and potential mortal injury	> 219 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	> 216 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		TTS	>> 186 dB	1600	27 km	17 km	22 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 213 dB	0.08 km²	160 m	160 m	160 m
		Recoverable injury	> 213 dB	0.08 km²	160 m	160 m	160 m
	SEL_{cum}	Mortal and potential mortal injury	> 219 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	> 216 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		TTS	>> 186 dB	1300 km²	24 km	14 km	20 km

Table 5-50 Summary of the unweighted single strike and cumulative impact ranges for fish (no swim bladder) using the impact piling criteria from Popper et al. (2014) for installation of a monopile at EA2 using the 100% maximum hammer blow energy of 4000 kJ

EA2		Popper *et al.* (2014) – Fish (no swim bladder)		Pin Pile (240kJ – soft start, 10%)			
				Area	Maximum	Minimum	Mean
WC	SPL_{peak}	Mortal and potential mortal injury	> 213 dB	0.01 km²	50 m	50 m	50 m
		Recoverable injury	> 213 dB	0.01 km²	50 m	50 m	50 m
AV	SPL_{peak}	Mortal and potential mortal injury	> 213 dB	0.01 km²	50 m	50 m	50 m
		Recoverable injury	> 213 dB	0.01 km²	50 m	50 m	50 m

Table 5-51 Summary of the unweighted single strike impact ranges for fish (no swim bladder) using the impact piling criteria from Popper et al. (2014) for installation of a pin pile at EA2 using the 10% soft start hammer blow energy of 240 kJ

EA2		Popper *et al.* (2014) – Fish (no swim bladder)		Pin Pile (2400kJ – main piling, 100%)			
				Area	Maximum	Minimum	Mean
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 213 dB	0.07 km²	150 m	150 m	150 m
		Recoverable injury	> 213 dB	0.07 km²	150 m	150 m	150 m
	SEL_{cum}	Mortal and potential mortal injury	> 219 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	> 216 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		TTS	>> 186 dB	1800 km²	29 km	19 km	24 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 213 dB	0.07 km²	150 m	150 m	150 m
		Recoverable injury	> 213 dB	0.07 km²	150 m	150 m	150 m
	SEL_{cum}	Mortal and potential mortal injury	> 219 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	> 216 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		TTS	>> 186 dB	1500 km²	26 km	15 km	22 km

Table 5-52 Summary of the unweighted single strike and cumulative impact ranges for fish (no swim bladder) using the impact piling criteria from Popper et al. (2014) for installation of a pin pile at EA2 using the 100% maximum hammer blow energy of 2400 kJ

EA2		Popper *et al.* (2014) – Fish (swim bladder not involved in hearing)		Monopile (400kJ – soft start, 10%)			
				Area	Maximum	Minimum	Mean
WC	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.16 km²	230 m	230 m	230 m
		Recoverable injury	> 207 dB	0.16 km²	230 m	230 m	230 m
AV	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.16 km²	230 m	230 m	230 m
		Recoverable injury	> 207 dB	0.16 km²	230 m	230 m	230 m

Table 5-53 Summary of the unweighted single strike impact ranges for fish (swim bladder not involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a monopile at EA2 using the 10% soft start hammer blow energy of 400 kJ

EA2		Popper *et al.* (2014) – Fish (swim bladder not involved in hearing)		Monopile (4000kJ – main piling, 100%)			
				Area	Maximum	Minimum	Mean
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.78 km²	500 m	500 m	500 m
		Recoverable injury	> 207 dB	0.78 km²	500 m	500 m	500 m
	SEL_{cum}	Mortal and potential mortal injury	210 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	203 dB	47 km²	4.5 km	3.1 km	3.9 km
		TTS	> 186 dB	1600 km²	27 km	17 km	22 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.76 km²	500 m	490 m	490 m
		Recoverable injury	> 207 dB	0.76 km²	500 m	490 m	490 m
	SEL_{cum}	Mortal and potential mortal injury	210 dB	0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	203 dB	32 km²	3.8 km	2.5 km	3.2 km
		TTS	> 186 dB	1300 km²	24 km	14 km	20 km

Table 5-54 Summary of the unweighted single strike and cumulative impact ranges for fish (swim bladder not involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a monopile at EA2 using the 100% maximum hammer blow energy of 4000 kJ

EA2		Popper *et al.* (2014) – Fish (swim bladder not involved in hearing)		Pin Pile (240kJ – soft start, 10%)			
				Area	Maximum	Minimum	Mean
WC	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.07 km²	150 m	150 m	150 m
		Recoverable injury	> 207 dB	0.07 km²	150 m	150 m	150 m
AV	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.07 km²	150 m	150 m	150 m
		Recoverable injury	> 207 dB	0.07 km²	150 m	150 m	150 m

Table 5-55 Summary of the unweighted single strike impact ranges for fish (swim bladder not involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a pin pile at EA2 using the 10% soft start hammer blow energy of 240 kJ

EA2		Popper *et al.* (2014) – Fish (swim bladder not involved in hearing)		Pin Pile (2400kJ – main piling, 100%)			
				Area	Maximum	Minimum	Mean
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.68 km²	470 m	470 m	470 m
		Recoverable injury	> 207 dB	0.68 km²	470 m	470 m	470 m
	SEL_{cum}	Mortal and potential mortal injury	210 dB	0.08 km²	230 m	< 100 m	140 m
		Recoverable injury	203 dB	84 km²	6.0 km	4.3 km	5.2 km
		TTS	> 186 dB	1800 km²	29 km	19 km	24 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.67 km²	460 m	460 m	460 m
		Recoverable injury	> 207 dB	0.67 km²	460 m	460 m	460 m
	SEL_{cum}	Mortal and potential mortal injury	210 dB	0.01 km²	110 m	< 100 m	< 100 m
		Recoverable injury	203 dB	58 km²	5.0 km	3.2 km	4.3 km
		TTS	> 186 dB	1500 km²	26 km	15 km	22 km

Table 5-56 Summary of the unweighted single strike and cumulative impact ranges for fish (swim bladder not involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a pin pile at EA2 using the 100% maximum hammer blow energy of 2400 kJ

EA2		Popper *et al.* (2014) – Fish (swim bladder involved in hearing)		Monopile (400kJ – soft start, 10%)			
				Area	**Maximum**	**Minimum**	**Mean**
WC	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.16 km²	230 m	230 m	230 m
		Recoverable injury	> 207 dB	0.16 km²	230 m	230 m	230 m
AV	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.16 km²	230 m	230 m	230 m
		Recoverable injury	> 207 dB	0.16 km²	230 m	230 m	230 m

Table 5-57 Summary of the unweighted single strike impact ranges for fish (swim bladder involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a monopile at EA2 using the 10% soft start hammer blow energy of 400 kJ

EA2		Popper *et al.* (2014) – Fish (swim bladder involved in hearing)		Monopile (4000kJ – main piling, 100%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.78 km²	500 m	500 m	500 m
		Recoverable injury	> 207 dB	0.78 km²	500 m	500 m	500 m
	SEL_{cum}	Mortal and potential mortal injury	207 dB	2.9 km²	1.2 km	690 m	960 m
		Recoverable injury	203 dB	47 km²	4.5 km	3.1 km	3.9 km
		TTS	186 dB	1600 km²	27 km	17 km	22 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.76 km²	500 m	490 m	490 m
		Recoverable injury	> 207 dB	0.76 km²	500 m	490 m	490 m
	SEL_{cum}	Mortal and potential mortal injury	207 dB	1.6 km²	870 m	520 m	700 m
		Recoverable injury	203 dB	32 km²	3.8 km	2.5 km	3.2 km
		TTS	186 dB	1300 km²	24 km	14 km	20 km

Table 5-58 Summary of the unweighted single strike and cumulative impact ranges for fish (swim bladder involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a monopile at EA2 using the 100% maximum hammer blow energy of 4000 kJ

EA2		Popper *et al.* (2014) – Fish (swim bladder involved in hearing)		Pin Pile (240kJ – soft start, 10%)			
				Area	**Maximum**	**Minimum**	**Mean**
WC	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.07 km²	150 m	150 m	150 m
		Recoverable injury	> 207 dB	0.07 km²	150 m	150 m	150 m
AV	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.07 km²	150 m	150 m	150 m
		Recoverable injury	> 207 dB	0.07 km²	150 m	150 m	150 m

Table 5-59 Summary of the unweighted single strike impact ranges for fish (swim bladder involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a pin pile at EA2 using the 10% soft start hammer blow energy of 240 kJ

EA2		Popper *et al.* (2014) – Fish (swim bladder involved in hearing)		Pin Pile (2400kJ – main piling, 100%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	**SPL$_{peak}$**	Mortal and potential mortal injury	> 207 dB	0.68 km^2	470 m	470 m	470 m
		Recoverable injury	> 207 dB	0.68 km^2	470 m	470 m	470 m
	SEL$_{cum}$	Mortal and potential mortal injury	207 dB	11 km^2	2.2 km	1.4 km	1.8 km
		Recoverable injury	203 dB	84 km^2	6.0 km	4.3 km	5.2 km
		TTS	186 dB	1800 km^2	29 km	19 km	24 km
Av. depth	**SPL$_{peak}$**	Mortal and potential mortal injury	> 207 dB	0.67 km^2	460 m	460 m	460 m
		Recoverable injury	> 207 dB	0.67 km^2	460 m	460 m	460 m
	SEL$_{cum}$	Mortal and potential mortal injury	207 dB	6.3 km^2	1.7 km	1.0 km	1.4 km
		Recoverable injury	203 dB	58 km^2	5.0 km	3.2 km	4.3 km
		TTS	186 dB	1500 km^2	26 km	15 km	22 km

Table 5-60 Summary of the unweighted single strike and cumulative impact ranges for fish (swim bladder involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a pin pile at EA2 using the 100% maximum hammer blow energy of 2400 kJ

5.2.2.1.2 EA1N

EA1N		Popper *et al.* (2014) – Fish (no swim bladder)		Monopile (400kJ – soft start, 10%)			
				Area	**Maximum**	**Minimum**	**Mean**
WC	**SPL$_{peak}$**	Mortal and potential mortal injury	> 213 dB	0.02 km^2	70 m	70 m	70 m
		Recoverable injury	> 213 dB	0.02 km^2	70 m	70 m	70 m
AV	**SPL$_{peak}$**	Mortal and potential mortal injury	> 213 dB	0.02 km^2	70 m	70 m	70 m
		Recoverable injury	> 213 dB	0.02 km^2	70 m	70 m	70 m

Table 5-61 Summary of the unweighted single strike impact ranges for fish (no swim bladder) using the impact piling criteria from Popper et al. (2014) for installation of a monopile at EA1N using the 10% soft start hammer blow energy of 400 kJ

EA1N		Popper *et al.* (2014) – Fish (no swim bladder)		Monopile (4000kJ – main piling, 100%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	**SPL$_{peak}$**	Mortal and potential mortal injury	> 213 dB	0.08 km^2	160 m	160 m	160 m
		Recoverable injury	> 213 dB	0.08 km^2	160 m	160 m	160 m
	SEL$_{cum}$	Mortal and potential mortal injury	> 219 dB	< 0.01 km^2	< 100 m	< 100 m	< 100 m
		Recoverable injury	> 216 dB	< 0.01 km^2	< 100 m	< 100 m	< 100 m
		TTS	>> 186 dB	1600 km^2	27 km	18 km	22 km
Av. depth	**SPL$_{peak}$**	Mortal and potential mortal injury	> 213 dB	0.08 km^2	160 m	160 m	160 m
		Recoverable injury	> 213 dB	0.08 km^2	160 m	160 m	160 m
	SEL$_{cum}$	Mortal and potential mortal injury	> 219 dB	< 0.01 km^2	< 100 m	< 100 m	< 100 m
		Recoverable injury	> 216 dB	< 0.01 km^2	< 100 m	< 100 m	< 100 m
		TTS	>> 186 dB	1700 km^2	26 km	22 km	23 km

Table 5-62 Summary of the unweighted single strike and cumulative impact ranges for fish (no swim bladder) using the impact piling criteria from Popper et al. (2014) for installation of a monopile at EA1N using the 100% maximum hammer blow energy of 4000 kJ

EA1N		Popper *et al.* (2014) – Fish (no swim bladder)		Pin Pile (240kJ – soft start, 10%)			
				Area	Maximum	Minimum	Mean
WC	SPL_{peak}	Mortal and potential mortal injury	> 213 dB	0.01 km²	50 m	50 m	50 m
		Recoverable injury	> 213 dB	0.01 km²	50 m	50 m	50 m
AV	SPL_{peak}	Mortal and potential mortal injury	> 213 dB	0.01 km²	50 m	50 m	50 m
		Recoverable injury	> 213 dB	0.01 km²	50 m	50 m	50 m

Table 5-63 Summary of the unweighted single strike impact ranges for fish (no swim bladder) using the impact piling criteria from Popper et al. (2014) for installation of a pin pile at EA1N using the 10% soft start hammer blow energy of 240 kJ

EA1N		Popper *et al.* (2014) – Fish (no swim bladder)		Pin Pile (2400kJ – main piling, 100%)			
				Area	Maximum	Minimum	Mean
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 213 dB	0.07 km²	150 m	150 m	150 m
		Recoverable injury	> 213 dB	0.07 km²	150 m	150 m	150 m
	SEL_{cum}	Mortal and potential mortal injury	> 219 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	> 216 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		TTS	>> 186 dB	1900 km²	29 km	20 km	24 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 213 dB	0.07 km²	150 m	150 m	150 m
		Recoverable injury	> 213 dB	0.07 km²	150 m	150 m	150 m
	SEL_{cum}	Mortal and potential mortal injury	> 219 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	> 216 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		TTS	>> 186 dB	2000 km²	28 km	23 km	25 km

Table 5-64 Summary of the unweighted single strike and cumulative impact ranges for fish (no swim bladder) using the impact piling criteria from Popper et al. (2014) for installation of a pin pile at EA1N using the 100% maximum hammer blow energy of 2400 kJ

EA1N		Popper *et al.* (2014) – Fish (swim bladder not involved in hearing)		Monopile (400kJ – soft start, 10%)			
				Area	Maximum	Minimum	Mean
WC	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.16 km²	230 m	230 m	230 m
		Recoverable injury	> 207 dB	0.16 km²	230 m	230 m	230 m
AV	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.16 km²	230 m	230 m	230 m
		Recoverable injury	> 207 dB	0.16 km²	230 m	230 m	230 m

Table 5-65 Summary of the unweighted single strike impact ranges for fish (swim bladder not involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a monopile at EA1N using the 10% soft start hammer blow energy of 400 kJ

EA1N		Popper *et al.* (2014) – Fish (swim bladder not involved in hearing)		Monopile (4000kJ – main piling, 100%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	**SPL$_{peak}$**	Mortal and potential mortal injury	> 207 dB	0.78 km^2	500 m	500 m	500 m
		Recoverable injury	> 207 dB	0.78 km^2	500 m	500 m	500 m
	SEL$_{cum}$	Mortal and potential mortal injury	210 dB	0.01 km^2	< 100 m	< 100 m	< 100 m
		Recoverable injury	203 dB	45 km^2	4.7 km	3.2 km	3.8 km
		TTS	> 186 dB	1600 km^2	27 km	18 km	22 km
Av. depth	**SPL$_{peak}$**	Mortal and potential mortal injury	> 207 dB	0.76 km^2	490 m	490 m	490 m
		Recoverable injury	> 207 dB	0.76 km^2	490 m	490 m	490 m
	SEL$_{cum}$	Mortal and potential mortal injury	210 dB	0.01 km^2	< 100 m	< 100 m	< 100 m
		Recoverable injury	203 dB	43 km^2	3.9 km	3.5 km	3.7 km
		TTS	> 186 dB	1700 km^2	26 km	22 km	23 km

Table 5-66 Summary of the unweighted single strike and cumulative impact ranges for fish (swim bladder not involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a monopile at EA1N using the 100% maximum hammer blow energy of 4000 kJ

EA1N		Popper *et al.* (2014) – Fish (swim bladder not involved in hearing)		Pin Pile (240kJ – soft start, 10%)			
				Area	**Maximum**	**Minimum**	**Mean**
WC	**SPL$_{peak}$**	Mortal and potential mortal injury	> 207 dB	0.07 km^2	150 m	150 m	150 m
		Recoverable injury	> 207 dB	0.07 km^2	150 m	150 m	150 m
AV	**SPL$_{peak}$**	Mortal and potential mortal injury	> 207 dB	0.07 km^2	150 m	150 m	150 m
		Recoverable injury	> 207 dB	0.07 km^2	150 m	150 m	150 m

Table 5-67 Summary of the unweighted single strike impact ranges for fish (swim bladder not involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a pin pile at EA1N using the 10% soft start hammer blow energy of 240 kJ

EA1N		Popper *et al.* (2014) – Fish (swim bladder not involved in hearing)		Pin Pile (2400kJ – main piling, 100%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	**SPL$_{peak}$**	Mortal and potential mortal injury	> 207 dB	0.68 km^2	470 m	470 m	470 m
		Recoverable injury	> 207 dB	0.68 km^2	470 m	470 m	470 m
	SEL$_{cum}$	Mortal and potential mortal injury	210 dB	0.05 km^2	230 m	< 100 m	130 m
		Recoverable injury	203 dB	80 km^2	6.2 km	4.3 km	5.0 km
		TTS	> 186 dB	1900 km^2	29 km	20 km	24 km
Av. depth	**SPL$_{peak}$**	Mortal and potential mortal injury	> 207 dB	0.67 km^2	460 m	460 m	460 m
		Recoverable injury	> 207 dB	0.67 km^2	460 m	460 m	460 m
	SEL$_{cum}$	Mortal and potential mortal injury	210 dB	0.03 km^2	120 m	< 100 m	100 m
		Recoverable injury	203 dB	78 km^2	5.3 km	4.7 km	5.0 km
		TTS	> 186 dB	2000 km^2	28 km	23 km	25 km

Table 5-68 Summary of the unweighted single strike and cumulative impact ranges for fish (swim bladder not involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a pin pile at EA1N using the 100% maximum hammer blow energy of 2400 kJ

EA1N		Popper *et al.* (2014) – Fish (swim bladder involved in hearing)		Monopile (400kJ – soft start, 10%)			
				Area	**Maximum**	**Minimum**	**Mean**
WC	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.16 km²	230 m	230 m	230 m
		Recoverable injury	> 207 dB	0.16 km²	230 m	230 m	230 m
AV	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.16 km²	230 m	230 m	230 m
		Recoverable injury	> 207 dB	0.16 km²	230 m	230 m	230 m

Table 5-69 Summary of the unweighted single strike impact ranges for fish (swim bladder involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a monopile at EA1N using the 10% soft start hammer blow energy of 400 kJ

EA1N		Popper *et al.* (2014) – Fish (swim bladder involved in hearing)		Monopile (4000kJ – main piling, 100%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.78 km²	500 m	500 m	500 m
		Recoverable injury	> 207 dB	0.78 km²	500 m	500 m	500 m
	SEL_{cum}	Mortal and potential mortal injury	207 dB	2.7 km²	1.2 km	760 m	930 m
		Recoverable injury	203 dB	45 km²	4.7 km	3.2 km	3.8 km
		TTS	186 dB	1600 km²	27 km	18 km	22 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.76 km²	490 m	490 m	490 m
		Recoverable injury	> 207 dB	0.76 km²	490 m	490 m	490 m
	SEL_{cum}	Mortal and potential mortal injury	207 dB	2.3 km²	930 m	780 m	860 m
		Recoverable injury	203 dB	43 km²	3.9 km	3.5 km	3.7 km
		TTS	186 dB	1700 km²	26 km	22 km	23 km

Table 5-70 Summary of the unweighted single strike and cumulative impact ranges for fish (swim bladder involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a monopile at EA1N using the 100% maximum hammer blow energy of 4000 kJ

EA1N		Popper *et al.* (2014) – Fish (swim bladder involved in hearing)		Pin Pile (240kJ – soft start, 10%)			
				Area	**Maximum**	**Minimum**	**Mean**
WC	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.07 km²	150 m	150 m	150 m
		Recoverable injury	> 207 dB	0.07 km²	150 m	150 m	150 m
AV	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.07 km²	150 m	150 m	150 m
		Recoverable injury	> 207 dB	0.07 km²	150 m	150 m	150 m

Table 5-71 Summary of the unweighted single strike impact ranges for fish (swim bladder involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a pin pile at EA1N using the 10% soft start hammer blow energy of 240 kJ

EA1N		Popper *et al.* (2014) – Fish (swim bladder involved in hearing)		Pin Pile (2400kJ – main piling, 100%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.68 km^2	470 m	470 m	470 m
		Recoverable injury	> 207 dB	0.68 km^2	470 m	470 m	470 m
	SEL_{cum}	Mortal and potential mortal injury	207 dB	10 km^2	2.3 km	1.5 km	1.8 km
		Recoverable injury	203 dB	80 km^2	6.2 km	4.3 km	5.0 km
		TTS	186 dB	1900 km^2	29 km	20 km	24 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.67 km^2	460 m	460 m	460 m
		Recoverable injury	> 207 dB	0.67 km^2	460 m	460 m	460 m
	SEL_{cum}	Mortal and potential mortal injury	207 dB	9.1 km^2	1.9 km	1.6 km	1.7 km
		Recoverable injury	203 dB	78 km^2	5.3 km	4.7 km	5.0 km
		TTS	186 dB	2000 km^2	28 km	23 km	25 km

Table 5-72 Summary of the unweighted single strike and cumulative impact ranges for fish (swim bladder involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a pin pile at EA1N using the 100% maximum hammer blow energy of 2400 kJ

6 Other noise impacts

6.1 Introduction

Although impact piling is expected to be the primary noise source during offshore wind farm construction and development (Bailey *et al.* 2014), several other noise sources will also be present. Each of these has been considered, and its impact assessed, in this section.

Table 6-1 provides a summary of the various noise producing sources, aside from impact piling, that are expected to be present during the construction and operation of EA2 and EA1N.

Activity	Description
UXO detonation	Unexploded Ordnance (UXO) has been identified within the boundaries of EA2 and EA1N, which need to be cleared before construction can begin.
Dredging	Trailer suction hopper dredger may be required on site for the export cable, array cable and interconnector cable installation.
Drilling	Necessary in case if impact piling refusal
Cable laying	Required during the offshore cable installation.
Rock placement	Potentially required on site for installation of offshore cables and scour protection.
Trenching	Plough trenching may be required during offshore cable installation.
Vessel noise	Jack-up barges for piling, substructure and turbine installation. Other large and medium sized vessels on site to carry out other construction tasks, dive support and anchor handling. Other small vessels for crew transport and maintenance on site.
Operational WTG	Noise transmitted through the water from operational wind turbine generators. The project design envelope gives turbine sizes of between 9 MW and 20 MW.

Table 6-1 Summary of the possible noise making activities at EA2 and EA1N other than piling

The NPL Good Practice Guide 133 for underwater noise (Robinson *et al*. 2014) indicates that under certain circumstances, a simple modelling approach may be considered acceptable. Such an approach has been used for these sources, which are variously either comparatively quiet (e.g. drilling and cable laying) or if detailed modelling would imply an unwarranted accuracy (e.g. where data is limited such as with turbine operational noise and UXO detonations). The high-level overview of modelling that has been presented is considered sufficient and there would be little benefit in using a more detailed model at this stage. The limitations of this approach are noted, including the lack of frequency or bathymetry dependence.

6.2 UXO detonation

A number of UXO devices with a range of charge weights (or quantity of contained explosive) have been identified within the boundary of the EA2 and EA1N sites. These need to be removed before construction can begin. There are expected be a variety of explosive types, many of which are likely to have been subject to degradation and burying over time. Two otherwise identical explosive devices are likely to produce different blasts in the case where one has spent an extended period on the sea bed. A selection of explosive sizes has been considered based on site surveys and in each case, it has been assumed that the maximum explosive charge in each device is present and detonates with the clearance.

6.2.1 <u>Estimation of underwater noise levels</u>

The noise produced by the detonation of explosives is affected by several different elements, only one of which, the charge weight, can easily be factored into a calculation. In this case the charge weight is based on the equivalent weight of TNT. Many other elements relating to its situation (e.g. its design, composition, age, position, orientation, whether it is covered by sediment) and exactly how they will affect the sound produced by detonation are usually unknown and cannot be directly considered in this type of assessment. This leads to a high degree of uncertainty in the estimation of the source noise level (i.e. the noise level at the position of the UXO). A worst-case estimation has therefore been used for calculations, assuming the UXO to be detonated is not buried, degraded or subject to any other significant attenuation from its 'as new' condition.

The consequence of this is that the noise levels produced, particularly by the larger explosives under consideration, are likely to be over-estimated as some degree of coverage by sediment and degradation would be expected.

The range of equivalent charge weights of the potential UXO devices that could be present within the EA2 and EA1N site boundaries have been provided as 200, 300, 400, and 700 kg. Estimation of the source noise level for each charge weight has been carried out in accordance with the methodology of Soloway and Dahl (2014), which follows Arons (1954) and MTD (1996).

6.2.2 Estimation of propagation of underwater noise

For this assessment, the attenuation of the noise from UXO detonation has been accounted for in calculations using geometric spreading and a sound absorption coefficient, primarily using the methodologies cited in Soloway and Dahl (2014), which establishes a trend based on measured data in open water given by, for SPL:

$$SPL_{peak} = 52.4\times10^{6}\left(\frac{R}{W^{1/3}}\right)^{-1.13}$$

and for SEL:

$$SEL = 6.14\times\log_{10}\left(W^{1/3}\left(\frac{R}{W^{1/3}}\right)^{-2.12}\right) + 219$$

These equations give a relatively simple calculation which has been used to give an indication of the range of effect. The equation does not take into account variable bathymetry or seabed type, and thus calculation results will be the same regardless where it is used. An attenuation correction has been added to the Soloway and Dahl (2014) equations for the absorption over long ranges (i.e. of the order of thousands of metres), based on measurements of high intensity noise propagation taken in the North and Irish Seas in similar depths to that present at EA2 and EA1N.

Despite this attenuation correction, the resulting noise levels still need to be considered carefully. For example, SPL_{peak} noise levels over larger distances are difficult to predict accurately (von Benda-Beckmann *et al*., 2015). Soloway and Dahl (2014) only verify results from the equation above for small charges and at ranges of less than 1 km, although the results do agree with the measurements presented by von Benda-Beckmann *et al*. (2014). At longer ranges, greater confidence is expected with the calculations using SELs.

A further limitation in the Soloway and Dahl (2014) equation that must be considered are that variation in noise levels at different depths are not taken into account. Where animals are swimming near the surface, the acoustics can cause the noise level, and hence the exposure, to be lower (MTD, 1996). The risk to animals near the surface may therefore be lower than indicated by the impact ranges given and therefore the results presented can be considered conservative in respect of the impact at different depths.

Additionally, an impulsive wave tends to be smoothed (i.e. the pulse becomes longer) over distance (Cudahy and Parvin, 2001), meaning the injurious potential of a wave at greater range can be even lower than just a reduction in the absolute noise level. An assessment in respect of SEL is considered preferential at long range as it takes into account the overall energy and the smoothing of the peak is less critical.

The selection of assessment criteria must also be considered in light of this. The smoothing of the pulse at range means that technically it develops into a 'non-pulse' of the order of 2 km to 5 km. This range is still to be formally determined and will be different depending on the noise source and conditions. This study has presented impact ranges for both non-impulsive and impulsive criteria at greater ranges, and it is suggested that, for any injury ranges calculated using the impulsive criteria in excess of 5 km, the non-pulse criteria should be considered more appropriate. Southall *et al.* (2007) and Lucke *et al.* (2009) are both considered 'impulsive' criteria.

A summary of the unweighted UXO source levels calculated using this method for this modelling are given in Table 6-2.

	200 kg charge weight	300 kg charge weight	500 kg charge weight	700 kg charge weight
SPL_{peak} source level (dB re 1 µPa @ 1 m)	291.7	293.0	294.7	295.8
SEL_{ss} source level (dB re 1 µPa^{2}s @ 1 m)	233.7	234.8	236.2	237.1

Table 6-2 Summary of the unweighted SPL_{peak} and SEL_{ss} source levels used for UXO modelling

6.2.3 Impact ranges

Table 6-3 to Table 6-10 present the impact ranges for UXO detonation, considering various charge weights and impact criteria. It should be noted that Popper *et al*. (2014) gives specific impact criteria for explosions (Table 2-13). Similarly to the impact piling modelling the previous section, all SEL_{cum} criteria assume a fleeing animal using the same assumptions as presented in section 2.2.2 and ranges smaller than 50 m have not been presented.

Although the impact ranges presented in the following tables are large, the duration the noise is present must be taken into account. For detonation of UXO each explosion is only a single noise event, compared to the multiple pulse nature of impact piling.

NMFS (2018) Unweighted SPL_{peak}		200 kg charge weight	300 kg charge weight	500 kg charge weight	700 kg charge weight
PTS (Impulsive)	219 dB (LF)	1.5 km	1.8 km	2.1 km	2.3 km
	230 dB (MF)	520 m	600 m	710 m	790 m
	202 dB (HF)	7.8 km	8.8 km	10 km	11 km
	218 dB (PW)	1.7 km	1.9 km	2.3 km	2.6 km
TTS (Impulsive)	213 dB (LF)	2.8 km	3.2 km	3.7 km	4.2 km
	224 dB (MF)	960 m	1.1 km	1.3 km	1.4 km
	196 dB (HF)	13 km	15 km	17 km	18 km
	212 dB (PW)	3.1 km	3.5 km	4.1 km	4.6 km

Table 6-3 Summary of the PTS and TTS impact ranges for UXO detonation using the impulsive, unweighted SPL_{peak}, noise criteria from NMFS (2018) for marine mammals at EA2 and EA1N

NMFS (2018) Weighted SEL_{ss}		200 kg charge weight	300 kg charge weight	500 kg charge weight	700 kg charge weight
PTS (Impulsive)	183 dB (LF)	5.0 km	6.0 km	7.3 km	8.3 km
	185 dB (MF)	< 50 m	< 50 m	50 m	60 m
	155 dB (HF)	2.1 km	2.5 km	3.1 km	3.6 km
	185 dB (PW)	1.0 km	1.2 km	1.5 km	1.8 km
TTS (Impulsive)	168 dB (LF)	30 km	33 km	37 km	40 km
	170 dB (MF)	460 m	560 m	710 m	840 m
	140 dB (HF)	17 km	20 km	23 km	25 km
	170 dB (PW)	11 km	12 km	14 km	16 km

Table 6-4 Summary of the PTS and TTS impact ranges for UXO detonation using the impulsive, weighted SEL_{ss}, noise criteria from NMFS (2018) for marine mammals at EA2 and EA1N

NMFS (2018) Weighted SEL_{ss}		200 kg charge weight	300 kg charge weight	500 kg charge weight	700 kg charge weight
PTS (Non-impulsive)	199 dB (LF)	350 m	430 m	550 m	650 m
	198 dB (MF)	< 50 m	< 50 m	< 50 m	< 50 m
	173 dB (HF)	90 m	110 m	140 m	170 m
	201 dB (PW)	60 m	80 m	100 m	110 m
TTS (Non-impulsive)	179 dB (LF)	9.0 km	10 km	12 km	14 km
	178 dB (MF)	110 m	130 m	170 m	200 m
	153 dB (HF)	2.9 km	3.4 km	4.3 km	5.0 km
	181 dB (PW)	2.0 km	2.4 km	3.0 km	3.5 km

Table 6-5 Summary of the PTS and TTS impact ranges for UXO detonation using the non-impulsive, weighted SEL_{ss}, noise criteria from NMFS (2018) for marine mammals at EA2 and EA1N

Southall *et al.* (2007) Unweighted SPL_{peak}		200 kg charge weight	300 kg charge weight	500 kg charge weight	700 kg charge weight
PTS	230 dB (Cetaceans)	520 m	600 m	710 m	790 m
	218 dB (Pinnipeds)	1.7 km	1.9 km	2.3 km	2.6 km
TTS	224 dB (Cetaceans)	960 m	1.1 km	1.3 km	1.4 km
	212 dB (Pinnipeds)	3.1 km	3.5 km	4.1 km	4.6 km

Table 6-6 Summary of the PTS and TTS impact ranges for UXO detonation using the single pulse, unweighted SPL_{peak}, noise criteria from Southall et al (2007) for marine mammals at EA2 and EA1N

Southall *et al.* (2007) M-Weighted SEL_{ss}		200 kg charge weight	300 kg charge weight	500 kg charge weight	700 kg charge weight
PTS	198 dB (LF)	530 m	640 m	820 m	960 m
	198 dB (MF)	390 m	480 m	610 m	720 m
	198 dB (HF)	350 m	430 m	550 m	650 m
	186 dB (PW)	3.5 km	4.1 km	5.2 km	5.9 km
TTS	183 dB (LF)	6.1 km	7.2 km	8.8 km	9.9 km
	183 dB (MF)	4.8 km	5.6 km	6.9 km	7.9 km
	183 dB (HF)	4.3 km	5.1 km	6.3 km	7.3 km
	171 dB (PW)	24 km	27 km	30 km	33 km

Table 6-7 Summary of the PTS and TTS impact ranges for UXO detonation using the single pulse, M-Weighted SEL_{ss}, noise criteria from Southall et al. (2007) for marine mammals at EA2 and EA1N

Southall *et al.* (2007) Unweighted SEL_{ss}	200 kg charge weight	300 kg charge weight	500 kg charge weight	700 kg charge weight
152 dB (LF likely avoidance)	87 km	91 km	97 km	100 km
142 dB (LF possible avoidance)	126 km	130 km	136 km	140 km
170 dB (MF likely avoidance)	28 km	31 km	35 km	38 km
160 dB (MF possible avoidance)	58 km	62 km	67 km	70 km

Table 6-8 Summary of the behavioural avoidance impact ranges for UXO detonation using the single pulse, Unweighted SEL_{ss}, noise criteria from Southall et al. (2007) for marine mammals at EA2 and EA1N

Lucke *et al.* (2009) Unweighted SEL_{ss}	200 kg charge weight	300 kg charge weight	500 kg charge weight	700 kg charge weight
179 dB (PTS)	11 km	12 km	15 km	16 km
164 dB (TTS)	45 km	49 km	53 km	56 km
145 dB (Behavioural)	114 km	118 km	124 km	128 km

Table 6-9 Summary of the impact ranges for UXO detonation using the unweighted SEL_{ss}, noise criteria from Lucke et al. (2009) for marine mammals at EA2 and EA1N

Popper *et al.* (2014) Unweighted SPL_{peak}	200 kg charge weight	300 kg charge weight	500 kg charge weight	700 kg charge weight
234 dB (Mortality and potential mortal injury)	350 m	400 m	470 m	530 m
229 dB (Mortality and potential mortal injury)	580 m	660 m	790 m	880 m

Table 6-10 Summary of the impact ranges for UXO detonation using the unweighted SPL_{peak}, explosion noise criteria from Popper et al. (2014) for marine mammals at EA2 and EA1N

It can be seen that the ranges of impact for PTS to LF and HF cetaceans using impulse-type criteria are in excess of 5 km. However, using the non-pulse criteria, the impact range all species for PTS criteria are less than 1 km. It is suggested that 5 km is likely to be the limit of risk of PTS onset.

6.3 Other construction activities

For the purposes of identifying the greatest noise impacts, approximate subsea noise levels have been predicted using a simple modelling approach based on measured data scaled to relevant parameters for the site and specific noise source. Predicted source levels at 1 m range for the construction activities are presented in Table 6-11. As previously, all SEL_{cum} criteria use the same assumptions as presented in section 2.2.2, and ranges smaller than 50 m (single strike) and 100 m (cumulative) have not been presented. Operational WTGs have been assessed separately in section 6.4.

At the modelled noise levels, any marine mammal would have to remain in close proximity (in most cases less than 50 m) from the source continuously for 24 hours to be exposed to levels sufficient to induce PTS as per NMFS (2018). In most hearing groups, the noise levels are low enough that there is negligible risk. There is a low to negligible risk of any injury or TTS to fish, in line with guidance for continuous noise sources in Popper *et al.* (2014). All sources presented here much quieter than those presented for impact piling in section 5.

These results are summarised in Table 6-12 to Table 6-15. It is worth noting that NMFS (2018), Southall *et al*. (2007) and Popper *et al.* (2014) give different criteria for non-impulsive or continuous noise sources (see section 2.2.2) and the discussion in section 6.2.2; all sources in this section are considered non-pulse or continuous-type.

	Estimated unweighted source level	**Comments**
Dredging	186 dB re 1 µPa @ 1 m (RMS)	Based on five datasets from suction and cutter suction dredgers.
Drilling	179 dB re 1 µPa @ 1 m (RMS)	Based on seven datasets of offshore drilling using a variety of drill sizes and powers.
Cable laying	171 dB re 1 µPa @ 1 m (RMS)	Based on eleven datasets from a pipe laying vessel measuring 300 m in length; this is considered a worst-case noise source for cable laying operations.
Rock placement	172 dB re 1 µPa @ 1 m (RMS)	Based on four datasets from rock placement vessel 'Rollingstone.'
Trenching	172 dB re 1 µPa @ 1 m (RMS)	Based on three datasets of measurements from trenching vessels more than 100 m in length.
Vessel noise (large)	171 dB re 1 µPa @ 1 m (RMS)	Based on five datasets of large vessels including container ships, FPSOs and other vessels more than 100 m in length. Vessel speed assumed as 12 knots.
Vessel noise (medium)	164 dB re 1 µPa @ 1 m (RMS)	Based on three datasets of moderate sized vessels less than 100 m in length. Vessel speed assumed as 12 knots.

Table 6-11 Summary of the estimated unweighted source levels for the different construction noise sources considered

NMFS (2018)		Dredging	Drilling	Cable Laying	Rock Place-ment	Trench-ing	Vessels (Large)	Vessels (Med.)
PTS	199 dB LF SEL_{cum}	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
	198 dB MF SEL_{cum}	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
	173 dB HF SEL_{cum}	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
	201 dB PW SEL_{cum}	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
TTS	179 dB LF SEL_{cum}	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
	178 dB MF SEL_{cum}	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
	153 dB HF SEL_{cum}	230 m	< 100 m	< 100 m	990 m	< 100 m	< 100 m	< 100 m
	181 dB PW SEL_{cum}	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m

Table 6-12 Summary of the impact ranges for the different construction noise sources using the non-impulsive noise criteria from NMFS (2018) for marine mammals at EA2 and EA1N

Southall *et al*. (2007)		Dredging	Drilling	Cable Laying	Rock Placement	Trenching	Vessels (Large)	Vessels (Medium)
PTS	215 dB LF SEL_{cum}	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
	215 dB MF SEL_{cum}	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
	215 dB HF SEL_{cum}	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
	203 dB PW SEL_{cum}	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
Behavioural avoidance	152 dB Unwtd SEL_{ss} (LF Likely)	60 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m
	142 dB Unwtd SEL_{ss} (LF Possible)	210 m	200m	180m	310m	210 m	260 m	60 m
	170 dB Unwtd SEL_{ss} (MF Likely)	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m
	160 dB Unwtd SEL_{ss} (MF Possible)	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m

Table 6-13 Summary of the impact ranges for the different construction noise sources using the non-pulsed criteria from Southall et al (2007) for marine mammals at EA2 and EA1N

Lucke *et al*. (2009)	Dredging	Drilling	Cable Laying	Rock Placement	Trenching	Vessels (Large)	Vessels (Medium)
179 dB Unwtd SEL_{ss} (PTS)	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m
164 dB Unwtd SEL_{ss} (TTS)	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m
145 dB Unwtd SEL_{ss} (Behavioural)	150 m	130 m	110 m	180 m	120 m	150 m	< 50 m

Table 6-14 Summary of the harbour porpoise impact ranges from Lucke et al (2009) for the different construction noise sources at EA2 and EA1N

Popper *et al*. (2014)	Dredging	Drilling	Cable Laying	Rock Placement	Trenching	Vessels (Large)	Vessels (Medium)
170 dB (48h) Unwtd SPL_{RMS} (Recoverable injury)	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m
158 dB (12h) Unwtd SPL_{RMS} (TTS)	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m

Table 6-15 Summary of the impact ranges from Popper et al (2014) for shipping and continuous noise covering the different construction noise sources for species of fish (swim bladder involved in hearing) at EA2 and EA1N

6.4 Operational WTG noise

It is believed that the main source of underwater noise from operational turbines will be mechanically generated vibration from the rotating machinery in the turbines, which is transmitted into the sea through the structure of the pile and foundations (Nedwell *et al.*, 2003a). Noise levels generated above the water surface are low enough that no significant airborne sound will pass from the air to the water.

The project design envelope for EA2 and EA1N gives the maximum potential WTG output as 19 MW. A summary of operational WTG where measurements have been collected is given in Table 6-16.

	Lynn	**Inner Dowsing**	**Gunfleet Sands 1 & 2**	**Gunfleet Sands 3**
Type of turbine used	Siemens SWT-3.6-107	Siemens SWT-3.6-107	Siemens SWT-3.6-107	Siemens SWT-6.0-120
Number of turbines	27	27	48	2
Rotor diameter	107 m	107 m	107 m	120 m
Water depths	6 to 18 m	6 to 14 m	0 to 15 m	5 to 12 m
Representative sediment type	Sandy gravel / Muddy sandy gravel	Sandy gravel / Muddy sandy gravel	Sand / Muddy sand / Muddy sandy gravel	Sand / Muddy sand / Muddy sandy gravel
Turbine separation (representative)	500 m	500 m	890 m	435 m

Table 6-16 Characteristics of measured operational wind farms used as a basis for modelling

The estimation of the effects of operational noise in these situations has two features that make it harder to assess compared with noise sources such as impact piling. Primarily, the problem is one of level; noise measurements made at many wind farms have demonstrated that the operational noise produced was at such a low level that it was difficult to measure relative to the background noise (Cheesman, 2016). Also, an offshore wind farm should be considered as an extended, distributed noise source, as opposed to a 'point source' as would be appropriate for pile driving at a single location, for example. The measurement techniques used at the sites above have dealt with these issues by considering the operational noise spectra in terms of levels within and on the edge of the wind farm (but relatively close to the turbines, so that some noise above background could be detected).

The considered turbine size for modelling at this wind farm is larger than those for which data is available. EA2 and EA1N are also in greater water depths, and as such, estimations of a scaling factor must be conservative to minimise the risk of underestimating the noise. However, it is recognised that the available data on which to base the scaling factor is limited and the extrapolation that must be made is significant.

The operational source levels (as SPL_{RMS}) for the measured sites are given in Table 6-17 (Cheesman, 2016), with an estimated source level for EA2 and EA1N in the bottom row. To predict operational WTG noise levels at EA2 and EA1N, the level sampled at each of the sites have been taken and then a linear correction factor has been included to scale up the source levels (see Figure 6-1). A linear fit was applied to the data available for operational wind turbine noise as this was the extrapolation that would lead to the highest, and thus worst case, estimation of source noise level from the larger 19 MW turbine. This resulted in an estimated source level of 164 dB SPL_{RMS}, 18 dB higher than the 6 MW turbine, the largest for which noise data is available. Alternative calculation methods were considered but rejected as they led to a lower source level. Using a logarithmic fit (3 dB per doubling of power output) to data would lead to a source level of 151 dB SPL_{RMS}. A larger 6 dB increase per doubling of power output would lead to a source level of 156 dB SPL_{RMS}.

A summary of the predicted impact ranges is given in Table 6-18 to Table 6-21. All SEL_{cum} criteria use the same assumptions as presented in section 2.2.2, ranges smaller than 50 m (single strike) and 100 m (cumulative) have not been presented, and NMFS (2018), Southall *et al*. (2007) and Popper *et al.* (2014) give different criteria for non-impulsive or continuous noise sources.

	Unweighted source level (RMS)
Lynn	141 dB re 1 µPa (RMS) @ 1 m
Inner Dowsing	142 dB re 1 µPa (RMS) @ 1 m
Gunfleet Sands 1 & 2	145 dB re 1 µPa (RMS) @ 1 m
Gunfleet Sands 3	146 dB re 1 µPa (RMS) @ 1 m
EA2/EA1N (19 MW)	164.1 dB re 1 µPa (RMS) @ 1 m

Table 6-17 Measured operational noise taken at operational wind farms and the predicted source levels for the turbine size considered at EA2 and EA1N

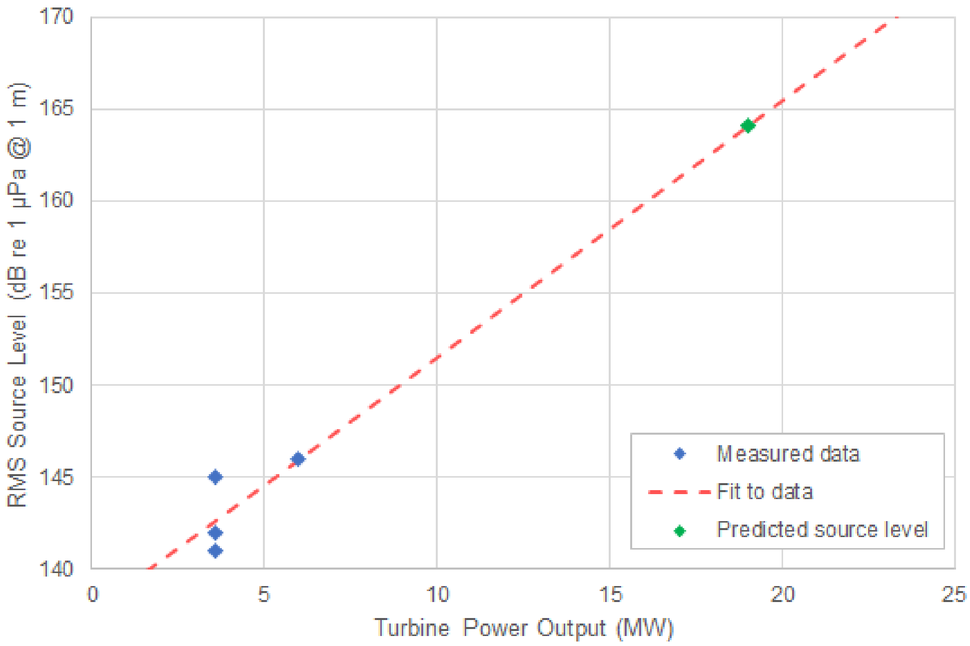

Figure 6-1 Extrapolated source levels from operational WTGs plotted with a linear fit to estimate source level for a 19 MW turbine

NMFS (2018)		Operational WTG (19 MW)
PTS	199 dB LF SEL_{cum}	< 100 m
	198 dB MF SEL_{cum}	< 100 m
	173 dB HF SEL_{cum}	< 100 m
	201 dB PW SEL_{cum}	< 100 m
TTS	179 dB LF SEL_{cum}	< 100 m
	178 dB MF SEL_{cum}	< 100 m
	153 dB HF SEL_{cum}	< 100 m
	181 dB PW SEL_{cum}	< 100 m

Table 6-18 Summary of the impact ranges for operational WTGs using the non-impulsive noise criteria from NMFS (2018) for marine mammals at EA2 and EA1N

Southall *et al*. (2007)		**Operational WTG (19 MW)**
PTS	215 dB LF SEL_{cum}	< 100 m
	215 dB MF SEL_{cum}	< 100 m
	215 dB HF SEL_{cum}	< 100 m
	203 dB PW SEL_{cum}	< 100 m
Behavioural avoidance	152 dB Unwtd SEL_{ss} (LF Likely avoidance)	< 50 m
	142 dB Unwtd SEL_{ss} (LF Possible avoidance)	160 m
	170 dB Unwtd SEL_{ss} (MF Likely avoidance)	< 50 m
	160 dB Unwtd SEL_{ss} (MF Possible avoidance)	< 50 m

Table 6-19 Summary of the impact ranges for operational WTGs using the non-pulsed noise criteria from Southall et al. (2007) for marine mammals at EA2 and EA1N

Lucke *et al*. (2009)	**Operational WTG (19 MW)**
179 dB Unwtd SEL_{ss} (PTS)	< 50 m
164 dB Unwtd SEL_{ss} (TTS)	< 50 m
145 dB Unwtd SEL_{ss} (Behavioural)	80 m

Table 6-20 Summary of the harbour porpoise impact ranges from Lucke et al (2009) for operational WTGs at EA2 and EA1N

Popper *et al*. (2014)	**Operational WTG (19 MW)**
170 dB Unwtd SPL_{RMS} (48h) (Recoverable injury)	< 50 m
158 dB Unwtd SPL_{RMS} (12h) (TTS)	< 50 m

Table 6-21 Summary of the impact ranges for shipping and continuous noise from Popper et al (2014) for operational WTGs for species of fish (swim bladder involved in hearing) at EA2 and EA1N

These results show that, for operational WTGs, any injury risk is minimal, even assuming the receptor (marine mammal or fish) stays close to the turbine for 24 hours. Taking both sets of results into account (operational WTG noise and noise sources related to construction in section 6.3) and comparing them to the impact piling source levels in the previous section (specifically section 5.2), it is clear that noise from impact piling results in much greater levels and hence should be considered the activity which has the potential to have the greatest effect during the OWF development.

7 Summary and conclusions

Subacoustech Environmental has undertaken a study on behalf of Royal HaskoningDHV to assess the effect of underwater noise during the development of the EA2 and EA1N Offshore Wind Farms. The study primarily focused on impact piling noise as this is the foundation installation method known to have the greatest potential underwater noise impacts.

The level of underwater noise from the installation of monopiles and pin piles during construction has been estimated by using the INSPIRE subsea noise modelling software, which considers a wide variety of input parameters including bathymetry, hammer blow energy and frequency content of the noise.

Two representative locations were chosen at each of the sites to give spatial variation as well as changes in depth. At each location, monopiles installed with a maximum hammer blow energy of 4000 kJ and pin piles installed with a maximum hammer blow energy of 2400 kJ were modelled. The results showed that greater levels of noise are predicted along transects travelling through deeper water.

The modelling results were analysed in terms of relevant noise metrics to assess the impacts of the predicted impact piling noise on marine mammals and fish.

NMFS (2018), Southall *et al*. (2007) and Lucke *et al*. (2009) all give impact criteria for various species of marine mammals using single pulse and cumulative metrics, both weighted (to account for the hearing sensitivity of the species under consideration) and unweighted. The largest impact ranges for these criteria are summarised in Table 7-1. For all cases in the table below, the worst-case location at EA1N has been used as this provided most of the largest impact ranges.

Criteria	Effect	Species	Monopile (4000 kJ)	Pin Pile (2400 kJ)
NMFS (2018)	PTS (Weighted SEL_{cum})	LF Cetacean	17 km	21 km
		MF Cetacean	< 100 m	< 100 m
		HF Cetacean	6.6 km	21 km
		PW Pinniped	5.2 km	7.1 km
	TTS (Weighted SEL_{cum})	LF Cetacean	40 km	45 km
		MF Cetacean	< 100 m	5.8 km
		HF Cetacean	27 km	45 km
		PW Pinniped	25 km	28 km
Southall *et al*. (2007)	PTS (M-Weighted SEL_{cum})	LF Cetacean	4.4 km	5.7 km
		MF Cetacean	3.0 km	5.8 km
		HF Cetacean	1.8 km	3.8 km
		PW Pinniped	22 km	26 km
	TTS (M-Weighted SEL_{ss})	LF Cetacean	2.1 km	1.9 km
		MF Cetacean	580 m	710 m
		HF Cetacean	440 m	490 m
		PW Pinniped	6.6 km	7.5 km
	Behavioural (SEL_{ss})	LF Cetacean	35 – 51 km	34 – 51 km
		MF Cetacean	11 – 23 km	11 – 22 km
Lucke *et al*. (2009)	Auditory injury (SEL_{ss})	Harbour porpoise	3.7 km	3.5 km
	TTS (SEL_{ss})		3.4 km	18 km
	Behavioural (SEL_{ss})		3.6 km	46 km

Table 7-1 Summary of the maximum predicted impact range for marine mammal criteria (EA1N, worst-case location)

Popper *et al*. (2014) gives impact range criteria for various groups of fish, with ranges of up to 500 m for recoverable injury (SPL_{peak}) and out to 29 km for TTS (SEL_{cum}) at the maximum blow energies, when considering monopiles at the worst-case modelling location at EA1N. For all SEL_{cum} criteria, greater impact ranges were calculated for pin piles compared to monopiles due to the faster strike rate assumed for those scenarios.

Further impact piling modelling was carried out to demonstrate the reductions in noise levels and impact ranges relating to only reaching 75% or 50% of the maximum blow energy compared to reaching 100%, these results are presented in Appendix A.

Noise sources other than piling have been considered using a high-level, simple noise modelling approaches, including UXO detonation, dredging, drilling, cable laying, rock placement, trenching, vessel noise and noise from operational wind turbines. For UXO detonation, there is a risk of PTS up to 11 km for the largest UXO considered, a 700 kg device using the impulsive NMFS criteria, for HF cetaceans. However, it has been suggested that at distances beyond five kilometres the smoothing of the noise pulse means that the 'non-pulse' criteria may be more appropriate; in this case the risk of PTS to any species reduces to less than one kilometre and thus the range of risk of PTS during UXO detonation is likely to be 5 km.

The predicted noise levels for the other construction noise sources and during turbine operation are well below those predicted for impact piling noise. The risk of any potential injurious effects to fish or marine mammals from these sources are expected to be negligible as the noise emissions from these are very close to, or below, the appropriate injury criteria at the source of the noise.

8 References

1. Arons A B (1954). *Underwater explosion shock wave parameters at large distances from the charge.* J. Acoust. Soc. Am. 26, 343-346.
2. Bailey H, Senior B, Simmons D, Rusin J, Picken G, Thompson P M (2010). *Assessing underwater noise levels during pile-driving at an offshore wind farm and its potential effects on marine mammals.* Marine Pollution Bulletin 60 (2010) 888-897.
3. Bailey H, Brookes K L, Thompson P M (2014). *Assessing environmental impacts of offshore wind farms: lessons learned and recommendations for the future*. Aquatic Biosystems 2014 10:8.
4. Bebb A H, Wright H C (1953). *Injury to animals from underwater explosions.* Medical Research Council, Royal Navy Physiological Report 53/732, Underwater Blast Report 31, January 1953.
5. Bebb A H, Wright H C (1954a). *Lethal conditions from underwater explosion blast.* RNP Report 51/654, RNPL 3/51, National archives reference ADM 298/109, March 1954.
6. Bebb A H, Wright H C (1954b). *Protection from underwater explosion blast. III. Animal experiments and physical measurements.* RNP report 57/792, RNPL 2/54, March. 1954
7. Bebb A H, Wright H C (1955). *Underwater explosion blast data from the Royal Navy Physiological Labs 1950/1955.* Medical Research Council, April 1955.
8. Bergström L, Kautsky L, Malm T, Rosenberg R, Wahlberg M, Capetillo N A and Wilhelmsson D. (2014) *Effects of offshore wind farms on marine wildlife—a generalized impact assessment*. Environ. Res. Lett. 9 (2014) 034012
9. Blix A S, Folkow L P (1995). *Daily energy expenditure in free living minke whales.* Acta Physio. Scand., 153: 61-66.
10. Brekhovskikh L M (1960). *Propagation of surface Rayleigh waves along the uneven boundary of an elastic body.* Sov. Phys. Acoust.
11. Caltrans (2001). *Pile installation demonstration project, San Francisco – Oakland Bridge, East Span Safety Project.* PIPD EA 01281, Caltrans contract 04A0148, August 2001.
12. Cheesman S (2016). *Measurement of operational wind turbine noise in UK waters.* In Popper A N, Hawkins A (eds) *The effects of Noise of Aquatic Life II. Advances in Experimental Medicine and Biology.* Vol 875, pp 153-160. DOI 10.1007/975-1-4939-2981-8_18.
13. Cudahy E A, Parvin S (2001). *The effects of underwater blast on divers.* Report 1218, Naval Submarine Medical Research Laboratory. #63706N M0099.001-5901.
14. Dahl P H, de Jong C A F, Popper A N (2015). *The underwater sound field from impact pile driving and its potential effects on marine life.* Acoustics Today, Spring 2015, Volume 11, Issue 2.
15. Dekeling R P A, Tasker M L, Van der Graaf A J, Ainslie M A, Andersson M H, André M, Borsani J F, Brensing K, Castellote M, Cronin D, Dalen J, Folegot T, Leaper R, Pajala J, Redman P, Robinson S P, Sigray P, Sutton G, Thomsen F, Werner S, Wittekind D, Young J V (2014). *Monitoring Guidance for Underwater Noise in European Seas, Part II: Monitoring Guidance Specifications*, JRC Scientific and Policy Report EUR 26555 EN, Publications Office of the European Union, Luxembourg, 2014, doi: 10.2788/27158.
16. Etter P C (2013). *Underwater Acoustic Modeling and Simulation*. CRC Press FL (2013), 10.1201/b13906

17. Goertner J F (1978). *Dynamical model for explosion injury to fish.* Naval Surface Weapons Center, White Oak Lab, Silver Spring, MD Report No. NSWC/WOL/TR-76-155.

18. Goertner J F, Wiley M L, Young G A, McDonald W W (1994). *Effects of underwater explosions on fish without swimbladders.* Naval Surface Warfare Center Report NSWC TR88-114.

19. Halvorsen M B, Casper B C, Matthews D, Carlson T J, Popper A N (2012). *Effects of exposure to pile driving sounds on the lake sturgeon, Nile tilapia, and hogchoker. Proc Roy Soc B 279:4705-4714.*

20. Hastings M C, Popper A N (2005). *Effects of sound on fish.* Report to the California Department of Transport, under Contract No. 43A01392005, January 2005.

21. Hirata K (1999). *Swimming speeds of some common fish. National Maritime Research Institute (Japan).* Data Sourced from Iwai T, Hisada M (1998). *Fishes – Illustrated Book of Gakken (in Japanese), Gakken.* Accessed 8th March 2017 at http://www.nmri.go.jp/oldpages2/eng/khirata/fish/general/speed/speede.htm

22. Jensen F B, Kuperman W A, Porter M B, Schmidt H (2011). *Computational Ocean Acoustics.* Modern Acoustics and Signal Processing. Springer-Verlag, New York. ISBN: 978-1-4419-8678-8.

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

24. Marine Technical Directorate Ltd (MTD) (1996). *Guidelines for the safe use of explosives under water.* MTD Publication 96/101. ISBN 1 870553 23 3.

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

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

27. Nedwell J R, Langworthy J, Howell D (2003a). *Assessment of subsea noise and vibration from offshore wind turbines and its impact on marine wildlife. Initial measurements of underwater noise during construction of offshore wind farms, and comparison with background noise.* Subacoustech report ref: 544R0423, published by COWRIE, May 2003.

28. Nedwell J R, Turnpenny A W H, Lovell J, Langworthy J W, Howell D M, Edwards B (2003b). *The effects of underwater noise from coastal piling on salmon (Salmo salar) and brown trout (Salmo trutta).* Subacoustech report to the Environment Agency, report ref: 576R0113, December 2003.

29. Nedwell J R, Parvin S J, Edwards B, Workman R, Brooker A G, Kynoch J E (2007). *Measurement and interpretation of underwater noise during construction and operation of offshore windfarms in UK waters.* Subacoustech report ref: 544R0738 to COWRIE. ISBN: 978-09554276-5-4.

30. Nedwell J R, Cheesman S T (2011). *Measurement and assessment of underwater noise during impact piling operations of the foundations of the met mast at hornsea windfarm.* Subacoustech Environmental report reference E322R0110.

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

32. Parvin S J, Nedwell J R, Workman R (2006). *Underwater noise impact modelling in support of the London Array, Greater Gabbard and Thanet offshore wind farm developments.* Report to CORE Ltd by Subacoustech, report ref: 710R0517.

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

34. Rawlins J S P (1987). *Problems in predicting safe ranges from underwater explosions.* Journal of Naval Science, Volume 13, No. 4 pp. 235-246.

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

36. Soloway A G, Dahl P H (2014). *Peak sound pressure and sound exposure level from underwater explosions in shallow water.* The Journal of the Acoustical Society of America, 136(3), EL219 - EL223. http://dx.doi.org/10.1121/1.4892668

37. Stephenson J R, Gingerich A J, Brown R S, *et al*. (2010). *Assessing barotrauma in neutrally and negatively buoyant juvenile salmonids exposed to simulated hydro-turbine passage using a mobile aquatic barotrauma laboratory.* Fisheries Res, 106:271-278.

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

39. Thomsen F, Lüdemann K, Kafemann R, Piper W (2006). *Effects of offshore wind farm noise on marine mammals and fish.* On behalf of COWRIE Ltd.

40. Urick R J (1983). *Principles of underwater sound (3rd edition)*. McGraw-Hill, New York.

41. von Benda-Beckmann A M, Aarts G, Sertlek H Ö, Lucke K, Verboom W C, Kastelein R A, Ketten D R, van Bemmelen R, Lam F-P A, Kirkwood R J, Ainslie M A (2015). *Assessing the impact of underwater clearance of unexploded ordnance on harbour porpoises (phocoena phocoena) in the southern North Sea.* Aquatic Mammals 2015, 41(4), 503-523, DOI 10.1578/AM.41.4.2015.503.

42. Würsig B, Greene C R, Jefferson T A (2000). *Development of an air bubble curtain to reduce underwater noise of percussive piling.* Mar. Environ. Res. 49 pp. 79-93.

Appendix A Additional impact piling modelling results (75% and 50% maximum blow energy)

A.1 Modelling parameters

An impact piling driveability study has not yet been completed, and as such additional modelling runs have been undertaken to assess noise levels assuming the blow energy only reaches 75% or 50% of the maximum hammer blow energy during the main piling. In each case the soft start remains 10% of the maximum hammer energy and the total number of strikes and strike rate remain the same as the 100% hammer blow energy scenarios for these modelling runs. The same modelling locations have also been used.

Table A-1 to Table A-4 summarise the ramp up scenarios used for these additional modelling runs and Table A-5 and Table A-6 present the single strike source levels used for the modelling. The results are presented in the following sections and compared with the 100% hammer blow energy scenarios in section A.4.

	Soft start (10%)	Ramp up	Main piling (75%)
Monopile blow energy	400 kJ	Gradual increase	3000 kJ
Number of strikes	150 strikes	300 strikes	8850 strikes
Duration	10 minutes	20 minutes	295 minutes
Strike rate	15 strikes per minute		30 strikes per minute

Table A-1 Summary of the ramp up scenario used for calculating cumulative SELs for monopiles up to 75% maximum hammer blow energy

	Soft start (10%)	Ramp up	Main piling (75%)
Pin pile blow energy	240 kJ	Gradual increase	1800 kJ
Number of strikes	150 strikes	300 strikes	6760 strikes
Duration	10 minutes	20 minutes	169 minutes
Strike rate	15 strikes per minute		40 strikes per minute

Table A-2 Summary of the ramp up scenario used for calculating cumulative SELs for a single pin pile up to 75% maximum hammer blow energy

	Soft start (10%)	Ramp up	Main piling (50%)
Monopile blow energy	400 kJ	Gradual increase	2000 kJ
Number of strikes	150 strikes	300 strikes	8850 strikes
Duration	10 minutes	20 minutes	295 minutes
Strike rate	15 strikes per minute		30 strikes per minute

Table A-3 Summary of the ramp up scenario used for calculating cumulative SELs for monopiles up to 50% maximum hammer blow energy

	Soft start (10%)	Ramp up	Main piling (50%)
Pin pile blow energy	240 kJ	Gradual increase	1200 kJ
Number of strikes	150 strikes	300 strikes	6760 strikes
Duration	10 minutes	20 minutes	169 minutes
Strike rate	15 strikes per minute		40 strikes per minute

Table A-4 Summary of the ramp up scenario used for calculating cumulative SELs for a single pin pile up to 50% maximum hammer blow energy

		SPL_{peak} source level	SEL_{ss} source level
Monopile	50% (2000kJ)	239.1 dB re 1 µPa @ 1 m	222.7 dB re 1 µPa²s @ 1 m
	75% (3000kJ)	239.4 dB re 1 µPa @ 1 m	223.1 dB re 1 µPa²s @ 1 m

Table A-5 Summary of the unweighted single strike source levels used for modelling monopiles in this study

		SPL_{peak} source level	SEL_{ss} source level
Pin pile	50% (1200kJ)	238.4 dB re 1 µPa @ 1 m	222.0 dB re 1 µPa^{2}s @ 1 m
	75% (1800kJ)	238.9 dB re 1 µPa @ 1 m	222.3 dB re 1 µPa^{2}s @ 1 m

Table A-6 Summary of the unweighted single strike source levels used for modelling pin piles in this study

A.2 75% maximum blow energy modelling results

The following sections present the impact ranges using the various noise metrics and criteria for reaching 75% of the maximum hammer blow energy. This modelling uses the parameters detailed in Table A-1, Table A-2 and Table A-5.

A.2.1 NMFS (2018) results

EA2	NMFS (2018) - PTS			Monopile (3000kJ – main piling, 75%)			
				Area	Maximum	Minimum	Mean
Worst case location	Unweighted SPL_{peak}	LF Cetacean	219 dB	0.01 km^2	50 m	50 m	50 m
		MF Cetacean	230 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	4.4 km^2	1.2 km	1.2 km	1.2 km
		PW Pinniped	218 dB	0.01 km^2	60 m	60 m	60 m
	Weighted SEL_{cum}	LF Cetacean	183 dB	560 km^2	16 km	11 km	13 km
		MF Cetacean	185 dB	< 0.01 km^2	< 100 m	< 100 m	< 100 m
		HF Cetacean	155 dB	90 km^2	6.2 km	4.4 km	5.3 km
		PW Pinniped	185 dB	53 km^2	4.7 km	3.3 km	4.1 km
	Weighted SEL_{ss}	LF Cetacean	183 dB	1.7 km^2	750 m	730 m	740 m
		MF Cetacean	185 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	155 dB	0.01 km^2	70 m	70 m	70 m
		PW Pinniped	185 dB	0.01 km^2	50 m	50 m	50 m
Average depth location	Unweighted SPL_{peak}	LF Cetacean	219 dB	0.01 km^2	50 m	50 m	50 m
		MF Cetacean	230 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	4.2 km^2	1.2 km	1.2 km	1.2 km
		PW Pinniped	218 dB	0.01 km^2	60 m	60 m	60 m
	Weighted SEL_{cum}	LF Cetacean	183 dB	430 km^2	14 km	7.8 km	12 km
		MF Cetacean	185 dB	< 0.01 km^2	< 100 m	< 100 m	< 100 m
		HF Cetacean	155 dB	64 km^2	5.3 km	3.4 km	4.5 km
		PW Pinniped	185 dB	36 km^2	4.0 km	2.6 km	3.4 km
	Weighted SEL_{ss}	LF Cetacean	183 dB	1.7 km^2	730 m	730 m	730 m
		MF Cetacean	185 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	155 dB	0.01 km^2	70 m	70 m	70 m
		PW Pinniped	185 dB	0.01 km^2	50 m	50 m	50 m

Table A-7 Summary of the single strike and cumulative impact ranges for PTS from NMFS (2018) for installation of a monopile at EA2 using the 75% maximum hammer blow energy of 3000 kJ

EA2	NMFS (2018) - PTS			Pin Pile (1800kJ – main piling, 75%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case location	**Unweighted SPL_{peak}**	LF Cetacean	219 dB	0.01 km²	50 m	50 m	50 m
		MF Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	3.7 km²	1.1 km	1.1 km	1.1 km
		PW Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	Weighted SEL_{cum}	LF Cetacean	183 dB	820 km²	20 km	12 km	16 km
		MF Cetacean	185 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		HF Cetacean	155 dB	940 km²	21 km	14 km	17 km
		PW Pinniped	185 dB	99 km²	6.5 km	4.7 km	5.6 km
	Weighted SEL_{ss}	LF Cetacean	183 dB	2.3 km²	860 m	840 m	850 m
		MF Cetacean	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	155 dB	0.45 km²	380 m	380 m	380 m
		PW Pinniped	185 dB	0.01 km²	50 m	50 m	50 m
Average depth location	**Unweighted SPL_{peak}**	LF Cetacean	219 dB	0.01 km²	50 m	50 m	50 m
		MF Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	3.6 km²	1.1 km	1.1 km	1.1 km
		PW Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	Weighted SEL_{cum}	LF Cetacean	183 dB	660 km²	17 km	9.2 km	14 km
		MF Cetacean	185 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		HF Cetacean	155 dB	760 km²	18 km	11 km	15 km
		PW Pinniped	185 dB	70 km²	5.5 km	3.5 km	4.7 km
	Weighted SEL_{ss}	LF Cetacean	183 dB	2.2 km²	840 m	840 m	840 m
		MF Cetacean	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	155 dB	0.44 km²	380 m	380 m	380 m
		PW Pinniped	185 dB	0.01 km²	50 m	50 m	50 m

Table A-8 Summary of the single strike and cumulative impact ranges for PTS from NMFS (2018) for installation of a pin pile at EA2 using the 75% maximum hammer blow energy of 1800 kJ

EA2	NMFS (2018) - TTS			Monopile (3000kJ – main piling, 75%)			
				Area	Maximum	Minimum	Mean
Worst case location	Unweighted SPL_{peak}	LF Cetacean	213 dB	0.08 km^2	160 m	160 m	160 m
		MF Cetacean	224 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	30 km^2	3.2 km	2.9 km	3.1 km
		PW Pinniped	212 dB	0.11 km^2	190 m	190 m	190 m
	Weighted SEL_{cum}	LF Cetacean	168 dB	3000 km^2	39 km	23 km	31 km
		MF Cetacean	170 dB	< 0.01 km^2	< 100 m	< 100 m	< 100 m
		HF Cetacean	140 dB	1500 km^2	26 km	17 km	22 km
		PW Pinniped	170 dB	1300 km^2	24 km	16 km	20 km
	Weighted SEL_{ss}	LF Cetacean	168 dB	150 km^2	7.5 km	6.5 km	7.0 km
		MF Cetacean	170 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	3.7 km^2	1.1 km	1.1 km	1.1 km
		PW Pinniped	170 dB	2.2 km^2	850 m	840 m	850 m
Average depth location	Unweighted SPL_{peak}	LF Cetacean	213 dB	0.08 km^2	160 m	160 m	160 m
		MF Cetacean	224 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	28 km^2	3.1 km	2.9 km	3.0 km
		PW Pinniped	212 dB	0.11 km^2	190 m	190 m	190 m
	Weighted SEL_{cum}	LF Cetacean	168 dB	2600 km^2	36 km	19 km	28 km
		MF Cetacean	170 dB	0.01 km^2	< 100 m	< 100 m	< 100 m
		HF Cetacean	140 dB	1300 km^2	23 km	14 km	20 km
		PW Pinniped	170 dB	1100 km^2	22 km	13 km	18 km
	Weighted SEL_{ss}	LF Cetacean	168 dB	140 km^2	7.0 km	6.2 km	6.6 km
		MF Cetacean	170 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	3.5 km^2	1.1 km	1.1 km	1.1 km
		PW Pinniped	170 dB	2.2 km^2	840 m	830 m	830 m

Table A-9 Summary of the single strike and cumulative impact ranges for TTS from NMFS (2018) for installation of a monopile at EA2 using the 75% maximum hammer blow energy of 3000 kJ

EA2	NMFS (2018) - TTS			Pin Pile (1800kJ – main piling, 75%)			
				Area	Maximum	Minimum	Mean
Worst case location	Unweighted SPL_{peak}	LF Cetacean	213 dB	0.07 km²	150 m	140 m	150 m
		MF Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	26 km²	3.0 km	2.7 km	2.9 km
		PW Pinniped	212 dB	0.09 km²	170 m	170 m	170 m
	Weighted SEL_{cum}	LF Cetacean	168 dB	3700 km²	43 km	25 km	34 km
		MF Cetacean	170 dB	64 km²	5.2 km	3.7 km	4.5 km
		HF Cetacean	140 dB	3900 km²	43 km	26 km	35 km
		PW Pinniped	170 dB	1600 km²	27 km	17 km	22 km
	Weighted SEL_{ss}	LF Cetacean	168 dB	180 km²	8.1 km	7.1 km	7.7 km
		MF Cetacean	170 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	65 km²	4.8 km	4.3 km	4.6 km
		PW Pinniped	170 dB	2.1 km²	830 m	820 m	830 m
Average depth location	Unweighted SPL_{peak}	LF Cetacean	213 dB	0.06 km²	140 m	140 m	140 m
		MF Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	24 km²	2.9 km	2.7 km	2.8 km
		PW Pinniped	212 dB	0.09 km²	170 m	170 m	170 m
	Weighted SEL_{cum}	LF Cetacean	168 dB	3200 km²	40 km	21 km	31 km
		MF Cetacean	170 dB	44 km²	4.4 km	2.8 km	3.7 km
		HF Cetacean	140 dB	3400 km²	40 km	23 km	32 km
		PW Pinniped	170 dB	1300 km²	24 km	14 km	20 km
	Weighted SEL_{ss}	LF Cetacean	168 dB	160 km²	7.5 km	6.7 km	7.1 km
		MF Cetacean	170 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	59 km²	4.6 km	4.2 km	4.4 km
		PW Pinniped	170 dB	2.1 km²	820 m	810 m	810 m

Table A-10 Summary of the single strike and cumulative impact ranges for TTS from NMFS (2018) for installation of a pin pile at EA2 using the 75% maximum hammer blow energy of 1800 kJ

EA1N	NMFS (2018) - PTS			Monopile (3000kJ – main piling, 75%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case location	**Unweighted SPL_{peak}**	LF Cetacean	219 dB	0.01 km²	50 m	50 m	50 m
		MF Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	4.3 km²	1.2 km	1.2 km	1.2 km
		PW Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	Weighted SEL_{cum}	LF Cetacean	183 dB	550 km²	16 km	11 km	13 km
		MF Cetacean	185 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		HF Cetacean	155 dB	86 km²	6.4 km	4.5 km	5.2 km
		PW Pinniped	185 dB	50 km²	5.0 km	3.4 km	4.0 km
	Weighted SEL_{ss}	LF Cetacean	183 dB	1.7 km²	740 m	740 m	740 m
		MF Cetacean	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	155 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PW Pinniped	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
Average depth location	**Unweighted SPL_{peak}**	LF Cetacean	219 dB	0.01 km²	50 m	50 m	50 m
		MF Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	4.2 km²	1.2 km	1.2 km	1.2 km
		PW Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	Weighted SEL_{cum}	LF Cetacean	183 dB	580 km²	15 km	13 km	14 km
		MF Cetacean	185 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		HF Cetacean	155 dB	85 km²	5.5 km	4.9 km	5.2 km
		PW Pinniped	185 dB	49 km²	4.2 km	3.7 km	3.9 km
	Weighted SEL_{ss}	LF Cetacean	183 dB	1.7 km²	730 m	730 m	730 m
		MF Cetacean	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	155 dB	0.01 km²	70 m	70 m	70 m
		PW Pinniped	185 dB	0.01 km²	50 m	50 m	50 m

Table A-11 Summary of the single strike and cumulative impact ranges for PTS from NMFS (2018) for installation of a monopile at EA1N using the 75% maximum hammer blow energy of 3000 kJ

EA1N	NMFS (2018) - PTS			Pin Pile (1800kJ – main piling, 75%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case location	**Unweighted SPL_{peak}**	LF Cetacean	219 dB	0.01 km²	50 m	50 m	50 m
		MF Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	3.7 km²	1.1 km	1.1 km	1.1 km
		PW Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	Weighted SEL_{cum}	LF Cetacean	183 dB	830 km²	20 km	13 km	16 km
		MF Cetacean	185 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		HF Cetacean	155 dB	940 km²	21 km	15 km	17 km
		PW Pinniped	185 dB	95 km²	6.8 km	4.7 km	5.5 km
	Weighted SEL_{ss}	LF Cetacean	183 dB	2.3 km²	860 m	850 m	850 m
		MF Cetacean	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	155 dB	0.45 km²	380 m	380 m	380 m
		PW Pinniped	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
Average depth location	**Unweighted SPL_{peak}**	LF Cetacean	219 dB	0.01 km²	50 m	50 m	50 m
		MF Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	3.5 km²	1.1 km	1.1 km	1.1 km
		PW Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	Weighted SEL_{cum}	LF Cetacean	183 dB	870 km²	19 km	16 km	17 km
		MF Cetacean	185 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		HF Cetacean	155 dB	980 km²	19 km	17 km	18 km
		PW Pinniped	185 dB	93 km²	5.8 km	5.1 km	5.5 km
	Weighted SEL_{ss}	LF Cetacean	183 dB	2.2 km²	840 m	840 m	840 m
		MF Cetacean	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	155 dB	0.44 km²	380 m	380 m	380 m
		PW Pinniped	185 dB	0.01 km²	50 m	50 m	50 m

Table A-12 Summary of the single strike and cumulative impact ranges for PTS from NMFS (2018) for installation of a pin pile at EA2 using the 75% maximum hammer blow energy of 1800 kJ

EA1N	NMFS (2018) - TTS			Monopile (3000kJ – main piling, 75%)			
				Area	Maximum	Minimum	Mean
Worst case location	Unweighted SPL_{peak}	LF Cetacean	213 dB	0.08 km²	160 m	160 m	160 m
		MF Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	30 km²	3.2 km	3.0 km	3.1 km
		PW Pinniped	212 dB	0.11 km²	190 m	190 m	190 m
	Weighted SEL_{cum}	LF Cetacean	168 dB	3100 km²	40 km	24 km	31 km
		MF Cetacean	170 dB	0.01 km²	< 100 m	< 100 m	< 100 m
		HF Cetacean	140 dB	1500 km²	27 km	18 km	22 km
		PW Pinniped	170 dB	1300 km²	25 km	17 km	20 km
	Weighted SEL_{ss}	LF Cetacean	168 dB	150 km²	7.5 km	6.6 km	7.0 km
		MF Cetacean	170 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	3.6 km²	1.1 km	1.1 km	1.1 km
		PW Pinniped	170 dB	2.2 km²	850 m	840 m	840 m
Average depth location	Unweighted SPL_{peak}	LF Cetacean	213 dB	0.08 km²	160 m	160 m	160 m
		MF Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	28 km²	3.0 km	3.0 km	3.0 km
		PW Pinniped	212 dB	0.11 km²	190 m	190 m	190 m
	Weighted SEL_{cum}	LF Cetacean	168 dB	3300 km²	37 km	29 km	32 km
		MF Cetacean	170 dB	0.01 km²	< 100 m	< 100 m	< 100 m
		HF Cetacean	140 dB	1600 km²	25 km	21 km	23 km
		PW Pinniped	170 dB	1400 km²	23 km	20 km	21 km
	Weighted SEL_{ss}	LF Cetacean	168 dB	150 km²	7.1 km	6.8 km	6.9 km
		MF Cetacean	170 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	3.5 km²	1.1 km	1.1 km	1.1 km
		PW Pinniped	170 dB	2.2 km²	830 m	830 m	830 m

Table A-13 Summary of the single strike and cumulative impact ranges for TTS from NMFS (2018) for installation of a monopile at EA1N using the 75% maximum hammer blow energy of 3000 kJ

EA1N	NMFS (2018) - TTS			Pin Pile (1800kJ – main piling, 75%)			
				Area	Maximum	Minimum	Mean
Worst case location	Unweighted SPL_{peak}	LF Cetacean	213 dB	0.07 km²	150 m	140 m	150 m
		MF Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	26 km²	2.9 km	2.8 km	2.9 km
		PW Pinniped	212 dB	0.09 km²	180 m	170 m	170 m
	Weighted SEL_{cum}	LF Cetacean	168 dB	3700 km²	44 km	26 km	34 km
		MF Cetacean	170 dB	61 km²	5.5 km	3.8 km	4.4 km
		HF Cetacean	140 dB	4000 km²	44 km	27 km	35 km
		PW Pinniped	170 dB	1600 km²	27 km	18 km	22 km
	Weighted SEL_{ss}	LF Cetacean	168 dB	180 km²	8.3 km	7.2 km	7.6 km
		MF Cetacean	170 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	65 km²	4.8 km	4.4 km	4.6 km
		PW Pinniped	170 dB	2.1 km²	830 m	820 m	820 m
Average depth location	Unweighted SPL_{peak}	LF Cetacean	213 dB	0.06 km²	140 m	140 m	140 m
		MF Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	24 km²	2.8 km	2.8 km	2.8 km
		PW Pinniped	212 dB	0.09 km²	170 m	170 m	170 m
	Weighted SEL_{cum}	LF Cetacean	168 dB	3900 km²	41 km	31 km	35 km
		MF Cetacean	170 dB	59 km²	4.6 km	4.1 km	4.4 km
		HF Cetacean	140 dB	4100 km²	42 km	32 km	36 km
		PW Pinniped	170 dB	1700 km²	26 km	22 km	23 km
	Weighted SEL_{ss}	LF Cetacean	168 dB	180 km²	7.8 km	7.4 km	7.5 km
		MF Cetacean	170 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	63 km²	4.6 km	4.4 km	4.5 km
		PW Pinniped	170 dB	2.1 km²	810 m	810 m	810 m

Table A-14 Summary of the single strike and cumulative impact ranges for TTS from NMFS (2018) for installation of a pin pile at EA2 using the 75% maximum hammer blow energy of 1800 kJ

A.2.2 Southall et al. (2007) results

EA2	Southall *et al.* (2007) - PTS			Monopile (3000kJ – main piling, 75%)			
				Area	Maximum	Minimum	Mean
Worst case	Unweighted SPL_{peak}	Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	M-Weighted SEL_{cum}	LF Cetacean	198 dB	34 km²	4.0 km	2.5 km	3.3 km
		MF Cetacean	198 dB	17 km²	2.7 km	1.8 km	2.3 km
		HF Cetacean	198 dB	5.2 km²	1.6 km	900 m	1.3 km
		PW Pinniped	186 dB	1000 km²	21 km	14 km	18 km
	M-Weighted SEL_{ss}	LF Cetacean	198 dB	0.05 km²	120 m	120 m	120 m
		MF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	1.1 km²	590 m	580 m	590 m
Average depth	Unweighted SPL_{peak}	Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	M-Weighted SEL_{cum}	LF Cetacean	198 dB	21 km²	3.2 km	1.7 km	2.6 km
		MF Cetacean	198 dB	11 km²	2.2 km	1.4 km	1.8 km
		HF Cetacean	198 dB	3.1 km²	1.2 km	700 m	980 m
		PW Pinniped	186 dB	820 km²	19 km	11 km	16 km
	M-Weighted SEL_{ss}	LF Cetacean	198 dB	0.05 km²	120 m	120 m	120 m
		MF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	1.1 km²	580 m	580 m	580 m

Table A-15 Summary of the single strike and cumulative impact ranges for PTS from Southall et al. (2007) for installation of a monopile at EA2 using the 75% maximum hammer blow energy of 3000 kJ

EA2	Southall *et al.* (2007) - PTS			Pin Pile (1800kJ – main piling, 75%)			
				Area	Maximum	Minimum	Mean
Worst case	Unweighted SPL_{peak}	Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	M-Weighted SEL_{cum}	LF Cetacean	198 dB	54 km²	5.2 km	3.1 km	4.1 km
		MF Cetacean	198 dB	65 km²	5.2 km	3.7 km	4.5 km
		HF Cetacean	198 dB	25 km²	3.3 km	2.2 km	2.8 km
		PW Pinniped	186 dB	1400 km²	25 km	17 km	21 km
	M-Weighted SEL_{ss}	LF Cetacean	198 dB	0.04 km²	110 m	110 m	110 m
		MF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	1.5 km²	700 m	690 m	700 m
Average depth	Unweighted SPL_{peak}	Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	M-Weighted SEL_{cum}	LF Cetacean	198 dB	33 km²	4.1 km	1.9 km	3.2 km
		MF Cetacean	198 dB	44 km²	4.4 km	2.8 km	3.7 km
		HF Cetacean	198 dB	16 km²	2.7 km	1.7 km	2.2 km
		PW Pinniped	186 dB	1200 km²	23 km	13 km	19 km
	M-Weighted SEL_{ss}	LF Cetacean	198 dB	0.04 km²	110 m	110 m	110 m
		MF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	1.5 km²	690 m	690 m	690 m

Table A-16 Summary of the single strike and cumulative impact ranges for PTS from Southall et al. (2007) for installation of a pin pile at EA2 using the 75% maximum hammer blow energy of 1800 kJ

EA2	Southall *et al.* (2007) - TTS			Monopile (3000kJ – main piling, 75%)			
				Area	Maximum	Minimum	Mean
Worst case	Unweighted SPL_{peak}	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.11 km²	190 m	190 m	190 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	12 km²	2.0 km	1.8 km	1.9 km
		MF Cetacean	183 dB	0.99 km²	570 m	560 m	560 m
		HF Cetacean	183 dB	0.55 km²	420 m	420 m	420 m
		PW Pinniped	171 dB	120 km²	6.5 km	5.7 km	6.1 km
Av. depth	Unweighted SPL_{peak}	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.11 km²	190 m	190 m	190 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	11 km²	2.0 km	1.8 km	1.9 km
		MF Cetacean	183 dB	0.96 km²	560 m	550 m	560 m
		HF Cetacean	183 dB	0.54 km²	420 m	420 m	420 m
		PW Pinniped	171 dB	100 km²	6.1 km	5.5 km	5.8 km

Table A-17 Summary of the single strike impact ranges for TTS from Southall et al. (2007) for installation of a monopile at EA2 using the 75% maximum hammer blow energy of 3000 kJ

EA2	Southall *et al.* (2007) - TTS			Pin Pile (1800kJ – main piling, 75%)			
				Area	Maximum	Minimum	Mean
Worst case	Unweighted SPL_{peak}	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.09 km²	170 m	170 m	170 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	10 km²	1.9 km	1.7 km	1.8 km
		MF Cetacean	183 dB	1.4 km²	670 m	660 m	670 m
		HF Cetacean	183 dB	0.67 km²	470 m	460 m	460 m
		PW Pinniped	171 dB	140 km²	7.2 km	6.3 km	6.8 km
Av. depth	Unweighted SPL_{peak}	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.09 km²	170 m	170 m	170 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	9.6 km²	1.8 km	1.7 km	1.8 km
		MF Cetacean	183 dB	1.4 km²	660 m	660 m	660 m
		HF Cetacean	183 dB	0.66 km²	460 m	460 m	460 m
		PW Pinniped	171 dB	130 km²	6.7 km	6.0 km	6.4 km

Table A-18 Summary of the single strike impact ranges for TTS from Southall et al. (2007) for installation of a pin pile at EA2 using the 75% maximum hammer blow energy of 1800 kJ

EA2	Southall *et al.* (2007) – Behavioural (Unweighted SEL_{ss})			Monopile (3000kJ – main piling 75%)			
				Area	Maximum	Minimum	Mean
WC	Likely avoidance	LF Cetacean	152 dB	2800 km²	34 km	24 km	30 km
		MF Cetacean	170 dB	300 km²	11 km	9.0 km	9.9 km
	Possible Avoidance	LF Cetacean	142 dB	5500 km²	50 km	33 km	42 km
		MF Cetacean	160 dB	1300 km²	23 km	18 km	20 km
Av. D	Likely avoidance	LF Cetacean	152 dB	2400 km²	31 km	21 km	27 km
		MF Cetacean	170 dB	260 km²	9.6 km	8.2 km	9.1 km
	Possible Avoidance	LF Cetacean	142 dB	4800 km²	47 km	29 km	39 km
		MF Cetacean	160 dB	1100 km²	21 km	15 km	19 km

Table A-19 Summary of the single strike impact ranges for behavioural response from Southall et al. (2007) for installation of a monopile at EA2 using the 75% soft start hammer blow energy of 3000 kJ

EA2	Southall *et al.* (2007) – Behavioural (Unweighted SEL_{ss})			Pin Pile (1800kJ – main piling, 75%)			
				Area	Maximum	Minimum	Mean
WC	Likely avoidance	LF Cetacean	152 dB	2700 km²	34 km	24 km	29 km
		MF Cetacean	170 dB	280 km²	10 km	8.6 km	9.4 km
	Possible Avoidance	LF Cetacean	142 dB	5300 km²	49 km	32 km	41 km
		MF Cetacean	160 dB	1200 km²	22 km	18 km	20 km
Av. D	Likely avoidance	LF Cetacean	152 dB	2300 km²	31 km	21 km	27 km
		MF Cetacean	170 dB	230 km²	9.2 km	7.9 km	8.7 km
	Possible Avoidance	LF Cetacean	142 dB	4700 km²	46 km	29 km	38 km
		MF Cetacean	160 dB	1000 km²	20 km	14 km	18 km

Table A-20 Summary of the single strike impact ranges for behavioural response from Southall et al. (2007) for installation of a pin pile at EA2 using the 75% maximum hammer blow energy of 1800 kJ

EA1N		Southall *et al.* (2007) - PTS		**Monopile (3000kJ – main piling, 75%)**			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	**Unweighted SPL$_{peak}$**	Cetacean	230 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	0.01 km^2	60 m	60 m	60 m
	M-Weighted SEL$_{cum}$	LF Cetacean	198 dB	32 km^2	4.2 km	2.6 km	3.2 km
		MF Cetacean	198 dB	16 km^2	2.8 km	1.9 km	2.2 km
		HF Cetacean	198 dB	4.8 km^2	1.6 km	1.0 km	1.2 km
		PW Pinniped	186 dB	1000 km^2	22 km	15 km	18 km
	M-Weighted SEL$_{ss}$	LF Cetacean	198 dB	0.05 km^2	120 m	120 m	120 m
		MF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	1.1 km^2	590 m	590 m	590 m
Average depth	**Unweighted SPL$_{peak}$**	Cetacean	230 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	0.01 km^2	60 m	60 m	60 m
	M-Weighted SEL$_{cum}$	LF Cetacean	198 dB	31 km^2	3.4 km	2.9 km	3.1 km
		MF Cetacean	198 dB	15 km^2	2.3 km	2.1 km	2.2 km
		HF Cetacean	198 dB	4.4 km^2	1.3 km	1.1 km	1.2 km
		PW Pinniped	186 dB	1100 km^2	20 km	17 km	18 km
	M-Weighted SEL$_{ss}$	LF Cetacean	198 dB	0.05 km^2	120 m	120 m	120 m
		MF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	1.1 km^2	580 m	580 m	580 m

Table A-21 Summary of the single strike and cumulative impact ranges for PTS from Southall et al. (2007) for installation of a monopile at EA1N using the 75% maximum hammer blow energy of 3000 kJ

EA1N		Southall *et al.* (2007) - PTS		**Pin Pile (1800kJ – main piling, 75%)**			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	**Unweighted SPL$_{peak}$**	Cetacean	230 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	0.01 km^2	60 m	60 m	60 m
	M-Weighted SEL$_{cum}$	LF Cetacean	198 dB	51 km^2	5.4 km	3.1 km	4.0 km
		MF Cetacean	198 dB	61 km^2	5.5 km	3.8 km	4.4 km
		HF Cetacean	198 dB	24 km^2	3.5 km	2.3 km	2.7 km
		PW Pinniped	186 dB	1400 km^2	26 km	18 km	21 km
	M-Weighted SEL$_{ss}$	LF Cetacean	198 dB	0.04 km^2	110 m	110 m	110 m
		MF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	1.5 km^2	700 m	690 m	700 m
Average depth	**Unweighted SPL$_{peak}$**	Cetacean	230 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	0.01 km^2	60 m	60 m	60 m
	M-Weighted SEL$_{cum}$	LF Cetacean	198 dB	50 km^2	4.4 km	3.6 km	4.0 km
		MF Cetacean	198 dB	59 km^2	4.6 km	4.1 km	4.4 km
		HF Cetacean	198 dB	22 km^2	2.9 km	2.5 km	2.7 km
		PW Pinniped	186 dB	1500 km^2	24 km	21 km	22 km
	M-Weighted SEL$_{ss}$	LF Cetacean	198 dB	0.04 km^2	110 m	110 m	110 m
		MF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	1.5 km^2	690 m	690 m	690 m

Table A-22 Summary of the single strike and cumulative impact ranges for PTS from Southall et al. (2007) for installation of a pin pile at EA1N using the 75% maximum hammer blow energy of 1800 kJ

<table>
<tr><th rowspan="2">EA1N</th><th colspan="3" rowspan="2">Southall et al. (2007) - TTS</th><th colspan="4">Monopile (3000kJ – main piling, 75%)</th></tr>
<tr><th>Area</th><th>Maximum</th><th>Minimum</th><th>Mean</th></tr>
<tr><td rowspan="6">Worst case</td><td rowspan="2">Unweighted SPL_{peak}</td><td>Cetacean</td><td>224 dB</td><td>< 0.01 km²</td><td>< 50 m</td><td>< 50 m</td><td>< 50 m</td></tr>
<tr><td>Pinniped</td><td>212 dB</td><td>0.11 km²</td><td>190 m</td><td>190 m</td><td>190 m</td></tr>
<tr><td rowspan="4">M-Weighted SEL_{ss}</td><td>LF Cetacean</td><td>183 dB</td><td>12 km²</td><td>2.0 km</td><td>1.9 km</td><td>2.0 km</td></tr>
<tr><td>MF Cetacean</td><td>183 dB</td><td>0.98 km²</td><td>560 m</td><td>560 m</td><td>560 m</td></tr>
<tr><td>HF Cetacean</td><td>183 dB</td><td>0.55 km²</td><td>420 m</td><td>420 m</td><td>420 m</td></tr>
<tr><td>PW Pinniped</td><td>171 dB</td><td>120 km²</td><td>6.5 km</td><td>5.8 km</td><td>6.1 km</td></tr>
<tr><td rowspan="6">Av. depth</td><td rowspan="2">Unweighted SPL_{peak}</td><td>Cetacean</td><td>224 dB</td><td>< 0.01 km²</td><td>< 50 m</td><td>< 50 m</td><td>< 50 m</td></tr>
<tr><td>Pinniped</td><td>212 dB</td><td>0.11 km²</td><td>190 m</td><td>190 m</td><td>190 m</td></tr>
<tr><td rowspan="4">M-Weighted SEL_{ss}</td><td>LF Cetacean</td><td>183 dB</td><td>11 km²</td><td>2.0 km</td><td>1.8 km</td><td>1.9 km</td></tr>
<tr><td>MF Cetacean</td><td>183 dB</td><td>0.96 km²</td><td>560 m</td><td>550 m</td><td>550 m</td></tr>
<tr><td>HF Cetacean</td><td>183 dB</td><td>0.54 km²</td><td>420 m</td><td>420 m</td><td>420 m</td></tr>
<tr><td>PW Pinniped</td><td>171 dB</td><td>110 km²</td><td>6.2 km</td><td>5.9 km</td><td>6.0 km</td></tr>
</table>

Table A-23 Summary of the single strike impact ranges for TTS from Southall et al. (2007) for installation of a monopile at EA1N using the 75% maximum hammer blow energy of 3000 kJ

<table>
<tr><th rowspan="2">EA1N</th><th colspan="3" rowspan="2">Southall et al. (2007) - TTS</th><th colspan="4">Pin Pile (1800kJ – main piling, 75%)</th></tr>
<tr><th>Area</th><th>Maximum</th><th>Minimum</th><th>Mean</th></tr>
<tr><td rowspan="6">Worst case</td><td rowspan="2">Unweighted SPL_{peak}</td><td>Cetacean</td><td>224 dB</td><td>< 0.01 km²</td><td>< 50 m</td><td>< 50 m</td><td>< 50 m</td></tr>
<tr><td>Pinniped</td><td>212 dB</td><td>0.09 km²</td><td>180 m</td><td>170 m</td><td>170 m</td></tr>
<tr><td rowspan="4">M-Weighted SEL_{ss}</td><td>LF Cetacean</td><td>183 dB</td><td>9.9 km²</td><td>1.9 km</td><td>1.7 km</td><td>1.8 km</td></tr>
<tr><td>MF Cetacean</td><td>183 dB</td><td>1.4 km²</td><td>670 m</td><td>670 m</td><td>670 m</td></tr>
<tr><td>HF Cetacean</td><td>183 dB</td><td>0.67 km²</td><td>460 m</td><td>460 m</td><td>460 m</td></tr>
<tr><td>PW Pinniped</td><td>171 dB</td><td>140 km²</td><td>7.3 km</td><td>6.4 km</td><td>6.8 km</td></tr>
<tr><td rowspan="6">Av. depth</td><td rowspan="2">Unweighted SPL_{peak}</td><td>Cetacean</td><td>224 dB</td><td>< 0.01 km²</td><td>< 50 m</td><td>< 50 m</td><td>< 50 m</td></tr>
<tr><td>Pinniped</td><td>212 dB</td><td>0.09 km²</td><td>170 m</td><td>170 m</td><td>170 m</td></tr>
<tr><td rowspan="4">M-Weighted SEL_{ss}</td><td>LF Cetacean</td><td>183 dB</td><td>9.6 km²</td><td>1.8 km</td><td>1.7 km</td><td>1.8 km</td></tr>
<tr><td>MF Cetacean</td><td>183 dB</td><td>1.4 km²</td><td>660 m</td><td>660 m</td><td>660 m</td></tr>
<tr><td>HF Cetacean</td><td>183 dB</td><td>0.65 km²</td><td>460 m</td><td>460 m</td><td>460 m</td></tr>
<tr><td>PW Pinniped</td><td>171 dB</td><td>140 km²</td><td>6.9 km</td><td>6.5 km</td><td>6.7 km</td></tr>
</table>

Table A-24 Summary of the single strike impact ranges for TTS from Southall et al. (2007) for installation of a pin pile at EA1N using the 75% maximum hammer blow energy of 1800 kJ

<table>
<tr><th rowspan="2">EA1N</th><th colspan="3" rowspan="2">Southall et al. (2007) – Behavioural (Unweighted SEL_{ss})</th><th colspan="4">Monopile (3000kJ – main piling 75%)</th></tr>
<tr><th>Area</th><th>Maximum</th><th>Minimum</th><th>Mean</th></tr>
<tr><td rowspan="4">WC</td><td rowspan="2">Likely avoidance</td><td>LF Cetacean</td><td>152 dB</td><td>2800 km²</td><td>35 km</td><td>26 km</td><td>30 km</td></tr>
<tr><td>MF Cetacean</td><td>170 dB</td><td>300 km²</td><td>11 km</td><td>9.1 km</td><td>9.7 km</td></tr>
<tr><td rowspan="2">Possible Avoidance</td><td>LF Cetacean</td><td>142 dB</td><td>5600 km²</td><td>51 km</td><td>34 km</td><td>42 km</td></tr>
<tr><td>MF Cetacean</td><td>160 dB</td><td>1300 km²</td><td>23 km</td><td>18 km</td><td>20 km</td></tr>
<tr><td rowspan="4">Av. D</td><td rowspan="2">Likely avoidance</td><td>LF Cetacean</td><td>152 dB</td><td>2900 km²</td><td>33 km</td><td>29 km</td><td>31 km</td></tr>
<tr><td>MF Cetacean</td><td>170 dB</td><td>290 km²</td><td>10 km</td><td>9.4 km</td><td>9.7 km</td></tr>
<tr><td rowspan="2">Possible Avoidance</td><td>LF Cetacean</td><td>142 dB</td><td>5800 km²</td><td>49 km</td><td>39 km</td><td>43 km</td></tr>
<tr><td>MF Cetacean</td><td>160 dB</td><td>1300 km²</td><td>22 km</td><td>20 km</td><td>21 km</td></tr>
</table>

Table A-25 Summary of the single strike impact ranges for behavioural response from Southall et al. (2007) for installation of a monopile at EA1N using the 75% soft start hammer blow energy of 3000 kJ

EA1N	Southall *et al.* (2007) – Behavioural (Unweighted SEL_{ss})			Pin Pile (1800kJ – main piling, 75%)			
				Area	**Maximum**	**Minimum**	**Mean**
WC	**Likely avoidance**	LF Cetacean	152 dB	2700 km²	34 km	25 km	29 km
		MF Cetacean	170 dB	270 km²	10 km	8.7 km	9.3 km
	Possible Avoidance	LF Cetacean	142 dB	5400 km²	50 km	34 km	41 km
		MF Cetacean	160 dB	1200 km²	22 km	18 km	20 km
Av. D	**Likely avoidance**	LF Cetacean	152 dB	2800 km²	33 km	29 km	30 km
		MF Cetacean	170 dB	270 km²	9.5 km	9.0 km	9.2 km
	Possible Avoidance	LF Cetacean	142 dB	5600 km²	48 km	38 km	42 km
		MF Cetacean	160 dB	1200 km²	21 km	19 km	20 km

Table A-26 Summary of the single strike impact ranges for behavioural response from Southall et al. (2007) for installation of a pin pile at EA1N using the 75% maximum hammer blow energy of 1800 kJ

A.2.3 *Lucke et al. (2009) results*

EA2	Lucke *et al.* (2009) (Unweighted SEL_{ss})		Monopile (3000kJ – main piling, 75%)			
			Area	**Maximum**	**Minimum**	**Mean**
WC	Auditory injury	179 dB	38 km²	3.7 km	3.3 km	3.5 km
	TTS	164 dB	790 km²	18 km	15 km	16 km
	Behavioural	145 dB	4600 km²	45 km	30 km	38 km
AV	Auditory injury	179 dB	35 km²	3.5 km	3.2 km	3.4 km
	TTS	164 dB	660 km²	16 km	12 km	14 km
	Behavioural	145 dB	4000 km²	42 km	27 km	36 km

Table A-27 Summary of the single strike impact ranges for criteria from Lucke et al. (2009) for installation of a monopile at EA2 using the 75% maximum hammer blow energy of 3000 kJ

EA2	Lucke *et al.* (2009) (Unweighted SEL_{ss})		Pin Pile (1800kJ – main piling, 75%)			
			Area	**Maximum**	**Minimum**	**Mean**
WC	Auditory injury	179 dB	33 km²	3.4 km	3.1 km	3.3 km
	TTS	164 dB	740 km²	17 km	14 km	15 km
	Behavioural	145 dB	4400 km²	44 km	30 km	37 km
AV	Auditory injury	179 dB	31 km²	3.3 km	3.0 km	3.1 km
	TTS	164 dB	610 km²	16 km	12 km	14 km
	Behavioural	145 dB	3900 km²	41 km	26 km	35 km

Table A-28 Summary of the single strike impact ranges for criteria from Lucke et al. (2009) for installation of a pin pile at EA2 using the 75% maximum hammer blow energy of 1800 kJ

EA1N	Lucke *et al.* (2009) (Unweighted SEL_{ss})		Monopile (3000kJ – main piling, 75%)			
			Area	**Maximum**	**Minimum**	**Mean**
WC	Auditory injury	179 dB	38 km²	3.6 km	3.4 km	3.5 km
	TTS	164 dB	780 km²	18 km	15 km	16 km
	Behavioural	145 dB	4700 km²	46 km	32 km	38 km
AV	Auditory injury	179 dB	36 km²	3.5 km	3.3 km	3.4 km
	TTS	164 dB	780 km²	17 km	15 km	16 km
	Behavioural	145 dB	4800 km²	44 km	36 km	39 km

Table A-29 Summary of the single strike impact ranges for criteria from Lucke et al. (2009) for installation of a monopile at EA1N using the 75% maximum hammer blow energy of 3000 kJ

<table>
<tr><th colspan="2" rowspan="2">EA1N</th><th colspan="2" rowspan="2">Lucke et al. (2009)
(Unweighted SELss)</th><th colspan="4">Pin Pile (1800kJ – main piling, 75%)</th></tr>
<tr><th>Area</th><th>Maximum</th><th>Minimum</th><th>Mean</th></tr>
<tr><td rowspan="3">WC</td><td colspan="2">Auditory injury</td><td>179 dB</td><td>33 km²</td><td>3.4 km</td><td>3.1 km</td><td>3.3 km</td></tr>
<tr><td colspan="2">TTS</td><td>164 dB</td><td>730 km²</td><td>17 km</td><td>14 km</td><td>15 km</td></tr>
<tr><td colspan="2">Behavioural</td><td>145 dB</td><td>4500 km²</td><td>45 km</td><td>31 km</td><td>38 km</td></tr>
<tr><td rowspan="3">AV</td><td colspan="2">Auditory injury</td><td>179 dB</td><td>32 km²</td><td>3.3 km</td><td>3.1 km</td><td>3.2 km</td></tr>
<tr><td colspan="2">TTS</td><td>164 dB</td><td>730 km²</td><td>16 km</td><td>15 km</td><td>15 km</td></tr>
<tr><td colspan="2">Behavioural</td><td>145 dB</td><td>4700 km²</td><td>43 km</td><td>36 km</td><td>39 km</td></tr>
</table>

Table A-30 Summary of the single strike impact ranges for criteria from Lucke et al. (2009) for installation of a pin pile at EA1N using the 75% maximum hammer blow energy of 1800 kJ

A.2.4 Popper et al. (2014) results

<table>
<tr><th colspan="2" rowspan="2">EA2</th><th colspan="2" rowspan="2">Popper et al. (2014) – Fish (no swim bladder)</th><th colspan="4">Monopile (3000kJ – main piling, 75%)</th></tr>
<tr><th>Area</th><th>Maximum</th><th>Minimum</th><th>Mean</th></tr>
<tr><td rowspan="5">Worst case</td><td rowspan="2">SPL_{peak}</td><td>Mortal and potential mortal injury</td><td>> 213 dB</td><td>0.08 km²</td><td>160 m</td><td>160 m</td><td>160 m</td></tr>
<tr><td>Recoverable injury</td><td>> 213 dB</td><td>0.08 km²</td><td>160 m</td><td>160 m</td><td>160 m</td></tr>
<tr><td rowspan="3">SEL_{cum}</td><td>Mortal and potential mortal injury</td><td>> 219 dB</td><td>< 0.01 km²</td><td>< 100 m</td><td>< 100 m</td><td>< 100 m</td></tr>
<tr><td>Recoverable injury</td><td>> 216 dB</td><td>< 0.01 km²</td><td>< 100 m</td><td>< 100 m</td><td>< 100 m</td></tr>
<tr><td>TTS</td><td>>> 186 dB</td><td>1500 km²</td><td>26 km</td><td>17 km</td><td>22 km</td></tr>
<tr><td rowspan="5">Av. depth</td><td rowspan="2">SPL_{peak}</td><td>Mortal and potential mortal injury</td><td>> 213 dB</td><td>0.08 km²</td><td>160 m</td><td>160 m</td><td>160 m</td></tr>
<tr><td>Recoverable injury</td><td>> 213 dB</td><td>0.08 km²</td><td>160 m</td><td>160 m</td><td>160 m</td></tr>
<tr><td rowspan="3">SEL_{cum}</td><td>Mortal and potential mortal injury</td><td>> 219 dB</td><td>< 0.01 km²</td><td>< 100 m</td><td>< 100 m</td><td>< 100 m</td></tr>
<tr><td>Recoverable injury</td><td>> 216 dB</td><td>< 0.01 km²</td><td>< 100 m</td><td>< 100 m</td><td>< 100 m</td></tr>
<tr><td>TTS</td><td>>> 186 dB</td><td>1300 km²</td><td>24 km</td><td>14 km</td><td>20 km</td></tr>
</table>

Table A-31 Summary of the unweighted single strike and cumulative impact ranges for fish (no swim bladder) using the impact piling criteria from Popper et al. (2014) for installation of a monopile at EA2 using the 75% maximum hammer blow energy of 3000 kJ

<table>
<tr><th colspan="2" rowspan="2">EA2</th><th colspan="2" rowspan="2">Popper et al. (2014) – Fish (no swim bladder)</th><th colspan="4">Pin Pile (1800kJ – main piling, 75%)</th></tr>
<tr><th>Area</th><th>Maximum</th><th>Minimum</th><th>Mean</th></tr>
<tr><td rowspan="5">Worst case</td><td rowspan="2">SPL_{peak}</td><td>Mortal and potential mortal injury</td><td>> 213 dB</td><td>0.07 km²</td><td>150 m</td><td>140 m</td><td>150 m</td></tr>
<tr><td>Recoverable injury</td><td>> 213 dB</td><td>0.07 km²</td><td>150 m</td><td>140 m</td><td>150 m</td></tr>
<tr><td rowspan="3">SEL_{cum}</td><td>Mortal and potential mortal injury</td><td>> 219 dB</td><td>< 0.01 km²</td><td>< 100 m</td><td>< 100 m</td><td>< 100 m</td></tr>
<tr><td>Recoverable injury</td><td>> 216 dB</td><td>< 0.01 km²</td><td>< 100 m</td><td>< 100 m</td><td>< 100 m</td></tr>
<tr><td>TTS</td><td>>> 186 dB</td><td>1800 km²</td><td>28 km</td><td>18 km</td><td>24 km</td></tr>
<tr><td rowspan="5">Av. depth</td><td rowspan="2">SPL_{peak}</td><td>Mortal and potential mortal injury</td><td>> 213 dB</td><td>0.06 km²</td><td>140 m</td><td>140 m</td><td>140 m</td></tr>
<tr><td>Recoverable injury</td><td>> 213 dB</td><td>0.06 km²</td><td>140 m</td><td>140 m</td><td>140 m</td></tr>
<tr><td rowspan="3">SEL_{cum}</td><td>Mortal and potential mortal injury</td><td>> 219 dB</td><td>< 0.01 km²</td><td>< 100 m</td><td>< 100 m</td><td>< 100 m</td></tr>
<tr><td>Recoverable injury</td><td>> 216 dB</td><td>< 0.01 km²</td><td>< 100 m</td><td>< 100 m</td><td>< 100 m</td></tr>
<tr><td>TTS</td><td>>> 186 dB</td><td>1500 km²</td><td>25 km</td><td>15 km</td><td>21 km</td></tr>
</table>

Table A-32 Summary of the unweighted single strike and cumulative impact ranges for fish (no swim bladder) using the impact piling criteria from Popper et al. (2014) for installation of a pin pile at EA2 using the 75% maximum hammer blow energy of 1800 kJ

EA2		Popper *et al.* (2014) – Fish (swim bladder not involved in hearing)		Monopile (3000kJ – main piling, 75%)			
				Area	Maximum	Minimum	Mean
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.73 km²	490 m	480 m	480 m
		Recoverable injury	> 207 dB	0.73 km²	490 m	480 m	480 m
	SEL_{cum}	Mortal and potential mortal injury	210 dB	0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	203 dB	44 km²	4.3 km	3.0 km	3.7 km
		TTS	> 186 dB	1500 km²	26 km	17 km	22 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.72 km²	480 m	480 m	480 m
		Recoverable injury	> 207 dB	0.72 km²	480 m	480 m	480 m
	SEL_{cum}	Mortal and potential mortal injury	210 dB	0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	203 dB	30 km²	3.6 km	2.4 km	3.1 km
		TTS	> 186 dB	1300 km²	24 km	14 km	20 km

Table A-33 Summary of the unweighted single strike and cumulative impact ranges for fish (swim bladder not involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a monopile at EA2 using the 75% maximum hammer blow energy of 3000 kJ

EA2		Popper *et al.* (2014) – Fish (swim bladder not involved in hearing)		Pin Pile (1800kJ – main piling, 75%)			
				Area	Maximum	Minimum	Mean
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.61 km²	440 m	440 m	440 m
		Recoverable injury	> 207 dB	0.61 km²	440 m	440 m	440 m
	SEL_{cum}	Mortal and potential mortal injury	210 dB	0.03 km²	140 m	< 100 m	< 100 m
		Recoverable injury	203 dB	75 km²	5.6 km	4.0 km	4.9 km
		TTS	> 186 dB	1800 km²	28 km	18 km	24 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.6 km²	440 m	440 m	440 m
		Recoverable injury	> 207 dB	0.6 km²	440 m	440 m	440 m
	SEL_{cum}	Mortal and potential mortal injury	210 dB	0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	203 dB	52 km²	4.7 km	3.0 km	4.0 km
		TTS	> 186 dB	1500 km²	25km	15 km	21 km

Table A-34 Summary of the unweighted single strike and cumulative impact ranges for fish (swim bladder not involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a pin pile at EA2 using the 75% maximum hammer blow energy of 1800 kJ

EA2		Popper *et al.* (2014) – Fish (swim bladder involved in hearing)		Monopile (3000kJ – main piling, 75%)			
				Area	Maximum	Minimum	Mean
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.73 km²	490 m	480 m	480 m
		Recoverable injury	> 207 dB	0.73 km²	490 m	480 m	480 m
	SEL_{cum}	Mortal and potential mortal injury	207 dB	2.4 km²	1.1 km	620 m	860 m
		Recoverable injury	203 dB	44 km²	4.3 km	3.0 km	3.7 km
		TTS	186 dB	1500 km²	26 km	17 km	22 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.72 km²	480 m	480 m	480 m
		Recoverable injury	> 207 dB	0.72 km²	480 m	480 m	480 m
	SEL_{cum}	Mortal and potential mortal injury	207 dB	1.3 km²	790 m	460 m	630 m
		Recoverable injury	203 dB	30 km²	3.6 km	2.4 km	3.1 km
		TTS	186 dB	1300 km²	24 km	14 km	20 km

Table A-35 Summary of the unweighted single strike and cumulative impact ranges for fish (swim bladder involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a monopile at EA2 using the 75% maximum hammer blow energy of 3000 kJ

EA2	Popper *et al.* (2014) – Fish (swim bladder involved in hearing)			Pin Pile (1800kJ – main piling, 75%)			
				Area	Maximum	Minimum	Mean
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.61 km²	440 m	440 m	440 m
		Recoverable injury	> 207 dB	0.61 km²	440 m	440 m	440 m
	SEL_{cum}	Mortal and potential mortal injury	207 dB	8.4 km²	2.0 km	1.2 km	1.6 km
		Recoverable injury	203 dB	75 km²	5.6 km	4.0 km	4.9 km
		TTS	186 dB	1800 km²	28 km	18 km	24 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.6 km²	440 m	440 m	440 m
		Recoverable injury	> 207 dB	0.6 km²	440 m	440 m	440 m
	SEL_{cum}	Mortal and potential mortal injury	207 dB	4.8 km²	1.5 km	900 m	1.2 km
		Recoverable injury	203 dB	52 km²	4.7 km	3.0 km	4.0 km
		TTS	186 dB	1500 km²	25 km	15 km	21 km

Table A-36 Summary of the unweighted single strike and cumulative impact ranges for fish (swim bladder involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a pin pile at EA2 using the 75% maximum hammer blow energy of 1800 kJ

EA1N	Popper *et al.* (2014) – Fish (no swim bladder)			Monopile (3000kJ – main piling, 75%)			
				Area	Maximum	Minimum	Mean
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 213 dB	0.08 km²	160 m	160 m	160 m
		Recoverable injury	> 213 dB	0.08 km²	160 m	160 m	160 m
	SEL_{cum}	Mortal and potential mortal injury	> 219 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	> 216 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		TTS	>> 186 dB	1600 km²	27 km	18 km	22 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 213 dB	0.08 km²	160 m	160 m	160 m
		Recoverable injury	> 213 dB	0.08 km²	160 m	160 m	160 m
	SEL_{cum}	Mortal and potential mortal injury	> 219 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	> 216 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		TTS	>> 186 dB	1600 km²	26 km	22 km	23 km

Table A-37 Summary of the unweighted single strike and cumulative impact ranges for fish (no swim bladder) using the impact piling criteria from Popper et al. (2014) for installation of a monopile at EA1N using the 75% maximum hammer blow energy of 3000 kJ

EA1N	Popper *et al.* (2014) – Fish (no swim bladder)			Pin Pile (1800kJ – main piling, 75%)			
				Area	Maximum	Minimum	Mean
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 213 dB	0.07 km²	150 m	140 m	150 m
		Recoverable injury	> 213 dB	0.07 km²	150 m	140 m	150 m
	SEL_{cum}	Mortal and potential mortal injury	> 219 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	> 216 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		TTS	>> 186 dB	1800 km²	29 km	20 km	24 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 213 dB	0.06 km²	140 m	140 m	140 m
		Recoverable injury	> 213 dB	0.06 km²	140 m	140 m	140 m
	SEL_{cum}	Mortal and potential mortal injury	> 219 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	> 216 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		TTS	>> 186 dB	1900 km²	28 km	23 km	25 km

Table A-38 Summary of the unweighted single strike and cumulative impact ranges for fish (no swim bladder) using the impact piling criteria from Popper et al. (2014) for installation of a pin pile at EA1N using the 75% maximum hammer blow energy of 1800 kJ

EA1N		Popper *et al.* (2014) – Fish (swim bladder not involved in hearing)		Monopile (3000kJ – main piling, 75%)			
				Area	Maximum	Minimum	Mean
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.73 km^2	480 m	480 m	480 m
		Recoverable injury	> 207 dB	0.73 km^2	480 m	480 m	480 m
	SEL_{cum}	Mortal and potential mortal injury	210 dB	0.01 km^2	< 100 m	< 100 m	< 100 m
		Recoverable injury	203 dB	42 km^2	4.5 km	3.1 km	3.6 km
		TTS	> 186 dB	1600 km^2	27 km	18 km	22 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.71 km^2	480 m	480 m	480 m
		Recoverable injury	> 207 dB	0.71 km^2	480 m	480 m	480 m
	SEL_{cum}	Mortal and potential mortal injury	210 dB	0.01 km^2	< 100 m	< 100 m	< 100 m
		Recoverable injury	203 dB	40 km^2	3.8 km	3.4 km	3.6 km
		TTS	> 186 dB	1600 km^2	26 km	22 km	23 km

Table A-39 Summary of the unweighted single strike and cumulative impact ranges for fish (swim bladder not involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a monopile at EA1N using the 75% maximum hammer blow energy of 3000 kJ

EA1N		Popper *et al.* (2014) – Fish (swim bladder not involved in hearing)		Pin Pile (1800kJ – main piling, 75%)			
				Area	Maximum	Minimum	Mean
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.61 km^2	440 m	440 m	440 m
		Recoverable injury	> 207 dB	0.61 km^2	440 m	440 m	440 m
	SEL_{cum}	Mortal and potential mortal injury	210 dB	0.02 km^2	< 100 m	< 100 m	< 100 m
		Recoverable injury	203 dB	71 km^2	5.9 km	4.1 km	4.8 km
		TTS	> 186 dB	1800 km^2	29 km	20 km	24 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.6 km^2	440 m	440 m	440 m
		Recoverable injury	> 207 dB	0.6 km^2	440 m	440 m	440 m
	SEL_{cum}	Mortal and potential mortal injury	210 dB	0.01 km^2	< 100 m	< 100 m	< 100 m
		Recoverable injury	203 dB	69 km^2	5.0 km	4.4 km	4.7 km
		TTS	> 186 dB	1900 km^2	28 km	23 km	25 km

Table A-40 Summary of the unweighted single strike and cumulative impact ranges for fish (swim bladder not involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a pin pile at EA1N using the 75% maximum hammer blow energy of 1800 kJ

EA1N		Popper *et al.* (2014) – Fish (swim bladder involved in hearing)		Monopile (3000kJ – main piling, 75%)			
				Area	Maximum	Minimum	Mean
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.73 km^2	480 m	480 m	480 m
		Recoverable injury	> 207 dB	0.73 km^2	480 m	480 m	480 m
	SEL_{cum}	Mortal and potential mortal injury	207 dB	2.2 km^2	1.1 km	680 m	830 m
		Recoverable injury	203 dB	42 km^2	4.5 km	3.1 km	3.6 km
		TTS	186 dB	1600 km^2	27 km	18 km	22 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.71 km^2	480 m	480 m	480 m
		Recoverable injury	> 207 dB	0.71 km^2	480 m	480 m	480 m
	SEL_{cum}	Mortal and potential mortal injury	207 dB	1.9 km^2	840 m	700 m	770 m
		Recoverable injury	203 dB	40 km^2	3.8 km	3.4 km	3.6 km
		TTS	186 dB	1600 km^2	26 km	22 km	23 km

Table A-41 Summary of the unweighted single strike and cumulative impact ranges for fish (swim bladder involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a monopile at EA1N using the 75% maximum hammer blow energy of 3000 kJ

EA1N		Popper *et al.* (2014) – Fish (swim bladder involved in hearing)		Pin Pile (1800kJ – main piling, 75%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.61 km²	440 m	440 m	440 m
		Recoverable injury	> 207 dB	0.61 km²	440 m	440 m	440 m
	SEL_{cum}	Mortal and potential mortal injury	207 dB	7.8 km²	2.1 km	1.3 km	1.6 km
		Recoverable injury	203 dB	71 km²	5.9 km	4.1 km	4.8 km
		TTS	186 dB	1800 km²	29 km	20 km	24 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.6 km²	440 m	440 m	440 m
		Recoverable injury	> 207 dB	0.6 km²	440 m	440 m	440 m
	SEL_{cum}	Mortal and potential mortal injury	207 dB	6.9 km²	1.7 km	1.4 km	1.5 km
		Recoverable injury	203 dB	69 km²	5.0 km	4.4 km	4.7 km
		TTS	186 dB	1900 km²	28 km	23 km	25 km

Table A-42 Summary of the unweighted single strike and cumulative impact ranges for fish (swim bladder involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a pin pile at EA1N using the 75% maximum hammer blow energy of 1800 kJ

A.3 50% maximum blow energy modelling results

The following sections present the impact ranges using the various noise metrics and criteria for reaching 50% of the maximum hammer blow energy. This modelling uses the parameters detailed in Table A-3, Table A-4, and Table A-6.

A.3.1 NMFS (2018) results

EA2		NMFS (2018) - PTS		Monopile (2000kJ – main piling, 50%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case location	**Unweighted** SPL_{peak}	LF Cetacean	219 dB	0.01 km²	50 m	50 m	50 m
		MF Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	3.9 km²	1.1 km	1.1 km	1.1 km
		PW Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	Weighted SEL_{cum}	LF Cetacean	183 dB	520 km²	16 km	10 km	13 km
		MF Cetacean	185 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		HF Cetacean	155 dB	79 km²	5.8 km	4.1 km	5.0 km
		PW Pinniped	185 dB	45 km²	4.4 km	3.1 km	3.8 km
	Weighted SEL_{ss}	LF Cetacean	183 dB	1.5 km²	700 m	690 m	690 m
		MF Cetacean	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	155 dB	0.01 km²	60 m	60 m	60 m
		PW Pinniped	185 dB	0.01 km²	50 m	50 m	50 m
Average depth location	**Unweighted** SPL_{peak}	LF Cetacean	219 dB	0.01 km²	50 m	50 m	50 m
		MF Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	3.7 km²	1.1 km	1.1 km	1.1 km
		PW Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	Weighted SEL_{cum}	LF Cetacean	183 dB	410 km²	14 km	7.6 km	1.1 km
		MF Cetacean	185 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		HF Cetacean	155 dB	56 km²	4.9 km	3.2 km	4.2 km
		PW Pinniped	185 dB	31 km²	3.7 km	2.4 km	3.1 km
	Weighted SEL_{ss}	LF Cetacean	183 dB	1.5 km²	690 m	680 m	680 m
		MF Cetacean	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	155 dB	0.01 km²	60 m	60 m	60 m
		PW Pinniped	185 dB	0.01 km²	50 m	50 m	50 m

Table A-43 Summary of the single strike and cumulative impact ranges for PTS from NMFS (2018) for installation of a monopile at EA2 using the 50% maximum hammer blow energy of 2000 kJ

EA2	NMFS (2018) - PTS			**Pin Pile (1200kJ – main piling, 50%)**			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case location	**Unweighted SPL$_{peak}$**	LF Cetacean	219 dB	0.01 km²	< 50 m	< 50 m	< 50 m
		MF Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	3.0 km²	990 m	970 m	980 m
		PW Pinniped	218 dB	0.01 km²	50 m	50 m	50 m
	Weighted SEL$_{cum}$	LF Cetacean	183 dB	860 km²	20 km	13 km	16 km
		MF Cetacean	185 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		HF Cetacean	155 dB	860 km²	20 km	13 km	17 km
		PW Pinniped	185 dB	81 km²	5.8 km	4.2 km	5.1 km
	Weighted SEL$_{ss}$	LF Cetacean	183 dB	1.8 m²	780 m	760 m	770 m
		MF Cetacean	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	155 dB	0.36 km²	340 m	340 m	340 m
		PW Pinniped	185 dB	0.01 km²	50 m	50 m	50 m
Average depth location	**Unweighted SPL$_{peak}$**	LF Cetacean	219 dB	0.01 km²	< 50 m	< 50 m	< 50 m
		MF Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	2.9 km²	970 m	960 m	960 m
		PW Pinniped	218 dB	0.01 km²	50 m	50 m	50 m
	Weighted SEL$_{cum}$	LF Cetacean	183 dB	600 km²	17 km	8.7 km	14 km
		MF Cetacean	185 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		HF Cetacean	155 dB	690 km²	18 km	10 km	15 km
		PW Pinniped	185 dB	56 km²	4.9 km	3.2 km	4.2 km
	Weighted SEL$_{ss}$	LF Cetacean	183 dB	1.8 km²	760 m	750 m	760 m
		MF Cetacean	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	155 dB	0.36 km²	340 m	340 m	340 m
		PW Pinniped	185 dB	0.01 km²	50 m	50 m	50 m

Table A-44 Summary of the single strike and cumulative impact ranges for PTS from NMFS (2018) for installation of a pin pile at EA2 using the 50% maximum hammer blow energy of 1200 kJ

EA2	NMFS (2018) - TTS			Monopile (2000kJ – main piling, 50%)			
				Area	Maximum	Minimum	Mean
Worst case location	**Unweighted SPL_{peak}**	LF Cetacean	213 dB	0.07 km²	150 m	150 m	150 m
		MF Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	27 km²	3.0 km	2.8 km	2.9 km
		PW Pinniped	212 dB	0.1 km²	180 m	180 m	180 m
	Weighted SEL_{cum}	LF Cetacean	168 dB	3000 km²	38 km	23 km	30 km
		MF Cetacean	170 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		HF Cetacean	140 dB	1400 km²	26 km	17 km	21 km
		PW Pinniped	170 dB	1200 km²	24 km	16 km	20 km
	Weighted SEL_{ss}	LF Cetacean	168 dB	140 km²	7.2 km	6.3 km	6.8 km
		MF Cetacean	170 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	3.2 km²	1.0 km	1.0 km	1.0 km
		PW Pinniped	170 dB	2.0 km²	800 m	780 m	790 m
Average depth location	**Unweighted SPL_{peak}**	LF Cetacean	213 dB	0.07 km²	150 m	150 m	150 m
		MF Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	25 km²	2.9 km	2.8 km	2.8 km
		PW Pinniped	212 dB	0.1 km²	180 m	180 m	180 m
	Weighted SEL_{cum}	LF Cetacean	168 dB	2500 km²	35 km	19 km	28 km
		MF Cetacean	170 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		HF Cetacean	140 dB	1200 km²	23 km	14 km	19 km
		PW Pinniped	170 dB	1000 km²	21 km	12 km	18 km
	Weighted SEL_{ss}	LF Cetacean	168 dB	130 km²	6.7 km	6.0 km	6.3 km
		MF Cetacean	170 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	3.1 km²	1.0 km	990 m	1.0 km
		PW Pinniped	170 dB	1.9 km²	780 m	780 m	780 m

Table A-45 Summary of the single strike and cumulative impact ranges for TTS from NMFS (2018) for installation of a monopile at EA2 using the 50% maximum hammer blow energy of 2000 kJ

EA2	NMFS (2018) - TTS			Pin Pile (1200kJ – main piling, 50%) Area	Maximum	Minimum	Mean
Worst case location	Unweighted SPL_{peak}	LF Cetacean	213 dB	0.05 km^2	130 m	130 m	130 m
		MF Cetacean	224 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	22 km^2	2.7 km	2.5 km	2.6 km
		PW Pinniped	212 dB	0.08 km^2	160 m	160 m	160 m
	Weighted SEL_{cum}	LF Cetacean	168 dB	3700 km^2	44 km	25 km	34 km
		MF Cetacean	170 dB	50 km^2	4.6 km	3.2 km	4.0 km
		HF Cetacean	140 dB	3700 km^2	42 km	26 km	34 km
		PW Pinniped	170 dB	1500 km^2	26 km	17 km	21 km
	Weighted SEL_{ss}	LF Cetacean	168 dB	200 km^2	8.4 km	7.3 km	7.9 km
		MF Cetacean	170 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	56 km^2	4.5 km	4.0 km	4.2 km
		PW Pinniped	170 dB	1.7 km^2	750 m	740 m	740 m
Average depth location	Unweighted SPL_{peak}	LF Cetacean	213 dB	0.05 km^2	130 m	130 m	130 m
		MF Cetacean	224 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	20 km^2	2.6 km	2.5 km	2.5 km
		PW Pinniped	212 dB	0.08 km^2	160 m	160 m	160 m
	Weighted SEL_{cum}	LF Cetacean	168 dB	3000 km^2	39 km	20 km	31 km
		MF Cetacean	170 dB	34 km^2	3.8 km	2.5 km	3.3 km
		HF Cetacean	140 dB	3200 km^2	39 km	22 km	32 km
		PW Pinniped	170 dB	1200 km^2	23 km	14 km	19 km
	Weighted SEL_{ss}	LF Cetacean	168 dB	140 km^2	7.1 km	6.4 km	6.7 km
		MF Cetacean	170 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	51 km^2	4.2 km	3.9 km	4.0 km
		PW Pinniped	170 dB	1.7 km^2	740 m	730 m	730 m

Table A-46 Summary of the single strike and cumulative impact ranges for TTS from NMFS (2018) for installation of a pin pile at EA2 using the 50% maximum hammer blow energy of 1200 kJ

EA1N	NMFS (2018) - PTS			Monopile (2000kJ – main piling, 50%)			
				Area	Maximum	Minimum	Mean
Worst case location	Unweighted SPL_{peak}	LF Cetacean	219 dB	0.01 km²	50 m	50 m	50 m
		MF Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	3.8 km²	1.1 km	1.1 km	1.1 km
		PW Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	Weighted SEL_{cum}	LF Cetacean	183 dB	520 km²	16 km	11 km	13 km
		MF Cetacean	185 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		HF Cetacean	155 dB	76 km²	6.0 km	4.2 km	4.9 km
		PW Pinniped	185 dB	1500 km²	26 km	18 km	22 km
	Weighted SEL_{ss}	LF Cetacean	183 dB	1.5 km²	690 m	690 m	690 m
		MF Cetacean	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	155 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PW Pinniped	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
Average depth location	Unweighted SPL_{peak}	LF Cetacean	219 dB	0.01 km²	50 m	50 m	50 m
		MF Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	3.7 km²	1.1 km	1.1 km	1.1 km
		PW Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	Weighted SEL_{cum}	LF Cetacean	183 dB	540 km²	15 km	12 km	13 km
		MF Cetacean	185 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		HF Cetacean	155 dB	74 km²	5.1 km	4.6 km	4.9 km
		PW Pinniped	185 dB	41 km²	3.8 km	3.4 km	3.6 km
	Weighted SEL_{ss}	LF Cetacean	183 dB	1.5 km²	680 m	680 m	680 m
		MF Cetacean	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	155 dB	0.01 km²	60 m	60 m	60 m
		PW Pinniped	185 dB	0.01 km²	50 m	50 m	50 m

Table A-47 Summary of the single strike and cumulative impact ranges for PTS from NMFS (2018) for installation of a monopile at EA1N using the 50% maximum hammer blow energy of 2000 kJ

EA1N	NMFS (2018) - PTS			Pin Pile (1200kJ – main piling, 50%)			
				Area	Maximum	Minimum	Mean
Worst case location	Unweighted SPL_{peak}	LF Cetacean	219 dB	0.01 km²	< 50 m	< 50 m	< 50 m
		MF Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	3.0 km²	980 m	970 m	980 m
		PW Pinniped	218 dB	0.01 km²	50 m	50 m	50 m
	Weighted SEL_{cum}	LF Cetacean	183 dB	760 km²	19 km	13 km	15 km
		MF Cetacean	185 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		HF Cetacean	155 dB	860 km²	20 km	14 km	17 km
		PW Pinniped	185 dB	77 km²	6.1 km	4.2 km	4.9 km
	Weighted SEL_{ss}	LF Cetacean	183 dB	1.8 km²	770 m	760 m	770 m
		MF Cetacean	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	155 dB	0.36 km²	340 m	340 m	340 m
		PW Pinniped	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
Average depth location	Unweighted SPL_{peak}	LF Cetacean	219 dB	0.01 km²	< 50 m	< 50 m	< 50 m
		MF Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	202 dB	2.9 km²	960 m	960 m	960 m
		PW Pinniped	218 dB	0.01 km²	50 m	50 m	50 m
	Weighted SEL_{cum}	LF Cetacean	183 dB	800 km²	18 km	15 km	16 km
		MF Cetacean	185 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		HF Cetacean	155 dB	900 km²	19 km	16 km	17 km
		PW Pinniped	185 dB	75 km²	5.2 km	4.6 km	4.9 km
	Weighted SEL_{ss}	LF Cetacean	183 dB	1.8 km²	760 m	750 m	760 m
		MF Cetacean	185 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	155 dB	0.35 km²	340 m	340 m	340 m
		PW Pinniped	185 dB	0.01 km²	50 m	50 m	50 m

Table A-48 Summary of the single strike and cumulative impact ranges for PTS from NMFS (2018) for installation of a pin pile at EA2 using the 50% maximum hammer blow energy of 1200 kJ

EA1N	NMFS (2018) - TTS			Monopile (2000kJ – main piling, 50%)			
				Area	Maximum	Minimum	Mean
Worst case location	Unweighted SPL_{peak}	LF Cetacean	213 dB	0.07 km^2	150 m	150 m	150 m
		MF Cetacean	224 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	27 km^2	3.0 km	2.9 km	2.9 km
		PW Pinniped	212 dB	0.1 km^2	180 m	180 m	180 m
	Weighted SEL_{cum}	LF Cetacean	168 dB	3000 km^2	39 km	24 km	31 km
		MF Cetacean	170 dB	< 0.01 km^2	< 100 m	< 100 m	< 100 m
		HF Cetacean	140 dB	1500 km^2	26 km	18 km	22 km
		PW Pinniped	170 dB	1200 km^2	24 km	16 km	20 km
	Weighted SEL_{ss}	LF Cetacean	168 dB	140 km^2	7.2 km	6.4 km	6.7 km
		MF Cetacean	170 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	3.2 km^2	1.0 km	1.0 km	1.0 km
		PW Pinniped	170 dB	2.0 km^2	790 m	790 m	790 m
Average depth location	Unweighted SPL_{peak}	LF Cetacean	213 dB	0.07 km^2	150 m	150 m	150 m
		MF Cetacean	224 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	25 km^2	2.9 km	2.8 km	2.9 km
		PW Pinniped	212 dB	0.1 km^2	180 m	180 m	180 m
	Weighted SEL_{cum}	LF Cetacean	168 dB	3200 km^2	37 km	28 km	32 km
		MF Cetacean	170 dB	< 0.01 km^2	< 100 m	< 100 m	< 100 m
		HF Cetacean	140 dB	1500 km^2	25 km	21 km	22 km
		PW Pinniped	170 dB	1300 km^2	23 km	19 km	20 km
	Weighted SEL_{ss}	LF Cetacean	168 dB	140 km^2	6.9 km	6.5 km	6.6 km
		MF Cetacean	170 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	3.1 km^2	1.0 km	990 m	1.0 km
		PW Pinniped	170 dB	1.9 km^2	780 m	780 m	780 m

Table A-49 Summary of the single strike and cumulative impact ranges for TTS from NMFS (2018) for installation of a monopile at EA1N using the 50% maximum hammer blow energy of 2000 kJ

EA1N	NMFS (2018) - TTS			Pin Pile (1200kJ – main piling, 50%)			
				Area	Maximum	Minimum	Mean
Worst case location	Unweighted SPL_{peak}	LF Cetacean	213 dB	0.05 km²	130 m	130 m	130 m
		MF Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	22 km²	2.7 km	2.6 km	2.6 km
		PW Pinniped	212 dB	0.08 km²	160 m	160 m	160 m
	Weighted SEL_{cum}	LF Cetacean	168 dB	3600 km²	43 km	25 km	33 km
		MF Cetacean	170 dB	48 km²	4.9 km	3.3 km	3.9 km
		HF Cetacean	140 dB	3800 km²	44 km	27 km	35 km
		PW Pinniped	170 dB	1500 km²	26 km	18 km	22 km
	Weighted SEL_{ss}	LF Cetacean	168 dB	160 km²	7.7 km	6.8 km	7.2 km
		MF Cetacean	170 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	56 km²	4.4 km	4.1 km	4.2 km
		PW Pinniped	170 dB	1.7 km²	740 m	740 m	740 m
Average depth location	Unweighted SPL_{peak}	LF Cetacean	213 dB	0.05 km²	130 m	130 m	130 m
		MF Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	196 dB	21 km²	2.6 km	2.5 km	2.6 km
		PW Pinniped	212 dB	0.07 km²	160 m	150 m	160 m
	Weighted SEL_{cum}	LF Cetacean	168 dB	3700 km²	41 km	30 km	35 km
		MF Cetacean	170 dB	46 km²	4.0 km	3.6 km	3.8 km
		HF Cetacean	140 dB	4000 km²	41 km	32 km	36 km
		PW Pinniped	170 dB	1600 km²	25 km	21 km	22 km
	Weighted SEL_{ss}	LF Cetacean	168 dB	160 km²	7.3 km	6.9 km	7.1 km
		MF Cetacean	170 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	140 dB	53 km²	4.3 km	4.0 km	4.1 km
		PW Pinniped	170 dB	1.7 km²	730 m	730 m	730 m

Table A-50 Summary of the single strike and cumulative impact ranges for TTS from NMFS (2018) for installation of a pin pile at EA2 using the 50% maximum hammer blow energy of 1200 kJ

A.3.2 Southall et al. (2007) results

EA2	Southall *et al.* (2007) - PTS			Monopile (2000kJ – main piling, 50%)			
				Area	Maximum	Minimum	Mean
Worst case	Unweighted SPL_{peak}	Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	M-Weighted SEL_{cum}	LF Cetacean	198 dB	28 km²	3.7 km	2.3 km	3.0 km
		MF Cetacean	198 dB	13 km²	2.4 km	1.6 km	2.0 km
		HF Cetacean	198 dB	3.7 km²	1.3 km	800 m	1.1 km
		PW Pinniped	186 dB	960 km²	21 km	14 km	17 km
	M-Weighted SEL_{ss}	LF Cetacean	198 dB	0.04 km²	110 m	110 m	110 m
		MF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	0.95 km²	550 m	550 m	550 m
Average depth	Unweighted SPL_{peak}	Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	M-Weighted SEL_{cum}	LF Cetacean	198 dB	18 km²	2.9 km	1.6 km	2.3 km
		MF Cetacean	198 dB	8.4 km²	2.0 km	1.2 km	1.6 km
		HF Cetacean	198 dB	2.1 km²	1.0 km	600 m	810 m
		PW Pinniped	186 dB	780 km²	19 km	11 km	16 km
	M-Weighted SEL_{ss}	LF Cetacean	198 dB	0.04 km²	110 m	110 m	110 m
		MF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	0.93 km²	550 m	540 m	550 m

Table A-51 Summary of the single strike and cumulative impact ranges for PTS from Southall et al. (2007) for installation of a monopile at EA2 using the 50% maximum hammer blow energy of 2000 kJ

EA2		Southall *et al.* (2007) - PTS		Pin Pile (1200kJ – main piling, 50%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	**Unweighted SPL_{peak}**	Cetacean	230 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	0.01 km^2	50 m	50 m	50 m
	M-Weighted SEL_{cum}	LF Cetacean	198 dB	41 km^2	4.6 km	2.6 km	3.6 km
		MF Cetacean	198 dB	50 km^2	4.6 km	3.2 km	4.0 km
		HF Cetacean	198 dB	17 km^2	2.8 km	1.8 km	2.3 km
		PW Pinniped	186 dB	1300 km^2	25 km	16 km	20 km
	M-Weighted SEL_{ss}	LF Cetacean	198 dB	0.03 km^2	100 m	100 m	100 m
		MF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	1.2 km^2	630 m	620 m	630 m
Average depth	**Unweighted SPL_{peak}**	Cetacean	230 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	0.01 km^2	50 m	50 m	50 m
	M-Weighted SEL_{cum}	LF Cetacean	198 dB	24 km^2	3.5 km	1.6 km	2.7 km
		MF Cetacean	198 dB	34 km^2	3.8 km	2.5 km	3.3 km
		HF Cetacean	198 dB	11 km^2	2.2 km	1.4 km	1.8 km
		PW Pinniped	186 dB	1100 km^2	22 km	13 km	18 km
	M-Weighted SEL_{ss}	LF Cetacean	198 dB	0.03 km^2	100 m	100 m	100 m
		MF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	1.2 km^2	620 m	620 m	620 m

Table A-52 Summary of the single strike and cumulative impact ranges for PTS from Southall et al. (2007) for installation of a pin pile at EA2 using the 50% maximum hammer blow energy of 1200 kJ

EA2		Southall *et al.* (2007) - TTS		Monopile (2000kJ – main piling, 50%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	**Unweighted SPL_{peak}**	Cetacean	224 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.1 km^2	180 m	180 m	180 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	10 km^2	1.9 km	1.7 km	1.8 km
		MF Cetacean	183 dB	0.86 km^2	530 m	520 m	530 m
		HF Cetacean	183 dB	0.48 km^2	400 m	390 m	390 m
		PW Pinniped	171 dB	110 km^2	6.2 km	5.4 km	5.9 km
Av. depth	**Unweighted SPL_{peak}**	Cetacean	224 dB	< 0.01 km^2	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.1 km^2	180 m	180 m	180 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	9.8 km^2	1.9 km	1.7 km	1.8 km
		MF Cetacean	183 dB	0.84 km^2	520 m	520 m	520 m
		HF Cetacean	183 dB	0.48 km^2	390 m	390 m	390 m
		PW Pinniped	171 dB	95 km^2	5.8 km	5.3 km	5.5 km

Table A-53 Summary of the single strike impact ranges for TTS from Southall et al. (2007) for installation of a monopile at EA2 using the 50% maximum hammer blow energy of 2000 kJ

EA2		Southall *et al.* (2007) - TTS		Pin Pile (1200kJ – main piling, 50%)			
				Area	Maximum	Minimum	Mean
Worst case	Unweighted SPL_{peak}	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.08 km²	160 m	160 m	160 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	8.4 km²	1.7 km	1.5 km	1.6 km
		MF Cetacean	183 dB	1.1 km²	610 m	600 m	600 m
		HF Cetacean	183 dB	0.54 km²	420 m	410 m	420 m
		PW Pinniped	171 dB	130 km²	6.7 km	5.9 km	6.4 km
Av. depth	Unweighted SPL_{peak}	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.08 km²	160 m	160 m	160 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	8.0 km²	1.7 km	1.5 km	1.6 km
		MF Cetacean	183 dB	1.1 km²	600 m	590 m	590 m
		HF Cetacean	183 dB	0.53 km²	410 m	410 m	410 m
		PW Pinniped	171 dB	110 km²	6.3 km	5.7 km	6.0 m

Table A-54 Summary of the single strike impact ranges for TTS from Southall et al. (2007) for installation of a pin pile at EA2 using the 50% maximum hammer blow energy of 1200 kJ

EA2		Southall *et al.* (2007) – Behavioural (Unweighted SEL_{ss})		Monopile (2000kJ – main piling 50%)			
				Area	Maximum	Minimum	Mean
WC	Likely avoidance	LF Cetacean	152 dB	2700 km²	34 km	24 km	29 km
		MF Cetacean	170 dB	280 km²	10 km	8.7 km	9.5 km
	Possible Avoidance	LF Cetacean	142 dB	5300 km²	49 km	32 km	41 km
		MF Cetacean	160 dB	1200 km²	23 km	18 km	20 km
Av. D	Likely avoidance	LF Cetacean	152 dB	2300 km²	31 km	21 km	27 km
		MF Cetacean	170 dB	240 km²	9.3 km	8.0 km	8.8 km
	Possible Avoidance	LF Cetacean	142 dB	4700 km²	46 km	29 km	39 km
		MF Cetacean	160 dB	1000 km²	21 km	14 km	18 km

Table A-55 Summary of the single strike impact ranges for behavioural response from Southall et al. (2007) for installation of a monopile at EA2 using the 50% soft start hammer blow energy of 2000 kJ

EA2		Southall *et al.* (2007) – Behavioural (Unweighted SEL_{ss})		Pin Pile (1200kJ – main piling, 50%)			
				Area	Maximum	Minimum	Mean
WC	Likely avoidance	LF Cetacean	152 dB	2500 km²	33 km	23 km	28 km
		MF Cetacean	170 dB	250 km²	9.4 km	8.1 km	8.9 km
	Possible Avoidance	LF Cetacean	142 dB	5100 km²	48 km	32 km	40 km
		MF Cetacean	160 dB	1100 km²	22 km	17 km	19 km
Av. D	Likely avoidance	LF Cetacean	152 dB	2200 km²	30 km	20 km	26 km
		MF Cetacean	170 dB	210 km²	8.7 km	7.6 km	8.2 km
	Possible Avoidance	LF Cetacean	142 dB	4500 km²	45 km	28 km	38 km
		MF Cetacean	160 dB	960 km²	20 km	14 km	17 km

Table A-56 Summary of the single strike impact ranges for behavioural response from Southall et al. (2007) for installation of a pin pile at EA2 using the 50% maximum hammer blow energy of 1200 kJ

EA1N		Southall *et al.* (2007) - PTS		**Monopile (2000kJ – main piling, 50%)**			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	**Unweighted SPL_{peak}**	Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	M-Weighted SEL_{cum}	LF Cetacean	198 dB	27 km²	3.8 km	2.3 km	2.9 km
		MF Cetacean	198 dB	13 km²	2.5 km	1.7 km	2.0 km
		HF Cetacean	198 dB	3.5 km²	1.4 km	800 m	1.0 km
		PW Pinniped	186 dB	960 km²	21 km	15 km	17 km
	M-Weighted SEL_{ss}	LF Cetacean	198 dB	0.04 km²	110 m	110 m	110 m
		MF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	0.95 km²	550 m	550 m	550 m
Average depth	**Unweighted SPL_{peak}**	Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	0.01 km²	60 m	60 m	60 m
	M-Weighted SEL_{cum}	LF Cetacean	198 dB	26 km²	3.1 km	2.6 km	2.9 km
		MF Cetacean	198 dB	12 km²	2.1 km	1.8 km	1.9 km
		HF Cetacean	198 dB	3.1 km²	1.1 km	900 m	990 m
		PW Pinniped	186 dB	1000 km²	20 km	17 km	18 km
	M-Weighted SEL_{ss}	LF Cetacean	198 dB	0.04 km²	110 m	110 m	110 m
		MF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	0.92 km²	540 m	540 m	540 m

Table A-57 Summary of the single strike and cumulative impact ranges for PTS from Southall et al. (2007) for installation of a monopile at EA1N using the 50% maximum hammer blow energy of 2000 kJ

EA1N		Southall *et al.* (2007) - PTS		**Pin Pile (1200kJ – main piling, 50%)**			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	**Unweighted SPL_{peak}**	Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	0.01 km²	50 m	50 m	50 m
	M-Weighted SEL_{cum}	LF Cetacean	198 dB	38 km²	4.7 km	2.7 km	3.5 km
		MF Cetacean	198 dB	48 km²	4.9 km	3.3 km	3.9 km
		HF Cetacean	198 dB	16 km²	2.9 km	1.9 km	2.3 km
		PW Pinniped	186 dB	1300 km²	25 km	17 km	21 km
	M-Weighted SEL_{ss}	LF Cetacean	198 dB	0.03 km²	100 m	100 m	100 m
		MF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	1.2 km²	630 m	620 m	630 m
Average depth	**Unweighted SPL_{peak}**	Cetacean	230 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	218 dB	0.01 km²	50 m	50 m	50 m
	M-Weighted SEL_{cum}	LF Cetacean	198 dB	37 km²	3.8 km	3.1 km	3.4 km
		MF Cetacean	198 dB	46 km²	4.1 km	3.6 km	3.8 km
		HF Cetacean	198 dB	15 km²	2.4 km	2.1 km	2.2 km
		PW Pinniped	186 dB	1400 km²	23 km	20 km	21 km
	M-Weighted SEL_{ss}	LF Cetacean	198 dB	0.03 km²	100 m	100 m	100 m
		MF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		HF Cetacean	198 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		PW Pinniped	186 dB	1.2 km²	620 m	620 m	620 m

Table A-58 Summary of the single strike and cumulative impact ranges for PTS from Southall et al. (2007) for installation of a pin pile at EA1N using the 50% maximum hammer blow energy of 1200 kJ

EA1N	Southall *et al.* (2007) - TTS			Monopile (2000kJ – main piling, 50%)			
				Area	Maximum	Minimum	Mean
Worst case	Unweighted SPL_{peak}	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.1 km²	180 m	180 m	180 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	11 km²	1.9 km	1.8 km	1.9 km
		MF Cetacean	183 dB	0.86 km²	530 m	520 m	530 m
		HF Cetacean	183 dB	0.48 km²	390 m	390 m	390 m
		PW Pinniped	171 dB	110 km²	6.2 km	5.6 km	5.8 km
Av. depth	Unweighted SPL_{peak}	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.1 km²	180 m	180 m	180 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	9.6 km²	1.8 km	1.7 km	1.8 km
		MF Cetacean	183 dB	0.84 km²	520 m	520 m	520 m
		HF Cetacean	183 dB	0.47 km²	390 m	390 m	390 m
		PW Pinniped	171 dB	100 km²	5.9 km	5.6 km	5.7 km

Table A-59 Summary of the single strike impact ranges for TTS from Southall et al. (2007) for installation of a monopile at EA1N using the 50% maximum hammer blow energy of 2000 kJ

EA1N	Southall *et al.* (2007) - TTS			Pin Pile (1200kJ – main piling, 50%)			
				Area	Maximum	Minimum	Mean
Worst case	Unweighted SPL_{peak}	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.08 km²	160 m	160 m	160 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	8.5 km²	1.7 km	1.6 km	1.7 km
		MF Cetacean	183 dB	1.1 km²	600 m	600 m	600 m
		HF Cetacean	183 dB	0.54 km²	420 m	410 m	420 m
		PW Pinniped	171 dB	130 km²	6.8 km	6.0 km	6.3 km
Av. depth	Unweighted SPL_{peak}	Cetacean	224 dB	< 0.01 km²	< 50 m	< 50 m	< 50 m
		Pinniped	212 dB	0.07 km²	160 m	150 m	160 m
	M-Weighted SEL_{ss}	LF Cetacean	183 dB	8.3 km²	1.7 km	1.5 km	1.6 km
		MF Cetacean	183 dB	1.1 km²	590 m	590 m	590 m
		HF Cetacean	183 dB	0.53 km²	410 m	410 m	410 m
		PW Pinniped	171 dB	120 km²	6.4 km	6.1 km	6.2 km

Table A-60 Summary of the single strike impact ranges for TTS from Southall et al. (2007) for installation of a pin pile at EA1N using the 50% maximum hammer blow energy of 1200 kJ

EA1N	Southall *et al.* (2007) – Behavioural (Unweighted SEL_{ss})			Monopile (2000kJ – main piling 50%)			
				Area	Maximum	Minimum	Mean
WC	Likely avoidance	LF Cetacean	152 dB	2700 km²	34 km	25 km	29 km
		MF Cetacean	170 dB	280 km²	10 km	8.8 km	9.4 km
	Possible Avoidance	LF Cetacean	142 dB	5400 km²	50 km	34 km	41 km
		MF Cetacean	160 dB	1200 km²	22 km	18 km	20 km
Av. D	Likely avoidance	LF Cetacean	152 dB	2800 km²	33 km	29 km	30 km
		MF Cetacean	170 dB	270 km²	9.6 km	9.1 km	9.3 km
	Possible Avoidance	LF Cetacean	142 dB	5700 km²	48 km	39 km	43 km
		MF Cetacean	160 dB	1300 km²	21 km	19 km	20 km

Table A-61 Summary of the single strike impact ranges for behavioural response from Southall et al. (2007) for installation of a monopile at EA1N using the 50% soft start hammer blow energy of 2000 kJ

EA1N	Southall *et al.* (2007) – Behavioural (Unweighted SEL_{ss})			Pin Pile (1200kJ – main piling, 50%)			
				Area	**Maximum**	**Minimum**	**Mean**
WC	**Likely avoidance**	LF Cetacean	152 dB	2600 km^2	33 km	25 km	29 km
		MF Cetacean	170 dB	240 km^2	9.6 km	8.3 km	8.8 km
	Possible Avoidance	LF Cetacean	142 dB	5200 km^2	49 km	33 km	41 km
		MF Cetacean	160 dB	1100 km^2	21 km	17 km	19 km
Av. D	**Likely avoidance**	LF Cetacean	152 dB	2700 km^2	32 km	28 km	29 km
		MF Cetacean	170 dB	240 km^2	9.0 km	8.5 km	8.7 km
	Possible Avoidance	LF Cetacean	142 dB	5400 km^2	47 km	38 km	42 km
		MF Cetacean	160 dB	1200 km^2	20 km	18 km	19 km

Table A-62 Summary of the single strike impact ranges for behavioural response from Southall et al. (2007) for installation of a pin pile at EA1N using the 50% maximum hammer blow energy of 1200 kJ

A.3.3 Lucke et al. (2009) results

EA2	Lucke *et al.* (2009) (Unweighted SEL_{ss})		Monopile (2000kJ – main piling, 50%)			
			Area	**Maximum**	**Minimum**	**Mean**
WC	Auditory injury	179 dB	34 km^2	3.5 km	3.1 km	3.3 km
	TTS	164 dB	750 km^2	17 km	14 km	16 km
	Behavioural	145 dB	4500 km^2	44 km	30 km	38 km
AV	Auditory injury	179 dB	32 km^2	3.3 km	3.1 km	3.2 km
	TTS	164 dB	620 km^2	16 km	12 km	14 km
	Behavioural	145 dB	3900 km^2	41 km	26 km	35 km

Table A-63 Summary of the single strike impact ranges for criteria from Lucke et al. (2009) for installation of a monopile at EA2 using the 50% maximum hammer blow energy of 2000 kJ

EA2	Lucke *et al.* (2009) (Unweighted SEL_{ss})		Pin Pile (1200kJ – main piling, 50%)			
			Area	**Maximum**	**Minimum**	**Mean**
WC	Auditory injury	179 dB	28 km^2	3.2 km	2.8 km	3.0 km
	TTS	164 dB	680 km^2	16 km	14 km	15 km
	Behavioural	145 dB	4300 km^2	43 km	29 km	37 km
AV	Auditory injury	179 dB	26 km^2	3.0 km	2.8 km	2.9 km
	TTS	164 dB	570 km^2	15 km	11 km	13 km
	Behavioural	145 dB	3700 km^2	40 km	26 km	34 km

Table A-64 Summary of the single strike impact ranges for criteria from Lucke et al. (2009) for installation of a pin pile at EA2 using the 50% maximum hammer blow energy of 1200 kJ

EA1N	Lucke *et al.* (2009) (Unweighted SEL_{ss})		Monopile (2000kJ – main piling, 50%)			
			Area	**Maximum**	**Minimum**	**Mean**
WC	Auditory injury	179 dB	34 km^2	3.4 km	3.2 km	3.3 km
	TTS	164 dB	740 km^2	17 km	14 km	15 km
	Behavioural	145 dB	4500 km^2	46 km	31 km	38 km
AV	Auditory injury	179 dB	33 km^2	3.3 km	3.1 km	3.2 km
	TTS	164 dB	740 km^2	16 km	15 km	15 km
	Behavioural	145 dB	4700 km^2	43 km	36 km	39 km

Table A-65 Summary of the single strike impact ranges for criteria from Lucke et al. (2009) for installation of a monopile at EA1N using the 50% maximum hammer blow energy of 2000 kJ

EA1N	Lucke *et al.* (2009) (Unweighted SEL_{ss})		Pin Pile (1200kJ – main piling, 50%)			
			Area	Maximum	Minimum	Mean
WC	Auditory injury	179 dB	28 km²	3.1 km	2.9 km	3.0 km
	TTS	164 dB	670 km²	16 km	14 km	15 km
	Behavioural	145 dB	4300 km²	44 km	31 km	37 km
AV	Auditory injury	179 dB	27 km²	3.0 km	2.8 km	2.9 km
	TTS	164 dB	670 km²	15 km	14 km	15 km
	Behavioural	145 dB	4500 km²	42 km	35 km	38 km

Table A-66 Summary of the single strike impact ranges for criteria from Lucke et al. (2009) for installation of a pin pile at EA1N using the 50% maximum hammer blow energy of 1200 kJ

A.3.4 <u>*Popper et al. (2014) results*</u>

EA2		Popper *et al.* (2014) – Fish (no swim bladder)		Monopile (2000kJ – main piling, 50%)			
				Area	Maximum	Minimum	Mean
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 213 dB	0.07 km²	150 m	150 m	150 m
		Recoverable injury	> 213 dB	0.07 km²	150 m	150 m	150 m
	SEL_{cum}	Mortal and potential mortal injury	> 219 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	> 216 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		TTS	>> 186 dB	1500 km²	26 km	17 km	22 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 213 dB	0.07 km²	150 m	150 m	150 m
		Recoverable injury	> 213 dB	0.07 km²	150 m	150 m	150 m
	SEL_{cum}	Mortal and potential mortal injury	> 219 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	> 216 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		TTS	>> 186 dB	1200 km²	23 km	14 km	20 km

Table A-67 Summary of the unweighted single strike and cumulative impact ranges for fish (no swim bladder) using the impact piling criteria from Popper et al. (2014) for installation of a monopile at EA2 using the 50% maximum hammer blow energy of 2000 kJ

EA2		Popper *et al.* (2014) – Fish (no swim bladder)		Pin Pile (1200kJ – main piling, 50%)			
				Area	Maximum	Minimum	Mean
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 213 dB	0.05 km²	130 m	130 m	130 m
		Recoverable injury	> 213 dB	0.05 km²	130 m	130 m	130 m
	SEL_{cum}	Mortal and potential mortal injury	> 219 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	> 216 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		TTS	>> 186 dB	1700 km²	27 km	18 km	23 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 213 dB	0.05 km²	13 m	130 m	130 m
		Recoverable injury	> 213 dB	0.05 km²	13 m	130 m	130 m
	SEL_{cum}	Mortal and potential mortal injury	> 219 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	> 216 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		TTS	>> 186 dB	1400 km²	25 km	15 km	21 km

Table A-68 Summary of the unweighted single strike and cumulative impact ranges for fish (no swim bladder) using the impact piling criteria from Popper et al. (2014) for installation of a pin pile at EA2 using the 50% maximum hammer blow energy of 1200 kJ

EA2		Popper *et al.* (2014) – Fish (swim bladder not involved in hearing)		Monopile (2000kJ – main piling, 50%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.64 km²	450 m	450 m	450 m
		Recoverable injury	> 207 dB	0.64 km²	450 m	450 m	450 m
	SEL_{cum}	Mortal and potential mortal injury	210 dB	0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	203 dB	37 km²	4.0 km	2.8 km	3.4 km
		TTS	> 186 dB	1500 km²	26 km	17 km	22 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.63 km²	450 m	450 m	450 m
		Recoverable injury	> 207 dB	0.63 km²	450 m	450 m	450 m
	SEL_{cum}	Mortal and potential mortal injury	210 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	203 dB	25 km²	3.3 km	2.2 km	2.8 km
		TTS	> 186 dB	1200 km²	23 km	14 km	20 km

Table A-69 Summary of the unweighted single strike and cumulative impact ranges for fish (swim bladder not involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a monopile at EA2 using the 50% maximum hammer blow energy of 2000 kJ

EA2		Popper *et al.* (2014) – Fish (swim bladder not involved in hearing)		Pin Pile (1200kJ – main piling, 50%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.49 km²	400 m	390 m	400 m
		Recoverable injury	> 207 dB	0.49 km²	400 m	390 m	400 m
	SEL_{cum}	Mortal and potential mortal injury	210 dB	0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	203 dB	59 km²	5.0 km	3.5 km	4.3 km
		TTS	> 186 dB	1700 km²	27 km	18 km	23 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.48 km²	390 m	390 m	390 m
		Recoverable injury	> 207 dB	0.48 km²	390 m	390 m	390 m
	SEL_{cum}	Mortal and potential mortal injury	210 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	203 dB	40 km²	4.2 km	2.7 km	3.6 km
		TTS	> 186 dB	1400 km²	25 km	15 km	21 km

Table A-70 Summary of the unweighted single strike and cumulative impact ranges for fish (swim bladder not involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a pin pile at EA2 using the 50% maximum hammer blow energy of 1200 kJ

EA2		Popper *et al.* (2014) – Fish (swim bladder involved in hearing)		Monopile (2000kJ – main piling, 50%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.64 km²	450 m	450 m	450 m
		Recoverable injury	> 207 dB	0.64 km²	450 m	450 m	450 m
	SEL_{cum}	Mortal and potential mortal injury	207 dB	1.6 km²	870 m	490 m	700 m
		Recoverable injury	203 dB	37 km²	4.0 km	2.8 km	3.4 km
		TTS	186 dB	1500 km²	26 km	17 km	22 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.63 km²	450 m	450 m	450 m
		Recoverable injury	> 207 dB	0.63 km²	450 m	450 m	450 m
	SEL_{cum}	Mortal and potential mortal injury	207 dB	0.79 km²	630 m	360 m	500 m
		Recoverable injury	203 dB	25 km²	3.3 km	2.2 km	2.8 km
		TTS	186 dB	1200 km²	23 km	14 km	20 km

Table A-71 Summary of the unweighted single strike and cumulative impact ranges for fish (swim bladder involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a monopile at EA2 using the 50% maximum hammer blow energy of 2000 kJ

EA2		Popper *et al.* (2014) – Fish (swim bladder involved in hearing)		Pin Pile (1200kJ – main piling, 50%)			
				Area	Maximum	Minimum	Mean
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.49 km²	400 m	390 m	400 m
Worst case	SPL_{peak}	Recoverable injury	> 207 dB	0.49 km²	400 m	390 m	400 m
Worst case	SEL_{cum}	Mortal and potential mortal injury	207 dB	5.0 km²	1.6 km	< 100 m	1.2 km
Worst case	SEL_{cum}	Recoverable injury	203 dB	59 km²	5.0 km	3.5 km	4.3 km
Worst case	SEL_{cum}	TTS	186 dB	1700 km²	27 km	18 km	23 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.48 km²	390 m	390 m	390 m
Av. depth	SPL_{peak}	Recoverable injury	> 207 dB	0.48 km²	390 m	390 m	390 m
Av. depth	SEL_{cum}	Mortal and potential mortal injury	207 dB	2.6 km²	1.2 km	600 m	890 m
Av. depth	SEL_{cum}	Recoverable injury	203 dB	40 km²	4.2 km	2.7 km	3.6 km
Av. depth	SEL_{cum}	TTS	186 dB	1400 km²	25 km	15 km	21 km

Table A-72 Summary of the unweighted single strike and cumulative impact ranges for fish (swim bladder involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a pin pile at EA2 using the 50% maximum hammer blow energy of 1200 kJ

EA1N		Popper *et al.* (2014) – Fish (no swim bladder)		Monopile (2000kJ – main piling, 50%)			
				Area	Maximum	Minimum	Mean
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 213 dB	0.07 km²	150 m	150 m	150 m
Worst case	SPL_{peak}	Recoverable injury	> 213 dB	0.07 km²	150 m	150 m	150 m
Worst case	SEL_{cum}	Mortal and potential mortal injury	> 219 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
Worst case	SEL_{cum}	Recoverable injury	> 216 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
Worst case	SEL_{cum}	TTS	>> 186 dB	1500 km²	26 km	18 km	22 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 213 dB	0.07 km²	150 m	150 m	150 m
Av. depth	SPL_{peak}	Recoverable injury	> 213 dB	0.07 km²	150 m	150 m	150 m
Av. depth	SEL_{cum}	Mortal and potential mortal injury	> 219 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
Av. depth	SEL_{cum}	Recoverable injury	> 216 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
Av. depth	SEL_{cum}	TTS	>> 186 dB	1600 km²	25 km	21 km	22 km

Table A-73 Summary of the unweighted single strike and cumulative impact ranges for fish (no swim bladder) using the impact piling criteria from Popper et al. (2014) for installation of a monopile at EA1N using the 50% maximum hammer blow energy of 2000 kJ

EA1N		Popper *et al.* (2014) – Fish (no swim bladder)		Pin Pile (1200kJ – main piling, 50%)			
				Area	Maximum	Minimum	Mean
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 213 dB	0.05 km²	130 m	130 m	130 m
Worst case	SPL_{peak}	Recoverable injury	> 213 dB	0.05 km²	130 m	130 m	130 m
Worst case	SEL_{cum}	Mortal and potential mortal injury	> 219 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
Worst case	SEL_{cum}	Recoverable injury	> 216 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
Worst case	SEL_{cum}	TTS	>> 186 dB	1700 km²	28 km	19 km	23 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 213 dB	0.05 km²	130 m	130 m	130 m
Av. depth	SPL_{peak}	Recoverable injury	> 213 dB	0.05 km²	130 m	130 m	130 m
Av. depth	SEL_{cum}	Mortal and potential mortal injury	> 219 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
Av. depth	SEL_{cum}	Recoverable injury	> 216 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
Av. depth	SEL_{cum}	TTS	>> 186 dB	1800 km²	27 km	22 km	24 km

Table A-74 Summary of the unweighted single strike and cumulative impact ranges for fish (no swim bladder) using the impact piling criteria from Popper et al. (2014) for installation of a pin pile at EA1N using the 50% maximum hammer blow energy of 1200 kJ

EA1N		Popper *et al.* (2014) – Fish (swim bladder not involved in hearing)		Monopile (2000kJ – main piling, 50%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.64 km²	450 m	450 m	450 m
		Recoverable injury	> 207 dB	0.64 km²	450 m	450 m	450 m
	SEL_{cum}	Mortal and potential mortal injury	210 dB	0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	203 dB	35 km²	4.2 km	2.8 km	3.3 km
		TTS	> 186 dB	1500 km²	26 km	18 km	22 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.62 km²	450 m	450 m	450 m
		Recoverable injury	> 207 dB	0.62 km²	450 m	450 m	450 m
	SEL_{cum}	Mortal and potential mortal injury	210 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	203 dB	34 km²	3.5 km	3.1 km	3.3 km
		TTS	> 186 dB	1600 km²	25 km	21 km	22 km

Table A-75 Summary of the unweighted single strike and cumulative impact ranges for fish (swim bladder not involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a monopile at EA1N using the 50% maximum hammer blow energy of 2000 kJ

EA1N		Popper *et al.* (2014) – Fish (swim bladder not involved in hearing)		Pin Pile (1200kJ – main piling, 50%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.49 km²	400 m	400 m	400 m
		Recoverable injury	> 207 dB	0.49 km²	400 m	400 m	400 m
	SEL_{cum}	Mortal and potential mortal injury	210 dB	0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	203 dB	56 km²	5.3 km	3.6 km	4.2 km
		TTS	> 186 dB	1700 km²	28 km	19 km	23 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.48 km²	390 m	390 m	390 m
		Recoverable injury	> 207 dB	0.48 km²	390 m	390 m	390 m
	SEL_{cum}	Mortal and potential mortal injury	210 dB	< 0.01 km²	< 100 m	< 100 m	< 100 m
		Recoverable injury	203 dB	54 km²	4.4 km	3.9 km	4.2 km
		TTS	> 186 dB	1800 km²	27 km	22 km	24 km

Table A-76 Summary of the unweighted single strike and cumulative impact ranges for fish (swim bladder not involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a pin pile at EA1N using the 50% maximum hammer blow energy of 1200 kJ

EA1N		Popper *et al.* (2014) – Fish (swim bladder involved in hearing)		Monopile (2000kJ – main piling, 50%)			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.64 km²	450 m	450 m	450 m
		Recoverable injury	> 207 dB	0.64 km²	450 m	450 m	450 m
	SEL_{cum}	Mortal and potential mortal injury	207 dB	1.4 km²	890 m	550 m	670 m
		Recoverable injury	203 dB	35 km²	4.2 km	2.8 km	3.3 km
		TTS	186 dB	1500 km²	26 km	18 km	22 km
Av. depth	SPL_{peak}	Mortal and potential mortal injury	> 207 dB	0.62 km²	450 m	450 m	450 m
		Recoverable injury	> 207 dB	0.62 km²	450 m	450 m	450 m
	SEL_{cum}	Mortal and potential mortal injury	207 dB	1.2 km²	670 m	560 m	620 m
		Recoverable injury	203 dB	34 km²	3.5 km	3.1 km	3.3 km
		TTS	186 dB	1600 km²	25 km	21 km	22 km

Table A-77 Summary of the unweighted single strike and cumulative impact ranges for fish (swim bladder involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a monopile at EA1N using the 50% maximum hammer blow energy of 2000 kJ

EA1N		Popper *et al.* (2014) – Fish (swim bladder involved in hearing)		**Pin Pile (1200kJ – main piling, 50%)**			
				Area	**Maximum**	**Minimum**	**Mean**
Worst case	**SPL_{peak}**	Mortal and potential mortal injury	> 207 dB	0.49 km^2	400 m	400 m	400 m
		Recoverable injury	> 207 dB	0.49 km^2	400 m	400 m	400 m
	SEL_{cum}	Mortal and potential mortal injury	207 dB	4.6 km^2	1.6 km	900 m	1.2 km
		Recoverable injury	203 dB	56 km^2	5.3 km	3.6 km	4.2 km
		TTS	186 dB	1700 km^2	28 km	19 km	23 km
Av. depth	**SPL_{peak}**	Mortal and potential mortal injury	> 207 dB	0.48 km^2	390 m	390 m	390 m
		Recoverable injury	> 207 dB	0.48 km^2	390 m	390 m	390 m
	SEL_{cum}	Mortal and potential mortal injury	207 dB	4.0 km^2	1.3 km	1.0 km	1.1 km
		Recoverable injury	203 dB	54 km^2	4.4 km	3.9 km	4.2 km
		TTS	186 dB	1800 km^2	27 km	22 km	24 km

Table A-78 Summary of the unweighted single strike and cumulative impact ranges for fish (swim bladder involved in hearing) using the impact piling criteria from Popper et al. (2014) for installation of a pin pile at EA1N using the 50% maximum hammer blow energy of 1200 kJ

A.4 Summary

The previous sections present impact ranges for scenarios where the blow energy only reaches 75% and 50% of the maximum hammer blow energy during the main piling. Table A-79, below, gives a brief summary of the reductions in impact ranges for TTS in LF cetaceans (NMFS, 2018) for the worst-case location at EA1N; one of the criteria with the largest expected impact ranges. The results show that the reduction in impact range is only minor when these lower hammer blow energies are reached instead of the maximum hammer blow energy.

Effect	**Maximum blow energy**	**Monopile (4000 kJ)**	**Pin Pile (2400 kJ)**
LF Cetacean TTS (Weighted SEL_{cum}) (NMFS, 2018)	100%	40 km	45 km
	75%	40 km	44 km
	50%	39 km	43 km

Table A-79 Summary of the LF cetacean TTS impact ranges showing the reductions in SEL_{cum} impact ranges when reducing the maximum hammer blow energy (EA1N, worst-case location).

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