



# **Sporad na Mara Offshore Wind Farm**

## **Offshore Project**

### **Environmental Impact Assessment Report**

#### **Appendix 13.3: Underwater Noise Modelling Assessment, Volume 2c**

Document Reference No.: SNM-SNM-PAC-APP-1133

Date: February 2026



## Quality Control Page

Document details	
Document title	Offshore Project Environmental Impact Assessment Report
Document subtitle	Appendix 13.3: Underwater Noise Modelling Assessment
Document reference no.	SNM-SNM-PAC-APP-1133
Date	February 2026
Version	1.0
Author	Subacoustech Environmental
Client Name	Spiorad na Mara Ltd

Document history						
Version	Revision	Issued	Checked	Approved	Date	Comments
1.0	A	Subacoustech Environmental	WSP	SnM Ltd	February 2026	Final for submission

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# 1 INTRODUCTION

## 1.1 OVERVIEW

1.1.1.1 This appendix of the Environmental Impact Assessment Report (EIAR) presents underwater noise modelling assessment of the proposed Spiorad na Mara Offshore Wind Farm (hereafter referred to as 'the Offshore Project') with respect to Marine Mammals. This appendix accompanies **Chapter 13: Marine Mammals, Volume 2a** of the EIAR.

1.1.1.2 This appendix should be read in conjunction with the project description provided in **Chapter 3: Project Description, Volume 1a** and the relevant parts of the following chapters and appendices:

- **Chapter 13, Volume 2a;**
- **Chapter 11: Benthic and Intertidal Ecology, Volume 2a;**
- **Chapter 19: Offshore Airborne Noise, Volume 2a;**
- **Appendix 13.1: Digital Aerial Survey (DAS) Report, Volume 2c;**
- **Appendix 13.2: Passive Acoustic Monitoring Survey Report, Volume 2c;**
- **Appendix 12.1: Fish Ecology Baseline Characterisation Report, Volume 2c;**
- **Appendix 13.4: iPCod, Volume 2c;**
- **Outline Marine Mammals Management Plan, Volume 3.**

### 1.1.2 PROJECT BACKGROUND

1.1.2.1 Spiorad na Mara Limited (hereafter referred to as 'the Applicant') is proposing to develop the Project. The Project is an offshore wind farm (OWF) that will consist of up to 60 fixed-bottom wind turbine generators (WTGs).

1.1.2.2 The Project will include both offshore and onshore infrastructure. This Offshore EIAR supports the application for the offshore components of the Project as outlined in **Chapter 1: Introduction, Volume 1a**. The offshore components of the Project (the Offshore Project) includes all infrastructure and activities located seaward of Mean High Water Springs (MHWS) within the Array Area and Offshore Cable Area of Search (OCAS) (**Figure 1.2: Offshore Project Location, Volume 1b**). Further detailed information is provided in **Chapter 3, Volume 1a**.

1.1.2.3 The Offshore Project is situated off the northwest coast of Isle of Lewis/*Eilean Leòdhais* and the Array Area is located approximately 5-13 km offshore and is approximately 161 km<sup>2</sup> in size. It will comprise WTGs, foundations, Offshore Cables, Offshore Substation Platform (OSP) (if required), and Landfall. The Array Area combined with the OCAS is defined as the Offshore Project Boundary. The water depths across the Array Area range from 37 m-67 m with the southwest corner of the Array Area reaching 72 m. The proposed WTGs and fixed foundations will be located within a Turbine Area of approximately 140 km<sup>2</sup>, within the Array Area.

## 1.2 PURPOSE OF THIS APPENDIX

- 1.2.1.1 The effect of the introduction of underwater noise depends on the sensitive receptors in the existing environment. Based on previous assessments undertaken by Subacoustech Environmental on similar situations, the effect of underwater noise on marine species, particularly fish and marine mammals, is an important consideration for regulators and statutory consultees. This includes noise from impact piling, other noise such as dredging and shipping, and operational WTG noise.
- 1.2.1.2 The Applicant has undertaken underwater noise modelling to consider the noise related to the construction of the Offshore Project. This appendix provides the results and findings of the detailed modelling assessment of all potentially significant noise sources associated with the Offshore Project. The modelling has been used to predict the sound pressure levels and sound exposure levels generated during these activities. The effects of underwater noise, as well as all other relevant impacts on these groups, are considered in further detail in **Chapter 11, Volume 2a, Chapter 12: Fish Ecology, Volume 2a** and **Chapter 13, Volume 2a**.
- 1.2.1.3 This Appendix describes the following:
- Section 2: Overview of background information on measuring and assessing underwater noise;
  - Section 3: Discussion of the modelling approach, input parameters and assumptions for the noise modelling undertaken;
  - Section 4: Presentation of detailed subsea noise modelling and interpretation of the results using suitable noise metrics and criteria;
  - Section 5: Other Noise Sources;
  - Section 6: Summary and Conclusions.

## 1.3 STUDY AREA

- 1.3.1.1 For the purposes of underwater noise modelling, there is no specific study area defining the region over which underwater noise levels are calculated. The modelling is unrestricted, calculating impact ranges to specified criteria in the waters surrounding the Array Area associated with project activities during construction, operation and decommissioning.
- 1.3.1.2 Water depths across the Array Area generally range from approximately 37 m-67 m, except for a localised depression in the southwest corner of the Array Area reaching up to 72 m. Piling will only be undertaken in a portion of the site and no piles are proposed to be driven in this deepest location (see Section 3.2 for more details on the piling locations, and **Chapter 3, Volume 1a** for further information and explanations about the construction methodology).

## 1.4 NOISE SOURCES

- 1.4.1.1 The proposed piling activities will be assessed quantitatively using underwater noise modelling and will comprise of modelling scenarios encompassing percussive piling of piles and casings associated with installation of WTG and OSP foundations, with and without noise mitigation.
- 1.4.1.2 Further details of the modelling of this noise source, including source level calculations and locations, are described in Section 3.2.
- 1.4.1.3 Noise sources other than piling considered include cable laying, cutting of piles, dredging, drilling, trenching and vessel movements during construction, and WTG operational noise.

## 2 UNDERWATER NOISE CONCEPTS

2.1.1.1 Sound travels much faster in water (approximately 1,500 m/s) than in air (340 m/s). Since water is a relatively incompressible, dense medium, the pressure associated with underwater sound tends to be much higher than in air. Therefore, it should be noted that stated underwater noise levels are different to those stated for airborne noise levels (as discussed in **Chapter 19, Volume 2a**), as a different scale is used for in-water and in-air measurements. Therefore, noise measurements in air are generally incomparable to noise measured underwater.

### 2.2 UNITS OF MEASUREMENT

2.2.1.1 Sound measurements underwater are usually expressed using the decibel (dB) scale, which is a logarithmic measure of sound. A logarithmic scale is used as this better reflects how sound is perceived. For example, equal increments of sound levels do not have an equal increase in the perceived sound. Instead, each doubling of sound level will cause an approximately equal increase of loudness. Any quantity expressed in this dB scale is termed a "level." For example, if the unit is sound pressure, it will be termed a "sound pressure level" on the dB scale.

2.2.1.2 The fundamental definition of the dB scale is given by:

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

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

2.2.1.4 The dB scale represents a ratio. 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 example, in the underwater environment, a value of 1  $\mu\text{Pa}$  is used.

2.2.1.5 When used with sound pressure, the pressure value is squared. So that variations in the units agree, the sound pressure must be specified as units of Root Mean Square (RMS) pressure squared. This is equivalent to expressing the sound as:

$$Sound\ pressure\ level\ (L_p) = 20 \times \log_{10} \left( \frac{P_{RMS}}{P_{ref}} \right)$$

2.2.1.6 For underwater sound, a unit of 1  $\mu\text{Pa}$  is typically used as the reference unit ( $P_{ref}$ ); a Pascal is equal to the pressure exerted by 1 Newton over 1 square metre, 1 micropascal equals 1 millionth of this.

#### 2.2.2 SOUND PRESSURE LEVEL (SPL, $L_p$ )

2.2.2.1 The Sound Pressure Level (SPL or  $L_p$ ) 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 RMS level of the time-varying sound. The SPL ( $L_{p,RMS}$ ) can therefore be considered a measure of the average unweighted level of sound over the measurement period.

2.2.2.2 Where SPL is used to characterise transient pressure waves, such as that from impact piling, seismic airgun or underwater blasting, it is critical that the period over which the RMS level is calculated is quoted (e.g.,  $L_{p,125ms}$ ). For instance, in the case of a pile strike lasting a tenth of a second, the mean taken over a tenth of a second will be 10 times higher than the mean averaged over 1 second. Often, transient sounds such as these are quantified using “peak” SPLs ( $L_{p,pk}$ ) or Sound Exposure Levels (SEL or  $L_{E,p}$ ).

2.2.2.3 Unless otherwise defined, all SPL noise levels in this report are referenced to 1  $\mu$ Pa as a conventional reference value for underwater sound.

### 2.2.3 PEAK SOUND PRESSURE LEVEL (PEAK SPL OR $L_{p,pk}$ )

2.2.3.1 The peak SPL, or  $L_{p,pk}$ , are often used to characterise transient sound from impulsive sources, such as percussive impact piling.  $L_{p,pk}$  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.

### 2.2.4 SOUND EXPOSURE LEVEL (SEL OR $L_{E,p}$ )

2.2.4.1 When considering the noise from transient sources, 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, 1955), and later by Rawlins (1987), to explain the apparent discrepancies in the physiological 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 injury ranges for fish and marine mammals from various noise sources (Popper *et al.*, 2014; Southall *et al.*, 2019; Southall *et al.*, 2007).

2.2.4.2 The  $L_{E,p}$  sums the acoustic energy over a measurement period, and effectively takes account of both the  $L_p$  of the sound and the duration it is present in the acoustic environment. Sound Exposure (SE) is defined by the equation:

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

2.2.4.3 where  $p$  is the acoustic pressure in Pascals,  $T$  is the total duration of sound in seconds, and  $t$  is time in seconds. The SE is a measurement of acoustic energy and has units of Pascal squared seconds ( $\text{Pa}^2\text{s}$ ).

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

$$L_{E,p} = 10 \times \log_{10} \left( \frac{\int_0^T p^2(t) dt}{p_{ref}^2 T_{ref}} \right)$$

2.2.4.5 By using a common reference pressure ( $p_{ref}$ ) of 1  $\mu$ Pa for assessments of underwater noise, the  $L_E$  and  $L_p$  can be compared using the expression:

$$L_{E,p} = L_p + 10 \times \log_{10} T$$

2.2.4.6 where the  $L_p$  is a measure of the average level of broadband noise and the  $L_{E,p}$  sums the cumulative broadband noise energy.

2.2.4.7 This means that, for continuous sounds of less than (i.e., fractions of) 1 second, the  $L_{E,p}$  will be lower than the  $L_p$ . For periods greater than 1 second, the  $L_{E,p}$  will be numerically greater than the  $L_p$  (i.e., for a continuous sound of 10 seconds duration, the  $L_{E,p}$  will be 10 dB higher than the  $L_p$ ; for a sound of 100 seconds duration the  $L_{E,p}$  will be 20 dB higher than the  $L_p$ , and so on).

2.2.4.8 Where a single impulse noise such as the soundwave from a pile strike is considered in isolation, this can be represented by a "single strike"  $L_{E,p}$  or  $SEL_{ss}$ . A cumulative  $L_{E,p}$ , or  $SEL_{cum}$ , accounts for the exposure from multiple impulses or pile strikes over time, where the number of impulses replaces the  $T$  in the equation above, leading to:

$$Cumulative L_{E,p} = L_{E,p} + 10 \times \log_{10} X$$

2.2.4.9 Where  $L_{E,p}$  is the sound exposure level of one impulse and  $X$  is the total number of impulses or strikes. Unless otherwise defined, all  $L_{E,p}$  noise levels in this report are referenced to 1  $\mu$ Pa<sup>2</sup>s.

## 2.3 PROPERTIES OF SOUND

### 2.3.1 IMPULSIVE VS NON-IMPULSIVE

2.3.1.1 Sound can be categorised loosely into 2 types: impulsive noise and non-impulsive noise. Non-impulsive noise can be defined as a steady-state noise which does not necessarily have a long duration (e.g. vibropiling, drilling). Impulsive noise can be defined as a sound with a high peak sound pressure, short duration, fast rise-time and a broad frequency content at the source (e.g., seismic airguns, explosives, impact piling).

2.3.1.2 These differences are important to consider regarding the potential for auditory injury, as impulsive noise is generally more injurious than non-impulsive noise.

2.3.1.3 Due to the differences between impulsive and non-impulsive noise sources, different metrics are appropriate for describing these different sound sources. For example:

- Impulsive noises: Use peak sound pressure level ( $L_{p,pk}$ ) and cumulative SEL ( $L_{E,p,t}$ );
- Non-impulsive noises: cumulative SEL ( $L_{E,p,t}$ ) or RMS sound pressure level ( $L_p$ ).

- 2.3.1.4 Objective categorisation of noise as impulsive or non-impulsive can sometimes be challenging. This is particularly the case if a sound is travelling over long distances. For example, if an impulsive sound propagates through an environment, the energy within the sound wave will also dissipate and it becomes less impulsive with distance from the noise source. This is important to consider regarding auditory injury and impact range calculations, as noise will become less injurious if it becomes less impulsive due to the spreading and elongation of the pulse with distance (Henderson and Hamernik, 1986).
- 2.3.1.5 Research has been undertaken to define the range-dependent transition from impulsive and non-impulsive noise (see Martin *et al.*, 2020). Although the situation is complex, Hastie *et al.* (2019) concluded that an impulsive sound can be considered effectively non-impulsive 3.5 km from the source. Using these findings, Southall (2021) suggests that noise should be considered non-impulsive when there is no longer energy content above 10 kHz.
- 2.3.1.6 The recent study by Matei *et al.* (2024) concludes that there is still insufficient evidence to clearly define a transition point suitable for an assessment such as this, although the paper makes it clear that there is a substantial reduction in impulsiveness within the first 5 km. Due to the uncertainty, no presumption of a change in impulsiveness has been made in this Technical Appendix, although non-pulse would be considered more relevant where Permanent Threshold Shift (PTS) ranges are calculated above 5 km.

## 2.3.2 PARTICLE MOTION

- 2.3.2.1 The motion of the particles that make up a medium is an important component of sound. Particle motion is present wherever there is sound, and it describes the back-and-forth movement of particles in water, which in the context of underwater noise, are caused by a sound wave passing through the water column. This back-and-forth movement means that, unlike sound pressure at a single point, particle motion always contains directional information (Hawkins and Popper, 2017). Regarding quantifying particle motion, it is usually defined in reference to the velocity of the particle (often a peak particle velocity), but sometimes the related acceleration or displacement of the particle is used.
- 2.3.2.2 It has been identified by several researchers that many fish species, (e.g., Popper and Hawkins, 2019; Nedelec *et al.*, 2016; Radford *et al.*, 2012), as well as marine invertebrates (see Sole *et al.*, 2023 for review and Section 2.4.4) are sensitive to particle motion. However, sound pressure metrics are still preferred and more widely used than particle motion due to a lack of supporting data (Popper and Hawkins, 2018). There continue to be calls for additional research on the levels of and effects on marine receptors with respect to levels of particle motion.

## 2.4 ANALYSIS OF ENVIRONMENTAL EFFECTS: ASSESSMENT CRITERIA

2.4.1.1 Over the last 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 adverse impacts in species is dependent upon the incident sound level, source 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 seismic airguns, impact piling, and blasting as these sources are likely to have the greatest immediate environmental impact and therefore the clearest observable effects, although interest in chronic noise exposure is increasing.

2.4.1.2 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);
- Behavioural responses.

2.4.1.3 The following sections discuss the underwater noise criteria used in this study with respect to species of marine mammals and fish that may be present around the study area.

2.4.1.4 The main metrics and criteria that have been used in this study to aid assessment of environmental effects come from 2 key papers covering underwater noise and its effects:

- Southall *et al.* (2019) marine mammal exposure criteria;
- Popper *et al.* (2014) sound exposure guidelines for fishes and sea turtles.

2.4.1.5 At the time of writing these are the criteria accepted by Scottish Statutory Nature Conservation Bodies for assessing environmental effects for use in impact assessments such as this.

### 2.4.2 MARINE MAMMALS

2.4.2.1 The Southall *et al.* (2019) paper is the most used and recognised reference for marine mammal hearing thresholds. It is effectively an update of the previous Southall *et al.* (2007) paper and provides identical thresholds to those from the National Marine Fisheries Service (NMFS) (2018) guidance for marine mammals. It should be noted that, despite the identical thresholds, the marine mammal hearing groups are described slightly differently in the Southall *et al.* (2019) paper to the NMFS (2018) guidance. Therefore, care should be taken when comparing results using the Southall *et al.* (2019) and NMFS (2018) criteria.

2.4.2.2 The Southall *et al.* (2019) guidance categorises marine mammals into groups of similar species and applies filters to the unweighted noise to approximate the hearing sensitivities of the receptor in question. The hearing groups given by Southall *et al.* (2019) are summarised in **Table 2-1** and the relevant auditory weighting functions are shown in **Plate 2-1**. Further groups for sirenians and

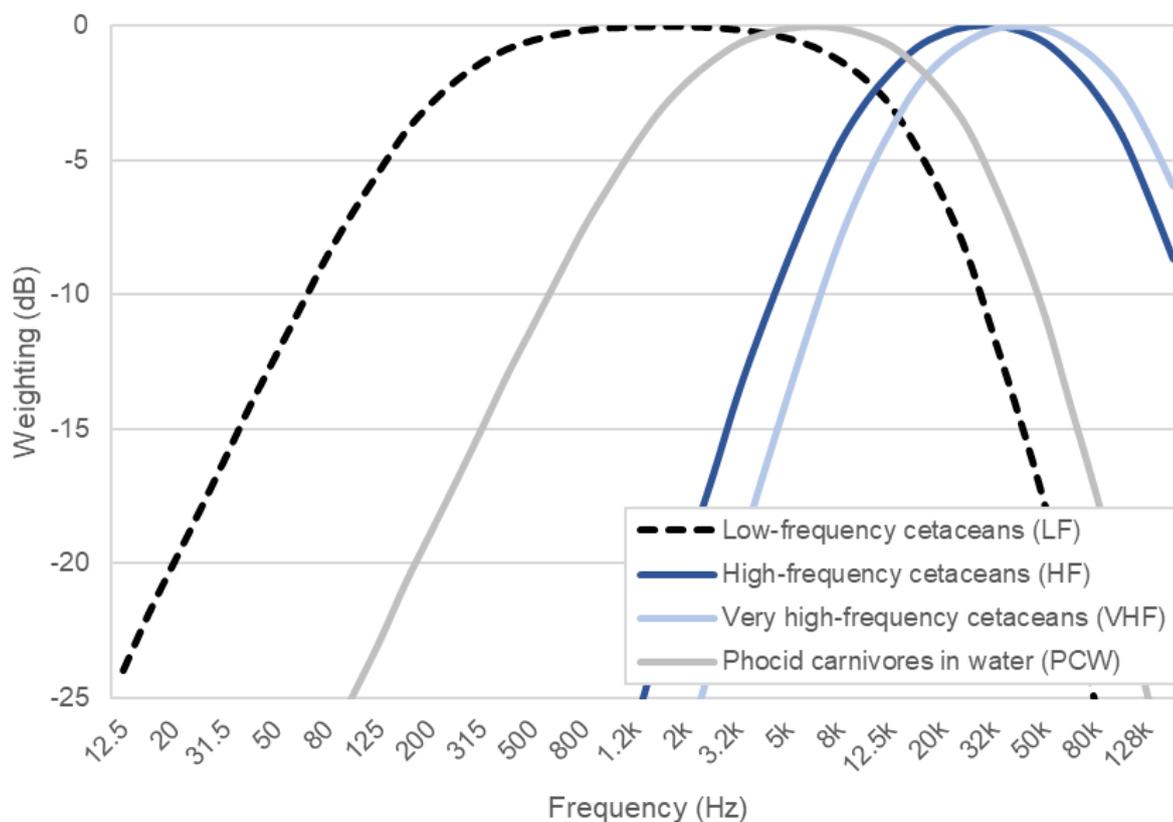
other marine carnivores in water (e.g. polar bears, fur seals, sea lions) are given, but these have not been included in this study as those species are not commonly found in the area (for further information see **Chapter 13, Volume 2a**).

2.4.2.3 It should be noted that despite Southall *et al.* (2019) referring to peak SPL as  $SPL_{peak}$ , the notation in the rest of this appendix will be  $L_{p,pk}$  as per International Organisation for Standardisation (ISO) 18405:2017.

Table 2-1 Marine mammal hearing groups (from Southall *et al.*, 2019).

Hearing group	Generalised hearing range	Example species
Low-frequency cetaceans (LF)	7 Hz-35 kHz	Baleen whales
High-frequency cetaceans (HF)	150 Hz-160 kHz	Dolphins, toothed whales, beaked whales, bottlenose whales (including bottlenose dolphin)
Very high-frequency cetaceans (VHF)	275 Hz-160 kHz	True porpoises (including harbour porpoise)
Phocid carnivores in water (PCW)	50 Hz-86 kHz	True seals (including harbour seals)

Plate 2-1 Auditory weighting functions for low-frequency cetaceans (LF), high-frequency cetaceans (HF), very high-frequency cetaceans (VHF), and phocid carnivores in water (PCW) (from Southall *et al.*, 2019)



2.4.2.4 Southall *et al.* (2019) presents noise impact thresholds for pre-categorised groups of marine mammals (described above), which are dependent on:

- The nature of the sound (impulsive vs non-impulsive);
- The type of auditory injury of concern.

2.4.2.5 Southall *et al.* (2019) considers the nature of the sound in the context of whether it is considered as impulsive or non-impulsive noise source (see Section 2.3.1 for details).

2.4.2.6 Although the use of impact ranges derived using the impulsive criteria are recommended for all but clearly non-impulsive sources, it should be recognised that where calculated ranges are beyond 5 km (see Section 2.3.1), the impact range is therefore likely to be somewhere between the modelled impulsive and non-impulsive impact range as the ranges will not be 'fully impulsive'.

2.4.2.7 **Table 2-2** and **Table 2-3** present the impulsive and non-impulsive criteria set out by Southall *et al.* (2019) for PTS and Temporary Threshold Shift (TTS) in marine mammals used in this study.

Table 2-2 Peak SPL ( $L_{p,pk}$ ) criteria for PTS and TTS in marine mammals (Southall *et al.*, 2019).

Southall <i>et al.</i> (2019)	$L_{p,pk}$ (dB re 1 $\mu$ Pa)	
	Impulsive	
	PTS	TTS
Low-frequency cetaceans (LF)	219	213
High-frequency cetaceans (HF)	230	224
Very high-frequency cetaceans (VHF)	202	196
Phocid carnivores in water (PCW)	218	212

Table 2-3 Cumulative SEL ( $L_{E,24h,wtd}$ ) criteria for PTS and TTS in marine mammals (Southall *et al.*, 2019).

Southall <i>et al.</i> (2019)	$L_{E,24h,wtd}$ (dB re 1 $\mu$ Pa <sup>2</sup> s)			
	Impulsive		Non-impulsive	
	PTS	TTS	PTS	TTS
Low-frequency cetaceans (LF)	183	168	199	179
High-frequency cetaceans (HF)	185	170	198	178
Very high-frequency cetaceans (VHF)	155	140	173	153
Phocid carnivores in water (PCW)	185	170	201	181

2.4.2.8 Where  $L_{E,p,t}$  thresholds are required for marine mammals, a fleeing animal model has been used in accordance with standard practice in underwater noise assessments in Scottish waters. This assumes that a marine mammal receptor, when exposed to high noise levels, will swim away from the noise source. For this, the following flee speeds have been used for each marine mammal group:

- 2.1 m/s for LF cetaceans (Scottish Natural Heritage; SNH, 2016);
- 1.52 m/s for HF cetaceans (Bailey and Thompson, 2006);
- 1.4 m/s for VHF cetaceans (SNH, 2016);
- 1.8 m/s for PCW pinnipeds (SNH, 2016).

2.4.2.9 These are considered worst case assumptions, as marine mammals are expected to be able to swim much faster under stress conditions (Kastelein *et al.* 2018), especially at the start of any noisy process when the receptor will be closest.

2.4.2.10 Within each of the impulsive and non-impulsive noise criteria set out by Southall *et al.* (2019), different impact thresholds are presented depending on the potential of different levels of auditory injury at different noise levels of that sound. Auditory injury has been categorised into two types:

- PTS: the greatest severity, which is unrecoverable (but incremental) reduction in hearing sensitivity;
- TTS: the least severity, which is a short-term reduction in hearing sensitivity.

2.4.2.11 It should be noted that the greatest calculated impact range is usually associated with TTS. However, the effects from PTS represent the most significant and permanent impairment, and thus, PTS is usually quoted as the most important impact threshold. In summary, when using Southall *et al.* (2019) as assessment criteria to calculate impact ranges, 3 variables are considered:

- The marine mammal receptors within the area;
- The nature of the sound (and subsequent appropriate metrics);
- The type of auditory injury of concern.

### 2.4.3 FISH

2.4.3.1 The Popper *et al.* (2014) guidelines are a suitable reference for underwater noise impacts on marine fauna (aside from marine mammals) in UK waters, and the guidelines remain as requested by the Scottish SNCBs. Popper *et al.* (2014) provides a summary of the research and guidelines for fish (and other marine fauna) exposure to sound and uses categories for fish that are representative of the species present in the UK.

2.4.3.2 The Popper *et al.* (2014) guidelines present criteria dependent on noise source type, species of marine fauna (and their hearing capabilities), and impact type. The guidelines consider the source of the sound, and provides separate criteria for, as relevant to this study, pile driving, and shipping and other continuous noise.

- 2.4.3.3 For each sound source, criteria for the marine fauna are categorised into values for sea turtles, eggs and larvae, and fish. Due to their diversity and quantity, fish are categorised further into 3 groups depending on their hearing capabilities, which can be indicated by whether they possess a swim bladder or not, and whether the swim bladder is involved in hearing. These 3 categories are:
- Fish: no swim bladder;
  - Fish: swim bladder not involved in hearing;
  - Fish: Swim bladder involved in hearing.
- 2.4.3.4 Popper *et al.* (2014) provides separate criteria, depending on the species and the noise source, for various degrees of impact associated with noise exposure. These include:
- Mortality and potential mortal injury;
  - Impairment;
    - Recoverable injury;
    - TTS;
    - Masking;
  - Behavioural effects.
- 2.4.3.5 Where insufficient data is available, Popper *et al.* (2014) also gives a non-numerical criterion. This criterion summarises the effect of the noise as having either a high, moderate, or low relative risk of an effect on an individual in either the near-field (tens of meters), intermediate-field (hundreds of meters) or far-field (thousands of meters).
- 2.4.3.6 Where  $SEL_{cum}$  thresholds are required for fish, both a stationary and moving animal model has been included. This is due to the diversity of species considered under this criterion, and as a result, both models encompass the diversity of responses to noise. However, as per regulatory guidance, an assessment should primarily be based on the precautionary stationary model.
- 2.4.3.7 For species that are likely to move, a speed of 1.5 m/s (based on Hirata, 1999) was used in the animal movement model. An additional slower speed of 0.6 m/s was also considered to account for the movement of salmon post smolt, see below and **Appendix 12.1, Volume 2c**, and **Appendix 12.2: Atlantic Salmon Assessment Consultation, Volume 2c** for more information. However, responses to loud noise (e.g. whether to swim or remain stationary) varies between species, particularly given the diversity described by Popper *et al.* (2014). While it is recognised that there is limited evidence for fish fleeing from high level noise sources in the wild, species that are most likely to remain stationary are expected to be benthic species or species without a swim bladder, due to their reduced hearing capabilities, making these species the least sensitive to noise (e.g., Goertner *et al.*, 1994, 1978; Stephenson *et al.*, 2010; Halvorsen *et al.*, 2012). Despite this, including only a stationary animal model as a worst-case scenario is likely to overestimate the potential risk to fish species. A combined approach should be considered, which considers impact ranges from both moving and stationary receptors. Impact ranges from both stationary and moving receptors are therefore included in this appendix.

- 2.4.3.8 Specific consideration for fish movement is important for the Offshore Project. One of the key fish species is migrating salmon, which, by definition, are moving and not expected to remain stationary (see **Appendix 12.1, Volume 2c**). To account for this, salmon post smolt are considered mobile in the modelling, while there is a presumption that adult salmon will remain stationary.
- 2.4.3.9 Depending on the noise source, quantitative criteria are given in appropriate metrics ( $SPL_{peak}$ ,  $SPL_{rms}$ ,  $SEL_{cum}$  etc.), which can then be used as thresholds for onsets of listed impact. It should be noted the notation used by Popper *et al.* (2014) will be referred to as  $L_{p,pk}$ ,  $L_{p,RMS}$  and  $L_{E,p}$  respectively in the rest of this report, as per ISO 18405:2017.
- 2.4.3.10 The criteria set out by Popper *et al.* (2014) for pile driving are summarised in **Table 2-4**. It should be noted that salmon fall into the category of Fish: swim bladder not involved in hearing. Although Lucke *et al.* (2024) suggests options to account for the different sensitivities of fish hearing groups and subgroups, the adaptations for each group have a negligible effect at the relatively low frequencies which are most important in piling noise, around 100 Hz, and therefore the standard unweighted noise has been applied in noise modelling.

Table 2-4 Recommended guidelines for pile driving according to Popper *et al.* (2014) for species of fish, sea turtles and eggs and larvae (N = Near-field; I = Intermediate-field; F = Far-field).

Type of fish	Mortality and potential mortal injury	Impairment			Behaviour
		Recoverable injury	TTS	Masking	
Fish: no swim bladder	$>219 L_{E,p}$ $>213 L_{p,pk}$	$>216 L_{E,p}$ $>213 L_{p,pk}$	$>> 186 L_{E,p}$	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder not involved in hearing	$210 L_{E,p}$ $>207 L_{p,pk}$	$203 L_{E,p}$ $>207 L_{p,pk}$	$> 186 L_{E,p}$	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder involved in hearing	$207 L_{E,p}$ $>207 L_{p,pk}$	$203 L_{E,p}$ $>207 L_{p,pk}$	$186 L_{E,p}$	(N) High (I) High (F) Moderate	(N) High (I) High (F) Moderate
Sea Turtles	$210 L_{E,p}$ $>207 L_{p,pk}$	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	(N) High (I) Moderate (F) Low	(N) High (I) Moderate (F) Low
Eggs and Larvae	$>210 L_{E,p}$ $>207 L_{p,pk}$	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low

2.4.3.11 Impact range results for impulsive sources based on the criteria above are given in Section 4.

2.4.3.12 Continuous, non-impulsive noise sources (e.g. drill and grout piling, operational WTG noise) will be considered in Section 5, and the following criteria in from Popper *et al.* (2014) are relevant. In this, only quantitative criteria exist for the most sensitive fish species.

Table 2-5 Recommended guidelines for shipping and continuous sounds according to Popper *et al.* (2014) for species of fish, sea turtles and eggs and larvae (N = Near-field; I = Intermediate-field; F = Far-field).

Type of fish	Mortality and 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 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	170 dB L <sub>p</sub> for 48 hrs	158 dB L <sub>p</sub> for 12 hours	(N) High (I) High (F) High	(N) High (I) Moderate (F) Low
Sea Turtles	(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) High (I) Moderate (F) Low
Eggs and Larvae	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) High (I) Moderate (F) Low	(N) Moderate (I) Moderate (F) Low

2.4.3.13 It is important to note that despite the emerging evidence that fish are sensitive to particle motion (see Section 2.3.2), the Popper *et al.* (2014) criteria define noise impacts in terms of sound pressure or sound pressure-associated functions (i.e. SEL).

2.4.3.14 It has been suggested that the criteria set out by Popper *et al.* (2014) could have been derived from unmeasured particle motion, as well as sound pressure. Whilst this may be true, sound pressure remains the preferred metric in the criteria due to a lack of data surrounding particle motion (Popper and Hawkins, 2018), particularly in regarding the ability to predict the consequences of the particle motion of a noise source, and the sensitivity of fish to a specific particle motion value. Therefore, as stated by Popper and Hawkins (2019): "*since there is an immediate need for updated criteria and guidelines on potential effects of anthropogenic sound on fishes, we recommend, as do our colleagues in Sweden (Andersson et al., 2017), that the criteria proposed by Popper et al. (2014) should be used.*"

#### 2.4.4 MARINE INVERTEBRATES

- 2.4.4.1 A review by Solé *et al.* (2023) highlights the increasing evidence that some types of anthropogenic noise can negatively impact a variety of marine invertebrate taxa. These impacts include changes in behaviour, physiology, and rate of mortality, as well as physical impairment, at the individual, population, or ecosystem level. Much of the damage from exposure to noise comes from vibration of the invertebrate body (André *et al.*, 2016) caused by the passage of sound.
- 2.4.4.2 Comparatively, the studies described by Solé *et al.* (2023) show a general inconsistency in the way noise impacts have been quantified for marine invertebrates. For example, Hubert *et al.* (2021) notes behavioural changes in blue mussels to 150 and 300 Hz tones, whereas Spiga *et al.* (2016) describes behavioural changes in the same species at  $L_{E,p}$  (single pulse) 153.47 dB re 1  $\mu$ Pa. These inconsistencies make it difficult to generate accurate thresholds for the onset of any impact for species. A notable exception is the cephalopods group, in which several studies, mainly by Solé *et al.* (2013, 2018, 2019) and André *et al.* (2011) show a consistent threshold for auditory damage on various species of cephalopod at 157 dB re 1  $\mu$ Pa. While further research is needed even on this group to ensure accurate thresholds which are satisfactory to regulators, the current state of research on cephalopods sets a goal for the research required for other marine invertebrate groups, if they are to be used usefully as impact thresholds.
- 2.4.4.3 The meta-analysis conducted by Solé *et al.* (2023) also reveals inconsistencies in the responses of taxonomically near species of marine invertebrates to the effect of anthropogenic noise. For example, Fields *et al.* (2019) demonstrates low mortality of zooplankton during seismic airguns, whereas for the same noise source, McCauley *et al.* (2017) showed mass mortality of krill larvae. Clearly, the effect of noise on one species may not necessarily be applicable on another species despite being taxonomically near, which again makes it difficult to generate a generalised impact threshold that can confidently be applied to different taxonomic groups of marine invertebrates.
- 2.4.4.4 In its current state, research on the effects of anthropogenic noise on marine invertebrates is emerging, but more slowly than for marine mammals and fish. At this time, this research is in too early a stage to be used to accurately generate impact thresholds which would be satisfactory to regulators. The data available could potentially be referenced for some species but with caution, as there are still considerable gaps in the knowledge that would enable reliable conclusions for the impact of noise for most species.

## 3 UNDERWATER NOISE MODELLING: METHODOLOGY

### 3.1 INTRODUCTION: INSPIRE

- 3.1.1.1 The modelling of impact piling has been undertaken using the INSPIRE underwater noise model. The INSPIRE model (currently version 5.3) is an underwater noise propagation model that is designed to calculate the propagation of noise in shallow (i.e., less than 100 m), mixed water, typical of the conditions around the UK and well suited to the area around the Offshore Project.
- 3.1.1.2 The scenarios that have been modelled using the INSPIRE model encompass 6 piling locations to fully represent the spatial variation across the site, using both mitigated (using noise abatement system) and unmitigated piling scenarios.
- 3.1.1.3 Further details of these scenarios are presented in Section 3.2. Noise sources likely to be present at Offshore Project during the construction (e.g. drill and grout piling) and operational (e.g. WTG operational noise) phases are presented in Section 5.

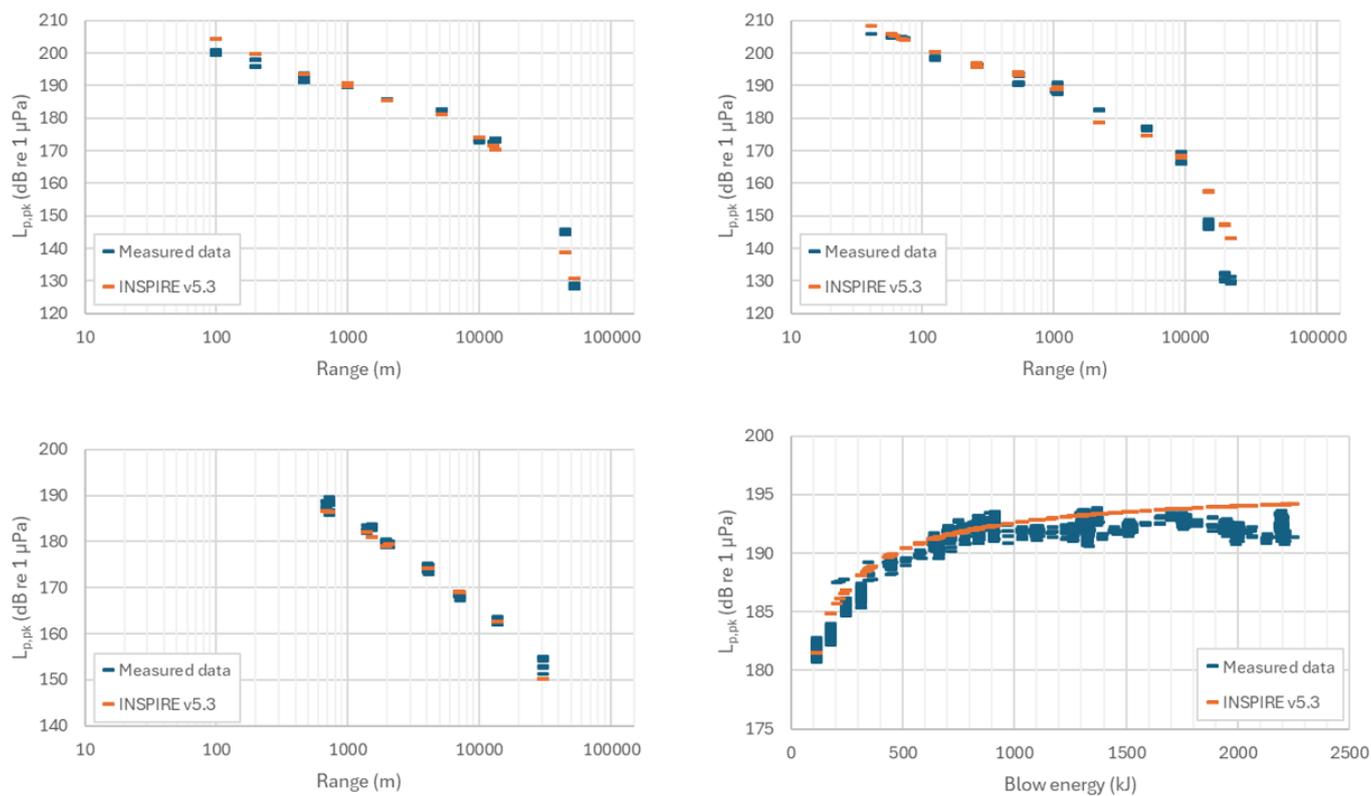
#### 3.1.2 CONFIDENCE

- 3.1.2.1 The INSPIRE model is semi-empirical and as such 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, either by Subacoustech Environmental or a third party, it is compared against the outputted levels from INSPIRE and, if necessary, the model can be adjusted. Currently over 100 separate impact piling noise datasets primarily from the North and Irish Seas have been used as part of the development for the latest version of INSPIRE, and in each case, an average, or slightly conservative, fit to the data is used. This means that for a given parameter set, some measured data points will be louder than the predicted level. Making the model over-predict for all parameters ultimately would lead to an over-precautionary and unrealistic model.
- 3.1.2.2 In addition, INSPIRE is validated by comparing the noise levels outputted from the model with measurements and modelling undertaken by third parties, for example Thompson *et al.* (2013) and Thomson *et al.* (in prep.).
- 3.1.2.3 The largest pile diameter included in the analysis was of 9.5 m, and the highest blow energy included was 3,000 kJ.
- 3.1.2.4 INSPIRE is designed to predict trends in the effect of increasing parameters beyond empirical data, and uses the data combined with standard acoustic theory to predict the effect of greater blow energies, larger piles and deeper water on the noise levels produced and propagated in the water.
- 3.1.2.5 The version of INSPIRE used for the Offshore Project (v5.3) is the product of reanalysing all the impact piling noise in Subacoustech Environmental's measurement database, and any other data available, and cross-referencing it with blow energy data from piling logs. This gives a database of

single strike noise levels referenced to a specific blow energy at a specific range and environmental conditions, primarily water depth.

- 3.1.2.6 Previous iterations of the INSPIRE model have endeavoured to give a worst-case estimate of underwater noise levels produced by various permutations of impact piling parameters. There is always some natural variability with underwater noise measurements, even when considering measurements of pile strikes under the same conditions (i.e., at the same blow energy, taken at the same range). For example, there can be variations in noise level of up to 5 or even 10 dB, as seen in Bailey *et al.* (2010) and the data shown in **Plate 3-1** and **Plate 3-2**. When modelling using the upper bounds of this range, in combination with other worst-case parameter selections, conservatism can be compounded to create excessively overcautious predictions, especially when calculating  $L_{E,p,t}$ . With this in mind, the current version of INSPIRE attempts to calculate closer to the average fit of the measured noise levels at all ranges, which maintains an additional degree of precaution in the estimation.
- 3.1.2.7 **Plate 3-1** and **Plate 3-2** present a small selection of the measured impact piling noise data plotted against outputs from INSPIRE. The plots show data points from measured data (in blue) plotted alongside modelled data (in orange) using INSPIRE v5.3, matching the pile size, blow energy and position of the measured data. These show the fit to the data, with the INSPIRE data points placed, more or less, in the middle of the measured noise levels at each range (as also shown in **Plate 3-3** and **Plate 3-4**). When combined with the worst-case assumptions in parameter selection, modelled results will remain precautionary. The greatest deviations from the model tend to be at the greatest distances (> 10 km), where INSPIRE appears over-precautionary in many cases, but due to the lower relative levels the influence on the overall  $L_{E,p,t}$  exposure will be small.
- 3.1.2.8 Statistical analysis has been carried out of the fits between measured data and modelled data to show the confidence present in INSPIRE modelling using v5.3. **Plate 3-3** and **Plate 3-4** show the distribution of the predicted against measured data for a slightly conservative fit with unweighted  $L_{p,pk}$  ( $R^2 = 0.79$ ) and unweighted  $L_{E,p,ss}$  ( $R^2 = 0.82$ ).

Plate 3-1 Comparison between example measured  $L_{p,pk}$  impact piling data (blue) and modelled data using INSPIRE version 5.3 (orange)<sup>1</sup>.



<sup>1</sup> Top Left: 6.0 m pile, 890 kJ max hammer energy, Irish Sea, 2010; Top Right: 5.2 m pile, 1,700 kJ max hammer energy, Lincolnshire Coast, 2011; Bottom Left: 1.8 m pile, 300 kJ max hammer energy, North Sea, 2011; Bottom Right: 8.9 m pile, 1.5 km range, 2,250 kJ max hammer energy, North Sea, 2024.

Plate 3-2 Comparison between example measured  $L_{E,p,ss}$  impact piling data (blue) and modelled data using INSPIRE version 5.3 (orange)!

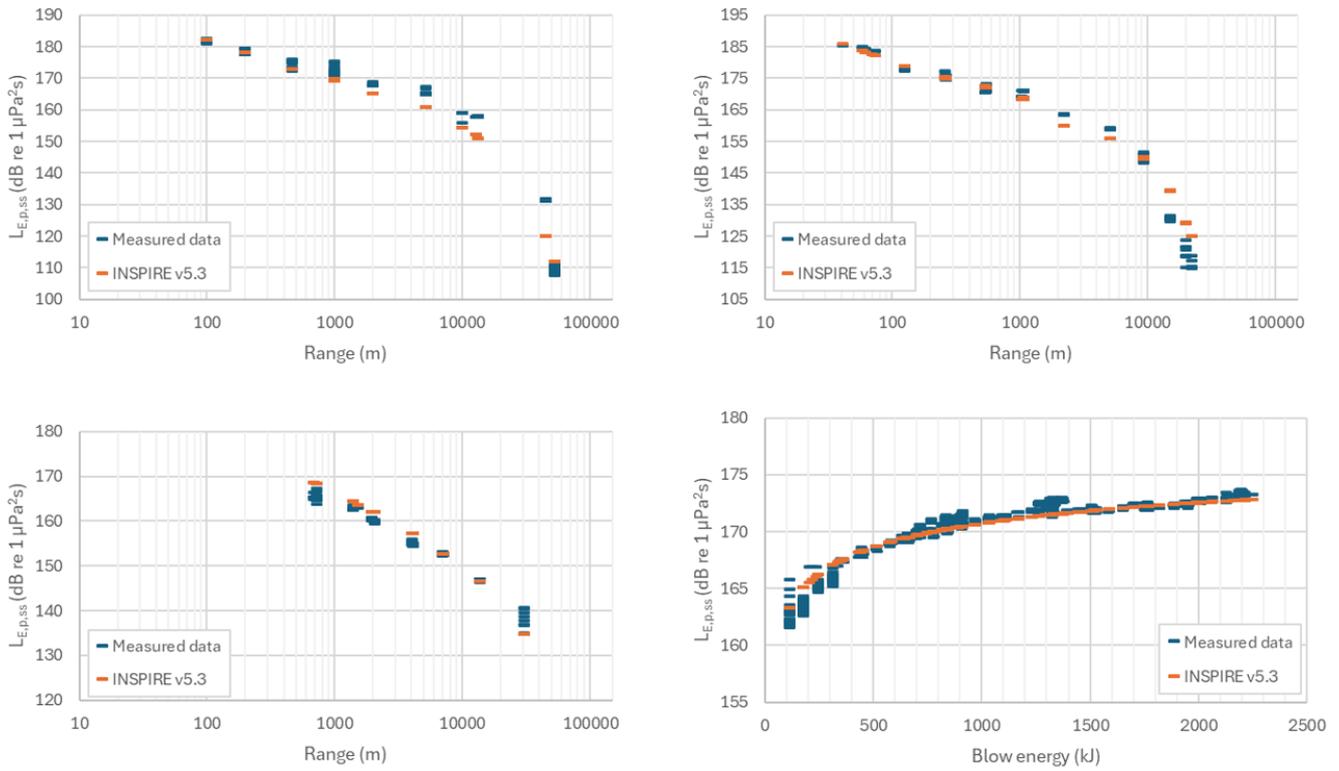


Plate 3-3 Distribution of measured impact piling data against modelled levels using INSPIRE v5.3 for unweighted  $L_{p,pk}$  ( $R^2 = 0.79$ ).

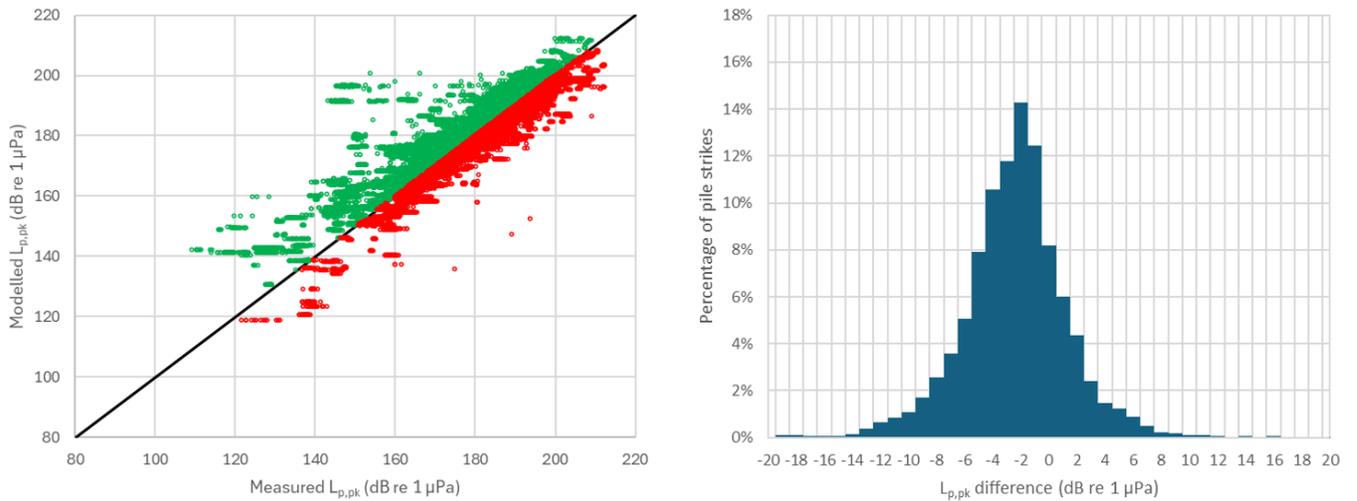
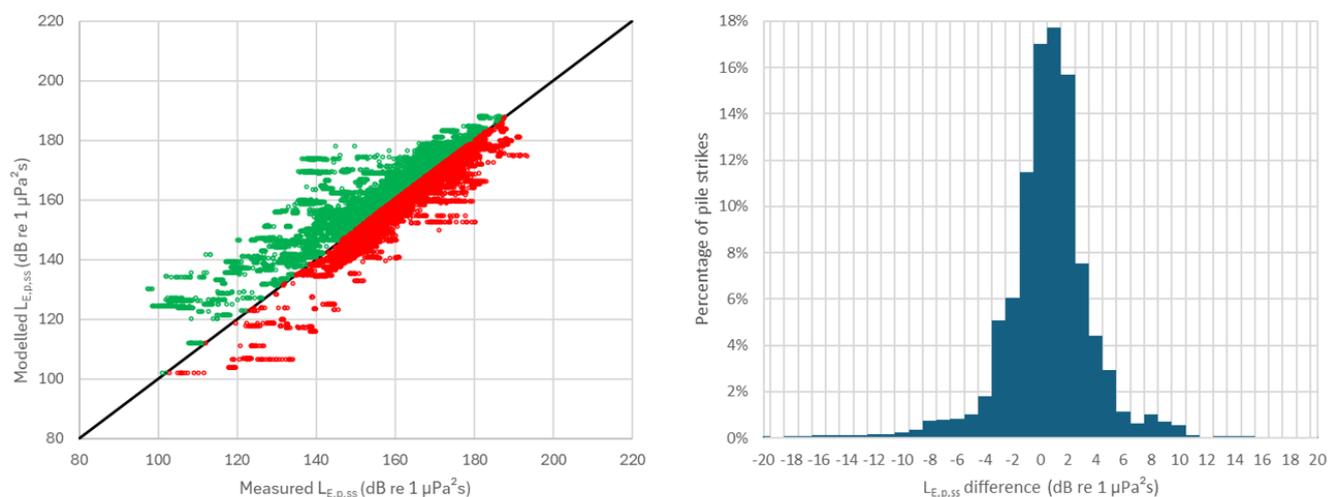


Plate 3-4 Distribution of measured impact piling data against modelled levels using INSPIRE v5.3 for unweighted  $L_{E,p,ss}$  ( $R^2 = 0.82$ ).



3.1.2.9 Additional validation has been undertaken using data presented by von Pein *et al.* (2022), which studied trends in noise level with changes in piling parameters using data primarily acquired in the North Sea and Baltic Sea. The data showed a strong correlation with blow energy, and a lower correlation with pile diameter, which Subacoustech Environmental agrees with, although the calculated correlation based on that data appears to overestimate its trend. **Plate 3-5** and **Plate 3-6** are adapted from von Pein *et al.* (2022), replicating their results and overlaying with measured data from Subacoustech Environmental (selecting samples taken at the reference distance) and results at equivalent datapoints using INSPIRE v5.3.

3.1.2.10 This shows a very good agreement with Subacoustech Environmental's data (relating to blow energy). It should be noted that the upper and lower bounds for a correlation of noise level with pile diameter, based on the von Pein *et al.* (2022) data alone, could easily be close to horizontal; there is also no control for blow energy, which is not constant. With the inclusion of Subacoustech Environmental's data, there is little correlation at greater pile diameters, and it can be seen that the variations at a single pile diameter are largely controlled by changes in blow energy.

Plate 3-5 Data relating blow energy to noise level ( $L_{E,p,ss}$ ) adapted from von Pein (2022) (green) overlaid with Subacoustech Environmental measured data (blue) and INSPIRE v5.3 predictions (orange). Upper and Lower bounds from von Pein (2022).

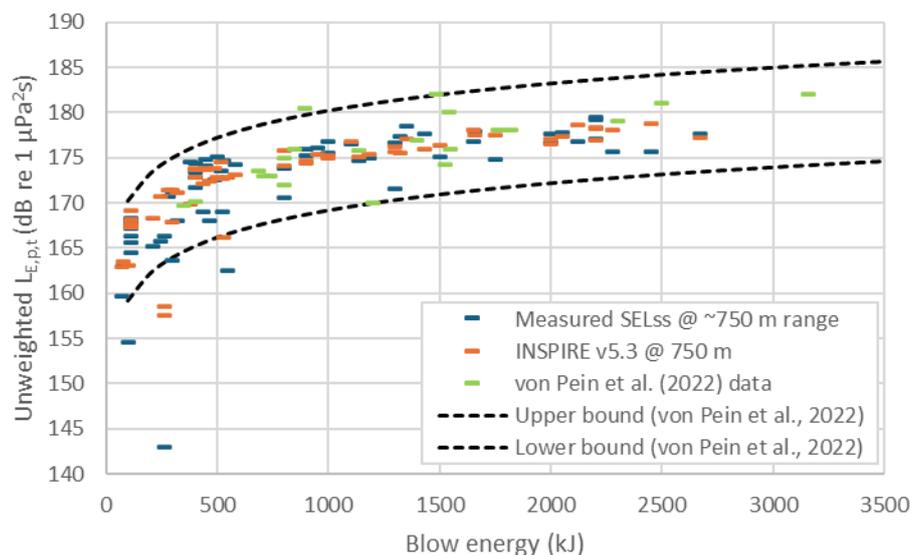
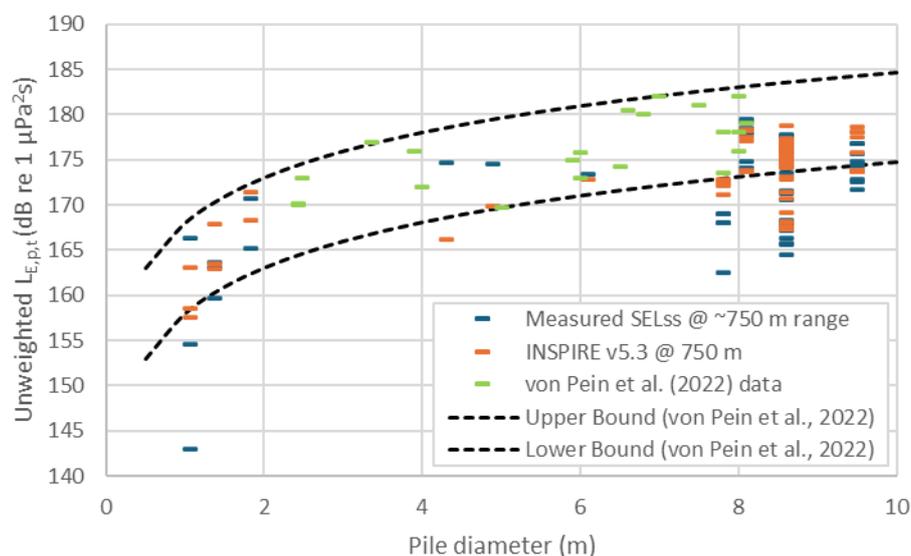


Plate 3-6 Data relating blow energy to noise level ( $L_{E,p,ss}$ ) adapted from von Pein (2022) (green) overlaid with Subacoustech Environmental measured data (blue) and INSPIRE v5.3 predictions (orange). Upper and Lower bounds from von Pein (2022).



### 3.1.3 OUTPUTS

3.1.3.1 The INSPIRE model estimates  $L_{p,pk}$ ,  $L_{E,p,ss}$  and  $L_{E,p,t}$  noise levels, as well as various other weighted noise metrics. Calculations are made along 180 equally spaced radial transects (one every 2 degrees). 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 can then be plotted over digital bathymetry

data so that impact ranges can be clearly visualised, as necessary. INSPIRE also produces these contours as Geographic Information System shapefiles.

3.1.3.2 INSPIRE considers a wide array of input parameters, including variations in bathymetry and source frequency to ensure accurate results are produced specific to the location and nature of the piling operation. It should also be noted that the results should be considered conservative as maximum design parameters and worst-case assumptions have been selected for:

- Piling hammer blow energies, with a maximum at each location used for the majority of the piling time;
- Strike rate;
- Total duration of piling.

3.1.3.3 Full details of these are provided in Section 3.2. These methods meet the requirements set by the National Physical Laboratory (NPL) Good Practice Guide 133 for underwater noise measurement (Robinson *et al.*, 2014).

## 3.2 INSPIRE MODELLING PARAMETERS

### 3.2.1 MODELLING LOCATION

3.2.1.1 Modelling for impact piling has been undertaken at 6 locations, shown in **Plate 3-7**. Within the Array Area is a section known as the buried channel. These locations were chosen to demonstrate the effect of noise from piling in different conditions, depths and restrictions across the site. Details are provided in Section 3.2.3. No modelling was undertaken in the south-west section of the Array Area as this is reserved for pile installation using a drill and grout technique, and no impact piling will take place here.

3.2.1.2 2 types of pile will be driven, inside and outside the part of the Array Area known as the Buried Channel, shown in **Plate 3-7**. The first will be within the Buried Channel, where pin piles will be installed as the main WTG foundation. Outside this, pile casings will be driven; both these and the pin piles are steel cylinders of 5 m diameter. The main difference between them in respect of noise modelling is the duration of piling, which is shown in detail in Section 3.2.3.

3.2.1.3 The underwater noise produced by impact piling is controlled to a great extent by the blow energy directed by the hammer to the pile and then radiated as sound into the surrounding water. The sensitivity of Loch Roag/*Loch Ròg* to the south of the site is a specific concern for salmon, which meant that special efforts were needed to reduce the noise that could reach this location. As a method of mitigation to reduce the underwater noise levels, the hammer energy is proposed to be restricted in parts of the Array Area closer to Loch Roag/*Loch Ròg*. This restriction would lead to a suitable attenuation such that the risk of TTS in fish does not interfere at Loch Roag/*Loch Ròg*. As

part of the process of blow energy limitation in modelling, the site was split into a series of bands where a certain maximum energy will not be exceeded in piling. This is shown in **Plate 3-7**.

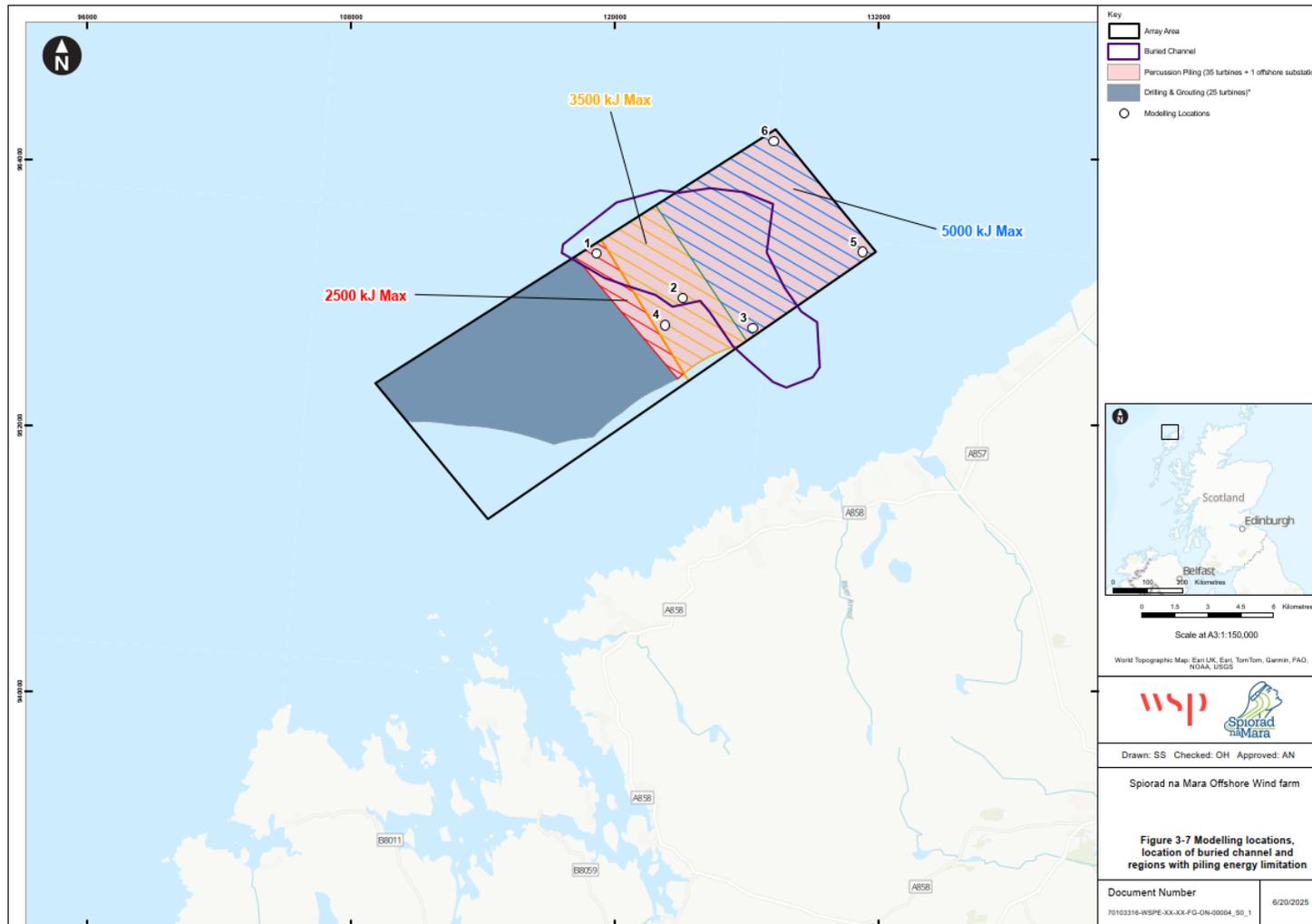
3.2.1.4 The locations chosen for modelling represent real proposed WTG locations, and therefore may not appear to be at the most 'extreme' position in the Array Area, note particularly Location 4. These locations, as well as the depth at Mean Sea Level, are summarised in **Table 3-1**.

Table 3-1 Summary of the underwater noise modelling locations.

Modelling locations		Co-ordinates (DD)		Depth (m)
		Latitude	Longitude	
1	WTG 19	58.4352	-6.8210	58.0
2	WTG 36	58.4193	-6.7444	52.6
3	WTG 49	58.4107	-6.6820	46.9
4	WTG 30	58.4086	-6.7720	49.9
5	WTG 60	58.4442	-6.6009	44.7
6	WTG 48	58.4887	-6.6826	62.1

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Plate 3-7 Map of each modelling location in the context of the Array Area



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## 3.2.2 ENVIRONMENTAL CONDITIONS

- 3.2.2.1 With the inclusion of measured noise propagation data for similar offshore piling operations in UK waters, the INSPIRE model intrinsically accounts for various environmental conditions. This includes the differences that can occur with the temperature and salinity of the water, as well as the sediment type surrounding the site.
- 3.2.2.2 Based on EUSeaMap 2021 data, the seabed across the Offshore Project Boundary is characterised by a range of substrata, including boulders and cobbles, pebbles and shingle, coarse sands, sands, fine sands, muds and mixed sediments.
- 3.2.2.3 EUNIS 2007 mapping predicted that the majority of the Offshore Project Boundary is comprised of A5.14 'Circalittoral coarse sediments' followed by A4.1 Atlantic and mediterranean high energy circalittoral rock. A5.15 'Deep circalittoral sediment' is also located outside of the Offshore Project Boundary. Habitats are displayed within **Figure 11.3: EUNIS 2007 habitats located within the vicinity of the Offshore Project Boundary, Volume 2b** and **Figure 11.4: EUNIS 2019 habitats located within the vicinity of the Offshore Project Boundary, Volume 2b**.
- 3.2.2.4 The site-specific survey at DDC stations within the Array Area identified a total of 3 EUNIS Level 3 Broad Scale Habitats (BSHs), 4 EUNIS Level 4 habitat complexes, 1 EUNIS Level 5 biotope complex and 1 EUNIS Level 6 biotope in the seabed imagery. **Chapter 11, Volume 2a** provides a full description of the seabed habitat, see Section 11.6.
- 3.2.2.5 Digital bathymetry obtained from SeaZone has been used for this modelling and water depths for average tide have been used throughout.

## 3.2.3 IMPACT PILING PARAMETERS

- 3.2.3.1 The piling parameters used in the modelled scenarios are as follows, with maximum energy limited in the bands noted above. Locations 1 to 3 represent locations where pin piles will be installed in the buried channel, Locations 4 to 6 are locations where casings will be installed outside the buried channel. The maximum blow energies used in each band reduce at locations closest to the south west of the area of the site where impact piling could occur. This is explained in Section 3.2.1.
- Pile types modelled per location:
    - Pin piles = 5 m diameter, in the buried channel, with a maximum blow energy of:
      - Location 1 (most south-western band): 2500 kJ;
      - Location 2 (central band): 3500 kJ;
      - Location 3 (most north-eastern band): 5000 kJ;
    - Casing = 5 m diameter, outside the buried channel with a maximum blow energy of:
      - Location 4 (south-west of buried channel): 3500 kJ;
      - Location 5 and 6 (north-east of buried channel): 5000 kJ;
  - Each pile could take up to a total of:

- Pin piles (buried channel): 5.5 hours to drive, including a soft start and ramp up;
- Casing (outside buried channel): 4.5 hours to drive, including a soft start and ramp up;
- Each pile will be installed at a strike rate of 34 blows per minute except in the soft start, where there is a single blow phase of 1 blow per minute for 5 minutes, after which it is up to 6 blows per minute for 15 minutes;
  - Therefore, per 24-hours, piling is modelled to include a total of:
    - 10,635 strikes during 5.5 hours of piling;
    - 8,595 strikes during 4.5 hours of piling.

3.2.3.2 In principle this could include any number of piles driven in a day, provided the total energy is not significantly exceeded (for example, a 10% exceedance would not lead to a noticeable increase in impact ranges). Where multiple piles were driven, this would be beneficial overall as it would occur over a longer period, and so where a receptor can move, this would allow greater time for the receptor to distance itself from the noise source. It would have no or negligible impact on a stationary receptor.

3.2.3.3 This information is summarised in **Table 3-2** to **Table 3-6**.

Table 3-2 Summary of the input parameters, used for modelling impact piling, Location 1 (Pin Piles)

Location 1	Single Blow	Soft Start	Ramp up				Maximum
Energy (kJ)	550	550	1,100	1,500	1,900	2,200	2,500
No. of strikes	5	90	340	340	340	340	9,180
Duration (s)	300	900	600	600	600	600	16,200
Strike rate (bl/min)	1	6	34	34	34	34	34

Total energy delivered: 25,280,250 kJ

Table 3-3 Summary of the input parameters, used for modelling impact piling, Location 2 (Pin Piles)

Location 2	Single Blow	Soft Start	Ramp up				Maximum
Energy (kJ)	550	550	1,100	1,800	2,500	3,000	3,500
No. of strikes	5	90	340	340	340	340	9,180
Duration (s)	300	900	600	600	600	600	16,200
Strike rate (bl/min)	1	6	34	34	34	34	34

Total energy delivered: 35,038,250 kJ

Table 3-4 Summary of the input parameters, used for modelling impact piling, Location 3 (Pin Piles)

Location 3	Single Blow	Soft Start	Ramp up				Maximum
Energy (kJ)	550	550	1,100	2,200	3,300	4,400	5,000
No. of strikes	5	90	340	340	340	340	9,180
Duration (s)	300	900	600	600	600	600	16,200
Strike rate (bl/min)	1	6	34	34	34	34	34

Total energy delivered: 49,692,250 kJ

Table 3-5 Summary of the input parameters, used for modelling impact piling, Location 4 (Casing)

Location 4	Single Blow	Soft Start	Ramp up			Maximum
Energy (kJ)	550	550	1,100	1,800	2,500	3,500
No. of strikes	5	90	340	340	680	7,140
Duration (s)	300	900	600	600	1,200	12,600
Strike rate (bl/min)	1	6	34	34	34	34

Total energy delivered: 27,728,250 kJ

Table 3-6 Summary of the input parameters, used for modelling impact piling, Location 5 and 6 (Casing)

Locations 5 and 6	Single Blow	Soft Start	Ramp up			Maximum
Energy (kJ)	550	550	1,100	2,200	3,300	4,400
No. of strikes	5	90	340	340	680	7,140
Duration (s)	300	900	600	600	1,200	12,600
Strike rate (bl/min)	1	6	34	34	34	34

Total energy delivered: 39,492,250 kJ

### 3.2.4 SOURCE LEVELS AND PREDICTED LEVELS AT 750 M

- 3.2.4.1 Noise modelling requires knowledge of the source level, which is the theoretical noise level at 1 m from the noise source. The source level is estimated based on the pile diameter and the blow energy used on it by the hammer. It is worth noting that the 'source level' technically does not exist in the context of many shallow water noise sources (Heaney *et al.* 2020). In underwater noise modelling such as this, it is effectively an 'apparent source level' and simply a value that can be used to produce correct noise levels at range (for a specific model), as required in impact assessments.
- 3.2.4.2 The unweighted  $SPL_{peak}$  and  $SEL_{ss}$  source levels estimated for this study are provided in **Table 3-7**. These are based on the maximum hammer energy predicted to be used at each site. These figures are presented in accordance with common requests by regulatory authorities, although as indicated above they are not 'real' or necessarily compatible or comparable with any other model or predicted source levels.
- 3.2.4.3 In addition to the apparent source levels, it is also useful to look at the potential noise levels at a range of 750 m from the noise source, which is a common feature of underwater noise studies where the primary consideration is impact piling. This has the added advantage of being comparable with other modelling or measurements (as a valid measurement can be taken at this distance), where the source level or apparent source level cannot. A summary of the modelled unweighted levels at a range of 750 m are given below, considering the transect with the greatest noise transmission at each location while piling at the maximum hammer blow energy.

Table 3-7 Summary of the unweighted SPL<sub>peak</sub> and SEL<sub>ss</sub> source levels used for modelling and predicted levels at 750 m

Location	Source level @ 1 m and Level @ 750 m			
	SPL <sub>peak</sub> (dB re 1 µPa)		SPL <sub>peak</sub> (dB re 1 µPa)	
	1 m	750 m	1 m	750 m
Location 1	245.6	201.9	217.1	179.5
Location 2	245.9	202.0	217.9	180.1
Location 3	246.2	201.9	218.6	180.7
Location 4	245.9	201.8	217.9	180.0
Location 5	246.1	201.7	218.6	180.6
Location 6	246.3	202.7	218.6	181.1

### 3.2.5 MODELLING SCENARIOS

- 3.2.5.1 Impact piling is modelled at all locations with the parameters in Section 3.2.3 without any physical noise mitigation other than the soft start and maximum piling energy restrictions as previously noted. Any piling undertaken for the Offshore Project will however include a system for noise abatement, which will provide a reduction in the noise that can spread to the surrounding water. A specific system for this is not yet confirmed but a noise reduction of 12 dB will be achieved and has been included in the mitigated modelling results.
- 3.2.5.2 Both mitigated and unmitigated scenarios are modelled; as the unmitigated condition is not proposed in practice, results for this are provided as a baseline.

## 4 UNDERWATER NOISE MODELLING: RESULTS

- 4.1.1.1 The results of these mitigated and unmitigated INSPIRE underwater noise modelling scenarios, for each location, are given in terms of the marine mammal assessment criteria using Southall *et al.* (2019) for impulsive noise, and the fish assessment criteria using Popper *et al.* (2014) for pile driving (see Section 2.3 for details).
- 4.1.1.2 Throughout this appendix, any predicted ranges smaller than 50 m and areas less than 0.01 km<sup>2</sup> for single strike criteria and ranges smaller than 100 m and areas less than 0.1 km<sup>2</sup> for cumulative criteria have not been presented precisely. At ranges this close to the noise source, the modelling processes are unable to model to a sufficient level of accuracy due to complex acoustic effects present near the source. These ranges are given as “less than” this limit (e.g. < 100 m).
- 4.1.1.3 Ranges not given, provided as a “-”, are for situations where the relevant threshold is not exceeded at source (i.e., the apparent source level is lower than the threshold).
- 4.1.1.4 The greatest impact ranges were found at Location 6, furthest to the north, on account of it being closest to the deepest water and where the highest hammer blow energies were used. At this location the maximum PTS impact ranges (using mitigation) for marine mammals were for LF cetaceans and were 1,500 m. The equivalent TTS range is 49 km for LF cetaceans. This is in contrast to the most southerly modelled location (Location 4), where the equivalent maximum PTS impact range was 500 m (TTS at a maximum of 38.5 km).
- 4.1.1.5 For fish, the maximum recoverable injury range (stationary fish, with noise mitigation) was 1,300 m, but less than 100 m where the fish are assumed to be moving. The equivalent maximum TTS range (stationary) was 15 km, or 4.9 km where fish are assumed to be moving. In Location 4 furthest south and closest to the entrance to Loch Roag/*Loch Ròg*, this recoverable injury range was 1,100 m (TTS max. 12 km), and also less than 100 m (TTS max. 2.7 km) where the fish are assumed to be moving.
- 4.1.1.6 As a visual aid, plots showing the fish impact range contours are given in **Annex 13.3.1, Volume 2c**.

## 4.2 LOCATION 1

### 4.2.1 MARINE MAMMALS

Table 4-1 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 1 using the Southall *et al.* (2019)  $L_{p,pk}$  marine mammal criteria for impulsive noise sources

Southall <i>et al.</i> (2019) $L_{p,pk}$ (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
PTS (impulsive)	LF	< 0.01	< 50	< 50	< 50	0.01	70	60	65
	HF	-	-	-	-	< 0.01	< 50	< 50	< 50
	VHF	0.05	130	130	130	1.7	750	740	750
	PCW	< 0.01	< 50	< 50	< 50	0.02	80	70	75
TTS (impulsive)	LF	< 0.01	< 50	< 50	< 50	0.07	160	150	150
	HF	-	-	-	-	< 0.01	< 50	< 50	< 50
	VHF	0.29	300	300	300	9.6	1,800	1,800	1,800
	PCW	< 0.01	< 50	< 50	< 50	0.1	180	170	175

Table 4-2 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 1 using the Southall *et al.* (2019)  $L_{E,p,t}$  marine mammal criteria for impulsive noise sources

Southall <i>et al.</i> (2019) $L_{E,p,t}$ (weighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
PTS (impulsive)	LF	0.2	400	100	200	1200	27,500	7,200	18,000
	HF	< 0.1	< 100	< 100	< 100	< 0.1	100	100	100
	VHF	< 0.1	100	100	100	58	5,000	2,900	4,300
	PCW	< 0.1	< 100	< 100	< 100	< 0.1	100	100	100
TTS (impulsive)	LF	2,400	41,000	8,400	25,000	34,000	210,000	10,000	82,000
	HF	< 0.1	< 100	< 100	< 100	< 0.1	100	100	100
	VHF	200	9,800	5,000	8,000	4,000	52,000	10,000	32,500
	PCW	< 0.1	< 100	< 100	< 100	1,300	28,000	7,100	19,000

## 4.2.2 FISH

Table 4-3 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 1 using the Popper *et al.* (2019)  $L_{p,pk}$  fish criteria for pile driving

Popper <i>et al.</i> (2014) $L_{p,pk}$ (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortality/Potential Mortal Injury & Recoverable Injury	No swim bladder	< 0.01	< 50	< 50	< 50	0.07	160	150	150
	Swim bladder	0.01	70	60	65	0.39	360	350	355

Table 4-4 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 1 using the Southall *et al.* (2019)  $L_{E,p,24hr}$  fish criteria for pile driving, assuming a stationary receptor.

Popper <i>et al.</i> (2014) $L_{E,p,t}$ (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortality/Potential Mortal Injury	No swim bladder	< 0.1	100	100	100	1.4	700	600	650
	Swim bladder not involved in hearing	0.4	400	400	400	17	2,500	2,000	2,500
	Swim bladder involved in hearing	1	600	600	600	48	4,000	3,900	4,000
Recoverable Injury	No swim bladder	< 0.1	150	200	200	2.9	1,000	900	950
	Swim bladder	3.7	1,100	1,100	1,100	145	7,000	6,600	6,900
TTS	All species	490	13,000	11,000	13,000	4,200	50,000	13,000	34,000

Table 4-5 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 1 using the Southall *et al.* (2019)  $L_{E,p,t}$  fish criteria for pile driving, assuming a receptor moving at 1.5 m/s

Popper <i>et al.</i> (2014) $L_{E,p,t}$ (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortality/Potential	No swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100

Popper <i>et al.</i> (2014) <i>L<sub>E,p,t</sub></i> (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortal Injury	Swim bladder not involved in hearing	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder involved in hearing	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
Recoverable Injury	No swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
TTS	All species	14	2,700	1,200	2,100	2,000	35,000	8,600	23,000

Table 4-6 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 1 using the Southall *et al.* (2019) *L<sub>E,p,t</sub>* fish criteria for pile driving, assuming a receptor moving at 0.6 m/s

Popper <i>et al.</i> (2014) <i>L<sub>E,p,t</sub></i> (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortality/ Potential Mortal Injury	No swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder not involved in hearing	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder involved in hearing	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
Recoverable Injury	No swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder	< 0.1	< 100	< 100	< 100	20	2,200	1,800	2,050
TTS	All species	160	7,900	5,400	7,000	3,100	43,000	11,000	29,000

## 4.3 LOCATION 2

### 4.3.1 MARINE MAMMALS

Table 4-7 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 2 using the Southall *et al.* (2019)  $L_{p,pk}$  marine mammal criteria for impulsive noise sources

Southall <i>et al.</i> (2019) $L_{p,pk}$ (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
PTS (impulsive)	LF	< 0.01	< 50	< 50	< 50	0.01	70	60	65
	HF	< 0.01	< 50	< 50	< 50	< 0.01	< 50	< 50	< 50
	VHF	0.05	130	130	130	1.8	770	750	760
	PCW	< 0.01	< 50	< 50	< 50	0.02	80	70	75
TTS (impulsive)	LF	< 0.01	< 50	< 50	< 50	0.07	160	150	155
	HF	< 0.01	< 50	< 50	< 50	< 0.01	< 50	< 50	< 50
	VHF	0.31	320	310	310	9.9	1,850	1,800	1,800
	PCW	< 0.01	< 50	< 50	< 50	0.1	180	170	175

Table 4-8 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 2 using the Southall *et al.* (2019)  $L_{E,p,t}$  marine mammal criteria for impulsive noise sources

Southall <i>et al.</i> (2019) $L_{E,p,t}$ (weighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
PTS (impulsive)	LF	0.4	650	100	300	1,100	29,000	4,600	17,000
	HF	< 0.1	< 100	< 100	< 100	< 0.1	100	100	100
	VHF	< 0.1	100	100	100	55	5,300	2,200	4,100
	PCW	< 0.1	< 100	< 100	< 100	< 0.1	100	100	100
TTS (impulsive)	LF	2,200	42,000	5,300	23,000	30,000	190,000	6,400	74,000
	HF	< 0.1	< 100	< 100	< 100	< 0.1	100	100	100
	VHF	190	10,000	3,600	7,500	3,600	53,000	6,800	30,000
	PCW	< 0.1	300	< 100	200	1,300	31,000	4,600	18,000

### 4.3.2 FISH

Table 4-9 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 2 using the Popper *et al.* (2019)  $L_{p,pk}$  fish criteria for pile driving

Popper <i>et al.</i> (2014) $L_{p,pk}$ (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortality/Potential Mortal Injury & Recoverable Injury	No swim bladder	< 0.01	< 50	< 50	< 50	0.07	200	150	150
	Swim bladder	0.01	65	60	65	0.42	370	360	365

Table 4-10 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 2 using the Popper *et al.* (2019)  $L_{E,p,t}$  fish criteria for pile driving, assuming a stationary receptor

Popper <i>et al.</i> (2014) $L_{E,p,t}$ (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortality/Potential Mortal Injury	No swim bladder	< 0.1	100	100	100	1.4	700	600	700
	Swim bladder not involved in hearing	0.5	400	400	400	23	2,800	2,600	2,800
	Swim bladder involved in hearing	1.2	700	600	700	55	4,300	4,100	4,300
Recoverable Injury	No swim bladder	< 0.1	200	200	200	3.6	1,100	1,000	1,100
	Swim bladder	4.5	1,300	1,200	1,200	160	7,500	6,800	7,200
TTS	All species	500	14,000	9,000	13,000	4,000	52,000	9,000	32,000

Table 4-11 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 2 using the Popper *et al.* (2014)  $L_{E,p,t}$  fish criteria for pile driving, assuming a receptor moving at 1.5 m/s

Popper <i>et al.</i> (2014) $L_{E,p,t}$ (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortality/Potential	No swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100

Popper <i>et al.</i> (2014) <i>L<sub>E,p,t</sub></i> (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortal Injury	Swim bladder not involved in hearing	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder involved in hearing	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
Recoverable Injury	No swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
TTS	All species	17	3,200	800	2,200	1,900	37,000	5,700	22,000

Table 4-12 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 2 using the Popper *et al.* (2014) *L<sub>E,p,t</sub>* fish criteria for pile driving, assuming a receptor moving at 0.6 m/s

Popper <i>et al.</i> (2014) <i>L<sub>E,p,t</sub></i> (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortality/ Potential Mortal Injury	No swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder not involved in hearing	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder involved in hearing	< 0.1	< 100	< 100	< 100	0.09	200	100	170
Recoverable Injury	No swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder	< 0.1	< 100	< 100	< 100	20	2,600	1,700	2,300
TTS	All species	160	8,700	4,300	7,000	2,900	45,500	7,600	27,500

## 4.4 LOCATION 3

### 4.4.1 MARINE MAMMALS

Table 4-13 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 3 using the Southall *et al.* (2019)  $L_{p,pk}$  marine mammal criteria for impulsive noise sources

Southall <i>et al.</i> (2019) $L_{p,pk}$ (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
PTS (impulsive)	LF	< 0.01	< 50	< 50	< 50	0.01	70	60	65
	HF	< 0.01	< 50	< 50	< 50	< 0.01	< 50	< 50	< 50
	VHF	0.05	130	130	130	1.73	750	740	745
	PCW	<0.01	< 50	< 50	< 50	0.02	80	70	75
TTS (impulsive)	LF	< 0.01	< 50	< 50	< 50	0.08	160	150	155
	HF	< 0.01	< 50	< 50	< 50	< 0.01	< 50	< 50	< 50
	VHF	0.3	320	300	310	9.5	1,800	1,700	1,700
	PCW	<0.01	< 50	< 50	< 50	0.1	180	170	175

Table 4-14 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 3 using the Southall *et al.* (2019)  $L_{E,p,t}$  marine mammal criteria for impulsive noise sources

Southall <i>et al.</i> (2019) $L_{E,p,t}$ (weighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
PTS (impulsive)	LF	0.5	680	100	400	990	28,000	2,900	15,000
	HF	< 0.1	< 100	< 100	< 100	< 0.1	100	100	100
	VHF	< 0.1	100	100	100	48	5,200	1,600	3,800
	PCW	< 0.1	< 100	< 100	< 100	< 0.1	100	100	100
TTS (impulsive)	LF	2,000	41,000	3,400	21,000	26,000	180,000	4,100	67,000
	HF	< 0.1	< 100	< 100	< 100	< 0.1	100	100	100
	VHF	160	10,000	2,600	6,800	3,300	52,000	4,700	27,000
	PCW	0.5	700	< 100	300	1,300	32,000	3,000	17,000

#### 4.4.2 FISH

Table 4-15 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 3 using the Popper *et al.* (2019)  $L_{p,pk}$  fish criteria for pile driving

Popper <i>et al.</i> (2014) $L_{p,pk}$ (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortality/Potential Mortal Injury & Recoverable Injury	No swim bladder	< 0.01	< 50	< 50	< 50	0.08	160	150	155
	Swim bladder	0.01	65	65	65	0.42	370	360	365

Table 4-16 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 3 using the Popper *et al.* (2019)  $L_{E,p,t}$  fish criteria for pile driving, assuming a stationary receptor

Popper <i>et al.</i> (2014) $L_{E,p,t}$ (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortality/Potential Mortal Injury	No swim bladder	< 0.1	200	100	200	1.8	800	700	800
	Swim bladder not involved in hearing	0.6	500	400	500	26	3,000	2,800	2,900
	Swim bladder involved in hearing	1.5	700	700	700	61	4,500	4,300	4,500
Recoverable Injury	No swim bladder	< 0.1	200	200	200	4.2	1,200	1,100	1,200
	Swim bladder	5.2	1,300	1,300	1,300	170	7,800	6,500	7,400
TTS	All species	460	15,000	6,700	12,000	3,700	52,000	6,700	30,000

Table 4-17 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 3 using the Popper *et al.* (2014)  $L_{E,p,t}$  fish criteria for pile driving, assuming a receptor moving at 1.5 m/s

Popper <i>et al.</i> (2014) $L_{E,p,t}$ (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortality/Potential	No swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100

Popper <i>et al.</i> (2014) <i>L<sub>E,p,t</sub></i> (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortal Injury	Swim bladder not involved in hearing	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder involved in hearing	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
Recoverable Injury	No swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
TTS	All species	17	2,200	400	2,100	1,700	37,000	3,900	20,000

Table 4-18 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 3 using the Popper *et al.* (2014) *L<sub>E,p,t</sub>* fish criteria for pile driving, assuming a receptor moving at 0.6 m/s

Popper <i>et al.</i> (2014) <i>L<sub>E,p,t</sub></i> (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortality/ Potential Mortal Injury	No swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder not involved in hearing	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder involved in hearing	< 0.1	< 100	< 100	< 100	0.19	300	100	240
Recoverable Injury	No swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder	< 0.1	< 100	< 100	< 100	20	2,800	1,400	2,300
TTS	All species	150	8,900	3,400	6,700	2,700	45,500	5,500	25,500

## 4.5 LOCATION 4

### 4.5.1 MARINE MAMMALS

Table 4-19 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 4 using the Southall *et al.* (2019)  $L_{p,pk}$  marine mammal criteria for impulsive noise sources

Southall <i>et al.</i> (2019) $L_{p,pk}$ (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
PTS (impulsive)	LF	< 0.01	< 50	< 50	< 50	0.02	80	70	75
	HF	< 0.01	< 50	< 50	< 50	< 0.01	< 50	< 50	< 50
	VHF	0.05	140	130	140	1.8	780	760	770
	PCW	< 0.01	< 50	< 50	< 50	0.02	90	80	85
TTS (impulsive)	LF	< 0.01	< 50	< 50	< 50	0.08	160	150	155
	HF	< 0.01	< 50	< 50	< 50	< 0.01	< 50	< 50	< 50
	VHF	0.31	320	320	320	10	1,800	1,800	1,800
	PCW	< 0.01	< 50	< 50	< 50	0.11	190	180	185

Table 4-20 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 4 using the Southall *et al.* (2019)  $L_{E,p,t}$  marine mammal criteria for impulsive noise sources

Southall <i>et al.</i> (2019) $L_{E,p,t}$ (weighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
PTS (impulsive)	LF	0.2	500	100	300	1,000	26,000	4,600	16,000
	HF	< 0.1	< 100	< 100	< 100	< 0.1	100	100	100
	VHF	< 0.1	100	100	100	48	4,800	2,200	3,700
	PCW	< 0.1	< 100	< 100	< 100	< 0.1	100	100	100
TTS (impulsive)	LF	2,000	38,500	5,300	22,000	25,000	170,000	6,500	69,000
	HF	< 0.1	< 100	< 100	< 100	< 0.1	100	100	100
	VHF	170	9,300	3,600	7,100	3,200	48,000	6,900	28,000
	PCW	< 0.1	< 100	< 100	< 100	1,100	28,000	4,600	17,000

## 4.5.2 FISH

Table 4-21 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 4 using the Popper *et al.* (2019)  $L_{p,pk}$  fish criteria for pile driving

Popper <i>et al.</i> (2014) $L_{p,pk}$ (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortality/Potential Mortal Injury & Recoverable Injury	No swim bladder	< 0.01	< 50	< 50	< 50	0.08	160	150	155
	Swim bladder	0.01	70	65	70	0.44	380	370	375

Table 4-22 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 4 using the Popper *et al.* (2019)  $L_{E,p,t}$  fish criteria for pile driving, assuming a stationary receptor

Popper <i>et al.</i> (2014) $L_{E,p,t}$ (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortality/Potential Mortal Injury	No swim bladder	< 0.1	100	100	100	1	600	500	600
	Swim bladder not involved in hearing	0.4	400	300	400	16	2,400	2,200	2,300
	Swim bladder involved in hearing	0.9	600	500	600	40	3,600	3,500	3,600
Recoverable Injury	No swim bladder	< 0.1	200	200	200	2.9	1,000	900	1,000
	Swim bladder	3.2	1,100	1,000	1,000	121	6,400	6,000	6,300
TTS	All species	390	12,000	9,000	11,000	3,300	46,000	9,100	29,500

Table 4-23 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 4 using the Popper *et al.* (2014)  $L_{E,p,t}$  fish criteria for pile driving, assuming a receptor moving at 1.5 m/s

Popper <i>et al.</i> (2014) $L_{E,p,t}$ (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortality/Potential	No swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100

Popper <i>et al.</i> (2014) <i>L<sub>E,p,t</sub></i> (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortal Injury	Swim bladder not involved in hearing	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder involved in hearing	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
Recoverable Injury	No swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
TTS	All species	13	2,700	700	1,900	1,600	33,000	5,700	20,000

Table 4-24 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 4 using the Popper *et al.* (2014) *L<sub>E,p,t</sub>* fish criteria for pile driving, assuming a receptor moving at 0.6 m/s

Popper <i>et al.</i> (2014) <i>L<sub>E,p,t</sub></i> (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortality/ Potential Mortal Injury	No swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder not involved in hearing	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder involved in hearing	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
Recoverable Injury	No swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder	< 0.1	< 100	< 100	< 100	12.5	2,200	1,600	2,000
TTS	All species	130	7,500	4,200	6,400	2,500	40,000	7,600	25,500

## 4.6 LOCATION 5

### 4.6.1 MARINE MAMMALS

Table 4-25 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 5 using the Southall *et al.* (2019)  $L_{p,pk}$  marine mammal criteria for impulsive noise sources

Southall <i>et al.</i> (2019) $L_{p,pk}$ (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
PTS (impulsive)	LF	< 0.01	< 50	< 50	< 50	0.01	70	60	65
	HF	< 0.01	< 50	< 50	< 50	< 0.01	< 50	< 50	< 50
	VHF	0.05	130	130	130	1.65	740	720	730
	PCW	< 0.01	< 50	< 50	< 50	0.02	80	70	75
TTS (impulsive)	LF	< 0.01	< 50	< 50	< 50	0.08	160	150	155
	HF	< 0.01	< 50	< 50	< 50	< 0.01	< 50	< 50	< 50
	VHF	0.29	310	300	310	8.9	1,700	1,600	1,700
	PCW	< 0.01	< 50	< 50	< 50	0.1	180	170	175

Table 4-26 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 5 using the Southall *et al.* (2019)  $L_{E,p,t}$  marine mammal criteria for impulsive noise sources

Southall <i>et al.</i> (2019) $L_{E,p,t}$ (weighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
PTS (impulsive)	LF	0.6	800	100	340	1,000	29,000	3,100	15,500
	HF	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	VHF	0.1	100	100	100	48	5,300	1,600	3,800
	PCW	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
TTS (impulsive)	LF	2,000	42,000	3,700	21,500	24,000	180,000	4,500	65,000
	HF	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	VHF	170	10,000	2,600	6,800	3,200	52,000	5,000	27,300
	PCW	0.5	800	< 100	300	1,300	33,000	3,200	17,000

## 4.6.2 FISH

Table 4-27 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 5 using the Popper *et al.* (2019)  $L_{p,pk}$  fish criteria for pile driving

Popper <i>et al.</i> (2014) $L_{p,pk}$ (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortality/Potential Mortal Injury & Recoverable Injury	No swim bladder	< 0.01	< 50	< 50	< 50	0.08	160	150	155
	Swim bladder	0.01	65	60	65	0.39	360	350	355

Table 4-28 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 5 using the Popper *et al.* (2019)  $L_{E,p,t}$  fish criteria for pile driving, assuming a stationary receptor

Popper <i>et al.</i> (2014) $L_{E,p,t}$ (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortality/Potential Mortal Injury	No swim bladder	< 0.1	100	100	100	1.4	700	600	700
	Swim bladder not involved in hearing	0.4	400	400	400	19	2,600	2,300	2,500
	Swim bladder involved in hearing	1	600	600	600	45	4,000	3,500	3,800
Recoverable Injury	No swim bladder	< 0.1	200	200	200	3.1	1,100	900	1,000
	Swim bladder	3.7	1,100	1,100	1,100	130	7,000	5,700	6,500
TTS	All species	400	13,000	7,100	11,000	3,400	50,000	7,100	29,000

Table 4-29 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 5 using the Popper *et al.* (2014)  $L_{E,p,t}$  fish criteria for pile driving, assuming a receptor moving at 1.5 m/s

Popper <i>et al.</i> (2014) $L_{E,p,t}$ (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortality/Potential	No swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100

Popper <i>et al.</i> (2014) <i>L<sub>E,p,t</sub></i> (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortal Injury	Swim bladder not involved in hearing	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder involved in hearing	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
Recoverable Injury	No swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
TTS	All species	16	3,500	300	2,000	1,700	38,500	4,100	20,000

Table 4-30 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 5 using the Popper *et al.* (2014) *L<sub>E,p,t</sub>* fish criteria for pile driving, assuming a receptor moving at 0.6 m/s

Popper <i>et al.</i> (2014) <i>L<sub>E,p,t</sub></i> (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortality/ Potential Mortal Injury	No swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder not involved in hearing	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder involved in hearing	< 0.1	< 100	< 100	< 100	0.12	300	100	180
Recoverable Injury	No swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder	< 0.1	< 100	< 100	< 100	14.5	2,600	1,300	2,100
TTS	All species	140	8,600	3,300	6,400	2,600	44,500	5,800	25,000

## 4.7 LOCATION 6

### 4.7.1 MARINE MAMMALS

Table 4-31 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 6 using the Southall *et al.* (2019)  $L_{p,pk}$  marine mammal criteria for impulsive noise sources

Southall <i>et al.</i> (2019) $L_{p,pk}$ (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
PTS (impulsive)	LF	< 0.01	< 50	< 50	< 50	0.02	80	70	75
	HF	< 0.01	< 50	< 50	< 50	< 0.01	< 50	< 50	< 50
	VHF	0.06	150	140	150	2.18	840	830	840
	PCW	< 0.01	< 50	< 50	< 50	0.02	90	80	85
TTS (impulsive)	LF	< 0.01	< 50	< 50	< 50	0.09	170	160	165
	HF	< 0.01	< 50	< 50	< 50	< 0.01	< 50	< 50	< 50
	VHF	0.37	350	340	345	12	2,000	2,000	2,000
	PCW	< 0.01	< 50	< 50	< 50	0.12	200	190	195

Table 4-32 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 6 using the Southall *et al.* (2019)  $L_{E,p,t}$  marine mammal criteria for impulsive noise sources

Southall <i>et al.</i> (2019) $L_{E,p,t}$ (weighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
PTS (impulsive)	LF	3	1,500	100	850	1,600	34,000	7,900	21,000
	HF	< 0.01	< 100	< 100	< 100	< 0.1	100	100	100
	VHF	< 0.01	< 100	< 100	< 100	86	6,300	3,600	5,200
	PCW	< 0.01	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
TTS (impulsive)	LF	3,100	49,000	9,100	29,000	39,000	220,000	11,100	87,000
	HF	< 0.01	< 100	< 100	< 100	< 0.1	100	100	100
	VHF	270	12,000	5,700	9,200	4,600	58,000	11,000	35,000
	PCW	3	1,500	< 100	850	2,000	38,500	8,100	23,000

## 4.7.2 FISH

Table 4-33 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 6 using the Popper *et al.* (2019)  $L_{p,pk}$  fish criteria for pile driving

Popper <i>et al.</i> (2014) $L_{p,pk}$ (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortality/Potential Mortal Injury & Recoverable Injury	No swim bladder	< 0.01	< 50	< 50	< 50	0.09	170	160	165
	Swim bladder	0.01	70	65	70	0.51	410	400	405

Table 4-34 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 6 using the Popper *et al.* (2019)  $L_{E,p,t}$  fish criteria for pile driving, assuming a stationary receptor

Popper <i>et al.</i> (2014) $L_{E,p,t}$ (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortality/Potential Mortal Injury	No swim bladder	< 0.1	100	100	100	1.4	700	600	700
	Swim bladder not involved in hearing	0.5	400	400	400	24	2,800	2,700	2,800
	Swim bladder involved in hearing	1.2	700	600	700	58	4,400	4,200	4,400
Recoverable Injury	No swim bladder	< 0.1	200	200	200	3.5	1,100	1,000	1,100
	Swim bladder	4.5	1,200	1,200	1,200	180	7,800	7,300	7,600
TTS	All species	590	15,000	12,000	14,000	5,000	57,000	14,000	37,000

Table 4-35 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 6 using the Popper *et al.* (2014)  $L_{E,p,t}$  fish criteria for pile driving, assuming a receptor moving at 1.5 m/s

Popper <i>et al.</i> (2014) $L_{E,p,t}$ (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortality/Potential	No swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100

Popper <i>et al.</i> (2014) <i>L<sub>E,p,t</sub></i> (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortal Injury	Swim bladder not involved in hearing	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder involved in hearing	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
Recoverable Injury	No swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
TTS	All species	45	4,850	2,200	3,700	2,750	45,000	9,500	27,000

Table 4-36 Estimated impact ranges for unmitigated and mitigated pile driving activities at Location 6 using the Popper *et al.* (2014) *L<sub>E,p,t</sub>* fish criteria for pile driving, assuming a receptor moving at 0.6 m/s

Popper <i>et al.</i> (2014) <i>L<sub>E,p,t</sub></i> (unweighted)		Mitigated				Unmitigated			
		Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)	Area (km <sup>2</sup> )	Max range (m)	Min range (m)	Mean range (m)
Mortality/ Potential Mortal Injury	No swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder not involved in hearing	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder involved in hearing	< 0.1	< 100	< 100	< 100	0.78	500	500	500
Recoverable Injury	No swim bladder	< 0.1	< 100	< 100	< 100	< 0.1	< 100	< 100	< 100
	Swim bladder	< 0.1	< 100	< 100	< 100	30	3,300	2,800	3,100
TTS	All species	250	10,500	6,800	8,900	3,950	52,000	12,000	33,000

## 5 OTHER NOISE SOURCES

5.1.1.1 Although impact piling is expected to be the greatest overall noise source during offshore construction and development (Bailey *et al.*, 2014), several other anthropogenic noise sources may be present. Each of these has been considered, and relevant biological noise criteria presented, in this section.

5.1.1.2 **Table 5-1** provides a summary of the various noise producing sources, aside from impact piling, that are expected to be present during the construction and lifecycle of the Offshore Project.

Table 5-1 Summary of the possible noise making activities for the Offshore Project other than impact piling

Activity	Description
Cable laying	Noise from the cable laying vessel and other associated noise during the offshore cable installation.
Cutting of piles	During decommissioning, piles may be cut using water jetting or grinding techniques.
Dredging	Dredging may be required on site for seabed preparation work for certain foundation options, as well as for the inter-array cable installation. Both backhoe and suction dredging have been included.
Drill (and grout)	There is the potential for WTG foundations to be installed using drilling depending on seabed type or if a pile refuses during impact piling operations. The grouting operation will not have a significant noise output.
Rock placement	May be required on site for installation of offshore cables (cable crossings and cable protection) and scour protection around foundation structures.
Trenching	Plough trenching may be required during installation of the offshore cables.
Vessel noise	Jack-up barges for piling substructure and WTG installation. Other large and medium sized vessels to carry out other construction tasks and anchor handling. Other small vessels for crew transport and maintenance on site.
Operational WTGs	Noise transmitted through the water from operational WTGs.

5.1.1.3 The majority of these activities are covered in Section 5.2, with operational WTG noise assessed in Section 5.3.

5.1.1.4 The NPL Good Practice Guide 133 for underwater noise measurements (Robinson *et al.*, 2014) indicates that under certain circumstances, a simple modelling approach may be considered appropriate. Such an approach has been used for these noise sources, which are variously either quiet compared to impact piling (e.g., drilling as part of a drill and grout pile installation technique), or where detailed modelling would imply unjustified accuracy. The high-level overview of modelling that has been presented here is considered sufficient and there would be little benefit in using a more detailed modelling approach at this stage due to their relatively low impacts. The limitations of this approach are noted, including the lack of frequency and bathymetric dependence.

## 5.2 NOISE MAKING ACTIVITIES (CONSTRUCTION)

5.2.1.1 For the purposes of identifying the greatest effects from noise, approximate subsea noise levels have been predicted using a simple modelling approach based on measurement data from Subacoustech Environmental’s own underwater noise measurement database scaled to relevant parameters for the Offshore Project and to the specific noise sources to be used. The calculation of underwater noise transmission loss for these non-impulsive sources is based on empirical analysis of the noise measurements taken along transects around these sources by Subacoustech Environmental. The predictions use the following principle fitted to the measured data, where  $R$  is the range from the source,  $N$  is the transmission loss coefficient, and  $\alpha$  is the absorption loss coefficient:

$$\text{Received level} = \text{Source level (SL)} - N \log_{10} R - \alpha R$$

5.2.1.2 Predicted source levels and propagation calculations for the construction activities are presented in **Table 5-2** along with a summary of the number of datasets used in each case. As previously, all criteria use the same assumptions as presented in Section 4, and ranges smaller than 50 m (single pulse) and 100 m (cumulative) have not been presented. It should be reiterated that this modelling approach does not take bathymetry or any other environmental conditions into account, and as such can be applied to any location at, or surrounding, the Offshore Project.

5.2.1.3 All values of  $N$  and  $\alpha$  are empirically derived and will be linked to the size and shape of the machinery, the transect on which the measurements were taken and the local environment at the time.

5.2.1.4 Special consideration should be given to the drilling (drill and grout) construction technique, as this is planned to be used for pile installation in a large section of the site. Subacoustech Environmental’s data used for the predictions in this assessment and documented in **Table 5-2** above aligns well with data presented in Koschinski & Lüdemann (2020) for offshore wind farm drill and grout, which estimated a source level of 167.8 dB  $L_p$ . Drill and grout are proposed for turbine foundation installation at much of the southwest portion of the Array Area.

5.2.1.5 For  $L_{E,p,t}$  calculations in this section, the duration the noise is present also needs to be considered, with all sources assumed to operate constantly for 24 hours to give a worst-case assessment of the noise. Due to the low noise level of the sources, both moving and stationary animals have been included for all  $L_{E,p,t}$  criteria.

Table 5-2 Summary of the estimated unweighted source levels and transmission losses for the different considered construction noise sources

Source	Estimated $L_p$ source level	Transmission loss parameters	Comments
Cable laying	171 dB re 1 $\mu$ Pa @ 1 m	$N$ : 13, $\alpha$ : 0 (no absorption)	Based on 11 datasets from a pipe laying vessel measuring 300 m in length; this is considered a worst-

Source	Estimated $L_p$ source level	Transmission loss parameters	Comments
			case noise source for cable laying operations.
Dredging (backhoe)	165 dB re 1 $\mu$ Pa @ 1 m	$N: 19, \alpha: 0.0009$	Based on 3 datasets from backhoe dredgers.
Dredging (suction)	186 dB re 1 $\mu$ Pa @ 1 m	$N: 19, \alpha: 0.0009$	Based on 5 datasets from suction and cutter suction dredgers.
Drilling (drill and grout)	169 dB re 1 $\mu$ Pa @ 1 m	$N: 16, \alpha: 0.0006$	Based on 6 datasets from various drilling operations covering ground investigations and pile installation. A 200 kW drill has been assumed for modelling.
Grinding	183 dB re 1 $\mu$ Pa @ 1 m	$N: 15, \alpha: 0.0002$	Based on measurements of divers using grinding equipment in Norwegian waters.
Rock placement	172 dB re 1 $\mu$ P @ 1 m	$N: 12, \alpha: 0.0005$	Based on 4 datasets from rock placement vessel <i>Rollingstone</i> .
Trenching	172 dB re 1 $\mu$ Pa @ 1 m	$N: 13, \alpha: 0.0004$	Based on 3 datasets of measurements from trenching vessels more than 100 m in length.
Vessel noise (large)	168 dB re 1 $\mu$ Pa @ 1 m	$N: 12, \alpha: 0.0021$	Based on 5 datasets of large vessels including container ships, FPSOs and other vessels more than 100 m in length. Vessel speed assumed as 10 knots.
Vessel noise (medium)	161 dB re 1 $\mu$ Pa @ 1 m	$N: 12, \alpha: 0.0021$	Based on 3 datasets of moderate sized vessels less than 100 m in length. Vessel speed assumed as 10 knots.
Water jetting	170 dB re 1 $\mu$ Pa @ 1 m	$N: 15, \alpha: 0.0002$	Based on Molvær and Gjestland (1981) where the best existing data for subsea, high-pressure water jetting exists.

5.2.1.6 To account for the weightings required for modelling using the Southall *et al.* (2019) criteria (see Section 2.4.2), reductions have been applied to the source levels of the various noise sources. **Plate 5-1** shows the representative noise measurements used to calculate these reductions, which have been adjusted based on the source levels given in **Table 5-2**. Details of the reductions in source level for each of the marine mammal weightings are given in **Table 5-3**.

Plate 5-1 Summary of the 1/3rd octave frequency bands to which Southall *et al.* (2019) weightings have been applied

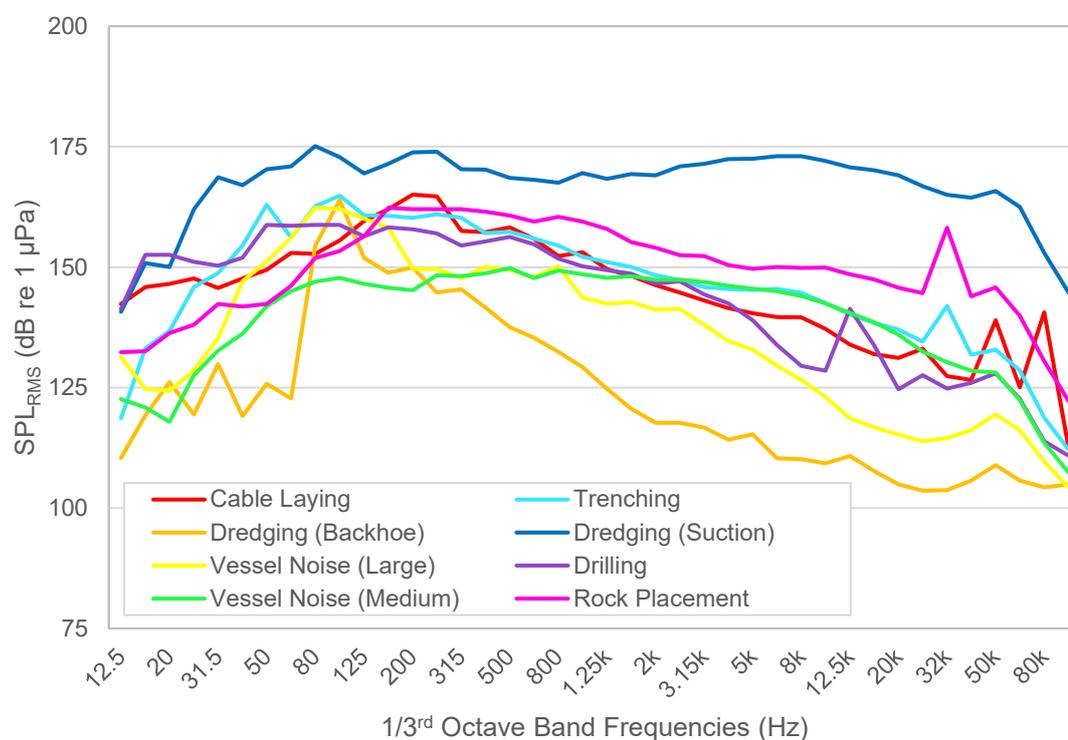


Table 5-3 Reductions in source level for the different construction noise sources considered when the Southall *et al.* (2019) weightings are applied

Source	Reduction in L <sub>p</sub> source level from the unweighted level (Southall <i>et al.</i> , 2019)			
	LF	HF	VHF	PCW
Cable laying	3.6 dB re 1 µPa	22.9 dB re 1 µPa	23.9 dB re 1 µPa	13.2 dB re 1 µPa
Dredging (backhoe)	6.3 dB re 1 µPa	46.7 dB re 1 µPa	48.7 dB re 1 µPa	23.1 dB re 1 µPa
Dredging (suction)	2.5 dB re 1 µPa	7.9 dB re 1 µPa	9.6 dB re 1 µPa	4.2 dB re 1 µPa
Drilling (drill and grout)	4.0 dB re 1 µPa	25.8 dB re 1 µPa	48.7 dB re 1 µPa	13.2 dB re 1 µPa
Grinding	1.2 dB re 1 µPa	28.3 dB re 1 µPa	31.5 dB re 1 µPa	11.7 dB re 1 µPa
Rock placement	1.6 dB re 1 µPa	11.9 dB re 1 µPa	12.5 dB re 1 µPa	8.2 dB re 1 µPa
Trenching	4.1 dB re 1 µPa	23.0 dB re 1 µPa	25.0 dB re 1 µPa	13.7 dB re 1 µPa
Vessel noise	5.5 dB re 1 µPa	34.4 dB re 1 µPa	38.6 dB re 1 µPa	17.4 dB re 1 µPa
Water jetting	0.5 dB re 1 µPa	10.1 dB re 1 µPa	13.8 dB re 1 µPa	2.5 dB re 1 µPa

5.2.1.7 The modelled impact ranges for these sources are presented in **Table 5-4** to **Table 5-6**. Given the modelled impact ranges, almost all marine mammals would have to be closer than 100 m from the noise sources at the start of the activity to acquire the necessary exposure to induce PTS as per Southall *et al.* (2019), with the possible exception of suction dredging, grinding, and rock placement for stationary receptors. The exposure calculations assume the same receptor fleeing speeds as the impact piling modelling in Section 2.4.2. These ranges only represent a range where the receptor reaches the 'onset' stage, which is the minimum exposure that could potentially lead

to the start of an effect and may only be marginal. In most hearing groups the noise levels are low enough that this only represents a minimal risk.

5.2.1.8 For fish, there is a minimal risk of any injury or TTS with reference to the  $L_p$  guidance for continuous noise sources in Popper *et al.* (2014).

Table 5-4 Summary of the impact ranges for the different noise sources related to the construction and lifecycle of Project using the non-impulsive criteria from Southall *et al.* (2019) for marine mammals assuming a fleeing receptor

Southall <i>et al.</i> (2019) $L_{E,p,24h, wtd}$ (Fleeing)	PTS (Non-impulsive)				TTS (Non-impulsive)			
	LF (199 dB)	HF (198 dB)	VHF (173 dB)	PCW (201 dB)	LF (179 dB)	HF (178 dB)	VHF (153 dB)	PCW (181 dB)
Cable laying	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
Dredging (backhoe)	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
Dredging (suction)	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	250 m	< 100 m
Drilling (drill and grout)	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
Grinding	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
Rock placement	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	1200 m	< 100 m
Trenching	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
Vessel noise (large)	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
Vessel noise (medium)	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
Water jetting	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m

Table 5-5 Summary of the impact ranges for the different noise sources related to the construction and lifecycle of Project using the non-impulsive criteria from Southall *et al.* (2019) for marine mammals assuming a stationary receptor

Southall <i>et al.</i> (2019) $L_{E,p,24h, wtd}$ (Fleeing)	PTS (Non-impulsive)				TTS (Non-impulsive)			
	LF (199 dB)	HF (198 dB)	VHF (173 dB)	PCW (201 dB)	LF (179 dB)	HF (178 dB)	VHF (153 dB)	PCW (181 dB)
Cable laying	< 100 m	< 100 m	< 100 m	< 100 m	810 m	< 100 m	2,300 m	110 m
Dredging (backhoe)	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
Dredging (suction)	< 100 m	< 100 m	570 m	< 100 m	640 m	390 m	4,300 m	420 m
Drilling (drill and grout)	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
Grinding	140 m	< 100 m	< 100 m	< 100 m	1,800 m	< 100 m	1,200 m	400 m

Southall <i>et al.</i> (2019) <i>L<sub>E,p,24h,wt</sub></i> (Fleeing)	PTS (Non-impulsive)				TTS (Non-impulsive)			
	LF (199 dB)	HF (198 dB)	VHF (173 dB)	PCW (201 dB)	LF (179 dB)	HF (178 dB)	VHF (153 dB)	PCW (181 dB)
Rock placement	< 100 m	< 100 m	900 m	< 100 m	2,100 m	410 m	1,300 m	460 m
Trenching	< 100 m	< 100 m	< 100 m	< 100 m	830 m	< 100 m	1.9 km	120 m
Vessel noise (large)	< 100 m	< 100 m	< 100 m	< 100 m	480 m	< 100 m	140 m	< 100 m
Vessel noise (medium)	< 100 m	130 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
Water jetting	< 100 m	< 100 m	< 100 m	< 100 m	150 m	< 100 m	820 m	< 100 m

5.2.1.9 It should be noted that ranges for stationary animals are theoretical only and are expected to be over-conservative – more so than for fish during piling – as the assumption is for the receptor to remain stationary in respect to the noise source for the entire assessment period (24 hours), when in a number of these instances, the noise source itself moves.

Table 5-6 Summary of the impact ranges for the different noise sources related to the construction and lifecycle of Project using the continuous noise criteria from Popper *et al.* (2014) for fish (swim bladder involved in hearing)

Popper <i>et al.</i> (2014) <i>L<sub>p</sub></i>	Recoverable injury 170 dB re 1 $\mu$ Pa (48 hours)	TTS 158 dB re 1 $\mu$ Pa (12 hours)
Cable laying	< 50 m	< 50 m
Dredging (backhoe)	< 50 m	< 50 m
Dredging (suction)	< 50 m	< 50 m
Drilling (drill and grout)	< 50 m	< 50 m
Grinding	< 50 m	< 50 m
Rock placement	< 50 m	< 50 m
Trenching	< 50 m	< 50 m
Vessel noise (large)	< 50 m	< 50 m
Vessel noise (medium)	< 50 m	< 50 m

## 5.3 OPERATIONAL WTG NOISE

5.3.1.1 The noise source for most operational WTGs is the radiating area of the foundation in the water, with noise a consequence of mechanically generated vibration from the rotating machinery in the WTGs transmitted into the sea through the structure of the WTG tower and foundations (Nedwell *et al.*, 2003; Tougaard *et al.*, 2020). For a fixed-bottom monopile foundation, this is the surface area of the cylindrical pile in the water column. The complexities of the acoustics in large structures such as these make it difficult to predict their effect on the noise output (Tougaard *et al.*, 2020). Noise

levels generated above the water surface are low enough that no significant airborne sound will pass from the air to the water.

5.3.1.2 Tougaard *et al.* (2020) published a study investigating noise data from 17 operational WTGs in Europe and the United States, from 0.2 MW to 6.15 MW nominal power output. The paper identified the nominal power output and wind speed as the 2 primary driving factors for underwater noise generation. Although the datasets were acquired under different conditions, the authors devised a formula based on the published data for the operational wind farms, allowing a broadband noise level to be estimated based on the application of wind speed, turbine size (by nominal power output) and distance from the turbine:

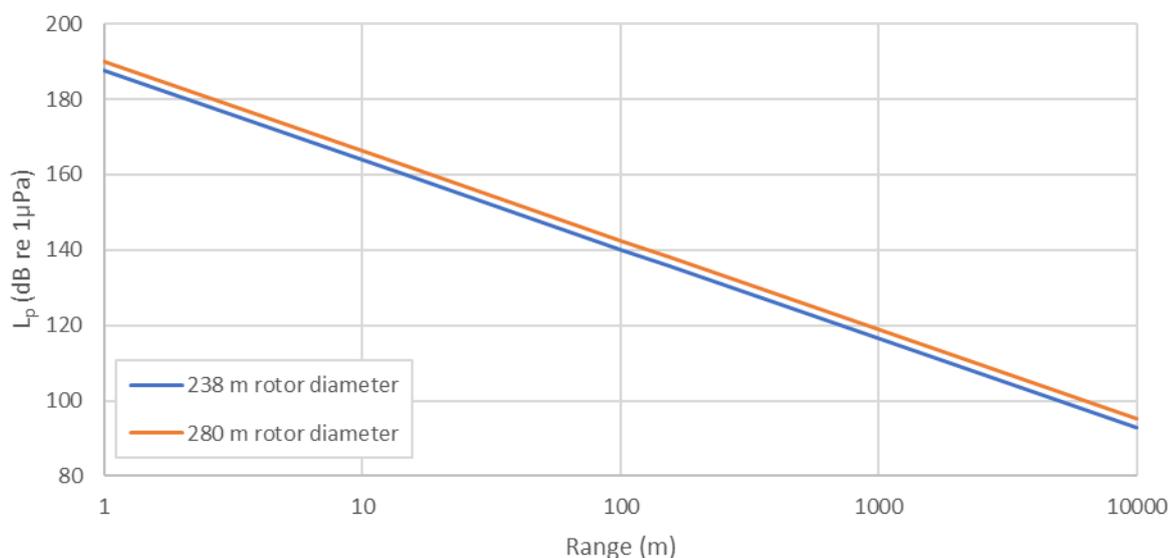
$$L_{eq} = C + \alpha \log_{10} \left( \frac{\text{distance}}{100\text{m}} \right) + \beta \log_{10} \left( \frac{\text{wind speed}}{10\text{ms}^{-1}} \right) + \gamma \log_{10} \left( \frac{\text{turbine size}}{1\text{MW}} \right)$$

5.3.1.3 where C is a fixed constant and the coefficients  $\alpha$ ,  $\beta$ , and  $\gamma$  are derived from the empirical data from the 17 datasets.

The WTG sizes under consideration for the Offshore Project are much larger than those used to develop the estimation above, so caution must be used when considering the results presented in this section. Nominal turbine power outputs are not yet confirmed, and so turbine rotor diameter has been used as a proxy, and as power output values in MW are required for the equation above, indicative power outputs have been used to calculate impacts for this study based on rotor diameters. The Offshore Project considers a range of rotor diameters, the smallest rotor diameter proposed is 236 m, and the maximum, 280 m. However, as can be seen in the following results, there is no significant impact expected irrespective of size.

5.3.1.4 **Plate 5-2** presents a level versus range plot for the WTG sizes using the Tougaard *et al.* (2020) calculation, assuming an average 11 m/s wind speed. Although wind speeds and thus operational levels may be greater than this, this will not represent the typical condition. It is also worth noting that the background noise levels will also naturally increase at high wind speeds, somewhat offsetting any additional impact this may have.

Plate 5-2: Predicted unweighted SPL<sub>RMS</sub> from operational WTGs using the calculation from Tougaard *et al.* (2020)



5.3.1.5 Using this data, a summary of the predicted impact ranges has been produced, shown in **Table 5-7** and **Table 5-8**.

5.3.1.6 All  $L_{E,p,t}$  criteria use the same assumptions as the previously presented modelling for continuous noise sources, and ranges smaller than 50 m (single strike) and 100 m (cumulative) have not been presented. For  $L_{E,p,t}$  calculations it has been assumed that the operational WTG noise is present 24 hours a day.

Table 5-7 Summary of the operational WTG noise impact ranges using the non-impulsive noise criteria from Southall *et al.* (2019) for marine mammals

Southall <i>et al.</i> (2019) Weighted SEL <sub>cum</sub> ( $L_{E,p,t}$ )	Operational WTG (238 m rotor diameter)	Operational WTG (280 m rotor diameter)	Southall <i>et al.</i> (2019) Weighted SEL <sub>cum</sub> ( $L_{E,p,t}$ )
<b>PTS</b> (non-impulsive)	199 dB (LF $L_{E,p,t}$ )	< 100 m	< 100 m
	198 dB (HF $L_{E,p,t}$ )	< 100 m	< 100 m
	173 dB (VHF $L_{E,p,t}$ )	< 100 m	< 100 m
	201 dB (PCW $L_{E,p,t}$ )	< 100 m	< 100 m
<b>TTS</b> (non-impulsive)	179 dB (LF $L_{E,p,t}$ )	< 100 m	< 100 m
	178 dB (HF $L_{E,p,t}$ )	< 100 m	< 100 m
	153 dB (VHF $L_{E,p,t}$ )	< 100 m	< 100 m
	181 dB (PCW $L_{E,p,t}$ )	< 100 m	< 100 m

5.3.1.7 Based on the Southall *et al.* (2019) non-impulsive criteria, a marine mammal would need to remain well within 100 m of the WTG for 12 hours to exceed threshold.

Table 5-8 Summary of the operational WTG noise impact ranges using the continuous noise criteria from Popper *et al.* (2014) for fish (swim bladder involved in hearing)

<b>Popper <i>et al.</i> (2014) Unweighted <math>L_p</math> (SPL<sub>RMS</sub>)</b>	<b>Operational WTG (15 MW)</b>	<b>Operational WTG (22.5 MW)</b>
<b>Recoverable injury 170 dB (48 hours) Unweighted <math>L_p</math></b>	< 50 m	< 50 m
<b>TTS 158 dB (12 hours) Unweighted <math>L_p</math></b>	< 50 m	< 50 m

5.3.1.8 Using this noise level and the Popper *et al.* (2014) criteria for continuous noise, the TTS threshold of 158 dB ( $L_p$ ) would require an individual to be closer than 50 m for 12 hours continuously.

## 6 SUMMARY AND CONCLUSIONS

- 6.1.1.1 Subacoustech Environmental have undertaken a study on behalf of the Applicant to assess potential underwater noise and its effects during the construction and operation of the Offshore Project, located off the northwest coast of Isle of Lewis/*Eilean Leòdhais* in the Outer Hebrides/*Na h-Eileanan Siar, Scotland/Alba*.
- 6.1.1.2 The level of underwater noise from impact piling for the installation of WTG foundations during construction has been estimated using the semi-empirical underwater noise model INSPIRE. The modelling considers a wide variety of input parameters including bathymetry, hammer blow energy, strike rate, and receptor fleeing speed.
- 6.1.1.3 6 representative modelling locations were chosen to give spatial variations across the Array Area, as well as accounting for 2 types of piling in 2 distinct geotechnical regions: within and outside the 'buried channel'. Within each region, 3 piling locations were modelled.
- Within the buried channel, a piled turbine foundation considering a 5 m diameter pile driven using a maximum hammer energy of 2,500 kJ, 3,500 kJ, or 5,500 kJ and driving for 5.5 hours in a day;
  - Outside the buried channel, a piled casing of 5 m diameter, installed using a maximum blow energy of 3,500 kJ or 5,500 kJ and driving for 4.5 hours in a day.
- 6.1.1.4 Noise mitigation is proposed, to provide up to 12 dB of attenuation using a suitable noise reduction system to be specified closer to the time of construction. Modelling of both mitigated and unmitigated scenarios are included in results.
- 6.1.1.5 The modelling results were analysed in terms of relevant noise metrics and criteria to assess the effects of the impact piling on marine mammals (Southall *et al.*, 2019) and fish (Popper *et al.*, 2014), which have been used to aid biological assessments. The loudest levels of noise and the greatest impact ranges were generally predicted for the scenarios with the highest energies in (and adjacent to) the deepest water, to the north of the Array Area.
- 6.1.1.6 For marine mammals, maximum PTS ranges were predicted for LF cetaceans (183 dB  $L_{E,p,t}$  re 1  $\mu\text{Pa}^2\text{s}$ ), with ranges of up to 1,500 m based on the piled casing (Location 6, northernmost) foundation scenario, and a maximum TTS impact range of 49 km. For fish, the largest recoverable injury ranges (203 dB SEL<sub>cum</sub>) were predicted to be 1,300 m for a stationary receptor, reducing to less than 100 m for a moving receptor at the fastest modelled speed. This worst case scenario has a maximum TTS range of 15 km for a stationary fish, reducing to 4.9 km where the fish can move at the faster rate. These include the benefit of noise mitigation. Ranges were much lower at the most southern location, closest to the entrance to Loch Roag/*Loch Ròg*.
- 6.1.1.7 Noise sources other than piling were considered using a high-level, simple modelling approach, including cable laying, dredging, drilling (drill and grout), rock placement, vessel movements, and

operational WTG noise. The predicted noise levels for the other construction noise sources and during WTG operation are well below those predicted for impact piling noise. Specifically, the drill and grout methodology, which is proposed to be used for some of the pile or casing installations in the southwest of the site, is predicted to require a marine mammal or fish receptor to remain closer than 100 m from the drilling machinery to lead to any risk of PTS in any species.

- 6.1.1.8 The outputs of this modelling have been used to inform analysis of the impacts of underwater noise on marine mammals and fish in their respective reports.

## 7 GLOSSARY OF TERMS AND ABBREVIATIONS

7.1.1.1 A list of key terms and acronyms used in this appendix are provided in **Table 7-1** and **Table 7-2**.

Table 7-1 Acronyms and abbreviations

Term	Definition
EIAR	Environmental Impact Assessment Report
HF	High-Frequency Cetaceans
INSPIRE	Impulsive Noise Sound Propagation and Impact Range Estimator
ISO	International Organisation for Standardisation
LF	Low-Frequency Cetaceans
MHWS	Mean High Water Springs
NMFS	National Marine Fisheries Service
NPL	National Physical Laboratory
OCAS	Offshore Cable Area of Search
OWF	Offshore Wind Farm
PCW	Phocid Carnivores in Water
PTS	Permanent Threshold Shift
RMS	Root Mean Square
SE	Sound Exposure
SEL ( $L_{E,p}$ )	Sound Exposure Level
SEL <sub>cum</sub> ( $L_{E,p,t}$ )	Cumulative Sound Exposure Level
SEL <sub>ss</sub> ( $L_{E,p,ss}$ )	Single Strike Sound Exposure Level
SPL	Sound Pressure Level
SPL <sub>peak</sub> ( $L_{p,pk}$ )	Peak Sound Pressure Level
SPL <sub>RMS</sub> ( $L_p$ )	Root Mean Square Sound Pressure Level
TTS	Temporary Threshold Shift
VHF	Very High-Frequency Cetaceans
WTG	Wind Turbine Generator

Table 7-2 Glossary

Term	Meaning
the Applicant	Sporad na Mara Limited (the Project owner).
Array Area	The offshore area within which the offshore wind turbine generators (WTGs), associated foundations, Offshore Cables, and Offshore Substation Platform (OSP) (if required), will be located. This area encompasses the Turbine Area that will contain all above water surface infrastructure (WTGs/OSP) and an additional area within which further below water infrastructure (foundations and cables) may also be located.

Term	Meaning
Decibel (dB)	A customary scale commonly used (in various ways) for reporting levels of sound. The dB represents a ratio/comparison of a sound measurement (e.g., sound pressure) over a fixed reference level. The dB symbol is followed by a reference value (e.g., re 1 $\mu$ Pa).
Offshore Project	The components of the Spiorad na Mara offshore wind farm (the Project) located seaward of Mean High Water Springs (MHWS).
Peak pressure	The highest pressure above or below ambient that is associated with a sound wave.
Permanent Threshold Shift (PTS)	Noise threshold that represents the onset level of a permanent impairment hearing caused by acoustic trauma. PTS results in irreversible damage to the sensory hair cells of the ear, and thus a permanent reduction of hearing acuity.
Root Mean Square (RMS)	The square root of the arithmetic average of a set of squared instantaneous values. Used for presentation of an average sound pressure level.
Sound Exposure Level (SEL or $L_{E,p}$ )	The constant sound level acting for 1 second, which has the same amount of acoustic energy, as indicated by the square of the sound pressure, as the original sound. It is the time-integrated, sound-pressure-squared level. SEL is typically used to compare transient sound events having different time durations, pressure levels, and temporal characteristics.
Sound Exposure Level, cumulative (SEL <sub>cum</sub> or $L_{E,p,t}$ )	Single value for the collected, combined total of sound exposure over a specified time or multiple instances of a noise source.
Sound Exposure Level, single strike (SEL <sub>ss</sub> )	Calculation of the sound exposure level representative of a single noise impulse, typically a pile strike.
Sound Pressure Level (SPL or $L_p$ )	The sound pressure level is an expression of sound pressure using the decibel (dB) scale; the standard frequency pressures of which are 1 $\mu$ Pa for water and 20 $\mu$ Pa for air.
Sound Pressure Level Peak (SPL <sub>peak</sub> or $L_{p,pk}$ )	The highest (zero-peak) positive or negative sound pressure, in decibels.
Temporary Threshold Shift (TTS)	Onset threshold level for a temporary reduction of hearing acuity caused by exposure to sound over time.
Unweighted sound level	Sound levels which are "raw" or have not been adjusted in any way, for example to account for the hearing ability of a species.
Weighted sound level	A sound level which has been adjusted with respect to a "auditory weighting function" or "weighting envelope" in the frequency domain, typically to make an unweighted level relevant to a particular species.

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## ANNEX 13.3.1: NOISE MODELLING PLOTS, FISH IMPACT CONTOURS WITH RESPECT TO LOCH ROAG/LOCH RÒG

- 8.1.1.1 **Annex 13.3.1, Volume 2c** is included to provide a visual context for the recoverable injury and TTS modelled contours on fish, particularly in reference to the entrance to Loch Roag/*Loch Ròg* to the south of the Offshore Project. The worst-case mitigated and unmitigated modelling scenarios are presented, assuming that any fish receptor remains stationary. The lowest Popper *et al.* (2014) thresholds are included, 186 dB  $L_{E,p,t}$  for TTS onset, and 203 dB  $L_{E,p,t}$  for recoverable injury to the most sensitive species, fish with a swim bladder involved with hearing. Higher thresholds, i.e. recoverable injury for less sensitive species (without a swim bladder, at 210 dB  $L_{E,p,t}$ ), are barely visible at this scale.
- 8.1.1.2 Equivalent impact ranges for modelling where salmon are mobile, a moving animal model, result in impact ranges that are considerably smaller: a maximum TTS onset range of 4,850 m at the most northern modelling location (Location 6) and 2,700 m at the most southerly modelling location (Location 4), compared to 15,000 m and 12,000 m respectively for the stationary animal model.

## A.1 LOCATION 1

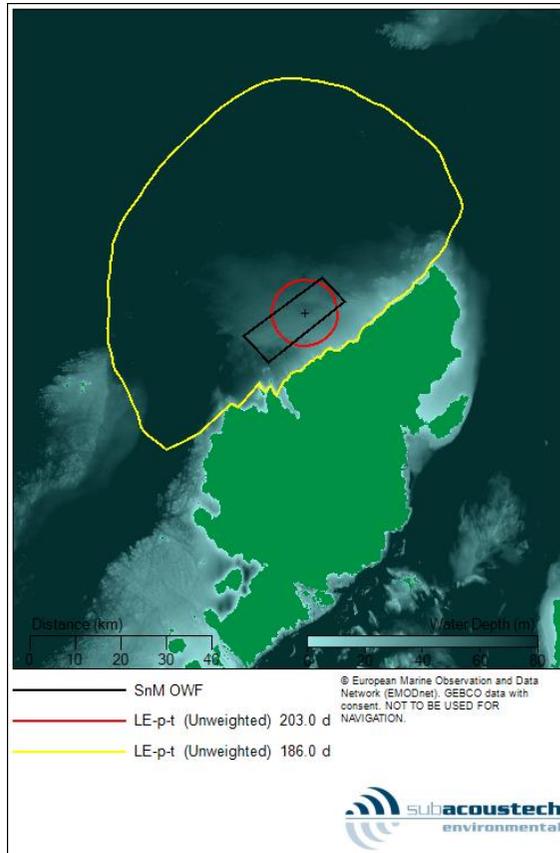


Plate A 1: Map of the impact range thresholds for the unweighted SEL metric (stationary fish) for Location 1 with no mitigation

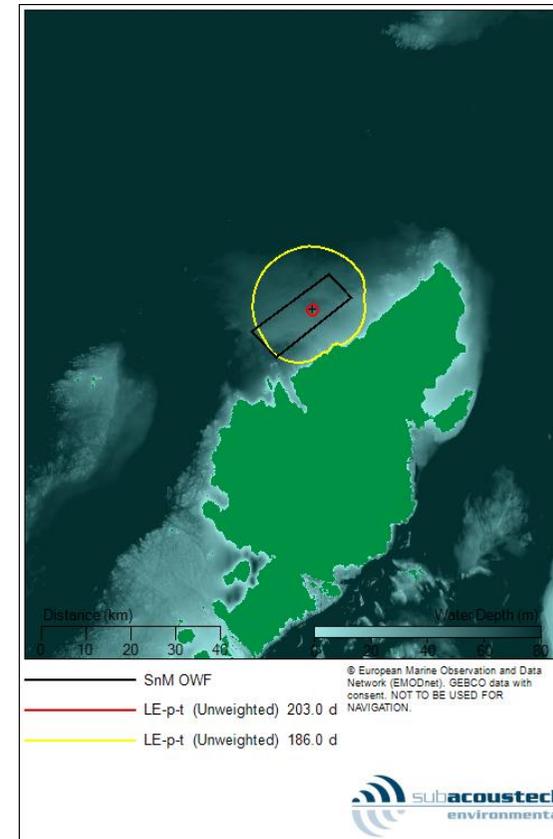


Plate A 2: Map of the impact range thresholds for the unweighted SEL metric (stationary fish) for Location 1 with mitigation

## A.2 LOCATION 2



Plate A 4 : Map of the impact range thresholds for the unweighted SEL metric (stationary fish) for Location 2 with no mitigation

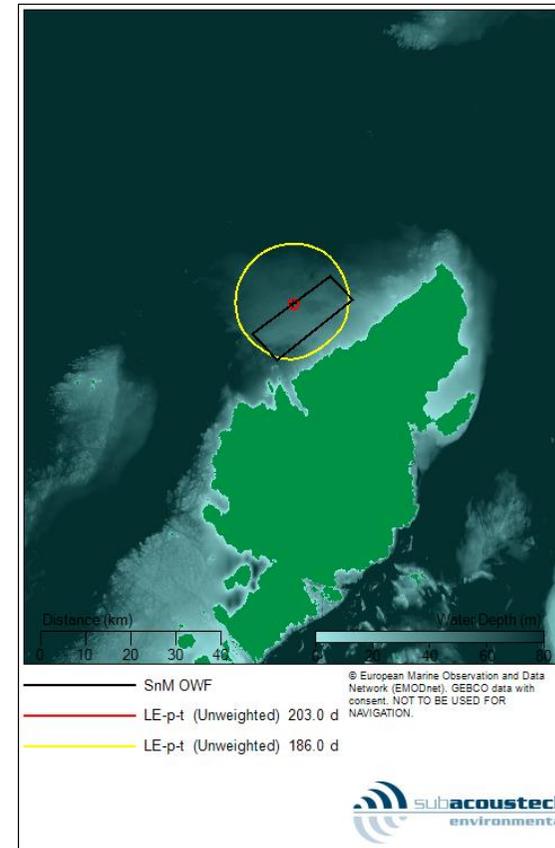


Plate A 3 : Map of the impact range thresholds for the unweighted SEL metric (stationary fish) for Location 2 with mitigation

### A.3 LOCATION 3

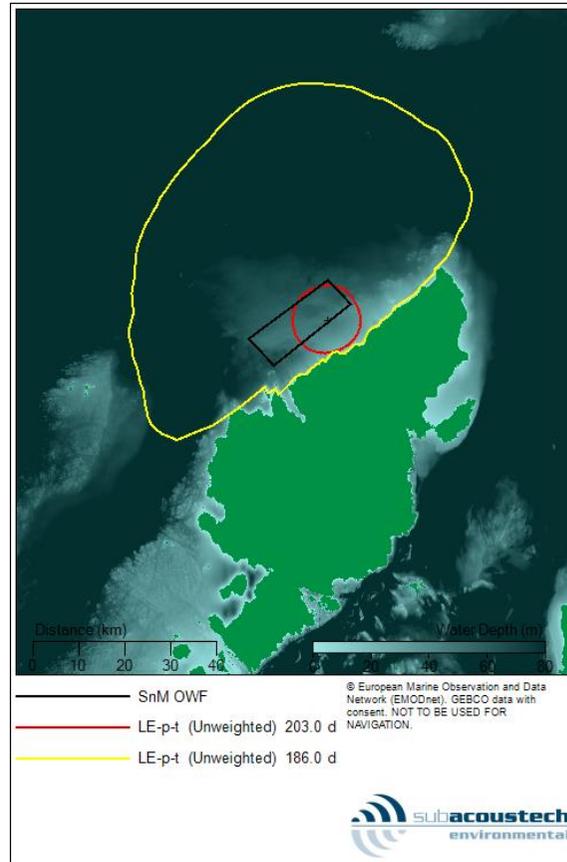


Plate A 5: Map of the impact range thresholds for the unweighted SEL metric (stationary fish) for Location 3 with no mitigation

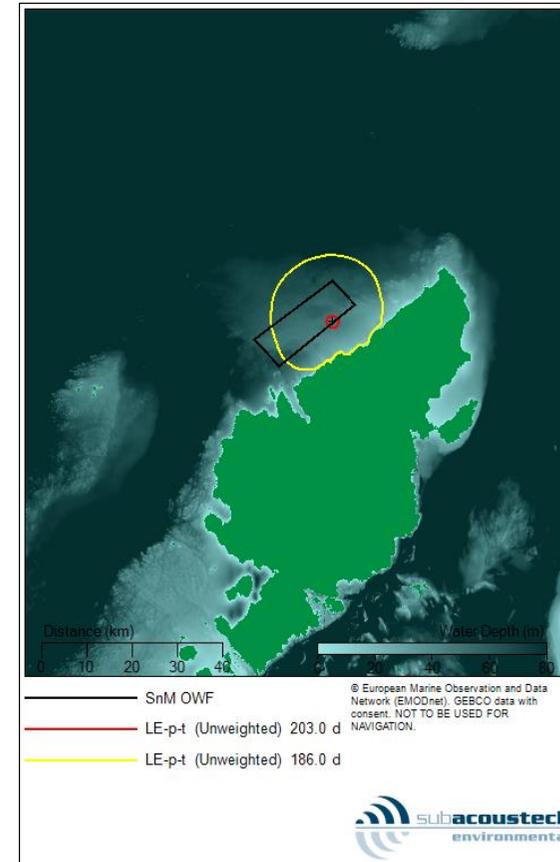


Plate A 6: Map of the impact range thresholds for the unweighted SEL metric (stationary fish) for Location 3 with mitigation

## A.4 LOCATION 4

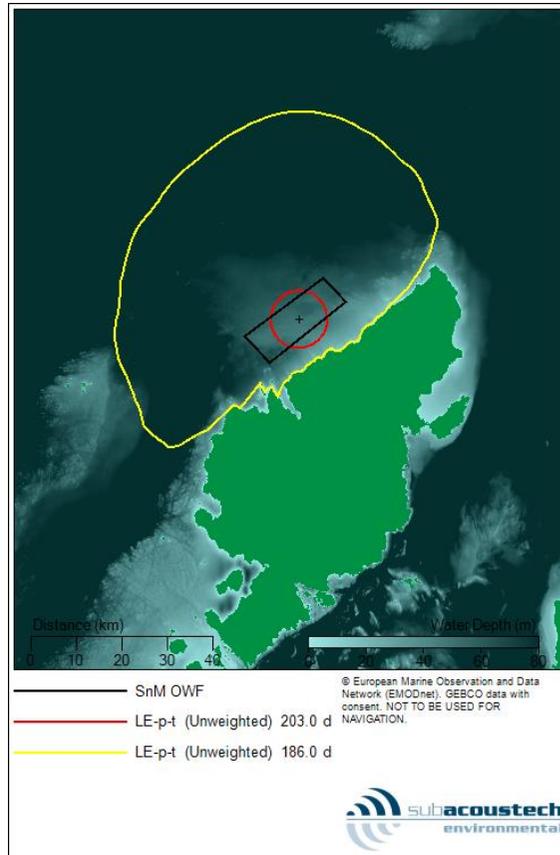


Plate A 7: Map of the impact range thresholds for the unweighted SEL metric (stationary fish) for Location 4 with no mitigation

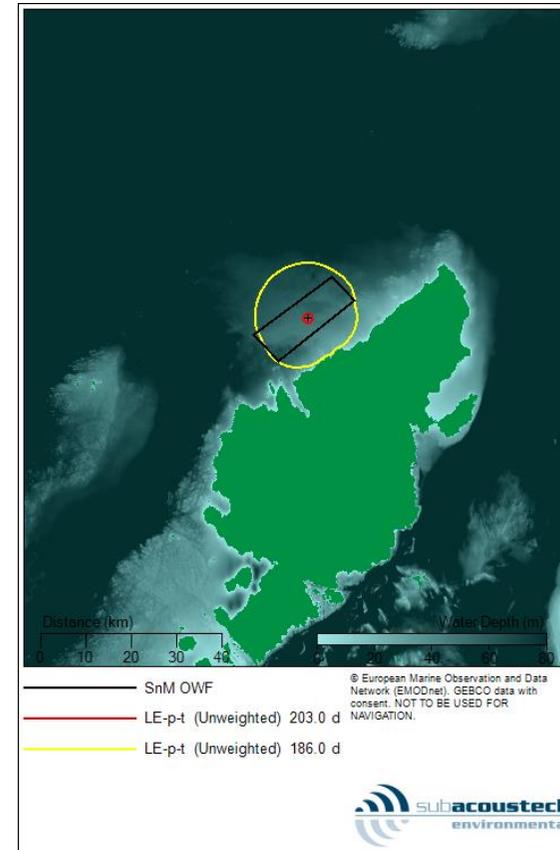


Plate A 8: Map of the impact range thresholds for the unweighted SEL metric (stationary fish) for Location 4 with mitigation

## A.5 LOCATION 5

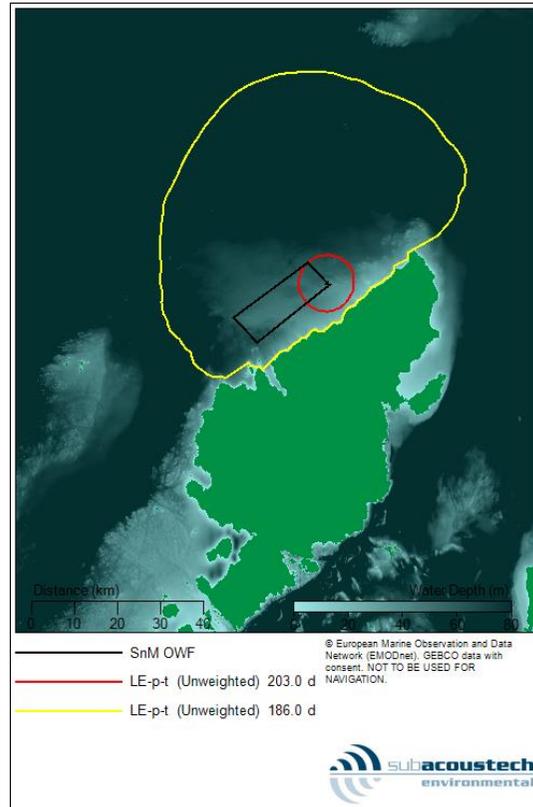


Plate A 9: Map of the impact range thresholds for the unweighted SEL metric (stationary fish) for Location 5 with no mitigation

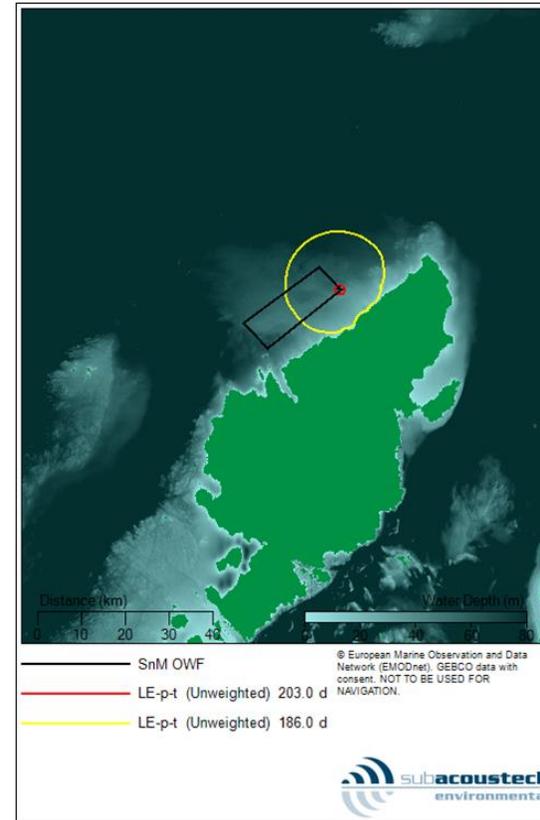


Plate A 10: Map of the impact range thresholds for the unweighted SEL metric (stationary fish) for Location 5 with mitigation

## A.6 LOCATION 6

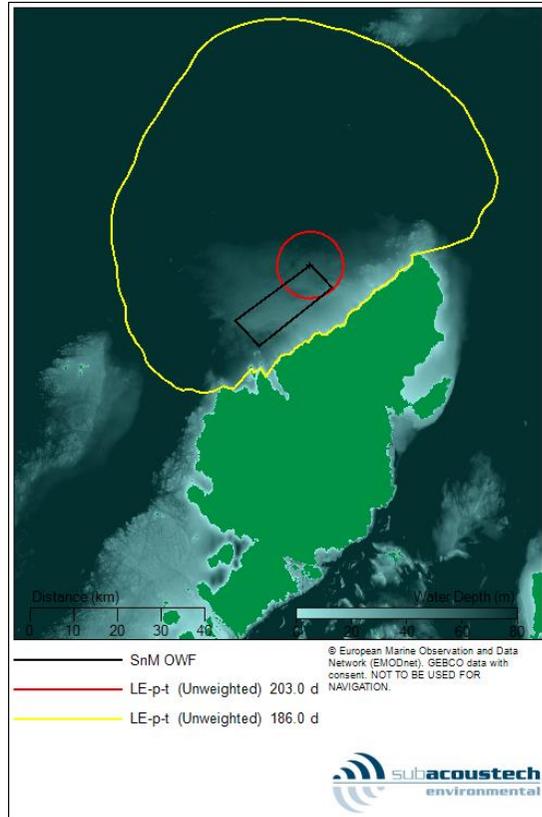


Plate A 11: Map of the impact range thresholds for the unweighted SEL metric (stationary fish) for Location 6 with no mitigation

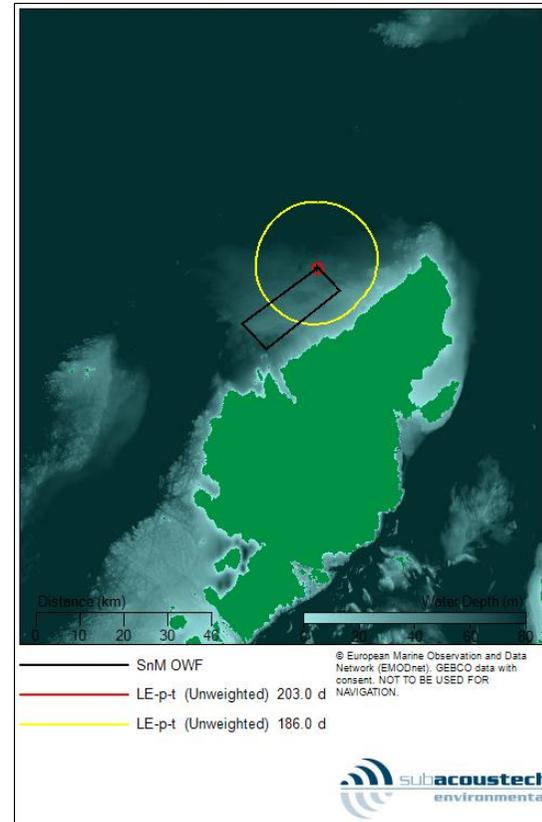


Plate A 12: Map of the impact range thresholds for the unweighted SEL metric (stationary fish) for Location 6 with mitigation