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Volume 7 Standalone Appendices

Appendix 6 Underwater Noise Assessment

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Volume 7 Appendix 6
Caledonia Offshore Wind Farm: Underwater noise assessment

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Executive Summary

Subacoustech Environmental Ltd., on behalf of GoBe Consultants Ltd., has undertaken a study in order to assess the potential underwater noise and its effects during the construction and operation of the proposed Caledonia Offshore Wind Farm (referred to as the Proposed Development (Offshore)).

Impact piling modelling for various foundation types was undertaken at eight representative locations, with the loudest levels of noise and the greatest impact ranges predicted for the multi-leg foundation scenario at the westernmost corner of the site, due to the deep water at, and surrounding, this location.

The modelling results were analysed in terms of relevant noise metrics and criteria to assess the effects of impact piling noise on marine mammals and fish, which have been used to aid biological assessments. For marine mammals, maximum permanent threshold shift (PTS) impact ranges were predicted for animals in the low-frequency (LF) cetacean category, with ranges out to 36 km. For fish, the largest recoverable injury ranges were predicted to be 11 km for a stationary receptor, reducing to 450 m when considering a fleeing receptor.

Noise sources other than impact piling, including cable laying, dredging, drilling, rock placement, trenching vibropiling, and vessel movements, and operational wind turbine generator (WTG) noise, were all predicted to be well below those predicted for impact piling noise. Noise from low order unexploded ordnance (UXO) clearance, using deflagration, showed a risk of PTS out to 990 m from any UXO device.

It should be stressed that, due to the nature of modelling, while the results present specific ranges at which each impact threshold is met, the ranges should be taken as indicative and worst case in determining where environmental effects may occur in receptors during the proposed operations.

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.

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Terminology

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 µPa).
Peak pressure	The highest pressure above or below ambient that is associated with a sound wave.
Peak-to-peak pressure	The sum of the highest positive and negative pressures that are associated with a sound wave.
Permanent Threshold Shift (PTS)	Noise threshold that represents the onset level of a permanent impairment of 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 one 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. $L_{E,p}$ is typically used to compare transient sound events having different time durations, pressure levels, and temporal characteristics.
Sound Exposure Level, cumulative (SEL_{cum} 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_{ss})	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 µPa for water and 20 µPa for air.
Sound Pressure Level Peak (SPL_{peak} 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. The mechanisms underlying TTS are not well understood, but there may be some temporary damage to the sensory cells.
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 “weighting envelope” in the frequency domain, typically to make an unweighted level relevant to a particular species.

Acronyms

ADD	Acoustic Deterrent Device
BGS	British Geological Survey
EIAR	Environmental Impact Assessment Report
EMODnet	European Marine Observation and Data Network
FPSO	Floating Production Storage and Offloading (vessel type)
GIS	Geographic Information System
HE	High Explosive
HF	High-Frequency Cetaceans
INSPIRE	Impulsive Noise Sound Propagation and Impact Range Estimator
ISO	International Organisation for Standardisation
LF	Low-Frequency Cetaceans
MTD	Marine Technical Directorate
NEQ	Net Explosive Quantity
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPL	National Physical Laboratory
OECC	Offshore Export Cable Corridor
OWF	Offshore Wind Farm
PCW	Phocid Carnivores in Water
PPV	Peak Particle Velocity
PTS	Permanent Threshold Shift
RMS	Root Mean Square
SE	Sound Exposure
SEL	Sound Exposure Level
SNH	Scottish Natural Heritage
SPL	Sound Pressure Level
TNT	Trinitrotoluene (explosive)
TTS	Temporary Threshold Shift
UXO	Unexploded Ordnance
VHF	Very High-Frequency Cetaceans

Units

dB	Decibel (sound pressure)
GW	Gigawatt (power)
Hz	Hertz (frequency)
kg	Kilogram (mass)
kHz	Kilohertz (frequency)
kJ	Kilojoule (energy)
km	Kilometre (distance)
km^2	Square kilometres (area)
kW	Kilowatt (power)
m	Metre (distance)
mm/s	Millimetres per second (particle velocity)
m/s	Metres per second (speed)
MW	Megawatt (power)
Pa	Pascal (pressure)
Pa^2s	Pascal squared seconds (acoustic energy)
µPa	Micropascal (pressure)

1 Introduction

The Caledonia Offshore Wind Farm (OWF) (hereafter referred to as the Proposed Development (Offshore)) is a proposed OWF in the Moray Firth, Scotland. As part of the Environmental Impact Assessment Report (EIAR) process, Subacoustech Environmental Ltd. has undertaken detailed modelling and analysis in relation to the effect of underwater noise on marine mammals and fish.

The Array Area covers an area of 423 km^2, is situated approximately 22 km from Wick, and is located immediately to the east of the existing Moray East OWF. The Array Area of the Proposed Development (Offshore) is split into the Caledonia North Site and Caledonia South Site. The Caledonia North Site will comprise up to 77 Wind Turbine Generators (WTGs) with bottom-fixed foundations, while the Caledonia South Site will comprise up to 78 WTGs using either bottom-fixed foundations only, or a combination of bottom-fixed and floating foundations. However, the maximum number of WTGs across the Caledonia North Site and Caledonia South Site will not exceed 140. The Proposed Development (Offshore) site is shown in Figure 1-1.

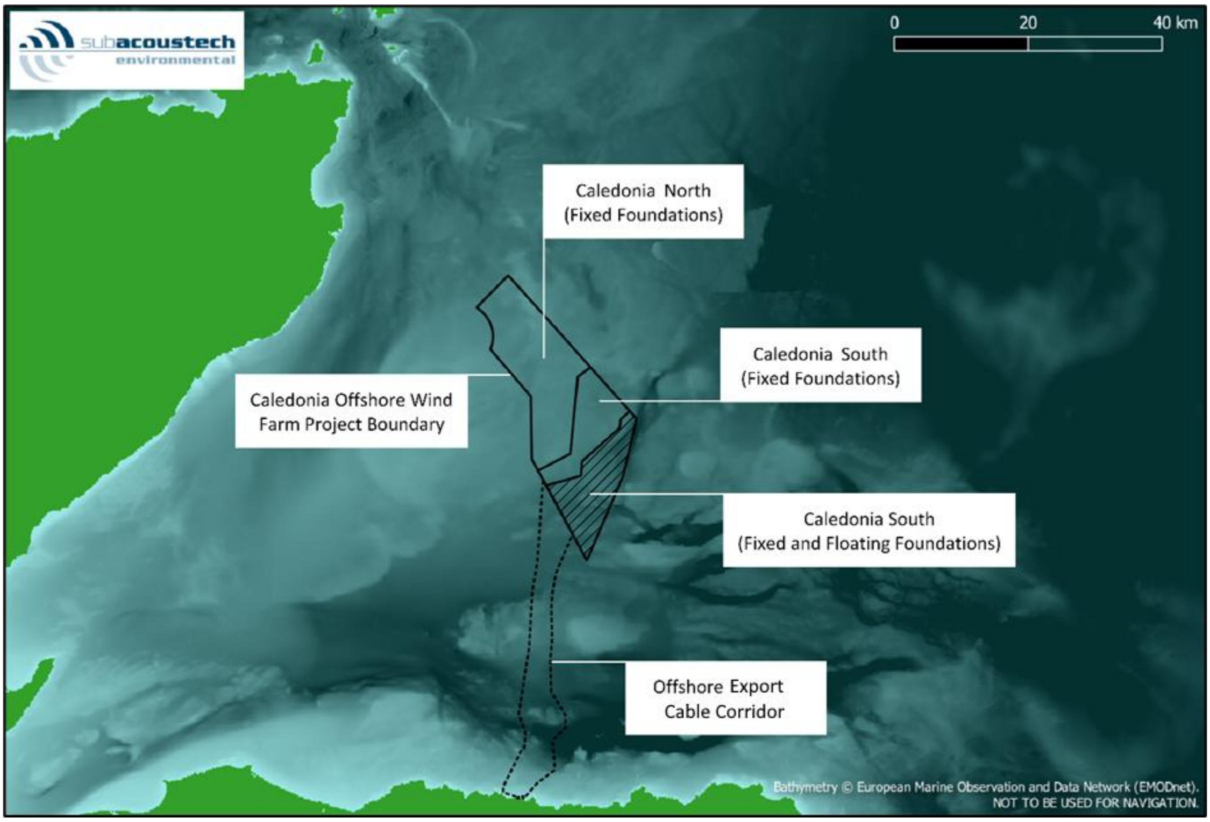

Figure 1-1 Overview map showing the Proposed Development (Offshore), and surrounding bathymetry and coastline.

This report presents a detailed assessment for the potential underwater noise during the construction and operation of the Proposed Development (Offshore), and includes the following:

- Background information covering the units for measuring and assessing underwater noise, and a review of the underwater noise metrics and criteria used to assess the possible environmental effects in marine receptors (Section 2).
- Discussion of the approach, input parameters and assumptions for the detailed modelling undertaken (Section 3)

- Presentation and interpretation of the detailed subsea noise modelling for impact piling with regards to its effect on marine mammals and fish (Section 4)
- Noise modelling of other noise sources expected around the construction and operation of Proposed Development (Offshore) including cable laying, dredging, drilling, rock placement, vessel movements, operational WTG noise, and Unexploded Ordnance (UXO) clearance (Section 5), and
- Summary and conclusions (Section 6).

The study area for this assessment includes the following areas:

- Caledonia North Site; and
- Caledonia South Site.

Further modelling results are presented in Annex 1.

2 Underwater noise concepts

2.1 Underwater noise

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

2.1.1 Units of measurement

Sound measurements underwater are usually expressed using the Decibel (dB) scale, which is a logarithmic measure of sound. A logarithmic scale is used, 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 a roughly 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.

The fundamental definition of the dB scale is given by:

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

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

The dB scale represents a ratio. 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, a reference quantity of 20µPa is used for sound in air since that is the lower threshold of human hearing.

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:

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

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

2.1.2 Sound pressure level (L_p or SPL)

The Sound Pressure Level (SPL or L_p) is normally used to characterise noise 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.

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 ten times higher than the mean averaged over one second. Often, transient sounds such as these are quantified using "peak" SPLs ($L_{p,pk}$) or Sound Exposure Levels (SELs, L_E).

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

2.1.3 Peak sound pressure level ($L_{p,pk}$ or SPL_{peak})

The peak SPL, or $L_{p,pk}$, is 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.

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

2.1.4 Sound exposure level ($L_{E,p,t}$ or SEL)

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 biological effect of short and long-range blast waves on human divers. More recently, this form of analysis has been used to develop criteria for assessing injury ranges for fish and marine mammals from various noise sources (Popper *et al.,* 2014; Southall *et al.,* 2019).

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

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

where p is the acoustic pressure in Pa, 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 (Pa^2s).

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

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

By using a common reference pressure (p_{ref}) of 1 µPa for assessments of underwater noise, the $L_{E,p}$ and L_p can be compared using the expression:

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

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

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

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 $L_{E,p,t}$, 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:

$$L_{E.p.t} = L_E + 10 \times \log_{10} X$$

where $L_{E,p,t}$ is the sound exposure level of one impulse and X is the total number of impulses or strikes. Unless otherwise defined, all $L_{E,p,t}$ noise levels in this report are references to 1 µPa²s.

2.2 Properties of sound

2.2.1 Impulsive and non-impulsive noise

Sound can be categorised loosely into two 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).

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

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 SPL ($L_{p,pk}$) and cumulative SEL ($L_{E,p,t}$)
- Non-impulsive noises: cumulative SEL ($L_{E,p,t}$)

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 becomes less impulsive with distance from the noise source. This is important to consider regarding auditory injury and impact range calculations, as impulsive noise will become less injurious if it becomes less impulsive.

Active research is currently underway to define the range-dependant 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 3.5km from the source. Using these findings, Southall (2021) suggests that noise should be considered non-impulsive when there is no longer energy content above 10kHz. However, research remains in progress, with work ongoing in an attempt to determine numerical values of other pulse characteristics, such as for kurtosis, that can aid categorisation of a pulse as either impulsive or non-impulsive.

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. Due to the uncertainty, no presumption of a change in impulsiveness has been made in this report, and instead results for both impulsive and non-impulsive for relevant noise sources have been presented.

2.2.2 Particle motion

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, PPV), but sometimes the related acceleration or displacement of the particle is used.

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 Solé *et al.*, 2023) 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 with respect to particle motion.

2.3 Analysis of environmental effects: Assessment criteria

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.

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); or
- Disturbance and behavioural responses.

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 at The Proposed Development (Offshore).

The main metrics and criteria that have been used in this study to aid assessment of environmental effects come from three 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.

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

2.3.1 Marine mammals

The Southall *et al*. (2019) paper is the most used and recognised reference for marine mammal hearing thresholds. It 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 if comparing results using the Southall *et al*. (2019) to NMFS (2018) criteria.

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 Figure 2-1. Further groups for sirenians and other marine carnivores in water are given, but these have not been included in this study as those species are not commonly found in the North Sea and Moray Firth.

It should be noted that despite Southall *et al*. (2019) referring to peak SPL as SPL_{peak}, this notation has since been deprecated (ISO 18405:2017) and will be referred to as $L_{p,pk}$ in the rest of this report.

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 to 35 kHz	Baleen whales (including minke whale)
High-frequency cetaceans (HF)	150 Hz to 160 kHz	Dolphins, toothed whales, beaked whales, bottlenose whales (including bottlenose dolphin)
Very high-frequency cetaceans (VHF)	275 Hz to 160 kHz	True porpoises (including harbour porpoise)
Phocid carnivores in water (PCW)	50 Hz to 86 kHz	True seals (including harbour seals)

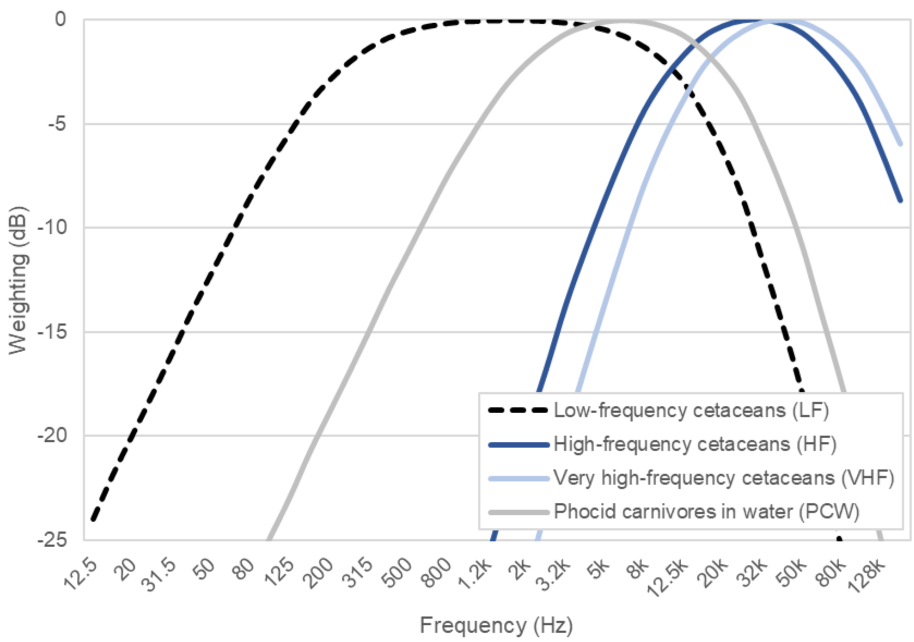

Figure 2-1 Auditory weighting functions for low-frequency cetaceans (LF), high-frequency cetaceans (HF), very high-frequency cetaceans (VHF), and phocid carnivores in water (PCW) (from Southall et al., 2019).

Southall *et al*. (2019) considers the nature of the sound in the context of whether it is an impulsive or non-impulsive noise source (see section 2.2.1 for details).

Although the use of impact ranges derived using the impulsive criteria are recommended for all but clearly defined non-impulsive sources, it should be recognised that where calculated ranges are beyond 3.5 km (see section 2.2.1), the impact range is likely to be somewhere between the impulsive and non-impulsive impact criteria. Therefore, if the modelled impact range of an impulsive noise has been predicted to be greater than 3.5 km, the non-impulsive impact range should also be considered. Both impulsive and non-impulsive criteria have been presented in this study.

Where $L_{E,p,t}$ thresholds are required for marine mammals, a fleeing animal model has been used. This assumes that a receptor, when exposed to high noise levels, will swim away from the noise source. For this study, the following flee speeds have been used for marine mammals:

- 2.1 m/s for low-frequency cetaceans (LF) (Scottish Natural Heritage; SNH, 2016)

- 1.52 m/s for high-frequency cetaceans (HF) (Bailey and Thompson, 2006)
- 1.4 m/s for very high-frequency cetaceans (VHF) (SNH, 2016), and
- 1.8 m/s for phocid carnivores in water (PCW) (SNH, 2016).

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. The fleeing animal model and the assumptions related to it are discussed in more detail in section 3.3.

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 noise level required to produce an onset, i.e. the minimum levels, for potential of different levels of auditory injury at different noise levels of that sound. Auditory injury is grouped into the following two types:

- Permanent Threshold Shift (PTS) – onset of unrecoverable (but incremental) hearing damage, and
- Temporary Threshold Shift (TTS) – onset of a temporary reduction in hearing sensitivity.

As it is a lower severity of effect, the greatest impact ranges are associated with TTS. The effects from PTS represent permanent (but only incremental, not total) impairment, and thus, PTS will be assessed and presented in this report, as the most important impact threshold.

There is no threshold for TTS that would indicate a biologically significant amount of TTS for an individual. Only the assessment of permanent threshold shift (PTS) and behavioural disturbance is required. Since TTS impacts of marine mammals from pile driving activities are not used in the marine mammal EIAR, they are not presented in this underwater noise technical report. Behavioural disturbance is assessed using modelling outputs with a dose-response methodology, which is described in detail in Volumes 2, 3 and 4, Chapter 7: Marine Mammals of the EIAR.

The assessment of UXO however will include TTS, although rather than in the context of auditory injury, this is as a proxy for disturbance in the absence of disturbance thresholds for exposure to explosive noise. The TTS thresholds are included in the tables below.

In summary, when using Southall *et al*. (2019) assessment criteria to calculate impacts, three variables are considered:

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

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

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

Southall *et al.* (2019)	$L_{p,pk}$ (dB re 1 µPa)	
	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 $L_{E,p,24h,wtd}$ criteria for PTS and TTS in marine mammals (Southall et al., 2019).

Southall *et al.* (2019)	$L_{E,p,24h,wtd}$ (dB re 1 µPa^{2}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

As above, TTS thresholds are included for use in the context of disturbance in the UXO assessment.

As well as impact ranges using criteria and thresholds provided above, underwater noise modelling also includes outputs for the noise levels at 5 dB increments from the piling location (i.e., noise contours are provided at 200 dB, 195 dB, 190 dB, etc.). These are used for the prediction of marine mammal behavioural reactions using dose-response methodology.

2.3.2 Fish

The Popper *et al*. (2014) guidelines are recognised as a suitable reference for underwater noise impacts on marine fauna (aside from marine mammals) in UK waters. While previous studies have applied broad criteria based on limited studies of fish that are not present in UK waters (McCauley *et al*. 2000), or measurement data not intended to be used as criteria (Hawkins *et al*., 2014), Popper *et al*. (2014) provides a summary of the latest research and guidelines for fish (and other marine fauna) exposure to sound and uses categories for fish that are representative of the species present around the Proposed Development (Offshore) site.

The Popper *et al*. (2014) guidelines present criteria dependent on the type of noise source, species of marine fauna and their hearing capabilities, and impact type. Noise sources considered in the guidance include explosions, pile driving, seismic airguns, sonar, and shipping and continuous noise. For this study, criteria for pile driving, explosions, and shipping and continuous noise have been used.

For each sound source, the marine fauna is categorised into groups of fish, sea turtles, and eggs and larvae. Due to their diversity and quantity, fish are categorised further into three 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.

Popper *et al*. (2014) provides separate criteria, depending on the species and the noise source, for various impacts associated with noise exposure. These are mortality and potential mortal injury, impairment (split into recoverable injury, TTS, and masking), and behavioural effects.

Depending on the noise source, quantitative criteria are given in appropriate metrics ($L_{p,pk}$, $L_{E,p,24h}$, etc.), which can then be used as thresholds for the onsets of listed impacts. Where insufficient data is available, Popper *et al.* (2014) also gives a qualitative description. This summarises the effect of the noise as having either a high, moderate or low relative risk of an effect on an individual in either near (tens of meters), intermediate (hundreds of meters) or far (thousands of meters) from the source.

Where $L_{E,p,t}$ thresholds are required for fish, both a stationary and fleeing animal model has been used. 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.

Most species described by Popper *et al.* (2014) are likely to move away from a sound that is loud enough to cause harm (Dahl *et al*., 2015; Popper *et al*., 2014). For those species that flee, a speed of 1.5m/s (based on Hirata, 1999) is considered a conservative speed at which to base a fleeing animal model. However, considering the diversity of species described by Popper *et al*. (2014), whether an animal flees or remains stationary in response to a loud noise will differ between species. It is recognised that there is limited evidence for fish fleeing from high level noise sources in the wild. Those species that are likely to remain stationary are thought more likely 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; Goertner *et al*., 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 greatly overestimate the potential risk to fish species. A combined approach is recommended, which considers impact ranges from both fleeing and stationary receptors. Impact ranges from both stationary and fleeing receptors are therefore included in this report.

The quantitative and qualitative thresholds from the Popper *et al*. (2014) used in this study are reproduced in Table 2-4 to Table 2-6, covering pile driving, explosions, and shipping and continuous noise. Similar to the Southall *et al*. (2019) criteria in section 2.3.1, the Popper *et al*. (2014) criteria use the deprecated SPL_{peak}, SPL_{RMS} and SEL_{cum} notation, and this report will use respectively the $L_{p,pk}$, L_p, and $L_{E,p,t}$ notation from ISO 18405:2017 from hereon.

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).

Popper *et al.* (2014) criteria for pile driving					
Receptor	Mortality and potential mortal injury	Impairment			Behaviour
		Recoverable injury	TTS	Masking	
Fish: no swim bladder	> 219 dB $L_{E,p,24h}$ > 213 dB $L_{p,pk}$	> 216 dB $L_{E,p,24h}$ > 213 dB $L_{p,pk}$	>> 186 dB $L_{E,p,24h}$	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder not involved in hearing	210 dB $L_{E,p,24h}$ > 207 dB $L_{p,pk}$	203 dB $L_{E,p,24h}$ > 207 dB $L_{p,pk}$	> 186 dB $L_{E,p,24h}$	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder involved in hearing	207 dB $L_{E,p,24h}$ > 207 dB $L_{p,pk}$	203 dB $L_{E,p,24h}$ > 207 dB $L_{p,pk}$	186 dB $L_{E,p,24h}$	(N) High (I) High (F) Moderate	(N) High (I) High (F) Moderate
Sea turtles	> 210 dB $L_{E,p,24h}$ > 207 dB $L_{p,pk}$	(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 dB $L_{E,p,24h}$ > 207 dB $L_{p,pk}$	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low

Table 2-5 Recommended guidelines for explosions 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).

Popper *et al.* (2014) criteria for explosions					
Receptor	Mortality and potential mortal injury	Impairment			Behaviour
		Recoverable injury	TTS	Masking	
Fish: no swim bladder	229 – 234 dB $L_{p,pk}$	(N) High (I) Low (F) Low	(N) High (I) Moderate (F) Low	N/A	(N) High (I) Moderate (F) Low
Fish: swim bladder not involved in hearing	229 – 234 dB $L_{p,pk}$	(N) High (I) Low (F) Low	(N) High (I) Moderate (F) Low	N/A	(N) High (I) Low (F) Low
Fish: swim bladder involved in hearing	229 – 234 dB $L_{p,pk}$	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	N/A	(N) High (I) Low (F) Low
Sea turtles	229 – 234 dB $L_{p,pk}$	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	N/A	(N) High (I) Low (F) Low
Eggs and larvae	> 13 mm/s peak velocity	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	N/A	(N) High (I) Low (F) Low

Table 2-6 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).

Popper *et al*. (2014) criteria for shipping and continuous					
Receptor	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 $L_{p,48h}$	158 dB $L_{p,12h}$	(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

It is important to note that despite the emerging evidence that fish are sensitive to particle motion (see section 2.2.2), the Popper *et al*. (2014) guidance defines noise impacts in terms of sound pressure or sound pressure-associated functions (i.e., $L_{E,p,t}$).

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."

2.3.3 Marine invertebrates

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.

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 µPa. 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.* (2019, 2018, 2013) and André *et al.* (2011) show a consistent threshold for auditory damage on various species of cephalopod at 157 dB re 1 µPa. 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.

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.

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. However, it cannot be ignored that convincing evidence of noise impacts to marine invertebrates does exist. 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 Modelling methodology

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

Of those considered, the noise source most important to consider is impact piling due to the noise level and duration it will be present (Bailey *et al*., 2014), and as such, the noise related to impact piling activity is the primary focus of this study.

The modelling of impact piling has been undertaken using the INSPIRE underwater noise model. The INSPIRE model (currently version 5.2) is a semi-empirical underwater noise propagation model based around a combination of numerical modelling, a combined geometric and energy flow/hysteresis loss method, and actual measured data. It 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 for use in the North Sea (it is noted that measured data for piling noise travelling into waters greater than 100 m have shown good correlation with the INSPIRE estimates; however, due to the limited data set, confidence is reduced compared to shallower areas). The model has been tuned for accuracy using over 80 datasets of underwater noise propagation from monitoring around offshore piling activities.

The model provides estimates of unweighted $L_{p,pk}$, $L_{E,p,ss}$ and $L_{E,p,t}$ noise levels, as well as other weighted noise metrics. Calculations are made along 180 equally spaced radial transects (one every two 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 GIS shapefiles.

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
- Soft start, hammer energy ramp up, and strike rate
- Total duration of piling, and
- Receptor swim speeds.

Simpler modelling approaches have been used for noise sources other than piling that may be present during the construction and operation of The Proposed Development (Offshore); these are discussed in section 5.

3.1 Modelling confidence

INSPIRE 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 or a third party, it is compared against the outputted levels from INSPIRE and, if necessary, the model can be adjusted. Currently over 80 separate impact piling noise datasets primarily from the Irish and North Sea have been used as part of the development for the latest version of INSPIRE, and in each case, an average fit is used. The largest pile diameter included in the analysis was of 9.5 m, and the highest blow energy included was 3,000 kJ.

INSPIRE is designed to predict trends in the effect of increasing parameters beyond empirical data, and uses the existing data combined with standard acoustic theory to predict the effect of high blow energies, large piles and deep water.

In addition, INSPIRE is also validated by comparing the noise levels outputted from the model with measurements and modelling undertaken by third parties, for example Thompson *et al*. (2013).

The current version of INSPIRE (version 5.2) 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.

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 five or even 10 dB, as seen in Bailey *et al*. (2010) and the data shown in Figure 3-1 and Figure 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.

Figure 3-1 and Figure 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 v5.2, matching the pile size, blow energy and position of the measured data. These show the fit to the data, with the INSPIRE data points sitting, more or less, in the middle of the measured noise levels at each range. 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, where, due to the lower levels, the influence on the $L_{E,p,t}$ will be small.

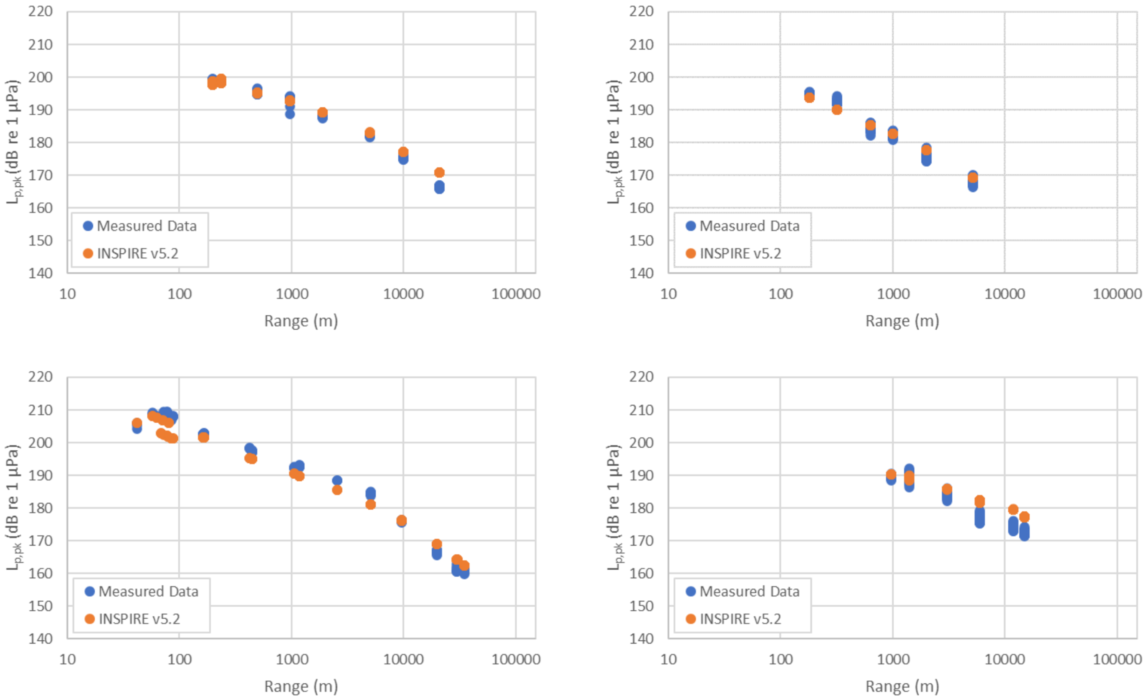

Figure 3-1 Comparison between example measured $L_{p,pk}$ impact piling data (blue points) and modelled data using INSPIRE version 5.2 (orange points)[1].

[1] Top Left: 6.0 m pile, 1,010 kJ max hammer energy, off the Suffolk coast, North Sea, 2009; Top Right: 1.8 m pile, 260 kJ max hammer energy, West of Barrow-in-Furness, Irish Sea, 2010; Bottom Left: 5.3 m pile, 1,560 kJ max hammer energy, off the North Welsh coast, 2012; Bottom Right: 9.5 m pile, 1,600 kJ max hammer energy, North Sea, 2020.

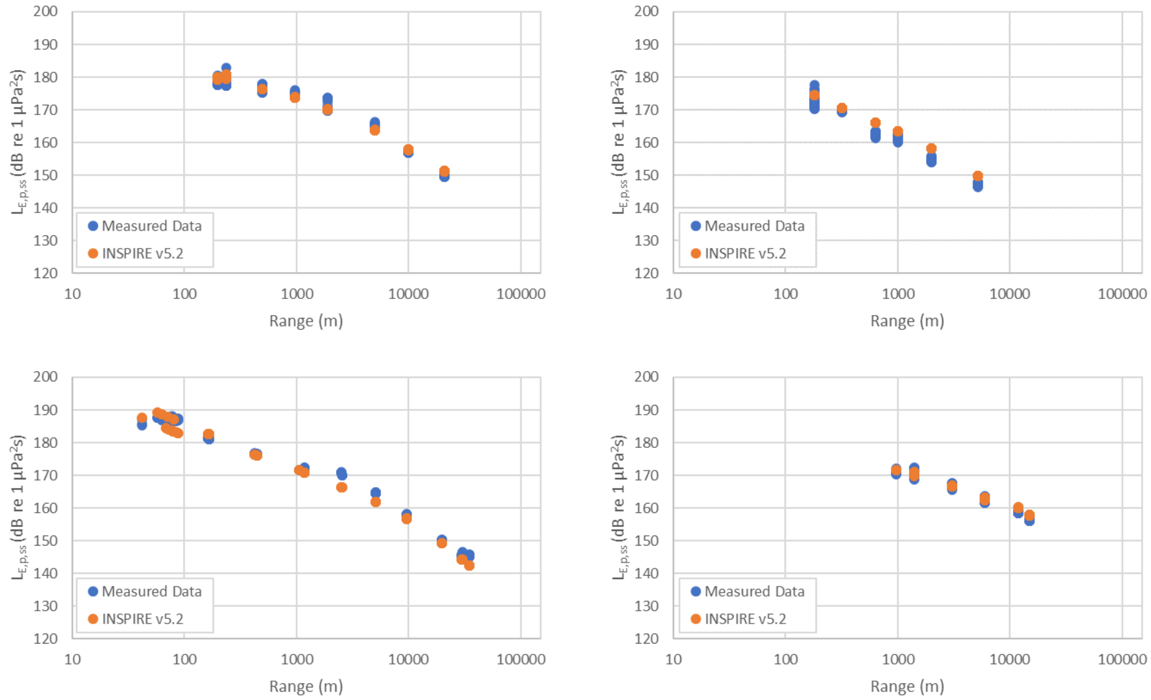

Figure 3-2 Comparison between example measured $L_{E,p,ss}$ impact piling data (blue points) and modelled data using INSPIRE version 5.2 (orange points)[2].

3.2 Modelling parameters

3.2.1 Modelling locations

Modelling for foundation impact piling, for both bottom-fixed and floating WTGs, has been undertaken at eight representative locations covering the extents of Caledonia North and Caledonia South. The eight modelling locations cover potential WTG locations within the Array Areas, as shown below, giving a spread of various water depths, distances to the shore and to the deeper water to the east into the North Sea.

These locations are summarised in Table 3-1 and illustrated in Figure 3-3.

[2] Top Left: 6.0 m pile, 1,010 kJ max hammer energy, off the Suffolk coast, North Sea, 2009; Top Right: 1.8 m pile, 260 kJ max hammer energy, West of Barrow-in-Furness, Irish Sea, 2010; Bottom Left: 5.3 m pile, 1,560 kJ max hammer energy, off the North Welsh coast, 2012; Bottom Right: 9.5 m pile, 1,600 kJ max hammer energy, North Sea, 2020.

Table 3-1 Summary of the underwater noise modelling locations used for this study.

Modelling locations	Latitude	Longitude	Water depth
Modelling location 1 (Caledonia North – North corner)	58.38183° N	002.62719° W	54.8 m
Modelling location 2 (Caledonia North – West corner)	58.33902° N	002.70798° W	53.0 m
Modelling location 3 (Caledonia North/Caledonia South – North-east edge)	58.25769° N	002.41868° W	54.4 m
Modelling location 4 (Caledonia North/Caledonia South – West edge)	58.11952° N	002.55437° W	54.7 m
Modelling location 5 (Caledonia South – East edge)	58.19835° N	002.31973° W	61.6 m
Modelling location 6 (Caledonia South – West edge)	58.09947° N	002.53405° W	64.4 m
Modelling location 7 (Caledonia South – East corner)	58.18807° N	002.30264° W	84.2 m
Modelling location 8 (Caledonia South – South corner)	57.99834° N	002.43197° W	71.0 m

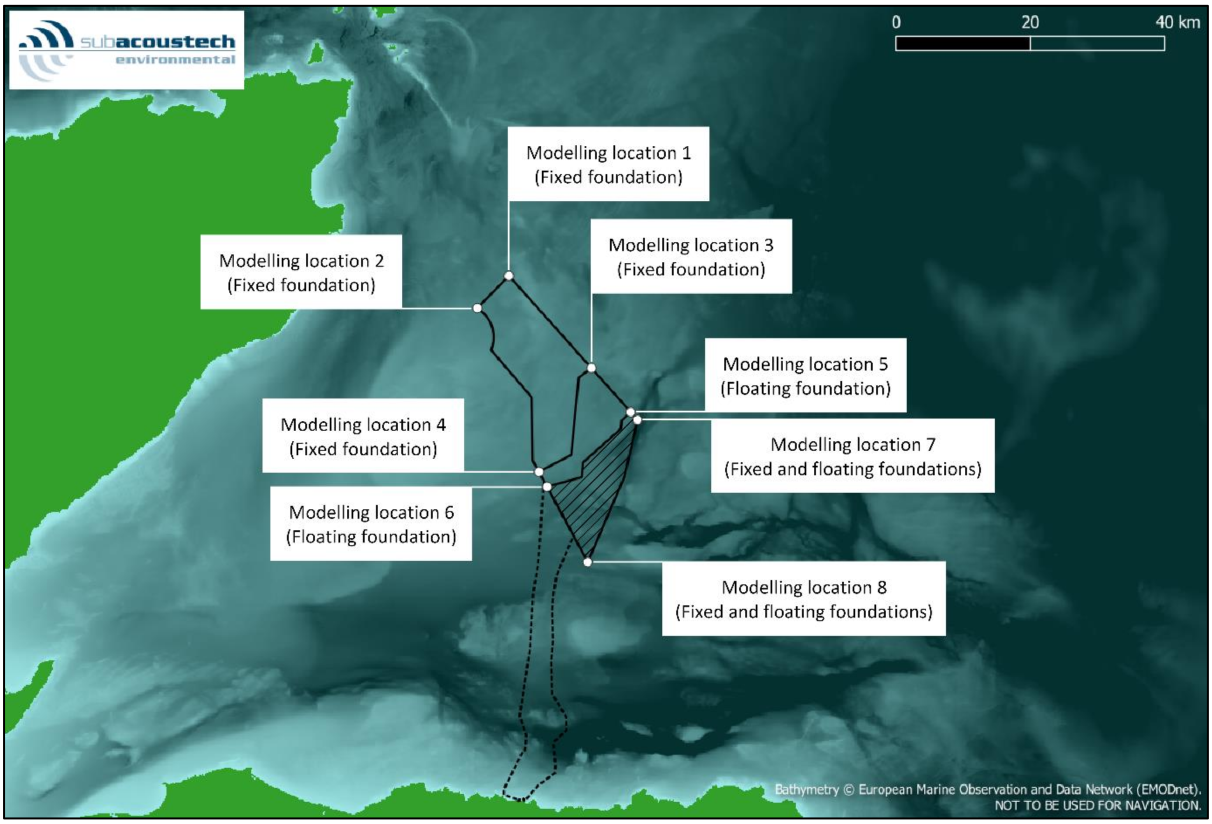

Figure 3-3 Approximate positions of the modelling locations at Caledonia.

3.2.2 Impact piling parameters

The foundation parameters used to inform this underwater noise assessment are taken from the design envelope for the Proposed Development (Offshore), which was informed by site-conditions and foundation designs from other OWFs developed by the Applicant. Three foundation designs have been considered for this study:

- A monopile foundation scenario for bottom-fixed WTGs, installing a 14 m diameter pile with a maximum blow energy of 6,600 kJ
- A multi-leg foundation scenario for bottom-fixed WTGs, installing a 4 m diameter pile with a maximum blow energy of 4,400 kJ, and
- An anchor pile foundation scenario for floating WTGs, installing a 4.8 m diameter pile with a maximum blow energy of 2,000 kJ.

In each case, only certain modelling locations have been considered, for the bottom-fixed monopile and multi-leg foundations, locations 1-4, 7 and 8 have been modelled, and for floating anchor pile foundations, locations 5 to 8 have been modelled.

For $L_{E,p,t}$ criteria, the soft start and ramp up of blow energies along with the total duration of piling and strike rate must also be considered, noting that, from experience (including other OWFs developed by the Applicant), most of the time 100% of the hammer energy is not reached. These are summarised for the three foundation scenarios in Table 3-2 to Table 3-4. Durations presented are illustrative for the purposes of modelling but would be subject to variation based on a number of factors including ground conditions at a given location (see Volume 13: Caledonia North Draft Marine Mammal Mitigation Protocol and Volume 14: Caledonia South Draft Marine Mammal Mitigation Protocol).

In a 24-hour period, it is expected that up to two monopile foundations, four multi-leg pile foundations, or two anchor pile foundations can be installed sequentially from the same piling vessel, which has been taken into consideration for the modelling. There is also the possibility that two piling vessels could be operational and concurrently piling across the Proposed Development (Offshore), or at another nearby OWF. These scenarios have also been modelled and are considered in section 4.2. Where multiple sequential piles are modelled, no break has been assumed between each one, as a worst-case scenario.

In the case of the anchor pile installation, a portion of the piling will take place subsea, with the piling hammer submerged. It has been assumed that each anchor pile measures 55 m in length, and once fully installed, 1.5 m of the pile will protrude from the seabed. This has been included in the modelling, as the radiating area for noise reduces as the pile is installed.

Table 3-2 Summary of the soft start and ramp up scenario used for the monopile foundation modelling.

Monopile foundation	10% (660 kJ)		20% (1,320 kJ)	40% (2,640 kJ)	60% (3,960 kJ)	80% (5,280 kJ)	100% (6,600 kJ)
No of strikes	6	570	300	300	300	300	1,724
Duration	1 min	19 mins	10 mins	10 mins	10 mins	10 mins	57 mins, 28 s
Strike rate (bl/min)	6	30	30	30	30	30	30
3,500 strikes over 1 hour, 57 minutes, 28 seconds per pile 7,000 strikes over 3 hours, 54 minutes, 56 seconds for two piles							

Table 3-3 Summary of the soft start and ramp up scenario used for the multi-leg foundation modelling.

Multi-leg foundation	10% (440 kJ)		20% (880 kJ)	40% (1,760 kJ)	60% (2,640 kJ)	80% (3,520 kJ)	100% (4,400 kJ)
No of strikes	6	570	300	300	300	300	1,724
Duration	1 min	19 mins	10 mins	10 mins	10 mins	10 mins	57 mins, 28 s
Strike rate (bl/min)	6	30	30	30	30	30	30
3,500 strikes over 1 hour, 57 minutes, 28 seconds per pile 14,000 strikes over 7 hours, 49 minutes, 52 seconds for four piles							

Table 3-4 Summary of the soft start and ramp up scenario used for the anchor pile foundation modelling.

Anchor pile foundation	10% (200 kJ)		20% (400 kJ)	40% (800 kJ)	60% (1,200 kJ)	80% (1,600 kJ)	100% (2,000 kJ)
No of strikes	6	570	300	300	300	300	1,224
Duration	1 min	19 mins	10 mins	10 mins	10 mins	10 mins	42 mins
Strike rate (bl/min)	6	30	30	30	30	30	~29
3,000 strikes over 1 hour, 42 minutes per pile							

3.2.3 Apparent source levels

Noise modelling requires knowledge of a source level, which is the theoretical noise level at one metre from the noise source. It is worth noting that the 'source level' technically does not exist in the context of many shallow water (< 100 m) noise sources (Heaney *et al*., 2020). The noise level at one metre from the pile will be highly complex and vary up and down the water column by the pile, which is a long, extended noise source, rather than being one simple noise level. In practice, for underwater noise modelling such as this, it is effectively an 'apparent source level' that is used, essentially a value that can be used to produce correct noise levels at range (for a specific model), as required in impact assessments.

The INSPIRE model requires an apparent source level, which is estimated based on the pile diameter and the blow energy imparted on the pile by the hammer. This is adjusted depending on the water depth at the modelling location to allow for the length of the pile (and effective surface area) in contact with the water, which can affect the amount of noise that is transmitted from the pile into its surroundings. The unweighted, single strike $L_{p,pk}$ and $L_{E,p,ss}$ apparent source levels estimated for this study are provided in Table 3-5. These figures are presented in accordance with requests commonly made by regulatory authorities, although as indicated above, they are not necessarily compatible with any other model or predicted apparent source level. In each case, the differences in apparent source level for each location are minimal as the water depths are all in excess of 50 m.

Table 3-5 Summary of the maximum unweighted source levels used for modelling (N.B. source levels are not given for all modelling location/piling scenario combinations as some foundation types are only considered at select locations).

Source levels	Modelling location	$L_{p,pk}$ @ 1 m	$L_{E,p,ss}$ @ 1 m
Monopile foundation (14 m diameter pile / 6,600 kJ maximum energy)	Modelling location 1	243.1 dB re 1 µPa @ 1 m	224.3 dB re 1 µPa²s @ 1 m
	Modelling location 2	243.1 dB re 1 µPa @ 1 m	224.3 dB re 1 µPa²s @ 1 m
	Modelling location 3	243.1 dB re 1 µPa @ 1 m	224.3 dB re 1 µPa²s @ 1 m
	Modelling location 4	243.1 dB re 1 µPa @ 1 m	224.3 dB re 1 µPa²s @ 1 m
	Modelling location 7	243.1 dB re 1 µPa @ 1 m	224.3 dB re 1 µPa²s @ 1 m
	Modelling location 8	243.1 dB re 1 µPa @ 1 m	224.3 dB re 1 µPa²s @ 1 m
Multi-leg foundation (4 m diameter pile / 4,400 kJ maximum energy)	Modelling location 1	242.4 dB re 1 µPa @ 1 m	223.4 dB re 1 µPa²s @ 1 m
	Modelling location 2	242.4 dB re 1 µPa @ 1 m	223.4 dB re 1 µPa²s @ 1 m
	Modelling location 3	242.4 dB re 1 µPa @ 1 m	223.4 dB re 1 µPa²s @ 1 m
	Modelling location 4	242.4 dB re 1 µPa @ 1 m	223.4 dB re 1 µPa²s @ 1 m
	Modelling location 7	242.5 dB re 1 µPa @ 1 m	223.5 dB re 1 µPa²s @ 1 m
	Modelling location 8	242.4 dB re 1 µPa @ 1 m	223.5 dB re 1 µPa²s @ 1 m
Anchor pile foundation (4.8 m diameter pile / 2,000 kJ maximum energy)	Modelling location 5	240.7 dB re 1 µPa @ 1 m	221.4 dB re 1 µPa²s @ 1 m
	Modelling location 6	240.7 dB re 1 µPa @ 1 m	221.4 dB re 1 µPa²s @ 1 m
	Modelling location 7	240.7 dB re 1 µPa @ 1 m	221.4 dB re 1 µPa²s @ 1 m
	Modelling location 8	240.7 dB re 1 µPa @ 1 m	221.4 dB re 1 µPa²s @ 1 m

There will be a variation in the anchor piles' apparent source levels as the length of the pile in the water reduces during driving, although the maximum levels are shown in the table above.

3.2.4 Predicted noise levels at 750 m from the noise source

In addition to the apparent source levels given in the previous section, it is 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 for where the primary consideration is impact piling. This has the added advantage of being comparable with other modelling or measurements, where the source level (or apparent source level) may not. A summary of the modelled unweighted levels at a range of 750 m, are given in Table 3-6 considering the transect with the greatest noise transmission at each location while piling at the maximum hammer blow energy. Due to the aforementioned deep water across the Proposed Development (Offshore) sites, there are minimal differences in the noise levels at different locations at this range.

Table 3-6 Summary of the maximum predicted $L_{p,pk}$ and $L_{E,p,ss}$ (single strike) noise levels at a range of 750 m from the noise source when considering the maximum hammer blow energy (n.b. noise levels are not given for all modelling location/piling scenario combinations as some foundation types are only considered at select locations).

Predicted levels at 750 m range	Modelling location	$L_{p,pk}$ @ 750 m	$L_{E,p,ss}$ @ 750 m
Monopile foundation (14 m diameter pile / 6,600 kJ maximum energy)	Modelling location 1	203.6 dB re 1 µPa	184.8 dB re 1 µPa^{2}s
	Modelling location 2	203.6 dB re 1 µPa	184.8 dB re 1 µPa^{2}s
	Modelling location 3	203.6 dB re 1 µPa	184.8 dB re 1 µPa^{2}s
	Modelling location 4	203.6 dB re 1 µPa	184.8 dB re 1 µPa^{2}s
	Modelling location 7	203.7 dB re 1 µPa	184.9 dB re 1 µPa^{2}s
	Modelling location 8	203.7 dB re 1 µPa	184.9 dB re 1 µPa^{2}s
Multi-leg foundation (4 m diameter pile / 4,400 kJ maximum energy)	Modelling location 1	202.9 dB re 1 µPa	183.9 dB re 1 µPa^{2}s
	Modelling location 2	202.9 dB re 1 µPa	183.8 dB re 1 µPa^{2}s
	Modelling location 3	202.9 dB re 1 µPa	183.9 dB re 1 µPa^{2}s
	Modelling location 4	202.9 dB re 1 µPa	183.9 dB re 1 µPa^{2}s
	Modelling location 7	203.0 dB re 1 µPa	184.0 dB re 1 µPa^{2}s
	Modelling location 8	203.0 dB re 1 µPa	184.0 dB re 1 µPa^{2}s
Anchor pile foundation (4.8 m diameter pile / 2,000 kJ maximum energy)	Modelling location 5	201.2 dB re 1 µPa	181.9 dB re 1 µPa^{2}s
	Modelling location 6	201.2 dB re 1 µPa	181.9 dB re 1 µPa^{2}s
	Modelling location 7	201.3 dB re 1 µPa	182.0 dB re 1 µPa^{2}s
	Modelling location 8	201.2 dB re 1 µPa	182.0 dB re 1 µPa^{2}s

3.2.5 Environmental conditions

With the inclusion of measured noise propagation data for other 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 in and around the site. Data from the British Geological Survey (BGS) that covers the outer Moray Firth show that the seabed in and around the Proposed Development (Offshore) site is generally made up of various combinations of sand and gravelly sand.

Digital bathymetry from the European Marine Observation and Data Network (EMODnet) has been used for this modelling. Mean tidal depth has been assumed throughout.

3.3 $L_{E,p,t}$ and fleeing receptors

Expanding on the information in section 2.3 regarding $L_{E,p,t}$ and the fleeing animal assumptions used for modelling, it is important to understand the meaning of the results presented in the following sections.

When an $L_{E,p,t}$ impact range is presented for a fleeing animal, this range can be considered a starting position (at the commencement of piling) for the fleeing receptor. For example, if a receptor began to flee in a straight line from the noise source, starting at the position (distance from a pile) denoted by a modelled PTS contour, the receptor would receive exactly the noise exposure as per the PTS criterion under consideration.

When considering a stationary receptor (i.e., one that stays at the same position throughout piling, with no flee response), calculating the $L_{E,p,t}$ is straightforward: all the noise levels produced and received at a single point along a transect are aggregated to calculate the $L_{E,p,t}$. If this calculated level is greater than the threshold being modelled, the model steps away from the noise source and the noise levels from that new location are aggregated to calculate a new $L_{E,p,t}$. This continues outward until the threshold is met.

For a fleeing animal, the receptor's distance from the noise source while moving away also needs to be considered. To model this, a starting point close to the source is chosen and the received noise level for each noise event (e.g., pile strike) is noted; the receptor moves away from the source at a defined speed. For example, if a noise event (i.e., a pulse from a pile strike) occurs every six seconds, and an animal is fleeing at a rate of 1.5 m/s, it is 9 m further from the source after each noise pulse, resulting in a slightly reduced noise level each time. Thes values are then aggregated into an $L_{E,p,t}$ value over the entire operation. The faster an animal is fleeing, the greater the distance travelled between noise events. The impact range outputted by the model for this situation is the distance the receptor must be at the start of the operation to exactly meet the exposure threshold.

As an example, the graphs Figure 3-4 and Figure 3-5 show the difference in the received $L_{E,p,t}$ from a stationary receptor and a fleeing receptor travelling at a constant speed of 1.5 m/s, using the monopile foundation scenario at modelling location 1 for a single pile installation.

The received single strike $L_{E,p,ss}$ from the stationary receptor, as illustrated in Figure 3-4, shows the noise level gradually increasing as the blow energy increases throughout the piling operation. These step changes are also visible for the fleeing receptor, but as the receptor is further from the noise source by the time the levels increase, the total received exposure reduces, resulting in progressively lower received noise levels. As an example, for the first 20 minutes of piling, where the blow energy for the monopile is 660 kJ (10% of maximum energy), fleeing at a rate of 1.5 m/s, a receptor has the potential to move 1.8 km from the noise source. After the full installation or just under two hours, the receptor has the potential to be over 10 km from the noise source.

Figure 3-5 shows the effect these different received levels have when calculating the $L_{E.p,t}$, clearly showing the difference in the cumulative levels between a receptor remaining still, as opposed to fleeing. To use an extreme example, starting at a range of 1 m, the first strike results in a received level of 217.2 dB re 1 µPa^{2}s. If the receptor were to remain stationary throughout the piling operation, it would receive a cumulative level of 258.6 dB re 1 µPa^{2}s, whereas when fleeing at 1.5 m/s over the same scenario, a cumulative received level of just 218.0 dB re 1 µPa^{2}s is achieved.

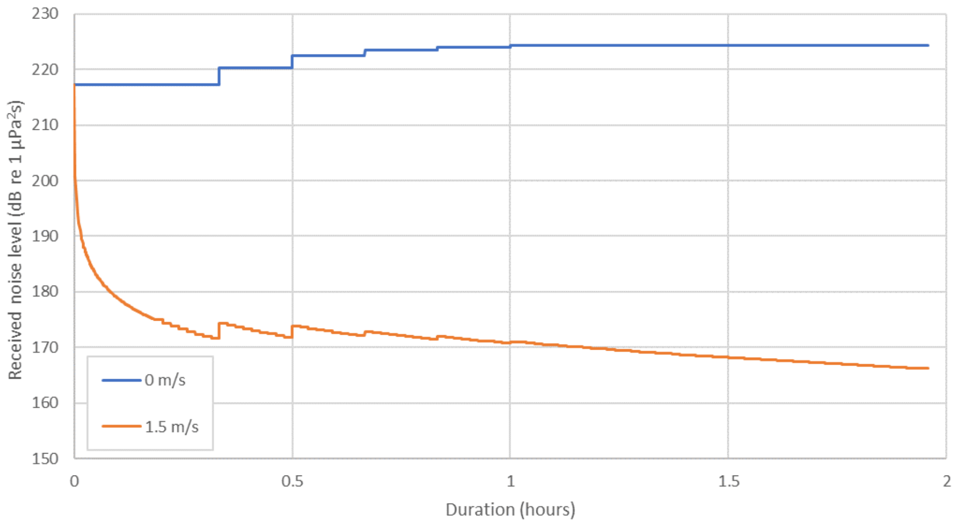

Figure 3-4 Received single strike noise levels ($L_{E,p,ss}$) for receptors during the monopile foundation installation at modelling location 1, assuming both a stationary and fleeing receptor starting at a location 1 m from the noise source.

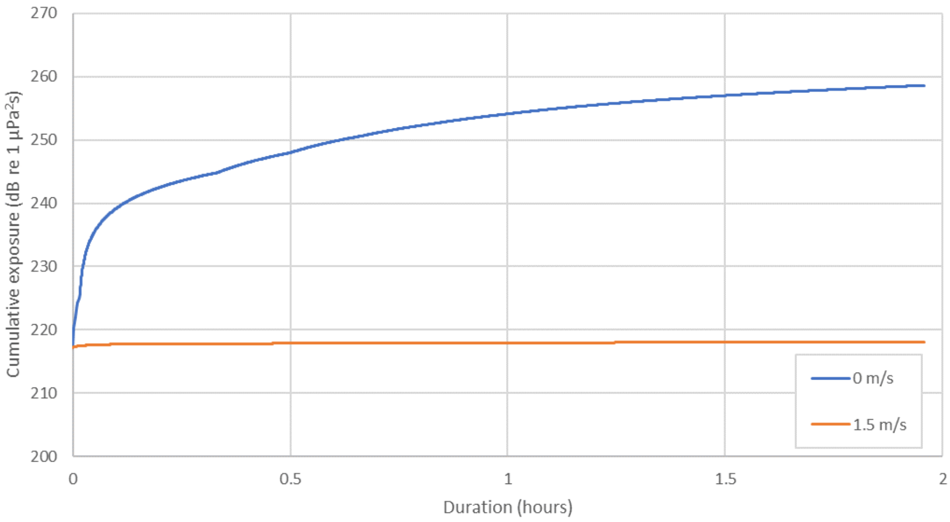

Figure 3-5 Cumulative received noise level ($L_{E,p,t}$) for receptors during monopile foundation installation at modelling location 1, assuming both a stationary and fleeing receptor starting at a location 1 m from the noise source.

To summarise, if the receptor were to start fleeing in a straight line from the noise source starting at a range closer than the modelled value, it would receive a noise exposure in excess of the criterion, and if the receptor were to start fleeing from a range further than the modelled value, it would receive a noise exposure below the criterion. This is illustrated in Figure 3-6.

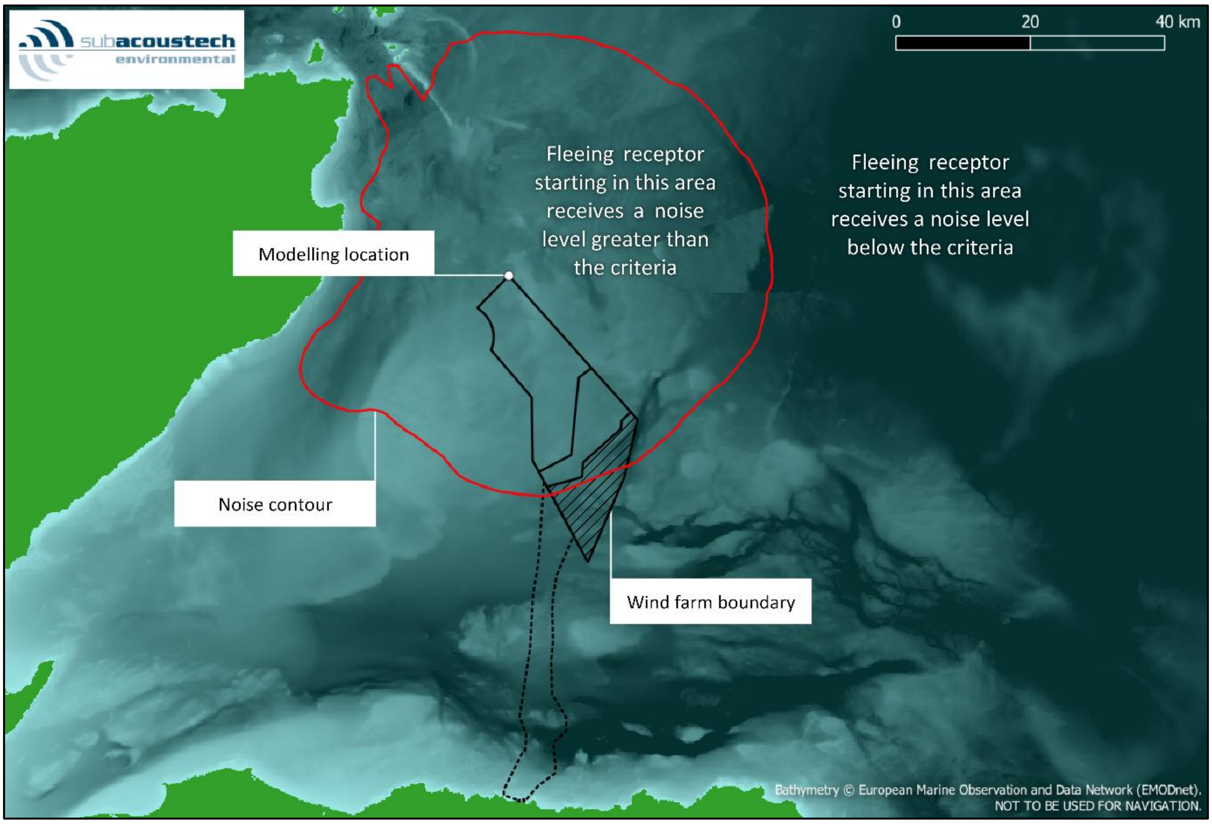

Figure 3-6 Example plot showing a fleeing animal $L_{E,p,t}$ criteria contour and the areas where the cumulative noise exposure will exceed an impact criteria.

Some modelling approaches include the effects of Acoustic Deterrent Devices (ADDs) that cause receptors to flee from the immediate area around the pile before activity commences. Subacoustech Environmental's approach does not include this, however the effects of using an ADD can still be inferred from the results. For example, if a receptor were to flee for 20 minutes from an ADD at a rate of 1.5 m/s, it would travel 1.8 km before piling begins. If a calculated cumulative $L_{E,p,t}$ impact range was below 1.8 km, it can be assumed that the ADD will be effective in eliminating the risk of exceedance of the threshold. The noise from an ADD is of a much lower level than impact piling, and as such its overall effect on the total $L_{E,p,t}$ exposure would be minimal.

3.3.1 The effects of input parameters on $L_{E,p,t}$ and fleeing receptors

As discussed in section 3.2.2, parameters such as bathymetry, hammer blow energies, piling ramp up, strike rate and duration all have an effect on predicted noise levels. When considering $L_{E,p,t}$ and a fleeing animal model, some of these parameters can have a greater influence on the predicted noise levels than others.

Parameters like hammer blow energy can have a clear effect on the impact ranges, with higher energies resulting in high apparent source noise levels and therefore larger impact ranges. When considering cumulative noise levels, these higher levels are compounded, sometimes thousands of times, due to the number of pile strikes. With this in mind, the ramp up from lower to higher blow energies requires careful consideration for fleeing receptors, as levels while the receptor is closer to the noise source will have a greater effect on the overall cumulative exposure level.

Linked to the effect of the ramp up is the strike rate, as the more pile strikes that occur while the receptor is close to the noise source, the greater the exposure and the greater effect it will have to the $L_{E,p,t}$. The faster the strike rate, the shorter the distance the receptor can flee between each pile strike, which leads to a greater exposure overall.

In general, the greatest contribution to the receptors' exposure is found when it is close to the noise source. If high blow energies or a fast strike rate are implemented at the start of piling activities, an increase in impact ranges will occur.

Another factor that can cause big differences in calculated impact ranges is the bathymetry, as deeper water results in a slower attenuation of noise (i.e., levels remain higher for greater distances). However, it is not always feasible to limit piling activity in or near to deep water.

3.4 Precaution in underwater noise modelling

It is worth reiterating the precaution that is included in the modelling when calculating environmental impacts. In an effort to minimise the risk under-prediction of the potential impact ranges that occur in respect of sensitive marine mammal and fish receptors, conservative parameters are included for every element, which can be broken down into three basic steps for acoustic modelling. The possibility that the worst-case conservative parameters could all occur together is highly unlikely, but necessary for the purposes of the assessment.

3.4.1 Source

The modelling locations were chosen to provide the greatest extents of the site, in the locations likely to lead to maximum underwater noise transmission. The largest diameter for all types of piles has been used for the worst case. The maximum blow energies were used for a duration unlikely to occur in practice. A fast strike rate has been included for much of the ramp-up.

3.4.2 Transmission

Sound attenuates over distance from the source. The model considers fundamental noise spreading predictions adjusted to empirical data, accounting for frequency content, water depth, and other environmental factors, but fits to this data still err on the side of caution.

3.4.3 Receiver

The thresholds used for the sensitivity of marine mammals and fish are based on respective guidance for species groups (e.g., Southall *et al*., 2019; Popper *et al*., 2014). However, these tend to be precautionary in themselves. Frequency specific hearing thresholds are not used for fish as they are with marine mammals, effectively assuming that fish are sensitive to sound at all frequencies, which is not the case. The thresholds calculated for PTS and TTS are the 'onset' to these effects, which means that this is the threshold at which the effect starts to be detected in test species, rather than where this effect is widespread.

4 Modelling results

This section presents the modelled impact ranges for impact piling noise following the parameters detailed in section 3.2, covering the Southall *et al*. (2019) and NOAA (2005) marine mammal criteria (section 2.3.1), and the Popper *et al*. (2014) fish criteria (section 2.3.2). To aid navigation, Table 4-1 contains a list of the impact range results tables included in section 4.1. The largest modelled ranges are predicted for the multi-leg foundation scenario at modelling location 7 due mainly to the sound transmission into the deep water to the east of the site. Modelling covering concurrent piling at multiple locations is covered in section 4.2

Throughout this report, any predicted ranges smaller than 50 m and areas less than 0.01 km^2 for single strike criteria and ranges smaller than 100 m and areas less than 0.1 km^2 for cumulative criteria have not been presented in detail. 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).

Additionally, the modelling results for the Southall *et al*. (2019) non-impulsive criteria are presented in Appendix A.

Table 4-1 Summary of the single location impact piling modelling results presented in section 4.1.

Table (page)	Parameters (section)		Criteria	
Table 4-2 (p29)	Modelling location 1 (4.1.1)	Monopile foundation (4.1.1.1)	Southall *et al*. (2019)	$L_{p,pk}$ (Impulsive)
Table 4-3 (p29)				$L_{E,p,24h,wtd}$ (Impulsive)
Table 4-4 (p29)			Popper *et al*. (2014)	$L_{p,pk}$ (Pile driving)
Table 4-5 (p29)				$L_{E,p,24h}$ (Pile driving)
Table 4-6 (p30)		Multi-leg foundation (4.1.1.2)	Southall *et al*. (2019)	$L_{p,pk}$ (Impulsive)
Table 4-7 (p30)				$L_{E,p,24h,wtd}$ (Impulsive)
Table 4-8 (p30)			Popper *et al*. (2014)	$L_{p,pk}$ (Pile driving)
Table 4-9 (p30)				$L_{E,p,24h}$ (Pile driving)
Table 4-10 (p31)	Modelling location 2 (4.1.2)	Monopile foundation (4.1.2.1)	Southall *et al*. (2019)	$L_{p,pk}$ (Impulsive)
Table 4-11 (p31)				$L_{E,p,24h,wtd}$ (Impulsive)
Table 4-12 (p31)			Popper *et al*. (2014)	$L_{p,pk}$ (Pile driving)
Table 4-13 (p31)				$L_{E,p,24h}$ (Pile driving)
Table 4-14 (p32)		Multi-leg foundation (4.1.2.2)	Southall *et al*. (2019)	$L_{p,pk}$ (Impulsive)
Table 4-15 (p32)				$L_{E,p,24h,wtd}$ (Impulsive)
Table 4-16 (p32)			Popper *et al*. (2014)	$L_{p,pk}$ (Pile driving)
Table 4-17 (p32)				$L_{E,p,24h}$ (Pile driving)
Table 4-18 (p33)	Modelling location 3 (4.1.3)	Monopile foundation (4.1.3.1)	Southall *et al*. (2019)	$L_{p,pk}$ (Impulsive)
Table 4-19 (p33)				$L_{E,p,24h,wtd}$ (Impulsive)
Table 4-20 (p33)			Popper *et al*. (2014)	$L_{p,pk}$ (Pile driving)
Table 4-21 (p33)				$L_{E,p,24h}$ (Pile driving)
Table 4-22 (p34)		Multi-leg foundation (4.1.3.2)	Southall *et al*. (2019)	$L_{p,pk}$ (Impulsive)
Table 4-23 (p34)				$L_{E,p,24h,wtd}$ (Impulsive)
Table 4-24 (p34)			Popper *et al*. (2014)	$L_{p,pk}$ (Pile driving)
Table 4-25 (p34)				$L_{E,p,24h}$ (Pile driving)
Table 4-26 (p35)	Modelling location 4 (4.1.4)	Monopile foundation (4.1.4.1)	Southall *et al*. (2019)	$L_{p,pk}$ (Impulsive)
Table 4-27 (p35)				$L_{E,p,24h,wtd}$ (Impulsive)
Table 4-28 (p35)			Popper *et al*. (2014)	$L_{p,pk}$ (Pile driving)
Table 4-29 (p35)				$L_{E,p,24h}$ (Pile driving)
Table 4-30 (p36)		Multi-leg foundation (4.1.4.2)	Southall *et al*. (2019)	$L_{p,pk}$ (Impulsive)
Table 4-31 (p36)				$L_{E,p,24h,wtd}$ (Impulsive)
Table 4-32 (p36)			Popper *et al*. (2014)	$L_{p,pk}$ (Pile driving)

Table 4-33 (p36)				$L_{E,p,24h}$ (Pile driving)
Table 4-34 (p37)	Modelling location 5 (4.1.5)	Anchor pile foundation (4.1.5.1)	Southall *et al*. (2019)	$L_{p,pk}$ (Impulsive)
Table 4-35 (p37)				$L_{E,p,24h,wtd}$ (Impulsive)
Table 4-36 (p37)			Popper *et al*. (2014)	$L_{p,pk}$ (Pile driving)
Table 4-37 (p37)				$L_{E,p,24h}$ (Pile driving)
Table 4-38 (p38)	Modelling location 6 (4.1.6)	Anchor pile foundation (4.1.6.1)	Southall *et al*. (2019)	$L_{p,pk}$ (Impulsive)
Table 4-39 (p38)				$L_{E,p,24h,wtd}$ (Impulsive)
Table 4-40 (p38)			Popper *et al*. (2014)	$L_{p,pk}$ (Pile driving)
Table 4-41 (p38)				$L_{E,p,24h}$ (Pile driving)
Table 4-42 (p39)	Modelling location 7 (4.1.7)	Monopile foundation (4.1.7.1)	Southall *et al*. (2019)	$L_{p,pk}$ (Impulsive)
Table 4-43 (p39)				$L_{E,p,24h,wtd}$ (Impulsive)
Table 4-44 (p39)			Popper *et al*. (2014)	$L_{p,pk}$ (Pile driving)
Table 4-45 (p39)				$L_{E,p,24h}$ (Pile driving)
Table 4-46 (p40)		Multi-leg foundation (4.1.7.2)	Southall *et al*. (2019)	$L_{p,pk}$ (Impulsive)
Table 4-47 (p40)				$L_{E,p,24h,wtd}$ (Impulsive)
Table 4-48 (p40)			Popper *et al*. (2014)	$L_{p,pk}$ (Pile driving)
Table 4-49 (p40)				$L_{E,p,24h}$ (Pile driving)
Table 4-50 (p41)		Anchor pile foundation (4.1.7.3)	Southall *et al*. (2019)	$L_{p,pk}$ (Impulsive)
Table 4-51 (p41)				$L_{E,p,24h,wtd}$ (Impulsive)
Table 4-52 (p41)			Popper *et al*. (2014)	$L_{p,pk}$ (Pile driving)
Table 4-53 (p41)				$L_{E,p,24h}$ (Pile driving)
Table 4-54 (p42)	Modelling location 8 (4.1.8)	Monopile foundation (4.1.8.1)	Southall *et al*. (2019)	$L_{p,pk}$ (Impulsive)
Table 4-55 (p42)				$L_{E,p,24h,wtd}$ (Impulsive)
Table 4-56 (p42)			Popper *et al*. (2014)	$L_{p,pk}$ (Pile driving)
Table 4-57 (p42)				$L_{E,p,24h}$ (Pile driving)
Table 4-58 (p43)		Multi-leg foundation (4.1.8.2)	Southall *et al*. (2019)	$L_{p,pk}$ (Impulsive)
Table 4-59 (p43)				$L_{E,p,24h,wtd}$ (Impulsive)
Table 4-60 (p43)			Popper *et al*. (2014)	$L_{p,pk}$ (Pile driving)
Table 4-61 (p43)				$L_{E,p,24h}$ (Pile driving)
Table 4-62 (p44)		Anchor pile foundation (4.1.8.3)	Southall *et al*. (2019)	$L_{p,pk}$ (Impulsive)
Table 4-63 (p44)				$L_{E,p,24h,wtd}$ (Impulsive)
Table 4-64 (p44)			Popper *et al*. (2014)	$L_{p,pk}$ (Pile driving)
Table 4-65 (p44)				$L_{E,p,24h}$ (Pile driving)

4.1 Single location modelling

Table 4-2 to Table 4-65 present the modelling results for the single location scenarios, covering monopile and multi-leg foundation scenarios for bottom-fixed turbines and anchor pile foundation scenarios for floating turbines. For these scenarios, the largest marine mammal impact ranges are predicted for the multi-leg foundation scenario at modelling location 7, due to the deep water at this location and out to the east into the North Sea. Maximum PTS ranges are predicted for LF cetaceans out to 36 km. For fish, the largest recoverable injury ranges (203 dB $L_{e,p,24h}$) are predicted out to 11 km when considering a stationary receptor, reducing to 450 m when a fleeing animal is assumed.

4.1.1 Modelling location 1 (Caledonia North – North corner)

4.1.1.1 Monopile foundation

Table 4-2 Summary of the $L_{p,pk}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at modelling location 1.

Southall *et al.* (2019) $L_{p,pk}$		Modelling location 1, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (219 dB)	0.01 km²	50 m	50 m	50 m
	HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	VHF (202 dB)	2.2 km²	840 m	830 m	840 m
	PCW (218 dB)	0.01 km²	60 m	60 m	60 m

Table 4-3 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at modelling location 1 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 1, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183 dB)	2,000 km²	30 km	17 km	25 km
	HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF (155 dB)	480 km²	13 km	11 km	12 km
	PCW (185 dB)	4.0 km²	1.2 km	1.1 km	1.1 km

Table 4-4 Summary of the $L_{p,pk}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at modelling location 1.

Popper *et al.* (2014) $L_{p,pk}$		Modelling location 1, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	0.06 km²	140 m	140 m	140 m
	207 dB	0.43 km²	370 m	370 m	370 m

Table 4-5 Summary of the $L_{E,p,24h}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at modelling location 1 assuming both a fleeing and stationary animal.

Popper *et al.* (2014) $L_{E,p,24h}$		Modelling location 1, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
Fleeing (1.5 m/s)	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	203 dB	1.8 km²	830 m	700 m	770 m
	186 dB	3,400 km²	40 km	20 km	33 km
Stationary (0 m/s)	219 dB	1.5 km²	700 m	680 m	690 m
	216 dB	3.7 km²	1.1 km	1.1 km	1.1 km
	210 dB	23 km²	2.8 km	2.7 km	2.7 km
	207 dB	56 km²	4.3 km	4.2 km	4.2 km
	203 dB	170 km²	7.6 km	7.2 km	7.5 km
	186 dB	5,800 km²	51 km	26 km	42 km

4.1.1.2 Multi-leg foundation

Table 4-6 Summary of the $L_{p,pk}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the multi-leg foundation modelling at modelling location 1.

Southall *et al.* (2019) $L_{p,pk}$		Modelling location 1, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (219 dB)	0.01 km²	< 50 m	< 50 m	< 50 m
	HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	VHF (202 dB)	1.7 km²	750 m	740 m	750 m
	PCW (218 dB)	0.01 km²	60 m	60 m	60 m

Table 4-7 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the multi-leg foundation modelling at modelling location 1 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 1, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183 dB)	1,900 km²	30 km	16 km	24 km
	HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF (155 dB)	420 km²	13 km	10 km	12 km
	PCW (185 dB)	1.7 km²	830 m	680 m	730 m

Table 4-8 Summary of the $L_{p,pk}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the multi-leg foundation modelling at modelling location 1.

Popper *et al.* (2014) $L_{p,pk}$		Modelling location 1, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	0.05 km²	130 m	130 m	130 m
	207 dB	0.35 km²	330 m	330 m	330 m

Table 4-9 Summary of the $L_{E,p,24h}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the multi-leg foundation modelling at modelling location 1 assuming both a fleeing and stationary animal.

Popper *et al.* (2014) $L_{E,p,24h}$		Modelling location 1, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
Fleeing (1.5 m/s)	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	203 dB	0.2 km²	300 m	250 m	270 m
	186 dB	3,300 km²	41 km	19 km	32 km
Stationary (0 m/s)	219 dB	2.6 km²	930 m	900 m	910 m
	216 dB	6.6 km²	1.5 km	1.4 km	1.5 km
	210 dB	41 km²	3.7 km	3.6 km	3.6 km
	207 dB	97 km²	5.7 km	5.5 km	5.6 km
	203 dB	290 km²	9.9 km	9.2 km	9.6 km
	186 dB	7,500 km²	60 km	26 km	48 km

4.1.2 Modelling location 2 (Caledonia North – West corner)

4.1.2.1 Monopile foundation

Table 4-10 Summary of the $L_{p,pk}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at modelling location 2.

Southall *et al.* (2019) $L_{p,pk}$		Modelling location 2, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (219 dB)	0.01 km^2	50 m	50 m	50 m
	HF (230 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	VHF (202 dB)	2.2 km^2	830 m	830 m	830 m
	PCW (218 dB)	0.01 km^2	60 m	60 m	60 m

Table 4-11 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at modelling location 2 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 2, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183 dB)	1,900 km^2	28 km	16 km	24 km
	HF (185 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF (155 dB)	440 km^2	13 km	11 km	12 km
	PCW (185 dB)	3.8 km^2	1.2 km	1.1 km	1.1 km

Table 4-12 Summary of the $L_{p,pk}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at modelling location 2.

Popper *et al.* (2014) $L_{p,pk}$		Modelling location 2, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	0.06 km^2	140 m	140 m	140 m
	207 dB	0.43 km^2	370 m	370 m	370 m

Table 4-13 Summary of the $L_{E,p,24h}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at modelling location 2 assuming both a fleeing and stationary animal.

Popper *et al.* (2014) $L_{E,p,24h}$		Modelling location 2, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
Fleeing (1.5 m/s)	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	203 dB	1.8 km^2	780 m	700 m	750 m
	186 dB	3,100 km^2	38 km	18 km	31 km
Stationary (0 m/s)	219 dB	1.5 km^2	700 m	680 m	690 m
	216 dB	3.7 km^2	1.1 km	1.1 km	1.1 km
	210 dB	23 km^2	2.7 km	2.7 km	2.7 km
	207 dB	56 km^2	4.3 km	4.2 km	4.2 km
	203 dB	170 km^2	7.6 km	7.3 km	7.4 km
	186 dB	5,400 km^2	48 km	23 km	41 km

4.1.2.2 Multi-leg foundation

Table 4-14 Summary of the $L_{p,pk}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the multi-leg foundation modelling at modelling location 2.

Southall *et al.* (2019) $L_{p,pk}$		Modelling location 2, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (219 dB)	0.01 km²	< 50 m	< 50 m	< 50 m
	HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	VHF (202 dB)	1.7 km²	750 m	740 m	740 m
	PCW (218 dB)	0.01 km²	60 m	60 m	60 m

Table 4-15 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the multi-leg foundation modelling at modelling location 2 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 2, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183 dB)	1,700 km²	28 km	15 km	23 km
	HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF (155 dB)	390 km²	13 km	9.6 km	11 km
	PCW (185 dB)	1.6 km²	780 m	630 m	700 m

Table 4-16 Summary of the $L_{p,pk}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the multi-leg foundation modelling at modelling location 2.

Popper *et al.* (2014) $L_{p,pk}$		Modelling location 2, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	0.05 km²	130 m	130 m	130 m
	207 dB	0.34 km²	330 m	330 m	330 m

Table 4-17 Summary of the $L_{E,p,24h}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the multi-leg foundation modelling at modelling location 2 assuming both a fleeing and stationary animal.

Popper *et al.* (2014) $L_{E,p,24h}$		Modelling location 2, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
Fleeing (1.5 m/s)	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	203 dB	0.2 km²	280 m	230 m	260 m
	186 dB	3,000 km²	39 km	18 km	31 km
Stationary (0 m/s)	219 dB	2.6 km²	930 m	900 m	910 m
	216 dB	6.7 km²	1.5 km	1.5 km	1.5 km
	210 dB	41 km²	3.6 km	3.6 km	3.6 km
	207 dB	97 km²	5.6 km	5.5 km	5.6 km
	203 dB	280 km²	9.8 km	9.3 km	9.5 km
	186 dB	7,000 km²	57 km	23 km	46 km

4.1.3 Modelling location 3 (Caledonia North/Caledonia South – North East edge)

4.1.3.1 Monopile foundation

Table 4-18 Summary of the $L_{p,pk}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at modelling location 3.

Southall *et al.* (2019) $L_{p,pk}$		Modelling location 3, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (219 dB)	0.01 km²	50 m	50 m	50 m
	HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	VHF (202 dB)	2.2 km²	840 m	830 m	830 m
	PCW (218 dB)	0.01 km²	60 m	60 m	60 m

Table 4-19 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at modelling location 3 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 3, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183 dB)	2,400 km²	32 km	22 km	27 km
	HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF (155 dB)	490 km²	13 km	12 km	13 km
	PCW (185 dB)	4.0 km²	1.2 km	1.1 km	1.1 km

Table 4-20 Summary of the $L_{p,pk}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at modelling location 3.

Popper *et al.* (2014) $L_{p,pk}$		Modelling location 3, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	0.06 km²	140 m	140 m	140 m
	207 dB	0.43 km²	370 m	370 m	370 m

Table 4-21 Summary of the $L_{E,p,24h}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at modelling location 3 assuming both a fleeing and stationary animal.

Popper *et al.* (2014) $L_{E,p,24h}$		Modelling location 3, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
Fleeing (1.5 m/s)	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	203 dB	1.8 km²	830 m	700 m	770 m
	186 dB	4,100 km²	42 km	28 km	36 km
Stationary (0 m/s)	219 dB	1.5 km²	700 m	680 m	690 m
	216 dB	3.7 km²	1.1 km	1.1 km	1.1 km
	210 dB	23 km²	2.8 km	2.7 km	2.7 km
	207 dB	56 km²	4.3 km	4.2 km	4.3 km
	203 dB	170 km²	7.6 km	7.4 km	7.5 km
	186 dB	6,800 km²	53 km	38 km	46 km

4.1.3.2 Multi-leg foundation

Table 4-22 Summary of the $L_{p,pk}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the multi-leg foundation modelling at modelling location 3.

Southall *et al.* (2019) $L_{p,pk}$		Modelling location 3, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (219 dB)	0.01 km^2	< 50 m	< 50 m	< 50 m
	HF (230 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	VHF (202 dB)	1.7 km^2	750 m	740 m	750 m
	PCW (218 dB)	0.01 km^2	60 m	60 m	60 m

Table 4-23 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the multi-leg foundation modelling at modelling location 3 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 3, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183 dB)	2,200 km^2	32 km	20 km	26 km
	HF (185 dB)	< 0.01 km^2	< 100 m	< 100 m	< 100 m
	VHF (155 dB)	450 km^2	13 km	11 km	12 km
	PCW (185 dB)	1.8 km^2	830 m	680 m	750 m

Table 4-24 Summary of the $L_{p,pk}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the multi-leg foundation modelling at modelling location 3.

Popper *et al.* (2014) $L_{p,pk}$		Modelling location 3, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	0.05 km^2	130 m	130 m	130 m
	207 dB	0.35 km^2	330 m	330 m	330 m

Table 4-25 Summary of the $L_{E,p,24h}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the multi-leg foundation modelling at modelling location 3 assuming both a fleeing and stationary animal.

Popper *et al.* (2014) $L_{E,p,24h}$		Modelling location 3, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
Fleeing (1.5 m/s)	219 dB	< 0.01 km^2	< 100 m	< 100 m	< 100 m
	216 dB	< 0.01 km^2	< 100 m	< 100 m	< 100 m
	210 dB	< 0.01 km^2	< 100 m	< 100 m	< 100 m
	207 dB	< 0.01 km^2	< 100 m	< 100 m	< 100 m
	203 dB	0.2 km^2	330 m	230 m	270 m
	186 dB	3,900 km^2	44 km	26 km	35 km
Stationary (0 m/s)	219 dB	2.6 km^2	930 m	900 m	910 m
	216 dB	6.6 km^2	1.5 km	1.4 km	1.5 km
	210 dB	41 km^2	3.7 km	3.6 km	3.6 km
	207 dB	98 km^2	5.7 km	5.5 km	5.6 km
	203 dB	290 km^2	9.9 km	9.4 km	9.6 km
	186 dB	9,100 km^2	63 km	42 km	54 km

4.1.4 Modelling location 4 (Caledonia North/Caledonia South – West edge)

4.1.4.1 Monopile foundation

Table 4-26 Summary of the $L_{p,pk}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at modelling location 4.

Southall *et al.* (2019) $L_{p,pk}$		Modelling location 4, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (219 dB)	0.01 km²	50 m	50 m	50 m
	HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	VHF (202 dB)	2.2 km²	840 m	830 m	830 m
	PCW (218 dB)	0.01 km²	60 m	60 m	60 m

Table 4-27 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at modelling location 4 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 4, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183 dB)	2,200 km²	32 km	21 km	26 km
	HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF (155 dB)	480 km²	14 km	11 km	12 km
	PCW (185 dB)	4.1 km²	1.2 km	1.1 km	1.1 km

Table 4-28 Summary of the $L_{p,pk}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at modelling location 4.

Popper *et al.* (2014) $L_{p,pk}$		Modelling location 4, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	0.06 km²	140 m	140 m	140 m
	207 dB	0.43 km²	370 m	370 m	370 m

Table 4-29 Summary of the $L_{E,p,24h}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at modelling location 4 assuming both a fleeing and stationary animal.

Popper *et al.* (2014) $L_{E,p,24h}$		Modelling location 4, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
Fleeing (1.5 m/s)	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	203 dB	1.9 km²	850 m	700 m	770 m
	186 dB	3,700 km²	41 km	27 km	34 km
Stationary (0 m/s)	219 dB	1.5 km²	700 m	680 m	690 m
	216 dB	3.7 km²	1.1 km	1.1 km	1.1 km
	210 dB	23 km²	2.8 km	2.7 km	2.7 km
	207 dB	57 km²	4.3 km	4.2 km	4.3 km
	203 dB	180 km²	7.7 km	7.3 km	7.5 km
	186 dB	6,500 km²	52 km	38 km	45 km

4.1.4.2 Multi-leg foundation

Table 4-30 Summary of the $L_{p,pk}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the multi-leg foundation modelling at modelling location 4.

Southall *et al.* (2019) $L_{p,pk}$		Modelling location 4, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (219 dB)	0.01 km²	< 50 m	< 50 m	< 50 m
	HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	VHF (202 dB)	1.7 km²	750 m	750 m	750 m
	PCW (218 dB)	0.01 km²	60 m	60 m	60 m

Table 4-31 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the multi-leg foundation modelling at modelling location 4 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 4, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183 dB)	1,900 km²	31 km	19 km	25 km
	HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF (155 dB)	440 km²	14 km	10 km	12 km
	PCW (185 dB)	1.8 km²	850 m	650 m	750 m

Table 4-32 Summary of the $L_{p,pk}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the multi-leg foundation modelling at modelling location 4.

Popper *et al.* (2014) $L_{p,pk}$		Modelling location 4, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	0.05 km²	130 m	130 m	130 m
	207 dB	0.35 km²	330 m	330 m	330 m

Table 4-33 Summary of the $L_{E,p,24h}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the multi-leg foundation modelling at modelling location 4 assuming both a fleeing and stationary animal.

Popper *et al.* (2014) $L_{E,p,24h}$		Modelling location 4, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
Fleeing (1.5 m/s)	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	203 dB	0.24 km²	330 m	230 m	270 m
	186 dB	3,500 km²	42 km	25 km	33 km
Stationary (0 m/s)	219 dB	2.6 km²	930 m	900 m	910 m
	216 dB	6.7 km²	1.5 km	1.5 km	1.5 km
	210 dB	41 km²	3.7 km	3.6 km	3.6 km
	207 dB	98 km²	5.7 km	5.5 km	5.6 km
	203 dB	290 km²	9.9 km	9.4 km	9.6 km
	186 dB	8,300 km²	60 km	43 km	51 km

4.1.5 Modelling location 5 (Caledonia South – East edge)

4.1.5.1 Anchor pile foundation

Table 4-34 Summary of the $L_{p,pk}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the anchor pile foundation modelling at modelling location 5.

Southall *et al.* (2019) $L_{p,pk}$		Modelling location 5, anchor pile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	VHF (202 dB)	1.0 km²	570 m	570 m	570 m
	PCW (218 dB)	0.01 km²	< 50 m	< 50 m	< 50 m

Table 4-35 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the anchor pile foundation modelling at modelling location 5 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 5, anchor pile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183 dB)	850 km²	19 km	14 km	16 km
	HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF (155 dB)	130 km²	7.0 km	6.1 km	6.4 km
	PCW (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m

Table 4-36 Summary of the $L_{p,pk}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the anchor pile foundation modelling at modelling location 5.

Popper *et al.* (2014) $L_{p,pk}$		Modelling location 5, anchor pile foundation			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	0.03 km²	100 m	100 m	100 m
	207 dB	0.2 km²	250 m	250 m	250 m

Table 4-37 Summary of the $L_{E,p,24h}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the anchor pile foundation modelling at modelling location 5 assuming both a fleeing and stationary animal.

Popper *et al.* (2014) $L_{E,p,24h}$		Modelling location 5, anchor pile foundation			
		Area	Maximum range	Minimum range	Mean range
Fleeing (1.5 m/s)	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	203 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	186 dB	1,600 km²	27 km	20 km	23 km
Stationary (0 m/s)	219 dB	0.36 km²	350 m	330 m	340 m
	216 dB	0.9 km²	550 m	530 m	540 m
	210 dB	5.8 km²	1.4 km	1.4 km	1.4 km
	207 dB	15 km²	2.2 km	2.2 km	2.2 km
	203 dB	49 km²	4.1 km	3.9 km	4.0 km
	186 dB	3,200 km²	36 km	29 km	32 km

4.1.6 Modelling location 6 (Caledonia South – West edge)

4.1.6.1 Anchor pile foundation

Table 4-38 Summary of the $L_{p,pk}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the anchor pile foundation modelling at modelling location 6.

Southall *et al.* (2019) $L_{p,pk}$		Modelling location 6, anchor pile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	VHF (202 dB)	1.0 km²	570 m	570 m	570 m
	PCW (218 dB)	0.01 km²	< 50 m	< 50 m	< 50 m

Table 4-39 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the anchor pile foundation modelling at modelling location 6 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 6, anchor pile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183 dB)	780 km²	19 km	13 km	16 km
	HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF (155 dB)	120 km²	6.7 km	5.8 km	6.3 km
	PCW (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m

Table 4-40 Summary of the $L_{p,pk}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the anchor pile foundation modelling at modelling location 6.

Popper *et al.* (2014) $L_{p,pk}$		Modelling location 6, anchor pile foundation			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	0.03 km²	100 m	100 m	100 m
	207 dB	0.2 km²	250 m	250 m	250 m

Table 4-41 Summary of the $L_{E,p,24h}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the anchor pile foundation modelling at modelling location 6 assuming both a fleeing and stationary animal.

Popper *et al.* (2014) $L_{E,p,24h}$		Modelling location 6, anchor pile foundation			
		Area	Maximum range	Minimum range	Mean range
Fleeing (1.5 m/s)	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	203 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	186 dB	1,500 km²	26 km	18 km	22 km
Stationary (0 m/s)	219 dB	0.36 km²	350 m	330 m	340 m
	216 dB	0.9 km²	550 m	530 m	540 m
	210 dB	5.8 km²	1.4 km	1.4 km	1.4 km
	207 dB	15 km²	2.2 km	2.2 km	2.2 km
	203 dB	49 km²	4.0 km	3.9 km	4.0 km
	186 dB	3,000 km²	35 km	27 km	31 km

4.1.7 Modelling location 7 (Caledonia South – East corner)

4.1.7.1 Monopile foundation

Table 4-42 Summary of the $L_{p,pk}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at modelling location 7.

Southall *et al.* (2019) $L_{p,pk}$		Modelling location 7, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (219 dB)	0.01 km^2	50 m	50 m	50 m
	HF (230 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	VHF (202 dB)	2.3 km^2	850 m	850 m	850 m
	PCW (218 dB)	0.01 km^2	60 m	60 m	60 m

Table 4-43 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at modelling location 7 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 7, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183 dB)	2,700 km^2	35 km	23 km	29 km
	HF (185 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF (155 dB)	560 km^2	15 km	12 km	13 km
	PCW (185 dB)	5.4 km^2	1.5 km	1.2 km	1.3 km

Table 4-44 Summary of the $L_{p,pk}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at modelling location 7.

Popper *et al.* (2014) $L_{p,pk}$		Modelling location 7, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	0.06 km^2	140 m	140 m	140 m
	207 dB	0.45 km^2	380 m	380 m	380 m

Table 4-45 Summary of the $L_{E,p,24h}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at modelling location 7 assuming both a fleeing and stationary animal.

Popper *et al.* (2014) $L_{E,p,24h}$		Modelling location 7, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
Fleeing (1.5 m/s)	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	203 dB	2.6 km^2	1.0 km	800 m	900 m
	186 dB	4,600 km^2	46 km	30 km	38 km
Stationary (0 m/s)	219 dB	1.5 km^2	700 m	680 m	690 m
	216 dB	3.9 km^2	1.1 km	1.1 km	1.1 km
	210 dB	25 km^2	2.9 km	2.8 km	2.8 km
	207 dB	61 km^2	4.5 km	4.3 km	4.4 km
	203 dB	190 km^2	8.1 km	7.6 km	7.8 km
	186 dB	7,500 km^2	56 km	39 km	49 km

4.1.7.2 Multi-leg foundation

Table 4-46 Summary of the $L_{p,pk}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the multi-leg foundation modelling at modelling location 7.

Southall *et al.* (2019) $L_{p,pk}$		Modelling location 7, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (219 dB)	0.01 km^2	< 50 m	< 50 m	< 50 m
	HF (230 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	VHF (202 dB)	1.8 km^2	770 m	760 m	770 m
	PCW (218 dB)	0.01 km^2	60 m	60 m	60 m

Table 4-47 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the multi-leg foundation modelling at modelling location 7 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 7, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183 dB)	2,500 km^2	36 km	22 km	28 km
	HF (185 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF (155 dB)	530 km^2	15 km	11 km	13 km
	PCW (185 dB)	2.6 km^2	1.0 km	780 m	920 m

Table 4-48 Summary of the $L_{p,pk}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the multi-leg foundation modelling at modelling location 7.

Popper *et al.* (2014) $L_{p,pk}$		Modelling location 7, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	0.05 km^2	130 m	130 m	130 m
	207 dB	0.36 km^2	340 m	340 m	340 m

Table 4-49 Summary of the $L_{E,p,24h}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the multi-leg foundation modelling at modelling location 7 assuming both a fleeing and stationary animal.

Popper *et al.* (2014) $L_{E,p,24h}$		Modelling location 7, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
Fleeing (1.5 m/s)	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	203 dB	0.44 km^2	450 m	300 m	370 m
	186 dB	4,500 km^2	48 km	28 km	38 km
Stationary (0 m/s)	219 dB	2.8 km^2	950 m	930 m	940 m
	216 dB	7.1 km^2	1.5 km	1.5 km	1.5 km
	210 dB	45 km^2	3.9 km	3.7 km	3.8 km
	207 dB	110 km^2	6.1 km	5.8 km	5.9 km
	203 dB	320 km^2	11 km	9.9 km	10 km
	186 dB	10,000 km^2	67 km	44 km	56 km

4.1.7.3 Anchor pile foundation

Table 4-50 Summary of the $L_{p,pk}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the anchor pile foundation modelling at modelling location 7.

Southall *et al.* (2019) $L_{p,pk}$		Modelling location 7, anchor pile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	VHF (202 dB)	1.0 km²	580 m	580 m	580 m
	PCW (218 dB)	0.01 km²	< 50 m	< 50 m	< 50 m

Table 4-51 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the anchor pile foundation modelling at modelling location 7 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 7, anchor pile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183 dB)	880 km²	19 km	14 km	17 km
	HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF (155 dB)	130 km²	7.1 km	6.1 km	6.6 km
	PCW (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m

Table 4-52 Summary of the $L_{p,pk}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the anchor pile foundation modelling at modelling location 7.

Popper *et al.* (2014) $L_{p,pk}$		Modelling location 7, anchor pile foundation			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	0.03 km²	100 m	100 m	100 m
	207 dB	0.2 km²	260 m	250 m	260 m

Table 4-53 Summary of the $L_{E,p,24h}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the anchor pile foundation modelling at modelling location 7 assuming both a fleeing and stationary animal.

Popper *et al.* (2014) $L_{E,p,24h}$		Modelling location 7, anchor pile foundation			
		Area	Maximum range	Minimum range	Mean range
Fleeing (1.5 m/s)	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	203 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	186 dB	1,700 km²	27 km	20 km	23 km
Stationary (0 m/s)	219 dB	0.36 km²	350 m	330 m	340 m
	216 dB	0.9 km²	550 m	530 m	540 m
	210 dB	5.9 km²	1,4 km	1.4 km	1.4 km
	207 dB	15 km²	2.2 km	2.2 km	2.2 km
	203 dB	51 km²	4.1 km	4.0 km	4.0 km
	186 dB	3,300 km²	36 km	29 km	33 km

4.1.8 Modelling location 8 (Caledonia South – South corner)

4.1.8.1 Monopile foundation

Table 4-54 Summary of the $L_{p,pk}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at modelling location 8.

Southall *et al.* (2019) $L_{p,pk}$		Modelling location 8, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (219 dB)	0.01 km²	50 m	50 m	50 m
	HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	VHF (202 dB)	2.2 km²	850 m	850 m	850 m
	PCW (218 dB)	0.01 km²	60 m	60 m	60 m

Table 4-55 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at modelling location 8 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 8, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183 dB)	2,500 km²	34 km	23 km	28 km
	HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF (155 dB)	580 km²	15 km	13 km	14 km
	PCW (185 dB)	5.4 km²	1.4 km	1.2 km	1.3 km

Table 4-56 Summary of the $L_{p,pk}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at modelling location 8.

Popper *et al.* (2014) $L_{p,pk}$		Modelling location 8, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	0.06 km²	140 m	140 m	140 m
	207 dB	0.44 km²	380 m	380 m	380 m

Table 4-57 Summary of the $L_{E,p,24h}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at modelling location 8 assuming both a fleeing and stationary animal.

Popper *et al.* (2014) $L_{E,p,24h}$		Modelling location 8, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
Fleeing (1.5 m/s)	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	203 dB	2.6 km²	950 m	830 m	910 m
	186 dB	4,000 km²	43 km	28 km	35 km
Stationary (0 m/s)	219 dB	1.5 km²	700 m	680 m	690 m
	216 dB	3.8 km²	1.1 km	1.1 km	1.1 km
	210 dB	25 km²	2.8 km	2.8 km	2.8 km
	207 dB	61 km²	4.5 km	4.4 km	4.4 km
	203 dB	190 km²	7.9 km	7.6 km	7.8 km
	186 dB	6,500 km²	54 km	35 km	45 km

4.1.8.2 Multi-leg foundation

Table 4-58 Summary of the $L_{p,pk}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the multi-leg foundation modelling at modelling location 8.

Southall *et al.* (2019) $L_{p,pk}$		Modelling location 8, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (219 dB)	0.01 km^2	< 50 m	< 50 m	< 50 m
	HF (230 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	VHF (202 dB)	1.8 km^2	760 m	760 m	760 m
	PCW (218 dB)	0.01 km^2	60 m	60 m	60 m

Table 4-59 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the multi-leg foundation modelling at modelling location 8 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 8, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183 dB)	2,300 km^2	34 km	22 km	27 km
	HF (185 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF (155 dB)	530 km^2	15 km	12 km	13 km
	PCW (185 dB)	2.6 km^2	1.0 km	850 m	910 m

Table 4-60 Summary of the $L_{p,pk}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the multi-leg foundation modelling at modelling location 8.

Popper *et al.* (2014) $L_{p,pk}$		Modelling location 8, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	0.05 km^2	130 m	130 m	130 m
	207 dB	0.36 km^2	340 m	340 m	340 m

Table 4-61 Summary of the $L_{E,p,24h}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the multi-leg foundation modelling at modelling location 8 assuming both a fleeing and stationary animal.

Popper *et al.* (2014) $L_{E,p,24h}$		Modelling location 8, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
Fleeing (1.5 m/s)	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	203 dB	0.41 km^2	400 m	330 m	360 m
	186 dB	3,900 km^2	45 km	26 km	35 km
Stationary (0 m/s)	219 dB	2.8 km^2	950 m	930 m	940 m
	216 dB	6.9 km^2	1.5 km	1.5 km	1.5 km
	210 dB	44 km^2	3.8 km	3.7 km	3.8 km
	207 dB	110 km^2	5.9 km	5.8 km	5.9 km
	203 dB	330 km^2	10 km	9.8 km	10 km
	186 dB	8,300 km^2	64 km	35 km	51 km

4.1.8.3 Anchor pile foundation

Table 4-62 Summary of the $L_{p,pk}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the anchor pile foundation modelling at modelling location 8.

Southall *et al.* (2019) $L_{p,pk}$		Modelling location 8, anchor pile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	VHF (202 dB)	1.0 km²	580 m	570 m	570 m
	PCW (218 dB)	0.01 km²	< 50 m	< 50 m	< 50 m

Table 4-63 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the anchor pile foundation modelling at modelling location 8 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 8, anchor pile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183 dB)	890 km²	20 km	15 km	17 km
	HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF (155 dB)	140 km²	7.1 km	6.2 km	6.7 km
	PCW (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m

Table 4-64 Summary of the $L_{p,pk}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the anchor pile foundation modelling at modelling location 8.

Popper *et al.* (2014) $L_{p,pk}$		Modelling location 8, anchor pile foundation			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	0.03 km²	100 m	100 m	100 m
	207 dB	0.2 km²	260 m	250 m	260 m

Table 4-65 Summary of the $L_{E,p,24h}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the anchor pile foundation modelling at modelling location 8 assuming both a fleeing and stationary animal.

Popper *et al.* (2014) $L_{E,p,24h}$		Modelling location 8, anchor pile foundation			
		Area	Maximum range	Minimum range	Mean range
Fleeing (1.5 m/s)	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	203 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
	186 dB	1,700 km²	27 km	21 km	23 km
Stationary (0 m/s)	219 dB	0.36 km²	350 m	330 m	340 m
	216 dB	0.9 km²	550 m	530 m	540 m
	210 dB	5.8 km²	1.4 km	1.4 km	1.4 km
	207 dB	15 km²	2.2 km	2.2 km	2.2 km
	203 dB	50 km²	4.1 km	4.0 km	4.0 km
	186 dB	3,400 km²	36 km	30 km	33 km

4.2 Multiple location modelling

Modelling has been carried out to investigate the potential impacts of multiple piling vessels installing foundations concurrently at separated locations. These scenarios represent the worst-case piling parameters in a 24-hour period. Using the monopile, multi-leg, and anchor pile scenarios from the previous sections, the following modelling has been carried out for concurrent piling at:

- Modelling locations 1 and 8, covering concurrent piling operations for bottom-fixed WTG foundations at the extents of both the Caledonia North Site and Caledonia South Site (monopile and multi-leg foundation scenarios)
- Modelling locations 1 and 4, covering concurrent piling operations for bottom-fixed WTG foundations at the extents of the Caledonia North Site (monopile and multi-leg foundation scenarios)
- Modelling locations 3 and 8, covering concurrent piling operations for bottom-fixed WTG foundations at the extents of the Caledonia South Site (monopile and multi-leg foundation scenarios), and
- Modelling locations 5 and 8 covering consurrent piling operations for floating WTG foundations at the extents of the floating turbine area of Caledonia South (anchor pile scenario).

Additionally, a location on the western edge of the nearby Broadshore OWF has been identified (58.17951°N, 1.89439°W; 89.6 m depth) to cover the potential for piling at both the Proposed Development (Offshore) and another nearby OWF. For the Broadshore OWF, the same modelling parameters as the Proposed Development (Offshore) have been assumed (as per section 3.2.2). The following modelling has been carried out to cover scenarios at both the Caledonia North and Caledonia South locations:

- Modelling location 3 and the western edge of Broadshore OWF, covering concurrent piling operations for bottom-fixed WTG foundations at the Caledonia North Site and the nearby Broadshore OWF (monopile and multi-leg scenarios), and
- Modelling location 7 and the western edge of Broadshore OWF, covering concurrent piling operations for bottom-fixed WTG foundations at the Caledonia South Site and the nearby Broadshore OWF (monopile and multi-leg scenarios).

These scenarios represent a worst-case spread of locations for each potential build-out scenario. All modelling in this section assumes that the piling operations at each location start at the same time.

When considering $L_{E,p,t}$ modelling, piling from multiple sources can increase impact ranges significantly as, in this case, it introduces noise from twice the number of pile strikes to the water. Unlike the sequential piling investigated in section 4.1, fleeing receptors can be closer to a source for a higher number of the pile strikes resulting in higher cumulative exposures. Figure 4-1 shows the TTS contour for fish from Popper *et al*. (2014) (186 dB $L_{E,p,24h}$) for a fleeing receptor as an example. The red contours show the impact from each location modelled individually (as presented in section 4.1), and the blue contour shows the increase in the predicted impacts when multiple locations are piling concurrently, resulting in a contour encircling both red contours.

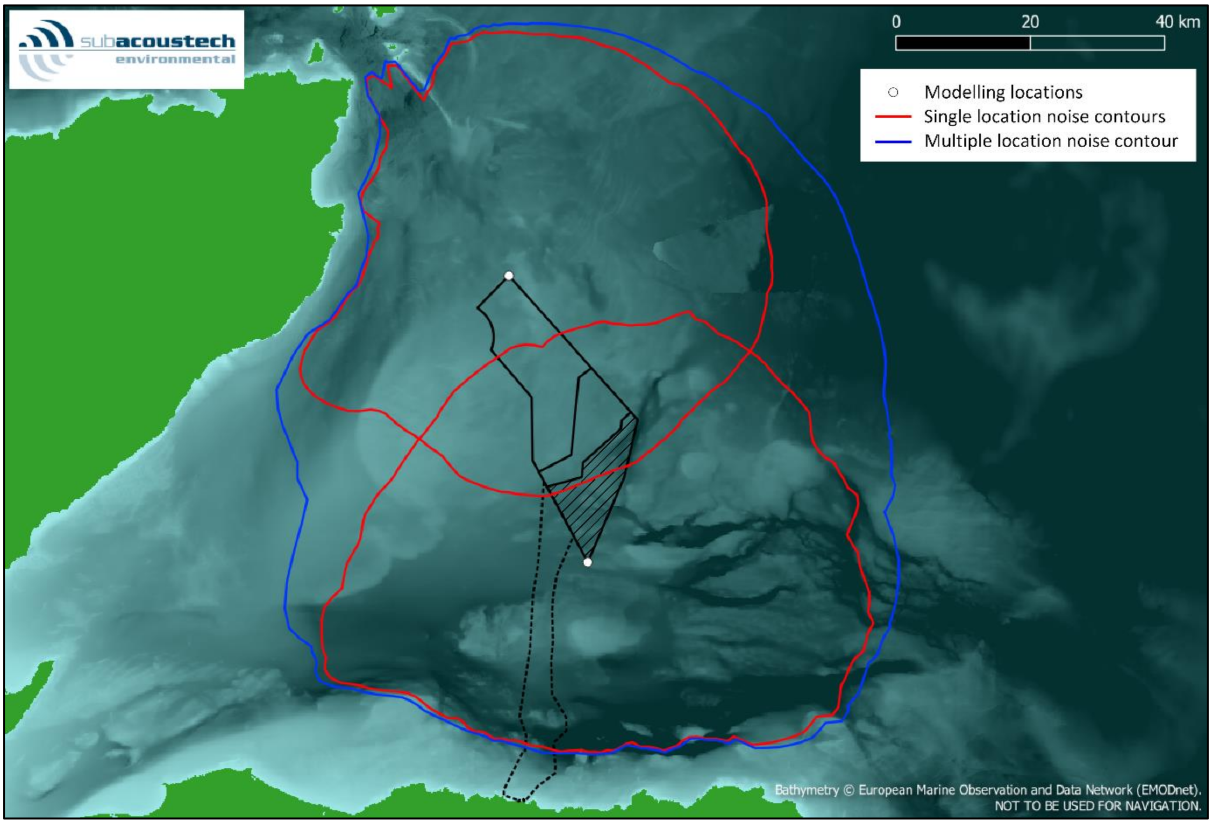

Figure 4-1 Example contour plot showing the interaction between two noise sources occurring simultaneously (TTS in fish, 186 dB $L_{E,p,24h}$, fleeing animal).

The scenarios modelled inside the Proposed Development (Offshore) boundaries were chosen to provide the greatest geographical spread of noise sources that would lead to the greatest impact range contours. In a modelling scenario where piles are installed close to each other, there would be an expansion of the single location contour in all directions, but by less overall than the spread seen in Figure 4-1.

Sections 4.2.1 to 4.2.6 present tables showing the increases in the combined impact areas for multiple location piling scenarios. Only areas are provided as results; impact ranges have not been presented due to there being multiple starting points for receptors (a linear impact range, such as those discussed in section 3.3, requires a single start point, which is not possible with multiple pile locations). Fields denoted with a dash "-" show where there is no in-combination effect when piling occurs at the two locations concurrently. This is generally where the ranges are small enough that the distant sites do not produce an influencing additional exposure, such as with the typically small HF cetacean-weighted impact ranges.

Specific circumstances would lead to the combined range being less than the two separated ranges combined: this is commonly where the two modelling locations are close, or individual ranges are very large. In other cases, the combined ranges may be greater than the two separated ranges in summation: this is often where the individual ranges are large but there is little overlap between the two when not in combination.

4.2.1 Concurrent piling at Caledonia North and Caledonia South (bottom-fixed turbines)

4.2.1.1 Monopile foundations

Table 4-66 Summary of the impact areas for the installation of monopile foundations at modelling locations 1 and 8 across the Caledonia North and Caledonia South Sites for marine mammals using the impulsive Southall et al. (2019) criteria assuming a fleeing animal.

Monopile foundations (Southall *et al.*, 2019) $L_{E,p,24h,wtd}$		Modelling location 1	Modelling location 8	In-combination area
PTS (Impulsive)	LF (183 dB)	2,000 km²	2,500 km²	5,800 km²
	HF (185 dB)	< 0.1 km²	< 0.1 km²	-
	VHF (155 dB)	480 km²	580 km²	2,200 km²
	PCW (185 dB)	4.0 km²	5.4 km²	13 km²

Table 4-67 Summary of the impact areas for the installation of monopile foundations at modelling locations 1 and 8 across the Caledonia North and Caledonia South Sites for fish using the pile driving Popper et al. (2014) criteria assuming both fleeing and stationary animals.

Monopile foundations (Popper *et al.*, 2014) $L_{E,p,24h}$		Modelling location 1	Modelling location 8	In-combination area
Fleeing (1.5 m/s)	219 dB	< 0.1 km²	< 0.1 km²	-
	216 dB	< 0.1 km²	< 0.1 km²	-
	210 dB	< 0.1 km²	< 0.1 km²	-
	207 dB	< 0.1 km²	< 0.1 km²	-
	203 dB	1.8 km²	2.6 km²	6.0 km²
	186 dB	3,400 km²	4,000 km²	8,000 km²
Stationary (0 m/s)	219 dB	1.5 km²	1.5 km²	3.5 km²
	216 dB	3.7 km²	3.8 km²	8.3 km²
	210 dB	23 km²	25 km²	50 km²
	207 dB	56 km²	61 km²	120 km²
	203 dB	170 km²	190 km²	380 km²
	186 dB	5,800 km²	6,500 km²	11,000 km²

4.2.1.2 Multi-leg foundations

Table 4-68 Summary of the impact areas for the installation of multi-leg foundations at modelling locations 1 and 8 across the Caledonia North and Caledonia South Sites for marine mammals using the impulsive Southall et al. (2019) criteria assuming a fleeing animal.

Multi-leg foundations (Southall *et al.*, 2019) $L_{E,p,24h,wtd}$		Modelling location 1	Modelling location 8	In-combination area
PTS (Impulsive)	LF (183 dB)	1,900 km²	2,300 km²	5,600 km²
	HF (185 dB)	< 0.1 km²	< 0.1 km²	-
	VHF (155 dB)	420 km²	530 km²	2,200 km²
	PCW (185 dB)	1.7 km²	2.6 km²	380 km²

Table 4-69 Summary of the impact areas for the installation of multi-leg foundations at modelling locations 1 and 8 across the Caledonia North and Caledonia South Sites for fish using the pile driving Popper et al. (2014) criteria assuming both fleeing and stationary animals.

Multi-leg foundations (Popper *et al.*, 2014) $L_{E,p,24h}$		Modelling location 1	Modelling location 8	In-combination area
Fleeing (1.5 m/s)	219 dB	< 0.1 km²	< 0.1 km²	-
	216 dB	< 0.1 km²	< 0.1 km²	-
	210 dB	< 0.1 km²	< 0.1 km²	-
	207 dB	< 0.1 km²	< 0.1 km²	-
	203 dB	0.2 km²	0.41 km²	300 km²
	186 dB	3,300 km²	3,900 km²	8,100 km²
Stationary (0 m/s)	219 dB	2.6 km²	2.8 km²	6.3 km²
	216 dB	6.6 km²	6.9 km²	15 km²
	210 dB	41 km²	44 km²	89 km²
	207 dB	97 km²	110 km²	210 km²
	203 dB	290 km²	330 km²	650 km²
	186 dB	7,500 km²	8,300 km²	14,000 km²

4.2.2 Concurrent piling at Caledonia North (bottom-fixed turbines)

4.2.2.1 Monopile foundations

Table 4-70 Summary of the impact areas for the installation of monopile foundations at modelling locations 1 and 4 across the Caledonia North Site for marine mammals using the impulsive Southall et al. (2019) criteria assuming a fleeing animal.

Monopile foundations (Southall *et al.*, 2019) $L_{E,p,24h,wtd}$		Modelling location 1	Modelling location 4	In-combination area
PTS (Impulsive)	LF (183 dB)	2,000 km²	2,200 km²	4,900 km²
	HF (185 dB)	< 0.1 km²	< 0.1 km²	-
	VHF (155 dB)	480 km²	480 km²	1,700 km²
	PCW (185 dB)	4.0 km²	4.1 km²	240 km²

Table 4-71 Summary of the impact areas for the installation of monopile foundations at modelling locations 1 and 4 across the Caledonia North Site for fish using the pile driving Popper et al. (2014) criteria assuming both fleeing and stationary animals.

Monopile foundations (Popper *et al.*, 2014) $L_{E,p,24h}$		Modelling location 1	Modelling location 4	In-combination area
Fleeing (1.5 m/s)	219 dB	< 0.1 km²	< 0.1 km²	-
	216 dB	< 0.1 km²	< 0.1 km²	-
	210 dB	< 0.1 km²	< 0.1 km²	-
	207 dB	< 0.1 km²	< 0.1 km²	-
	203 dB	1.8 km²	1.9 km²	7.5 km²
	186 dB	3,400 km²	3,700 km²	7,100 km²
Stationary (0 m/s)	219 dB	1.5 km²	1.5 km²	3.5 km²
	216 dB	3.7 km²	3.7 km²	8.3 km²
	210 dB	23 km²	23 km²	51 km²
	207 dB	56 km²	57 km²	120 km²
	203 dB	170 km²	180 km²	390 km²
	186 dB	5,800 km²	6,500 km²	11,000 km²

4.2.2.2 Multi-leg foundations

Table 4-72 Summary of the impact areas for the installation of multi-leg foundations at modelling locations 1 and 4 across the Caledonia North Site for marine mammals using the impulsive Southall et al. (2019) criteria assuming a fleeing animal.

Multi-leg foundations (Southall *et al.*, 2019) $L_{E,p,24h,wtd}$		Modelling location 1	Modelling location 4	In-combination area
PTS (Impulsive)	LF (183 dB)	1,900 km^2	1,900 km^2	4,700 km^2
	HF (185 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (155 dB)	420 km^2	440 km^2	1,600 km^2
	PCW (185 dB)	1.7 km^2	1.8 km^2	240 km^2

Table 4-73 Summary of the impact areas for the installation of multi-leg foundations at modelling locations 1 and 4 across the Caledonia North Site for fish using the pile driving Popper et al. (2014) criteria assuming both fleeing and stationary animals.

Multi-leg foundations (Popper *et al.*, 2014) $L_{E,p,24h}$		Modelling location 1	Modelling location 4	In-combination area
Fleeing (1.5 m/s)	219 dB	< 0.1 km^2	< 0.1 km^2	-
	216 dB	< 0.1 km^2	< 0.1 km^2	-
	210 dB	< 0.1 km^2	< 0.1 km^2	-
	207 dB	< 0.1 km^2	< 0.1 km^2	-
	203 dB	0.2 km^2	0.24 km^2	180 km^2
	186 dB	3,300 km^2	3,500 km^2	7,000 km^2
Stationary (0 m/s)	219 dB	2.6 km^2	2.6 km^2	5.6 km^2
	216 dB	6.6 km^2	6.7 km^2	15 km^2
	210 dB	41 km^2	41 km^2	88 km^2
	207 dB	97 km^2	98 km^2	210 km^2
	203 dB	290 km^2	290 km^2	670 km^2
	186 dB	7,500 km^2	8,300 km^2	13,000 km^2

4.2.3 Concurrent piling at Caledonia South (bottom-fixed turbines)

4.2.3.1 Monopile foundations

Table 4-74 Summary of the impact areas for the installation of monopile foundations at modelling locations 3 and 8 across the Caledonia South Site for marine mammals using the impulsive Southall et al. (2019) criteria assuming a fleeing animal.

Monopile foundations (Southall *et al.*, 2019) $L_{E,p,24h,wtd}$		Modelling location 3	Modelling location 8	In-combination area
PTS (Impulsive)	LF (183 dB)	2,400 km^2	2,500 km^2	5,300 km^2
	HF (185 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (155 dB)	490 km^2	580 km^2	1,800 km^2
	PCW (185 dB)	4.0 km^2	5.4 km^2	250 km^2

Table 4-75 Summary of the impact areas for the installation of monopile foundations at modelling locations 3 and 8 across the Caledonia South Site for fish using the pile driving Popper et al. (2014) criteria assuming both fleeing and stationary animals.

Monopile foundations (Popper *et al.*, 2014) $L_{E,p,24h}$		Modelling location 3	Modelling location 8	In-combination area
Fleeing (1.5 m/s)	219 dB	< 0.1 km^2	< 0.1 km^2	-
	216 dB	< 0.1 km^2	< 0.1 km^2	-
	210 dB	< 0.1 km^2	< 0.1 km^2	-
	207 dB	< 0.1 km^2	< 0.1 km^2	-
	203 dB	1.8 km^2	2.6 km^2	150 km^2
	186 dB	4,100 km^2	4,000 km^2	7,600 km^2
Stationary (0 m/s)	219 dB	1.5 km^2	1.5 km^2	3.6 km^2
	216 dB	3.7 km^2	3.8 km^2	8.3 km^2
	210 dB	23 km^2	25 km^2	53 km^2
	207 dB	56 km^2	61 km^2	130 km^2
	203 dB	170 km^2	190 km^2	410 km^2
	186 dB	6,800 km^2	6,500 km^2	11,000 km^2

4.2.3.2 Multi-leg foundations

Table 4-76 Summary of the impact areas for the installation of multi-leg foundations at modelling locations 3 and 8 across the Caledonia South Site for marine mammals using the impulsive Southall et al. (2019) criteria assuming a fleeing animal.

Multi-leg foundations (Southall *et al.*, 2019) $L_{E,p,24h,wtd}$		Modelling location 3	Modelling location 8	In-combination area
PTS (Impulsive)	LF (183 dB)	2,200 km^2	2,300 km^2	5,100 km^2
	HF (185 dB)	< 0.01 km^2	< 0.1 km^2	-
	VHF (155 dB)	450 km^2	530 km^2	1,700 km^2
	PCW (185 dB)	1.8 km^2	2.6 km^2	240 km^2

Table 4-77 Summary of the impact areas for the installation of multi-leg foundations at modelling locations 3 and 8 across the Caledonia South Site for fish using the pile driving Popper et al. (2014) criteria assuming both fleeing and stationary animals.

Multi-leg foundations (Popper *et al.*, 2014) $L_{E,p,24h}$		Modelling location 3	Modelling location 8	In-combination area
Fleeing (1.5 m/s)	219 dB	< 0.01 km²	< 0.1 km²	-
	216 dB	< 0.01 km²	< 0.1 km²	-
	210 dB	< 0.01 km²	< 0.1 km²	-
	207 dB	< 0.01 km²	< 0.1 km²	-
	203 dB	0.2 km²	0.41 km²	190 km²
	186 dB	3,900 km²	3,900 km²	7,700 km²
Stationary (0 m/s)	219 dB	2.6 km²	2.8 km²	6.3 km²
	216 dB	6.6 km²	6.9 km²	15 km²
	210 dB	41 km²	44 km²	92 km²
	207 dB	98 km²	110 km²	220 km²
	203 dB	290 km²	330 km²	770 km²
	186 dB	9,100 km²	8,300 km²	13,000 km²

4.2.4 Concurrent piling at Caledonia South (floating turbines)

4.2.4.1 Anchor pile foundations

Table 4-78 Summary of the impact areas for the installation of anchor pile foundations at modelling locations 5 and 8 across the Caledonia South Site for marine mammals using the impulsive Southall et al. (2019) criteria assuming a fleeing animal.

Anchor pile foundations (Southall *et al.*, 2019) $L_{E,p,24h,wtd}$		Modelling location 5	Modelling location 8	In-combination area
PTS (Impulsive)	LF (183 dB)	850 km²	890 km²	2,400 km²
	HF (185 dB)	< 0.1 km²	< 0.1 km²	-
	VHF (155 dB)	130 km²	140 km²	700 km²
	PCW (185 dB)	< 0.1 km²	< 0.1 km²	95 km²

Table 4-79 Summary of the impact areas for the installation of anchor pile foundations at modelling locations 5 and 8 across the Caledonia South Site for fish using the pile driving Popper et al. (2014) criteria assuming both fleeing and stationary animals.

Anchor pile foundations (Popper *et al.*, 2014) $L_{E,p,24h}$		Modelling location 5	Modelling location 8	In-combination area
Fleeing (1.5 m/s)	219 dB	< 0.1 km²	< 0.1 km²	-
	216 dB	< 0.1 km²	< 0.1 km²	-
	210 dB	< 0.1 km²	< 0.1 km²	-
	207 dB	< 0.1 km²	< 0.1 km²	-
	203 dB	< 0.1 km²	< 0.1 km²	-
	186 dB	1,600 km²	1,700 km²	3,800 km²
Stationary (0 m/s)	219 dB	0.36 km²	0.36 km²	1.3 km²
	216 dB	0.9 km²	0.9 km²	2.7 km²
	210 dB	5.8 km²	5.8 km²	13 km²
	207 dB	15 km²	15 km²	32 km²
	203 dB	49 km²	50 km²	110 km²
	186 dB	3,200 km²	3,400 km²	6,100 km²

4.2.5 Concurrent piling at Caledonia North and a nearby wind farm site

4.2.5.1 Monopile foundations

Table 4-80 Summary of the impact areas for the installation of monopile foundations at modelling location 3 at Caledonia North and another at the western edge of Broadshore OWF for marine mammals using the impulsive Southall et al. (2019) criteria assuming a fleeing animal.

Monopile foundations (Southall *et al.*, 2019) $L_{E,p,24h,wtd}$		Modelling location 3	Broadshore OWF western edge	In-combination area
PTS (Impulsive)	LF (183 dB)	2,400 km²	3,500 km²	6,500 km²
	HF (185 dB)	< 0.1 km²	< 0.1 km²	-
	VHF (155 dB)	490 km²	680 km²	2,000 km²
	PCW (185 dB)	4.0 km²	6.9 km²	280 km²

Table 4-81 Summary of the impact areas for the installation of monopile foundations at modelling location 3 at Caledonia North and another at the western edge of Broadshore OWF for fish using the pile driving Popper et al. (2014) criteria assuming both fleeing and stationary animals.

Monopile foundations (Popper *et al.*, 2014) $L_{E,p,24h}$		Modelling location 3	Broadshore OWF western edge	In-combination area
Fleeing (1.5 m/s)	219 dB	< 0.1 km²	< 0.1 km²	-
	216 dB	< 0.1 km²	< 0.1 km²	-
	210 dB	< 0.1 km²	< 0.1 km²	-
	207 dB	< 0.1 km²	< 0.1 km²	-
	203 dB	1.8 km²	3.6 km²	9.4 km²
	186 dB	4,100 km²	5,700 km²	9,400 km²
Stationary (0 m/s)	219 dB	1.5 km²	1.8 km²	3.6 km²
	216 dB	3.7 km²	4.1 km²	8.3 km²
	210 dB	23 km²	27 km²	53 km²
	207 dB	56 km²	64 km²	130 km²
	203 dB	170 km²	200 km²	420 km²
	186 dB	6,800 km²	8,900 km²	13,000 km²

4.2.5.2 Multi-leg foundations

Table 4-82 Summary of the impact areas for the installation of multi-leg foundations at modelling location 3 at Caledonia North and another at the western edge of Broadshore OWF for marine mammals using the impulsive Southall et al. (2019) criteria assuming a fleeing animal.

Multi-leg foundations (Southall *et al.*, 2019) $L_{E,p,24h,wtd}$		Modelling location 3	Broadshore OWF western edge	In-combination area
PTS (Impulsive)	LF (183 dB)	2,200 km²	3,400 km²	6,400 km²
	HF (185 dB)	< 0.01 km²	< 0.1 km²	-
	VHF (155 dB)	450 km²	670 km²	2,000 km²
	PCW (185 dB)	1.8 km²	3.9 km²	280 km²

Table 4-83 Summary of the impact areas for the installation of multi-leg foundations at modelling location 3 at Caledonia North and another at the western edge of Broadshore OWF for fish using the pile driving Popper et al. (2014) criteria assuming both fleeing and stationary animals.

Multi-leg foundations (Popper *et al.*, 2014) $L_{E,p,24h}$		Modelling location 3	Broadshore OWF western edge	In-combination area
Fleeing (1.5 m/s)	219 dB	< 0.01 km²	-	-
	216 dB	< 0.01 km²	-	-
	210 dB	< 0.01 km²	-	-
	207 dB	< 0.01 km²	-	-
	203 dB	0.2 km²	0.8 km²	220 km²
	186 dB	3,900 km²	5,900 km²	9,600 km²
Stationary (0 m/s)	219 dB	2.6 km²	3.5 km²	6.3 km²
	216 dB	6.6 km²	7.5 km²	15 km²
	210 dB	41 km²	48 km²	93 km²
	207 dB	98 km²	120 km²	230 km²
	203 dB	290 km²	350 km²	750 km²
	186 dB	9,100 km²	12,000 km²	17,000 km²

4.2.6 Concurrent piling at Caledonia South and a nearby OWF

4.2.6.1 Monopile foundations

Table 4-84 Summary of the impact areas for the installation of monopile foundations at modelling location 7 at Caledonia South and another at the western edge of Broadshore OWF for marine mammals using the impulsive Southall et al. (2019) criteria assuming a fleeing animal.

Monopile foundations (Southall *et al.*, 2019) $L_{E,p,24h,wtd}$		Modelling location 7	Broadshore OWF western edge	In-combination area
PTS (Impulsive)	LF (183 dB)	2,700 km²	3,500 km²	6,200 km²
	HF (185 dB)	< 0.1 km²	< 0.1 km²	-
	VHF (155 dB)	560 km²	680 km²	1,800 km²
	PCW (185 dB)	5.4 km²	6.9 km²	230 km²

Table 4-85 Summary of the impact areas for the installation of monopile foundations at modelling location 7 at Caledonia South and another at the western edge of Broadshore OWF for fish using the pile driving Popper et al. (2014) criteria assuming both fleeing and stationary animals.

Monopile foundations (Popper *et al.*, 2014) $L_{E,p,24h}$		Modelling location 7	Broadshore OWF western edge	In-combination area
Fleeing (1.5 m/s)	219 dB	< 0.1 km²	< 0.1 km²	-
	216 dB	< 0.1 km²	< 0.1 km²	-
	210 dB	< 0.1 km²	< 0.1 km²	-
	207 dB	< 0.1 km²	< 0.1 km²	-
	203 dB	2.6 km²	3.6 km²	200 km²
	186 dB	4,600 km²	5,700 km²	9,400 km²
Stationary (0 m/s)	219 dB	1.5 km²	1.8 km²	3.6 km²
	216 dB	3.9 km²	4.1 km²	8.3 km²
	210 dB	25 km²	27 km²	54 km²
	207 dB	61 km²	64 km²	140 km²
	203 dB	190 km²	200 km²	500 km²
	186 dB	7,500 km²	8,900 km²	13,000 km²

4.2.6.2 Multi-leg foundations

Table 4-86 Summary of the impact areas for the installation of multi-leg foundations at modelling location 7 at Caledonia South and another at the western edge of Broadshore OWF for marine mammals using the impulsive Southall et al. (2019) criteria assuming a fleeing animal.

Multi-leg foundations (Southall *et al.*, 2019) $L_{E,p,24h,wtd}$		Modelling location 7	Broadshore OWF western edge	In-combination area
PTS (Impulsive)	LF (183 dB)	2,500 km^2	3,400 km^2	6,400 km^2
	HF (185 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (155 dB)	530 km^2	670 km^2	1,900 km^2
	PCW (185 dB)	2.6 km^2	3.9 km^2	220 km^2

Table 4-87 Summary of the impact areas for the installation of multi-leg foundations at modelling location 7 at Caledonia South and another at the western edge of Broadshore OWF for fish using the pile driving Popper et al. (2014) criteria assuming both fleeing and stationary animals.

Multi-leg foundations (Popper *et al.*, 2014) $L_{E,p,24h}$		Modelling location 7	Broadshore OWF western edge	In-combination area
Fleeing (1.5 m/s)	219 dB	< 0.1 km^2	-	-
	216 dB	< 0.1 km^2	-	-
	210 dB	< 0.1 km^2	-	-
	207 dB	< 0.1 km^2	-	-
	203 dB	0.44 km^2	0.8 km^2	170 km^2
	186 dB	4,500 km^2	5,900 km^2	9,700 km^2
Stationary (0 m/s)	219 dB	2.8 km^2	3.5 km^2	6.9 km^2
	216 dB	7.1 km^2	7.5 km^2	16 km^2
	210 dB	45 km^2	48 km^2	100 km^2
	207 dB	110 km^2	120 km^2	250 km^2
	203 dB	320 km^2	350 km^2	910 km^2
	186 dB	10,000 km^2	12,000 km^2	17,000 km^2

5 Other noise sources

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.

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 of the Proposed Development (Offshore) sites.

Table 5-1 Summary of the possible noise making activities at the Proposed Development (Offshore) other than impact piling.

Activity	Description
Cable laying	Noise from the cable laying vessel and other associated noise during the offshore cable installation.
Dredging	Dredging may be required on site for seabed preparation work for certain foundation options, as well as for the export cable, array cables and interconnector cable installation. Both backhoe and suction dredging have been included.
Drilling	There is the potential for WTG foundations to installed using drilling depending on seabed type of if a pile refuses during impact piling operations.
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.
Vibropiling	There is the potential for a vibratory hammer to be used to install foundation piles or sheet piles for coffer dams, etc.
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. The project design envelope has made predictions for turbine parameters which could be available for the Proposed Development (Offshore) and has allowed for power outputs of between 15 and 25 MW.
UXO clearance	There is a possibility that Unexploded ordnance (UXO) may exist within the Proposed Development (Offshore) red line boundaries, which would need to be cleared before construction can begin.

Most of these activities are covered in section 5.1, with operational WTG noise and UXO clearance assessed in sections 5.2 and 5.3 respectively.

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., cable laying and dredging), or where detailed modelling would imply unjustified accuracy (e.g., for small charges such as those used in low order clearances). 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.

5.1 Noise making activities

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 Proposed Development (Offshore) 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 α is the absorption loss coefficient:

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

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 2.3, 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 Proposed Development (Offshore).

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

Source	Estimated L_p source level	Transmission loss parameters	Comments
Cable laying	171 dB re 1 µPa @ 1 m	N: 13, α: 0 (no absorption)	Based on 11 datasets from a pipe laying vessel measuring 300 m in length; this is considered a worst-case noise source for cable laying operations.
Dredging (backhoe)	165 dB re 1 µPa @ 1 m	N: 19, α: 0.0009	Based on three datasets from backhoe dredgers.
Dredging (suction)	186 dB re 1 µPa @ 1 m	N: 19, α: 0.0009	Based on five datasets from suction and cutter suction dredgers.
Drilling	169 dB re 1 µPa @ 1 m	N: 16, α: 0.0006	Based on six datasets from various drilling operations covering ground investigations and pile installation. A 200 kW drill has been assumed for modelling.
Rock placement	172 dB re 1 µPa @ 1 m	N: 12, α: 0.0005	Based on four datasets from rock placement vessel *Rollingstone*.
Trenching	172 dB re 1 µPa @ 1 m	N: 13, α: 0.0004	Based on three datasets of measurements from trenching vessels more than 100 m in length.
Vibropiling	193 dB re 1 µPa @ 1 m	N: 18, α: 0 (no absorption)	Based on four datasets of vibropiling installation from sheet piles and tubular piles
Vessel noise (large)	168 dB re 1 µPa @ 1 m	N: 12, α: 0.0021	Based on five datasets of large vessels including container ships, FPSOs and other vessels more than 100 m in length. Vessel speed assumed as 10 knots.

Source	Estimated L_p source level	Transmission loss parameters	Comments
Vessel noise (medium)	161 dB re 1 µPa @ 1 m	N: 12, α: 0.0021	Based on three datasets of moderate sized vessels less than 100 m in length. Vessel speed assumed as 10 knots.

All values of N and α 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.

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 fleeing and stationary animals have been included for all $L_{E,p,t}$ criteria.

To account for the weightings required for modelling using the Southall *et al*. (2019) criteria (see section 2.3.1), reductions have been applied to the source levels of the various noise sources. Figure 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.

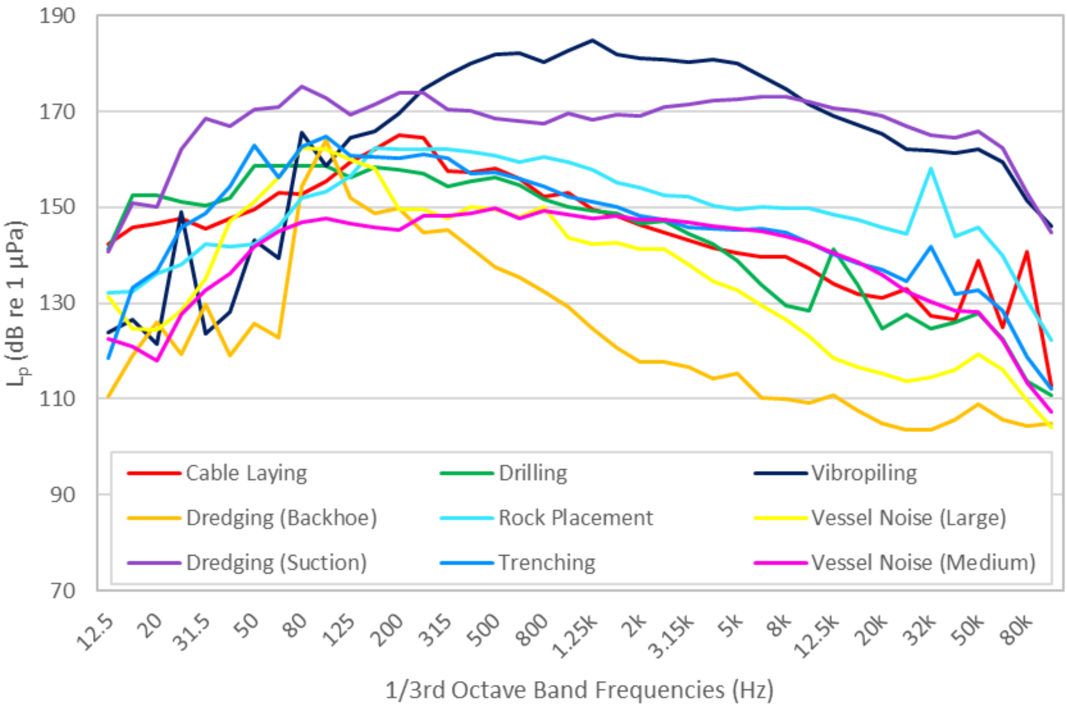

Figure 5-1 Summary of the 1/3rd octave frequency bands to which Southall et al. (2019) weightings have been applied.

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_p source level from the unweighted level (Southall *et al.*, 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	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	4.0 dB re 1 µPa	25.8 dB re 1 µPa	48.7 dB re 1 µPa	13.2 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
Vibropiling	2.4 dB re 1 µPa	16.0 dB re 1 µPa	20.8 dB re 1 µPa	4.4 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

Table 5-4 to Table 5-6 summarise the predicted impact ranges for these noise sources. All the sources in this section are considered non-impulsive or continuous. As with the previous results, ranges smaller than 50 m (single pulse) and 100 m (cumulative) have not been presented.

Given the modelled impact ranges, almost any marine mammal would have to be closer than 100 m from the continuous source 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 rock placement. The exposure calculation assumes the same receptor swim speeds as the impact piling modelling in section 4. As explained in section 3.3, this would only mean that the receptor reaches the 'onset' stage at these ranges, 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 there is minimal risk.

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).

All sources presented here produce much quieter levels than those predicted for impact piling in section 4.

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

Southall *et al*. (2019)	PTS (non-impulsive)			
$L_{E,p,24h,wtd}$	LF (199 dB)	HF (198 dB)	VHF (173 dB)	PCW (201 dB)
Cable laying	< 100 m	< 100 m	< 100 m	< 100 m
Dredging (backhoe)	< 100 m	< 100 m	< 100 m	< 100 m
Dredging (suction)	< 100 m	< 100 m	< 100 m	< 100 m
Drilling	< 100 m	< 100 m	< 100 m	< 100 m
Rock placement	< 100 m	< 100 m	< 100 m	< 100 m
Trenching	< 100 m	< 100 m	< 100 m	< 100 m
Vibropiling	< 100 m	< 100 m	< 100 m	< 100 m
Vessel noise (large)	< 100 m	< 100 m	< 100 m	< 100 m
Vessel noise (medium)	< 100 m	< 100 m	< 100 m	< 100 m

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

Southall *et al.* (2019) $L_{E,p,24h,wtd}$	PTS (non-impulsive)			
	LF (199 dB)	HF (198 dB)	VHF (173 dB)	PCW (201 dB)
Cable laying	< 100 m	< 100 m	< 100 m	< 100 m
Dredging (backhoe)	< 100 m	< 100 m	< 100 m	< 100 m
Dredging (suction)	< 100 m	< 100 m	570 m	< 100 m
Drilling	< 100 m	< 100 m	< 100 m	< 100 m
Rock placement	< 100 m	< 100 m	900 m	< 100 m
Trenching	< 100 m	< 100 m	< 100 m	< 100 m
Vibropiling	< 100 m	< 100 m	< 100 m	< 100 m
Vessel noise (large)	< 100 m	< 100 m	< 100 m	< 100 m
Vessel noise (medium)	< 100 m	< 100 m	< 100 m	< 100 m

Ranges for a stationary animal are theoretical only and are expected to be over-conservative as the assumption is for the animal to remain stationary in respect to the noise source, when, in all cases other than drilling, the source of the noise moves.

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

Popper *et al.* (2014) L_p	Recoverable injury 170 dB re 1 µPa (48 hours)	TTS 158 dB re 1 µPa (12 hours)
Cable laying	< 50 m	< 50 m
Dredging (backhoe)	< 50 m	< 50 m
Dredging (suction)	< 50 m	< 50 m
Drilling	< 50 m	< 50 m
Rock placement	< 50 m	< 50 m
Trenching	< 50 m	< 50 m
Vibropiling	< 50 m	90 m
Vessel noise (large)	< 50 m	< 50 m
Vessel noise (medium)	< 50 m	< 50 m

5.2 Operational WTG noise

The main source of underwater noise from operational WTGs will be mechanically generated vibration from the rotating machinery in the WTGs, which is transmitted into the sea through the structure of the WTG tower and foundations (Nedwell *et al.*, 2003; Tougaard *et al.*, 2020). Noise levels generated above the water surface are low enough that no significant airborne noise will pass from the air to the water.

Tougaard *et al.* (2020) published a study investigating underwater 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 two 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:

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

where C is a fixed constant, and the coefficients α, β, and γ are derived from empirical data for the 17 datasets. This enables the calculation to extrapolate to greater turbine power outputs such as those used at the Proposed Development (Offshore).

Indicative power outputs have been used to calculate the impacts for this study. For bottom-fixed foundation WTGs, power outputs up to 25 MW have been assumed. Floating WTGs measuring up to 20 MW have been considered in section 5.2.1.

The maximum turbine sizes considered at the Proposed Development (Offshore) are much larger than those used for the equation above, so caution must be used when considering the results presented in this section; no empirical data is available for large wind turbines close to the specifications proposed here. Figure 5-2 presents a level against range plot for the range of WTG sizes at the Proposed Development (Offshore) using the Tougaard *et al*. (2020) equation, assuming an average 6 m/s wind speed.

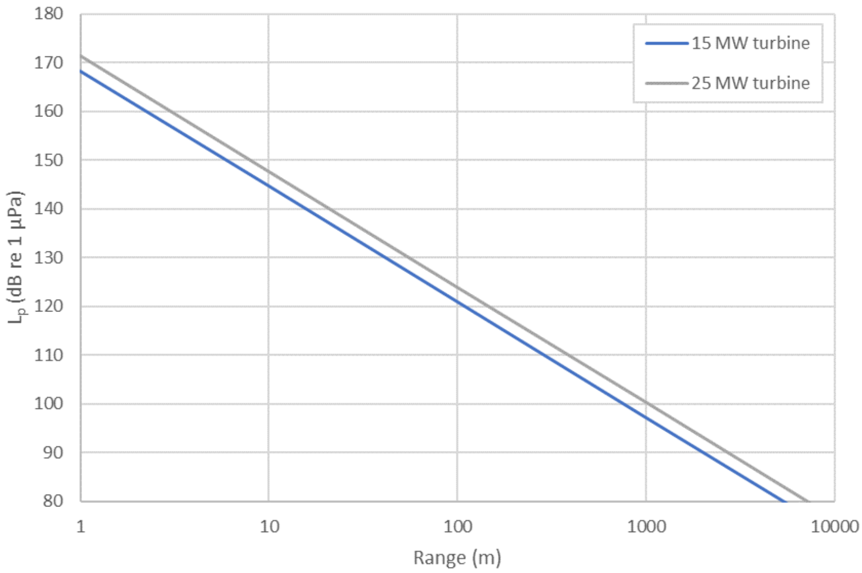

Figure 5-2 Predicted unweighted L_p from operational WTGs using the calculation from Tougaard et al. (2020).

Using this data, a summary of the predicted impact ranges for operational WTGs using bottom-fixed foundations has been produced, shown in Table 5-7 and Table 5-8. All operational WTG modelling uses the same assumptions as presented in the previous sections. Ranges smaller than 50 m (single pulse) and 100 m (cumulative) have not been presented. The operational WTG source is considered non-impulsive or continuous. For $L_{E,p,t}$ calculations, a worst-case stationary animal has been used and it is assumed that the operational WTG noise is present 24 hours a day.

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

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Operational WTG (15 MW)	Operational WTG (25 MW)
PTS (non-impulsive)	LF (199 dB)	< 100 m	< 100 m
	HF (198 dB)	< 100 m	< 100 m
	VHF (173 dB)	< 100 m	< 100 m
	PCW (201 dB)	< 100 m	< 100 m

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

Popper *et al*. (2014) L_p,	Operational WTG (15 MW)	Operational WTG (25 MW)
Recoverable injury 170 dB (48 hours)	< 50 m	< 50 m
TTS 158 dB (12 hours)	< 50 m	< 50 m

These results show that, for operational WTGs with bottom-fixed foundations, injury risk is minimal.

Stöber and Thomsen (2021) produced a similar study of operational WTG datasets and raises the potential for behavioural disturbance caused by larger wind turbines. While prospective WTG sizes are increasing, Stöber and Thomsen (2021) conclude that these might only have limited impacts related to behavioural responses in marine mammals and fish, although there is considerable uncertainty in criteria available to assess these. That the study utilises, it is estimated that the larger WTGs may only achieve this at ranges of approximately 140 m. As the distance between the turbines at the Proposed Development (Offshore) will be much greater than this, any array effect from the turbines is not expected. More recent field study research by Bellmann *et al.* (2023) takes this further and shows that the predictions of underwater noise during the operational phase in Stöber and Thomsen (2021) represent significant over-estimations of the actual levels seen on site.

5.2.1 Floating turbines

The noise source for most operational WTGs is the radiating area of the foundation in the water. For a bottom-fixed monopile foundation, this is the surface area of the cylindrical pile in the water column. Other bottom-fixed foundations such as jacket or tripod foundations are more complex. 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). The radiating area source for a floating WTG is limited to the weighted and buoyant section that rests beneath the sea surface, a significantly smaller area than a fixed WTG. With a much smaller submerged radiating area, the noise is expected to be lower, with a reasonable assumption of equivalent sound generation within the WTG and transmission through the tower.

Little empirical data exists for the operational noise produced by floating WTGs. For example, Bellmann *et al.* (2023), Tougaard *et al*. (2020) and the study by Stöber and Thomsen (2021) did not consider any floating designs. Measurements taken by Jasco Applied Science (Martin *et al*., 2011) of the HYWIND demonstrator, west of Stavanger, Norway, showed broadband noise levels of the order of 120 dB re 1 µPa (L_p) over an approximate 10-week period in June to August 2011, at a range of 150 m from the WTG. However, much of this was found to be influenced by ambient noise from existing shipping sources and none of the components of noise relating to WTG operation appeared to exceed 110 dB re 1 µPa (L_p) at the monitoring location. It is worth noting that this is dominated by noise at low frequency (< 100 Hz), which is below the auditory sensitivity for most marine mammals, and they differ minimally from background noise over the long term at all measured frequencies up to 16 kHz (1/3rd octave band). It is therefore likely that even if the noise measurement at the position near the WTG was influenced by operational WTG noise, ambient noise levels will typically reach this level naturally; the WTG at this study was 2.3 MW (82.4 m rotor diameter). While some other monitoring data for floating wind far projects do exist (Molinero, 2020), comparing potential noise levels to worst-case examples such as those from HYWIND are considered best practice for this study as they are the largest available.

Using the Tougaard *et al*. (2020) calculator from the previous section, an uplift of approximately 13 dB would need to be applied to the sound output from a 2.3 MW WTG to the approximate sizes proposed for the Proposed Development (Offshore) (up to 20 MW). This would suggest an upper limit of 133 dB re 1 µPa (L_p) at 150 m for floating turbines at the Proposed Development (Offshore).

Using this extrapolated 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 20 m for 12 hours continuously. For a source near the surface in water depths of the order of 80 m, this would be very low risk. As studies have shown that fish populations have increased in the vicinity of OWFs (Stenberg *et al*., 2015), there appears to be minimal risk to fish from operational WTGs.

To compare this to the relevant marine mammal impact thresholds in Southall *et al*. (2019), at a range of 100 m from the floating WTG for an hour, a receptor would receive an unweighted 173 dB ($L_{E,p,1h}$). With weighting considered, this is still well below potentially injurious or TTS thresholds for any Southall *et al*. (2019) criteria. Therefore, for noise from operational floating WTGs, TTS risk is small. Importantly this assumes a stationary animal model with an individual remaining within 100 m from a WTG for much more than a 1-hour period. This is a highly unlikely scenario: when the animal is able to move, the risk of direct harm from the noise is minimal.

5.2.2 Cable noise

As well as relatively low noise levels from the operational machinery in a variety of conditions (see section 5.2.1), measurements taken by Jasco (2011) for Statoil in Norway identified what appeared to be a “snapping” noise that was thought to be related to tension release in the mooring system, although this has not been verified. It is understood that the mooring cables are designed to be permanently in tension such that no line should ever go into slack, even in extreme conditions, partly to avoid the risk of entanglement of marine mammals (Statoil, 2015). If the cables are the source of the noise, this will be caused by the specific circumstances at the HYWIND 1 project: that is, the depth of water, length of cables in use, current and current fluctuations. The findings at HYWIND 1 were isolated, and it does not necessarily follow that this will occur at the Proposed Development (Offshore) but does not rule out the potential for it either. Unless there was further evidence that other floating WTG moorings, or some other noise source associated with the WTGs, is shown to create this snap then it may be an anomaly or potentially even an artifact of the monitoring system (although the latter is unlikely).

According to Jasco (2011), up to 23 of these snaps were identified per day. Over the two months of monitoring undertaken by Jasco, less than 10 snaps exceeding 160 dB re 1 µPa (L_p) at the measurement position, 150 m from the WTG, were identified on most days.

As the source of noise is unclear, its distance from the monitor cannot be ascertained and thus a prediction of the noise closer to the source is not possible for estimation of PTS in terms of $L_{p,pk}$. Subsequent analysis of the HYWIND 1 data by Xodus (2015) for the HYWIND Scotland Pilot Park Project predicted a potential $L_{E,p,24h}$ of up to 157 dB re 1 µPa^{2}s caused by snapping chains from six WTGs; the equivalent for ten would be approximately 160 dB re 1 µPa^{2}s. This prediction makes a series of worst-case assumptions (e.g., all WTGs producing the maximum number of snaps in a day, equivalent noise levels from multiple locations affecting a receptor to the same degree) and this level is below any PTS or injury criteria to marine mammals or fish.

There are no reliable noise thresholds that would be recommended to identify disturbance for rare/intermittent impulses of this type. As any snapping occurs at an average rate of less than one snap per hour, disturbance leading to avoidance behaviour is considered unlikely.

5.3 UXO clearance

It is possible that UXO devices with a range of charge weights (or quantity of contained explosive) are present within the Proposed Development (Offshore) including Caledonia North Site, Caledonia South Site and the Offshore Export Cable Corridor (OECC). These would need to be cleared before any construction can begin. This will be undertaken using deflagration techniques, which avoids the detonation of the device itself.

5.3.1 Estimation of underwater noise levels through low-order (deflagration) technique

Estimation of the source noise level for each charge weight has been carried out in accordance with the methodology of Soloway and Dahl (2014), which follows Arons (1954) and the Marine Technical Directorate Ltd. (MTD) (1996).

Deflagration is proposed for destruction of the UXO, intended to result in a 'low order' burn of the explosive material in a UXO, which destroys, but does not detonate, the internal explosive.

Where the technique proceeds as intended, it is still not without noise impact. The process requires an initial shaped explosive donor charge, typically 250 g or less, to breach the casing and ignite the internal high explosive (HE) material without full detonation. The shaped charge and burn will both produce noise, although it will be significantly less than the high order detonation of the much larger UXO. It may not destroy all of the HE, necessitating further deflagration events or collection of the remnants. The deflagration may produce an unintentional high-order event, although this is rare (Oliva *et al.,* 2024).

For calculation of the scenario of total destruction of the HE material using deflagration, it is anticipated that the initial shaped charge is the greatest source of noise (Cheong *et al.*, 2020, Oliva *et al.*, 2024). The shaped charge is treated as a bulk charge with NEQ (net explosive quantity) determined according to the size of UXO on which it is placed. A prediction of this impact is based on a charge weight of 250 g.

5.3.2 Estimation of underwater noise propagation

For this assessment, the attenuation of the noise from low order UXO clearance has been accounted for in calculations using geometric spreading and a sound absorption coefficient, primarily using the methodologies cited in Soloway and Dahl (2014), which establishes a trend based on measured data in open water. These are, for $L_{p,pk}$:

$$L_{p,pk} = 52.4 \times 10^6 \left(\frac{R}{W^{1/3}}\right)^{-1.13}$$

and for $L_{E,p}$:

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

where W is the equivalent charge weight for TNT in kg and R is the range from the source.

These equations give a relatively simple calculation which can be used to give an indication of the range of effect. The equation does not consider variable bathymetry or seabed type, and thus calculation results will be the same regardless of where it is used. An attenuation correction can be added to the Soloway and Dahl (2014) equations for the absorption over long ranges (i.e., of the order of thousands of metres), based on measurements of high intensity noise propagation taken in the North Sea and Irish Sea. This uses standard frequency-based absorption coefficients for the seawater conditions expected in the region.

Despite this attenuation correction, the resulting noise levels still need to be considered carefully. For example, $L_{p,pk}$ noise levels over larger distances are difficult to predict accurately (von Benda-Beckmann *et al.*, 2015). Soloway and Dahl (2014) only verify results from the equation above for small charges at ranges of less than 1 km, although the results are similar to the measurements presented by von Benda-Beckmann *et al*. (2015). At longer ranges, greater confidence is expected with the $L_{E,p}$ calculations. A review of equation based predictions such as used here against empirical measurements of deflagration noise found that the predictions typically over-estimated the impact and can therefore be considered precautionary.

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

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

The selection of assessment criteria must also be considered in light of this. As discussed in Section 2.2.1, the smoothing of the pulse at range means that a pulse may be considered non-impulsive at distance, suggesting that, at greater ranges, it may be more appropriate to use the non-impulsive criteria. This consideration may begin at 3.5 km (Hastie *et al*., 2019).

A summary of the unweighted UXO clearance source levels, calculated using the equations above, are given in Table 5-9.

Table 5-9 Summary of the $L_{p,pk}$ and $L_{E,p}$ source levels used for UXO clearance modelling.

Charge weight	$L_{p,pk}$ source level	$L_{E,p}$ source level
Low-order (0.25 kg)	269.8 dB re 1 µPa @ 1 m	215.2 dB re 1 µPa²s @ 1 m

5.3.3 Impact ranges

Table 5-10 to Table 5-13 present the impact ranges for low order UXO clearance, considering various impact criteria and deflagration. It should be noted that Popper *et al*. (2014) gives specific impact criteria for explosions (Table 2-5). A low order UXO clearance source is defined as a single pulse, as such the $L_{E,p}$ criteria from Southall *et al*. (2019) have been given as single pulse values in the following tables and fleeing animal assumptions do not apply. As with the previous sections, ranges smaller than 50 m have not been presented.

Table 5-10 Summary of the PTS and TTS impact ranges for deflagration using the impulsive $L_{p,pk}$ noise criteria from Southall et al. (2019) for marine mammals.

Southall *et al*. (2019) $L_{p,pk}$	PTS (impulsive)				TTS (impulsive)			
	LF 219 dB	HF 230 dB	VHF 202 dB	PCW 218 dB	LF 213 dB	HF 224 dB	VHF 196 dB	PCW 212 dB
Low order (0.25 kg)	170 m	60 m	990 m	190 m	320 m	100 m	1.8 km	360 m

Table 5-11 Summary of the PTS and TTS impact ranges for deflagration using the impulsive $L_{E,p}$ (single pulse) noise criteria from Southall et al. (2019) for marine mammals.

Southall *et al*. (2019) $L_{E,p}$ (single pulse)	PTS (impulsive)				TTS (impulsive)			
	LF 183 dB	HF 185 dB	VHF 155 dB	PCW 185 dB	LF 168 dB	HF 170 dB	VHF 140 dB	PCW 170 dB
Low order (0.25 kg)	230 m	< 50 m	80 m	< 50 m	3.2 km	< 50 m	750 m	570 m

Table 5-12 Summary of the PTS and TTS impact ranges for deflagration using the non-impulsive $L_{E,p}$ (single pulse) noise criteria from Southall et al. (2019) for marine mammals.

Southall *et al.* (2019) $L_{E,p}$ (single pulse)	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
Low order (0.25 kg)	< 50 m	< 50 m	< 50 m	< 50 m	460 m	< 50 m	110 m	80 m

Table 5-13 Summary of the impact ranges for deflagration using the explosions $L_{p,pk}$ noise criteria from Popper et al. (2019) for species of fish.

Popper *et al.* (2014) $L_{p,pk}$	Mortality and potential mortal injury	
	234 dB	229 dB
Low order (0.25 kg)	< 50 m	60 m

5.3.4 Summary

The maximum PTS ranges calculated for low order UXO clearance by deflagration is 990 m for the VHF cetacean category when considering the $L_{p,pk}$ criteria. For $L_{E,p}$ criteria, the largest PTS range is calculated for LF cetaceans with a predicted impact range of 230 m using the impulsive noise criteria. As explained earlier, this assumes the effect of a 250 g detonation of a deflagration charge, and is likely to over-estimate the actual noise this will produce on site (Oliva *et al.* (2024).

6 Summary and conclusions

Subacoustech Environmental has undertaken a study to assess the potential underwater noise and its effects during the construction and operation of the Proposed Development (Offshore), located in the Moray Firth, Scotland.

The level of underwater noise from the installation of offshore structure foundations and anchors 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.

Eight representative modelling locations were chosen to give spatial variation across the sites as well as accounting for changes in water depth. Three scenarios were considered across the modelling locations:

- A monopile foundation considering a 14 m diameter pile installed using a maximum hammer energy of 6,600 kJ and up to 2 piles installed per vessel per day,
- A multi-leg foundation considering a 4 m diameter pile installed using a maximum hammer energy of 4,400 kJ and up to 4 piles installed per vessel per day, and
- Anchor piles for floating WTG considering a 4.8 m diameter pile installed using a maximum hammer energy of 2,000 kJ, with 1 pile installed per vessel per day.

The loudest levels of noise and the greatest impact ranges were generally predicted for the multi-leg foundation scenarios at the westernmost corner of the Proposed Development (Offshore) site.

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; NOAA, 2005) and fish (Popper *et al.*, 2014), which have been used to inform biological assessments.

For marine mammals, maximum PTS ranges were predicted for LF cetaceans, with ranges of up to 36 km based on the multi-leg foundation scenario. For fish, the largest recoverable injury ranges (203 dB $L_{E,p,24h}$) were predicted to be 11 km for a stationary receptor, reducing to 450 m for a fleeing receptor.

Further modelling involving multiple piling vessels operating concurrently were also considered, covering scenarios for concurrent piling at two sites in Caledonia North, two sites in the Caledonia South; one site in Caledonia North and one site in the Caledonia South; one site in Caledonia North and another site in another nearby OWF; and one site in Caledonia South and another site in another nearby OWF.

Noise sources other than piling have been considered using a high-level, simple modelling approach, including vibropiling, cable laying, dredging, drilling, rock placement, vessel movement, and operational WTG noise. The predicted noise levels for these construction noises are well below those predicted for impact piling noise. The risk of any potentially injurious effects to fish or marine mammals from these sources are expected to be minimal as the noise emissions from these are close to, or below, the appropriate injury criteria, even when very close to the source of the noise.

Low order UXO clearance has also been considered across the Proposed Development (Offshore), and for the potential UXO clearance noise by deflagration, there is a risk of PTS up to 990 m irrespective of the UXO device considered as a consequence of the deflagration technique, using the $L_{p,pk}$ criteria for VHF cetaceans. However, based on recent measurements of deflagration in the Moray Firth (Oliva *et al.*), this predicted range is likely to be precautionary.

The outputs of this modelling have been used to inform assessments of the impacts of underwater noise on marine mammals (Volumes 2, 3 and 4, Chapter 7: Marine Mammals) and fish (Volumes 2, 3 and 4, Chapter 5: Fish and Shellfish Ecology) at the Proposed Development (Offshore) in their respective reports.

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Appendix A Additional modelling results

Following the impulsive Southall *et al*. (2019) modelled impact piling ranges presented in section 4, the modelling results for the non-impulsive criteria from impact piling noise at the Proposed Development (Offshore) are presented below. The predicted ranges here fall well below the impulsive criteria presented in the main report.

A.1 Single location modelling

Table A 1 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the monopile foundation modelling at modelling location 1 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 1, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km²	150 m	100 m	120 m
	HF (198 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF (173 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	PCW (201 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m

Table A 2 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the multi-leg foundation modelling at modelling location 1 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 1, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	HF (198 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF (173 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	PCW (201 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m

Table A 3 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the monopile foundation modelling at modelling location 2 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 2, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km²	130 m	100 m	110 m
	HF (198 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF (173 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	PCW (201 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m

Table A 4 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the multi-leg foundation modelling at modelling location 2 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 2, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	HF (198 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF (173 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	PCW (201 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m

Table A 5 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the monopile foundation modelling at modelling location 3 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 3, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km^2	150 m	100 m	120 m
	HF (198 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF (173 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	PCW (201 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m

Table A 6 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the multi-leg foundation modelling at modelling location 3 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 3, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	HF (198 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF (173 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	PCW (201 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m

Table A 7 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the monopile foundation modelling at modelling location 4 assuming a fleeing animal

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 4, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km^2	150 m	100 m	120 m
	HF (198 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF (173 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	PCW (201 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m

Table A 8 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the multi-leg foundation modelling at modelling location 4 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 4, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	HF (198 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF (173 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	PCW (201 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m

Table A 9 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the anchor pile foundation modelling at modelling location 5 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 5, anchor pile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	HF (198 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF (173 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	PCW (201 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m

Table A 10 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the anchor pile foundation modelling at modelling location 6 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 6, anchor pile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	HF (198 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF (173 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	PCW (201 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m

Table A 11 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the monopile foundation modelling at modelling location 7 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 7, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km^2	180 m	130 m	150 m
	HF (198 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF (173 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	PCW (201 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m

Table A 12 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the multi-leg foundation modelling at modelling location 7 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 7, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	HF (198 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF (173 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	PCW (201 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m

Table A 13 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the anchor pile foundation modelling at modelling location 7 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 7, anchor pile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	HF (198 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF (173 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	PCW (201 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m

Table A 14 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the monopile foundation modelling at modelling location 8 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 8, monopile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km^2	180 m	130 m	150 m
	HF (198 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF (173 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	PCW (201 dB)	< 0.1 km^2	< 100 m	< 100 m	< 100 m

Table A 15 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the multi-leg foundation modelling at modelling location 8 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 8, multi-leg foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	HF (198 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF (173 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	PCW (201 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m

Table A 16 Summary of the $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the anchor pile foundation modelling at modelling location 8 assuming a fleeing animal.

Southall *et al.* (2019) $L_{E,p,24h,wtd}$		Modelling location 8, anchor pile foundation			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	HF (198 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF (173 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	PCW (201 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m

A.2 Multiple location modelling

Table A 17 Summary of the impact areas for the installation of monopile foundations at modelling locations 1 and 8 across the Caledonia North and Caledonia South Sites for marine mammals using the non-impulsive Southall et al. (2019) criteria assuming a fleeing animal.

Monopile foundations (Southall *et al.*, 2019) $L_{E,p,24h,wtd}$		Modelling location 1	Modelling location 8	In-combination area
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km²	< 0.1 km²	-
	HF (198 dB)	< 0.1 km²	< 0.1 km²	-
	VHF (173 dB)	< 0.1 km²	< 0.1 km²	-
	PCW (201 dB)	< 0.1 km²	< 0.1 km²	-

Table A 18 Summary of the impact areas for the installation of multi-leg foundations at modelling locations 1 and 8 across the Caledonia North and Caledonia South Sites for marine mammals using the non-impulsive Southall et al. (2019) criteria assuming a fleeing animal.

Multi-leg foundations (Southall *et al.*, 2019) $L_{E,p,24h,wtd}$		Modelling location 1	Modelling location 8	In-combination area
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km²	< 0.1 km²	-
	HF (198 dB)	< 0.1 km²	< 0.1 km²	-
	VHF (173 dB)	< 0.1 km²	< 0.1 km²	-
	PCW (201 dB)	< 0.1 km²	< 0.1 km²	-

Table A 19 Summary of the impact areas for the installation of monopile foundations at modelling locations 1 and 4 across the Caledonia North Site for marine mammals using the non-impulsive Southall et al. (2019) criteria assuming a fleeing animal.

Monopile foundations (Southall *et al.*, 2019) $L_{E,p,24h,wtd}$		Modelling location 1	Modelling location 4	In-combination area
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km^2	< 0.1 km^2	130 km^2
	HF (198 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (173 dB)	< 0.1 km^2	< 0.1 km^2	-
	PCW (201 dB)	< 0.1 km^2	< 0.1 km^2	-

Table A 20 Summary of the impact areas for the installation of multi-leg foundations at modelling locations 1 and 4 across the Caledonia North Site for marine mammals using the non-impulsive Southall et al. (2019) criteria assuming a fleeing animal.

Multi-leg foundations (Southall *et al.*, 2019) $L_{E,p,24h,wtd}$		Modelling location 1	Modelling location 4	In-combination area
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km^2	< 0.1 km^2	95 km^2
	HF (198 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (173 dB)	< 0.1 km^2	< 0.1 km^2	-
	PCW (201 dB)	< 0.1 km^2	< 0.1 km^2	-

Table A 21 Summary of the impact areas for the installation of monopile foundations at modelling locations 3 and 8 across the Caledonia South Site for marine mammals using the non-impulsive Southall et al. (2019) criteria assuming a fleeing animal.

Monopile foundations (Southall *et al.*, 2019) $L_{E,p,24h,wtd}$		Modelling location 3	Modelling location 8	In-combination area
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km^2	< 0.1 km^2	140 km^2
	HF (198 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (173 dB)	< 0.1 km^2	< 0.1 km^2	-
	PCW (201 dB)	< 0.1 km^2	< 0.1 km^2	-

Table A 22 Summary of the impact areas for the installation of multi-leg foundations at modelling locations 3 and 8 across the Caledonia South Site for marine mammals using the non-impulsive Southall et al. (2019) criteria assuming a fleeing animal.

Multi-leg foundations (Southall *et al.*, 2019) $L_{E,p,24h,wtd}$		Modelling location 3	Modelling location 8	In-combination area
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km^2	< 0.1 km^2	100 km^2
	HF (198 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (173 dB)	< 0.1 km^2	< 0.1 km^2	-
	PCW (201 dB)	< 0.1 km^2	< 0.1 km^2	-

Table A 23 Summary of the impact areas for the installation of anchor pile foundations at modelling locations 5 and 8 across the Caledonia South Site for marine mammals using the non-impulsive Southall et al. (2019) criteria assuming a fleeing animal.

Anchor pile foundations (Southall *et al.*, 2019) $L_{E,p,24h,wtd}$		Modelling location 5	Modelling location 8	In-combination area
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km^2	< 0.1 km^2	-
	HF (198 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (173 dB)	< 0.1 km^2	< 0.1 km^2	-
	PCW (201 dB)	< 0.1 km^2	< 0.1 km^2	-

Table A 24 Summary of the impact areas for the installation of monopile foundations at modelling location 3 at Caledonia North and another at the western edge of Broadshore OWF for marine mammals using the non-impulsive Southall et al. (2019) criteria assuming a fleeing animal.

Monopile foundations (Southall *et al.*, 2019) $L_{E,p,24h,wtd}$		Modelling location 3	Broadshore OWF western edge	In-combination area
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km^2	0.2 km^2	150 km^2
	HF (198 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (173 dB)	< 0.1 km^2	< 0.1 km^2	-
	PCW (201 dB)	< 0.1 km^2	< 0.1 km^2	-

Table A 25 Summary of the impact areas for the installation of multi-leg foundations at modelling location 3 at Caledonia North and another at the western edge of Broadshore OWF for marine mammals using the non-impulsive Southall et al. (2019) criteria assuming a fleeing animal.

Multi-leg foundations (Southall *et al.*, 2019) $L_{E,p,24h,wtd}$		Modelling location 3	Broadshore OWF western edge	In-combination area
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km^2	< 0.1 km^2	120 km^2
	HF (198 dB)	< 0.1 km^2	<0.1 km^2	-
	VHF (173 dB)	< 0.1 km^2	< 0.1 km^2	-
	PCW (201 dB)	< 0.1 km^2	< 0.1 km^2	-

Table A 26 Summary of the impact areas for the installation of monopile foundations at modelling location 7 at Caledonia South and another at the western edge of Broadshore OWF for marine mammals using the non-impulsive Southall et al. (2019) criteria assuming a fleeing animal.

Monopile foundations (Southall *et al.*, 2019) $L_{E,p,24h,wtd}$		Modelling location 7	Broadshore OWF western edge	In-combination area
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km^2	0.2 km^2	120 km^2
	HF (198 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (173 dB)	< 0.1 km^2	< 0.1 km^2	-
	PCW (201 dB)	< 0.1 km^2	< 0.1 km^2	-

Table A 27 Summary of the impact areas for the installation of multi-leg foundations at modelling location 7 at Caledonia South and another at the western edge of Broadshore OWF for marine mammals using the non-impulsive Southall et al. (2019) criteria assuming a fleeing animal.

Multi-leg foundations (Southall *et al.*, 2019) $L_{E,p,24h,wtd}$		Modelling location 7	Broadshore OWF western edge	In-combination area
PTS (Non-impulsive)	LF (199 dB)	< 0.1 km^2	< 0.1 km^2	93 km^2
	HF (198 dB)	< 0.1 km^2	<0.1 km^2	-
	VHF (173 dB)	< 0.1 km^2	< 0.1 km^2	-
	PCW (201 dB)	< 0.1 km^2	< 0.1 km^2	-

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