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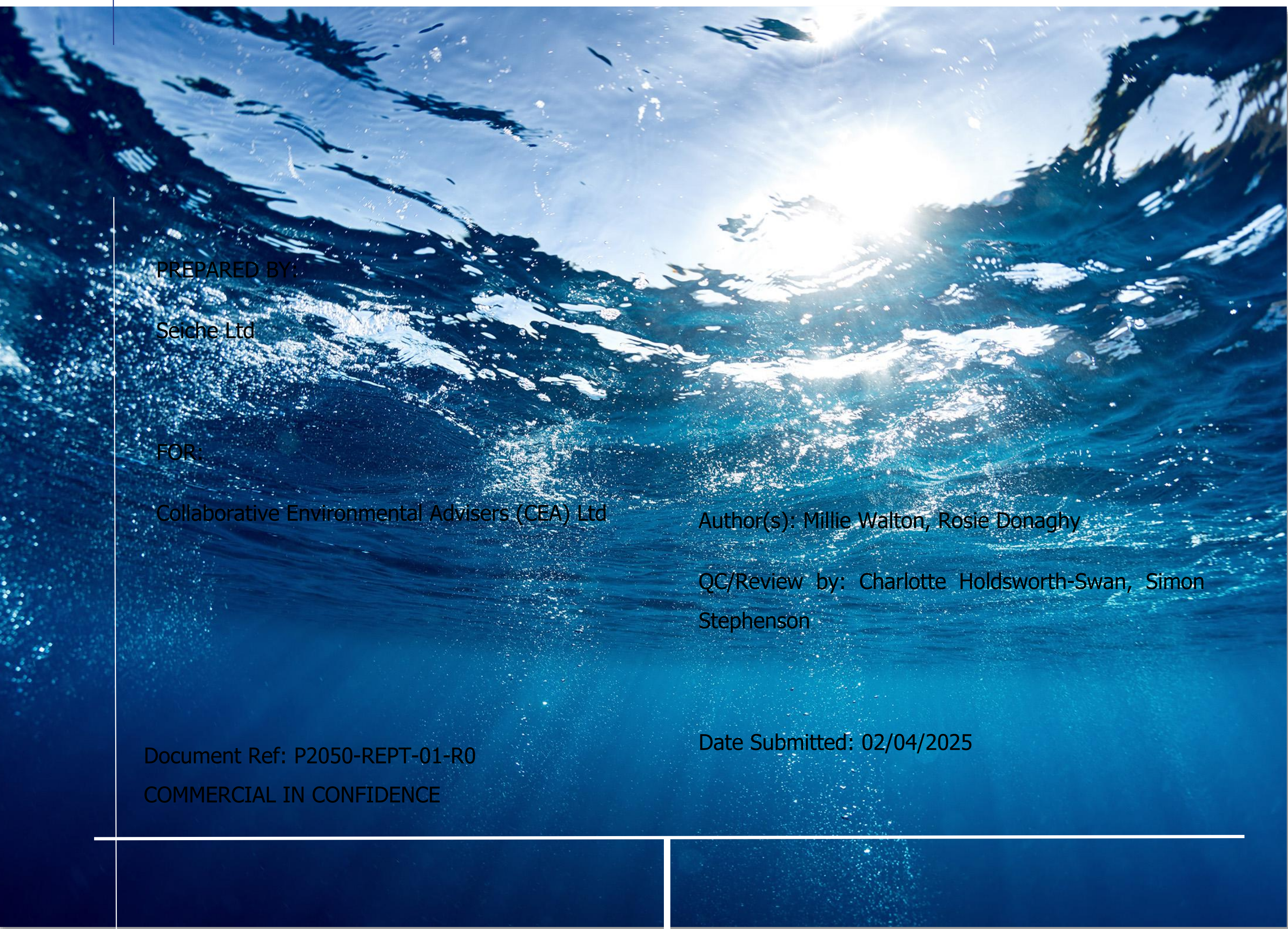
Eastern Green Link 3 and 4

Underwater Noise Modelling Technical Report



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Acronyms and Units

Acronym	Meaning
dB	Decibel
GEBCO	General Bathymetric Chart of the Oceans
HF	High frequency cetaceans
Hz	Hertz
HVDC	High Voltage Direct Current
kgm^{-3}	Kilograms per cubic metre
km^2	Square kilometres
LF	Low Frequency Cetaceans
m	Metre
MBES	Multi beam echo sounder
ms^{-1}	Metres per second
ms^{-2}	Metres per second squared
MW	Megawatt (106)
NAS	Noise Abatement System
OCW	Other Carnivores in Water
OSP	Offshore Substation Platform
PCW	Phocid Carnivores in Water
PTS	Permanent Threshold Shift
RL	Received Level
RMS	Root Mean Square
s	Second
SBES	Side beam echo sounder
SBP	Sub bottom profiler
SEL	Sound Exposure Level
SL	Source Level
SPL	Sound Pressure Level
SSS	Side scan sonar
TL	Transmission Loss
TTS	Temporary Threshold Shift
USBL	Ultra short baseline transponder
UXO	Unexploded Ordnance
VHF	Very-high Frequency Cetaceans
μPa	Micro Pascal (10^{-6} Pascals)

1 Introduction

This Underwater Noise Technical Report presents the results of a desktop study undertaken by Seiche Ltd. considering the potential effects of underwater noise on the marine environment from the development of the Eastern Green Link 3 and 4. EGL 3 is being jointly developed by National Grid Electricity Transmission plc (NGET) and Scottish and Southern Electricity Networks Transmission (SSEN Transmission), and is a 2 GW High Voltage Direct Current (HVDC) link between Peterhead, Aberdeenshire in Scotland, and King's Lynn and West Norfolk, Norfolk in England. In parallel with this NGET is also developing proposals with Scottish Power Energy Networks (SPEN) for a 2 GW HVDC link between Westfield, Fife in Scotland and King's Lynn and West Norfolk in England, known as EGL 4. Overview of EGL 3 and 4 is shown in Figure 1-1.

Sound is readily transmitted into the underwater environment and there is potential for the noise emissions from construction, operation, maintenance and decommissioning of the project to affect marine mammals and fish. At a close range from a noise source with high noise levels, permanent or temporary hearing damage may occur to marine species, while at a very close range gross physical trauma is possible. At wider ranges, the introduction of any additional noise could potentially cause short term behavioural changes, for example the ability of a species to communicate and to determine the presence of predators, food, underwater features and obstructions.

The primary purpose of this Technical Report is to present the likely distances at which the onset of potential auditory injury (i.e., Permanent Threshold Shifts (PTS) in hearing) and behavioural effects on different marine species may occur when exposed to the different anthropogenic noises that occur during different developmental phases of the project. The results from this Technical Report have been used to inform the following chapters of the preliminary Environmental Information Report (PEIR) in England and the Marine Environmental Appraisal in Scotland in order to determine the potential impact of underwater noise on marine species:

- Marine Mammals and Marine Reptiles; and
- Fish and Shellfish.

Consequently, the sensitivity of species, magnitude of potential impact and significance of effect from underwater noise associated with the project are addressed within the relevant chapters.

This Technical Report uses sound propagation models to calculate the impact ranges to marine mammals and fish for each phase of the project. Key modelled sources include:

- clearance of Unexploded Ordnance (UXO), an impulsive sound source;
- geophysical surveys, using non-impulsive sonar based sound sources; and
- vessels and other non-impulsive sources.

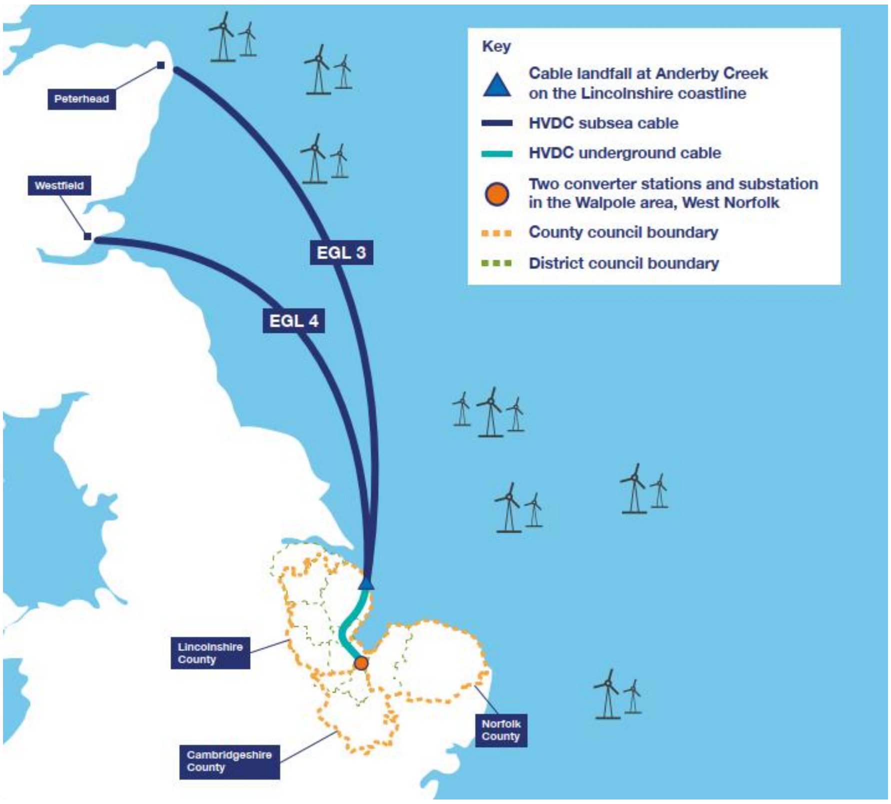

Figure 1-1: Location of the proposed Eastern Green link 3 and 4 subsea cable corridors.

2 Acoustic Concepts and Terminology

Noise travels through water as vibrations of the fluid particles in a series of pressure waves. These waves comprise a series of alternating compressions (positive pressure) and rarefactions (negative pressure). As noise consists of variations in pressure, the unit for measuring noise is usually referenced to a unit of pressure, the Pascal (Pa). The decibel (dB) is a logarithmic ratio scale used to communicate the large range of acoustic pressures that can be perceived or detected, with a known pressure amplitude chosen as a reference value (i.e., 0 dB). In the case of underwater noise, the reference value (P_{ref}) is taken as 1 µPa, whereas the airborne noise is usually referenced to a pressure of 20 µPa. To convert from a sound pressure level referenced to 20 µPa to a sound pressure referenced to 1 µPa, a factor of 20 log (20/1) (i.e. 26 dB has to be added to the former quantity). Thus 60 dB re 20 µPa is the same as 86 dB re 1 µPa, although differences in sound speeds and different densities mean that the decibel level difference in sound intensity is much more than 26 dB when converting pressure from air to water. All underwater sound pressure levels in this report are quantified in dB re 1 µPa.

There are several descriptors used to characterise a sound wave. The difference between the lowest pressure variation (rarefaction) and the highest-pressure variation (compression) is called the peak-to-peak (or pk-pk) sound pressure level. The difference between the highest variation (either positive or negative) and the mean pressure is called the peak pressure level. Lastly, the Root Mean Square (rms) sound pressure level is used as a description of the average amplitude of the variations in pressure over a specific time window. Decibel values reported should always be quoted along with the Pref value employed during calculations. For example, the measured sound pressure level (SPL_{rms}) value of a pulse may be reported as 100 dB re 1 µPa. These descriptions are shown graphically in Figure 2-1.

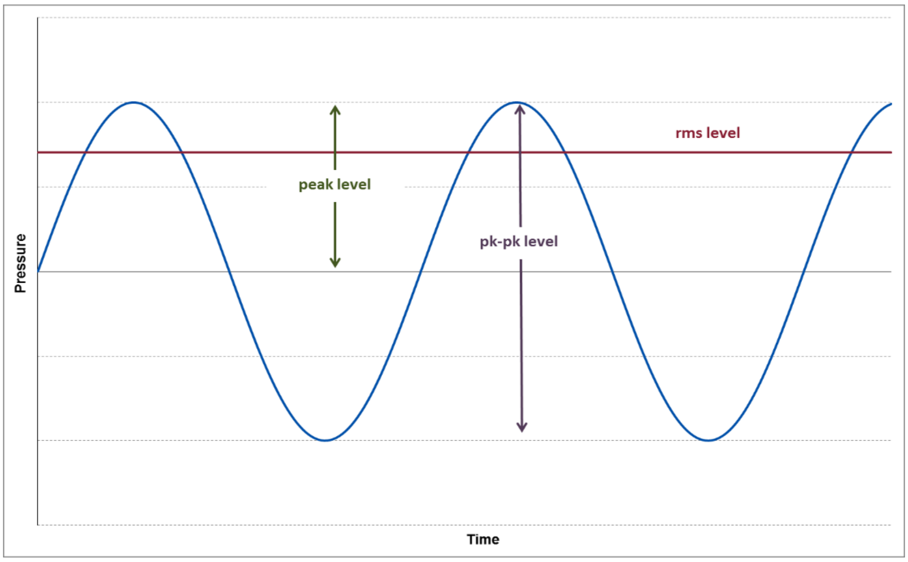

Figure 2-1: Graphical representation of acoustic wave descriptors.

The SPL_{rms} is defined as:

$$SPL_{rms} = 10log_{10}\left(\frac{1}{T}\int_{0}^{T}\left(\frac{p^2}{p_{ref}^2}\right)dt\right)$$

The magnitude of the rms sound pressure level for an impulsive noise (such as airguns from a seismic survey source) will depend upon the integration time, T, used for the calculation (Madsen, 2005). It has become customary to utilise the T90 time period for calculating and reporting rms sound pressure levels. This T90 time period is the interval over which the cumulative energy curve rises from 5% to 95% of the total energy and therefore contains 90% of the sound energy.

Another useful measure of noise used in underwater acoustics is the Sound Exposure Level (SEL). This descriptor is used as a measure of the total sound energy of an event or a number of events (e.g. over the course of a day) and is normalised to one second. This allows the total acoustic energy contained in events lasting a different amount of time to be compared on a like for like basis.

The SEL is defined as:

$$SEL = 10log_{10}\left(\int_{0}^{T}\left(\frac{p^2(t)}{p_{ref}^2 t_{ref}}\right)dt\right)$$

where T is the integration time of the noise "event", $p^2(t)$ is the squared sound pressure at a time t and $p_{ref}^2 t_{ref}$ is the reference time-integrated squared sound pressure of 1 $\mu Pa^2 s$.

The frequency of the noise is the rate at which the acoustic oscillations occur in the medium (air/water) and is measured in cycles per second, or Hertz (Hz). When noise is measured in a way which approximates to how a human would perceive it using an A-weighting filter on a noise level meter, the resulting level is described in values of dBA. However, the hearing capability of marine species is not the same as humans, with marine mammals hearing over a wider range of frequencies and with a different sensitivity. It is therefore important to understand how an animal's hearing varies over its entire frequency range to assess the effects of anthropogenic noise on marine mammals. Consequently, use can be made of frequency weighting scales (M-weighting) to determine the level of the noise in comparison with the auditory response of the animal concerned.

The broadband acoustic power (i.e., containing all the possible frequencies) emitted by a noise source, measured/modelled at a location within the project is generally split into and reported in a series of frequency bands. In marine acoustics, the spectrum is generally reported in standard one-third octave band frequencies, where an octave represents a doubling in noise frequency.

The source level is the sound pressure level of an equivalent and infinitesimally small version of the source (known as point source) at a hypothetical distance of 1 m from it. The source level is commonly used in combination with the Transmission Loss (TL) associated with the environment to obtain the Received Level (RL) at distances from (in the far field of) the source. The far field distance is chosen so that the behaviour of a distributed source can be approximated to that of a point source. Source levels do not indicate the real sound pressure level at 1 m. TL at a frequency of interest is defined as the loss of acoustic energy as the signal propagates from a hypothetical (point) source location to the chosen receiver location. The TL is dependent on water depth, source depth, receiver depth, frequency, geology, and environmental conditions. The TL values are generally evaluated using an acoustic propagation model (various numerical methods exist) accounting for these dependencies.

The RL is the noise level of the acoustic signal recorded (or modelled) at a given location, that corresponds to the acoustic pressure/energy generated by a known active noise source. This considers the acoustic output of a source and is modified by propagation effects. This RL value is strongly dependant on the source, environmental properties, geological properties and measurement location/depth. The RL is reported in dB either in rms or peak-to-peak sound pressure level (SPL), and SEL metrics, within the relevant one-third octave band frequencies. The RL is related to the SL as:

$$RL = SL - TL$$

where TL is the transmission loss of the acoustic energy within the survey region.

The directional dependence of the source signature and the variation of TL with azimuthal direction (which is strongly dependent on bathymetry) are generally combined and interpolated to report a two-Dimensional (2-D) plot of the RL around the chosen source point up to a chosen distance.

3 Acoustic Assessment Criteria

This section of the report describes the background and criteria on which the assessment has been based.

3.1 Introduction

Underwater noise has the potential to affect marine species in different ways depending on its noise level and characteristics. Richardson *et al.* (1995) defined four zones of noise influence which vary with distance from the source and level. These are:

- **The zone of audibility**: this is the area within which the animal can detect the noise. Audibility itself does not implicitly mean that the noise will affect the marine mammal.
- **The zone of masking**: this is defined as the area within which noise can interfere with the detection of other noises such as communication or echolocation clicks. This zone is very hard to estimate due to a paucity of data relating to how marine mammals detect noise in relation to masking levels (for example, humans can hear tones well below the numeric value of the overall noise level).
- **The zone of responsiveness**: this is defined as the area within which the animal responds either behaviourally or physiologically. The zone of responsiveness is usually smaller than the zone of audibility because, as stated previously, audibility does not necessarily evoke a reaction.
- **The zone of injury/hearing loss**: this is the area where the noise level is high enough to cause tissue damage in the ear. This can be classified as either a Temporary Threshold Shift (TTS) or Permanent Threshold Shift (PTS)/injury. At even closer ranges, and for very high intensity noise sources (e.g., underwater explosions), physical trauma or even death are possible.

For the study contained within this Technical Report, it is the zones of injury and disturbance (i.e., responsiveness) that are of interest (there is insufficient scientific evidence to properly evaluate masking). To determine the potential spatial range of injury and disturbance, a review has been undertaken of available evidence, including international guidance and scientific literature. The following sections summarise the relevant thresholds for onset of effects and describe the evidence base used to derive them.

3.2 Injury (Physiological Damage) To Mammals

Noise propagation models can be constructed to allow the received noise level at different distances from the source to be calculated. To determine the potential consequence of these received levels on any marine mammals which might experience such noise emissions, it is necessary to relate the levels to known or estimated potential impact thresholds. The auditory injury (PTS/TTS) threshold criteria proposed by Southall *et al.* (2019), and injury/TTS threshold criteria proposed by NMFS (2024) are based on a combination of unweighted peak pressure levels and mammal hearing weighted SEL. The hearing weighting function is designed to represent the frequency characteristics (bandwidth and noise level) for each group within which acoustic signals can be perceived and therefore assumed have auditory effects. The categories relevant to this study are:

- **Low Frequency (LF) cetaceans**: marine mammal species such as baleen whales (e.g., minke whale *Balaenoptera acutorostrata*).
- **High Frequency (HF) cetaceans**: marine mammal species such as dolphins, toothed whales, beaked whales and bottlenose whales (e.g., bottlenose dolphin *Tursiops truncates* and white-beaked dolphin *Lagenorhynchus albirostris*).
- **Very High Frequency (VHF) cetaceans**: marine mammal species such as true porpoises, river dolphins and pygmy/dwarf sperm whales and some oceanic dolphins, generally with auditory centre frequencies above 100 kHz) (e.g., harbour porpoise *Phocoena phocoena*).
- **Phocid Carnivores in Water (PCW)**: true seals (e.g., harbour seal *Phoca vitulina* and grey seal *Halichoreus grypus*); hearing in air is considered separately in the group Phocid Carnivores in Air (PCA). *(Note – the corresponding group within NMFS 2024 is Pinnipeds in Water, denominated PW.)*
- **Other Marine Carnivores in Water (OCW)**: including otariid pinnipeds (e.g., sea lions and fur seals), sea otters and polar bears; air hearing considered separately in the group Other Marine Carnivores in Air (OCA).

These weighting functions from both Southall *et al.* (2019) and NMFS (2024), have therefore been used in this study and are shown in Figure 3-1.

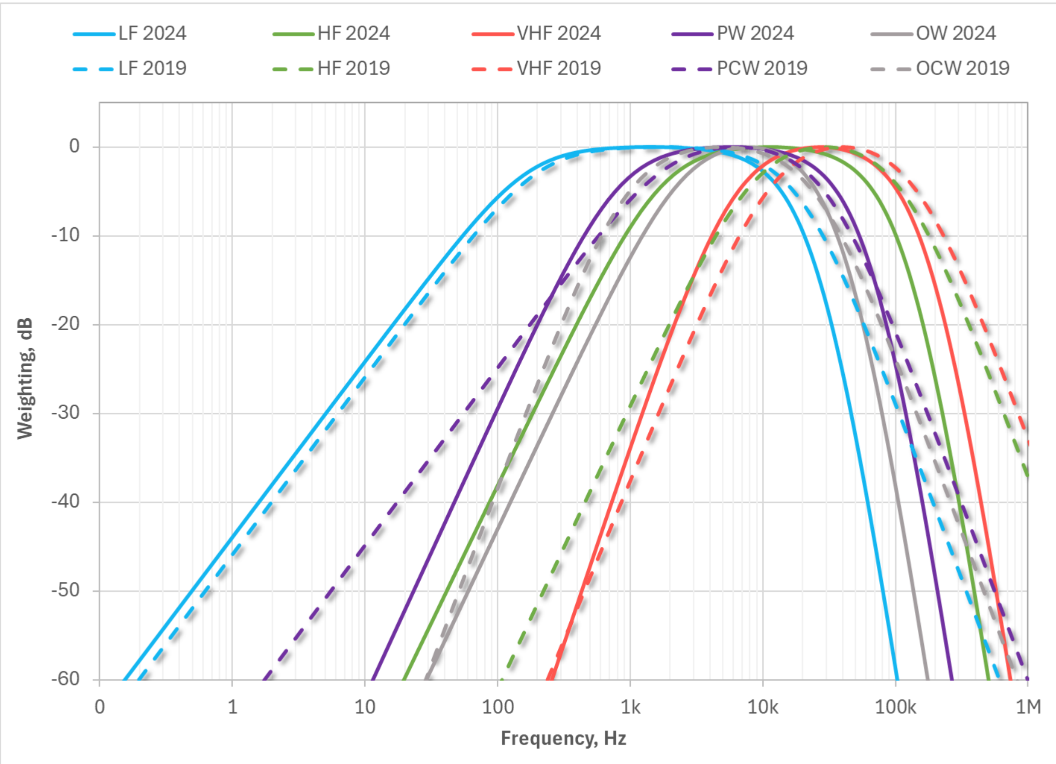

Figure 3-1: Hearing weighting functions for Pinnipeds and Cetaceans (Southall *et al.*, 2019, and NMFS, 2024).

Auditory injury criteria proposed in Southall *et al.* (2019) and NMFS (2024) are for two different types of noise as follows:

- **Impulsive sounds** which are typically transient, brief (less than one second), broadband, and consist of high peak sound pressure with rapid rise time and rapid decay (ANSI, 1986 and 2005; NIOSH, 1998). This category includes noise sources such as seismic surveys, impact piling and underwater explosions.
- **Non-impulsive sounds** which can be broadband, narrowband or tonal, brief or prolonged, continuous or intermittent and typically do not have a high peak sound pressure with rapid rise/decay time that impulsive noises do (ANSI, 1995; NIOSH, 1998) This category includes noise sources such as continuous running machinery, sonar, and vessels.

The criteria for impulsive and non-impulsive sound have been adopted for this study given the nature and variety of noise sources used during the various activities. The relevant criteria proposed by Southall *et al.* (2019) are as summarised in Table 3-1, and for NMFS (2024) in Table 3-2.

Table 3-1: Summary of TTS and PTS onset acoustic thresholds (Southall *et al.*, 2019)

Hearing Group	Parameter	Impulsive		Non-Impulsive	
		TTS	PTS	TTS	PTS
LF cetaceans	Peak, unweighted	213	219	-	-
	SEL, LF weighted	168	183	179	199
HF cetaceans	Peak, unweighted	224	230	-	-
	SEL, HF weighted	170	185	178	198
VHF cetaceans	Peak, unweighted	196	202	-	-
	SEL, VHF weighted	140	155	153	173
PCW	Peak, unweighted	212	218	-	-
	SEL, PCW weighted	170	185	181	201

Table 3-2: Summary of TTS and injury onset acoustic thresholds (NMFS, 2024)

Hearing Group	Parameter	Impulsive		Non-Impulsive	
		TTS	PTS	TTS	PTS
LF cetaceans	Peak, unweighted	216	222	-	-
	SEL, LF weighted	168	183	177	197
HF cetaceans	Peak, unweighted	224	230	-	-
	SEL, HF weighted	177	193	181	201
VHF cetaceans	Peak, unweighted	196	202	-	-
	SEL, VHF weighted	143	159	160	181
PCW	Peak, unweighted	217	223	-	-
	SEL, PCW weighted	168	183	175	195

3.3 Disturbance to Marine Mammals

Beyond the area in which auditory injury may occur, effects on marine mammal behaviour are an important measure of potential impact. Non-trivial disturbance may occur when there is a risk of animals incurring sustained or chronic disruption of behaviour or when animals are displaced from an area, with subsequent redistribution being significantly different from that occurring due to natural variation.

To consider the possibility of disturbance resulting from the project, it is necessary to consider:

- whether or not a noise can be detected/heard by an animal above background noise levels or level of acclimatisation above background levels;
- the likelihood that the noise could cause non-trivial disturbance;
- the likelihood that the sensitive animals will be exposed to that noise; and
- whether the number of animals exposed are likely to be significant at the population level.

Assessing these impacts is however a very difficult task due to the complex and variable nature of noise propagation, the variability of documented animal responses to similar levels of noise, and the availability of population estimates and regional density estimates for all marine mammal species. Behavioural responses are widely recognised as being highly variable and context specific (Southall *et al.*, 2007; 2019; 2021).

Southall *et al.* (2007 and 2021) both present a summary of observed behavioural responses for various mammal groups exposed to different types of noise: continuous (non-pulsed) or impulsive (single or multiple pulsed).

3.3.1 Non-Impulsive Sound (e.g. Vessels) and Sonar Based Geophysical Surveys

For non-impulsive noise (e.g., sonar based geophysical surveys, vessels etc.), the National Marine Fisheries Service (NMFS) (2024) guidance sets the marine mammal Level B harassment threshold (analogous to disturbance) for continuous noise at 120 dB re 1 µPa (rms). This threshold is based on studies by Malme *et al.* (1984) which investigate the effects of noise from the offshore petroleum industry on migrating gray whale behaviour offshore Alaska. Considering the paucity and high-level variation of data relating to onset of behavioural effects due to continuous noise, any ranges predicted using this number are likely to be probabilistic and potentially over precautionary.

For geophysical surveys, an effective deterrence range (EDR) of 5 km may be used based on JNCC *et al.* (2020).

It is worth nothing that the distinction between impulsive and non-impulsive noise was removed from Southall *et al.* (2021) as "some source types, such as airguns, may produce impulsive noises near the source and non-impulsive noises at greater ranges". However, Southall *et al.* (2021) does not present thresholds for assessing disturbance, therefore the thresholds discussed in section 3.3.1 have been adopted.

3.3.2 Impulsive Sound due to UXO

NMFS (2024) suggests that TTS should be used as a proxy for disturbance due to UXO clearance activities. The TTS threshold is used to assess behavioural response where one detonation occurs per day, and the behavioural threshold (-5 dB from TTS onset) is taken for multiple detonations within a 24-hour period.

3.3.3 Summary of Disturbance Thresholds

It is important to understand that exposure to noise levels in excess of the behavioural change threshold stated above does not necessarily imply that the noise will result in significant disturbance. As noted previously, it is also necessary to assess the likelihood that the sensitive receptors will be exposed to that noise and whether the numbers exposed are likely to be significant at the population level.

Table 3-3: Disturbance criteria for marine mammals used in this Technical Report

Geophysical Surveys	UXO clearance	Non-Impulsive sources (Vessels, construction activities, etc.)
JNCC *et al*. (2020) 5 km EDR [non-impulsive geophysical sources]	TTS Onset – worst case for SPL or SEL (thresholds from Table 3-1 and Table 3-2) scenarios for a single clearance per day	120 dB re 1µPa (rms)

There is, however, a considerable degree of uncertainty and variability in the onset of disturbance and therefore any disturbance ranges should be treated as potentially over precautionary. Another important consideration is that all noise produced by project activities, will be either temporary or transitory, as opposed to permanent and fixed. These important considerations are not taken into account in the noise modelling but will be assessed in the relevant marine ecology topic chapters.

3.4 Injury and Disturbance to Fish

For fish, the most relevant criteria for injury effects are those contained in the Noise Exposure Guidelines for Fishes and Sea Turtles (Popper *et al.*, 2014), with the numerical classification of groups taken from Popper and Hawkins (2019). These guidelines broadly group fish into the following categories based on their anatomy and the available information on hearing of other fish species with comparable anatomies:

- Group 1: fishes with no swim bladder or other gas chamber (e.g., elasmobranchs, flatfishes and lampreys). These species are less susceptible to barotrauma and are only sensitive to particle motion, not sound pressure. Basking shark *Cetorhinus maximus*, which do not have a swim bladder, also fall into this hearing group.
- Group 2: fishes with swim bladders but the swim bladder does not play a role in hearing (e.g., salmonids). These species are susceptible to barotrauma, although hearing only involves particle motion, not sound pressure.
- Group 3: fishes with swim bladders that are close, but not connected, to the ear (e.g., gadoids and eels). These fishes are sensitive to both particle motion and sound pressure and show a more extended frequency range than Groups 1 and 2, extending to about 500 Hz.

- Group 4: fishes that have special structures mechanically linking the swim bladder to the ear (e.g., clupeids such as herring, sprat and shads). These fishes are sensitive primarily to sound pressure, although they also detect particle motion. These species have a wider frequency range, extending to several kHz and generally show higher sensitivity to sound pressure than fishes in Groups 1, 2 and 3.
- Fish eggs and larvae: separated due to greater vulnerability and reduced mobility. Very few peer-reviewed studies report on the response of eggs and larvae to anthropogenic noise.

The guidelines set out criteria for injury effects due to different sources of noise. The criteria include a range of indices including SEL, rms and peak SPLs. Where insufficient data exist to determine a quantitative guideline value, the risk is categorised in relative terms as "high", "moderate" or "low" at three distances from the source: "near" (i.e., in the tens of metres), "intermediate" (i.e., in the hundreds of metres) or "far" (i.e., in the thousands of metres). It should be noted that these qualitative criteria cannot differentiate between exposures to different noise levels and therefore all sources of noise, no matter how loud, would theoretically elicit the same assessment result. However, because the qualitative risks are generally qualified as "low", with the exception of a moderate risk at "near" range (i.e., within tens of metres) for some types of hearing groups and impairment effects, this is not considered to be a significant issue with respect to determining the potential effect of noise on fish.

The criteria used in this underwater noise assessment for non-impulsive and continuous noise sources, such as vessels, are given in Table 3-4. The only numerical criteria for these sources are for recoverable injury and TTS for Groups 3 and 4 Fish. Physiological effects relating to injury criteria are described below (Popper *et al.*, 2014; Popper and Hawkins, 2016):

- **Mortality and potential mortal injury**: either immediate mortality or tissue and/or physiological damage that is sufficiently severe (e.g., a barotrauma) that death occurs sometime later due to decreased fitness. Mortality has a direct effect upon animal populations, especially if it affects individuals close to maturity.
- **Recoverable injury**: Tissue and other physical damage or physiological effects, that are recoverable, but which may place animals at lower levels of fitness, may render them more open to predation, impaired feeding and growth, or lack of breeding success, until recovery takes place.
- **TTS**: Short term changes in hearing sensitivity may, or may not, reduce fitness and survival. Impairment of hearing may affect the ability of animals to capture prey and avoid predators, and also cause deterioration in communication between individuals affecting growth, survival, and reproductive success. After termination of a noise that causes TTS, normal hearing ability returns over a period that is variable, depending on many factors, including the intensity and duration of noise exposure.

Table 3-4: Criteria for onset of injury to fish due to non-impulsive noise (Popper *et al.*, 2014)

Type of Animal	Mortality and Potential Mortal Injury	Recoverable Injury	TTS
Group 1 Fish: no swim bladder (particle motion detection)	(Near) Low (Intermediate) Low (Far) Low	(Near) Low (Intermediate) Low (Far) Low	(Near) Moderate (Intermediate) Low (Far) Low
Group 2 Fish: where swim bladder is not involved in hearing (particle motion detection)	(Near) Low (Intermediate) Low (Far) Low	(Near) Low (Intermediate) Low (Far) Low	(Near) Moderate (Intermediate) Low (Far) Low
Groups 3 and 4 Fish: where swim bladder is involved in hearing (primarily pressure detection)	(Near) Low (Intermediate) Low (Far) Low	170 dB re 1µPa (rms) for 48 hours	158 dB re 1µPa (rms) for 12 hours
Eggs and larvae	(Near) Low (Intermediate) Low (Far) Low	(Near) Low (Intermediate) Low (Far) Low	(Near) Low (Intermediate) Low (Far) Low

The criteria used in this underwater noise assessment for explosives are given in Table 3-5. It should be noted that there are no thresholds in Popper *et al.* (2014) in relation to eggs and larvae in terms of sound pressure.

Table 3-5: Criteria for injury to fish due to explosives (Popper *et al.*, 2014)

Type of animal	Parameter	Mortality and Potential Mortal Injury	Recoverable Injury	TTS
Group 1 Fish: no swim bladder (particle motion detection)	Peak, dB re 1µPa	229 - 234	(Near) High (Intermediate) Low (Far) Low	(Near) High (Intermediate) Moderate (Far) Low
Group 2 Fish: where swim bladder is not involved in hearing (particle motion detection)	Peak, dB re 1µPa	229 - 234	(Near) High (Intermediate) High (Far) Low	(Near) High (Intermediate) Moderate (Far) Low
Group 3 and 4 Fish: where swim bladder is involved in hearing (primarily pressure detection)	Peak, dB re 1µPa	229 - 234	(Near) High (Intermediate) High (Far) Low	(Near) High (Intermediate) High (Far) Low

It should also be noted that there are no thresholds in Popper *et al.* (2014) in relation to noise from high frequency sonar-based surveys (>10 kHz) (i.e., for the geophysical survey sound sources covered in this assessment). This is because the hearing range of fish species falls well below the frequency range of high frequency sonar systems. Consequently, the effects of noise from high frequency sonar surveys on fish has not been conducted as part of this study, due to the frequency of the source being beyond the range of hearing and also due to the lack of any suitable thresholds.

Behavioural reaction of fish to noise has been found to vary between species based on their hearing sensitivity. Typically, fish sense noise via particle motion in the inner ear which is detected from noise-induced motions in the fish's body (refer to section 9 for further details on particle motion). The detection of sound pressure is restricted to those fish which have air filled swim bladders; however, particle motion (induced by noise) can be detected by fish without swim bladders.

Highly sensitive species such as herring (group 3 and 4) have elaborate specialisations of their auditory apparatus, known as an otic bulla (a gas filled sphere connected to the swim bladder), which enhances hearing ability. The gas filled swim bladder in species groups such as cod and salmon (group 2) may be involved in their hearing capabilities, so although there is no direct link to the inner ear, these species are able to detect lower noise frequencies and as such are considered to be of medium sensitivity to noise. Flat fish and elasmobranchs have no swim bladders (group 1) and as such are considered to be relatively less sensitive to sound pressure.

The most recent criteria for disturbance are those contained in Popper *et al.* (2014) which set out qualitative criteria for disturbance due to different sources of noise. The risk of behavioural effects is categorised in relative terms as "high", "moderate" or "low" at three distances from the source: "near" (i.e., in the tens of metres), "intermediate" (i.e., in the hundreds of metres) or "far" (i.e., in the thousands of metres), as shown in Table 3-6.

Table 3-6: Criteria for onset of behavioural effects in fish for impulsive and non-impulsive noise (Popper *et al.*, 2014)

Type of Animal	Relative Risk of Behavioural Effects	
	Explosives	Non-Impulsive Noise
Group 1 Fish: no swim bladder (particle motion detection)	(Near) High (Intermediate) Moderate (Far) Low	(Near) Moderate (Intermediate) Moderate (Far) Low
Group 2 Fish: where swim bladder is not involved in hearing (particle motion detection)	(Near) High (Intermediate) High (Far) Low	(Near) Moderate (Intermediate) Moderate (Far) Low
Groups 3 and 4 Fish: where swim bladder is involved in hearing (primarily pressure detection)	(Near) High (Intermediate) High (Far) Low	(Near) High (Intermediate) Moderate (Far) Low
Eggs and larvae	(Near) High (Intermediate) Low (Far) Low	(Near) Moderate (Intermediate) Moderate (Far) Low

It is important to note that the Popper *et al.* (2014) criteria for disturbance due to noise are qualitative rather than quantitative. Consequently, a source of noise of a particular type (e.g., UXO clearance) would be predicted to result in the same potential impact, no matter the level of noise produced or the propagation characteristics.

Therefore, the criteria presented in the Washington State Department of Transport (WSDOT) Biological Assessment Preparation for Transport Projects Advanced Training Manual (WSDOT, 2011) are also used in this assessment for predicting the distances at which behavioural effects may occur. The manual suggests an unweighted sound pressure level of 150 dB re 1 µPa (rms) as the criterion for onset of behavioural effects, based on work by (Hastings, 2002). Sound pressure levels in excess of 150 dB re 1 µPa (rms) are expected to cause temporary behavioural changes, such as elicitation of a startle response, disruption of feeding, or avoidance of an area. The document notes that levels exceeding this threshold are not expected to cause direct permanent injury but may indirectly affect the individual fish (such as by impairing predator detection). It is important to note that this threshold is for onset of potential effects, and not necessarily an 'adverse effect' threshold.

4 Source Noise Levels

4.1 General

The noise sources and activities which were investigated during the development of this Technical Report are summarised in Table 4-1.

Table 4-1: Summary of noise sources and activities included in the Underwater Noise Technical Report.

Phase	Source/Activity
Pre-Construction	Geophysical site investigation activities including: • Multi-Beam Echosounder (MBES); • Sidescan Sonar (SSS); • Parametric Sub-Bottom Profilers (SBP); and • Ultra short baseline (USBL) Use of geophysical survey vessels. Clearance of UXOs including the preferred use of low-order and low-yield techniques as well as possible high order detonation.
Construction	Construction activities/equipment including: • Controlled flow excavation, • Plough, • Jet trencher, • Mechanical trencher, • Vertical injector, • Range of construction vessels including: o Survey vessels, o Trailing suction hopper dredger, o Cable lay vessel, o Jack-up/spud barge, o Small work boats, o Construction support vessels (including multi-cats) o Rock placement vessels, o Guard vessel, o Crew transfer vessels.
Operation and maintenance	Periodic geophysical surveys. Operations and maintenance vessels, including: • Survey vessels, • Rock placement vessels.
Decommissioning	Vessels for a range of decommissioning activities, assumed as per vessel activity described for construction phase.

Noise sources included in Table 4-1 are considered in more detail in the following sections.

4.2 Pre-Construction Phase

4.2.1 Geophysical Surveys

Several sonar-like survey types will potentially be used for the pre-construction geophysical surveys. During the survey, a transmitter emits an acoustic signal directly toward the seabed (or alongside, at an angle to the seabed, in the case of side scan techniques). The equipment likely to be used can typically work at a range of signal frequencies, depending on the distance to the bottom and the required resolution. The signal is highly directional and acts as a beam, with the energy narrowly concentrated within a few degrees of the direction in which it is aimed. The signal is emitted in pulses, the length of which can be varied as per the survey requirements. The assumed pulse rate, pulse width and beam width used in the assessment are based on a review of typical units used in other similar surveys. It should be noted that sonar like survey sources (e.g., MBES, SSS, SBP, USBL) are classed as non-impulsive noise because they generally comprise a single (or multiple discrete) frequency (e.g., a sine wave or swept sine wave) as opposed to a broadband signal with high kurtosis, high peak pressures and rapid rise times. A parametric sub-bottom profiler (SBP) generates a lower-frequency signal through non-linear interaction of two high-frequency signals. While the resulting signal is at a lower frequency, its propagation characteristics and attenuation still follow those of the original high-frequency signals.

The characteristics assumed for each device modelled in this Technical Report are summarised in Table 4-2, these sources are considered to be continuous (non-impulsive).

Table 4-2: Typical survey equipment parameters used in the Underwater Noise Technical Report.

Survey Equipment Type	Frequency(s), kHz	Source Level, dB re 1 µPa re 1 m	Pulse Rate, s^{-1}	Pulse Width, ms	Beam Width, degrees
MBES	200	240	10	1.5	2
SSS	300	228	15	0.1	1.5
SBP	100	248	40	1	1
USBL	14	200	3	100	80

The assumed pulse rate has been used to calculate the SEL, which is normalised to 1 s, from the rms sound pressure level. Directivity corrections were calculated based on the transducer dimensions and ping frequency and taken from manufacturer's datasheets. It is important to note that directivity will vary significantly with frequency, but that these directivity values have been used in line with the modelling assumptions stated in Table 4-2.

Directivity corrections have been applied to the source noise level data based on directivity characteristics for the proposed sources. Directivity factors were derived based on source take-off angle for an animal on the seabed. This results in a larger correction (reduction in level) due to directivity at distances further from the source than for receivers close to the source.

At distances closer to the source (i.e., less than the water depth), no directivity correction is made because the animal could be directly underneath the source. As the source to receiver range increases, the take-off angle between the source and animal becomes larger. Hence, when the range to source is large in comparison to the water depth, the effects of the source's directivity will have a much greater bearing on the received noise level. Once the range to source becomes larger than the water column depth then the source directivity effects will become increasingly more important.

4.2.2 UXO Clearance

The precise details and locations of potential UXOs is unknown at this time. For the purposes of this assessment, it has been assumed that the worst case UXO size will be 697 kg, and a most likely case UXO size of 295 kg.

The Applicant has indicated the preference for the use of deflagration (subsonic combustion) as the methodology for clearance of UXO. The technique uses a single charge of 30 g to 80 g Net Explosive Quantity (NEQ) which is placed proximal to the UXO to target a specific entry point. When detonated, a shaped charge penetrates the casing of the UXO to introduce a small, clinical plasma jet into the main explosive filling. The intention is to excite the explosive molecules within the main filling to generate enough pressure to burst the UXO casing, producing a deflagration of the main filling and neutralising the UXO.

Recent controlled experiments showed low order deflagration to result in a substantial reduction in acoustic output over traditional high order methods, with $L_{p,0\text{-}pk}$ and SEL being typically significantly lower for the deflagration of the same size munition, and with the acoustic output being proportional to the size of the shaped charge, rather than the size of the UXO itself (Robinson *et al.*, 2020). Using this low order deflagration method, the probability of a low order outcome is high; however, there is a small risk with these clearance methods that the UXO will detonate or deflagrate violently.

It is possible that some residual explosive material remains on the seabed following deflagration. In this case, recovery will be performed which may require a small (500 g) 'clearing shot'.

The noise modelling has been undertaken for 80 g deflagration disposal tool charge configurations (Table 4-3). In addition, the noise modelling investigated the potential range of effects for an accidental high order detonation based on a realistic maximum scenario UXO size and a maximum (but unlikely) UXO size.

Table 4-3: Details of UXO and their relevant deflagration charge sizes employed for modelling.

Charge Size (kg TNT Equivalent)	Notes/Assumptions
Deflagration (Low Order Disposal)	
80 g	Maximum size of disposal tool charge used for deflagration
500 g	Maximum size of clearing shot to neutralise any residual explosive material
Detonation (High Order Disposal)	
295 kg	Realistic maximum UXO size

Charge Size (kg TNT Equivalent)	Notes/Assumptions
697 kg	Worst case UXO size

4.2.3 Vessels

Use of Vessels is assessed in section 4.6 for all phases of the project.

4.3 Construction Phase

The noise source potentially active during the construction phase are related to cable construction (i.e., trenching and cable laying activities), and their related operations such as the jack-up rigs. The source levels are presented in Table 4-4. Noise from the vessels themselves (e.g., propeller, thrusters and sonar (if used)) primarily dominates the emission level, hence noise from activities such as seabed preparation, trenching and rock placement (if required) have not been included separately.

Table 4-4: Source levels for other sources.

Sources	Description/ Assumptions	Data Source	RMS, dB re 1 µPa
Trailing suction hopper dredger	'Gerardus Mercator' trailer hopper suction dredger using DP as proxy	Wyatt *et al.* (2020)	180
Controlled flow excavation, Plough, Jet trencher, Mechanical trencher, Vertical injector (unlikely to be used)	Cable trenching / cutting	Nedwell *et al.* (2003)	178

4.3.1 Vessels

Use of vessels is addressed in section 4.6 for all phases of the Array.

4.4 Operation and Maintenance Phase

4.4.1 Geophysical Surveys

Periodic geophysical surveys will be similar to the geophysical surveys already discussed for the pre-construction phase (refer to section 4.2).

4.4.2 Routine Operation and Maintenance

There are very few activities during the operations and maintenance phase that generate significant amounts of underwater noise. These noise generating activities are anticipated at this stage to be characterised by vessel movements and reinstatement of rock or other protection features, similar to those already discussed in the construction phase (refer to section 4.3).

4.4.3 Vessels

The potential for vessel use to create underwater noise is presented in section 4.6 for all phases of the project.

4.5 Decommissioning Phase

4.5.1 Vessels

Only the potential impact of noise from vessel activity has been included in the underwater noise assessment for the decommissioning phase of the project. It should be noted that cavitation from the vessels themselves is likely to dominate the noisescape for other decommissioning activities (e.g., removal of cables). The potential impact of vessels noise emissions is addressed in section 4.6 for all phases of the project.

4.6 Vessels (all phases)

The noise emissions from the types of vessels that may be used for the project are quantified in Table 4-5, based on a review of publicly available data. Noise from the vessels themselves (e.g., propeller, thrusters and sonar (if used)) primarily dominates the emission level, hence noise from activities such as seabed preparation, trenching and rock placement (if required) have not been included separately.

Source noise levels for vessels depend on the vessel size and speed, as well as propeller design and other factors. There can be considerable variation in noise magnitude and character between vessels even within the same class. Therefore, source data for the project has been based on maximum design assumptions (i.e., using noise data toward the higher end of the scale for the relevant class of ship as a proxy). The '*Gerardus Mercator'* is considered an appropriate proxy for the rock placement vessels because it is a similar size of vessel using DP and therefore likely to have a similar acoustic footprint.

Table 4-5: Source noise data for preconstruction, construction, operation and maintenance and decommissioning vessels.

Item	Description/ Assumptions	Data Source	Source SPL, dB re 1 µPa re 1 m (rms)
Survey vessels	Offshore support vessel used as proxy	McCauley (1998)	179
Cable lay vessel	Cable laying	Wyatt (2008)	180
Jack-up/spud barge	Jack up rig	Evans (1996)	127
Multi-cat	Workboat - Catamaran	Johansson *et al.* (2024)	143
Small work boats	Workboat - Monohull	Johansson *et al.* (2024)	140
Construction support vessels	Offshore support vessel used as proxy	McCauley (1998)	179
Trailing suction hopper dredger, Rock placement vessels	'*Gerardus Mercator'* trailer hopper suction dredger using DP	Wyatt *et al.* (2020)	180
Guard vessel	Tug used as proxy	Richardson (1995)	172
Crew transfer vessels	*'Gwydyr Bay'* Crew vessel	Wyatt *et al.* (2020)	168

5 Propagation Modelling

5.1 Propagation of noise underwater

As the distance from the noise source increases the level of received or recorded noise reduces, primarily due to the spreading of the noise energy with distance, in combination with attenuation due to absorption of noise energy by molecules in the water. This latter mechanism results in higher attenuation at higher frequency noise than for lower frequencies.

The way that the noise spreads (geometrical divergence) will depend upon several factors such as water column depth, pressure, temperature gradients, salinity as well as water surface and bottom (i.e., seabed) conditions. Thus, even for a given locality, there are temporal variations to the way that noise will propagate. However, in simple terms, the noise energy may spread out in a spherical pattern (close to the source) or a cylindrical pattern (much further from the source), although other factors mean that decay in noise energy may be somewhere between these two simplistic cases. The distance at which cylindrical spreading dominates is highly dependent on water depth. Noise propagation in shallow water depths will be dominated by cylindrical spreading as opposed to spherical spreading.

In acoustically shallow waters in particular, the propagation mechanism is influenced by multiple interactions with the seabed and the water surface (Lurton, 2002; Etter, 2013; Urick, 1983; Brekhovskikh *et al*, 2003; Kinsler *et al*., 1999). Whereas in deeper waters, the noise will propagate further without encountering the surface or bottom of the sea (seabed).

At the sea surface, the majority of the noise is reflected into the water due to the difference in acoustic impedance (i.e., product of noise speed and density) between air and water. However, the scattering of noise at the surface of the sea can be an important factor in the propagation of noise. In an ideal case (i.e., for a perfectly smooth sea surface), the majority of noise energy will be reflected into the sea. However, for rough seas, much of the noise energy is scattered (e.g., Eckart, 1953; Fortuin, 1970; Marsh, Schulkin, and Kneale, 1961; Urick and Hoover, 1956). Scattering can also occur due to bubbles near the surface such as those generated by wind or fish or due to suspended solids in the water such as particulates and marine species. Scattering is more pronounced for higher frequencies than for low frequencies and is dependent on the sea state (i.e., wave height). However, the various factors affecting this mechanism are complex.

As surface scattering results in differences in reflected noise, its effect will be more apparent at longer ranges from the noise source and in acoustically shallow water (i.e., where there are multiple reflections between the source and receiver). The degree of scattering will depend upon the sea state/wind speed, water depth, frequency of the noise, temperature gradient, grazing angle and range from source. It should be noted that variations in propagation due to scattering will vary temporally within an area primarily due to different sea-states/wind speeds at different times. However, over shorter ranges (e.g., several hundred meters or less) the noise will experience fewer reflections and so the effect of scattering should not be significant.

When noise waves encounter the seabed, the amount of noise reflected will depend on the geoacoustic properties of the bottom (e.g., grain size, porosity, density, noise speed, absorption coefficient and roughness) as well as the grazing angle and frequency of the noise (Cole, 1965; Hamilton, 1970; Mackenzie, 1960; McKinney and Anderson, 1964; Etter, 2013; Lurton, 2002; Urick, 1983). Thus, seabeds comprising primarily mud or other acoustically soft sediments will reflect less noise than acoustically harder bottoms such as rock or sand. This will also depend on the profile of the bottom (e.g., the depth of the sediment layer and how the geoacoustic properties vary with depth below the seafloor). The effect is less pronounced at low frequencies (a few kHz and below). A scattering effect (similar to that which occurs at the surface) also occurs at the seabed (Essen, 1994; Greaves and Stephen, 2003; McKinney and Anderson, 1964; Kuo, 1992), particularly on rough substrates (e.g., pebbles).

The waveguide effect should also be considered, which defines the shallow water columns that do not allow the propagation of low frequency noise (Urick, 1983; Etter, 2013). The cut-off frequency of the lowest mode in a channel can be calculated based on the water depth and knowledge of the sediment geoacoustic properties but, for example, the cut-off frequency as a function of water depth (based on the equations set out in Urick, 1983) is shown in Figure 5-1 for a range of seabed types. Any noise below this frequency will not propagate far due to energy losses through multiple reflections.

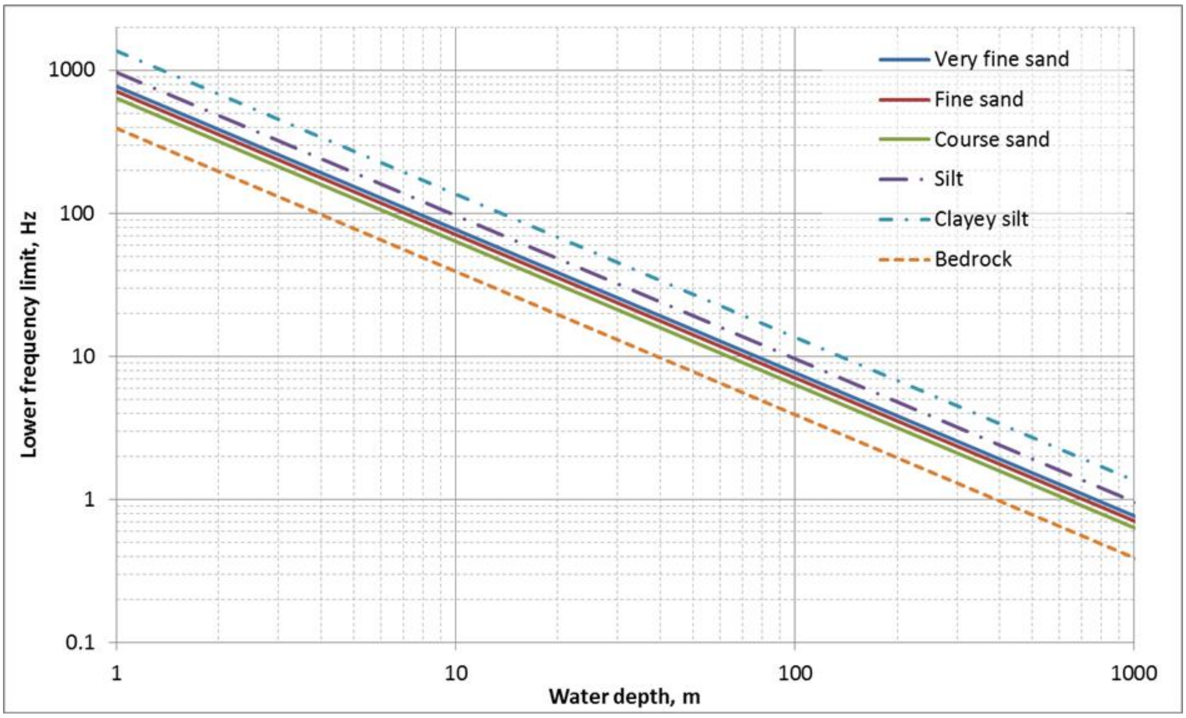

Figure 5-1: Lower cut-off frequency as a function of depth for a range of seabed types.

Changes in the water temperature and the hydrostatic pressure with depth mean that the speed of noise varies throughout the water column. This can lead to significant variations in noise propagation and can also lead to noise channels, particularly for high-frequency noise (Lurton 2002). Noise can propagate in a duct-like manner within these channels, effectively focussing the noise, and conversely, they can also lead to shadow zones. The frequency at which this occurs depends on the characteristics of the noise channel and since the temperature gradient can vary throughout the year there will be potential variation in noise propagation depending on the season.

Noise energy is also absorbed due to interactions at the molecular level converting the acoustic energy into heat (Urick 1983). This is another frequency-dependent effect with higher frequencies experiencing much higher losses than lower frequencies.

5.2 Modelling Approach

There are several methods available for modelling the propagation of noise between a source and receiver ranging from very simple models which simply assume spreading effects according to a 10 log (R) or 20 log (R) relationship (as discussed above, and where R is the range from source) to full acoustic models (e.g., ray tracing, normal mode, parabolic equation, wavenumber integration and energy flux models). In addition, semi-empirical models are available, in which complexity and accuracy are somewhere in between these two extremes.

In choosing the correct propagation model to employ, it is important to ensure that it is fit for purpose and produces results with a suitable degree of accuracy for the application in question, taking into account the context, as detailed in "Monitoring Guidance for Underwater Noise in European Seas Part III", National Physical Laboratory Guidance (Dekeling *et al*., 2014) and in Farcas *et al*. (2016). Thus, in some situations (e.g., low risk of auditory injury due to underwater noise, where range dependent bathymetry is not an issue, i.e., for non-impulsive noise) a simple (N log R) model might be sufficient, particularly where other uncertainties (such as uncertainties in source level or the impact thresholds) outweigh the uncertainties due to modelling. On the other hand, some situations (e.g., very high source levels, impulsive noise, complex source and propagation path characteristics, highly sensitive receivers, and low uncertainties in assessment criteria) warrant a more complex modelling methodology.

The first step in choosing a propagation model is thus to examine these various factors, such as:

- balancing of errors/uncertainties;
- range dependant bathymetry;
- frequency dependence; and
- source characteristics.

5.3 Modelling Approach for Vessels and Continuous Sources

For the noise field model, relevant survey parameters were chosen based on a combination of data provided by the Applicant combined with the information gathered from the publicly available literature. Two locations were selected and modelled, one taken from each of the EGL 3 and 4 cable routes. These parameters were fed into an appropriate propagation model routine, in this case the Weston Energy Flux model (for more information refer to Weston, 1971; 1980a; 1980b), suited to the region and the frequencies of interest. The frequency-dependent loss of acoustic energy with distance (TL) values were then evaluated along different transects around the chosen source points. The frequencies of interest in the present study are from 20 Hz to 80 kHz, with different noise sources operating in different frequency bands.

The propagation loss is calculated using one of four regions, depending on the distance of the receiver location from the source, and related to the frequency and the seafloor conditions such as depth and its composition.

The spherical spreading region exists in the immediate vicinity of the source, which is followed by a region where the propagation follows a cylindrical spread out until the grazing angle is equal to the critical grazing angle. Above the critical grazing angle in the mode stripping region an additional loss factor is introduced which is due to seafloor reflection loss, where higher modes are attenuated faster due to their larger grazing angles. In the final region, the single-mode region, all modes but the lowest have been fully attenuated.

5.4 Geo-Acoustic Input Parameters

Based on BGS core data in the vicinity of the Project, the geo-acoustic model is based on the parameters presented in Table 5-1.

Table 5-1: Geoacoustic properties used in the modelling.

Layer	Compressional Sound Speed (V_p, m/s)	Sheer Sound Speed (V_s, m/s)	Compressional Attenuation Coefficient (α_p, dB/λ_p)	Density (kg/m^3)
Top layer - Fine Sand	1,685	110	0.89	1,941

5.5 Batch Processing

To improve the performance and reduce the time taken to process and evaluate multiple TL calculations required for this study, Seiche Ltd.’s proprietary software was employed. This software iteratively evaluates the propagation modelling routine for the specified number of azimuthal bearings radiating from a source point, providing a fan of range-dependent TL curves departing from the noise source for each given frequency and receiver depth. In-house routines are then employed to interpolate the TL values across transects, to give an estimate of the noise field for the whole area around the source point.

Once the TL values were evaluated at the source points, in all azimuthal directions, and at all frequencies of interest for various sources, the results were then coupled with the corresponding SL values in third octave frequency bands. The combination of SL with TL data provided us with the third octave band RL at each point in the receiver grid (i.e., at each modelled range, depth, and azimuth of the receiver).

The received levels were evaluated for the $L_{p,0\text{-}pk}$, $L_{p,rms}$ or SEL metric, for each source type, source location, and azimuthal transect to produce the associated TL. The broadband RL were then calculated for these metrics and from the third octave band results. The set of simulated RL transects were circularly interpolated to generate the broadband RL maps centred around each source point. Representations of these RLs are provided in Chapter 10 Marine Mammals in the form of contour maps.

RMS sound pressure levels were calculated assuming a typical T90 pulse duration for impulsive sources (i.e. the period that contains 90% of the total cumulative noise energy) of 100 ms. It should be noted that in reality, the rms T90 period will increase significantly with distance which means that any ranges based on rms sound pressure levels at ranges of more than a few kilometres are likely to be significant overestimates and should therefore be treated as highly conservative.

5.5.1 Exposure Calculations

As well as calculating the unweighted noise levels at various distances from different source, it is also necessary to calculate the received acoustic signal in terms of the SEL metric (where necessary and possible) for a marine mammal using the relevant hearing weighting functions. For different operations related noise sources, the numerical SEL value is equal to the $L_{p,rms}$ value integrated over a one second window as the sources are continuous and non-impulsive. These SEL values are employed for calculation of SEL_{cum} (cumulative SEL) metric for different marine mammal groups to assess potential impact ranges.

Simplified exposure modelling could assume that the animal is either static and at a fixed distance away from the noise source, or that the animal is swimming at a constant speed in a perpendicular direction away from a noise source. For fixed receiver calculations, it has generally been assumed (in literature) that an animal will stay at a known distance from the noise source for a period of 24 hours. As the animal does not move, the noise will be constant over the integration period of 24 hours (assuming the source does not change its operational characteristics over this time). This, however, would give an unrealistic level of exposure, as the animals are highly unlikely to remain stationary when exposed to loud noise, and are therefore expected to swim away from the source. The approximation used in these calculations, therefore, is that the animals move directly away from the source. Nevertheless, in the case of fish exposure, calculations have also been undertaken based on a static receiver assumption.

It should be noted that the noise exposure calculations are based on the simplistic assumption that the noise source is active continuously (or intermittently based on source activation timings) over a 24 hour period. The real-world situation, however, is more complex. The SEL calculations presented in this study do not take any breaks in activity into account, such as downtime due to mechanics, logistics or weather.

Furthermore, the noise criteria described in the Southall *et al.* (2019) guidelines assume that the animal does not recover hearing between periods of activity. It is likely that both the intervals between operations could allow some recovery from temporary hearing threshold shifts for animals exposed to the noise (von Benda-Beckmann *et al*. 2022) and, therefore, the assessment of sound exposure level is conservative.

In order to carry out the moving marine mammal calculation, it has been assumed that a mammal will swim away from the noise source at the onset of activities. As an animal swims away from the noise source, the noise it experiences will become progressively lower (more attenuated); the cumulative SEL is derived by logarithmically adding the SEL to which the mammal is exposed as it travels away from the source. This calculation was used to estimate the approximate minimum start distance for an animal in order for it not to be exposed to sufficient noise energy to result in the onset of potential auditory injury. It should be noted that the noise exposure calculations are based on the simplistic assumption that the animal will continue to swim away at a fairly constant relative speed. The real-world situation is more complex, and the animal is likely to move in a more complex manner: at varying speed and direction.

The assumed swim speeds for animals likely to be present across the project are in Table 5-2.

Table 5-2 Assessment swim speeds of marine mammals and fish that are likely to occur within the north sea for the purpose of exposure modelling.

Species	Hearing group	Swim speed (m/s)	Source reference
Harbour seal	Phocid Carnivores in Water (PCW)	1.8	Thompson *et al.* (2015)
Grey seal	Phocid Carnivores in Water (PCW)	1.8	Thompson *et al.* (2015)
Harbour porpoise	Very High Frequency (VHF)	1.5	Otani *et al.* (2000)
Minke whale	Low Frequency (LF)	2.3	Boisseau *et al.* (2021)
Bottlenose dolphin	High Frequency (HF)	1.52	Bailey *et al.* (2010)
White-beaked dolphin	High Frequency (HF)	1.52	Bailey *et al.* (2010)
Short beaked common dolphin *Delphinus delphis*	High Frequency (HF)	1.52	Bailey *et al.* (2010)
Risso’s dolphin *Grampus griseus*	High Frequency (HF)	1.52	Bailey *et al.* (2010)
All fish hearing groups	Group 1 to 4 fish	0.5	Popper *et al.* (2014)

5.6 UXO Noise Modelling

5.6.1 Detonation

Noise modelling for UXO clearance has been undertaken using the methodology described in Soloway and Dahl (2014). The equation provides a simple relationship between distance from an explosion and the weight of the charge (or equivalent TNT weight) but does not take into account bottom topography or sediment characteristics.

$$P_{peak} = 52.4\ \times 10^6 \left(\frac{R}{W^{1/3}}\right)^{-1.13}$$

Where W is the equivalent TNT charge weight and R is the distance from source to receiver.

Since the charge is assumed to be freely standing in mid-water, unlike a UXO which would be resting on the seabed and could potentially be buried, degraded or subject to other significant attenuation, this estimation of the source level can be considered conservative.

According to Soloway and Dahl (2014), the SEL can be estimated by the following equation:

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

In order to compare to the marine mammal hearing weighted thresholds, it is necessary to apply the frequency dependent weighting functions at each distance from the source. This was accomplished by determining a transfer function between unweighted and weighted SEL values at various distances based on an assumed spectrum shape (see Figure 5-2) and taking into account molecular absorption at various ranges. A maximum of one UXO clearance event per day is assumed.

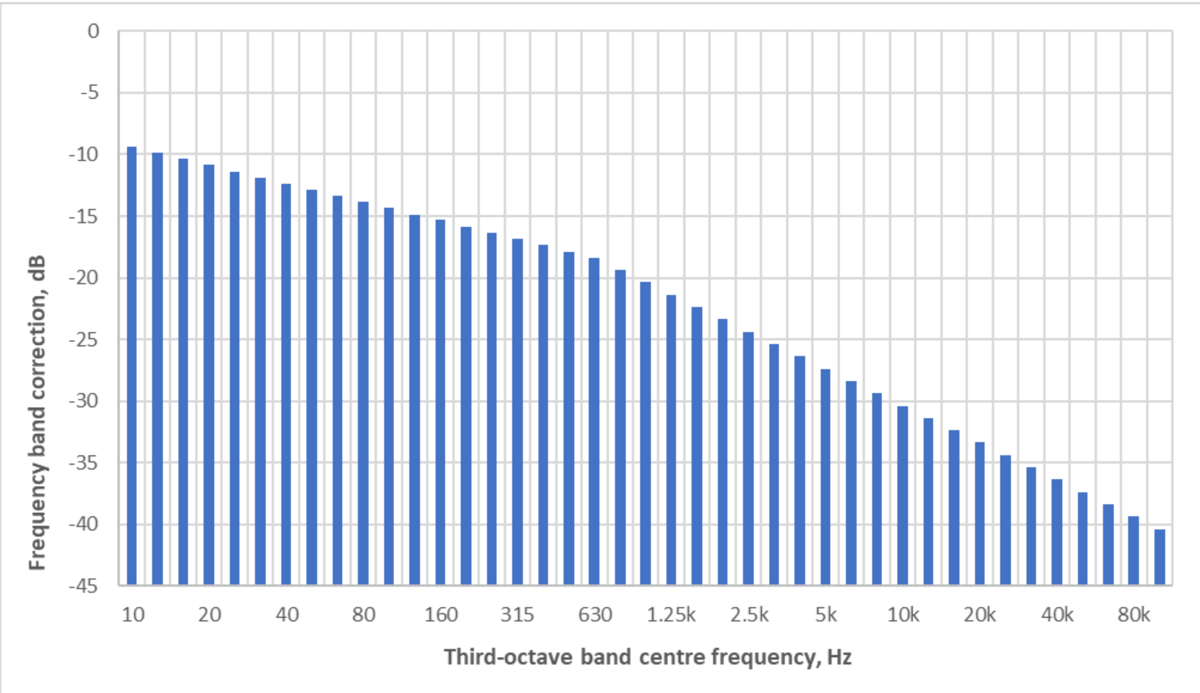

Figure 5-2: Assumed explosive spectrum shape used to estimate hearing weighting corrections to SEL.

5.6.2 Deflagration

According to Robinson *et al.* (2020) and Stephenson *et al.* (2024), low order deflagration results in a much lower amplitude of peak sound pressure than high order detonations. The study concluded that peak sound pressure during deflagration is due only to the size of the shaped charge used to initiate deflagration and, consequently, that the acoustic output can be predicted for deflagration as long as the size of the shaped charge is known.

Noise modelling for deflagration has therefore been based on the methodology described above for detonations, using a smaller disposal tool charge size.

6 Noise Modelling Results

6.1 Pre-construction Phase

The estimated ranges for auditory injury to marine mammals due to various proposed activities undertaken during the pre-construction phase of the operations are presented in this section. These include geophysical survey activities, UXO clearance and support vessel activities.

The potential ranges presented for injury and behavioural response are not a clearly delineated 'line' where an impact will occur on one side and not on the other. Potential impact is more probabilistic; in reality, dose dependency in PTS onset, individual variations, and uncertainties regarding behavioural response and swim speed/direction combine to create a probability field around the source location. Defining a single distance around this area of probability allows visualisation of the spatial extent of different source types and levels and allows comparison of the impacts on a like-for-like basis.

6.1.1 Geophysical Surveys

Geophysical surveying includes many sonar like noise sources and the resulting injury and disturbance ranges for marine mammals are presented in Table 6-1, based on a comparison between the non-impulsive thresholds set out in Southall *et al*. (2019) and NMFS (2024). The newer NMFS (2024) injury ranges are presented in brackets where they differ from the Southall *et al*. (2019) ranges.

The potential impact distances from these operations vary based on their frequencies of operation and source levels and are rounded to the nearest 5 m. It should be noted that sonar like systems have very strong directivity which effectively means that there is only potential for injury when a marine mammal is directly underneath or within the swathe of the noise source. Once the animal moves outside of the main beam, there is significantly reduced potential for injury. The same is true in many cases for TTS where an animal is only exposed to enough energy to cause TTS when inside the direct beam of the sonar like source.

Table 6-1: Potential impact ranges (m) for marine mammals during the various geophysical investigation activities based on the non-impulsive SEL thresholds from Southall *et al.* (2019). NMFS (2024) SEL thresholds are shown in brackets where they differ from the Southall results. (N/E refers to a threshold not exceeded).

Survey type	Effect	Hearing group				
		LF	HF	VHF	PCW	OCW
MBES	PTS	155 (N/E)	294 (265)	315 (290)	215 (120)	40 (10)
	TTS	287 (10)	300 (290)	430 (340)	293 (280)	205 (115)
SSS	PTS	N/E	150 (10)	293 (215)	15 (N/E)	N/E
	TTS	65 (N/E)	285 (105)	294 (290)	110 (15)	N/E
Parametric SBP	PTS	41 (15)	43 (100)	195 (150)	41 (99)	36 (86)
	TTS	41 (90)	165 (115)	620 (430)	43 (100)	41 (99)
USBL	PTS	N/E	N/E	70 (25)	N/E	N/E
	TTS	20 (N/E)	40 (N/E)	1,285 (635)	25 (85)	N/E

6.1.2 Vessels

The potential impact ranges for vessels are included in section 6.3, which summarises the vessel modelling results for all phases of the campaign.

6.1.3 UXO Clearance

6.1.3.1 Deflagration – Low Order Disposal

The predicted injury ranges for deflagration with the Southall *et al.* 2019 weightings and thresholds are presented in Table 6-2, for the NMFS (2024) weightings and thresholds in Table 6-3, and Table 6-4 for fish. The predicted ranges for the clearance shot to remove any residual explosive material from the seabed are shown in Table 6-5, for the Southall *et al.* (2019) weightings and thresholds, and Table 6-6 for the MNFS (2024) weightings and thresholds and Table 6-7 for fish.

All UXO injury and disturbance ranges are based on a comparison to the relevant impulsive sound thresholds as set out in section 4.2.2. Note for the NMFS (2024) thresholds the TTS threshold is used to assess behavioural response where one detonation occurs per day, and the behavioural threshold (-5 dB from TTS onset) is taken for multiple detonations within a 24-hour period.

Table 6-2: Injury ranges for marine mammals, Southall *et al.* (2019) weightings and thresholds, due to detonation of 0.08 kg donor charge (deflagration). (N/E refers to a threshold not exceeded).

Group	PTS Range				TTS Range			
	$L_{p,0\text{-}pk}$		SEL (Weighted)		$L_{p,0\text{-}pk}$		SEL (Weighted)	
	Threshold	Range (m)	Threshold	Range (m)	Threshold	Range (m)	Threshold	Range (m)
LF	219	122	183	47	213	224	168	660
HF	230	40	185	N/E	224	73	170	23

Group	PTS Range				TTS Range			
	$L_{p,0-pk}$		SEL (Weighted)		$L_{p,0-pk}$		SEL (Weighted)	
	Threshold	Range (m)	Threshold	Range (m)	Threshold	Range (m)	Threshold	Range (m)
VHF	202	685	155	191	196	1,265	140	1,495
PCW	218	135	185	9	212	247	170	125
OCW	232	32	203	N/E	226	60	188	6

Table 6-3: Injury ranges for marine mammals, NMFS (2024) weightings and thresholds, due to detonation of 0.08 kg donor charge (deflagration). (N/E refers to a threshold not exceeded).

Group	Injury Range				TTS Range				Behavioural	
	$L_{p,0-pk}$		SEL (Weighted)		$L_{p,0-pk}$		SEL (Weighted)		Threshold	Range (m)
	Threshold	Range (m)	Threshold	Range (m)	Threshold	Range (m)	Threshold	Range (m)		
LF	222	90	183	51	216	165	168	715	163	1,705
HF	230	40	193	N/E	224	73	178	6	173	14
VHF	202	685	159	175	196	1,265	144	1,480	139	2,455
PCW	223	81	183	16	217	149	168	222	163	525
OCW	230	40	185	5	224	73	170	75	165	178

Table 6-4: Injury ranges for fish due to detonation of 0.08 kg donor charge (deflagration)

Group	Mortality		Recoverable Injury	TTS
	Threshold	Range (m)		
Group 1 fish	*229 - 234*	44-27	(Near) High (Intermediate) Low (Far) Low	(Near) High (Intermediate) Moderate (Far) Low
Group 2 fish	*229 - 234*	44-27	(Near) High (Intermediate) High (Far) Low	(Near) High (Intermediate) Moderate (Far) Low
Group 3 and 4 fish	*229 - 234*	44-27	(Near) High (Intermediate) High (Far) Low	(Near) High (Intermediate) High (Far) Low
Sea turtles	*229 - 234*	44-27	(Near) High (Intermediate) Low (Far) Low	(Near) High (Intermediate) Moderate (Far) Low

Table 6-5: Injury ranges for marine mammals, Southall *et al.* (2019) weightings and thresholds, due to detonation of 0.5 kg clearance shot. (N/E refers to a threshold not exceeded).

Group	PTS Range				TTS Range			
	$L_{p,0\text{-}pk}$		SEL (Weighted)		$L_{p,0\text{-}pk}$		SEL (Weighted)	
	Threshold	Range (m)	Threshold	Range (m)	Threshold	Range (m)	Threshold	Range (m)
LF	219	223	183	115	213	415	168	1,585
HF	230	73	185	4	224	134	170	56
VHF	202	1,265	155	425	196	2,325	140	2,435
PCW	218	247	185	22	212	455	170	301
OCW	232	60	203	N/E	226	110	188	14

Table 6-6: Injury ranges for marine mammals, NMFS (2024) weightings and thresholds, due to detonation of 0.5 kg clearance shot.

Group	Injury Range				TTS Range				Behavioural	
	$L_{p,0\text{-}pk}$		SEL (Weighted)		$L_{p,0\text{-}pk}$		SEL (Weighted)		Threshold	Range (m)
	Threshold	Range (m)	Threshold	Range (m)	Threshold	Range (m)	Threshold	Range (m)		
LF	222	165	183	125	216	303	168	1,725	163	4,010
HF	230	73	193	N/E	224	134	178	14	173	33
VHF	202	1,265	159	395	196	2,325	144	2,475	139	3,735
PCW	223	149	183	39	217	274	168	535	163	1,210
OCW	230	73	185	13	224	134	170	181	165	420

Table 6-7: Injury ranges for fish due to detonation of 0.5 kg clearance shot

Group	Mortality		Recoverable Injury	TTS
	Threshold	Range (m)		
Group 1 fish	*229 - 234*	81-49	(Near) High (Intermediate) Low (Far) Low	(Near) High (Intermediate) Moderate (Far) Low
Group 2 fish	*229 - 234*	81-49	(Near) High (Intermediate) High (Far) Low	(Near) High (Intermediate) Moderate (Far) Low
Group 3 and 4 fish	*229 - 234*	81-49	(Near) High (Intermediate) High (Far) Low	(Near) High (Intermediate) High (Far) Low
Sea turtles	*229 - 234*	81-49	(Near) High (Intermediate) Low (Far) Low	(Near) High (Intermediate) Moderate (Far) Low

6.1.3.2 Detonation – High Order Disposal

There is a small (10% to 20%) chance that low order deflagration could result in a high order detonation event. The predicted injury ranges in the most likely scenario for a detonation of a 295 kg UXO, for marine mammals for Southall *et al.* (2019) thresholds in Table 6-8 and with NMFS (2024) thresholds in Table 6-9, fish are shown in Table 6-10. The predicted injury ranges in the worst case scenario for a detonation of a 697 kg UXO, for marine mammals for Southall *et al.* (2019) thresholds in Table 6-11 and with NMFS (2024) thresholds in Table 6-12, fish are shown in

Table 6-13. It should be noted that, due to a combination of dispersion (i.e., where the waveform elongates), multiple reflections from the sea surface and bottom and molecular absorption of high frequency energy, the sound is unlikely to still be impulsive in character once it has propagated more than a few kilometres. Consequently, great caution should be used when interpreting any results with predicted injury ranges in the order of tens of kilometres. Furthermore, the modelling assumes that the UXO acts like a charge suspended in open water whereas in reality it is likely to be partially buried in the sediment. In addition, it is possible that the explosive material will have deteriorated over time meaning that the predicted noise levels are likely to be over-estimated. In combination, these factors mean that the results should be treated as precautionary impact ranges which are likely to be significantly lower than predicted.

Whist the results below report the threshold for behavioural disturbance suggested by NMFS (2024), it is worth noting that the JNCC guidance for assessing the impacts of noise on harbour porpoise SACs (JNCC, 2020) suggest an EDR for UXO high order detonations of 26 km, as derived from monopile installations. Whilst this EDR is specifically referenced to harbour porpoise (a VHF cetacean), it could indicate that the higher behavioural impact ranges presented below are potentially over precautionary.

Table 6-8: Injury ranges for marine mammals, Southall *et al.* (2019) weightings and thresholds, due to detonation of 295 kg UXO.

Group	PTS Range				TTS Range			
	$L_{p,0\text{-}pk}$		SEL (Weighted)		$L_{p,0\text{-}pk}$		SEL (Weighted)	
	Threshold	Range (m)	Threshold	Range (m)	Threshold	Range (m)	Threshold	Range (m)
LF	219	1,870	183	2,510	213	3,450	168	23,710
HF	230	610	185	89	224	1,125	170	930
VHF	202	10,570	155	3,035	196	19,480	140	7,675
PCW	218	2,075	185	475	212	3,820	170	4,495
OCW	232	500	203	22	226	920	188	295

Table 6-9: Injury ranges for marine mammals, NMFS (2024) weightings and thresholds, due to detonation of 295 kg UXO

Group	Injury Range				TTS Range				Behavioural	
	$L_{p,0-pk}$		SEL (Weighted)		$L_{p,0-pk}$		SEL (Weighted)		Threshold	Range (m)
	Threshold	Range (m)	Threshold	Range (m)	Threshold	Range (m)	Threshold	Range (m)		
LF	222	1,380	183	2,730	216	2,540	168	25,400	163	47,095
HF	230	610	193	90	224	1,125	178	1,100	173	2,270
VHF	202	10,570	159	3,120	196	19,480	144	8,010	139	10,085
PCW	223	1,245	183	835	217	2,295	168	6,820	163	11,070
OCW	230	610	185	286	224	1,125	170	2,680	165	4,665

Table 6-10: Injury ranges for fish due to detonation of 295 kg UXO

Group	Mortality		Recoverable Injury	TTS
	Threshold	Range (m)		
Group 1 fish	*229 - 234*	405-680	(Near) High (Intermediate) Low (Far) Low	(Near) High (Intermediate) Moderate (Far) Low
Group 2 fish	*229 - 234*	405-680	(Near) High (Intermediate) High (Far) Low	(Near) High (Intermediate) Moderate (Far) Low
Group 3 and 4 fish	*229 - 234*	405-680	(Near) High (Intermediate) High (Far) Low	(Near) High (Intermediate) High (Far) Low
Sea turtles	*229 - 234*	405-680	(Near) High (Intermediate) Low (Far) Low	(Near) High (Intermediate) Moderate (Far) Low

Table 6-11: Injury ranges for marine mammals, Southall *et al.* (2019) weightings and thresholds, due to detonation of 697 kg UXO.

Group	PTS Range				TTS Range			
	$L_{p,0-pk}$		SEL (Weighted)		$L_{p,0-pk}$		SEL (Weighted)	
	Threshold	Range (m)	Threshold	Range (m)	Threshold	Range (m)	Threshold	Range (m)
LF	219	2,495	183	3,740	213	4,590	168	31,550
HF	230	815	185	134	224	1,500	170	1,260
VHF	202	14,080	155	3,630	196	25,940	140	8,620
PCW	218	2,760	185	710	212	5,085	170	5,960
OCW	232	665	203	33	226	1,225	188	445

Table 6-12: Injury ranges for marine mammals, NMFS (2024) weightings and thresholds, due to detonation of 697 kg UXO

Group	Injury Range				TTS Range				Behavioural	
	$L_{p,0\text{-}pk}$		SEL (Weighted)		$L_{p,0\text{-}pk}$		SEL (Weighted)		Threshold	Range (m)
	Threshold	Range (m)	Threshold	Range (m)	Threshold	Range (m)	Threshold	Range (m)		
LF	222	1,835	183	4,060	216	3,385	168	33,905	163	64,000
HF	230	815	193	136	224	1,500	178	1,575	173	3,090
VHF	202	14,080	159	3,755	196	25,940	144	8,975	139	38,845
PCW	223	1,660	183	1,225	217	3,055	168	8,710	163	13,470
OCW	230	815	185	425	224	1,500	170	3,540	165	5,860

Table 6-13: Injury ranges for fish due to detonation of 697 kg UXO

Group	Mortality		Recoverable Injury	TTS
	Threshold	Range (m)		
Group 1 fish	*229 - 234*	900 - 545	(Near) High (Intermediate) Low (Far) Low	(Near) High (Intermediate) Moderate (Far) Low
Group 2 fish	*229 - 234*	900 - 545	(Near) High (Intermediate) High (Far) Low	(Near) High (Intermediate) Moderate (Far) Low
Group 3 and 4 fish	*229 - 234*	900 - 545	(Near) High (Intermediate) High (Far) Low	(Near) High (Intermediate) High (Far) Low
Sea turtles	*229 - 234*	900 - 545	(Near) High (Intermediate) Low (Far) Low	(Near) High (Intermediate) Moderate (Far) Low

6.2 Construction phase

6.2.1 Construction Operations

The potential impact ranges from construction related activities (such as Trailing suction hopper dredging, Controlled flow excavation, plough, jet trencher, mechanical trencher and vertical injector) on different marine mammal groups with both Southall *et al.* 2019 and NMFS 2024 weightings and thresholds in Table 6-14 and Table 6-15.

Table 6-14: Potential impact ranges (m) for marine mammals from other construction related operations for EGL 3, incorporating the Southall *et al.* 2019 weightings and thresholds, and NMFS 2024 weightings and thresholds included in brackets were they differ. (N/E refers to a threshold not exceeded).

Source	Potential Impact Ranges (m)										
	LF		HF		VHF		PCW		OCW		All
	PTS	TTS	PTS	TTS	PTS	TTS	PTS	TTS	PTS	TTS	Disturbance
Trailing suction hopper dredger	N/E	N/E	N/E	N/E	N/E	108 (30)	N/E	N/E	N/E	N/E	2,506
Controlled flow excavation, Plough, Jet trencher, Mechanical trencher, Vertical injector (unlikely to be used)	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	2,522

Table 6-15: Potential impact ranges (m) for marine mammals from other construction related operations for EGL 4, incorporating the Southall *et al.* 2019 weightings and thresholds, and NMFS 2024 weightings and thresholds included in brackets were they differ. (N/E refers to a threshold not exceeded).

Source	Potential Impact Ranges (m)										
	LF		HF		VHF		PCW		OCW		All
	PTS	TTS	PTS	TTS	PTS	TTS	PTS	TTS	PTS	TTS	Disturbance
Trailing suction hopper dredger	N/E	N/E	N/E	N/E	N/E	118 (33)	N/E	N/E	N/E	N/E	2,827
Controlled flow excavation, Plough, Jet trencher, Mechanical trencher, Vertical injector (unlikely to be used)	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	2,751

The ranges for recoverable injury and TTS for Groups 3 and 4 Fish are presented in Table 6-16 and Table 6-17, based on the thresholds contained in Popper *et al.* (2014). It should be noted that fish would need to be exposed within these potential impact ranges for a period of 48 hours continuously in the case of recoverable injury and 12 hours continuously in the case of TTS for the effect to occur. It is therefore considered that these ranges are highly precautionary, and injury is unlikely to occur.

Table 6-16: Potential injury and TTS ranges (m) for Group 3 and 4 Fish exposed to other construction related operations for EGL 3.

Source	Injury Zone Radius (m)	
	Recoverable Injury 170 dB re 1 µPa (rms) for 48 hrs	TTS 158 dB re 1 µPa (rms) for 12 hrs
Trailing suction hopper dredger	N/E	17
Controlled flow excavation, Plough, Jet trencher, Mechanical trencher, Vertical injector (unlikely to be used)	N/E	7

Table 6-17: Potential injury and TTS ranges (m) for Group 3 and 4 Fish exposed to other construction related operations for EGL 4.

Source	Injury Zone Radius (m)	
	Recoverable Injury 170 dB re 1 µPa (rms) for 48 hrs	TTS 158 dB re 1 µPa (rms) for 12 hrs
Trailing suction hopper dredger	N/E	15
Controlled flow excavation, Plough, Jet trencher, Mechanical trencher, Vertical injector (unlikely to be used)	N/E	7

6.2.2 Construction Vessels

The potential impact ranges for vessels are included in section 6.3, which summarises the vessel modelling results for all phases of the campaign.

6.3 Vessel noise (All Phases)

Estimated ranges for injury and disturbance to marine mammals due to the continuous noise sources (vessels) during different phases of the construction and operations are presented below. For the Southall *et al.* 2019 and NMFS 2024 weightings and thresholds in Table 6-18, and

Table 6-19. The exposure metrics for different marine mammal and swim speeds (as detailed in section 5.5.1) were employed.

It should be borne in mind that there is a considerable degree of uncertainty and variability in the onset of disturbance and therefore any disturbance ranges should be treated as potentially over precautionary. Another important consideration is that vessels and construction noise will be temporary and transitory, as opposed to permanent and fixed. In this respect, construction noise is unlikely to differ significantly from vessel traffic already in the area.

Table 6-18: Potential impact ranges (m) for marine mammals from vessel noise during all phases for EGL 3, incorporating the Southall *et al.* 2019 weightings and thresholds, and NMFS 2024 weightings and thresholds included in brackets were they differ. (N/E refers to a threshold not exceeded).

Source	Potential Impact Ranges (m)										
	LF		HF		VHF		PCW		OCW		All
	PTS	TTS	PTS	TTS	PTS	TTS	PTS	TTS	PTS	TTS	Disturbance
Survey vessels, Construction support vessels	N/E	N/E	N/E	N/E	N/E	11 (N/E)	N/E	N/E	N/E	N/E	3,107
Cable lay vessel	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	725
Jack-up/spud barge	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E
Multi-cat	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	14
Small work boats	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	9
Trailing suction hopper dredger, Rock placement vessels	N/E	N/E	N/E	N/E	N/E	108 (30)	N/E	N/E	N/E	N/E	2,506
Guard vessel	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	1,021
Crew transfer vessels	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	583

Table 6-19: Potential impact ranges (m) for marine mammals from vessel noise during all phases for EGL 4, incorporating the Southall *et al.* 2019 weightings and thresholds, and NMFS 2024 weightings and thresholds included in brackets were they differ. (N/E refers to a threshold not exceeded).

Source	Potential Impact Ranges (m)										
	LF		HF		VHF		PCW		OCW		All
	PTS/ Injury	TTS	PTS/ Injury	TTS	PTS/ Injury	TTS	PTS/ Injury	TTS	PTS/ Injury	TTS	Disturbance
Survey vessels, Construction support vessels	N/E	N/E	N/E	N/E	N/E	12 (N/E)	N/E	N/E	N/E	N/E	3,367
Cable lay vessel	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	905
Jack-up/spud barge	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E
Multi-cat	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	13
Small work boats	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	12
Trailing suction hopper dredger, Rock placement vessels	N/E	N/E	N/E	N/E	N/E	118 (33)	N/E	N/E	N/E	N/E	2,827
Guard vessel	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	1,097
Crew transfer vessels	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	625

The ranges for recoverable injury and TTS for Groups 3 and 4 Fish are presented in Table 6-20 and Table 6-21 based on the thresholds contained in Popper *et al.* (2014). It should be noted that fish would need to be exposed within these potential impact ranges for a period of 48 hours continuously in the case of recoverable injury and 12 hours continuously in the case of TTS for the effect to occur. It is therefore considered that these ranges are highly precautionary, and injury is unlikely to occur.

Table 6-20: Estimated recoverable injury and TTS ranges for vessels for Group 3 and 4 Fish for EGL 3.

Source	Injury Zone Radius (m)	
	Recoverable injury 170 dB re 1 µPa (rms) for 48 hrs	TTS 158 dB re 1 µPa (rms) for 12 hrs
Survey vessels, Construction support vessels	N/E	9
Cable lay vessel	N/E	10
Jack-up/spud barge	N/E	N/E
Multi-cat	N/E	N/E
Small work boats	N/E	N/E
Trailing suction hopper dredger, Rock placement vessels	N/E	17
Guard vessel	N/E	N/E
Crew transfer vessels	N/E	N/E

Table 6-21: Estimated recoverable injury and TTS ranges for vessels for Group 3 and 4 Fish for EGL 4.

Source	Injury Zone Radius (m)	
	Recoverable injury 170 dB re 1 µPa (rms) for 48 hrs	TTS 158 dB re 1 µPa (rms) for 12 hrs
Survey vessels, Construction support vessels	N/E	10
Cable lay vessel	N/E	N/E
Jack-up/spud barge	N/E	N/E
Multi-cat	N/E	N/E
Small work boats	N/E	N/E
Trailing suction hopper dredger, Rock placement vessels	N/E	15
Guard vessel	N/E	N/E
Crew transfer vessels	N/E	N/E

7 Summary

Acoustic modelling has been undertaken to determine distances at which potential effects on marine mammals and fish may occur due to noise from relevant underwater noise generating activities associated with pre-construction, construction, operations and maintenance and decommissioning of the Project. Based on the assessment it is concluded that:

- For the geophysical surveys, the greatest injury ranges results from the MBES, with Southall *et al.*, (2019) PTS range for VHF cetaceans of 315 m, and NMFS injury range of 290 m.
- For UXO clearance, with low order deflagration, the greatest PTS range occurs for VHF cetaceans at 685 m according to Southall *et al.* (2019) criteria. And maximal behavioural disturbance of 2,455 m for multiple disposals in a 24 hour period or 1,480 m for single clearance, for VHF cetaceans according to the NMFS (2024) criteria.
- For UXO clearance, with high order detonation, for the most likely UXO size (295 kg) the greatest PTS range occurs for VHF at 10,570 m according to both Southall *et al.* (2019) and NMFS (2024) criteria. The maximum behavioural disturbance for multiple detonations in a 24 hour period is for LF cetaceans, at 47,095 m and for a single detonation at 25,400 m according to NMFS (2024) criteria.
- For construction operations, the greatest TTS range occurs for VHF at 118 m with the Southall *et al.*, (2019) thresholds and weightings and disturbance range of 2,827 m from the trailing suction hopper dredger.
- For vessel noise, the greatest TTS range occurs for VHF at 118 m with the Southall *et al.* (2019) thresholds and weightings from the trailing suction hopper dredger and rock placement vessels, and the greatest disturbance range is 3,367 m from the survey vessels and construction support vessels.

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