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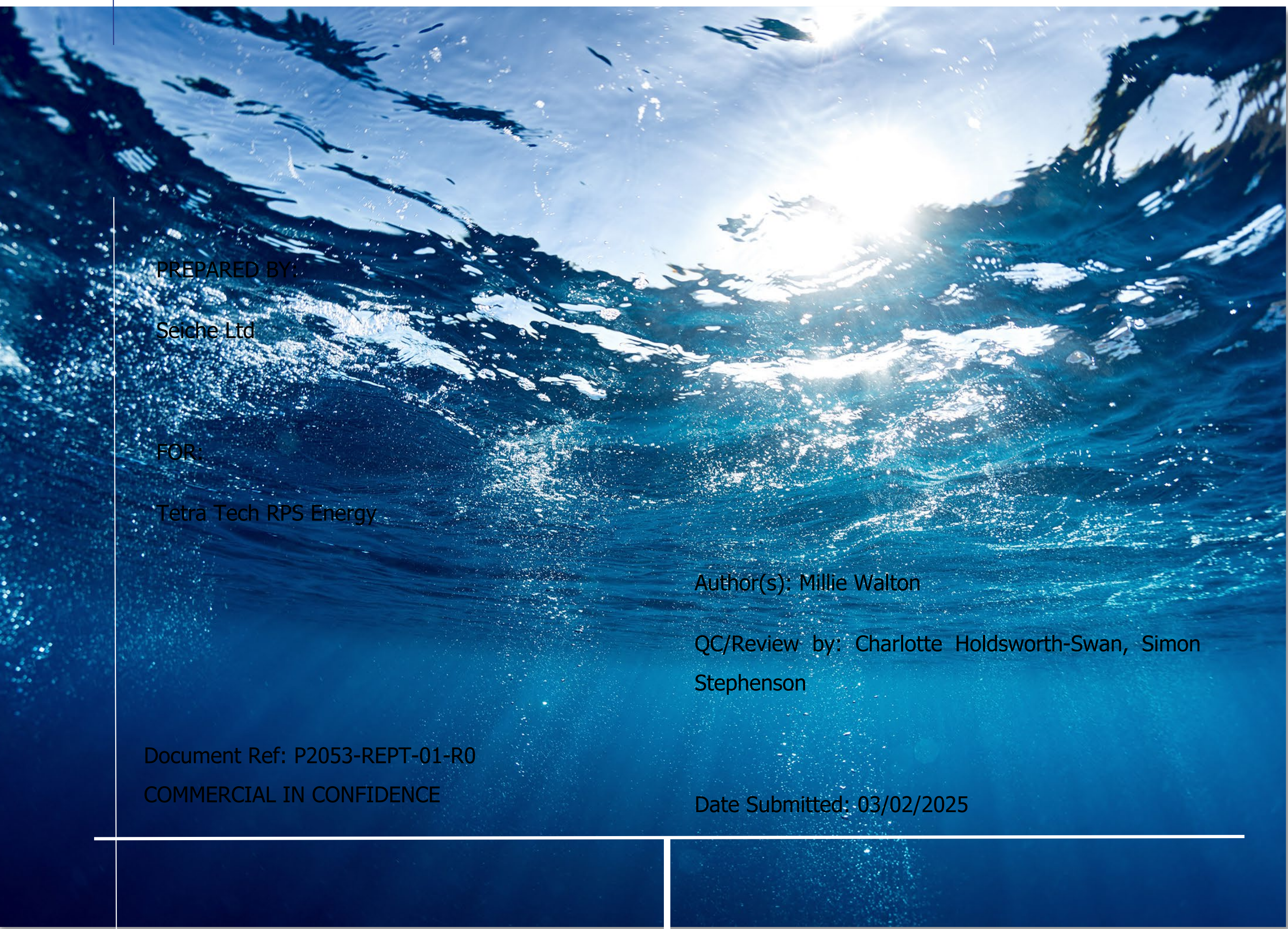
Valero Jetty Milford Haven

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
kgm^{-3}	Kilograms per cubic metre
km^2	Square kilometres
LF	Low Frequency Cetaceans
m	Metre
ms^{-1}	Metres per second
ms^{-2}	Metres per second squared
MW	Megawatt (106)
NAS	Noise Abatement System
OCW	Other Carnivores in Water
PCW	Phocid Carnivores in Water
PTS	Permanent Threshold Shift
RL	Received Level
RMS	Root Mean Square
s	Second
SEL	Sound Exposure Level
SL	Source Level
SPL	Sound Pressure Level
SSS	Side scan sonar
TL	Transmission Loss
TTS	Temporary Threshold Shift
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 for the jetty maintenance activities at the Valero Pembrokeshire Oil Terminal (VPOT) located in Milford Haven, Wales. The location is shown in Figure 1-1. The maintenance activities involve the replacement of a defective dual pile with a monopile arrangement.

The proposed works entail cutting and removal of the defective dual pile from either a jack-up barge or flat top barge, and installation of the new monopile with vibro-piling and drilling from a jack-up barge.

Figure 1-1: Location of Valero Berth 2, Milford Haven.

Sound is readily transmitted into the underwater environment and there is potential for the sound emissions from the Valero jetty project to adversely affect marine mammals and fish. At a close range from a sound source with high sound levels, permanent or temporary hearing damage may occur to marine species, while at a very close range gross physical trauma is possible. At more distant ranges the introduction of any additional sound could potentially cause short-term behavioural changes, for example to the ability of species to communicate and to determine the presence of predators, food, underwater features, and obstructions. (It should be noted that it is unclear whether/how close range or short-term impacts may translate to long term population level impacts. This is an area of active research). This report provides an overview of the potential effects due to underwater sound from the proposed survey of the surrounding marine environment.

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 ($L_{p.rms}$) value of a pulse may be reported as 100 dB re 1 µPa. These descriptions are shown graphically in Figure 2-1.

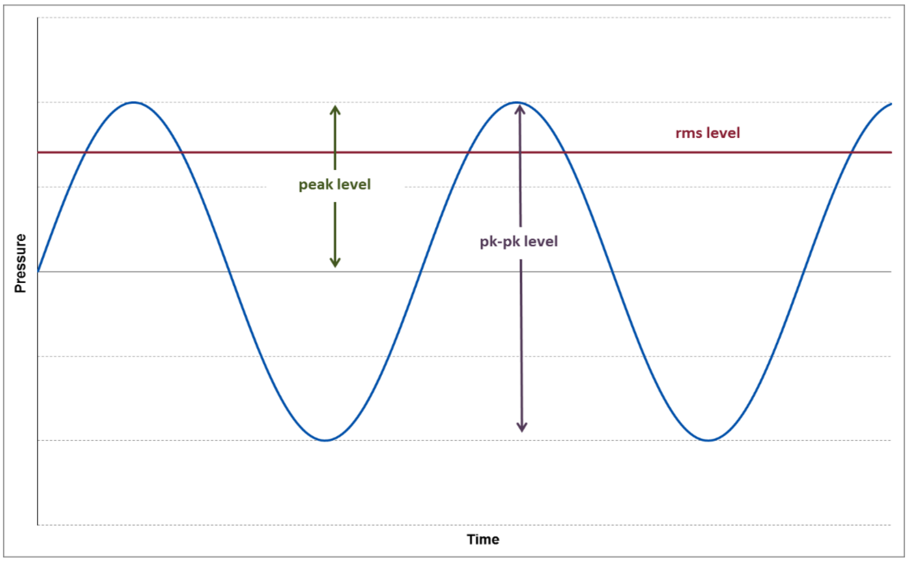

Figure 2-1: Graphical representation of acoustic wave descriptors.

The $L_{p,rms}$ is defined as:

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

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 or L_E). 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 µPa^{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).
- **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.

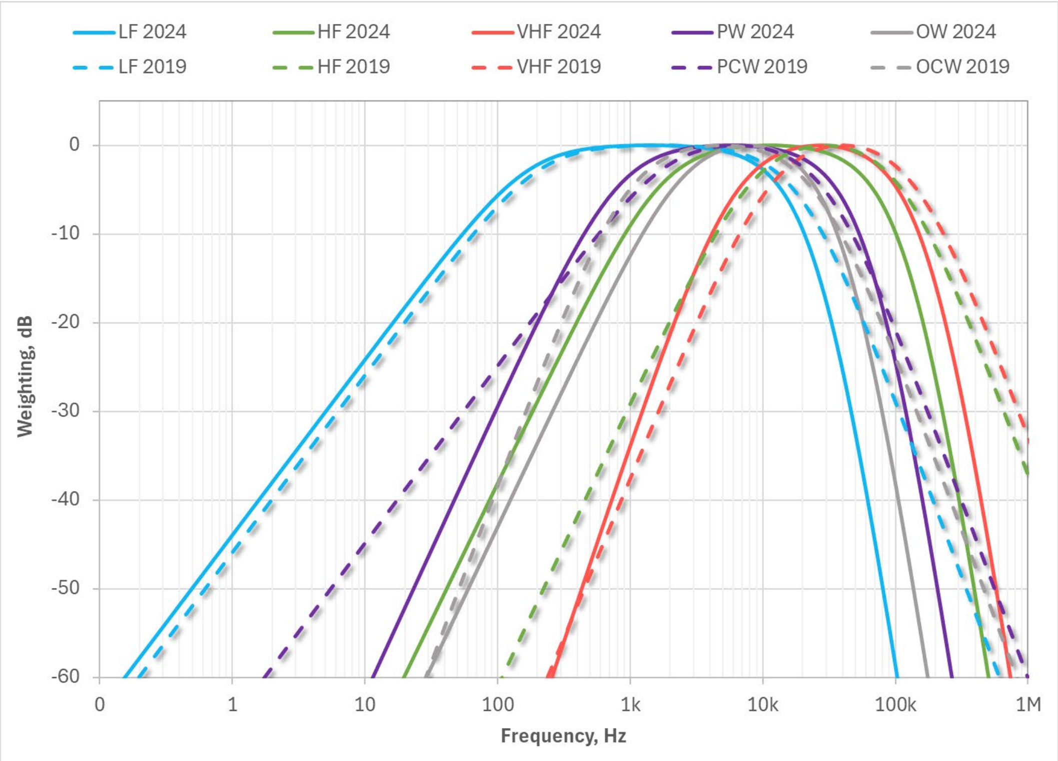

Figure 3-1: Hearing weighting functions for Pinnipeds and Cetaceans (Southall *et al*., 2019, and NMFS, 2024).

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

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

Table 3-1: Summary of TTS and PTS onset acoustic thresholds (Southall *et al*., 2019 and NMFS, 2024)

Hearing Group	Parameter	Southall *et al.* (2019) Non-Impulsive		NMFS (2024) Non-Impulsive	
		TTS	PTS	TTS	Injury
LF cetaceans	SEL, LF weighted	179	199	177	197
HF cetaceans	SEL, HF weighted	178	198	181	201
VHF cetaceans	SEL, VHF weighted	153	173	160	181
PCW (PW)	SEL, PCW (PW) weighted	181	201	175	195
OCW (OW)	SEL, OCW (OW) weighted	199	219	178	198

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). Assessing the severity of such potential impacts and development of probability-based response functions continues to be an area of ongoing scientific research interest (Graham *et al.*, 2019; Harris *et al.*, 2018; Southall *et al.*, 2021).

Southall *et al.* (2007) recommended that at the time the only feasible way to assess whether a specific noise could cause disturbance is to compare the circumstances of the situation with empirical studies. Joint Nature Conservation Committee (JNCC) guidance in the United Kingdom (UK) (JNCC, 2010) indicates that a score of five or more on the Southall *et al.* (2007) behavioural response severity scale could be significant. The more severe the response on the scale, the lower the amount of time that the animals will tolerate it before there could be adverse consequences to life functions, which would constitute a disturbance. The severity scale was revised in Southall *et al.* (2021), which included splitting severity assessment methods on captive studies from assessments on field studies. Behavioural responses related to field studies included impacts to survival, reproduction and foraging.

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).

For non-impulsive noise (e.g. vibro-piling, pile drilling, vessels etc.), the lowest sound pressure level at which a score of five or more on the Southall *et al.* (2007) behavioural response severity scale occurs for low frequency cetaceans is 90 dB to 100 dB re 1 µPa (rms). However, this relates to a study involving only migrating gray whales (*Eschrichtius robustus*). A study for minke whale showed a response score of three at a received level of 100 dB to 110 dB re 1 µPa (rms), with no higher severity score encountered for this species. For mid frequency cetaceans, a response score of eight was encountered at a received level of 90 dB to 100 dB re 1 µPa (rms), but this was for one mammal (a sperm whale Physeter macrocephalus) and might not be applicable for the species likely to be encountered in the vicinity of the project. For Atlantic white-beaked dolphin, a response score of three was encountered for received levels of 110 dB to 120 dB re 1 µPa (rms), with no higher severity score encountered. For high frequency cetaceans such as bottlenose dolphins a number of individual responses with a response score of six are noted ranging from 80 dB re 1 µPa (rms) and upwards. There is a significant increase in the number of mammals responding at a response score of six once the received sound pressure level is greater than 140 dB re 1 µPa (rms).

It is worth noting that the above sound pressure levels are based on the rms sound pressure level metric, which was historically often reported in such studies. More recent studies often use other metrics such as the SEL and care must be taken not to directly compare noise levels quoted using different parameters (refer to section 2 for a discussion of these different metrics).

The National Marine Fisheries Service (NMFS) (2024b) 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. This value sits approximately mid-way between the range of values identified in Southall *et al.* (2007) for continuous noise but is lower than the value at which the majority of marine mammals responded at a response score of six (i.e. once the received rms sound pressure level is greater than 140 dB re 1 µPa). 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.

It is worth noting 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 have been adopted.

3.4 Injury and Disturbance to Fish

For fish, the most relevant criteria for injury effects are considered to be those contained in the Noise Exposure Guidelines for Fishes and Sea Turtles (Popper *et al.*, 2014). 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:

- Fish 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.
- Fish 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.
- Fish 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 the previous two groups, extending to about 500 Hz.
- Fish 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 the previous three groups.
- 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 3-2. The only numerical criteria for these sources are for recoverable injury and TTS for fish with a swim bladder involved in hearing. 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 3-2: 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
Fish with no swim bladder (particle motion detection)	(Near) Low (Intermediate) Low (Far) Low	(Near) Low (Intermediate) Low (Far) Low	(Near) Moderate (Intermediate) Low (Far) Low
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
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

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 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 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 and as such are considered to be relatively less sensitive to sound pressure.

The most recent criteria for disturbance are considered to be 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 3-3.

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

Type of Animal	**Relative Risk of Behavioural Effects**
	Non-Impulsive Noise
Fish with no swim bladder (particle motion detection)	(Near) Moderate (Intermediate) Moderate (Far) Low
Fish where swim bladder is not involved in hearing (particle motion detection)	(Near) Moderate (Intermediate) Moderate (Far) Low
Fish where swim bladder is involved in hearing (primarily pressure detection)	(Near) High (Intermediate) Moderate (Far) Low
Eggs and larvae	(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. piling) would be predicted to result in the same potential impact, no matter the level of noise produced or the propagation characteristics.

4 Source Noise Levels

4.1 General

Underwater sound source level is usually quantified using a decibel (dB) scale with values generally referenced to 1 µPa pressure amplitude as if measured at a distance of 1 m from a hypothetical, infinitesimally small point source (sometimes referred to as the Source Level, SL). This quantity is often referred to as an equivalent monopole source level. In practice, it is not usually possible to measure sound at 1 m from a large structure, which, in reality, is more akin to a distributed sound source, but the source level metric allows comparisons and reporting of different source sound emissions on a like-for-like basis, as well as a standard input parameter for sound propagation models. In reality, for a large sound source such as a pile or vessel, the source level value at this conceptual point at 1 m from the (theoretical, infinitesimally small) acoustic centre does not exist. Furthermore, the energy is distributed across the source and does not all emanate from this imagined acoustic centre point. Therefore, the stated sound pressure level at 1 m does not occur at any point in space for these large sources. In the acoustic near field (i.e. close to the source), the sound pressure level will be significantly lower than the value predicted by the Source Level.

A wealth of experimental data and literature-based information is available for quantifying the sound emission from different construction operations. This information, which allows us to predict with a good degree of accuracy the sound generated by a source, at discrete frequencies in one-third octave bands, has been employed to characterise their acoustic emission in the underwater environment. Section 4.2 details the types of sound sources present during different construction activities, their potential signatures in different frequency bands, and acoustic levels.

4.2 Types of sound sources

4.2.1 Demolition

The project will commence with the demolition of the existing twin pile dolphin structure, using wire saw cutting equipment or other appropriate tools. Measurement data obtained during wire cutting operations indicates the sound radiated from the diamond wire cutting of a conductor was not easily discernible above the background noise (Pangerc *et al.* 2016). Given the project location within an industrial area, with a high level of ship movements this activity, it was not considered practical or necessary to include modelling of the cutting source. Resulting noise levels are expected to be below that of the area.

Vessels associated with the demolition activities are included in section 4.2.4.

4.2.2 Vibratory Piling

The design indicates the construction will include vibro-piling of 2.5 m diameter piles, approximately 10 m into the seabed, or as far as the ground conditions allow. This will operate with a 'soft start' where the power of the vibro-hammer is gradually increased over a period of 15 minutes.

An indicative source level has been extracted from literature as described in Table 4-1, scaled appropriately for the conditions (for example the water depth), and applied to a Seiche assumed spectrum shape.

Table 4-1: Summary of vibro-piling sound source.

Item	Data Source	Description	Measured Sound Level	Scaled Source Level
Vibro-piling	OSPAR (2020)	Alpha ventus OWF 2.6 m monopile installation	142 dB re 1 µPa (rms) @ 750 m	183 dB re 1 µPa (rms) re 1 m

4.2.3 Drilling

For drilled pile installation, source noise levels have been based on pile driving for the Oyster 800 project (Kongsberg, 2011) and are shown in Table 4-2. Rotary drilling is non-impulsive in character and therefore the non-impulsive injury and behavioural thresholds have been adopted for the assessment.

Table 4-2: Summary of pile drilling sound source.

Item	Description	Data Source	Source SPL
Drilling	Pile Drilling	Kongsberg (2011)	163 dB re 1 µPa (rms) re 1 m

4.2.4 Vessels

The noise emissions from the types of vessels that may be used for the project are quantified in Table 4-3, based on a review of publicly available data. Noise from the vessels themselves (e.g. propeller and thrusters) primarily dominate the emission levels.

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).

Table 4-3: Source noise data for vessels used in all activities.

Item	Description	Data Source	Source SPL, dB re 1 µPa @ 1 m (rms)
Crew Transfer Vessel	'Gwydyr Bay' Crew Vessel	Wyatt *et al.*(2020)	168
Jack up rig	Jack up rig	Evans (1996)	127
Tow	Tug	Richardson (1995)	172
Flat top barge	'MV Garrett' Partially loaded self propelled barge	Zykov and Hannay (2006)	174

5 Propagation Modelling

5.1 Propagation of Sound 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.

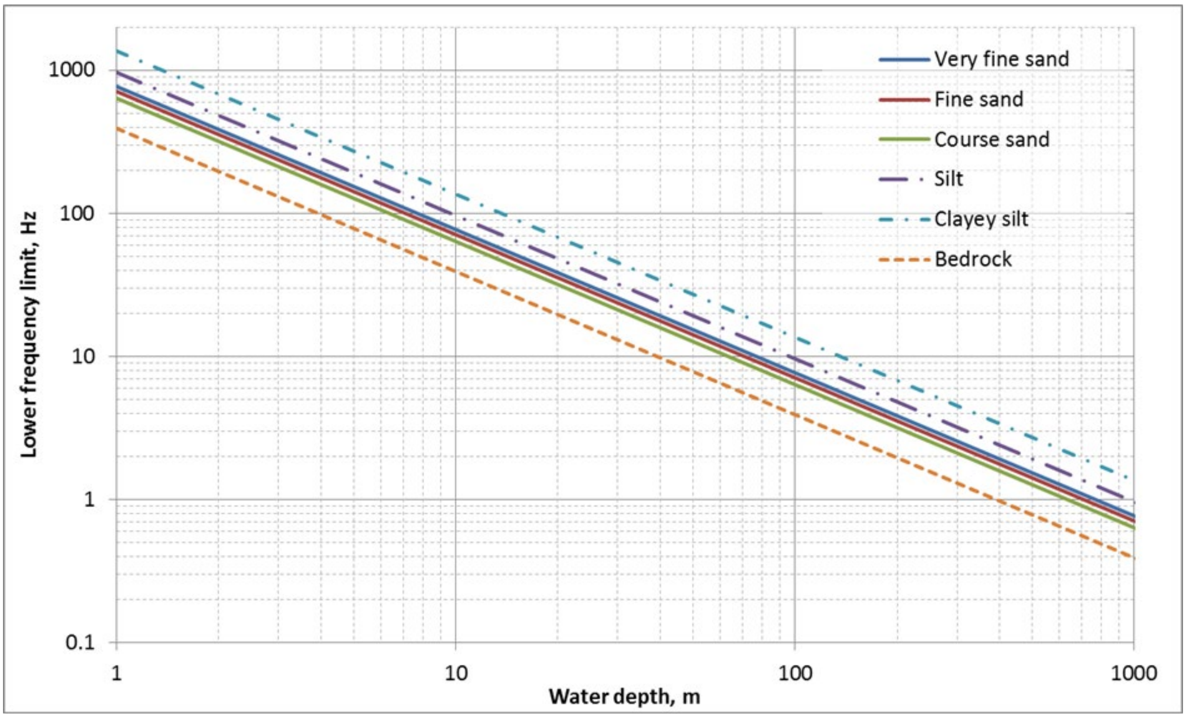

Figure 5-1: Lower cut-off frequency as a function of depth for a range of seabed types.

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.

For the noise field model, relevant model parameters were chosen based on a combination of data provided by the Applicant combined with the information gathered from the publicly available literature. 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.

5.3 Geo-Acoustic Input Parameters

Based on EMODnet 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.

Start Depth (m)	Layer	Compressional Sound Speed (Vp, m/s)	Sheer Sound Speed (Vs, m/s)	Compressional Attenuation Coefficient (αp, dB/λp)	Sheer Attenuation Coefficient (αs, dB/λs)	Density (kg/m3)
0	Coarse sand and gravel	1,961	135	0.89	1.5	2,000

5.4 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 $L_{p,pk}$, $L_{p,rms}$ 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.

5.4.1 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 Milford Haven waterway for the purpose of exposure modelling.

Species	Hearing group	Swim speed (m/s)	Source reference
Eurasian Otter *lutra lutra*	Other Marine Carnivores in Water (OCW)	1.5[1]	-
Harbour seal *phoca vitulina*	Phocid Carnivores in Water (PCW)	1.8	Thompson *et al.* (2015)
Grey seal h*alichoerus grypus*	Phocid Carnivores in Water (PCW)	1.8	Thompson *et al.* (2015)
Harbour porpoise *phocoena phocoena*	Very High Frequency (VHF) Cetacean	1.5	Otani *et al.* (2000)
Minke whale *balaenoptera acutorostrata*	Low Frequency (LF) Cetacean	2.3	Boisseau *et al.* (2021)
Bottlenose dolphin *tursiops*	High Frequency (HF) Cetacean	1.52	Bailey *et al.* (2010)
White-beaked dolphin *lagenorhynchus albirostris*	High Frequency (HF) Cetacean	1.52	Bailey *et al.* (2010)
Short beaked common dolphin *Delphinus delphis*	High Frequency (HF) Cetacean	1.52	Bailey *et al.* (2010)
Risso's dolphin *Grampus griseus*	High Frequency (HF) Cetacean	1.52	Bailey *et al.* (2010)
Fish	All hearing groups	0.5	Popper *et al.* (2014)

The OCW group has been included in order to carry out an assessment for the Euroasian otter. Although auditory thresholds for the species have only been established in air (Voight et al.2019), there are no available in-water hearing data for this species, however audiograms have been obtained for the sea otter (Ghoul & Reichmuth 2014). These indicate that the sea otter's peak underwater hearing sensitivity lies in the range 7 kHz to 16 kHz, while overall sensitivity levels are somewhat reduced compared with pinniped species, demonstrating that sea otters hearing is primarily adapted to receive airborne sounds. In this respect it may be important to consider that this assessment presumes that the otter is underwater all the time whereas in reality this may be a precautionary assumption.

[1] *Few references available for Eurasian Otter swim speeds, with APEM (2021) using 5.6 mph (2.5 m/s), therefore 1.5 m/s is considered a conservative estimate.*

6 Noise Modelling Results

6.1 Marine Mammals

Estimated ranges for industry and disturbance to marine mammals due to the continuous noise sources (vessels, vibro-piling, drilling) during all phases of the project are presented below. For the Southall *et al.* (2019) weightings and thresholds in Table 6-1, with the NMFS 2024 weightings and thresholds shown in brackets where they differ. The exposure metrics for different marine mammals and swim speeds (as detailed in section 5.4.1) were employed.

It should be noted that there is a considerable degree of uncertainty and variability in the onset of disturbance and therefore and 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 6-1: Potential impact ranges (m) for marine mammals from vessel noise during all phases, 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
	TTS	PTS	TTS	PTS	TTS	PTS	TTS	PTS	TTS	PTS	Disturbance
Vibro-piling	28 (36)	8 (10)	N/E	N/E	N/E	N/E	5 (N/E)	N/E	N/E	N/E	606
Pile Drilling	N/E	N/E	N/E	N/E	7 (N/E)	N/E	N/E	N/E	N/E	N/E	277
Crew Transfer Vessel	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	503
Jack up rig	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E
Tow	N/E	N/E	N/E	N/E	9 (N/E)	N/E	N/E	N/E	N/E	N/E	772
Self Propelled Flat Top Barge (when moving)	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	890

It is worth noting that whilst the vibro-piling source results in the largest injury ranges, the barge produces the greatest range of disturbance. The is due to the shallow water depth meaning that the lowest frequencies do not propagate (see section 5.1 and Figure 5-1). It is further noted that this is only the case when the barge is running it's own engines, and has been included as a precautionary measure.

6.2 Fish where swim bladder is involved in hearing

The ranges for recoverable injury and TTS for fish where swim bladder is involved in hearing are presented in Table 6-2 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 6-2: Estimated recoverable injury and TTS ranges from continuous sources for fish where swim bladder is involved in hearing. (N/E refers to a threshold not exceeded).

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
Vibro-piling	59	103
Drilling	N/E	N/E
Crew Transfer Vessel	N/E	6
Jack up rig	N/E	N/E
Tow	N/E	9
Self Propelled Flat Top Barge (when moving)	5	17

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 the removal of the defunct dual pile and installation of the new monopile. Based on the assessment it is concluded that:

- For vibratory piling, the greatest injury range is for LF cetaceans of 10 m and a TTS range of 36 m, (based on the NMFS (2024) threshold), the disturbance range for marine mammals is 606 m. And for fish the recoverable injury range is 59 m, and a TTS range of 103m.
- For drilling, the greatest TTS range is for VHF cetaceans at 7 m (based on the Southall *et al.* (2019) thresholds), with a disturbance range of 277 m. And for fish the thresholds are not exceeded.
- For vessel noise, the greatest range is from the tow vessel, with TTS impact ranges for VHF cetaceans of 9 m (based on the Southall *et al.* (2019) thresholds), and the greatest disturbance range is from the flat top barge, at 890 m. For fish the greatest ranges are from the flat top barge, with 5 m for recoverable injury and 17 m for TTS.

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