ESB MONEYPOINT HUB PROJECT

SI Works – Subsea Noise Technical Report

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GLOSSARY

Term	Meaning
Decibel (dB)	A customary scale most commonly used (in various ways) for reporting levels of sound. The actual sound measurement is compared to a fixed reference level and the "decibel" value is defined to be $10 \cdot \log_{10}$(actual/reference), where (actual/reference) is a power ratio. The standard reference for underwater sound pressure is 1 micro-Pascal (μPa), and 20 micro-Pascals is the standard for airborne sound. The dB symbol is followed by a second symbol identifying the specific reference value (i.e. re 1 μPa).
Grazing angle	A glancing angle of incidence (the angle between a ray incident on a surface and the line perpendicular to the surface).
Permanent Threshold Shift (PTS)	A total or partial permanent loss of hearing caused by some kind of acoustic trauma. PTS results in irreversible damage to the sensory hair cells of the ear, and thus a permanent reduction of hearing acuity.
Temporary Threshold Shift (TTS)	Temporary loss of hearing as a result of exposure to sound over time. Exposure to high levels of sound over relatively short time periods (minutes to few hours) will cause the same amount of TTS as exposure to lower levels of sound over longer time periods. The mechanisms underlying TTS are not well understood, but there may be some temporary damage to the sensory cells. The duration of TTS varies depending on the nature of the stimulus, but there is generally recovery of full hearing over time.
Sound Exposure Level (L_E)	The cumulative sound energy in an event, formally: "ten times the base-ten logarithm of the integral of the squared pressures divided by the reference pressure squared". Equal to the often seen "SEL" or "dB SEL" quantity. Defined in: ISO 18405:2017, 3.2.1.5
Sound Pressure level (SPL)	The average sound energy over a specified period of time, formally: "ten times the base-ten logarithm of the arithmetic mean of the squared pressures divided by the squared reference pressure". Equal to the deprecated "RMS level", "dB_{rms}" and to L_{eq} if the period is equal to the whole duration of an event. Defined in ISO 18405:2017, 3.2.1.1
Peak Level, Peak Pressure Level (L_P)	The maximal sound pressure level of an event, formally: "ten times the base-ten logarithm of the maximal squared pressure divided by the reference pressure squared" or "twenty time the base-ten logarithm of the peak sound pressure divided by the reference pressure, where the peak sound pressure is the maximal deviation from ambient pressure". Defined in ISO 18405:2017, 3.2.2.1

ACRONYMS

Term	Meaning
ADD	Acoustic Deterrent Device
LF	Low Frequency (Cetaceans)
HF	High Frequency (Cetaceans)
VHF	Very High Frequency (Cetaceans)
MF	*Mid Frequency (Cetaceans) – DEPRECATED only for reference to NOAA/NMFS 2018 groups*
NMFS	National Marine Fisheries Service
OW/OCW	Otariid pinnipeds/Other Carnivores in water (refers to the same weighting and animal groups)
PTS	Permanent Threshold Shift
PW/PCW	Phocid pinnipeds
RMS	Root Mean Square
L_E	Sound Exposure Level, [dB]
SPL	Sound Pressure Level, [dB]
L_P	Peak Pressure Level, [dB]
TTS	Temporary Threshold Shift
PTS	Permanent Threshold Shift

UNITS

Unit	Description
dB	Decibel (Sound)
Hz	Hertz (Frequency)
kHz	Kilohertz (Frequency)
kJ	Kilojoule (Energy)
km	Kilometre (Distance)
km^2	Kilometre squared (Area)
m	Metre
ms	Millisecond (10^{-3} seconds) (Time)
ms^{-1} or m/s	Metres per second (Velocity)
µPa	Micro Pascal
Pa	Pascal (Pressure)
psu	Practical Salinity Units (parts per thousand of equivalent salt in seawater)
kg/m^3	Specific density (of water, sediment or air)
Z	Acoustic impedance [$kg/(m^2 \cdot s)$ or $(Pa \cdot s)/m^3$]

Units will generally be enclosed in square brackets e.g.: “[m/s]”

1 INTRODUCTION

1.1 Overview

This Subsea Noise Technical Report presents the results of a desktop study considering the potential for Momentary, Brief and Temporary effects[1] of underwater noise on the marine environment from the site investigation works, which includes a geophysical survey to map the application area (hereafter referred to as "the Project"). The site forms a single contiguous area of approximately 9 km², or a ~1.3 km wide band of 6 km length along the north edge of the Shannon Estuary, centred on the Moneypoint power station, 5 km south-east of Kilrush, Co. Clare.

Sound is readily transmitted into the underwater environment and there is potential for the sound emissions from anthropogenic sources to adversely affect marine mammals and fish. At close ranges from a noise source with high noise levels, permanent or brief hearing damage may occur to marine species, while at a very close range gross physical trauma is possible. At long ranges (several kilometres) the introduction of any additional noise could, for the duration of the activity, potentially cause behavioural changes, for example to the ability of species to communicate and to determine the presence of predators, food, underwater features, and obstructions.

This report provides an overview of the potential effects due to underwater noise from the Project on the surrounding marine environment based on the Southall et al. 2019 and Popper et al. 2014 framework for assessing impact from noise on marine mammals and fishes.

Consequently, the primary purpose of the subsea noise assessment is to predict the likely range of onset of injury as given in the relevant guidance (Temporary Threshold Shift) and ranges to potential behavioural effects due to anthropogenic noise as a result of the Project.

1.2 Statement of Authority

This report has been prepared by RPS on behalf of the ESB. The technical competence of the authors is outlined below:

[redacted] is a Senior Project Scientist with RPS. He holds a master's degree in biology, biosonar and marine mammal hearing from University of Southern Denmark. Rasmus has over 10 years' experience as a marine biologist and over 8 years' experience with underwater noise modelling and marine noise impact assessments. [redacted] has co-developed commercially available underwater noise modelling software, as well developed multiple source models for e.g. impact piling, seismic airgun arrays and sonars.

[redacted] is an Associate in Acoustics with RPS. He holds a BA BAI in Mechanical Engineering from Trinity College Dublin (2004) and a PhD in Acoustics and Vibration from Trinity College Dublin (2008). He is a Chartered Engineer with Engineers Ireland. [redacted] has 19 years' experience in environmental projects including planning applications and environmental impact assessments for a wide range of strategic infrastructure projects.

[redacted] is Technical Director in the Environmental Services Business Unit in RPS. He has over 24 years' experience. He holds an honours degree in Civil Engineering (B.E.) from NUI, Galway, a postgraduate diploma in Environmental Sustainability from NUI, Galway, and a Masters in Business Studies from the Irish Management Institute/ UCC. [redacted] is also a Chartered Engineer. He has managed the delivery of numerous environmental projects including marine and terrestrial projects that have required environmental impact assessment, appropriate assessment and Annex IV species reports.

[1] Effects are defined in accordance with the EPA Guidelines on the information to be contained in Environmental Impact Assessment Reports (2022), Table 3.4 Description of Effects, pp.50-52.

2 ASSESSMENT CRITERIA

2.1 General

To determine the potential spatial range of injury and disturbance, assessment criteria have been developed based on a review of available evidence including national and international guidance and scientific literature. The following sections summarise the relevant assessment criteria and describe the evidence base used to derive them.

Underwater noise has the potential to affect marine life in different ways depending on its noise level and characteristics. Assessment criteria generally separate sound into two distinct types, as follows:

- Impulsive sounds which are typically transient, momentary (less than one second), broadband, and consist of high peak sound pressure with rapid rise time and rapid decay (ANSI 1986; NIOSH 1998; ANSI 2005). This category includes sound sources such as seismic surveys, impact piling and underwater explosions. Also included are sounds under 1 second in duration with a weighted kurtosis over 40 (see note below*).
- Non-impulsive (continuous) sounds which can be broadband, narrowband or tonal, momentary, brief or prolonged, continuous or intermittent and typically do not have a high peak sound pressure with rapid rise/decay time that impulsive sounds do (ANSI 1995; NIOSH 1998). This category includes sound sources such as continuous vibro-piling, running machinery, some sonar equipment and vessels.

* Note that the European Guidance: “Monitoring Guidance for Underwater Noise in European Seas, Part II: Monitoring Guidance Specifications” (MSFD Technical Subgroup on Underwater Noise, 2014) includes sonar as impulsive sources (section 2.2 of document). However, the guidance suggests that “all loud sounds of duration less than 10 seconds should be included” as impulsive. This contradicts research on impact from impulsive sounds suggesting that a limit for “impulsiveness” can be set at a kurtosis[2] of 40 (Martin, et al., 2020). This latter criterion has been used for classification of impulsive versus non-impulsive for sonars and similar sources. The justification for departing from the MSFD criterion is that the Southall 2019 framework limits are based on the narrower definition of impulsive as given above under “Impulse sounds”.

The acoustic assessment criteria for marine mammals and fish in this report has followed the latest international guidance (based on the best available scientific information), that are widely accepted for assessments in the UK, Europe and worldwide (Southall, et al.; Popper, et al., 2014).

2.2 Injury to Marine mammals

Underwater noise has the potential to affect marine life 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. This assessment has added a fifth zone, the “zone of temporary hearing loss”. The five zones are as follows:

- **The zone of audibility**: this is the area within which the animal can detect the sound. Audibility itself does not implicitly mean that the sound 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 sounds 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 sound 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 audibility does not necessarily evoke a reaction. For most species there is very little data on response, but for species like harbour porpoise there exist several studies showing a relationship between received level and probability of response (Graham IM, 2019; Sarnoci ́nska J, 2020; BOOTH, 2017; Benhemma-Le Gall A, 2021).

[2] Statistical measure of the asymmetry of a probability distribution.

- **The zone of temporary hearing loss**: The area where the sound level is high enough to cause the auditory system to lose sensitivity for minutes to few hours, causing loss of “acoustic habitat”: the volume of water that can be sensed acoustically by the animal. This effect is abbreviated “TTS”.
- **The zone of injury / permanent hearing loss**: this is the area where the sound level is high enough to cause tissue damage in the ear. This is usually classified as permanent threshold shift (PTS). At even closer ranges, and for very high intensity sound sources (e.g. underwater explosions), physical trauma or acute mortal injuries are possible.

  Note that guidance from the Irish regulatory body classifies TTS (hearing loss persisting minutes to few hours) as causing injury, given the potential secondary effects of impacted hearing sensitivity.

For this study, it is the **zones of temporary hearing loss (area within range to TTS risk)**[3] that are of primary interest, along with estimates of behavioural impact ranges. To determine the potential spatial range of injury and behavioural change, 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.

The zone of injury in this study is classified as the distance over which a marine mammal will likely suffer TTS. Injury thresholds are based on a dual criteria approach using both un-weighted LP (maximal instantaneous SPL) and marine mammal hearing weighted LE. The hearing weighting function is designed to represent the sensitivity for each group within which acoustic exposures can have auditory effects. The categories include:

- **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, earless seals, e.g.: harbour seal (*Phoca vitulina*) and grey seal (*Halichoreus grypus*); hearing in air is considered separately in the group 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).
- **Sirenians (SI):** Manatees and dugongs. This group is only represented in the NOAA guidelines.

These weightings have therefore been used in this study and are shown in Figure 2.1. It should be noted that not all the above categories of marine mammal will be present in the Project area, but criteria are presented in this report for completeness.

Both the criteria for impulsive and non-impulsive sound are relevant for this study given the nature of the sound sources proposed for this Project. The PTS and TTS criteria proposed by Southall et al. (2019) are summarised in Table 2 1.

Note that in Ireland the TTS limits are the main criteria, with PTS limits given for completeness.

[3] Department of Arts, Heritage and the Gaeltacht (2014) p. 11 establishes TTS as an injury.

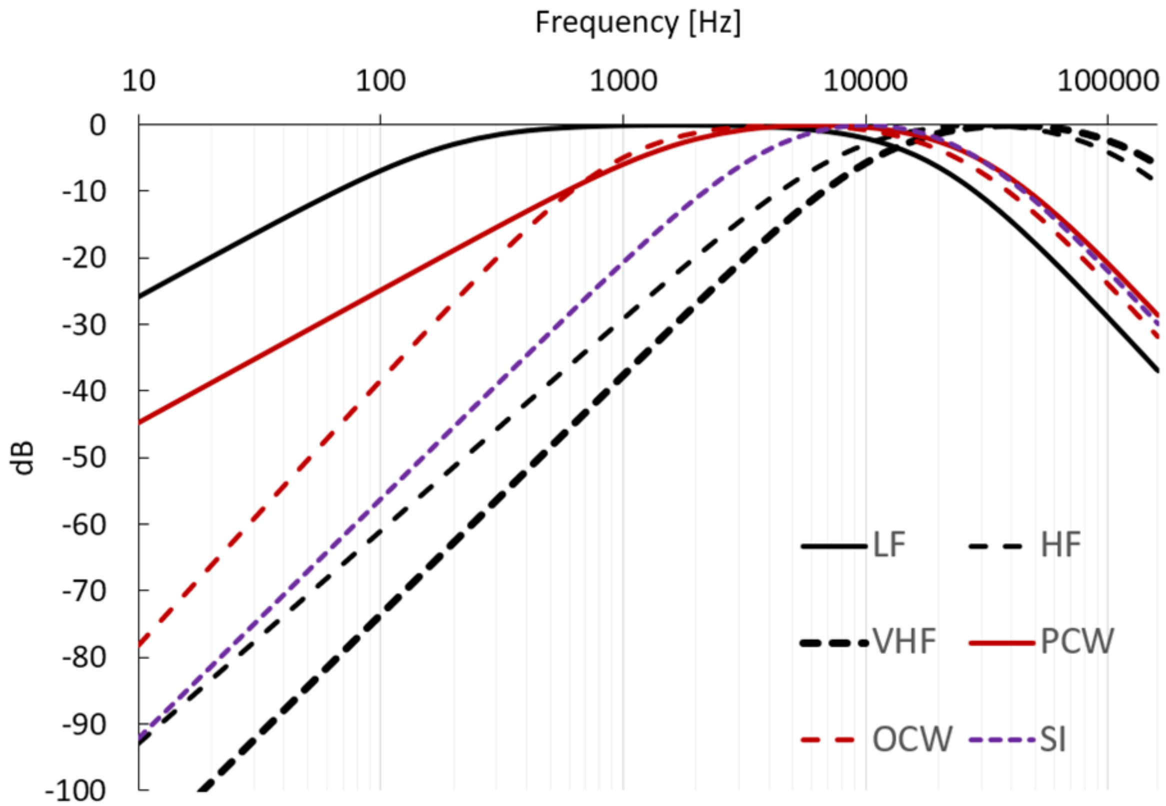

Figure 2.1 Hearing weighting functions for pinnipeds, cetaceans and sirenians (NMFS, 2018; Southall et al. 2019)

Table 2.1 PTS and TTS onset acoustic thresholds (Southall et al., 2019; Tables 6 and 7). TTS criteria in bold

Hearing Group	Parameter	Impulsive [dB]		Non-impulsive [dB]	
		PTS	TTS	PTS	TTS
Low frequency (LF) cetaceans	L_P, (unweighted)	219	**213**	-	**-**
	L_E, (LF weighted)	183	**168**	199	**179**
High frequency (HF) cetaceans	L_P, (unweighted)	230	**224**	-	**-**
	L_E, (MF weighted)	185	**170**	198	**178**
Very high frequency (VHF) cetaceans	L_P, (unweighted)	202	**196**	-	**-**
	L_E, (HF weighted)	155	**140**	173	**153**
Phocid carnivores in water (PCW)	L_P, (unweighted)	218	**212**	-	**-**
	L_E, (PW weighted)	185	**170**	201	**181**
Other marine carnivores in water (OCW)	L_P, (unweighted)	232	**226**	-	**-**
	L_E, (OW weighted)	203	**188**	219	**199**
Sirenians (SI) (NOAA only)	L_P, (unweighted)	226	**220**	-	**-**
	L_E, (OW weighted)	190	**175**	206	**186**

These updated marine mammal injury criteria were published in March 2019 (Southall, et al.). The paper utilised the same hearing weighting curves and thresholds as presented in the preceding regulations document NMFS (2018) with the main difference being the naming of the hearing groups and introduction of additional thresholds for animals not covered by NMFS (2018). A comparison between the two naming conventions is shown in Table 2.2.

The naming convention used in this report is based upon those set out in Southall et al. (2019). Consequently, this assessment utilises criteria which are applicable to both NMFS (2018) and Southall et al. (2019).

Table 2.2 PTS and TTS onset acoustic thresholds (Southall et al., 2019; Tables 6 and 7). TTS criteria in bold

NMFS (2018) hearing group name	Southall et al. (2019) hearing group name
Low-frequency cetaceans (LF)	LF
Mid-frequency cetaceans (MF)	HF
High-frequency cetaceans (HF)	VHF
Phocid pinnipeds in water (PW)	PCW
Otariid pinnipeds in water (OW)	OCW
Sirenians (SI)	Not included

2.3 Disturbance to Marine Mammals

Disturbance thresholds for marine mammals are summarised in Table 2.3. These are based on “Level B harassment” of NMFS (National Marine Fisheries Service, 2005). Note that the non-impulsive threshold can often be lower than ambient noise for coastal waters with some human activity, meaning that ranges determined using this limit will tend to be higher than actual ranges.

Table 2.3 Disturbance Criteria for Marine Mammals

Effect	Non-Impulsive Threshold	Impulsive Threshold
Disturbance (all marine mammals)	120 dB SPL	160 dB $L_{E\ \text{single impulse}}$ or 1-second L_E

2.4 Injury and Disturbance to Fish and Sea Turtles

The injury criteria used in this noise assessment are given in Table 2.4 and Table 2.5 for impulsive noises and continuous noise respectively. Peak pressure level (L_P) and exposure level (L_E) criteria presented in the tables are unweighted. Physiological effects relating to injury criteria are described below (Popper, et al., 2014):

- **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 (“PTS” in tables and figures)**: Tissue damage 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.

  The PTS term is used here to describe this, more serious impact, even though it is not strictly permanent for fish. This is to better reflect the fact that this level of impact is perceived as serious and detrimental to the fish.
- **Temporary Threshold Shift (TTS)**: Short term changes (minutes to few hours) 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 sound that causes TTS, normal hearing ability returns over a period that is variable, depending on many factors, including the intensity and duration of sound exposure.

Popper et al. 2014 does not set out specific TTS limits for L_P and for disturbance limits for impulsive noise for fishes. Therefore publications: “Washington State Department of Transport Biological Assessment Preparation for Transport Projects Advanced Training Manual” (WSDOT, 2011) and “Canadian Department of Fisheries and Ocean Effects of Seismic energy on Fish: A Literature review” (Worcester, 2006) on effects of seismic noise on fish are used to determine limits for these:

1. The criteria presented in the Washington State Department of Transport Biological Assessment Preparation for Transport Projects Advanced Training Manual (WSDOT, 2011). The manual suggests an un-weighted sound pressure level of 150 dB SPL (assumed to be duration of 95 % of energy) as the criterion for onset of behavioural effects, based on work by (Hastings, 2002). Sound pressure levels in excess of 150 dB SPL are expected to cause brief 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. Again, the threshold is implemented as either single impulse LE or 1 second LE, whichever is greater.
2. The report from the Canadian Department of Fisheries and Ocean "Effects of Seismic energy on Fish: A Literature review on fish" (Worcester, 2006) found large differences in response between experiments. Onset of behavioural response varied from 107-246 dB LP, the 10th percentile level for behavioural response was 158 dB L_P, given the large variations in the data, this has been rounded to 160 dB L_P as the behavioural limit for fishes for impulsive noise, given the already considerable variation in the underlying data.

Table 2.4 Criteria for onset of injury to fish and sea turtles due to impulsive noise

Type of animal	Unit	Mortality and potential mortal injury [dB]	Recoverable injury (PTS) [dB]	TTS [dB]	Behavioural [dB]
Fish: no swim bladder (particle motion detection)	L_E	219[1]	216[1]	186[1]	150[3]
	L_P	213[1]	213[1]	193[2]	189[2]
Fish: where swim bladder is not involved in hearing (particle motion detection)	L_E	210[1]	203[1]	186[1]	150[3]
	L_P	207[1]	207[1]	193[2]	189[2]
Fish: where swim bladder is involved in hearing (primarily pressure detection)	L_E	207[1]	203[1]	186	150[3]
	L_P	207[1]	207[1]	193[2]	189[2]
Sea turtles	L_E	210[1]	(*Near*) High (*Intermediate*) Low (*Far*) Low	-	-
	L_P	207[1]		-	-
Eggs and larvae	L_E	210[1]	(*Near*) Moderate (*Intermediate*) Low (*Far*) Low	-	-
	L_P	207[1]		-	-

1 (Popper et al. 2014)

2 (Worcester, 2006)

3 (WSDOT, 2011)

Where Popper et al. 2014 present limits as ">" 207 or ">>" 186, the analysis ignores the "greater than" and uses the threshold level as given.

Relevant limits for fishes relating to PTS, TTS, and behaviour are given in the Table 2.5. Note that for the behaviour limit the impulsive limit has been used as the basis for the continuous noise limit, in the absence of better evidence.

Table 2.5 Criteria for fish from non-impulsive noise from Popper et al. 2014

Type of animal	Unit	Mortality and potential mortal injury	Recoverable injury (PTS) [dB]	TTS [dB]	Behavioural [dB]
All fishes	L_E	-	222	210	150 [SPL]*

*Based on the impulsive criteria.

3 SITE, SURVEY METHOD, AND ENVIRONMENT

3.1 Site Location

Moneypoint is located on the northern shore of the Shannon Estuary in Co. Clare, approximately 3 km west of Killimer and 6 km south-east of Kilrush (Figure 3.1). The site was acquired by ESB in the late-1970s to develop a coal fired power plant as part of its strategy to diversify from oil dependent electricity generation. It consists of both a terrestrial and marine area; along with the interface between the two.

The site investigation works form a single contiguous area of approximately 9 km², or a ~1.3 km wide band of 6 km length along the north edge of the Shannon Estuary, centred on the Moneypoint power station (see Figure 3.2).

The sediment is mainly sand to fine/medium gravel, and depths are <60 m (assuming high tide).

Figure 3.1 Location of Moneypoint Generating Station Site in the context of the Shannon Estuary, Co. Clare

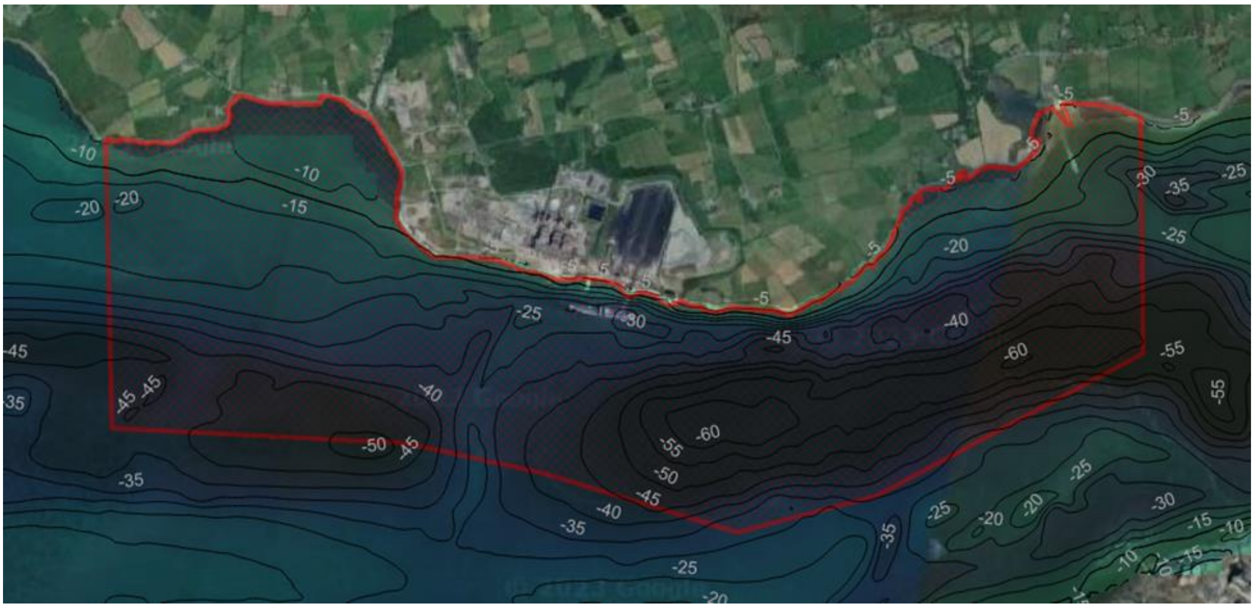

Figure 3.2 Site Investigation Survey Area

3.2 Survey Method

3.2.1 Overview

For a full description of the site investigation works (which includes both geophysical and geotechnical marine site investigations) please refer to Section 2 of the accompanying Assessment of Impact on the Maritime Usage (AIMU) Report.

In summary, the site will be surveyed by a small to medium vessel (15-80 m length, a 70 m vessel forming the basis of this assessment) with various geophysical survey equipment (see Table 4.1 in Section 4), with survey lines to cover the total area. The density of survey lines will depend on the local depth, as the “width of detection” (swath) is a constant angle, thus greater depths will mean that survey lines are spread further apart.

Details on the expected equipment to be used (or representative equipment) can be found in Section 4, Source Noise Levels.

The vessel is assumed to move at 4 knots during surveying (2 m/s). This speed affects the time a stationary receiver is exposed to the survey, and hence a slower speed is precautionary. The actual speed will likely be over 4 knots (> 2 m/s).

Survey line layouts as given in Section 3.2.2 are designed to be representative of the acoustic impact of the survey, not the actual survey layout. The acoustic impact is mainly affected by the survey speed and the total time spent in a given area, not the precise line layout.

3.2.2 Survey Layout Example

For the survey a line spacing of 25 m has been assumed as this is the largest line spacing for the magnetometer, and smaller than any required line spacing for the geophysical equipment. Even if the magnetometer is not equipped/active for all vessels, this spacing will be conservative as it is at least as dense as required for the remaining survey equipment. Where the magnetometer is not in use the actual line spacing will be 2-5 times the local depth, meaning that it is more practical to run survey lines along the shore (consistent depths means consistent swath width). See Figure 3.3 for example of this as well as the assumed 25 m survey grid.

At a speed of 4 knots (2 m/s) the longest transect will be approximately 50 minutes (6200 m / 2.06 m/s / 60 sec/min = 50 min).

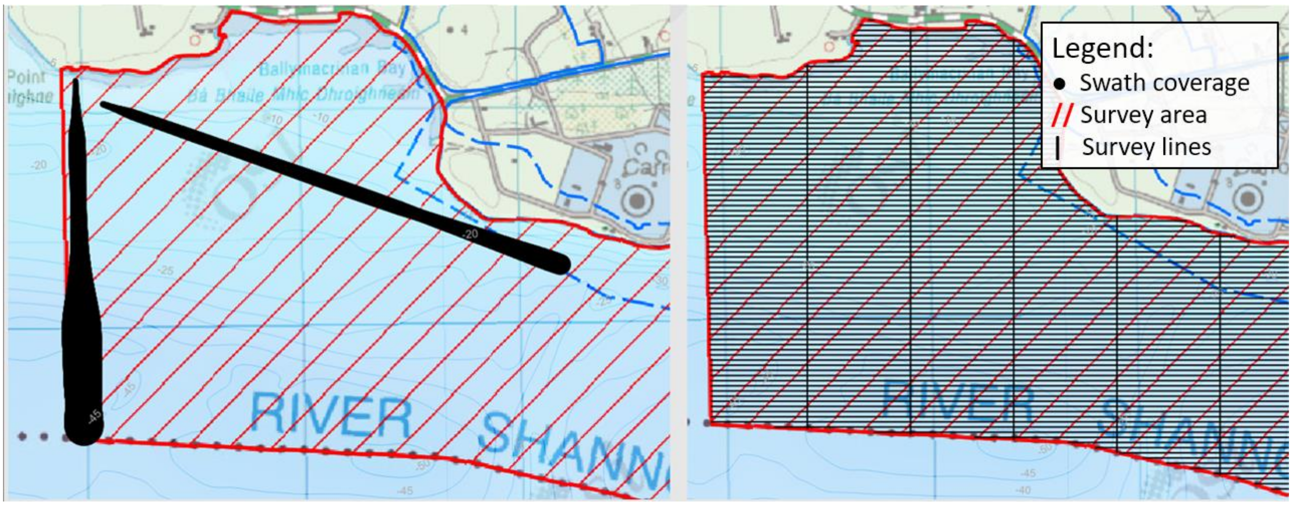

Figure 3.3 Left: Example transects showing swath width (black areas) as an effect of depth. Right: Survey lines given 25 m spacing, and validation transects at 500 m spacing

3.3 Environment

3.3.1 Water Properties

Water properties were determined from historical data for the area. Where a range of values are expected, the value leading to the lowest transmission loss, highest received level, was used, resulting in a more conservative assessment. This use of values leading to lowest transmission loss (highest temperature, lowest salinity, highest tide) also covers seasonal variation at the site.

- Temperature: 20 degrees – Based on maximal temperature given by Met Eireann for Irish marine waters (16 degrees)[4] along with data from seatemperature.net for water temperatures near Shannon town. A higher temperature is more conservative.
- Salinity: Set at 30 psu - lowest, most conservative, value observed 2007-2011 (INFOMAR, 2012).
- Soundspeed profile: Assumed uniform given high mixing as a result of tidal flows. A uniform soundspeed profile is conservative compared to the likely downward refracting soundspeed profiles seen during summer months (higher temperature in the surface leads to higher soundspeeds). No significant halocline is expected, due to the relative proximity to the sea, and distance to the River Shannon outflow into the estuary.

3.3.2 Sediment Properties

Sediment properties are taken from EMODnet[5] "Folk 7-class Classification" and nautical charts[6]. A sediment model (Ainslie, 2010) was used to derive the acoustic properties of the sediments from the grain size. An "acoustically harder" sediment (higher density and soundspeed) will be conservative, in that it will improve sound propagation in the water column. Therefore, while it is expected to find finer, acoustically softer sediments present, these will have higher transmission losses, and will thus be covered by the more conservative assumption of the coarser sediment.

Table 3.1 Sediment properties

Sediment type (Folk 7)	Density [kg/m³]	Soundspeed [m/s]	Grain size [mm] (nominal)
Coarse substrate	2595	2034	3.5

[4] https://www.met.ie/climate/average-monthly-sea-temperature-at-malin-head/

[5] https://emodnet.ec.europa.eu/ sediment model "Folk 7-class" classification.

[6] https://fishing-app.gpsnauticalcharts.com/i-boating-fishing-web-app/fishing-marine-charts-navigation.html

4 SOURCE NOISE LEVELS

Underwater noise sources are usually quantified in dB scale with values generally referenced to 1 µPa pressure amplitude as if measured at a hypothetical distance of 1 m from the source (called the Source Level). In practice, it is not usually possible to measure at 1 m from a source, but the metric allows comparison and reporting of different source levels on a like-for-like basis. In reality, for a large sound source this imagined point at 1 m from the 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 for large sources. For such large source, 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 back-calculated source level (SL).

4.1 Source Models

The noise sources and activities investigated during the subsea noise assessment study are summarised in Table 4.1.

Source levels for the active equipment were combined to produce a “combined” source that represents the survey vessel’s sound signature while actively surveying during the survey (see Figure 4.1 and Figure 4.2).

Note that source levels vary depending on the location of the survey due to the ping rate, and therefore the SPL of the source, varies with the local depth.

Multibeam echosounders have been included in the assessment even though their main frequencies lie well above the hearing range of the VHF hearing group. This is because, given the way the signals are produced some spectral leakage (energy “leakage” into other frequencies due to the acoustic properties of the transducer) will occur, resulting in significant acoustic energy to frequencies audible to both dolphins and porpoises.

As sonars and echosounder have narrow beams and therefore “sweep” through the water body, they are harder to model for expected received level. For the assessment the energy in the beam has been converted to an equivalent spherical source (of lower spherical SPL than the in-beam level) to ensure that a randomly positioned receiver would receive the same energy. Note that while extremely narrow beams (0.1-1 degree) are often stated for sonars and echosounders, this is the width of the beam where the received level drops by a set amount, usually 3 dB (if stated at all). There is a significant amount of acoustic energy outside the beam, and this has been included in the assessment.

The parametric sub-bottom profilers have quite narrow beams directed vertically down, with levels attenuating rapidly as the angle away from vertical increases. For exposure modelling [dB L_E], the source level at an angle corresponding to the specular reflection of the sediment, 47 degrees from vertical[7], has been used for the assessment. This means that for the deeper sites (60 m) there will be a cone of diameter approximately 65 m radius at the sediment (depth of 60 m) which will underpredict the impact for animals. As this zone is a cone, the radius at half depth, is half as big, approximately 33 m at 30 m depth. Risk ranges tend to be larger than 65 m, and animals will be able to hear the vessel approaching with time to evade this cone.

Given that a parametric system introduces a significant increase in sound levels around the most sensitive region of the HF hearing group, compared with the remaining systems, it was chosen to split the assessment into two parts. This assessment presents (a) scenario with no parametric system active and (b) scenario with a parametric system active. This approach provides a better insight into the effect of including a parametric system, while also covering the scenario where no such system is used.

For peak pressure level [dB L_P] propagation modelling the actual directivity of common SBPs has been used to model the peak pressures at range.

[7] There is still reflection at steeper angles, but also a large loss to the sediment, meaning rapid attenuation, with increasing number of surface-bottom reflections.

Table 4.1 Summary of Noise Sources and Activities Included in the Subsea Noise Assessment

Equipment	Source level [SPL]	Primary frequencies (-20 dB width)	Source model details	Impulsive/non-impulsive
Survey vessel (based on “Fugro Discovery”, IMO 9152882)	165 dB SPL	10-2,500 Hz	(Wittekind, 2014; Simard, et al., 2016; Heitmeyer, 2001)	Non-impulsive
Multibeam echosounder Based on: “Teledyne Reson Seabat T50-R”, “Kongsberg GeoAcoustics GeoSwath Plus interferometric” & “R2 Sonic 2024”	182 dB SPL (ping rate dependent, equivalent spherical level)	200,000 Hz & 250,000 Hz	Source levels based on von Hann windowed FM or CW pulses at max SPL as given by manufacturer.	Impulsive
Side scan sonar Based on: “Kongsberg Geoacoustic 160”, “Edgetech 4200”, “C-Max CM2 system” & “Klein Hydro Scan”	170 dB SPL (ping rate dependent, equivalent spherical level)	300,000 – 445,000 Hz	Source levels based on von Hann windowed FM or CW pulses at max SPL as given by manufacturer.	Impulsive
Sub-bottom profiler 1 Based on: “Edgetech 3100, “Edgetech 3300, “Geopulse 5430A, “400 Joule Generic sparker”, “350 Joule Generic Boomer”	188 dB SPL (ping rate dependent, off-axis level) 220 dB Lp (on-axis)	600 – 12,000 Hz	Source levels based on von Hann windowed FM or CW pulses at max SPL as given by manufacturer as well as generic models for Sparker and Boomer.	Impulsive
Sub-bottom profiler 2 Based on: “Sub-bottom profiler 1” & “Innomar Parametric (dual frequency)”	197 dB SPL (ping rate dependent, off-axis level) 247 dB Lp (on-axis)	1000 – 4,000 Hz & 85,000 – 115,000 Hz	Source levels based on von Hann windowed FM or CW pulses at max SPL as given by manufacturer.	Impulsive
Vibro-coring / drilling	195 dB SPL	10 – 3,000 Hz	(Bureau of Ocean Energy Management) (Center for Marine Acoustics, 2023)	Non-impulsive

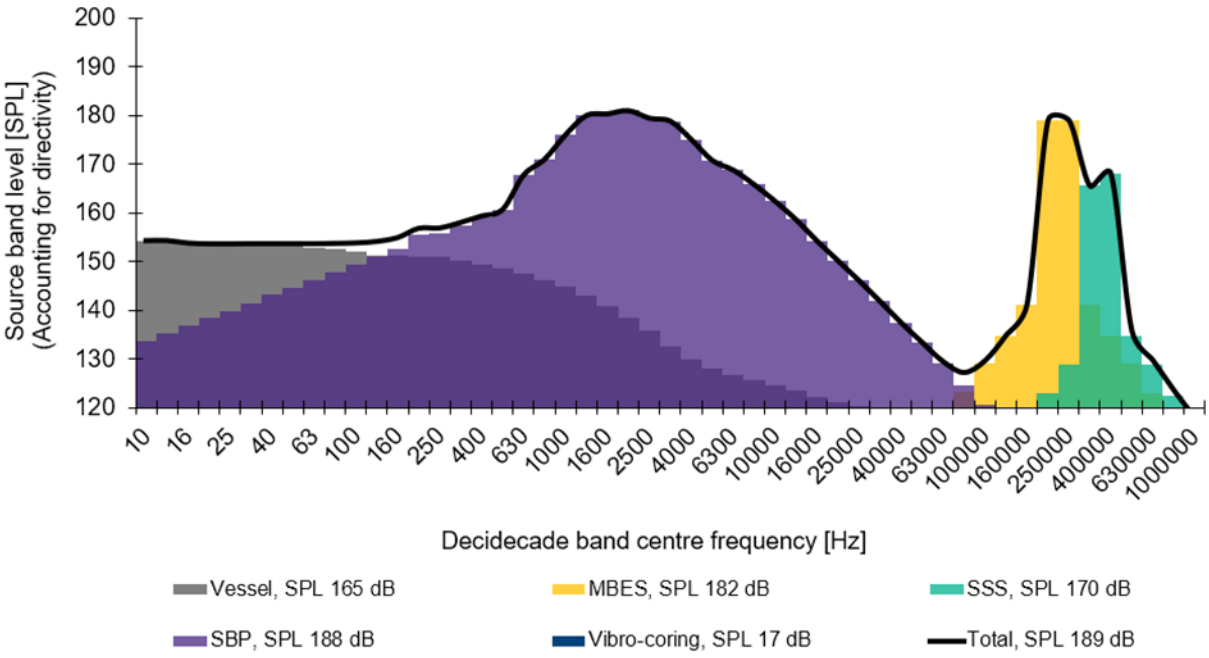

Figure 4.1 **Overview of sound sources as SPL at 1 m. Combined source (black solid line) represents source during survey without a parametric SBP (SBP 2 in Table 4.1)**

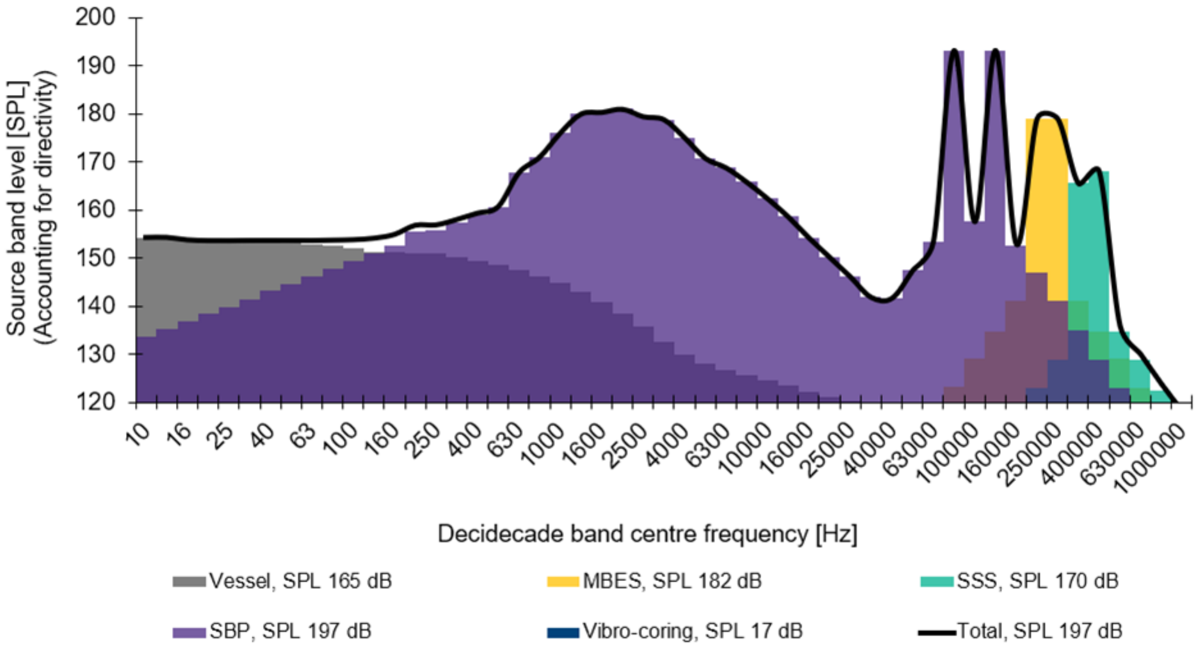

Figure 4.2 **Overview of sound sources as SPL at 1 m. Combined source (black solid line) represents source during survey with a parametric SBP (SBP 2 in Table 4.1)**

5 SOUND PROPAGATION MODELLING METHODOLOGY

There are several methods available for modelling the propagation of sound between a source and receiver ranging from very simple models which simply assume spreading according to a $10\times\log_{10}$(range) or $20\times\log_{10}$(range) relationship 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 which lie somewhere in between these two extremes in terms of complexity, e.g. Rogers, 1981; Weston, 1971.

For this project a semi-empirical model ("Roger's" model) was used for calculating transmission losses of SPL and L_E, measures related to acoustic energy, where modelling of peak pressure levels (L_P) was done with full waveform propagation in dBSea's ray tracing algorithm (dBSeaRay).

5.1 Semi-empirical models

For simpler scenarios where the sediment is relatively uniform and mostly flat or where great detail in modelling is not warranted, due to uncertainty in model input or where the source level is relatively low compared to the receiver sensitivity, the speed of these simpler models is preferred over the higher accuracy of numerical models and are routinely used for these types of assessments. For this assessment the "Roger's" model (Rogers, 1981) has been used. This produces very similar output to the also regularly applied "Weston" model (Weston, 1971), but Roger's produces a smoother transition between spherical/cylindrical spreading, mode-stripping and single mode regions of the loss and would normally be preferred unless comparing to earlier work done using the Weston model. Both these models are compared to measurements in the papers describing them and are both capable of accurate modelling in acoustically simpler scenarios[8]. A comparison between Roger's and Weston's model has been included in this report for a 30 m deep scenario to show the similarities in the transmission losses they predict. The Roger's model is, however, preferred, as it is more conservative for lower frequencies, as it does not have "sharp" steps between different propagation regions.

These semi-empirical models will tend to underestimate the transmission losses (leading to estimated greater than actual impact) due primarily to the omission of surface roughness, wind effects and shear waves in the sediment.

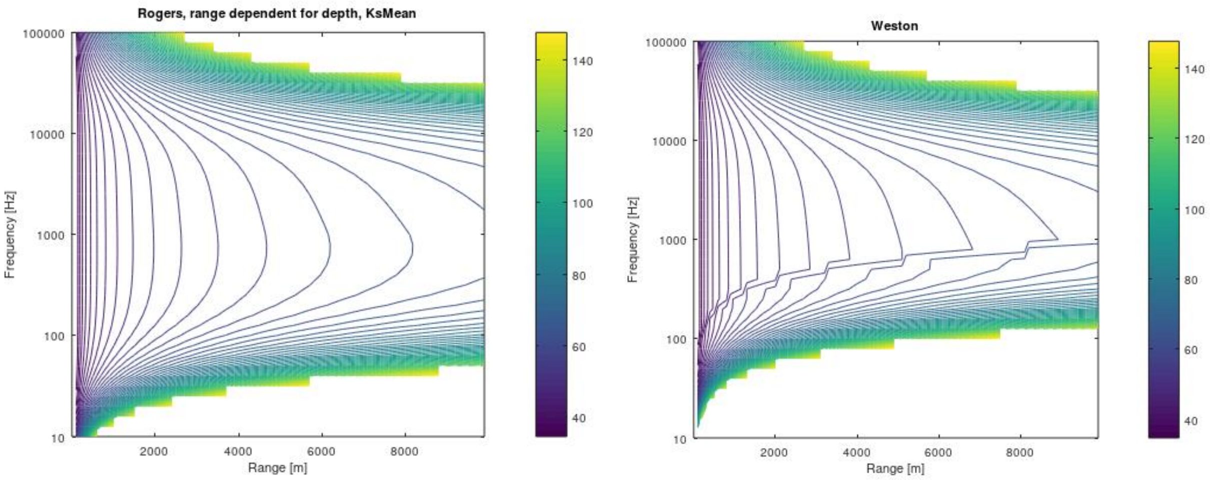

Figure 5.1 Comparison of two semi-empirical models over a sandy bottom at 30 m depth. Transmission loss in dB versus range and frequency

[8] Simpler meaning shallow in relation to the wavelengths and with no significant sound speed gradient in the water column.

5.2 Analytical models

For the impulsive sources dBSea software's ray tracing solver dBSeaRay has been used as this accounts for the full waveform propagation of the impulsive. This means including surface and bottom reflections as well as time-of-arrival in the calculations, as these are important to include to correctly estimate the effects of constructive and destructive interference. dBSea solvers are validated against a range of opensource solvers for so-called "standard scenarios" that have agreed solutions[9].

5.3 Exposure Calculations (dB L_E)

To compare modelled levels with the two impact assessment frameworks (Southall et al. 2019 & Popper et al. 2014) it is necessary to calculate received levels as exposure levels, L_E, weighted for marine mammals, and unweighted for fish. For ease of implementation sources have generally been converted to an SPL source level. Converting to L_E from SPL or from a number of events is relatively simple:

To convert from L_E to SPL the following relation can be used:

$$L_E = \mathrm{SPL} + 10 \cdot Log_{10}(t_2 - t_1) \tag{1}$$

Or where it is inappropriate to convert to SPL by relating to the number of events as:

$$L_{E,n\ events} = L_{E,single\ event} + 10 \cdot Log_{10}(n) \tag{2}$$

As a marine mammal swims away from the sound source, the noise it experiences will become progressively more attenuated; the cumulative, fleeing L_E is derived by logarithmically adding the L_E 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 a marine mammal in order for it to be exposed to sufficient sound energy to result in the onset of potential injury or if a set exclusion zone is sufficient for an activity (e.g. will an exclusion zone of 500 m be sufficient to prevent exceeding a limit). It should be noted that the sound 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.

Reported swim speeds are summarised in Table 5 1 along with the source papers for the assumptions.

For this assessment, a swim speed of 1.5 m/s was used for marine mammals and 0.5 m/s for fishes.

Table 5.1 Swim speed examples from literature

Species	Hearing Group	Swim Speed (m/s)	Source Reference
Harbour porpoise	VHF	1.5	Otani *et al.,* 2000
Harbour seal	PCW	1.8	Thompson, 2015
Grey seal	PCW	1.8	Thompson, 2015
Minke whale	LF	2.3	Boisseau *et al.,* 2021
Bottlenose dolphin	HF	1.52	Bailey and Thompson, 2010
White-beaked dolphin	HF	1.52	Bailey and Thompson, 2010
Basking shark	Group 1 fish	1.0	Sims, 2000
All other fish groups	All fish groups	0.5	Popper *et al.,* 2014

[9] https://www.dbsea.co.uk/validation/

6 RESULTS AND ASSESSMENT

Tables of various risk measures are presented in this section. The values given represent a "reasonable worst-case scenario" where the upper 90th percentile value from the results is used, meaning 90% of the results have a smaller risk range than the stated.

Main assumptions for the validity of the results:

- Final equipment configuration is not louder at any decidecade band nor broadband than the presented equipment (Table 4.1, Figure 4.1 and Figure 4.2).
- All ranges are horizontal ranges. Therefore, at a risk range of 50 m, and a depth of 70 m an animal could be >50 m away (deep below the equipment) but be within the beam of a transducer thus experiencing more exposure than at 50 m horizontal range.

Six types of results are presented to inform this assessment:

1. **"1-second exposure risk range":**

   This is the range of acute risk of impact from the activity (a one second exposure) and is presented to indicate momentary term risk and for comparison with other studies. This assumes a stationary animal (during the 1-second exposure).

2. **"10-minute exposure risk range":**

   This is the risk range for a stationary animal. Over this duration the vessel will have moved 1200 m (at 4 knots). This represents a single survey line going in the north-south direction, the shortest survey line likely.

3. **"50-minute exposure risk range":**

   This is the risk range for a stationary animal. Over this duration the vessel will have moved 6200 m (at 4 knots). This represents a single survey line running east-west, the longest likely single survey line.

4. **"Minimal starting range for a fleeing animal":**

   The minimal range a fleeing animal needs to start fleeing from to avoid being exposed to noise exceeding its TTS limit. All these are for animals moving in a straight line away from the source at a constant speed of 1.5 m/s. This metric forms the main basis of the assessment.

5. **"Peak level risk range":**

   The range of acute risk of impact from peak pressure levels associated with the impulsive sources. This measure is not included in tables as the range to the lowest TTS limit (fish 186 dB L_P) was <50 m (all other groups are shorter).

6. **"Behavioural response range":**

   The range at which the behavioural limit for the marine mammals (160 dB SPL) or the fishes (150 dB SPL) behavioural limits for impulsive noise is exceeded.

6.1 TTS Risk Ranges

The following summarises risks from cumulative noise, split into hearing groups, exposure durations and stationary vs fleeing receiver and risk from peak pressure level.

The assessment is split into two "combined sources":

- **Combined Source A:**

  Survey vessel, multi-beam echosounder, side-scan sonar, sub-bottom profiler excluding parametric models (Figure 4.1).

- **Combined Source B:**

  Same as "A" above, but with the addition of a parametric sub-bottom profiler (Figure 4.2).

6.2 Combined Source A, Without Parametric Sub-Bottom Profiler

This includes all sources given in Table 4.1 except the parametric sub-bottom profiler and the vibrocore. The results are presented in Table 6.1.

Table 6.1 Summary of risk ranges from noise exposure, L_E. All are risk ranges to TTS limits

Condition	LF	HF	VHF	PCW	OCW	Fish
1 second exposure TTS risk [m]	20	0	90	5	0	0
10-minute exposure TTS risk [m]	1700	200	2900	970	70	13
50-minute exposure TTS risk [m]	3900	580	5700	2400	210	50
Minimal starting range to avoid TTS [m] for fleeing animal	2000	41	3100	950	2.5	1
Peak [dB L_P] range [m]	<20	<20	<20	<20	<20	<50
Behavioural response range [m]	510	510	510	510	510	2000

6.3 Combined Source B, With Parametric Sub-Bottom Profiler

The parametric SBP introduces additional energy near the region of most sensitivity of the HF and VHF weighting (dolphins and porpoises). Risk ranges for porpoises are not affected as much by the additional energy at these higher frequencies as the risk ranges are too large already, but the HF group will see increased risk ranges. The results are presented in Table 6.2 with changes from Table 6.1 highlighted.

Table 6.2 Summary of risk ranges from noise exposure, L_E. All are risk ranges to TTS limits

Condition	LF	HF	VHF	PCW	OCW	Fish
1 second exposure TTS risk [m]	20	33	430	5	0	0
10-minute exposure TTS risk [m]	1700	500	2900	970	70	43
50-minute exposure TTS risk [m]	3900	770	5700	2400	210	100
Minimal starting range to avoid TTS [m] for fleeing animal	2000	280	3100	950	2.5	5
Peak [dB L_P] range [m]	<20	<20	<20	<20	<20	<50
Behavioural response range [m]	510	510	510	510	510	2000

6.4 Vibro-coring and Drilling

The results for the Vibro-coring and Drilling modelling are presented in Table 6.3.

Table 6.3 Summary of risk ranges from noise exposure, L_E. All are risk ranges to TTS limits

Condition	LF	HF	VHF	PCW	OCW	Fish
1 second exposure TTS risk [m]	0	0	0	0	0	0
10-minute exposure TTS risk [m]	830	20	510	270	10	0
50-minute exposure TTS risk [m]	2200	70	1400	790	50	20
Minimal starting range to avoid TTS [m] for fleeing animal	740	0	300	75	0	0
Behavioural response range [km]	15	15	15	15	15	1

7 SUMMARY AND CONCLUSIONS

At shorter ranges < 500-1000 m the inclusion of a parametric SBP in the combined source determines the risk ranges for TTS, while without a parametric SBP or at longer ranges the sparker determines the risk ranges for TTS.

Risk ranges for the Vibro-coring (covering drilling as well) are all at or below 300 m for species expected to be present (but >700 m for the LF hearing group).

The following focuses on the three hearing groups relating to Harbour porpoises (VHF), Seals (PCW) and Common and Bottlenose dolphins (HF). The remaining hearing groups are either assumed not present (LF) or have risk ranges that are considered too low to be significant (OCW and Fish). The focus is on minimal starting range for a fleeing animal to avoid TTS, with notes on what equipment determines this range (i.e., what equipment, if quieter, would reduce the range).

For porpoises (VHF hearing group) the minimal starting range to avoid TTS risk is 3100 m. This range is mainly determined by the sparker. If the sparker output is reduced, the range will be determined by the parametric SBP if used.

The HF hearing group (which includes bottlenose dolphins) has minimal starting ranges to avoid TTS at <50 m (or approximately 300 m if using parametric SBP). This range is determined by a sparker if no parametric SBP is used, otherwise the parametric SBP will determine the range.

The seals (hearing group PCW) have minimal starting ranges to avoid TTS at approximately 1 km. The sparker is driving this range.

For all hearing groups the TTS risk range for peak pressure is below 50 meters.

7.1 Mitigation and Limitations

7.1.1 Exclusion Zone – Marine Mammal Observer

The large risk ranges for the VHF and PCW groups mean that extra care must be taken in establishing presence of these animal groups prior to starting a survey line.

Assuming that the main species of concern is the bottlenose dolphin a pre-activity MMO search to 500 m to establish absence of this species will be sufficient to mitigate TTS risk from noise.

7.1.2 Equipment limitations

Any equipment used should not exceed the modelled equipment broadband levels (Table 4.1) or band-wise levels for overall levels (Figure 4.1 and Figure 4.2).

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