ABWP Phase I Decommissioning

Underwater Sound Modelling Report

Volume 2, Appendix 5.2



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Statement of Authority

Author	Qualifications	Relevant Experience
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Dr Jackie Hill	Marine Ecology Director	Jackie is a marine ecologist with over 20 years of experience across academic, research and consultancy roles. In the past 13 years she has been providing technical expertise for the consenting and permitting of a wide range of marine developments ranging from small jetty developments to offshore wind farms and geological disposal facilities. Jackie has developed particular expertise in the assessment of underwater sound effects in relation to marine receptors, particularly marine mammals and fish. This has included developing the parameters for underwater sound modelling, application of results to determining population effects and recommending the most appropriate mitigation measures and developing Marine Mammal Mitigation Protocols. She has also personal practical experience as a Marine Mammal Observer for seismic survey operations.

Glossary

Term	Meaning
Arklow Bank Wind Park (ABWP) Phase I	Arklow Bank Wind Park (ABWP) Phase I comprises: • Offshore infrastructure seaward of High Water Mark (HWM), including: – Seven Wind Turbine Generators (WTG) with a combined capacity of 25.2 MW; – One meteorological (met) mast; – Inter-array cables connecting the WTGs and met mast; and – One offshore export cable connecting WTG T4 with landfall at HWM; • Onshore infrastructure landward of HWM including: – One onshore cable connecting landfall at HWM with the onshore substation; and – One onshore substation compound, where the onshore substation and ancillary infrastructure are located.
ABWP Phase II	ABWP Phase II comprises: • Offshore Infrastructure, including: – 53 or 47 WTGs and two Offshore Substation Platforms (OSPs) located within the "Array Area"; – Inter-array cables connecting WTGs with the OSPs; and – Two offshore export cables;

Term	Meaning
	• Onshore grid connection infrastructure, including a 220 kV substation at Shelton Abbey with an associated connection to the existing National Electricity Transmission Network; • Operations and Maintenance Facility (OMF) at South Dock, Arklow Harbour; • EirGrid Upgrade Works.
Amplitude (as it relates to sound)	Amplitude is defined as the maximum height of a sound wave, representing the extent of particle displacement as the wave travels through a medium. In simpler terms, it can be thought of as the "height" of the wave. Greater amplitude means that particles are displaced further from their equilibrium position, resulting in a louder sound.
Anthropogenic	Originating from human activity or influence.
Audiogram	An audiogram or hearing curve, is a graph that illustrates the hearing range of an individual animal or animals, at various frequencies, and that may be extrapolated to the species to which individuals belong.
Auditory weighting function	Auditory weighting functions are mathematical functions used to emphasize frequencies where animals, including humans and marine mammals, are more sensitive and de-emphasize frequencies where they are less sensitive.
Bathymetry	Ocean's depth relative to sea level.
Decommissioning	The final closing down and putting into a state of safety of a development, project or process when it has come to the end of its useful life (EPA, 2022).
Effect	The consequence of an impact on a receptor. For example, in the offshore environment, vessel activity (activity) results in increased levels of underwater noise (impact), with the potential to disturb marine mammals (effect).
Environmental Impact Assessment (EIA)	Process of assessment of the effects of a project or development proposal on the environment. In the planning area, it is undertaken by a planning authority or An Coimisiún Pleanála during the consideration of applications for planning permission, taking account of an Environmental Impact Assessment Report (EIAR). The projects which require EIA are listed in Annex I and Annex II of the EIA Directive, as amended (Office of the Planning Regulator, n.d.).
Environmental Impact Assessment Report (EIAR)	A report or statement of the effects, if any, that Proposed Works, if carried out, would have on the environment. It is prepared by the developer to inform the EIA process (Office of the Planning Regulator, n.d.).
Geoacoustics	Study of the acoustic properties of rock, primarily to explore the potential use of rock systems as carriers of seismic signals in communications systems. It involves the examination of sonic, infrasonic, and ultrasonic phenomena occurring in the earth's crust, including both natural processes and those associated with the use of elastic waves for studying the structure and properties of the upper layers of the earth's crust.
Hertz	Hertz is a unit of frequency that measures how often a sound wave cycles per second. Specifically, 1 hertz means one cycle per second, and in audio, indicates how fast sound waves vibrate. Faster vibrations correspond to higher pitches, while slower vibrations produce lower pitches.
High Water Mark (HWM)	Level reached by the sea at high tide, measured as the mean of high tides.
Impact	A change brought about by the Proposed Works.
Impulsive sound	Sound that is broadband, extremely short in duration, with a rapid rise time and a peak level higher than its energy-averaged level.
Inter-array cables	Subsea power lines that link individual wind turbine generators (WTGs) together in an offshore wind farm, forming an electrical network. In ABWP Phase I, inter-array cables connect WTGs and the met mast to each other and have an overall length of 7.4 km.
Landfall	The point where the offshore export cable transitions from the offshore marine environment to the onshore terrestrial environment.
Meteorological (Met) mast	A mast with a number of meteorological sensors located at different heights to record meteorological and sea condition data

Term	Meaning
Monopile (MP)	Hollow steel cylinder driven into the seabed typically used to anchor an offshore wind turbine generator (WTG). In ABWP Phase I, MPs support the seven WTGs as well as the meteorological (met) mast.
Noise	The terms noise and sound are often used interchangeably. Noise usually refers to unwanted or disturbing sounds that interfere with normal hearing and can be unpleasant or harmful. It is often characterised by irregularities in the sound waves and is considered a form of sound pollution.
Non-impulsive sound	Sound that is continuous or occurs intermittently but does not exhibit the distinctive features associated with impulsive sound.
Offshore export cable	Subsea power cable that transports the total generated power from an offshore wind farm to the onshore power grid. In ABWP Phase I, the offshore export cable connects the wind turbine generator (WTG) T4 to landfall with an approximate overall length of 15.6 km. At landfall, the offshore export cable transitions to the onshore cable connecting to the onshore substation.
Offshore Site	Part of the Site where Proposed Works Offshore are proposed to take place. In this application for planning permission, the Offshore Site comprises the Sub Lease Area, where the ABWP Phase I wind turbine generators (WTGs), met mast and inter-array cables are located, and the offshore export cable 10 m corridor connecting WTG T4 to the landfall at high water mark (HWM) near Arklow Harbour.
Particle motion	Transport of particles through water or sediment.
Pascal	In the context of sound, Pascal is the unit of measurement for sound pressure. It represents the force per unit area, equivalent to newtons per square metre.
Permanent Threshold Shift	A permanent, irreversible increase in the threshold of audibility at a specified frequency or portion of an individual's hearing range above a previously established reference level.
Planning permission	Formal, legal approval required from a local planning authority or An Coimisiún Pleanála (ACP) to carry out development. The Proposed Works require planning permission submitted from ACP under Section 291 of the Planning and Development Act 2000, as amended.
Propagation of underwater sound	The process by which acoustic waves travel through water, influenced by factors such as temperature, salinity, pressure, and the presence of boundaries like the sea surface and seabed.
Proposed Works	The Proposed Works include decommissioning of ABWP Phase I offshore infrastructure (Proposed Works Offshore) and decommissioning of ABWP Phase I onshore infrastructure (Proposed Works Onshore).
Scour protection	Engineered barrier typically placed on the seabed around WTG foundations and subsea cables to prevents sediment erosion caused by accelerated water currents and waves, safeguarding the WTG's stability and protecting subsea cables. In ABWP Phase I, scour protection was originally introduced in the form of rock armour, however, this proved ineffective, and was removed in 2005. Since then, scour protection has been introduced through sandbags.
Side scan sonar (SSS)	Underwater remote sensing device that captures an image of the seabed surface across the extent of the area over which the device is deployed
Sound	The terms noise and sound are often used interchangeably. Sound is a broad term that refers to any auditory experience created by vibrations that travel through a medium such as air, water, or solids to the ear.
Sound exposure level	A metric used to measure the cumulative sound energy exposed to a receptor.
Sound pressure	Measurement of the resulting change in pressure due to particle vibration in fluid or gas.
Sound speed profile	The variation of sound speed with depth in water, determined by temperature, salinity, and pressure.
Sub Lease Area	Area where the ABWP Phase I WTGs, met mast and inter-array cables are located, as defined in the Sub Lease granted by Sure Partners Limited (SPL) to Arklow Energy Limited (Arklow Energy) to construct and operate ABWP Phase I.

Term	Meaning
Temporary Threshold Shift (TTS)	A recoverable reversible increase in the threshold of audibility.
Transition Piece	The steel connection structure between the tower and the monopile (MP) foundation.
Wind Turbine Generator (WTG)	Structure that converts the kinetic energy of ocean winds into electrical energy. ABWP Phase I includes seven GE Energy 3.6s WTGs with a rated capacity of 3.6 megawatts (MW) per WTG.

Acronyms

Acronym	Meaning
3D	Three-Dimensional
2D	Two-Dimensional
ANSI	American National Standards Institute
AUD INJ	Auditory Injury
dB	Decibel
DP	Dynamic positioning
CLV	Cable Lay Vessel
CPT	Cone Penetration Testing
cum	Cumulative
EIA	Environmental Impact Assessment
EMODnet	European Marine Observation and Data Network
H	High risk of an acoustic effect
HF	High Frequency
Hz	Hertz
ICES	International Council for the Exploration of the Sea
L	Low risk of an acoustic effect
LF	Low Frequency
M	Moderate risk of an acoustic effect
MBES	Multi-Beam Echo Sounder
MDS	Maximum Design Scenario
NEQ	Net Explosive Quantity
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
OWF	Offshore Wind Farm
P	Pressure
Pa	Pascal
PCW	Phocid Carnivores in Water
PEIR	Preliminary Environmental Information Report
PTS	Permanent Threshold Shift
rms	Route Mean Squared
SAC	Special Area of Conservation
SBES	Single Beam Echosounder
SBP	Sub-Bottom Profiler

Acronym	Meaning
sCPT	Seismic Cone Penetration Testing
SEL	Sound Exposure Level
SoS	Secretary of State
SPL	Sound Pressure Level
SSL	Sound Source Level
SSP	Sound Speed Profile
ss	Single strike
SSS	Side-scan Sonar
TNT	Trinitrotoluene
TTS	Temporary Threshold Shift
UK	United Kingdom
USBL	Ultra-short Baseline
VHF	Very High Frequency
WTG	Wind Turbine Generator

Sound Specific Metrics

Metric	Meaning
c	Sound velocity
E	Energy
f	Frequency
n	Count
PTS	Permanent threshold shift
SEL	Sound exposure level
SEL_{cum}	Cumulative sound exposure level
SELss	Single-strike sound exposure level
SPL	Sound pressure level
SPL$_{pk}$	Zero-to-peak sound pressure level
SPL$_{pk\text{-}pk}$	Peak-to-peak sound pressure level
SPL$_{rms}$	Averaged (route-mean squared) sound pressure level
T	Averaging time
TL	Transmission loss
TTS	Temporary threshold shift
Z	Acoustic characteristic impedance

Units

Unit	Meaning
µm/s	Micrometre per second
µPa	Micropascal
dB	Decibel
deg	Degrees

Unit	Meaning
g	Gram
Hz	Hertz
kg	Kilogram
kHz	Kilohertz
km	Kilometre
m	Metre
m/s	Metres per second
min	Minute
mm	Millimetre
MW	Megawatt
µ	Micro
Pa	Pascal
s	Second

EXECUTIVE SUMMARY

This Underwater Sound Modelling Report presents the methodology and results of the underwater sound propagation associated with the proposed decommissioning of Arklow Bank Wind Park (ABWP) Phase I (hereafter referred to as the 'Proposed Works'). The Proposed Works include decommissioning of ABWP Phase I offshore infrastructure (Proposed Works Offshore) and decommissioning of ABWP Phase I onshore infrastructure (Proposed Works Onshore).

Sound plays a fundamental ecological role for many marine species, being used for communication, navigation, prey detection and predator avoidance. Quantitative threshold criteria are available primarily for marine mammals and fish, and to a lesser extent for marine turtles, and these have been applied within this report.

The modelling approach is based on three-dimensional (3D) underwater sound propagation modelling using the dBSea software (version 2.3.4), incorporating site-specific environmental parameters representative of the Offshore Site, where Proposed Works Offshore will take place. These include detailed bathymetry, seabed composition and layering, and the sound speed profile of the water column. Source characteristics have been defined for all relevant activities, based on a combination of empirical data, literature sources and Proposed Works Offshore-specific assumptions.

The propagation of underwater sound has been modelled to estimate the radiated sound field as a function of distance from each source and water depth. As sound propagates through the marine environment, its intensity decreases due to geometric spreading and environmental attenuation, commonly referred to as transmission loss. Received sound levels at defined receptor locations have been calculated by combining source levels with transmission loss, taking into account directionality where relevant. These values have subsequently been compared with recognised threshold criteria that reflect the hearing sensitivity of marine fauna.

The modelling includes all relevant non-impulsive sound sources associated with the Proposed Works Offshore, such as sub-bottom profilers (Chirp SBP), ultra-short baseline (USBL) acoustic positioning systems, small survey vessels and tugboats (including potential use of dynamic positioning (DP) systems), dredging activities including cutter suction dredgers and associated equipment, vibratory extraction tools, jet lancing operations, underwater mechanical cutting, and vessel noise generated by jack-up barges and the wider vessel spread.

Underwater sound has been characterised using both sound pressure level (SPL) and sound exposure level (SEL) metrics, with SEL accounting for both the amplitude and duration of exposure. The potential effects on marine receptors have been assessed considering established categories of impact, including auditory injury, temporary threshold shift (TTS), behavioural disturbance and masking.

For marine mammals, threshold criteria for auditory injury have been based on the most recent guidance from the National Marine Fisheries Service (NMFS) (2024), while behavioural disturbance thresholds follow those defined by the National Oceanic and Atmospheric Administration (NOAA) (2019). Marine mammals have been assessed according to functional hearing groups, reflecting differences in sensitivity across taxa. For fish, criteria have been applied following the Americal National Standards Institute (ANSI) Accredited Standards Committee (Popper *et al*., 2012), which categorises species based on their hearing capabilities. Where quantitative thresholds are not available, qualitative considerations have been included to provide a complete characterisation of the thresholds that will be applied to the assessment of underwater sound impacts presented in the Environmental Impact Assessment Report (EIAR) and associated assessments.

The modelling results indicate that, for marine mammals, the largest potential impact ranges are associated with the USBL acoustic positioning system and the potential use of friction removal tools using vibration. TTS is predicted to occur at distances up to 1,000 m for low frequency (LF) hearing cetaceans (SBP and USBL), up to 800 m for high frequency (HF) hearing cetaceans (USBL), up to 900 m for very high frequency (VHF) hearing cetaceans (USBL), and up to 100 m for pinniped carnivores (seals) in water (PCW) (USBL). For all other sound sources and hearing groups, predicted TTS ranges are generally restricted to the immediate vicinity of the source (<10 m). Auditory injury is not predicted for any activity, with the exception of the USBL system, for which potential injury is predicted up to 400 m for VHF cetaceans and up to 40 m for pinnipeds.

For fish, including larvae and turtles, the modelling indicates that no mortality, mortal injury, recoverable injury or TTS is expected to occur beyond the immediate vicinity of the source (<10 m) for any of the assessed sound sources. Some limited behavioural disturbance may occur in proximity to certain activities, with predicted disturbance ranges up to 320 m for Group 3 fish and 150 m for Group 2 fish associated with the operation of the USBL acoustic positioning system.

Overall, the modelling indicates that underwater sound generated during the Proposed Works Offshore is expected to result predominantly in localised and temporary effects, with limited spatial extent for auditory impacts and a generally low risk of injury to marine mammals and fish when evaluated against current international threshold criteria.

1 INTRODUCTION

1.1 Overview

1.1.1.1 Arklow Energy Limited (Arklow Energy) is seeking planning permission to decommission Arklow Bank Wind Park (ABWP) Phase I (referred to hereafter as 'the Proposed Works'). The Proposed Works include decommissioning of ABWP Phase I offshore infrastructure (Proposed Works Offshore) and decommissioning of ABWP Phase I onshore infrastructure (Proposed Works Onshore).

1.1.1.2 This Underwater Sound Modelling Report aims to present the results of underwater sound anticipated to be generated by the Proposed Works Offshore. This report includes details of the underwater noise modelling methods and results for the propagation of underwater noise, required to inform **Volume 2, Chapter 5: Marine Biodiversity** of the Environmental Impact Assessment Report (EIAR). The outputs of the modelling are used to inform the evaluation of potential impacts on marine mammals, fish and fish larvae, including the risk of auditory injury and disturbance effects.

1.1.1.3 The Proposed Works Offshore that are anticipated to generate underwater sound are pre-decommissioning geophysical surveys, dredging operations, foundation and infrastructure removal techniques, inter-array and offshore export cable recovery activities, and associated vessel operations. These activities will generate underwater sound with the potential to disturb marine mammals and fish in the vicinity of the Offshore Site, where Proposed Works Offshore will take place.

1.1.1.4 This Underwater Sound Modelling Report is informed by:

- **Volume 2, Chapter 1: Introduction**; and
- **Volume 2, Chapter 3: Proposed Works Description**;
- **Volume 2, Chapter 5: Marine Biodiversity**.

1.1.1.5 The specific objectives of this Underwater Sound Modelling Report are to:

- Characterise potential sources of underwater sound during Proposed Works Offshore; and
- Provide the expected underwater noise levels and exposure levels, modelled against industry accepted threshold criteria.

1.2 Noise Generating Activities

1.2.1.1 There will be a range of activities associated with the Proposed Works Offshore that will generate underwater sound. The activities considered within the underwater sound propagation modelling reflect the Maximum Design Scenario (MDS) and include all relevant offshore operations, as detailed in **Table 1.1.**

Table 1.1: Sound generating activities to be undertaken during the Proposed Works Offshore

Proposed Works Offshore	Sound Generating Activity
Pre- and post-decommissioning surveys	Operation of geophysical survey equipment, including Multi-Beam Echo-Sounder (MBES), Side Scan Sonar (SSS), Sub-Bottom Profiler (SBP) and Ultra-Short Baseline (USBL) acoustic positioning systems, together with associated survey vessel noise (including the potential use of Dynamic Positioning (DP) systems)
Dredging and vessel access preparation	Dredging activities, including Cutter Suction Dredger (CSD), Backhoe Dredger (BHD) and plough dredging, together with associated vessel operations (including tugboats and support vessels)
Wind Turbine Generator (WTG) and meteorological mast removal	Jack-Up Barge (JUB) operations, including associated vessel movements (tugboats and transport barges) and vessel noise, including Dynamic Positioning and positioning systems
Transition piece (TP) and monopile (MP) removal	Foundation removal activities including potential use of vibratory extraction or jet lancing to remove shaft friction, internal dredging and underwater mechanical cutting, together with associated JUB operations and supporting vessel activity (including DP and USBL systems)

Proposed Works Offshore	Sound Generating Activity
Scour protection removal (where required)	Removal of scour protection using grab dredgers, together with associated vessel and barge operations
Inter-array cable removal	Cable recovery operations including running methods such as the use of grapnel runs, cable lifting, cutting and removal, undertaken using multicat vessels and associated equipment
Offshore export cable removal	Cable recovery operations including running methods such as the use of grapnel runs, cable lifting, cutting and removal, undertaken using multicat vessels and associated equipment
Vessel movements and support operations	Vessel activity associated with all project phases, including survey vessels, tugboats, multicat vessels and JUB, including DP systems and general vessel noise

1.3 Underwater Noise and Marine Fauna

1.3.1.1 Many marine organisms, including most marine mammals and fish, use sound for communication, mate location, prey detection, predator avoidance and navigation over both short and long distances. Increasing evidence indicates that other taxonomic groups, particularly invertebrates, may also have important ecological relationships with underwater sound (e.g. Spiga *et al*., 2012; Aimon *et al*., 2021).

1.3.1.2 Recognised quantitative threshold criteria for the effects of underwater sound are currently only available for marine mammals, fish and, to a more limited extent, marine turtles (see **Section 4**). Accordingly, the underwater sound modelling undertaken for the Proposed Works Offshore focuses on these faunal groups.

2 ACOUSTIC TERMINOLOGY AND METRICS

2.1 Nature of Underwater Sound

2.1.1.1 Underwater sound, like sound in air, is disturbance from a source in a medium, here water, travelling in a three-dimensional (3D) manner as the disturbance propagates with the speed of sound.

2.1.1.2 Sound travels at different speeds in different media. The speed of sound is determined by the density and compressibility of the medium. Density is the amount of material in a given volume, and compressibility is a measure of how much a substance could be compacted for a given pressure. The denser and the more compressible the medium, the slower the sound waves would travel. Water is much denser than air, but since it is nearly incompressible, the speed of sound is about four times faster in water than in air.

2.1.1.3 Underwater sound can be measured as a change in pressure and is described as the sound pressure level (SPL) which can be measured with a pressure sensitive device (hydrophone). The change in pressure, which can also be referred to as the intensity, or loudness of the sound is indicated by the height or amplitude of the sound pressure wave.

2.1.1.4 As there is a very large range of pressure amplitudes in sound, it is convenient to use a logarithmic scale to quantify pressure levels, using decibel (dB) units. The underwater SPL in dB is defined by the following equation[1]:

$$Sound\ Pressure\ Level\ (SPL) = 20 \cdot \log_{10} \frac{P}{P_0}$$

2.1.1.5 The reference pressure is 1 micropascal (μPa) for underwater sound which is different from SPL in the air. For this reason, SPL in the water and air cannot be directly compared.

2.1.1.6 However, underwater sound also varies depending on the time duration of the sound source. Thus, sound exposure over time is also commonly used in underwater sound by the sound exposure level (SEL) metric.

2.1.1.7 SEL is a measure of energy that takes into account both the received level (i.e. the SPL) and the duration of the exposure. SEL is a common metric since it allows sound exposures of different durations to be related to one another in terms of total acoustic energy. However, the duration of a sound event should be specified because there is no accepted standard duration over which the summation of energy is measured.

2.1.1.8 Thus, SEL can be computed for a single pulse or signal, which is often referred to as single-strike SEL (SEL_{ss}). The definition for SEL_{ss} is defined by the following equation[2]:

$$Sound\ Expsoure\ Level\ Single\ Strike\ (SEL_{ss}) = 10 \cdot \log_{10} \int_{t_0}^{t_{100}} p(t)^2 dt$$

2.1.1.9 The cumulative exposure can be found by adding all single events together in the period of time the source is emitting sound. This can be expressed mathematically for N events using the following equation[3]:

$$Sound\ Exposure\ Cumulative\ (SEL_{cum}) = 10 \cdot \log_{10} \frac{\sum_{n=1}^{N} E_n}{E_0}$$

[1] Where P is the pressure and P_0 is the reference pressure. The reference pressure is 1 micropascal (μPa) for underwater sound which is different from sound pressure levels in the air.

[2] Where t_0 and t_{100} are the start and end time of the source for the sound exposure of a single event. P is the pressure from the source at any given time.

[3] Where E_n is the energy from the single event, where E_0 is the reference value 1μPa²s.

2.2 Sound Source Characteristics

2.2.1.1 When analysing the auditory effects of sound exposure, it is often helpful to broadly categorise sound as either impulsive sound, with high peak sound pressure, short duration, fast rise-time and broad frequency content, or non-impulsive (also referred to as continuous or steady state sounds)[4] (NMFS, 2024).

2.2.1.2 When considering auditory effects, sonars and similar active sources are considered to be non-impulsive sound sources, as is vessel sound, whilst explosions and sound sources that use pingers, like USBL acoustic positioning, are treated as impulsive sources. All sound sources identified for the Proposed Works Offshore, and their sound characteristics, are provided in **Section 3.3**.

2.2.1.3 The following acoustic parameters (see **Table 2.1**) are commonly used to assess the noise impact from underwater sound sources for the identified local marine life:

Table 2.1: Different acoustic descriptors used for the modelling of underwater sound

Parameter	Abbreviation	Description	Units
Sound Pressure Level	SPL	Magnitude of sound at a given point.	dB re. 1 µPa
Peak SPL	SPL_{pk}	Zero-to-peak sound pressure at a given point.	dB re. 1 µPa
Peak to Peak SPL	$SPL_{pk\text{-}pk}$	Peak (maximum positive)-to-peak (maximum negative) sound pressure at a given point.	dB re. 1 µPa
Root Mean Square SPL	SPL_{rms}	Averaged sound pressure level.	dB re. 1 µPa
Sound Exposure Level	SEL	Amount of sound energy from a single event over a given time.	dB re. 1 µPa2s
Cumulative SEL	SEL_{cum}	Total sound energy exposure from multiple events.	dB re. 1 µPa2s
Pulsed/Impulsive Sound	-	A pulsed, discontinuous sound, such as from acoustic pingers and seismic sources.	-
Non-impulsive/Continuous Sound	-	A constant continuous sound, such as from drilling or a vessel engine.	-

2.3 Ambient Sound

2.3.1.1 Ambient sound in the ocean is the background sound that incorporates the broad range of individual sound sources present in the ocean and is made up of natural as well as anthropogenic sources (Hildebrand, 2004). Underwater noise pollution from shipping is globally pervasive and has a range of adverse impacts on species which depend on sound and a rise in global shipping has led to a correlated rise in underwater noise pollution (Frisk, 2012).

2.3.1.2 Background underwater sound levels in the Irish Sea where the Offshore Site is located, are influenced by a combination of shipping activity, wind-driven processes and other natural and anthropogenic sources. While site-specific baseline measurements are not available for the Offshore Site, regional datasets and studies from comparable northwest European shelf seas, including the North Sea, provide a suitable proxy.

2.3.1.3 Based on the intensity of shipping traffic and available baseline underwater sound data for these regions, average background underwater sound levels associated with wind and vessel activity are typically in the range of approximately 95 dB to 115 dB re 1 µPa (e.g. International Council for the Exploration of the Sea, 2025), adopted as a representative broadband proxy based on

[4] Note that the terms non-impulsive, continuous or steady-state do not necessarily imply long duration signals, only that the acoustic signal has sufficient duration to overcome starting transients and reach a steady-state condition. For harmonic signals, sounds with duration greater than approximately 5 to 10 cycles are generally considered to be steady state.

regional studies. These values are considered representative of conditions in moderately trafficked shelf seas such as the Irish Sea.

2.3.1.4 The ambient sound level is not a variable that is considered in the underwater sound modelling but is presented here in order to provide context to the overall sound scape that can help inform the assessment of impacts to marine receptors. **Figure 2.1**, shows example broadband (63–4000 Hz) underwater sound maps around the UK and Ireland, including total (shipping and wind) (a) and excess (shipping only) noise (b), as well as the 50th (c) and 90th percentile (d) distributions based on annual statistics (Farcas *et al.*, 2020; EMSA, 2021).

2.3.1.5 No site-specific studies on ambient underwater noise are currently available for the Offshore Site; therefore, regional datasets are used as a representative reference.

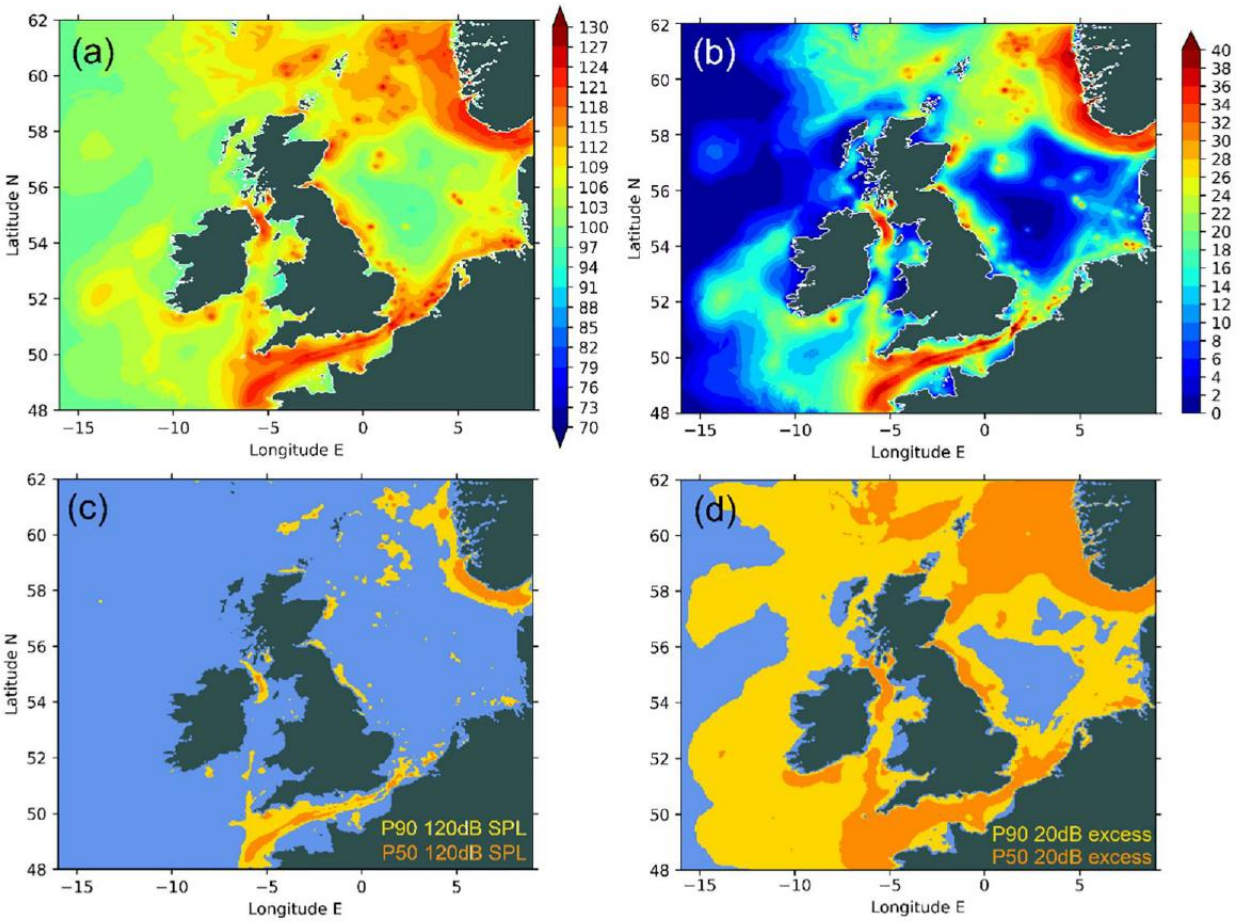


Figure 2.1: Example broadband (63-4000 Hz) sound maps for the North Sea for 2017

3 UNDERWATER NOISE PROPAGATION METHODOLOGY

3.1 Modelling Approach

3.1.1.1 For the underwater sound propagation model, the well-established 3D underwater sound propagation modelling program dBSea 2.4.2 was used. Based on the sound source location and underwater sound source level (SSL), the acoustic field at any range from the source is estimated by using the propagation model, using the Parabolic equation method for low frequency sounds (≤500 Hz), and ray tracing above 500 Hz (Jensen *et al*., 2011).

3.1.1.2 The sound propagation modelling also uses acoustic parameters appropriate for the Offshore Site, including the expected water column sound speed profile, the contours of the seabed floor (the bathymetry) and the nature of the seabed (the geo-acoustic properties), to produce site specific estimates of the radiated sound field as a function of distance from the sound source and depth. As an underwater sound wave propagates outwards from a source, there is a decrease in acoustic intensity due to spreading and/or attenuation, a process known as transmission loss.

3.1.1.3 The received sound level at any 3D location away from the source is calculated by combining the source level and transmission loss, both of which are direction dependent. Underwater acoustic transmission loss and received underwater sound levels are a function of depth, range, bearing and environmental properties. The output values are then compared to threshold values and application of weightings to reflect frequency-dependent marine animal hearing capabilities.

3.1.1.4 The model assumes that outgoing energy dominates over scattered energy and computes the solution for the outgoing wave equation. An approximation is used to provide two-dimensional (2D) transmission loss values in range and depth (i.e. computation of the transmission loss as a function of range and depth within a given radial plane is carried out independently of neighbouring radials, reflecting the assumption that sound propagation is predominantly away from the source).

3.1.1.5 The received underwater sound levels computed from the 1/3-octave band source levels by subtracting the numerically modelled transmission loss at each 1/3-octave band centre frequency and summing across all frequencies to obtain a broadband value. For this Underwater Sound Modelling Report, transmission loss and received levels were modelled for 1/3-octave frequency bands between 20 and 120,000Hz based on the modelled sound sources. The received levels were then converted to all the applicable underwater acoustic parameters.

3.1.1.6 To provide adequate resolution of impact distances, the calculation grid set in dBSea can be seen in **Table 3.1**.

Table 3.1: The settings for dBSea calculation, the interpolation grid given in x, y and z points

Parameter	Value	Description
Points (x)	50	x-value for calculation grid
Points (y)	50	y-value for calculation grid
Points (z)	100	z-value for calculation grid
Radial slices*	20	The amount of calculation slices around a sound source
Range points†	4000	The number of calculation points along each slice

* Radial slices refer to the number of slices a 360o circle around the sound source the propagation model is divided into.

† Range points define the amount of calculation points per radial slice

3.1.1.7 Parameters for sound source characteristic and environmental conditions have been selected to represent a reasonable worst-case scenario, as determined by the parameters presented in **Volume 2, Chapter 3**, industry accepted standards and professional judgement. These are discussed in **Sections 3.2** and **3.3**.

3.2 Environmental Parameters

3.2.1 Bathymetry

3.2.1.1 The structure of the seabed is a key parameter influencing the propagation of underwater sound, and accurate bathymetric data of sufficient spatial scope are therefore essential for reliable modelling. A base-level resolution bathymetric dataset for the Offshore Site and wider area was obtained from the publicly available General Bathymetric Chart of the Oceans (GEBCO, 2026) dataset, as Offshore Site-specific bathymetry data, although of higher resolution, is spatially limited to the Offshore Site boundaries, excluding bathymetry in the wider area.

3.2.2 Modelling Location

3.2.2.1 The water depth within the Sub Lease Area ranges between approximately 2 m and 15 m below Low Astronomical Tide (LAT). Along the export cable corridor connecting the Sub Lease Area to the landfall, water depths vary between approximately 3 m and 30 m LAT. A representative modelling location, at a water depth of approximately 10 m, has been selected to characterise underwater sound propagation across the Offshore Site and wider area (**Figure 3.1**). Differences in propagation characteristics across the range of depths within the Offshore Site are considered to be relatively limited and not expected to materially influence the modelling outcomes. The selected location is considered representative of the environmental conditions within the Offshore Site.

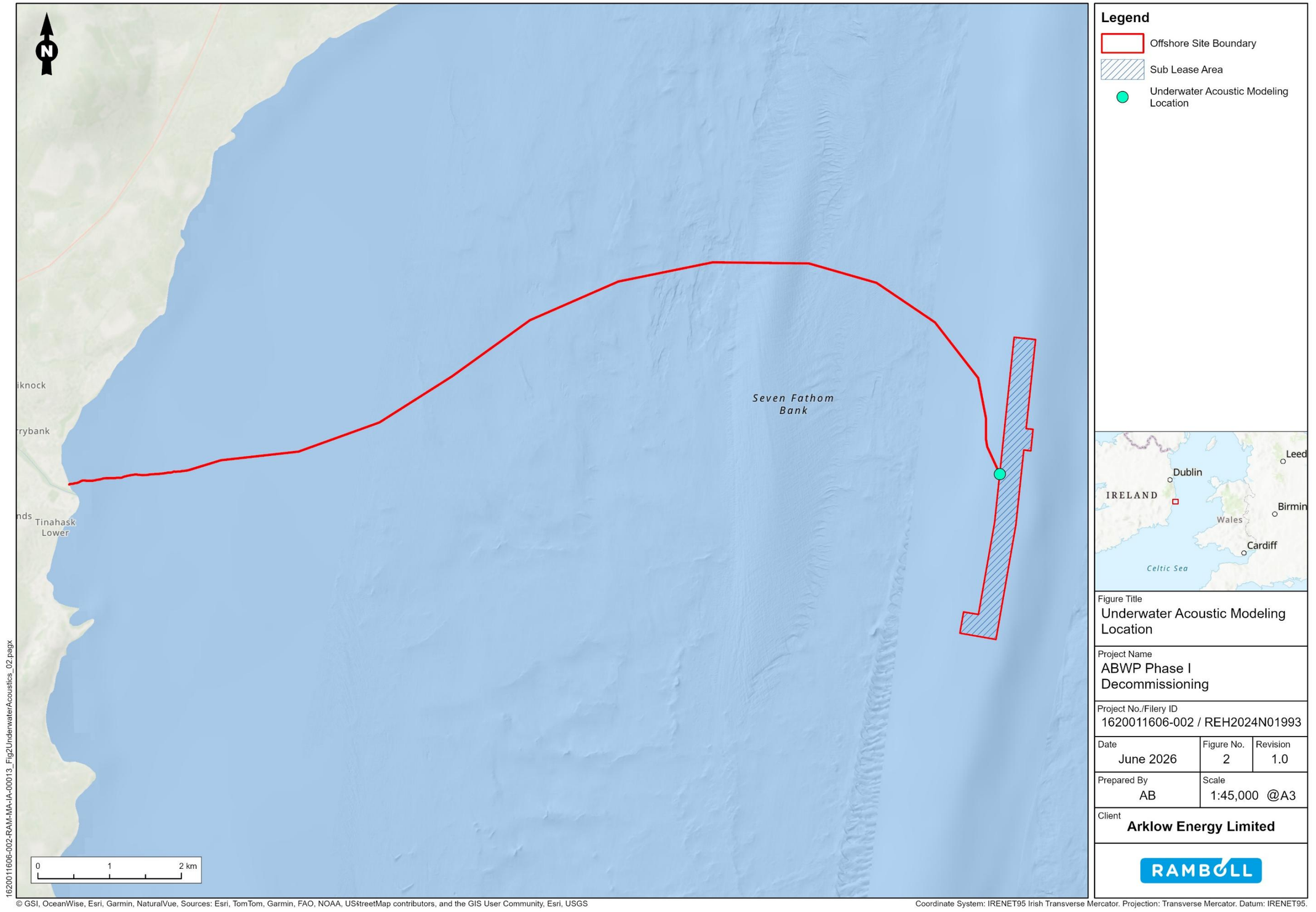


Figure 3.1: Underwater acoustics modelling location

3.2.3 Geoacoustic Properties

3.2.3.1 The interaction of underwater sound with the seabed is strongly influenced by its geoacoustic properties, including grain size, porosity, density, sound speed, absorption coefficient and seabed roughness, as well as the angle of incidence and frequency of the incoming sound waves (e.g. Jackson and Richardson, 2007). The determination of site-specific geoacoustic parameters typically requires dedicated geophysical and geotechnical investigations, including sediment sampling and in situ measurements, which are beyond the scope of this Underwater Sound Modelling Report.

3.2.3.2 In the absence of project-specific geoacoustic data, it is standard practice to adopt representative values based on available literature and regional geological information. For the Offshore Site, seabed conditions are predominantly characterised by sand and fine grained sediment, based on EMODNET (2026) and baseline information presented in **Volume 2, Chapter 4: Coastal Processes, Water and Sediment Quality**. Accordingly, representative geoacoustic parameters have been assigned to reflect these conditions.

3.2.3.3 The assumed seabed layer structure parameters, as applied to the sound propagation model, including layer thickness, sediment composition and associated acoustic parameters are detailed in **Table 3.2** below.

Table 3.2: Geoacoustic Properties for Arklow Bank Wind Park (ABWP) Phase I Decommissioning Project (Jackson & Richardson, 2007)

Seabed layer (m)	Material	Geoacoustic properties
0 to 20	Sand	Cp = 1,700m/s and α = 0.5dB/λ
2 to 30	Clay	Cp = 1,550m/s and α = 0.4dB/λ
Cp denotes compressional wave speed expressed in metres per second (m/s); α denotes the attenuation coefficient expressed in decibels per wavelength (dB/λ); and λ denotes wavelength.		

3.2.4 Sound Speed Profile

3.2.4.1 The sound speed profile (SPP), determined by the vertical structure of the water column, strongly influences how sound propagates in the marine environment. The vertical structure of the water column varies as a function of temperature, salinity and pressure. These factors lead to variations in the SSP, and consequently in sound propagation, both with depth (due to increasing pressure) and seasonally, particularly in temperate shelf seas such as those between Ireland and the UK, where surface water temperatures exhibit marked seasonal variability. For the purposes of this sound modelling, winter conditions (e.g. December to February), characterised by a well-mixed water column, are considered to represent the MDS for underwater sound propagation.

3.2.4.2 In this region, there is seasonal stratification during summer and a more homogeneous water column during winter which can result in different propagation conditions, with potential implications for sound transmission ranges.

3.2.4.1 Water column profile data (including salinity, temperature and depth) for both summer and winter conditions are publicly available from the International Council for the Exploration of the Sea, 2026, Marine Institute Ireland – CTD datasets, and Hydrography of the Irish Sea SEA6 Technical Report, POL Internal Document 174, M.J. Howarth. Data from stations located in proximity to the Offshore Site , derived from the International Council for the Exploration of the Sea, 2026, Marine Institute Ireland – CTD datasets, and Hydrography of the Irish Sea SEA6 Technical Report, POL Internal Document 174, M.J. Howarth will be used to derive representative sound speed profiles for the modelling, following established methodologies (e.g. Anderson et al., 2017).

3.2.4.2 For the purposes of the underwater sound modelling, the winter SSP has been selected to provide a conservative representation of sound propagation conditions across the Offshore Site.

3.3 Underwater Sound Source Levels

3.3.1 Overview of Sound Source Levels

3.3.1.1 The modelling is based on the design parameters of the Proposed Works Offshore, as described in **Volume 2, Chapter 3: Proposed Works Description** of the EIAR, and on SSL defined using industry standards and available literature. Where specific equipment details are not yet confirmed (e.g. specific SBP systems or removal tools), representative and precautionary source levels have been adopted to reflect a reasonable worst-case scenario. The modelling includes the estimation of distances to relevant underwater sound threshold criteria for the identified activities, to inform the assessment of potential impacts on marine receptors.

3.3.2 Characterisation of Sound Source Levels

3.3.2.1 The sound characteristics of the equipment and activities that generate underwater sound during the Proposed Works Offshore are provided in **Table 3.3**. These include key parameters such as operating frequency, SSL, and other characteristics relevant to sound emission (e.g. duty cycle, operational mode and, where applicable, acoustic beam properties). The parameters have been defined based on available measurement data, published literature and supplier technical specifications, and adapted to reflect the anticipated equipment and activities associated with the Proposed Works Offshore. These values have been used as input to the underwater sound propagation model.

3.3.2.2 Where required, in order to derive an equivalent source level at 1 m from the source for use in acoustic propagation modelling, sound levels have been back-calculated using an appropriate spreading model (typically assuming cylindrical spreading, i.e. 15log(r)). This approach allows for the estimation of a representative source level at 1 m from measurements or reference data reported at other distances.

3.3.2.3 Where applicable, the SSLs have been adjusted to account for the directionality of the acoustic emission. Certain sound sources, particularly geophysical survey equipment such as sub-bottom profilers, emit sound in a highly directional beam focused towards the seabed, thereby reducing sound propagation in the horizontal plane. To reflect this effect, source levels used in the propagation modelling have been adjusted in accordance with recognised guidance (e.g. NMFS, 2024), where sufficient information on beamwidth and orientation is available.

3.3.2.4 The sound sources for the Proposed Works Offshore activities identified in **Section 1.2** are provided in **Table 3.3** below.

Table 3.3: Sound source characteristics and sound source levels for Proposed Works Offshore activities

Source	Model Type#	Sound Type *	Operating frequency (kHz)	SPLrms	SELss	SPLpk	Pulse Duration (width, ms)	Repetition Rate (s-1)	Beam Width Angle (degrees)	Reference
SBP chirp	Teledyne Benthos Chirp III - TTV 170 (used as a reference)	I	0.2 to 14	197 186†	189 186†	212	5 to 60	15	100	BOEM, 2023
USBL Transponder/ Transceiver	Acoustic positioning	I	21 to 31	181	172	191	20	1Hz	360	Applied Acoustics 1113H mini beacon /iXblue GAPS gen 4
Support vessels including tugs, barges & multicat	Medium (50 to 100m) and small (<50m) boats	C	0.005 to 3.2	160 to184	157 to 181	170 to 194	Vessel transit speeds: 4 to 12 knots.			Richardson, 1996.
Dredging (including CSD/BHD and Plough Dredging)	N/A	C	0.1 to 2	179	179	183	Constant level assumed		360	Wyatt *et al.* 2008.
DP	N/A	C	0.1 to 1	175	175	176	Constant level assumed		360	Chorney *et al.* (2011) in (BOEM, 2023)
Jet lancing (option 2)	N/A	C	0.1 to 10	175	175	199	Constant level assumed		360	Hinzmann *et al.* (2014)
Underwater mechanical cutting	N/A	C	0.1 to 2	175	175	185	Constant level assumed		360	(Fowler *et al.* 2022) in (BOEM, 2023
Vibratory Extraction Tool (option 1)	Steel pipe pile (loudest) (example in BOEM, 2023)	C	0.002 to 0.004	185	185	190	Constant level assumed		360	Buehler *et al.* (2015) in (BOEM, 2023)
Vessel Noise from the JUB	N/A	C	0.14 to 0.17	160 to184	157 to 181	170 to 194	Constant level assumed		360	Marine Acoustics Inc. (2011) in (BOEM, 2023)

N/A = not applicable. * C = Continuous/Non-impulsive, I= Impulsive

† The SSL adjusted to account for the directionality of the acoustic beam.

3.4 Fleeing Receptor Modelling

3.4.1.1 The activities that generate underwater sound during the Proposed Works Offshore are predominantly mobile or transient in nature, with the exception of certain stationary operations such as foundation removal and vessel positioning. Mobile or transient activities include pre-decommissioning geophysical surveys, dredging operations, cable recovery activities and associated vessel movements. Stationary or semi-stationary activities include foundation removal techniques and vessel positioning.

3.4.1.2 For marine mammals, it is generally assumed that individuals will tend to minimise the time spent in close proximity to an anthropogenic sound source (NMFS, 2024). Sound exposure at the closest point of approach is therefore expected to represent the primary contribution to the total accumulated SEL (Gedamke et al., 2011). Accordingly, marine animal movement has been incorporated into the exposure modelling, particularly for the determination of SEL, using simplified movement pathways either radially away from the source or perpendicular to the direction of source movement.

3.4.1.3 For fish, both mobile and stationary scenarios have been considered within the modelling to account for variability in behavioural responses. While uncertainty remains regarding the extent to which fish actively avoid sound sources, available evidence suggests that avoidance behaviour may occur for certain species, including salmonids (Oppedal *et al.*, 2025).

3.4.1.4 The movement speeds of marine animals considered within the exposure modelling, including representative marine mammal species and broad fish groups, are provided in **Table 3.4**.

Table 3.4: Flee speeds for different animals used in the underwater sound modelling

Animal	Flee speed (m/s)	Reference
Harbour seal (*Phoca vitulina*)	1.8	Thompson *et al.* (2015)
Grey seal (*Halichoerus grypus*)	1.8	Thompson *et al.* (2015)
Harbour porpoise (*Phocoena phocoena*)	1.5	Otani *et al.* (2000)
Minke whale (*Balaenoptera acutorostrata*)	2.3	Boisseau *et al.* (2021)
Bottlenose dolphin (*Tursiops truncatus*)	1.52	Bailey *et al.* (2010)
Short beaked common dolphin (*Delphinus delphis*)		
Risso's dolphin (*Grampus griseus*)		
Basking shark (*Cetorhinus maximus*)	1.0	Sims (2000)
Group 2 (medium sensitivity hearing) fish, such as salmon	1.0	Hvas and Oppedal (2017)
All other fish (excluding basking shark)	0 to 0.5	Popper *et al.* (2014)

4 ACOUSTIC EFFECTS THRESHOLD CRITERIA

4.1 Overview

4.1.1.1 Many marine organisms, including most marine mammals and marine fish, use sound for a range of ecologically important activities such as communication, locating mates, searching for prey and avoiding predators and hazards and for short and long-range navigation. Generally, the effect of underwater sound on marine receptors can be divided into broad categories that largely depend on the intensity of the sound and an animal's proximity to the sound source. These effects range from physical injury through to disturbance and the masking of other sound sources and audibility (Richardson *et al.*, 1995).

4.1.1.2 The effect of anthropogenic underwater sound on marine animals has been the subject of several decades of research effort, culminating in a number of internationally accepted threshold criteria for the key effects of concern. In particular, these guidelines cover the acoustic effects of injury and disturbance in marine mammals and fish. The acoustic effects criteria for marine mammals are detailed in **Section 4.2** and in **Section 4.3** for fish.

4.2 Marine Mammals

4.2.1 Underwater sound and marine mammals

4.2.1.1 The impact of anthropogenic sound on marine mammals depends on a range of factors including the frequency and intensity of the sound source, the duration of the sound, normal background sound levels, as well as the sensitivity and behaviour of the receiving animal and possible habituation to background sound sources (Southall *et al*., 2007).

4.2.1.2 Depending on the intensity and frequency of the sound source, exposure to underwater sound can result in the following effects for marine mammals:

- Auditory injury: this includes but is not limited to a permanent threshold shift (PTS) in hearing which is a permanent, irreversible increase in the threshold of audibility at a specified frequency or portion of an individual's hearing range above a previously established reference level. PTS can occur from a variety of causes, but it is most often the result of intense and/or long-term repeated sound exposures;
- Temporary threshold shift (TTS): a recoverable reversible increase in the threshold of audibility, most commonly resulting from long-term sound exposure not high enough to auditory injury;
- Behavioural responses: these are highly variable and context specific. Can include increased alertness, alteration of movement or diving behaviour, interruption of social interactions and temporary or permanent habitat abandonment; and
- Masking: where anthropogenic underwater sound partially, or entirely, reduces the audibility of signals of interest such as those used for communication and prey detection.

4.2.2 Auditory Weighting Function

4.2.2.1 Different species have different hearing ranges. For marine mammals Southall *et al*. (2007) assigned species of cetaceans and pinnipeds to one of five functional hearing groups based on behavioural psychophysics, evoked potential audiometry and auditory morphology. Cetaceans and pinnipeds are broadly separable based on phylogenetic and functional differences. Cetaceans were further subdivided according to differences in their measured or estimated hearing characteristics and not necessarily according to their phylogeny. Since publication, marine mammal hearing groups have been revised and updated as new audiograms and other data have become available (NMFS, 2018 and Southall *et al.,* 2019).

4.2.2.2 The most up-to-date published hearing ranges for marine mammals are found in the most recent National Marine Fisheries Service guidance, published in 2024 (NMFS, 2024). These are provided in **Table 4.1**. However, the ability to hear sounds varies across a species' generalised hearing range, with higher sensitivity across a smaller frequency range, as seen in the typical 'U-shape' of most animal audiogram plots of hearing sensitivity against sound frequency (e.g. see audiograms in NMFS, 2024).

4.2.2.3 The threshold guidance for marine mammals, therefore, also includes auditory weighting functions in the criteria for identifying which received sound levels and sound frequencies are predicted to cause changes in individual marine mammals hearing sensitivity for acute (less than 24 hours) exposure. These weightings are specifically associated with the auditory injury and the TTS acoustic thresholds and are applied to the SEL_{cum} metric only as per the guidance (NMFS, 2024).

Table 4.1: Marine mammal hearing groups relevant to the Arklow Bank Wind Park (ABWP) Phase I Decommissioning Project

Hearing Group	Common Species in ABWP Project Marine Mammal Study Area	Generalised Hearing Range*
Low-frequency (LF) cetaceans	Minke whale	7Hz to 36kHz
High-frequency (HF) cetaceans (dolphins, toothed whales, beaked whales, bottlenose whales)	Common dolphin Bottlenose dolphin Risso's dolphin	150Hz to 160kHz
Very High-frequency (VHF) cetaceans	Harbour porpoise	200Hz to 165kHz
Phocid carnivores (seals) in water (PCW)	Grey seal Harbour/common seal	40Hz to 90kHz
*The generalised hearing range for the entire group as a composite (i.e. all species within the group), where individual species' hearing ranges may not be as broad. Additionally, animals are able to detect very loud sounds above and below the generalised hearing range.		

4.2.3 Threshold Criteria

4.2.3.1 For impulsive sounds, thresholds for auditory injury (AUD INJ) are based on dual metrics of peak SPL (SPL_{pk}) and M-weighted cumulative SEL (SEL_{cum}). The impulsive thresholds are provided in **Table 4.2**. For continuous sounds, thresholds are SEL_{cum} only (see **Table 4.3**).

4.2.3.2 The SEL_{cum} metric accounts for both the received level and the duration of exposure (NMFS, 2024). This enables a comparison of the total energy attributed to different pulsed sound sources with different time intervals. For example, exposure to a low sound source over a long time period can present an equal risk of auditory effects as exposure to a louder source over a shorter period.

4.2.3.3 For all Proposed Works Offshore activities considered, the SEL_{cum} duration used for determining distances to threshold criteria is based on a 24-hour period (in line with NMFS, 2024). This standardised duration allows for consistency and comparability across different sound sources and studies. However, where the duration of specific noise-generating activities is known to be substantially shorter, alternative exposure durations may be applied to provide a more representative determination of sound exposure, where appropriate.

4.2.3.4 However, it is recognised that weighted SEL_{cum} is not an appropriate metric to capture all the effects of impulsive sounds, as it can contradict the equal energy hypothesis, and why an instantaneous peak level is included in the NMFS' dual metric thresholds for impulsive sounds.

Table 4.2: Threshold criteria for AUD INJ and TTS from impulsive underwater sound sources for marine mammals

Hearing group	AUD INJ		TTS	
	SPL_{pk}	SEL_{cum}	SPL_{pk}	SEL_{cum}
LF	222	183	216	168
HF	230	193	224	178
VHF	202	159	196	144
PCW	223	183	217	168

NB. Units for SPL are dB re. 1µPa and units for SEL are dB re. 1µPa2s.

Table 4.3: Threshold criteria for AUD INJ and TTS from non-impulsive underwater sound sources for marine mammals

Hearing group	AUD INJ	TTS
	SEL_{cum}	SEL_{cum}
LF	197	177
HF	201	181
VHF	181	161
PCW	195	175

NB. Units for SEL are dB re. 1µPa2s.

4.2.3.5 For behavioural disturbance, there are no widely agreed quantitative thresholds, reflecting both a lack of empirical evidence and a high level of variability in observed responses. Behavioural reactions to underwater sound can vary significantly between species, individuals and contexts, and are not always directly correlated with the received sound level (Gomez et al., 2016). Current guidance also recognises that further research is required to better define robust and universally applicable thresholds for behavioural effects (e.g. NMFS, 2024; Southall et al., 2019). As such, any thresholds applied for behavioural disturbance should be considered precautionary.

4.2.3.6 Behavioural response thresholds are based on the National Oceanic and Atmospheric Administration (NOAA) Level B Harassment criteria (NOAA, 2005), for non-explosive impulsive or intermittent sounds and non-impulsive (continuous) sounds [see **Table 4.4**]. These thresholds indicate the sound level at which marine mammals are likely to be disturbed in a manner that qualifies as Level B harassment. Level B harassment is defined by NOAA as "acts that have the potential to disturb (but not injure) a marine mammal or marine mammal stock in the wild by disrupting behavioural patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering."

4.2.3.7 The NOAA Level B harassment threshold (NOAA, 2005) originates from a study on a grey whale (*Eschrichtius robustus*) (a LF hearing group species) mother and calf, which were shown to exhibit avoidance responses when exposed to seismic air gun playback signals at levels above an SPL_{rms} of 160 dB re 1µPa (Malme *et al*., 1984). Thus, the Level B harassment criterion is based on limited data and so is unlikely to be relevant for all species, including those in the VHF group such as the harbour porpoise, in UK and Irish waters.

Table 4.4: Threshold criteria for behavioural disturbance from underwater sound for marine mammals (NOAA, 2005)

Hearing Group	SPLrms Threshold	
	Impulsive Sound	Non-impulsive Sound
All marine mammal hearing groups	160	120

NB. Units for SPL are dB re. 1µPa.

4.3 Fish (and Turtles)

4.3.1 Hearing Groups

4.3.1.1 The majority of the underwater sound threshold criteria for fish and turtles come from the US ANSI-Accredited Standards Committee (Popper et al., 2014). This guidance groups fish into the broad hearing categories, based on their anatomy and available evidence on hearing:

- Group 1: fishes with no swim bladder or other gas chamber. This group includes elasmobranchs, such as the basking shark, flatfish and lampreys. These species are less susceptible to barotrauma and are only sensitive to particle motion, not sound pressure.
- Group 2: fishes with swim bladders but the swim bladder does not play a role in hearing (e.g. salmonids). These species are susceptible to barotrauma, although hearing only involves particle motion, not sound pressure.
- Group 3: Fishes that have special structures mechanically linking the swim bladder to the ear (e.g. clupeids such as herring (*Clupea harengus*), sprat (*Sprattus sprattus*) 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 other fish.

- Sea turtles: There is limited information on auditory criteria for sea turtles but since high frequencies are attenuated by bone, the range of hearing is limited to low frequencies only. For leatherback turtle (*Dermochelys coriacea*), the hearing range has been recorded as between 50 and 1,200 Hz with maximum sensitivity between 100 and 400 Hz.
- 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 sound.

4.3.1.2 The effects of underwater sound in fish are described by Popper *et al.* (2014):

- Mortality and potential mortal injury: either immediate mortality or delayed mortality due to tissue and/or damage, such as barotrauma, that is sufficiently severe (e.g. a barotrauma) that death occurs sometime later due to decreased fitness;
- Recoverable injury: tissue injuries including hair cell damage, minor internal or external hematoma etc., which are not likely to result in mortality;
- TTS: Short term changes in hearing sensitivity may, or may not, reduce fitness and survival.
- Masking: impairment of hearing sensitivity by greater than 6 dB, including all components of the auditory scene, in the presence of sound; and
- Behavioural effects: substantial change in behaviour for the animals exposed to a sound. This may include long-term changes in behaviour and distribution, such as moving from preferred sites for feeding and reproduction, or alteration of migration patterns. This behavioural criterion does not include effects on single animals, or where animals become habituated to the stimulus, or small changes in behaviour such as a startle response or small movements.

4.3.2 Threshold Criteria

4.3.2.1 Thresholds for both impulsive and non-impulsive sound sources are applied in accordance with Popper *et al.* (2014). However, not all effects have quantitative thresholds and instead are given relative risk ratings, at three relative distances from the sound source, and so cannot be modelled. However, for completeness, these relative risk ratings are included in **Table 4.5** for impulsive and **Table 4.6** for non-impulsive sounds.

4.3.2.2 The relative risk ratings are given as low (L), moderate (M) and high (H) risk of the effect occurring at distances from the sound source given as near (in the 10s of metre, intermediate (in the 100s of metres) and the far (1000s of metres). These are noted in the tables in the form L/M/H for example, with a rating for each of the relative distances given by Popper *et al.* (2014), which are near, intermediate and far from the sound source.

4.3.2.3 In addition, findings from Hawkins *et al.* (2014) are also included in the modelling of underwater sound, with criteria to further inform behavioural response considerations. This study reported that SPL causing a 50% response rate in fish schools were 163.2 and 163.3 dB re 1µPa (SPL peak-to-peak), with corresponding single-strike SEL of 135.0 and 142.0 dB re 1µPa²s for sprat (a Group 3 species in the Clupeidae family) and mackerel (*Scomber scombrus*) (a Group 2 species), respectively, as estimated from dose response curves.

4.3.2.4 The SBP equipment operates at frequencies <1kHz and so is within the hearing range of fish. SBP systems essentially work in a similar way to sonar, radar and other reflective positioning systems. Popper *et al.* (2014) provide threshold criteria for low frequency (≤1kHz) and mid-frequency sonar (1 to 10 kHz). On the basis of the most likely operating range for SBP, the threshold criteria for mid-frequency sonar can be used as a proxy (see **Table 4.7**).

Table 4.5: Acoustic Threshold Criteria for effects in fish from impulsive sounds (Popper *et al.*, 2014)

Hearing group	Mortality and potential mortal injury*	Recoverable injury	TTS	Behaviour†
Group 1 - Fish: no swim bladder	SEL_{cum} 219 dB SPL_{pk} 213 dB	SEL_{cum} 216 dB SPL_{pk} 213 dB	SEL_{cum} 186 dB	H/M/L
Group 2 - Fish: swim bladder is not involved in hearing	SEL_{cum} 210 dB SPL_{pk} 207 dB	SEL_{cum} 203 dB SPL_{pk} 207 dB		H/M/L

Hearing group	Mortality and potential mortal injury*	Recoverable injury	TTS	Behaviour†
Group 3 - Fish: swim bladder involved in hearing	SEL_{cum} 207 dB SPL_{pk} 207 dB	SEL_{cum} 203 dB SPL_{pk} 207 dB		H/H/M
Fish eggs and larvae	SEL_{cum} 210 dB SPL_{pk} 20 7dB	H/L/L	M/L/L	M/L/L
Turtles	SEL_{cum} 210 dB SPL_{pk} 207 dB	H/L/L	H/L/L	H/M/L

* SPL units are dB re 1µPa and SEL units are dB re 1µPa²s.

† Non-quantitative thresholds given a relative risk ratings of low, moderate or high (L, M or H) in order of the relative distances of near, intermediate and far.

Table 4.6: Acoustic threshold criteria for effects in fish from non-impulsive (continuous) sounds (Popper *et al.*, 2014)

Hearing group	Mortality and potential mortal injury*	Recoverable injury	TTS	Behaviour†
Group 1 - Fish: no swim bladder	L/L/L	L/L/L	M/L/L	M/M/L
Group 2 - Fish: swim bladder is not involved in hearing	L/L/L	L/L/L	M/L/L	M/M/L
Group 3 - Fish: swim bladder involved in hearing	L/L/L	SPL_{rms} 170 dB for 48 hours	SPL_{rms} 158 dB for 12 hours	H/M/L
Fish eggs and larvae	L/L/L	L/L/L	L/L/L	H/M/L
Turtles	L/L/L	L/L/L	M/L/L	M/M/L

* Non-quantitative thresholds given a relative risk ratings (L, M or H) in order of three relative distances of near, intermediate and far.

† SPL units are dB re 1 µPa; SEL units are dB re 1 µPa²s.

Table 4.7: Acoustic Threshold Criteria for effects in fish from SBP (Popper *et al.*, 2014)

Hearing group	Mortality and potential mortal injury*	Recoverable injury	TTS	Behaviour†
Group 1 - Fish: no swim bladder	L/L/L	L/L/L	n/a	n/a
Group 2 - Fish: swim bladder is not involved in hearing	SPL_{rms} >210 dB	SPL_{rms} >210 dB	n/a	n/a
Group 3 - Fish: swim bladder involved in hearing	SPL_{rms} >210 dB	SPL_{rms} >210 dB	SPLrms >210 dB	SPL_{rms} >209 dB
Fish eggs and larvae	n/a	n/a	n/a	n/a
Turtles	n/a	n/a	n/a	n/a

* Non-quantitative thresholds given a relative risk ratings (L, M or H) in order of three relative distances of near, intermediate and far.

† SPL units are dB re 1 µPa; SEL units are dB re 1 µPa²s.

Table 4.8: Behavioural Threshold Criteria for effects in fish from impulsive sounds (Hawkins *et al.*, 2014)

Hearing group	SELSS Threshold (dB re 1 µPa²s)
Group 2 - Fish: swim bladder is not involved in hearing	135.0
Group 3 - Fish: swim bladder involved in hearing	142.0

4.3.2.5 For the consideration of fish, terminology differs from that used for marine mammals. While marine mammals are assessed in terms of auditory injury and TTS, fish are assessed in terms of physical injury (including mortal and recoverable injury) and TTS (Popper et al., 2014). Mortal injury refers to the immediate or delayed death of fish as a result of exposure to sound, typically associated with large pressure differentials affecting tissues and, where present, the swim bladder. Recoverable injury refers to non-lethal physical damage, such as barotrauma, internal or external injury, or damage to sensory structures. TTS in fish refers to a temporary reduction in hearing sensitivity following exposure to sound, from which recovery is expected over time.

5 UNDERWATER NOISE MODELLING RESULTS

5.1 Overview of Modelling Results

5.1.1.1 The impact ranges resulting from the modelling exercise for the Proposed Works Offshore are provided in metres to indicate the distance at which the relevant threshold criteria are met.

5.1.1.2 Whilst the potential impact ranges are given in metres there is not a hard and fast 'line' where an impact occurs or does not occur. Potential impacts are also determined by several uncertainties such as behavioural responses, ecological context and animal motivations, life cycle stage and natural physiological variations between individual animals. However, such estimated distances provide a range where potential effects may be observed and give an understandable way in which a wider audience can appreciate the potential spatial extent of the impact.

5.2 Marine Mammals

5.2.1.1 The distances predicted to the various threshold limits are the maximum at any water depth down to the seabed. For the purposes of undertaking a MDS for assessments, the maximum distances are given for the impact threshold limits specified in **Section 4**. The potential impact distances to the TTS and AUD INJ thresholds for both impulsive and non-impulsive sounds are presented in a table for each of the marine mammal hearing groups as follows: **Table 5.1** for LF cetaceans, **Table 5.2** for HF cetaceans, **Table 5.3** for VHF cetaceans and **Table 5.4** for PCW seals.

5.2.1.2 The most sensitive group of marine mammals, in terms of TTS and AUD INJ from any sound source, is the VHF hearing group, for which the harbour porpoise is the only species in this group found in Irish waters. However, the modelling results show that only the USBL activities result in potential AUD INJ and TTS distances beyond the immediate vicinity (400 to 900 m) of the sound source (see **Table 5.3**).

5.2.1.3 For LF cetaceans, such as the minke whale, AUD INJ is not predicted to occur for any activity associated with the ABWP Project and TTS effects beyond the immediate vicinity of the source is predicted only for the operation of the USBL and vibratory extraction tool, which has a potential impact distance of 800-1000m (see **Table 5.1**).

5.2.1.4 For HF cetaceans, which includes most dolphin species, AUD INJ is not predicted and the potential for TTS is predicted in proximity of the USBL (see **Table 5.2**). A potential AUD INJ is predicted for the PCW seals group in the immediate proximity of the USBL, and TTS only to a maximum of 100 m from the sound source (see **Table 5.4**).

5.2.1.5 The distances predicted to the behavioural thresholds are found in **Table 5.5**. The results show that level B harassment of all marine mammal hearing groups is predicted to a maximum distance of 45,500 m from the sound source, assuming 24 hours of exposure.

Table 5.1: Potential Impact Ranges (m) for marine mammals in the LF hearing group for the different underwater sound equipment[5]

Sound Source	AUD INJ SPL_{pk} Impulsive	AUD INJ SEL_{cum} Impulsive	TTS SPL_{pk} Impulsive	TTS SEL_{cum} Impulsive	AUD INJ SEL_{cum} Non-impulsive	TTS SEL_{cum} Non-impulsive
SBP Chirp	<10	<10	<10	<10	-	-
USBL transponder/ transceiver	<10	<10	<10	1000	-	-
Dredging	-	-	-	-	<10	<10
Support vessels	-	-	-	-	<10	<10
Dynamic Positioning	-	-	-	-	<10	<10
Jet lancing	-	-	-	-	<10	<10
Underwater mechanical cutting	-	-	-	-	<10	<10
Vibratory Extraction Tool	-	-	-	-	<10	800
Vessel Noise from the JUB	-	-	-	-	<10	<10

Table 5.2: Potential Impact Ranges (m) for marine mammals in the HF hearing group for the different underwater sound equipment

Sound Source	AUD INJ SPL_{pk} Impulsive	AUD INJ SEL_{cum} Impulsive	TTS SPL_{pk} Impulsive	TTS SEL_{cum} Impulsive	AUD INJ SEL_{cum} Non-impulsive	TTS SEL_{cum} Non-impulsive
SBP Chirp	<10	<10	<10	<10	-	-
USBL transponder/ transceiver	<10	<10	<10	800	-	-
Dredging	-	-	-	-	<10	<10
Support vessels	-	-	-	-	<10	<10
Dynamic Positioning	-	-	-	-	<10	<10
Jet lancing	-	-	-	-	<10	<10

[5] For all potential impact range tables, a dashed cell (-) indicates that the threshold is not relevant for that particular activity.

Sound Source	AUD INJ SPL_{pk} Impulsive	AUD INJ SEL_{cum} Impulsive	TTS SPL_{pk} Impulsive	TTS SEL_{cum} Impulsive	AUD INJ SEL_{cum} Non-impulsive	TTS SEL_{cum} Non-impulsive
Underwater mechanical cutting	-	-	-	-	<10	<10
Vibratory Extraction Tool	-	-	-	-	<10	<10
Vessel Noise from the JUB	-	-	-	-	<10	<10

Table 5.3: Potential Impact Ranges (m) for marine mammals in the VHF hearing group for the different underwater sound equipment

Sound Source	AUD INJ SPL_{pk} Impulsive	AUD INJ SEL_{cum} Impulsive	TTS SPL_{pk} Impulsive	TTS SEL_{cum} Impulsive	AUD INJ SEL_{cum} Non-impulsive	TTS SEL_{cum} Non-impulsive
SBP Chirp	<10	<10	<10	<10	-	-
USBL Transponder/ Transceiver	<10	400	<10	900	-	-
Dredging	-	-	-	-	<10	<10
Support vessels	-	-	-	-	<10	<10
Dynamic Positioning	-	-	-	-	<10	<10
Jet lancing	-	-	-	-	<10	<10
Underwater mechanical cutting	-	-	-	-	<10	<10
Vibratory Extraction Tool	-	-	-	-	<10	<10
Vessel Noise from the JUB	-	-	-	-	<10	<10

Table 5.4: Potential Impact Ranges (m) for marine mammals in the PCW hearing group for the different underwater sound equipment

Sound Source	AUD INJ SPL_{pk} Impulsive	AUD INJ SEL_{cum} Impulsive	TTS SPL_{pk} Impulsive	TTS SEL_{cum} Impulsive	AUD INJ SEL_{cum} Non-impulsive	TTS SEL_{cum} Non-impulsive
SBP Chirp	<10	<10	<10	<10	-	-
USBL transponder/ transceiver	<10	40	<10	100	-	-
Dredging	-	-	-	-	<10	<10

Sound Source	AUD INJ SPL_{pk} Impulsive	AUD INJ SEL_{cum} Impulsive	TTS SPL_{pk} Impulsive	TTS SEL_{cum} Impulsive	AUD INJ SEL_{cum} Non-impulsive	TTS SEL_{cum} Non-impulsive
Support vessels	-	-	-	-	<10	<10
Dynamic Positioning	-	-	-	-	<10	<10
Jet lancing	-	-	-	-	<10	<10
Underwater mechanical cutting	-	-	-	-	<10	<10
Vibratory Extraction Tool	-	-	-	-	<10	<10
Vessel Noise from the JUB Jack Up Boat	-	-	-	-	<10	<10

Table 5.5: Potential behavioural disturbance impact ranges (m) for marine mammals in all hearing groups for the different underwater sound equipment

Sound source	Impulsive sound sources	Non-impulsive sound sources
SBP Chirp	50	-
USBL transponder/transceiver	200	-
Dredging	-	32,000
Support vessels	-	6,500
Dynamic Positioning	-	14,000
Jet lancing	-	13,000 – 14,000
Underwater mechanical cutting	-	13,000 – 14,000
Vibratory Extraction Tool	-	45,500
Vessel Noise from the JUB	-	6,500

5.3 Fish, including Larvae, and Turtles

5.3.1.1 The distances to thresholds for fish hearing groups are provided for both stationary fish and turtles (see **Table 5.6**) and mobile fish (see **Table 5.7**) In addition, behavioural disturbance distances, for impulsive sounds, in relation to fish hearing groups 2 and 3 only (as per Hawkins et al. (2014) thresholds detailed in **Section 4.3.2**) are shown in **Table 5.8**.

Table 5.6: Potential impact ranges (m) for stationary fish, for all hearing groups for the different underwater sound equipment

Sound source	Hearing group	Mortality and potential mortal injury	Recoverable injury	TTS
All sound sources	Group 1 - Fish: no swim bladder	<10	<10	<10
	Group 2 - Fish: swim bladder is not involved in hearing	<10	<10	<10
	Group 3 - Fish: swim bladder involved in hearing	<10	<10	<10
	Fish eggs and larvae	<10	-	-
	Turtles	<10	-	-

Table 5.7: Potential impact ranges (m) for mobile fish, for all hearing groups, for the different underwater sound equipment

Sound source	Hearing group	Mortality and potential mortal injury	Recoverable injury	TTS
All sound sources	Group 1 - Fish: no swim bladder	<10	<10	<10
	Group 2 - Fish: swim bladder is not involved in hearing	<10	<10	<10
	Group 3 - Fish: swim bladder involved in hearing	<10	<10	<10
	Turtles	<10	-	-

Table 5.8: Potential disturbance impact ranges (m) for all fish hearing groups, from impulsive sounds

Sound source	Hearing Group 2	Hearing Group 3
USBL	150	320
SBP Chirp	10	10

6 CONCLUSIONS

6.1.1.1 Acoustic modelling, using dBSea, has been undertaken to estimate the distances at which potential effects on marine mammals and fish may occur as a result of underwater sound generated by activities associated with the Proposed Works Offshore. All relevant activities associated with the Proposed Works Offshore have been considered within the modelling.

6.1.1.2 For marine mammals, auditory injury ranges have been derived based on the thresholds set out in NMFS (2024) and NOAA (2005) for behavioural disturbance. The potential impact ranges in relation to marine mammals are:

- The maximum AUD INJ range, for any sound source was 400 m in relation to the operation of the USBL acoustic positioning sound source for harbour porpoise;
- For all other activities, for all marine mammal hearing groups, AUD INJ thresholds were met only in very close proximity (<10m) to the sound source;
- TTS was predicted to occur to a maximum distance of 1,000 m for LF cetaceans from both SBP Chirp and USBL, and to 800 m from the Vibratory Extraction Tool. For HF cetaceans, TTS was predicted only for USBL to a maximum distance of 800 m. For VHF cetaceans, TTS was predicted to a maximum distance of 900 m from USBL. For pinnipeds (PCW group), TTS was predicted to a maximum distance of 100 m from USBL. All TTS maximum impact ranges were in relation to the SEL threshold, which assumes operations, and hence sound exposure, occur over a period of 24 hours;
- Behavioural disturbance impact ranges for all marine mammal hearing groups were greatest for the Vibratory Extraction Tool, occurring to a maximum distance of 45,500 m. Behavioural disturbance was also predicted to 32,000 m for dredging, 14,000 m for Dynamic Positioning, 13,000 m to 14,000 m for jet lancing and underwater mechanical cutting, and 6,500 m for support vessels and vessel noise from the JUB. For the USBL acoustic positioning system, behavioural disturbance was predicted to 200 m.

6.1.1.3 For fish and turtles, effect thresholds come from Popper *et al.* (2014) and Hawkins *et al.* (2014). Where quantitative threshold criteria were available, there were no impact ranges predicted for mortality or mortal injury, recoverable injury or TTS beyond 10 m for all hearing groups of fish, for both stationary and mobile fish. The same applies to fish eggs and larvae and to turtles.

6.1.1.4 Disturbance from impulsive sound sources was predicted to occur to a maximum distance of 320 m for the Group 3 hearing fish (herring and other Clupidae), and 150 m for Group 2 fish, as a result of the operation of the USBL acoustic positioning.

6.1.1.5 Where quantitative thresholds only are provided, there are no modelling results. Instead, the relative risk ratings identified will be used to assess potential effects in the relevant assessments undertaken for the Proposed Works Offshore.

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