Deep Sea Drilling at ANACONDA-1 – Black Sea, Romania: Underwater Noise Modelling Assessment

Issy Morgan

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Submitted to: Gabriela Stanciu

Tel: + 4 0341 139 922

E-mail: gabriela.stanciu@blumenfield.ro
Website: www.blumenfield.ro

Submitted by: Issy Morgan

Tel: +44 (0)23 80 236 330

E-mail: issy.morgan@subacoustech.com
Website: www.subacoustech.com

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Executive Summary

An assessment of the likely effect on marine mammals and fish of underwater noise from two planned deep-sea drilling operations in the Black Sea, Romania, has been undertaken by Subacoustech Environmental Ltd. Separate reports are provided for each drill site. The assessment presented here covers the noise generated from drilling operations and associated vessel noise at the ANACONDA-1 drill site. For drilling noise, detailed numerical modelling of the works was used to generate noise contours. For vessel noise, a simple model was used to estimate noise propagation, based on previous measured data. These predictions were then used to estimate the likely ranges to the relevant noise exposure criteria for marine mammals and fish.

The results have been interpreted using the guidelines provided in Southall *et al.* (2019) for marine mammals, and Popper *et al.* (2014) for fish. These interpretations are based on worst-case parameters with no implemented mitigation measures. Marine mammals, such as porpoise, are likely to be at risk of permanent auditory injury at 40 m from the drilling activities, whereas dolphins are likely to be at risk if they are < 10 m away. Fish with a swim bladder not involved in hearing are likely to be at risk of recoverable injury 40 m from the drill site. Regarding vessel noise, both marine mammals and fish are unlikely to be at risk of negative impacts at < 10 m from the vessel.

Note that the modelling calculations and predicted impact ranges will produce results that should be considered indicative of the onset of effects on receptors during the works and should not be considered as absolute ranges.

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Terminology

Decibel (dB)	A customary scale commonly used (in various ways) for reporting levels of sound. The dB represents a ratio/comparison of a sound measurement (e.g sound pressure) over a fixed reference level. The dB symbol is followed by a second symbol identifying the specific reference value (e.g., re 1 µPa).
Peak pressure	The highest pressure above or below ambient that is associated with a sound wave.
Peak-to-peak pressure	The sum of the highest positive and negative pressures that are associated with a sound wave.
Permanent Threshold Shift (PTS)	A permanent total or partial loss of hearing caused by acoustic trauma. PTS results in irreversible damage to the sensory hair cells of the ear, and thus a permanent reduction of hearing acuity.
Root Mean Square (RMS)	The square root of the arithmetic average of a set of squared instantaneous values. Used for presentation of an average sound pressure level.
Sound Exposure Level (SEL or $L_{E,p}$)	The constant sound level acting for one second, which has the same amount of acoustic energy, as indicated by the square of the sound pressure, as the original sound. It is the time-integrated, sound-pressure-squared level. SEL is typically used to compare transient sound events having different time durations, pressure levels, and temporal characteristics.
Sound Exposure Level, cumulative (SEL_{cum})	Single value for the collected, combined total of sound exposure over a specified time or multiple instances of a noise source.
Sound Exposure Level, single strike (SEL_{ss})	Calculation of the sound exposure level representative of a single noise impulse, typically a pile strike.
Sound Pressure Level (SPL or L_p)	The sound pressure level is an expression of sound pressure using the decibel (dB) scale; the standard frequency pressures of which are 1 µPa for water and 20 µPa for air.
Sound Pressure Level Peak (SPL_{peak} or $L_{p,pk}$)	The highest (zero-peak) positive or negative sound pressure, in decibels.
Temporary Threshold Shift (TTS)	Temporary reduction of hearing acuity because of exposure to sound over time. 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.
Unweighted sound level	Sound levels which are “raw” or have not been adjusted in any way, for example to account for the hearing ability of a species.
Weighted sound level	A sound level which has been adjusted with respect to a “weighting envelope” in the frequency domain, typically to make an unweighted level relevant to a particular species.

Units

dB	Decibel (sound pressure)
Hz	Hertz (frequency)
kg/m^3	Kilogram per cubic metre (density)
kHz	Kilohertz (frequency)
km	Kilometre (distance)
km^2	Square kilometres (area)
m	Metre (distance)
mms^{-1}	Millimetres per second (particle velocity)
ms^{-1}	Metres per second (speed)
Pa	Pascal (pressure)
Pa^2s	Pascal squared seconds (acoustic energy)
μPa	Micropascal (pressure)

Acronyms

EMODnet	European Marine Observation and Data Network
HF	High-Frequency Cetaceans
LF	Low-Frequency Cetaceans
PCW	Phocid Carnivores in Water
PPV	Peak Particle Velocity
PTS	Permanent Threshold Shift
RMS	Root Mean Square
SE	Sound Exposure
SEL ($L_{E,p}$)	Sound Exposure Level
SEL_{cum}	Cumulative Sound Exposure Level
SEL_{ss}	Single Strike Sound Exposure Level
SPL	Sound Pressure Level
SPL_{peak} (L_{p-pk})	Peak Sound Pressure Level
$SPL_{peak-to-peak}$	Peak-to-peak Sound Pressure Level
SPL_{RMS} (L_p)	Root Mean Square Sound Pressure Level
TTS	Temporary Threshold Shift
VHF	Very High-Frequency Cetaceans

1 Introduction

1.1 Project Overview

Subacoustech Environmental have been requested by Blumenfield to undertake an underwater noise modelling assessment for the anticipated deep-sea drilling operations planned to take place in the Black Sea, Romania.

The works are planned for the drilling of two natural gas exploration wells in Romania: Lira-2A and ANACONDA-1. The drilling method that will be applied for all three deepwater wells is traditional offshore vertical rotary drilling by a deepwater modular offshore drilling unit (MODU) for conventional fields. The drilling installation is a drill ship Globetrotter II. Two support vessels are likely to be associated with the works, from the Tidewater fleet or similar. An underwater noise assessment is required to consider the potential impact from the noise generated from the works on all marine mammals and fish in the region.

This report provides the results of a detailed modelling assessment for the planned deep-sea drilling operations at the ANACONDA-1 site. The modelling has been used to predict the sound pressure levels and sound exposure levels generated during these activities, and to assess the impact of these levels on sensitive marine species in the region, with particular focus on the impact on marine mammals and fish. It should be noted that a separate report is provided for each well.

1.2 Study Area

Drilling will be conducted from a MODU at a single location shown in Figure 1-1. The modelling area spans 25 km × 25 km, with deep water towards the east, with various channels of deep water running across various parts of the extent. Maximum depth reaches 1,774.5 m.

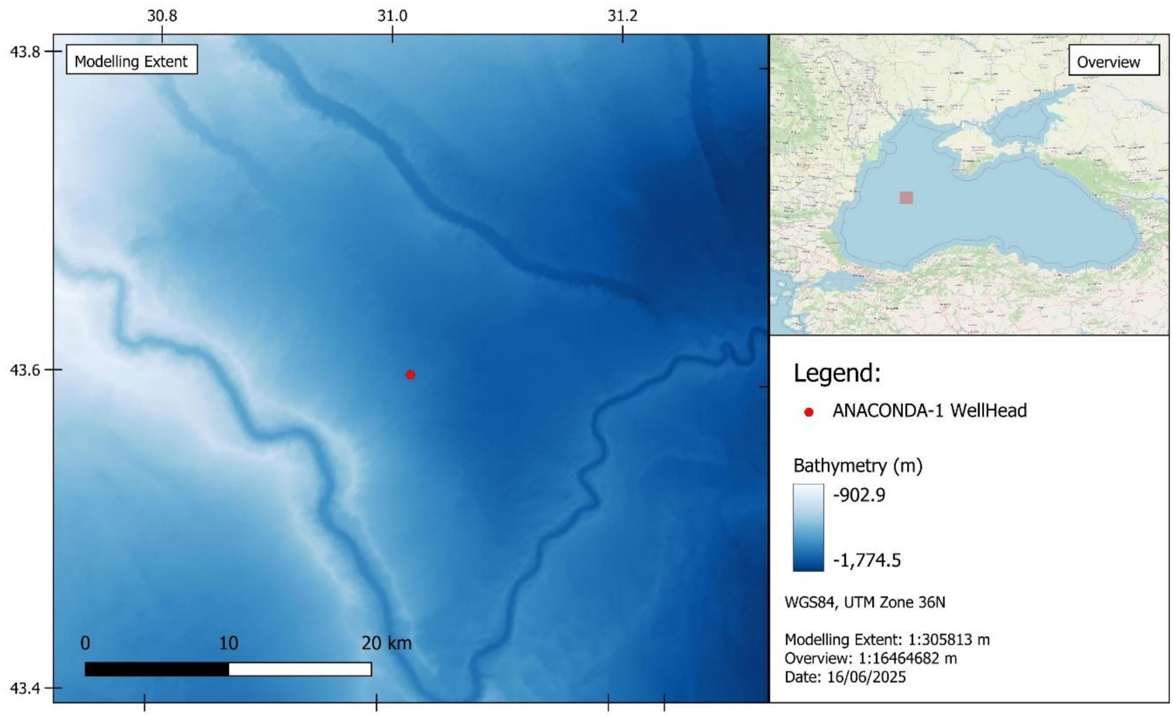

Figure 1-1: The modelling location and extent for the drilling operations at ANACONDA-1 in the Black Sea. Map data from OpenStreetMap

1.3 Sound Sources

Underwater noise sources that could impact marine fauna, and have therefore been included in the assessment include:

- Drilling
- Vessel Noise

Details of the input parameters used for the modelling of each of these sources in the assessment are presented in Section 3.1 and Section 3.2.

1.4 Document Overview

This report presents a detailed assessment of the potential underwater noise from the deep-sea drilling and associated vessel noise at the ANACONDA-1 drill site in the Black Sea, and covers the following:

- Section 2: Review of background information on measuring and assessing underwater noise.
- Section 3: Discussion of the modelling approach, input parameters and assumptions for the noise modelling undertaken.
- Section 4: Presentation of detailed subsea noise modelling and interpretation of the results using suitable noise metrics and criteria.
- Section 5: Summary and conclusions.

2 Underwater Noise Concepts

Sound travels much faster in water (approximately 1,500 ms^{-1}) than in air (343 ms^{-1}) as water is relatively incompressible and has a higher density than air. This affects the way in which sound measurements are expressed between the two mediums, which means that underwater sound levels are not directly comparable to airborne sound levels. This is noted for context; this report does not contain or include any reference to airborne sound levels.

2.1 Units of Measurement

Sound measurements are usually expressed using the decibel (dB) scale, which is a logarithmic measure of sound. The dB scale represents a ratio, and therefore, it is used with a reference unit, which is the base from which the ratio is expressed. The fundamental definition of the dB scale is given in Equation 1:

$$Sound\ pressure\ level\ (L_p) = 20\log_{10}\left(\frac{P}{P_{ref}}\right) \quad (1)$$

where P is pressure, measured in Pascals (Pa), and P_{ref} is the reference pressure, also measured in Pa. For underwater noise, a reference pressure of 1 µPa (1×10^{-6} Pa) is used as defined in ISO 18405:2017. Sound can be quantified using various metrics depending on the nature of the sound, as discussed below.

2.1.1 Sound Pressure Level

Sound Pressure Level (SPL or L_p) is a measure of the pressure variation caused by sound waves, expressed in decibels (dB), as seen in Equation 1. Variations of SPL are used depending on the noise source being measured. Unless otherwise defined, all SPLs in this report are referenced to 1 µPa.

2.1.1.1 Level of the Mean Squared Sound Pressure

For continuous, non-impulsive noise sources such as drilling or vibropiling, an unweighted sound pressure level, averaged over a measurement period, known as a root mean squared (RMS) sound pressure level (SPL_{RMS} or $L_{p,RMS}$), can be used to represent the noise levels. The RMS period must be specified (e.g. $L_{p,RMS(125ms)}$), as the mean level can vary significantly depending on the measurement duration.

2.1.1.2 Level of the Peak Sound Pressure

Transient, impulsive pressure waves, such as generated from impact piling are usually expressed using level of the peak sound pressure (SPL_{peak} or $L_{p,pk}$). This is calculated using the maximum pressure variation from positive to zero, representing the peak change in pressure as the transient wave propagates. A further variation of this is the peak-to-peak sound pressure level ($SPL_{peak\text{-}peak}$ or $L_{p,pk\text{-}pk}$) which considers the maximum pressure variation from positive to negative. For a symmetrically distributed wave, the peak-to-peak pressure is twice the peak level, or 6 dB higher.

2.1.2 Sound Exposure Level

Sound Exposure Level (SEL) is a measures Sound Exposure (SE), which represent the total acoustic energy of a sound event in decibels (dB), accounting for both the sound's intensity and duration. SEL provides a way to quantify the total energy in a sound, making it useful for assessing the impact of both continuous and transient sounds. Variations of SEL are used depending on the noise source being measured. For context, SEL can be compared SPL using Equation 2:

$$L_{E,p} = L_p + 10 \times \log_{10} T \tag{2}$$

where the L_p is a measure of the average level of broadband noise and the $L_{E,p}$ sums the cumulative broadband noise energy. For continuous sounds shorter than one second, the SEL is lower than the SPL. For durations longer than one second, the SEL exceeds the SPL (e.g., a 10-second sound results in a 10 dB higher SEL and a 100-second sound gives a 20 dB higher SEL). Unless otherwise defined, all $L_{E,p}$ noise levels in this report are referenced to 1 μPa^{2}s.

2.1.2.1 Single Strike Sound Exposure Level

Single strike Sound Exposure Level (SEL_{ss} or $L_{E,p,ss}$) refers to the total acoustic energy from a single, loud, short duration noise event (such as a blast or impact) measured over a specified duration. This can be expressed using Equation 3:

$$L_{E,p,ss} = 10 \times \log_{10}\left(\frac{\int_0^T p^2(t)dt}{{p^2}_{ref}T_{ref}}\right) \tag{3}$$

where p is the acoustic pressure in Pascals, T is the total duration of sound in seconds, and t is time in seconds.

2.1.2.2 Cumulative Sound Exposure Level

A cumulative Sound Exposure Level (SEL_{cum} or $L_{E,cum}$) accounts for the exposure from multiple impulses or pile strikes over time, where the number of impulses replaces the T in the Equation 3, leading to Equation 4:

$$L_{E,cum} = L_{E,p,ss} + 10 \times \log_{10} X \tag{4}$$

Where $L_{E,p,ss}$ is the SEL_{ss} and X is the total number of impulses or strikes.

2.2 Properties of Sound

2.2.1 *Impulsive vs Non-impulsive*

Sound can be categorised loosely into two types: impulsive and non-impulsive. These can be defined as:

- Non-impulsive: a steady-state sound. It does not necessarily have to have a long duration.
    - Examples: drilling, vibropiling, vessel noise
- Impulsive: a sound with a high peak sound pressure, short duration, fast rise-time and broad frequency content at the source.
    - Examples: seismic airguns, explosives, impact piling

These differences are crucial for assessing auditory injury, as impulsive sound is typically more harmful than non-impulsive sound. Different metrics are needed to describe these distinct sound sources:

- Impulsive: Use SPL_{peak} ($L_{p,pk}$) or SEL_{cum} ($L_{E,p,ss}$ or $L_{E,cum}$)
- Non-impulsive: Use SPL_{rms} ($L_{p,rms}$) or SEL_{cum} ($L_{E,cum}$)

2.2.2 *Particle Motion*

Particle motion, a key component of sound, describes the back-and-forth movement of particles in a medium, such as water, caused by sound waves. Unlike sound pressure, particle motion contains directional information (Hawkins and Popper, 2017). It is typically quantified by peak particle velocity (PPV), though acceleration or displacement can also be used. Research shows many fish species and marine invertebrates are sensitive to particle motion (e.g., Popper and Hawkins, 2019; Nedelec *et al.,* 2016, Radford *et al.,* 2012, Sole *et al.,* 2023), but sound pressure metrics are still more commonly used due to limited data (Popper and Hawkins, 2018). Calls for further research on particle motion levels and effects continue.

2.3 Analysis of Environmental Effects: Assessment Criteria

Over the past 20 years, it has become clear that human-generated underwater noise impacts marine species. The severity of these effects depends on factors like sound level, frequency, exposure duration, and repetition rate (Hastings and Popper, 2005). As a result, research on aquatic species' hearing abilities has grown, with studies focused on high-level noise sources such as seismic airguns, impact piling, and blasting, which have the most immediate environmental effects, though interest in chronic noise exposure is rising.

The impacts of underwater sound on marine species can be broadly summarised as follows:

- Physical traumatic injury and fatality.
- Auditory injury (either permanent or temporary).
- Behavioural responses

The following sections outline the underwater noise criteria used in this study for marine mammals and fish species in the Black Sea.

2.3.1 Marine Mammals

2.3.1.1 Southall *et al.* (2019): Auditory Injury (PTS and TTS) criteria

Southall *et al.* (2019), an update of the 2007 version, is the most recognised reference for marine mammal hearing thresholds and aligns with the thresholds provided in the National Marine Fisheries Service (NMFS, 2018) guidance. However, the hearing groups are described differently, so caution is needed when comparing results using these criteria.

The Southall *et al.* (2019) guidance categorises marine mammals into groups based on similar species and applies filters to the unweighted noise levels to approximate their hearing sensitivities. These groups are summarised in Table 2-1, with auditory weighting functions in Figure 2-1. Additional groups for low frequency cetaceans, pinnipeds, sirenians and other marine carnivores are provided but not included in this study, as these species are not common in the Black Sea.

Table 2-1: Marine mammal hearing groups (from Southall et al., 2019).

Hearing group	Auditory Weighting Function	Generalised hearing range	Species group	Example species
High-frequency Cetaceans	HF	150 Hz to 160 kHz	Toothed whales, including dolphins and beaked whales	Black Sea Bottlenose Dolphin, Black Sea Common Dolphin
Very high-frequency Cetaceans	VHF	275 Hz to 160 kHz	True porpoise	Black Sea Harbour Porpoise

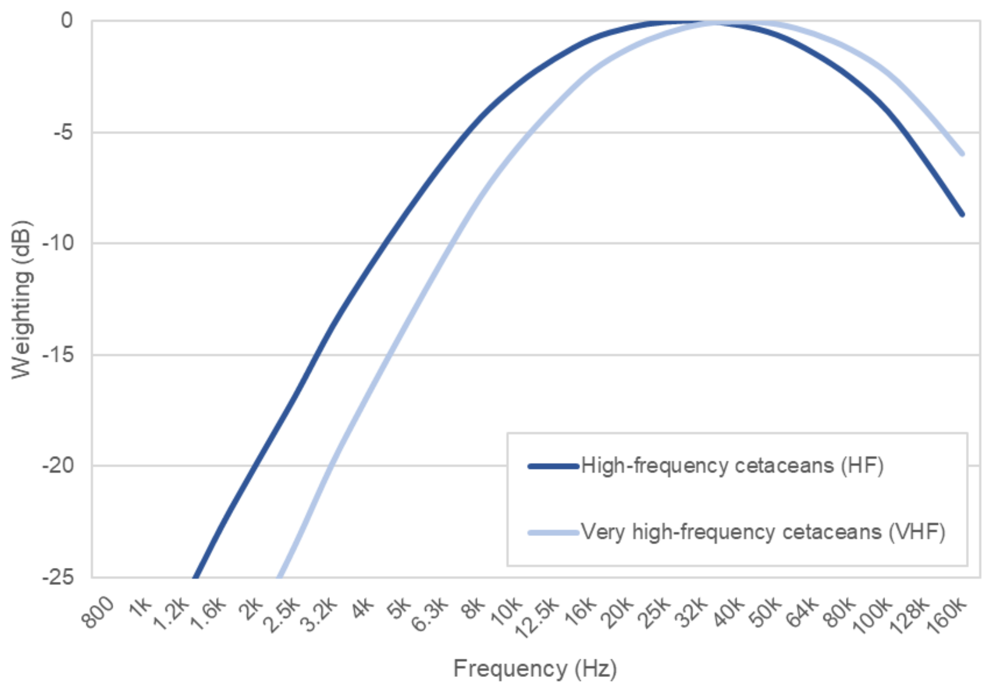

Figure 2-1: Auditory weighting functions for HF cetaceans and VHF cetaceans from Southall et al., (2019).

Southall *et al.* (2019) presents noise impact thresholds for marine mammal groups based on:

- The sound type (impulsive vs non-impulsive)
- The type of auditory injury of concern

For SEL_{cum} thresholds in marine mammals, a fleeing animal model is used, assuming the animal swims away from the sound source. These are worst-case assumptions, as marine mammals can swim faster under stress (Kastelein *et al*., 2018), particularly at the start of a noisy event when they are closest to the source. The following flee speeds are applied for each relevant marine mammal group:

- 1.5 ms^{-1} for HF and VHF cetaceans (Otani *et al*., 2000)

Southall *et al.* (2019) presents different impact thresholds for impulsive and non-impulsive sound criteria, based on varying levels of auditory injury at different sound levels. Auditory injury is categorised into two types:

- PTS (permanent threshold shift): the greatest severity, which is unrecoverable (but incremental) reduction in hearing sensitivity.
- TTS (temporary threshold shift): the least severity, which is a short-term reduction in hearing sensitivity.

TTS typically results in the largest impact range, but PTS represents the most significant and permanent impairment, making it the key impact threshold.

Since drilling and vessel noise is a non-impulsive sound source, this study considered the non-impulsive sound criteria for marine mammal PTS and TTS thresholds from Southall *et al.* (2019), which is summarised in Table 2-2.

Table 2-2: SEL ($L_{E,24h,wtd}$) non-impulsive criteria for marine mammals (Southall et al., 2019)

Southall *et al.* (2019)	$L_{E,24h,wtd}$ (dB re 1 µPa²s)	
	PTS	TTS
High-frequency cetaceans (HF)	198	178
Very high-frequency cetaceans (VHF)	173	153

2.3.2 Fish

2.3.2.1 Popper *et al.* (2014): Mortality, injury and behavioural effects

The Popper *et al.* (2014) guidelines are a reliable reference for underwater noise impacts on marine fauna, excluding marine mammals. Unlike previous studies based on limited or irrelevant data, Popper *et al.* (2014) provides updated research and guidelines.

Popper *et al.* (2014) provides specific criteria for common anthropogenic underwater sound sources. If a source is not listed, it is common practice to use the criteria which is the best fit to the source required in the assessment. Across all sources, marine faunae are categorised into sea turtles, eggs and larvae, and fish. Fish are further divided into three groups based on their hearing capabilities, determined by the presence and role of a swim bladder:

- Fish: no swim bladder
- Fish: swim bladder not involved in hearing
- Fish: Swim bladder involved in hearing.

Popper *et al.* (2014) then provides impact thresholds for each marine faunae category related to sound exposure, including:

- Mortality and potential mortal injury: immediate or delayed death.
- Impairment, such as:
  - Recoverable injury: injuries unlikely to result in mortality.
  - Temporary Threshold Shift (TTS): short or long-term changes in hearing sensitivity that may or may not reduce fitness.
  - Masking: Reduction in sound detectability due to the simultaneous presence of another sound.
- Behavioural effects: substantial change in behaviour for the animals exposed to a sound (long or short term).

Despite emerging evidence of fish sensitivity to particle motion, the Popper *et al.* (2014) criteria provide a quantitative criterion as thresholds for impact onsets in terms of sound pressure related functions (e.g., SPL_{peak}, SPL_{rms}, SEL_{ss}, SEL_{cum}). Most species in Popper *et al.* (2014) are likely to flee from harmful sounds (Dahl *et al.,* 2015), and these flee speeds are likely to vary widely across species. Therefore, a conservative fleeing speed of 1.5 ms^{-1} (Hirata, 1999) is used in fleeing animal models. However, some species in Popper *et al.* (2014) have lower sensitivity not sound, such as benthic or swim bladderless species, remain stationary even when exposed to high intensity sounds (e.g., Goertner *et al.,* 1994, 1978; Stephenson *et al.,* 2010; Halvorsen *et al.,* 2012). To avoid overestimating risk, a combined approach, which presents both fleeing and stationary models, is used in this report.

Since drilling and vessel noise are continuous sound sources, this study uses the criteria from Popper *et al.* (2014) for shipping and continuous sounds as a proxy, summarised in Table 2-3.

Popper *et al.* (2014) only provides a quantitative criterion for fish with a swim bladder involved in hearing for shipping and continuous sounds as data is insufficient for other impacts, and other fish categories. Therefore, to assess the other fish categories (fish with no swim bladder and fish with a swim bladder not involved in hearing), Popper *et al.* (2014) provides a relative risk associated with various impacts, which describes the risk of an effect on a receptor occurring in either the near-field (tens of meters), intermediate-field (hundreds of meters) or far-field (thousands of meters) from the sound source, as high, moderate or low.

Table 2-3: Recommended guidelines for shipping and continuous sounds according to Popper et al. (2014) for speices of fish, sea turtles and eggs and larvae (N = Near-field; I = Intermediate-field; F = Far-field).

Popper *et al.* (2014) criteria for Shipping and Continuous sounds					
Type of fish	**Mortality and potential mortal injury**	**Impairment**			**Behaviour**
		Recoverable injury	**TTS**	**Masking**	
Fish: no swim bladder	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
Fish: swim bladder not involved in hearing	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
Fish: swim bladder involved in hearing	(N) Low (I) Low (F) Low	**170 $L_{p,48h}$**	**158 $L_{p,12h}$**	((N) High (I) High (F) High	(N) High (I) Moderate (F) Low
Sea Turtles	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) High (I) Moderate (F) Low
Eggs and Larvae	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) High (I) Moderate (F) Low	(N) Moderate (I) Moderate (F) Low

2.3.3 Marine Invertebrates

A review by Sole *et al.* (2023) highlights growing evidence that certain anthropogenic noises harm marine invertebrates, affecting behaviour, physiology, mortality rates, and causing physical impairment at individual, population, or ecosystem levels. Much of this damage results from vibrations of the invertebrate's body caused by sound (André et al., 2016).

Studies reviewed by Sole *et al.* (2023) show inconsistency in quantifying noise impacts on marine invertebrates. For example, Hubert *et al.* (2021) reports behavioural changes in blue mussels at 150-300 Hz tones, while Spiga *et al.* (2016) notes a behavioural change at $L_{E,p,ss}$ 153.47 dB re 1 µPa. These inconsistencies make it challenging to develop accurate thresholds. A notable exception is cephalopods, where studies (e.g., Sole *et al.,* 2019, 2018, 2013a; André et al., 2011) show consistent auditory damage at 157 dB re 1 µPa, providing a benchmark for other groups. However, further research is needed for more accurate thresholds.

Furthermore, Sole *et al.* (2023) highlights inconsistencies in the responses of taxonomically similar marine invertebrates to anthropogenic noise. For instance, Fields *et al.* (2019) reports low mortality in zooplankton exposed to seismic airguns, while McCauley *et al.* (2017) observes mass mortality in krill larvae from the same source. This suggests that noise impacts vary by species, complicating the development of generalised impact thresholds for marine invertebrates

For now, research on the effects of anthropogenic noise on marine invertebrates is emerging, but at a slower pace than for marine mammals and fish. Currently, the data is insufficient to establish reliable impact thresholds for regulatory use. However, convincing evidence of noise impacts exists, and while some species' data may be referenced, caution is needed due to significant knowledge gaps.

3 Underwater Noise Modelling: Methodology

3.1 Drilling

Modelling of underwater noise is complex and can be approached in several different ways. Measurements are only possible at limited locations, so modelling has been undertaken to provide a more comprehensive set of results. To estimate the noise levels generated by the drilling, Subacoustech have chosen to utilise the dBSea noise modelling software, which uses various numerical solvers to calculate underwater noise. This assessment uses two different solvers:

- A parabolic equation (PE) method for lower frequencies (12.5 Hz to 250 Hz)
  - Widely used within the underwater acoustics community but has computational limitations at high frequencies.
- A ray tracing method for higher frequencies (315 Hz to 100 kHz).
  - More computationally efficient at higher frequencies but is not suited to low frequencies (Etter, 1991).

These solvers account for a wide array of environmental input parameters within the study area, including bathymetry, sediment data and sound speed, as well as the characteristics of the noise source, such as source frequency content, to ensure as detailed results as possible. The input parameters used in this study are described in the following sections.

3.1.1 Input Parameters

3.1.1.1 Modelling Location

A single modelling location was selected at the drill site for ANACONDA-1. Since the equipment will be suspended from a drilling vessel, the noise source was assumed to be radiating from a depth of 8 m from the sea surface. Details of the noise source location used are presented in Table 3-1.

Table 3-1: Details of the modelling locations. Eastings/Northings are given in WGS84, UTM Zone 36N.

Modelling location	Easting (m)	Northing (m)	Source depth below surface (m)	Depth at source location (m)
Drill Site (ANACONDA-1)	340396	4829627	8	1,547

3.1.1.2 Bathymetry

The bathymetry data used in the modelling was obtained from The European Marine Observation and Data Network (EMODnet, 2018). This data has a resolution of 1/16th arcminutes (approximately 115 × 115 m). The bathymetry used for modelling covers an area of 25 km × 25 km surrounding the drill site.

3.1.1.3 Seabed Properties

Characteristics of the seabed were based on core samples from the Han Asparuh Block as well as information provided in Simmons *et al.* (2018), which suggested that the seabed in the area is comprised entirely of a thick sediment layer of mud. Geo-acoustic properties for the seabed were based on available data from Jensen *et al.* (1994, 2011), which are provided in Table 3-2.

Table 3-2: Seabed geo-acoustic properties of the area.

Material	Compressive sound speed profile in substrate (m/s)	Density profile in substrate (kg/m³)	Attenuation profile in substrate (dB/wavelength)
Mud	1,700	1,500	1

3.1.1.4 Sound Speed Profile

The speed of sound in the water has been calculated for the average annual temperature and salinity using the Mackenzie (1981) equation, with data from Goncharov *et al.* (2025) for the modelling location. The resulting profile is shown in Figure 3-1.

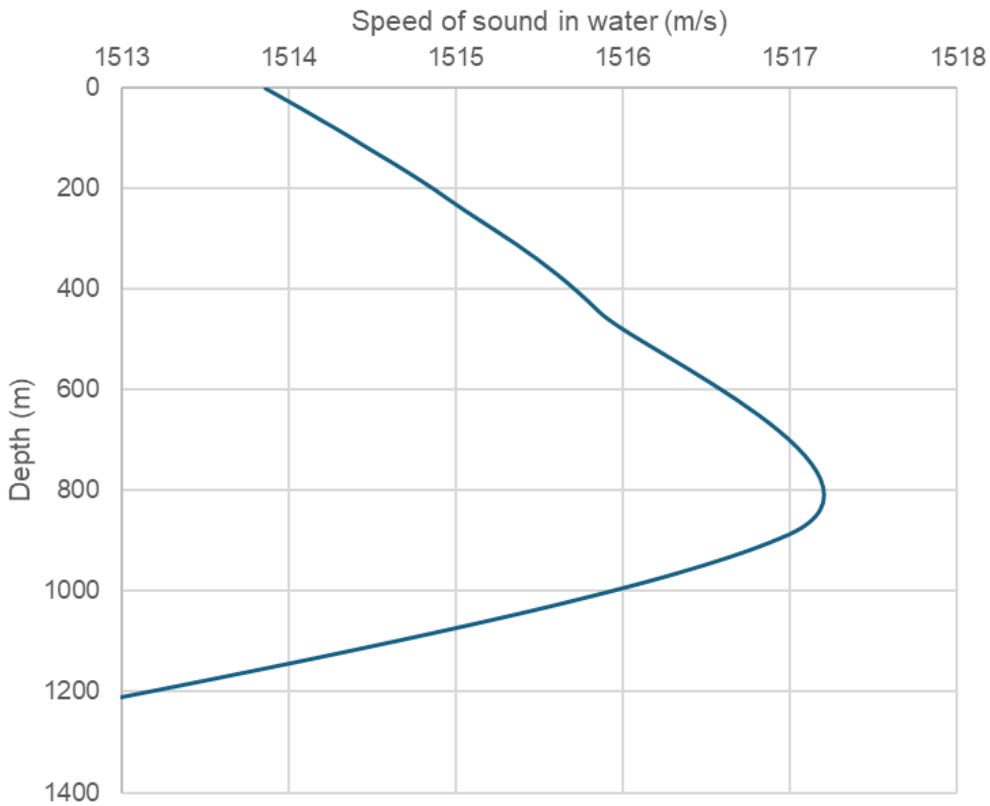

Figure 3-1: Sound speed profile used for detailed modelling of the area.

3.1.1.5 Noise Source

It is understood that the drilling method anticipated will be traditional offshore rotary drilling by a deepwater modular offshore drilling unit (MODU). No further information was provided for drill itself, so the noise source characteristics were based off previously measured data by Subacoustech of drilling in at the Khan Asparuh Block in the Black Sea, as detailed in East (2018). The measured levels were scaled based propagation to estimate source levels. The source levels used in modelling for the drill are presented in Table 3-3.

Table 3-3: Summary of the combined calculated $L_{p,rms}$ source levels for the drilling operations.

Equipment	Estimated source level @ 1 m ($L_{p,RMS}$ dB re 1 µPa)
Drill	195.2

A source spectrum used in the modelling for the drilling was based on previous data for a drilling in a similar location. From this measured data, the 1/3rd octave levels were then adjusted to achieve the required source levels estimated for the drill (values stated in Table 3-3). The 1/3rd octave source spectrum for the drilling is shown in Figure 3-2. It should be noted that this source spectrum will also encompass noise from associated drill vessels, which could not be isolated from the drill noise itself.

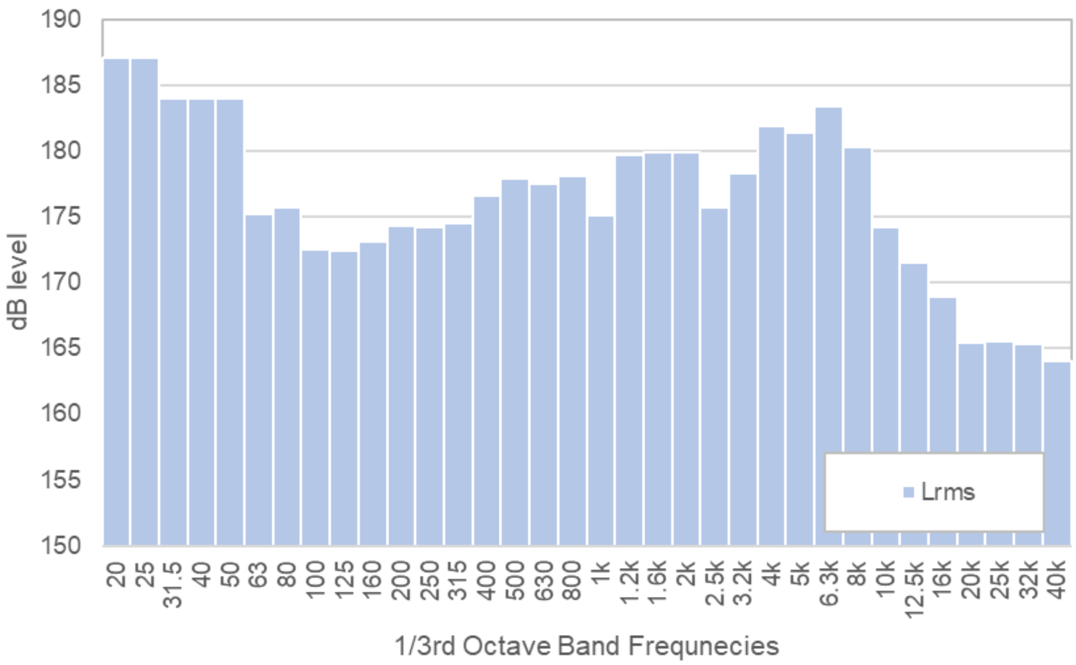

Figure 3-2: The source spectrum containing 1/3rd octave band levels used to model the drilling operations.

For $L_{E,p,t}$, it was assumed that drilling operations will take place over a period of 24-hours per day, as a worst-case scenario.

3.2 Vessel Noise

Subacoustech's Sound Propagation Estimator and Ranking (SPEAR) model is a simplified modelling method that predicts noise levels using Subacoustech's measurement data, scaled to site-specific and source-specific parameters. It is suitable for quieter sources like vessel noise, and a more detailed model is unlikely to offer significant benefits in this case.

3.2.1 Input Parameter Calculations

The noise generated from vessel noise is usually considered as a non-impulsive, continuous noise source. The calculation of underwater noise transmission loss for non-impulsive sources is based on an empirical analysis of the noise measurements taken along transects around the source by Subacoustech. The predictions Equation 5, fitted to the measured data as follows:

$$RL = SL - N\log_{10} R - \alpha R \qquad (5)$$

where RL is the received level at the receptor, SL is the source level at 1 m, N is the geometrical spreading coefficient, R is the range from the source (m) and α is the absorption coefficient.

Predicted source levels and propagation data for vessel noise are shown in along with the number of datasets used. Values for N and α are empirically derived and depend on the machinery's size and shape, the noise source, measurement transect, and local environmental conditions.

Table 3-4 along with the number of datasets used. Values for N and α are empirically derived and depend on the machinery's size and shape, the noise source, measurement transect, and local environmental conditions.

Table 3-4: Summary of the $L_{p,rms}$ source levels, and associated transmission loss coefficients for the vessel noise.

Source	Estimated Unweighted Source Level dB re 1 µPa @ 1 m (RMS)	Transmission Loss Coefficients		Comments
		N	α	
Vessel noise	168	12	0.0021	Based on five datasets of large vessels including container ships, FPSOs and other vessels more than 100 m in length. Vessel speed assumed as 10 knots.

For the $L_{E,p,t}$ calculations in this section, the duration the noise is present also needs to be considered, with all sources assumed to operate constantly for 24 hours. To account for the weightings required for modelling using the Southall *et al.* (2019) criteria, reductions in source level have been applied to the noise sources. Figure 3-3 shows the representative noise measurements used, which have been adjusted for the source levels given in Table 3-4.

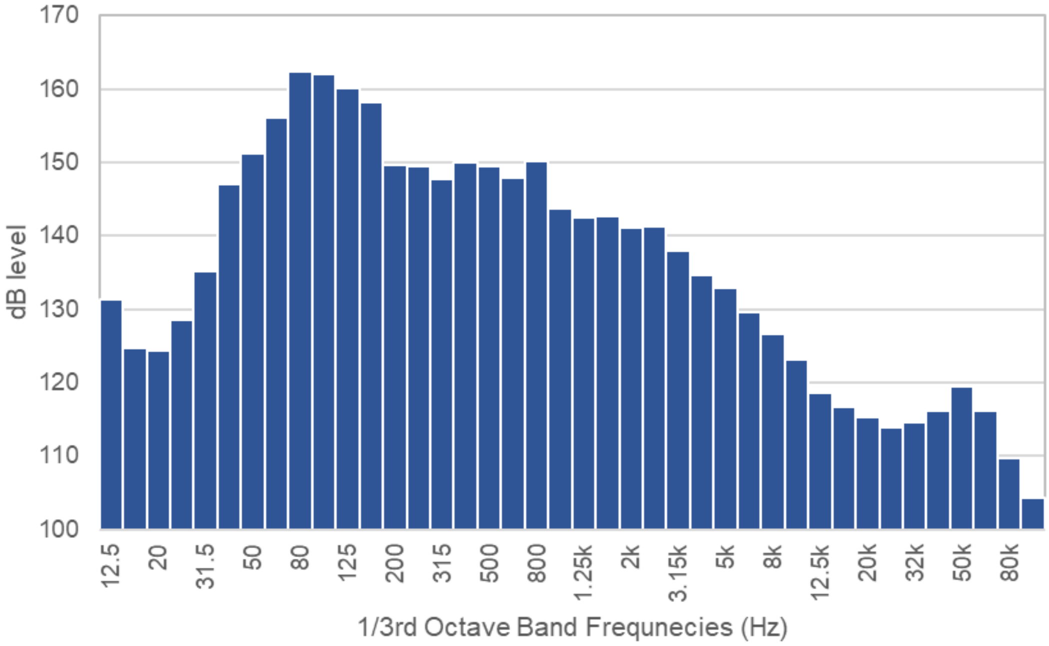

Figure 3-3: The source spectrum containing 1/3rd octave band levels used to model the vessel noise

Table 3-5 presents details of the reductions in source levels for each of the Southall *et al*. (2019) weightings (HF cetaceans and VHF cetaceans) used for modelling.

Table 3-5: Reductions in source level for the different noise sources considered when the Southall et al. (2019) weightings are applied

Noise Source	Reduction in source level from the unweighted level (Southall *et al.*, 2019)	
	HF	VHF
Vessel Noise	34.4	38.6

4 Underwater Noise Modelling: Results

4.1 Drilling

4.1.1 Predicted Noise Levels

The distribution of noise from the drilling operations at ANACONDA-1 is presented as a noise contour plot in Figure 4-1. These plots show the maximum predicted noise level in the water column.

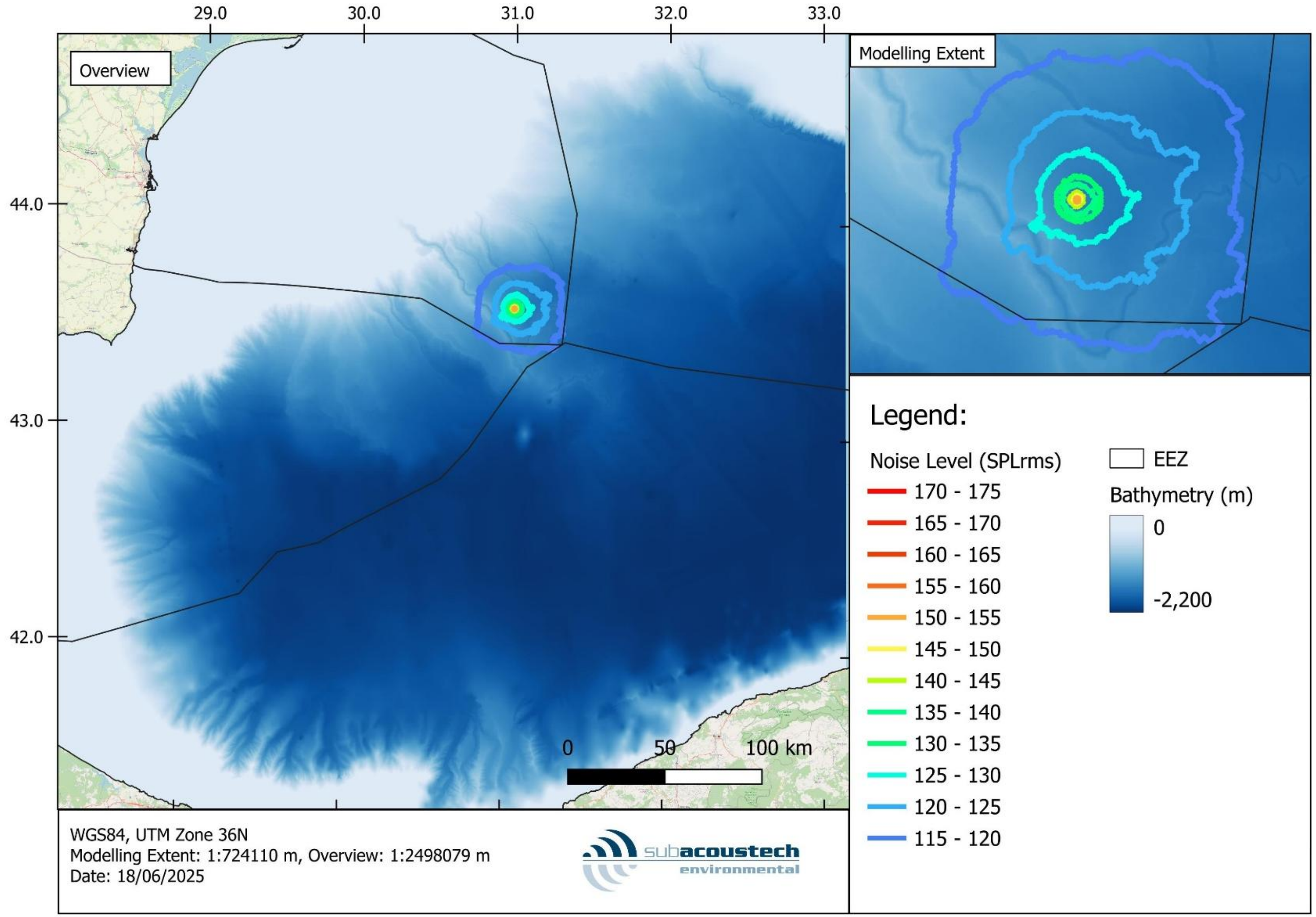

Figure 4-1: $L_{p,rms}$ noise level contours of the predicted for drilling at ANACONDA-1. Map data from OpenStreetMap.

4.1.2 Interpretation

Due to the complexity in noise conditions at close range to the source, estimated impact ranges are limited to a resolution of 10 m from the source, as such, ranges smaller than this have been presented as "< 10 m".

4.1.2.1 Assessment: Marine Mammals

The noise level results from Section 4.1.1 were assessed against the Southall *et al.* (2019) guidelines and weightings to predict the likely range at which the thresholds for non-impulsive sounds would be exceeded by marine mammals.

When the $L_{E,p,24h,wtd}$ criteria for non-impulsive noise is applied to the predicted noise contours, the VHF cetacean group are predicted to have the largest PTS range. Animals within 40 m of the drill location are likely to exceed the PTS threshold for VHF cetaceans, if they flee away from the source at a constant speed. These details, along with PTS impact ranges predicted for other species groups, and TTS impact ranges predicted across all groups, are presented in Figure 4-1.

Table 4-1: Predicted impact ranges associated with the drilling operations at ANACONDA-1 for marine mammals, using the Southall et al. (2019) $L_{E,p,24h,wtd}$ criteria for non-impulsive noise sources assuming a fleeing receptor.

Southall *et al.* (2019) criteria $L_{E,p,24h,wtd}$ (Non-impulsive)		Estimated Impact Range (m)		
		Maximum	Mean	Minimum
HF Cetaceans	PTS	< 10	< 10	< 10
	TTS	50	50	50
VHF Cetaceans	PTS	40	40	40
	TTS	4800	4080	3700

4.1.2.2 Assessment: Fish

The noise level results from Section 4.1.1 were assessed against the Popper *et al.* (2014) guidelines to predict the likely range at which the thresholds for shipping and continuous sounds would be exceeded by fish.

Based on the results for the $L_{p,rms}$ metric, animals within 40 m of the drilling activities may exceed the recoverable injury threshold for fish with a swim bladder involved in hearing. These details, along with TTS impact ranges are provided in Table 4-2.

Table 4-2: Predicted impact ranges associated with the drilling operations at ANACONDA-1 for fish using the Popper et al. (2014) $L_{p,RMS}$ criteria for shipping and continuous sounds.

Popper *et al.* (2014) criteria $L_{p,RMS}$ (Continuous Sounds)		Estimated Impact Range (m)		
		Maximum	Mean	Minimum
Fish: swim bladder involved in hearing	Recoverable injury	40	40	40
	TTS	160	160	160

Across all species of fish, the relative risk of mortality and potential mortal injury, as well as recoverable injury associated with drilling is low in the near-field, intermediate field and far field distance. Of all the potential impacts, the impact associated with the highest relative risk for all species of fish is masking, which is deemed as high in the near-field and intermediate field, and moderate in the far-field. These details are presented in Table 4-3.

Table 4-3: The relative risk of impacts on fish in the near-field (N), intermediate field (I) and far-field (F) for the drilling operations at ANACONDA-1 using the Popper et al. (2014) $L_{p,rms}$ fish criteria for shipping and continuous sounds.

Popper *et al.* (2014) criteria for Shipping and Continuous sounds					
Type of fish	**Mortality and potential mortal injury**	**Impairment**			**Behaviour**
		Recoverable injury	**TTS**	**Masking**	
Fish: no swim bladder	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
Fish: swim bladder not involved in hearing	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
Fish: swim bladder involved in hearing	(N) Low (I) Low (F) Low	**See Table 4-2**	**See Table 4-2**	((N) High (I) High (F) High	(N) High (I) Moderate (F) Low

4.2 Vessel Noise

The impact ranges estimated for vessel noise are indicative of the 'onset' stage to each receptor considered at these ranges. This is the minimum exposure that could potentially lead to the start of an effect and may only be marginal. For most receptors, the noise levels are low enough that there is a minimal risk.

Due to the complexity in noise conditions at close range to the source, estimated impact ranges are limited to a resolution of 10 m from the source, as such, ranges smaller than this have been presented as "< 10 m".

4.2.1 Interpretation

4.2.1.1 Assessment: Marine Mammals

The calculated noise level results were assessed against the Southall *et al.* (2019) guidelines to predict the likely ranges at which the threshold for non-impulsive sounds would be exceeded by marine mammals. Using the $L_{E,p,24h}$ criteria, all marine mammal species are unlikely to exceed their PTS threshold at any range from the drilling activities. This is assuming they flee away from the source at a constant speed. These details, along with TTS impact ranges are provided in Table 4-4.

Table 4-4: Summary of the impact ranges associated with vessel noise at ANACONDA-1 using the non-impulsive criteria from Southall et al. (2019) for marine mammals assuming a fleeing animal.

Southall *et al.* (2019) criteria $L_{E,p,24h,wtd}$ (Non-impulsive)		Estimated Impact Range	
		Maximum (m)	Area (km²)
HF Cetaceans	PTS	< 10	< 1
	TTS	< 10	< 1
VHF Cetaceans	PTS	< 10	< 1
	TTS	40	< 1

4.2.1.2 Assessment: Fish

For fish, the $L_{p,RMS}$ metrics are assessed using the Popper *et al.* (2014) guidance for shipping and other continuous noises as a proxy for vessel noise. Using the $L_{E,p,24h}$ criteria, fish with a swim bladder involved in hearing group remaining stationary within <10m of the works at the start of the works could exceed their recoverable injury threshold. These details, as well as their TTS ranges, are provided in Table 4-5.

Table 4-5: Predicted impact ranges associated with vessel noise at ANACONDA-1 for fish using the Popper et al. (2014) $L_{p,RMS}$ criteria for shipping and continuous sounds.

Popper *et al.* (2014) criteria $L_{p,RMS}$ (Continuous Sounds)		Estimated Impact Range	
		Maximum (m)	Area (km²)
Fish: swim bladder involved in hearing	Recoverable injury	< 10	< 1
	TTS	10	< 1

Across all species of fish, the relative risk of mortality and potential mortal injury, as well as recoverable injury associated with vessel noise is low in the near-field, intermediate field and far field distance. Of all the potential impacts, the impact associated with the highest relative risk for all species of fish is masking, which is deemed as high in the near-field and intermediate field, and moderate in the far-field. These details are presented in Table 4-6.

Table 4-6: The relative risk of impacts on fish in the near-field (N), intermediate field (I) and far-field (F) for the vessel noise at ANACONDA-1 using the Popper et al. (2014) $L_{p,rms}$ fish criteria for shipping and continuous sounds.

<table>
<tr><th colspan="6">Popper et al. (2014) criteria for Shipping and Continuous sounds</th></tr>
<tr><th rowspan="2">Type of fish</th><th rowspan="2">Mortality and potential mortal injury</th><th colspan="3">Impairment</th><th rowspan="2">Behaviour</th></tr>
<tr><th>Recoverable injury</th><th>TTS</th><th>Masking</th></tr>
<tr><td>Fish: no swim bladder</td><td>(N) Low
(I) Low
(F) Low</td><td>(N) Low
(I) Low
(F) Low</td><td>(N) Moderate
(I) Low
(F) Low</td><td>(N) High
(I) High
(F) Moderate</td><td>(N) Moderate
(I) Moderate
(F) Low</td></tr>
<tr><td>Fish: swim bladder not involved in hearing</td><td>(N) Low
(I) Low
(F) Low</td><td>(N) Low
(I) Low
(F) Low</td><td>(N) Moderate
(I) Low
(F) Low</td><td>(N) High
(I) High
(F) Moderate</td><td>(N) Moderate
(I) Moderate
(F) Low</td></tr>
<tr><td>Fish: swim bladder involved in hearing</td><td>(N) Low
(I) Low
(F) Low</td><td>See Table 4-5</td><td>See Table 4-5</td><td>((N) High
(I) High
(F) High</td><td>(N) High
(I) Moderate
(F) Low</td></tr>
</table>

5 Conclusion

Subacoustech Environmental has undertaken an underwater noise modelling study in anticipation of two planned deep-sea drilling in the Black Sea, Romania. The works are proposed to use of a vertical rotatory drill from a modular offshore drilling unit, as well as several support vessels. Separate reports are provided for each deep-sea drilling site; the results presented here is for the ANACONDA-1 site.

The level of underwater noise generated by the drilling at the ANACONDA-1 site was estimated using a combined parabolic equation and ray tracing modelling approach. The modelling considers a wide array of input parameters including the equipment source level, sound frequency content, seabed properties and the sound speed profile in the water column. Full account is also taken of the bathymetry in the areas surrounding the survey site. Simple modelling was then completed for vessel noise, using empirical analysis of previous noise measurements of this source.

The modelled noise levels were then interpreted in accordance with the guidelines outlined in Southall *et al.* (2019) for marine mammals in relation to non-impulsive noise sources, and Popper *et al.* (2014) for fish in relation to shipping and continuous sounds.

For drilling, the largest PTS impact range was for VHF cetaceans, whereby animals within 40 m of the drilling are likely to exceed this threshold, assuming they flee away from the source at a constant speed. Fish with a swim bladder involved in hearing are predicted to be at risk of recoverable injury if they are within 40 m from the drilling. For associated vessel noise, all marine mammals, and all fish considered in the assessment are predicted to exceed their PTS (marine mammals) and recoverable injury thresholds (fish) if they are within 10 m of the vessel.

By its nature, mathematical modelling will produce results that indicate a precise range at which a criterion will be reached, but this does not reflect the inherent uncertainty in the physical processes, including many that change constantly under real world conditions. While the results present specific ranges at which each impact threshold is met based on the modelling results, the ranges should be taken as indicative in determining where environmental effects may occur in receptors during the proposed operations.

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