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Technical Note

DATE: 22 October 2024

DOCUMENT: 03068, Version 2.1

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TO: Gippsland Dawn OWP Project Pty Ltd

Subject: Geophysical and Geotechnical Survey Investigation Sources: Acoustic Effect Estimation

The purpose of this Technical Note is to support Gippsland Dawn OWP Project Pty Ltd's Geophysical and Geotechnical Survey Environmental Management Plan. The purpose of the geophysical and geotechnical investigations is to assess and characterise the seabed and sub-seafloor geology. The Technical Note was commissioned to help assess possible effects of sounds from the proposed geophysical and geotechnical investigations on marine fauna and addresses the following:

- Geotechnical vessels under dynamic positioning.
- Sparker sources for ultra-high resolution seismic (UHRS) geophysical surveys
- Single-beam echo sound (SBES)
- Multi-beam echo sounder (MBES)
- Side scan sonar (SSS)
- Boomer sub-bottom profiler (SBP).
- Acoustic positioning systems may be used to assist the survey activities.

Acoustic sources that are planned to be used for the proposed geophysical investigations include a single-beam echo sound (SBES), multi-beam echo sounder (MBES), a side scan sonar (SSS), and a boomer sub-bottom profiler (SBP). In addition, acoustic positioning systems may be used to assist the survey activities.

Site and source specific modelling were not conducted, however JASCO completed a review of previously completed public and confidential studies in the Gippsland region to inform this Technical Note.

1. Noise Effect Criteria

To assess the potential effects of a sound-producing activity, it is necessary to first establish exposure criteria (thresholds) for which sound levels may be expected to have a negative effect on animals. Whether acoustic exposure levels might injure or disturb marine fauna is an active research topic. Since 2007, several expert groups have developed SEL-based assessment approaches for evaluating auditory injury, with key works including Southall et al. (2007), Finneran and Jenkins (2012), Popper et al. (2014), United States National Marine Fisheries Service (NMFS 2018) and Southall et al. (2019). The number of studies that investigate the level of behavioural disturbance to marine fauna by anthropogenic sound has also increased substantially.

Two sound level metrics, SPL, and SEL, are commonly used to evaluate noise and its effects on marine life. In this report, the duration of the SEL accumulation is defined as integrated over a 24 h time period. The acoustic metrics in this report reflect the updated ANSI and ISO standards for acoustic terminology, ANSI S1.1 (S1.1-2013) and ISO 18405:2017 (2017b).

The following thresholds and guidelines for this study were chosen because they represent the best available science, and sound levels presented in literature for fauna with no defined thresholds:

1. Peak pressure levels (PK; L_{pk}) and frequency-weighted accumulated sound exposure levels (SEL; $L_{E,24\mathrm{h}}$) from Southall et al. (2019) for the onset of permanent threshold shift (PTS) and temporary threshold shift (TTS) in marine mammals for non-impulsive and impulsive sources.
2. Marine mammal behavioural threshold based on the current interim US National Oceanic and Atmospheric Administration (NOAA) (2019) criterion for marine mammals of 120 dB re 1 µPa (SPL; L_p) and 160 dB re 1 µPa (SPL; L_p) for non-impulsive and impulsive sound sources.
3. Sound exposure guidelines for fish, fish eggs, and larvae (Popper et al. 2014).
4. Peak pressure levels (PK; L_{pk}) and frequency-weighted accumulated sound exposure levels (SEL; $L_{E,24\mathrm{h}}$) from Finneran et al. (2017) for the onset of permanent threshold shift (PTS) and temporary threshold shift (TTS) in turtles.

Multibeam sonar and vessels are characterised by the US National Marine Fisheries Service (NMFS) ([NMFS] National Marine Fisheries Service (US) 2023) as non-impulsive sound sources respectively.

- Non-impulsive sound sources can be continuous or intermittent, and produce sounds that can be broadband, narrowband or tonal, and brief or prolonged. Non-impulsive sources do not have the high peak sound pressure with rapid rise time typical of impulsive sounds.

Sparkers and sub-bottom profilers, including boomers, are characterised as impulsive sound sources, and thus the impulsive criteria listed above apply.

The metrics used to describe both impulsive and non-impulsive sound sources are:

- Sound exposure level (SEL or L_E; dB re 1 µPa^2·s) is the time-integral of the squared acoustic pressure over a duration (T).
- Sound pressure level (SPL or L_p; dB re 1 µPa) is the root-mean-square (rms) pressure level in a stated frequency band over a specified time window (T; s). It is important to note that SPL always refers to an rms pressure level and therefore not instantaneous pressure.
- Additionally, for sonar sources peak sound pressure (PK or $L_{p,pk}$; dB re 1 µPa), which is the decibel level of the maximum instantaneous acoustic pressure, can be used as an additional descriptor.

1.1. Marine Mammals

The criteria applied in this Technical Note to assess possible effects of non-impulsive and impulsive noise sources on marine mammals are summarised in Tables 1 and 2. Cetaceans and otariid seals were identified as the hearing groups requiring assessment.

There are two categories of auditory threshold shifts or hearing loss: permanent threshold shift (PTS), a physical injury to an animal's hearing organs; and temporary threshold shift (TTS), a temporary reduction in an animal's hearing sensitivity as the result of receptor hair cells in the cochlea becoming fatigued.

1.1.1. Behavioural Response

Numerous studies on marine mammal behavioural responses to sound exposure have not resulted in consensus in the scientific community regarding the appropriate metric for assessing behavioural reactions. However, it is recognised that the context in which the sound is received affects the nature and extent of responses to a stimulus (Southall et al. 2007, Ellison and Frankel 2012, Southall et al. 2016, Southall et al. 2021).

NMFS currently uses step function (all-or-none) threshold of 120 dB re 1 μPa SPL (unweighted) for non-impulsive, continuous sounds to assess and regulate noise-induced behavioural impacts on marine mammals (NOAA 2019). The 120 dB re 1 μPa threshold is associated with continuous sources and was derived based on studies examining behavioural responses to drilling and dredging, referring to Malme et al. (1983), Malme et al. (1984), and Malme et al. (1986), which were considered in Southall et al. (2007).

For impulsive noise, NMFS currently uses step function threshold of 160 dB re 1 μPa SPL (unweighted) to assess and regulate noise-induced behavioural impacts for marine mammals (NOAA 2018, NOAA 2019).

1.1.2. Threshold Tables

The threshold criteria are provided in Tables 1 and 2.

Table 1. Criteria for effects of non-impulsive noise exposure, including vessel noise, for marine mammals: Unweighted sound pressure level (SPL) and 24 h sound exposure level (SEL_{24h}) thresholds.

Hearing group	NOAA (2019)	Southall et al. (2019)	
	Behaviour	PTS onset thresholds (received level)	TTS onset thresholds (received level)
	SPL (L_p; dB re 1 µPa)	Weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa^2·s)	Weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa^2·s)
Low-Frequency (LF) cetaceans	120	199	179
High-frequency (HF) cetaceans		198	178
Very high-frequency (VHF) cetaceans		173	153
Otariid seals		219	199

L_p denotes sound pressure level period and has a reference value of 1 µPa.
L_E denotes cumulative sound exposure over a 24 h period and has a reference value of 1 µPa^2·s.

Table 2. Acoustic effects of impulsive noise on marine mammals: Unweighted sound pressure level (SPL), 24 h sound exposure level (SEL_{24h}), and peak (PK) thresholds.

Hearing group	NOAA (2019)	Southall et al. (2019)			
	Behaviour	PTS onset thresholds [a] (received level)		TTS onset thresholds [a] (received level)	
	SPL (L_p; dB re 1 µPa)	Weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa^2·s)	PK (L_{pk}; dB re 1 µPa)	Weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa^2·s)	PK (L_{pk}; dB re 1 µPa)
Low-Frequency (LF) cetaceans	160	183	219	168	213
High-frequency (HF) cetaceans		185	230	170	224
Very high-frequency (VHF) cetaceans		155	202	140	196
Otariid seals		183	232	168	226

[a] Dual metric acoustic thresholds for impulsive sounds: Use whichever results in the largest isopleth for calculating PTS onset. If a non-impulsive sound has the potential of exceeding the peak sound pressure level thresholds associated with impulsive sounds, these thresholds should also be considered.
L_p denotes sound pressure level period.
$L_{pk,flat}$ denotes peak sound pressure is flat weighted or unweighted.
L_E denotes cumulative sound exposure over a 24 h period.

2. Vessel Description (Geotechnical activities)

A representative example vessel for the geotechnical work program is the *Fugro Mariner*, a 76m long survey vessel, with the following propulsion characteristics:

- Bow thruster: 2 x 600 kW electric-driven Wartsila LIPS Tunnel Type (CPP); 10 mT thrust
- Propulsion: 2 x Azimuth cpp type, Wartsila Lips

This vessel is not too dissimilar to the *Skandi Feistein*, which is 88m long with the following propulsion characteristics:

- Bow thruster: 1 x 880 kW Rolls-Royce TT2200
- Bow Azimuth Thruster: 1 x 880 kW Swing-Up TCNS Azimuthing Thruster
- Propulsion: 2 x Azimuth cpp type, Rolls-Royce Contaz

The *Skandi Feistein* was modelled by JASCO for Esso Australia Resources Pty Ltd (Esso) in a jackup rig (JUR) assessment, titled 'JUR Drilling Environment Plan' (EP) (https://docs.nopsema.gov.au/A821197) in the shallow water Gippsland region. For dynamic positioning operations associated with a fixed platform, Scenario 4 in the EP, the JUR with normal operations was stated to have a source level of 160.4 dB re 1 μPa, whilst the Feistein at 45% power alongside the rig was stated to have a source level of 177.6 dB re 1 μPa.

2.1. Estimated Ranges to Effect

The results presented in the Esso EP for the *Skandi Feistein* in Scenario 4 are recommended to be used as a proxy in the absence of activity and site specific modelling.

The predicted distance to thresholds for 8 and 24 hours of operation of the *Skandi Feistein* in Scenario 4, Tables 5-5 and 5-6 in the EP, are summarised in Table 3, these relate to the non-impulsive criteria defined in Table 1.

Table 3. Summary of EP Results for the relevant proxy scenario for continuous non-impulsive noise.

Effect Criteria	8 hours of Operation	24 hours of Operation
Behavioural Response	4.51 km	
Temporary Threshold Shift	0.56 km	1.29 km
Permanent Threshold Shift	0.03 km	0.03 km

3. Dura Spark (UHRS Geophysical Survey, Sparker Source)

JASCO Applied Sciences (JASCO) performed a numerical estimation study of underwater sound levels associated with a generic ultra-high resolution seismic (UHRS) survey to assist in understanding the potential acoustic effect on marine fauna (Koessler and Stephen 2024). The modelling considered a sparker source in fourfold configuration with triggering at an energy rating of 3000 J. The survey was modelled with a 25 m impulse interval (inter-pulse interval) and a 3.1 m crossline source separation. The sparker source consisted of two decks, each deck consisted of 400 electrode tips and each deck was located at different tow depths, 30 cm and 60 cm respectively.

While this study considered 3D UHRS, it is considered a conservative proxy for 2D UHRS as well (provided the 2D UHRS sparker source used is not greater in energy rating/ noise generation than described above), since 2D UHRS would use fewer sparker sources in parallel.

3.1. Predicted Ranges to Effect

The predicted ranges to acoustic effect criteria for impulsive noise for marine mammals (Table 2) in Koessler and Stephen (2024) are presented in Table 4, which summarises the maximum distances for the SPL and SEL_{24h} criteria, along with the relevant metric.

The results for marine mammal injury considered the criteria from Southall et al. (2019). These criteria contain two metrics (PK and SEL_{24h}), both required for the assessment of marine mammal PTS and TTS. The longest distance associated with either metric is required to be applied for assessment of impulsive noise and in this case it was associated with SEL_{24h}.

Table 4. Summary of maximum (R_{max}) horizontal distances (in km) from all modelled sites and scenarios to behavioural response thresholds and temporary threshold shift (TTS) and permanent threshold shift (PTS) for marine mammals for impulsive noise showing the relevant metric.

Hearing group	Maximum modelled distance to effect threshold (R_{max})		
	Behavioural response[1]	Scenario 1	
		TTS[2] (km)	PTS[2] (km)
Low-frequency cetaceans	0.24 (SPL)	0.04 (SEL_{24h})	–
High-frequency cetaceans		–	–
Very high-frequency cetaceans		0.02 (PK)	–
Otariid Pinnipeds		–	–

Noise exposure criteria: [1] NOAA (2019) and [2] Southall et al. (2019).
A dash indicates the threshold was not reached within the limits of the modelling resolution (20 m).

4. Survey Noise Sources

4.1. Estimating Sound Exposure from Single and Multi-Beam Echo Sounders

A Multi-beam Echo Sounder (MBES) is a marine survey tool that is used to produce an image of the seafloor and generate detailed bathymetric contours. This type of survey technique typically comprises transducers mounted on the hull of a vessel. Transducers may also be mounted on a towed vehicle (e.g. towfish) and/or remotely-operated vehicle (ROV). Measurement data of MBES sources are discussed below in context of the criteria outlined in Section 1.

Measurements of a Reson SeaBat 8101 sonar operating at 240 kHz were reported in Chorney et al. (2011), and are shown in Figure 1. Figure 1 indicates a horizontal distance of 330 m from the MBES source to the marine mammal behavioural response criterion of 120 dB re 1 µPa (SPL; L_p) for continuous non-impulsive sound sources.

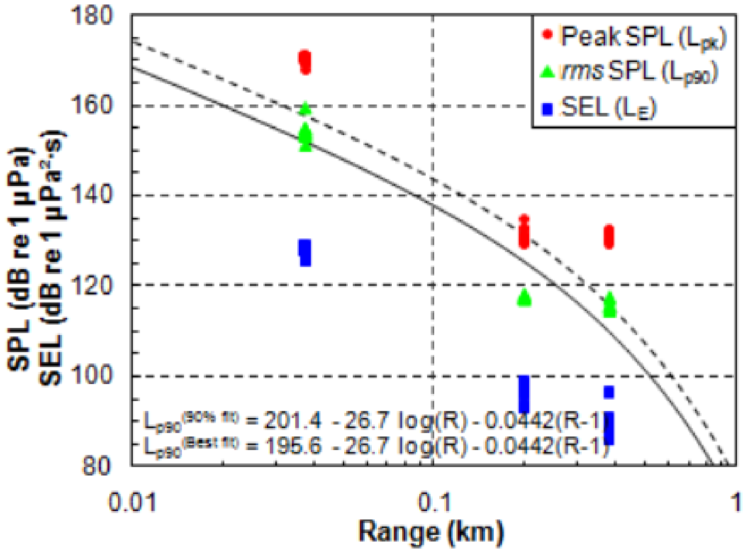

Figure 1. Figure 3.103 in Chorney et al. (2011). Multibeam sonar (RESON SeaBat 8101) 240 kHz pulse in-beam PK (peak SPL), 90% rms SPL, and SEL versus range, at 7 m receiver depth. Solid line is best fit of the empirical function to L_{p90} values. Dashed line is the best-fit shifted to exceed 90% of the L_{p90} values (90th percentile fit). Measurements at 200 and 380 m range are near background noise levels of these recordings.

Martin et al. (2012a) also provide measurements of MBESs. Martin et al. (2012a) considered measurements along a trackline where the closest point of approach of the MBES was 4 m. Their study indicated that PTS and TTS thresholds for marine fauna based on accumulated sound exposure (i.e. SEL_{24h}) were not predicted to be exceeded. The measurements did not result in accumulated unweighted levels higher than 121.5 dB re 1 µPa^{2}s, which is well below the frequency-weighted PTS and TTS criteria outlined above for all marine mammal hearing groups.

Crocker and Fratantonio (2016) reported measurements of source level and source characteristics for two different MBESs. Table 5 provides nominal, but upper bound values for the MBESs from the Crocker and Fratantonio (2016) report, which have been written in units to align with the updated ANSI and ISO standards for acoustic terminology, ANSI S1.1 (2013) and ISO 18405:2017 (2017a).

Table 5. Multi-beam echo sounder specifications, adapted from Crocker and Fratantonio (2016)

Equipment	Operational Mode (kHz)	Source Level (dB re 1 µPa m)	Peak Source Level (dB re 1 µPa m)	Energy source level (dB re 1 µPa^{2}s m^2)	Beam Width[a] (°)	Pulse Duration (ms)	Repetition Rate[2] (Hz)
Reson Seabat 7111	100	224	228	197	80	2.68	20
Reson Seabat T20P FM[1] Mode	300	218	225	195	75	4.9	50

[1]FM: Frequency Modulated
[2]Repetition rates taken from specification documents. These are typical maxima and can be configurable depending on usage.

To estimate the distances at which noise effect criteria may be exceeded by MBES systems, JASCO utilised a simple spreading loss model to calculate estimates of sound propagation based on the information provided by Crocker and Fratantonio (2016). Since MBESs operate at very high frequencies the corresponding wavelength of sound produced is small; a simple spreading loss model is an appropriate tool to provide distances estimates to effect criteria. Received levels were calculated based on an assumption of spherical spreading with absorption loss; the method is described in Appendix A.

Sound emissions that exceed 100 kHz would not be heard by low-frequency cetaceans, fish, and turtles, which are most sensitive to signals well below 110 kHz. The frequencies of sound produced by the SSS unit considered here will only be relevant to fauna sensitive to higher frequencies that may be impacted by accumulated SEL (i.e. high-frequency cetaceans and very-high-frequency cetaceans).

Table 6 presents the frequency weighted horizontal distances to SEL_{24h} thresholds for accumulated sound exposure criteria for a nominal MBES survey, considering the two equipment types listed in Table 5 and calculation method explained in Appendix A. The estimated horizontal distances are associated with the equipment configuration in Table 5, and the estimates in Table 6 will differ if different equipment configurations are used.

Table 6. Horizontal distances (m) for frequency-weighted SEL_{24h} based PTS and TTS marine mammal thresholds from Southall et al. (2019) for a nominal multi-beam survey.

Hearing group	Threshold for SEL_{24h} ($L_{E,24h}$; dB re 1 µPa²·s)	Nominal estimated horizontal distance (m) to SEL threshold	
		Reson Seabat 7111	Reson Seabat T20P FM[1] Mode
PTS			
High-Frequency (HF) cetaceans	198	10	*
Very High-frequency (VHF) cetaceans	173	277	79
TTS			
High-Frequency (HF) cetaceans	178	166	31
Very High-frequency (VHF) cetaceans	153	700	251

An asterisk indicates that the sound level threshold will likely not be reached.
[1]FM: Frequency Modulated

The spreading loss calculation predicted maximum horizontal distances between 565 – 1,212m for marine mammal behavioural response criteria for non-impulsive continuous sound sources (120 dB re 1 µPa (SPL; L_p)). Considering the distances in Table 6, spreading loss calculations predict larger ranges than those reported in Martin et al. (2012a) and Chorney et al. (2011). Whilst the source levels in Martin et al. (2012a) and Chorney et al. (2011) were not directly reported, the near-source sound levels of the considered MBESs in their studies suggest they were operating in a configuration with lower source levels. The specification inputs to the spreading loss distance estimation method used by JASCO represent higher sound source levels and a more conservative source parameterisation, which result in larger distances compared to those reported in the literature.

MBES is outside the hearing range for fish and sea turtles, therefore no effects are predicted.

4.2. Estimating Sound Exposure from Side Scan Sonar Surveys

Side Scan Sonar (SSS) is a marine geophysical survey technique that is used to produce an image of the seafloor to identify obstructions or features. This type of survey comprises of transducers mounted on either side of a towed vehicle (e.g. towfish), towed above the seabed. SSS transducers may also be mounted on Autonomous Underwater Vehicle (AUV) systems, vessel hulls or mounted to and ROV.

The side scan sonar is highly directional in the horizontal plane, with distances to sound levels outside the beam significantly less than those in the beam. However, a wide swath of beam energy is outputted in the vertical plane perpendicular to the tow direction. SSS towfish are typically towed approximately 10-20 m above the seabed, thus the beam will be restricted to a swath close to the seabed. These towfish can use a range of operating frequencies, but typically they are between 70 and 400 kHz.

Representative systems could include those from EdgeTech, such as the 4200 SSS model. The 4200 SSS produces signals at 120 and 410 kHz when operated at 100 and 400 kHz modes. Some models may contain additional operational modes; however, measurements exist for these modes, and they are different enough to represent the different operational regimes.

Measurements of an EdgeTech 4200 were reported in Crocker and Fratantonio (2016) for 100 and 400 kHz modes, with a maximum per-pulse source level of 176 dB re 1 μPa^{2}s m (SEL), 205 dB re 1 μPa m (SPL) and 210 dB re 1 μPa m (PK). Table 7 provides nominal, but upper bound values for the EdgeTech 4200 SSS extracted from Crocker and Fratantonio (2016), which have be written in units to align with the updated ANSI and ISO standards for acoustic terminology, ANSI S1.1 (S1.1-2013) and ISO 18405:2017 (2017b).

Table 7. Side scan sonar source specifications.

Equipment	Operational Mode (kHz)	Source Level (dB re 1 μPa m)	Peak Source Level (dB re 1 μPa m)	Energy source level (dB re 1 μPa^{2}s m^2)	Beam Width[a] (°)	Pulse Duration (ms)	Repetition Rate (Hz)
EdgeTech 4200	400	205	210	176	178	1.3	10[a]
	100	201	206	179	178	7.2	

[a]SSS nominal repetition rate estimated from manufacture specifications which stating that repetition rate is selected to ensure three pings incident on a 1 m^3 target volume at range of 100 m for a given vessel survey speed in accordance with hydrographic standards (NOAA 2016).

Austin et al. (2013) also measured the EdgeTech 4200 system during an operational program, focusing on the 120 kHz signals (100 kHz mode). They reported a PK of less than 175 dB re 1 μPa and an SPL of less than 170 dB re 1 μPa at 39 m, with the distance from in-beam pulses to an SPL of 160 dB re 1 μPa calculated to be 130 m.

In considering the sound levels from SSS are described in Section 4.2 the per-pulse peak pressure source level of the SSS (210 dB re 1 μPa m) is below most of the PK criteria thresholds; therefore these criteria cannot be exceeded. Considered a spreading calculation the PK criteria for VHF cetaceans may exceed at very short horizontal distances from the SSS source, 2 and 5 m for PTS and TTS respectively considering a per-pulse peak pressure source level of 210 dB re 1 μPa m.

The nominal SSS model presented above may generate only high frequency signals, and in this case, will only be relevant for fauna with sensitivity to signals of approximately 110 kHz or higher as discussed in Austin *et al*. (2013). This would exclude low-frequency cetaceans, otariid seals, fish, and turtles, which are more sensitive to signals well below 110 kHz. For frequencies above 110 kHz the nominal SSS unit considered here will only be relevant to higher frequency sensitive fauna which may be impacted by accumulated SEL (i.e. HFC and VFC).

For the 100 and 400 kHz operational modes, Table 8 presents the frequency weighted horizontal impact distances for a nominal side scan sonar survey considering a spreading loss calculation (Appendix A).

Table 8. Horizontal impact distances (m) for frequency-weighted SEL_{24h} based PTS and TTS marine mammal thresholds from Southall et al. (2019) for a nominal side scan sonar survey. An N/A indicates that the operational model produces the majority of the acoustic energy outside the hearing group sensitivity range.

Hearing group	Threshold for SEL_{24h} ($L_{E,24h}$; dB re 1 µPa²·s)	Estimated horizontal impact distance (m) to SEL threshold	Estimated horizontal impact distance (m) to SEL threshold
		400 kHz Mode	100 kHz Mode
PTS			
High-frequency (HF) cetaceans	185	N/A	*
Very High-frequency (VHF) cetaceans	155	5	125
Otariid seals	203	N/A	*
TTS			
High-frequency (HF) cetaceans	170	N/A	10
Very High-frequency (VHF) cetaceans	140	45	378
Otariid seals	188	N/A	*

An asterisk indicates that the sound level threshold was not reached.

For similar surveying equipment (i.e. multibeam echo sounders, MBES), a measurement study from Martin et al. (2012b) indicates that the PTS and TTS thresholds due to accumulated SEL (i.e. SEL_{24h}) are not predicted to be exceeded. Martin et al. (2012b) considered measurements of along a trackline with a closest point of approach of 4 m and the measurements did not result in accumulated unweighted levels higher than 121.5 dB re 1 µPa²s, which is well below the PTS and TTS criteria above for all hearing groups. Considering the measured per-pulse sound levels for the EdgeTech 4200 unit at 40 m (Austin et al. 2013) are like those from the MBES, which isn't predicted to exceed either the PTS or TTS thresholds considering SEL metrics it is likely that neither will the SSS when under standard operational conditions

Furthermore, the SEL_{24h} is a cumulative metric that reflects the dosimetric impact of noise levels within 24 hours based on the assumption that an animal is consistently exposed to such noise levels at a fixed position. The corresponding SEL_{24h} distances in Table 8 represent an unlikely worst-case scenario. More realistically, marine mammals would not stay in the same location for 24 hours. Therefore, a reported distance for SEL based criteria does not mean that marine fauna travelling within this radius of the source will be injured, but rather that an animal could be exposed to the sound level associated with impairment if it remained in that location for 24 hours

The measurements conducted in Austin et al. (2013) indicates that the behavioural threshold could be exceeded within a distance up to 130 m for marine mammals SSS unit. The spreading loss calculation comparatively predicts a maximum horizontal distance of 81.5 m. Survey equipment could cause masking of vocalisations of cetaceans due to the overlap in frequency range between signals and vocalisations. Masking will therefore most likely apply to HF and VHF cetaceans for the SSS. However, due to the limited propagation range of the relevant frequencies (higher frequencies attenuate rapidly), the range at which the impact could occur will be small, within hundreds of meters.

Given the transient and mobile nature of the survey and the likelihood that the SSS will be towed behind a survey vessel, the operating frequencies and noise maxima of the SSS equipment considered here, effects of survey equipment noise on marine mammals are expected to be limited to behavioural responses proximal to the survey vessel rather than the SSS.

The source sound levels for the SSS in Section 4.2 are below those associated with the PK criteria for injury for turtles and therefore these criteria cannot be exceeded. Furthermore, source levels are low enough that SEL criteria will not be reached.

Turtles are unlikely to experience masking even at close range to the SSS. This is in part because the sounds from SSS are all outside of the hearing frequency range for turtles, which for green and loggerhead turtles is approximately 50–2000 Hz, with highest sensitivity to sounds between 200 and 400 Hz (Ridgway et al. 1969, Ketten and Bartol 2005, Bartol and Ketten 2006, Bartol 2008, Yudhana et al. 2010, Piniak et al. 2011, Lavender et al. 2012, 2014).

Similar to marine mammals, the transient and mobile nature of the SSS the effects of SSS survey equipment noise on turtles are expected to be limited to behavioural responses proximal to a survey vessel rather than the SSS. Furthermore, considering the behavioural response criterion for turtles is greater than marine mammals the behavioural responses distance will be less than that for marine mammals.

Based on available criteria from Popper et al (2014), potential impacts of SSS equipment on fish have been assessed. Impulsive noises from survey equipment could result in physiological impacts to fish located within metres of the SSS considering source sound levels for the SSS in Section 4.2 above. The likelihood of fish being close enough to the sound source for physiological impacts to occur is considered remote.

5. Estimating Sound Exposure from Sub-Bottom Profilers

Sub-bottom profilers (SBPs) are marine geophysical survey equipment that are used to generate cross-sectional images of shallow geological structure below the seafloor. There are a variety of SBP instrument types including, but not limited to, boomers, sparkers, airguns and transducer (Chirp) type systems. The following section addresses both transducer and boomer type systems.

5.1. Transducer Type Sub-Bottom Profilers

Transducer type SBP systems typically produce a swept-frequency signal, i.e. the signal is emitted over time and over a specific frequency range. The pulse length, frequency bandwidth, and phase/amplitude characteristics of a pulse are generally selectable. The transducer that transmits a signal also receives the signal reflected from the seafloor. These types of SBPs operate at medium to high frequencies (~1 kHz – 25 kHz); a given instrument and processing systems specifications define the bandwidth of the signal and characteristics, which can vary by SBP system and manufacturer.

JASCO have previously modelled an EdgeTech X-Star SBP (manufactured by EdgeTech) mounted on SBP-216 tow-fish (McPherson and Wood 2017). In that modelling study, the operational frequency range was 2 kHz to 16 kHz. Sound levels associated with the marine mammal behavioural response criterion of 160 dB re 1 µPa (SPL; L_p) for impulsive sound sources were not exceeded beyond a horizontal distance of less than 2 m from the SBP.

Crocker and Fratantonio (2016) reported source levels for several different SBPs. Table 9 provides nominal, but upper bound values for the three transducer SBPs extracted from Crocker and Fratantonio (2016). Units have been written to align with the updated ANSI and ISO standards for acoustic terminology, ANSI S1.1 (2013) and ISO 18405:2017 (2017).

Table 9. Sub-bottom profiler source specifications, adapted from Crocker and Fratantonio (2016)

Equipment	Operational Mode	Frequency Bandwidth (kHz)	Source Level (dB re 1 µPa m)	Peak Source Level (dB re 1 µPa m)	Energy source level (dB re 1 µPa²s m²)	Beam Width (°)	Pulse Duration (ms)	Repetition Rate (Hz)[1]
EdgeTech 424	100% Power	8.5-12.4	178	184	154	71	3.5	5
EdgeTech 512	100% Power	5.7-9	179	184	159	51	9.1	

[1] Repetition rate proposed in considering specification documents and previous public information (Vineyard Wind and JASCO Applied Sciences 2020). These are nominal and depend on usage.

A simple spreading loss model was used to calculate estimates of sound propagation r or the SBPs listed in Table 9and to provide distances estimates to noise effect criteria for marine fauna. Received levels have been calculated based on an assumption of spherical spreading with absorption loss; the method is described in Appendix A ., the considered frequencies are sufficiently high enough, and the corresponding wavelengths are sufficiently short enough, such that a simple spreading loss model is an applicable tool to provide distance estimates to impact criteria. The application of this method may not hold for all SPB systems and per-case, per-system considerations are required. Table 10 presents the frequency weighted SEL PTS and TTS horizontal impact distance estimates for a nominal sub-bottom survey (refer to Appendix A for calculation details).

Table 10. Horizontal distances (m) for frequency-weighted SEL_{24h} based PTS and TTS marine mammal thresholds from Southall et al. (2019) for a nominal sub-bottom profiling survey. An N/A indicates that the operational model produces the majority of the acoustic energy outside the hearing group sensitivity range.

Hearing group	Threshold for SEL_{24h} ($L_{E,24h}$; dB re 1 µPa²·s)	Nominal estimated horizontal distance (m) to SEL threshold	
		EdgeTech 424	EdgeTech 512
PTS			
Low-Frequency (LF) cetaceans	183	*	*
High-frequency (HF) cetaceans	185	*	*
Very High-frequency (VHF) cetaceans	155	*	*
TTS			
Low-Frequency (LF) cetaceans	168	*	*
High-frequency (HF) cetaceans	170	*	*
Very High-frequency (VHF) cetaceans	140	20	16

An asterisk indicates that the sound level threshold may not be reached.

In considering the sound levels from SBPs above, the per-pulse peak pressure source levels are close to most of the PK noise effect criteria thresholds (outlined in Section 2), and in some cases the reported sources levels are below PK criteria thresholds. Therefore, PK noise effect criteria thresholds may be exceeded but only within very close proximity to SBP sources. Indeed, the simple spreading loss model suggests that PK criteria for all marine mammal groups may be exceeded at very short horizontal distances from the considered SPB sources, ~2m and ~5 m for PTS and TTS, respectively. The spreading loss calculation predicts a maximum horizontal distance of approximately 4-8 m for the marine mammal behavioural response criterion of 160 dB re 1 µPa (SPL; L_p). The spreading loss distance estimates for the two EdgeTech SBPs in Table 10 are similar to those reported in McPherson and Wood 2017.

5.2. Boomer Sub-bottom Profiler

As the boomer source had not been decided at the time of this assessment, a commonly-used representative system was considered, with levels derived from a previous JASCO field measurement campaign. JASCO previously modelled a AP3000 triple-plate boomer (manufactured by Subsea Systems, Inc.) for a confidential client in the Gippsland region, and the modelling approach and results have been used to inform this assessment.

In that modelling study, the source was represented by scaling JASCO's measurement results from a source verification study on an AP3000 system (Martin et al. 2012b) from a double-plate configuration to a triple-plate configuration. This resulted in a source level of the AP3000 triple-plated boomer operating at 1800 J per pulse energy was calculated to be 169.0 dB 1 µPa^{2}m^{2}s.

In the modelling study a conservative sound speed profile that would be most supportive of sound propagation conditions for the period of the investigations was defined and applied, and single-impulse sound fields were predicted at a single location, and accumulated sound exposure fields were predicted for likely scenarios of geophysical investigations over 24 hours. The modelling methodology considered source directivity and range-dependent environmental properties in each of the areas assessed. Estimated underwater acoustic levels are presented as sound pressure levels (SPL, L_p), zero-to-peak pressure levels (PK, L_{pk}), peak-to-peak pressure levels (PK-PK; L_{pk-pk}), and either single-impulse (i.e., per-pulse) or accumulated sound exposure levels (SEL, L_E) as appropriate for different noise effect criteria. The analysis considered the distances away from the source or survey lines at which several effects criteria or relevant sound levels were reached.

Sound levels associated with the considered behavioural effect criteria are not reached beyond a distance of less than 10 m for the boomer, and no criteria associated with injury are reached.

The likelihood of fish being close enough to the sound source for physiological impacts to occur is considered remote (McPherson and Wood 2017). Behavioural impacts to fish from survey equipment noise will be limited to behavioural responses within metres of the noise source.

6. Estimating Sound Exposure from Acoustic Positioning Systems

Acoustic positioning systems for Long Base Line (LBL) and Ultra Short Base Line (USBL) will likely involve Sonardyne or Kongsberg systems, which could include the Ranger or High Precision Acoustic Positioning (HiPAP) acoustic positioning system (Table 11). The source level and an empirical spreading loss equation was applied as obtained from previous field measurements of one of the proposed acoustic positioning systems (Warner and McCrodan 2011) with the results presented in Table 12. This is a similar approach as applied in Austin et al. (2012).

Table 11. Specifications of Acoustic Positioning Systems

Manufacturer	Model	Source Frequency (kHz)	Source Level (dB re 1 µPa @ 1 m)
Kongsberg	HiPAP 500	33	206
Sonardyne	Ranger USBL	18-36	204

Table 12. Ranges to SPL isopleths for acoustic positioning systems, extracted from Austin et al. (2012).

SPL (dB re 1 µPa)	Radius (m)	
	Sonardyne Ranger, 18 to 36 kHz*	Kongsberg HiPap 500, 33 kHz*
200	0.002	5
190	0.005	9
180	0.008	17
170	0.018	30
160	0.036	42
150	0.066	64
140	0.17	120

* Based on empirical spreading loss estimate measured by Warner and McCrodan (2011)

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Appendix A. Calculation Methods

A.1. Empirical Spreading Loss Calculations

The general method specified in the Interim Recommendation for Sound Source Level and Propagation Analysis for High Resolution Geophysical (HRG) Sources (NOAA September 9, 2019) were followed to preform loss calculations. We note that there is an updated set of interim recommendations (Guan 2020) from the author of the 2019 guidance document. This updated method provides adjusted calculation methods to consider water depth in the prediction of the horizontal impact distance, the method described herein is equivalent to the case where the water depth is greater than the vertical component of the slant distance (see Figure 2 for a diagram). We have not considered water depth in the prediction of the horizontal impact distance, to allow for operational flexibility.

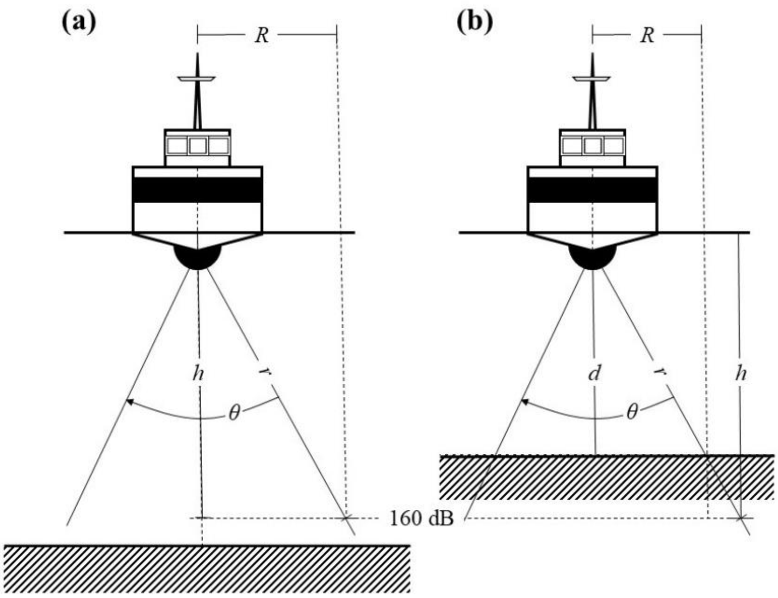

Figure 2. Excerpt from (Guan 2020). The calculation methods described herein is equivalent to the left diagram labelled (a).

The calculation method is described as follows.

The sonar equation is used to calculate the received level:

$$RL(r) = SL - PL(r), \tag{1}$$

where *RL* is a generalised the pressure level (dB re 1 µPa or dB re 1 µPa^{2}s) and applies to PK, SPL and SEL calculations, *r* is the distance from the source (m), *SL* is the source level (dB re 1 µPa m or dB re 1 µPa^{2}s m), and *PL* is the propagation loss as a function of distance. Propagation loss is calculated using:

$$PL(r) = 20\log_{10}\left(\frac{r}{1\ \mathrm{m}}\right)\ \mathrm{dB} + \alpha(f) \cdot r/1000, \tag{2}$$

where $\alpha(f)$ is the absorption coefficient (dB/km) and f is frequency (kHz). The absorption coefficient is approximated by discarding the boric acid term from Ainslie (2010; p29; eq 2.2):

$$\alpha(f) \approx 0.000339f^2 + 48.5f^2/(75.6^2 + f^2)\,. \tag{3}$$

When a range of frequencies is produced by a source, the lowest frequency for determining the absorption coefficient was used.

A.2. Estimating Range to Thresholds Levels

Distances to PK thresholds and SPL Criteria were calculated using the PK or SPL source level and applying propagation loss from Equation 2. The PK and SPL calculations were performed at radial distances *r*, which varied between 1 m and 10 km to determine when levels cross a threshold or exceed a criterion. For a downwards-pointing source with a beamwidth less than 180°, the horizontal impact distance (*R*) is calculated from the in-beam range using:

$$R = r \cdot \sin\left(\frac{\delta\theta}{2}\right), \tag{4}$$

where $\delta\theta$ is the beamwidth.

For the weighted SEL thresholds, the following steps were performed:

1. Modelled propagation loss as a function of oblique range using Equation 2.
2. Modelled per-pulse SEL for a stationary receiver at a fixed distance off a straight survey line, using a vessel transit speed and source-specific pulse length and repetition rate. The calculation considered a nominal vessel transit speed of 3.5 knots. The off-line distance is referred to as the closest point of approach (CPA) and was performed for CPA distances between 1 m and 10 km. The survey line length was modelled as 10 km long (analysis showed longer survey lines increased SEL by a negligible amount). SEL is calculated as $SPL + 10\log_{10}\frac{T}{1\text{ s}}$ dB, where T is the pulse duration. A flat spectrum between the source minimum and maximum frequency is assumed, which was weighted according to the marine mammal hearing group weighting function (Southall et al. 2019) and summed across frequency.
3. Calculated the SEL for each survey line to produce curves of weighted SEL as a function of CPA distance.
4. Used the curves from Step 4 to estimate the CPA distance to the threshold.

This method accounts for the hearing sensitivity of the marine mammal group and seawater absorption for downwards-facing transducers