ORANGE BASIN MC3D MSS

3D Seismic Survey Underwater Acoustics Modelling
Project ZA24-010_Orange Basin MC3D MSS

Searcher Seismic

Suite 1, Level 4, South Shore Centre,
85 South Perth Esplanade, South Perth,
Western Australia 6151, Australia

Prepared by:

SLR Consulting Australia

SLR Project No.: 675.30056.00102

25 June 2024

Revision: 1.2

Revision Record

Revision	Date	Prepared By	Checked By	Authorised By
675.30056.00101-R01-v1.0	4 June 2024	Luke Zoontjens	DRAFT	Luke Zoontjens
675.30056.00102-R01-v1.1	21 June 2024	Jonathan Vallarta	Luke Zoontjens	Luke Zoontjens
675.30056.00102-R01-v1.2	25 June 2024	Jonathan Vallarta	Luke Zoontjens	Luke Zoontjens

Basis of Report

This report has been prepared by SLR Consulting Australia (SLR) with all reasonable skill, care and diligence, and taking account of the timescale and resources allocated to it by agreement with Searcher Seismic (the Client). Information reported herein is based on the interpretation of data collected, which has been accepted in good faith as being accurate and valid.

SLR disclaims any responsibility to the Client and others in respect of any matters outside the agreed scope of the work.

Executive summary

Searcher Geodata UK Limited (Searcher) is proposing to undertake a 3D seismic survey within the Orange Basin off the West and South-West Coast of South Africa. The proposed survey areas are considered with respect to proposed or existing Ecologically or Biologically Significant Marine Areas (EBSAs), including Orange Seamount and Canyon Complex, Orange Cone, Childs Bank and Shelf Edge, and Cape Canyon and Associated Islands, Bays and Lagoon. Marine Protected Areas (MPAs) are also situated near the proposed survey areas, namely the Orange Shelf Edge, Childs Bank, Benguela Muds, Cape Canyon, Robben Island, and the Southeast Atlantic Seamount MPA.

SLR Consulting Australia Pty Ltd (SLR) has been engaged by Searcher Seismic to undertake a detailed underwater acoustics modelling study for the proposed activities, in order to assist with the assessment of potential noise impact on marine fauna species of interest, particularly for these major marine sensitive areas of concerns. The noise modelling results have been used to identify zones of impact for marine mammals and other species of concern based on relevant noise impact assessment criteria. Zones of impact have been evaluated for physiological effects and behavioural disturbance, due to the immediate impact from single airgun pulses, as well as the cumulative effects of exposure to multiple airgun pulses over a period of 24 hours.

The noise impact assessment criteria for the marine fauna species of concerns are detailed in **Section 2.0** of this report, and the identified relevant zones of impact are summarised in **Section 6.4** of the report. The identified relevant zones of impact for marine mammals, fish and sea turtle species are summarised in the following tables. Bold text indicates the maximum offset distance for each species between individual shots and cumulative effects.

Marine mammals

Impact from immediate exposure to individual airgun array pulses

Due to the high level of impulsive signal emissions from the array source, marine mammals are predicted to experience a permanent auditory threshold shift (PTS) at close proximity to the source arrays due to the immediate exposure to individual pulses. Marine mammals of all hearing groups except very-high-frequency cetaceans are predicted to experience PTS effect within approximately 45 m from the 3D source array at all assessed water depth scenarios. The maximum zones of PTS effect for very-high-frequency cetaceans are predicted to be within 270 m from the 3D array source.

The zones of a temporary auditory threshold shift (TTS) due to a single pulse exposure for marine mammals of all hearing groups except very-high-frequency cetaceans are predicted to be within approximately 85 m from the source array. The maximum zones of TTS effect for very-high-frequency cetaceans are predicted to be within 500 m from the array source. Behavioural disturbance caused by the immediate exposure to individual pulses are predicted to be within 4.0 km from the array source for marine mammals of all hearing groups.

Impact from cumulative exposure to multiple airgun array pulses

The zones of cumulative impact (i.e. the maximum horizontal perpendicular distances from assessed survey lines to cumulative impact threshold levels) are estimated based on the modelling results and relevant assessment criteria. Among marine mammals of all six hearing groups, low-frequency cetaceans have the highest zones of PTS and TTS impact.

The zones of PTS impact are predicted to range up to 800 m for the 3D survey, from the adjacent survey lines for the relevant typical 24-hour survey operation scenarios considered, and the maximum zone of TTS impact is predicted to be around 8.0 km from the adjacent survey lines. Much lower zones of cumulative PTS and TTS impact are predicted for marine mammals of other hearing groups.

Hearing group	Zones of impact – maximum horizontal distances from source to impact threshold levels, m				
	Single shot			Cumulative	
	Injury (PTS) onset	TTS onset	Behaviour disturbance	Injury (PTS) onset	TTS
Low-frequency cetaceans (LF)	40	80	4,000	**800**	**8,000**
High-frequency cetaceans (HF)	**10**	**25**	4,000	-	< 10
Very-high-frequency cetaceans (VHF)	**270**	500	4,000	80	**2,500**
Sirenians (SI)	**20**	**40**	4,000	-	< 10
Phocid carnivores in water (PCW)	**45**	85	-	10	**500**
Other marine carnivores in water (OCW)	**< 10**	**20**	-	-	< 10
Sea turtles	**15**	**30**	1,140	10	**50**

Fish

Impact from immediate exposure to individual airgun array pulses

The zones of potential injuries for fish species with a swim bladder, turtles and fish eggs and fish larvae are predicted to be within 160 m from the array source. However, fish species without swim bladders have higher injury impact thresholds, and therefore have smaller zones of potential injuries within 80 m from the airgun array source.

Impact from cumulative exposure to multiple airgun array pulses

The zones of potential mortal injuries for fish species with and without a swim bladder, fish eggs, and fish larvae are predicted to be within 60 m from the adjacent survey lines for all the 24-hour survey operation scenarios considered. For recoverable injury, the zones of impact are predicted to be within 20 m from the adjacent survey lines for fish without a swim bladder, and within 200 m for fish with a swim bladder for all the operation scenarios considered. The zones of TTS effect for fish species with and without swim bladders are predicted to be within 3.50 km from the adjacent survey lines for the relevant 24-hour survey operation scenarios considered.

Existing experimental data regarding recoverable injury and TTS impacts for fish eggs and larvae is sparse and no guideline recommendations have been provided. However, based on a subjective approach, noise impacts are expected to be moderate for fish eggs and larvae. Low grade impacts are predicted for all at intermediate and far field from the source location.

Hearing group	Zones of impact – maximum horizontal distances from source to impact threshold levels, m				
	Single shot		Cumulative		
	Mortality, potential mortal injury	Recoverable injury	Mortality, potential mortal injury	Recoverable injury	TTS
Fish: no swim bladder (particle motion detection)	**80**	**80**	< 10	20	3,500
Fish: swim bladder is not involved in hearing (particle motion detection)	**160**	160	30	**200**	3,500
Fish: swim bladder involved in hearing (primarily pressure detection)	**160**	160	60	**200**	3,500
Fish eggs and fish larvae	**160**	-	30	-	-

Sea turtles

Impact from immediate exposure to individual airgun array pulses

The maximum zones of PTS effect for sea turtles are predicted to be within 15 m from the source location. On the other hand, the maximum zones of TTS effect for sea turtles are predicted to be within 30 m of the source array. The behavioural disturbance for sea turtles due to immediate exposure to individual pulses are predicted to be within 1.14 km of the array.

Impact from cumulative exposure to multiple airgun array pulses

Noise impacts related to recoverable injury and TTS on sea turtles are expected to be high at the near field from the source location. The maximum zones of PTS impact are predicted to range within 10 m of the source array. The maximum zones of TTS effect for sea turtles are predicted to be within 50 m of the source array.

Mitigation measures

Mitigation measures are recommended to minimise impacts on assessed marine fauna. Recommended safety zones are based on the maximum threshold distances modelled for PTS (marine mammals and sea turtles) and potential mortal injury (fish) due to immediate exposure from single pulses and cumulative exposure from multiple pulses. Implement a soft-start procedure if testing multiple seismic sources. Delay soft-starts if shoaling large pelagic fish, turtles, seals, or cetaceans are observed within the zone of impact.

Model validation

SLR conducted a detailed review of Seiche noise monitoring measurements and SSV and reviewed the noise monitoring data to validate the model predictions. The model is fit for the purpose based on the data analysed and reviewed. It remains slightly above (1 dB) for the peak noise levels measured and remains below (-3 dB) for the noise exposure levels (SEL) recorded at ranges between 2 and 4 km from the source.

Table of contents

Tables in text

Figures in text

1.0 Introduction

1.1 Project description

Searcher Seismic Pty Ltd (Searcher Seismic) is proposing to undertake a 3D seismic survey within the Orange Basin off the West Coast of South Africa. Water depths in the proposed survey area range from 1,500 m to beyond 3,600 m. The proposed 3D survey acquisition area is within the entire Reconnaissance area of approximately 30,000 km^2 as shown in **Figure 1**.

Figure 1 The locality of the Reconnaissance and Acquisition Survey Area (red polygon).

With respect to this area,

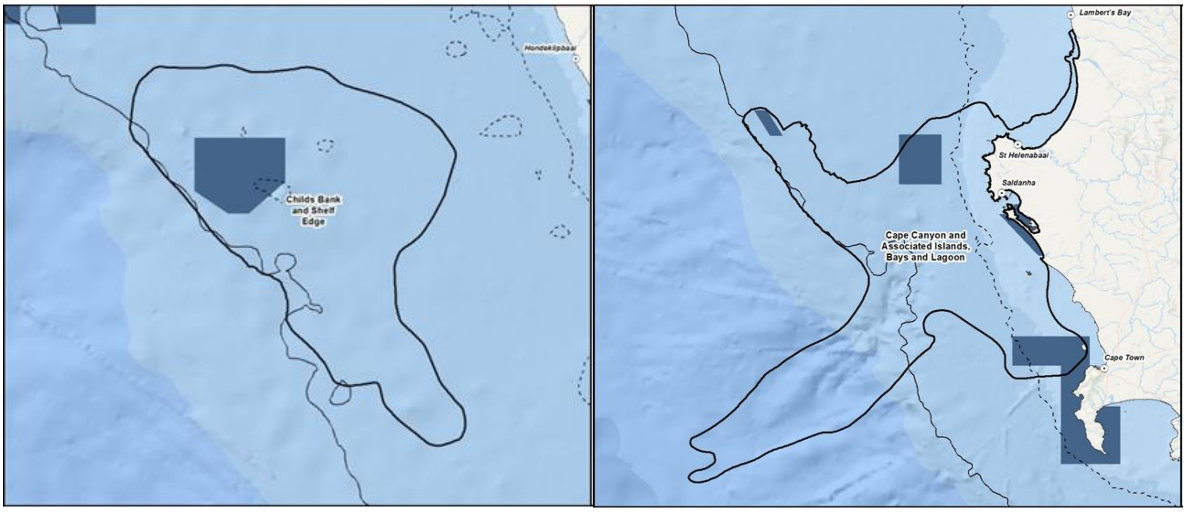
- The Western boundary of the Reconnaissance Permit lie on the limit of the South African 200nm Exclusive Economic Zone which may be subject to change from time to time and takes precedence to the supplied indicative co-ordinate points.
- The Northern boundary of the Reconnaissance Permit lie on the border of the international median between the Exclusive Economic Zones of the South Africa and Namibia which may be subject to change from time to time and takes precedence to the supplied indicative co-ordinate points.

There are a few Ecologically or Biologically Significant Marine Areas (EBSAs) and Marine Protected Areas (MPAs)[1] near the proposed survey areas, particularly the Child Bank and Shelf Edge, as well as Cape Canyon and Associated Islands, Bays and Lagoon, as shown in **Figure 2** below.

[1] https://cmr.mandela.ac.za/Research-Projects/EBSA-Portal/South-Africa accessed on May 20th, 2021.

- **Childs Bank and Shelf Edge** is a unique submarine bank feature occurring within South Africa's Exclusive Economic Zone (EEZ), rising from 180 m to 400 m in water depth on the western continental margin on South Africa, about 130 km east of Hondeklip Bay; This area includes seven ecosystem types, including those comprising the bank itself, the outer shelf and the shelf edge, supporting hard and unconsolidated ecosystem types.
- **Cape Canyon and Associated Islands, Bays and Lagoon** is bounded along the shore from the Sixteen Mile Beach MPA in the south to about 10 km south of Lamberts Bay in the north, extending much further offshore (approximately 70 km) in the southern part compared to that in the northern part (<10 km). The area comprises a collection of special features, ecosystems and species that support a rich diversity and high productivity. The area supports numerous threatened species and ecosystems, and many fragile, sensitive species.

Figure 2 EBSA boundaries (black polygons) for 'Childs Bank and Shelf Edge' (left) and 'Cape Canyon and Associated Islands, Bays and Lagoon' (right). Dark blue areas represent Marine Protected Areas (MPAs).



SLR Consulting Australia Pty Ltd (SLR) has been engaged by Searcher Seismic to undertake a detailed underwater acoustics modelling study for the proposed activities, in order to assist with the assessment of potential noise impact on marine fauna species of interest, particularly for these major marine sensitive areas of concern detailed as above.

This underwater acoustic modelling study predicts received noise levels of various metrics (i.e. sound exposure levels (SELs) from single pulses, cumulative SELs from multiple pulses over 24 hours (SEL_{24hr}), peak sound pressure levels (Pk SPLs) and root-mean-square sound pressure levels (RMS SPLs)) at noise sensitive locations within and adjacent to the proposed 3D survey areas. These noise levels are used to estimate the threshold distances to potential sound effects on marine fauna species of interest, including marine mammals, fish and sea turtle species.

1.2 Structure of the report

This modelling study for the proposed 3D seismic surveys within the Orange Basin off the west coast of South Africa includes the following modelling components:

- Airgun source modelling, i.e. modelling of sound energy emissions from the source arrays proposed to be used in the 3D seismic survey, including the far-field signature and its power spectral density (PSD), as well as the beam pattern of each source array.

- Short range modelling, i.e. prediction of the received noise levels over a range of up to four kilometres from the selected array source location of various depths, in order to investigate sound field variations due to the water depth changes, as well as to assess the potential high-risk immediate noise impact to marine fauna species of interest.
- Long range modelling, i.e. prediction of the received noise levels over a range of up to two hundred kilometres from the selected array source locations, in order to assess the potential noise impact from the surveys on relevant far-field marine sensitive areas.
- Cumulative noise exposure modelling, i.e. prediction of the cumulative SELs over a 24-hour period for selected representative survey scenarios adjacent to marine sensitive areas, to assess the potential cumulative noise impact to marine fauna species of interest.

Section 2.0 of the report provides relevant noise impact assessment criteria for marine fauna species of interest. **Section 3.0** details the modelling methodology, procedure and results for the seismic survey array source modelling. **Section 4.0** outlines the methodologies and procedures for the seismic survey acoustic modelling components (including short range and long-range transmission loss modelling and the cumulative noise exposure modelling). **Section 0** presents the major modelling results and the estimated zones of impact for marine fauna species of interest. **Section 6.6.3** provides discussions and summaries of the acoustic modelling study. Relevant references cited throughout the report are listed in **Section 8.0**.

Relevant acoustic terminologies used throughout the report are presented in **Appendix A**.

An explanation of marine mammal and sea turtle auditory weighting functions are presented in **Appendix B**.

Classifications of various marine mammal hearing groups are presented in **Appendix C**.

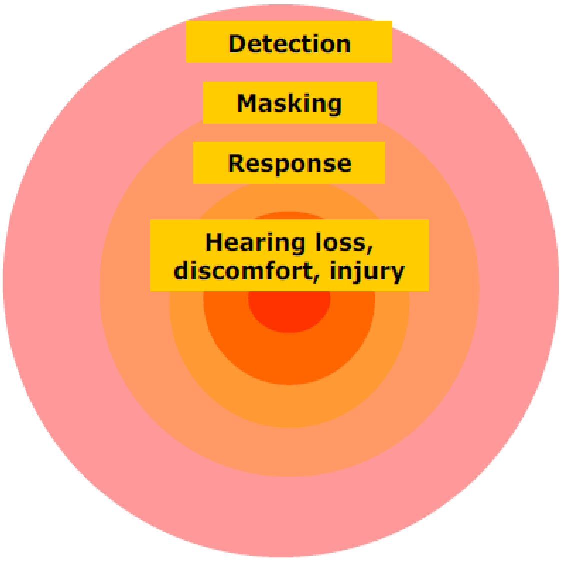
2.0 Noise assessment criteria

2.1 Impact of noise on marine fauna species

The effects of noise and the range over which these effects take place depend on the acoustic characteristics of the noise (e.g. source level, spectral content, temporal characteristics (e.g. impulsive[2] or non-impulsive/continuous[3]), directionality, etc.), the sound propagation environment as well as the hearing ability and physical reaction of individual marine fauna species. The potential impacts of noise on marine fauna species include audibility, detection and masking of communication and other biological important sounds, behavioural responses and physiological impacts which generally include discomfort, hearing loss, physical injury, and mortality (Richardson et al, 1998; Erbe *et al.*, 2018; Popper and Hawkins, 2019)).

The theoretical zones of noise influence based on the severity of noise impact is illustrated in **Figure 3** below.

Figure 3 Theoretical zones of noise influence (Richardson et al. 1998)



2.1.1 Audibility/Detection

A sound is audible when the receiver is able to perceive it over background noise. The audibility is also determined by the threshold of hearing that varies with frequency. The frequency dependant hearing sensitivity is expressed in the form of a hearing curve (i.e. audiogram). In general, marine mammals and fish species usually have U-shaped audiograms, meaning that within their respective hearing ranges, they are more sensitive to the sound energy component in the mid frequency range, and less sensitive to the energy components in the lower and upper frequency ranges (Finneran 2016, Southall *et al.*, 2019; Popper *et al.*, 2019).

[2] Impulsive noise is typically very short (with seconds) and intermittent with rapid time and decay back to ambient levels. E.g. noise from pile driving, seismic airguns and seabed survey sonar signals.

[3] Non-impulsive or continuous noise refers to a noise event with pressure level remains above ambient levels during an extended period of time (minutes to hours), but varies in intensity with time. E.g. noise from marine vessels.

For fish species, their sound detection is based on the response of the auditory portion of their ears (i.e. the otolithic organs) to particle motion of the surrounding fluid (Popper and Hawkins, 2018). Some fish species have the ability to detect sound pressure via gas-filled structures near the ear and/or extensions of the swim bladder that functionally affect the ear, in addition to purely the fluid particle motion, which as a result increase hearing sensitivity and broaden the hearing bandwidth (Nedelec *et al.*, 2016; Popper and Hawkins, 2018).

2.1.2 Masking

Masking occurs when the noise is high enough to impair detection of biologically relevant sound signals such as communication signals, echolocation clicks and passive detection cues that are used for navigation and finding prey. The zone of masking is defined by the range at which sound levels from the noise source are received above threshold within the 'critical ban'[4] centred on the signal (Richardson *et al.*, 1998), and therefore strongly dependent on background noise environment.

The potential for masking can be reduced due to an animal's frequency and temporal discrimination ability, directional hearing, co-modulation masking release (if noise is amplitude modulated over a number of frequency bands) and multiple looks (if the noise has gaps or the signal is repetitive), as well as anti-masking strategies (increasing call level, shifting frequency, repetition, etc.) (Erbe *et al*. 2016).

2.1.3 Behavioural responses

Behavioural responses to noise include changes in vocalisation, resting, diving and breathing patterns, changes in mother-infant relationships, and avoidance of the noise sources. For behavioural responses to occur, a sound would mostly have to be significantly above ambient levels and the animal's audiogram.

The behavioural response effects can be very difficult to measure and depend on a wide variety of factors such as the physical characteristics of the signal, the behavioural and motivational state of the receiver, its age, sex and social status and many others. Therefore, the extent of behavioural disturbance for any given signal can vary both within a population as well as within the same individual. Behavioural reactions can vary significantly, ranging from very subtle changes in behaviour to strong avoidance reactions (Ellison *et al.*, 2012; Richardson et al, 1998).

2.1.4 Physiological impacts / hearing loss and physical injury

Physiological effects of underwater noise are primarily associated with the auditory system which is likely to be most sensitive to noise. The exposure of the auditory system to a high level of noise for a specific duration can cause a reduction in the animal's hearing sensitivity, or an increase in hearing threshold (Finneran 2016, Popper and Hawkins, 2019; Southall *et al.*, 2019). If the noise exposure is below some critical sound energy level, the hearing loss is generally only temporary, and this effect is called temporary hearing threshold shift (TTS). If the noise exposure exceeds the critical sound energy level, the hearing loss can be permanent, and this effect is called permanent hearing threshold shift (PTS).

In a broader sense, physiological impacts also include non-auditory physiological effects. Other physiological systems of marine animals potentially affected by noise include the vestibular system, reproductive system, nervous system, liver or organs with high levels of

[4] In biological hearing systems, noise is integrated over several frequency filters, called the critical bands.

dissolved gas concentrations and gas filled spaces. Noise at high levels may cause concussive effects, physical damage to tissues and organs, cavitation or result in rapid formation of bubbles in venous system due to massive oscillations of pressure (Groton 1998).

From an adverse impact assessment perspective, among the potential noise impacts above, physiological impacts are deemed as the primary adverse impact, and behavioural responses as the secondary adverse impact. The following sub-sections outline the corresponding impact assessment criteria for marine mammals and fish and sea turtle species, as well as human divers and swimmers, based on a review of relevant guidelines and/or literature published.

2.2 Marine mammals, fish and sea turtles

There have been extensive scientific studies and research efforts to develop quantitative links between marine noise and impacts on marine mammal species, fish, and sea turtles. For example, Southall et al (2019) have proposed noise exposure criteria associated with various sound types, including impulsive noise (e.g. piling noise and seismic airgun noise) and non-impulsive noise (e.g. vessel and drilling noise)) for certain marine mammal species (i.e. cetaceans, sirenians and carnivores), based on review of expanding literature on marine mammal hearing and on physiological and behavioural responses to anthropogenic sounds. Popper *et al*. (2014) proposed sound exposure guidelines for fishes considering the diversity of fish, the different ways they detect sound, as well as various sound sources and their acoustic characteristics. Finneran et al. (2017) presented a revision of the thresholds for sea turtle injury and hearing impairment (TTS and PTS). The following subsection provides the noise exposure levels above which adverse effects on various groups of marine mammals, fish, and sea turtles. The latter is based on all available relevant data and published literature (i.e. the state of current knowledge). For more details, see Appendix B.

2.2.1 Noise impact criteria for marine mammals

The newly updated scientific recommendations in marine mammal noise exposure criteria (Southall et al, 2019) propose PTS-onset and TTS-onset criteria for impulsive noise events. The PTS-onset and TTS-onset criteria for impulsive noise are outlined in **Table 1**, which incorporate a dual-criteria approach based on both peak sound pressure level (SPL) and cumulative sound exposure level (SEL) within a 24-hour period (SEL_{24hr}).

Table 1 PTS and TTS threshold levels for individual marine mammals exposed to impulsive noise events (Southall *et al.*, 2019)

Marine mammal hearing group	PTS and TTS threshold levels – impulsive noise events			
	Injury (PTS) onset		TTS onset	
	Pk SPL, dB re 1μPa	Weighted SEL_{24hr}, dB re 1μPa^2·S	Pk SPL, dB re 1μPa	Weighted SEL_{24hr}, dB re 1μPa^2·S
Low-frequency cetaceans (LF)	219	183	213	168
High-frequency cetaceans (HF)	230	185	224	170
Very-high-frequency cetaceans (VHF)	202	155	196	140
Sirenians (SI)	226	203	220	175
Phocid carnivores in water (PCW)	218	185	212	170
Other marine carnivores in water (OCW)	232	203	226	188

For behavioural changes, the widely used assessment criterion for the onset of possible behavioural disruption in marine mammals is root-mean-square (RMS) SPL of 160 dB re 1µPa for impulsive noise, as shown in **Table 2.**

Table 2 The behavioural disruption threshold level for individual marine mammals – impulsive noise events (NOAA, 2021)

Marine mammal hearing group	Behavioural disruption threshold levels – impulsive noise events
	RMS SPL, dB re 1µPa
All hearing groups	160

2.2.2 Noise criteria for fish, fish eggs, and fish larvae

In general, limited scientific data are available regarding the effects of sound for fishes. As such, assessment procedures and subsequent regulatory and mitigation measures are often severely limited in their relevance and efficacy. To reduce regulatory uncertainty for all stakeholders by replacing precaution with scientific facts, the U.S. National Oceanic and Atmospheric Administration (NOAA) convened an international panel of experts to develop noise exposure criteria for fishes and sea turtles in 2004, primarily based on published scientific data in the peer-reviewed literature. The panel was organized as a Working Group (WG) under the ANSI-Accredited Standards Committee S3/SC 1, Animal Bioacoustics, which is sponsored by the Acoustical Society of America.

The sound exposure criteria for seismic airgun sources are presented in **Table 3.** Within the table, where data exist that can be used to suggest provisional guidelines, received signal levels are reported in appropriate forms (e.g., peak SPL, SEL).

Table 3 Noise exposure criteria for seismic airguns – fish, fish eggs and fish larvae (Popper *et al.*, 2014)

Type of animal	Mortality and potential mortal injury	Impairment			Behaviour
		Recovery injury	TTS	Masking	
Fish: no swim bladder (particle motion detection)	>219 dB SEL_{cum}, or >213 dB Pk SPL	>216 dB SEL_{cum} or >213 dB Pk SPL	>>186 dB SEL_{cum}	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder is not involved in hearing (particle motion detection)	210 dB SEL_{cum} or >207 dB Pk SPL	203 dB SEL_{cum} or >207 dB Pk SPL	>>186 dB SEL_{cum}	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder involved in hearing (primarily pressure detection)	207 dB SEL_{cum} or >207 dB Pk SPL	203 dB SEL_{cum} or >207 dB Pk SPL	186 dB SEL_{cum}	(N) High (I) High (F) Moderate	(N) High (I) High (F) Moderate
Fish eggs and fish larvae	>210 dB SEL_{cum} or >207 dB Pk SPL	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low **(F) Low**	(N) Moderate (I) Low (F) Low

Notes: Peak sound pressure levels (Pk SPL) dB re 1 µPa; Cumulative sound exposure level (SEL_{cum}) dB re 1 µPa^2·s. All criteria are presented as sound pressure even for fish without swim bladders since no data for particle motion exist. Relative risk (high, moderate, low) is given for animals at three distances from the source defined in relative terms as near (N), intermediate (I), and far (F).

Where insufficient data exist to make a recommendation for guidelines, a subjective approach is adopted in which the relative risk of an effect is placed in order of rank at three distances from the source – near (N), intermediate (I), and far (F) (top to bottom within each cell of the table, respectively). In general, "near" might be considered to be in the tens of meters from the source, "intermediate" in the hundreds of meters, and "far" in the thousands of meters.

The relative risk of an effect is then rated as being "high," "moderate," and "low" with respect to source distance and animal type. The rating for effects in these tables is highly subjective and represents general consensus within the WG.

It should be noted that the period over which the cumulative sound exposure level (SEL_{cum}) is calculated must be carefully specified. For example, SEL_{cum} may be defined over a standard period (e.g., 12 hours of pile driving) or for the duration of an activity (e.g., the full period of construction), or over the total period that the animal will be exposed. Whether an animal would be exposed to a full period of sound activity will depend on its behaviour, as well as the source movements. To be in line with assessment criteria for marine mammals, an exposure period of 24 hours is specified for fish. The receiving exposure levels over this period are expected to reflect the total exposure at near field where the major adverse impacts are expected to occur for fish species.

2.2.3 Noise criteria for sea turtles

Popper *et al.* (2014) suggested threshold levels for the occurrence of mortality and potential mortal injuries (PTS) of sea turtles. However, these adopted levels were extrapolated from other animal groups such as fish, based on the logic that the hearing range of turtles is much closer to that of poorly hearing fish.

More recently, Finneran *et al.* (2017) revised the sea turtle thresholds (PTS) by reviewing individual references from at least five different species (see **Appendix C**) to construct their composite audiograms and provide thresholds for onset of temporary hearing impairment (TTS). Finneran *et al.* (2017) agreed that sea turtles, even within their best hearing range, have low sensitivity with audiograms more similar to those of fish without specialized hearing adaptations for high frequency like some marine mammals. The revised thresholds for sea turtles are presented in **Table 4.**

Table 4 PTS and TTS threshold levels for sea turtles exposed to impulsive noise events (Finneran *et al.*, 2017)

Type of animal	PTS and TTS threshold levels – impulsive noise events			
	Injury (PTS) onset		TTS onset	
	Pk SPL, dB re 1µPa	Weighted SEL_{24hr}, dB re $1\mu Pa^2 \cdot S$	Pk SPL, dB re 1µPa	Weighted SEL_{24hr}, dB re $1\mu Pa^2 \cdot S$
Sea turtles	232	204	226	189

The behavioural threshold for sea turtles was initially established by McCauley *et al.* (2000) at 166 dB re 1 µPa SPL RMS and then it was adopted by NMFS to identify the distances at which behavioural response may occur (NSF, 2011). However, the received sound level at which sea turtles are expected to actively avoid repeated air gun exposures is 175 dB re 1 µPa SPL RMS (McCauley et al., 2000) as shown in **Table 5**.

Table 5 The behavioural threshold level for sea turtles – air guns events (McCauley *et al.*, 2000; Finneran *et al.,* 2017)

Type of animal	Behavioural disturbance threshold levels – air guns events
	RMS SPL, dB re 1µPa
Sea turtles	175

Therefore, this threshold has been applied by NMFS to estimate sea turtle behaviour reactions to repeated air gun activities such as seismic surveys (Finneran *et al.*, 2017).

2.3 Zones of impact

Received noise levels can be predicted using known source levels in combination with models of sound propagation transmission loss between the source and the receiver locations. Zones of impact can then be determined by comparison of the predicted received levels to the noise exposure criteria for the marine fauna species of concern.

It should be noted that the proposed noise exposure assessment criteria for impulsive noise events are all significantly higher than typical natural ambient noise levels, which have overall RMS SPLs in the range of 80 – 120 dB re 1µPa in the case of calm to strong sea state conditions, respectively. Therefore, the natural ambient noise is not given consideration in the assessment of the zones of impact.

Predicted zones of impact define the environmental footprint of the noise generating activities and indicate the locations within which the activities may have an adverse impact on marine fauna species of interest. In this report, zones of impact are defined as follows:

- For immediate impact from single pulses – the zone of impact represents the maximum horizontal distance from the sound source,
- For cumulative impact from a typical survey operation scenario – the zone of impact represents the maximum perpendicular horizontal distance from an active seismic survey line.

In all cases, zones of impact are conservatively determined by using the maximum predicted noise level across the water column to determine the zone of impact. Since noise levels vary with depth at any location, there will be areas in the water column within the identified zone of impact that are exposed to lower noise levels than implied by the identified zones of impact, which represent the worst case.

3.0 Seismic airgun array source modelling

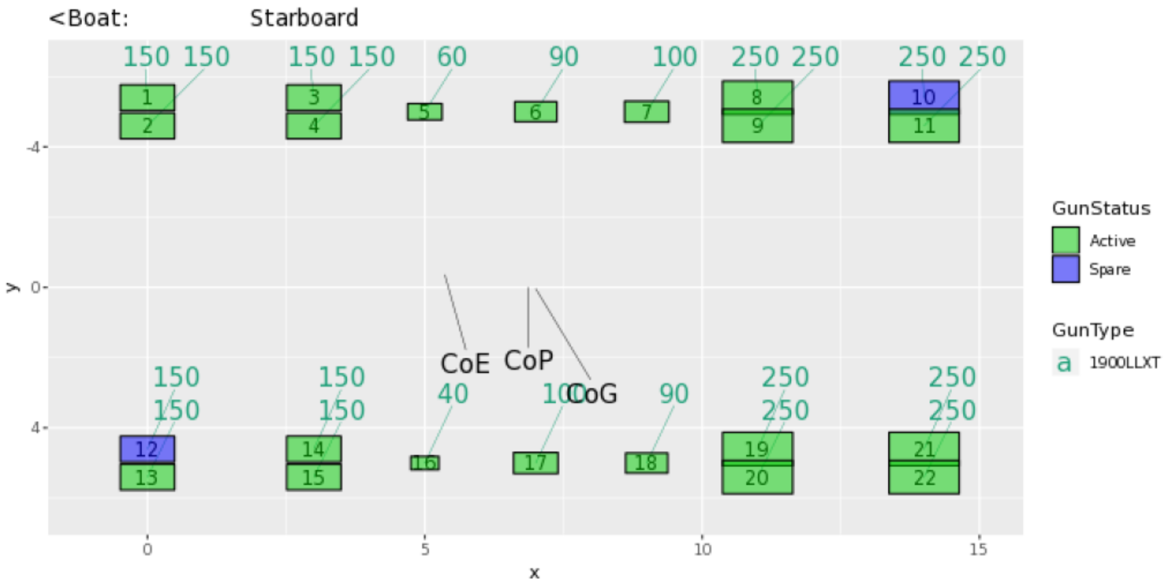
3.1 Airgun array configuration

The airgun array proposed for the 3D seismic survey is summarised in **Table 6** with configuration shown in **Figure 4**. The array has a towing depth of 8.0 m and an operating pressure of 2 000 pounds per square inch (PSI).

Table 6 Summary of the 3D airgun array source

Seismic Survey	Number of Active guns	Gun Type	Total Source Volume (cubic inches)
3D	20 (2 spare)	1900-LLXT	3 280

Figure 4 Configuration of the 3 280 CUI 3D source array (green–active, blue-spare)



3.2 Modelling methodology

For each source array configuration, the outputs of the source modelling include:

- A set of "notional" signatures for each of the array elements; and
- The far-field signature of the array source, including its directivity/beam patterns.

3.2.1 Notional signature

The notional signatures are the pressure waveforms of individual source elements at a standard reference distance of 1 m.

Notional signatures are modelled using the Gundalf Designer software package (2021). The Gundalf source model is developed based on the fundamental physics of the oscillation and radiation of source bubbles as described by Ziolkowski (1970), and for an array source case, taking into account non-linear pressure interactions between source elements (Ziolkowski *et al.*, 1982; Dragoset, 1984; Parkes *et al.*, 1984; Vaage *et al.*, 1984; Laws *et al.*, 1988 & 1990).

The model solves a complex set of differential equations combining both heat transfer and dynamics and has been calibrated against multiple measurements of both non-interacting source elements and interacting clusters for all common source types at a wide range of deployment depths.

The model has the capability to predict noise spectra with frequency range up to tens of kHz. For frequencies above 1 kHz, the modelled spectra generally follow a close to *1/f* attenuation (Landrø *et al.*, 2011). As the noise emissions from an airgun array are predominantly below hundreds of Hz, the following result section only demonstrates modelling results within frequency range below 1 kHz.

3.2.2 Far-field signatures

The notional signatures from all airguns in the array are combined using appropriate phase delays in three dimensions to obtain the far-field source signature of the array. This procedure to combine the notional signatures to generate the far-field source signature is summarised as follows:

- The distances from each individual acoustic source to nominal far-field receiving location are calculated. A 9 km receiver set is used for the current study;
- The time delays between the individual acoustic sources and the receiving locations are calculated from these distances with reference to the speed of sound in water;
- The signal at each receiver location from each individual acoustic source is calculated with the appropriate time delay. These received signals are summed to obtain the overall array far-field signature for the direction of interest; and
- The far-field signature also accounts for ocean surface reflection effects by inclusion of the “surface ghost”. An additional ghost source is added for each acoustic source element using a sea surface reflection coefficient of -1.

3.2.3 Beam patterns

The beam patterns of the acoustic source array are obtained as follows:

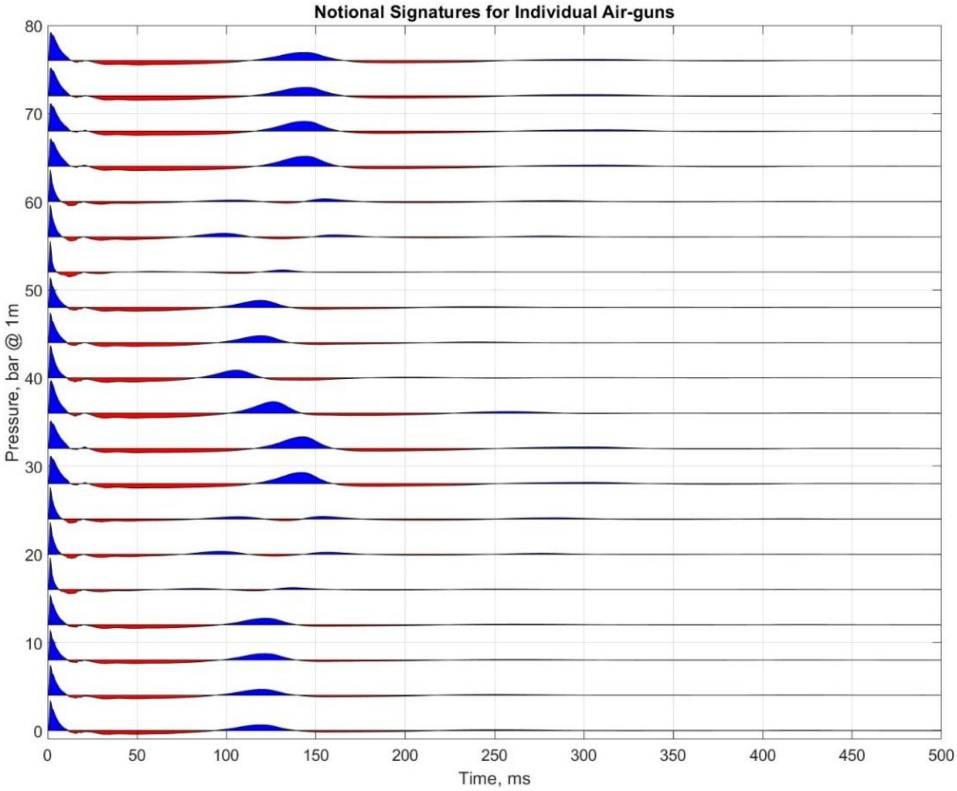
- The far-field signatures are calculated for all directions from the source using azimuthal and dip angle increments of 1-degree;
- The PSD (dB re 1 µPa^{2}s/Hz @ 1m) for each pressure signature waveform is calculated using a Fourier transform technique; and
- The PSDs of all resulting signature waveforms are combined to form the frequency-dependent beam pattern for the array.

3.3 Modelling results

3.3.1 Notional signatures

Figure 5 shows the notional source signatures for the airgun array elements for the source array. Each line within the figure represents the notional source signature of the corresponding array element as shown in **Figure 4**.

Figure 5 Notional source signatures for the 3D source array (3 280 CUI)



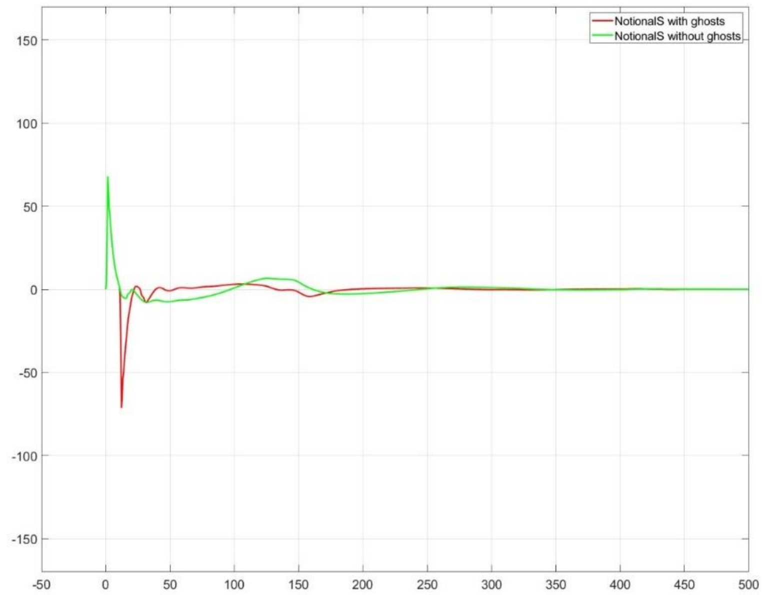
3.3.2 Far-field signature and its power spectral density

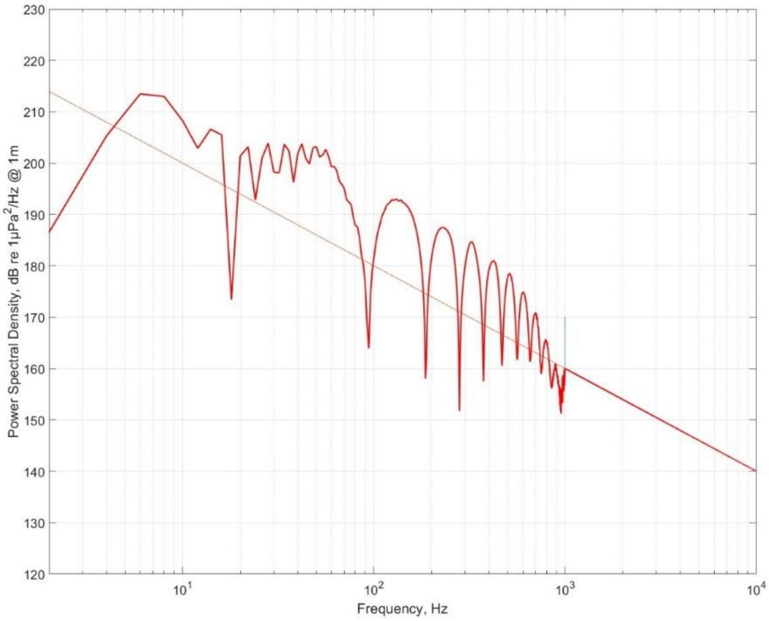
Figure 6 shows the far-field signature waveform and its power spectral density for the proposed airgun array. The signatures are for the vertically downward direction with surface ghost included. The source modelling result shows the parameters presented in **Table 7**.

Table 7 Source levels of the array source (3 280 CUI)

Source Levels	3D source array
Peak sound pressure level (Pk SPL) (dB re 1 µPa @ 1m)	257.2
Root-mean-square sound pressure level (RMS SPL) (dB re 1 µPa @ 1m with a 90%-energy pulse duration of 12.5 milliseconds)	243.2
Sound exposure level (SEL) (dB re µPa^2·s @ 1m)	233.2

Figure 6 The far-field signature in vertically downward direction (top) and its power spectral density (bottom) for the 3D Source Array (1900 LLXT 3 280 in^3 Array)





3.3.3 Beam patterns

Array far-field beam patterns of the following three cross sections are presented in **Figure 7**:

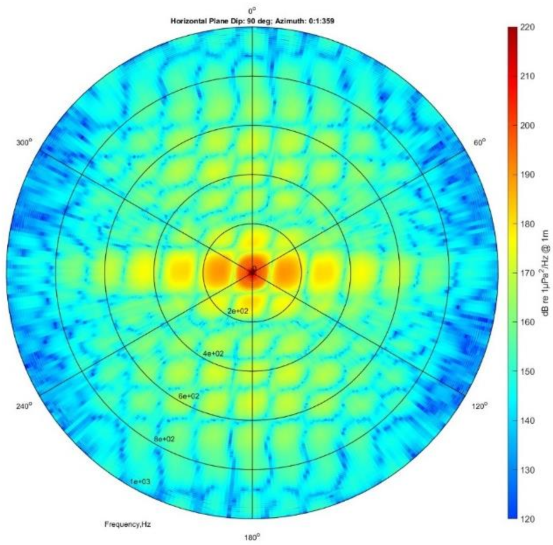
a) The horizontal plane (i.e. dip angle of 90 degrees) with azimuthal angle of 0 degree corresponding to the in-line direction;

b) The vertical plane for the in-line direction (i.e. azimuthal angle of 0 degree) with dip angle of 0 degree corresponding to the vertically downward direction; and

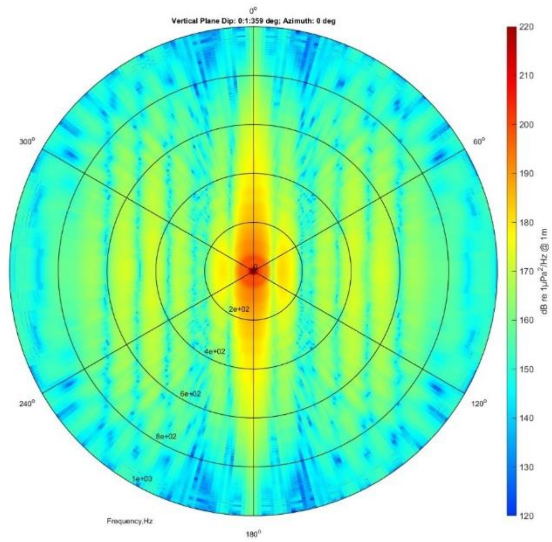
c) The vertical plane for the cross-line direction (i.e. azimuthal angle of 90 degrees) with dip angle of 0 degree corresponding to the vertically downward direction.

The beam patterns in **Figure 7** illustrate strong angle and frequency dependence of the energy radiation from the array. The beam pattern of the horizontal plane shows relatively stronger energy radiation in the cross-line direction than in the in-line direction. The beam patterns of the in-line and cross-line vertical planes have the strongest radiation in the vertical direction.

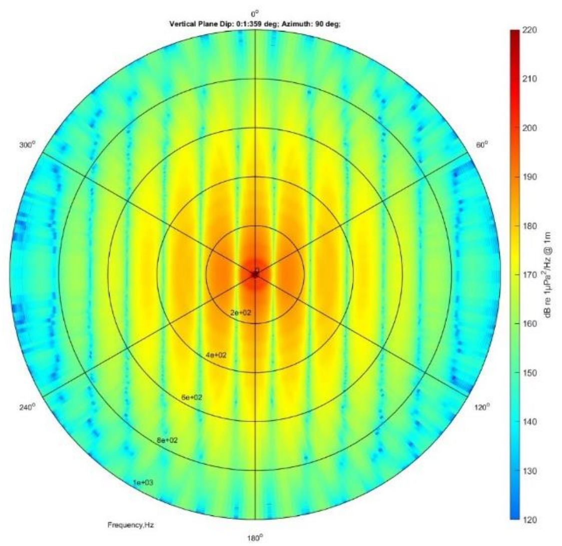
Figure 7 Array far-field beam patterns for the 1900-LLXT 3 280 in^3 Source Array proposed for the 3D seismic survey, as a function of orientation and frequency.



Beam pattern horizontal plane dip: 90° azimuth: 0° to 360°



Beam pattern vertical plane dip: 0° to 360° azimuth: 0°



Beam Pattern Vertical Plane Dip: 0° to 360° Azimuth: 90°

4.0 Transmission loss modelling

4.1 Modelling input parameters

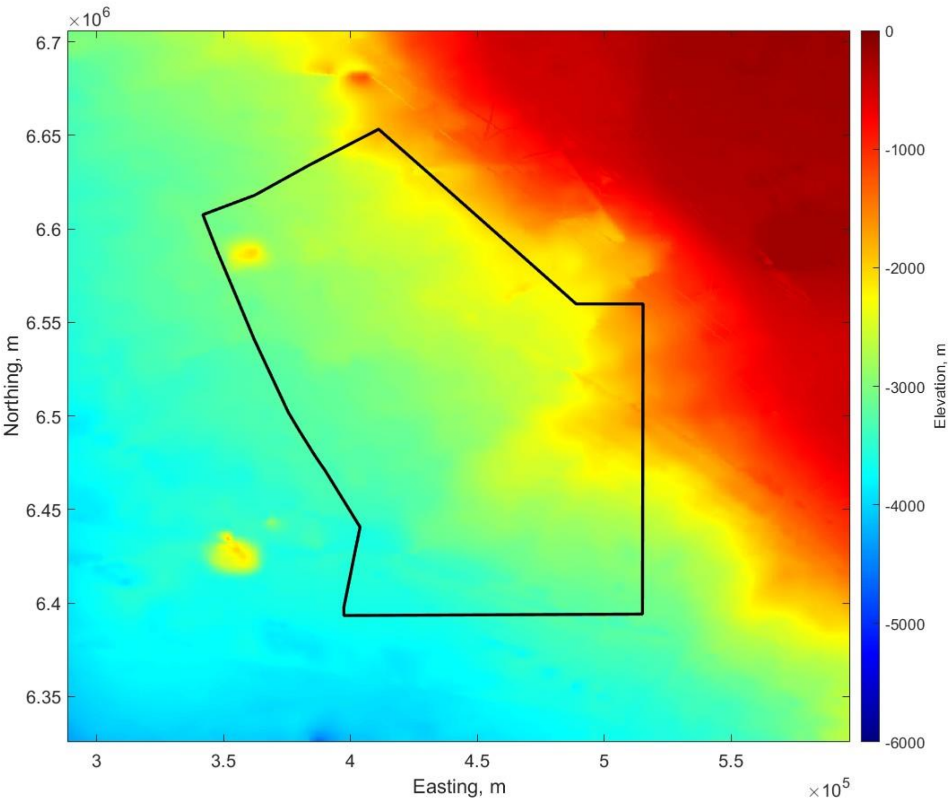
4.1.1 Bathymetry

The bathymetry data used for the sound propagation modelling was obtained from the 15 arc seconds bathymetric dataset GEBCO_2020 Grid (GEBCO, 2020). The GEBCO_2020 Grid is the latest global bathymetric product released by the General Bathymetric Chart of the Oceans (GEBCO) and has been developed through the Nippon Foundation-GEBCO 'Seabed 2030 Project' (https://seabed2030.gebco.net/), which is a collaborative project between the Nippon Foundation of Japan and GEBCO.

The ocean currents within the survey area are not expected to have significant effects on sound propagation, due to limited current heights compared with overall water depths and low current speed compared with sound speed within typical sea water.

The bathymetric imagery within and surrounding the acquisitions area presented in **Figure 8**.

Figure 8 Bathymetry data for study area. The reconnaissance area is shown with a black polygon, based on WGS 84/UTM Zone 33S.



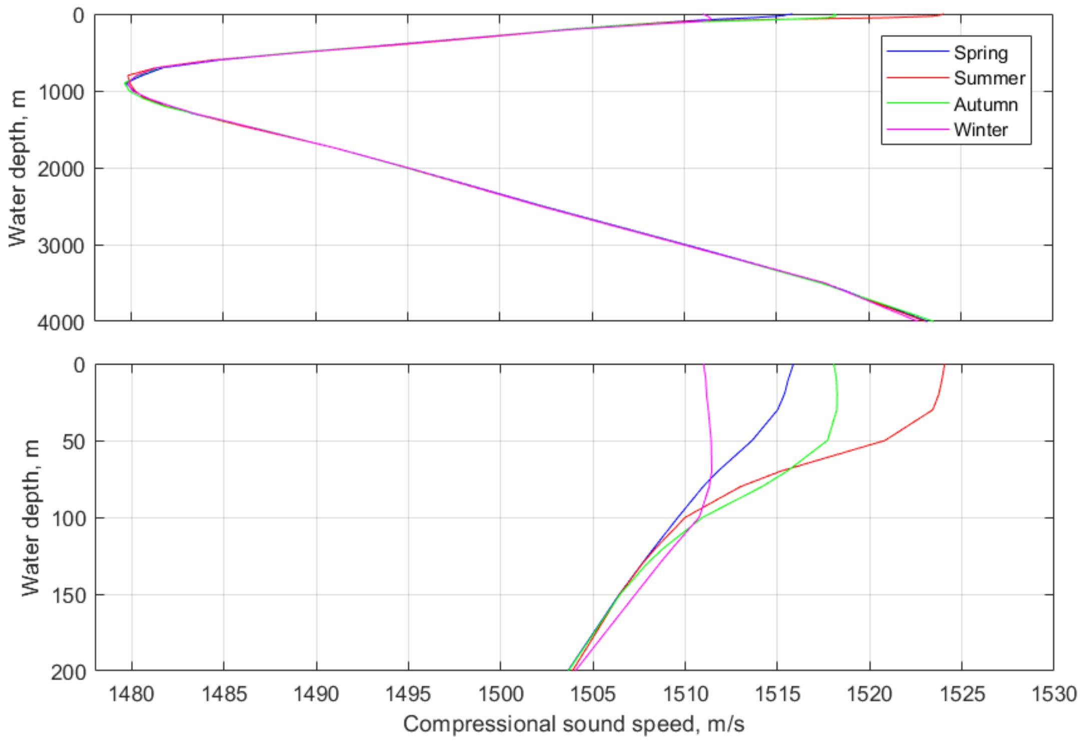
4.1.2 Sound speed profiles

Temperature and salinity data required to derive the sound speed profiles were obtained from the World Ocean Atlas 2009 (WOA09) (Locarnini *et al.*, 2010; Antonov *et al.*, 2010). The hydrostatic pressure needed for calculation of the sound speed based on depth and latitude of each particular sample was obtained using Sanders and Fofonoff's formula (Sanders and Fofonoff, 1976). The sound speed profiles were derived based on Del Grosso's equation (Del Grosso, 1974).

Figure 9 presents typical sound speed profiles for four seasons within the application area. The figure demonstrates that the most significant distinctions for the profiles of four seasons occur within the mixed layer near the surface. The summer season has the strongest downwardly refracting feature among the four seasons, and the winter season exhibits a deeper surface duct than the other three seasons. Due to the stronger surface duct within the profile, it is expected that the winter season will favour the propagation of sound from a near surface acoustic source array.

As can be seen in the figure below, the overall speed profiles of different seasons across the water column are quite similar, although in shallower water (less than 200 m) there is slight seasonal variation. As such, the differences in sound fields between different seasons are not expected to be significant.

Figure 9 Typical sound speed profiles within the survey areas for different seasons. The top panel shows profiles across the entire deep-water column, and the bottom panel shows profiles across the water column section near the surface.



4.1.3 Seafloor geoacoustic model

To inform the 2018 national marine ecosystem classification and mapping efforts, Sink et al. (2019) collated sediment data from numerous samples acquired by grab or core under 13 different projects to produce a national layer of sediment types. The data sample classification reveals that the seafloor of the South African shelf is primarily composed of sand with a noticeable proportion of mud.

Relevant literature shows that from continental shelf to deep sea basin, the sediment spatial distribution has a general transition from sand to deep sea ooze sediment, as a result of the regional oceanography and terrigenous sediment supply, as well as the deep sea sedimentary processes (Dingle *et al.*, 1987; Dutkiewicz *et al.*, 2015).

For the stratified layers beneath the superficial sediment layer within the offshore Orange Basin, relevant geological modelling studies (Paton et al, 2007; Campher et al, 2009) show that, for a typical east-west trending transect across the Orange Basin, a dominant layer of leaky shale/mudstone is predicted to be up to 2,000 m – 4,000 m from the seabed depth, followed by layers of sandstone and rock basement.

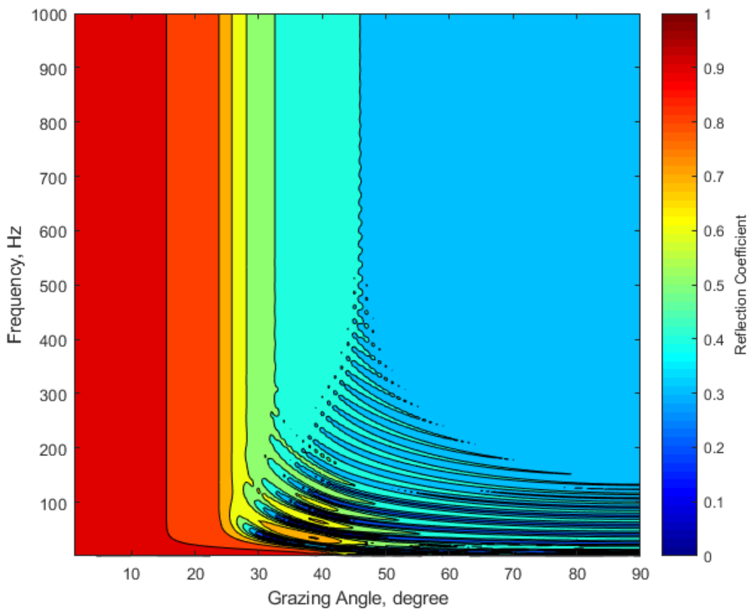
Based on above as well as a conservative consideration, it is proposed that for the entire modelling area, the seafloor geoacoustic model comprises of a 50 m fine sand sediment layer, followed by a soft to sei-cemented mudstone / shale sediment layer and a semi to full-cemented mudstone /shale substrate as detailed in **Table 8**. The geoacoustic properties for the sediment layers are as described in Hamilton (1980), with attenuations referred to Jensen *et al.* (2011). The elastic properties of sands are treated as negligible.

Table 8 Geoacoustic parameters for the proposed seafloor model

Seafloor Materials	Depth Range, m	Density, ρ, (kg.m^{-3})	Compressional Wave	
			Speed, c_p, (m.s^{-1})	Attenuation, α_p, (dB/λ)
Fine/silty sand	0 - 50	1,900	1,650	0.8
Soft to semi-cemented mudstone / shale sediment layer	50 - 500	2,000	1,900	1.0
Semi to full- cemented mudstone / shale half-space	500 - ∞	2,300	2,500	1.0

Figure 10 below shows the reflection coefficient variation with grazing angle and frequency for the proposed seafloor geoacoustic model, calculated using the plane-wave reflection coefficient program Bounce (Porter, 2020).

Figure 10 Reflection coefficient vs grazing angle and frequency for the proposed geoacoustic model



As shown in the figure, the seafloor acoustic reflection is dominated by the top sediment layer across the frequency range, with high reflection at low grazing angles and low reflection (high refraction) at higher grazing angles.

4.2 Detailed modelling methodologies and procedures

The sub-sections below describe the modelling methodologies and procedures for predicting received noise levels of relevant metrics associated with seismic survey activities.

The modelling components as detailed in **Section 4.2.1** to **Section 4.3** involve SELs and noise levels in relevant acoustic metrics (i.e. Peak SPLs and RMS SPLs) for single shots from the G-Gun II 2 820 in^3 Source Array for the 3D seismic survey, as well as for the cumulative SELs within a 24-hour period for the representative 3D survey scenario.

4.2.1 Short range modelling

4.2.1.1 Modelling methodology and procedure

Short range modelling has been used to model received SELs in relatively close proximity to the airgun source, with consideration of the near-field effect of the sound field. As such, the predictions for the short range case are modelled by reconstructing the received signal waveforms from individual airgun source units within the array.

The wavenumber integration modelling algorithm SCOOTER (Porter, 2020) is used to calculate the transfer functions (both amplitudes and phases) between sources and receivers. SCOOTER is a finite element code for computing acoustic fields in range-independent environments. The method is based on direct computation of the spectral integral and is capable of dealing with an arbitrary layered seabed with both fluid and elastic characteristics.

The following procedures have been followed to calculate received SELs for short range cases:

1. The modelling algorithm SCOOTER is executed for frequencies from 1 Hz to 1 kHz, in 1 Hz increments. The source depth is taken to be the array depth of 8.0 m. A receiver grid of 1 m in range (maximum range 4.0 km) and 1 m in depth is applied for the selected receivers. For each gridded receiver, the received SEL is calculated by following steps 2) – 5);
2. The range from the source to each receiver is calculated, and the transfer function between the source and the receiver is obtained by interpolation of the results produced by modelling algorithm SCOOTER in Step 1). This interpolation involves both amplitude and phase of the signal waveform in frequency domain;
3. The complex frequency domain signal of the notional signature waveform for each source element is calculated via Fourier Transform, and multiplied by the corresponding transfer function from Step 2) to obtain the frequency domain representation of the received signal from the source element;
4. The waveform of received signal from the array source is reconstructed via Inverse Fourier Transform. The received signal waveforms from all airgun sources in the array are summed to obtain the overall received signal waveform; and
5. The signal waveform is squared and integrated over time to obtain the received SEL value. Alternatively, the SEL value can also be calculated via integration of the energy power density (ESD) over frequency in Step 3).

4.2.1.2 Modelling scenarios

The modelling inputs for the short range modelling case, such as sound speed profile and seabed geoacoustic models, has been detailed in **Section 4.1**. To analyse the received SEL at 50 m water depth, modelling has been undertaken for such water depth case for the 3D survey area.

4.2.2 Long range modelling

4.2.2.1 Modelling methodology and procedure

The long range modelling generally involves complex and variable environmental factors (such as sound speed profiles and bathymetric variations) along an extended range of sound propagation environments, and requires an efficient modelling prediction algorithm with reasonable accuracy. Therefore, the modelling prediction for the long range case is carried out using the far-field source levels of octave frequency bands and their corresponding transmission loss calculations.

The fluid parabolic equation (PE) modelling algorithm RAMGeo (Collins, 1993) is used to calculate the transmission loss between the source and the receiver. RAMGeo is an efficient and reliable PE algorithm for solving range-dependent acoustic problems with fluid seabed geo-acoustic properties.

The received sound exposure levels are calculated following the procedure as below:

1) One-third octave source levels for each azimuth to be considered are obtained by integrating the horizontal plane source spectrum over each frequency band, these levels are then corrected to SELs;

2) Transmission loss is calculated using RAMGeo at one-third octave band central frequencies from 8 Hz to 1 kHz, with a maximum range of 200 km and at 5-degree azimuth increments. The bathymetry variation along each modelling track is obtained via interpolation from the bathymetry dataset;

3) The one-third octave source SEL levels and transmission loss are combined to obtain the received SEL levels as a function of range, depth and frequency;

4) The overall received SEL levels are calculated by summing all frequency band SEL levels.

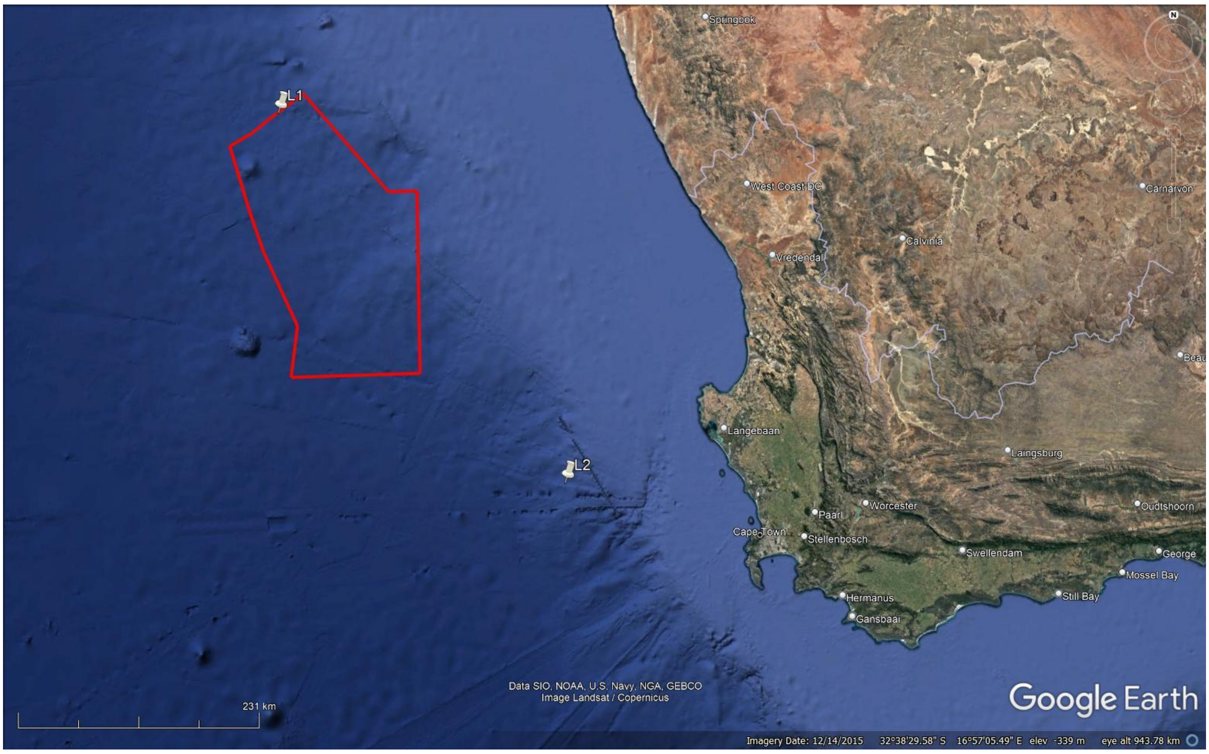
4.2.2.2 Modelling scenarios

Two (2) long range modelling source locations are proposed for the the 3D seismic survey as detailed in **Table 9** and shown in **Figure 11.** The in-line survey directions for the 3D survey modelling locations are assumed to be NE-SW. It should be noted that the modelling locations were chosen prior to the acquisition area being finalised. The modelling is representative of the noise propagation within the acquisition area. L2 lies at a similar depth to the eastern side of the acquisition area along the continental shelf.

Table 9 Details of the two selected single source locations for the long range modelling

Source Location	Water Depth, m	[Easting, Northing], m	Locality
L1	~2,670	[3.87374 x 10^5, 6.635553 x 10^6]	Adjacent to Childs Bank and Shelf Edge
L2	~2,100	[6.44294 x 10^5, 6.291740 x 10^6]	Adjacent to Cape Canyon and Associated Islands, Bays and Lagoon

Figure 11 The selected long range modelling source locations L1 and L2 – white placemarks.



4.2.3 Cumulative SEL modelling

4.2.3.1 Modelling methodology and procedure

The cumulative SEL accounts for the total acoustic energy received from all seismic impulses within a specific period of exposure (i.e. 24 hours). There will be thousands of survey shots during a typical survey operation within a 24-hour period, and it is not practical to perform sound modelling for every survey shot in an efficient manner. However, the propagation environments for a set of consecutive survey shots are similar, and therefore one propagation model could be performed as representative for the set group. The sound field for the representative survey shot then could be adjusted to represent the rest of the survey shots within the set group accounting for their source positions.

The cumulative SELs (frequency unweighted and weighted) are modelled based on the steps as below:

1. The received SELs at individual grid locations (a 100-m grid size for this study) from individual representative survey shot considered (one in every ten shots for this study) is modelled based on the long range modelling methodology and procedure as detailed

in **Section 4.2.2.1**, and then the results are adjusted for the rest of survey shots based on their shot locations;

2. The SEL_{24hr} at individual receiving grid locations are obtained by summing SEL contribution from all survey shots within a 24-hour period for the survey operation scenario considered;
3. For weighted SEL_{24hr} for individual marine mammal hearing groups, the source spectra are adjusted accounting for the frequency weighting functions for individual hearing groups (as in **Appendix B**), and the weighted SEL_{24} for individual hearing groups to be obtained by repeating the first two steps as above;
4. For high frequency energy component which is important for marine mammals with high frequency hearing range, the source spectra and propagation modelling are extended up to 10 kHz, with the source spectra being close to $1/f$ attenuation for frequencies above 1 kHz (Landrø *et al.*, 2011), so that the high frequency energy component to be included for the weighted SEL_{24hr} predictions.

   It should be noted that the source level inputs for long range modelling as detailed in **Section 4.2.2.1** are based on the array source noise emissions in the horizontal plane, and this approach may underestimate the actual sound field close to the array source (< 4 km). As such, the sound fields close to the array source predicted by the long-range modelling as described in Step (1) above are benchmarked against short range modelling results to account for the near-field effects.

4.2.3.2 Modelling scenarios

Based on relevant project information provided, the survey schedules for the survey is outlined in **Table 10**. Two survey line sections are assumed to be acquired within the 24-hour period for each scenario.

Table 10 Survey Schedule

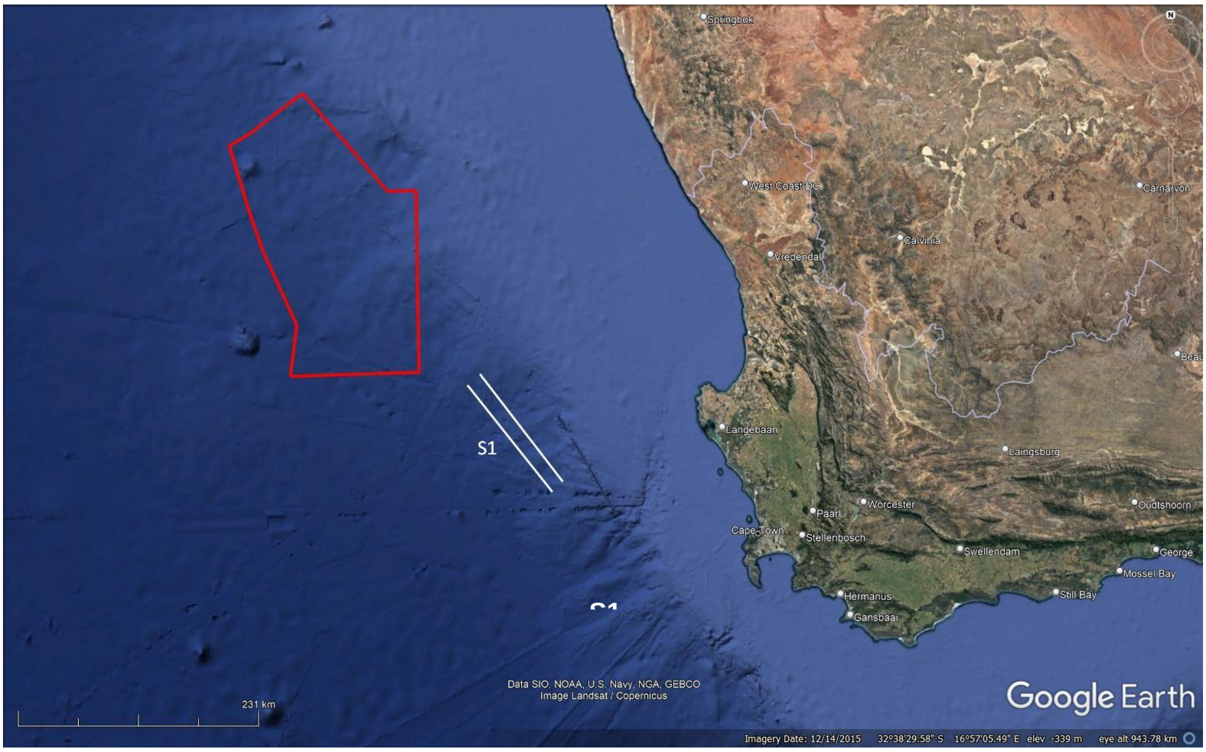
Survey	Shot spacing (m)	Vessel Speed (knots)	Survey Orientation
3D	18.75	4.3	NE-SW

The survey line details for the modelling scenario is detailed in **Table 11** and indicated in **Figure 12**. The rationale of the selected cumulative modelling scenario is on the basis that the scenario is representative with regards to the adjacent EBSAs (i.e. Cape Canyon and Associated Islands, Bays and Lagoon). As in the long-range case, the modelling was completed prior to the acquisition area being finalised. The modelling is representative of the noise propagation within the acquisition area.

Table 11 Details of the selected survey lines for the cumulative SEL modelling scenarios

Scenario	Survey Lines	[Easting, Northing], m	Length, km	Locality
S1	1	[6.43610×10^5, 6.292217×10^6]	96	Adjacent to Cape Canyon and Associated Islands, Bays and Lagoon
	2	[5.59039×10^5, 6.381401×10^6]	96	

Figure 12 The selected 24-hour survey scenario



4.2.4 Pk SPLs and RMS SPLs – estimate methodology from modelled SELs

For received individual signals emitted from impulsive sources such as seismic airguns, the differences between the SEL and other sound parameters, such as the Pk SPL/RMS SPL, are expected to be greatest at the source location, and then gradually decrease with receiving locations further away from the source location. This is due to the following effects:

- Theoretically, the airgun pulse goes through increasing waveguide distortion effects (e.g. dispersion, interference effects, seafloor and surface reflections, differences of time arrivals, etc.) with increasing range from the source, which impact predominantly on temporal characteristics of the pulse (e.g. lower peak level, extended pulse duration, etc.) rather than the energy based metric levels.
- The above statement is reliably supported by numerous theoretical and empirical research studies, e.g. the relevant seismic survey signal modelling and measurement studies (e.g. Austin *et al.*, 2013, Matthews and MacGillivray, 2013, Galindo-Romero *et al.*, 2015, McCauley *et al.*, 2000 & 2016) show that the differences between the three temporal parameters (i.e. Pk SPL, and RMS SPL) and SEL are increasingly higher at the receiver closer to the source location.

SEL vs Pk SPL

As presented in **Section 3.3.2**, the difference between the Pk SPL and SEL of the far-field signature of the source arrays (at a reference distance of 1 m from the centre of the array) is 24.0 dB for 3D array. This value is taken as the conversion factor applied to the SELs for calculating the received Pk SPLs over the receiving range close to the source location. This approach is regarded as conservative for estimating relevant near-field acoustic parameters based on SEL predictions.

SEL vs RMS SPL

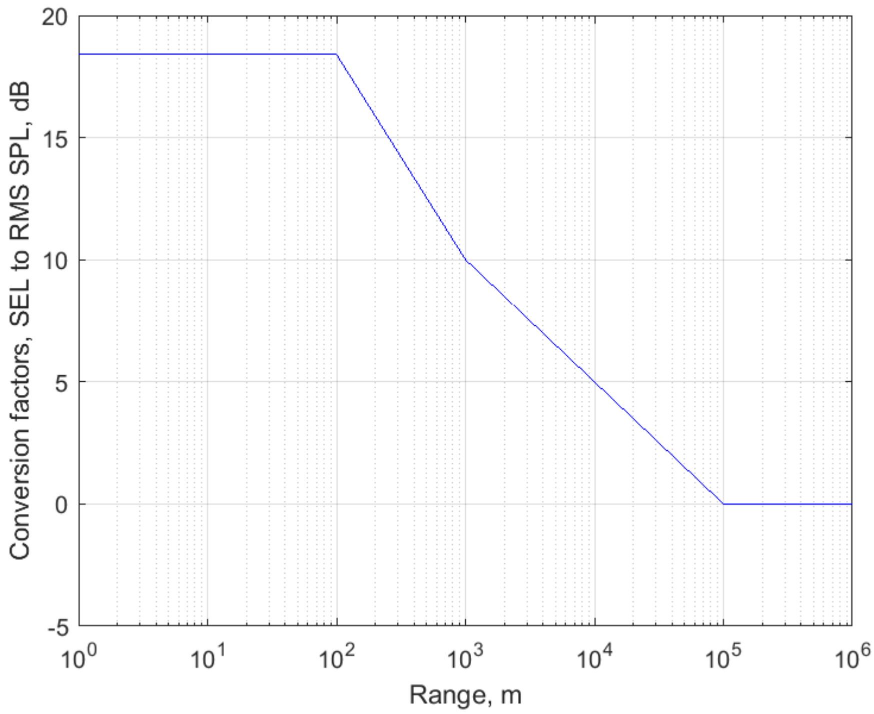
Previous empirical studies demonstrate that at relatively close distances from the airgun sources (within 1.0 km), the difference between SELs and RMS SPLs could be between 10 dB to 15 dB (Austin *et al.*, 2013, McCauley *et al.*, 2000,). The differences could drop to under 5 dB when the distances are close to 10 km (Austin *et al.*, 2013). The differences are expected to drop further with the increasing distances beyond 10 km (Simon *et al.*, 2018).

For this project, the RMS SPLs were estimated using the following conversion factors to be applied to the modelled SELs within different distance ranges. These conversion factors are conservatively estimated based on the source array modelling results and above previous measurement results:

- 0 – 100 m, a conversion factor of 17.6 dB for the 3D array. This is the difference between RMS SPL and SEL of the far-field signature of the source arrays as modelled in **Section 3.3.2**.
- 100 – 1,000 m, conversion factors 18.4 dB to 10.0 dB, following a logarithmic trend with distance;
- 1,000 – 10,000 m, conversion factors 10.0 dB to 5.0 dB, following a logarithmic trend with distance;
- 10,000 – 100,000 m, conversion factors 5.0 dB to 0.0 dB, following a logarithmic trend with distance;
- > 100,000 m, a conversion factor of 0.0 dB.

The SEL to RMS SPL conversion factors as a function of horizontal ranges from 3D source array are demonstrated in **Figure 13** as below.

Figure 13 SEL to RMS SPL conversion factors as a function of horizontal range from 3D source array



4.3 Model validation – airgun seismic survey noise modelling

The accuracy of airgun array sound field modelling depends on the suitability and accuracy of the airgun array source model and the transmission loss model, as well as the realism of the parameters defining the sound propagation environment, including the bathymetry, seafloor geo-acoustics and sound speed profiles.

The following model validation exercises have been undertaken previously in regard to the airgun array source model, short range model and long range model that have been used in this modelling study:

- The source modelling software Gundalf has been calibrated against various datasets of near-field recorded signatures, and has been verified against other airgun array source signature models (Ainslie *et al.*, 2016);
- The short range model and long range model have been validated from a few underwater acoustic measurement programs undertaken by independent third parties, with good agreements between modelled and measured results being reported (e.g. Simon *et al.* (2018) and Li *et al.* (2021)).

Please refer to Section 5.0 for specific model validation undertaken in respect to this project.

5.0 Model validation

Searcher Geodata UK Limited (Searcher), a subsidiary of Searcher Seismic Pty Ltd, conducted a 3D seismic survey approximately 256 km offshore of Hondeklip Bay, West Coast, South Africa. Sound Source Verification (SSV) and marine mammal (MM) surveys were carried out for Searcher Seismic in late December 2023 and early January 2024.

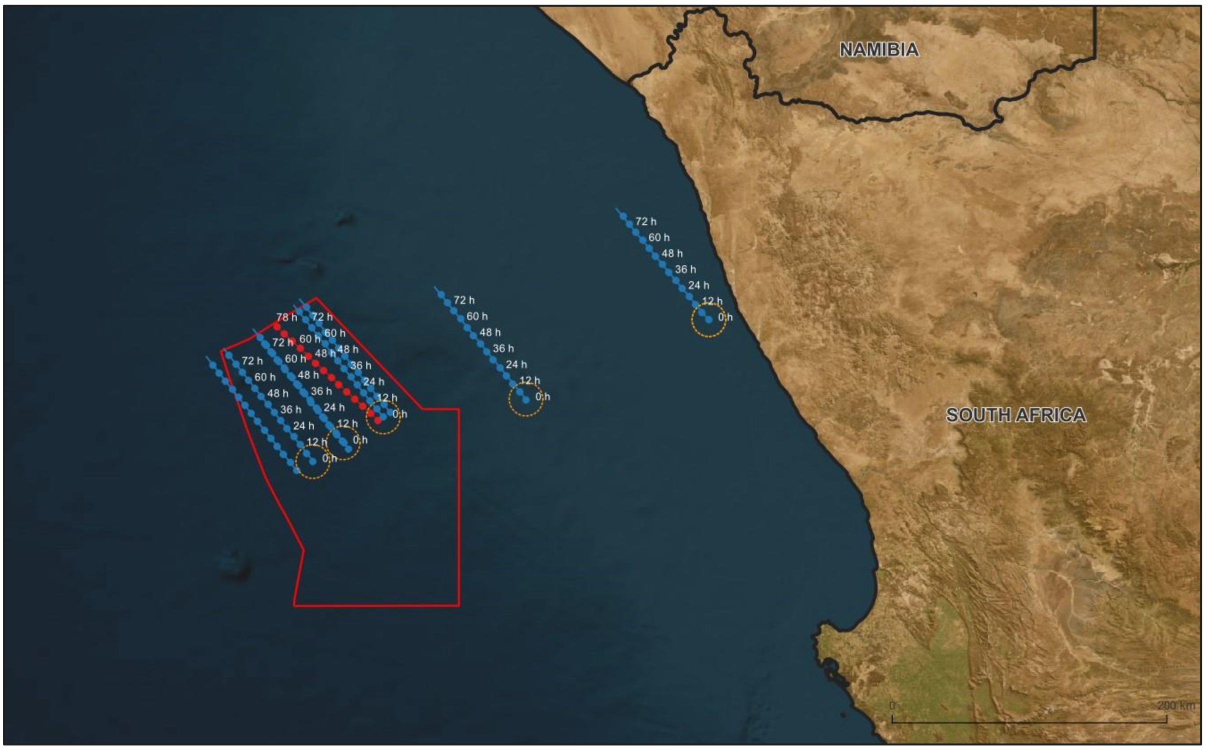
As part of the survey commitments, Searcher subcontracted Seiche Ltd (Seiche) to conduct an SSV involving the recording and analysis of underwater sound levels during seismic acquisition operations in key fisheries areas. These measurements included the offshore ringfenced and inshore snoek fishery areas, as well as Marine Mammal detection.

Drift buoys (equipped with hydrophones) were deployed during the survey route to conduct an underwater Sound Source Verification (SSV), in order to record and analyse sound levels (for comparison against background ambient levels in key fisheries areas) and to provide input and assist in Fisheries Research on how fish species on the West Coast such as snoek respond to seismic surveying and to record Marine Mammal presence within the area.

Acoustic data was collected using these drifting sound recorders in the following zones as indicated in **Figure 14**:

- ‘Drift A’ – offshore operational area, prior to the beginning of a seismic survey
- ‘Drift C’ – offshore ring-fenced fishery area close to the continental shelf edge
- ‘Drift D’– inshore area of the Snoek fishery, and
- ‘Drift SSV’ – SSV sound recording at the offshore operational area adjacent to the seismic source vessel.

Figure 14 Annotated aerial map indicating field survey data campaigns in January 2024 (indicative)



Data obtained was provided to SLR in May 2024. The data was reviewed to check assumptions around the modelled source depth, temperature profile and source emission strengths.

SLR conducted a detailed review of Seiche noise monitoring measurements and used the data to test the accuracy of the model predictions. A short-range model validation model was specifically developed for the array and water depths matching the SSV measurements. For further details of this model, refer to Section 3.0.

The updated array was modelled with a Pk SPL of 257 dB re 1 µPa, an RMS SPL of 243 dB re 1 µPa and an effective volume of 3 280 CUI and operating at 2 000 PSI. The water depth for the short-range hydrophone was modelled at 50 metres based on supplied logs.

The results for the updated model are presented in Section 6.1, and the predicted received levels are shown in Table 12. The individual scattered measurements conducted by Seiche were all reviewed and validated by SLR. Only measurements determined to be valid were included, and regression model estimates were used to validate the accuracy of the source levels and propagation coefficients.

These results are best displayed in the short-range plots of Figure 15 (SELs) and Figure 16 (Pk SPLs), containing the predicted levels, the measured noise levels by Seiche (already validated) and the extrapolated values with a regression model.

Figure 15 Predicted maximum SELs and extrapolated received SELs as a function of range (10 – 4 010 m)

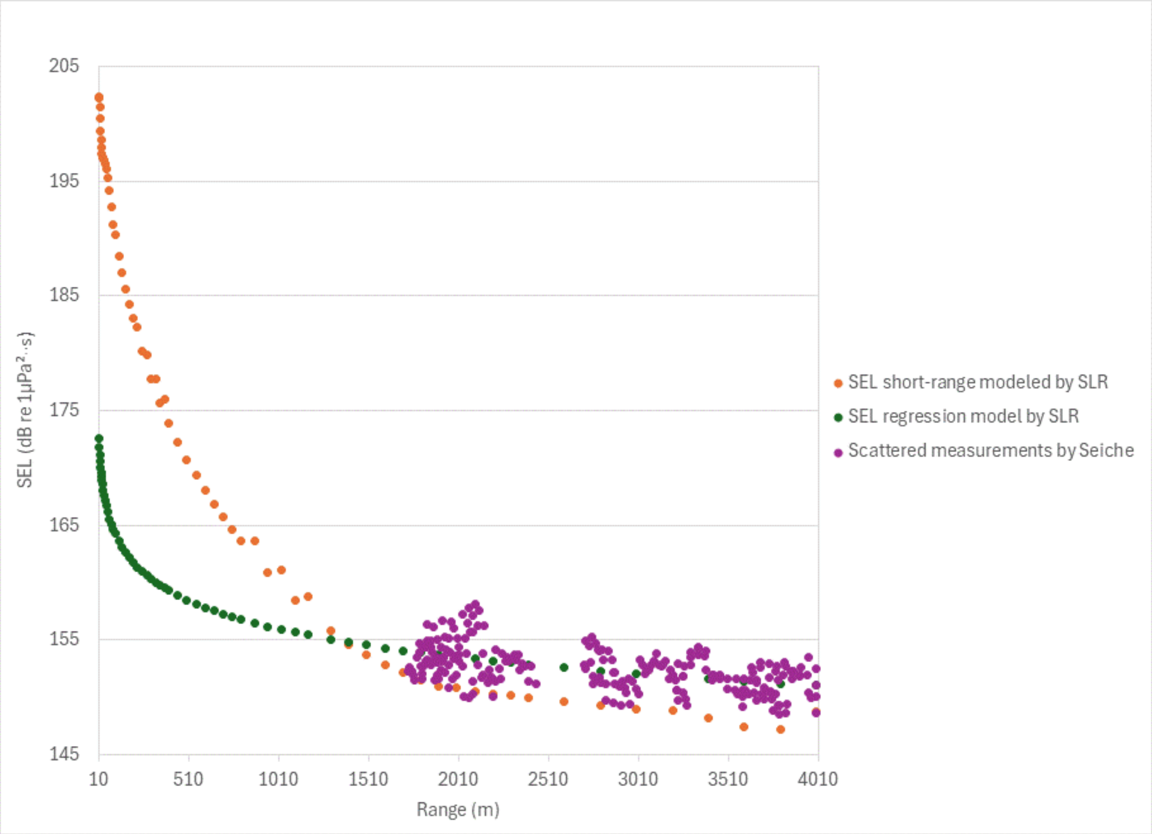
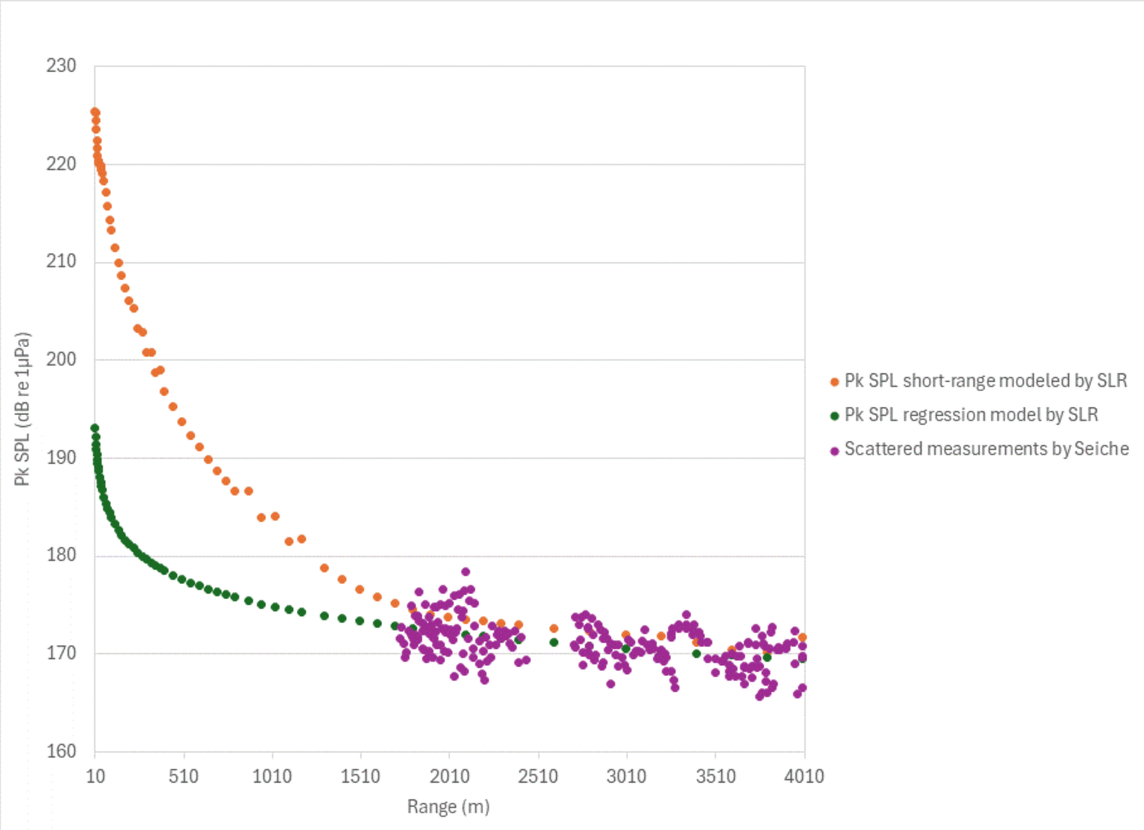


Figure 15 shows a difference of up to 3 dB in SEL values between modelled and the simplified regression models used to estimate received noise levels between 1710 and 4010 m. Differences in Pk SPL values were typically 1 dB (Figure 16). These differences are well within the typical range of prediction uncertainty and therefore are considered to be negligible.

The differences at closer ranges to the source (10 to 1500 m) are due in part that the applied short-range model is substantially more detailed and trained to a specific depth. Also, the variations in short-range acoustic results between modelling the 3 280 CUI array and the SSV analysis performed by Seiche pertain to differences in the data used to fit the regression curve.

Figure 16 Predicted maximum Pk SPLs and extrapolated received Pk SPLs as a function of range (10 – 4 010 m)



Variations between the modelled and actual results of the 3 280 CUI airgun array are attributed to differences in 3D directivity (not accounted for in the analysis of field data), variable water column conditions (e.g. sound speed profile) at the exact time of measurement. Locally bathymetric variations (e.g. deviation from a flat bottom in shallow) will also introduce additional variance between model and measurement.

SEL modelling predictions below measured values are primarily attributed to range independent model factors (e.g., water depth is assumed to be constant in all directions). In-situ acoustic energy released by seismic pulses propagates both into deeper and shallow waters (at differing transmission loss coefficients) from the source position.

These differences are within normal and expected ranges. Model accuracies are highly dependent upon knowing the precise position of the source and receiver. For a mobile source and a drifting receiver, the strong directionality in the seismic source signal, varying sound-to-noise ratios and changes related to local environmental variables of the region (such as sound speed profile and bathymetry) all add additional layers of complexity.

In summary, the short-range Scooter model is considered validated and fit for purpose, based on the data analysed and reviewed to date.

6.0 Modelling results

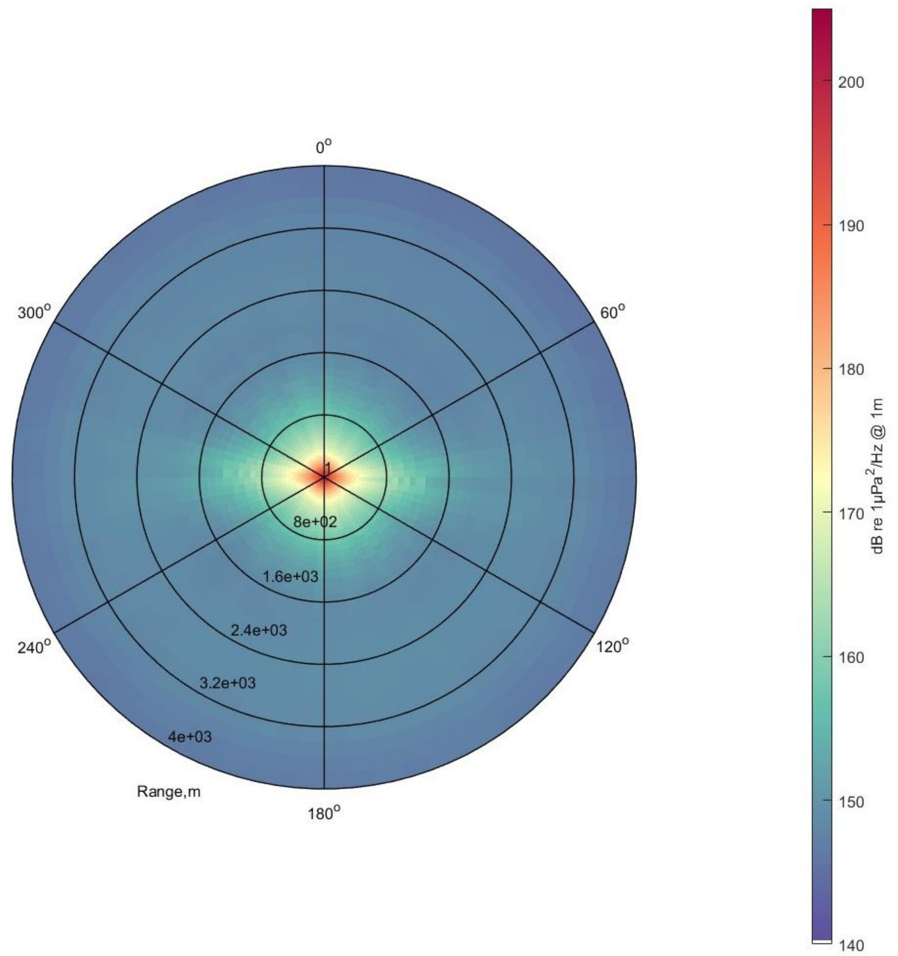
This section presents the modelling results for seismic surveys which include three modelling components (i.e., short range modelling, long range modelling and cumulative noise exposure modelling).

6.1 Short range modelling

The received SELs has been modelled for 2 500 m water depth case for the 3D survey area from the G-Gun II 3 820 in^3 source array and with a receiver placed at 50 m water depth.

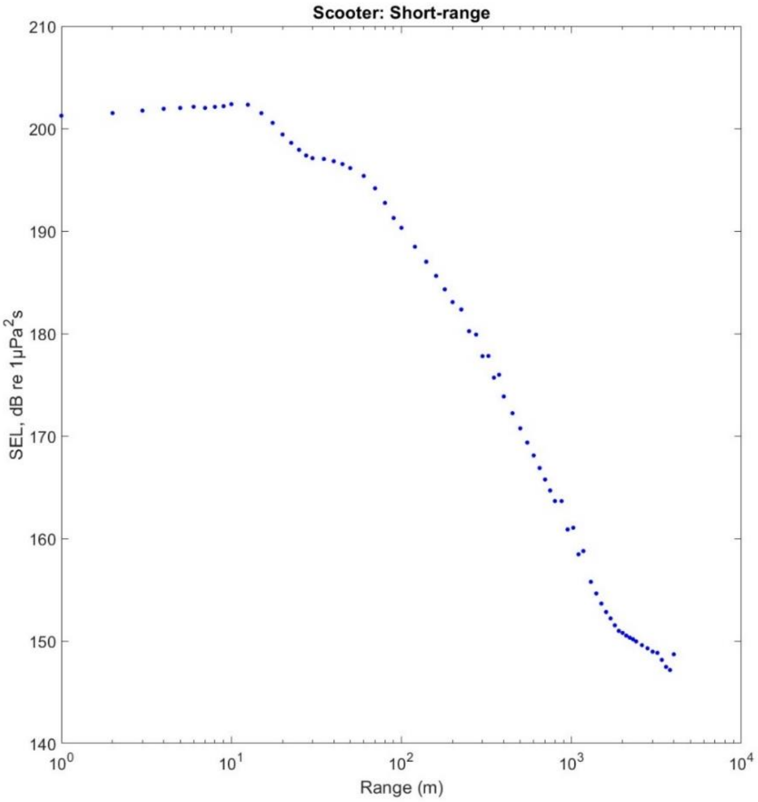
Figure 17 shows the maximum received SELs across the water column for a single survey shot as a function of azimuth (0 – 360º) and near-field horizontal range (0 – 4 km) from the centre of the array. The figure illustrates slightly higher SEL levels in the cross-line directions as a result of the directionality of the source array.

Figure 17 The predicted maximum SELs across the water column as a function of azimuth and horizontal range from the centre of the array. A degree of 0˚ azimuth corresponds to the in-line direction.



The scatter plot of the predicted maximum SELs across the water column (2 500 m depth) for all azimuths as a function of horizontal range (0 – 4 km) from the source array (3 280 CUI) at a receiver depth of 50 m is displayed in **Figure 18**.

Figure 18 The predicted maximum SELs across the water column (2 500 m depth) for all azimuths as a function of range (0 – 4 km) from the source locations for the 3D source array at a receiver depth of 50 m



6.2 Long range modelling

Figure 19 and **Figure 20** show the horizontal contour image of the predicted maximum SELs received at locations up to 200 km from source locations L1 and L2 respectively, overlaying the local bathymetry contours. **Figure 21** and show the vertical contour images of predicted SELs across the water column along the propagation paths to the west, east, north and south of the modelled location.

Both horizontal and vertical contour images for all other long range modelling locations are attached in **Appendix C**.

As can be seen from the horizontal and vertical contour figures, the received noise levels at far-field locations vary at different angles and distances from the source locations. This directivity of received levels is due to a combination of the directivity of the source array, and propagation effects caused by bathymetry and sound speed profile variations.

In general, the bathymetry profiles with significant upslope section across the continental slope region have the sound propagations experiencing significant attenuation due to the strong interaction between the sound signal and the seabed. The bathymetry profiles with downslope section have much less sound attenuation. These effects are evident for both locations for propagation paths towards shoreline directions.

For both source locations, the seabed depth variations are not significant along the propagation paths within the deep-water region. Therefore, the directivity of received noise is dominated by the directionality of the source array.

Figure 19 Modelled maximum SEL (maximum level across water column) contours for source location L1 to a maximum range of 200 km, overlayed with bathymetry contour lines. Coordinates in WGS 84/UTM Zone 33S.

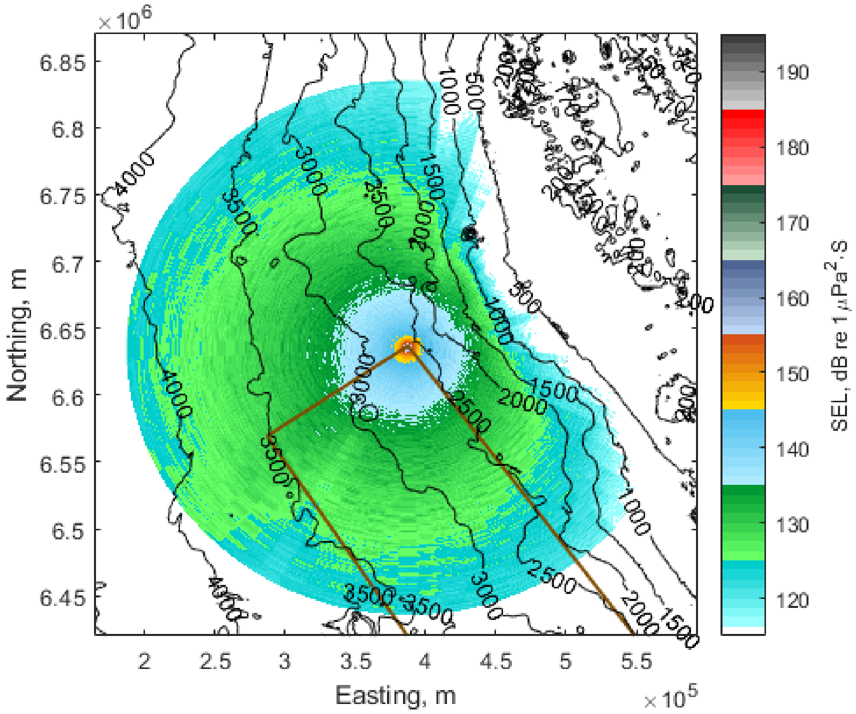


Figure 20 Modelled maximum SEL (maximum level across water column) contours for source location L2 to a maximum range of 200 km, overlayed with bathymetry contour lines. Coordinates in WGS 84/UTM Zone 33S.

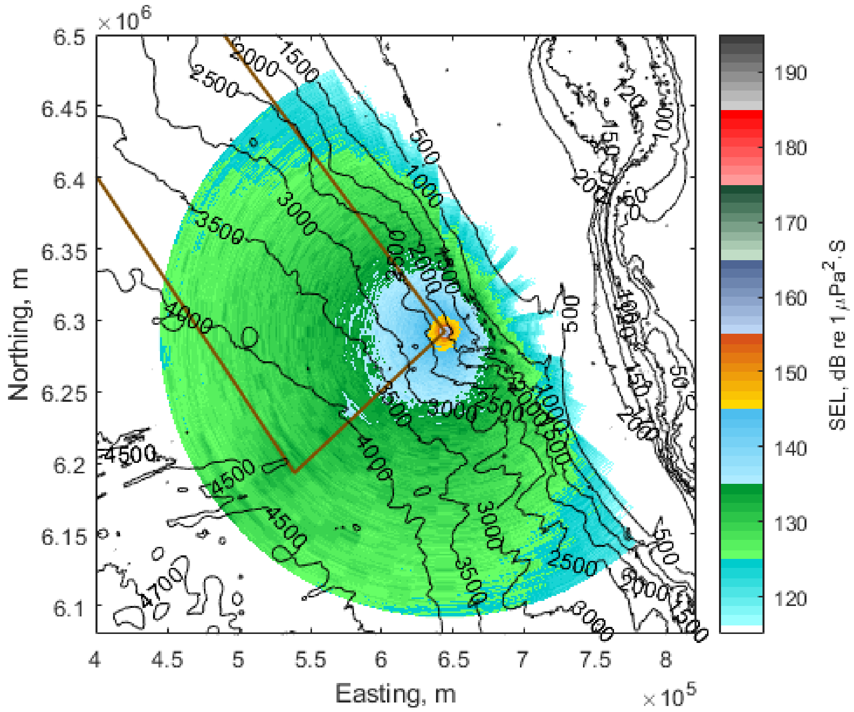


Figure 21 Modelled SELs vs range and depth along the propagation path towards a) west b) east c) north and d) south direction from the source location L1. Black line shows the seabed depth.

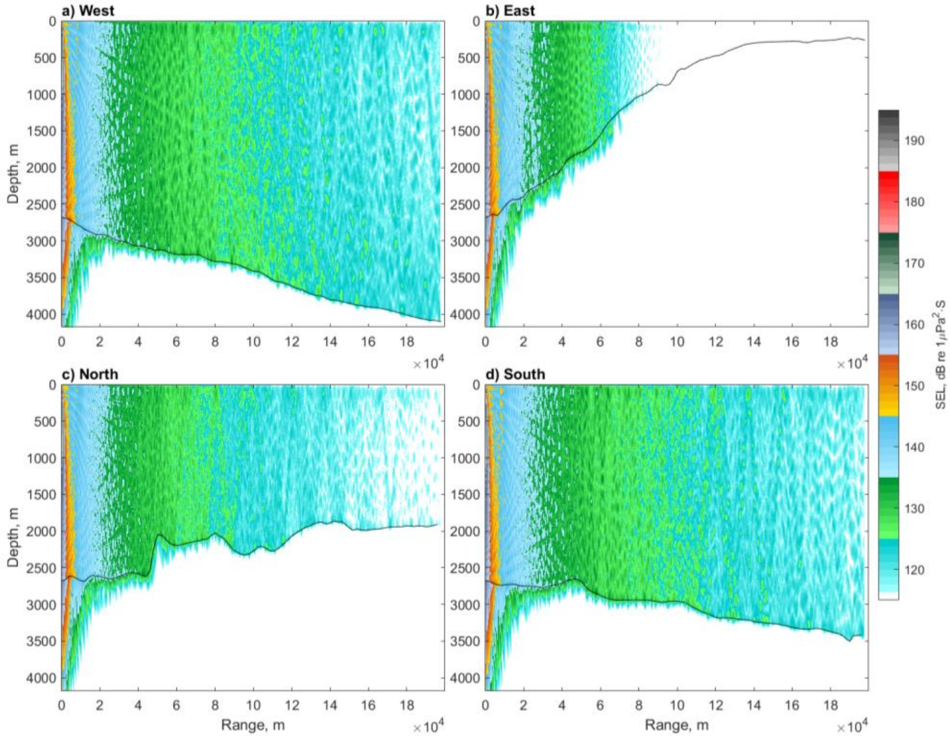
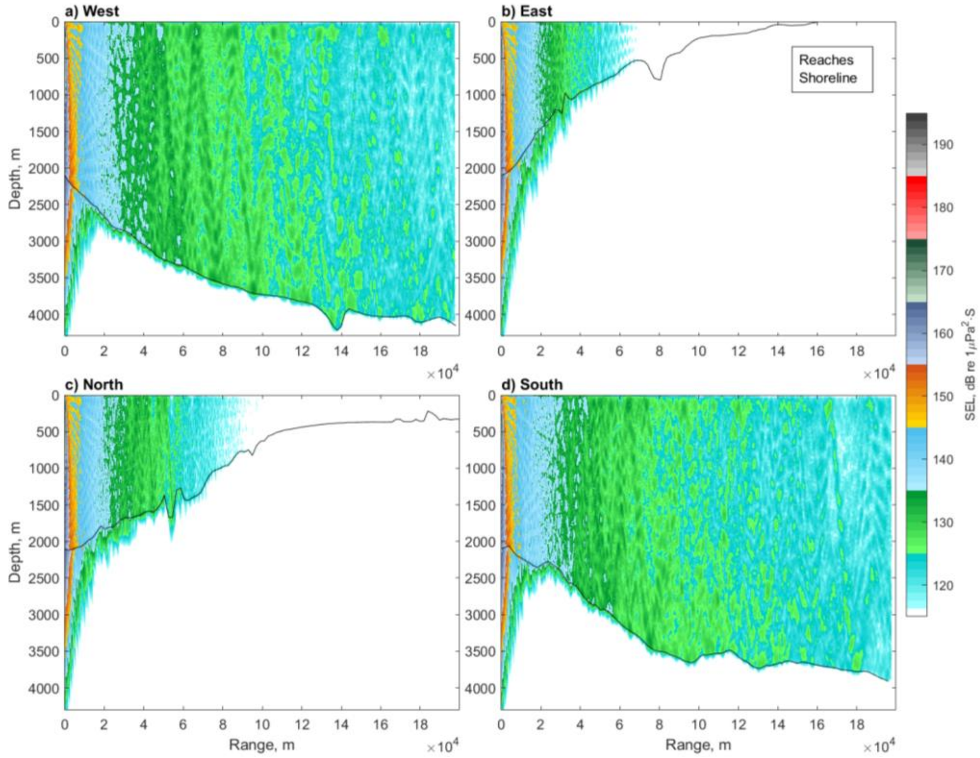


Figure 22 Modelled SELs vs range and depth along the propagation path towards a) west b) east c) north and d) south direction from the source location L2. Black line shows the seabed depth.



6.3 Cumulative SEL modelling

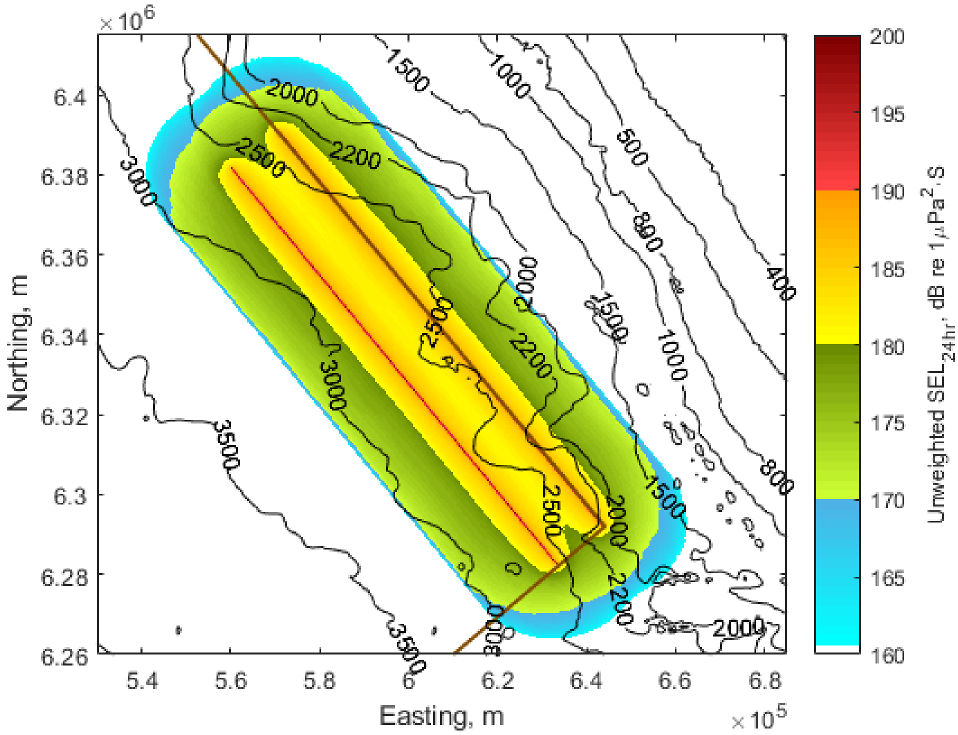
The sound exposure contributions from adjacent survey shots vary with the distances from the receiving locations to the survey line. From the short range modelling results as presented in **Section 6.1**, sound exposure level from a survey shot received at a receiving location with a distance of 1.0 km is predicted to be up to 15 dB lower than the level from a survey shot at a close distance of 30 m.

With the receiving location perpendicularly further away from the survey lines, the distance differences between the survey location and adjacent survey shots become smaller, and the sound exposure contributions from adjacent multiple shots along the survey lines become more significant proportionally compared with the survey shots closer to the survey lines. Based on this consideration, cumulative modelling is carried out for a modelling area within a 60-km zone around the survey lines and with a 100-m grid size, so that the modelling area is sufficiently large to include all potential zones of impact for assessed marine fauna species.

The cumulative SEL modelling has been carried out for the 24-hour survey operation scenarios as described in **Section 4.2.3.2**, based on the modelling methodology and procedure as laid out in **Section 4.2.3.1**, for unweighted SEL_{24} case and weighted SEL_{24} cases with frequency weighting functions of different marine mammal hearing groups applied.

The modelled unweighted SEL_{24hr} contour map for the survey scenario S1 for the 3D survey is presented in **Figure 23**.

Figure 23 The predicted maximum unweighted SEL_{24hr} across the water column for assessed survey scenario S1 for the 3D survey



6.4 Zones of impact

Based on the noise modelling prediction results presented above, the zones of impact (i.e. maximum horizontal threshold distance from array source location/survey lines) for marine fauna species of interest are summarized in the following sub sections.

6.4.1 Zones of impact – immediate exposure from single pulses

Table 12 below outlines the predicted maximum SELs and the estimated Pk SPLs and RMS SPL across the water column for all azimuths as a function of horizontal distance from the seismic airgun source array, for water depth range within the survey area, based on the short range SEL modelling results as in **Section 6.1** and relevant estimate approach as in **Section 4.2.4**.

Table 12 The maximum SELs, Pk SPLs and RMS SPL across the water column (2500 m depth) for all azimuths as a function of distance from the source array (3280 CUI) at a receiver depth of 50 m

Horizontal distance from the source array, m	The predicted maximum levels across the water column for all azimuths, for water depth range within the survey area		
	SEL, dB re 1 μPa^2·s	**Pk SPL, dB re 1μPa**	**RMS SPL, dB re 1μPa**
10	210	233	220
20	205	225	215
50	197	217	207
80	193	216	203
100	191	214	201
200	185	208	195
500	178	201	188
800	176	199	186
1 000	174	197	184
2 000	168	191	176
4 000	162	185	169

The zones of impact from seismic surveys based on per-pulse SEL, Pk SPL and RMS SPL metrics are estimated and presented in **Table 13** for PTS and TTS effects for marine mammals, **Table 14** for fish and sea turtles, and **Table 16** for behavioural disturbance for marine mammals and sea turtles.

6.4.1.1 Marine mammal physiological effects

Due to the high level of impulsive signal emissions from the array source, marine mammals are predicted to experience a permanent auditory threshold shift (PTS) at close proximity to the source arrays due to the immediate exposure to individual pulses. Based on zones of impact estimated Pk-SPL metric criteria as in **Table 13**, marine mammals of all hearing groups except very-high-frequency cetaceans are predicted to experience PTS effect within approximately 45 m from the 3D source array at all assessed water depth scenarios. The maximum zones of PTS effect for very-high-frequency cetaceans are predicted to be within 270 m from the 3D array source.

The zones of a temporary auditory threshold shift (TTS) due to a single pulse exposure for marine mammals of all hearing groups except very-high-frequency cetaceans are predicted to be within approximately 85 m from the source array. The maximum zones of TTS effect for very-high-frequency cetaceans are predicted to be within 500 m from the array source as presented in **Table 13**.

It should be noted that the zones of immediate impact assessed are for the airgun array source under the full-power operation condition (with an operating pressure of 2,000 psi). During the soft start process, the airgun array source is under reduced operating pressure conditions, and consequently has lower noise emissions.

As such, the zones of impact during the soft start process are predicted to be less than the full-power operation condition. As an example, under a reduced operating pressure of 1,000 psi, the noise emissions from the airgun array source are approximately 6 dB lower than from the full-power operation, and the resulted zones of impact are estimated to be approximately half of those zones assessed under the full-power operation condition.

Table 13 Zones of immediate impact from single seismic airgun array pulses for PTS and TTS – marine mammals

Marine mammal hearing group	Zones of impact – maximum horizontal distances from source to impact threshold levels			
	Injury (PTS) onset		TTS onset	
	Criteria– Pk SPL dB re 1µPa	Maximum threshold distance, m	Criteria– Pk SPL dB re 1µPa	Maximum threshold distance, m
Low-frequency cetaceans (LF)	219	40	213	80
High-frequency cetaceans (HF)	230	10	224	25
Very-high-frequency cetaceans (VHF)	202	270	196	500
Sirenians (SI)	226	20	220	40
Phocid carnivores in water (PCW)	218	45	212	85
Other marine carnivores in water (OCW)	232	< 10	226	20

6.4.1.2 Fish physiological effects

For seismic surveys, as presented in Table 14, the zones of potential injuries for fish species with a swim bladder, turtles and fish eggs and fish larvae are predicted to be within 160 m from the airgun array source.

Table 14 Zones of immediate impact from single airgun array pulses for mortality and recovery injury– fish, turtles, fish eggs and fish larvae

Type of animal	Zones of impact – maximum horizontal distances from source to impact threshold levels			
	Mortality and potential mortal injury		Recovery injury	
	Criteria– Pk SPL dB re 1μPa	Maximum threshold distance, m	Criteria– Pk SPL dB re 1μPa	Maximum threshold distance, m
Fish: no swim bladder (particle motion detection)	> 213	80	>213	80
Fish: swim bladder is not involved in hearing (particle motion detection)	>207	160	>207	160
Fish: swim bladder involved in hearing (primarily pressure detection)	>207	160	>207	160
Fish eggs and fish larvae	>207	160	-	-
Note: a dash indicates the threshold is not applicable.				

However, fish species without swim bladders have higher injury impact thresholds, and therefore have smaller zones of potential injuries within 80 m from the airgun array source.

6.4.1.3 Sea turtle physiological effects

The sea turtles are predicted to experience PTS effect in the close proximity to the source array due to the immediate exposure to individual pulses within approximately 15 m. The maximum zones of TTS due to a single pulse exposure for sea turtles are predicted to be within approximately 30 m from the array source as presented in **Table 15**.

Table 15 Zones of immediate impact from single seismic airgun array pulses for PTS and TTS – sea turtles

Type of animal	Zones of impact – maximum horizontal distances from source to impact threshold levels			
	Injury (PTS) onset		TTS onset	
	Criteria– Pk SPL dB re 1μPa	Maximum threshold distance, m	Criteria– Pk SPL dB re 1μPa	Maximum threshold distance, m
Sea turtles	232	15	226	30
Note: a dash indicates the threshold is not applicable.				

6.4.1.4 Marine mammal, fish and sea turtle behavioural responses

The zones of behavioural disturbance for marine mammals and turtles caused by the immediate exposure to individual seismic airgun array pulses for seismic surveys are presented in **Table 16** below.

The results show that behavioural disturbance caused by the immediate exposure to individual pulses are predicted to be within 4.0 km from the array source for marine mammals of all hearing groups, and within 1.14 km from the array source for sea turtles.

Based on the noise exposure criteria provided by Popper et al. (2014), relatively high to moderate behavioural risks are expected at near to intermediate distances (tens to hundreds of meters) from the source location. Relatively low behavioural risks are expected for fish species at far field distances (thousands of meters) from the source location.

Table 16 Zones of immediate impact from single seismic airgun array pulses for behavioural disturbance – marine mammals and sea turtles

Type of animal	Zones of impact – maximum horizontal distances from source to impact threshold levels	
	Behavioural disturbance	
	Criteria– RMS SPL, dB re 1µPa	Maximum threshold distance, m
Marine mammals	160	4,000
Sea turtles	175	1,140

6.4.2 Zones of impact – cumulative exposure from multiple pulses

As described in **Section 6.3**, for seismic surveys, the cumulative sound fields in unweighted SEL_{24hr} and weighted SEL_{24hr} with relevant frequency weighting functions applied are modelled based on an assumed survey scenario for the 3D survey.

The zones of cumulative impact for seismic surveys (i.e. the maximum horizontal perpendicular distances from assessed survey lines to cumulative impact threshold levels) are estimated based on the above modelling results. **Table 17** presents the cumulative PTS and TTS effects for marine mammals, and **Table 18** the cumulative mortality, injury and TTS effects for fish; and **Table 19** the cumulative PTS and TTS effects for sea turtles.

6.4.2.1 Cumulative impacts for marine mammals

For seismic surveys, among marine mammals of all six hearing groups, low-frequency cetaceans have the highest zones of PTS and TTS impact, as can be seen in **Table 17**. The zones of PTS impact are predicted to range up to 800 m from the source location, from the adjacent survey lines for the relevant typical 24-hour survey operation scenarios considered, and the maximum zone of TTS impact is predicted to be around 8.0 km from their relevant adjacent survey lines.

The cumulative PTS criteria SEL_{24hr} are predicted not to be exceeded for high-frequency cetaceans, sirenians and other marine carnivores in water, but the cumulative TTS criteria SEL_{24hr} to be slightly exceeded, with zones of impact within 10 m from the adjacent survey lines.

The cumulative PTS criteria SEL_{24hr} are predicted to be slightly exceeded for both very-high-frequency cetaceans and phocid carnivores in water, with zones of impact within 10 m from the adjacent survey lines. For very-high frequency cetaceans the zones of TTS impact are predicted to range around 2,500 m from the source location, and for phocid carnivores in water around 500 m from the source location, from the relevant adjacent survey lines for the 24-hour survey operation scenario considered.

It should be noted that the cumulative zones of impact presented above are conservative, and since cetaceans are highly mobile, they are likely to have moved considerable distances away from the source over the cumulative survey period. Thus, cumulative effects would only be expected where the animals do not move away from the area, e.g. from specific coastal areas used as calving sites of from feeding focal points such as Tripp Seamount. As Tripp Seamount is approximately 80 km to the northwest of the survey area, cumulative effects would not be expected.

Table 17 Zones of cumulative impact from multiple airgun array pulses of the 3D survey for PTS and TTS – marine mammals

Marine mammal hearing group	Zones of impact – maximum horizontal perpendicular distances from assessed survey lines to cumulative impact threshold levels			
	Injury (PTS) onset		TTS onset	
	Criteria – Weighted SEL_{24hr} dB re 1 $\mu Pa^2 \cdot s$	Maximum threshold distance, m	Criteria – Weighted SEL_{24hr} dB re 1 $\mu Pa^2 \cdot s$	Maximum threshold distance, m
Low-frequency cetaceans (LF)	183	800	168	8,000
High-frequency cetaceans (HF)	185	-	170	< 10
Very-high-frequency cetaceans (VHF)	155	80	140	2,500
Sirenians (SI)	203	-	175	< 10
Phocid carnivores in water (PCW)	185	10	170	500
Other marine carnivores in water (OCW)	203	-	188	< 10
Note: a dash indicates the threshold is not reached.				

6.4.2.2 Cumulative impacts for fish

As presented in Table 18, the zones of potential mortal injuries for fish species with and without a swim bladder, turtles and fish eggs and fish larvae are predicted to be within 60 m from the adjacent survey lines for all the 24-hour survey operation scenarios considered.

Table 18 Zones of cumulative impact from multiple airgun array pulses of 3D surveys for mortality and recovery injury– fish, turtles, fish eggs and fish larvae

Type of animal	Zones of impact – maximum horizontal perpendicular distances from assessed survey lines to cumulative impact threshold levels					
	Mortality and potential mortal injury		Recoverable injury		TTS	
	Criteria– SEL_{24hr} dB re 1 $\mu Pa^2 \cdot s$	Maximum threshold distance, m	Criteria– SEL_{24hr} dB re 1 $\mu Pa^2 \cdot s$	Maximum threshold distance, m	Criteria– SEL_{24hr} dB re 1 $\mu Pa^2 \cdot s$	Maximum threshold distance, m
Fish: no swim bladder (particle motion detection)	219	< 10	216	20	186	3,500
Fish: swim bladder is not involved in hearing (particle motion detection)	210	30	203	200	186	3,500
Fish: swim bladder involved in hearing (primarily pressure detection)	207	60	203	200	186	3,500
Fish eggs and fish larvae	210	30	-	-	-	-
Note: a dash indicates the threshold is not applicable.						

For recoverable injury, the zones of impact are predicted to be within 20 m from the adjacent survey lines for fish without a swim bladder, and within 200 m for fish with a swim bladder for all the operation scenarios considered. The zones of TTS effect for fish species with and without swim bladders are predicted to be within 3,500 m, from the adjacent survey lines for the 24-hour survey operation scenario considered.

Existing experimental data regarding recoverable injury and TTS impacts for sea turtles and fish eggs and larvae is sparse and no guideline recommendations have been provided. However, based on a subjective approach as indicated in **Table 3**, noise impacts related to recoverable injury and TTS on sea turtles are expected to be high at the near field from the source location while impacts are expected to be moderate for fish eggs and larvae. Impact is expected to be low for all of them at intermediate and far field from the source location.

6.4.2.3 Cumulative impacts for sea turtles

Noise impacts related to recoverable injury and TTS on sea turtles are expected to be high at the near field from the source location as shown in **Table 19**. The maximum zones of PTS impact are predicted to range within 10 m from the source location, from the adjacent survey line for the relevant typical 24-hour survey operation scenario considered. The maximum zones of TTS impact are predicted to be around 50 m.

Table 19 Zones of cumulative impact from multiple airgun array pulses of the survey for PTS and TTS – sea turtles

Type of animal	Zones of impact – maximum horizontal perpendicular distances from assessed survey lines to cumulative impact threshold levels			
	Injury (PTS) onset		TTS onset	
	Criteria – Weighted SEL_{24hr} dB re 1 µPa²·s	Maximum threshold distance, m	Criteria – Weighted SEL_{24hr} dB re 1 µPa²·s	Maximum threshold distance, m
Sea turtles	204	< 10	189	50

6.5 Discussion

As detailed in **Section 2.0**, dual metric criteria (i.e. per-pulse impact criteria Pk SPL and cumulative exposure impact criteria SEL_{24hr}) are applied to assess PTS and TTS impact for marine mammals, and mortality and recovery injury for fish and sea turtles. The combined threshold distance for each impact effect is considered as the maximum threshold distances (i.e. the worst-case scenario) estimated from either metric criteria being applied.

For marine mammals, the combined zones of impact from seismic surveys for all six hearing groups based on estimated results in **Table 13** and **Table 17** are presented in Table 20**Table 20.**

Table 20 Combined zones of impact from airgun array pulses for PTS and TTS – marine mammals

Marine mammal hearing group	Combined zones of impact – maximum horizontal distances to either Pk SPL or cumulative SEL threshold levels			
	Injury (PTS) onset		TTS onset	
	Criteria applied– Pk SPL, dB re 1 µPa / Weighted SEL_{24hr} dB re 1 µPa²·s	Maximum threshold distance, m	Criteria applied– Pk SPL, dB re 1 µPa / Weighted SEL_{24hr} dB re 1 µPa²·s	Maximum threshold distance, m
Low-frequency cetaceans (LF)	183 Weighted SEL_{24hr}	800	168 Weighted SEL_{24hr}	8,000
High-frequency cetaceans (HF)	230 Pk SPL	10	224 Pk SPL	25
Very-high-frequency cetaceans (VHF)	202 Pk SPL	270	140 Weighted SEL_{24hr}	2,500
Sirenians (SI)	226 Pk SPL	20	220 Pk SPL	40
Phocid carnivores in water (PCW)	218 Pk SPL	45	170 Weighted SEL_{24hr}	500
Other marine carnivores in water (OCW)	232 Pk SPL	< 10	226 Pk SPL	20

As can be seen from this table, the cumulative noise exposure results in extended zones of PTS and TTS impact for low-frequency cetaceans, and extended zones of TTS impact for very-high-frequency cetaceans and phocid carnivores in water.

The combined zones of mortal and recoverable injury impact from seismic surveys for fish species are the zones of impact estimated based on immediate impact criteria Pk SPL as in **Table 14**, and the zones of TTS impact from seismic surveys for fish species based on cumulative impact criteria SEL as in **Table 18**.

For marine seismic surveys, the cumulative exposure level at certain locations is modelled based on the assumption that the animals are constantly exposed to the survey airgun noise at a fixed location over the entire 24-hour period.

However, in reality marine fauna species, particularly marine mammals and fish species assessed in this study, would not stay in the same location for the entire period unless individuals are attached to a specific feeding or breeding area or those species that can’t move away, e.g. plankton and fish eggs/larvae.

Therefore, the zones of impact assessed for marine mammals and fish species represent the worst-case consideration.

6.6 Recommended management measures

This section includes recommended underwater noise mitigation measures from seismic survey activities related to zones of impact and implementation of soft-starts.

- Safety zones – these are observation and shut-down zones sized based on the likely noise levels produced by the seismic activity.
- Soft-starts – these procedures are recommended for all seismic activities, irrespective of location and time of year, when marine mammal species may potentially be present within the noise footprint of the seismic activity.

6.6.1 Safety zones

Recommended safety zones around the survey vessel and seismic array to allow adequate avoidance and escape routes based on the seismic activity to be performed:

- Immediate Exposure from Single Pulses – refer to maximum threshold distances in PTS for marine mammals and sea turtles (**Table 13** and **Table 15**), and potential mortal injury for fish (**Table 14**).
- Cumulative Exposure from Multiple Pulses–- refer to maximum threshold distances in PTS for marine mammals and sea turtles (**Table 17** and **Table 19**), and potential mortal injury for fish (**Table 18**).

6.6.2 Soft-starts

Implement a soft-start procedure if testing multiple seismic sources. The soft-start should be carried out over a time proportional to the number of seismic sources being tested and not exceed 20 minutes; source arrays should be tested in order of increasing volume.

- If testing the seismic source at full operational capacity, a 20-minute soft-start is required.
- If testing a single lowest power source, a soft-start is not required.

Delay soft-starts if shoaling large pelagic fish, turtles, or marine mammals are observed within the zone of impact.

- A soft-start should not begin until 30 minutes after cetaceans depart the zone of impact or 30 minutes after they are last seen or acoustically detected in the zone of impact.
- Schedule soft-starts to minimise, as far as possible, the interval between reaching full power operation and commencing a survey line. The period between the end of the soft start and commencing with a survey line must not exceed 20 minutes.

6.6.3 Cumulative impacts from multiple simultaneous survey campaigns

In the unlikely event that multiple surveys would take place at the same time within the same survey area (**Figure 1**), the risk of cumulative noise impact must be considered and is suggested to be managed as follows:

- The maximum number of simultaneous surveys in the entire survey area would be limited to three;
- During airgun releases, each survey vessel is at least 40 kilometres from any other survey vessel until sufficient objective evidence is obtained to demonstrate that a reduced buffer distance is acceptable; and

Note: This 40km buffer maintained by any other survey vessels aligns to advice by authorities[5] and is considered sufficient on the basis that it provides a corridor between vessels where airgun noise approaches ambient levels such that animals may pass between, and/or the potential cumulative effect beyond this distance is considered to be negligible. Further modelling is only considered required in the case where a 40 km buffer distance between active survey ships cannot be maintained.

- Additional activities to that described in this report (such as increased shot frequency or additional survey vessels simultaneously firing guns within 40km of each other) would be modelled or otherwise considered in terms of the cumulative noise levels and with reference to the criteria described in this report.

7.0 Summary

Searcher Seismic Pty Ltd (Searcher Seismic) is proposing to undertake a 3D seismic survey within the Orange Basin off the West Coast of South Africa. There are a few Ecologically or Biologically Significant Marine Areas (EBSAs) and Marine Protected Areas (MPAs) near the proposed survey areas, particularly the Child Bank and Shelf Edge, as well as Cape Canyon and Associated Islands, Bays and Lagoon.

SLR Consulting Australia Pty Ltd (SLR) has been engaged by Searcher Seismic to undertake a detailed underwater acoustics modelling study for the proposed activities, in order to assist with the assessment of potential noise impact on marine fauna species of interest, particularly for these major marine sensitive areas of concerns.

The noise modelling results have been used to identify zones of impact for marine mammals and other species of concern based on relevant noise impact assessment criteria. Zones of impact have been evaluated for physiological effects and behavioural disturbance, due to the immediate impact from single airgun pulses, as well as the cumulative effects of exposure to multiple airgun pulses over a period of 24 hours.

The identified relevant zones of impact for marine mammals and fish and sea turtle species are summarised as follows:

Marine mammals

Impact from immediate exposure to individual airgun array pulses

Due to the high level of impulsive signal emissions from the array source, marine mammals are predicted to experience a permanent auditory threshold shift (PTS) at close proximity to the source arrays due to the immediate exposure to individual pulses. Marine mammals of all hearing groups except very-high-frequency cetaceans are predicted to experience PTS effect within approximately 45 m from the 3D source array at all assessed water depth scenarios. The maximum zones of PTS effect for very-high-frequency cetaceans are predicted to be within 270 m from the source array.

The zones of a temporary auditory threshold shift (TTS) due to a single pulse exposure for marine mammals of all hearing groups except very-high-frequency cetaceans are predicted to

[5] U.S. Department of the Interior Bureau of Ocean Energy Management 2014, Proposed Geological and Geophysical Activities, Mid-Atlantic and South Planning Areas, Final Programmatic Environmental Impact Statement, Gulf of Mexico OCS Region. New Orleans, https://www.loc.gov/item/2014450290/ *Volume 1, Section 2.2.2.3; p2-37.*

be within approximately 85 m from the source array. The maximum zones of TTS effect for very-high-frequency cetaceans are predicted to be within 500 m from the array source.

Behavioural disturbance caused by the immediate exposure to individual pulses are predicted to be within 4.0 km from the array source for marine mammals of all hearing groups.

Impact from cumulative exposure to multiple airgun array pulses

The zones of cumulative impact (i.e. the maximum horizontal perpendicular distances from assessed survey lines to cumulative impact threshold levels) are estimated based on the modelling results and relevant assessment criteria. Among marine mammals of all six hearing groups, low-frequency cetaceans have the highest zones of PTS and TTS impact.

The zones of PTS impact are predicted to range up to 800 m for the 3D survey, from the adjacent survey lines for the relevant typical 24-hour survey operation scenarios considered, and the maximum zone of TTS impact is predicted to be around 8.0 km from the adjacent survey lines. Much lower zones of cumulative PTS and TTS impact are predicted for marine mammals of other hearing groups.

Fish

Impact from immediate exposure to individual airgun array pulses

The zones of potential injuries for fish species with a swim bladder, turtles and fish eggs and fish larvae are predicted to be within 160 m from the array source. However, fish species without swim bladders have higher injury impact thresholds, and therefore have smaller zones of potential injuries within 80 m from the airgun array source.

Impact from cumulative exposure to multiple airgun array pulses

The zones of potential mortal injuries for fish species with and without a swim bladder, fish eggs, and fish larvae are predicted to be within 60 m from the adjacent survey lines for all the 24-hour survey operation scenarios considered. For recoverable injury, the zones of impact are predicted to be within 20 m from the adjacent survey lines for fish without a swim bladder, and within 200 m for fish with a swim bladder for all the operation scenarios considered. The zones of TTS effect for fish species with and without swim bladders are predicted to be within 3 500 m from the adjacent survey lines for the relevant 24-hour survey operation scenarios considered.

Existing experimental data regarding recoverable injury and TTS impacts for fish eggs and larvae is sparse and no guideline recommendations have been provided. However, based on a subjective approach, noise impacts are expected to be moderate for fish eggs and larvae. Impact is expected to be low for all of them at intermediate and far field from the source location.

Sea Turtles

Impact from immediate exposure to individual airgun array pulses

The maximum zones of PTS effect for sea turtles are predicted to be within 15 m from the source location. On the other hand, the maximum zones of TTS effect for sea turtles are predicted to be within 30 m of the source array.

The behavioural disturbance for sea turtles caused by the immediate exposure to individual pulses are predicted to be within 1.14 km of the source array.

Impact from cumulative exposure to multiple airgun array pulses

Noise impacts related to recoverable injury and TTS on sea turtles are expected to be high at the near field from the source location. The maximum zones of PTS impact are predicted to range within 10 m of the source array. The maximum zones of TTS effect for sea turtles are predicted to be within 50 m of the source array.

Mitigation measures

Relevant mitigation measures are recommended to minimise the seismic impact on assessed marine fauna species. Recommended safety zones are based on the maximum threshold distances modelled for PTS (marine mammals and sea turtles) and potential mortal injury (fish) due to immediate exposure from single pulses and cumulative exposure from multiple pulses.

Implement a soft-start procedure if testing multiple seismic sources. Delay soft-starts if shoaling large pelagic fish, turtles, seals, or cetaceans are observed within the zone of impact.

In the unlikely event that multiple surveys would take place at the same time within the same survey area, the risk of cumulative noise impact must be considered and managed to achieve the same targets. Further modelling is only considered required if a 40 km buffer distance between survey ships cannot be maintained.

Model validation

SLR conducted a detailed review of Seiche noise monitoring measurements and SSV and reviewed the noise monitoring data to validate the model predictions (Section 5.0).

The model is fit for the purpose based on the data analysed and reviewed. It remains slightly above (1 dB) for the peak noise levels measured and remains below (-3 dB) for the noise exposure levels (SEL) recorded at ranges between 2 and 4 km from the source.

8.0 References

Ainslie, M. A., Laws, R. M., and Sertlek, H. O. 2016, International Airgun Modelling Workshop: Validation of source signature and sound propagation models. *J. Ocean. Eng*, 16 July 2016, IEEE Dublin (Ireland).

Antonov, J. I., Seidov, D., Boyer, T. P., Locarnini, R. A., Mishonov, A. V., Garcia, H. E., Baranova, O. K., Zweng, M. M., and Johnson, D. R. 2010, *World Ocean Atlas 2009, Volume 2: Salinity*. S. Levitus, Ed. NOAA Atlas NESDIS 69, U.S. Government Printing Office, Washington, D.C., 184 pp.

Austin, M., McCrodan, A., Wladichuk, J. 2013, Marine mammal monitoring and mitigation during Shell's activities in the Chukchi Sea, July–September 2013: Draft 90-Day Report. (Chapter 3) *In* Reider, H. J., L. N. Bisson, M. Austin, A. McCrodan, J. Wladichuk, C. M. Reiser, K.B. Matthews, J.R. Brandon, K. Leonard, *et al.*, (eds.). *Underwater Sound Measurements*. LGL Report P1272D–2. Report from LGL Alaska Research Associates Inc., Anchorage, AK, USA, and JASCO Applied Sciences, Victoria, BC, Canada, for Shell Gulf of Mexico, Houston, TX.

Campher, C. J., di Primio, R., Kuhlmann, G., van der Spuy, D. and Domoney, R. 2009, Geological Modelling of the Offshore Orange Basin, West Coast of South Africa (2nd Edition), *AAPG International Conference and Exhibition*, Rio de Janeiro, Brazil, November 15-18, 2009.

Childerhouse, S. & Douglas, L. 2016, Information Document: Review of multibeam echosounder surveys and potential impacts on marine mammals, Document Reference Number: BPM-16-MDC-Review of multibeam echosounder surveys and marine mammals v1.2.Collins, M. D., 1993, A split-step Padé solution for the parabolic equation method, *J. Acoust. Soc. Am.*, 93: 1736-1742.

Collins, M.D. 1993, A split-step Padé solution for the parabolic equation method, *J. Acoust. Soc. Am.,* 93: 1736-1742.

Del Grosso, V. A. 1974, New equation for the speed of sound in natural waters (with comparisons to other equations), *J. Acoust. Soc. Am.* 56: 1084-1091.

Dingle, R.V., Birch, G. F., Bremner, J. M., De Decker, R. H., Plessis, A. D., Engelbrecht, J. C, Fincham, M. J., Fitton, T., Flemming, B. W., Gentle, R. I., Goodlad, S. W., Martin, A. K., Mills, E. G, Moir, G. J., Parker, R. J., Robson, S. H., Rogers, J., Salmon, D. A., Siesser, W. G., Simpson, E. S. W., Summerhayes, C. P., Westall, F., Winter, A. and Woodborne, M. W. 1987, Deep sea sedimentary environments around southern Africa (South-East Atlantic and South- West Indian Oceans), Annals of the South African Museum, 98. 1-27. DOC (Ed), 2016, *Report of the Sound Propagation and Cumulative Exposure Models Technical Working Group*, Marine Species and Threats, Department of Conservation, Wellington, New Zealand, 59p.

Dragoset, W. H. 1984, A comprehensive method for evaluating the design of airguns and airgun arrays, *16th Annual Proc. Offshore Tech. Conf.* 3: 75-84.

Dutkiewicz, A., Müller, R. D., O'Callaghan, S. and Jónasson H. 2015, Census of seafloor sediments in the world's ocean, *GEOLOGY*, September 2015; v. 43; no. 9; p. 795–798, doi:10.1130/G36883.1.

Ellison, W.T., Southall, B.L., Clark, C.W. and Frankel, A.S. 2012, A new context-based approach to assess marine mammal behavioral responses to anthropogenic sounds. *Conservation Biology*, 26(1), pp.21-28.

Erbe, C. 2008, Critical ratios of beluga whales (Delphinapterus leucas) and masked signal duration, *J. Acoust. Soc. Am.* 124(4), 2216-2223.

Erbe, C., Reichmuth, C., Cunningham, K., Lucke, K. and Dooling, R. 2016, Communication masking in marine mammals: A review and research strategy. *Marine Pollution Bulletin*, 103(1-2), pp.15-38.

Erbe, C., Dunlop, R. and Dolman, S. 2018, Effects of noise on marine mammals. *In Effects of anthropogenic noise on animals* (pp. 277-309). Springer, New York, NY.

Finneran, J. J. 2015, Auditory weighting functions and TTS/PTS exposure functions for cetaceans and marine carnivores, San Diego: SSC Pacific.

Finneran, J. J. 2016, Auditory weighting functions and TTS/PTS exposure functions for marine mammals exposure to underwater noise, Technical Report, 49 pp.

Finneran, J.J., Henderson, E.E., Houser, D.S., Jenkins, K., Kotecki, S. and Mulsow, J. 2017, Criteria and thresholds for U.S. Navy acoustic and explosive effects analysis (Phase III). Technical report by Space and Naval Warfare Systems Center Pacific (SSC Pacific). 183 pp.

Galindo-Romero, M., Lippert, T. and Gavrilov, A. 2015, Empirical prediction of peak pressure levels in anthropogenic impulsive noise. Part I: Airgun arrays signals. *J. Acoust. Soc. Am.* 138 (6), December: EL540-544.

GEBCO Compilation Group (2020) GEBCO 2020 Grid (doi:10.5285/836f016a-33be-6ddc-e053-6c86abc0788e).

Groton, C.T. 1998. Non-hearing physiological effects of sound in the marine environment. *Workshop on the effects of anthropogenic noise in the marine environment*, 10-12 February 1998 (p. 58).

Gundalf Designer, Cloud vC8.2k, 05 March 2021, Oakwood Computing Associates Limited. (https://www.gundalf.com/).

Hamilton, E. L. 1980, Geoacoustic modelling of the sea floor, *J. Acoust. Soc. Am.* 68: 1313:1340.

Hastings, M. C. and Popper, A. N. 2005, Effects of sound on fish, Sub consultants to Jones & Stokes Under California Department of Transportation Contract No. 43A0139 Report, 82 pp.

Jensen, F. B., Kuperman, W. A., Porter, M. B. and Schmidt, H. 2011, Computational Ocean Acoustics, Springer-Verlag New York.

Landrø, M., Amundsen, L., and Barker, D. 2011, High-frequency signals from air-gun arrays, *Geophysics*, vol. 76, pp. Q19–Q27.

Laws, R. M., Parkes, G. E., and Hatton, L. 1988, Energy-interaction: The long-range interaction of seismic sources, *Geophysical Prospecting*, 36: 333-348.

Laws, M., Hatton, L. and Haartsen, M. 1990, Computer Modelling of Clustered Airguns, *First Break*, 8(9): 331-338.

Li, B., Pine, M. and Childerhouse, S. 2021, Sound modelling and field validation for Māui 4D Seismic Survey in the Taranaki Basin offshore New Zealand, *Acoustics 2021* (draft).

Locarnini, R. A., Mishonov, A. V., Antonov, J. I., Boyer, T. P., Garcia, H. E., Baranova, O. K., Zweng, M. M., and Johnson, D. R. 2010, World Ocean Atlas 2009, Volume 1: Temperature. S. Levitus, Ed. NOAA Atlas NESDIS 68, U.S. Government Printing Office, Washington, D.C., 184 pp.

Matthews, M. N. and Macgillivray, A. O. 2013, Comparing modeled and measured sound levels from a seismic survey in the Canadian Beaufort Sea, *Proceedings of meetings on Acoustics,* Acoustical Society of America, 2 – 7 June 2013, Montreal, Canada.

McCauley R. D., Fewtrell J., Duncan A. J., Jenner, C., Jenner M. N., Penros J. D., Prince R. I. T., Adhitya A., Murdoch J. and McCabe K. 2000. Marine Seismic Surveys: Analysis and Propagation of Air Gun Signals, and Effects of Exposure on Humpback Whales, Sea Turtles, Fishes and Squid. *Prepared for the APPEA*. CMST, Curtin University.

McCauley, R. D., Duncan, A. J., Gavrilov, A. N. and Cato, D. H. 2016, Transmission of marine seismic survey, air gun array signals in Australian waters. *Proceedings of ACOUSTICS 2016*, 9-11 November 2016, Brisbane, Australia.

National Marine Fisheries Services (NMFS) 2016, Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustics Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Administration, U.S. Department of Commerce, NOAA. NOAA Technical Memorandum NMFS-OPR-55. 178 pp.

National Marine Fisheries Service (NMFS) 2018, 2018 Revisions to: Technical guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum, NMFS-OPR-59.

National Marine Fisheries Services (NMFS) 2013, Marine mammals: Interim Sound Threshold Guidance (webpage), National Marine Fisheries Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

National Research Council of the U.S. National Academies (NRC) 2003, Ocean Noise and Marine Mammals (National Academy Press, Washington, District of Columbia), 192 pp.

National Science Foundation (NSF) (U.S.), U.S. Geological Survey, and National Oceanic and Atmospheric Administration (NOAA) (U.S.) 2011, *Final Programmatic Environmental Impact Statement/Overseas, Environmental Impact* Statement *for Marine Seismic Research Funded by the National Science Foundation or Conducted by the U.S. Geological Survey*, National Science Foundation, Arlington, VA.

Nedelec, S.L., Campbell, J., Radford, A.N., Simpson, S.D., Merchant, N.D. 2016, Particle motion: the missing link in underwater acoustic ecology, *Methods Ecol. Evol*., 7, pp. 836-842

Parkes, G. E., Ziolkowski, A. M., Hatton L. and Haugland T. 1984, The signature of an airgun array: computation from near-field measurements – practical considerations, *Geophysics*, 49: 105-111.

Paton, D., di Primio, R., Kuhlmann, G. and Van der Spuy, D. 2007, Insights into the Petroleum System Evolution of the southern Orange Basin, South Africa, *South African Journal Of Geology*, 2007, Vol 110 p261-274, doi:10.2113/gssajg.110.2-3.261.

Popper A. N., Hawkins A. D., Fay R. R., Mann D. A., Bartol S., Carlson T. J., Coombs S., Ellison W. T., Gentry R. L., Halworsen M. B., Lokkeborg S., Rogers P. H., Southall B. L., Zeddies D. G. and Tavolga W. N. 2014, ASA S3/SC1.4 TR-2014 Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI.

Popper, A.N. and Hawkins, A.D. 2018. The importance of particle motion to fishes and invertebrates. *J. Acoust. Soc. Am.*, 143(1), pp.470-488

Popper, A.N. and Hawkins, A.D. 2019. An overview of fish bioacoustics and the impacts of anthropogenic sounds on fishes. *Journal of fish biology*, 94(5), pp.692-713.

Popper, A.N., Hawkins, A.D., Sand, O. and Sisneros, J.A. 2019. Examining the hearing abilities of fishes. *J. Acoust. Soc. Am.*, 146(2), pp.948-955

Porter, M. B. 2020, Acoustics Toolbox in Ocean Acoustics Library (http://oalib.hlsresearch.com/).

Porter, M. B. 2019, The BELLHOP Manual and User's Guide: PRELIMINARY DRAFT, Heat, Light, and Sound Research, Inc. La Jolla, CA, USA.

Porter, M. B. and Bucker, H. P. 1987, Gaussian beam tracing for computing ocean acoustic fields, *J. Acoust. Soc. Am.*. 82, 1349—1359.

Richardson W. J., Charles R. G. J., Charles I. M. and Denis H. T. 1998, Marine mammals and noise: Academic press.

Sanders, P. M. and Fofonoff, N. P. 1976, Conversion of pressure to depth in the ocean, *Deep-Sea Res*. 23: 109-111.

Simon, C., Matthew, P. and David, P. 2018, Results of deployment of acoustic monitoring equipment for Taranaki Ltd for 2018 Māui 4D Seismic Survey, Report No. PM-18-Shell-Report 3 Results of acoustic equipment deployment 2018 Māui 4D MSS-v1.1.

Sink, K. J., Harris, L. R., Skowno, A. L., Livingstone, T., Franken, M., Porter, S., Atkinson, L. J., Bernard, A., Cawthra, H., Currie, J., Dayaram, A., de Wet, W., Dunga, L. V., Filander, Z., Green, A., Herbert, D., Karenyi, N., Palmer, R., Pfaff, M., Makwela, M., Mackay, F., van Niekerk, L., van Zyl, W., Bessinger, M., Holness, S., Kirkman, S. P., Lamberth, S., Lück-Vogel, M. 2019, Chapter 3: Marine Ecosystem Classification and Mapping. In: Sink KJ, van der Bank MG, Majiedt PA, Harris LR, Atkinson LJ, Kirkman SP, Karenyi N (eds), 2019, South African National Biodiversity Assessment 2018 Technical Report Volume 4: Marine Realm. South African National Biodiversity Institute, Pretoria. South Africa. http://hdl.handle.net/20.500.12143/6372.

Southall, B., Bowles, A., Ellison, W., Finneran, J., Gentry, R., Greene, C. Jr., Kastak, D., Ketten, D., Miller, J., Nachtigall, P., Richardson, W., Thomas, J., Tyack, P. 2007, Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. *Aquatic Mammals*, 33(4), 411-521.

Southall B. L., Finneran J. J., Reichmuth C., Nachtigall P. E., Ketten D. R., Bowles A. E., Ellison W. T., Nowacek D. P., Tyack P. L. 2019, Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects. *Aquatic Mammals* 2019, 45(2), 125-232, DOI 10.1578/AM.45.2.2019.125.

Vaage, S., Strandness, S. and Utheim, T. 1984, Signatures from single airguns, *Geophysical Prospecting*, 31: 87-97.

Whitlow, W. L. A. and Hastings, M. C. 2008, *Principles of Marine Bioacoustics*, Springer.

Ziolkowski, A. M., Parkes, G. E., Hatton, L. and Haugland, T. 1982, The signature of an airgun array: computation from near-field measurements including interactions, *Geophysics*, 47: 1413-1421.

Ziolkowski, A. M. 1970, A method for calculating the output pressure waveform from an airgun, *Geophys.J.R.Astr.Soc.*, 21: 137-161.

.

Appendix A Key terms

ORANGE BASIN MC3D MSS

3D Seismic Survey Underwater Acoustics Modelling Project ZA24-010_Orange Basin MC3D MSS

Searcher Seismic

SLR Project No.: 675.30056.00102

25 June 2024

ANSI	American National Standards Institute
EBSA	Ecologically or Biologically Significant Marine Area
EEZ	Exclusive Economic Zone
HF	High-frequency cetaceans (HF)
LF	Low-frequency cetaceans (LF)
MPA	Marine Protected Areas
NOAA	U.S. National Oceanic and Atmospheric Administration
OCW	Other marine carnivores in water (OCW)
Peak Sound Pressure Level (Pk SPL, Peak SPL)	The peak sound pressure level is the logarithmic ratio of the peak pressure over the impulsive signal event to the reference pressure
Peak-to-Peak Sound Pressure Level (Peak-Peak SPL)	The peak-to-peak sound pressure level is the logarithmic ratio of the difference between the maximum and minimum pressure over the impulsive signal event to the reference pressure
PCW	Phocid carnivores in water
PE	Parabolic equation
PTS	Permanent auditory threshold shift
Power Spectral Density (PSD)	PSD describes how the power of a signal is distributed with frequency
RMS	Root mean square
Root-Mean-Square Sound Pressure Level (RMS SPL)	The mean-square sound pressure is the average of the squared pressure over the pulse duration. The root-mean-square sound pressure level is the logarithmic ratio of the root of the mean-square pressure to the reference pressure. Pulse duration is taken as the duration between the 5% and the 95% points on the cumulative energy curve
SI	Sirenians (SI)
Sound Exposure Level (SEL)	SEL is a measure of energy, defined as the dB level of the time integral of the squared instantaneous sound pressure, normalised to one second.
Sound Exposure Level (SEL_{24hr})	The SEL representing a 24 hour continuous period.
SEL_{cum}	The SEL representing an entire period of time (overall cumulative result)
Sound Pressure	A deviation from the ambient hydrostatic pressure caused by a sound wave
Sound Pressure Level (SPL)	The logarithmic ratio of sound pressure to the reference pressure. The reference pressure underwater is P_{ref} = 1 µPa
Sound Speed Profile	A graph of the speed of sound in the water column as a function of depth
Source Level (SL)	The acoustic source level is the level referenced to a distance of 1m from a point source
1/3 Octave Band Levels	The energy of a sound split into a series of adjacent frequency bands, each being 1/3 of an octave wide
UTM	Universal Transverse Mercator
VHF	Very-high-frequency cetaceans (VHF)
WGS	World Geodetic System

Appendix B Marine mammal and sea turtle auditory weighting functions

ORANGE BASIN MC3D MSS

3D Seismic Survey Underwater Acoustics Modelling Project ZA24-010_Orange Basin MC3D MSS

Searcher Seismic

SLR Project No.: 675.30056.00102

25 June 2024

The following appendix provides the recommended frequency-weighting functions for use in assessing the effects of relatively intense sounds on hearing. This information is derived based on all available relevant data and published literature (i.e. the state of current knowledge).

Marine animals do not hear equally well at all frequencies within their functional hearing range. Based on the hearing range and sensitivities, Southall et al (2019) have categorised marine mammal species (i.e. cetaceans and pinnipeds) into six underwater hearing groups: low-frequency (LF), high-frequency (HF), very high-frequency (VHF) cetaceans, Sirenians (SI), Phocid carnivores in water (PCW) and Other marine carnivores in water (OCW). For each specific marine mammal species, refer to Appendix I – 6 within the reference document (Southall et al, 2019) for their corresponding hearing groups.

The potential noise effects on animals depend on how well the animals can hear the noise. Frequency weighting is a method of quantitatively compensating for the differential frequency response of sensory systems (Southall *et al.*, 2019).

When developing updated scientific recommendations in marine mammal noise exposure criteria, Southall *et al.* (2019) adopted the auditory weighting functions as expressed in the equation below, which are based on the quantitative method by Finneran (2016) and are consistent with the U.S. National Oceanic and Atmospheric Administration (NOAA) technical guidance (NMFS, 2016 & 2018).

$$W(f) = C + 10log10\left\{\frac{(f/f_1)^{2a}}{[1+(f/f_1)^2]^a[1+(f/f_2)^2]^b}\right\} \qquad (2.1)$$

Where:

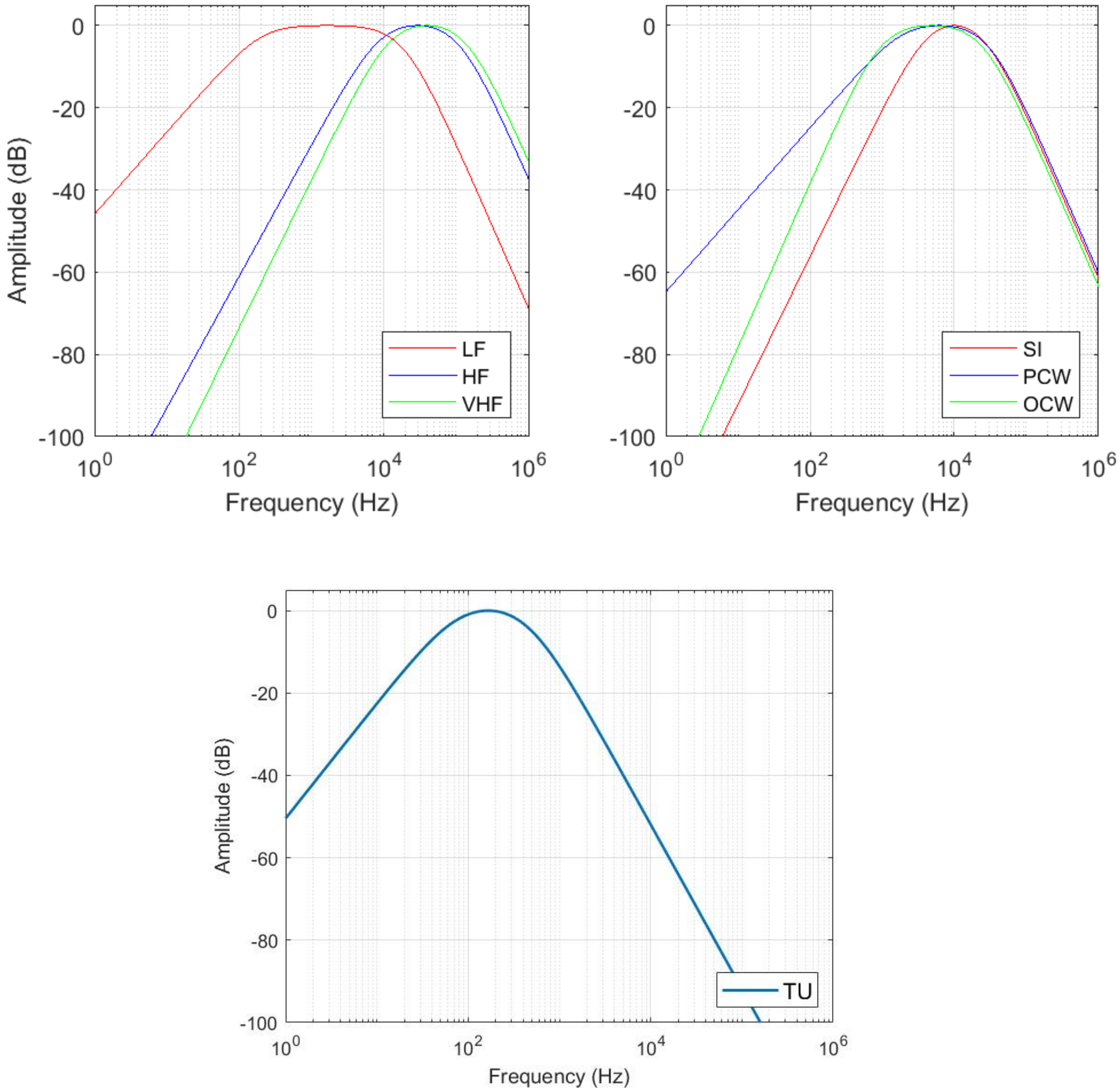
- ***W(f)*** is the weighting function amplitude (in dB) at frequency f (in kHz).
- ***f_1*** represents LF transition value (in kHz), i.e. the lower frequency at which the function amplitude begins to change from the flat, central portion of the curve.
- ***f_2*** represents HF transition value (in kHz), i.e. the upper frequency at which the function amplitude begins to change from the flat, central portion of the curve.
- **a** represents the LF exponent value (dimensionless) which defines the rate of decline of the weighting function amplitude at low frequencies. The change in weighting function amplitude with frequency at low frequencies (the LF slope) is 20a dB/decade.
- **b** represents the HF exponent value (dimensionless) which defines the rate of decline of weighting function amplitude at high frequencies, becoming linear with the logarithm of frequency. The change in weighting function amplitude with frequency at high frequencies (the HF slope) is -20b dB/decade.
- **C** is the constant that defines the vertical position of the curve. It is defined so that the maximum amplitude of the weighting function equals 0 dB (with all other values being negative).

Table B.1 lists the auditory weighting parameters as defined above for the six hearing groups. The corresponding auditory weighting functions for all hearing groups are presented in **Figure B.1.**

Table B.1 Parameters for the auditory weighting functions (Southall *et al.*, 2019)

Marine mammal hearing group	*a*	*b*	f_1 (kHz)	f_2 (kHz)	*C* (dB)
Low-frequency cetaceans (LF)	1.0	2	0.20	19	0.13
High-frequency cetaceans (HF)	1.6	2	8.8	110	1.20
Very-high-frequency cetaceans (VHF)	1.8	2	12	140	1.36
Sirenians (SI)	1.8	2	4.3	25	2.62
Phocid carnivores in water (PCW)	1.0	2	1.9	30	0.75
Other marine carnivores in water (OCW)	2.0	2	0.94	25	0.64
Sea turtles (TU)	1.4	2	0.077	0.44	2.35

Figure B.1 Auditory weighting functions - LF, HF, VHF, SI, PCW, OCW and TU (Southall *et al.*, 2019; Finneran *et al.*, 2017)



Appendix C Marine mannal hearing group classifications

ORANGE BASIN MC3D MSS

3D Seismic Survey Underwater Acoustics Modelling Project ZA24-010_Orange Basin MC3D MSS

Searcher Seismic

SLR Project No.: 675.30056.00102

25 June 2024

The following appendix gives a summary of marine mammal hearing group classification. Not all animals listed in Table C.1 are found in the vicinity of the survey area.

Table C.1 Summary of marine mammal classification

Classification	Common Name	Scientific Name
Low frequency cetaceans (extracted from Appendix 1 Southall *et al.* (2019))	Bowhead whale	*Balaena mysticetus*
	Southern right whale	*Eubalaena australias*
	North Atlantic right whale	*Eubalaena glacialis*
	North Pacific right whale	*Eubalaena japonica*
	Common minke whale	*Balaenoptera acutorostrata*
	Antarctic minke whale	*Balaenoptera bonaerensis*
	Sei whale	*Balaenoptera borealis*
	Bryde's whale	*Balaenoptera edeni*
	Omura's whale	*Balaenoptera omurai*
	Fin whale	*Balaenoptera physalus*
	Humpback whale	*Megaptera novaeangliae*
	Pygmy right whale	*Caperea marginate*
	Gray whale	*Eschrichtius robustus*
High frequency cetaceans (extracted from Appendix 2 Southall *et al.* (2019))	Sperm whale	*Physeter macrocephalus*
	Arnoux' beaked whale	*Berardius arnuxii*
	Baird's beaked whale	*Berardius bairdii*
	Northern bottlenose whale	*Hyperoodon ampullatus*
	Southern bottlenose whale	*Hyperoodon planifrons*
	Tropical bottlenose whale	*Indopacetus pacificus*
	Sowerby's beaked whale	*Mesoplodon bidens*
	Andrews' beaked whale	*Mesoplodon bowdoini*
	Hubb's beaked whale	*Mesoplodon carlbubbsi*
	Blainville's beaked whale	*Mesoplodon densirostris*
	Gervais' beaked whale	*Mesoplodon europaeus*
	Ginkgo-toothed beaked whale	*Mesoplodon ginkgodens*
	Gray's beaked whale	*Mesoplodon grayi*
	Hector's beaked whale	*Mesoplodon hectori*
	Deraniyagala's beaked whale	*Mesoplodon hotaula*
	Layard's beaked whale	*Mesoplodon layardii*
	True's beaked whale	*Mesoplodon mirus*
	Perrin's beaked whale	*Mesoplodon perrini*
	Pygmy beaked whale	*Mesoplodon peruvianus*
	Stejneger's beaked whale	*Mesoplodon stejnegeri*
	Spade-toothed whale	*Mesoplodon traversii*
	Tasman beaked whale	*Tasmacetus shepherdi*
	Cuvier's beaked whale	*Ziphius cavirostris*
	Killer whale	*Orcinus orca*

Classification	Common Name	Scientific Name
	Beluga	*Delphinapterus leucas*
	Narwhal	*Monodon monoceros*
	Short- and long-beaked common dolphins	*Delphinus delphis*
	Pygmy killer whale	*Feresa attenuata*
	Short-finned pilot whale	*Globicephala macrorhynchus*
	Long-finned pilot whale	*Globicephala melas*
	Risso's dolphin	*Grampus griseus*
	Fraser's dolphin	*Lagenodelphis hosei*
	Atlantic white-sided dolphin	*Lagenorhynchus acutus*
	White-beaked dolphin	*Lagenorhynchus albirostris*
	Pacific white-sided dolphin	*Lagenorhynchus obliquidens*
	Dusky dolphin	*Lagenorhynchus obscurus*
	Northern right whale dolphin	*Lissodelphis borealis*
	Southern right whale dolphin	*Lissodelphis peronii*
	Irrawaddy dolphin	*Orcaella brevirostris*
	Australian snubfin dolphin	*Orcaella heinsohni*
	Melon-headed whale	*Peponocephala electra*
	False killer whale	*Pseudorca crassidens*
	Indo-Pacific humpback dolphin	*Sousa chinensis*
	Indian Ocean humpback dolphin	*Sousa plumbea*
	Australian humpback dolphin	*Sousa sahulensis*
	Atlantic humpback dolphin	*Sousa teuszii*
	Tucuxi	*Sotalia fluviatilis*
	Guiana dolphin	*Sotalia guianensis*
	Pantropical spotted dolphin	*Stenella attenuata*
	Clymene dolphin	*Stenella clymene*
	Striped dolphin	*Stenella coeruleoalba*
	Atlantic spotted dolphin	*Stenella frontalis*
	Spinner dolphin	*Stenella longirostris*
	Rough-toothed dolphin	*Steno bredanensis*
	Indo-Pacific bottlenose dolphin	*Tursiops aduncus*
	Common bottlenose dolphin	*Tursiops truncatus*
	South Asian river dolphin	*Platanista gangetica*
Very high frequency cetaceans (extracted from Appendix 3 Southall *et al.* (2019))	Peale's dolphin	*Lagenorhynchus australis*
	Hourglass dolphin	*Lagenorhynchus cruciger*
	Commerson's dolphin	*Cephalorhynchus commersonii*
	Chilean dolphin	*Cephalorhynchus eutropia*
	Heaviside's dolphin	*Cephalorhynchus heavisidii*
	Hector's dolphin	*Cephalorhynchus hectori*

Classification	Common Name	Scientific Name
	Narrow-ridged finless porpoise	*Neophocaena asiaeorientalis*
	Indo-Pacific finless porpoise	*Neophocaena phocaenoides*
	Spectacled porpoise	*Phocoena dioptrica*
	Harbor porpoise	*Phocoena*
	Vaquita	*Phocoena sinus*
	Burmeister's porpoise	*Phocoena spinipinnis*
	Dall's porpoise	*Phocoenoides dalli*
	Amazon river dolphin	*Inia geoffrensis*
	Yangtze river dolphin	*Lipotes vexillifer*
	Franciscana	*Pontoporia blainvillei*
	Pygmy sperm whale	*Kogia breviceps*
	Dwarf sperm whale	*Kogia sima*
Sirenians (extracted from Appendix 4 Southall *et al.* (2019))	Amazonian manatee	*Trichechus inunguis*
	West Indian manatee	*Trichechus manatus*
	West African manatee	*Trichechus senegalensis*
	Dugong	*Dugong dugon*
Phocid carnivores (extracted from Appendix 5 Southall *et al.* (2019))	Hooded seal	*Cystophora cristata*
	Bearded seal	*Erignathus barbatus*
	Gray seal	*Halichoerus grypus*
	Ribbon seal	*Histriophoca fasciata*
	Leopard seal	*Hydrurga leptonyx*
	Weddell seal	*Leptonychotes weddellii*
	Crabeater seal	*Lobodon carcinophaga*
	Northern elephant seal	*Mirounga angustirostris*
	Southern elephant seal	*Mirounga leonina*
	Mediterranean monk seal	*Monachus*
	Hawaiian monk seal	*Neomonachus schauinslandi*
	Ross seal	*Ommatophoca rossii*
	Harp seal	*Pagophilus groenlandicus*
	Spotted seal	*Phoca largha*
	Harbor seal	*Phoca vitulina*
	Caspian seal	*Pusa caspica*
	Ringed seal	*Pusa hispida*
	Baikal seal	*Pusa sibirica*
Other marine carnivores (extracted from Appendix 6 Southall *et al.* (2019))	Walrus	*Odobenus rosmarus*
	South American fur seal	*Arctocephalus australis*
	New Zealand fur seal	*Arctocephalus forsteri*
	Galapagos fur seal	*Arctocephalus galapagoensis*
	Antarctic fur seal	*Arctocephalus gazella*

Classification	Common Name	Scientific Name
	Juan Fernandez fur seal	*Arctocephalus philippii*
	Cape fur seal	*Arctocephalus pusillus*
	Subantarctic fur seal	*Arctocephalus tropicalis*
	Northern fur seal	*Callorhinus ursinus*
	Steller sea lion	*Eumetopias jubatus*
	Australian sea lion	*Neophoca cinerea*
	South American sea lion	*Otaria byronia*
	Hooker’s sea lion	*Phocarctos hookeri*
	California sea lion	*Zalophus californianus*
	Galapagos sea lion	*Zalophus wollebaeki*
	Polar bear	*Ursus maritimus*
	Sea otter	*Enhydra lutris*
	Marine otter	*Lontra feline*

Making Sustainability Happen