Eramurra Solar Salt Project

19 March 2025

Marine Fauna Underwater Noise and Vessel Collision Risk Assessment

Document Information

REPORT NO.	MSA314.1R03
LEICHHARDT DOC NO.	ESSP-EN-14-TRPT-0050
DATE	March 19, 2025
CLIENT	Leichhardt Salt Pty Ltd
DOCUMENT TITLE	Eramurra Solar Salt Project. Marine Fauna Underwater Noise and Vessel Collision Risk Assessment
USAGE	This report is provided for use as an assessment of risk to marine fauna of interest from vessel collision and underwater noise impacts associated with construction and operation activities for the Eramurra Solar Salt Project (the Proposal). It is provided for use as part of a broader assessment of the environmental impacts of the Proposal and may be used to support part of a referral to State and Federal regulators.
KEYWORDS	Vessel collision, underwater noise, marine fauna, risk assessment
CITATION	MScience 2025. Eramurra Solar Salt Project. Marine Fauna Underwater Noise and Vessel Collision Risk Assessment. Unpublished report MSA314.1R03 to Leichhardt Salt Pty Ltd, Perth Western Australia, pp50

Version History

Version/Date	Issued as	Author	Reviewed	Approved
1/21.01.2025	Draft for client review	IJP	JAS	IJP
2/24.01.2025	Final	IJP	MJF	IJP
3/19.03.2025	Update to Appendix A	IJP	-	IJP

Disclaimer

Acronyms and Abbreviations

Abbreviation	Definition
AIS	Automated Identification System
AMSA	Australian Maritime Safety Authority
BIA	Biologically Important Area
CI	
CITIC	CITIC Pacific
CSD	Cutter Suction Dredge
dB	decibel
dB re 1 µPa	Level of sound at a nominal reference distance
DBCA	Department of Biodiversity, Conservation and Attractions
DSDMMP	Dredging Spoil and Disposal Monitoring and Management Plan
EP Act	*Environmental Protection Act 1986*
EPA	Environmental Protection Authority
EPBC Act	*Environment Protection and Biodiversity Act 1999*
ERD	Environmental Referral Document
ESD	Environmental Scoping Document
HF	High frequency
Hz	Hertz
JASCO	JASCO Applied Sciences
Leichhardt	Leichhardt Salt Pty Ltd, the Proponent
LF	Low frequency
MS	Ministerial Statement
Mtpa	Million tonnes per annum
NaCl	Sodium Chloride
NMFS	National Marine Fisheries Servies
NOAA	National Oceanic and Atmospheric Administration
OGV	Ocean-going vessel
PK	Peak Sound Pressure Level
P_{lethal}	Potential of a Lethal Injury
PTS	Permanent threshold shift - the threshold for permanent hearing impairment
R_{max}	Maximum Horizontal Distance
SEL	Sound Exposure Level, computed as the time-integral of the squared pressure, before applying 10log10(), and it is expressed in dB relative to 1 µPa^{2}s.
SEL_{24h}	SEL accumulation, defined as a 24-hour period over which sound energy may be integrated
SPL	Sound Pressure Level, reported in dB with respect to a specific reference pressure value. In water, this reference pressure is generally 1 µPa.
The jetty	Cape Preston East Multi-Commodity Export Facility jetty
The Proposal	Eramurra Solar Salt Project
TSV	Transhipment vessel
TTS	Temporary threshold shift – the threshold for temporary hearing impairment
WA	Western Australia
µPa	micro-Pascal

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EXECUTIVE SUMMARY

Leichhardt Salt Pty Ltd (Leichhardt) proposes to construct and operate the Eramurra Solar Salt Project, to extract up to an average of 5.2 million tonnes per annum (Mtpa) of high-grade salt (Sodium Chloride (NaCl)) from seawater (the Proposal). The export of salt is proposed to be via a trestle jetty. The jetty and associated stockpiles will be located at the Cape Preston East Port approved by Ministerial Statements (MS) 949 and 1149. Although the potential environmental impacts associated with development of the Cape Preston East Port jetty, specifically underwater noise impacts from pile driving, are not part of the current Proposal, they have been included here for completeness.

Dredging of the proposed channel and berth pocket will be undertaken as part of the current Proposal. Bitterns will be transported as part of this Proposal by pipeline attached to the trestle jetty structure and discharged via a diffuser located off the trestle jetty.

Leichhardt has referred the Proposal to the Western Australian Environmental Protection Authority (EPA), under Section 38 of Part IV of the *Environmental Protection Act* 1986 (EP Act), and Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) under a bilateral agreement. Leichhardt developed an Environmental Scoping Document (ESD) for the Proposal to specify the form, content, indicative timing and procedure of an Environmental Review Document (ERD). The ESD identified marine fauna as one of the preliminary key environmental factors which has the potential to be impacted by the Proposal. To assess the potential impacts to marine fauna, Leichhardt has committed to:

- ESD Item 66 - Undertake an underwater noise risk assessment that includes a sensitivity assessment of the marine fauna likely to occur in the area during construction activities such as dredging. The risk assessment is to include, but not limited to, disturbance to resting or nursing humpback whale mothers and calves;
- ESD Item 67 - Quantify and assess the potential impacts of all shipping and proposal-related boat traffic and identify mitigation measures to avoid and minimise marine fauna collisions and noise related impacts. The impact to marine fauna from shipping activity is not part of the current Proposal, but it has been included here for completeness.
- ESD Item 71 - Identify the likelihood of significant marine fauna species (excluding shore and seabirds) occurring near the Development Envelope, including:
    - e) Discussion and determination of the significance of potential direct, indirect (including downstream) residual and cumulative impacts to conservation significant marine fauna as a result of the Proposal at a local and regional level.
- ESD Item 72 - Identify the proposed activities and the potential scale and significance of potential direct and indirect impacts to marine fauna during construction and operation of the Proposal. Evaluate potential impacts on the behaviour of significant marine fauna (excluding shore and seabirds) including but not limited to marine turtles, dugongs, cetaceans, green sawfish and species important to commercial and recreational fisheries such as bluespotted emperor.

This document addresses ESD items 66 and 67, as outlined above, and ESD items 71 and 72 in the context of indirect impacts to marine fauna from underwater noise generated by construction and operation of the Proposal. The methodology used to fulfill the ESD items was to estimate the likelihood of occurrence of susceptible marine fauna of significance, including humpback whales, and then quantify the proposal-related vessel traffic and underwater noise source levels to provide the basis for a risk assessment. The assessments have been based on Proposal information received from Leichhardt, underwater noise modelling by JASCO Applied Sciences (JASCO) and desktop literature review of studies that have been conducted on dredging/shipping impacts (noise and collision) to marine fauna, with a focus on studies completed at Cape Preston and within the Pilbara Region.

A desktop assessment for the marine fauna of significance (excluding marine birds) with the potential of occurring within and/or adjacent to the Proposal location has identified a number of species with a high and medium likelihood of occurrence, being: humpback whale, blue whale, Indo-Pacific bottlenose dolphin, Australian humpback dolphin, dugong, green turtle, hawksbill turtle, flatback turtle, loggerhead turtle, green sawfish and reef manta ray. These marine animals were considered for the underwater noise and vessel collision risk assessment.

Quantification of the Proposal-related shipping identified the majority of marine shipping activity during construction to be associated with the dredging and transport of spoil material to the proposed disposal locations. It is anticipated a single medium sized Cutter Suction Dredge (CSD) and two split hopper barges (each with a capacity of ~1,500 m^3) will be utilised for the Proposal. Approximately 315 movements of the split hopper barges are estimated to occur between the dredge and disposal grounds. During operations, Handysize, Handymax and/or Panamax sized ocean-going vessels (OGVs), transhipment vessels (TSVs) and a pilot/work vessel will be utilised. Approximately 990 operational vessel movements per year are anticipated, an increase to the existing vessel traffic at Cape Preston of ~ 46%.

Vessel Collision

The vessel collision risk to marine fauna from the Proposal was assessed as low, but above negligible. The potential for vessel traffic to impact marine fauna is mainly influenced by the size of vessel, the operating speed of the vessel and the number of vessel movements. Cape Preston is an existing facility which has been in operation since 2013. No incidents of marine fauna strike were found in the literature as a result of port operations over that time. OGVs will be piloted within port limits and will operate at speeds (10 knots) which are not considered to provide a risk of significant impact on marine fauna. It has been estimated that during operations the Proposal will increase existing vessel traffic, in the category which has the potential to significantly impact marine fauna (i.e. fast-moving vessels), by just 12.5%.

Project management plans will specify the application of controls including observations, reporting, separation distances and vessel speed limitations to reduce the likelihood and consequence of vessel strike for all species and will comply with current marine fauna interaction guidelines (Part 8 of the EPBC regulations 2000 and the *Biodiversity Conservation Regulations 2018*). Therefore, after accounting for the low level of risk, the management actions for marine fauna disturbance identified in this assessment are comparable with the current practices used by other operators of export facilities in Australia.

Underwater Noise

The potential impacts to marine fauna from potential underwater noise sources have been reviewed in detail. Potential impacts can be broadly divided into behavioural impacts (displacement, attraction, avoidance, masking or interfering with biologically important sounds) and physiological impacts (stress, hearing damage and/or impairment). Physiological impacts can be temporary, termed temporary threshold shift (TTS) or permanent, termed permanent threshold shift (PTS).

Based on a comprehensive underwater noise modelling study (JASCO 2025), the following conclusions have been drawn regarding the risk of underwater noise impacts to marine fauna from the Proposal construction and operational activities.

The assessment period for sound exposure level (SEL) accumulation has been defined as a 24-hour period over which sound energy may be integrated; the level is specified with the abbreviation SEL_{24h}. SEL_{24h} is a cumulative metric that reflects the dosimetric effect of noise levels within 24 hours, based on the assumption that a receiver (e.g., an animal) is consistently exposed to such noise levels at a fixed position. More realistically, marine mammals, fish, and marine turtles would not stay in the same location for 24 hours (especially in the absence of location-specific habitat) but rather a shorter period, depending on the animal's behaviour and the source's proximity and movements. Therefore, a reported radius for SEL_{24h} criteria does not mean that marine fauna travelling within this radius of the source will be impaired, but rather that an animal could be exposed to the sound level associated with impairment (either PTS or TTS) if it remained in that location for 24 hours. Results are thus conservative.

Pile Driving

The study predicted underwater sound levels associated with impact driving of two types of piles, cylindrical pipe piles (for the jetty construction approved under MS 949/1149) and sheet piles (for the proposed seawater intake construction in McKay Creek). The pile driving scenarios are based on approximated and likely designs and installation approaches using driveability for the Juntaan HHK 20S and Juntaan HHK 10S hammers, respectively.

- The inherent risk to dugongs, marine turtles, elasmobranchs and fish of interest from the Proposal's pile driving activities was considered moderate for both cylindrical pipe pile driving and sheet pile driving.
  - The onset of TTS and PTS for dugongs using the worst case SEL_{24h} criteria did not extend beyond 1.52 km and 350 m, respectively, from the cylindrical pipe pile driving noise source. For sheet pile driving, predicted sound levels for impairment extended for 270 m (TTS) and 60 m (PTS) from the noise source.
  - The onset of TTS and PTS for marine turtles were comparable to those for dugongs at 1.51 km and 360 m, respectively, from the cylindrical pipe pile driving. Onset of TTS during sheet pile driving was predicted to extend for 130 m from the noise source. Onset of PTS in marine turtles was not predicted to occur during sheet pile driving. Sound levels triggering a behavioural response did not extend beyond 1.59 km and 50 m of the pipe pile driving and sheet pile driving noise source, respectively.
  - Onset of TTS for fish and elasmobranchs did not extend beyond 2.71 km and 310 m from the cylindrical pipe and sheet pile driving noise source, respectively. An impact level consistent with a recoverable injury or potential mortal injury extended for 90 m and 60 m, respectively, from the pipe pile driving noise source. Injury (recoverable or mortal) of fish and elasmobranchs was not predicted to occur during sheet pile driving activities.
- The inherent risk to marine mammals (excluding dugongs) was considered high for the cylindrical pipe pile driving and moderate for the sheet pile driving noise sources.
  - A marine mammal behavioural response did not extend beyond 2.66 km and 130 m of the cylindrical pipe pile driving and sheet pile driving noise source, respectively.
  - Onset of TTS and PTS for the low frequency (LF) cetacean group, including humpback whales, using the worst case SEL_{24h} criteria was did not extend beyond 11.8 km and 3.37 km, respectively, of the pipe pile driving sound source. This extent was reduced to 1.05 km (TTS) and 350 m (PTS) for the sheet pile driving noise source.
  - Onset of TTS and PTS for the high frequency (HF) cetacean, including the Indo-Pacific bottlenose dolphin and Australian humpback dolphin, was predicted to extend for 1.79 km and 430 m, respectively, for the cylindrical pipe pile driving noise source. This extent was reduced to 310 m (TTS) and 70 m (PTS) from the sheet pile driving noise source.

Dredging Activities

- The inherent risk to the marine fauna of interest from dredging activities was considered moderate.
  - A marine mammal behavioural response was estimated to extend for 6.3 km from the dredging noise source.
  - Onset of TTS and PTS for the low frequency (LF) cetacean group, including humpback whales, using the worst case SEL_{24h} criteria did not extend beyond 2.21 km and 330 m, respectively, from the dredging noise source.

  - Onset of TTS and PTS for the high frequency (HF) cetacean, including the Indo-Pacific bottlenose dolphin and Australian humpback dolphin, was estimated to extend for 240 m and 10 m, respectively, of the dredging noise source.
  - Onset of TTS in dugongs, using the worst case SEL_{24h} criteria, extends for 50 m from the dredging noise source. Onset of PTS in dugongs was not predicted to occur during dredging activities.
  - Onset of TTS and PTS in marine turtles did not extend beyond 260 m and 10 m, respectively, from the dredging noise source.
  - Dredging noise criteria thresholds for fish without a swim bladder (relevant to this assessment) were not reached.

Transhipment Vessel (TSV) Movements

- The inherent risk to the marine fauna of interest from TSV movements (transit and berthing), with the exception of the LF cetacean group, was considered low.
  - TSV movement noise criteria thresholds for all modelled marine megafauna (except the LF cetacean group) were not reached.
- The risk to LF cetaceans, including humpback whales, was considered moderate.
  - Onset of TTS in LF cetaceans did not extend beyond 170 m from TSV operations.

Seawater Intake Pump

- The inherent risk to the marine fauna of interest from operation of the seawater intake pump was considered low.
  - The modelled intake pump noise was too quiet to reach any of the noise exposure threshold criteria for marine mammals, marine turtles or fish within the modelling resolution of 10 m.

The recommended management measures for the prevention of injury to marine megafauna (turtles, dolphins, and other cetaceans) from potential underwater noise impacts include:

- Conducting checks for marine megafauna in the immediate vicinity of operations prior to start-up of operations. Checks should be made by a person suitably qualified to identify marine megafauna.
- Implementing a soft start procedure for any impact hammer piling activities.
- Applying practical observation and shut down zones during pile driving activities based on the JASCO modelling results. In addition, the Government of South Australia published the *Underwater Piling Noise Guidelines* (DPTI 2012), which are adapted from EPBC Act Policy Statement 2.1 – *Interaction between offshore seismic exploration and whales*. The piling noise guidelines provide practical management and mitigation measures for the purpose of minimising the risk of injury to occur in marine fauna within the vicinity of piling activities, consistent with international good practice.
- Applying practical observation/exclusion zones during dredging activities and vessel movements based on the JASCO modelling results.
- Use of a spotter vessel or maintain communication with the port authority regarding sightings of marine megafauna if clear observations cannot be made from land.
- Stopping construction activity when marine megafauna are observed within the adopted observation/exclusion zones; until the animals have moved beyond the extent or have not been sighted for 30 minutes.

The application of the above underwater noise management controls reduces the probability of marine megafauna being within the vicinity of active construction operations. As such, the residual risks of the Proposal's noise generating activities impacting on marine fauna were assessed as low.

Summary Conclusions

Mapping of areas of risk of vessel operations or marine noise demonstrates that these risks are confined to areas of existing disturbance from current port operations and are cumulative in nature rather than novel impacts. Noise impacts and the density of vessel movements will be greatest during construction activity. Such activity is limited in time, rather than extending over years and is predominantly in inshore areas which minimises impacts on more offshore marine fauna.

The probability of marine megafauna being within the vicinity of active construction operations for sufficient time periods to accumulate the requisite length of exposure to noise at damaging levels and the mitigating potential of the recommended management measures, further reduce risk profiles.

Overall, risks for noise generating activities and vessel collision impacts were assessed as low.

1 INTRODUCTION

1.1 Project Description

Leichhardt Salt Pty Ltd (Leichhardt) proposes to construct and operate the Eramurra Solar Salt Project (the Proposal), to extract up to an average of 5.2 million tonnes per annum (Mtpa) of high-grade salt (Sodium Chloride (NaCl)) from seawater (up to 6.8 Mtpa in a low rainfall year), using a series of concentration and crystallisation ponds and processing plant, transport corridor, stockpiling and export from the Cape Preston East Port. The concentration and crystalliser ponds will be located on Mining Leases.

The export of salt is proposed to be via a trestle jetty. The jetty and associated stockpiles will be located at the Cape Preston East Port which has been approved previously by Ministerial Statements (MS) 949 and 1149. Although the potential environmental impacts associated with development of the Cape Preston East Port jetty, specifically underwater noise impacts from pile driving, are not part of the current Proposal, they have been included here for completeness.

Dredging of the proposed channel and berth pocket will be undertaken as part of this Proposal to remove high points at the Cape Preston East Port. Dredged material will either be disposed of at an offshore disposal location, or onshore within the Ponds and Infrastructure Development Envelope. A seawater intake, pump and pipeline will provide the seawater required for the Proposal during operations. Bitterns will be transported as part of this Proposal by pipeline attached to the trestle jetty structure and discharged via a diffuser located off the trestle jetty.

The Proposal is located in the western Pilbara region of Western Australia (WA), approximately 55 km south-west of Karratha (Figure 1-1). The summary description of the Proposal has been provided in Table 1-1.

Table 1-1. Summary of Proposal

Proposal Title	Eramurra Solar Salt Project
Proponent Name	Leichhardt Salt Pty Ltd
Short Description	Leichhardt Salt Pty Ltd (Leichhardt) is seeking to develop a solar salt project in the Cape Preston East area, approximately 55 km west-south-west of Karratha in WA (the Proposal). The Proposal will utilise seawater and evaporation to produce a concentrated salt product for export. The Proposal includes the development of a series of concentrator and crystalliser ponds and processing plant. Supporting infrastructure includes bitterns outfall, drainage channels, product dewatering facilities, desalination plant, pumps, pipelines, power supply, access roads, administration buildings, workshops, laydown areas, landfill facility, communications facilities and other associated infrastructure. The Proposal also includes dredging at the Cape Preston East Port with disposal of dredge material at an offshore location and onshore within the Ponds and Infrastructure Development Envelope.

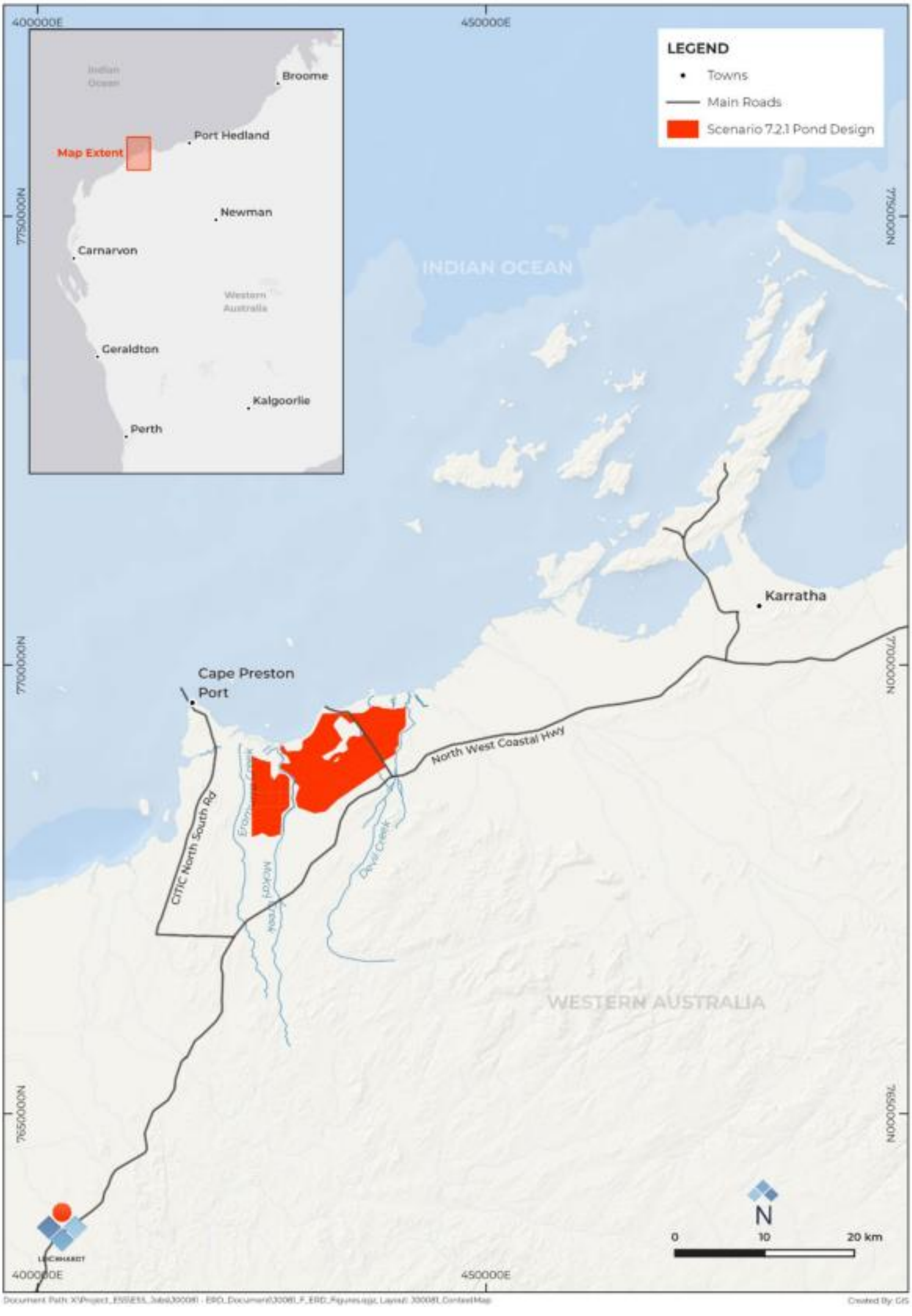

Figure 1-1. Proposal location

1.1.1 State and Commonwealth Approvals

Leichhardt has referred the Proposal to the Western Australian Environmental Protection Authority (EPA), under Section 38 of Part IV of the *Environmental Protection Act* 1986 (EP Act), and Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) under a bilateral agreement.

The EP Act is the primary legislative instrument for environmental assessment in WA. Under Part IV of the EP Act, the EPA is responsible for providing advice to the WA Minister for the Environment on Proposal's assessed under Part IV of the EP Act and considered by the EPA as likely to have significant impact on the environment.

The EPA decision on the Proposal referral information was 'Assess – Public Environmental Review'. Prior to developing the Environmental Review Document (ERD), an Environmental Scoping Document (ESD) was developed for the Proposal to specify the form, content, indicative timing and procedure of the environmental review. The EPA provided comments and recommendations for further work to be included in the ESD for the Proposal. These EPA ESD requirements were addressed by Leichhardt before a draft ERD was developed for EPA review. On review of the draft ERD, the EPA provided comments and recommended actions for the ESD requirements where information was still lacking in the ERD.

1.2 Purpose and Objectives

The ESD identified marine fauna as one of the preliminary key environmental factors (EPA 2021a) which has the potential to be impacted by the Proposal. To assess the potential impacts to marine fauna, the EPA provided Leichhardt with a number of ESD requirements. On review of the draft ERD, the EPA provided comment as to where information was lacking in relation to these ESD requirements.

This document addresses the ESD requirements and EPA comments specifically relating to impacts on marine fauna from underwater noise and vessel collision generated by construction and operation of the Proposal.

The ESD requirements and EPA comments relating to underwater noise and vessel collision impacts have been provided in Table 1-2. The table also includes the relevant section of this document that addresses the requirement/comment.

Table 1-2. Proposal ESD requirements and EPA comments relevant to underwater noise and vessel traffic

ESD Requirement	EPA Comment on Draft ERD	Relevant Document Section
ESD Requirement 66 - Undertake an underwater noise risk assessment that includes a sensitivity assessment of the marine fauna likely to occur in the area during construction activities such as dredging. The risk assessment is to include, but not limited to, disturbance to resting or nursing Humpback Whale mothers and calves	The underwater noise assessment is not considered to be fit for purpose. Specifically: • Predictions of impact are based on instantaneous thresholds and do not consider realistic sound exposure scenarios and 24 hr sound exposure thresholds. • The prediction of ranges to effects is based on a simple spherical spreading calculation that is not appropriate for shallow coastal waters. • The full frequency of piling noise has not been considered. Please revise the draft ERD to include an appropriate evaluation of the potential impacts of underwater noise on key marine fauna species.	The underwater noise assessment is provided in Section 6, Section 7 and Appendix B

ESD Requirement	EPA Comment on Draft ERD	Relevant Document Section
ESD Requirement 67 - Quantify and assess the potential impacts of construction and maintenance boat traffic and identify mitigation measures to avoid and minimise marine fauna collisions and noise/light related impacts.	The evaluation of potential vessel strike impacts is not adequate, particularly noting the development envelope overlaps biologically important areas for a number of key marine fauna species. Please update the draft ERD to provide an appropriate evaluation of vessel strike risk and include commitment to maintain minimum separation distances between vessels and specified marine fauna species, as required under the *Biodiversity Conservation Regulations 2018* (BC Regulations	The vessel collision assessment is provided in Section 5 and Section 7.
ESD Requirement 71 – Identify the likelihood of significant marine fauna species (excluding shore and seabirds) occurring near the Development Envelope, including: e) Discussion and determination of the significance of potential direct, indirect (including downstream) residual and cumulative impacts to conservation significant marine fauna as a result of the Proposal at a local and regional level.	A number of key impact pathways for conservation significant marine fauna have not been identified within the draft ERD. These include indirect impacts on important habitat for marine fauna, noise, lighting and vibration from the construction and operation of the seawater intake facility. Provide further information to clearly identify the full extent (local and regional) of impacts (direct, indirect and cumulative) of the Proposal, including during construction and operation on conservation significant marine fauna.	The underwater noise assessment for construction of the seawater intake facility (via sheet pile driving) is provided in Section 6.3.1, Section 7 and Appendix B
ESD Requirement 72 – Identify the proposed activities and the potential scale and significance of potential direct and indirect impacts to marine fauna during construction and operation of the Proposal. Evaluate potential impacts on the behaviour of significant marine fauna (excluding shore and seabirds) including but not limited to marine turtles, dugongs, cetaceans, green sawfish and species important to commercial and recreational fisheries such as bluespotted emperor.	The Proposal has the potential to significantly impact on a number of key marine fauna species however some impacts and risks, including seawater intake have not been appropriately evaluated. The intake area at the mouth of the McKay Creek is an important habitat for marine fauna. Please update the ERD to provide additional information on the proposed seawater intake regime and address the potential impacts on marine fauna including the generation of underwater noise.	The underwater noise assessment of the seawater intake is provided in Section 6.3.3, Section 7 and Appendix B

Impacts to marine fauna that are specific to the dredge vessel, such as entrainment of animals, habitat degradation, increased suspended sediments, have been addressed in the Dredging and Spoil Disposal Management and Monitoring Plan (DSDMMP) (O2 Marine 2023a) developed for the Proposal.

This document provides a desktop assessment covering:

- A summary of the marine fauna of significance identified as relevant to the Proposal;
- Quantification of the existing and Proposal-related shipping movements at Cape Preston;
- The risk assessment framework;
- A detailed assessment of the impacts of vessel collision due the Proposal-related vessel traffic on marine fauna, including potential mitigation measures to avoid and minimise those impacts;
- A detailed assessment of the impacts of underwater noise from multiple sources (dredging, pile driving, shipping and the seawater intake), including a marine fauna noise sensitivity assessment and identification of potential mitigation measures to avoid and minimise those impacts; and
- Risk assessment and likelihood of potential impacts occurring.

The document is current as at the date on the cover page and is referenced as Version 2 (Documents with a lower version number are superseded by this document).

2 MARINE FAUNA OF SIGNIFICANCE

O2 Marine (2023b) has completed a desktop assessment and likelihood of occurrence assessment for the marine fauna of significance (excluding marine birds) with the potential to occur within and/or adjacent to the Proposal location (with a 20 km buffer). Table 2-1 lists the marine fauna species of environmental significance assessed by O2 Marine (2023b) as having the potential to occur within or adjacent to the Proposal area. Table 2-2 lists the marine fauna species with a biologically important area (BIA) that overlap the Proposal area. The assessments provided in the following sections have been limited to marine fauna of Table 2-1 with a high and medium likelihood to occur within or adjacent to the Proposal area.

Table 2-1. Marine fauna of significance likely to occur in the Proposal area (from O2 Marine 2022)

Species	Likelihood of Occurrence
Marine Mammals	
Blue whale (*Balaenoptera musculus)*	Low
Dugong (*Dugong dugon)*	High
Humpback whale (*Megaptera novaeangliae)*	High
Australian humpback dolphin (*Sousa sahulensis)*	High
Indo-Pacific bottlenose dolphin (*Tursiops aduncus)*	High
Marine Reptiles	
Short-nosed sea snake (*Aipysurus apraefrontalis)*	Low
Leaf-scaled sea snake (*Aipysurus foliosquama)*	Low
Loggerhead turtle (*Caretta caretta)*	Low
Green turtle (*Chelonia mydas)*	High
Leatherback turtle (*Dermochelys coriacea)*	Low
Hawksbill turtle (*Eretmochelys imbricata)*	High
Flatback turtle (*Natator depressus)*	High
Elasmobranchs and other fish	
Narrow sawfish (*Anoxypristis cuspidate*)	Low
Green sawfish (*Pristis zijsron)*	High
Grey nurse shark (*Carcharias taurus)*	Low
Whale shark (*Rhincodon typus)*	Low
Scalloped hammerhead shark (*Sphyrna lewini)*	Low
Giant manta ray (*Mobula birostris*)	Low
Reef manta ray (*Mobula alfredi*)	Medium
Southern bluefin tuna (*Thunnus thynnus*)	Low

ESD item 66 refers specifically to the risk of underwater noise to resting and nursing humpback whales. The Cape Preston area was not identified by O2 Marine (2023b) as a known important resting or nursing area. However, the Proposal development envelope falls within a BIA for the migration of the species (Table 2-2). In addition, O2 Marine (2023b) note there is uncertainty in the occurrence of humpback whale mother-calf behaviour within the Proposal Area and recent literature suggests calving grounds for the species may occur between Camden Sound, in the Kimberley, and North West Cape, in the Gascoyne Region.

ESD item 72 refers specifically to McKay Creek as an intertidal system fringed by mangroves which support a diverse range of conservation significant marine fauna, including the green sawfish and juvenile green turtles, which indicates a potentially important habitat for these species.

Table 2-2. Marine fauna biologically important areas that spatially overlap with the Proposal (O2 Marine 2023b)

Species	BIA Type	Proposal Marine Component
Humpback whale	Migration	Nearshore and offshore
Blue whale	Distribution	Nearshore and offshore
Flatback turtle	Inter-nesting	Nearshore and offshore
Green turtle	Inter-nesting	Nearshore and offshore
Hawksbill turtle	Inter-nesting	Nearshore and offshore

3 QUANTIFICATION OF SHIPPING AT CAPE PRESTON

Quantifying the occurrence of the shipping and proposal-related boat traffic was required to quantify the impacts of vessel collision and underwater noise to marine fauna.

3.1 Existing Shipping at Cape Preston

Quantification of the existing vessel movements for Cape Preston have been based on available information for the vessels owned and operated by CITIC Pacific (CITIC) for transhipment and export of product from their Sino Iron Project.

CITIC produces approximately 21 Mtpa of magnetite which is exported via 12 purpose built oceangoing vessels (OGVs) with a capacity of 115,000 t each. Four self-propelled transhipment vessels/barges (TSV), with a capacity of 12,000 to 14,000 t, are used to transport the magnetite to an OGV waiting offshore where a transhipper loads magnetite from the TSV to the OGV (Figure 3-1). The CITIC operation also utilises four tugs and a work vessel/pilot vessel. Using the available information, an estimate of the current annual shipping movements for Cape Preston has been provided in Table 3-1.

Table 3-1. Existing shipping at Cape Preston

Vessel Type	Movements per year
Oceangoing Vessels (115,000 t)	~180
Transhipment Vessels (12,000 to 14,000 t) incl Tugs	~1,620*
Pilot Vessel	~360
Total	**~2,160**

*Based on nine TSV/tug cycles required to load each OGV

3.2 Proposal-Related Shipping

3.2.1 Construction Shipping

The majority of marine shipping activity during construction will be associated with the dredging and transport of spoil material to the proposed disposal locations (Figure 3-2). Dredging is required to develop the proposed berth pocket, TSV channel and anchorages, and the bitterns pipeline channel. The current Proposal design does not require any dredging along the selected channel route for the OGVs. It is anticipated up to 400,000 m^3 of material (in situ volume) will be dredged for the Proposal, utilising a single medium sized Cutter Suction Dredge (CSD) and two split hopper barges (each with a capacity of ~1,500 m^3) to dispose of the dredge material. The details of the dredging contractor and dredge vessel/dredge plant to be engaged will be dependent on the availability of dredging plant during the construction phase of the Proposal. Dredging will continue for 24 hours per day, seven days per week and is estimated to last for a period of up to 105 days. The split-hopper barges are expected to transit between the CSD and the disposal grounds every eight hours. On this basis, approximately 315 movements of the split hopper barges are estimated to occur between the dredge and disposal grounds (Figure 3-2). This is considered a worst-case scenario. In the case that spoil is disposed onshore, a large component of these vessel movements would be avoided.

Post-dredging, a 15 – 25 m survey vessel will complete a bathymetric survey (~1,200 km of survey line) of the TSV channel, the OGV anchorages and the approach channel.

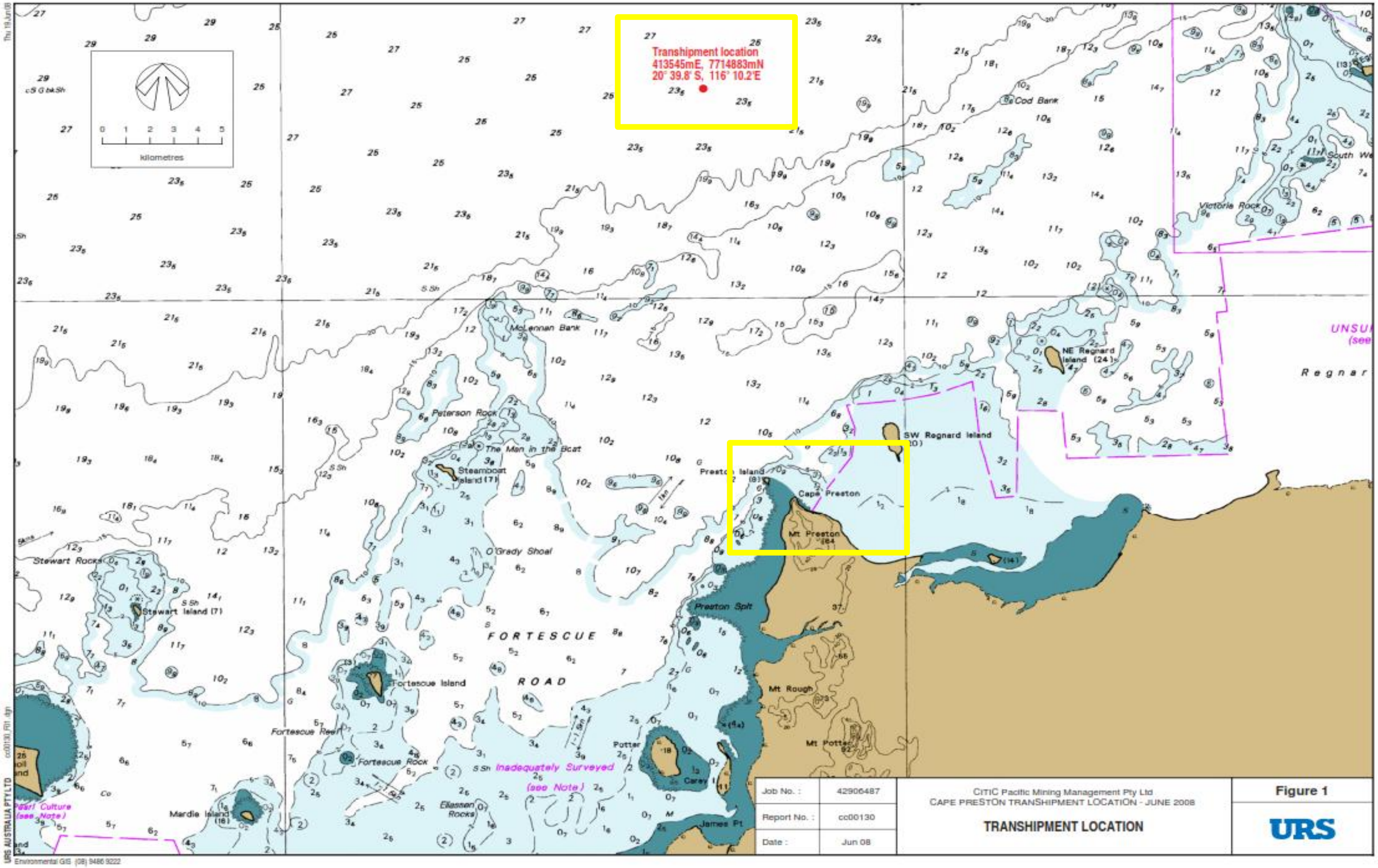

Figure 3-1. CITIC transhipment location

Figure 3-2. Proposal marine development envelope, spoil disposal, anchorage and shipping locations

Construction activities for this Proposal include the laying of the bittern's pipeline that will extend along the seabed out from the Cape Preston East Multi-Commodity Export Facility jetty (the jetty, approved under MS 949/1149). It is anticipated that these works will utilise up to two barges and two workboats operating close to shore.

Marine delivery of machinery, construction equipment or materials for this Proposal is expected to be minimal.

Shipping activity generated as part of the jetty construction (approved under MS 949/1149) is not part of the current Proposal, but it is important to consider the potential vessel movements during these works to inform an assessment of the cumulative impacts of the Proposal. During the jetty construction there will be two barges and up to two workboats assisting with the works. The jetty will be built from the land outwards. The associated ship loader may be assembled on land, barged from shore and lifted into place at the head of the jetty. Alternatively, it may be brought to Australia as deck cargo and transferred onto a barge anchored offshore.

Overall, shipping movements during construction of the Proposal will be low in frequency, limited in time and confined spatially to the nearshore environment and dredge disposal corridors between the proposed dredging areas and spoil grounds. Construction vessels working on the Proposal will not be moving at high speeds (typically less than 10 kts).

3.2.2 Shipping During Operations

Leichhardt proposes to produce up to an average of 5.2 Mtpa of salt which will be exported via Handysize, Handymax and Panamax sized OGVs, with a maximum cargo capacity of 50,000 to 60,000 t per vessel. TSVs of ~6,500 t capacity will shuttle the product between the loading berth at the head of the jetty and the OGV anchored offshore (Figure 3-2). A smaller pilot/workboat based at Cape Preston East will attend each OGV to transfer pilots on/off ships transiting the channel and assisting with draft survey after loading. Using the available information, an estimate of the proposed additional annual shipping movements for Cape Preston has been provided in Table 3-2.

Table 3-2. Proposed additional shipping at Cape Preston

Vessel Type	Movements per year	Change Compared to Existing Movements
Oceangoing Vessels (50,000 to 60,000 t)	~90	+50%
Transhipment Vessels (6,500 t)	~720*	+44%
Pilot Vessel	~180	+50%
Total	**~990**	**+46%**

*Based on eight TSV cycles required to load each OGV

The additional total ~990 operational vessel movements per year increases the vessel traffic at Cape Preston by approximately 46% from the estimate of existing shipping presented in Section 3.1.

4 ASSESSMENT FRAMEWORK

The underwater noise and vessel collision impact assessments presented in the following sections have been based on Proposal information received from Leichhardt, an acoustic underwater noise modelling study and desktop literature review of studies that have been conducted on underwater noise and vessel collision impacts to marine fauna, with a focus on studies completed at Cape Preston and within the Pilbara Region.

4.1 Guidance Documents

The following State, Federal and published literature guidance was considered relevant for assessing impacts to Marine Fauna associated with the ESD items listed in Section 1.2:

- Environmental Factor Guideline – Marine Fauna (EPA 2016);
- Technical Guidance – Environmental Impact Assessment of Marine Dredging Proposal's (EPA 2021b);
- National Strategy for Reducing Vessel Strike on Cetaceans and other Marine Megafauna (Commonwealth of Australia 2017a);
- Quantification of Risk from Shipping to Large Marine Fauna Across Australia (Peel et al. 2019);
- Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (NMFS 2024);
- Marine Mammal Behavioural Response Acoustic Thresholds (NOAA Fisheries 2024);
- Criteria and Thresholds for U.S. Navy Acoustic and Explosive Effects Analysis (Phase III) (Finneran et al. 2017);
- Sound Exposure Guidelines for Fishes and Sea Turtles (Popper et al. 2014); and
- Marine seismic surveys: Analysis and propagation of air-gun signals; and effects of air-gun exposure on humpback whales, sea turtles, fishes and squid (McCauley et al. 2000).

4.2 Vessel Collison Assessment Approach

The National Strategy for Reducing Vessel Strike on Cetaceans and other Marine Megafauna (Commonwealth of Australia 2017a) refers to two types of vessel collision risk: relative and absolute risk. Absolute risk quantifies the actual probability of a collision occurring in a defined geographical area. To assess absolute risk, detailed information on key parameters (e.g. vessel speed vs probability of death models, precise marine fauna species distribution models and proposed vessel draft and propeller specifications) is needed. There would be low confidence in any assessment of absolute risk of vessel collision specific to the Proposal due to the level of uncertainty around proposed vessel specifications and the lack of local distribution data for the relevant marina fauna of significance. As such, the risk metric discussed here is relative risk which can be used to predict the probability of where a fatal collision is more likely to occur. Simple measures of relative risk can be achieved by looking at animal and vessel density within a given area. Specifically, this assessment quantified the relative risk of a fatal collision at Cape Preston with comparison to vessel size and vessel speed, and the difference in risk between nearshore and offshore environments and other areas in the Pilbara. The risk assessment compiled readily available data on the factors affecting the risk of collision and analysed these in relation to the marine fauna of interest and Cape Preston area.

4.3 Underwater Noise Assessment Approach

The assessment of underwater noise impacts to marine fauna during construction and operation of the Proposal has been informed via an acoustic underwater noise modelling study undertaken by JASCO Applied Sciences (JASCO) (Appendix B). The study assessed distances from Proposal-related underwater noise generating activities where underwater sound levels reached thresholds corresponding to a behavioural response and acoustic impairment relevant to the marine fauna of significance listed in Section 2. The noise modelling study was conducted using the currently accepted methodology and standards for assessment of underwater noise impacts on marine fauna (refer to documents listed in Section 4.1)

5 VESSEL COLLISION IMPACT ASSESSMENT

5.1 Vessel Collision Source and Potential Impacts

There is the potential for moving vessels associated with the Proposal, such as marine construction vessels (dredge, crew transfer, hydrographic survey, barge vessels) and operations vessels (bulk carriers, transhippers and support vessels) to collide with the marine fauna of significance listed in Section 2.

Impacts specific to marine animal welfare as a consequence of a vessel collision incident can be divided into three types (Schoeman et al. 2020):

1. Direct – physical consequences that are the immediate result of a collision, which can be lethal on impact or occur several hours, days or weeks after the incident;
2. Long-term – a decrease in animal fitness over time e.g. locomotive impairments that effect foraging; and
3. Population consequences - such as a decrease in population growth rate due to high mortality or a decline in fertile animals.

5.2 Species of Concern

The National Strategy for Reducing Vessel Strike on Cetaceans and other Marine Megafauna (Commonwealth of Australia 2017a) has identified whales (specifically humpback whales and southern right whales), dolphins, dugongs, whale sharks and marine turtles as the fauna most vulnerable to vessel strike in Australian waters. On this basis, the following marine fauna of interest (with a medium or high likelihood of occurrence in the Proposal area) are most relevant to this assessment:

- Humpback whale (including resting and nursing females);
- Indo-Pacific bottlenose dolphin and Australian humpback dolphin;
- Whale shark;
- Dugong; and
- Green turtle, flatback turtle, hawksbill turtle.

Consideration of blue whales (distribution BIA overlaps the Proposal area), green sawfish (high likelihood of occurrence in inshore areas) and reef manta rays (medium likelihood of occurrence) has also been included for completeness.

5.3 Factors Affecting the Risk of Collision

The majority of information available on vessel collisions with marine fauna is specific to cetaceans and large vessels, however there is increasing research on other marine species, especially within coastal areas frequented by smaller vessels. Schoeman et al. (2020) broadly divided the reasons for vessel-marine animal collisions into three categories:

1. Vessel-related factors.
2. Animal-related factors.
3. High risk areas.

5.3.1 Vessel-Related Factors

Factors such as vessel speed, type and size are relevant in considering the risk of vessel impact on marine fauna. Vanderlaan and Tagart (2007) examined the influence of vessel speed of large ocean-going vessels in contributing to either a lethal injury (defined as killed or severely injured) or a non-lethal injury (defined as minor or no apparent injury) to a large whale when struck (Figure 5-1). A logistic regression model fitted to the observations demonstrated that the greatest rate of change in the probability of a lethal injury (P_{lethal}) to a large whale occurred between vessel speeds of 8.6 and 15 knots where P_{lethal} increases from 0.21 to

0.79. The probability of a lethal injury drops below 0.5 at 11.8 knots. Above 15 knots, P_{lethal} asymptotically approaches 1. The uncertainties in the logistic regression estimates are relatively large at relatively low speeds (e.g. at 8 knots the probability is 0.17 with a 95% confidence interval [CI] of 0.03–0.6) (Vanderlaan and Taggart 2007). Small vessels travelling at a speed of 10 knots are likely to have a lower probability of lethal injury for whales. Laist et al. (2001) suggest that all sizes and types of vessel have been involved in collisions (from cargo ships to sailing vessels), although severe or lethal impacts were largely restricted to vessels over 80m in length. Quantifying the rate of occurrence of these collisions is difficult because many incidents are not detected (particularly from large vessels) and go unreported (Peel et al. 2018). Collision reports for smaller marine species are generally scarce, likely due to a reporting bias rather than being less frequent. In addition, fatal collisions with most cetaceans and marine turtles likely go unnoticed because carcasses of these species sink quickly (Schoeman et al. 2020). Although the most fatal injuries are reported from larger vessels, the speed at which the vessel travels has the greatest bearing on the severity of injury. In addition to a high probability of lethal injury, high vessel speeds result in a decreased probability of detection of marine animals by vessel operators and vice versa (Hazel et al. 2007).

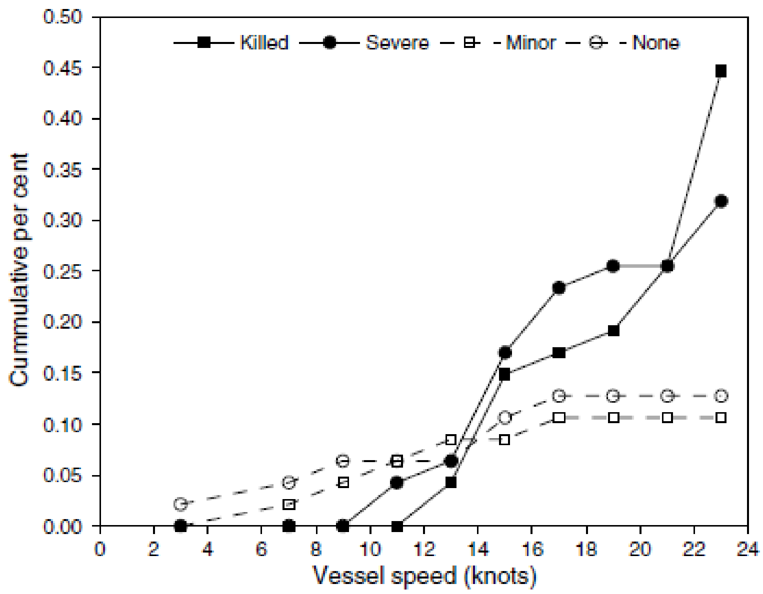

Figure 5-1. Probability of cetacean injury in relation to vessel speed (source: Vanderlann & Taggart (2007))

The main risk of physical interaction with marine fauna during construction of the Proposal will be in relation to the movement of construction support vessels (e.g. survey vessels, crew transfer vessel and barges) and the CSD (the impacts of which have been addressed in the DSDMMP developed for the Proposal). These vessels will be stationary during most of the works. When moving within the Proposal footprint, the CSD and support vessels will transit at low speeds (<10 knots) and only over small distances during each move.

Physical interaction between marine fauna and the OGVs and TSVs will remain a possibility throughout operations. Cetaceans and marine turtles may potentially occur within proximity to the jetty and transhipping route.

The potential for Proposal-related vessel traffic to impact marine fauna will mainly be influenced by:

- The size of vessel;
- The operating speed of the vessel; and
- The number of vessel movements.

The type and size of vessels related to the Proposal have been detailed in Section 3.2. Proposed vessel sizes and the estimated number of movements are approximately half the size/quantity of the current CITIC operations in the area. The average speed at which the proposed OGVs cruise is between 13 and 17 knots, a typical CSD transits at around 12 knots while tugs, barges and TSVs operate at around 10 knots – that is, speeds which would place them in the lower risk category for vessel strikes (refer to Section 5.3). Only the OGVs and work/pilot vessel will have the ability to reach speeds above 15 knots. Research has shown that the probability for vessels to collide with marine fauna is directly related to the speed at which the vessel travels, and can be limited by reducing operational speeds to <13 knots (Laist et al. 2001; Schoeman et al. 2020; Vanderlaan and Taggart 2007). Thiele (2010) has demonstrated small fast-moving vessels operating in the nearshore are a bigger threat to marine fauna, specifically dolphins, than larger vessels working offshore.

Based on this information we may assume that although overall vessel traffic in the Proposal area will increase, only the OGVs and work/pilot vessel will operate at the speeds required to have a significant potential to impact marine fauna. The exact number of movements by the pilot vessel is currently unknown and will be determined by demand but is estimated to be at least one return movement between Cape Preston East and the pilot boarding ground for each of the estimated 90 OGV visits. Pilot vessel transits and OGVs approaching and departing their anchorage location will mostly occur in port waters and would be subject to Port controls. Outside of port-controlled waters, there is minimal capacity to regulate the speed or passage of OGVs. However, it is important to note the density of vessel movements outside the port area is an order of magnitude less than inside the port area (refer to Section 5.3.3). Thus, most of the key vessel movements can be controlled.

5.3.2 Animal-Related Factors

Dolman et al. (2006) determined that cetaceans are more likely to be hit if they are young or sick, slow swimmers, distracted by feeding or mating activities or congregated in an area for feeding or breeding. There are conflicting studies regarding the response of certain large whale species to vessels (Schoeman et al. 2020). Some researchers suggest that large whale species, such as the humpback, can detect and change course to avoid a vessel over large distances, sometimes kilometres from the approaching vessel. Others maintain that whales allow vessels to approach very closely before they react, particularly when feeding or socialising. Further, blue whales at the surface have been found to be limited in their ability to avoid collisions with fast ships because individuals responded to approaching ships with a slow descent and no lateral movement away from the ship.

The probability of being struck can be influenced by species and population differences. One important factor is the amount of time a species spends at or near the surface, due to behavioural patterns, because at the surface marine animals are within reach of a vessel's hull and/or propeller (Schoeman et al. 2020).

The following sections show that vessel speed and approach direction are the primary factors that disrupt normal behaviour or elicit an agonistic response in the marine fauna occurring in the Proposal area.

5.3.2.1 MARINE MAMMALS

Stamation et al. (2009) assessed the short-term responses of humpback whales to whale-watching vessels during their southward migration in eastern Australia. While some individuals showed obvious signs of horizontal avoidance, others approached vessels, initiating interactions. Whale pods with calves were more sensitive to the presence of vessels than pods without calves. Dive times and the overall percentage of time whales spent submerged were higher in the presence of vessels, but respiration intervals did not differ. Some surface behaviours occurred less often in the presence of vessels. In the Ningaloo Marine Park, during swim with humpback whale experiences, Sprogis et al. (2020) showed that the most common type of vessel approach to place swimmers in the water was in the path of whales. During in-path approaches, vessels travelled significantly faster compared to when approaching from the side. When vessels approached in the whales' path, whales exhibited horizontal and vertical avoidance strategies by adopting a less predictable path, increasing turning angles away from the vessel, increasing swim speeds, and decreasing the duration of their dives. Whales displayed a higher frequency of agonistic behaviours when a vessel was <100 m distance from them compared to >100 m away.

Studies on humpback dolphin interactions with vessels have indicated that dolphins dove for a longer duration in areas of heavy vessel traffic or in the presence of an oncoming vessel. Dependent upon the type of vessel and the relative distance, dolphins might flee, continue their ongoing activity, perform a new activity, or approach the vessel. Whilst slow-moving vessels appeared not to cause immediate stress on the dolphin community, fast-moving vessels often cause disruption of behaviour and social life (Ng and Leung 2003). Similarly, the Indo-Pacific bottlenose dolphin has been reported to be less likely to stay in a resting or socialising activity and more likely to start travelling or foraging in response to the presence of vessels (Christiansen et al. 2010).

One of the primary responses of dugongs to the sound of an approaching boat is to move towards deeper water. Hodgson (2004) suggests that the point at which dugongs initiate their response to an approaching vessel is more likely to be a function of the distance of the vessel rather than its speed. The practical consequence of this behaviour is that when a vessel is approaching quickly, dugongs may fail to attempt to evade it until such time an impact is unavoidable (Hodgson 2004).

5.3.2.2 MARINE TURTLES

Hazel et al. (2007) conducted a field experiment to evaluate behavioural responses of green turtles to a research vessel approaching at slow, moderate or fast speed (4, 11 and 19 km h–1, respectively). Data were recorded for 1890 encounters with turtles sighted within 10 m of the research vessel's track. The proportion of turtles that fled to avoid the vessel decreased significantly as vessel speed increased, and turtles that fled from moderate and fast approaches did so at significantly shorter distances from the vessel than turtles that fled from slow approaches.

Whittlock et al. (2017) found during an active dredging operation, flatback turtles increased their use of the dredging areas. Dive behaviour results showed turtles undertook longer and deeper resting dives during dredging, utilising the now deeper waters of the dredging areas. Despite their increased use and the presence of active dredge vessels, no events of injury or mortality were recorded during the study.

5.3.2.3 ELASMOBRANCHS (WHALE SHARKS, SAWFISH AND RAYS)

Whale sharks spend extended periods of time at the surface and their long migrations make them more susceptible to strikes from ships and propellers. A recent study of the Ningaloo population found that 15.5% of the sharks had evidence of major scarring, and 38.8% had minor or major scarring (Lester et al. 2020). Womersley et al. (2022) showed that, during their annual movements, whale sharks moving away from aggregations routinely crossed busy shipping routes. Furthermore, Womersley et al. (2022) noted observational anecdotes and formalised research dating back to the 1820s suggest that whale sharks show limited horizontal or vertical avoidance behaviours in the presence of vessels moving at normal operational speeds, even those approaching at close range.

Reef manta rays are known to exhibit diel movements, spending daylight hours inshore in shallow waters (<20 m), then moving back offshore to deeper waters at night (IUCN 2018). The species often exhibit avoidance behaviour in response to vessel presence. This can include changing their swimming patterns, diving deeper, or moving away from their preferred habitats (Perryman et al. 2022).

Specific studies on sawfish behaviour in response to a vessels approach are limited, however, the general pattern of a response can be inferred based on their preferred habitat, movement patterns and response to human disturbances. Green sawfish forage in shallow, sandy or muddy, substrate, hunting on the incoming and low tide. Morgan et al (2017) used acoustic telemetry to track individual green sawfish near Onslow and found they occupied depths up to 2 m and moved up to 10 km during each tidal cycle. In addition, analysis of the movements of acoustically tagged sawfish has shown that hard barriers (e.g. rock walls) cause individuals moving along the coast to turn around, rather than following the structure offshore into deeper water and continuing along the coast (Morgan and Lear, unpublished data). On this basis, sawfish like other elasmobranchs are likely to alter their typical movement patterns in response to an approaching vessel, such as swimming away, changing swimming speed and/or moving erratically.

5.3.3 High Risk Areas

Geographical location is an important factor to consider. The probability of collision between a vessel and a marine animal increases with a higher vessel and/or greater animal density i.e. within ports and shipping lanes or marine animal feeding or breeding grounds (e.g. BIAs). Most cetacean collisions occur on the continental shelf, reflecting high usage by both vessels and cetaceans (Laist et al. 2001).

Peel et al. (2019) quantified the relative risk of a vessel collision with nationally significant marine species relevant to this assessment (including the humpback whale, dugong and green turtle) in the waters around Australia. That work was conducted to address data acquisition and analysis objectives identified in the National Strategy for Reducing Vessel Strike on Cetaceans and other Marine Megafauna (Commonwealth of Australia 2017a). The study modelled the relative risk of a fatal collision with large (>80 m) vessels, and a collision with fast moving (>15 knots) vessels and smaller recreational vessels. Modelling was based on vessel data from AMSA and animal density data from the scientific literature. For WA, the study focussed on the humpback whale.

Peel et al. (2019) found the relative risk of vessel collision with the southern migration of the Western Australian population of humpback whales to be slightly higher than for the northern migration of the species. For the Pilbara Region, the relative risk of a fatal collision with humpback whales and large vessels was two times higher around Dampier and Port Hedland than around Cape Preston. In Cape Preston, the relative risk of a fatal collision was lower nearshore than offshore. The relative risk of a collision with smaller vessels was equivalent between Dampier and Cape Preston, and there was not much difference between nearshore and offshore areas. However, the relative risk of a collision with fast moving vessels and recreational vessels was lower in Cape Preston than other locations in the Pilbara, but the risk was higher nearshore than offshore. In general, the risk of collision was shown to be highest along the known shipping routes throughout the Pilbara.

For a generic marine species (assuming uniform animal density), the relative risk of a collision with a large vessel was less at Cape Preston compared to Dampier, but the risk of a fatal collision with a generic marine species was equivalent between these areas within the established shipping routes. For fast-moving vessels, the relative risk of a collision with a generic marine species was lower in Cape Preston compared to all other port locations in the Pilbara and the risk decreased with distance offshore.

O2 Marine (2023b) has discussed the BIAs for relevant marine fauna which overlap the Proposal area (refer to Table 2-2), the report findings are summarised below:

- Humpback whales may be encountered in the Proposal area during their northern and southern migrations. The Cape Preston area is not known to support calving, aggregation or feeding areas for this species and migrating whales typically remain well offshore. However, recent literature indicates humpback whale calving grounds may extend to include the nearshore waters from Camden Sound in the Kimberley to at least the North-West Cape in the Gascoyne Region. Given the uncertainty of humpback whale mother-calf behaviour within the Proposal area, O2 Marine suggest that the species may display the same behaviour in the waters adjacent to the Proposal as has been reported between Camden Sound and the North-West Cape.
- The blue whale distribution BIA is a broad area shown to overlap with the entire Pilbara coastal waters area. However, research has shown that these whales have a preference for offshore waters, migrating along the coastal slope, with limited use of the continental shelf. During their northern migration the blue whales move further offshore after they pass the North-West Cape. Therefore, in practice, it is unlikely blue whales would be encountered in the Proposal area.
- The flatback turtle inter-nesting BIA overlaps both nearshore and offshore marine components of the Proposal. The inter-nesting BIAs for the green turtle and hawksbill turtle overlap the proposed spoil ground location and may be encountered during construction of the Proposal.

Based on the above, the Proposal location was not considered a high-risk area for vessel collisions with blue whales. Similarly, Peel et al. (2019) did not consider Cape Preston to be a high-risk area for vessel collisions (of any marine species) compared to other locations in the Pilbara. Dredging activities during construction of the Proposal will increase the risk of an interaction with marine turtles, however these risks will be managed by the Proposal's DSDMMP. The proposed increase in vessel traffic from Proposal-related shipping is envisaged to increase the risk of marine fauna collision with large (>80 m) vessels offshore of Cape Preston but is not expected to be greater than the high-risk areas of Dampier and Port Hedland.

5.4 Recommended Vessel Collision Mitigation Measures

The risk of vessel collision cannot be eliminated entirely. The following measures are proposed to reduce the likelihood and severity of physical interaction between protected marine species and vessels under the control of the Proposal:

- Vessels under the control of the Proposal will travel no faster than 10 knots within port limits.
- Any time a vessel is underway, an observer (briefed in the identification of protected marine fauna species that may occur in the Proposal area) will monitor a Caution Zone (500 m or greater from any sighted whales and 50 m or greater from any other marine fauna species visible at the surface, unless the marine fauna is actively approaching the vessel) to ensure detection of that animal in time to take necessary measures to avoid striking the animal.
- EPBC Regulations 2000 – Part 8 Division 8.1 Interacting with cetaceans (Commonwealth of Australia 2017b) and the minimum separation distances between vessels and specified marine fauna species as required by the WA *Biodiversity Conservation Regulations 2018* will be applied as follows:
    - Proposal related vessels will not travel faster than six knots within 300 m of a cetacean or turtle (caution zone).
    - Proposal related vessels will not approach closer than 50 m for a dolphin or turtle and/or 100 m for a whale (with the exception of animals' bow-riding).
    - If the cetacean or turtle shows signs of being disturbed, Proposal related vessels will immediately withdraw from the Caution Zone at a constant speed of less than six knots.
    - Proposal related vessels will not travel faster than eight knots within 250 m of a whale shark and will not approach closer than 30 m to a whale shark.
    - Proposal related vessels will not approach, circle or wait in front of protected marine species for the purposes of casual viewing.
- Any incidents or injuries to marine fauna will be documented and reported to the port authority, as required, and to the DBCA under the WA *Biodiversity Conservation Act 2016*.

The actions of the OGVs will be under control of the Port and AMSA rather than the Proposal and it is expected that EPBC Act and State regulation will apply as above.

These mitigation measures were considered when scoring the risk assessment of potential vessel collision impacts, outlined in Section 7.

6 UNDERWATER NOISE IMPACT ASSESSMENT

6.1 Underwater Noise Sources and Potential Impacts

The assessment considered impacts to the relevant marine fauna of significance from the following Proposal related underwater noise generating activities:

- Activity 1 – Nearshore pile driving,
  - Pile driving of tubular piles for construction of the jetty approved under MS 949/1149.
  - Pile driving of sheet piles for construction of the seawater intake in McKay Creek.
- Activity 2 – Dredging action, CSD movements and two barges for material removal.
- Activity 3 – TSV movements (transit movements and berthing).
- Activity 4 – Operational noise of the seawater intake pump station in McKay Creek.

Sound is important for most marine animals. Sound production and detection serve key biological functions including communication, foraging, reproduction, navigation and predator avoidance (OSPAR 2009).

The potential impacts to marine fauna from underwater noise have been reviewed in detail (Erbe et al. 2019; ERM 2018; Finneran 2016; Hawkins and Popper 2017; OSPAR 2009; Popper and Hawkins 2019; Southall et al. 2019). The potential effects of noise can be broadly categorised into:

- Behavioural Impacts.
  - Behavioural response; and
    - displacement, attraction or avoidance.
  - Masking or interfering with biologically important sounds.
    - communication and echolocation.
- Physiological Impacts.
  - Stress, concussive effect and physical damage to tissues; and
  - Hearing damage and/or impairment.
    - Temporary – termed temporary threshold shift (TTS); or
    - Permanent – termed permanent threshold shift (PTS).

6.2 JASCO Acoustic Underwater Noise Modelling Study

The JASCO report detailing the results of the quantitative modelling study of acoustic underwater noise has been provided in Appendix B, it details:

- Sound types, acoustic metrics and sound propagation;
- The noise generated by pile driving, dredging, vessel movements and the seawater intake pump;
- Pile driving, dredging and vessel sound acoustic models;
- The methods and parameters of the study;
- The impacts of noise on relevant marine fauna species;
- Noise effect criteria for the marine fauna species relevant to the Proposal; and
- Estimated distance to behavioural response and auditory injury for the marine fauna species relevant to the Proposal from each noise generating activity.

The result of the assessment provided in the JASCO report was used to inform the risk assessment of potential underwater noise impacts, detailed in Section 7 of this document.

6.3 Underwater Noise Modelling Study – Executive Summary

JASCO performed a modelling study of underwater sound levels associated with proposed pile driving, dredging and vessel activities, and operation of a seawater intake pump as part of the environmental approvals process for the Leichhardt Eramurra Solar Salt Project, near Cape Preston in Northwestern Australia.

The modelling study specifically assessed distances from operations where underwater sound levels reached thresholds corresponding to behavioural response and acoustic impairment (TTS and PTS). The animals considered here included low-frequency cetaceans (LF-cetaceans, including the humpback whale and blue whale), high-frequency cetaceans (HF-cetaceans, including the Indo-Pacific bottlenose dolphin and Australian humpback dolphin), sirenians (including the dugong), fish (including elasmobranchs, fish larvae and eggs), and marine turtles.

The modelling methodology considered scenario-specific source levels and range-dependent environmental properties. Estimated underwater acoustic levels are presented as sound pressure levels (SPL, L_p); zero-to-peak pressure levels (PK, L_{pk}); and either single-strike (i.e., per-strike) or accumulated sound exposure levels (SEL, L_E) as appropriate for different noise effect criteria and noise sources.

In the study, the assessment period for SEL accumulation is defined as a 24-hour period over which sound energy may be integrated; the level is specified with the abbreviation SEL_{24h}. SEL_{24h} is a cumulative metric that reflects the dosimetric effect of noise levels within 24 hours, based on the assumption that a receiver (e.g., an animal) is consistently exposed to such noise levels at a fixed position. More realistically, marine mammals, fish, and marine turtles would not stay in the same location for 24 hours (especially in the absence of location-specific habitat) but rather a shorter period, depending on the animal's behaviour and the source's proximity and movements. Therefore, a reported radius for SEL_{24h} criteria does not mean that marine fauna travelling within this radius of the source will be impaired, but rather that an animal could be exposed to the sound level associated with impairment (either PTS or TTS) if it remained in that location for 24 hours. Results are thus conservative.

The key results of this acoustic modelling study are summarised in the sections below. Maps are provided in the JASCO report (Appendix B) to assist with contextualising tabulated distances.

6.3.1 Pile Driving Activities

The study predicted underwater sound levels associated with impact driving of two types of piles, cylindrical pipe piles (Scenario 1 – jetty construction approved under MS 949/1149) and sheet piles (Scenario 2 – seawater intake construction proposed in McKay Creek), for the Eramurra Solar Salt Project. The pile driving scenarios are based on approximated and likely designs and installation approaches using Leichhardt-supplied driveability for the Juntaan HHK 20S and Juntaan HHK 10S hammers, respectively.

6.3.1.1 MARINE MAMMALS

Table 6-1 summarises the distances to criteria for marine mammals:

- The maximum distance where the NOAA (2024) marine mammal behavioural response criterion of 160 dB re 1 µPa (SPL) for impulsive noise could be exceeded was 2.66 km from pipe pile driving (based on a pipe pile being driven to 10.1 m depth).
- The results for marine mammal injury considered the criteria from NMFS (2024). These criteria contain two metrics (PK and SEL_{24h}), both required for the assessment of marine mammal PTS and TTS. The furthest distance associated with either metric was applied for the assessment (i.e. SEL_{24h}), as summarised in Table 6-1.

Table 6-1. Summary of marine mammal results: Summary of maximum (Rmax) horizontal distances (in km) from piling activities to behavioural response thresholds and temporary threshold shift (TTS) and permanent threshold shift (PTS) for marine mammals showing the relevant metric.

Hearing Group	Maximum modelled distance to effect threshold (R_{max}) (km)					
	Behavioural Response		Impairment: TTS		Impairment: PTS	
	Pipe Pile	Sheet Pile	Pipe Pile	Sheet Pile	Pipe Pile	Sheet Pile
LF cetaceans	2.66	0.13	11.8 (SEL_{24h})	1.05 (SEL_{24h})	3.37 (SEL_{24h})	0.35 (SEL_{24h})
HF cetaceans			1.79 (SEL_{24h})	0.31 (SEL_{24h})	0.43 (SEL_{24h})	0.07 (SEL_{24h})
Sirenians			1.52 (SEL_{24h})	0.27 (SEL_{24h})	0.35 (SEL_{24h})	0.06 (SEL_{24h})

6.3.1.2 MARINE TURTLES

Table 6-2 summarises the distances to criteria for marine turtles:

- The PK marine turtle injury threshold of 232 dB re 1 µPa for PTS and 226 dB re 1 µPa for TTS from Finneran et al. (2017) were not predicted to occur.
- The maximum distance to the SEL_{24h} metrics for PTS and TTS onset for marine turtles (Finneran et al. 2017) was modelled to occur at 0.36 and 1.51 km from the pipe pile source, respectively. As is the case with marine mammals, a reported radius for SEL_{24h} criteria does not mean that marine turtles travelling within this radius of the source will be injured, but rather that an animal could be exposed to the sound level associated with either PTS or TTS if it remained in that location for 24 hours.
- The distances within which the criteria for behavioural response (166 dB re 1 µPa (SPL)) and behavioural disturbance (175 dB re 1 µPa (SPL)) (McCauley et al. 2000) could be exceeded for a pipe pile was at 1.59 and 0.78 km, respectively.

Table 6-2. Summary of marine turtle results: Summary of horizontal distances (in km) from piling activities to turtle behavioural response criteria, temporary threshold shift (TTS), and permanent threshold shift (PTS).

Hearing Group	Maximum modelled distance to effect threshold (R_{max}) (km)							
	Behavioural Response		Behavioural Disturbance		Impairment: TTS		Impairment: PTS	
	Pipe Pile	Sheet Pile	Pipe Pile	Sheet Pile	Pipe Pile	Sheet Pile	Pipe Pile	Sheet Pile
Marine turtles	1.59	0.05	0.78	-	1.51 (SEL_{24h})	0.13 (SEL_{24h})	0.36 (SEL_{24h})	-

A dash indicates the threshold is not reached within the limits of the modelling resolution (20 m).

6.3.1.3 FISH (INCLUDING SHARKS), FISH EGGS AND FISH LARVAE

The JASCO modelling study assessed the ranges for quantitative criteria based on Popper et al. (2014) and considered both PK and SEL_{24h} metrics associated with mortality and potential mortal injury as well as impairment.

Table 6-3 summarises distances to effect criteria for fish (including elasmobranchs), fish eggs, and fish larvae along with the relevant metric.

- Fish without a swim bladder (also appropriate for elasmobranchs in the absence of other information),
- Fish with a swim bladder that do not use it for hearing,
- Fish that use their swim bladders for hearing,
- Fish eggs and fish larvae.

Table 6-3. Summary of fish results from piling activities: Summary of maximum fish, fish eggs, and larvae injury and temporary threshold shift (TTS) onset distances 24-hour sound exposure level (SEL_{24h}) modelled scenarios.

Relevant Hearing Group	Effect Criteria	Water Column R_{max} (km)	
		Pipe Pile	Sheet Pile
Fish (also applied to elasmobranchs): No swim bladder	Mortality and potential mortal injury	0.06 (SEL_{24h})	-
	Recoverable injury	0.09 (SEL_{24h})	-
	TTS	2.71 (SEL_{24h})	0.31 (SEL_{24h})
Fish: Swim bladder not involved in hearing	Mortality and potential mortal injury	0.29 (SEL_{24h})	0.02 (SEL_{24h})
	Recoverable injury	0.64 (SEL_{24h})	0.06 (SEL_{24h})
	TTS	2.71 (SEL_{24h})	0.31 (SEL_{24h})
Fish: Swim bladder involved in hearing, and fish eggs and larvae (relevant to plankton)	Mortality and potential mortal injury	0.42 (SEL_{24h})	0.03 (SEL_{24h})
	Recoverable injury	0.64 (SEL_{24h})	0.06 (SEL_{24h})
	TTS	2.71 (SEL_{24h})	0.31 (SEL_{24h})

A dash indicates the threshold is not reached within the limits of the modelling resolution (20 m).

6.3.2 Dredging and Vessel Activities

The study predicted underwater sound levels associated with:

- Scenario 1 - Dredging action via a CSD, movement of the CSD and two barges, either alongside the dredge under dynamic positioning (DP), or transiting to the disposal area; and
- Scenario 2 - A TSV both berthing and transiting.

Vessel noise was modelled as a point source that is omni-directional, therefore variation in propagation in different directions is primarily influenced by bathymetric features.

6.3.2.1 MARINE MAMMALS

The maximum distances to the NOAA (2024) marine mammal behavioural response criterion of 120 dB re 1 µPa (SPL) was 3.17 km from the TSV movement noise source and 6.30 km from the noise associated with dredging activities (Table 6-4). The furthest TTS and PTS ranges were associated with low-frequency (LF) cetaceans. Table 6-4 summarises the maximum horizontal distances to frequency-weighted TTS and PTS thresholds (NMFS 2024) for each scenario.

Table 6-4. Summary of marine mammal results: Summary of maximum (R_{max}) horizontal distances (in km), from dredging and vessel movements to the marine mammal behavioural response criterion of 120 dB re 1 μPa (SPL) and frequency-weighted TTS and PTS thresholds (with frequency-weighting in parentheses) based on NMFS (2024). Ensonified areas are also provided for TTS and PTS thresholds.

Scenario	Marine Mammal Behavioural Response – SPL R_{max} (km)	TTS – SEL_{24h}		PTS - SEL_{24h}	
		R_{max} (km)	Area (km²)	R_{max} (km)	Area (km²)
Dredging, CSD + 2 Barges	6.30	2.21 (LF-cetacean)	9.61	0.33 (LF-cetacean)	0.32
		0.24 (HF-cetacean)	0.15	0.01 (HF-cetacean)	/
		0.05 (Sirenians)	0.01	- (Sirenians)	/
TSV Movement	3.17	0.17 (LF-cetacean)	0.26	-	/
		- (HF-cetacean)	/	- (HF-cetacean)	/
		- (Sirenians)	/	- (Sirenians)	/

A dash indicates the level was not reached within the limits of the modelled resolution (10 m).
A slash indicates that the area is less than an area associated with the modelled resolution (0.0013 km²)

6.3.2.2 MARINE TURTLES

The threshold criteria from Finneran et al. (2017) were used to assess PTS and TTS for marine turtles. For the dredging scenario, the maximum distance to threshold were 260 m for TTS and 10 m for PTS. For the TSV movements, TTS and PTS for marine turtles was not exceeded within the modelling resolution (10 m).

6.3.2.3 FISH

Sound produced by the modelled dredging reached the sound levels associated with recoverable injury and TTS for fish species with a swim bladder involved in hearing in close proximity to the sound sources (Table 6-5). In order for the thresholds to be exceeded, the fish must remain within those distances for either 48 or 12 h, respectively.

Sound levels associated with recoverable injury and TTS for fish species without a swim bladder (i.e. those relevant to this assessment) were not reached.

Table 6-5. Summary of fish (with a swim bladder involved in hearing)results: Maximum (R_{max}) horizontal distances (in km), from dredging and vessel movements, to sound pressure level (SPL) criteria based on Popper et al. (2014).

Scenario	Description	Maximum (R_{max}) distance to threshold (km)	
		Recoverable injury (48 h)	TTS (12 h)
1	Dredging, CSD + 2 Barges	0.01	0.11
2	TSV Movement	-	-

A dash indicates the level was not reached within the limits of the modelled resolution (10 m).

6.3.3 Intake Pump Activities

For the modelling of the intake pump, the thresholds used for assessing marine mammal behaviour included the 120 dB re 1 µPa (SPL) behavioural response threshold from NOAA (2024) and the frequency-weighted TTS and PTS thresholds from NMFS (2024). For marine turtle species within the area, the PTS and TTS threshold criteria from Finneran et al. (2017) were used, and for fish species within the area, the recoverable injury and TTS thresholds from Popper et al. (2014) were used.

The modelled intake pump noise was too quiet to reach any of the noise exposure threshold criteria for marine mammals, marine turtles or fish within the modelling resolution of 10 m.

The bathymetry of McKay Creek significantly inhibits the propagation of sound from the intake pump. Due to the shallowness of the creek (2.1 m at the intake pump) and the modelled sandy bottom, low frequencies at approximately 340 Hz or lower are cut off (Jensen et al. 2011). This cuts off the bulk of the sound produced by the intake pump, which are concentrated towards lower frequencies. It is also worth noting that the meandering path of the creek and the modelled sandy bottom also make it difficult for the sound to propagate far, with there being no line-of-sight from the intake pump site to deep waters.

For these reasons, the modelled noise from the intake pumps do not exceed any of the thresholds for marine mammals, marine turtles, or fish. The noise was modelled for highest astronomical tide to provide a conservative estimate of propagation distances.

6.4 Recommended Underwater Noise Mitigation Measures

The recommended management measures for the prevention of injury to marine megafauna (cetaceans, marine turtles and fish) from potential underwater noise impacts are:

- Conducting checks for marine megafauna in the immediate vicinity of operations prior to start-up of operations. Checks should be made by a person suitably qualified to identify marine megafauna.
- Implementing a soft start procedure for any impact hammer piling activities.
- Applying practical observation and shut down zones during pile driving activities based on the JASCO modelling results. In addition, the Government of South Australia published the *Underwater Piling Noise Guidelines* (DPTI 2012), which are adapted from EPBC Act Policy Statement 2.1 – *Interaction between offshore seismic exploration and whales*. The piling noise guidelines provide practical management and mitigation measures for the purpose of minimising the risk of injury to occur in marine fauna within the vicinity of piling activities, consistent with international good practice.
- Applying practical observation/exclusion zones during dredging activities and vessel movements based on the JASCO modelling results.
- Use of a spotter vessel or maintain communication with the port authority regarding sightings of marine megafauna if clear observations cannot be made from land.
- Stopping construction activity when marine megafauna are observed within the adopted observation/exclusion zones; until the animals have moved beyond the extent or have not been sighted for 30 minutes.

These mitigation measures were considered when scoring the risk assessment of potential underwater noise impacts, outlined in Section 7.

7 RISK ASSESSMENT OF POTENTIAL IMPACTS

7.1 Risk Assessment

An assessment of the risks of the Proposal's construction and operation activities (specifically underwater noise and vessel collision impacts) to environmental values at Cape Preston has been undertaken. The risk assessment was undertaken using a systematic approach, based on international best practice standards (AS/NZS ISO 31000:2018: Risk Management – Guidelines), of assigning a consequence and probability to potential negative outcomes.

Risk ratings were assigned to each impacting activity using the risk matrix in Appendix A.

The assessment of inherent risks for underwater noise impacts has assumed the worst-case scenario i.e. the furthest modelled distance associated with a marine mammal injury (the maximum horizontal distances for a behavioural response and exceedance of frequency-weighted TTS and PTS thresholds for marine turtles and fish were much less than for marine mammals).

Table 7-1 presents the outcomes of the risk assessment, including the inherent and residual risks after proposed mitigation measures, as detailed in Section 5 and 6 of this document.

Table 7-1. Risk assessment of underwater noise and vessel collision impacts to marine fauna and management controls

Scenario	Potential Impact	Cause	Consequence	Likelihood	Inherent Risk	Mitigation Measures	Consequence	Likelihood	Residual Risk
Interaction of marine megafauna with: • Transit of dredging and support vessels during construction • Transit of Proposal-related shipping	Injury to or fatality of marine megafauna (including protected species).	• Proposal-related vessel collision with marine megafauna.	3	C	Mod	• Vessels will be contractually required to comply with all relevant maritime legislation and operate safely and use only authorised shipping routes for all travel. • Vessels will comply with all requests from AMSA and the relevant harbour master unless it is unsafe to do so.	3	E	Low

Scenario	Potential Impact	Cause	Consequence	Likelihood	Inherent Risk	Mitigation Measures	Consequence	Likelihood	Residual Risk
and vessel traffic during operations.						• Vessel tracking systems, including automated identification systems (AIS) will be used on all Proposal related vessels. • Vessels under the control of the Proposal will travel no faster than 10 knots within port limits. • When a vessel under the control of the Proposal is in transit, an observer will monitor a Caution Zone (refer to Section 5.4 for definition) to ensure detection of that animal in time to take necessary measures to avoid striking the animal. • If a whale (including mother and calf pair) or whale shark are identified within 500 m of the forward path of a vessel under the control of the Proposal, the vessel master will steer a course away from the animal at six knots or less until the 500 m minimum separation distance has been established.			

Scenario	Potential Impact	Cause	Consequence	Likelihood	Inherent Risk	Mitigation Measures	Consequence	Likelihood	Residual Risk
						Vessels may also reduce to idling speed if feasible. • EPBC Regulations 2000 - Part 8 Division 8.1 and the minimum separation distances between vessels and specified marine fauna species as required by the WA *Biodiversity Conservation Regulations 2018* will be applied (refer to Section 5.4 for details). • A watch will be maintained throughout Proposal operations for stranded, injured or dead marine fauna; if observed, the DBCA Wildcare Helpline (08 9474 9055) will be contacted for advice on retrieval, treatment or post-mortem by the DBCA Parks and Wildlife Service.			
Noise emissions from: • Cylindrical pipe pile driving for construction of the	Behavioural and physiological impacts to marine megafauna (detail provided in Section 6.1 and Appendix B).	• Proposal-related cylindrical pipe pile driving related noise (detail provided in Appendix B).	3	B	High	• Conduct checks for marine megafauna in the immediate vicinity of operations using a qualified marine fauna observer.	2	D	Low

Scenario	Potential Impact	Cause	Consequence	Likelihood	Inherent Risk	Mitigation Measures	Consequence	Likelihood	Residual Risk
trestle jetty at Cape Preston East Port						• Implement a soft start procedure. • Apply observation zones for relevant marine megafauna species in accordance with DPTI (2012) guidelines during pile driving activities. • Use a spotter vessel or maintain communication with the port authority regarding sightings of marine megafauna if clear observations cannot be made from land. • Stop pile driving activity when marine megafauna are observed within shut-down zones for relevant marine megafauna species in accordance with DPTI (2012) guidelines during pile driving activities.; until the animals have moved beyond 500 m or have not been sighted for 30 minutes. • Only conduct piling activities during daylight hours.			
Noise emissions from: • Sheet pile driving for construction of the seawater intake in McKay Creek.	Behavioural and physiological impacts to marine megafauna (detail provided in Section 6.1 and Appendix B).	• Proposal-related sheet pile driving related noise (detail provided in Appendix B).	2	C	Mod		2	D	Low

Scenario	Potential Impact	Cause	Consequence	Likelihood	Inherent Risk	Mitigation Measures	Consequence	Likelihood	Residual Risk
Noise emissions from: • Dredging during construction.	Behavioural and physiological impacts to marine megafauna (detail provided in Section 6.1 and Appendix B).	• Proposal-related dredging vessel and dredging action related noise (detail provided in Appendix B).	2	C	Mod	• Ensure all dredging equipment and machinery is in good condition and subject to regular maintenance while engaged on the Project. • Conduct checks for marine megafauna in the immediate vicinity of operations using a qualified marine fauna observer. • Apply the observation zones recommended by the Proposal Dredging Spoil and Disposal Monitoring and Management Plan during dredging and disposal activities. • When in transit, all Project vessels will be operated in accordance with EPBC Regulations 2000 – Part 8 Division 8.1 and the minimum separation distances between vessels and specified marine fauna species as required by the WA *Biodiversity Conservation Regulations 2018* (refer to Section 5.4 for details).	2	D	Low

Scenario	Potential Impact	Cause	Consequence	Likelihood	Inherent Risk	Mitigation Measures	Consequence	Likelihood	Residual Risk
						• Minimise the duration of run-time for vessel engines by avoiding stand-by or running mode to the degree practical and consistent with safe operations.			
Noise emissions from: • Proposal-related shipping and vessel traffic (i.e. TSVs) during operations.	Behavioural and physiological impacts to marine megafauna (detail provided in Section 6.1 and Appendix B).	• Proposal-related shipping and vessel traffic related noise (detail provided in Appendix B).	2	C	Mod	• Ensure all vessel equipment and machinery is in good condition and subject to regular maintenance while engaged on the Project. • When in transit, all Project vessels will be operated in accordance with EPBC Regulations 2000 – Part 8 Division 8.1 and the minimum separation distances between vessels and specified marine fauna species as required by the WA *Biodiversity Conservation Regulations 2018* (refer to Section 5.4 for details). • Minimise the duration of run-time for vessel engines by avoiding stand-by or running mode to the degree practical	2	D	Low

Scenario	Potential Impact	Cause	Consequence	Likelihood	Inherent Risk	Mitigation Measures	Consequence	Likelihood	Residual Risk
						and consistent with safe operations.			
Noise emissions from: • Operation of the seawater intake pumps	Behavioural and physiological impacts to marine megafauna (detail provided in Section 6.1 and Appendix B).	• Proposal-related seawater intake pump related noise (detail provided in Appendix B).	1	E	Low	N/A - The modelled seawater intake pump noise was too quiet to reach any of the noise exposure threshold criteria for marine mammals, marine turtles or fish	1	E	Low

7.2 Risk Assessment Summary

7.2.1 Vessel Collision

The residual vessel collision risk to marine fauna from the Proposal was considered to be low, but greater than negligible:

- Cape Preston is an existing facility which has been in operation since 2013. No incidents of marine fauna strike were found in the literature as a result of port operations in this time.
- OGVs will be piloted within port limits and will operate at speeds (≤10 knots) which are not considered to provide a risk of significant impact on marine fauna.
- During operations the Proposal will increase existing vessel traffic, in the category which has the potential to significantly impact marine fauna, by just 12.5%.

The application of controls including observations, separation distances, reporting and vessel speed limitations reduces the likelihood and consequence of vessel strike for all species and complies with current marine fauna interaction guidelines (Part 8 of the EPBC regulations 2000 and the *Biodiversity Conservation Regulations 2018*). Therefore, after accounting for the low level of risk, the management actions for marine fauna disturbance identified in this assessment are comparable with the current practices used by other operators of export facilities in Australia.

7.2.2 Underwater Noise

On the basis of the JASCO underwater noise modelling study, the following conclusions can be drawn regarding the risk of underwater noise impacts to marine fauna from the Proposal's construction and operational activities. Noting a reported radius for SEL_{24h} criteria does not mean that marine fauna travelling within this radius of the source will be injured, but rather that an animal could be exposed to the sound level associated with either PTS or TTS if it remained in that location for 24 hours.

<u>Pile Driving</u>

- The inherent risk to dugongs, marine turtles, elasmobranchs and fish of interest from the Proposal's pile driving activities was considered moderate for both cylindrical pipe pile driving and sheet pile driving.
    - The onset of TTS and PTS for dugongs using the worst case SEL_{24h} criteria did not extend beyond 1.52 km and 350 m, respectively, from the cylindrical pipe pile driving noise source. For sheet pile driving, predicted sound levels for impairment extended for 270 m (TTS) and 60 m (PTS) from the noise source.
    - The onset of TTS and PTS for marine turtles were comparable to those for dugongs at 1.51 km and 360 m, respectively, from the cylindrical pipe pile driving. Onset of TTS during sheet pile driving was predicted to extend for 130 m from the noise source. Onset of PTS in marine turtles was not predicted to occur during sheet pile driving. Sound levels triggering a behavioural response did not extend beyond 1.59 km and 50 m of the pipe pile driving and sheet pile driving noise source, respectively.
    - Onset of TTS for fish and elasmobranchs did not extend beyond 2.71 km and 310 m from the cylindrical pipe and sheet pile driving noise source, respectively. An impact level consistent with a recoverable injury or potential mortal injury extended for 90 m and 60 m from the pipe pile driving noise source, respectively. Injury (recoverable or mortal) of fish and elasmobranchs was not predicted to occur during sheet pile driving activities.
- The inherent risk to marine mammals (excluding dugongs) was considered high for the cylindrical pipe pile driving and moderated for the sheet pile driving noise sources.

    - A marine mammal behavioural response did not extend beyond 2.66 km and 130 m of the cylindrical pipe pile driving and sheet pile driving noise source, respectively.
    - Onset of TTS and PTS for the low frequency (LF) cetacean group, including humpback whales, using the worst case SEL_{24h} criteria was did not extend beyond 11.8 km and 3.37 km, respectively, of the pipe pile driving sound source. This extent was reduced to 1.05 km (TTS) and 350 m (PTS) for the sheet pile driving noise source.
    - Onset of TTS and PTS for the high frequency (HF) cetacean, including the Indo-Pacific bottlenose dolphin and Australian humpback dolphin, was predicted to extend for 1.79 km and 430 m, respectively, for the cylindrical pipe pile driving noise source. This extent was reduced to 310 m (TTS) and 70 m (PTS) from the sheet pile driving noise source.

<u>Dredging Activities</u>

- The inherent risk the marine fauna of interest from dredging activities was considered moderate.
    - A marine mammal behavioural response was estimated to extend for 6.3 km from the dredging noise source.
    - Onset of TTS and PTS for the low frequency (LF) cetacean group, including humpback whales, using the worst case SEL_{24h} criteria did not extend beyond 2.21 km and 330 m, respectively, from the dredging noise source.
    - Onset of TTS and PTS for the high frequency (HF) cetacean, including the Indo-Pacific bottlenose dolphin and Australian humpback dolphin, was estimated to extend for 240 m and 10 m, respectively, of the dredging noise source.
    - Onset of TTS in dugongs, using the worst case SEL_{24h} criteria, extends for 50 m from the dredging noise source. Onset of PTS in dugongs was not predicted to occur during dredging activities.
    - Onset of TTS and PTS in marine turtles did not extend beyond 260 m and 10 m, respectively, from the dredging noise source.
    - Dredging noise criteria thresholds for fish without a swim bladder (relevant to this assessment) were not reached.

<u>TSV Movements</u>

- The inherent risk to the marine fauna of interest from TSV movements (transit and berthing), with the exception of the LF cetacean group, was considered low.
    - TSV movement noise criteria thresholds were not reached.
- The risk to LF cetaceans, including humpback whales, was considered moderate.
    - Onset of TTS in LF cetaceans did not extend beyond 170 m from TSV operations.

<u>Seawater Intake</u>

- The inherent risk to the marine fauna of interest from operation of the seawater intake pump was considered low.
    - The modelled intake pump noise was too quiet to reach any of the noise exposure threshold criteria for marine mammals, marine turtles or fish within the modelling resolution of 10 m.

The application of underwater noise management controls (including observations, applying exclusion/shut down zones, soft start procedures, equipment maintenance and compliance with State and Commonwealth regulations) reduces the probability of marine megafauna being within the vicinity of active construction operations. As such, the residual risks of the Proposal's noise generating activities impacting on marine fauna were assessed as low.

7.2.3 Conclusions

Mapping of areas of risk of vessel operations or marine noise demonstrates that these risks are confined to areas of existing disturbance from current port operations and are cumulative in nature rather than novel impacts. Noise impacts and the density of vessel movements will be greatest during construction activity. Such activity is limited in time, rather than extending over years and is predominantly in inshore areas which minimises impacts on more offshore marine fauna.

The probability of marine megafauna being within the vicinity of active construction operations for sufficient time periods to accumulate the requisite length of exposure to noise at damaging levels and the mitigating potential of the recommended management measures, further reduce risk profiles.

Overall, risks for noise generating activities and vessel collision impacts were assessed as low.

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9 APPENDIX A – RISK ASSESSMENT MATRIX

	Consequence	1-Insignificant Localised disturbance to marine fauna that is confined to the operating footprint and can be rectified or reversed within a day	2-Minor Localised harm to marine fauna that is confined to the operating footprint and can be rectified or reversed within weeks of work effort or natural recovery	3-Moderate Harm to regionally significant marine fauna that can be rectified or reversed within weeks to months of work effort or natural recovery	4-Major Harm to nationally significant marine fauna that can be rectified or reversed within months to years of work effort or natural recovery	5-Catastrophic Widespread harm to globally significant marine fauna that can be rectified or reversed within years to decades of work effort or natural recovery
Likelihood	**A-Almost certain** Recurring event during the lifetime of an operation / project. Occurs more than twice per year	Moderate	High	High	Critical	Critical
	B-Likely Event that may occur frequently during the lifetime of an operation / project. Typically occurs once or twice per year	Moderate	Moderate	High	High	Critical
	C-Possible Event that may occur during the lifetime of an operation / project. Typically occurs in 1-10 years	Low	Moderate	Moderate	High	Critical
	D-Unlikely Event that is unlikely to occur during the lifetime of an operation / project. Typically occurs in 10-100 years	Low	Low	Moderate	Moderate	High
	E-Rare Event that is very unlikely to occur during the lifetime of an operation / project. Greater than 100-year event	Low	Low	Low	Moderate	High

10 APPENDIX B – JASCO UNDERWATER NOISE MODELLING STUDY REPORT

Eramurra Solar Salt Project

Acoustic Modelling for Assessing Marine Fauna Sound Exposures

JASCO Applied Sciences (Australia) Pty Ltd

23 January 2025

Submitted to:

Iain Posnett

MScience Marine Research

Order No. MSA314–03

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P001942-001

Document 03672

Version 2.0

Suggested citation:

Stephen, T.J, S.C. Connell, S. Li, and C.R. McPherson. 2025. Eramurra Solar Salt Project: Acoustic Modelling for Assessing Marine Fauna Sound Exposures. Document 03672, Version 2.0. Technical report by JASCO Applied Sciences for MScience Marine Research.

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Executive Summary

JASCO Applied Sciences (JASCO) performed a modelling study of underwater sound levels associated with proposed pile driving, dredging, and vessel activities as part of the environmental approvals process for the Leichhardt Eramurra Solar Salt Project, near Cape Preston in Northwestern Australia.

The modelling study specifically assessed distances from operations where underwater sound levels reached thresholds corresponding to behavioural response and acoustic impairment (temporary threshold shift (TTS), and permanent threshold shift (PTS)). The animals considered here included low- and high-frequency cetaceans, sirenians, fish (including fish larvae and eggs), and sea turtles.

The modelling methodology considered scenario-specific source levels and range-dependent environmental properties. Estimated underwater acoustic levels are presented as sound pressure levels (SPL, L_{p}); zero-to-peak pressure levels (PK, L_{pk}); and either single-strike (i.e., per-strike) or accumulated sound exposure levels (SEL, L_{E}) as appropriate for different noise effect criteria and noise sources.

In this report, the assessment period for SEL accumulation is defined as a 24-hour period over which sound energy may be integrated; the level is specified with the abbreviation SEL_{24h}. SEL_{24h} is a cumulative metric that reflects the dosimetric effect of noise levels within 24 hours, based on the assumption that a receiver (e.g., an animal) is consistently exposed to such noise levels at a fixed position. More realistically, marine mammals, fish, and sea turtles would not stay in the same location for 24 hours (especially in the absence of location-specific habitat) but rather a shorter period, depending on the animal’s behaviour and the source’s proximity and movements. Therefore, a reported radius for SEL_{24h} criteria does not mean that marine fauna travelling within this radius of the source will be impaired, but rather that an animal could be exposed to the sound level associated with impairment (either permanent threshold shift (PTS) or temporary threshold shift (TTS)) if it remained in that location for 24 hours.

The key results of this acoustic modelling study are summarised in the marine mammal, sea turtle and fish sections below. Maps are provided in the report to assist with contextualising tabulated distances.

Pile Driving Activities

Marine mammals

Table 1 summarises the distances to criteria for marine mammals.

- The maximum distance where the NOAA (2024) marine mammal behavioural response criterion of 160 dB re 1 µPa (SPL) for impulsive noise could be exceeded was 2.66 km from the pile.
- The results for marine mammal injury considered the criteria from NMFS (2024). These criteria contain two metrics (PK and SEL_{24h}), both required for the assessment of marine mammal PTS and TTS. The longest distance associated with either metric is required to be applied for assessment as summarised in Table 1.

Table 1. Summary of marine mammal results: Summary of maximum (R_{max}) horizontal distances (in km) from piling activities to behavioural response thresholds and temporary threshold shift (TTS) and permanent threshold shift (PTS) for marine mammals showing the relevant metric.

Hearing group	Maximum modelled distance to effect threshold (R_{max})		
	Behavioural response[1] (km)	Impairment (km): TTS[2]	Impairment (km): PTS[2]
LF cetaceans	2.66	11.8 (SEL_{24h})	3.37 (SEL_{24h})
HF cetaceans		1.79 (SEL_{24h})	0.43 (SEL_{24h})
Sirenians		1.51 (SEL_{24h})	0.35 (SEL_{24h})

Noise exposure criteria: [1] NOAA (2024) and [2] NMFS (2024).

Sea turtles

Table 2 summarises the distances to criteria for sea turtles.

- The PK sea turtle injury threshold of 232 dB re 1 µPa for PTS and 226 dB re 1 µPa for TTS from Finneran et al. (2017) were not predicted to occur.
- The maximum distance to the SEL_{24h} metrics for PTS and TTS onset for sea turtles (Finneran et al. 2017). As is the case with marine mammals, a reported radius for SEL_{24h} criteria does not mean that sea turtles travelling within this radius of the source will be injured, but rather that an animal could be exposed to the sound level associated with either PTS or TTS if it remained in that location for 24 hours.
- The distances within which the criteria for behavioural response (166 dB re 1 µPa (SPL)) and behavioural disturbance (175 dB re 1 µPa (SPL)) (McCauley et al. 2000) could be exceeded.

Table 2. Summary of sea turtle results: Summary of horizontal distances (in km) to turtle behavioural response criteria, temporary threshold shift (TTS), and permanent threshold shift (PTS).

Hearing group	Maximum modelled distance to effect threshold (R_{max}) (km)			
	Behavioural response[1]	Behavioural disturbance[2]	Impairment: TTS[3]	Impairment: PTS[3]
Sea Turtles	1.59	0.78	1.51 (SEL_{24h})	0.36 (SEL_{24h})

Noise exposure criteria: [1,2] McCauley et al. (2000), and [3] Finneran et al. (2017)
A dash indicates the level was not reached within the limits of the modelled resolution (10 m).

Fish, fish eggs, and fish larvae

This modelling study assessed the ranges for quantitative criteria based on Popper et al. (2014) and considered both PK and SEL_{24h} metrics associated with mortality and potential mortal injury as well as impairment in the following groups.

Table 3 summarises distances to effect criteria for fish, fish eggs, and fish larvae along with the relevant metric.

- Fish without a swim bladder (also appropriate for sharks in the absence of other information),
- Fish with a swim bladder that do not use it for hearing,
- Fish that use their swim bladders for hearing,
- Fish eggs and fish larvae.

Table 3. Summary of fish results: Summary of maximum fish, fish eggs, and larvae injury and temporary threshold shift (TTS) onset distances for single impulse (PK) and 24-hour sound exposure level (SEL_{24h}) modelled scenarios.

Relevant hearing group	Effect criteria	Water column	
		Metric associated with longest distance to criteria	R_{max} (km)
Fish: No swim bladder	Mortality and potential mortal injury	SEL_{24h}	0.06
	Recoverable injury	SEL_{24h}	0.09
	TTS	SEL_{24h}	2.71
Fish: Swim bladder not involved in hearing	Mortality and potential mortal injury	SEL_{24h}	0.29
	Recoverable injury	SEL_{24h}	0.64
	TTS	SEL_{24h}	2.71
Fish: Swim bladder involved in hearing and Fish eggs, and larvae (relevant to plankton)	Mortality and potential mortal injury	SEL_{24h}	0.42
	Recoverable injury	SEL_{24h}	0.64
	TTS	SEL_{24h}	2.71

Dredging and Vessel Activities

Marine mammals

The maximum distances to the NOAA (2024) marine mammal behavioural response criterion of 120 dB re 1 µPa (SPL) ranged from 3.17 km (Scenario 2) to 6.30 km (Scenario 1) (Table 4). The longest TTS and PTS ranges were associated with low-frequency (LF) cetaceans.
Table 4 summarises the maximum horizontal distances to frequency-weighted TTS and PTS thresholds (NMFS 2024) for each scenario.

Table 4. Summary of marine mammal results : Summary of maximum (R_{max}) horizontal distances (in km), from all scenarios considered, to the marine mammal behavioural response criterion of 120 dB re 1 µPa (SPL) and frequency-weighted TTS and PTS thresholds (with frequency-weighting in parentheses) based on NMFS (2024). Ensonified areas are also provided for TTS and PTS thresholds.

Scenario Number	Description	Marine Mammal Behavioural Response - SPL [a] R_{max} (km)	TTS - SEL_{24h} [b]		PTS - SEL_{24h} [b]	
			R_{max} (km)	Area (km^2)	R_{max} (km)	Area (km^2)
1	Dredging, CSD + 2 Barges	6.30	2.21 (LF-cetacean)	9.61	0.33 (LF-cetacean)	0.32
2	TSV Movement	3.17	0.17 (LF-cetacean)	0.26	–	–

Noise exposure criteria: [a] NOAA (2024) and [b] NMFS (2024).
A dash indicates the level was not reached within the limits of the modelled resolution (10 m).

Sea turtles

The threshold criteria from Finneran et al. (2017) were used to assess PTS and TTS for sea turtles. Across both scenarios, the maximum distances to threshold were 260 m for TTS and 10 m for PTS, both for scenario 1. For scenario 2, TTS and PTS for sea turtles was not exceeded within the modelling resolution (10 m), if at all.

Fish

Sound produced by the modelled dredging and vessel activities reached the sound levels associated with recoverable injury and TTS for fish species with a swim bladder involved in hearing in close proximity to the sound sources (Table 5), but in order for the thresholds to be exceeded, the fish must remain within those distances for either 48 or 12 h, respectively.

Table 5. Summary of fish results : Maximum (R_{max}) horizontal distances (in km), from all scenarios considered, to sound pressure level (SPL) criteria based on Popper et al. (2014).

Scenario Number	Description	Maximum (R_{max}) distance to threshold (km)	
		Recoverable injury (48 h)	TTS (12 h)
1	Dredging, CSD + 2 Barges	0.01	0.11
2	TSV Movement	–	–

A dash indicates the level was not reached within the limits of the modelled resolution (10 m).

Intake Pump Activities

For the modelling of the intake pump, the thresholds used for assessing marine mammal behaviour included the 120 dB re 1 µPa (SPL) behavioural response threshold from NOAA (2024) and the frequency-weighted TTS and PTS thresholds from NMFS (2024). For sea turtle species within the area, the PTS and TTS threshold criteria from Finneran et al. (2017) were used, and for fish species within the area, the recoverable injury and TTS thresholds from Popper et al. (2014) were used.

The modelled intake pump noise was too quiet to reach any of the thresholds above within the modelling resolution of 10 m.

1. Introduction

JASCO Applied Sciences (JASCO) performed a modelling study of underwater acoustic noise levels associated with proposed pile driving, dredging, seawater intake pump, and vessel activities as part of the environmental approvals process for the Leichhardt Eramurra Solar Salt Project. The modelling study specifically predicted the distances from operations at which underwater sound levels reached noise effect thresholds and criteria applicable to marine fauna. Due to the variety of species considered, and the fact that proposed activities produce both impulsive and non-impulsive (continuous) noise, there are several different thresholds for evaluating effects, including: mortality, injury, temporary reduction in hearing sensitivity, and behavioural disturbance.

For the impulsive sound source of pile driving, estimated underwater acoustic levels are presented as sound pressure levels (SPL, L_p); zero-to-peak pressure levels (PK, L_{pk}), and either single-strike (i.e., per-strike) or accumulated sound exposure levels (SEL, L_E) as appropriate for different noise effect criteria and noise sources.

Estimated underwater acoustic levels for non-impulsive (continuous) noise sources of vessel activity and dredging are presented as sound pressure levels (SPL, L_p), and as accumulated sound exposure levels (SEL, L_E) as appropriate for different noise effect criteria. The SPL metric is the root-mean-square pressure level over a stated frequency band over a specified time window. In this study, for continuous noise, a time window of 1 s was used.

In this report, the duration period for SEL accumulation is defined as a 24-hour period over which sound energy is integrated; the level is specified with the abbreviation SEL_{24h}. SEL_{24h} is a cumulative metric that reflects the dosimetric effect of noise levels within 24 hours, based on the assumption that a receiver (e.g., an animal) is consistently exposed to such noise levels at a fixed position. More realistically, marine mammals, fish, and sea turtles would not stay in the same location for 24 hours (especially in the absence of location-specific habitat) but rather a shorter period, depending on the animal's behaviour and the source's proximity and movements. Therefore, a reported radius for the SEL_{24h} criteria does not mean that marine fauna travelling within this radius of the source will be impaired, but rather that an animal could be exposed to the sound level associated with impairment (either permanent threshold shift (PTS) or temporary threshold shift (TTS)) if it remained at that location for 24 hours.

Section 1.1 outlines the specific details of the modelling study. Section 2 details the metrics used to represent underwater acoustic fields and the associated effect criteria considered. Section 3 details the methodology for predicting the source levels and modelling the sound propagation, including source levels and environmental parameters required by the propagation models. Section 4.1.2 presents the acoustic results as tabulated ranges to thresholds, Section 4.1.3 provides sound level contour maps and the acoustic modelling results are discussed in Section 5.

1.1. Modelling Scenarios

The modelled activities included both pile driving (impulsive noise source) and dredging and vessel activities (non-impulsive/continuous noise sources).

1.1.1. Pile Driving Activities

JASCO modelled a Juntaan HHK 20S and a Juntaan HHK 10S impact hammer for use with driving of one pipe pile at the Jetty North Limit location and one sheet pile at the intake pump location. Modelling incorporated client-supplied drivability information. The modelling considered a cylindrical pipe pile, 20 m in length and 1.1 m in diameter with a pile wall thickness of 2.5 cm, and a sheet pile, 8 m in length and 0.5 m in diameter with a pile wall thickness of 1.25 cm.

The total noise exposure (SEL) for the pile driving scenario depends on the total number of hammer blows required to drive the pile. Based on the provided drivability information for each pile, it is estimated that it would take approximately 3,248 blows (5.8 h driving at 9.4 blows per minute) to drive the cylindrical pile 20 m into the substrate with the Juntaan HHK 20S hammer and 6,496 blows (3.6 h driving at 30 blows per minute) to drive the sheet pile 8 m into the substrate with the Juntaan HHK 10S hammer.

The pile driving modelling location is detailed in Table 6 and indicated graphically in Figure 1. For the purposes of the modelling, both piles were considered to be installed in the same location. Table 7 summarises the modelled pile specifications.

Table 6. Location of the piling activities in MGA coordinates (MGA Zone 50).

Piling Scenario	Latitude (S)	Longitude (E)	MGA[1] Zone 50		Water depth (m)
			X (m)	Y (m)	
1	20° 50' 12.74"	116° 13' 22.00"	419135	7695711	7.1
2	20° 52' 46.43"	116° 17' 54.25"	427024	7691022	2.1

[1] Map Grid of Australia

Table 7. Pile specifications for the driven cylindrical steel piles.

Scenario	Pile Number	Pile Description	MGA[1] Zone 50			Final Penetration Depth (m)	Hammer(s)	Number of installed piles per day
			Length (m)	Diameter (m)	Wall Thickness (mm)			
1	1	Piling Cylindrical Pipe Pile	20	1.1	25	70	Juntaan HHK 20S	1
2	2	Sheet Pile	8	0.5	12.5	80	Juntaan HHK 10S	1

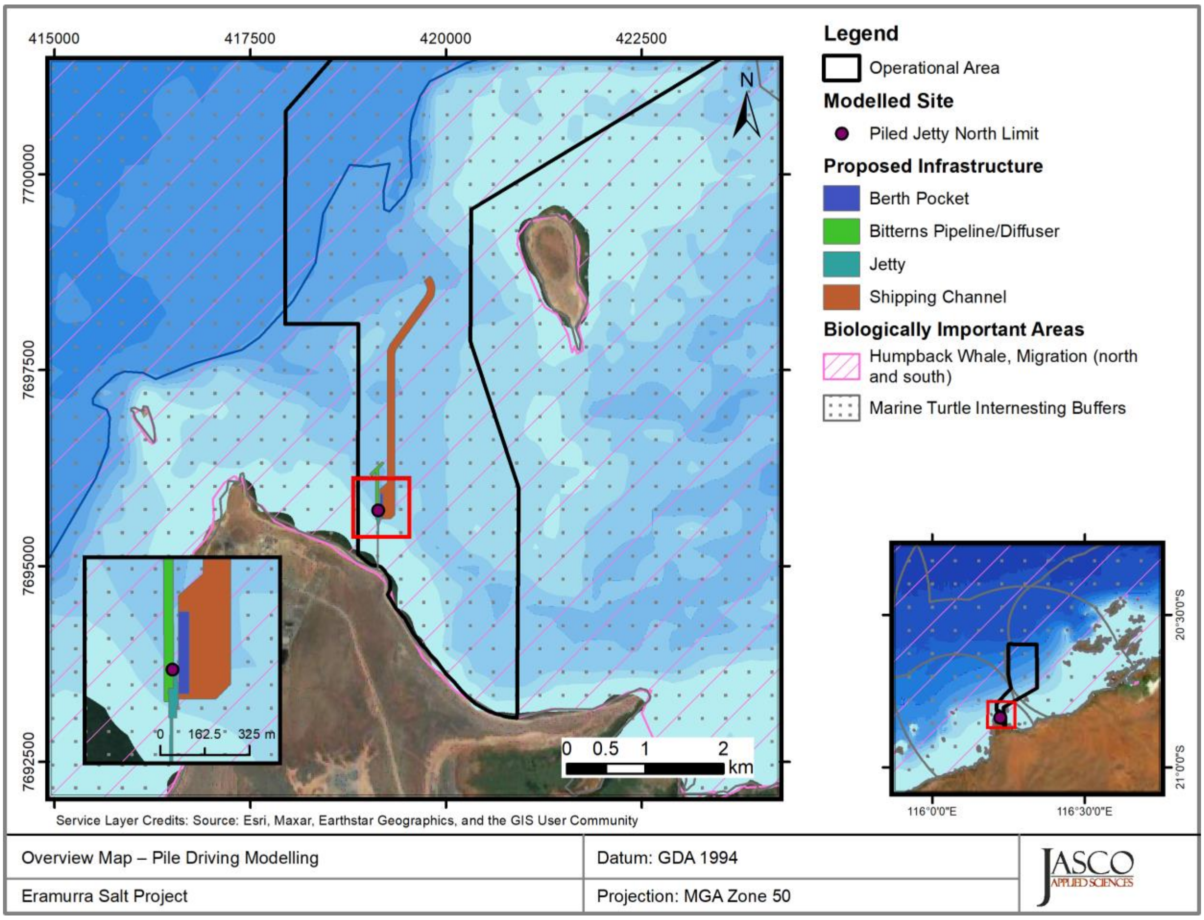

Figure 1. Overview map of the relevant features of the modelled pile driving within the project's construction area.

1.1.2. Dredging and Vessel Activities

This study considered the following sound-producing activities:

- Dredging noise from a cutter suction dredge (CSD) located at the dredging site (Site 1),
- Material removal noise from two barges with at most one under dynamic positioning (DP) next to the dredge, and transiting to the disposal area otherwise (Sites 2–6), and
- Vessel noise from a transshipment vessel (TSV) located along transit and berthing paths in the operational area (Sites 7–11).

Tables 8 and 9 outline the dredging and vessel modelling locations and scenarios, and these are indicated graphically in Figure 2. It should be noted that the dredging and berthing sites (modelled Sites 1 and 7, Table 8) is near modelled Site 1 and 2 (in the dredging area) for pile driving activities (Table 6), however they are presented in this report with two different references for clarity.

Table 8. Modelled site locations and vessel type information.

Site	Source/Vessel	Latitude (°S)	Longitude (°E)	MGA[1] Zone 50		Water depth (m)
				X (m)	Y (m)	
1	CSD	20° 49' 25.69"	116° 13' 28.22"	419298	7697158	6.0
2	Barge on DP	20° 49' 25.69"	116° 13' 28.22"	419298	7697158	6.0
3	Barge in transit	20° 49' 25.69"	116° 13' 28.22"	419298	7697158	6.0
4	Barge in transit	20° 48' 41.05"	116° 13' 45.81"	419809	7698533	5.8
5	Barge in transit	20° 47' 13.41"	116° 13' 22.71"	4191289	7701224	14.7
6	Barge in transit	20° 45' 15.54"	116° 15' 34.05"	422910	7704866	15.6
7	Barge in transit	20° 43' 29.14"	116° 17' 20.86"	425984	7708151	7.5
8	TSV berthing	20° 50' 10.74"	116° 13' 23.46"	419173	7695621	5.0
9	TSV in transit	20° 50' 10.74"	116° 13' 23.46"	419173	7695621	5.0
10	TSV in transit	20° 49' 25.69"	116° 13' 28.22"	419298	7697158	6.0
11	TSV in transit	20° 48' 41.05"	116° 13' 45.81"	419810	7698533	5.8
12	TSV in transit	20° 47' 13.41"	116° 13' 22.71"	419129	7701224	14.7
13	TSV in transit	20° 45' 15.54"	116° 15' 34.05"	422910	7704866	15.6
14	TSV in transit	20° 43' 29.14"	116° 17' 20.86"	425984	7708151	7.5

[1]Map Grid of Australia (MGA)

Table 9. Description of modelled scenarios for dredging and vessel activities.

Scenario	Site(s)	Operation Description	Operation Time
1	1–7	Dredging, CSD + 2 Barges for material removal + barge transiting to disposal area	24 hr, 3x transit paths (every 8h)
2	8–14	1xTSV movements: 2 round trips. 1xtransiting for 1.3hrs, over 18.2 km at a speed of 7.5 knots. Berthing at jetty Assumes noiseless cargo transfer	5.2 hr transiting, 30 min berthing

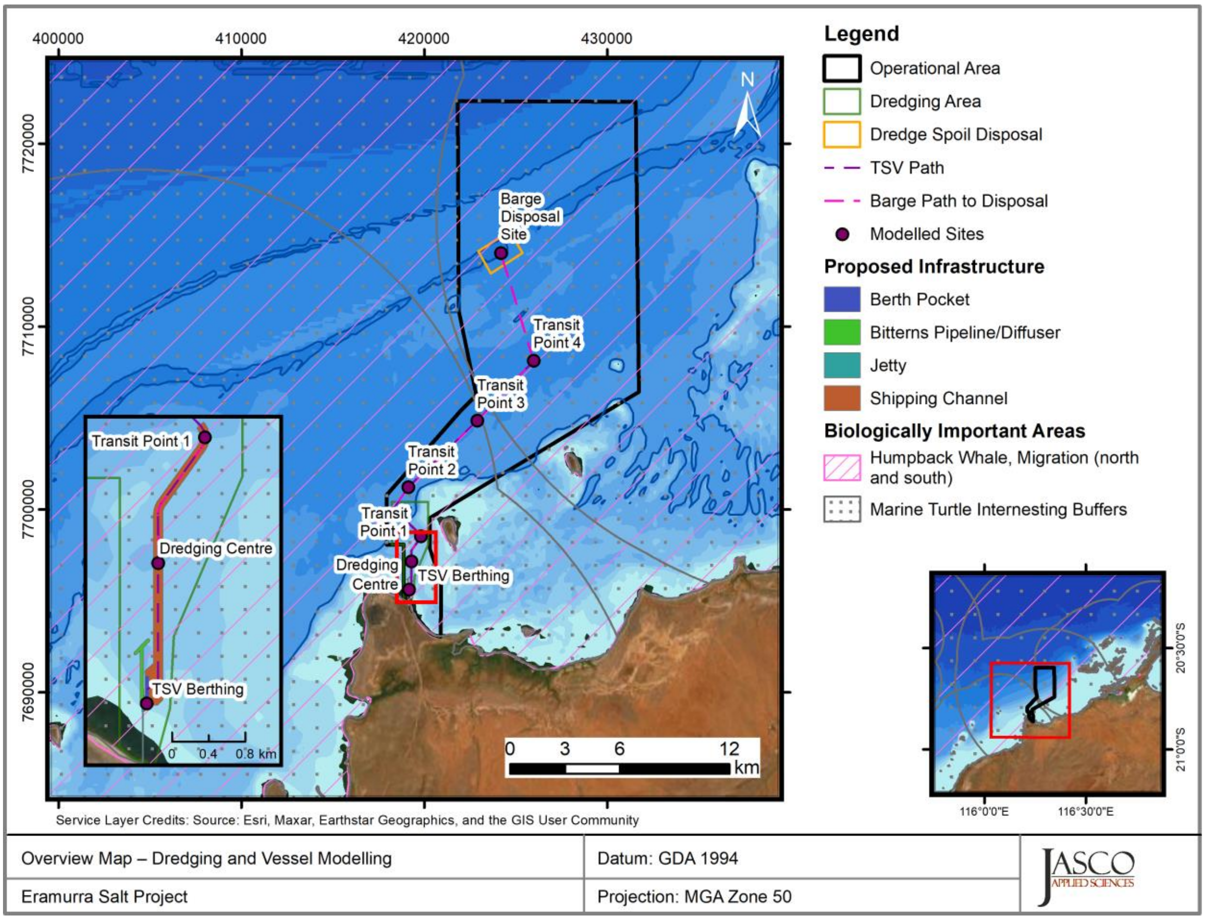

Figure 2. Overview map of the relevant features of the modelled dredging and vessel activities within the project's construction area.

1.1.3. Intake Pump

This study considers the sound produced by the intake pump activities in McKay Creek. Tables 10 and 11 outline the dredging and vessel modelling location and scenario, and these are indicated graphically in Figure 3.

Table 10. Modelled site location.

Site	Source/Vessel	Latitude (°S)	Longitude (°E)	MGA[1] Zone 54		Water depth (m)
				X (m)	Y (m)	
15	Intake Pump	20° 52' 46.42"	116° 17' 54.25"	427024	7691022	2.1

[1] Map Grid of Australia (MGA)

Table 11. Description of modelled scenario for intake pump activities.

Scenario	Site(s)	Operation Description	Operation Time
1	15	8x Intake Pumps Continuously Operating	24 hr

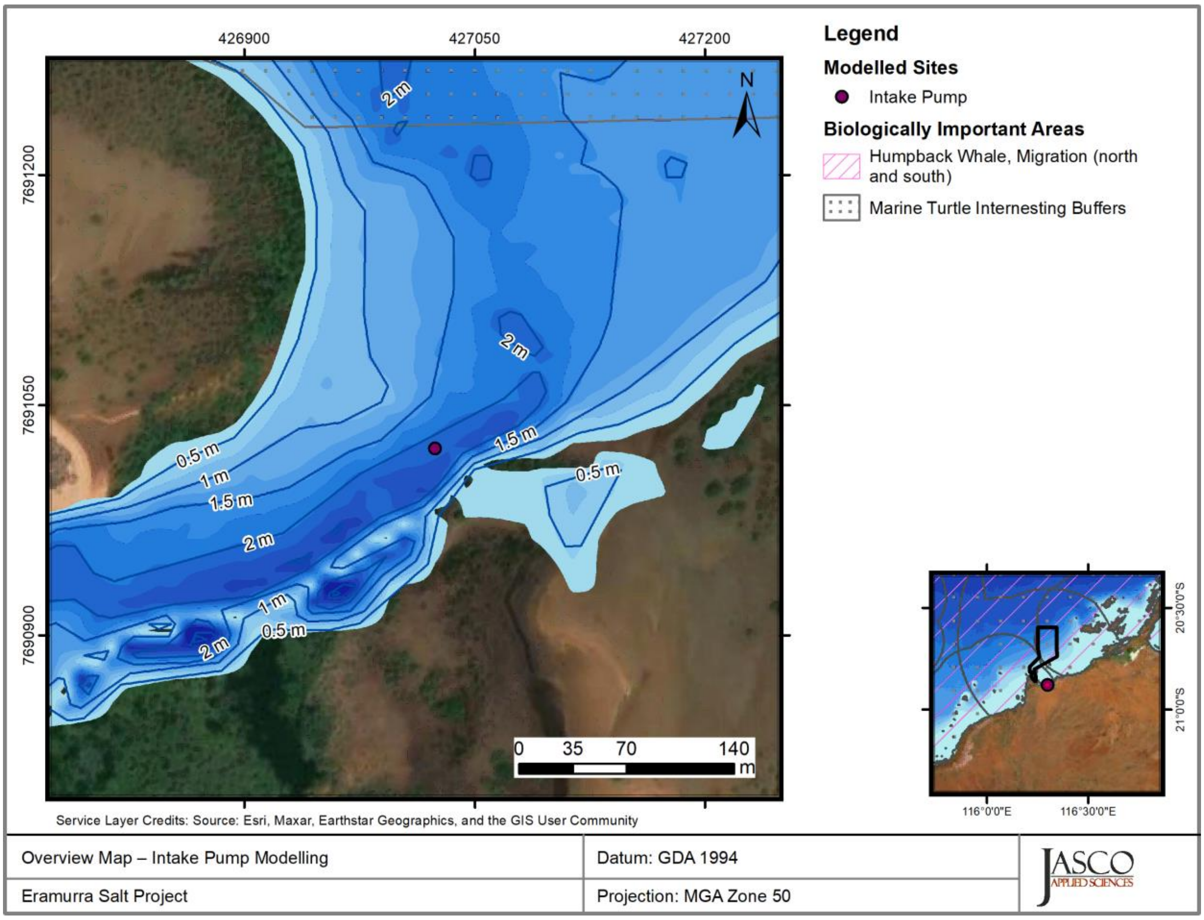

Figure 3. Overview map of the relevant features of the intake pump activities within the project's construction area.

2. Noise Effect Criteria

To assess the potential effects of a sound–producing activity, it is necessary to first establish exposure criteria (thresholds) for which sound levels may be expected to have a negative effect on animals. Whether acoustic exposure levels might injure or disturb marine fauna is an active research topic. Since 2007, several expert groups have developed SEL–based assessment approaches for evaluating auditory injury, with key works including Southall et al. (2007), Finneran and Jenkins (2012), Popper et al. (2014) and United States National Marine Fisheries Service NMFS (2018), (Southall et al. 2019) and NMFS (2024). The number of studies that investigate the level of behavioural disturbance to marine fauna by anthropogenic sound has also increased substantially.

The perceived loudness of sound, especially impulsive noise such as from pile driving, is not generally proportional to the instantaneous acoustic pressure. Rather, perceived loudness depends on the pulse rise-time and duration, and the frequency content. Several sound level metrics, such as PK, SPL, and SEL, are commonly used to evaluate noise and its effects on marine life (Appendix A). The period of accumulation associated with SEL is defined, with this report referencing either a "per-strike" assessment or over 24 h. For non-impulsive sound sources, such as vessels, SPL and SEL are the relevant metrics. The acoustic metrics in this report reflect the ISO standard for acoustic terminology, ISO/DIS 18405:2017 (2017).

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

1. Marine mammals:
   a. Peak pressure levels (PK; L_{pk}) and frequency–weighted accumulated sound exposure levels (SEL; $L_{E,24h}$) from NMFS (2024) for the onset of permanent threshold shift (PTS) and temporary threshold shift (TTS) in marine mammals for impulsive sources.
   b. Frequency-weighted accumulated sound exposure levels (SEL; $L_{E,24h}$) from NMFS (2024) for the onset of permanent threshold shift (PTS) and temporary threshold shift (TTS) in marine mammals for non-impulsive sound sources.
   c. Marine mammal behavioural thresholds based on the current interim U.S. National Oceanic and Atmospheric Administration (NOAA) (2024) unweighted criterion for marine mammals of 160 dB re 1 µPa (SPL; L_p) for impulsive sound sources and 120 dB re 1 µPa (SPL; L_p) for non-impulsive sound sources.
2. Fish, fish eggs, and larvae:
   a. Sound exposure guidelines for fish, fish eggs, and larvae (used as a surrogate for plankton) (Popper et al. 2014).
3. Sea turtles:
   a. Frequency–weighted accumulated sound exposure levels (SEL; $L_{E,24h}$) from Finneran et al. (2017) for the onset of PTS and TTS in turtles for non–impulsive and impulsive sound sources.
   b. Sea turtle behavioural response threshold of 166 dB re 1 µPa (SPL; L_p) for impulsive noise, along with a sound level associated with behavioural disturbance 175 dB re 1 µPa (SPL; L_p) (McCauley et al. 2000).

The following sections (along with Appendices A.3 and A.4), expand on the thresholds, guidelines and sound levels for all marine fauna.

2.1. Impulsive Noise

Impact pile driving activities have been assessed as an impulsive noise source consistent with the considered thresholds and guidelines.

2.1.1. Marine Mammals

The NMFS (2024) criteria applied in this study to assess possible effects of impulsive noise sources on marine mammals are summarised in Table 12; cetaceans and sirenians were identified as the hearing groups requiring assessment.

There are two categories of auditory threshold shifts or hearing loss: permanent threshold shift (PTS), a physical injury to an animal's hearing organs; and Temporary Threshold Shift (TTS), a temporary reduction in an animal's hearing sensitivity as the result of receptor hair cells in the cochlea becoming fatigued. Details on thresholds related to auditory threshold shifts or hearing loss and behavioural response are provided in Appendix A.3, with frequency weighting explained in detail in Appendix A.4. Of particular note, whilst Southall et al. (2021) provide recommendations and discusses the nuances of assessing behavioural response, the paper does not recommend new numerical thresholds for onset of behavioural responses for marine mammals. The behavioural response criteria from the current interim U.S. National Oceanic and Atmospheric Administration (NOAA) (2024) unweighted criterion for marine mammals has been applied.

Table 12. Acoustic effects of impulsive noise on marine mammals: Unweighted SPL, SEL_{24h}, and PK thresholds.

Hearing group	NOAA (2024)	NMFS (2024)			
	Behaviour	PTS onset thresholds* (received level)		TTS onset thresholds* (received level)	
	SPL (L_p; dB re 1 µPa)	Weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa²·s)	PK (L_{pk}; dB re 1 µPa)	Weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa²·s)	PK (L_{pk}; dB re 1 µPa)
Low–Frequency (LF) cetaceans	160	183	222	168	216
High–frequency (HF) cetaceans		193	230	178	224
Sirenians		186	225	171	219

* Dual metric acoustic thresholds for impulsive sounds: Use whichever results in the largest isopleth for calculating PTS onset.
L_p denotes sound pressure level and has a reference value of 1 µPa.
L_{pk} denotes peak sound pressure is flat weighted or unweighted and has a reference value of 1 µPa.
$L_{E,24h}$ denotes cumulative sound exposure over a 24 h period and has a reference value of 1 µPa²s.

2.1.2. Fish, Sea turtles, Fish Eggs, and Fish Larvae

In 2006, the Working Group on the Effects of Sound on Fish and Sea Turtles was formed to continue developing noise exposure criteria for fish and sea turtles, work begun by a NOAA panel two years earlier. The Working Group developed guidelines with specific thresholds for different levels of effects for several species groups (Popper et al. 2014). The guidelines define quantitative thresholds for three types of immediate effects:

- Mortality, including injury leading to death,
- Recoverable injury, including injuries unlikely to result in mortality, such as hair cell damage and minor haematoma, and
- TTS.

Masking and behavioural effects can be assessed qualitatively, by assessing relative risk rather than by specific sound level thresholds. However, as these depend upon activity–based subjective ranges, these effects are not addressed in this report and are included in Tables 13 for completeness only.

Because the presence or absence of a swim bladder has a role in hearing, fish's susceptibility to injury from noise exposure depends on the species and the presence and possible role of a swim bladder in hearing. Thus, different thresholds were proposed for fish without a swim bladder (also appropriate for sharks and applied to whale sharks in the absence of other information), fish with a swim bladder not used for hearing, and fish that use their swim bladders for hearing. Sea turtles, fish eggs, and fish larvae are considered separately.

Impulsive noise from pile driving is assessed in this study based on the relevant effects thresholds from Popper et al. (2014) listed in Table 13. In general, whether an impulsive sound adversely effects fish behaviour depends on the species, the state of the individual exposed, and other factors.

The SEL metric integrates noise intensity over some period of exposure. Because the period of integration for regulatory assessments is not well defined for sounds that do not have a clear start or end time, or for very long–lasting exposures, an exposure evaluation time must be defined. Southall et al. (2007) defines the exposure evaluation time as the greater of 24 h or the duration of the activity. Popper et al. (2014) recommend a standard period of the duration of the activity; however, the publication also includes caveats about considering the actual exposure times if fish move. Integration times in this study for piling have been applied over the time taken to install two piles as two piles are expected to be driven per day.

Table 13. Criteria for pile driving noise exposure for fish, adapted from Popper et al. (2014).

Type of animal	Mortality and Potential mortal injury	Impairment			Behaviour
		Recoverable injury	TTS	Masking	
Fish: No swim bladder (particle motion detection)	> 219 dB SEL_{24h} or > 213 dB PK	> 216 dB SEL_{24h} or > 213 dB PK	>> 186 dB SEL_{24h}	Pile driving: (N) Moderate (I, F) Low Seismic: (N, I, F) Low	(N) High (I) Moderate (F) Low
Fish: Swim bladder not involved in hearing (particle motion detection)	210 dB SEL_{24h} or > 207 dB PK	203 dB SEL_{24h} or > 207 dB PK	>> 186 dB SEL_{24h}	Pile driving: (N) Moderate (I, F) Low Seismic: (N, I, F) Low	(N) High (I) Moderate (F) Low
Fish: Swim bladder involved in hearing (primarily pressure detection)	207 dB SEL_{24h} or > 207 dB PK	203 dB SEL_{24h} or > 207 dB PK	186 dB SEL_{24h}	Pile driving: (N, I) High (F) Moderate Seismic: (N, I) Low (F) Moderate	(N, I) High (F) Moderate
Fish eggs and fish larvae (relevant to plankton)	> 210 dB SEL_{24h} or > 207 dB PK	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	Pile driving: (N) Moderate (I, F) Low Seismic: (N, I, F) Low	(N) Moderate (I, F) Low

Peak sound pressure level: dB re 1 µPa; SEL_{24h} dB re 1µPa^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).

There is a paucity of data regarding responses of turtles to acoustic exposure, and no studies of hearing loss due to exposure to loud sounds. Popper et al. (2014) suggested thresholds for onset of mortal injury (including PTS) and mortality for sea turtles and, in absence of taxon–specific information, adopted the levels for fish that do not hear well (suggesting that this likely would be conservative for sea turtles). Finneran et al. (2017) in turn presented revised thresholds for sea turtle injury and hearing impairment (TTS and PTS). Their rationale is that sea turtles have best sensitivity at low frequencies and are known to have poor auditory sensitivity (Bartol and Ketten 2006, Dow Piniak et al. 2012). Accordingly, TTS and PTS thresholds for turtles are likely more similar to those of fishes than to marine mammals (Popper et al. 2014).

McCauley et al. (2000) observed the behavioural response of caged sea turtles—green (*Chelonia mydas*) and loggerhead (*Caretta caretta*)—to an approaching seismic airgun. For received levels above 166 dB re 1 µPa (SPL), the sea turtles increased their swimming activity, and above 175 dB re 1 µPa they began to behave erratically, which was interpreted as an agitated state. The Recovery Plan for Marine Turtles in Australia (Department of the Environment and Energy et al. 2017) acknowledges the 166 dB re 1 µPa SPL reported (McCauley et al. 2000) as the level that may result in a behavioural response to marine turtles. The 175 dB re 1 µPa level from McCauley et al. (2000) is recommended as a criterion for behavioural disturbance; these thresholds are shown in Table 14.

Table 14. Acoustic effects of impulsive noise on sea turtles: Unweighted sound pressure level (SPL), 24-hour sound exposure level (SEL_{24h}), and peak pressure (PK) thresholds.

Effect type	Criterion	SPL (L_p; dB re 1 µPa)	Weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa^2·s)	PK (L_{pk}; dB re 1 µPa)
Behavioural response	McCauley et al. (2000)	166	NA	
Behavioural disturbance		175		
PTS onset thresholds[1] (received level)	Finneran et al. (2017)	NA	204	232
TTS onset thresholds[1] (received level)			189	226

[1] Dual metric acoustic thresholds for impulsive sounds: Use whichever results in the largest isopleth for calculating PTS and TTS onset.
L_p denotes sound pressure level and has a reference value of 1 µPa.
L_{pk} denotes peak sound pressure is flat weighted or unweighted and has a reference value of 1 µPa.
$L_{E,24h}$ denotes cumulative sound exposure over a 24 h period and has a reference value of 1 µPa^{2}s.

2.2. Non-impulsive Noise

Dredging and vessel activities have been assessed as non-impulsive noise sources consistent with the considered thresholds and guidelines.

2.2.1. Marine Mammals

The NMFS (2024) criteria applied in this study to assess possible effects of non-impulsive noise sources on marine mammals are summarised in Table 15. Cetaceans and sirenians were identified as the marine mammals requiring assessment. Details on thresholds related to auditory threshold shifts or hearing loss and behavioural response are provided in Appendix A.3, with frequency weighting explained in detail in Appendix A.4.

Table 15. Criteria for effects of non-impulsive noise exposure, including vessel noise, for marine mammals: unweighted SPL and weighted SEL_{24h} thresholds.

Hearing group	NOAA (2024)	NMFS (2024)	
	Behaviour	PTS onset thresholds (received level)	TTS onset thresholds (received level)
	SPL (L_p; dB re 1 µPa)	Weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa²·s)	Weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa²·s)
Low-frequency (LF) cetaceans	120	197	177
High-frequency (HF) cetaceans		201	181
Sirenians		200	180

L_p denotes sound pressure level and has a reference value of 1 µPa.
L_E denotes cumulative sound exposure over a 24 h period and has a reference value of 1 µPa²·s.

2.2.1.1. Behavioural Response

The NOAA continuous noise criterion was selected for this assessment because it represents the most commonly applied behavioural response criterion by regulators. The distances at which behavioural responses could occur are therefore determined by areas ensonified above an unweighted SPL of 120 dB re 1 µPa (NMFS 2014, NOAA 2024). Appendix A.3 provides more information about the development of this criteria. Whilst Southall et al. (2021) provides recommendations and discusses the nuances of assessing behavioural response, the authors do not recommend new numerical thresholds for onset of behavioural responses for marine mammals.

2.2.1.2. Injury and Hearing Sensitivity Changes

To assist in assessing the potential for effect on marine mammals, this report applies the criteria recommended by NMFS (2024), considering both PTS and TTS (see Table 15). Appendix A.3 provides more information about the NMFS (2024) criteria.

2.2.2. Fish, Sea Turtles, Fish Eggs, and Fish Larvae

Table 16 lists the relevant effects thresholds from Popper et al. (2014) for shipping and continuous noise. Some evidence suggests that fish sensitive to acoustic pressure show a recoverable loss in hearing sensitivity, or injury when exposed to high levels of noise (Scholik and Yan 2002, Amoser and Ladich 2003, Smith et al. 2006); this is reflected in the SPL thresholds for fish with a swim bladder involved in hearing (shaded cells in Table 16). Finneran et al. (2017) presented revised thresholds for sea turtle PTS and TTS onset from continuous noise sources, considering frequency weighted SEL, which have been applied in this study (Table 17).

Table 16. Criteria for vessel noise exposure for fish and sea turtles, adapted from Popper et al. (2014).

Type of animal	Mortality and Potential mortal injury	Impairment			Behaviour
		Recoverable injury	TTS	Masking	
Fish: No swim bladder (particle motion detection)	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
Fish: Swim bladder not involved in hearing (particle motion detection)	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
Fish: Swim bladder involved in hearing (primarily pressure detection)	(N) Low (I) Low (F) Low	170 dB SPL for 48 h	158 dB SPL for 12 h	(N) High (I) High (F) High	(N) High (I) Moderate (F) Low
Sea Turtles	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) High (I) Moderate (F) Low
Fish eggs and fish larvae	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) High (I) Moderate (F) Low	(N) Moderate (I) Moderate (F) Low

Sound pressure level dB re 1 µPa.
Relative risk (high, moderate, low) is given for animals at three distances from the source defined in relative terms as near (N) – tens of metres, intermediate (I) – hundreds of metres, and far (F) – thousands of metres.

Table 17. Acoustic effects of continuous noise on sea turtles, weighted SEL_{24h}, Finneran et al. (2017).

PTS onset thresholds (received level)	TTS onset thresholds (received level)
Weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa^{2}s)	Weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa^{2}s)
220	200

L_E denotes cumulative sound exposure over a 24 h period and has a reference value of 1 µPa^{2}s.

3. Methods and Parameters

The modelled sites for the activities considered in this study were located in the Northern Carnarvon Basin, northern Australia (refer to wide regional bathymetry in Appendix D.3.1). The modelled sites were situated in water depths of approximately 4.5 – 15.6 m.

To allow for operational flexibility, the sound speed profile implemented within the modelling was selected through a sensitivity analysis considering all months of the year. The month of June was believed to be the most favourable to longer-range sound propagation, resulting in the largest ranges to considered isopleths criteria. As such, June was selected as the conservative choice for modelling. Additional detail can be found in Appendix D.3.2.

The seabed beneath the modelled sites will likely consist of layers of sand, calcarenite and basalt, and the sediment profile for the modelling area was taken from the geotechnical assessment at Cape Preston provided by MScience. Further details on the associated geoacoustic properties used in this modelling study are provided in Appendix D.3.3.

The following sections provide a description of the models, methods and sources used for this underwater noise modelling study.

3.1. Pile Driving Activities

3.1.1. Per-strike Modelling

When driven with impact hammers, piles deform, creating a stress wave that travels down the pile and radiates sound into the surrounding air, water, and seabed. This sound may be received as a direct transmission from the sound source to biological receivers (such as marine mammals, sea turtles, and fish) through the water or as the result of reflected paths from the surface or re-radiated into the water from the seabed. Sound transmission depends on many environmental parameters, such as the sound speeds in water and substrates; material parameters of the pile and how it is driven, including the pile material, size (length, diameter, and thickness) and the type and energy of the hammer.

To predict the acoustic field from the pipe pile driving, JASCO's Pile Driving Source Model (PDSM; Appendix B.1), a physical model of pile vibration and near-field sound radiation (MacGillivray 2014), was used in conjunction with the GRLWEAP 14; 2010 wave equation model (GRLWEAP, Pile Dynamics 2010) to predict source levels associated with impact pile driving activities. Piles are modelled as a vertical installation using a finite-difference structural model of pile vibration based on thin-shell theory. The sound radiating from the pile itself was simulated using a vertical array of discrete point sources. GRLWEAP 14 was used to compute the force at the top of each pile assuming direct contact between the representative hammers, and piles. The pile was modelled at three representative depths to account for variability over the entire drive; details are provided in Table 18. The client-supplied drivability information advised that each pile is likely to self-settle to 3 m penetration, therefore the modelled driving depths began at 3 m (Table 18). The modelling has considered that each hammer has a nominal helmet of one fifth the ram weight between the hammer and the pile.

Table 18. Modelled pile driving hammer parameters.

Pile Number	Hammer model	Modelled Depths (m)	Modelled Energy (kJ)	Hammer Efficiency (%)	Ram weight (t)	Helmet weight (t)	Modelled blow rate (per min)
1	Juntaan HHK 20S	4.4	294	80	20	4	9.4
		7.3					
		10.1					
2	Juntaan HHK 10S	N/A	147	80	10	2	30

The forcing function serves as input to JASCO's pile driving source model (PDSM), which was used to estimate equivalent acoustic source characteristics detailed in Appendix B.1.2. The forcing function was modelled assuming that driving was carried out using the associated hammer energy (Figure 4).

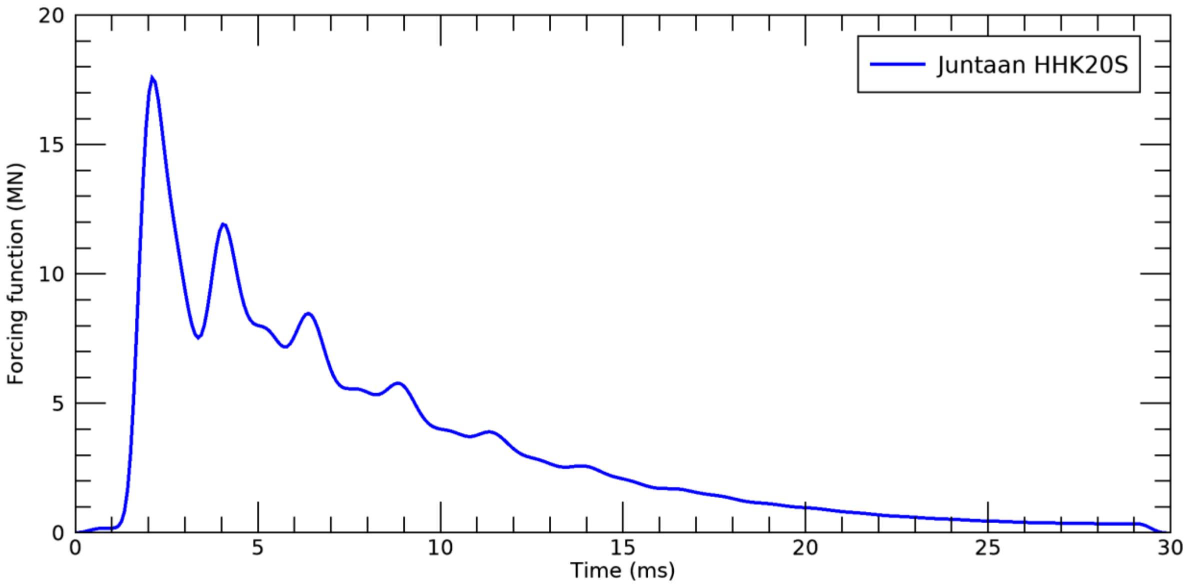

Figure 4. Force (in meganewtons) at the top of the pile corresponding to impact pile driving using Juntaan HHK20S impact hammer with no helmet, computed using the GRLWEAP 2010 wave equation model for the modelled 90 m pile.

JASCO's FWRAM propagation model (Appendix B.2) was used to combine the outputs of the source model with spatial environmental factors (e.g., location, oceanographic conditions, and seabed type, see Appendix D.2 for detail) to get time-domain representations of the sound signals in the environment and estimate sound field levels. This model is used to estimate the energy distribution per frequency (source spectrum) at a close distance from the source (10 m) from 10 Hz to 1024 Hz. In addition, an empirical extrapolation was applied to these results to extend the frequency range up to 25 kHz and a 20 dB/decade decay rate was applied to match acoustic measurements of impact pile driving of similarly-sized piles (Illingworth & Rodkin 2007, Matuschek and Betke 2009). Examples of decidecade band levels are provided in Section 4.1. Appendix A.1 describes the sound level metrics in further detail.

To produce maps of received sound level distributions and to calculate distances to specified sound level thresholds, the maximum-over-depth level is calculated at each modelled received level within the considered region. The radial grids of maximum-over-depth levels are then resampled (by linear triangulation) to produce a regular Cartesian grid with a cell size of 10 m. The contours and threshold ranges were calculated from these flat Cartesian projections of the modelled acoustic fields (Appendix D.2).

3.1.2. Accumulated SEL Modelling for Pile Driving

The modelling approach outlined in Section 3.1 provides per-strike SEL for three stages of pile driving (i.e., three penetration depths) for each modelled pile. Two piles will be driven per day for Pile 1 and one pile per day for Pile 2. The piling noise level is likely to exceed any background noise level, so the corresponding sound exposure level can be denoted as SEL_{24h} even though the effective period of accumulation is the estimated time for fully driving the two piles. The accumulated SEL, or the SEL_{24h}, depends on the total number of strikes to drive each pile to the target penetration depth.

Total driving time was estimated assuming continuous piling at an average rate of 9.4 strikes/minute for the Juntaan HHK 20S and 30 strikes/minute for the Juntaan HHK 10S. As per the pile design, likely hammer and installation approach, the number of strikes required for the driving of each pile was estimated using the provided drivability. The SEL_{24h} was computed by adjusting the single-strike SEL by $10*\log_{10}(N)$, where N is the total number of strikes. A summary of the total number of strikes per penetration depth and per pile is provided in Table 19.

Table 19. Total number of strikes and driving time per pile. Strikes were broken down into stages corresponding to the three modelled penetration depths. Hammer specifications are shown in Table 18.

Scenario	Hammer	Full penetration depth (m)	Modelled penetration depth (m)	Penetration range for accumulated SEL (m)	Number of strikes per pile	Average Penetration rate (mm/strike)	Total number of strikes per pile	Time for full penetration per pile (hr)	Number of installed piles per day
1	Juntaan HHK 20S	11.5	4.4	3.0 – 5.8	922	3.07	3248	5.8	1
			7.3	5.8 – 8.7	1024	2.77			
			10.1	8.7 – 11.5	1302	2.18			
2	Juntaan HHK 10S	N/A	N/A	N/A	3248	N/A	3248	1.8	1

3.1.3. Sheet Pile Driving

The source level for the impact piling of the sheet pile has been derived from a previous study in which source levels for a Juntaan HHK7A hammer of weight of 13,500 kg were obtained from publicly available measurements (Illingworth & Rodkin 2007). A correction factor of -1.3 dB is applied across all frequency bands to get a resultant source level for the Juntaan HHK10S with hammer weight of 10,000 kg. The resulting broadband SEL source level estimate is 190.9 dB re 1 uPa^2m^2s for impact piling of sheet piles. The estimated source level is shown in Figure 5.

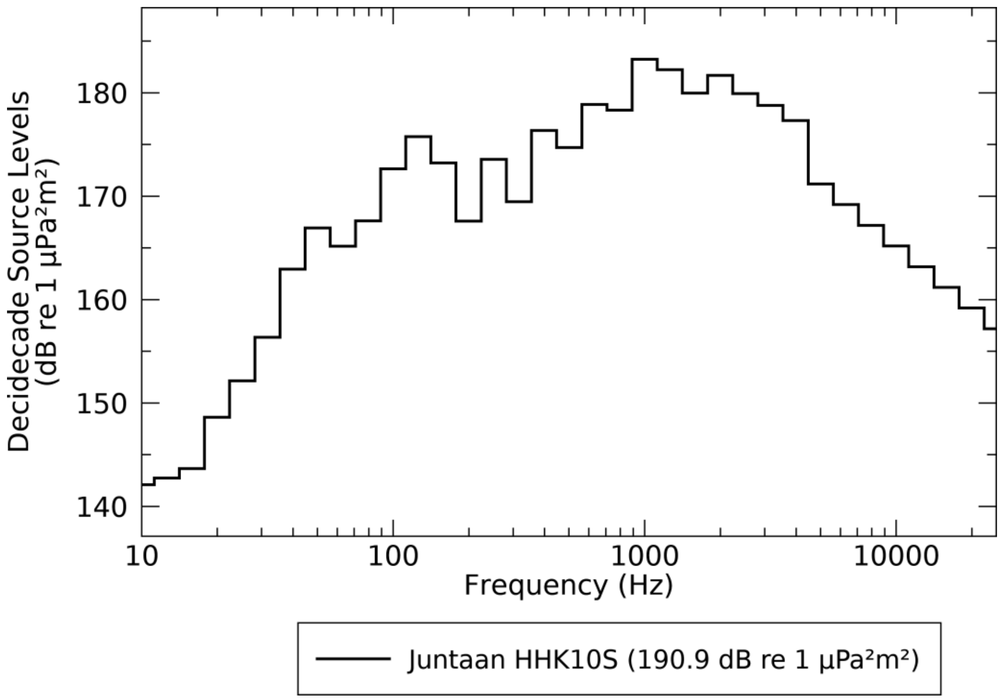

Figure 5. *Scenario 1, Sheet Pile*: Source level (SL) spectra (in decidecade frequency-band) for the Juntaan HHK10S impact hammer.

3.2. Dredging, Vessel and Intake Pump Activities

3.2.1. Dredging, Vessel and Intake Pump Noise Sources

Underwater sound that radiates from vessels is produced mainly by propeller and thruster cavitation, with a smaller fraction of noise produced by sound transmitted through the hull, such as by engines, gearing, and other mechanical systems. Sound levels tend to be the highest when thrusters are used to position the vessel and when the vessel is transiting at high speeds. A vessel's sound signature depends on the vessel's size, power output, propulsion system (e.g., conventional propellers vs. Voith Schneider propulsion), and the design characteristics of the given system (e.g., blade shape and size). A vessel produces broadband acoustic energy with most of the energy emitted below a few kilohertz. Sound from onboard machinery, particularly sound below 200 Hz, dominates the sound spectrum before cavitation begins (Spence et al. 2007).

The acoustic energy from intake pumps is mainly low-frequency noise produced by the pump motors under operation, and the remaining noise is generally from the circulation and cavitation of the surrounding water.

Figure 6 presents a summary plot of all considered source spectra for comparison purposes. The source spectra plot shows the distribution of sound across the decidecade frequency bands that the modelling considers. Additional detail on the sources is provided in Sections 3.2.1.1 and 3.2.2.

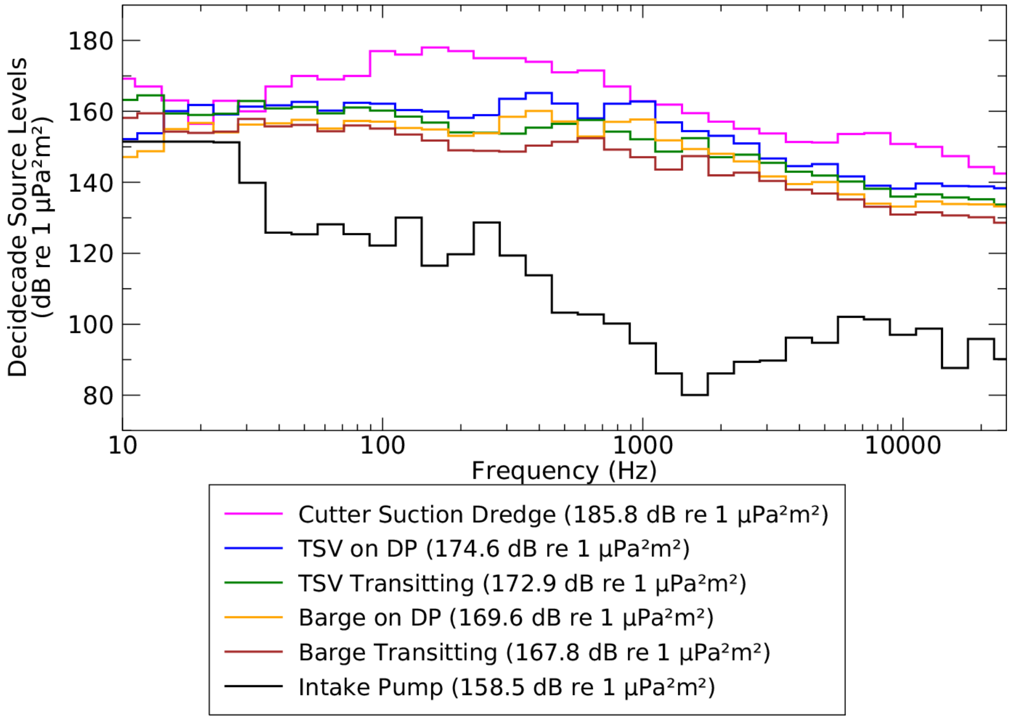

Figure 6. Monopole source level (MSL) spectra (in decidecade frequency-band) for all sound sources.

3.2.1.1. Cutter Suction Dredge (CSD)

It is anticipated that a single medium-sized cutter suction dredge will be used to dredge a channel. As the exact specifications of the CSD was unknown at the time of modelling the source levels for the dredge are based on the combined source levels of three, previously-measured CSDs: Jan De Nul's *J.F.J. de Nul* (Hannay et al. 2004), Dredging Corporation of India Ltd's (DCI) *Aquarius* (Malme et al. 1989) and Fraser River Pile & Dredge (GP) Inc.'s *Columbia* (McHugh et al. 2007). The *J.F.J. de Nul* and *Aquarius* are thruster-powered, unlike the *Columbia* which is winch powered. Hence the loudest of the *J.F.J. de Nul* and *Aquarius* levels were chosen for each decidecade band. For bands where neither of the two thruster-powered CSDs have measured source levels, the *Columbia* levels are used instead. The resulting spectrum has a broadband source level (BBSL) of 185.8 dB re 1 µPa m. Its monopole source depth is modelled at 3.0 m, half the water depth at the modelled dredging site.

Table 20. Parameters of the three surrogate CSDs being used to construct the source level spectrum.

Equipment	Cutter Power (kW)	Dredging depth (m)	Length (m)	Breadth (m)	Draft (m)	Suction pipe diameter (m)	Propulsion power (kW)
J.F.J. De Nul	6000	35	124.4	27.8	6.51	1.1	2 × 3800
Aquarius	1984	N/A	107	19	4.85	0.85	12889
Columbia	375	18	49	13.4	2.14	0.66	N/A

3.2.2. Vessel Radiated Noise

3.2.2.1.1. Transshipment Vessel (TSV)

The transshipment vessel is likely to be similar to the *CSL Whyalla* with a length of 141.4 m, a width of 24 m, and a draft of 7.02 m and may operate under DP or in transit. The TSV has a maximum installed thruster power of 13670 kW. The TSV will berth at the jetty for loading where berthing will be performed under DP for an estimated 30 mins. After loading, the TSV will transit to an offshore location at ~7.5 kts for cargo transfer to the shipping vessel, assumed noiseless for modelling.

The source level for the *CSL Whyalla* has not been measured and were based on source levels of a proxy source. For a conservative estimate, the proxy source used was the *Skandi Feistein*, a platform supply vessel with length 87.9 m, a width of 19.0 m, and a draft of 6.6 m and a maximum installed thruster power of 12820 kW. The *Skandi Feistein* has been measured (Esso and ExxonMobil 2021) under DP to be 174.4 dB re 1 µPa^{2}m^2 and while transiting as 172.6 dB re 1 µPa^{2}m^2. A nominal spectral shape for the TSV was selected based on the *Siem Sapphire* measured on DP and standby (McPherson et al. 2021); this shape was adjusted to match the broadband levels of the *Skandi Feistein*. The values for the *Skandi Feistein* were scaled based on the difference in max installed thruster power following Equation (1).

$$\mathrm{SL} = \mathrm{SL_{ref}} + 10\log_{10}\left(\frac{\mathrm{P}}{\mathrm{P_{ref}}}\right), \tag{1}$$

where SL is the source level of the TSV, $\mathrm{SL_{ref}}$ is the corresponding source level of the *Skandi Feistein*, P is the TSV's installed thruster power and $\mathrm{P_{ref}}$ is the *Skandi Feistein*'s installed thruster power of 12820 kW.

The maximum broadband (10 Hz to 25 kHz) source level of the TSV under DP is 174.4 dB re 1 µPa^{2}m^2 and for the TSV transiting is 172.9 dB re 1 µPa^{2}m^2. The monopole source depth was chosen at 6 m based on the approximate location of cavitation. The CSL Whyalla and the source level spectrum for the TSV is shown in Figure 7.

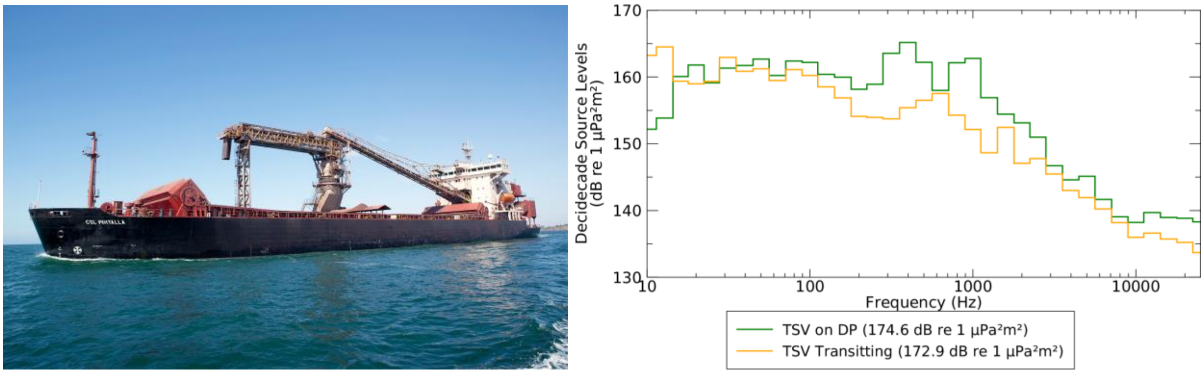

Figure 7. Photo of the *CSL Whyalla* (left) and the proposed source level spectrum (right) (Photo source: CSL 2023)

3.2.2.1.2. Split Hopper Barge

The split hopper barge that will be included in the operational activities is likely to be similar to the *Jan De Nul Tiger* which may operate both under DP and in transit. The *Jan De Nul Tiger* has dimensions 99.5 m length, 19.4 m width and 5.85 m depth and a maximum installed thruster power of 4250 kW. The split hopper barge is on DP alongside the CSD loading the dredged materials and, once full, it transits to the disposal site. It is expected that two split hopper barges are used, each with a capacity of 1,500 m^3.

Following the approach outlined above for the TSV, the estimated spectra and source levels for the vessel are based on the *Skandi Feistein* for the source levels and a nominal spectrum based on the *Siem Sapphire*. These were scaled following Equation (1).

The maximum broadband (10 Hz to 25 kHz) source level of the split hopper barge under DP is 169.6 dB re 1 µPa^{2}m^2 and for the split hopper barge transiting is 168.7 dB re 1 µPa^{2}m^2. The monopole source depth was chosen at 6 m based on the approximate location of cavitation. The *Jan De Nul Tiger* and the source level spectrum for the barge is shown in Figure 8.

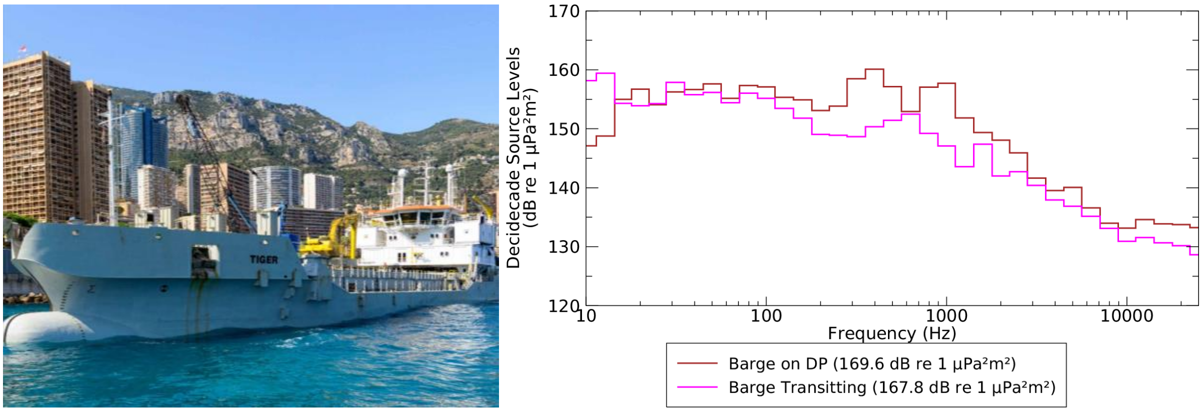

Figure 8. Photo of the *Jan De Nul Tiger* (left) and the proposed source level spectrum (right) (Photo source: CSL 2023)

3.2.2.1.3. Intake Pump

The seawater intake site is expected to use up to eight intake pumps. The source level for the intake site for this study were derived from measurements of a water intake pontoon from Lu et al. (2022). The water intake pontoon source level measurements in Lu et al. (2022) used 5 hydrophones to sample the sound field. Lu et al. (2022) provide a source level of 149.5±0.2 dB re 1 µPa for the water intake pontoon. For this study all 8 intake pumps were modelled as continuously operating. Using the results from Lu et al. (2022) and scaling the 149.5±0.2 dB re 1 µPa level by the equation below,

$$\mathrm{SL} = \mathrm{SL}_{\mathrm{ref}} + 10\log_{10}(8), \tag{2}$$

a source level for all 8 intake pumps was estimated to be 158.5 dB re 1 µPa^{2}m^2. The measurements for the water intake pontoon from Lu et al. (2022) began from 20 Hz and was extrapolated to 10 Hz for modelling by maintaining the same level to allow for a conservative estimate.

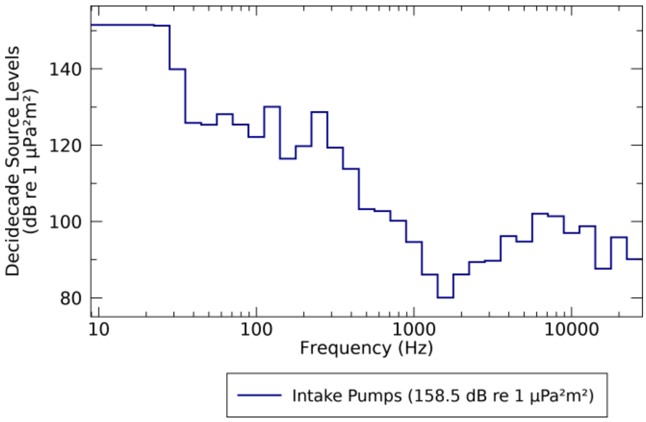

Figure 9. Modelled source level spectrum of intake pumps.

3.2.3. Geometry and Modelled Regions

JASCO's Marine Operations Noise Model (MONM-BELLHOP; see Appendix C.1) was used to predict the acoustic field at frequencies of 10 Hz to 25 kHz for all vessels. To supplement the MONM results (10 Hz to 1 kHz), high-frequency results for propagation loss were modelled using BELLHOP (Porter and Liu 1994) for frequencies from 1.26 to 25 kHz. The MONM and BELLHOP results were combined to produce results for the full frequency range of interest.

The sound field modelling calculated propagation losses up to 80 km from each source, with a horizontal separation of 10 m between receiver points along the modelled radials. The sound fields were modelled with a horizontal angular resolution of $\Delta\theta$ = 2.5° for a total of N = 144 radial planes. Receiver depths were chosen to span the entire water column over the modelled area, from 2 m to a maximum of 150 m.

To produce the maps of received sound level isopleths, and to calculate distances to specified sound level thresholds, the maximum-over-depth level was calculated at each sampling point within the modelled region. The radial grids of maximum-over-depth levels were then resampled (by linear triangulation) to produce a regular Cartesian grid. The contours and threshold ranges were calculated from these grids of the modelled acoustic fields.

3.2.4. Accumulated SEL

In this study, the dredging and vessel sound sources were considered to be continuously operating with new sound energy constantly being introduced to the environment. The reported source levels are usually in terms of sound pressure levels (SPL), representing the root-mean-square (rms) pressure level of a considered source. The evaluation of the cumulative sound field (i.e., in terms of SEL_{24h}) depends on the number of seconds of operation during the accumulation period.

The SPL modelling results were converted to SEL by the duration of the measurement, which is appropriate for a non-impulsive noise source. Here, SEL was assessed over 24 hours. For a stationary vessel, the conversion from SPL was obtained by increasing the levels by $10*\log_{10}(T)$, where T is 86,400 (the number of seconds in 24 h). For scenarios where a vessel was transiting along a track, a similar adjustment to the SPL was applied, however the time factor was determined based on the step size along the track and the vessel’s speed. See Appendix C.2 for detail.

4. Results

4.1. Pile Driving Activities

4.1.1. Received Levels at 10 m – Pipe Pile

Since piles are distributed and directional sources, they cannot be accurately approximated by a point source with corresponding source levels. It is possible to compare the maximum modelled levels at short distances from the piles. Figure 10 shows the decidecade–band levels for the receiver with the highest SEL at a horizontal range of 10 m, for each of the three modelled penetration depths and each of the three modelling scenarios. The levels above 1000 Hz were extrapolated using a 20 dB/decade decay rate to match acoustic measurements of impact pile driving of similarly sized piles (Illingworth & Rodkin 2007, Matuschek and Betke 2009). The modelled results at a distance of 10 m are included to provide results comparable to other pile driving reports and literature, such as Illingworth & Rodkin (2007), and Denes et al. (2016).

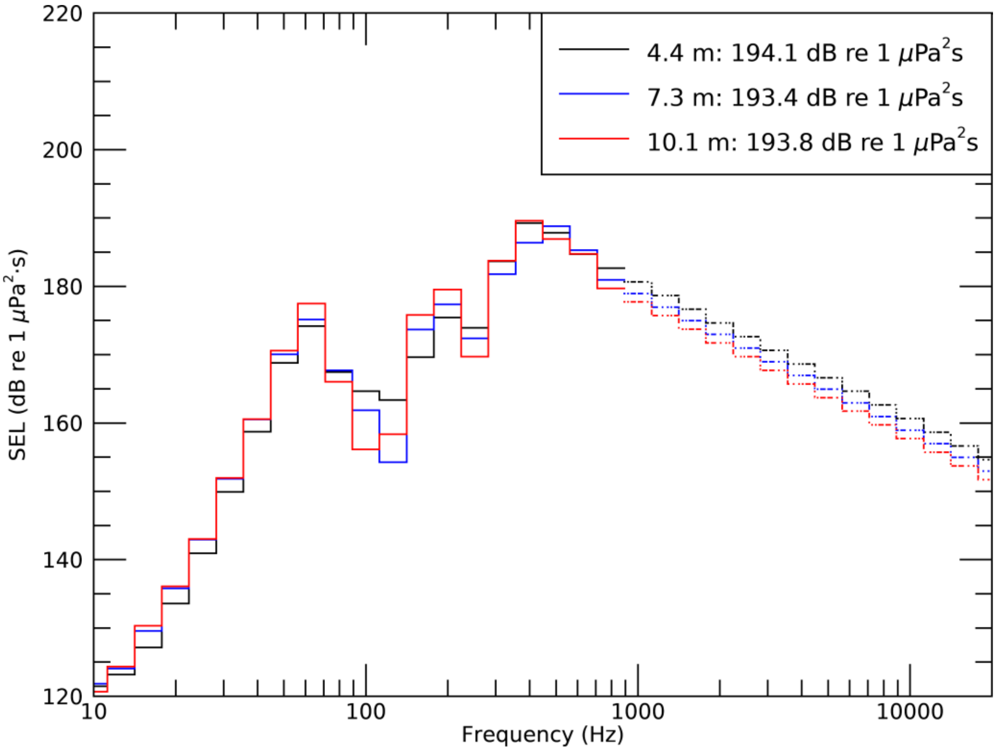

Figure 10. *Scenario 1, Pipe Pile*: Decidecade–band levels for the receiver with highest SEL at 10 m horizontal range for impact pile driving using the Juntaan HHK20S hammer, after high–frequency extrapolation (dashes indicate extrapolated portion of the spectrum above 1000 Hz). Legend items indicate the modelled pile penetration and the broadband SEL in dB re 1 μPa²·s.

4.1.2. Tabulated Results

This section presents the per-strike sound fields in terms of maximum-over-depth SPL, SEL, and PK. The different metrics are presented for the following reasons:

- SPL sound fields (Table 21) were used to determine the distances to marine mammal and turtle behavioural thresholds (see Section 2.1).

- Per-pulse SEL sound fields (Table 22) are used as inputs into the 24 h SEL scenario.
- PK metrics within the water column (Table 23) are relevant to thresholds and guidelines for marine mammals, sea turtles, fish, fish eggs and larvae (as well as plankton; see Section 2.1).

Frequency-weighted SEL_{24h} sound fields were used to estimate the maximum and 95% distances (R_{max} and $R_{95\%}$; calculated as detailed in Appendix D.2) to marine mammals and turtle PTS and TTS thresholds (listed in Table 24), and to estimate maximum distance and the area to injury and TTS guidelines for fish (Table 25).

Table 21. *Modelled maximum–over–depth per–strike SPL isopleths*: Maximum (R_{max}) and 95% ($R_{95\%}$) horizontal distances (in km) from each pile and for each penetration depth.

SPL (L_p; dB re 1 µPa)	Scenario 1: Pipe Pile Juntaan HHK 20S						Scenario 2: Sheet Pile Juntaan HHK 10S	
	4.4 m		7.3 m		10.1 m		N/A	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$(km)
200	0.03	0.03	0.03	0.03	0.03	0.03	–	–
190	0.11	0.10	0.12	0.10	0.12	0.10	–	–
180	0.47	0.40	0.44	0.38	0.47	0.41	–	–
175[1]	0.77	0.63	0.70	0.60	0.78	0.65	–	–
170	1.14	0.98	1.13	0.97	1.17	1.06	0.03	0.03
166[2]	1.49	1.33	1.50	1.34	1.59	1.42	0.05	0.05
160[3]	2.50	2.01	2.50	2.05	2.66	2.18	0.13	0.11
150	4.70	3.72	4.70	3.79	5.21	4.20	0.29	0.23
140	13.1	10.9	14.6	11.6	16.0	13.6	0.40	0.36
130	30.7	25.3	31.2	26.0	39.2	31.7	1.07	0.92

[1] Threshold for turtle behavioural disturbance from impulsive noise (McCauley et al. 2000).
[2] Threshold for turtle behavioural response to impulsive noise (McCauley et al. 2000).
[3] Marine mammal behavioural threshold for impulsive sound sources (NOAA 2024).
A slash indicates the $R_{95\%}$ radius to threshold is not reported when the R_{max} is greater than the maximum modelling extent.

Table 22. *Modelled maximum–over–depth per–strike SEL isopleths*: Maximum (R_{max}) and 95% ($R_{95\%}$) horizontal distances (in km) from each pile and for each penetration depth.

Per–strike SEL (L_E; dB re 1 µPa²·s)	Scenario 1: Pipe Pile Juntaan HHK 20S						Scenario 2: Sheet Pile Juntaan HHK 10S	
	4.4 m		7.3 m		10.1 m			
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
190	0.03	0.03	0.03	0.03	0.03	0.03	–	–
180	0.14	0.13	0.14	0.12	0.14	0.12	–	–
170	0.53	0.45	0.50	0.42	0.53	0.46	0.03	0.03
160	1.26	1.12	1.24	1.11	1.31	1.18	0.05	0.05
150	2.85	2.23	2.83	2.25	3.31	2.48	0.13	0.11
140	5.36	4.18	5.63	4.35	8.32	4.95	0.29	0.23
130	15.2	12.1	15.8	12.6	17.2	14.6	0.40	0.36

Table 23. *Modelled maximum–over–depth per–strike PK isopleths*: Maximum (R_{max}) horizontal distances (in km) from the piling source to modelled maximum-over-depth peak pressure level (PK) thresholds based on NMFS (2024) for marine mammals, and Popper et al. (2014) for fish and Finneran et al. (2017) for sea turtles.

Hearing group	PK threshold (L_{pk}; dB re 1 µPa)	Scenario 1: Pipe Pile Juntaan HHK 20S			Scenario 2: Sheet Pile Juntaan HHK 10S
		4.4 m	7.3 m	10.1 m	N/A
		R_{max} (km)	R_{max} (km)	R_{max} (km)	R_{max} (km)
PTS					
LF cetaceans	222	–	–	–	–
HF cetaceans	230	–	–	–	–
Sirenians	225	–	–	–	–
Sea turtles	232	–	–	–	–
TTS					
LF cetaceans	216	0.03	0.03	0.03	0.02
HF cetaceans	224	–	–	–	–
Sirenians	219	0.03	0.02	–	–
Sea turtles	226	–	–	–	–
Fish					
Fish I (also applied to sharks)[1]	213	0.03	0.03	0.03	–
Fish II, III[1] Fish eggs, and larvae[2]	207	0.08	0.08	0.06	–

[1] Threshold for recoverable injury, potential mortal injury and mortality
[2] Threshold for potential mortal injury and mortality
Fish I–No swim bladder; Fish II–Swim bladder not involved with hearing; Fish III–Swim bladder involved with hearing.
A dash indicates the threshold is not reached within the limits of the modelling resolution (20 m).

Table 24. *Modelled maximum–over–depth SEL_{24h} isopleths, marine mammals and sea turtles:* Maximum-over-depth distances (in km) to frequency-weighted 24 h sound exposure level (SEL_{24h}) based PTS and TTS for marine mammals from NMFS (2024) and sea turtles (Finneran et al. 2017) considering impact driving.

Fauna group	Threshold for SEL_{24h} ($L_{E,24h}$; dB re 1 µPa²·s)	Scenario 1: Pipe Pile Juntaan HHK 20S		Scenario 2: Sheet Pile Juntaan HHK 10S	
		R_{max} (km)	Area (km²)	R_{max} (km)	Area (km²)
PTS					
LF cetaceans	183	3.37	10.3	0.35	0.11
HF cetaceans	193	0.43	0.32	0.07	0.01
Sirenians	186	0.35	0.23	0.06	0.01
Sea turtles	204	0.36	0.28	–	–
TTS					
LF cetaceans	168	11.8	75.8	1.05	0.26
HF cetaceans	178	1.79	3.83	0.31	0.09
Sirenians	171	1.52	2.96	0.27	0.06
Sea turtles	189	1.51	3.34	0.13	0.02

Table 25. *Modelled maximum–over–depth SEL$_{24h}$ isopleths, fish*: Maximum-over-depth distances (in km) to 24 h sound exposure level (SEL$_{24h}$) based fish criteria in the water column for fish (Popper et al. 2014) considering impact driving.

Marine fauna group	Threshold for SEL$_{24h}$ ($L_{E,24h}$; dB re 1 µPa²·s)	Scenario 1: Pipe Pile Juntaan HHK 20S		Scenario 2: Sheet Pile Juntaan HHK 10S	
		R_{max} (km)	Area (km²)	R_{max} (km)	Area (km²)
Mortality and potential mortal injury					
Fish I	219	0.06	0.01	–	–
Fish II, fish eggs and fish larvae	210	0.29	0.16	0.02	–
Fish III	207	0.42	0.32	0.03	–
Recoverable injury					
Fish I	216	0.09	0.02	–	–
Fish II, III	203	0.64	0.66	0.06	0.01
Temporary threshold shift (TTS)					
Fish I, II, III	186	2.71	8.63	0.31	0.09

Fish I–No swim bladder; Fish II–Swim bladder not involved with hearing; Fish III–Swim bladder involved with hearing.

4.1.3. Sound Field Maps

Maps of the per strike sound fields are presented as maximum-over-depth sound level contour maps in Figures 11–14 and as vertical slice plots in Figures 15–18 for north-south transects. An accumulated SEL_{24h} map is shown for pipe and sheet pilin in Figures 19 and 20, respectively.

4.1.3.1. SPL Sound Level Contour Maps

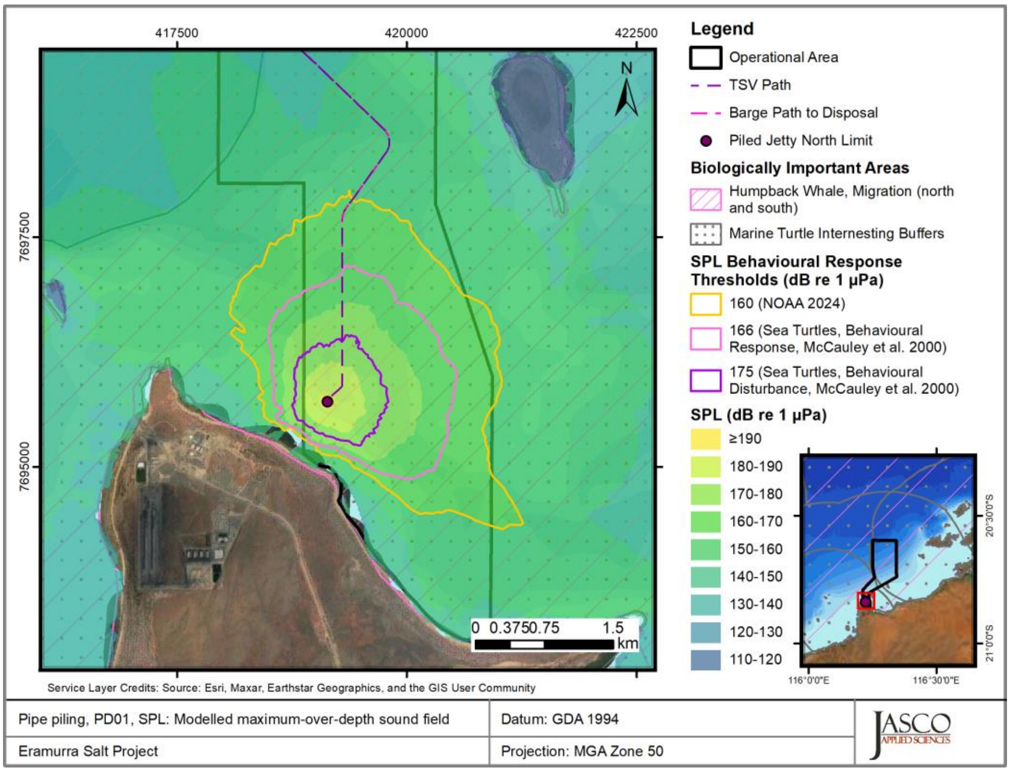

Figure 11. *Pile Driving, Scenario 1, Penetration Depth – 25 m, SPL*: Sound level contour map showing the unweighted maximum-over-depth sound field in 10 dB steps, and the isopleths for behavioural thresholds for marine mammals and sea turtles.

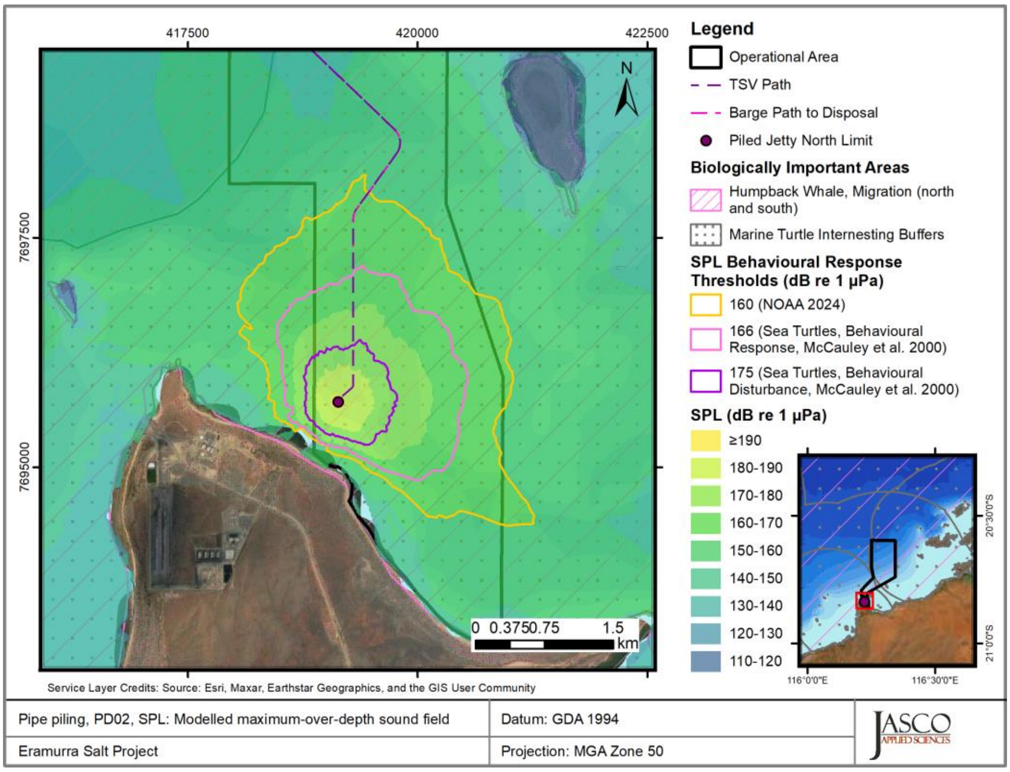

Figure 12. *Pile Driving, Scenario 1, Penetration Depth – 43 m, SPL*: Sound level contour map showing the unweighted maximum-over-depth sound field in 10 dB steps, and the isopleths for behavioural thresholds for marine mammals and sea turtles.

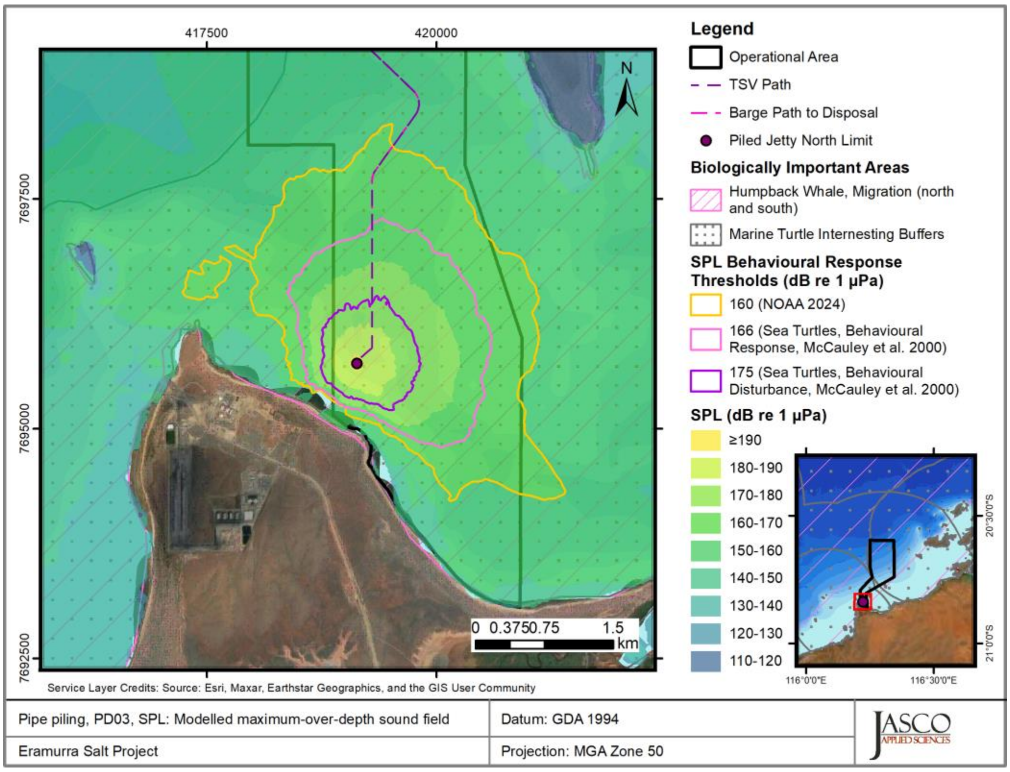

Figure 13. *Pile Driving, Scenario 1, Penetration Depth – 61 m, SPL*: Sound level contour map showing the unweighted maximum-over-depth sound field in 10 dB steps, and the isopleths for behavioural thresholds for marine mammals and sea turtles.

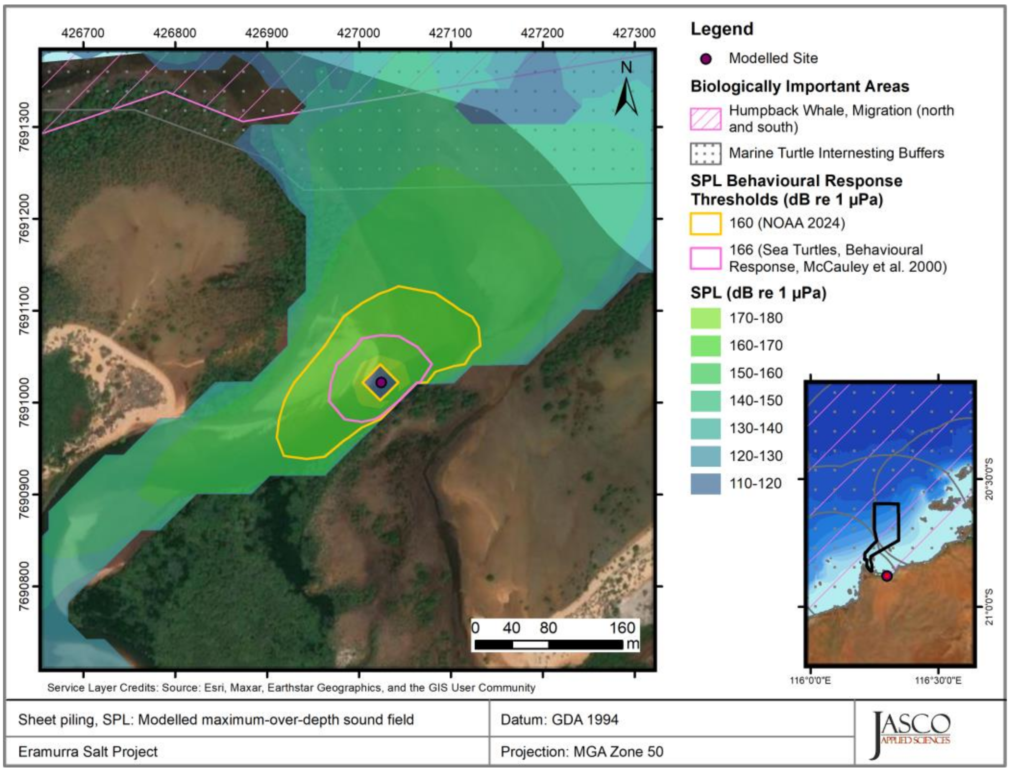

Figure 14. *Pile Driving, sheet pile, SPL*: Sound level contour map showing the unweighted maximum-over-depth sound field in 10 dB steps, and the isopleths for behavioural thresholds for marine mammals and sea turtles.

4.1.3.2. SPL Per-strike Vertical Slice Plots

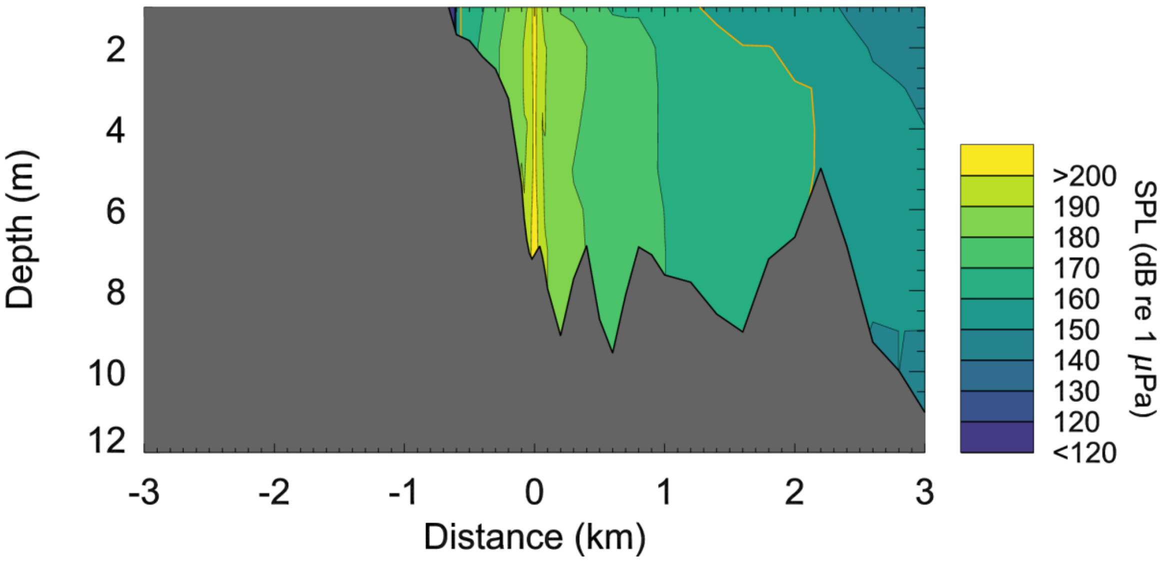

Figure 15. *Pile Driving, Scenario 1, Penetration Depth – 4.4 m, SPL*: Vertical slice plot showing variations with depth and distance from the pile. The seabed is shown as dark grey. Cross section shows directly north from the pile location.

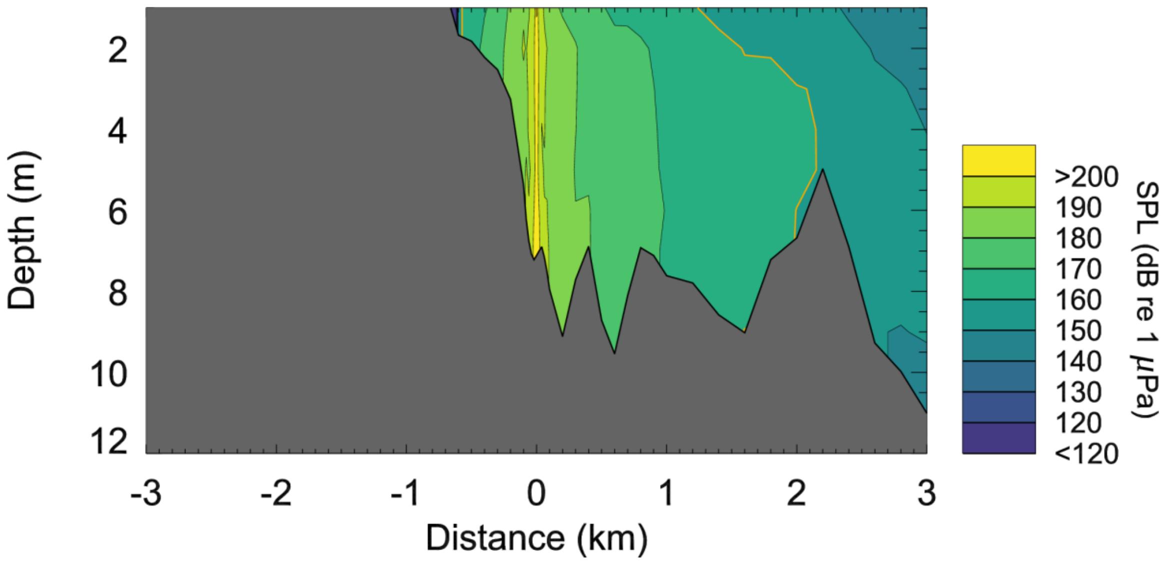

Figure 16. *Pile Driving, Scenario 1, Penetration Depth – 7.3 m, SPL*: Vertical slice plot showing variations with depth and distance from the pile. The seabed is shown as dark grey. Cross section shows directly north from the pile location.

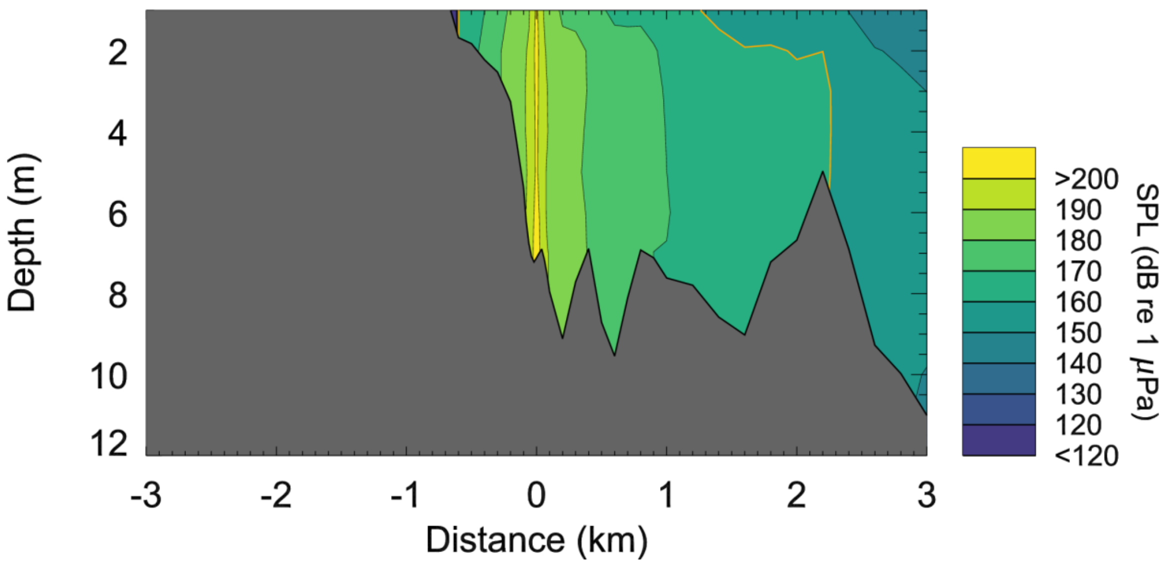

Figure 17. *Pile Driving, Scenario 1, Penetration Depth – 10.1 m, SPL*: Vertical slice plot showing variations with depth and distance from the pile. The seabed is shown as dark grey. Cross section shows directly north from the pile location.

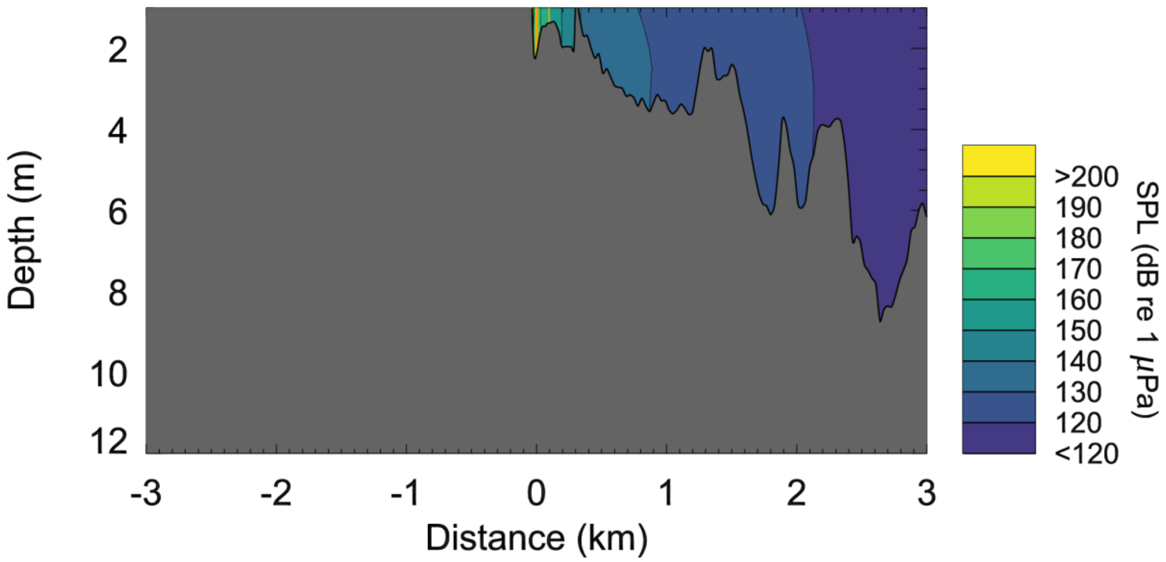

Figure 18. *Pile Driving, Scenario 2, Source Depth – 1 m, SPL*: Vertical slice plot showing variations with depth and distance from the pile. The seabed is shown as dark grey. Cross section shows directly north from the pile location.

4.1.3.3. Accumulated SEL_{24h} Sound level Contour Maps

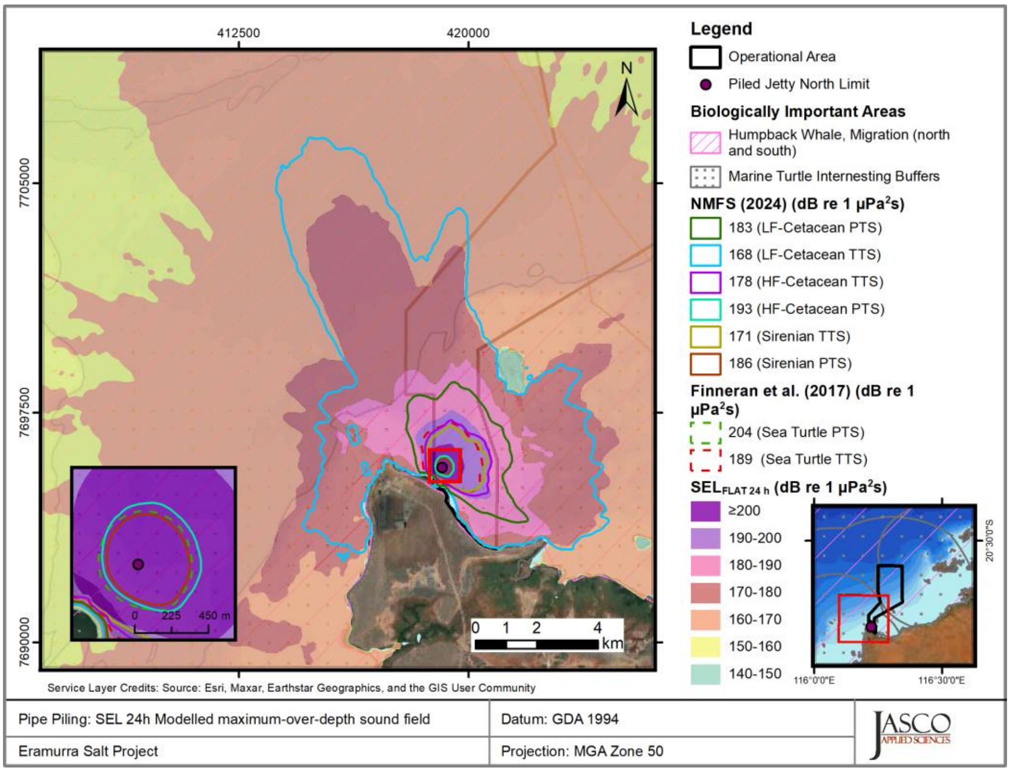

Figure 19. *Pipe piling, accumulated SEL_{24h}*: Sound level contour map showing maximum-over-depth SEL_{24h} results (unweighted/flat), along with frequency weighted isopleths for low- and high-frequency cetaceans, sirenians, sea turtles and fish. Thresholds omitted here were not reached or not long enough to display graphically.

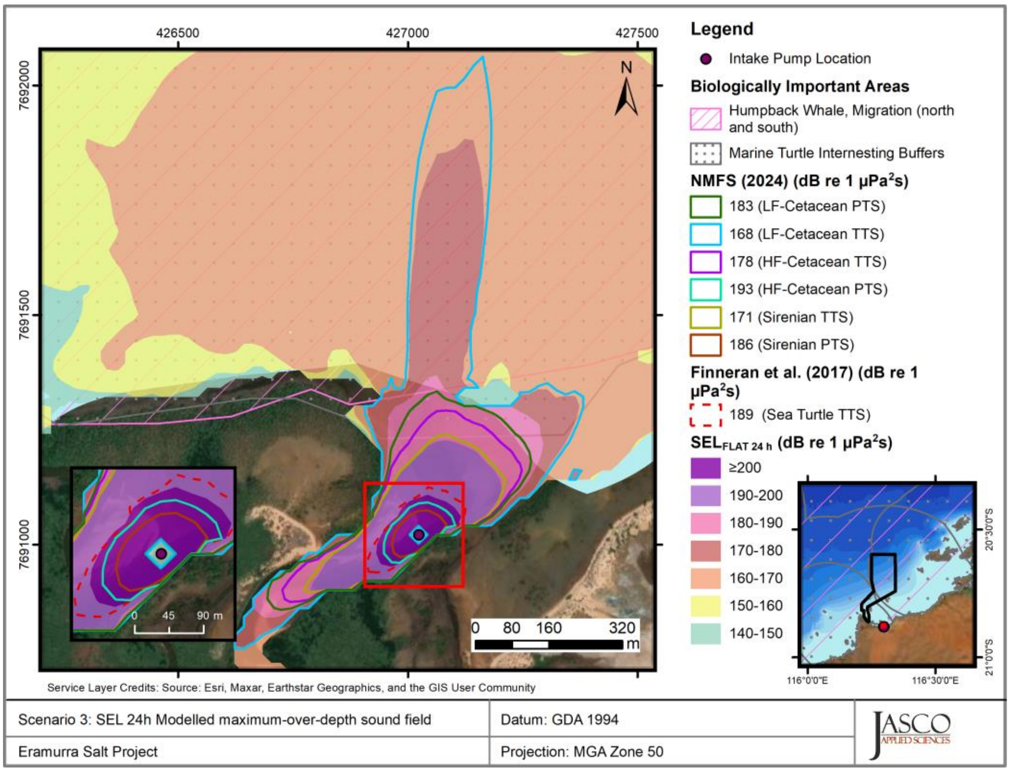

Figure 20. *Sheet piling, accumulated SEL$_{24h}$*: Sound level contour map showing maximum-over-depth SEL$_{24h}$ results (unweighted/flat), along with frequency weighted isopleths for low- and high-frequency cetaceans, sirenians, sea turtles and fish. Thresholds omitted here were not reached or not long enough to display graphically.

4.2. Dredging and Vessel Activities

The maximum-over-depth sound fields for the modelled scenarios are presented below in two formats: as tables of distances to sound levels and, where the distances are long enough, as contour maps showing the directivity and range to various sound levels.

For the results below, the distances to isopleths/thresholds were reported from either the centroid of several sources or from the most dominant single source. When an isopleth completely envelopes multiple sources the centroid was used. When several closed isopleths exist the most dominant source was used. Maps are provided in Section 4.2.2 to assist with contextualising tabulated distances.

4.2.1. Tabulated Results

Table 26 presents the maximum and 95% horizontal distances to specific SPL contours. The SPL sound footprints represent instantaneous sound fields and do not depend on time accumulation.

Table 27 presents the maximum distances to frequency-weighted SEL$_{24h}$ thresholds, as well as total ensonified areas.

Table 26. *SPL*: Maximum (R_{max}) and 95% ($R_{95\%}$) horizontal distances (in km) to sound pressure level (SPL) from most appropriate location for considered sources per scenario. Scenario descriptions are provided in Section 1.1.

SPL (L_p; dB re 1 µPa)	Scenario 1: Dredging, CSD + 2 Barges		Scenario 2: TSV Movement	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
180	–	–	–	–
170[a]	0.01	0.01	–	–
160	0.07	0.07	–	–
158[b]	0.11	0.11	–	–
150	0.33	0.31	0.05	0.05
140	0.98	0.86	0.32	0.29
130	2.17	1.79	1.11	0.95
120[c]	6.30	5.09	3.17	2.49
110	15.9	13.9	6.86	5.15
100	41.8	33.7	19.8	17.1

[a] 48 h threshold for recoverable injury for fish with a swim bladder involved in hearing (Popper et al. 2014).
[b] 12 h threshold for TTS for fish with a swim bladder involved in hearing (Popper et al. 2014).
[c] Threshold for marine mammal behavioural response to non-impulsive noise (NOAA 2024).
A dash indicates the level was not reached within the limits of the modelled resolution (10 m).
A slash indicates the $R_{95\%}$ radius to threshold is not reported when the R_{max} is greater than the maximum modelling extent.

Table 27. *SEL24h*: Maximum (R_{max}) horizontal distances (in km) to frequency-weighted SEL_{24h} PTS and TTS thresholds based on NMFS (2024) and Finneran et al. (2017) from most appropriate location for considered sources per scenario, along with ensonified area (km^2).

Hearing group	Frequency-weighted SEL_{24h} threshold ($L_{E,24h}$; dB re 1 µPa²·s)	Scenario 1: Dredging, CSD + 2 Barges		Scenario 2: TSV Movement	
		R_{max} (km)	Area (km²)	R_{max} (km)	Area (km²)
PTS					
LF cetaceans	197	0.33	0.32	–	–
HF cetaceans	201	0.01	/	–	–
Sirenians	200	–	–	–	–
Sea turtles	220	0.01	/	–	–
TTS					
LF cetaceans	177	2.21	9.61	0.17	0.26
HF cetaceans	181	0.24	0.15	–	–
Sirenians	180	0.05	0.01	–	–
Sea turtles	200	0.26	0.19	–	–

A dash indicates the level was not reached within the limits of the modelled resolution (10 m).
A slash indicates that the area is less than an area associated with the modelled resolution (0.0013 km²).

4.2.2. Sound Field Maps

Maps of the estimated sound fields, threshold contours, and isopleths of interest for SPL and SEL_{24h} sound fields are presented for the modelled drilling and vessel scenarios.

The SPL metric represents the sound emitted at a given point in time, and hence the sound fields presented do not reflect the combined SPL across all modelled sites, but rather the SPL of each modelled vessel at one time.

4.2.2.1. SPL Sound Level Contour Maps

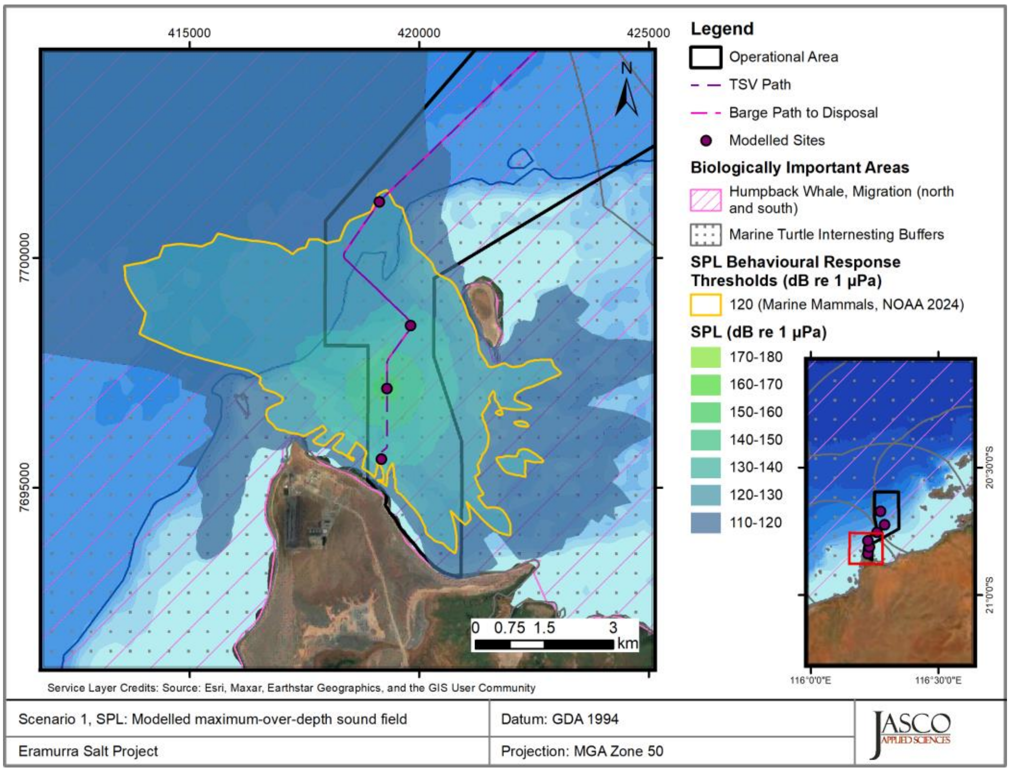

Figure 21. *Scenario 1, Dredging and barge movement, SPL*: Sound level contour map showing the unweighted maximum-over-depth sound field in 10 dB steps, and the isopleths for behavioural response threshold for marine mammals.

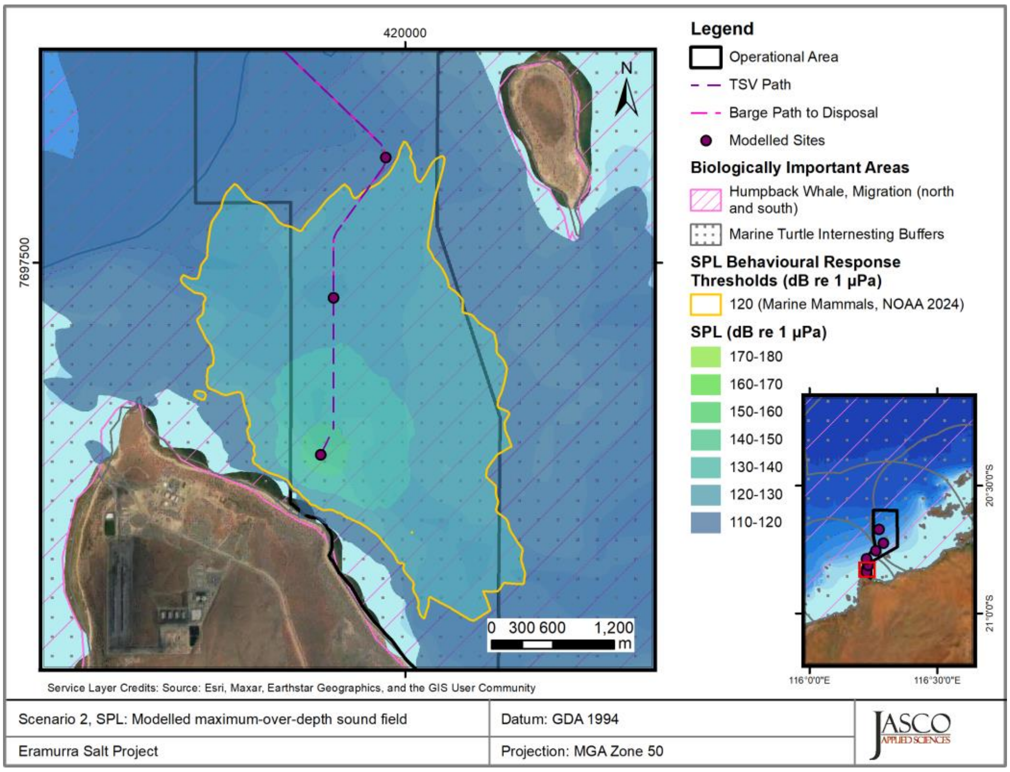

Figure 22. *Scenario 2, TSV movement, SPL*: Sound level contour map showing the unweighted maximum-over-depth sound field in 10 dB steps, and the isopleths for behavioural response threshold for marine mammals.

4.2.2.2. Accumulated SEL_{24h} Sound level Contour Maps

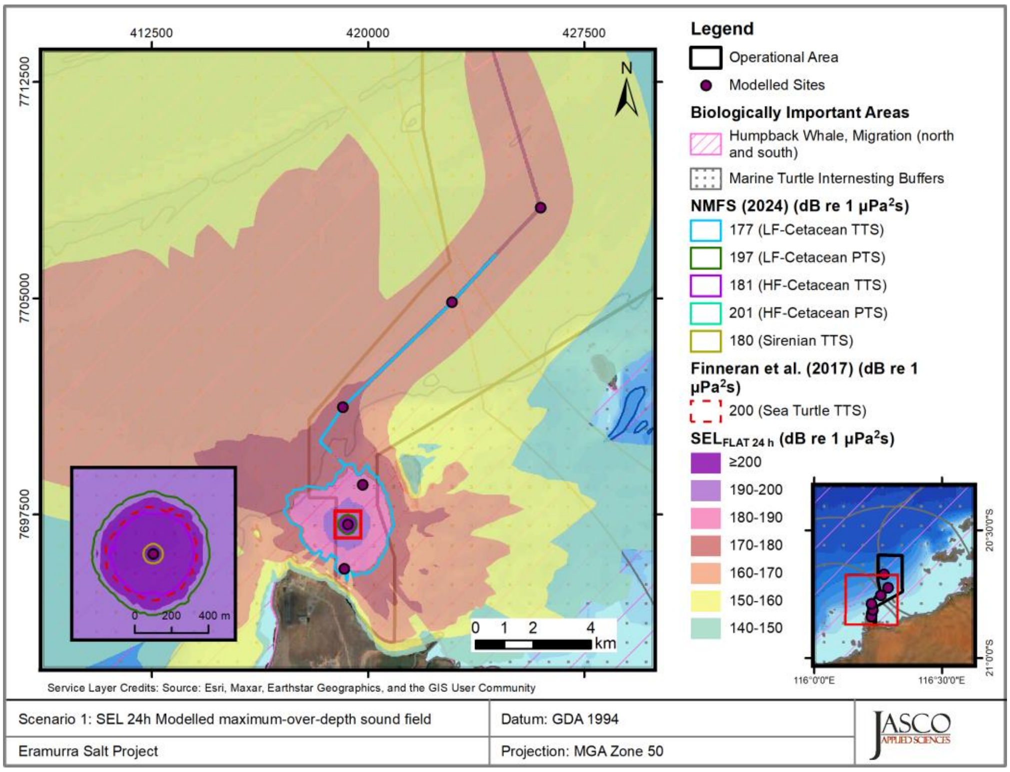

Figure 23. *Scenario 1, Dredging and barge movement, accumulated SEL_{24h}*: Sound level contour map showing maximum-over-depth SEL_{24h} results (unweighted/flat), along with frequency weighted isopleths for TTS in low, high, and very high-frequency cetaceans and turtles. Thresholds omitted here were not reached or not long enough to display graphically.

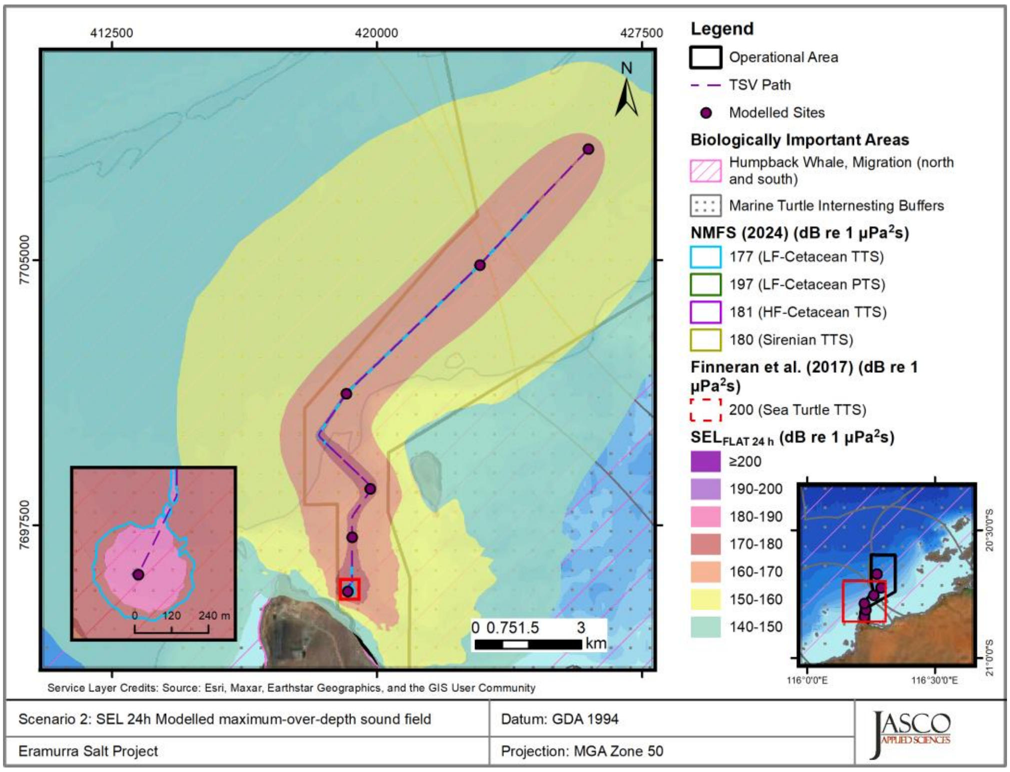

Figure 24. *Scenario 2, TSV movement, accumulated SEL$_{24h}$*: Sound level contour map showing maximum-over-depth SEL$_{24h}$ results (unweighted/flat), along with frequency weighted isopleths for TTS in low, high, and very high-frequency cetaceans and turtles. Thresholds omitted here were not reached or not long enough to display graphically.

4.3. Intake Pump

4.3.1. Tabulated Results

Table 28 presents the maximum and 95% horizontal distances to specific SPL contours. The SPL sound footprints represent instantaneous sound fields and do not depend on time accumulation.

Table 29 presents the maximum distances to frequency-weighted SEL$_{24h}$ thresholds, as well as total ensonified areas.

Table 28. *SPL*: Maximum (R_{max}) and 95% ($R_{95\%}$) horizontal distances (in km) to sound pressure level (SPL) from most appropriate location for considered sources per scenario. Scenario descriptions are provided in Section 1.1.

SPL (L_p; dB re 1 µPa)	Scenario 3: Intake Pump Noise	
	R_{max} (km)	$R_{95\%}$ (km)
180	–	–
170[a]	–	–
160	–	–
158[b]	–	–
150	–	–
140	–	–
130	–	–
120[c]	–	–
110	0.04	0.04
100	0.13	0.10

[a] 48 h threshold for recoverable injury for fish with a swim bladder involved in hearing (Popper et al. 2014).
[b] 12 h threshold for TTS for fish with a swim bladder involved in hearing (Popper et al. 2014).
[c] Threshold for marine mammal behavioural response to non-impulsive noise (NOAA 2024).
A dash indicates the level was not reached within the limits of the modelled resolution (10 m).
A slash indicates the $R_{95\%}$ radius to threshold is not reported when the R_{max} is greater than the maximum modelling extent.

Table 29. *SEL24h*: Maximum (R_{max}) horizontal distances (in km) to frequency-weighted SEL_{24h} PTS and TTS thresholds based on NMFS (2024) and Finneran et al. (2017) from most appropriate location for considered sources per scenario, along with ensonified area (km^2).

Hearing group	Frequency-weighted SEL_{24h} threshold ($L_{E,24h}$; dB re 1 µPa²·s)	Scenario 3: Intake Pump Noise	
		R_{max} (km)	R_{max} (km)
PTS			
LF cetaceans	197	–	–
HF cetaceans	201	–	–
Sirenians	200	–	–
Sea turtles	220	–	–
TTS			
LF cetaceans	177	–	–
HF cetaceans	181	–	–
Sirenians	180	–	–
Sea turtles	200	–	–

A dash indicates the level was not reached within the limits of the modelled resolution (10 m).

4.3.2. Sound Field Maps

Since the intake pump activities were too quiet to exceed any of the effects thresholds, maps are not given for the intake pump activities.

5. Discussion

The modelling study predicted underwater sound levels associated with key activities for the planned Eramurra Solar Salt project. The underwater sound field was modelled for a variety of sound sources including pile driving, dredging, vessel operations, and an intake pump. The key distinction between these noise sources is that impact piling is classified as impulsive noise, while dredging, intake pump, and vessel noise are categorized as non-impulsive. The criteria and assessment guidelines for impulsive and non-impulsive noise classifications differ, as outlined in Sections 2.1 and 2.2. Maximum and 95th percentile distances (R_{max} and $R_{95\%}$, refer to Appendix D.2) and ensonified areas were calculated for thresholds associated with permanent threshold shift (PTS), temporary threshold shift (TTS), behavioural response, behavioural disturbance, mortality, potential mortal injury, and recoverable injury for marine fauna. These distances provide an initial assessment of the potential spatial extent of acoustic impacts from the project's construction activities. For a more precise understanding of the spatial extent of these impacts, contour maps presented in Sections 4.1.3, 4.2.2, and 4.3.2 and offer detailed visualisations. These maps contextualise the effect of the environmental effects and determine the predicted sound field extents.

An analysis of seasonal sound speed profiles indicated that June was the most conducive to sound propagation; as such it was selected to ensure a conservative estimation of distances to received sound level thresholds (Appendix D.3.2) and hence operational flexibility. Modelling also accounts for site-specific bathymetric variations (Appendix D.3.1) and local geoacoustic properties (Appendix D.3.3).

The modelled sites encompassed water depths from 4.9 to 15.6 m across one defined geological area with a single representative water column sound speed profile. The sound speed profile was primarily upwards refracting across the entire water column with a minimum sound speed of 1530 m/s at the surface. The bathymetry throughout the modelled area varied slowly, generally deepening to the north. Most of the acoustic energy from the considered sound sources was output at lower frequencies, in the tens to hundreds of hertz.

The bathymetry in the modelled area showed water depths were generally less than 20 m. The sea surface and sea floor create a waveguide which can only support energy of certain frequencies. For typical water depths of 2–16 m the cutoff frequencies (Jensen et al. 2011) will be 340–44 Hz, leading to higher low frequency loss. For successive reflections between the sea surface and the seafloor energy is stripped from the water column, mainly due to interaction with the seabed. The combination of these effects leads to higher attenuation near shore, where the water depth is the least. This is particularly prevalent for the sound from the intake pump, where the bulk of sound energy is emitted below the cutoff frequency.

Within the results and summary tables, where a dash is used in place of a horizontal distance, these thresholds may or may not be reached. Due to the discretely sampled 10 m radial increments of the modelled sound fields, distances to those levels could not be estimated within the computational resolution of the closest step to the source. It is likely that in the case of per-strike SPL, SEL, PK, and continuous SPL some thresholds would be reached at distances between the source and the modelled horizontal resolution (10 m); the injury thresholds based on accumulated SEL on the other hand may not be reached at any range due to the species-specific frequency weighing functions. A dash therefore is an indication that effect levels for the associated metric may only be reached within a very close proximity to a given source, if at all.

5.1. Pile Driving Activities

This study predicted underwater sound levels associated with impact driving of two types of piles, cylindrical pipe piles (Pile 1) and sheet piles (Pile 2), for the Eramurra Solar Salt Project. The pile driving scenarios are based on approximated and likely designs and installation approaches using client supplied driveability for the Juntaan HHK 20S and Juntaan HHK 10S hammers.

Distances to relevant acoustic thresholds for pile driving are shown in Table 30.

Table 30. *Piling Operations:* Maximum (R_{max}) horizontal distances (in km) to relevant thresholds for marine fauna.

Hearing group	Threshold Type	Metric	Threshold	Pile 1	Pile 2
				R_{max} (km)	R_{max} (km)
Low frequency cetaceans	PTS [a]	$L_{E,24h}$	183	3.37	0.35
	TTS [a]	$L_{E,24h}$	168	11.8	1.05
High frequency cetaceans	PTS [a]	$L_{E,24h}$	193	0.43	0.07
	TTS [a]	$L_{E,24h}$	178	1.79	0.31
Sirenians	PTS [a]	$L_{E,24h}$	186	0.35	0.06
	TTS [a]	$L_{E,24h}$	171	1.52	0.27
All Marine Mammal Groups	Behavioural Response [b]	L_p	160	2.66	0.13
Fish without swim bladder	Mortality and Potential mortal injury [c]	$L_{E,24h}$	219	0.06	–
	Recoverable injury [c]	$L_{E,24h}$	216	0.09	–
	TTS [c]	$L_{E,24h}$	186	2.71	0.31
	Recoverable injury [c]	L_{pk}	213	0.03	–
Fish with swim bladder not involved in hearing	Mortality and Potential mortal injury [c]	$L_{E,24h}$	210	0.29	0.02
	Recoverable injury [c]	$L_{E,24h}$	203	0.64	0.06
	TTS [c]	$L_{E,24h}$	186	2.71	0.31
	Recoverable injury [c]	L_{pk}	207	0.08	–
Fish with swim bladder involved in hearing	Mortality and Potential mortal injury [c]	$L_{E,24h}$	207	0.42	0.03
	Recoverable injury [c]	$L_{E,24h}$	203	0.64	0.06
	TTS [c]	$L_{E,24h}$	186	2.71	0.31
	Recoverable injury [c]	L_{pk}	207	0.08	–
Sea turtles	PTS [d]	$L_{E,24h}$	204	0.36	–
	TTS [d]	$L_{E,24h}$	189	1.51	0.13
	Behavioural disturbance [e]	L_p	166	1.59	0.05
	Behavioural response [e]	L_p	175	0.78	–

L_{pk}= unweighted peak sound pressure level (dB re 1 µPa)
L_p= unweighted root-mean-square sound pressure level (dB re 1 µPa)
L_E= sound exposure level for single strike (dB re 1 µPa^2 s)
$L_{E,24h}$= sound exposure level over 24 hours (dB re 1 µPa^2 s), unweighted for fish and frequency weighted for all other groups
[a] NMFS (2024) criteria for marine fauna
[b] NOAA (2024) recommended unweighted behavioural threshold for marine mammals
[c] Popper et al. (2014)
[d] Finneran et al. (2017)
[e] McCauley et al. (2000)

5.2. Dredging and Vessel Activities

This study predicted underwater sound levels associated with several vessel scenarios which included a cutter suction dredge, a TSV both berthing and transiting, and two barges, either alongside the dredge under DP, or transiting to the disposal area.

Vessel noise was modelled as a point source that is omni-directional, therefore variation in propagation in different directions is primarily influenced by bathymetric features.

Maximum distances to isopleths are shown in Table 31.

Table 31. *Vessel operations*: Maximum (R_{max}) and 95% ($R_{95\%}$) horizontal distances (in km) to the marine mammal behavioural response criterion of 120 dB re 1 µPa (SPL) and maximum (R_{max}) horizontal distances (in km) and ensonified area (km^2) for the frequency-weighted LF-cetacean SEL_{24h} TTS thresholds from the most appropriate location for considered sources per scenario.

Scenario Number	Description	SPL		SEL_{24h}	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	Area (km^2)
1	Dredging, CSD + 2 Barges for material removal + barge transiting to disposal area	6.30	5.09	2.21	9.61
2	1xTSV movements: 2 round trips. 1xtransiting for 1.3hrs, over 18.2 km at a speed of 7.5 knots. Berthing at jetty Assumes noiseless cargo transfer	3.17	2.49	0.17	0.26

5.3. Intake Pump

The bathymetry of the McKay Creek significantly inhibits the propagation of sound from the intake pump. Due to the shallowness of the creek (2.1 m at the intake pump) and the modelled sandy bottom, low frequencies at approximately 340 Hz or lower are cut off (Jensen et al. 2011). As seen by the source level spectrum at Figure 9, this cuts off the bulk of the sound produced by the intake pump, which are concentrated towards lower frequencies. It is also worth noting that the meandering path of the creek and the modelled sandy bottom also make it difficult for the sound to propagate far, with there being no line-of-sight from the intake pump site to deep waters.

For these reasons, the modelled noise from the intake pumps do not exceed any of the thresholds for marine mammals, sea turtles, or fish. The noise was modelled for highest astronomical tide to provide a conservative estimate of propagation distances.

Glossary

Unless otherwise stated in an entry, these definitions are consistent with ISO 18405 (2017).

Light blue text indicates related terms that might be in this glossary. Dark blue text indicates clickable links to related terms in this glossary

1/3-octave

One third of an octave. A 1/3-octave is approximately equal to one decidecade (1/3 oct ≈ 1.003 ddec).

1/3-octave-band

Frequency band whose bandwidth is one 1/3 octave. The bandwidth of a 1/3-octave-band increases with increasing centre frequency.

90 % energy time window

The time interval over which the cumulative energy rises from 5 to 95 % of the total pulse energy. This interval contains 90 % of the total pulse energy. Used to compute the 90 % sound pressure level. Unit: second (s). Symbol: T_{90}.

90 % sound pressure level (90 % SPL)

The sound pressure level calculated over the 90 % energy time window of a pulse. Unit: decibel (dB).

absorption

The conversion of sound energy to heat energy. Specifically, the reduction of sound pressure amplitude due to particle motion energy converting to heat in the propagation medium.

acoustic impedance

The ratio of the sound pressure in a medium to the volume flow rate of the medium through a specified surface due to the sound wave. It is a measure of how well sound propagates through a particular medium.

ambient sound

Sound that would be present in the absence of a specified activity (ISO 18405:2017). It is usually a composite of sound from many sources near and far, e.g., shipping vessels, seismic activity, precipitation, sea ice movement, wave action, and biological activity.

attenuation

The gradual loss of acoustic energy from absorption and scattering as sound propagates through a medium. Attenuation depends on frequency—higher frequency sounds are attenuated faster than lower frequency sounds.

auditory frequency weighting

The process of applying an auditory frequency-weighting function. An example for marine mammals are the auditory frequency-weighting functions published by Southall et al. (2007).

auditory frequency-weighting function

Frequency-weighting function describing a compensatory approach accounting for a species' (or functional hearing group's) frequency-specific hearing sensitivity.

azimuth

A horizontal angle relative to a reference direction, which is often magnetic north or the direction of travel. In navigation it is also known as bearing.

background noise

Combination of ambient sound, acoustic self-noise, and, where applicable, sonar reverberation (ISO 18405:2017) that is detected, measured, or recorded with a signal.

bandwidth

A range within a continuous band of frequencies. Unit: hertz (Hz).

broadband level

The total level measured over a specified frequency range. If the frequency range is unspecified, the term refers to the entire measured frequency range.

cavitation

A rapid formation and collapse of vapor cavities (i.e., bubbles or voids) in water, most often caused by a rapid change in pressure. Fast-spinning vessel propellers typically cause cavitation, which creates a lot of noise.

cetacean

Member of the order Cetacea. Cetaceans are aquatic mammals and include whales, dolphins, and porpoises.

compressional wave

A mechanical vibration wave in which the direction of particle motion is parallel to the direction of propagation. Also called a longitudinal wave. In seismology/geophysics, it's called a primary wave or P-wave. Shear waves in the seabed can be converted to compressional waves in water at the water-seabed interface.

continuous sound

A sound whose sound pressure level remains above the background noise during the observation period and may gradually vary in intensity with time, e.g., sound from a marine vessel.

decade

Logarithmic frequency interval whose upper bound is ten times larger than its lower bound (ISO 80000-3:2006). For example, one decade up from 1000 Hz is 10,000 Hz, and one decade down is 100 Hz.

decibel (dB)

Unit of level used to express the ratio of one value of a power quantity to another on a logarithmic scale. Especially suited to quantify variables with a large dynamic range.

decidecade

One tenth of a decade. Approximately equal to one third of an octave (1 ddec ≈ 0.3322 oct), and for this reason sometimes referred to as a 1/3 octave.

decidecade band

Frequency band whose bandwidth is one decidecade. The bandwidth of a decidecade band increases with increasing centre frequency.

delphinid

Member of the family of oceanic dolphins (Delphinidae), composed of approximately 35 extant species, including dolphins, porpoises, and killer whales.

energy source level

A property of a sound source equal to the sound exposure level measured in the far field plus the propagation loss from the acoustic centre of the source to the receiver position. Unit: decibel (dB). Reference value: 1 μPa^2 m^2 s.

ensonified

Exposed to sound.

equal-loudness-level contour

Curve that shows, as a function of frequency, the sound pressure level required to produce a given loudness for a listener having normal hearing, listening to a specified kind of sound in a specified manner (ANSI S1.1-2013).

far field

The zone where, to an observer, sound originating from an array of sources (or a spatially distributed source) appears to radiate from a single point.

Fourier transform, Fourier synthesis

A mathematical technique which, although it has varied applications, is referenced in a physical data acquisition context as a method used in the process of deriving a spectrum estimate from time-series data (or the reverse process, termed the inverse Fourier transform). A computationally efficient numerical algorithm for computing the Fourier transform is known as the fast Fourier transform (FFT).

frequency

The rate of oscillation of a periodic function measured in cycles per unit time. The reciprocal of the period. Unit: hertz (Hz). Symbol: f. 1 Hz is equal to 1 cycle per second.

frequency weighting

The process of applying a frequency-weighting function.

frequency-weighting function

The squared magnitude of the sound pressure transfer function (ISO 18405:2017). For sound of a given frequency, the frequency-weighting function is the ratio of output power to input power of a specified filter, sometimes expressed in decibels. Examples include the following:

- *Auditory frequency-weighting function*: compensatory frequency-weighting function accounting for a species' (or functional hearing group's) frequency-specific hearing sensitivity.
- *System frequency-weighting function*: frequency-weighting function describing the sensitivity of an acoustic recording system, which typically consists of a hydrophone, one or more amplifiers, and an analog-to-digital converter.

functional hearing group

Category of animal species when classified according to their hearing sensitivity, hearing anatomy, and susceptibility to sound. For marine mammals, initial groupings were proposed by Southall et al. (2007), and revised groupings are developed as new research/data becomes available. Revised groupings proposed by Southall et al. (2019) include low-frequency cetaceans, high-frequency cetaceans, very high-frequency cetaceans, phocid carnivores in water, other carnivores in water, and sirenians. Example hearing groups for fish include species for which the swim bladder is involved in hearing, species for which the swim bladder is not involved in hearing, and species without a swim bladder (Popper et al. 2014). See also auditory frequency-weighting functions, which are often applied to these groups.

geoacoustic

Relating to the acoustic properties of the seabed.

hearing threshold

For a given species or functional hearing group, the sound level for a given signal that is barely audible (i.e., that would be barely audible for a given individual in the presence of specified background noise during a specific percentage of experimental trials).

hertz (Hz)

Unit of frequency defined as one cycle per second. Often expressed in multiples such as kilohertz (1 kHz = 1000 Hz).

high-frequency (HF) cetaceans

See functional hearing group. The mid- and high-frequency cetaceans groups proposed by Southall et al. (2007) were renamed high- and very high-frequency cetaceans, respectively, by Southall et al. (2019).

hydrostatic pressure

The pressure at any given depth in a static liquid that is the result of the weight of the liquid acting on a unit area at that depth, plus any pressure acting on the surface of the liquid. Unit: pascal (Pa).

impulsive sound

Qualitative term meaning sounds that are typically transient, brief (less than 1 s), broadband, with rapid rise time and rapid decay. They can occur in repetition or as a single event. Sources of impulsive sound include, among others, explosives, seismic airguns, and impact pile drivers.

isopleth

A line drawn on a map through all points having the same value of some specified quantity (e.g., sound pressure level isopleth).

knot (kn)

Unit of vessel speed equal to 1 nautical mile per hour.

level

A measure of a quantity expressed as the logarithm of the ratio of the quantity to a specified reference value of that quantity. For example, a value of sound pressure level with reference to 1 μPa^2 can be written in the form *x* dB re 1 μPa^2.

low-frequency (LF) cetaceans

See functional hearing group.

median

The 50th percentile of a statistical distribution.

monopole source level (MSL)

A source level that has been calculated using an acoustic model that accounts for the effect of the sea-surface and seabed on sound propagation, assuming a point source (monopole). Often used to quantify source levels of vessels or industrial operations from measurements. See also radiated noise level.

multiple linear regression

A statistical method that seeks to explain the response of a dependent variable using multiple explanatory variables.

M-weighting

A set of auditory frequency-weighting functions proposed by Southall et al. (2007).

mysticete

Member of the Mysticeti, a suborder of cetaceans. Also known as baleen whales, mysticetes have baleen plates (rather than teeth) that they use to filter food from water (or from sediment as for grey whales). This group includes rorquals (Balaenopteridae, such as blue, fin, humpback, and minke whales), right and bowhead whales (Balaenidae), and grey whales (*Eschrichtius robustus*).

non-impulsive sound

Sound that is not an impulsive sound. Not necessarily a continuous sound.

octave

The interval between a sound and another sound with double or half the frequency. For example, one octave above 200 Hz is 400 Hz, and one octave below 200 Hz is 100 Hz.

odontocete

Member of Odontoceti, a suborder of cetaceans. These whales, dolphins, and porpoises have teeth (rather than baleen plates). Their skulls are mostly asymmetric, an adaptation for their echolocation. This group includes sperm whales, killer whales, belugas, narwhals, dolphins, and porpoises.

otariid

Member of the family Otariidae, one of the three groupings of pinnipeds (along with phocids and walrus). These eared seals, commonly called fur seals and sea lions, are adapted to semi-aquatic life; they use their large fore flippers for propulsion underwater and can walk on all four limbs on land.

parabolic equation method

A computationally efficient solution to the acoustic wave equation that is used to model propagation loss. The parabolic equation approximation omits effects of backscattered sound (which are negligible for most ocean-acoustic propagation problems), simplifying the computation of propagation loss.

peak sound pressure level (PK), zero-to-peak sound pressure level

The level (L_{pk}) of the squared maximum magnitude of the sound pressure (p^2_{pk}) in a stated frequency band and time window. Defined as $L_{pk} = 10\log_{10}(p^2_{\mathrm{pk}}/p^2_0) = 20\log_{10}(p_{\mathrm{pk}}/p_0)$. Unit: decibel (dB). Reference value (p^2_0) for sound in water: 1 µPa^2.

peak-to-peak sound pressure

The difference between the maximum and minimum sound pressure over a specified frequency band and time window. Unit: pascal (Pa).

percentile level

The sound level not exceeded *N* % of the time during a specified time interval. The *N*th percentile level is equal to the (100−*N*) % exceedance level.

permanent threshold shift (PTS)

An irreversible loss of hearing sensitivity caused by excessive noise exposure. Considered auditory injury. Compare with temporary threshold shift.

phocid

Member of the family Phocidae, one of the three groupings of pinnipeds (along with otariids and walrus). These true/earless seals are more adapted to in-water life than are otariids, which have more terrestrial adaptations. Phocids use their hind flippers to propel themselves underwater.

pinniped

Member of the superfamily Pinnipedia, which is composed of phocids (true seals or earless seals), otariids (eared seals or fur seals and sea lions), and walrus.

point source

A source that radiates sound as if from a single point.

power spectral density

Generic term, formally defined as power in a unit frequency band. Unit: watt per hertz (W/Hz). The term is sometimes loosely used to refer to the spectral density of other parameters such as squared sound pressure. Ratio of energy spectral density, E_f, to time duration, Δt, in a specified temporal observation window. In equation form, the power spectral density P_f is given by $P_f = E_f / \Delta t$. Power spectral density can be expressed in terms of various field variables (e.g., sound pressure, sound particle displacement).

power spectral density level

The level ($L_{P,f}$) of the power spectral density (P_f) in a stated frequency band and time window. Defined as: $L_{P,f} = 10\log_{10}(P_f / P_{f,0})$. Unit: decibel (dB).

As with power spectral density, power spectral density level can be expressed in terms of various field variables (e.g., sound pressure, sound particle displacement). The reference value ($P_{f,0}$) for power spectral density level depends on the nature of the field variable.

power spectral density source level

A property of a sound source equal to the power spectral density level of the sound pressure measured in the far field plus the propagation loss from the acoustic centre of the source to the receiver position. Unit: decibel (dB). Reference value: 1 μPa^2 m^2/Hz.

propagation loss (PL)

Difference between a source level (SL) and the level at a specified location, PL(x) = SL − L(x). Unit: decibel (dB). See also transmission loss.

radiated noise level (RNL)

A source level that has been calculated assuming sound pressure decays geometrically with distance from the source, with no influence of the sea-surface or seabed. Often used to quantify source levels of vessels or industrial operations from measurements. See also monopole source level.

received level

The level of a given field variable measured (or that would be measured) at a given location.

reference value

Standard value of a quantity used for calculating underwater sound level. The reference value depends on the quantity for which the level is being calculated:

Quantity	Reference value
Sound pressure	p_0^2 = 1 μPa² or p_0 = 1 μPa
Sound exposure	E_0 = 1 μPa² s
Sound particle displacement	δ_0^2 = 1 pm²
Sound particle velocity	u_0^2 = 1 nm²/s²
Sound particle acceleration	a_0^2 = 1 μm²/s⁴

shear wave

A mechanical vibration wave in which the direction of particle motion is perpendicular to the direction of propagation. Also called a secondary wave or S-wave. Shear waves propagate only in solid media, such as sediments or rock. Shear waves in the seabed can be converted to compressional waves in water at the water-seabed interface.

sirenians (SI)

Members of the order Sirenia, which includes several manatee species and the dugong. See also functional hearing group.

sound

A time-varying disturbance in the pressure, stress, or material displacement of a medium propagated by local compression and expansion of the medium. In common meaning, a form of energy that propagates through media (e.g., water, air, ground) as pressure waves.

sound exposure

Time integral of squared sound pressure over a stated time interval in a stated frequency band. The time interval can be a specified time duration (e.g., 24 h) or from start to end of a specified event (e.g., a pile strike, an airgun pulse, a construction operation). Unit: pascal squared second (Pa^2 s). Symbol: E.

sound exposure level (SEL)

The level (L_E) of the sound exposure (E) in a stated frequency band and time window: $L_E = 10\log_{10}(E/E_0)$ (ISO 18405:2017). Unit: decibel (dB). Reference value (E_0) for sound in water: 1 μPa^2 s.

sound exposure spectral density

Distribution as a function of frequency of the time-integrated squared sound pressure per unit bandwidth of a sound having a continuous spectrum (ISO 18405:2017). Unit: pascal squared second per hertz (Pa^2 s/Hz).

sound field

Region containing sound waves.

sound intensity

Product of the sound pressure and the sound particle velocity (ISO 18405:2017). The magnitude of the sound intensity is the sound energy flowing through a unit area perpendicular to the direction of propagation per unit time. Unit: watt per meter squared (W/m^2). Symbol: I.

sound pressure

The contribution to total pressure caused by the action of sound (ISO 18405:2017). Unit: pascal (Pa). Symbol: p.

sound pressure level (SPL), rms sound pressure level

The level (L_p) of the time-mean-square sound pressure ($p^2_{\rm rms}$) in a stated frequency band and time window: L_p = 10log$_{10}$($p^2_{\rm rms}/p^2_0$) = 20log$_{10}$($p_{\rm rms}/p_0$), where rms is the abbreviation for root-mean-square. Unit: decibel (dB). Reference value (p^2_0) for sound in water: 1 μPa^2. SPL can also be expressed in terms of the root-mean-square (rms) with a reference value of p_0 = 1 μPa. The two definitions are equivalent.

sound speed profile

The speed of sound in the water column as a function of depth below the water surface.

source level (SL)

A property of a sound source equal to the sound pressure level measured in the far field plus the propagation loss from the acoustic centre of the source to the receiver position. Unit: decibel (dB). Reference value: 1 μPa^2 m^2.

spectrum

Distribution of acoustic signal content over frequency, where the signal's content is represented by its power, energy, mean-square sound pressure, or sound exposure.

surface duct

The upper portion of a water column within which the gradient of the sound speed profile causes sound to refract upward and therefore reflect repeatedly off the surface resulting in relatively long-range sound propagation with little loss.

temporary threshold shift (TTS)

Reversible loss of hearing sensitivity caused by noise exposure. Compare with permanent threshold shift.

thermocline

A depth interval near the ocean surface that experiences larger temperature gradients than the layers above and below it due to warming or cooling by heat conduction from the atmosphere and by warming from the sun.

transmission loss (TL)

The difference between a specified level at one location and that at a different location: TL(x_1,x_2) = $L(x_1) - L(x_2)$ (ISO 18405:2017). Unit: decibel (dB). See also propagation loss.

unweighted

Term indicating that no frequency-weighting function is applied.

very high-frequency (VHF) cetaceans

See functional hearing group.

wavelength

Distance over which a wave completes one cycle of oscillation. Unit: meter (m). Symbol: λ.

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Appendix A. Acoustic Metrics

This section describes in detail the acoustic metrics, impact criteria, and frequency weighting relevant to the modelling study.

A.1. Pressure Related Acoustic Metrics

Underwater sound pressure amplitude is measured in decibels (dB) relative to a fixed reference pressure of p_0 = 1 μPa. Because the perceived loudness of sound, especially pulsed sound such as from seismic airguns, pile driving, and sonar, is not generally proportional to the instantaneous acoustic pressure, several sound level metrics are commonly used to evaluate sound and its effects on marine life. Here we provide specific definitions of relevant metrics used in the accompanying report. Where possible, we follow International Organization for Standardization definitions and symbols for sound metrics (e.g., ISO 2017, ANSI S1.1-2013).

The zero-to-peak sound pressure, or peak sound pressure (PK or $L_{p,pk}$; dB re 1 µPa), is the decibel level of the maximum instantaneous acoustic pressure in a stated frequency band attained by an acoustic pressure signal, $p(t)$:

$$L_{p,\mathrm{pk}} = 10\log_{10}\frac{\max|p^2(t)|}{p_0^2} = 20\log_{10}\frac{\max|p(t)|}{p_0} \quad \text{(A-1)}$$

PK is often included as a criterion for assessing whether a sound is potentially injurious; however, because it does not account for the duration of an acoustic event, it is generally a poor indicator of perceived loudness.

The peak-to-peak sound pressure (PK-PK or $L_{p,pk\text{-}pk}$; dB re 1 µPa) is the difference between the maximum and minimum instantaneous sound pressure, possibly filtered in a stated frequency band, attained by an impulsive sound, $p(t)$:

$$L_{p,\mathrm{pk\text{-}pk}} = 10\log_{10}\frac{[\max(p(t)) - \min(p(t))]^2}{p_0^2} \quad \text{(A-2)}$$

The sound pressure level (SPL or L_p; dB re 1 µPa) is the root-mean-square (rms) pressure level in a stated frequency band over a specified time window (T; s). It is important to note that SPL always refers to an rms pressure level and therefore not instantaneous pressure:

$$L_p = 10\log_{10}\left(\frac{1}{T}\int_T g(t)\,p^2(t)\,dt/p_0^2\right)\ \mathrm{dB} \quad \text{(A-3)}$$

where $g(t)$ is an optional time weighting function. In many cases, the start time of the integration is marched forward in small time steps to produce a time-varying SPL function. For short acoustic events, such as sonar pulses and marine mammal vocalizations, it is important to choose an appropriate time window that matches the duration of the signal. For in-air studies, when evaluating the perceived loudness of sounds with rapid amplitude variations in time, the time weighting function $g(t)$ is often set to a decaying exponential function that emphasizes more recent pressure signals. This function mimics the leaky integration nature of mammalian hearing. For example, human-based fast time-weighted SPL ($L_{p,fast}$) applies an exponential function with time constant 125 ms. A related simpler approach used in underwater acoustics sets $g(t)$ to a boxcar (unity amplitude) function of width 125 ms; the results can be referred to as $L_{p,boxcar\ 125ms}$. Another approach, historically used to evaluate SPL of impulsive signals underwater, defines $g(t)$ as a boxcar function with edges set to the times corresponding to 5% and 95% of the cumulative square pressure function encompassing the duration of an impulsive acoustic event. This calculation is applied individually to each impulse signal, and the results are referred to as 90% SPL ($L_{p,90\%}$).

The sound exposure level (SEL or L_E; dB re 1 µPa²·s) is the time-integral of the squared acoustic pressure over a duration (T):

$$L_E = 10 \log_{10}\left(\int_T p^2(t)\, dt / T_0 p_0^2 \right) \text{ dB} \tag{A-4}$$

where T_0 is a reference time interval of 1 s. SEL continues to increase with time when non-zero pressure signals are present. It is a dose-type measurement, so the integration time applied must be carefully considered for its relevance to impact to the exposed recipients.

SEL can be calculated over a fixed duration, such as the time of a single event or a period with multiple acoustic events. When applied to pulsed sounds, SEL can be calculated by summing the SEL of the N individual pulses. For a fixed duration, the square pressure is integrated over the duration of interest. For multiple events, the SEL can be computed by summing (in linear units) the SEL of the N individual events:

$$L_{E,N} = 10 \log_{10}\left(\sum_{i=1}^{N} 10^{\frac{L_{E,i}}{10}} \right) \text{ dB} . \tag{A-5}$$

If applied, the frequency weighting of an acoustic event should be specified, as in the case of weighted SEL (e.g., $L_{E,LFC,24h}$; Appendix A.4). The use of fast, slow, or impulse exponential-time-averaging or other time-related characteristics should also be specified.

A.2. Decidecade Band Analysis

The distribution of a sound's power with frequency is described by the sound's spectrum. The sound spectrum can be split into a series of adjacent frequency bands. Splitting a spectrum into 1 Hz wide bands, called passbands, yields the power spectral density of the sound. This splitting of the spectrum into passbands of a constant width of 1 Hz, however, does not represent how animals perceive sound.

Because animals perceive exponential increases in frequency rather than linear increases, analysing a sound spectrum with passbands that increase exponentially in size better approximates real-world scenarios. In underwater acoustics, a spectrum is commonly split into decidecade bands, which are one tenth of a decade wide. A decidecade is sometimes referred to as a "1/3 octave" because one tenth of a decade is approximately equal to one third of an octave. Each decade represents a factor 10 in sound frequency. Each octave represents a factor 2 in sound frequency. The centre frequency of the ith band, $f_c(i)$, is defined as:

$$f_c(i) = 10^{\frac{i}{10}} \text{ kHz} \tag{A-6}$$

and the low (f_{lo}) and high (f_{hi}) frequency limits of the ith decade band are defined as:

$$f_{lo,i} = 10^{\frac{-1}{20}} f_c(i) \quad \text{and} \quad f_{hi,i} = 10^{\frac{1}{20}} f_c(i) \tag{A-7}$$

The decidecade bands become wider with increasing frequency, and on a logarithmic scale the bands appear equally spaced (Figure A-1). The acoustic modelling spans from band 10 ($f_c(10)$ = 10 Hz) to band 44 ($f_c(44)$ = 25 kHz).

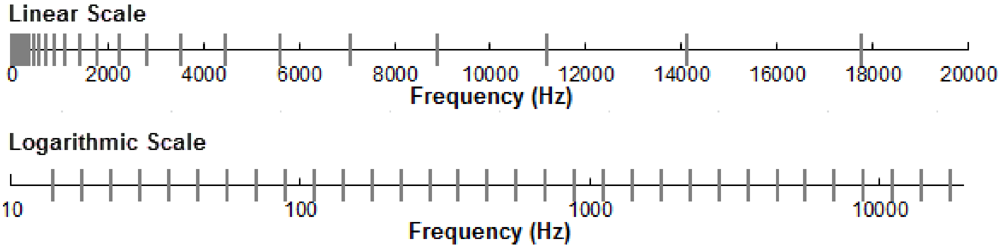

Figure A-1. Decidecade frequency bands (vertical lines) shown on a linear frequency scale and a logarithmic scale.

The sound pressure level in the ith band ($L_{p,i}$) is computed from the spectrum $S(f)$ between $f_{\mathrm{lo},i}$ and $f_{\mathrm{hi},i}$:

$$L_{p,i} = 10\,log_{10} \int_{f_{\mathrm{lo},i}}^{f_{\mathrm{hi},i}} S(f)\,\mathrm{d}f \;\; \mathrm{dB} \qquad \text{(A-8)}$$

Summing the sound pressure level of all the bands yields the broadband sound pressure level:

$$\text{Broadband SPL} = 10\log_{10}\sum_i 10^{\frac{L_{p,i}}{10}} \;\; \mathrm{dB} \qquad \text{(A-9)}$$

Figure A-2 shows an example of how the decidecade band sound pressure levels compare to the sound pressure spectral density levels of an ambient sound signal. Because the decidecade bands are wider than 1 Hz, the decidecade band SPL is higher than the spectral levels at higher frequencies. Acoustic modelling of decidecade bands requires less computation time than 1 Hz bands and still resolves the frequency-dependence of the sound source and the propagation environment.

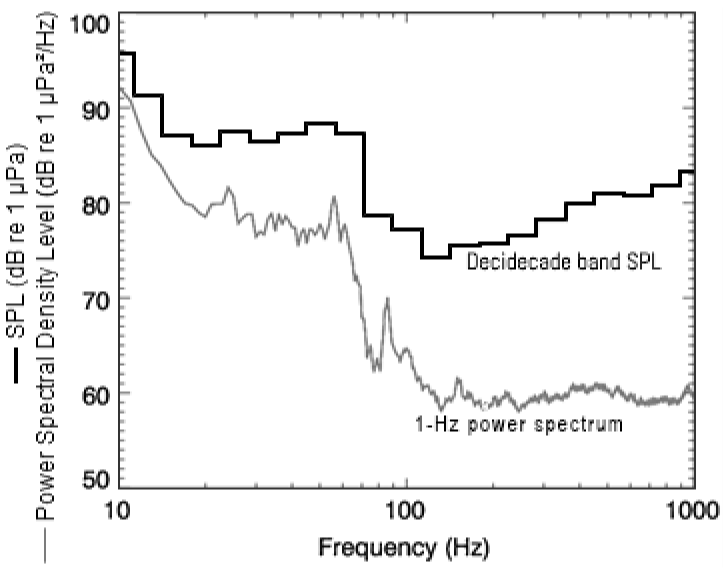

Figure A-2. Sound pressure spectral density levels and the corresponding decidecade band sound pressure levels of example ambient noise shown on a logarithmic frequency scale.Because the decidecade bands are wider with increasing frequency, the decidecade band SPL is higher than the power spectrum.

A.3. Marine Mammal Noise Effect Criteria

It has been long recognised that marine mammals can be adversely affected by underwater anthropogenic noise. For example, Payne and Webb (1971) suggested that communication distances of fin whales are reduced by shipping sounds. Subsequently, similar concerns arose regarding effects of other underwater noise sources and the possibility that impulsive sources—primarily airguns used in seismic surveys—could cause auditory injury. This led to a series of workshops held in the late 1990s, conducted to address acoustic mitigation requirements for seismic surveys and other underwater noise sources (NMFS 1998, ONR 1998, Nedwell and Turnpenny 1998, HESS 1999, Ellison and Stein 1999). In the years since these early workshops, a variety of thresholds have been proposed for both injury and disturbance. The following sections summarize the recent development of thresholds; however, this field remains an active research topic.

A.3.1. Acoustic Injury and Hearing Sensitivity Changes

In recognition of shortcomings of the SPL-only based injury criteria, in 2005 NMFS sponsored the Noise Criteria Group to review literature on marine mammal hearing to propose new noise exposure criteria. Some members of this expert group published a landmark paper (Southall et al. 2007) that suggested assessment methods similar to those applied for humans. The resulting recommendations introduced dual acoustic injury criteria for impulsive sounds that included peak pressure level thresholds and SEL_{24h} thresholds, where the subscripted 24h refers to the accumulation period for calculating SEL. The peak pressure level criterion is not frequency weighted whereas the SEL_{24h} is frequency weighted according to one of four marine mammal species hearing groups: low-, mid- and high-frequency cetaceans (LF, MF, and HF cetaceans, respectively) and Pinnipeds in Water (PINN). These weighting functions are referred to as M-weighting filters (analogous to the A-weighting filter for humans; Appendix A.3). The SEL_{24h} thresholds were obtained by extrapolating measurements of onset levels of Temporary Threshold Shift (TTS) in belugas by the amount of TTS required to produce Permanent Threshold Shift (PTS) in chinchillas. The Southall et al. (2007) recommendations do not specify an exchange rate, which suggests that the thresholds are the same regardless of the duration of exposure (i.e., it implies a 3 dB exchange rate).

Wood et al. (2012) refined Southall et al.'s (2007) thresholds, suggesting lower PTS and TTS values for LF and HF cetaceans while retaining the filter shapes. Their revised thresholds were based on TTS-onset levels in harbour porpoises from Lucke et al. (2009), which led to a revised impulsive sound PTS threshold for HF cetaceans of 179 dB re 1 $\mu Pa^2 \cdot s$. Because there were no data available for baleen whales, Wood et al. (2012) based their recommendations for LF cetaceans on results obtained from MF cetacean studies. In particular they referenced the Finneran and Schlundt (2010) research, which found mid-frequency cetaceans are more sensitive to non-impulsive sound exposure than Southall et al. (2007) assumed. Wood et al. (2012) thus recommended a more conservative TTS-onset level for LF cetaceans of 192 dB re 1 $\mu Pa^2 \cdot s$.

As of present, a definitive approach is still not apparent. There is consensus in the research community that an SEL-based method is preferable, either separately or in addition to an SPL-based approach to assess the potential for injuries. In August 2016, after substantial public and expert input into three draft versions and based largely on the above-mentioned literature (NOAA 2013, 2015, 2016), NMFS finalised technical guidance for assessing the effect of anthropogenic sound on marine mammal hearing (NMFS 2016). The guidance describes auditory injury criteria with new thresholds and frequency weighting functions for the five hearing groups described by Finneran and Jenkins (2012). The latest revision to this work was published in 2024 (NMFS 2024).

A.3.2. Behavioural response

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

For impulsive noise, NMFS currently uses a step function threshold of 160 dB re 1 µPa SPL (unweighted) to assess and regulate noise-induced behavioural impacts for marine mammals (NOAA 2018, NOAA 2024). The threshold for impulsive sound is derived from the High-Energy Seismic Survey (HESS) panel (HESS 1999) report that, in turn, is based on the responses of migrating mysticete whales to airgun sounds (Malme et al. 1984). The HESS team recognised that behavioural responses to sound may occur at lower levels, but significant responses were only likely to occur above a SPL of 140 dB re 1 µPa. Southall et al. (2007) found varying responses for most marine mammals between a SPL of 140 and 180 dB re 1 µPa, consistent with the HESS (1999) report, but lack of convergence in the data prevented them from suggesting explicit step functions.

NMFS currently uses a step function (all-or-none) threshold of 120 dB re 1 µPa SPL (unweighted) for non-impulsive sounds to assess and regulate noise-induced behavioural impacts on marine mammals (NOAA 2024). The 120 dB re 1 µPa threshold is associated with continuous sources and was derived based on studies examining behavioural responses to drilling and dredging (NOAA 2018), referring to Malme et al. (1983), Malme et al. (1984), and Malme et al. (1986), which were considered in Southall et al. (2007). Malme et al. (1986) found that playback of drillship noise did not produce clear evidence of disturbance or avoidance for levels below 110 dB re 1 µPa (SPL), possible avoidance occurred for exposure levels approaching 119 dB re 1 µPa. Malme et al. (1984) determined that measurable reactions usually consisted of rather subtle short-term changes in speed and/or heading of the whale(s) under observation. It has been shown that both received level and proximity of the sound source is a contributing factor in eliciting behavioural reactions in humpback whales (Dunlop et al. 2017, Dunlop et al. 2018).

A.4. Marine Mammal Frequency Weighting

The potential for noise to affect animals depends on how well the animals can hear it. Noises are less likely to disturb or injure an animal if they are at frequencies that the animal cannot hear well. An exception occurs when the sound pressure is so high that it can physically injure an animal by non-auditory means (i.e., barotrauma). For sound levels below such extremes, the importance of sound components at particular frequencies can be scaled by frequency weighting relevant to an animal's sensitivity to those frequencies (Nedwell and Turnpenny 1998, Nedwell et al. 2007).

A.4.1. Marine Mammal Frequency Weighting Functions

In 2015, a US Navy technical report by Finneran (2015) recommended new auditory weighting functions. The overall shape of the auditory weighting functions is similar to human A-weighting functions, which follows the sensitivity of the human ear at low sound levels. The new frequency-weighting function is expressed as:

$$G(f) = K + 10\log_{10}\left[\left(\frac{(f/f_{lo})^{2a}}{\left[1+(f/f_{lo})^2\right]^a\left[1+(f/f_{hi})^2\right]^b}\right)\right] \tag{A-10}$$

Finneran (2015) proposed five functional hearing groups for marine mammals in water: low-, mid- and high-frequency cetaceans (LF, MF, and HF cetaceans, respectively), phocid pinnipeds, and otariid pinnipeds. The parameters for these frequency-weighting functions were further modified the following year (Finneran 2016) and were adopted in NOAA's technical guidance that assesses acoustic impacts on marine mammals (NMFS 2018). NOAA's 2018 updates did not affect the parameters of the weighting functions or the threshold values. NMFS revised the parameters of the weighting functions and thresholds in 2024 (NMFS 2024), largely based on a revised report from Finneran (2024) containing revised auditory weighting functions that incorporated new relevant data on the effects of noise on marine mammal hearing. The terminology for mid- and high-frequency cetaceans was changed to high- and very high-frequency cetaceans (VHF cetaceans).

Table A-1. Parameters for the auditory weighting functions recommended by NMFS (2024).

Functional hearing group	NMFS (2024)				
	a	b	f_1 (Hz)	f_2 (Hz)	K[1] (dB)
Low-frequency cetaceans	0.99	5	168	26,600	0.12
High-frequency cetaceans	1.55	5	1,730	129,000	0.32
Very high-frequency cetaceans	2.23	5	5,930	186,000	0.91
Phocid pinnipeds underwater	1.63	5	810	68,300	0.29
Otariid pinnipeds underwater	1.58	5	2530	43,800	1.37

[1] In NMFS (2018) and (2024), this constant is symbolized by C.

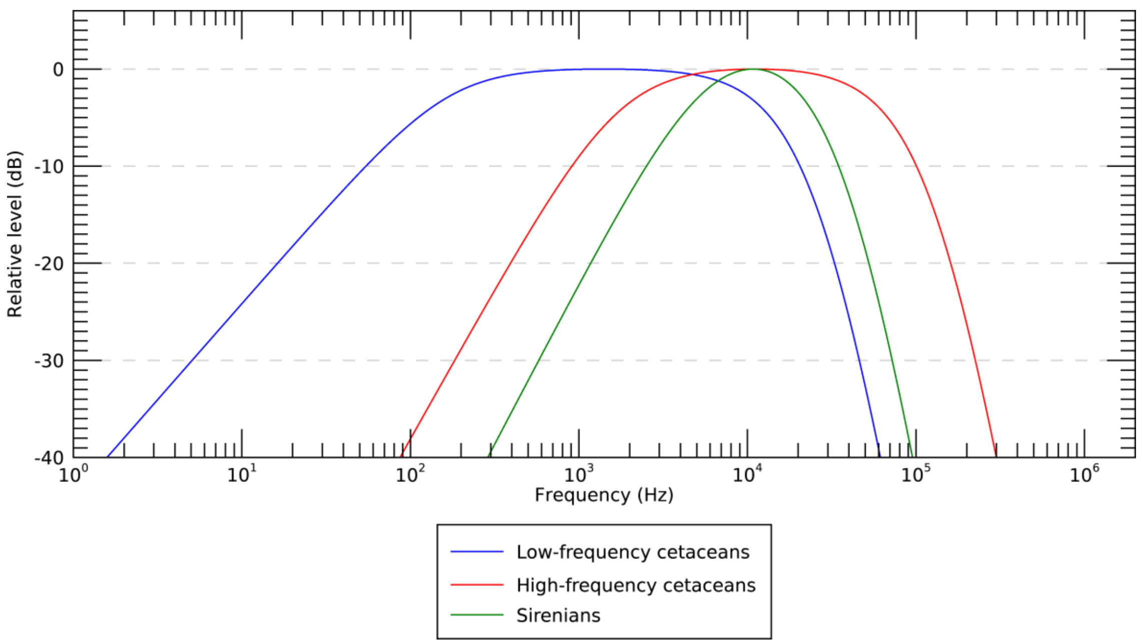

Figure A-3. Auditory weighting functions for the functional marine mammal hearing groups as recommended by NMFS (2024).

Appendix B. Pile Driving Models

B.1. Acoustic Source Model – Pile Driving

B.1.1. Source Properties

For most projects involving pile driving, there is potential for direct transmission from the sound source to biological receivers, and there are reflected sound paths from the water's surface and bottom that may be perceived by marine fauna. Normally, ground-radiated sound is dominated by low frequencies that cannot propagate efficiently through shallow water. When pile driving is the sound source, there is the potential for substrate-borne sound caused by the hammer's action on the pile to be re-radiated back into the water where it may reach a biological receiver. For pile driving, energy transmission through water depends on the following factors (Christopherson and Lundberg 2013):

1. Direct contact between the pile and the water
2. The depth of the water column
3. The size of the pile
4. The type of hammer
5. The hammer energy
6. The addition of re-radiation of substrate-borne sound

The way sound propagates in water is affected by obstructions (barges, breakwater walls, other piles, etc.) and the bathymetric characteristics (Buehler et al. 2015). Figure B-1 illustrates these basic propagation concepts.

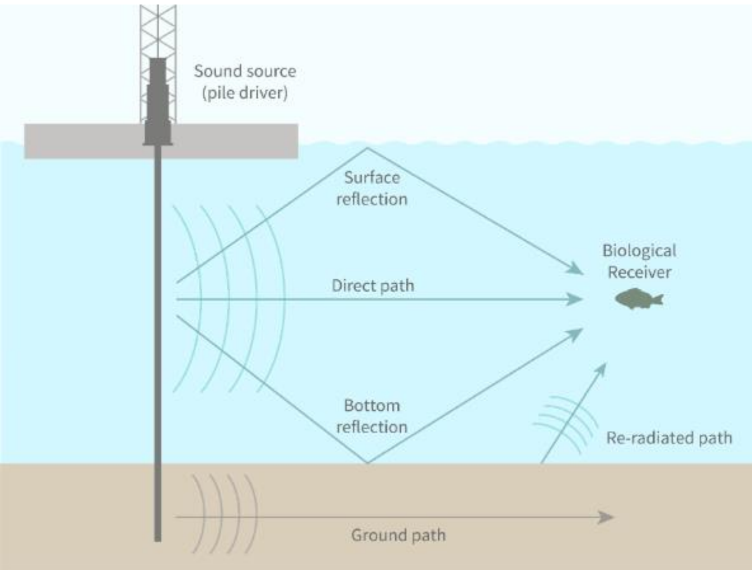

Figure B-1 Underwater sound propagation paths associated with pile driving (Buehler et al. 2015).

B.1.2. Source Model

A physical model of pile vibration and near-field sound radiation is used to calculate source levels of piles. The physical model employed in this study computes the underwater vibration and sound radiation of a pile by solving the theoretical equations of motion for axial and radial vibrations of a cylindrical shell. These equations of motion are solved subject to boundary conditions, which describe the forcing function of the hammer at the top of the pile and the soil resistance at the base of the pile, as shown in Figure B-2. Damping of the pile vibration due to radiation loading is computed for Mach waves emanating from the pile wall. The equations of motion are discretised using the finite difference (FD) method and are solved on a discrete time and depth mesh.

To model the sound emissions from the piles, the force of the pile driving hammers also had to be modelled. The force at the top of each pile was computed using the GRLWEAP 2010 wave equation model (GRLWEAP, Pile Dynamics 2010), which includes a large database of simulated hammers—both impact and vibratory—based on the manufacturer's specifications. The forcing functions from GRLWEAP were used as inputs to the FD model to compute the resulting pile vibrations.

The sound radiating from the pile itself is simulated using a vertical array of discrete point sources. The point sources are centred on the pile axis. Their amplitudes are derived using an inverse technique, such that their collective particle velocity, calculated using a near-field wave-number integration model, matches the particle velocity in the water at the pile wall. The sound field propagating away from the vertical source array is then calculated using a time-domain acoustic propagation model (FWRAM, Appendix B.2). MacGillivray (2014) describes the theory behind the physical model in more detail.

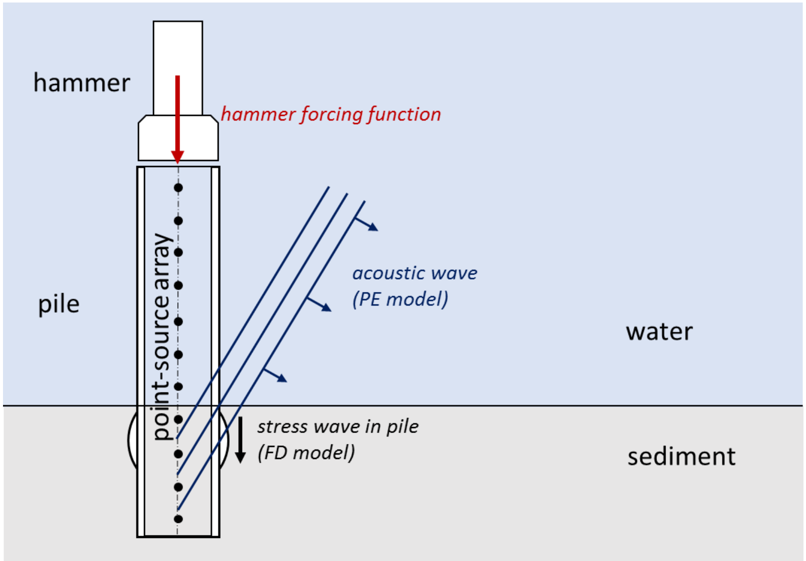

Figure B-2. Physical model geometry for impact driving of a cylindrical pile(vertical cross-section). The hammer forcing function is used with the finite difference (FD) model to compute the stress wave vibration in the pile. A vertical array of point sources is used with the parabolic equation (PE) model to compute the acoustic waves that the pile wall radiates.

B.2. Full Waveform Range-dependent Acoustic Model: FWRAM

For impulsive sounds from impact pile driving, time-domain representations of the pressure waves generated in the water are required for calculating SPL and peak pressure level. Furthermore, the pile must be represented as a distributed source to accurately characterise vertical directivity effects in the near-field zone.

For this study, synthetic pressure waveforms were computed using the Full Waveform Range-dependent Model (FWRAM), which is a time-domain acoustic model based on the wide-angle parabolic equation (PE) algorithm (Collins 1993). FWRAM computes synthetic pressure waveforms versus range and depth for range-varying marine acoustic environments, and it takes bathymetry, water sound speed profile, and seabed geoacoustic profile, as environmental inputs. FWRAM computes pressure waveforms via Fourier synthesis of the modelled acoustic transfer function in closely spaced frequency bands.

FWRAM employs the array starter method to accurately model sound propagation from a spatially distributed source (MacGillivray and Chapman 2012). Synthetic pressure waveforms were modelled over the frequency range 10 – 1024 Hz, inside a 1 s window. These waveforms are post-processed, after applying a travel time correction, to calculate standard SPL and SEL metrics versus range and depth from the source.

Appendix C. Dredging and Vessel Models

C.1. MONM-BELLHOP

Long-range sound fields were computed using JASCO's Marine Operations Noise Model (MONM). While other models may be more accurate for steep-angle propagation in high-shear environment, MONM is well suited for effective longer-range estimation. This model computes sound propagation at frequencies of 10 Hz to 1 kHz via a wide-angle parabolic equation solution to the acoustic wave equation (Collins 1993) based on a version of the U.S. Naval Research Laboratory's Range-dependent Acoustic Model (RAM), which has been modified to account for a solid seabed (Zhang and Tindle 1995). MONM computes sound propagation at frequencies > 1 kHz via the BELLHOP Gaussian beam acoustic ray-trace model (Porter and Liu 1994).

The parabolic equation method has been extensively benchmarked and is widely employed in the underwater acoustics community (Collins et al. 1996). MONM accounts for the additional reflection loss at the seabed, which results from partial conversion of incident compressional waves to shear waves at the seabed and sub-bottom interfaces, and it includes wave attenuations in all layers. MONM incorporates the following site-specific environmental properties: a bathymetric grid of the modelled area, underwater sound speed as a function of depth, and a geoacoustic profile based on the overall stratified composition of the seafloor.

MONM computes acoustic fields in three dimensions by modelling propagation loss within two-dimensional (2-D) vertical planes aligned along radials covering a 360° swath from the source, an approach commonly referred to as N×2-D. These vertical radial planes are separated by an angular step size of $\Delta\theta$, yielding N = 360°/$\Delta\theta$ number of planes (Figure C-1).

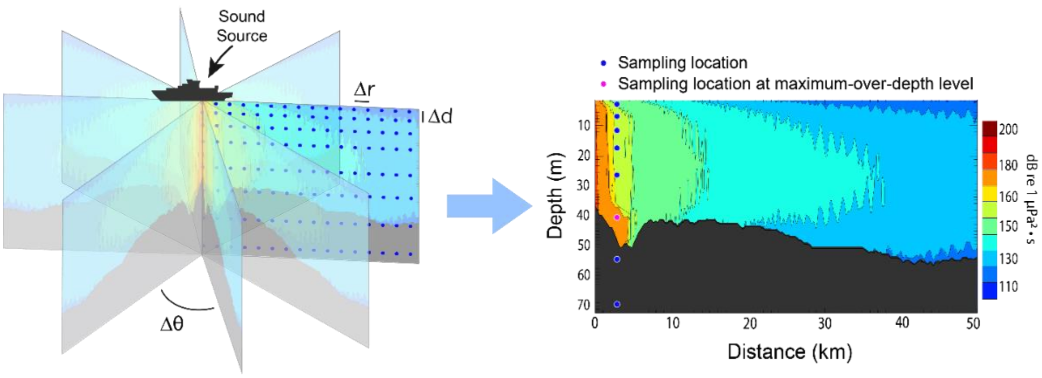

Figure C-1. The N×2-D and maximum-over-depth modelling approach used by MONM.

MONM treats frequency dependence by computing acoustic propagation loss at the centre frequencies of decidecade bands. Sufficiently many decidecade frequency-bands, starting at 10 Hz, are modelled to include most of the acoustic energy emitted by the source. At each centre frequency, the propagation loss is modelled within each of the N vertical planes as a function of depth and range from the source. The decidecade received per-second SEL are computed by subtracting the band propagation loss values from the directional source level in that frequency band. Composite broadband received per-second SEL are then computed by summing the received decidecade levels.

The received 1-s SEL sound field within each vertical radial plane is sampled at various ranges from the source, generally with a fixed radial step size. At each sampling range along the surface, the sound field is sampled at various depths, with the step size between samples increasing with depth below the surface. The step sizes are chosen to provide increased coverage near the depth of the source and at depths of interest in terms of the sound speed profile. For areas with deep water, sampling is not performed at depths beyond those reachable by marine mammals. The received per-second SEL at a surface sampling location is taken as the maximum value that occurs over all samples within the water column, i.e., the maximum-over-depth received per-second SEL. These maximum-over-depth per-second SEL are presented as colour contours around the source.

C.2. Estimating Sound Fields from Moving Vessels

During vessel transit, new sound energy is constantly being introduced to the environment. The noise footprint for the transiting vessels considered in this report were estimated by modelling the 1-s maximum over depth SEL footprints for the vessel at one location, and by translating and summing these footprints along the vessel transit routes. The vessel locations along the tracks were spaced uniformly, with an approximate step of $\Delta s \approx 10$ m.

The SEL sound field at any given point along the track is dependent upon the time duration within each 10 m segment of the track. When the track segment spacing is fixed, the duration of exposure depends upon the speed of the vessel during each segment of the transit. The 1-s SEL footprint at each vessel location (i) was therefore scaled based on the speed of the vessel following:

$$\mathrm{SEL}_i = \mathrm{SEL}_{1s} + 10\log_{10}\left(\frac{\Delta s}{v}\right) . \qquad \text{(C-1)}$$

where v represents the vessel speed in m/s.

The present method acceptably reflects large-scale sound propagation features, primarily dependent on water depth, which dominate the cumulative field and is thus considered to provide a meaningful estimate of the SEL_{24h} field.

Appendix D. Methods and Parameters

D.1. Propagation Loss

The propagation of sound through the environment was modelled by predicting the acoustic propagation loss—a measure, in decibels, of the decrease in sound level between a source and a receiver some distance away. Geometric spreading of acoustic waves is the predominant way by which propagation loss occurs. Propagation loss also happens when the sound is absorbed and scattered by the seawater, and absorbed scattered, and reflected at the water surface and within the seabed. Propagation loss depends on the acoustic properties of the ocean and seabed; its value changes with frequency.

If the acoustic energy source level (ESL), expressed in dB re 1 μPa^2·s m^2, and propagation loss (PL), in units of dB, at a given frequency are known, then the received level (RL) at a receiver location can be calculated in dB re 1 μPa^2·s by:

$$\mathrm{RL} = \mathrm{SL} - \mathrm{PL}. \tag{D-1}$$

D.2. Estimating Range to Thresholds Levels

Sound level contours were calculated based on the underwater sound fields predicted by the propagation models, sampled by taking the maximum value over all modelled depths above the sea floor for each location in the modelled region. The predicted distances to specific levels were computed from these contours. Two distances relative to the source are reported for each sound level: 1) R_{max}, the maximum range to the given sound level over all azimuths, and 2) $R_{95\%}$, the range to the given sound level after the 5% farthest points were excluded (see examples in Figure D-1).

The $R_{95\%}$ is used because sound field footprints are often irregular in shape. In some cases, a sound level contour might have small protrusions or anomalous isolated fringes. This is demonstrated in the image in Figure D-1 a). In cases such as this, where relatively few points are excluded in any given direction, R_{max} can misrepresent the area of the region exposed to such effects, and $R_{95\%}$ is considered more representative. In strongly asymmetric cases such as shown in Figure D-1(b), on the other hand, $R_{95\%}$ neglects to account for significant protrusions in the footprint. In such cases R_{max} might better represent the region of effect in specific directions. Cases such as this are usually associated with bathymetric features affecting propagation. The difference between R_{max} and $R_{95\%}$ depends on the source directivity and the non-uniformity of the acoustic environment.

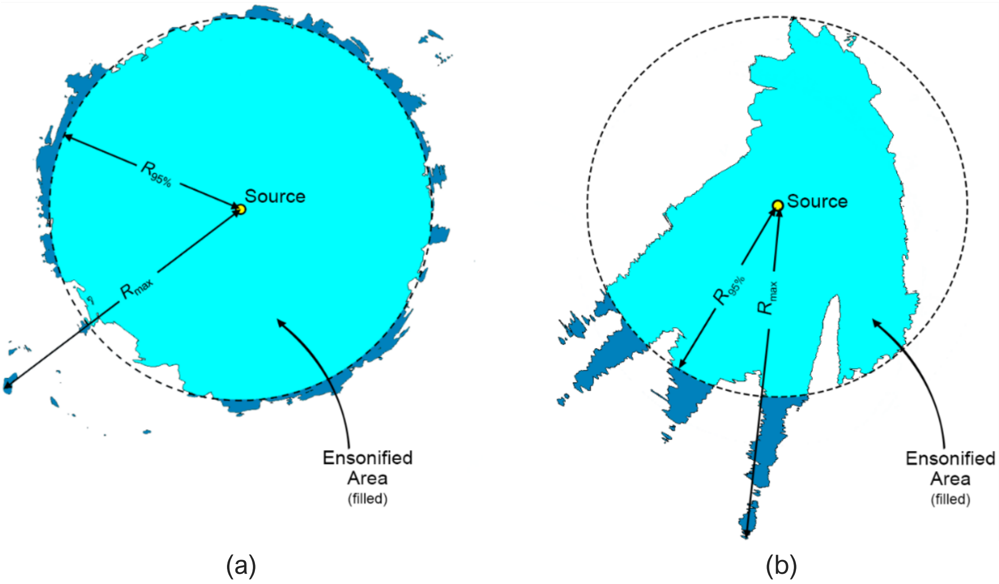

Figure D-1. Sample areas ensonified to an arbitrary sound level with R_{max} and $R_{95\%}$ ranges shown for two different scenarios. (a) Largely symmetric sound level contour with small protrusions. (b) Strongly asymmetric sound level contour with long protrusions. Light blue indicates the ensonified areas bounded by $R_{95\%}$; darker blue indicates the areas outside this boundary which determine R_{max}.

D.3. Environmental Parameters

D.3.1. Bathymetry

Two bathymetries were used for modelling, dependant on source location. For the sheet piling and intake pump modelling, located in McKay creek, data from client supplied bathymetry within the creek and the high-resolution depth model for Northern Australia (Beaman 2018) were combined, extracted and re-gridded onto a Map Grid of Australia (MGA) coordinate projection (Zone 50) with a regular grid spacing of 10 × 10 m, as shown in Figure D-2. For the remaining scenarios, involving pipe piling, vessels and dredging, not operating within McKay creek, data from only the high-resolution depth model for Northern Australia (Beaman 2018) were extracted and re-gridded similarly, with a regular grid spacing of 30 × 30 m, as shown in Figure D-3.

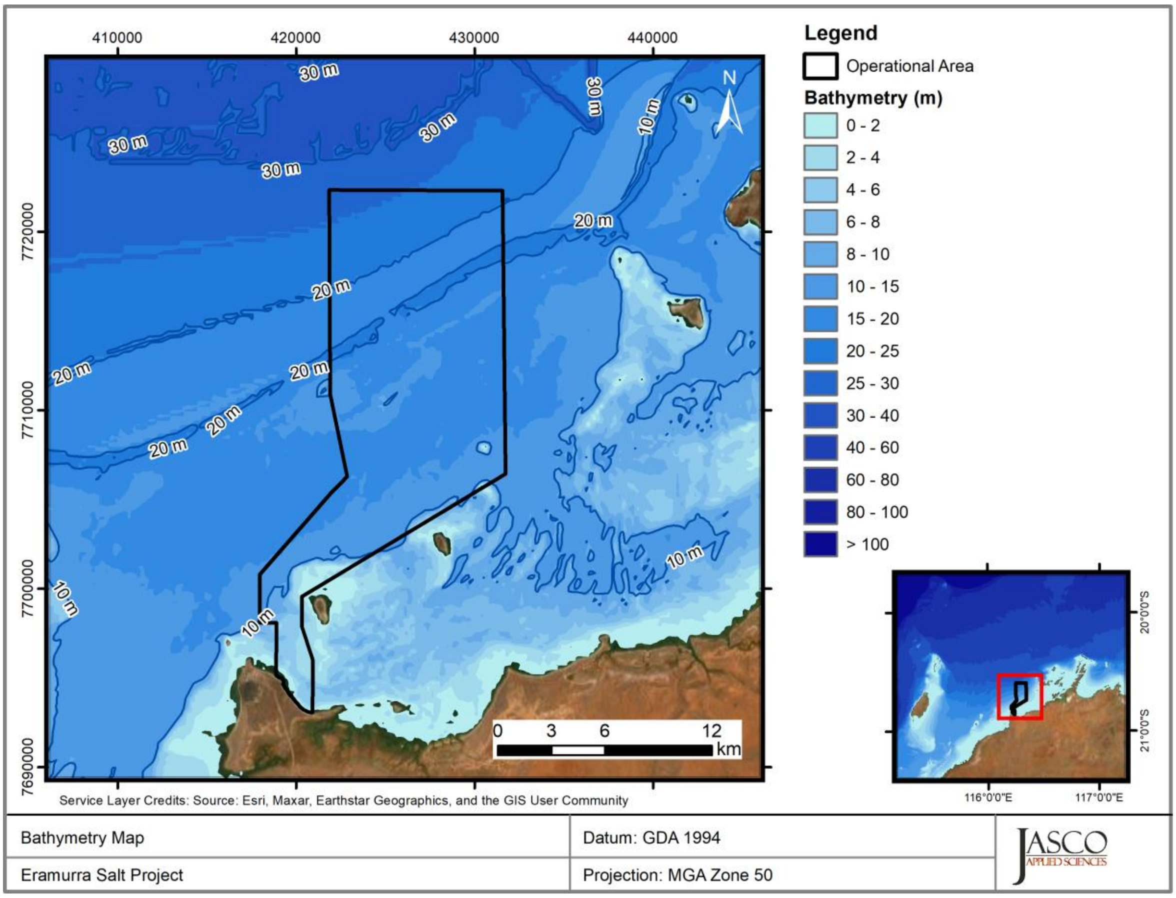

Figure D-2. Bathymetry in the modelled area.

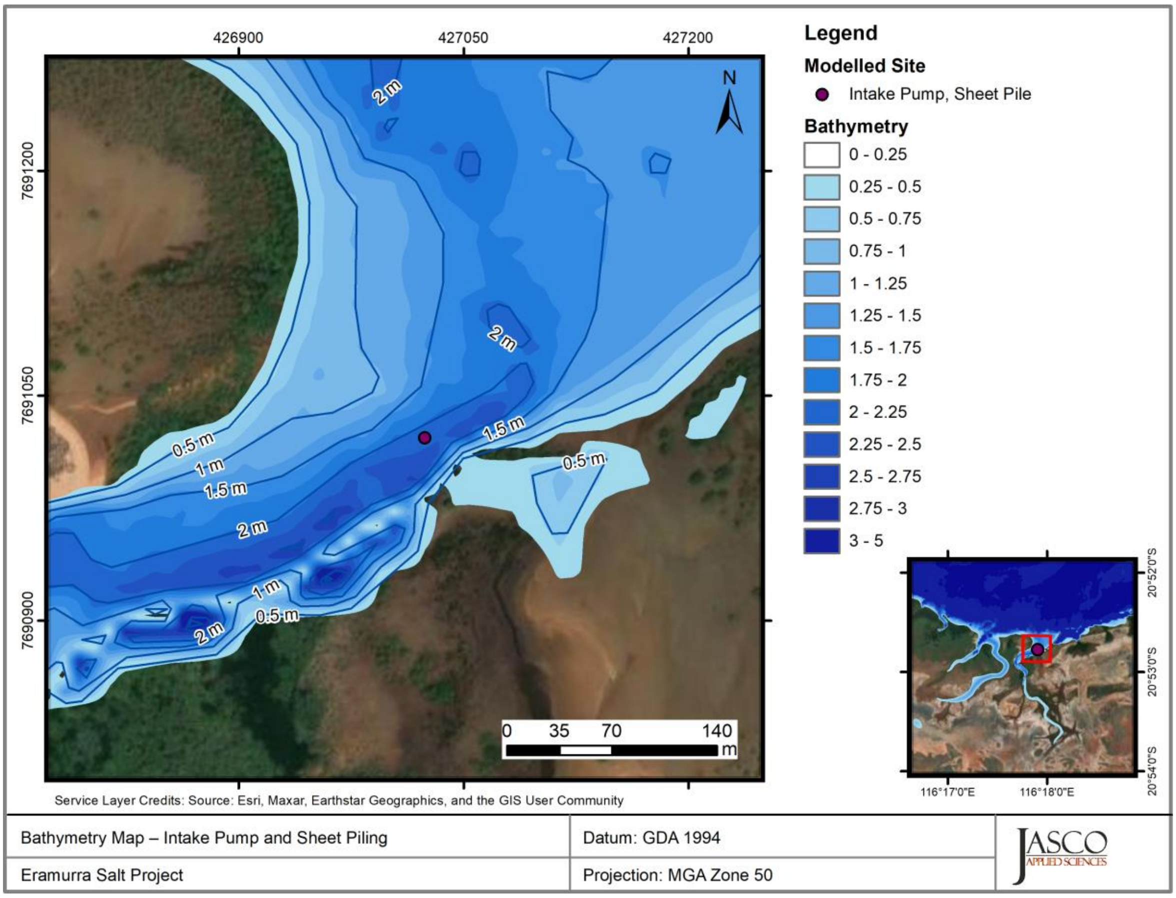

Figure D-3. Bathymetry in the modelled area.

D.3.2. Sound Speed Profile

The sound speed profile in the area was derived from temperature and salinity profiles from the U.S. Naval Oceanographic Office's Generalized Digital Environmental Model V 3.0 (GDEM; Teague et al. 1990, Carnes 2009). GDEM provides an ocean climatology of temperature and salinity for the world's oceans on a latitude-longitude grid with 0.25° resolution, with a temporal resolution of one month, based on global historical observations from the U.S. Navy's Master Oceanographic Observational Data Set (MOODS). The climatology profiles include 78 fixed depth points to a maximum depth of 6800 m (where the ocean is that deep). The GDEM temperature-salinity profiles were converted to sound speed profiles according to Coppens (1981).

Mean monthly sound speed profiles were derived from the GDEM profiles in the locality of the modelled sites. The June sound speed profile was believed to be the most favourable to longer-range sound propagation, as it is most conducive to upwards propagation of underwater sound. As such, June was selected for sound propagation modelling to ensure precautionary estimates of distances to received sound level thresholds. Figure D-4 shows the resulting profile, which was used as input to the sound propagation modelling.

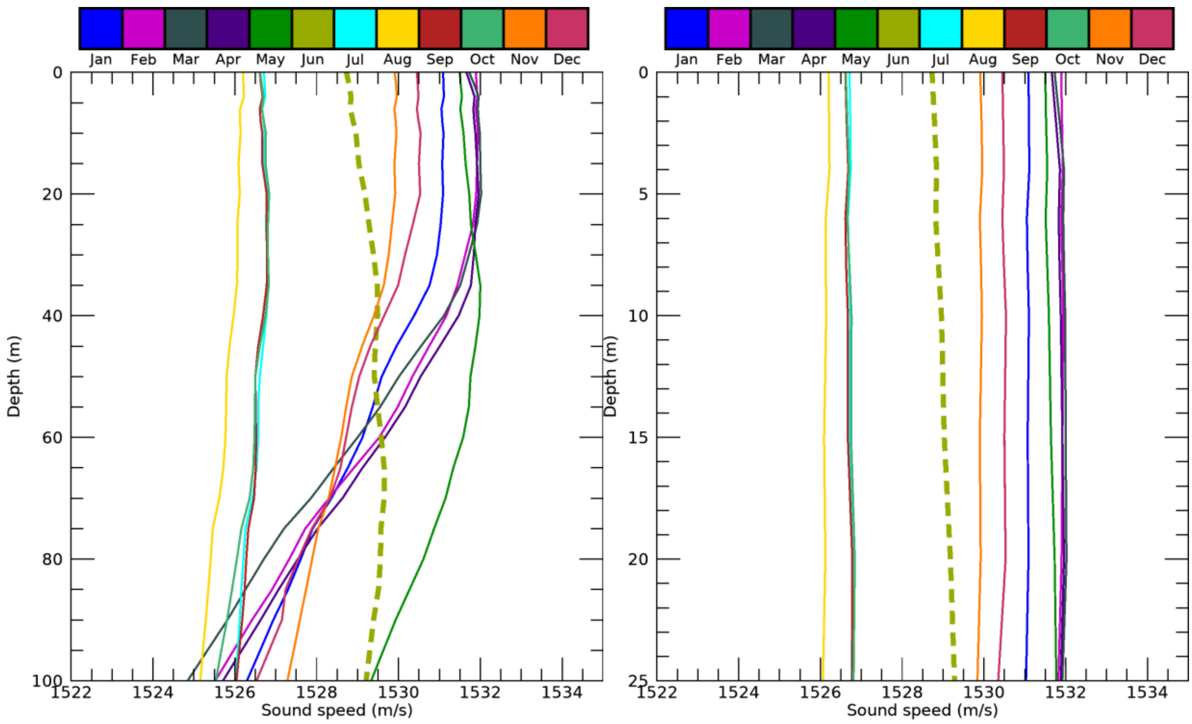

Figure D-4. Sound speed profiles for all months, with the applied month (June) displayed as a dotted line: full profile (left) and top 25 m (right). Profiles are calculated from temperature and salinity profiles from Generalized Digital Environmental Model V 3.0 (GDEM; Teague et al. 1990, Carnes 2009).

D.3.3. Geoacoustics

The propagation model used in this study considered a single geoacoustic profile for all sites. This profile determines how sound is reflected from the seabed, as well as how it is transmitted, reflected and absorbed into the sediment layers. The geology in this area was generated using client-supplied geotechnical reports. Within the vicinity of the Eramurra Solar Salt Project the geology is characterised by layers of various thickness of unconsolidated sediment over cemented layers of calcrete and ferricrete underlain by hard dacite and/or basalt rock. Layer thicknesses were determined by median thicknesses of boreholes in the vicinity of the modelled sites.

Representative grain sizes for the unconsolidated sediment layer from the client-supplied geotechnical report indicate a predominant composition of sand and were used in the grain-shearing model proposed by Buckingham (2005) to estimate the geoacoustic parameters required by the sound propagation models. Cemented calcrete and ferricrete layers were represented with calcarenite from Duncan et al. (2013), due to similar geoacoustic properties. The dacite and basalt bottom was approximated using geoacoustic properties of basalt from Jensen et al. (2011). Table D-1 presents the geoacoustic profile used for all modelled sites.

Table D-1. Geoacoustic profile for all modelled sites. Each parameter varies linearly within the stated range.

Depth below seafloor (m)	Predicted lithology	Density (g/cm^3)	Compressional wave		Shear wave	
			Speed (m/s)	Attenuation (dB/λ)	Speed (m/s)	Attenuation (dB/λ)
0-2	Sand	2.08	1811.6	0.64	271.0	3.65
2-8	Calcarenite	1.90	2200.0	0.12	650.0	0.25
>8	Basalt	2.70	5250.0	0.10	2500.0	0.20

D.4. Model Validation Information

Predictions from JASCO's propagation models (MONM, FWRAM, and VSTACK) have been validated against experimental data from a number of underwater acoustic measurement programs conducted by JASCO globally, including programs in the United States and Canadian Arctic, Canadian and southern United States waters, Greenland, Russia and Australia (Hannay and Racca 2005, Aerts et al. 2008, Funk et al. 2008, Ireland et al. 2009, O'Neill et al. 2010, Warner et al. 2010, Racca et al. 2012a, Racca et al. 2012b, Matthews and MacGillivray 2013, Martin et al. 2015, Racca et al. 2015, Martin et al. 2017a, Martin et al. 2017b, Warner et al. 2017, MacGillivray 2018, McPherson et al. 2018, McPherson and Martin 2018).

In addition, JASCO has conducted measurement programs associated with a significant number of anthropogenic activities that have included internal validation of the modelling (including McCrodan et al. 2011, Austin and Warner 2012, McPherson and Warner 2012, Austin and Bailey 2013, Austin et al. 2013, Zykov and MacDonnell 2013, Austin 2014, Austin et al. 2015, Austin and Li 2016, Martin and Popper 2016, Austin et al. 2018, Beach Energy Limited 2020).