Underwater Piling and Dredging Noise Guidelines

EHTM Attachment 7E

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Document Amendment Record

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Contents

Abbreviations

Acronym	Meaning
ADS Act	*Adelaide Dolphin Sanctuary Act 2005*
DIT or the Department	Department for Infrastructure and Transport
DTH	'Down the Hole' Piling
DPTS	Director, Planning and Technical Services
EPA	South Australian Environment Protection Authority
EPBC Act	Environment Protection and Biodiversity Conservation Act 1999
FM Act	*Fisheries Management Act 2007*
MNES	Matters of National Environmental Significance
MP Act	*Marine Parks Act 2007*
NPW Act	*National Parks and Wildlife Act 1972*
PEA	Principal Environment Advisor
SA	South Australia
SEA	Senior Environment Advisor

Glossary

Term	Meaning
Ambient sound	Sound that would be present in the absence of a specified activity. Examples of specified activity include the act of measuring the underwater sound and the radiation of sound by specified sound sources. Ambient sound can be anthropogenic (e.g. shipping) or natural (e.g. wind, biota).
Auditory frequency weighting	The process of band-pass filtering sounds to reduce the importance of inaudible or less-audible frequencies for individual species or groups of species of aquatic mammals. In other terms, a frequency weighting function that compensates for a species' (or functional hearing group's) frequency-specific hearing sensitivity.
Contract Documentation	Contract Scope and Technical Requirements; Functional and Operational Requirements; Contract or Project Scope.
Contractors	Contractor engaged by the Department to undertake the planning, design or construction of a project (including maintenance projects).
Decibel (dB)	Unit used in the logarithmic measure of sound strength.
Frequency	Rate at which water particles move backwards and forwards measured in cycles per seconds or Hertz (Hz).
Frequency range	The frequency range is expressed as the lowest frequency to the highest frequency.
Hammer energy	This is equal to the kinetic energy with which the hammer mass strikes the pile.
Hearing group	Category of animal species when classified according to their hearing sensitivity and to the susceptibility to sound. Examples for marine mammals include low-frequency (LF) cetaceans, high-frequency (HF) cetaceans, very high-frequency (VHF) cetaceans, otariid pinnipeds in water (OPW), phocid pinnipeds in water (PPW), sirenians (SI), other marine carnivores in air (OCA), and other marine carnivores in water (OCW). (Southall et al. 2019).

Term	Meaning
Hearing threshold	The hearing threshold represents the lowest signal level an animal can detect at a particular frequency, usually referred (and measured) as the threshold at which an animal will indicate detection 50% of the time.
Impulsive sound	Transient sound that has extremely short duration and a high peak sound pressure level. Under these Guidelines, impulsive sound means sound generated from pile driving with the use of an impact hammer to strike the top of a pile.
Continuous sound	Sound that is continuous in nature. Under these Guidelines, continuous sound means sound generated from vibratory pile driving, DHT pile driving and dredging activities. Note that whilst DHT pile driving also has impulsive characteristics, it is assessed as continuous under these Guidelines.
MFO Level 1	Marine Fauna Observer, Level 1. A person with qualifications in ecology, zoology or environmental sciences and demonstrated experience with the identification and management of dolphins or whales, including behaviour, as well as distance estimation.
MFO Level 2	Marine Fauna Observer, Level 2. A person who has sufficient experience in marine fauna identification and distance estimation.
Noise	A sound or sounds that may cause disturbance.
TTS	Temporary threshold shift (TTS) is a temporary reduction in hearing sensitivity as a result of exposure to sound. Exposure to high levels of sound over relatively short time periods can cause the same amount of TTS as exposure to lower levels of sound over longer time periods. The duration of TTS varies depending on the nature of the stimulus.
PTS	Permanent threshold shift (PTS) is a permanent reduction in hearing sensitivity caused by irreversible damage to the sensory hair cells of the ear.
Transmission loss	Reduction in a specified level between two specified points.
Peak pressure	Peak pressure (L_{PK}) as defined in ISO 18405. Greatest magnitude of the sound pressure during a specified time interval, for a specified frequency range. A zero-to-peak sound pressure can arise from a positive or negative sound pressure. Units: Pa
Pile dimensions	Dimensions of the pile in terms of the overall length, diameter, and wall thickness (if hollow).
Propagation loss	difference between source level in a specified direction and the SPL at a specified position.
Pulse duration	Percentage energy signal duration as defined in ISO 18405. The energy percentage over which the pulse duration has been calculated should be stated with the result. For the purposes of this Guidelines, the energy percentage for the pulse duration is 100%.
Pulse repetition frequency	Typically stated as the number of strikes (or acoustic pulses) per second.
Reference value	The standard reference value in water for root mean-squared sound pressure (rms) is 1 μPa and for sound exposure 1 μPa^2 s. The sound level is defined as the logarithm of the ratio of the value to its reference value.
Sound exposure propagation loss	The difference between sound exposure source level in a specified direction and SEL at a specified position.
SEL	Level of the sound exposure as defined in ISO 18405. In underwater acoustics, the reference value of time-integrated squared sound pressure is 1 μPa^2 s.
SEL_{ss}	The sound exposure level for an individual acoustic pulse (corresponding to a single hammer strike) is calculated over the pulse duration relating to 100% of the pulse energy as defined in ISO 18405. For the purposes of this Guidelines, this is termed the single strike sound exposure level (abbreviated as SEL_{ss}).

Term	Meaning
$SEL_{24\ hour}$	The cumulative sound exposure level, which includes multiple acoustic pulses from piling or the time duration of dredging within a 24 hour period. When reporting the cumulative sound exposure level, the number of pulses and/or the time duration over which the cumulative sound exposure level has been calculated must be stated. Under these Guidelines, the accumulation period is 24 hours to allow for a precautionary approach to an assessment of effects. It is also assumed for intermittent, repeated exposure that there is no recovery between subsequent exposures.
Significant impact	Under the *Environment Protection and Biodiversity Conservation Act 1999* a 'significant impact' is an impact which is important, notable, or of consequence, having regard to its context or intensity. Whether or not an action is likely to have a significant impact depends upon the sensitivity, value, and quality of the marine environment, which is impacted, and upon the intensity, duration, magnitude and geographic extent of the marine related impacts.
Source level	Source level (SL) is the sound pressure level at a distance of 1 m from a hypothetical point source radiating the same amount of sound energy as the actual source. Units: dB re 1 $\mu Pa^2 \cdot m^2$ (sound pressure level), dB re 1 $\mu Pa^2 \cdot m^2$ s (sound exposure level).
Spectrum	Distribution of sound energy versus frequency.
SPL	Sound pressure level (SPL) is the root-mean-square sound pressure expressed in the decibel (dB) scale. Units: dB re 1 μPa^2.
Underwater acoustics specialist	A suitably qualified person with qualifications in engineering or science, eligible to become a Member of the Australian Acoustical Society and demonstrated professional experience in underwater acoustics.

ISO 18405:2017 Underwater acoustics — Terminology may also be referenced for further information.

1 Introduction

The Underwater Piling and Dredging Noise Guidelines (the Guidelines) have been developed by the Department for Infrastructure and Transport (the Department). They provide guidance to Departmental staff, and Departmental engaged consultants and contractors in addressing underwater noise as a key part of marine maintenance activities or a marine infrastructure project.

Pile driving during infrastructure works can produce nuisance or high noise levels both underwater and above water. Minimising the impacts of underwater noise (as well as above water noise) from piling activities is now widely accepted as an important environmental issue, with assessments undertaken for various marine infrastructure projects within Australia and around the world.

The South Australian Environment Protection Authority (EPA) acknowledge in their Dredging Guideline (2020) that underwater noise may also impact marine megafauna such as whales and dolphins, particularly when activities such as piling occurs. They also advise that dredge operators need to consider movements of megafauna to ensure the potential for noise impacts are minimised.

In addition to standard underwater piling methods, the Guidelines include provision for the assessment of down-the-hole (DTH) pile driving as well as dredging activities and guidance on the assessment of noise impacts upon other marine fauna in addition to marine mammals.

These Guidelines form *Attachment 7E of the Environment and Heritage Technical Manual (EHTM) – Part 7: Noise*.

1.1 Structure of the Guidelines

The Guidelines has been structured as follows:

- *Part A* – Provides an outline of the assessment process and the management measures to be undertaken.
- *Part B* – Provides additional information relating to:
  - Noise sources and modelling
  - Underwater noise environments
  - Noise sensitive receptor groups.

1.2 Supporting Documentation

The following Departmental documentation applies to assessments undertaken under these Guidelines:

- Marine Fauna Noise Threshold Calculator (available to Professional and Technical Services Prequalified companies by request (email: DPTI.SSDTechnicalServices@sa.gov.au)); and
- Fauna Impact Assessment Guideline.

1.3 Application and Objectives of the Guidelines

The Guidelines apply to any proposed piling or dredging activity to be undertaken in South Australian (SA) waters by the Department and its contractors that have the potential to impact on marine fauna.

The aims of the Guidelines are as follows:

- Provide advice to the Department and its contractors on their legal responsibilities under relevant Commonwealth and State legislation.
- Provide practical management and mitigation measures to minimise the risk of injury to marine mammals (as well as fish and marine turtles) as a result of underwater noise generated by piling or dredging activities.
- Provide a framework that minimises the risk of underwater noise generated by piling or dredging activities causing significant impacts on marine fauna in biologically important habitats or during critical behaviours (e.g. breeding and calving).

1.4 Performance Outcomes

To meet the performance requirements under these Guidelines, unless specified otherwise in the Contract Documentation, the following shall be achieved:

- Completion of an Underwater Noise Impact Assessment that demonstrates compliance with the Guidelines.
- Identification of mitigation and management measures to be adopted in accordance with the Guidelines.

1.5 Legislative Context

Users of the Guidelines are responsible for complying with relevant legislation and obtaining relevant approvals, permits or authorisations (where required by the Contract Documentation). The following legislation may apply to Departmental marine construction and maintenance activities:

- *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)

  The EPBC Act applies to any action which is likely to have a significant impact on a Matter of National Environmental Significance. Referral and approval may be required if marine areas of international importance, threatened species/ecological communities and/or migratory species listed under the EPBC Act are potentially impacted.

  The approval process under the EPBC Act will vary depending on the nature of the project and the level of assessment required. For the purpose of maintenance activities, Section 43B of the EPBC Act should be considered. Any referrals under the EPBC Act are to be endorsed by the Director, Planning and Technical Services (DPTS) prior to submission.

- *Australian Whale Sanctuary*

  Section 225 of the EPBC Act establishes the Australian Whale Sanctuary to give formal recognition of the high level of protection and management afforded to cetaceans in Commonwealth marine areas and prescribed waters.

  The Australian Whale Sanctuary includes all Commonwealth waters from the three nautical mile state waters limit out to the boundary of the Exclusive Economic Zone (EEZ), i.e. out to 200 nautical miles and further in some places and under certain circumstances. Under the EPBC Act (Part 13, Division 3, Subdivision C), it is an offence to kill, injure, take, trade, keep, move, harass, chase, herd, tag, mark or brand a cetacean within the Australian Whale Sanctuary.

- *Adelaide Dolphin Sanctuary Act 2005* (ADS Act)

  The *Adelaide Dolphin Sanctuary Act 2005* establishes the Adelaide Dolphin Sanctuary within the Port Adelaide River and Barker Inlet marine area and aims to protect dolphins and their habitat within the sanctuary. Section 32 of this Act states that there is a general duty of care for a person to take all reasonable measures to prevent or minimise any harm to the sanctuary through his or her actions or activities.

- *National Parks and Wildlife Act 1972* (NPW Act)

  Section 68 of the *National Parks and Wildlife Act 1972* states that a person must not interfere with, harass or molest a protected animal, or undertake or continue an act or activity that is, or is likely to be, detrimental to the welfare of a protected animal unless authorised by a permit granted by the Minister responsible for implementation of the Act. The marine mammal species listed as 'protected animals' under the NPW Act are also listed under the EPBC Act.

- *Fisheries Management Act 2007* (FM Act)

  Section 77 of the *Fisheries Management Act 2007* states that a person must not engage in an operation involving or resulting in interference with aquatic animals of any waters forming part of an aquatic reserve, except as authorised by the regulations or a permit issued by the Minister responsible for the FM Act.

- *Marine Parks Act 2007* (MP Act)

  Section 37 of the *Marine Parks Act 2007* states that there is a general duty of care for a person to take all reasonable measures to prevent or minimise harm to a marine park through his or her actions or activities.

1.6 Limitations of the Guidelines

The Guidelines include piling and dredging activities as underwater noise sources relevant to the Department's marine infrastructure projects and maintenance works. Other sources of underwater noise, such as vessels, drilling, blasting, geophysical or seismic surveys and helicopters (etc.) are not considered in this document.

Research into the effects of underwater noise on marine fauna is an evolving field and gaps in knowledge still exist. The Guidelines will be reviewed periodically and amended as further information becomes available.

The Guidelines have been developed by the Department for use in South Australia by the Department and its contractors only. Other agencies and jurisdictions that refer to these Guidelines are responsible for ensuring independent verification of the accuracy, currency, or completeness specific to their jurisdiction.

1.7 Master Specification

The Department's Master Specification sets out the requirements to achieve the quality and/or performance outcomes expected for planning/design, construction projects, maintenance and professional services.

The Guidelines should be read in conjunction with the following Master Specification identified in Table 1-1.

Table 1-1 Departmental Master Specification Parts

Master Specification	Specification name
Project Controls:	PC-PL1 – Framework for Planning Studies
	PC-PL2 – Planning Investigations
	PC-PL3 – Concept Design Development
	PC-ENV3 - Environmental Protection Requirements
	PC-ENV3 – Environmental Design
	PC-ENV4 – Noise Assessment, Treatment Design and Implementation
	PC–SI2 – Site Investigations
	PC-EDM3 – Independent Design Certifier

PART A

Assessment Process and Management Measures

2 Underwater Noise Impact Assessment Process

An underwater noise impact assessment is to be completed to determine the noise mitigation measures required for piling or dredging activities. This section describes the typical process to be followed for such assessment.

An overview of the assessment process is presented in Figure 2-1. The Deliverables for each step of the process are identified in Section 6. Should alternative methods for assessing underwater noise be proposed, demonstration that the proposed approach is suitable must be provided and discussed/ agreed with the Department's Technical Services, Environmental and Sustainability Unit prior to being undertaken.

The underwater noise impact assessment would be undertaken during either the Proving, Pre-delivery or Delivery phase, the minimum requirements are:

Step 1 – Define the project activity and extent of works; what, where, when and how

- Establish what works are planned at what location, and whether piling or dredging activities will be undertaken in South Australian waters as part of the proposed works. These Guidelines only apply if these works will occur in marine waters.
- Identify the nature of the proposed works, that is:
  - What piling method is likely to be used for the proposed works (e.g. impact, vibratory or DTH pile driving), and obtain information on the likely pile dimensions and material of the pile.
  - What dredging method is likely to be used for the proposed works (e.g. cutter suction dredging or trailing suction hopper dredging), and obtain information on the area to be dredged.
  - Determine the duration, time of the day, and time of the year (e.g. during whale migration season) of the activity.
- Undertake an 'alternatives' assessment to consider options for minimising noise while meeting project objectives where reasonable and practicable.

Step 2 – Define the marine fauna that may be affected

- With reference to the Department's Fauna Impact Assessment Guideline, during the preliminary and/ or detailed fauna impact assessment, determine the presence of species that reside in or utilise marine water in the region for where works are located. The marine region to be searched is the area within a minimum 10 km buffer zone surrounding the extent of works. *In situations where there is perceived ecological risk to sensitive areas immediately surrounding the minimum buffer zone, the zone should be extended to include these areas.*
  - Use the *Environment Protection and Biodiversity Conservation (EPBC) Protected Matters Search Tool* to identify listed marine species that are likely to be present in the marine region for where works are located. EPBC listed marine species to which the Guidelines apply include 'threatened', and/or 'migratory' marine mammals, fishes and marine turtles. For all other species (including EPBC 'marine' listed species), adopting the precautionary principal is applicable.
  - Determine the sensitivity of the relevant marine species to underwater noise (refer to Sections 3.1 and 3.2 for further information).
- In relation to listed threatened species and ecological communities and listed migratory species, the EPBC Act protected matters search tool is intended to be of guidance only and should not be regarded as definitive. Further desktop assessment, investigation and/ or surveys in the area where an action is proposed may assist in verifying the results of the EPBC Act protected matters search tool. It is also important to note that some species may be detectable at certain times of the year only. Specific fauna surveys are not generally undertaken by the Department, however marine fauna may be identified if an underwater vegetation survey was to occur. A literature survey shall also be undertaken, including assessment of the latest scientific (peer-reviewed) information where available.
- If no EPBC species are likely to be affected, standard operational procedures apply (refer Section 4.3).

Step 3 – Assess the likelihood of a significant impact on any MNES protected under the EPBC Act

- Where listed species are present, determine if the work will occur in a biologically important habitat for the species, such as a breeding, calving or resting area, or a migratory route or feeding area during season.
- Assess the likelihood of works having a significant impact on *Matters of National Environmental Significance* (MNES) under the EPBC Act in accordance with the *Significant Impact Guidelines 1.1 – Matters of National Environmental Significance*.

The outcome of this assessment will be in the form of a risk assessment. Refer Section 6 for reporting and deliverables.

What is a significant impact?

A 'significant impact' is an impact which is important, notable, or of consequence, having regard to its context or intensity. Whether or not an action is likely to have a significant impact depends upon the sensitivity, value, and quality of the environment which is impacted, and upon the intensity, duration, magnitude and geographic extent of the impacts. You should consider all of these factors when determining whether an action is likely to have a significant impact on matters of national environmental significance. Source: *Significant Impact Guidelines 1.1*

When is a significant impact likely?

To be 'likely', it is not necessary for a significant impact to have a greater than 50% chance of happening; it is sufficient if a significant impact on the environment is a real or not remote chance or possibility. If there is scientific uncertainty about the impacts of your action and potential impacts are serious or irreversible, the precautionary principle is applicable. Accordingly, a lack of scientific certainty about the potential impacts of an action will not itself justify a decision that the action is not likely to have a significant impact on the environment. Source: *Significant Impact Guidelines 1.1*

Step 4 – Undertake an underwater noise impact assessment

- If the risk assessment, undertaken in Step 3, identifies that the proposed works will not have, or "unlikely" to have, a significant impact on any MNES protected under the EPBC Act, standard operational procedures are to be adopted during the proposed works. Refer to Section 4.2 for information on how to predict the standard safety zones for marine mammals and potential effects zones for fishes and marine turtles using the Department's *Marine Fauna Noise Thresholds Calculator*. In scenarios where the project plans activities that operate outside of the standard parameters, an underwater acoustics specialist shall undertake a site-specific assessment.
- If the risk assessment, undertaken in Step 3, identifies a "likely" significant impact on any MNES protected under the EPBC Act (e.g. Pile driving during whale migration season), a detailed underwater noise impact assessment will be required to be undertaken by an underwater acoustics specialist (in collaboration with a marine ecologist/ scientist, where relevant). The following outlines the minimum impact assessment requirements:
  - Obtain bathymetry and geology for input into an underwater noise model for predicting noise emissions from the project activities.
  - Determine the existing ambient noise environment based on measurements or from referring to available literature relevant to the marine area.
  - For the considered marine species, establish the likely hearing sensitivity and bandwidth, and determine noise exposure impact threshold criteria for behavioural and physiological impacts, where relevant.
  - Predict the source levels for the proposed piling or dredging works and then predict the received levels versus distance from the activity using a suitable noise propagation modelling method. As a minimum, noise modelling must factor in the effects of the bathymetry profile, geological composition of the seabed and the sound speed profile of the water column.
  - Estimate the sizes of the safety and potential effects zones. Refer to Section 4.2 for more information.
  - Consider reasonable and practicable additional mitigation and management measures. Refer to Sections 4.3 and 4.4.
  - Develop an *Underwater Noise Management Framework* and/or *Underwater Noise Management Plan*. Refer Section 6 for reporting/deliverables.

Step 5 – Are approvals/permits required?

- Where the likelihood of a significant impact on MNES protected under the EPBC Act has increased (from baseline conditions) as the result of the risk assessment undertaken, consider the preparation and submission of a referral in accordance with the requirements of the EPBC Act. The EPBC referral shall detail the additional mitigation and management measures that will be put in place to minimise the potential impacts of underwater piling or dredging noise to MNES. Given the potential for long approval timeframes, the process should be implemented early in the project's lifecycle.

  There may be circumstances where a referral under the EPBC Act is made for a particular action or project despite the assessments indicating that there are unlikely to be significant impacts to MNES. Suitable documentation shall be provided to the Department's Project Manager to enable a decision on the need to refer.
- If the potential noise footprint of the piling and/or dredging activity overlaps with the Adelaide Dolphin Sanctuary, advise the Adelaide Dolphin Sanctuary Advisory Board on the proposed works.
- If the potential noise footprint of the piling and/or dredging activity overlaps with an aquatic reserve or marine park, establish whether legislative approvals are required under the *Fisheries Management Act 2007* or *Marine Parks Act 2007*.

Step 6 – Implementation

- Include or comply with legislative approvals (where relevant), standard operational procedures, and additional mitigation and management measures if applicable, in contract documentation.
- For Delivery (Construction and Maintenance) activities, the development of an *Underwater Noise Management Plan* will be required. Refer Section 6 for reporting/deliverables.
- Develop a compliance and sighting report. Refer to Section 4.3.4.

For projects with longer term works, undertake auditing of the works to ensure compliance with the requirements of the *Underwater Noise Management Plan*.

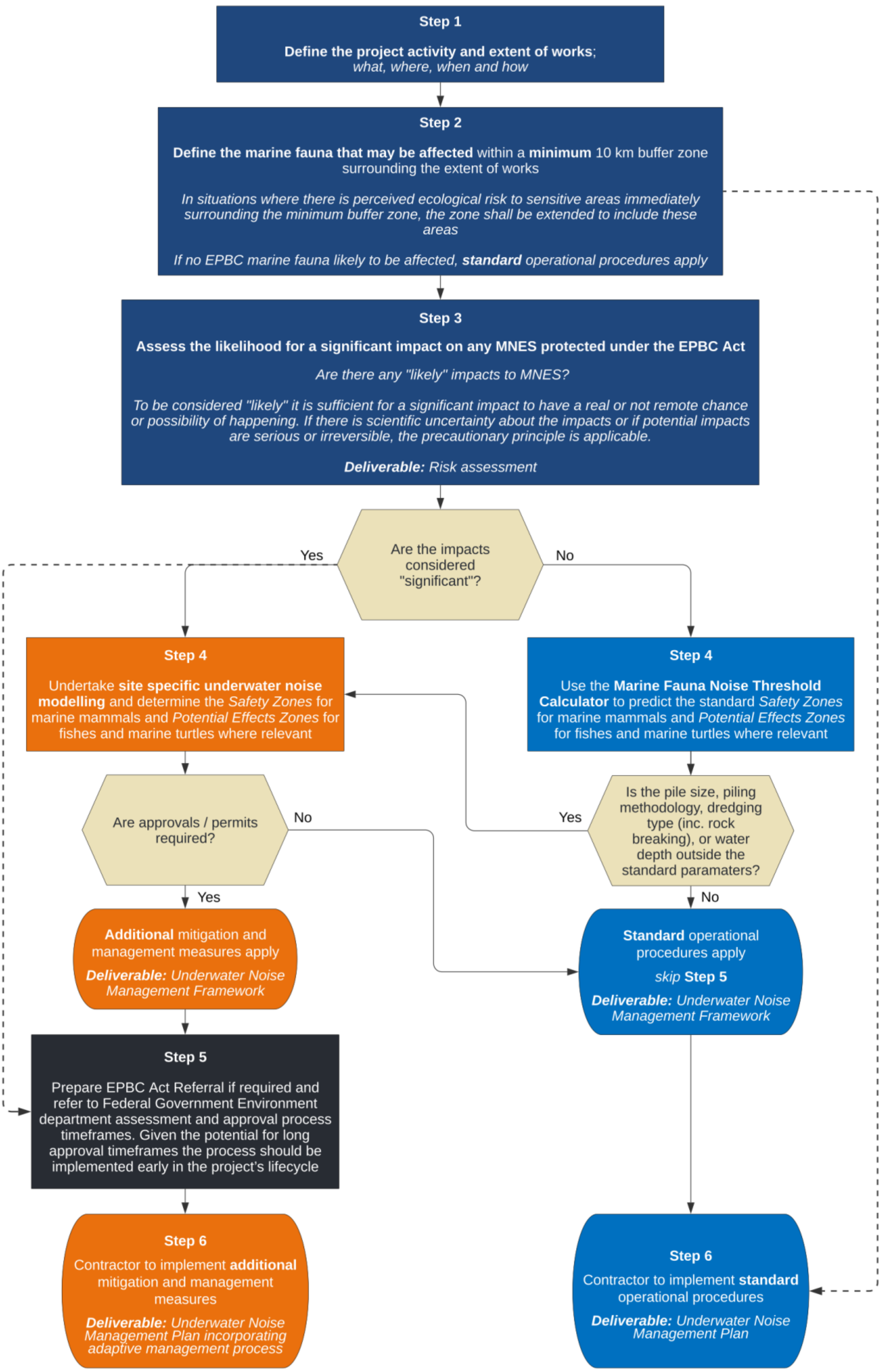


Figure 2-1 Overview of Underwater Noise Impact Assessment Process

3 Assessment Criteria

The following sections outline the relevant assessment criteria applicable under these Guidelines.

3.1 Marine Mammal Functional Hearing Groups

Species of cetaceans and pinnipeds were assigned to functional hearing groups based on their hearing characteristics by Southall et al. (2019). Table 3-1 presents the four functional hearing groups, the estimated auditory bandwidth for each group, the listed species that may occur in SA state waters for each functional hearing group, and the group-specific frequency weightings.

Table 3-1 Marine mammals and group-specific auditory frequency weightings (Southall et al. 2019)

Functional hearing group	Generalised hearing range	Listed species that are known to, likely to, or may occur in SA state waters	Auditory Frequency Weighting
Low-frequency cetaceans (All baleen whales)	7 Hz to 22 kHz	• Southern Right Whale (*Eubalaena australis*) – Migratory, endangered • Minke Whale (*Balaenoptera acutorostrata*) – Migratory • Bryde's Whale (*Balaenoptera edeni*) – Migratory • Blue Whale (*Balaenoptera musculus*) – Migratory, endangered • Pygmy Right Whale (*Caperea marginate*) – Migratory • Humpback Whale (*Megaptera novaeangliae)* – Migratory, vulnerable	LF
High-frequency cetaceans (Majority of toothed whales)	150 Hz to 160 kHz	• Bottlenose Dolphin (*Tursiops truncates*) • Common Dolphin (*Delphinus delphis*) • Dusky Dolphin (*Lagenorhynchus obscurus)* – Migratory • Killer Whale (*Orcinus orca*) – Migratory • Spotted Bottlenose Dolphin (*Tursiops aduncus*)	HF
Very High-frequency cetaceans (Other toothed whales)	275 Hz to 160 kHz	• None that may occur in SA waters	VHF
Pinnipeds Phocid carnivores (earless seals, or true seals) in water	50 Hz to 86 kHz	• Leopard seal (*Hydrurga leptonyx*)	PCW
Pinnipeds Other carnivores (eared seals: sea lions and fur seals) in water	60 Hz to 39 kHz	• Australian Sea Lion (*Neophoca cinerea*) – Vulnerable • Australian Fur Seal (*Arctocephalus pusillus*) • New Zealand Fur Seal (*Arctocephalus forsteri*)	OCW

The low-frequency cetaceans group includes all baleen whales. Most toothed whales are represented in the high-frequency cetaceans group. The very high-frequency cetaceans group contain the pygmy and dwarf sperm whales, which are not present in SA waters.

The auditory frequency weightings account for the fact that marine mammals do not hear equally well at all frequencies within their functional hearing range. Noise levels are weighted to de-emphasize frequencies that are near the lower and upper frequency end of the estimated hearing range, where noise levels must be higher to result in the same auditory effect.

Auditory weighting function

The auditory weighting (dB) is calculated as a function of frequency (f) as follows (Southall et al. 2019):

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

Table 3-2 Relevant marine mammal group specific auditory weighting function parameters (Southall 2019)

Weighting Function Parameters	Low-Frequency Cetaceans	High-Frequency Cetaceans	Very High-Frequency Cetaceans	Pinnipeds (Phocid carnivores in water)	Pinnipeds (other carnivores in water)
a	1	1.6	1.8	1	2
b	2	2	2	2	2
f_1 (kHz)	0.2	8.8	12	1.9	0.94
f_2 (kHz)	19	110	140	30	25
C (dB)	0.13	1.2	1.36	0.75	0.64

As an example, consider an underwater piling noise impact assessment for the Southern Right Whale. This species is represented in the low-frequency cetacean functional hearing group. Utilising Table 3-2 the resulting auditory weighting function for the Southern Right Whale is illustrated in Figure 3-1.

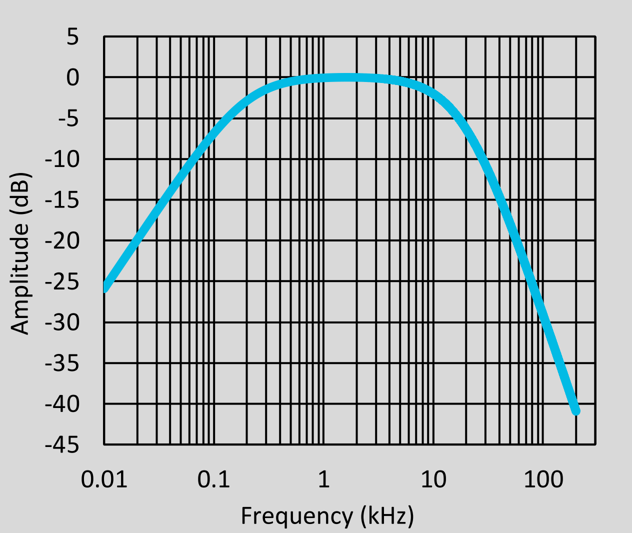


Figure 3-1 Auditory weighting function for Southern Right Whale. This species is represented in the low-frequency cetaceans functional hearing group

3.1.1 Physiological Impacts – Temporary threshold shift (TTS) and Permanent threshold shift (PTS)

Substantial progress has been made in quantifying marine mammal hearing and the effects of noise on hearing for a range of taxa since the review provided by Southall et al. (2007), which formed the basis of the former DIT (2012) underwater piling noise Guidelines. Southall et al. (2019), considering subsequent scientific findings over the past decade, presented estimated audiograms for six species groupings, including all marine mammal species. Southall et al. (2019) also advise that substantial uncertainties and data gaps remain in the understanding marine mammal hearing.

Southall et al. (2019) provides dual exposure metrics for impulsive noise criteria, including frequency-weighted SEL and unweighted peak sound pressure level. Exposures exceeding the specified respective criteria level for any exposure metric are interpreted as resulting in predicted temporary threshold shift (TTS) or permanent threshold shift (PTS) onset. For continuous noise sources, exposure criteria are given in frequency-weighted SEL.

Table 3-3 summarises the Southall et al. (2019) noise exposure criteria for physiological impacts adopted by these Guidelines. The criteria are essentially identical to that adopted by NFMS (2018). Note that SEL_{cum} is expressed as $SEL_{24\ hour}$ under these Guidelines for clarity on the assessment period.

Table 3-3 Underwater noise exposure criteria for physiological impacts on marine mammals

Functional hearing group	Impact	Physiological noise exposure onset criteria	
		Impact piling (Impulsive)	Vibratory / DTH piling and Dredging (Continuous)
Low-frequency cetaceans	TTS	Peak 213 dB $SEL_{24\ hour}$ 168 dB(LF)	$SEL_{24\ hour}$ 179 dB(LF)
	PTS	Peak 219 dB $SEL_{24\ hour}$ 183 dB(LF)	$SEL_{24\ hour}$ 199 dB(LF)
High-frequency cetaceans	TTS	Peak 224 dB $SEL_{24\ hour}$ 178 dB(HF)	$SEL_{24\ hour}$ 179 dB(HF)
	PTS	Peak 230 dB $SEL_{24\ hour}$ 185 dB(HF)	$SEL_{24\ hour}$ 198 dB(HF)
Very high-frequency cetaceans	TTS	Peak 196 dB $SEL_{24\ hour}$ 140 dB(VHF)	$SEL_{24\ hour}$ 153 dB(VHF)
	PTS	Peak 202 dB $SEL_{24\ hour}$ 155 dB(VHF)	$SEL_{24\ hour}$ 173 dB(VHF)
Pinnipeds (Phocid carnivores in water)	TTS	Peak 212 dB $SEL_{24\ hour}$ 170 dB(PCW)	$SEL_{24\ hour}$ 181 dB(PW)
	PTS	Peak 218 dB $SEL_{24\ hour}$ 185 dB(PCW)	$SEL_{24\ hour}$ 201 dB(PCW)
Pinnipeds (other carnivores in water)	TTS	Peak 226 dB $SEL_{24\ hour}$ 188 dB(OCW)	$SEL_{24\ hour}$ 199 dB(OCW)
	PTS	Peak 232 dB $SEL_{24\ hour}$ 203 dB(OCW)	$SEL_{24\ hour}$ 219 dB(OCW)

(1) Note: TTS = Temporary threshold shift, PTS = Permanent threshold shift

3.1.2 Behavioural Response

Behavioural responses to noise include changes in vocalisation, resting, diving and breathing patterns, changes in mother-infant spatial relationships, and avoidance of the noise source (NRC 2005). Masking of biologically important sounds that interfere with communication and social interaction can also cause changes in behaviour.

Behavioural reactions can vary not only among individuals, but also within an individual animal, depending on previous experience with a sound source, hearing sensitivity, sex, age, reproductive status, geographic location, season, health, social behaviour, or context (Ellison et al. 2012).

Severity of behavioural responses can also vary depending on the following (as per Richardson et al. 1995; NRC 2003; Wartzok et al. 2004; NRC 2005; Southall et al. 2007; Bejder et al. 2009; Archer et al. 2010):

- characteristics associated with the sound source, for example, whether it is moving or stationary, the number of sound sources and distance from the source;
- the potential for the source and individuals to co-occur temporally and spatially;
- the persistence or recurrence of a sound in specific areas and how close to shore, where animals may be unable to avoid exposure;
- noise propagation characteristics that are either enhancing or reducing exposure.

Summaries of behavioural responses of marine mammals to human-made noise show a large variability in the received levels (differing by many tens of decibels) and the severity in the response from minor to severe (C.Erbe et al. 2018). Furthermore, there is limited data on behavioural responses of marine mammals exposed to pile driving activities (both impact and vibratory), especially associated with smaller near shore projects (Appendix A - NOAA Ocean Noise Strategy).

Under these Guidelines, Table 3-4 summarises noise exposure criteria adopted for the assessment of behavioural impacts. The noise exposure criteria are based on recognised criteria adopted by the US National Oceanic and Atmospheric Administration and may be revised in future as further research becomes available. Noise exposure criteria for impulsive sources (i.e. impact piling) are different to that for continuous sources (e.g. vibro-driving or dredging) due to their different noise character.

Table 3-4 Underwater noise exposure criteria for behavioural response

Species	Behavioural noise exposure criteria	
	Impact piling	Vibratory / DTH Piling and Dredging [1]
Cetaceans	SPL 160 dB rms	SPL 120 dB rms
Pinnipeds	SPL 160 dB rms	SPL 120 dB rms

(1) The 120 dB rms threshold may be adjusted if it can be demonstrated that the ambient levels are above this level.

Note that a ‘zone of potential audibility’ assessment may be requested by the Department if works occur during whale migration season and in areas that are in the vicinity of important habitat or breeding areas. This is in recognition of the probabilistic nature of individual animal responses, the limited scientific data available and the importance of minimising disturbance to biologically sensitive areas. This assessment may then inform further risk evaluation and the consideration of additional project controls if required.

3.2 Sound Exposure Guidelines for Fishes and Marine Turtles

The *Sound Exposure Guidelines for Fishes and Sea Turtles* (Popper et al., 2014) provide a widely accepted approach to assessment of the potential noise impact upon the relevant species. These Guidelines present the outcome of a Working Group that was established to determine broadly applicable sound exposure Guidelines. After consideration of the diversity of fish and sea turtles, Guidelines were developed for broad groups of animals, defined by the way they detect sound.

It was noted that the data on the effects of underwater noise on sea turtles is lacking. Popper et al. (2014) adopts the levels for fish that do not hear well since it is likely these would be conservative for sea turtles. Because of their rigid external anatomy, it is possible that sea turtles are highly protected from impulsive sound effects, for example from pile driving. Table 3-5 provides the underwater noise exposure criteria for physiological impacts on fishes and marine turtles.

Table 3-5 Underwater noise exposure criteria for fishes and marine turtles

Functional Hearing Group	Source character	Organ damage / increased risk of fatality	PTS	TTS	Behavioural Response
Fish (no swim bladder) For example: • Great White Shark • Mackeral Shark	Continuous	**N**: Low **I**: Low **F**: Low	**N**: Low **I**: Low **F**: Low	**N**: Moderate **I**: Low **F**: Low	**N**: Moderate **I**: Moderate **F**: Low
	Impulsive	Peak 213 dB $SEL_{24\ hour}$ 219 dB	Peak 213 dB $SEL_{24\ hour}$ 216 dB	$SEL_{24\ hour}$ 186 dB	**N**: High **I**: Moderate **F**: Low
Fish (with swim bladder) For example: • Pipefish • Seahorses • Seadragons	Continuous	**N**: Low **I**: Low **F**: Low	SPL 170 dB for 48 h	SPL 158 dB for 12 h	**N**: High **I**: Moderate **F**: Low
	Impulsive	Peak >207 dB $SEL_{24\ hour}$ 207 dB	Peak >207 dB $SEL_{24\ hour}$ 203 dB	$SEL_{24\ hour}$ 186 dB	**N**: High **I**: High **F**: Moderate
Marine Turtles For example: • Loggerhead Turtle • Green Sea Turtle • Leatherback Turtle • Pacific Ridley Turtle	Continuous	**N**: Low **I**: Low **F**: Low	**N**: Low **I**: Low **F**: Low	**N**: Moderate **I**: Low **F**: Low	**N**: High **I**: Moderate **F**: Low
	Impulsive	Peak 207 dB $SEL_{24\ hour}$ 210 dB	**N**: High **I**: Low **F**: Low	**N**: High **I**: Low **F**: Low	**N**: High **I**: Moderate **F**: Low

(1) TTS = Temporary threshold shift, PTS = Permanent threshold shift

(2) Popper et al. (2014) note that where insufficient data exist to make a recommendation for Guidelines, a subjective approach is adopted in which the relative risk of an effect is placed in order of rank at three distances from the source:

- Near (N) = tens of meters from the source
- Intermediate (I) = hundreds of meters from the source
- Far (F) = thousands of meters from the source.

Given that it is generally not practical to assign safety zones for these species, a potential effects zone is defined to assist a risk-based assessment for those species known to occur within the marine area of interest, in context with the known location of any associated sensitive habitat.

4 Mitigation and Management Procedures

4.1 Mitigation and Management of Underwater Noise Impacts

The following measures for the mitigation and management of underwater noise impact from piling or dredging works has been adapted from the *Environment Protection and Biodiversity Conservation Act 1999* Policy Statement 2.1 in context with recent scientific research.

These include safety zones for marine mammals, potential effects zones for fishes and marine turtles, standard operational procedures, and additional management and mitigation measures. These are to be implemented as follows.

- *Safety zones* – Safety zones (refer Section 4.2), that includes the observation zone and shut-down zone, are applicable for marine mammals and are sized based on the predicted noise levels produced by piling or dredging activity. The safety zones are a requirement for standard operational procedures. Safety zones may also be calculated by an underwater acoustics specialist in consideration of site-specific conditions and in situations of increased complexity or risk. Safety zones are not applicable to fishes and marine turtles.
- *Potential effects zones* – These zones are applicable to the risk assessment of fishes and marine turtles from underwater noise.
- *Underwater noise impact assessment* – An underwater noise impact assessment shall be conducted to determine the *safety zones* and *potential effects zones*.
- *Standard operational procedures* – These procedures are to be used for all piling or dredging works irrespective of location and time of year. Marine fauna observer (MFO) Level 2 required.
- *Additional mitigation and management measures* – Additional mitigation and/or management measures to the standard operational procedures are to be used when the impacts of the proposed works on listed marine mammal species have the potential to be significant. Marine fauna observer (MFO) Level 1 required to be present for the duration of related works or to train MFO Level 2 with project and site-specific details.

Under these Guidelines, the requirements for different levels of marine fauna observers are as follows:

- *Marine Fauna Observer (MFO) Level 1* – a person who is a suitably qualified marine fauna specialist with experience in marine mammal identification, including behaviour, as well as distance estimation.
- *Marine Fauna Observer (MFO) Level 2* – a person who has sufficient experience in marine fauna identification and distance estimation.

4.2 Safety Zones

The safety zones to be used in the management and mitigation procedures of piling or dredging activities include an *Observation* Zone and S*hut-down Zone* for marine mammals.

In the *observation zone*, the movement of marine mammals shall be monitored to determine whether they are approaching or entering the *shut-down zone*. When a marine mammal is sighted within or appears to enter the *shut-down zone*, piling or dredging activities must be stopped as soon as reasonably practical. Under these Guidelines, the *shut-down zone* is equivalent to an *exclusion zone*. The *observation zone* is sized based on a nominal 250 m distance from the outer edge of the *shut-down zone*.

Shut-down zones are sized based on the potential for a Temporary Threshold Shift (TTS). This approach is consistent with that adopted by the Commonwealth Department of Climate Change, Energy, the Environment and Water (DCCEEW).

Safety zones aim to minimise the likelihood of temporary or permanent hearing injury to occur to marine mammals, where the sizing of which is only applicable in non-biologically important habitat. The zones are not intended to prevent behavioural responses to audible, but non-physical injury noise events. It is likely that marine mammals in the vicinity of a noisy activity will show an avoidance reaction to the noise, which reduces the chance of marine mammals approaching the source close enough to enter the zone of hearing injury (i.e. shut-down zone). The impacts of such a temporary displacement are unlikely to be significant unless it occurs during critical behaviours, such as breeding, feeding and resting, or in important areas such as migratory corridors, calving or nursery grounds and foraging areas.

Where the noise emission is likely to impact during times of critical behaviours and/ or in a biologically important area, the safety zones shall be revised (as required) in consideration of the risk to behavioural disturbance as well, although noting that this is a conservative approach. Furthermore, adaptive management requirements shall also be incorporated into the project's Underwater Noise Management Framework/Plan (refer Section 5 for reporting/deliverables) to provide a mechanism for feedback and adjustment of mitigation measures based on site observation.

The shut-down zone allows for the cumulative effect of multiple hammer strikes during impact piling and the time duration of a continuous noise source. This allows some time to move away from the noise source thereby reducing the likelihood of hearing injury to occur. However, the cumulative sound exposure from other underwater noise sources (i.e. industrial sources of noise, major shipping channels or piling whilst dredging and vice versa), in addition to the piling or dredging activity, may also contribute to the cumulative sound exposure. In this case, the standard safety zones would not apply, and an underwater acoustic specialist shall determine revised safety zones in consideration of the cumulative sound exposure from all relevant underwater noise sources.

Figure 4-1 provides a diagram of safety zones around a jetty where piling works are undertaken (for example). Safety zones for dredging activities shall follow a similar approach to piling activities, however, must also consider the spatial area that the dredge will operate within.

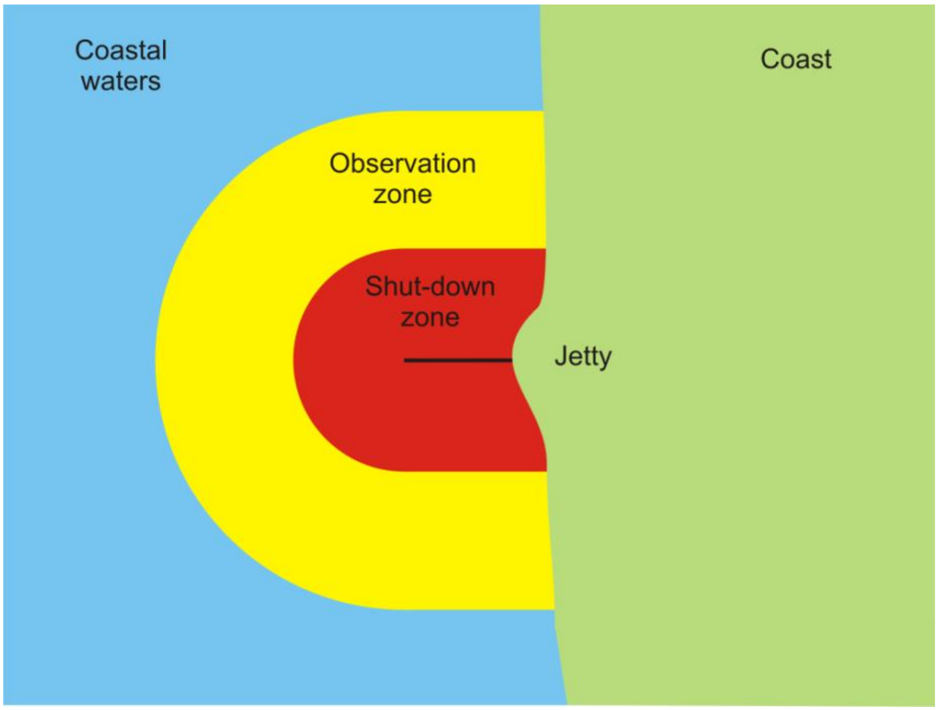


Figure 4-1 Diagram showing safety zones around a jetty (not to scale).

4.2.1 Potential Effects Zone

The potential effects zones are applicable to the impact assessment upon fishes and marine turtles for impact piling activities (i.e. impulsive sound) only. The potential effects zones are not applicable for vibratory or DTH piling driving and dredging activities (i.e. continuous sound sources).

The potential effects zones for fishes and marine turtles are not to be considered a *shut-down zone*, but zones to inform the projects risk evaluation process and identification of reasonable and practicable noise mitigation measures where required. Mitigation measures could include the adoption of alternative lower noise methods, design changes (e.g. pile material type, number of piles required) and soft starts to warn fish and marine turtles.

4.2.2 Standard Noise Sources

Standard noise source types identified in this section relate to the standard safety and potential effects zones calculated under the Guidelines. PART B provides further detailed information on each of the noise sources and their characteristics.

4.2.2.1 Piling activities

Standard source reference levels for impact as well as vibratory and DTH piling are listed in Table 4-1 and Table 4-2 respectively. Works that propose to use a pile size larger than that listed or undertaken in a coastal area with Mean Higher High Water (MHHW) greater than 15 m at the pile location, shall be referred to an underwater acoustics specialist for assessment.

Table 4-1 Source reference levels for impact pile driving activities

Approximate Pile Size	Pile Type	Hammer Type	Peak at 10 m dB re 1 μPa	SPL at 10 m dB re 1 μPa^2	SEL_{ss} at 10m dB re 1 μPa^2 s
0.20 m	Stainless Steel SHS (200mm x 200mm)[2]	Impact	197	175	168
0.30 m	Steel H[1]	Impact	200	183	170
0.30 m	Steel Pipe[1]	Impact	211	194	180
0.30 m	Concrete[1]	Impact	189	176	163
0.60 m	AZ Steel Sheet[1]	Impact	205	190	180
0.61 m	Steel Pipe[1]	Impact	205	192	178
0.61 m	Concrete[1]	Impact	187	168	163

(1) Source Levels have been derived from Rodkin and Pommerenck (2014), where results presented for a similar pile type at different water depths have been averaged.

(2) Source level from Newitt et al. (2022), based on noise measurements undertaken at Kingscote Jetty, South Australia.

Table 4-2 Source reference levels for vibratory or DTH pile driving activities

Approximate Pile Size	Pile Type	Hammer Type	SPL at 10 m dB re 1 μPa^2	SEL at 10 m dB re 1 μPa^2 s
0.30 m	Steel H[1]	Vibratory	150	150
0.30 m	Steel[1]	Vibratory	155	170
0.46 m	Steel[2]	DTH	171	171
0.61 m	AZ Steel Sheet[1]	Vibratory	163	163
0.61	Steel Pipe[1]	Vibratory	-	159
0.61 m	Steel[2]	DTH	171	171
0.91 m	Steel Pipe[1]	Vibratory	175	175
1.07 m	Steel[2]	DTH	171	171

(1) Source Levels have been determined from Rodkin and Pommerenck (2014),

(2) Source levels derived from Illingworth and Rodkin (2017), Denes et al. (2016), Reyff (2020).

4.2.2.2 Dredging activities

Standard source levels for the screening assessment of underwater noise from dredging activities are provided in Table 4-3. The provided noise levels include noise from the various individual noise sources associated with each dredging process.

Table 4-3 Screening source levels for dredging activities (broadband 10 Hz to 1 kHz)

Dredge Type	SEL at 1 m dB re 1 μPa^2 m^2 s
Trailer Suction Hopper Dredge (TSHD)[1]	189
Cutter Suction Dredge (CSD) – Large (>25,000 kW total installed power)[1]	186
Cutter Suction Dredge (CSD) – Small (<1000 kW total installed power)[2]	157
Backhoe Dredge (BHD)[1]	175

(1) Source Levels have been determined from Jones et al. (2015), Reine et al. (2012), Reine et al. (2014).

(2) Source level from Henrys et al. (2022), based on noise measurements undertaken during typical dredging activity with Cutter Suction Dredge (CSD) 'Ngurunderi' at the North Haven Marina, South Australia.

4.2.3 Standard Safety and Potential Effects Zones

Standard safety zones for marine mammals and potential effects zones for fishes and marine turtles are calculated using the Department's *Marine Fauna Noise Thresholds Calculator* for underwater noise emitted within a typical shallow water coastal environment with a sandy bottom.

> The Department's *Marine Fauna Noise Thresholds Calculator* is available to DIT Professional and Technical Services Prequalified companies and DIT Repair or Upgrading of Marine Structures Prequalified companies by request (email: DIT.SSDTechnicalServices@sa.gov.au).

The standard zones calculated by the prediction tool are not suitable for deeper water environments or areas with complex bathymetry (e.g. deep shipping channel) such that sound focussing effects may occur.

In all cases, an underwater acoustics specialist may model alternative safety and potential effects zones based on site specific piling methodology, bathymetry and sediment conditions where required.

The underwater acoustics specialist may calculate the zones by comparing the predicted sound levels to the criteria outlined in Section 3 and noting the following:

- Shut-down zone for marine mammals is based on potential onset of hearing injury (TTS).
- Observation zone for marine mammals to be sized based on the shut-down zone plus an additional 250 m range as a minimum.
- Potential effects zones for fishes and marine turtles to be sized based on both the ranges relating to risk to fatality and hearing injury (TTS).

4.3 Standard Mitigation and Management Measures

4.3.1 Planning of Activities

The planning stage of piling or dredging activities shall consider the following:

- *Timing and duration* – Where possible, avoid conducting piling or dredging activities during times when marine mammals are likely to be breeding, calving, feeding, or resting in biologically important habitats located within the potential noise impact footprint. Where possible, also avoid conducting piling activities in areas adjacent calving and nursing habitat, migratory corridors, or important feeding grounds during migration season. If work is proposed in these areas, the planned activities and associated mitigation measures may require further assessment under the EPBC Act.

> Areas adjacent means where predicted noise levels are above relevant behavioural threshold criteria – refer Section 3.1.2.

- *Piling method* – In defining the construction methodology, use low noise piling methods, such as vibro-driving, instead of impact piling methods where possible. Vibro-driving methods produce lower noise levels and are not impulsive in character. This reduces the likelihood of hearing injury to occur within marine mammals. The piling method shall be optimised considering program, time on-site and likely noise levels.
- *Dredging method* – Use lower noise dredging methods where practical. Should it be anticipated that dredging activities may require rock breaking with the use of a hydro hammer (or similar), specialist advice shall be sought in these cases.
- *Marine Fauna Observer (MFO)* – Ensure that an MFO Level 2 is available during piling activities (and dredging, where relevant) to conduct the standard operational procedures outlined below.
- *Education materials* - A briefing on environmental matters, including information on these Guidelines, marine mammal identification, and the environmental legal obligations for companies operating in SA waters, shall be provided to all staff involved in the planned activities. Likely marine mammal concentration areas, peak migration paths and times, key feeding sites, and other aggregation areas shall be identified during the planning stage and this information shall be utilised by the MFO (and/or other approved personnel by the department) to improve the identification and observation of marine fauna.
- *Contract documentation* – Include the standard operational procedures, and any additional measures to be put in place, in the contract documentation.

4.3.2 Standard Operational Procedures for Piling

Standard operational procedures that must be undertaken by contractors during piling activities include pre-start, soft start, normal operation, stand-by operation, and shut-down procedures.

Note that specific regulatory conditions, as outlined in environmental approvals documentation obtained for project works, may also apply to piling activities. These conditions must be observed in addition to the standard operational procedures where relevant.

- *Pre-start procedure* – The presence of marine mammals (and other relevant marine fauna where able to be observed) shall be visually monitored by a person suitably experienced in identifying marine fauna (MFO Level 2) for at least 30 minutes before the commencement of the soft start procedure. Particular focus shall be put on the shut-down zone but the observation zone shall be inspected as well, for the full extent where visibility allows. Observations should be made from a high vantage point, ideally >6 m above sea level, if possible.
- *Soft start procedure* – If marine mammals have not been sighted within or are likely to enter the shut-down zone during the pre-start procedure, the soft start procedure may commence in which the piling impact energy is gradually increased over a 10-minute period. The soft start procedure shall also be used after long breaks of more than 30 minutes in piling activity. Visual observations of marine mammals within the safety zones shall be maintained by the MFO throughout soft starts. The soft start procedure is an added precaution and may alert marine fauna to the presence of the piling rig and enable animals to move away to distances where injury is unlikely.
- *Normal operation procedure* – If marine mammals have not been sighted within or are not likely to enter the shut-down or observation zone during the soft start procedure, piling may start at full impact energy. The MFO shall continuously undertake visual observations during piling activities. After long breaks in piling activity or when visual observations ceased or were hampered by poor visibility, the pre-start procedure shall be re-initiated. Piling activities at night-time or during low visibility operations may proceed, provided that there were no target marine mammal sightings during the preceding 24 hour period.
- St*and-by operations procedure* – If a marine mammal is sighted within the observation zone during the soft start or normal operation procedures, the operator of the piling rig shall be placed on stand-by to shut-down the piling rig (should the mammal enter the shut-down zone). The MFO shall continuously monitor the marine mammal in sight.
- *Shut-down procedure* – If a marine mammal is sighted within or about to enter the shut-down zone, the piling activity shall be stopped immediately. If a shut-down procedure occurred and marine mammals have been observed to move outside the shut-down zone, or 30 minutes have lapsed since the last marine mammal sighting, then piling activities shall recommence using the soft start procedure. If marine mammals are detected in the shut-down zone during poor visibility, operations shall stop until visibility improves. A flow chart illustrating the standard operation procedures is included in Appendix A.

4.3.3 Standard Operational Procedures for Dredging

Standard operational procedures that must be undertaken by contractors during dredging activities, include pre-start, normal operation and shut-down procedures.

- *Pre-start procedure* – Where identified by the risk assessment process under these Guidelines, the presence of marine mammals shall be visually monitored by a person suitably experienced in identifying marine fauna (i.e. MFO Level 2) for a period of 30 minutes before the commencement of dredging activities. Particular focus shall be put on the shut-down zone but the observation zone shall be inspected as well, for the full extent where visibility allows. Observations shall be made from the dredge or from a higher vantage point, ideally >6 m above sea level, if possible.
- *Normal operation procedure* – If marine mammals have not been sighted within or are not likely to enter the shut down or observation zone during the pre-start procedure, dredging may commence. The MFO shall regularly undertake visual observations during dredging activities where relevant. After long breaks in dredging activity, the pre-start procedure shall again be used. Night-time or low visibility operations may proceed provided that a shut-down event has not occurred during the preceding 24 hour period.
- *Shut-down procedure* – If a marine mammal is sighted within the shutdown zone, observation shall continue to determine if the animal moves away from the dredge activities in a timely manner i.e. up to 30 minutes. If marine mammals have been observed to move outside the shut-down zone, or 30 minutes have lapsed since the last marine mammal sighting, then dredging activities shall recommence. If marine mammals are detected in the shut-down zone during poor visibility, operations shall stop until visibility improves.

4.3.4 Compliance and Sighting Report

The contractor conducting the piling or dredging activities shall maintain a record of procedures employed during operations. Information on any marine mammals sighted during the activities, and their reaction to the activity, may be used in the planning and assessment of future projects. It is also encouraged to get in contact with local researchers to access site specific information on marine fauna presence, distribution, abundance, and to contribute sightings data from the MFO to established national government databases.

A report on the activity shall at a minimum contain the location, date, start and completion time of the noise generating activity, information on the piling rig (hammer weight and drop height, pile size, number of piles, number of impacts per pile, etc.), information on the dredge and operating parameters, details on the trained crew members conducting the visual observations, times when observations were hampered by poor visibility or high winds, times when start-up delays or shut-down procedures occurred, and the time and distance of any marine mammal sightings.

4.4 Additional Mitigation and Management Measures

If the proposed activities are deemed by the risk assessment to potentially have a significant impact on any MNES under the EPBC Act, additional mitigation measures shall be considered to further minimise the likelihood for impacts to occur. Note that term ‘potentially’ in this context means if the impact occurrence is either ‘unlikely’ or ‘likely’. Furthermore, if there is scientific uncertainty about the impacts of the activities and the potential impacts are serious or irreversible, the precautionary principle is applicable and additional measures must also be considered.

It may not be necessary, practical, or possible to apply the additional mitigation and/or management measures outlined below. In planning an activity, the contractor undertaking the works shall consider which of the measures best apply to their circumstances. Details of the measures to be applied shall be provided to the Department by the contractor.

In considering additional measures, there may be a trade-off between the noise reduction that can be achieved and the additional construction time that results from the mitigation measures. This needs to be considered when assessing the overall benefit of any additional measures.

4.4.1 Additional Management Measures

Additional management measures that need to be considered include some, or all of the following:

- *Increased safety zones* – For biologically important habitats, such as breeding, resting or feeding areas, the safety zone (i.e. shut-down or exclusion zone) shall be increased to minimise behavioural disturbance impacts to mammals as much as possible. Such a measure may not be needed for all marine mammal species or for the entire construction period. As an example, it should be used for piling activities undertaken adjacent known whale breeding and calving sites during whale migration season. The size of increased safety zones shall be established on a precautionary basis. Noise propagation modelling and relevant scientific evidence shall be used to determine and justify an appropriate size of the safety zone. In these cases, an assessment of the behavioural disturbance risk may also inform the sizing of safety zones in context with the cumulative sound exposure criteria for physical injury.
- *Marine Fauna Observer* – The contractor conducting the piling shall engage a suitably qualified marine fauna observer (i.e. MFO Level 1) when migratory, vulnerable or endangered marine mammals are likely to be present within the area surrounding the piling activity. They shall be experienced in marine mammal identification including behaviour, as well as distance estimation, assist other supporting MFO's and provide advice should marine mammals enter the safety zone. Dredging operators shall also engage an MFO Level 1 when identified by the risk assessment process, to conduct visual observations and keep records in accordance with the requirements of these Guidelines.
- *Noise model validation* – Where works are identified as having an increased likelihood for a significant impact, in the absence of any control measures being adopted, the noise model predictions shall be validated by a suitable in-field monitoring programme. Refer to Section 5.2 for further information on measurement methodology.
- *Adaptive management plan* – Where works are identified as having an increased likelihood for a significant impact, the underwater noise management approach for the project shall incorporate an adaptive management plan to enable a mechanism for adjustment of the mitigation or management measures (e.g. size of safety zones) in response to feedback from the in-field noise model validation process and MFO visual observations. The adaptive management plan shall be developed in consultation with relevant marine specialists.
- *Operations during poor visibility* – For piling activities, the soft start procedure shall not be initiated until conditions allow visual inspection of the safety zones.
- *Spotter vessel* – If clear observations cannot be made, visual observations for the presence of marine fauna by an MFO within the safety zones may be improved by employing a spotter vessel or similar. The spotter vessel shall maintain continuous contact with the piling operator. An MFO shall be on board the vessel.

> Note that vessel operators must not approach closer than 100m to any whale or 50m to any dolphin. Furthermore, the caution zone for vessels is the area within 300m of a whale and 150m of a dolphin. No more than three vessels are allowed within the caution zone at any one time and vessels should operate at no wake speeds within this zone.

4.4.2 Additional Mitigation Measures

Additional mitigation measures that need to be considered include some, or all of the following:

- *Pile type selection* – Use of alternative piles that produce less noise shall be considered where practical.
- *Bubble curtain* – A bubble curtain is a sheet of air bubbles that are produced around the location where piling activity occurs. The bubbles are created by forcing air through small holes drilled in metal or PVC rings using air compressors, with either one ring deployed on the sea bottom or several vertically stacked rings forming a bubble 'tree'. The bubbles in the bubble curtain create an acoustic impedance mismatch between the water and air trapped in the bubble, which results in sound attenuation across the bubble curtain. Reported noise reductions range from 3 to 20 dB. The use of bubble curtains may be limited by the water depth and practical or cost reasons, but may be considered where there is increased risk of significant impacts occurring. Under these Guidelines, the maximum applicable attenuation is 10 dB, with 5 dB considered a default level for shallow water environments. Higher levels of attenuation must be justified and approved by the Department prior to adoption in any noise modelling.

- *Press-in piling* – Press-in piling machines use static forces to install piles such that impacts are not required. Underwater noise levels have not been reported but are expected to be significantly less than those produced by conventional piling methods as all impulsive type of noise associated with the impact are removed. The technology has been used on land and in shallow waters when low noise construction methods were required. The current technology allows for installation of piles with diameters of up to 1.5 metres, with larger piles being replaced by multiple smaller piles.
- *Suction piling* – Suction piling uses tubular piles that are driven into the seabed, or dropped a few metres into a soft seabed, after which air and water are sucked out the top of the tubular pile thereby sinking the pile into the ground. Suction piles are often used to secure offshore floating platforms, in both shallow and deep waters. Although noise levels have not been reported, they are expected to be low as the only source of noise is the pump.
- *Cofferdam* – A cofferdam is created by placing a solid casing around a pile and removing the water from within the casing. This approach has the potential to result in significant noise reductions as noise from the pile is radiated into the cofferdam rather than the water. The solid casing can be constructed from a single hollow pile or by interlocking sheet piles. The construction of cofferdams often requires piling of the solid casing to achieve a watertight seal at the sea bottom, which should be of a significantly lower noise level and duration than the piling activity the cofferdam is put in place for. The use of cofferdams may be limited by the water depth and practical or cost reasons, but may be considered where there is increased risk of significant impacts occurring.

Note when considering the level of attenuation of mitigation measures:

- Generally, the more pile surface area that is exposed underwater, the more underwater sound will radiate in the marine environment.
- Bubble curtains typically work well within deeper water (given the greater pile surface area in the water column), however care should be taken in the design of the bubble curtain to withstand tidal currents. Piling during periods of ‘slack tide’ (i.e. short period at the turn of the tide) or adopting a confined bubble curtain could be considered.
- Shallower water (e.g. less than 1 m) does not propagate underwater sound as effectively as deeper water. However, the sound level may still be high because of refraction, that is, propagation of sound from the pile through the substrate and radiated into the water column.

5 Underwater Noise Modelling and Measurement

5.1 Underwater Noise Propagation Modelling

The DIT *Marine Fauna Noise Threshold Calculator* was developed to inform standard safety zones for marine mammals and potential effects zones for fishes and marine turtles where risk assessment identifies that the proposed works will not have, or are unlikely to have, a significant impact on MNES. The DIT *Marine Fauna Noise Threshold Calculator* noise propagation approach for impact piling is based on Lippert et al. (2018), which adopts a damped cylindrical spreading (DCS) noise propagation model. This same process can be adopted for site and project specific scenarios as well by an underwater acoustics specialist.

The DCS modelling assumptions are conservative, and include:

- Worst case grazing angle (mach cone angle) of 17 degrees
- Horizontal decay rate based on the plane wave reflection coefficient of sand.

The approach for vibratory and DTH piling adopt a conservative $10\log_{10}(R1) + 15\log_{10}(R2)$ approach, where R1=Range<100m and R2=Range >100m.

The approach for dredging noise propagation is based on a $15\log_{10}(R)$ approach, where R=Range.

To calculate the $SEL_{24\ hours}$ for impact piling, the number of pile blows needs to be considered and calculated using the following equation.

$$\boldsymbol{SEL\ (24\ hours) = SEL\ single\ strike + 10\log\ (\text{total number of strikes in 24 hours})}$$

To calculate the $SEL_{24\ hours}$ for vibratory and DTH piling, as well as dredging, the number of noise generating minutes over 24 hours needs to be considered and calculated using the following equation.

$$\boldsymbol{SEL\ (24\ hours) = SEL + 10\log\ (\text{total number of noise generating minutes over 24 hours} \times 60)}$$

Where required, noise modelling undertaken by an underwater acoustics specialist must factor in the effects of the bathymetry profile, geological composition of the seabed and the sound speed profile of the water column as a minimum.

Source levels used for modelling purposes (if not from these Guidelines) must be derived from peer reviewed scientific literature or previous reports prepared by underwater acoustics specialists relevant to the source being modelled.

Care is to be taken in the selection of source reference levels and the propagation model to be utilised. All details and assumptions of the modelling process must be reported in project documentation.

Validation of the noise model, and any adopted attenuation measures, shall be undertaken through measurement (refer Section 5.2 for more information) of relevant activities at project commencement.

For further information on noise modelling and assessment in general, NOPSEMA have developed an information paper to provide advice to improve the quality of environmental impact assessments for marine seismic surveys to ensure common deficiencies are avoided. This information, when reviewed in context with these Guidelines, provides useful additional advice for practitioners undertaking specialist modelling and environmental impact assessment where relevant.

https://www.nopsema.gov.au/assets/Information-papers/A625748.pdf

5.2 Underwater Noise Measurement

For all projects, particularly where the risk assessment process triggers an EPBC referral, the ambient underwater noise environment shall either be estimated or measured. Where there is the potential for cumulative noise impacts to marine fauna from other anthropogenic noise sources, noise measurement is the preferred approach.

Measurement of underwater noise is complex and must be undertaken in a standard manner that will allow comparison with other published scientific literature. Measurement of underwater noise may be undertaken for the monitoring of ambient noise, validation of noise modelling and/or to assist with adaptive management plans.

Measurement of impact piling shall be undertaken in accordance with ISO 18406 *Underwater acoustics – Measurement of radiated underwater sound from percussive pile driving* (2017).

Whilst ISO 18406 is not directly applicable for the monitoring of vibratory, DTH pile driving or dredging activities, the standard is nevertheless a useful reference when considered in context. Furthermore, the *Good Practice Guide for Underwater Noise Measurement* (2014) is a useful reference to assist the planning of underwater noise measurements.

Measurement of ambient noise, where required, shall be undertaken for a duration considered representative by the acoustic specialist to adequately describe the environment inclusive of natural biological and anthropogenic sounds. All proposed monitoring and associated locations must be agreed with the Department.

6 Reporting and Deliverables

Unless specified otherwise in Contract Documentation the following reporting applies to each phase of the project. The Department's Project Manager will engage with the Technical Services, Environment and Sustainability section to assist with the review where necessary. An Independent Design Certifier (IDC) may also be required to review and accept the deliverables.

6.1 Proving Phase

During the Proving Phase (planning/concept development) of a project, information may be required for input into planning study documentation (or similar), the Preliminary Environment and Heritage Impact Assessment Report (EHIAR) and to inform the cost estimation or program of the project.

6.2 Pre-delivery/Delivery Phase

During the Pre-delivery/Delivery phase of the project or once a preferred (or reference) design and construction method has been selected, the following documentation will be required.

The outcomes of this underwater noise assessment steps identified in the sections above shall be included in the project's Detailed Environment and Heritage Impact Assessment (EHIA) Report.

Risk Assessment A risk assessment addressing the criteria in the *Significant Impact Guidelines 1.1 - Matters of National Environmental Significance*. In addition, other relevant documents including the Commonwealth Marine Parks Network Management Plans, Commonwealth Marine Bioregional Plans, South Australian Marine Park Management Plans, and Adelaide Dolphin Sanctuary Management Plan shall be assessed. The Commonwealth Conservation Values Atlas can also be referred for specific information on the location and area of important marine habitats, ecological features, known breeding and feeding areas for protected species and other conservation values in the marine regions. A summary of this risk assessment shall be provided in the EHIA Report.

AND

Underwater Noise Management Framework (UNMF) Framework addressing the requirements of the Guidelines and other relevant legislation as required. The framework shall outline the relevant environmental performance outcomes, standards (e.g. ISO 18406), measurement criteria for monitoring and reporting as well as the adaptive management approach where relevant. The UNMF is typically required where project planning / pre-delivery works have been undertaken separately for issue to a design/construct or construct only contractor, who then prepare an *Underwater Noise Management Plan* (UNMP) in response to the UNMF requirements. Depending on the project delivery method, it may be preferable to prepare the UNMP instead of the UNMF.

AND/OR

Underwater Noise Management Plan (UNMP) Management Plan that forms part of a project's *Contractor's Environmental Management Plan* (CEMP) identifying methods for addressing the requirements or recommendations of the Underwater Noise Management Framework, as well as applicable approvals, and managing potential impacts to marine fauna in biologically important habitats or during critical behaviours. The *Underwater Noise Management Plan* may also be integrated into an overall *Construction Noise and Vibration Management Plan* (CNVMP) where relevant.

AND, WHERE REQUIRED

Approvals/Permits Commonwealth and State legislation applications, permits, referrals, approvals as required.

PART B

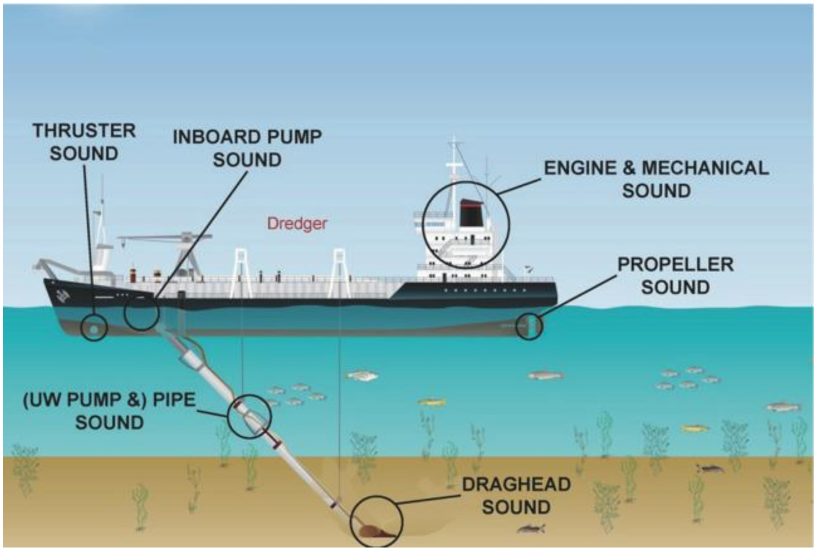
Additional Information

7 Noise Sources and Modelling

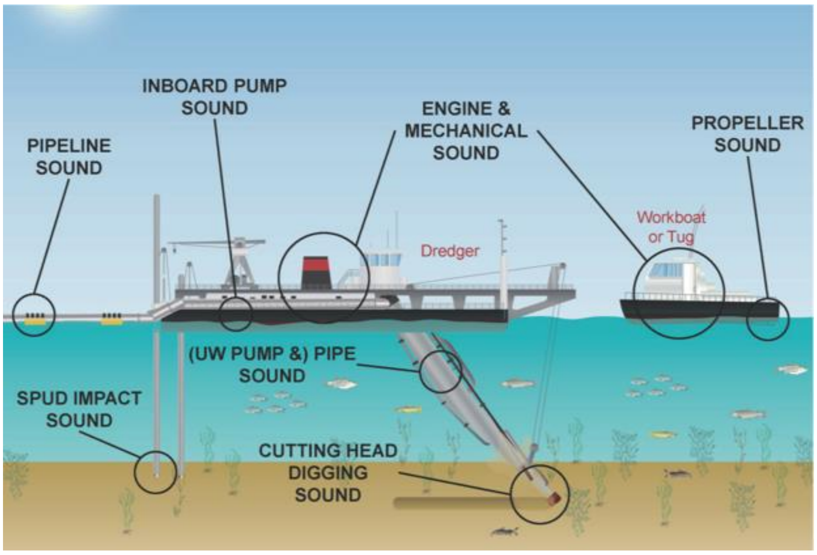
7.1 Noise Source Characteristics

An overview of the characteristics of the noise sources considered under these Guidelines are provided below:

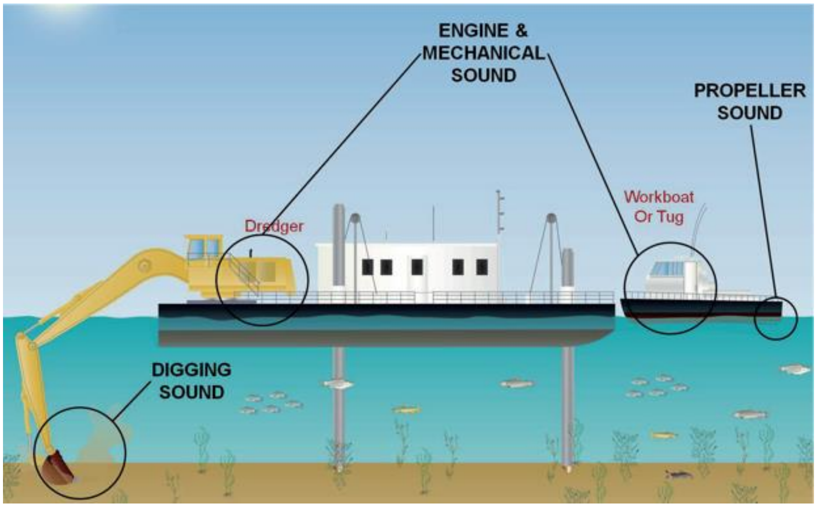
- *Impact piling* – Impulsive in character with multiple pulses occurring at blow rates in the order of 30 to 60 impacts per minute. Typical source levels range from SEL 170–225 dB re 1 µPa^2·m^2 s for a single pulse, and peak level 190–245 dB re 1 µPa m. Most of the sound energy usually occurs at lower frequencies between 100 Hz and 1 kHz. Factors that influence the source level include the size, shape, length and material of the pile, the weight and drop height of the hammer, and the seabed material and depth.
- *Vibro-driving* – Continuous in character and usually of a much lower level than impact piling. Typical source levels range from SPL 160–200 dB re 1 µPa, with most of the sound energy occurring between 100 Hz and 2 kHz. Strong tones at the driving frequency and associated harmonics may occur with the driving frequency typically ranging between 10 and 60 Hz. Sound propagation at such low frequencies is often poor in shallow water environments, such that the tones may not be noticeable at greater distances from the source.
- *Down-the-hole (DTH) piling* – This piling method uses a combination of percussive and drilling mechanisms. During pile installation, a percussive hammer acts directly upon the bedrock to create a hole for the pile to enter, while the drill cuttings and debris are removed by an airlift exhaust through the inside of the pile. The sound therefore contains both impulsive, intermittent components (i.e. from percussive hammer strikes) and non-impulsive, continuous components (from drilling actions and airlifts of debris) with the hammer acting directly on the sediment to advance the pile (Guan et al. 2020). Most of the sound energy is likely to occur between 100 Hz and 2.5 kHz. Under the Guidelines, the overall character is assessed as continuous.
- *Dredging* – Relevant categories of dredge types include backhoe dredges (BHD), hydraulic cutterhead suction dredges (CSD), and trailing suction hopper dredges (TSHD). CSDs use a rotating cutterhead that swings laterally across an arc in front of the dredge. TSHD dredges are self-propelled vessels that hydraulically remove sediment from the seafloor through dragheads. For CSD and TSHD operations, the major processes contributing to underwater sound include sound from dredged material collection originating from the rotating cutterhead in contact with the seabed and intake of the sediment-water slurry, sounds generated by pumps and impellers driving the suction of material through the pipes, transport sounds involving the movement of sediment through the pipes, and ship and machinery sounds. The sound produced by a BHD is repetitive rather than continuous and typically generate less underwater noise than CSD or TSHD dredging operations. Generally, there is a lack of information related to biological responses to dredging sounds which are thought to be limited to nonlethal effects such as temporary impaired hearing (i.e. TTS), masking, and behavioural responses (McQueen et al. 2020). Figure 7-1 indicates the typical sound sources associated with each relevant dredger type.



Trailing suction hopper dredger (TSHD)



Cutter suction dredger (CSD)



Backhoe dredge (BHD)

Figure 7-1 Sound sources for relevant dredge types (Source: CEDA 2011)

7.2 Underwater Noise Propagation Modelling

An underwater noise model can predict the sound propagation loss (PL) between the source and a receiver. The source level (SL) of the considered noise source and the predicted PL in a particular direction is used to predict the sound pressure level (SPL) at the receiver location as SPL = SL – PL.

Factors that determine the propagation loss are discussed below.

- *Spherical spreading* – Along the direct path between the source and the receiver, spherical spreading of the sound energy causes the noise level to drop off at $20\log_{10}(R)$ with R the distance from the source.
- *Reflection, absorption, scattering and refraction* – The transmission path is often not only the direct path between the source and receiver. Multiple transmission paths can occur due to reflections from the surface and seafloor. A rough surface or seafloor causes scattering of the source noise, and some of the noise impacting on the seafloor is absorbed. Temperature variations in the water column cause refraction of sound. These transmission loss mechanisms are generally frequency dependent and depend on the seafloor geo-acoustic properties and the surface and seafloor roughness.
- *Substrate-borne sound* – When impact pile driving is the sound source, there is the potential for substrate-borne sound caused when the hammer strikes the pile to be re-radiated back into the water. This can significantly complicate the prediction of sound to any point within the water column and potential degrade the effect of a bubble curtain or coffer dam in shallow water (Refer Figure 7-2).
- *Total transmission loss* – The combination of the various transmission loss mechanisms gives a total transmission loss that may be smaller than due to spherical spreading alone, especially in shallow water environments. For example, this occurs when surface and seafloor reflected sound waves interfere at the receiver location such that the noise level is increased, i.e. the transmission loss is reduced.

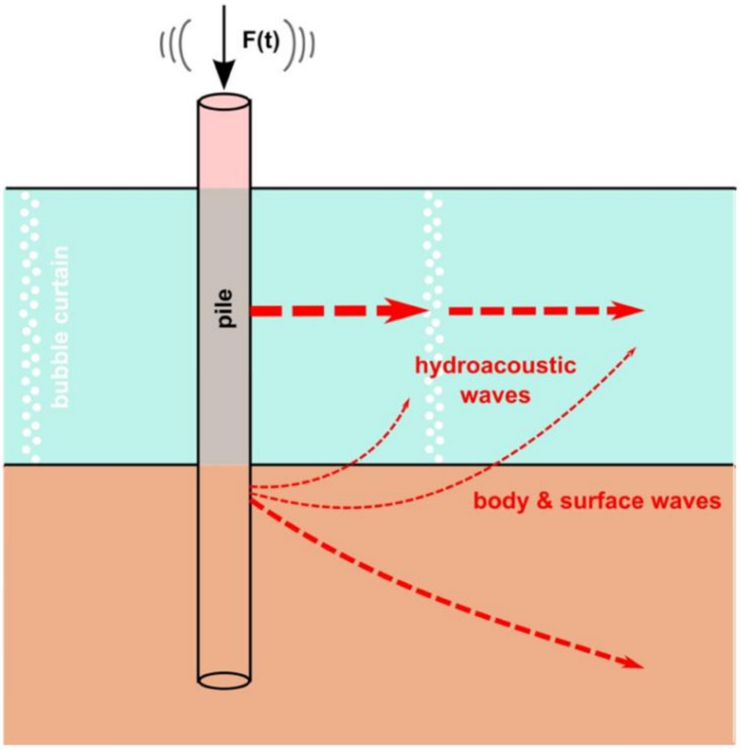


Figure 7-2 Mechanisms for sound propagation during impact piling (Source: Lippert, Berlin 2018)

Given the complexities described above, empirical data rather than mathematical models are generally used to predict the propagation of sound in shallow water environments.

8 Underwater Noise Environments

8.1 Ambient Noise

The level and frequency characteristics of the ambient noise environment are two factors that control how far away a given noise source can be detected.

In general, noise is only detectable if it is of a higher level than the ambient noise environment at similar frequencies. A lower ambient noise environment results in noise propagating out to greater ranges before diminishing below the background noise level. The potential zone in which noise emissions from pile driving or dredging activities are detectable thus depends on the levels and types of ambient noise in the marine waters surrounding the site.

The main sources of ambient noise in the ocean are man-made sources including shipping and sonar activity, and environmental sources including wind-dependent noise and biological noise from a variety of sources such as snapping shrimp. Other environmental sources include surf noise typically localised near the coast, precipitation noise from rain and hail, seismic noise from volcanic and tectonic activity, and thermal noise.

Figure 8-1 provides an example of a marine traffic density map, which can provide insight to the level of shipping movements within a region and potential shipping traffic noise.

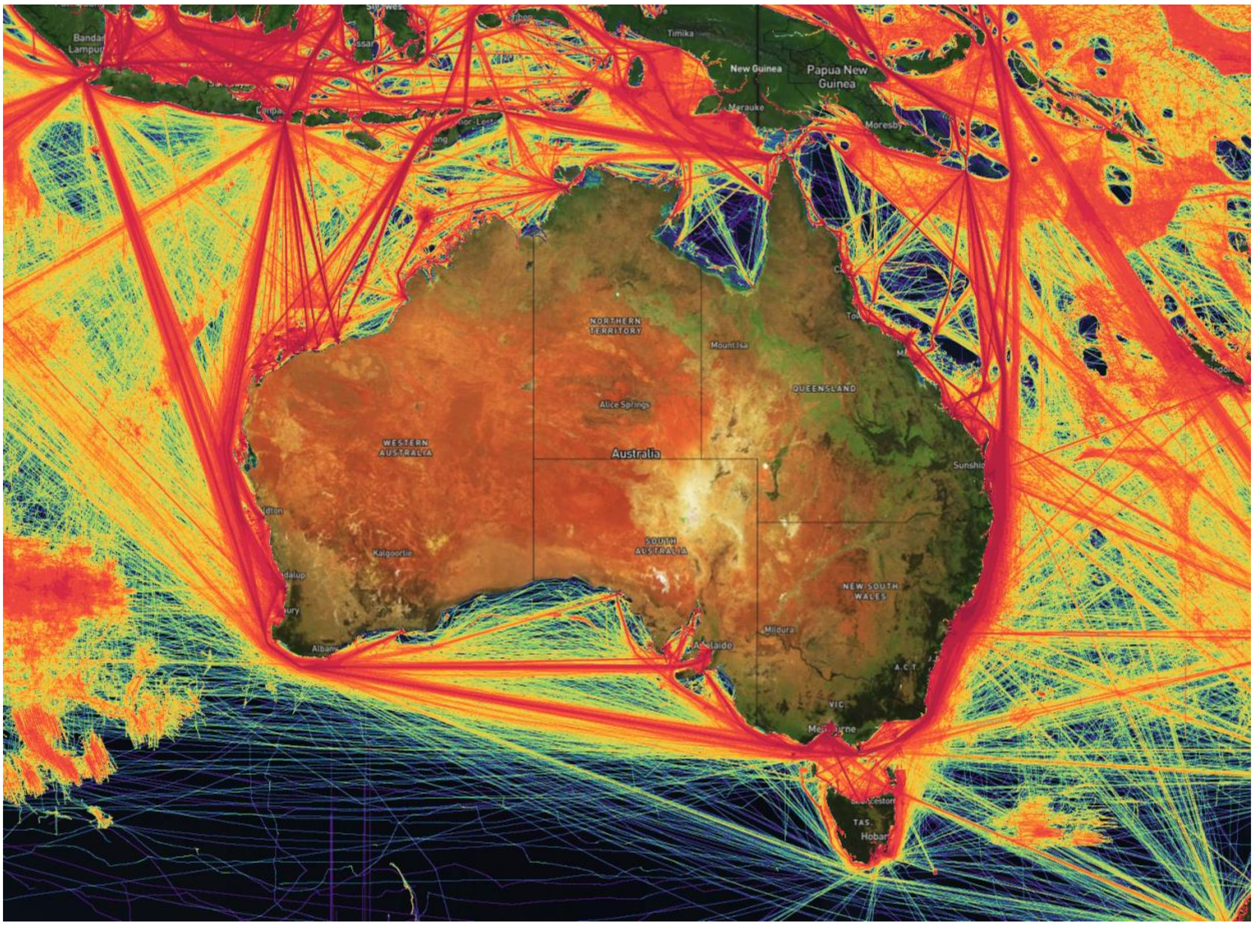


Figure 8-1 Marine traffic density (Source: www.marinetraffic.com, 2022 Density Map)

The biological contribution to ambient noise is most significant when large numbers of animals are calling and, at times, there are so many calls that they merge into a continuous noise. These are usually referred to as choruses (Cato 2008). Figure 8-2 provides a summary of example choruses measured in the Australian region, in context with shipping traffic noise and wind dependent noise.

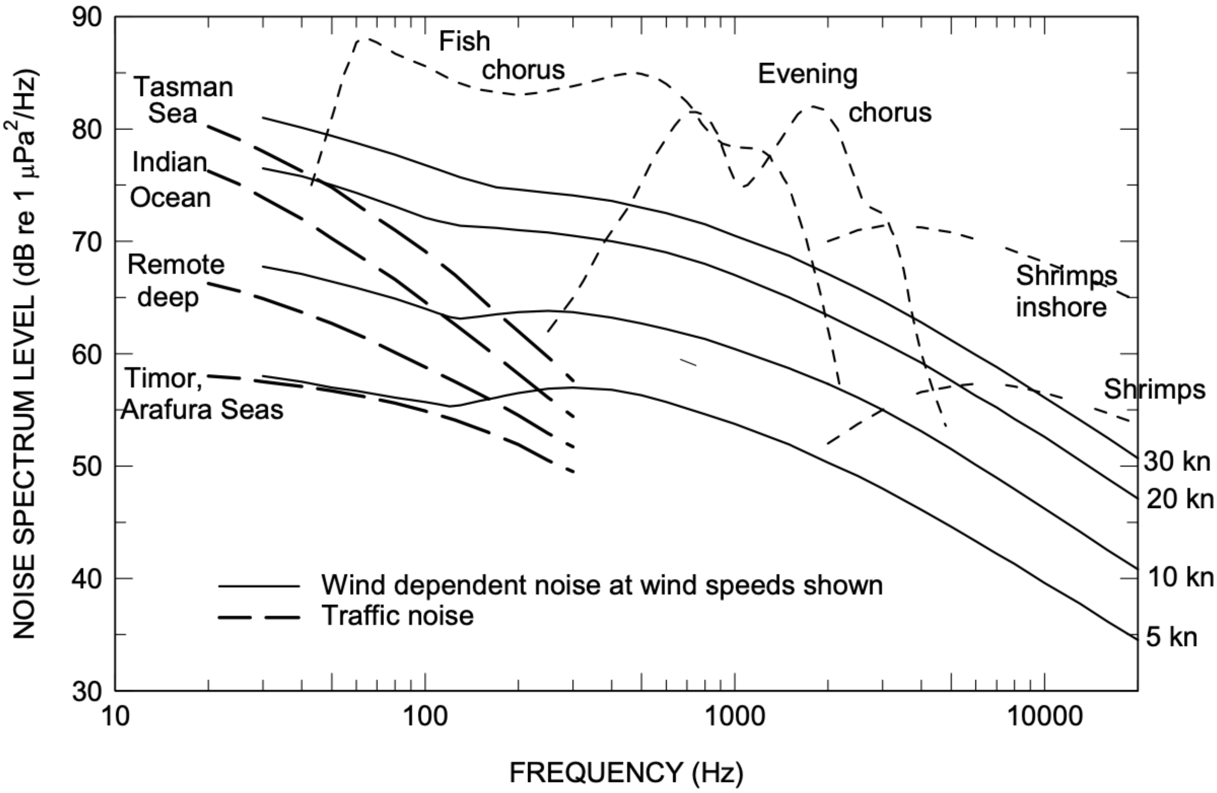


Figure 8-2 Summary of ambient noise spectra for the Australian region showing a wide range of traffic noise levels and biological choruses (Source: Cato 2008)

9 Noise Sensitive Receptor Groups

9.1 Overview of Noise Effects

The following provides a brief overview of the effects that may occur because of an animal being exposed to underwater noise. Consideration of this information, together with information on the biological importance of the environment that may be affected as a habitat for the considered species, e.g. breeding, calving or resting areas, or confined migratory routes or feeding areas, is used to assess the likely impact of a noise source.

- *Risk of fatality* – When exposed to significant noise levels, either immediate mortality or tissue and/or physiological damage can result. The injury may be sufficiently severe that death occurs sometime later due to decreased fitness. Mortality can also have a direct effect upon animal populations, especially if it affects individuals close to maturity. Tissue and other physical damage or physiological effects, that are recoverable, but which may place animals at lower levels of fitness, may render them more open to predation, impaired feeding and growth, or lack of breeding success, until recovery takes place.
- *Hearing injury* – Short or long term changes in hearing sensitivity (TTS or PTS) may, or may not, reduce fitness and survival. Impairment of hearing may affect the ability of animals to capture prey and avoid predators, as well as cause deterioration in communication between individuals. This may affect growth, survival, and reproductive success.
- *Masking* – The presence of man-made sounds may make it difficult to detect biologically significant sounds against the noise background. Masking of sounds from predators may result in reduced survival. Masking of sounds used for orientation and navigation may affect the ability to find preferred habitats and in the case of fish, spawning areas, affecting recruitment, growth, survival, and reproduction.
- *Behavioural responses* – Behavioural responses may cause displacement from preferred habitats, which could affect feeding, growth, predation, survival, and reproductive success (if a mammal is displaced from preferred habitat).

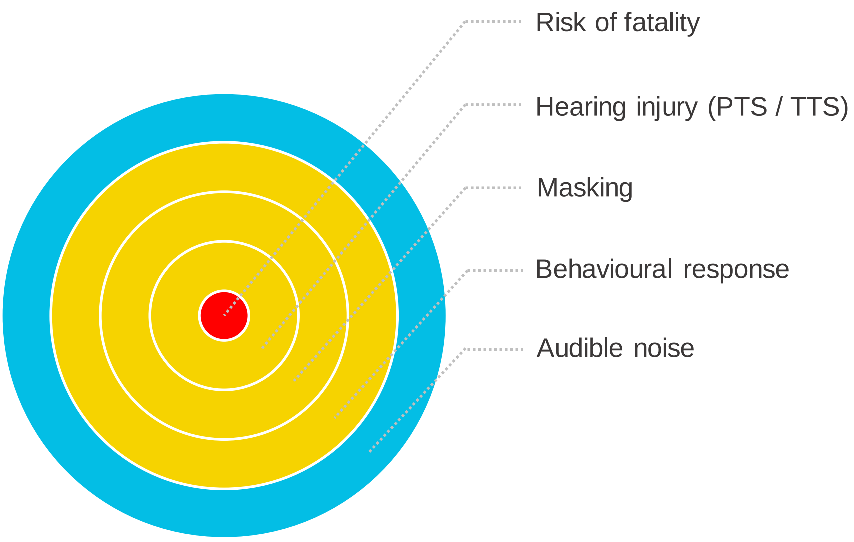


Figure 9-1 Overview of potential noise effects upon marine fauna

While Figure 9-1 acknowledges that the severity of noise effects relates to distance from the noise source, however, note that the 'zones' of hearing injury, masking and behavioural response may overlap. Overlap, results, from comparing cumulative sound exposure threshold metrics with single event peak or behavioural sound level metrics.

It is important that the above potential noise effects are considered in context as part of a holistic risk assessment undertaken by the project with input by suitable marine specialists.

9.2 Marine Mammals

Marine mammals live in an environment in which vision is not the primary sense because light does not penetrate far beneath the surface of the ocean. As such, marine mammals have become reliant upon sound, instead of light, as their primary sense for communication and being aware of their surrounding environment. Marine mammal communication has a variety of functions such as intra-sexual selection, mother/calf cohesion, group cohesion, individual recognition and danger avoidance.

- Baleen whales form one of the two suborders of cetaceans, and include all of the great whales such as the Southern Right and Humpback Whales. These species produce sounds that are primarily at frequencies below 1 kHz, and have durations from approximately 0.5 to over 1 second and sometimes much longer. Humpback whales and some other species produce sounds with frequencies above 1 kHz. Many baleen whale sounds are uncomplicated tonal moans or sounds described as knocks, pulses, ratchets, thumps, and trumpet-like. Blue whales for example produce low frequency moans in the frequency range of 10–15 Hz.
- Toothed whales form the other of the two suborders of cetaceans, and include all dolphins, porpoises, beaked whales, sperm whales, and killer whales. These species communicate underwater with whistles at frequencies below 20 kHz with most energy typically occurring around 10 kHz. The killer whale produces whistles with energy between 1–6 kHz and most of its sounds are pulsed. Sperm whales and some porpoises (phocoenid) produce clicks that are sometimes used for communication. Toothed whales also use echolocation sounds to determine the physical features of their surroundings. The echolocation sounds are pulses with most energy generally occurring at high frequencies between 30–130 kHz or higher. Killer whale echolocation clicks, however, have most energy at 22–80 kHz.
- Pinnipeds include all seals and sea lions, and produce underwater vocalisations sounding like bark and clicks with frequencies ranging from below 1–4 kHz. Pinnipeds are especially vocal during the breeding season.

In summary, baleen whales produce sounds that are dominant at frequencies that overlap with man-made industrial noise, such as piling or dredging. In contrast, the social sounds produced by toothed whales occur above the low-frequency range where most man-made sounds have their dominant energy.

9.2.1 Marine Mammal Hearing Sensitivity

The hearing sensitivity of marine mammals varies with frequency. Audiograms are used to represent an animal's sensitivity to sounds of different frequencies. An audiogram of a species relates the absolute threshold of hearing (in dB re 1 µPa) of that species to frequency. An animal is most sensitive to sounds at frequencies where its absolute threshold of hearing is lowest. As an example, humans are most sensitive to sounds between 2–4 kHz where the absolute threshold is lowest.

- *Toothed whales* – Hearing is most sensitive at frequencies ranging from 8–90 kHz. The upper limits of auditory sensitivity are believed to range from 100 kHz in the killer whale to over 150 kHz and sensitivity is typically poor below 1 kHz. The hearing of the beluga whale and bottlenose dolphin extends at least as low as 75 Hz but their sensitivity at these low frequencies seems quite poor.
- *Baleen whales* – There are no underwater audiograms available for baleen whales, and there is a little data available on their hearing sensitivity. Baleen whale vocalisations are low in frequency content for a number of species, and the frequency range of acute hearing presumably includes the frequency range of vocalisations. From behavioural observations, it is apparent that baleen whales are quite sensitive to frequencies below 1 kHz, but can hear sounds up to a considerably higher but unknown frequency.
- *Pinnipeds* – In comparison to toothed whales, pinnipeds tend to have lower frequencies of maximum hearing sensitivity, poorer sensitivity at frequencies of maximum hearing sensitivity, and lower high-frequency hearing cut-offs. However, some species may have better sensitivity at frequencies below 1 kHz than toothed whales.

9.3 Fishes and Marine Turtles

9.3.1 Fishes Hearing Sensitivity

All fishes have ears to detect sound and convey sensitivity to gravity and to linear and angular acceleration (Popper et al. 2014). The adaptations that provide fish with additional sensitivity to sound pressure are gas-filled structures near the ear and/or extensions of the swim bladder that functionally affect the ear. The enclosed gas changes volume in response to fluctuating sound pressure, generating particle motion. In fishes where the swim bladder is near the ear (or connected to it mechanically as in the Otophysi), the particle motion radiated from the bladder is sufficiently large to cause the sensory epithelium to move relative to the otolith. Fishes with these adaptations generally have lower sound pressure thresholds and wider frequency ranges of hearing than do the purely particle motion-sensitive species.

Conversely, fish species that lack a gas-filled cavity, including sharks, are not as vulnerable to trauma from extreme sound pressure changes as fish with a gas-filled space. This difference has been demonstrated by comparing the effects of pile driving sounds on fishes with and without a swim bladder (Halvorsen et al. 2012c).

Hearing abilities among sharks have demonstrated highest sensitivity to low frequency sound (40 Hz to approximately 800 Hz), which is sensed solely through the particle-motion component of an acoustical field. Free-ranging sharks are attracted to sounds possessing specific characteristics: irregularly pulsed, broad-band (most attractive frequencies: below 80 Hz), and transmitted without a sudden increase in intensity. Such sounds are reminiscent of those produced by struggling prey. A sound, even an attractive one, can also result in immediate withdrawal by sharks from a source, if its intensity suddenly increases 20 dB or more above a previous transmission (Myrberg 2001).

9.3.2 Marine Turtles Hearing Sensitivity

Data on hearing of marine turtles is very limited. Electrophysiological studies on hearing have been conducted on juvenile green sea turtles, juvenile Kemp’s Ridleys, and on juvenile loggerheads. Ridgway et al. (1969) obtained an audio evoked potential (AEP) audiogram to aerial and vibrational stimuli that extended from below 100 Hz to 2000 Hz with the lowest threshold at 400 Hz. Other studies using AEPs found similar low-frequency responses to vibrations delivered to the tympanum (the external ear on the surface of the head) for the loggerhead sea turtle, and to underwater sound stimuli for the loggerhead, Kemp’s Ridley, and green sea turtles.

Martin et al. (2012) measured underwater thresholds in the loggerhead sea turtle (Caretta caretta) by both behavioural and AEP methods. Behavioural sensitivity showed the lowest thresholds between 100 and 400 Hz, with thresholds at about 100 dB re 1 µPa. AEP measurements on the same individual were up to 8 dB higher; however, both techniques showed a similar frequency response and a high frequency loss of sensitivity above 400 Hz of about 37 dB per octave.

Appendix A – Piling Flow Chart

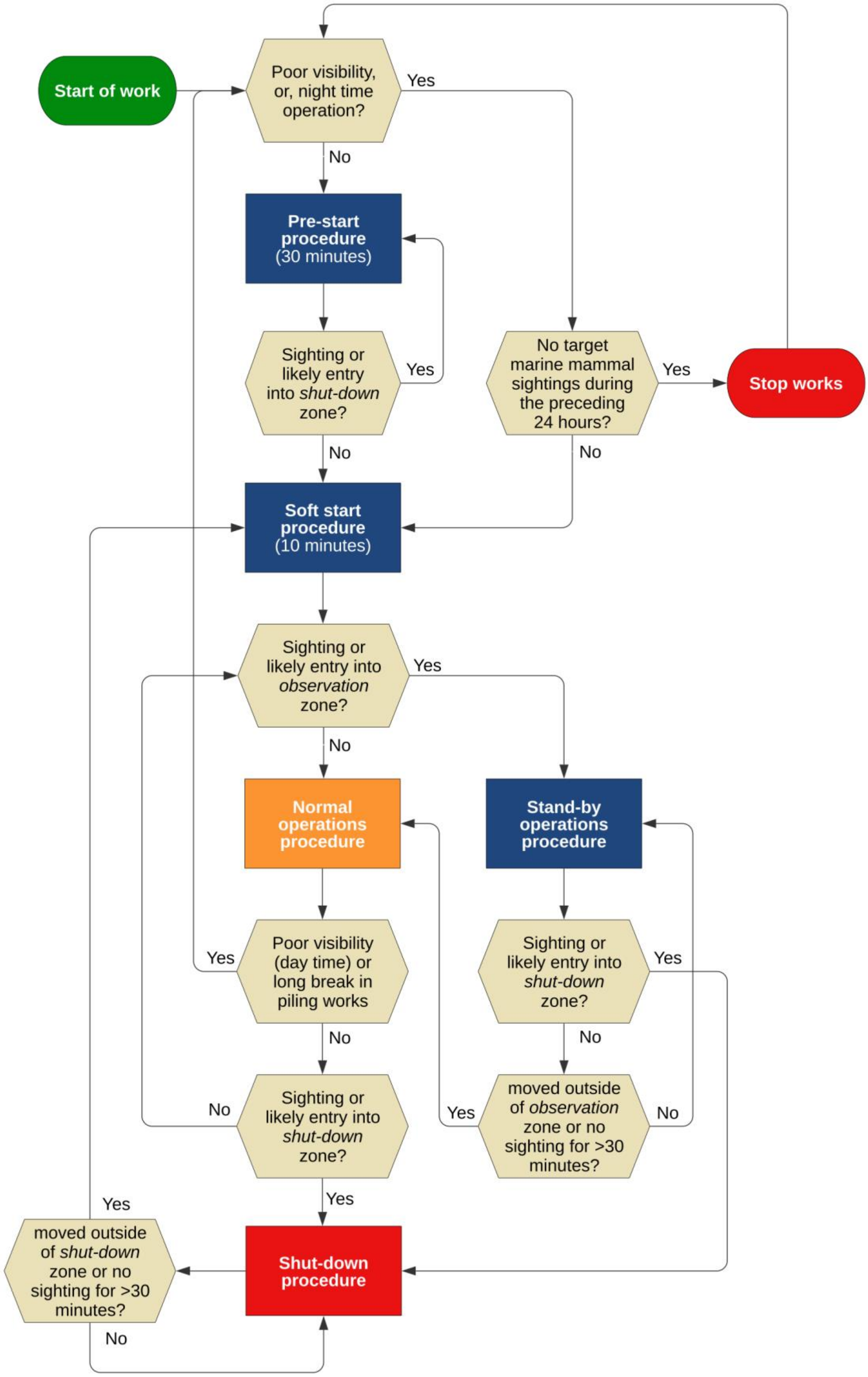


Figure A-1 – Flow chart for procedures to be undertaken by contractor during piling activities

Appendix B – References

Scientific Literature

The following scientific literature was referenced and/or considered in the development of these Guidelines.

Brandon L. Southall, James J. Finneran, Colleen Reichmuth, Paul E. Nachtigall, Darlene R. Ketten, Ann E. Bowles, William T. Ellison, Douglas P. Nowacek, and Peter L. Tyack (2019), “Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects”, Aquatic Mammals 2019, 45(2), 125-232, DOI 10.1578/AM.45.2.2019.125

Caltrans (California Department of Transportation) (2015), “Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish”. November 2015. Sacramento, California: California Department of Transportation.

Carroll A.G., Przeslawski R., Gunning M.-E., Bruce B., Duncan A.J. (2017), “A critical review of the potential impacts of marine seismic surveys on fish & invertebrates**”**, *Mar. Pollut. Bull.,* 114, pp. 9-24.

[CEDA] Central Dredging Association (2011). CEDA position paper: Underwater sound in relation to dredging. Terra et Aqua 125:23–28.

[CEDA] Central Dredging Association (2015). Integrating adaptive environmental management into dredging projects. Position paper. Delft (NL). 20 p. http://www.dredging.org

Denes, S.L., G.A. Warner, M.E. Austin, and A.O. MacGillivray (2016), *Hydroacoustic Pile Driving Noise Study ¨C Comprehensive Report*. Document Number 001285, Version 2.0. Technical report by JASCO Applied Sciences for Alaska Department of Transportation & Public Facilities. http://www.dot.alaska.gov/stwddes/research/assets/pdf/4000-135.pdf

Department of the Environment and Heritage (2005), “EPBC Act Policy Statement 2.1 – Interaction between offshore seismic exploration and whales”.

Department of the Environment and Water Resources (DEWR 2007), “Australian National Guidelines for Whale and Dolphin Watching*”,* p.16.

Deruiter, S.L., B.L. Southall, J. Calambokidis, W.M. Zimmer, D. Sadykova, E.A. Falcone, A.S. Friedlaender, J.E. Joseph, D. Moretti, et al. 2013. First direct measurements of behavioural responses by Cuvier's beaked whales to mid-frequency active sonar. *Biology Letters* 9(4): 1-5.

DeRuiter, Stacy L.; Langrock, Roland; Skirbutas, Tomas; Goldbogen, Jeremy A.; Calambokidis, John; Friedlaender, Ari S.; Southall, Brandon L. A multivariate mixed hidden Markov model for blue whale behaviour and responses to sound exposure. Ann. Appl. Stat. 11 (2017), no. 1, 362--392. doi:10.1214/16-AOAS1008. https://projecteuclid.org/euclid.aoas/1491616885

Douglas H. Cato (2008), “Ocean ambient noise: its measurement and its significance to marine animals”, Defence Science and Technology Organisation, and University of Sydney Institute of Marine Science, Sydney, NSW 2006 Australia.

Ellison, William & Southall, Brandon & Clark, Christopher & Frankel, Adam (2011), “A New Context-Based Approach to Assess Marine Mammal Behavioral Responses to Anthropogenic Sounds”. Conservation biology : the journal of the Society for Conservation Biology. 26. 21-8. 10.1111/j.1523-1739.2011.01803.x.

Ellison, W.T., R. Racca, C.W. Clark, B. Streever, A.S. Frankel, E. Fleishman, R. Angliss, J. Berger, D. Ketten, et al. 2016. Modeling the aggregated exposure and responses of bowhead whales *Balaena mysticetus* to multiple sources of anthropogenic underwater sound. *Endangered Species Research*. http://www.int- res.com/articles/esr2016/30/n030p095.pdf.

South Australian Environment Protection Authority (2020), Dredge Guideline.

Erbe C, Marley SA, Schoeman RP, Smith JN, Trigg LE and Embling CB (2019), “The Effects of Ship Noise on Marine Mammals—A Review.” Front. Mar. Sci. 6:606. doi: 10.3389/fmars.2019.00606

Finneran J.J., Schlundt C.E., Dear R., Carder D.A., and Ridway S.H. (2002). “Temporary shift in masked hearing thresholds in odontocetes after exposure to single underwater impulses from a geophysical watergun.”, *Journal of the Acoustical Society of America* 111(6):pp.2929-2940.

Finneran J.J., Carder D.A., Schlundt C.E., and Ridway S.H. (2005). “Temporary threshold shift in bottlenose dolphins (Tursiops truncates) exposed to mid-frequency tones.”, *Journal of the Acoustical Society of America* 118(4):pp.2696-2705.

Finneran J.J and Schlundt C.E. (2007). “Underwater sound pressure variation and bottlenose dolphin (*Tursiops truncates*) hearing thresholds in a small pool.”, *Journal of the Acoustical Society of America* 122(1):pp.606-614.

Finneran J.J., Houser D., Blasko D., Hicks C., Hudson J., Osborn M. (2008). “Estimating bottlenose dolphin (Tursiops truncatus) hearing thresholds from single and multiple simultaneous auditory evoked potentials”, *The Journal of the Acoustical Society of America.* 123. 542-51. 10.1121/1.2812595.

Finneran J.J., Mulsow J., Houser D., Burkard, R.F. (2016). “Place specificity of the click-evoked auditory brainstem response in the bottlenose dolphin (Tursiops truncatus).” *The Journal of the Acoustical Society of America*. 140. 2593-2602. 10.1121/1.4964274.

Friedlaender, A. S., Hazen, E. L., Goldbogen, J. A., Stimpert, A. K., Calambokidis, J., and Southall, B. L. (2016). "Prey-mediated behavioral responses of feeding blue whales in controlled sound exposure experiments," Ecol Appl 26, 1075-1085.

Good Practice Guide for Underwater Noise Measurement, National Measurement Office, Marine Scotland, The Crown Estate, Robinson, S.P., Lepper, P. A. and Hazelwood, R.A., NPL Good Practice Guide No. 133, ISSN: 1368-6550, 2014.

Gomez, C., J.W. Lawson, A.J. Wright, A.D. Buren, D. Tollit, and V. Lesage. (2016). A systematic review on the behavioural responses of wild marine mammals to noise: the disparity between science and policy. *Canadian Journal of Zoology* 94(12): 801-819. http://dx.doi.org/10.1139/cjz-2016-0098.

Goldbogen JA, Southall BL, DeRuiter SL, Calambokidis J, Friedlaender AS, Hazen EL, Falcone EA, Schorr GS, Douglas A, Moretti DJ, Kyburg C, McKenna MF, Tyack PL. Blue whales respond to simulated mid-frequency military sonar. Proc Biol Sci. 2013 Jul 3;280(1765):20130657. doi: 10.1098/rspb.2013.0657. PMID: 23825206; PMCID: PMC3712439.

Government of South Australia (2012). *Underwater Piling Noise Guidelines, Version 1*. Document Number 4785592. Department of Planning, Transport and Infrastructure (DPTI).

Guan, S.; Brookens, T.;Vignola, J. (2021). “Use of Underwater Acoustics in Marine Conservation and Policy: Previous Advances, Current Status, and Future Needs”. J. Mar. Sci. Eng. 2021, 9, 173. https://doi.org/10.3390/jmse9020173

Halvorsen MB, Zeddies DG, Ellison WT, Chicoine DR, PopperAN (2012c), Effects of mid-frequency active sonar on hearing in fish, *The Journal of the Acoustical Society of America 131, 599 (2012); https://doi.org/10.1121/1.3664082*

Hemilä S., Nummela S., Reuter T. (2001), “Modeling whale audiograms: Effects of bone mass on high-frequency hearing.” *Hearing research.* 151. 221-226. 10.1016/S0378-5955(00)00232-X.

Henrys, N. Newitt, L. Jurevicius, D. (2022), "Underwater Noise Measurements of a Cutter Suction Dredge in Shallow Water", Conference of the Acoustical Society of New Zealand, Wellington, 31 Oct-2 Nov 2022.

Illingworth & Rodkin Inc (2017), Pile-Driving Noise Measurements at Atlantic Fleet Naval Installations: 28 May 2013 – 28 April 2016.

ISO 18405:2017 Underwater acoustics — Terminology

ISO 18406:2017 Underwater acoustics — Measurement of radiated underwater sound from percussive pile driving

Jefferson T.A., Hung S.K., Würsig B. (2009). “Protecting small cetaceans from coastal development: impact assessment and mitigation experience in Hong Kong.” *Marine Policy* **33**:305–311.

Jones, Diane & Marten, Kerry & Harris, K. (2015). Underwater Sound from Dredging Activities: Establishing source levels and modelling the propagation of underwater sound.

Kastak D., Southall B.L., Schusterman R.J. and Kastak C.R. (2005). “Underwater temporary threshold shift in pinnipeds: Effects of noise level and duration.”, *Journal of the Acoustical Society of America* 118(5):pp.3154-3163.

Katherine F. Whyte, Debbie J. F. Russell, Carol E. Sparling, Bas Binnerts, and Gordon D. Hastie (2020), “Estimating the effects of pile driving sounds on seals: Pitfalls and possibilities”, The Journal of the Acoustical Society of America 147, 3948 (2020); doi: 10.1121/10.0001408

Klaus Lucke, S. Bruce Martin, and Roberto Racca, "Evaluating the predictive strength of underwater noise exposure criteria for marine mammals", The Journal of the Acoustical Society of America 147, 3985-3991 (2020) https://doi.org/10.1121/10.0001412.

Lucke, K., Lepper, P. A., Blanchet, M.-A., and Siebert, U. (2011). "The use of an air bubble curtain to reduce the received sound levels for harbor porpoises (*Phocoena phocoena)*," J. Acoust. Soc. Am. 130, pp.3406–3412; https://doi.org/10.1121/1.3626123.

Malme, C.I., P.R. Miles, C.W. Clark, P. Tyack, and J.E. Bird. (1983). "Investigations of the potential effects of underwater noise from petroleum industry activities on migrating gray whale behavior". BBN Rep. 5366. Rep. from Bolt Beranek & Newman Inc., Cambridge, MA, for U .S. Minerals Manage. Serv., Anchorage, AK. Var. pag. NTIS PB86-174174.

Malme, C.I., P.R. Miles, C.W. Clark, P. Tyack, and J.E. Bird. (1984). "Investigations of the potential effects of underwater noise from petroleum industry activities on migrating gray whale behavior/Phase II: January 1984 migration". BBN Rep. 5586. Rep. from Bolt Beranek & Newman Inc., Cambridge, MA, for U.S. Minerals Manage. Serv., Anchorage, AK. NTIS PB86-218377.

Malme, C.I., P.R. Miles, G.W. Miller, W.J. Richardson, D.G. Roseneau, and D.H. Thomson. (1989). "Analysis and ranking of the acoustic disturbance potential of petroleum industry activities and other sources of noise in the environment of marine mammals in Alaska". Report Number BBN Report No. 6945; OCS Study MMS 89-0006; NTIS PB90-188673. BBN Systems and Technologies Corp.

Martin, Kelly & Alessi, Sarah & Gaspard, Joseph & Tucker, Anton & Bauer, Gordon & Mann, David. (2012). "Underwater Hearing in the Loggerhead Turtle (Caretta caretta): A Comparison of Behavioral and Auditory Evoked Potential Audiograms". The Journal of experimental biology. 215. 3001-9. 10.1242/jeb.066324.

McCauley R.D., Fewtrell J., Duncan A.J., Jenner C., Jenner M.N., Penrose J.D., Prince R.I.T., Adhitya A., Murdoch J., McCabe K. (2002). "Marine seismic surveys - a study of environmental implications**"**, APPEA J., 40, pp. 692-706

McQueen, Andrew & Suedel, Burton & Jong, Christ & Thomsen, Frank. (2020). "Ecological Risk Assessment of Underwater Sounds from Dredging Operations". Integrated Environmental Assessment and Management. 16. 10.1002/ieam.4261.NED Project (2006), Northeast Gateway Energy Bridge, L.L.C. Liquefied Natural Gas Deepwater Port License Application, Environmental Impact Statement pp. 4-62 to 63

Michael A. Ainslie, Michele B. Halvorsen, Roel A. J. Müller, and Tristan Lippert (2020), "Application of damped cylindrical spreading to assess range to injury threshold for fishes from impact pile driving", The Journal of the Acoustical Society of America 148, 108-121 (2020) https://doi.org/10.1121/10.0001443

National Research Council (NRC 2005). Marine Mammal Populations and Ocean Noise – Determining When Noise Causes Biologically Significant Effects.

[NFMS] National Marine Fisheries Service (2018). 2018 Revisions to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-OPR-59, 167 p.

Nedwell, J. R., Edwards, B., Turnpenny, A. W. H., & Gordon, J. (2004). *"*Fish and Marine Mammal Audiograms: A summary of available information"*.* Subacoustech *Report* ref: 534R0214.

Nedwell J. R., Brooker A. G., (2008) "Measurement and assessment of background underwater noise and its comparison with noise from pin pile drilling operations during installation of the SeaGen tidal turbine device", Strangford Lough. Subacoustech Report No. 724R0120 to COWRIE Ltd. ISBN: 978-0-9557501-9-9.

Newitt, L. Jurevicius, D. Henrys, N. (2022), "Underwater Noise Measurements of Impact Driving of 200 mm Square Hollow Section Piles", Conference of the Acoustical Society of New Zealand, Wellington, 31 Oct-2 Nov 2022.

Popov V.V., Supin, A.Y., Wang D.W., Wang K., Xiao J. and Li S. (2005). "Evoked-potential audiogram of the Yangtze finless porpoise *Neophocaena phocanoides asiaeorientalis* (L).", *Journal of the Acoustical Society of America* 117(5):pp.2728-2731.

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

Reine, Kevin & Clarke, Douglas & Dickerson, Charles. (2012). “Characterization of Underwater Sounds Produced by a Backhoe Dredge Excavating Rock and Gravel”. U.S. Army Engineer Research and Development Center, Vicksburg, MS,39180.

Reine, Kevin & Clarke, Douglas & Dickerson, Charles. (2014). “Characterization of underwater sounds produced by hydraulic and mechanical dredging operations”. The Journal of the Acoustical Society of America. 135. 3280. 10.1121/1.4875712.

Reyff J. (2020), “Review of Down-the-Hole Rock Socket Drilling Acoustic Data Measured for White Pass & Yukon Route (WP&YR) Mooring Dolphins”, May 28, 2020

Richardson W.J., Würsig B. and Greene C.R. Jr. (1990). “Reactions of bowhead whales, Balaena mysticetus, to drilling and dredging noise in the Canadian Beaufort Sea.”, *Marine Environmental Research* 29(2):pp.135-160.

Richardson W.J., Greene C. Jr., Malme C., Thomson, D. (1995). “Marine Mammals and Noise.” *San Diego: Academic Press.*

Rodkin R., Pommerenck K. (2014), “Caltrans compendium of underwater sound data from pile driving – 2014 update”, *Inter-noise 2014, Melbourne Australia, 16 – 19 November 2014*.

Shane Guan, Robert Miner (2020), “Underwater noise characterization of down-the-hole pile driving activities off Biorka Island, Alaska”, Marine Pollution Bulletin, Volume 160, 2020, 111664, ISSN 0025-326X,https://doi.org/10.1016/j.marpolbul.2020.111664.

Southall, B. L., Bowles, A. E., Ellison, W. T., Finneran, J. J., Gentry, R. L., Greene, C. R., ... & Tyack, P. L. (2007). Overview. *Aquatic mammals*, *33*(4), 411-414.

Southall, B.L., D.P. Nowaceck, P.J.O. Miller, and P.L. Tyack. (2016). “Experimental field studies to measure behavioral responses of cetaceans to sonar”. *Endangered Species Research* 31: 293-315. https://research-repository.st-andrews.ac.uk/bitstream/handle/10023/9942/Miller_2016_ESR_CetaceansToSonar_CC.pdf?sequence=1&isAllowed=y.

Stadler, J.H., and D.P. Woodbury (2009), “Assessing the effects to fishes from pile driving: Application of new hydroacoustic criteria”. Internoise 2009.

Stephan Lippert (2018), “Offshore Pile driving noise: Capability of numerical prediction models and ways to consider new technologies”, Hamburg University of Technology, Institute of Modelling and Computation, International Conference on Noise Mitigation, Berlin, November 22-23, 2018.

Szymanski M.S., Bain D.E, Kiehl K., Pennington S., Wong S. and Henry K.R. (1999). “Killer whale (*Orcinus orca*) hearing: Auditory brainstem response and behavioural audiograms.”, *Journal of the Acoustical Society of America* 106(2):pp.1134-1141.

Tristan Lippert, Michael A. Ainslie, and Otto von Estorff, (2018), "Pile driving acoustics made simple: Damped cylindrical spreading model", The Journal of the Acoustical Society of America 143, 310-317 (2018) https://doi.org/10.1121/1.5011158

Victoria L. G. Todd, Ian B. Todd, Jane C. Gardiner, Erica C. N. Morrin, Nicola A. MacPherson, Nancy A. DiMarzio, Frank Thomsen, A review of impacts of marine dredging activities on marine mammals, ICES Journal of Marine Science, Volume 72, Issue 2, January/February 2015, Pages 328–340, https://doi.org/10.1093/icesjms/fsu187

Wenz, G. M. (1962). “Acoustic ambient noise in the ocean: Spectra and sources”. *Journal of the Acoustical Society of America*, 34 (12), 1936-1956.

[WODA] World Organization of Dredging Associations. (2013). Technical guidance on underwater sound in relation to dredging. Delft (NL). 8 p.

Wood, J., Southall, B.L. and Tollit, D.J. (2012). PG&E offshore 3-D Seismic Survey Project EIR – Marine Mammal Technical Draft Report. SMRU Ltd.

Useful Weblinks

Websites

EPBC Act

http://www.environment.gov.au/epbc

EPBC protected matters search tool

http://www.environment.gov.au/erin/ert/epbc/index.html

Listed threatened species and ecological communities under EPBC Act

http://www.environment.gov.au/epbc/what-is-protected/threatened-species-ecological-communities

Listed migratory species under EPBC Act

https://www.environment.gov.au/epbc/what-is-protected/migratory-species

Whales, dolphins and porpoises

http://www.environment.gov.au/coasts/species/cetaceans/index.html

Australian Whale Sanctuary

http://www.environment.gov.au/coasts/species/cetaceans/conservation/sanctuary.html

http://www.environment.gov.au/system/files/pages/e0444cc5-6dd7-4afb-b3f5-2d9642482e96/files/sanctuary-map.pdf

Adelaide Dolphin Sanctuary

https://www.parks.sa.gov.au/parks/adelaide-dolphin-sanctuaryAquatic reserves and marine parks

https://www.environment.sa.gov.au/marineparks/find-a-park

Documents

Significant impact Guidelines 1.1 – Matters of National Environmental Significance

https://www.environment.gov.au/epbc/publications/significant-impact-Guidelines-11-matters-national-environmental-significance

Significant impact Guidelines 1.2 – Actions on, or impacting upon, Commonwealth land, and actions by Commonwealth agencies

https://www.environment.gov.au/epbc/publications/significant-impact-Guidelines-12-actions-or-impacting-upon-commonwealth-land-and-actions

Marine Parks Network Management Plans

https://parksaustralia.gov.au/marine/

Marine Bioregional Plans

https://www.environment.gov.au/marine/marine-bioregional-plans