# Underwater noise impact assessment

## Technical Report A - Annexure I

# AGL Gas Import Jetty Facility

## Underwater Noise Impact Assessment

Submitted to:
[redacted]
AECOM Australia Pty Ltd


Authors:
Klaus Lucke
Craig McPherson


11 June 2020

P001487-001
Document 002019
Version 2.0


JASCO Applied Sciences (Australia) Pty Ltd
Unit 1, 14 Hook Street
Capalaba, Queensland, 4157
Tel: +61 7 3823 2620
www.jasco.com


Suggested citation:

Lucke, K., and C.R. McPherson. 2020. *AGL Gas Import Jetty Facility: Underwater Noise Impact Assessment.* Document 002019, Version 2.0. Technical report by JASCO Applied Sciences for AECOM Australia Pty Ltd.

Disclaimer:

The results presented herein are relevant within the specific context described in this report. They could be misinterpreted if not considered in the light of all the information contained in this report. Accordingly, if information from this report is used in documents released to the public or to regulatory bodies, such documents must clearly cite the original report, which shall be made readily available to the recipients in integral and unedited form.

# Contents

# Figures



# Tables

# Executive Summary

This report assesses the potential impacts of underwater sound on marine fauna as a result of the operation of the Gas Import Jetty as part of the and Gas Import Jetty and Pipeline Project (GIJPP, the Project) in Western Port Bay, VIC. The species considered in this report represent four taxa–marine mammals, fish, invertebrates and diving birds. Species listed as threatened or vulnerable under the Environment Protection and Biodiversity Conservation Act 1999 (Southern right whales, humpback whales and Australian sea lions) and species listed under the Victorian Flora and Fauna Guarantee Act 1988 (such as white shark or Australian grayling) are given special consideration.

The underwater noise impact criteria used are based on the most recent criteria for onset of behavioural responses, and temporary and permanent threshold shift in marine mammals (NMFS 2018), as well as the sound exposure guidelines for fish, fish eggs and larvae (Popper et al. 2014). There are no noise exposure criteria for birds and invertebrates.

The existing ambient sound field at the Gas Import Jetty has not been measured and cannot be approximated from measurements at other locations. The Gas Import Jetty is located at an existing operating Port jetty with ongoing industrial and recreational vessel activities in the main shipping channel. In this assessment, it is assumed that the existing harbour operations create a noise field that already alters the natural sound field and impacts the marine receptors in the surrounding area.

The impact assessment of underwater noise on marine fauna is based on model-predicted sound levels for the planned operation at the Gas Import Jetty (Koessler et al. 2019) and their spatial extent. As no suitable data are available to determine the sound emitted by the planned activities, measurement results from a similar operation were applied as a proxy for each vessel considered in the technical report by Koessler et al. (2019).

The likelihood of impact is assessed based on existing grey and peer-reviewed scientific literature. Noise-induced effects can include sound-perception and stress, behavioural responses, acoustic masking, temporary or permanent impairment of the hearing system, injury and mortality. Scientific information on the importance of sound, sensitivity to underwater sound or susceptibility to sound-induced effects on invertebrates and birds is scarce or not existing and the risk for noise-induced behavioural responses or physical impacts/ injury could not be assessed for these animals. For all other species groups and types of impact, however, there is at least some scientific information allowing to assess the risk for noise-induced-impacts. The assessment of likelihood and consequence of impact shows that individual animals can be at a medium or high risk of being impacted by the sound while on population level the impact risk is low or very low for all species and species groups considered.

The planned operations at the Gas Import Jetty will contribute to the soundscape in this harbour area but not change the ecological character or reduce the biodiversity of this environment.

None of the species listed as endangered or vulnerable under the EPBC Act (Southern right whales, humpback whales and Australian sea lions) nor species listed under the FFG Act (such as white sharks or Australian grayling) and little penguins are at risk from the planned operations as the Gas Import Jetty.

# 1. Methodology

## 1.1. Background

Sound is a natural phenomenon occurring in all aquatic environments and marine fauna evolved in the presence of this natural soundscape. Natural sounds vary constantly due to biological, oceanographic, and meteorologic processes. Anthropogenic activities such as the operation of the Gas Import Jetty introduce additional sound into the water. The multitude of parameters influencing the natural and anthropogenic contributions to the overall soundscape create a complex scenario for an impact assessment.

The hearing system of marine mammals is very sensitive, and these animals use underwater sound for communicating and foraging. The sensitivity of fish to sound varies, but sound plays an important role in their life too. Marine invertebrates are sensitive to sound, but it remains unclear if and to what extent underwater sound has a functional role for these species. All marine fauna can theoretically be affected by acute or chronic exposure of sound depending on their susceptibility to sound effects and the temporal and acoustic characteristics of the sound.

Acoustic signals have evolved as the principal mode of information transmission for many marine species. It is well known that cetaceans (whales, dolphins, and porpoises) use sound both passively when listening to the environment and actively when communicating and foraging. Many fish species can hear and use sounds for learning about their environment (Ladich and Fay 2013). Fish use sound actively to communicate, most often aiming at nearby prospective mates (Lobel et al. 2010) and mainly associated with two behavioural contexts: reproduction and aggression.

The sounds that marine animals hear and generate vary in characteristics such as dominant frequency, bandwidth, energy, temporal pattern, and directivity. Just as many terrestrial animals integrate multiple stimuli from their visual landscape, marine life must discriminate a signal (meaningful sound) among multiple stimuli in their acoustic seascape. Anthropogenic sounds can affect marine life in a variety of ways.

The potential for sounds to impact marine animals varies with the characteristics of the sound source, sound propagation characteristics of the physical environment, and biological factors. Biological factors include the hearing range of marine mammal species (broad range and most sensitive frequencies), animals' state of activity (feeding versus resting or migrating), individual hearing loss, animals' previous exposure to sound type (habituation), life history stage, reproductive status, and health status all contribute to the impacts of anthropogenic sound on marine animals. Past studies on the reactions of marine mammals to anthropogenic sound have shown widely varied responses, depending on the individual, context, age, gender, and activity in which the animals were engaged (Simmonds et al. 2003, Ellison et al. 2012).

Richardson et al. (1995) identified four concentric zones of influence with decreasing size and increasing intensity of the signal. These zones are:

1. Audibility–Signal source levels decrease with range from a source due to propagation losses; their audibility is limited by the signal dropping either below the animal's hearing threshold or below ambient sound levels.
2. Responsiveness–The zone of behavioural response is generally smaller than the zone of audibility, as an animal is not likely to respond to a sound that is just detectable.
3. Masking–The zone overlaps with zone of responsiveness; masking occurs when a noise impedes the ability of the animal to perceive a biologically relevant signal.
4. Injury–Direct physical injury resulting in mortality, temporary or permanent impairment of the auditory (hearing) system, (non-lethal) injury to non-auditory organs;

These zones of influence broadly define the nature of potential response and impact from acoustic exposure (Figure 1). The outer three zones can be considered essentially contiguous and partially overlapping.

An additional effect of sound on marine mammals that is not defined in a zonal sense, is the potential reduction in prey availability as prey responds to anthropogenic sound and is displaced from a feeding area.

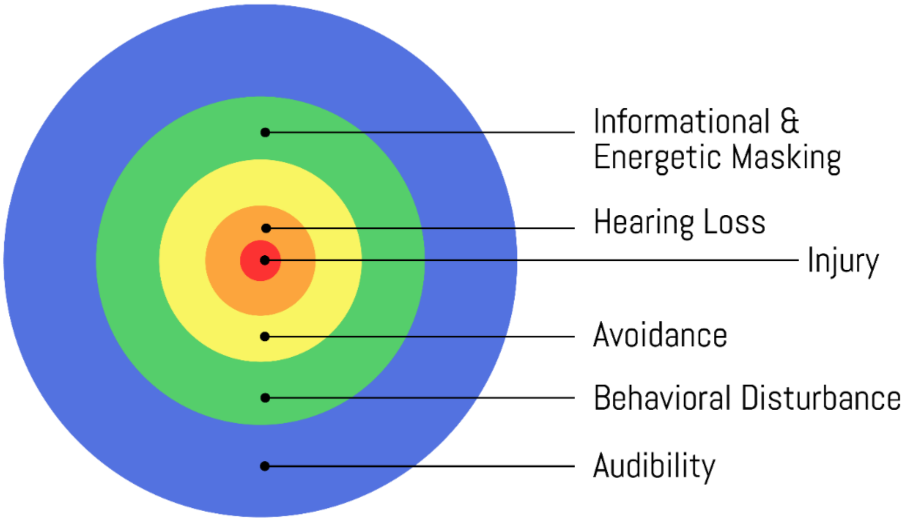


Figure 1. Theoretical zones of acoustic influence on marine life, with highest levels of sound at the sound source at the centre (not to scale). Adapted from Richardson et al. (1995).

An overview of the physical characteristics of underwater sound can be found in Appendix A.

Understanding the scale of sound exposure in Western Port Bay is important for protecting marine fauna in this area. The scientific information related to the importance of underwater sound and the effect of noise exposure for marine fauna has improved for some taxa but is insufficient for all species of concern. There is strong individual, context-specific and species-specific variability in hearing sensitivity, as well as susceptibility to noise impacts. This variability, along with the fact that most receptors are actively moving through complex sound fields, make assessing noise-induced impact complicated.

This technical report documents the known cause-effect relationship between the noise emitted by activities around the Gas Import Jetty, such as the operation of the Floating Storage Regasification Unit (FSRU) and the vessels offloading. However, this report does not assess the potential for anthropogenic sound impacts resulting from increased shipping activity on the marine receptors cetaceans or impacts from potential collisions.

A systematic risk-based approach has been applied to understand the existing environment, the potential impacts of the Project, and how to avoid, minimise, and/or manage the risk of impact. The following subsections outline the method for assessing the impact of underwater noise.

## 1.2. Existing Conditions Assessment

The existing soundscape in the Western Port Bay area has not been measured. The existing conditions assessment is substituted by a general assessment of the soundscape that can be expected from operations correlated with the operations of the existing port.

## 1.3. Risk Assessment Method

The risk assessment is based on available scientific information on effects of underwater noise on marine fauna. The criteria for rating the consequence of underwater noise are listed in Table 1, the noise-induced impacts are described in Section 1.4 (for modelled scenarios see Table 2) and the impact likelihood for each receptor group is provided in Table 3.

A likelihood rating and the consequences of a risk occurring were assigned based on expert judgement using a consequence guide. The specific consequence categories are described in Table 1, considering existing conditions in the project area where possible.

Table 1. Criteria for rating the consequence of underwater noise.

| Level | Qualitative description – re. noise | Qualitative description – re. abundance |
|---|---|---|
| Negligible | Noise is audible but has no measurable effect. | No detectable change in species abundance or species richness within in local ecosystem community boundaries (approximately 1 km of the FSRU) |
| Minor | Received noise causes acoustic masking [effect ceases upon cessation of noise exposure] or mild physiological (stress) or behavioural response. | Minor change (may not be detectable) in abundance of species or species richness in local ecosystem community boundaries. (approximately 1 km of the FSRU) |
| Moderate | Received noise triggers significant behavioural response (e.g., resulting in a missed foraging opportunity or long-term avoidance). | Detectable change in abundance of species or species richness in local ecosystem community boundaries (approximately 1 km of the FSRU) |
| Major | Received noise levels exceed criteria for physiological effects [temporary effect, can persist after cessation of noise exposure] such as TTS. | Detectable change in abundance of species or species richness in wider ecosystem community (North Arm) |
| Severe | Received noise levels exceed injury criteria and cause direct mortality or permanent damage such as PTS. | Substantial change in abundance of species or species richness in wider ecosystem community (North Arm) |

The consequences of these potential impacts are assessed on an individual and population level. Aspects considered in assessing potential consequences of noise exposure are apparent direct or indirect pathways that are likely to affect:

- Area of occupancy;
- Critical habitat;
- Breeding cycle.

Additionally, on a population level the following aspects have been considered:

- Population size;
- Population continuity;
- Species recovery.

## 1.4. Impact Assessment Method

The impact assessment of underwater noise on marine fauna is based on model-predicted sound levels for the planned operation at the Gas Import Jetty (Koessler et al. 2019) and their spatial extent. As no suitable data are available to determine the sound emitted by the planned activities, measurement results from a similar operation were applied as a proxy for each vessel.

Koessler et al. (2019) modelled the sound propagation loss for the noise emitted at the Gas Import Jetty for four scenarios representing different levels of operational activity at Berth 1 and 2 (Table 2). The report provides horizontal ranges to the threshold levels that are relevant for each taxonomic or function group of receivers (i.e., marine fauna).

Table 2. Modelling scenarios

| Scenario number | Scenario description | Scenario rationale |
|---|---|---|
| 1 | Petroleum carrier offloading | Existing operations at Crib Point Jetty |
| 2 | FSRU berthed and offloading | Proposed new facility (FSRU) in isolation |
| 3 | FSRU berthed and Liquefied Natural Gas (LNG) carrier offloading | Proposed new facility (FSRU) plus offloading (predicted to be the loudest scenario for the future operations) |
| 4 | FSRU berthed, LNG carrier offloading, and petroleum carrier offloading | Scenario 3 in tandem with existing operations at Crib Point Jetty |

Impacts are assessed for species or, in the absence of species-specific information, on taxa by correlating the predicted sound levels and threshold ranges to the available information on sensitivity to underwater sound and susceptibility to noise-induced effects. The impact assessment is conducted following the most recent set of guidelines for exposure of marine fauna to underwater sound.

The acoustic characteristics (such as the continuous nature of the sound and frequency content) of the sound emitted by GIJPP operations are taken into account as only sounds that fall within the hearing range and exceed the hearing threshold of a species have the potential to cause any effect.

## 1.5. Assumptions And Limitations

- The existing underwater ambient sound field at the Gas Import Jetty has not been measured and cannot be approximated from measurements other locations. In this assessment, it is assumed that the existing harbour operations create a noise field that already alters the natural sound field and impacts the marine receptors in the surrounding area.
- To date, no suitable data in either grey or peer reviewed literature is available to determine the sound emitted for berthed FSRU, LNG, or petroleum carriers. Therefore, sound emissions derived from measured levels of two Floating Production Storage and Offload (FPSO) facilities detailed in Erbe et al. (2013) were applied as a proxy for each vessel considered in their technical report (Koessler et al. 2019). The predicted sound levels and their spatial extent are used as the basis for this impact assessment of underwater noise on marine fauna and diving birds.
- Scientific information on the importance of sound, sensitivity to underwater sound or susceptibility to sound-induced effects on invertebrates and birds is scarce or not existing and the risk for noise-induced behavioural responses or physical impacts/ injury could not be assessed for these animals.

# 2. Existing Conditions

The existing conditions in Western Port Bay include an existing operating Port jetty with vessels unloading petroleum products on a weekly basis. The jetty is located within a larger Port zone within 700 m of the main shipping channel with a present total of ~150 shipping movements per year of commercial vessels to 250 m (excluding tug movements). The jetty is located in a popular recreational fishing area with a high number of small (5 to 8 m) recreational vessels passing near the jetty in peak season. There is no information on the prevailing sound levels in the GIJPP area.

# 3. Risk Assessment

Impact risks are assessed based on information available on the occurrence and habitat use of the species/taxa in Western Port Bay area, information on their sensitivity to underwater sound and the predicted ranges for sound levels to exceed impact thresholds around the GIJPP operations (Koessler et al. (2019). Impact risks are assessed for each type of noise-induced impact (Section 1) separately. Impact consequences are assessed for the longest impact ranges predicted by the modelling (see modelling scenarios, Section 1.4).

## 3.1. Marine Mammals

### 3.1.1. Audibility

The predicted range of audibility for sound emitted by the activities at the Gas Import Jetty is expected to exceed the range of onset of behavioural responses for all cetaceans and pinnipeds. The exceedance of this range, however, cannot be assessed quantitatively due to the lack of information on the ambient noise level and, for baleen whales, the lack of robust information on their hearing sensitivity. It is **likely** that the sound will be audible to marine mammals in most circumstances if they are entering the Western Port Bay area.

The consequence of being able to hear the noise emitted from the vessels and operations at the Gas Import Jetty for individual marine mammals is considered to be **minor** and **negligible** on a population level.

### 3.1.2. Acoustic Masking

This impact cannot be quantified without prior knowledge of the absolute hearing sensitivity and related auditory parameters for each marine mammal species of concern. The impact is strongest close to the source and gradually decreases with increasing distance from the source. Based on the existing information about hearing sensitivity in these species it is, however, **possible** that low-and mid-frequency cetaceans as well as pinnipeds will experience acoustic masking if they enter the wider area around the Gas Import Jetty.

The consequence of acoustic masking for individual marine mammals is considered to be **minor** and **negligible** on a population level.

#### *3.1.2.1. Behavioural Responses*

The maximum range for onset of behavioural responses by marine mammals was calculated for scenario 4 with a maximum range of 2.42 km (Koessler et al. 2019), thereby clearly extending into Western Port Bay (Figure 2). The range calculation was based on the single-threshold behavioural response criterion for all marine mammals.

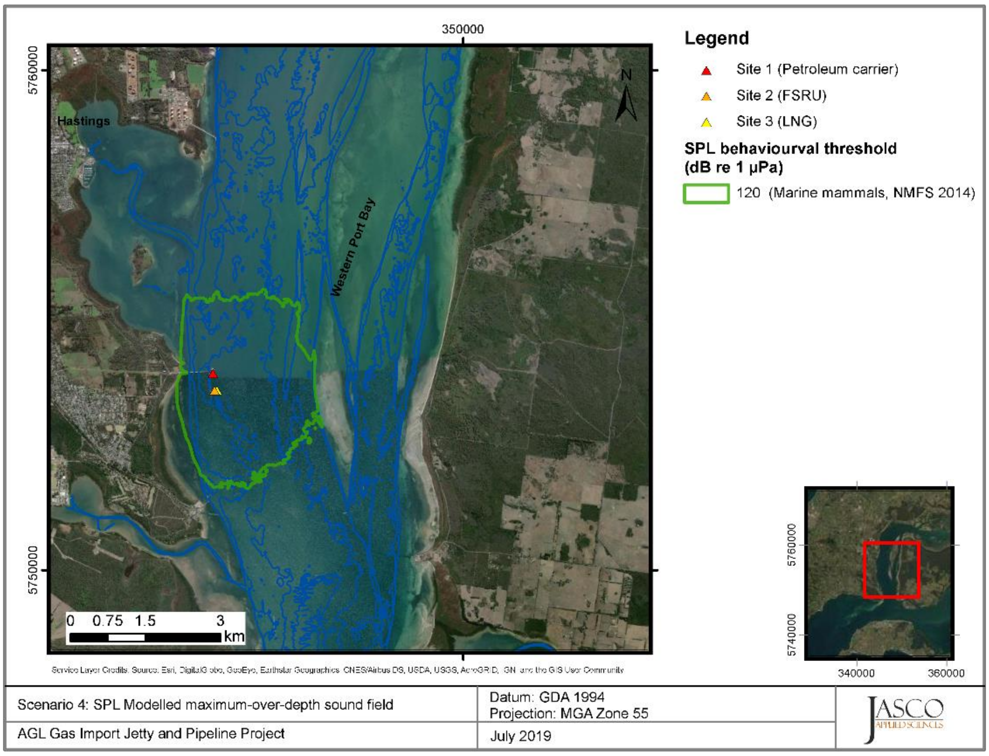


Figure 2. *Scenario 4 – Petroleum tanker + FSRU + LNG Carrier, SPL*: Sound level contour map showing unweighted maximum-over-depth results (adapted from Koessler et al. 2019).

It is possible that marine mammals may be exposed to levels exceeding the behavioural threshold once they enter the Western Port Bay area. The likelihood for baleen whales to enter this area, however, is relatively low whereas delphinids and pinnipeds are more likely to enter the Bay area. Accordingly, the likelihood for causing behavioural responses is **unlikely** for low-frequency cetaceans (baleen whales) and **possible** for mid-frequency cetaceans and pinnipeds.

As the Western Port area is not an important habitat for marine mammals, the consequence of avoidance is therefore negligible to **minor** for individual marine mammals and **negligible** on a population level.

### *3.1.2.2. Auditory Injury*

The longest range for reaching the criteria for onset of auditory injury (TTS or PTS) for marine mammals was calculated for scenario 4 (Koessler et al. 2019) (Figure 3). For mid-frequency cetaceans and pinnipeds (otariids), the maximum range to the onset of TTS and PTS would be 60 m and <20 m, respectively. While for low-frequency cetaceans, the exceedance distances were 650 m (TTS) and 380 m. The threshold criteria are based on exposure to sound over a period of 24 hours.

While it is **possible** that marine mammals will come within the exceedance range for the TTS threshold (and for low-frequency cetaceans also for the PTS threshold), it is unrealistic (**rare**) that any marine mammal would remain within this area for 24 hours.

The consequences of exposure to TTS inducing sound levels is **major** for individual marine mammals and **minor** on a population level.

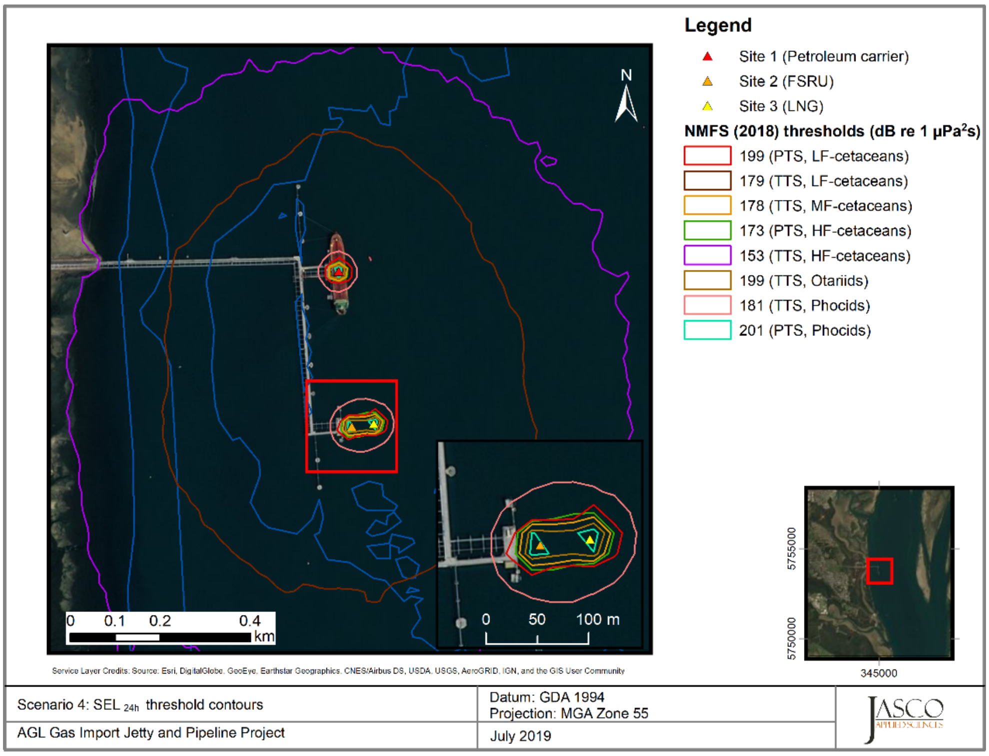


Figure 3. *Scenario 4 – Petroleum carrier + FSRU + LNG Carrier, $SEL_{24h}$:* Sound level threshold map for maximum-over-depth results. PTS threshold for mid–frequency cetaceans and otariids was not reached (taken from Koessler et al. 2019).

## 3.2. Fish

Fish species such as the Australian anchovy are expected to have a good hearing sensitivity and are **likely** to hear the noise emitted by the vessels and operations at the Gas Import Jetty.

It is **possible** that these species will show behavioural responses (such as spatial avoidance) relative to the sound source and that their communication will be acoustically masked.

It is also **possible** that these fish species enter the area around the Gas Import Jetty where threshold levels for onset of TTS or recoverable injury (maximum horizontal distance: 80 m, see Table 9 for onset levels) are predicted to be exceeded, but it is unreasonable (**rare**) to assume that any fish would remain in this area for an extended period of time to experience any of these impacts (12 h or 48 h, respectively).

It is **possible** that fish species with a moderate sensitivity to sound such as whiting, sea bream gobies, flathead or Australian grayling will hear the noise emitted by the vessels and operations and will show behavioural responses to it or that their communication will be acoustically masked.

It is also **possible** that these species enter the area around the Gas Import Jetty where threshold levels for onset of TTS or recoverable injury. However, the spatial extent of the area where.

Sharks and rays have a poor hearing sensitivity, but it is **possible** that these species will be able to detect the noise emitted from the vessels and operations at the Gas Import Jetty at close ranges. It is **unlikely** that these species will show behavioural responses to the noise. Acoustic masking is not expected for these species, as they are not known to use acoustic signals for communicating. It is possible that these species will enter the zone near the sound sources where they could experience TTS or recoverable injury, but it is unreasonable (**rare**) to assume that they will remain in this small area for a long duration.

The consequence of being able to hear the noise emitted from the vessels and operations at the Gas Import Jetty for individual fish is considered to be **minor** and **negligible** on a population level. The consequence of acoustic masking for individual fish is considered to be **moderate** and, due to a limited number of animals likely experiencing this effect would be **minor** on a population level. The

consequence for individual fish would be **moderate**, as only a limited portion of the fish population in Western Port Bay is likely to experience negative consequences from behavioural responses, the consequences would be **minor** at a population level. Any temporary hearing impairment (in this case TTS and PTS) would have minor to **moderate** consequences for an individual and **minor** consequences on a population level.

## 3.3. Invertebrates

Invertebrates are likely to be distributed throughout the Western Port Bay. Their exact abundance and (temporal) occurrence in the ensonified area around the Gas Import Jetty is unpredictable.

It is almost certain that invertebrate species enter the area ensonified by the noise emitted by the vessels and operations at the Gas Import Jetty at levels above ambient (background) noise. However, there is no information on the sensitivity to sound (sound pressure or particle motion) for any invertebrate species.

Based on the limited quantitative information available on effects of non-impulsive noise it is **likely** that invertebrates will be able to detect the exposed the noise emitted from the vessels and operations at the Gas Import Jetty at close ranges and **possible** that behavioural responses are elicited. Since the data on onset of noise-induced injury are inconclusive it is impossible to provide a scientifically robust assessment of these impacts for marine invertebrates. Stress responses to non-impulsive sound exposure have been documented for marine invertebrates. The worst-case consequence for individual animals can be expected to be moderate to **major**, but due to the limited spatial extent of the affected area population consequences are considered to be **minor**.

The consequence of (acoustic/vibrational) masking is considered to be, in the worst case, **moderate** for individuals and, due an expected limited number of individuals experiencing this masking, as **negligible** on a population level. In the absence of conclusive scientific information on the scope of these effects and the animals' ability to compensate for the effects, however, it is impossible to assess the consequences of behavioural responses and noise-induced impairment or injury.

## 3.4. Avifauna

The Gas Import Jetty falls within the boundary of the Western Port Ramsar Wetland which is an important area for wading birds. This faunal group is not considered at risk from underwater acoustic emissions. However, bird species that plunge dive or surface dive (such as cormorants, penguins and ducks), readily transit between air and water and enact important behaviours underwater. While immersed (fully, or at least partially, e.g., swans) they are potentially at risk of experiencing noise-induced effects such as hearing impairment.

It is **almost certain** that bird species such as penguins, cormorants, swans, and waterfowl would be able to hear the noise emitted from the vessels and operations at the Gas Import Jetty. At close ranges, their communication (if they use sound for communication underwater) could possibly (**possible**) be masked. The effect of hearing underwater sound and experiencing acoustic masking is considered **negligible** for birds, both individually and on a population level.

In the absence of quantitative information on onset thresholds for behavioural responses and data on injury, it is impossible to provide a scientifically robust assessment of the risk to marine birds.

## 3.5. Risk Summary

The likelihood of underwater noise impacts is summarised for each impact category and receptor group in Table 3. The risk for each underwater noise impact category and receptor group is summarised for individual receptors in Table 4 and on a population level in Table 5..

Table 3. Impact likelihood for each receptor group LF = low frequency; MF = Mid -frequency (n/a: not available, i.e., not possible to assess due to lack of data).

| Impact | Likelihood | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Marine mammal functional hearing group | | | Fish | | | Invertebrates | Birds |
| | LF-cetaceans | MF-cetaceans | Otariids | High sensitivity | Moderate sensitivity | Low sensitivity | | |
| Audibility | Almost certain | Almost certain | Almost certain | Likely | Possible | Possible | Likely | Likely |
| Acoustic masking | Likely | Likely | Likely | Possible | Possible | Unlikely | Possible | Possible |
| Behavioural response | Possible | Possible | Possible | Possible | Possible | Unlikely | Possible | n/a |
| Physical impact/ injury | Rare | Rare | Rare | Rare | Rare | Rare | n/a | n/a |

Table 4. Underwater noise impact risk assessment for individual animals.(n/a: not available, i.e., not possible to assess due to lack of data).

| Impact | Marine mammal functional hearing group | | | Fish | | | Invertebrates | Birds |
|---|---|---|---|---|---|---|---|---|
| | LF-cetaceans | MF-cetaceans | Otariids | High sensitivity | Moderate sensitivity | Low sensitivity | | |
| Audibility | Medium | Medium | Medium | Medium | Low | Low | High | Low |
| Acoustic masking | Medium | Medium | Medium | Medium | Medium | Low | Medium | Low |
| Behavioural response | Low | Low | Low | Medium | Medium | Low | n/a | n/a |
| Physical impact/ injury | Medium | Medium | Medium | Low | Low | Low | n/a | n/a |

* Effect is only theoretical possible, i.e., unrealistic to assume.

Table 5. Underwater noise impact risk assessment on population level.(n/a: not available, i.e., not possible to assess due to lack of data).

| Impact | Likelihood | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Marine mammal functional hearing group | | | Fish | | | Invertebrates | Birds |
| | LF-cetaceans | MF-cetaceans | Otariids | High sensitivity | Moderate sensitivity | Low sensitivity | | |
| Audibility | Low | Low | Low | Low | Low | Low | Low | Low |
| Acoustic masking | Low | Low | Low | Low | Low | Low | Low | Low |
| Behavioural response | Low | Low | Low | Low | Low | Low | n/a | n/a |
| Physical impact/ injury | Very low* | Very low* | Very low* | Very low | Very low | Very low | n/a | n/a |

* Effect is only theoretical, i.e., unrealistic to assume.

# 4. Impact Assessment

The potential for underwater noise impacts to occur depends on abundance or frequency of occurrence of the receiver in the study area, the temporal and spectral characteristics of the emitted sound, the distance between the source and the receiver and the sensitivity of the receiver. Furthermore, the received signal is influenced by the sound propagation along the path from the source to the receiver.

The sound field around the Gas Import Jetty was modelled and ranges to exposure thresholds were calculated by Koessler et al. (2019). The assessment of potential impact to the different receiver groups (below) is based on the calculated propagation ranges to the impact thresholds and takes into account the available information on their (auditory) sensitivity to sound into account.

## 4.1. Estimated Sound Fields at the Gas Import Jetty

Sound interacts with the environment as it propagates away from its source. Interactions with area-specific environmental parameters (such as water temperature and density (affecting sound velocity), bottom type and bathymetry) may result in irregular propagation patterns around the source. The distance at which an animal may be exposed to sound levels exceeding a threshold is predicted from numerical modelling of sound propagation loss.

The sound field expected to be generated by activities at the Gas Import Jetty is dominated by non-impulsive, low-frequency sounds with highest levels reached below 100 Hz but extending to over 10 kHz. Due to the non-impulsive nature of the sounds emitted by the vessels and operations at the Gas Import Jetty, only effects of non-impulsive (i.e., continuous or intermittent) sounds on marine receptors are considered in the assessment. Comprehensive and detailed information on the sound field expected for each of the four scenarios can be found in Koessler et al. (2019).

## 4.2. Underwater Noise Receptors

Underwater noise can only affect receptor species that a) live permanently in a marine environment or enter it temporarily and b) are sensitive to sound. Based on these considerations, species representing four taxonomic groups were identified and are considered in this impact assessment (Table 6).

Table 6. Taxonomic groups and species considered in this Impact Assessment, and their occurrence and sensitivity to underwater sound based on morphological and functional criteria (see Section 3.1.1). The frequency range of vocalizations are low <1 kHz, medium 1–20 kHz, and high >20 kHz.

| Taxonomic group | Common name | Scientific name | Status under EPBC Act/FFG Act | Frequency range of vocalizations† | Sensitivity to underwater sound | Lifestyle |
|---|---|---|---|---|---|---|
| Marine mammals | | | | | | |
| Baleen whales | Humpback whales | *Megaptera novaeangliae* | Vulnerable | Low | High | Aquatic |
| | Southern right whales | *Eubalaena australis* | Endangered | Low | High | Aquatic |
| Toothed whales | Killer whales | *Orcinus orca* | Not listed | Medium to high | High | Aquatic |
| | Bottlenose dolphins | *Tursiops aduncus* | Not listed | Medium to high | High | Aquatic |
| | Short-beaked Common Dolphins | *Delphinus delphis* | Not listed | Medium to high | High | Aquatic |

| Taxonomic group | Common name | Scientific name | Status under EPBC Act/FFG Act | Frequency range of vocalizations† | Sensitivity to underwater sound | Lifestyle |
|---|---|---|---|---|---|---|
| Pinnipeds | Australian sea lion | *Neophoca cinerea* | Vulnerable | Low to medium | High | Amphibious |
| | Australian fur seal | *Arctocephalus pusillus doriferus* | Not listed | Low to medium | High | Amphibious |
| | New Zealand fur seal | *Arctophoca fosteri* | Not listed | Low to medium | High | Amphibious |
| Fishes | | | | | | |
| Finfish (ray-finned fish, Teleost) | Australian anchovy | Engraulis australis | Not listed | Low | High | Aquatic |
| | Whiting | Sillago spp. | Not listed | Low | Moderate | Aquatic |
| | Snapper (Silver sea bream) | Chrysophrys auratus (previously Pagrus auratus) | Not listed | Low | Moderate | Aquatic |
| | Mangrove goby | Mugilogobius paludis | Not listed | Low | Moderate | Aquatic |
| | Flathead | Platycehphalus spp. | Not listed | Low | Moderate | Aquatic |
| | Australian grayling | Prototroctes maraena | Listed | Low | Moderate | Aquatic |
| Sharks, rays (Chondrichthyes) | White shark | Carcharodon carcharias | Vulnerable | Unknown | Low | Aquatic |
| | Stingrays | Myliobatiformes | Not listed | Unknown | Low | Aquatic |
| Invertebrates | | | | | | |
| Crustaceans | Crabs | *Brachyura* | Not listed | Unknown | Unknown | Aquatic |
| Burrowing shrimps | Western port ghost shrimp | *Eucalliax tooradin* | Listed | Unknown | Unknown | Aquatic |
| | Ghost shrimp | *Michelea microphylla* | Listed | Unknown | Unknown | Aquatic |
| Snapping shrimps | Snapping shrimps | *Alpheidae spp.* | Not listed | Unknown | Unknown | Aquatic |
| Shellfish/ Molluscs | Bivalves | *Bivalvia* | Some listed | Unknown | Unknown | Aquatic |
| Cephalopods | Squid | *Coleoidea* | Not listed | Unknown | Unknown | Aquatic |
| Avifauna | | | | | | |
| Penguins | Little (Fairy) penguin | *Eudyptula minor* | Listed | Low to medium* | Moderate | Occasionally diving |
| Cormorants | Australian pied cormorant | *Phalacrocorax varius* | Not listed | Low to medium* | Moderate | Occasionally diving |
| | Little black cormorant | *Phalacrocorax sulcirostris* | Not listed | Low to medium* | Moderate | Occasionally diving |
| | Black cormorant | *Phalacrocorax carbo* | Not listed | Low to medium* | Moderate | Occasionally diving |

| Taxonomic group | Common name | Scientific name | Status under EPBC Act/FFG Act | Frequency range of vocalizations† | Sensitivity to underwater sound | Lifestyle |
|---|---|---|---|---|---|---|
| | Black-faced cormorant | *Phalacrocorax fuscescens* | Not listed | Low to medium* | Moderate | Occasionally diving |
| Swans | Black swan | *Cygnus atratus* | Not listed | Low to medium* | Unknown | Occasionally partially immersed |
| Waterfowl | Ducks | *Anatidae* | Some listed | Low to medium* | Moderate | Occasionally diving; occasionally partially immersed |

† Including echolocation signals
* Based on in-air vocalizations

## 4.3. Marine Mammals

### 4.3.1. Audibility

Current data and predictions on hearing sensibility show that marine mammal species differ in their hearing capabilities, in absolute hearing sensitivity, as well as their frequency band of hearing (Richardson et al. 1995, Wartzok and Ketten 1999, Southall et al. 2007). While hearing measurements are available for a small number of species based on captive animal studies, direct measurements of many odontocetes and all mysticetes do not exist. As a result, hearing ranges for many odontocetes are grouped with similar species, and predictions for mysticetes are based on other methods, such as anatomical studies and modelling (Houser et al. 2001, Parks et al. 2007b, Tubelli et al. 2012, Cranford and Krysl 2015), vocalizations (see reviews in Richardson et al. 1995, Wartzok and Ketten 1999, Au and Hastings 2008a), taxonomy, and behavioural responses to sound (Dahlheim and Ljungblad 1990).

#### *4.3.1.1. Marine Mammal Hearing Groups*

To better reflect the auditory similarities between phylogenetically closely related species, but also significant differences between species groups among the marine mammals, Southall et al. (2007) assigned the extant marine mammal species to functional hearing groups based on their hearing capabilities and sound production. This division into broad categories was intended to provide a realistic number of categories for which individual noise exposure criteria were developed. These groups were revised by NMFS (2018) (Table 7), but the categorisation as such has proven to be a scientifically justified and useful approach in developing auditory weighting functions and deriving noise exposure criteria for marine mammals.

Table 7. Marine mammal hearing groups (NMFS 2018).

| Hearing group | Generalized hearing range* |
|---|---|
| Low-frequency (LF) cetaceans (mysticetes or baleen whales) | 7 Hz to 35 kHz |
| Mid-frequency (MF) cetaceans (odontocetes: delphinids, beaked whales) | 150 Hz to 160 kHz |
| High-frequency (HF) cetaceans (other odontocetes) | 275 Hz to 160 kHz |
| Phocid pinnipeds (PW) (underwater) | 50 Hz to 86 kHz |
| Otariid pinnipeds (OW) (underwater) | 60 Hz to 39 kHz |

*The generalized hearing range for all species within a group. Individual hearing will vary.

#### *4.3.1.2. Marine Mammal Weighting Functions*

The potential for anthropogenic sounds to impact marine mammals is largely dependent on whether the sound occurs at frequencies that an animal can hear well, unless the sound pressure level is so high that it can cause physical tissue damage regardless of frequency. Auditory (frequency) weighting functions reflect an animal's ability to hear a sound (Nedwell and Turnpenny 1998, Nedwell et al. 2007). Auditory weighting functions have been proposed for marine mammals, specifically associated with PTS thresholds expressed in metrics that consider what is known about marine mammal hearing (e.g., SEL ($L_E$)) (Southall et al. 2007, Erbe et al. 2016a, Finneran 2016). Marine mammal auditory weighting functions published by Finneran (2016) are included in the NMFS (2018) Technical Guidance for use in conjunction with corresponding PTS (injury) onset acoustic criteria. Figure 4 shows the resulting frequency-weighting curves.

Applying marine mammal auditory weighting functions emphasizes the importance of making measurements and characterizing sound sources in terms of their overlap with biologically-important frequencies (e.g., frequencies of environmental signals, communication, or the detection of predators or prey), and not only the frequencies of interest or concern for the sound-producing activity such as a vessel (i.e., context of sound source; NMFS 2018).

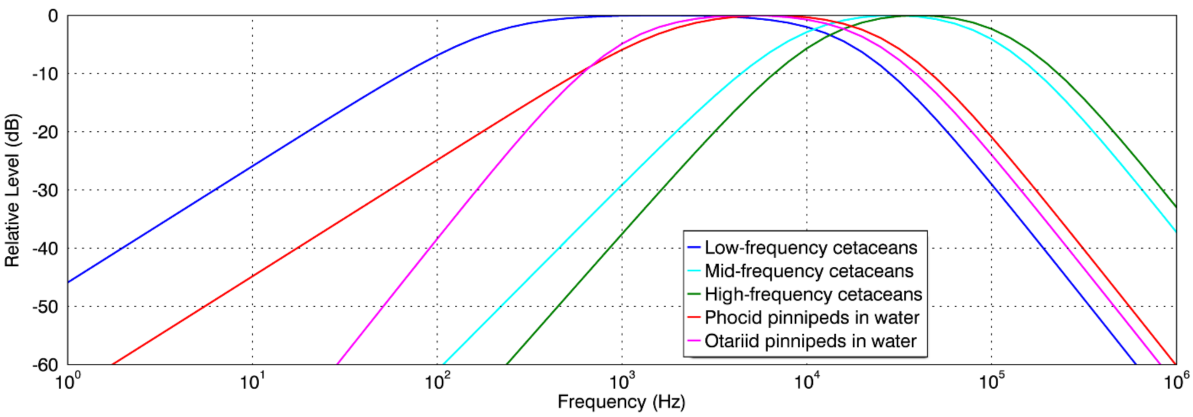


Figure 4. Auditory weighting functions for functional marine mammal hearing groups as recommended by NMFS (2018).

### 4.3.2. Acoustic Masking

Acoustic masking occurs when a sound impedes the ability of the animal to perceive a biologically relevant signal. For this to occur, the sound must be loud enough, have overlapping frequency content with the signal, and must happen at the same time. Both anthropogenic and natural marine sound can affect hearing and partially or completely reduce an individual's ability to effectively communicate; detect important predator, prey, and/or conspecific signals; and distinguish important environmental features associated with spatial orientation (Clark et al. 2009).

The effects of auditory masking range from behavioural disruption or lack of appropriate behavioural reactions, increased vulnerability to predators or reduced access to prey, changes in vocal behaviour to reduced communication space (Clark et al. 2009) or listening range (Pine et al. 2018). These effects can be detrimental to the fitness and survival of individuals. Erbe et al. (2019) provide an overview of the effects of ship noise on marine mammals including masking effects.

The severity and extent of auditory masking depends on the spectral and temporal characteristics of both the signal and the noise. The masking effect can be reduced if the signal and noise are separated in time, frequency, or direction (space). The zone of auditory masking can maximally be as large as the zone of audibility, i.e., a faint noise might mask a faint signal. Auditory masking ends immediately after the masking sound ceases.

Repeating a signal or lengthening it may reduce the amount of masking because whales seem most reactive when the sound level is increasing and at the onset of a sound. Although limited, the data suggest that stationary industrial activities producing non-impulsive sounds (such as dredging, drilling, and oil-production-related activities) result in less dramatic vocal reactions by cetaceans than do moving sound sources, particularly ships (Richardson et al. 1995). Masking and the potential effects of masking on communication and listening space of marine mammals are not fully understood and remain an area of active research (Terhune et al. 1979, Cunningham and Mountain 2014, Tennessen and Parks 2016, Cholewiak et al. 2018, Dunlop 2018, Gabriele et al. 2018, Putland et al. 2018, Dunlop 2019).

Detailed information on documented masking effects of noise exposure and compensation strategies of marine mammals is provided in Appendix B.1.1.

#### *4.3.2.1. Acoustic Masking Criteria*

To date, there are no exposure criteria for the onset of acoustic masking.

### 4.3.3. Behavioural Responses

Behavioural changes in response to underwater sound vary greatly, and there are many examples of individuals of the same species exposed to the same sound level reacting differently (Nowacek et al. 2007). An individual's response to a stimulus is dependent on the context in which the stimulus is received and the individual's perceived relevance of that stimulus. Several biological and environmental factors can affect the response, including age, sex, behavioural state at the time of exposure (e.g., resting, foraging, migrating, or socializing), perceived motion of the sound, and proximity and nature of the sound source. As a result, there is currently no consensus in the scientific community on the appropriate sound exposure metric for assessing behavioural reactions. Erbe et al. (2019) provide an overview of the effects of ship noise on marine mammals including behavioural effects. However, it is recognized that the context in which the sound is received affects the nature and extent of responses to a stimulus (Southall et al. 2007, Ellison and Frankel 2012); this means that individual animals will react differently depending on their previous experience, their life stage (e.g., mother-calf pairs versus solitary adult males), and the motivation to continue the ongoing activity (feeding).

Detailed information on documented behavioural responses of marine mammals to noise exposure is provided in Appendix B.1.2.

#### *4.3.3.1. Behavioural Exposure Criteria*

Because of the complexity and variability of marine mammal behavioural responses to acoustic exposure, NMFS has not yet released technical guidance on behaviour thresholds for use in calculating animal exposures.

The NMFS (2018) noise criterion for non-impulsive sounds was selected for this assessment because it represents the most commonly applied behavioural response criterion by regulators for non-impulsive noise sources. The distances at which behavioural responses could occur were therefore determined to occur in areas ensonified above an unweighted SPL of 120 dB re 1 µPa (NMFS 2014).

This behavioural criterion, however, is a conservative estimate. Moreover, it will vary between functional hearing groups and species due to differences in hearing sensitivity and, as mentioned, it will vary with the behavioural context.

## 4.3.4. Noise-Induced Physical Impacts/ Injury

Noise-induced injury leading to mortality may occur from exposure to high levels of impulsive sound or events characterized by rapid overpressure in water (Ketten 1995, Landsberg 2000). Physical impacts to the auditory apparatus can occur from exposure to intense sound and may result in a loss of hearing sensitivity. A temporary threshold shift (TTS) is hearing loss that is recovered over time, whereas permanent threshold shift (PTS) is hearing loss that does not recover. The severity of TTS is expressed as the magnitude of the shift in hearing sensitivity relative to pre-exposure sensitivity and the duration of hearing impairment. TTS occurs at lower sound levels than PTS. Though the relationship between the onset levels of TTS and the onset levels of PTS is not fully understood for marine mammal species, PTS onset acoustic thresholds have been extrapolated from marine mammal TTS measurements using growth rates from terrestrial and marine mammal data (NMFS 2018).

Injury to the hearing apparatus of a marine mammal may result from a noise exposure measured in terms of sound exposure level (SEL), which considers the sound level and duration of the exposure signal. Intense sounds may also damage the hearing apparatus independent of their duration, so an additional metric of peak pressure (PK) is needed for assessing acoustic exposure injury risk.

Detailed information on documented noise-induced physical impacts on marine mammals is provided in Appendix B.1.3.

### *4.3.4.1. Injury Exposure Criteria*

There are data that indicate the received sound levels at which TTS occurs, so PTS onset is extrapolated from TTS onset level and an assumed growth function (Southall et al. 2007). NMFS (2018) criteria incorporate the best available science to estimate PTS onset in marine mammals from sound energy accumulated over 24 h (SEL), or very loud, instantaneous peak sound pressure levels (PK). These dual threshold criteria of SEL and PK are used to calculate marine mammal exposures (Table 8).

Table 8. Summary of relevant PTS and TTS onset acoustic thresholds (NMFS 2018)

| Hearing group | PTS onset thresholds* (received level) | | TTS onset thresholds* (received level) | |
|---|---|---|---|---|
| | Impulsive | Non-impulsive | Impulsive | Non-impulsive |
| Low-frequency (LF) cetaceans | $L_{pk, flat}$: 219 dB<br>$L_{E, LF, 24h}$: 183 dB | $L_{E, LF, 24h}$: 199 dB | $L_{pk}$: 213 dB<br>$L_{E, LF}$: 168 dB | $L_{E, LF}$: 179 dB |
| Mid-frequency (MF) cetaceans | $L_{pk, flat}$: 230 dB<br>$L_{E, MF, 24h}$: 185 dB | $L_{E, MF, 24h}$: 198 dB | $L_{pk}$: 224 dB<br>$L_{E, MF}$: 170 dB | $L_{E, MF}$: 178 dB |
| High-frequency (HF) cetaceans | $L_{pk, flat}$: 202 dB<br>$L_{E, HF, 24h}$: 155 dB | $L_{E, HF, 24h}$: 173 dB | $L_{pk}$: 196 dB<br>$L_{E, HF}$: 140 dB | $L_{E, HF}$: 153 dB |
| Phocid pinnipeds (PW) (underwater) | $L_{pk, flat}$: 218 dB<br>$L_{E,PW, 24h}$: 185 dB | $L_{E, PW, 24h}$: 201 dB | $L_{pk}$: 212 dB<br>$L_{E, PW}$: 170 dB | $L_{E, PW}$: 181 dB |
| Otariid pinnipeds (OW) (underwater) | $L_{pk, flat}$: 232 dB<br>$L_{E, OW, 24h}$: 203 dB | $L_{E, OW, 24h}$: 219 dB | $L_{pk}$: 226 dB<br>$L_{E, OW}$: 188 dB | $L_{E, OW}$: 199 dB |

* Dual metric acoustic thresholds for impulsive sounds: Use whichever results in the largest isopleth for calculating PTS onset. If a non-impulsive sound has the potential of exceeding the peak sound pressure level thresholds associated with impulsive sounds, these thresholds should also be considered.
$L_{pk, flat}$–peak sound pressure is flat weighted or unweighted and has a reference value of 1 µPa.
$L_E$ denotes cumulative sound exposure over a 24-hour period and has a reference value of 1 µPa²s.
The subscript associated with cumulative sound exposure level thresholds indicates the designated marine mammal auditory weighting.

### 4.3.5. Potential Impacts

There are indications that detecting anthropogenic noise can cause stress in marine mammals (e.g., Richardson et al. 1995, Nowacek et al. 2007, Erbe et al. 2019). However, it remains unclear what aspects of the noise (unfamiliarity, acoustic characteristics, behavioural context) are relevant in this context, to what extent stress is caused by non-impulsive noise, and what consequences an audible noise exposure would have for an individual.

The effect of acoustic masking will cease as soon as the noise emission ends, either by switching off the sound source or if the animal is leaving the ensonified area. The information conveyed by environmental sounds to marine mammals in the Western Port Bay area can be of significance for the fitness and survival of an individual as predators (e.g., killer whales) may enter the area but acoustic masking of their vocalizations is unlikely as they operate at frequencies different to the noise emitted by the operations at the Gas Import Jetty. Masking of mother-calf communication is the only aspect of increased significance in this context, but this is likely limited to low-frequency cetaceans, which are unlikely to enter the area and have means of compensating for increased masking in noisy environments (Lombard effect). Any acoustic masking by the noise emitted from the vessels and operations at the Gas Import Jetty would have a minor impact for individual marine mammals and a negligible impact on a population level.

Due to the non-impulsive nature of the noise emitted by the vessels and operations at the Gas Import Jetty, behavioural changes in response to the noise are likely limited to spatial avoidance of the area. Marine mammals have been documented to tolerate high levels of non-impulsive noise (such as vessel noise) when they are most likely motivated by food availability in the area. As the Western Port area is not an important habitat for marine mammals, avoidance of the area would have negligible on at the population level.

Sounds resembling the acoustic signature of vessels or operations at the Gas Import Jetty have not been tested in any of the TTS studies. Exposure to noise levels exceeding the TTS and PTS thresholds is limited to the direct vicinity of the sound sources. The acoustic propagation model used by Koessler et al. (2019) assumed that all noise originated at a single point in the middle of the vessels/FSRU. As multiple noise sources (pumps, machinery, etc.) are located at various points at the Gas Import Jetty, this assumption leads to a precautionary but, ultimately, unrealistic overestimation of the of emitted noise levels. Moreover, the range at which the PTS threshold is reached is too small to be practically approached by any marine mammal. The TTS range is equally small and restricted to the direct proximity of the Gas Import Jetty. While marine mammals have been reported to tolerate high noise levels, it is highly unlikely that any animal would remain within the TTS zone long enough to exceed the exposure duration required to experience this effect. In the unlikely event that the exposure duration was exceeded, it could potentially have a major for the individual marine mammals, however this would still only have a minor impact at the population level.

The endangered southern right whales as well as the vulnerable humpback whales and Australian sea lions are not likely to be negatively affected to an extent that would negatively affect their population size, population continuity or species recovery.

## 4.4. Fishes

Most fish are primarily sensitive to particle motion effects, while fish with hearing that involves the swim bladder are more sensitive to sound pressure (Popper and Hawkins 2019, Popper et al. 2019). Therefore, the most relevant metric for perceiving underwater sound for most fish species is particle motion. With the exception of few species (Popper and Fay 2011, Popper et al. 2014), there is an almost complete lack of relevant data on particle motion sensitivity in fish (Popper and Hawkins 2018).

Auditory masking and behavioural effects can be assessed qualitatively, by assessing relative risk rather than by specific sound level thresholds. However, as these depend upon activity-based subjective ranges, these effects are not addressed in this report and are included for completeness only. Because the presence or absence of a swim bladder has a role in hearing, fish's susceptibility to injury from noise exposure depends on the species and the presence and possible role of a swim bladder in hearing. Thus, different thresholds were proposed for fish without a swim bladder (also appropriate for sharks and applied to whale sharks in the absence of other information), fish with a

swim bladder not used for hearing, and fish that use their swim bladders for hearing (see Figure 5 for hearing curves ('audiograms')). Turtles, fish eggs, and fish larvae are considered separately.

Based on their morphology, the Popper et al. (2014) classifications can be assigned to the following families or species of fish, common in Australian waters:

- Fish with swim bladders or other gas volumes, whose hearing does not directly involve the swim bladder, e.g., snappers, emperors, groupers and rock cods (Lutjanids and Lethrinids such as *Pristipomoides* spp., *Lethrinus* spp., *Lutjanus* spp., and family Serranidae), and some species of tuna (Thunnus sp.) (Tavolga and Wodinsky 1963, Bertrand and Josse 2000, Ramcharitar et al. 2006, Braun and Grande 2008, Engineering-Environmental Management 2008, Song et al. 2008, Caiger et al. 2012);
- Fish whose hearing does directly involve a swim bladder or other gas volume, e.g., family Clupeidae (herrings, sardines, pilchards, and shads), family Gadidae (true cods such as whiting), and potentially some nearshore/reef species relevant to tropical Australia, including some Pomacentridae (damsel fish and clown fish), some Holocentridae (soldierfish and squirrelfish), and some Haemulidae (grunters and sweetlips) (Nedwell et al. 2004, Braun and Grande 2008, Popper et al. 2014); and
- Fish without a swim bladder (e.g., mackerel, *Scomberomorus spp*., some species of tuna, *Thunnus spp*, and sharks, including whale sharks, *Rhincodon* typus) (Casper et al. 2012, Popper et al. 2014, Carroll et al. 2017).

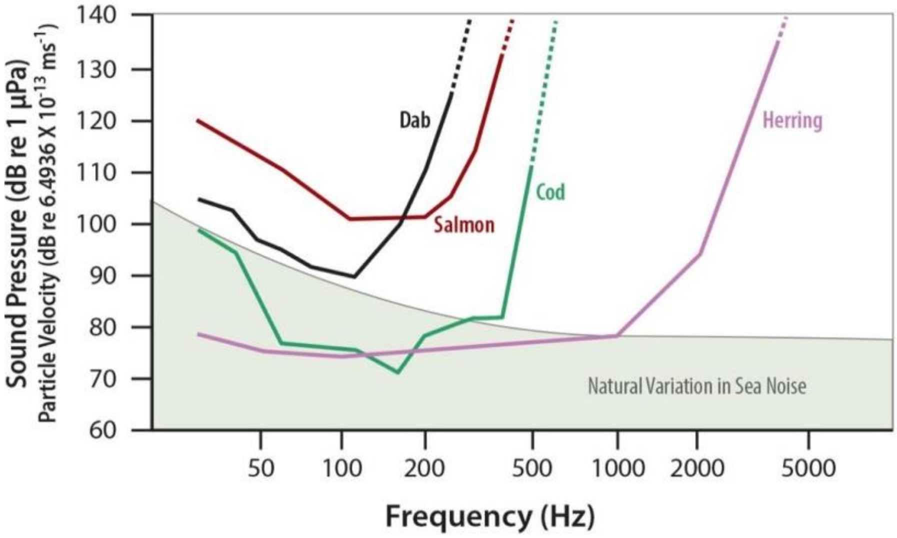


Figure 5. Fish audiograms obtained under open sea, free-field conditions (taken from Popper et al. (2019)). Dab (*Limanda limanda*) are bottom-living fish with no swim bladder (category I in Table 9), salmon (*Salmo salar*) have a swim bladder that does appear to play a role in hearing (category II in Table 9), cod (*Gadus morhua*) have a swim bladder that is involved in hearing but not intimately connected to the ear (category III in Table 9) and herring have special structures mechanically linking the swim bladder to the ear (category III. in Table 9).

Detailed information on documented noise-induced impacts on fish is provided in Appendix B.2.

### 4.4.1. Exposure Criteria

The US Working Group on the Effects of Sound on Fish and Turtles developed guidelines with specific thresholds for different levels of effects for several species groups (Popper et al. 2014). The guidelines define quantitative thresholds for three types of immediate effects:

- Mortality, including injury leading to death;
- Recoverable injury, including injuries unlikely to result in mortality, such as auditory hair cell damage and minor haematoma; and
- Temporary threshold shift (TTS).

Table 9 lists the relevant effects thresholds from Popper et al. (2014) for shipping and non-impulsive noise. Some evidence suggests that fish sensitive to acoustic pressure show a recoverable loss in hearing sensitivity or injury when exposed to high levels of noise (Scholik and Yan 2002, Amoser and Ladich 2003, Smith et al. 2006).; This is reflected in the SPL thresholds for fish with a swim bladder involved in hearing.

Table 9. Criteria for vessel noise exposure for fish and turtles, adapted from Popper et al. (2014)

| Type of animal | Mortality and Potential mortal injury | Impairment | | | Behaviour |
|---|---|---|---|---|---|
| | | Recoverable injury | TTS | Masking | |
| I. Fish:<br>No swim bladder1 (particle motion detection) | (N) Low<br>(I) Low<br>(F) Low | (N) Low<br>(I) Low<br>(F) Low | (N) Moderate<br>(I) Low<br>(F) Low | (N) High<br>(I) High<br>(F) Moderate | (N) Moderate<br>(I) Moderate<br>(F) Low |
| II. Fish:<br>Swim bladder not involved in hearing (particle motion detection) | (N) Low<br>(I) Low<br>(F) Low | (N) Low<br>(I) Low<br>(F) Low | (N) Moderate<br>(I) Low<br>(F) Low | (N) High<br>(I) High<br>(F) Moderate | (N) Moderate<br>(I) Moderate<br>(F) Low |
| III. Fish:<br>Swim bladder involved in hearing[2]<br>(primarily pressure detection) | (N) Low<br>(I) Low<br>(F) Low | 170 dB SPL for 48 h | 158 dB SPL for 12 h | (N) High<br>(I) High<br>(F) High | (N) High<br>(I) Moderate<br>(F) Low |
| Fish eggs and fish larvae | (N) Low<br>(I) Low<br>(F) Low | (N) Low<br>(I) Low<br>(F) Low | (N) Low<br>(I) Low<br>(F) Low | (N) High<br>(I) Moderate<br>(F) Low | (N) Moderate<br>(I) Moderate<br>(F) Low |

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

## 4.4.2. Potential Impacts

Noise exposure can elevate stress levels in fish. Depending on their sensitivity to sound (mediated by sound pressure or particle motion), this level varies between species. The rationale for assessing the consequences of detecting noise for fish is similar to marine mammals, as there is little to no information on the relevant aspects of the noise (unfamiliarity, acoustic characteristics, behavioural context) potentially causing stress, to what extent stress is caused by non-impulsive noise, and what consequences a noise exposure would have for an individual. Being able to hear the noise emitted from the vessels and operations at the Gas Import Jetty is considered to have minor consequences for individual fish and a negligible impact at a population level.

The acoustic masking effect directly linked to the duration of the operation (or an animal's presence in the area) and will therefore cease as soon as the noise emission ends. The information conveyed by environmental sounds to fish, in contrast to marine mammals, may be relevant to individual fish if it reveals the presence of food or masks the presence of a predator. The consequence of acoustic masking for individual fish is considered to be moderate and, due to a limited number of animals likely experiencing this effect have only a minor impact on a population level.

Behavioural changes by fish to exposure to non-impulsive noise are likely limited to spatial avoidance of the ensonified area. Fish have been documented to tolerate high levels of non-impulsive noise (such as vessel noise), which is most likely motivated by food availability in the area or to desensitize to the sound exposure. The worst-case scenario would be a permanent exclusion from a spatially limited area around the Gas Import Jetty, and the consequence for individual fish would be moderate,

[1] The swim bladder is missing in some bottom-dwelling and deep-sea bony fish (teleosts) and in all cartilaginous fish (sharks, skates, and rays)
[2] The group includes some of the squirrelfish (Holocentridae), drums and croakers (Sciaenidae), herrings (Clupeidae), and the large group of Otophysan fish (a non-taxonomic) group consisting of four distinct orders: Cypriniformes (minnows), Characiformes (characins), Siluriformes (catfish) and Gymnotiformes (knifefish).

as only a limited portion of the fish population in Western Port Bay is likely to experience negative consequences from behavioural responses, the impact would be minor at a population level.

The relevance of PTS for fish is reduced compared to marine mammals, as fish can regenerate their auditory sensory cells, i.e., their hearing sensitivity recovers even after the most intense (but not mortal) noise exposure. The number of fish exposed to such levels can be expected to be low. If it were to occur, any temporary hearing impairment (in this case TTS and PTS) would have minor to moderate consequences for an individual and a minor impact on a population level.
None of the fish species listed under the FFG Act are likely to be negatively affected to an extent that would negatively affect their population size, population continuity or species recovery.

## 4.5. Invertebrates

Documented noise-induced impacts on marine invertebrates are detailed in Appendix B.3.

### 4.5.1. Exposure Thresholds

There are no thresholds or guidelines regulating the exposure of marine invertebrates to underwater noise.

### 4.5.2. Potential Impact

Stress responses to non-impulsive sound exposure have been documented for marine invertebrates. The worst-case consequence for individual animals can be expected to be moderate to major, but due to the limited spatial extent of the affected area population consequences are considered to be minor.

There is no systematic information available if and to which extent marine invertebrates use acoustic cues to communicate with conspecifics or their environment. Anecdotal information indicates no functional relevance of sound for these animals; vibration, such as ground-borne or near-field particle motion, however, can be assumed to have functional relevance as it provides information about potential food availability or approaching predators. This information could potentially be masked by the noise/particle motion emitted by the vessels and operations at the Gas Import Jetty, even though this effect would be limited to the direct vicinity to the Jetty. The consequence of (acoustic/vibrational) masking is considered to be, in the worst case, moderate for individuals. Due to an expected limited number of individuals experiencing this masking, it would have a negligible on a population level.

There are limited and inconclusive data available on the potential for behavioural responses and noise-induced physical effects on marine invertebrates. Theoretically, behavioural responses as well as significant sensory impairment or injury can have moderate to major consequences for an individual. In the absence of conclusive scientific information on the scope of these effects and the animals' ability to compensate for the effects, however, it is impossible to assess the consequences of behavioural responses and noise-induced impairment or injury.

## 4.6. Avifauna

There is very little scientific information available on the potential impact of non-impulsive noise on marine birds (Appendix B.4).

### 4.6.1. Exposure Thresholds

There are no thresholds or assessment criteria for noise impacts to seabirds.
Auditory cues are critical to marine birds in their communication with conspecifics in air (Jouventin 1982). To date, only the Macaroni penguin (*Eudyptes chrysolophus*), has been proven to produce sound underwater; Markov (1977) documented that their vocalizations at frequencies range from 2.5 to 7 kHz, but the functionality of these sounds and therefore the role acoustic cues play for birds underwater remains unclear. As yet, hearing in birds has been tested predominantly in terrestrial

species (Dooling 2010). Anderson-Hansen et al. (2017) provided the first underwater audiogram for a diving bird, the great cormorant (*Phalacrocorax carbo*) showing sensitivity for at least 1–4 kHz with greatest sensitivity of 70 dB SPL found at 2 kHz. Mooney et al. (2019) found comparable results for two seabird species, the common murre (*Uria aalge*) and the Atlantic puffin (*Fratercula arctica*); best hearing sensitivity was measured at 2 kHz for the puffin and 1 kHz for the murre, the overall hearing range was greatest for the puffin including frequencies between 0.5 to 6 kHz. Wever et al. (1969) investigated the hearing of African (Black-footed) penguins (*Pheniscus demersus*) and documented a similar hearing range for this species. Apart from this, there is limited data on the hearing range or sound-induced effects for birds underwater.

### 4.6.2. Potential Impact

The existing literature indicates that diving birds may be able to perceive underwater sound, but to date there is no indication that birds use underwater sound to forage or communicate, or that they would be impacted by exposure to underwater noise. The effect of hearing underwater sound and experiencing acoustic masking is considered negligible for birds, both individually and on a population level.

Because of the lack of information related to the underwater hearing capabilities of birds, no assessment of consequences of potential behavioural responses or noise-induced impairment or injury was conducted.

# 5. Conclusion

This underwater noise impact assessment has been undertaken to determine the potential impacts of the Project on marine fauna receptors, and to identify recommended mitigation measures where appropriate in order to reduce potential risks of the Project. Based on the outcomes of the assessment of potential impacts of underwater noise emitted by the operations at the Gas Import Jetty, the Project is considered to satisfy the relevant draft evaluation objective. There is no risk for direct loss of fauna species listed as threatened under the FFG Act. The ecological character of the Western Port Bay area will not be altered by the underwater noise emissions from the Gas Import Jetty beyond the already existing harbour area.

## 5.1. Impact Assessment Summary

The key noise-related impacts on the marine fauna of operating the Gas Import Jetty will be related to an increase in stress levels, acoustic masking, and behavioural responses such as avoidance. The risk of noise-induced physical impacts or injuries is either very low or unlikely to occur. The noise emission will not cause significant changes to the soundscape in a pre-existing harbour area. The Gas Import Jetty is located at an existing operating Port jetty with vessels unloading petroleum products on a weekly basis and is within a larger Port zone. The jetty is within 700 m of the main shipping channel with a present total of ~150 shipping movements per year of commercial vessels to 250 m (excluding tug movements). The jetty is located in a popular recreational fishing area with a high number of small (5 to 8 m) recreational vessels passing near the jetty in peak season. The additional noise input caused by the operation of the Gas Import Jetty may lead to consequences for individual marine animals, but it is not expected to influence species on a population level.
Behavioural responses of marine animals to the noise emitted by GIJPP operations will be limited in range; it is therefore unlikely that recreational fisheries will be affected beyond the immediate vicinity of the operations. Few species listed as threatened or vulnerable under the EPBC Act or listed under the FFG Act occur and for those that do, it is the occasional presence of one to a few individuals.

## 5.2. Residual Risk

A risk assessment was used that identified potential construction and operational risks and associated risk pathways, consequences of impacts on underwater noise and the likelihood of these impacts occurring to arrive at a risk rating. There are no risks with a residual risk of rating of medium or above.

# Abbreviations

| Abbreviation | Definition |
|---|---|
| ANSI | American National Standards Institute |
| DOSITS | Discovery of Sound in the Sea |
| EPBC | Environment Protection and Biodiversity Conservation Act 1999 |
| FFG | Flora and Fauna Guarantee Act 1988 |
| FPSO | Floating Production Storage and Offload |
| FSRU | Floating Storage Regasification Unit |
| GIJPP | Gas Import Jetty and Pipeline Project |
| HF | High frequency (cetacean) |
| IEC | International Electrotechnical Commission |
| ISO | International Organization for Standardization |
| JASCO | JASCO Applied Sciences (Australia) Pty Ltd. |
| LF | Low frequency (cetacean) |
| LNG | Liquified Natural Gas |
| MF | Mid frequency (cetacean) |
| NITS | Noise-induced threshold shift |
| NMFS | National Marine Fisheries Service |
| NRC | National Research Council |
| OW | Otariids (water) |
| PK | Peak |
| PL | Propagation loss |
| PW | Phocid (water) |
| PTS | Permanent Threshold Shift |
| RMS | Root Mean Square |
| SEL | Sound Exposure Level |
| SL | Source Level |
| SPL | Sound Pressure Level |
| TL | Transmission loss |
| TTS | Temporary Threshold Shift |
| U.S. | United States of America |

# Glossary

| Term | Definition |
|---|---|
| 1/3-octave | One third of an octave. Note: A one-third octave is approximately equal to one decidecade (1/3 oct ≈ 1.003 ddec; ISO 2017). |
| 1/3-octave-band | Frequency band whose bandwidth is one one-third octave. Note: The bandwidth of a one-third octave-band increases with increasing centre frequency. |
| 90%-energy time window | The time interval over which the cumulative energy rises from 5 to 95% of the total pulse energy. This interval contains 90% of the total pulse energy. Symbol: $T_{90}$. |
| 90% sound pressure level (90% SPL) | The root-mean-square sound pressure levels calculated over the 90%-energy time window of a pulse. Used only for pulsed sounds. |
| A-weighting | Frequency-selective weighting for human hearing in air that is derived from the inverse of the idealized 40-phon equal loudness hearing function across frequencies. |
| Absorption | The reduction of acoustic pressure amplitude due to acoustic particle motion energy converting to heat in the propagation medium. |
| Acoustic masking | Obscuring of sounds of interest by sounds at similar frequencies. |
| Ambient noise | All-encompassing sound at a given place, usually a composite of sound from many sources near and far (ANSI S1.1-1994 R2004), e.g., shipping vessels, seismic activity, precipitation, sea ice movement, wave action, and biological activity. |
| Attenuation | The gradual loss of acoustic energy from absorption and scattering as sound propagates through a medium. |
| Audiogram | A graph of hearing threshold level (sound pressure levels) as a function of frequency, which describes the hearing sensitivity of an animal over its hearing range. |
| Auditory frequency weighting (auditory weighting function, frequency-weighting function) | 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 (ISO 2017). |
| Azimuth | A horizontal angle relative to a reference direction, which is often magnetic north or the direction of travel. In navigation it is also called bearing. |
| Background noise | Total of all sources of interference in a system used for the production, detection, measurement, or recording of a signal, independent of the presence of the signal (ANSI S1.1-1994 R2004). Ambient noise detected, measured, or recorded with a signal is part of the background noise. |
| Bandwidth | The range of frequencies over which a sound occurs. Broadband refers to a source that produces sound over a broad range of frequencies (e.g., seismic airguns, vessels) whereas narrowband sources produce sounds over a narrow frequency range (e.g., sonar) (ANSI/ASA S1.13-2005 R2010). |
| Bar | Unit of pressure equal to 100 kPa, which is approximately equal to the atmospheric pressure on Earth at sea level. 1 bar is equal to 105 Pa or 1011 µPa. |
| Continuous sound | A sound whose sound pressure level remains above ambient sound during the observation period (ANSI/ASA S1.13-2005 R2010). A sound that gradually varies in intensity with time, for example, sound from a marine vessel. |
| Decibel (dB) | One-tenth of a bel. Unit of level when the base of the logarithm is the tenth root of ten, and the quantities concerned are proportional to power (ANSI S1.1-1994 R2004). |
| Frequency | The rate of oscillation of a periodic function measured in cycles-per-unit-time. The reciprocal of the period. Unit: hertz (Hz). Symbol: $f$. 1 Hz is equal to 1 cycle per second. |
| Functional hearing group | Groups of marine mammal species with similar hearing ranges. Commonly defined functional hearing groups include low-, mid-, and high-frequency cetaceans, phocid pinnipeds (in air and water) and otariid pinnipeds (in air and water). |

| Term | Definition |
|---|---|
| Hearing threshold | The sound pressure level for any frequency of the hearing group that is barely audible for a given individual in the absence of significant background noise during a specific percentage of experimental trials. |
| High-frequency cetacean | The functional cetacean hearing group that represents those odontocetes (toothed whales) specialized for hearing high frequencies. |
| Hertz (Hz) | A unit of frequency defined as one cycle per second. |
| Impulsive sound | Sound that is typically brief and intermittent with rapid (within a few seconds) rise time and decay back to ambient levels (NOAA 2013, ANSI S12.7-1986 R2006). For example, seismic airguns and impact pile driving. |
| Intermittent sound | A level of sound that abruptly drops to the background noise level several times during the observation period. |
| Low-frequency cetacean | The functional cetacean hearing group that represents mysticetes (baleen whales) specialized for hearing low frequencies. |
| Mid-frequency cetacean | The functional cetacean hearing group that represents those odontocetes (toothed whales) specialized for mid-frequency hearing. |
| Non-impulsive sound | Sound that is broadband, narrowband or tonal, brief or prolonged, continuous or intermittent, and typically does not have a high peak pressure with rapid rise time (typically only small fluctuations in decibel level) that impulsive signals have (ANSI/ASA S3.20-1995 R2008). For example, marine vessels, aircraft, machinery, construction, and vibratory pile driving (NIOSH 1998, NOAA 2015). |
| Odontocete | The presence of teeth, rather than baleen, characterizes these whales. Members of the Odontoceti are a suborder of cetaceans, a group comprised of whales, dolphins, and porpoises. The skulls of toothed whales are mostly asymmetric, an adaptation for their echolocation. This group includes sperm whales, killer whales, belugas, narwhals, dolphins, and porpoises. |
| Otariid | A common term used to describe members of the Otariidae, eared seals, commonly called sea lions and fur seals. Otariids are adapted to a semi-aquatic life; they use their large fore flippers for propulsion. Their ears distinguish them from phocids. Otariids are one of the three main groups in the superfamily Pinnipedia; the other two groups are phocids and walrus. |
| Particle motion, sound | The magnitude and direction of movement of particles making up the media due to presence of a sound wave. Particle motion is expressed as a vector quantifying movement such as displacement, velocity, or acceleration |
| Peak pressure level (PK) | The maximum instantaneous sound pressure level, in a stated frequency band, within a stated period. Also called zero-to-peak pressure level. Unit: decibel (dB). |
| Permanent threshold shift (PTS) | A permanent loss of hearing sensitivity caused by excessive noise exposure. PTS is considered auditory injury. |
| Phocid | A common term used to describe all members of the family Phocidae. These true/earless seals are more adapted to in-water life than are otariids, which have more terrestrial adaptations. Phocids use their hind flippers to propel themselves. Phocids are one of the three main groups in the superfamily Pinnipedia; the other two groups are otariids and walrus. |
| Pinniped | A common term used to describe all three groups that form the superfamily Pinnipedia: phocids (true seals or earless seals), otariids (eared seals or fur seals and sea lions), and walrus. |
| Pressure, acoustic | The deviation from the ambient hydrostatic pressure caused by a sound wave. Also called overpressure. Unit: pascal (Pa). Symbol: $p$. |
| Sound exposure level (SEL) | A cumulative measure related to the sound energy in one or more pulses. Unit: dB re 1 $\mu Pa^2 \cdot s$. SEL is expressed over the summation period (e.g., per-pulse SEL [for airguns], single-strike SEL [for pile drivers], 24-hour SEL). |

| Term | Definition |
|---|---|
| Sound pressure level (SPL) | The decibel ratio of the time-mean-square sound pressure, in a stated frequency band, to the square of the reference sound pressure (ANSI S1.1-1994 R2004).<br>For sound in water, the reference sound pressure is one micropascal ($p_0$ = 1 µPa) and the unit for SPL is dB re 1 µPa²:<br>$L_p = 10\log_{10}(p^2/p_0^2) = 20\log_{10}(p/p_0)$<br>Unless otherwise stated, SPL refers to the root-mean-square (rms) pressure level. See also 90% sound pressure level and fast-average sound pressure level. Non-rectangular time window functions may be applied during calculation of the rms value, in which case the SPL unit should identify the window type. |
| Source level | The sound level measured in the far-field and scaled back to a standard reference distance of 1 metre from the acoustic centre of the source. Unit: dB re 1 µPa·m (pressure level) or dB re 1 µPa²·s·m (exposure level). |
| Temporary threshold shift (TTS) | Temporary loss of hearing sensitivity caused by excessive noise exposure. |

# Literature Cited

[DOSITS] Discovery of Sound in the Sea. 2019. University of Rhode Island and Inner Space Center. http://www.dosits.org/. (Accessed 5 Dec 2019).

[IEC] International Electrotechnical Commission. 1994. *IEC 60050-801:1994 International Electrotechnical Vocabulary: Acoustics and electroacoustics*. Geneva. http://www.electropedia.org.

[ISO] International Organization for Standardization. 2017. *ISO 18405:2017. Underwater acoustics – Terminology*. Geneva. https://www.iso.org/standard/62406.html.

[NIOSH] National Institute for Occupational Safety and Health. 1998. *Criteria for a recommended standard: Occupational noise exposure. Revised Criteria*. Document Number 98-126. US Department of Health and Human Services, NIOSH, Cincinnati, OH, USA. 122 pp. https://www.cdc.gov/niosh/docs/98-126/pdfs/98-126.pdf.

[NMFS] National Marine Fisheries Service. 2014. *Marine Mammals: Interim Sound Threshold Guidance* (webpage). National Marine Fisheries Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce. http://www.westcoast.fisheries.noaa.gov/protected_species/marine_mammals/threshold_guidance.html.

[NMFS] National Marine Fisheries Service (US). 2018. *2018 Revision 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*. US Department of Commerce, NOAA. NOAA Technical Memorandum NMFS-OPR-59. 167 pp. https://www.fisheries.noaa.gov/webdam/download/75962998.

[NOAA] National Oceanic and Atmospheric Administration (US). 2013. *Draft guidance for assessing the effects of anthropogenic sound on marine mammals: Acoustic threshold levels for onset of permanent and temporary threshold shifts*. National Oceanic and Atmospheric Administration, US Department of Commerce, and NMFS Office of Protected Resources, Silver Spring, MD, USA. 76 pp.

[NOAA] National Oceanic and Atmospheric Administration (US). 2015. *Draft guidance for assessing the effects of anthropogenic sound on marine mammal hearing: Underwater acoustic threshold levels for onset of permanent and temporary threshold shifts*. NMFS Office of Protected Resources, Silver Spring, MD, USA. 180 pp.

[NRC] National Research Council (US). 2003. *Ocean Noise and Marine Mammals*. National Research Council (US), Ocean Studies Board, Committee on Potential Impacts of Ambient Noise in the Ocean on Marine Mammals. The National Academies Press, Washington, DC, USA. https://www.nap.edu/read/10564/chapter/1.

Aguilar de Soto, N., M. Johnson, P.T. Madsen, P.L. Tyack, A. Bocconcelli, and J.F. Borsani. 2006. Does intense ship noise disrupt foraging in deep-diving Cuvier's beaked whales (*Ziphius cavirostris*)? *Marine Mammal Science* 22(3): 690-699. https://doi.org/10.1111/j.1748-7692.2006.00044.x.

Aicher, B. and J. Tautz. 1990. Vibrational communication in the fiddler crab, *Uca pugilator*. *Journal of Comparative Physiology A* 166(3): 345-353. https://doi.org/10.1007/BF00204807.

Amoser, S. and F. Ladich. 2003. Diversity in noise-induced temporary hearing loss in otophysine fishes. *Journal of the Acoustical Society of America* 113(4): 2170-2179. https://doi.org/10.1121/1.1557212.

Amoser, S., L.E. Wysocki, and F. Ladich. 2004. Noise emission during the first powerboat race in an Alpine lake and potential impact on fish communities. *J Acoust Soc Am* 116(6): 3789.

Anderson-Hansen, K., A. Maxwell, U. Siebert, O.N. Larsen, and M. Wahlberg. 2017. Great cormorants (*Phalacrocorax carbo*) can detect auditory cues while diving. *The Science of Nature* 104(5): 45. https://doi.org/10.1007/s00114-017-1467-3.

André, M., M. Solé, M. Lenoir, M. Durfort, C. Quero, A. Mas, A. Lombarte, M. van der Schaar, M. López-Bejar, et al. 2011. Low-frequency sounds induce acoustic trauma in cephalopods. *Frontiers in Ecology and the Environment* 9(9): 489-493. https://doi.org/10.1890/100124.

Andrew, R.K., B.M. Howe, and J.A. Mercer. 2011. Long-time trends in ship traffic noise for four sites off the North American West Coast. *Journal of the Acoustical Society of America* 129(2): 642-651. https://doi.org/10.1121/1.3518770.

ANSI S12.7-1986. R2006. *American National Standard Methods for Measurements of Impulsive Noise*. American National Standards Institute, NY, USA.

ANSI S1.1-1994. R2004. *American National Standard Acoustical Terminology*. American National Standards Institute, NY, USA.

ANSI S1.1-2013. 2013. *American National Standard Acoustical Terminology*. American National Standards Institute, NY, USA.

ANSI/ASA S1.13-2005. R2010. *American National Standard Measurement of Sound Pressure Levels in Air*. American National Standards Institute and Acoustical Society of America, NY, USA.

ANSI/ASA S3.20-1995. R2008. *American National Standard Bioacoustical Terminology*. American National Standards Institute and Acoustical Society of America, NY, USA.

Au, W.L.W. and M.C. Hastings. 2008a. Hearing in Marine Animals. 337-400.

Au, W.W.L. and M.C. Hastings. 2008b. *Principles of Marine Bioacoustics*. Springer, New York. 510 pp. https://doi.org/10.1007/978-0-387-78365-9.

Bailey, H., G. Clay, E.A. Coates, D. Lusseau, B. Senior, and P.M. Thompson. 2010. Using T-PODs to assess variations in the occurrence of coastal bottlenose dolphins and harbour porpoises. *Aquatic Conservation: Marine and Freshwater Ecosystems* 20(2): 150-158. https://doi.org/10.1002/aqc.1060.

Barlow, J. 1988. Harbor porpoise, *Phocoena phocoena*, abundance estimation for California, Oregon, and Washington. I: Ship surveys. *Fishery Bulletin* 86(3): 417-432. https://www.st.nmfs.noaa.gov/spo/FishBull/863/barlow.pdf.

Berthe, C. and D. Lecchini. 2016. Influence of boat noises on escape behaviour of white-spotted eagle ray Aetobatus ocellatus at Moorea Island (French Polynesia). *C R Biol* 339(2): 99-103.

Bertrand, A. and E. Josse. 2000. Tuna target-strength related to fish length and swimbladder volume. *ICES Journal of Marine Science* 57(4): 1143-1146. https://doi.org/10.1006/jmsc.2000.0881.

Blair, H.B., N.D. Merchant, A.S. Friedlaender, D.N. Wiley, and S.E. Parks. 2016. Evidence for ship noise impacts on humpback whale foraging behaviour. *Biology Letters* 12(8). https://doi.org/10.1098/rsbl.2016.0005.

Braun, C.B. and T. Grande. 2008. Evolution of Peripheral Mechanisms for the Enhancement of Sound Reception. *In* Webb, J.F., R.R. Fay, and A.N. Popper (eds.). *Fish Bioacoustics*. Springer, NY, USA. pp 99-144. https://doi.org/10.1007/978-0-387-73029-5_4.

Buckstaff, K.C. 2004. Effects of watercraft noise on the acoustic behavior of bottlenose dolphins, *Tursiops truncatus*, in Sarasota Bay, Florida. *Marine Mammal Science* 20(4): 709-725. https://doi.org/10.1111/j.1748-7692.2004.tb01189.x.

Buerkle, U. 1974. Gill-net catches of cod (Gadus morhua L.) in relation to trawling noise. *Mar. Behav. Physiol.* 2: 277-281.

Burgess, W.C., P.L. Tyack, B.J. Le Boeuf, and D.P. Costa. 1998. A programmable acoustic recording tag and first results from free-ranging northern elephant seals. *Deep Sea Research Part II: Topical Studies in Oceanography* 45(7): 1327-1351. http://www.sciencedirect.com/science/article/pii/S0967064598000320.

Burnham, R., D. Duffus, and X. Mouy. 2018. Gray Whale (*Eschrictius robustus*) Call Types Recorded During Migration off the West Coast of Vancouver Island. *Frontiers in Marine Science* 5(329). https://doi.org/10.3389/fmars.2018.00329.

Caiger, P.E., J.C. Montgomery, and C.A. Radford. 2012. Chronic low-intensity noise exposure affects the hearing thresholds of juvenile snapper. *Marine Ecology Progress Series* 466: 225–232.

Carroll, A.G., R. Przeslawski, A. Duncan, M. Gunning, and B. Bruce. 2017. A critical review of the potential impacts of marine seismic surveys on fish & invertebrates. *Marine Pollution Bulletin* 114: 9-24. https://doi.org/10.1016/j.marpolbul.2016.11.038.

Casper, B.M., M.B. Halvorsen, and A.N. Popper. 2012. Are Sharks Even Bothered by a Noisy Environment? *In* Popper, A.N. and A.D. Hawkins (eds.). *The Effects of Noise on Aquatic Life*. Volume 730. Springer, New York. pp 93-97. https://doi.org/10.1007/978-1-4419-7311-5_20.

Cato, D.H. 1992. The biological contribution to the ambient noise in waters near Australia. *Acoustics Australia* 20(3): 76-80. http://www.acoustics.asn.au/journal/Vol20No3.pdf#page=10.

Celi, M., F. Filiciotto, D. Parrinello, G. Buscaino, M.A. Damiano, A. Cuttitta, S. D'Angelo, S. Mazzola, and M. Vazzana. 2013. Physiological and agonistic behavioural response of *Procambarus clarkii* to an acoustic stimulus. *The Journal of Experimental Biology* 216(4): 709-718. https://jeb.biologists.org/content/jexbio/216/4/709.full.pdf.

Cholewiak, D., C.W. Clark, D. Ponirakis, A. Frankel, L.T. Hatch, D. Risch, J.E. Stanistreet, M. Thompson, E. Vu, et al. 2018. Communicating amidst the noise: modeling the aggregate influence of ambient and vessel noise on baleen whale communication space in a national marine sanctuary. *Endangered Species Research* 36: 59-75. http://www.int-res.com/abstracts/esr/v36/p59-75/.

Clark, C.W., W.T. Ellison, B.L. Southall, L.T. Hatch, S.M. Van Parijs, A.S. Frankel, and D.W. Ponirakis. 2009. Acoustic masking in marine ecosystems: Intuitions, analysis, and implication. *Marine Ecology Progress Series* 395: 201-222. https://doi.org/10.3354/meps08402.

Codarin, A., L.E. Wysocki, F. Ladich, and M. Picciulin. 2009. Effects of ambient and boat noise on hearing and communication in three fish species living in a marine protected area (Miramare, Italy). *Marine Pollution Bulletin* 58(12): 1880-1887. https://doi.org/10.1016/j.marpolbul.2009.07.011.

Cranford, T.W. and P. Krysl. 2015. Fin whale sound reception mechanisms: Skull vibration enables low-frequency hearing. *PLOS ONE* 10(1). https://doi.org/10.1371/journal.pone.0116222.

Cunningham, K.A. and D.C. Mountain. 2014. Simulated masking of right whale sounds by shipping noise: Incorporating a model of the auditory periphery. *Journal of the Acoustical Society of America* 135(3): 1632-1640. https://doi.org/10.1121/1.4864470.

Dahlheim, M.E., H.D. Fisher, and J.D. Schempp. 1984. Sound production by the gray whale and ambient noise levels in Laguna San Ignacio, Baja California Sur, Mexico. *In* Jones, M.L., S.L. Swartz, and S. Leatherwood (eds.). *The Gray Whale: Eschrichtius Robustus*. Elsevier, NY. pp 511-541.

Dahlheim, M.E. 1987. *Bio-acoustics of the gray whale (Eschrichtius robustus)*. PhD Thesis. University of British Columbia, Vancouver, BC.

Dahlheim, M.E. and D.K. Ljungblad. 1990. Preliminary hearing study on gray whales (*Eschrichtius robustus*) in the field. *In* Thomas, J. and R.A. Kastelein (eds.). *Sensory Abilities of Cetaceans*. Volume 196. Springer US. pp 335-346.

Dahlheim, M.E. and M. Castellote. 2016. Changes in the acoustic behavior of gray whales *Eschrichtius robustus* in response to noise. *Endangered Species Research* 31: 227-242. https://doi.org/10.3354/esr00759.

De Robertis, A., C.D. Wilson, N.J. Williamson, M.A. Guttormsen, and S. Stienessen. 2010. Silent ships sometimes do encounter more fish. 1. Vessel comparisons during winter pollock surveys. *ICES Journal of Marine Science* 67: 985-995.

Delarue, J.D., K.A. Kowarski, E.E. Maxner, J.T. MacDonnell, and S.B. Martin. 2018. *Acoustic Monitoring Along Canada's East Coast: August 2015 to July 2017*. Document Number 01279, Environmental Studies Research Funds Report Number 215, Version 1.0. Technical report by JASCO Applied Sciences for Environmental Studies Research Fund, Dartmouth, NS, Canada. 120 pp + appendices.

Di Iorio, L. and C.W. Clark. 2009. Exposure to seismic survey alters blue whale acoustic communication. *Biology Letters* 6(3): 51-54. https://doi.org/10.1098/rsbl.2009.0967.

Dooling, R.J. 2010. *Animal hearing*. *Journal of the Acoustical Society of America*. Volume 127.

Dunlop, R.A., M.J. Noad, R.D. McCauley, E. Kniest, D. Paton, and D.H. Cato. 2015. The behavioural response of humpback whales (*Megaptera novaeangliae*) to a 20 cubic inch air gun. *Aquatic Mammals* 41(4): 412-433. http://dx.doi.org/10.1578/AM.41.4.2015.412.

Dunlop, R.A. 2016. The effect of vessel noise on humpback whale, *Megaptera novaeangliae*, communication behaviour. *Animal Behaviour* 111: 13-21. https://doi.org/10.1016/j.anbehav.2015.10.002.

Dunlop, R.A., M.J. Noad, R.D. McCauley, E. Kniest, R. Slade, D. Paton, and D.H. Cato. 2017a. The behavioural response of migrating humpback whales to a full seismic airgun array. *Proceedings of the Royal Society B* 284(1869): 20171901. https://doi.org/10.1098/rspb.2017.1901.

Dunlop, R.A., M.J. Noad, R.D. McCauley, L. Scott-Hayward, E. Kniest, R. Slade, D. Paton, and D.H. Cato. 2017b. Determining the behavioural dose–response relationship of marine mammals to air gun noise and source proximity. *Journal of Experimental Biology* 220(16): 2878-2886. https://jeb.biologists.org/content/220/16/2878.

Dunlop, R.A. 2018. The communication space of humpback whale social sounds in wind-dominated noise. *Journal of the Acoustical Society of America* 144: 540-551.

Dunlop, R.A., M.J. Noad, R.D. McCauley, E. Kniest, R. Slade, D. Paton, and D.H. Cato. 2018. A behavioural dose-response model for migrating humpback whales and seismic air gun noise. *Marine Pollution Bulletin* 133: 506-516. https://doi.org/10.1016/j.marpolbul.2018.06.009.

Dunlop, R.A. 2019. The effects of vessel noise on the communication network of humpback whales6 *R. Soc. open sci.* 6.

Ellers, O. 1995. Discrimination Among Wave-Generated Sounds by a Swash-Riding Clam. *The Biological Bulletin* 189(2): 128-137. https://doi.org/10.2307/1542463.

Ellison, W.T. and A.S. Frankel. 2012. A common sense approach to source metrics. *In* Popper, A.N. and A.D. Hawkins (eds.). *The Effects of Noise on Aquatic Life*. Volume 730. Springer, New York. pp 433-438. https://doi.org/10.1007/978-1-4419-7311-5_98.

Ellison, W.T., B.L. Southall, C.W. Clark, and A.S. Frankel. 2012. A New Context-Based Approach to Assess Marine Mammal Behavioral Responses to Anthropogenic Sounds. *Conservation Biology* 26(1): 21-28. https://doi.org/10.1111/j.1523-1739.2011.01803.x.

Engås, A., O.A. Misund, A.V. Soldal, B. Horvei, and A. Solstad. 1995. Reactions of penned herring and cod to playback of original, frequency-filtered and time-smoothed vessel sound. *Fisheries Research* 22(3-4): 243-254. https://doi.org/10.1016/0165-7836(94)00317-P.

Engineering-Environmental Management, Inc. 2008. *United States Coast Guard and Maritime Administration draft environmental impact statement for Port Dolphin LLC Deepwater Port licence application*. USCG Deepwater Ports Standards Division, Washington, DC.

Erbe, C., R. McCauley, C.R. McPherson, and A. Gavrilov. 2013. Underwater noise from offshore oil production vessels. *Journal of the Acoustical Society of America* 133(6): EL465-EL470. https://doi.org/10.1121/1.4802183.

Erbe, C., R.D. McCauley, and A. Gavrilov. 2016a. Characterizing marine soundscapes. *In* Popper, A.N. and A.D. Hawkins (eds.). *The Effects of Noise on Aquatic Life II*. Springer, New York. pp 265-271. https://dx.doi.org/10.1007/978-1-4939-2981-8_31.

Erbe, C., C. Reichmuth, K. Cunningham, K. Lucke, and R. Dooling. 2016b. Communication masking in marine mammals: A review and research strategy. *Marine Pollution Bulletin* 103(1): 15-38. https://doi.org/10.1016/j.marpolbul.2015.12.007.

Erbe, C., S.A. Marley, R.P. Schoeman, J.N. Smith, L.E. Trigg, and C.B. Embling. 2019. The Effects of Ship Noise on Marine Mammals—A Review. *Frontiers in Marine Science* 6(606). https://www.frontiersin.org/article/10.3389/fmars.2019.00606.

Finneran, J.J., D.A. Carder, C.E. Schlundt, and R.L. Dear. 2010. Temporary threshold shift in a bottlenose dolphin (*Tursiops truncatus*) exposed to intermittent tones. *Journal of the Acoustical Society of America* 127(5): 3267-3272. https://doi.org/10.1121/1.3377052.

Finneran, J.J. 2016. *Auditory weighting functions and TTS/PTS exposure functions for marine mammals exposed to underwater noise*. Technical Report for Space and Naval Warfare Systems Center Pacific, San Diego, CA, USA. 49 pp. http://www.dtic.mil/dtic/tr/fulltext/u2/1026445.pdf.

Fletcher, S., B.J.L. Boeuf, D.P. Costa, P.L. Tyack, and S.B. Blackwell. 1996. Onboard acoustic recording from diving northern elephant seals. *J Acoust Soc Am* 100(4): 2531-2539. https://asa.scitation.org/doi/abs/10.1121/1.417361.

Foote, A.D., R.W. Osborne, and A.R. Hoelzel. 2004. Whale-call response to masking boat noise. *Nature* 428(6986): 910. https://doi.org/10.1038/428910a.

Fournet, M.E.H., L.P. Matthews, C.M. Gabriele, S. Haver, D.K. Mellinger, and H. Klinck. 2018. Humpback whales *Megaptera novaeangliae* alter calling behavior in response to natural sounds and vessel noise. *Marine Ecology Progress Series* 607: 251-268. https://doi.org/10.3354/meps12784.

Frankel, A.S. and C.W. Clark. 2002. ATOC and other factors affecting the distribution and abundance of humpback whales (*Megaptera novaeangliae*) off the north shore of Kauai. *Marine Mammal Science* 18(3): 644-662. https://doi.org/10.1111/j.1748-7692.2002.tb01064.x

Frankel, A.S. and C.M. Gabriele 2017. Predicting the acoustic exposure of humpback whales from cruise and tour vessel noise in Glacier Bay, Alaska, under different management strategies. *Endangered Species Research* 34: 397-415. https://doi.org/10.3354/esr00857.

Gabriele, C.M., D.W. Ponirakis, C.W. Clark, J.N. Womble, and P.B.S. Vanselow. 2018. Underwater acoustic ecology metrics in an alaska marine protected area reveal marine mammal communication masking and management alternatives. *Frontiers in Marine Science*.

Hermannsen, L., K. Beedholm, J. Tougaard, and P.T. Madsen. 2014. High frequency components of ship noise in shallow water with a discussion of implications for harbor porpoises (*Phocoena phocoena*). *Journal of the Acoustical Society of America* 136(4): 1640-1653. https://doi.org/10.1121/1.4893908.

Hildebrand, J.A. 2009. Anthropogenic and natural sources of ambient noise in the ocean. *Marine Ecology Progress Series* 395: 5-20. https://doi.org/10.3354/meps08353.

Holmes, L.J., J. McWilliam, M.C.O. Ferrari, and M.I. McCormick. 2017. Juvenile damselfish are affected but desensitize to small motor boat noise. *Journal of Experimental Marine Biology and Ecology* 494: 63-68. https://doi.org/10.1016/j.jembe.2017.05.009.

Holt, M.M., D.P. Noren, V. Veirs, C.K. Emmons, and S. Veirs. 2009. Speaking up: Killer whales (*Orcinus orca*) increase their call amplitude in response to vessel noise. *Journal of the Acoustical Society of America* 125(1): EL27-EL32. https://doi.org/10.1121/1.3040028.

Holt, M.M., D.P. Noren, and C.K. Emmons. 2011. Effects of noise levels and call types on the source levels of killer whale calls. *Journal of the Acoustical Society of America* 130(5): 3100-3106. https://doi.org/10.1121/1.3641446.

Hotchkin, C. and S. Parks. 2013. The Lombard effect and other noise-induced vocal modifications: Insight from mammalian communication systems. *Biological Reviews* 88(4): 809-824. https://doi.org/10.1111/brv.12026

Houser, D.S., D.A. Helweg, and P.W.B. Moore. 2001. A bandpass filter-bank model of auditory sensitivity in the humpback whale. *Aquatic Mammals* 27(2): 82-91. https://www.aquaticmammalsjournal.org/share/AquaticMammalsIssueArchives/2001/AquaticMammals_27-02/27-02_Houser.PDF.

Jouventin, P. 1982. Visual and vocal signals in penguins, their evolution and adaptive characters. *Fortschritte der Verhaltensforschung* 24: 148-148.

Kastelein, R.A. 2008. Effects of vibrations on the behaviour of cockles (bivalve molluscs). *Bioacoustics* 17(1-3): 74-75. https://doi.org/10.1080/09524622.2008.9753770.

Kastelein, R.A., L. Hoek, R. Gransier, M. Rambags, and N. Claeys. 2014. Effect of level, duration, and inter-pulse interval of 1–2 kHz sonar signal exposures on harbor porpoise hearing. *Journal of the Acoustical Society of America* 136(1): 412-422. https://doi.org/10.1121/1.4883596.

Kastelein, R.A., R. Gransier, J. Schop, and L. Hoek. 2015. Effects of exposure to intermittent and continuous 6–7 kHz sonar sweeps on harbor porpoise (*Phocoena phocoena*) hearing. *Journal of the Acoustical Society of America* 137(4): 1623-1633. https://doi.org/10.1121/1.4916590.

Ketten, D.R. 1995. Estimates of blast injury and acoustic trauma zones for marine mammals from underwater explosions. *In* Kastelein, R.A., J.A. Thomas, and P.E. Nachtigall (eds.). *Sensory Systems of Aquatic Mammals*. De Spil Publishers, Woerden, The Netherlands. pp 391-407.

Koessler, M., C. McPherson, and K. Lucke. 2019. *AGL Gas Import Jetty Facility; Underwater Acoustic Modelling*. Document Number 01816, Version 1.1. Draft. Technical report by JASCO Applied Sciences for AECOM. 28 pp pp.

Lacroix, D.L., R.B. Lanctot, J.A. Reed, and T.L. Mcdonald. 2003. Effect of underwater seismic surveys on molting male Long-tailed Ducks in the Beaufort Sea, Alaska. *Canadian Journal of Zoology* 81(11): 1862-1875. https://doi.org/10.1139/z03-185.

Ladich, F. and A.A. Myrberg, Jr. . 2006. Agonistic behavior and acoustic communication. *In* Ladich, F., S.P. Collin, P. Moller, and B.G. Kapoor (eds.). *Communication in fishes*. Volume 1. Science Publishers. Inc., Enfield, NH. pp 121-148.

Ladich, F. and R.R. Fay. 2013. Auditory evoked potential audiometry in fish. *Reviews in Fish Biology and Fisheries* 23(3): 317-364. https://doi.org/10.1007/s11160-012-9297-z.

Landsberg, P.G. 2000. Underwater blast injuries. *Trauma & Energy Medicine* 17(2).

Lesage, V., C. Barrette, M.C.S. Kingsley, and B. Sjare. 1999. The effect of vessel noise on the vocal behavior of belugas in the St. Lawrence River estuary, Canada. *Marine Mammal Science* 15(1): 65-84.

LGL. 2012. *Environmental Assessment of Marine Geophysical Surveys by the R/V Marcus G. Langseth in the Northeastern Pacific Ocean, June–July 2012*. *In*: LGL Ltd., E.R.A. (ed.). 225 pp.

Lobel, P.S., I.M. Kaatz, and A.N. Rice. 2010. Acoustical behavior of coral reef fishes. *In* Cole, K.S. (ed.). *Reproduction and sexuality in marine fishes: Patterns and processes*. Elsevier Academic Press, San Diego, CA. pp 307-386.

Luís, A.R., M.N. Couchinho, and M.E. dos Santos. 2014. Changes in the acoustic behavior of resident bottlenose dolphins near operating vessels. *Marine Mammal Science* 30(4): 1417-1426. https://doi.org/10.1111/mms.12125.

Lusseau, D., D.E. Bain, R. Williams, and J.C. Smith. 2009. Vessel traffic disrupts the foraging behavior of southern resident killer whales *Orcinus orca*. *Endangered Species Research* 6(3): 211-221. https://doi.org/10.3354/esr00154.

Markov, V.I. 1977. Underwater sounds in Macaroni Penguins. *In Adaptations of Penguins*. Moscow, Nauka. pp 111-121.

Marley, S.A., C.P. Salgado Kent, C. Erbe, and I.M. Parnum. 2017. Effects of vessel traffic and underwater noise on the movement, behaviour and vocalisations of bottlenose dolphins in an urbanised estuary. *Sci Rep* 7(1): 13437. https://doi.org/10.1038/s41598-017-13252-z.

Martin, B., D.G. Zeddies, B.J. Gaudet, and J. Richard. 2016. Evaluation of Three Sensor Types for Particle Motion Measurement. *In* Popper, A.N. and A.D. Hawkins (eds.). *The Effects of Noise on Aquatic Life II*. Springer, NY, USA. pp 679-686. https://doi.org/10.1007/978-1-4939-2981-8_82.

May-Collado, L.J. and S.G. Quiñones-Lebrón. 2014. Dolphin changes in whistle structure with watercraft activity depends on their behavioral state. *Journal of the Acoustical Society of America* 135(4): EL193-EL198. https://doi.org/10.1121/1.4869255.

McDonald, M.A., J.A. Hildebrand, S.M. Wiggins, and D. Ross. 2008. A 50 year comparison of ambient ocean noise near San Clemente Island: A bathymetrically complex coastal region off southern California. *Journal of the Acoustical Society of America* 124(4): 1985-1992. https://doi.org/10.1121/1.2967889.

Melcon, M.L., A.J. Cummins, S.M. Kerosky, L.K. Roche, S.M. Wiggins, and J.A. Hildebrand. 2012. Blue whales respond to anthropogenic noise. *PLOS ONE* 7(2): 1-6. https://doi.org/10.1371/journal.pone.0032681.

Mikkelsen, L., M. Johnson, D.M. Wisniewska, A. van Neer, U. Siebert, P.T. Madsen, and J. Teilmann. 2019. Long-term sound and movement recording tags to study natural behavior and reaction to ship noise of seals. *Ecol Evol* 9(5): 2588-2601. https://www.ncbi.nlm.nih.gov/pubmed/30891202 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6405890/.

Miksis-Olds, J.L. and S.M. Nichols. 2016. Is low frequency ocean sound increasing globally? *Journal of the Acoustical Society of America* 139(1): 501-511. https://doi.org/10.1121/1.4938237.

Mitson, R.B. and H.P. Knudsen. 2003. Causes and effects of underwater noise on fish abundance estimation. *Aquatic Living Resources* 16(3): 255-263. https://doi.org/10.1016/S0990-7440(03)00021-4.

Mooney, T.A., P.E. Nachtigall, and S. Vlachos. 2009. Sonar-induced temporary hearing loss in dolphins. *Biol Lett* 5(4): 565-7. http://www.ncbi.nlm.nih.gov/pubmed/19364712.

Mooney, T.A., R.T. Hanlon, J. Christensen-Dalsgaard, P.T. Madsen, D.R. Ketten, and P.E. Nachtigall. 2010. Sound detection by the longfin squid (*Loligo pealeii*) studied with auditory evoked potentials: sensitivity to low-frequency particle motion and not pressure. *Journal of Experimental Biology* 213(21): 3748-3759. https://jeb.biologists.org/content/213/21/3748.

Mooney, T.A., J.E. Samson, A.D. Schlunk, and S. Zacarias. 2016. Loudness-dependent behavioral responses and habituation to sound by the longfin squid (*Doryteuthis pealeii*). *Journal of Comparative Physiology A* 202(7): 489-501. https://doi.org/10.1007/s00359-016-1092-1.

Mooney, T.A., A.B. Smith, O.N. Larsen, K. Anderson Hansen, M. Wahlberg, and M.H. Rasmussen. 2019. Field-based hearing measurements of two seabird species. *Journal of Experimental Biology* 222(4). https://jeb.biologists.org/content/jexbio/222/4/jeb190710.full.pdf.

Moore, S.E. and D.K. Ljungblad. 2012. Gray whales in the Beaufort, Chukchi, and Bering Seas: Distribution and sound production. (Chapter 23) *In* Jones, M.L., S.L. Swartz, S. Leatherwood, and P.A. Folkens (eds.). *The gray whale: Eschrichtius robustus*. Academic Press. pp 543–559.

Morley, E.L., G. Jones, and A.N. Radford. 2014. The importance of invertebrates when considering the impacts of anthropogenic noise. *Proceedings of the Royal Society of London Series B* 281(1776). https://doi.org/10.1098/rspb.2013.2683.

Mosher, J.I. 1972. The responses of *Macoma balthica* (bivalvia) to vibrations. *Journal of Molluscan Studies* 40(2): 125-131. https://doi.org/10.1093/oxfordjournals.mollus.a065209.

Myrberg, A.A., Jr.  and M. Lugli. 2006. Reproductive behavior and acoustical interactions *In* Ladich, F., S.P. Collin, P. Moller, and B.G. Kapoor (eds.). *Communication in fishes*. Volume 1. Science Publishers. Inc., Enfield, NH. pp 149-176.

Nedelec, S.L., A.N. Radford, S.D. Simpson, B. Nedelec, D. Lecchini, and S.C. Mills. 2014. Anthropogenic noise playback impairs embryonic development and increases mortality in a marine invertebrate. *Scientific Reports* 4(5891): 1-4. https://doi.org/10.1038/srep05891.

Nedelec, S.L., J. Campbell, A.N. Radford, S.D. Simpson, and N.D. Merchant. 2016. Particle motion: The missing link in underwater acoustic ecology. *Methods in Ecology and Evolution* 7: 1-7. https://doi.org/10.1111/2041-210X.12544.

Nedwell, J.R. and A.W. Turnpenny. 1998. The use of a generic frequency weighting scale in estimating environmental effect. *Workshop on Seismics and Marine Mammals*. 23–25 Jun 1998, London, UK.

Nedwell, J.R., B. Edwards, A.W.H. Turnpenny, and J. Gordon. 2004. *Fish and Marine Mammal Audiograms: A summary of available information*. *In*: Subacoustech (ed.). Document Number 534R0214. 278 pp. pp.

Nedwell, J.R., A.W. Turnpenny, J. Lovell, S.J. Parvin, R. Workman, J.A.L. Spinks, and D. Howell. 2007. *A validation of the* $dB_{ht}$ *as a measure of the behavioural and auditory effects of underwater noise*. Document Number 534R1231 Report prepared by Subacoustech Ltd. for the UK Department of Business, Enterprise and Regulatory Reform under Project No. RDCZ/011/0004. 74 pp. https://tethys.pnnl.gov/sites/default/files/publications/Nedwell-et-al-2007.pdf.

Nieukirk, S.L., K.M. Stafford, D.K. Mellinger, R.P. Dziak, and C.G. Fox. 2004. Low-frequency whale and seismic airgun sounds recorded in the mid-Atlantic Ocean. *Journal of the Acoustical Society of America* 115(4): 1832-1843. https://doi.org/10.1121/1.1675816.

Noren, D.P., A.H. Johnson, D. Rehder, and A. Larson. 2009. Close approaches by vessels elicit surface active behaviors by southern resident killer whales. *Endangered Species Research* 8(3): 179-192.

Nowacek, D., M. Johnson, and P.L. Tyack. 2004. North Atlantic right whales (*Eubalaena glacialis*) ignore ships but respond to alarm stimuli. *Proceedings of the Royal Society of London Series B* 271: 227-231.

Nowacek, D.P., L.H. Thorne, D.W. Johnston, and P.L. Tyack. 2007. Responses of cetaceans to anthropogenic noise. *Mammal Review* 37(2): 81-115. https://doi.org/10.1111/j.1365-2907.2007.00104.x.

Olsen, K., J. Agnell, F. Pettersen, and A. Løvik. 1983. Observed fish reactions to a surveying vessel with special reference to herring, cod, capelin and polar cod. *FAO Fisheries Reports* 300: 131-138.

Ona, E., O.R. Godø, N.O. Handegard, V. Hjellvik, R. Patel, and G. Pedersen. 2007. Silent research vessels are not quiet. *Journal of the Acoustical Society of America* 121(4): EL145-EL150. https://doi.org/10.1121/1.2710741.

Packard, A., H.E. Karlsen, and O. Sand. 1990. Low frequency hearing in cephalopods. *Journal of Comparative Physiology A* 166(4): 501-505. https://doi.org/10.1007/BF00192020.

Parks, S.E., C.W. Clark, and P.L. Tyack. 2007a. Short-and long-term changes in right whale calling behavior: The potential effects of noise on acoustic communication. *Journal of the Acoustical Society of America* 122(6): 3725-3731. https://doi.org/10.1121/1.2799904.

Parks, S.E., D.R. Ketten, J.T. O'Malley, and J. Arruda. 2007b. Anatomical predictions of hearing in the North Atlantic right whale. *The Anatomical Record* 290(6): 734-744. https://doi.org/10.1002/ar.20527.

Parks, S.E., I.R. Urazghildiiev, and C.W. Clark. 2009. Variability in ambient noise levels and call parameters of North Atlantic right whales in three habitat areas. *Journal of the Acoustical Society of America* 125(2): 1230-1239. https://doi.org/10.1121/1.3050282.

Parks, S.E., M. Johnson, D.P. Nowacek, and P.L. Tyack. 2010. Individual right whales call louder in increased environmental noise. *Biology Letters* 7: 33-35. https://doi.org/10.1098/rsbl.2010.0451.

Pine, M., D.E. Hannay, S.J. Insely, W.D. Halliday, and F. Juanes. 2018. Assessing vessel slowdown as an option for reducing acoustic masking for Arctic cod in the western Canadian Arctic. *Journal of the Acoustical Society of America* 144(3). https://doi.org/10.1121/1.5067412.

Pine, M.K., A.G. Jeffs, and C.A. Radford. 2012. Turbine sound may influence the metamorphosis behaviour of estuarine crab Megalopae. *PLOS ONE* 7(12). https://doi.org/10.1371/journal.pone.0051790.

Pirotta, E., R. Milor, N. Quick, D. Moretti, N. Di Marzio, P.L. Tyack, I. Boyd, and G. Hastie. 2012. Vessel noise affects beaked whale behavior: Results of a dedicated acoustic response study. *PLOS ONE* 7(8). https://doi.org/10.1371/journal.pone.0042535.

Polacheck, T. and L. Thorpe. 1990. The swimming direction of harbor porpoise in relationship to a survey vessel. *Report for the International Whaling Commission* 40: 463-470.

Popper, A.N. 2003. Effects of anthropogenic sounds on fishes. *Fisheries Magazine* 28(10): 24-31. https://doi.org/10.1577/1548-8446(2003)28[24:EOASOF]2.0.CO;2.

Popper, A.N. and R.R. Fay. 2011. Rethinking sound detection by fishes. *Hearing Research* 273(1): 25-36. https://doi.org/10.1016/j.heares.2009.12.023.

Popper, A.N., A.D. Hawkins, R.R. Fay, D.A. Mann, S. Bartol, T.J. Carlson, S. Coombs, W.T. Ellison, R.L. Gentry, et al. 2014. *Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI*. ASA S3/SC1.4 TR-2014. SpringerBriefs in Oceanography. ASA Press and Springer. https://doi.org/10.1007/978-3-319-06659-2.

Popper, A.N. and A.D. Hawkins. 2018. The importance of particle motion to fishes and invertebrates Physical aspects of swimbladder function. *Journal of the Acoustical Society of America* 143(1): 470-488. https://doi.org/10.1121/1.5021594.

Popper, A.N. and A.D. Hawkins. 2019. An overview of fish bioacoustics and the impacts of anthropogenic sounds on fishes (Review Paper). *Journal of Fish Biology*: 1-22. https://doi.org/10.1111/jfb.13948.

Popper, A.N., A.D. Hawkins, and M.B. Halvorsen. 2019. *Anthropogenic Sound and Fishes*. Report Number WA-RD 891.1. Report by ICF for Washington State Department of Transportation, Research Office. 170 pp.

Putland, R.L., N.D. Merchant, A. Farcas, and C.A. Radford. 2018. Vessel noise cuts down communication space for vocalizing fish and marine mammals. *Global Change Biology* 24(4): 1708-1721. https://onlinelibrary.wiley.com/doi/abs/10.1111/gcb.13996.

Ramcharitar, J., D.P. Gannon, and A.N. Popper. 2006. Bioacoustics of fishes of the family Sciaenidae (croakers and drums). *Transactions of the American Fisheries Society* 135(5): 1409-1431. https://doi.org/10.1577/T05-207.1.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. 1995. *Marine Mammals and Noise*. Academic Press, San Diego, CA, USA. 576 pp.

Roberts, L., S. Cheesman, T. Breithaupt, and M. Elliott. 2015. Sensitivity of the mussel *Mytilus edulis* to substrate-borne vibration in relation to anthropogenically generated noise. *Marine Ecology Progress Series* 538: 185-195. https://doi.org/10.3354/meps11468.

Roberts, L., S. Cheesman, M. Elliott, and T. Breithaupt. 2016. Sensitivity of *Pagurus bernhardus* (L.) to substrate-borne vibration and anthropogenic noise. *Journal of Experimental Marine Biology and Ecology* 474: 185-194. https://doi.org/10.1016/j.jembe.2015.09.014.

Roberts, L. and M. Elliott. 2017. Good or bad vibrations? Impacts of anthropogenic vibration on the marine epibenthos. *Science of The Total Environment* 595: 255-268. https://doi.org/10.1016/j.scitotenv.2017.03.117.

Ross, D. 1976. *Mechanics of Underwater Noise*. Pergamon Press, NY, USA.

Sand, O., H.E. Karlsen, and F.R. Knudsen. 2008. Comment on “Silent research vessels are not quiet” [J. Acoust. Soc. Am. 121, EL145–EL150]. *Journal of the Acoustical Society of America* 123(4): 1831-1833. https://doi.org/10.1121/1.2839134.

Sarà, G., J.M. Dean, D. D'Amato, G. Buscaino, A. Oliveri, S. Genovese, S. Ferro, G. Buffa, M. Lo Martire, et al. 2007. Effect of boat noise on the behaviour of bluefin tuna *Thunnus thynnus* in the Mediterranean Sea. *Marine Ecology Progress Series* 331: 243-253. https://www.int-res.com/abstracts/meps/v331/p243-253/.

Scholik, A.R. and H.Y. Yan. 2001. Effects of underwater noise on auditory sensitivity of a cyprinid fish. *Hearing Research* 152(1-2): 17-24. https://doi.org/10.1016/S0378-5955(00)00213-6.

Scholik, A.R. and H.Y. Yan. 2002. Effects of boat engine noise on the auditory sensitivity of the fathead minnow, *Pimephales promelas*. *Environmental Biology of Fishes* 63(2): 203-209. https://doi.org/10.1023/A:1014266531390.

Schwarz, A.L. and G.L. Greer. 1984. Responses of Pacific Herring, *Clupea harengus pallasi*, to Some Underwater Sounds. *Canadian Journal of Fisheries and Aquatic Sciences* 41(8): 1183-1192. https://doi.org/10.1139/f84-140.

Simmonds, M., S. Dolman, and L. Weilgart. 2003. *Oceans of noise*. WDCS Science Report. Whale and Dolphin Conservation Society. 129 pp.

Sivle, L.D., P.J. Wensveen, P.H. Kvadsheim, F.-P.A. Lam, F. Visser, C. Curé, C.M. Harris, P.L. Tyack, and P.J.O. Miller. 2016. Naval sonar disrupts foraging in humpback whales. *Marine Ecology Progress Series* 562: 211-220. https://doi.org/10.3354/meps11969.

Smith, M.E., A.B. Coffin, D.L. Miller, and A.N. Popper. 2006. Anatomical and functional recovery of the goldfish (*Carassius auratus*) ear following noise exposure. *Journal of Experimental Biology* 209(21): 4193-4202. http://jeb.biologists.org/content/209/21/4193.abstract.

Solé, M., M. Lenoir, M. Durfort, M. López-Bejar, A. Lombarte, and M. André. 2013. Ultrastructural Damage of *Loligo vulgaris* and *Illex coindetii* statocysts after Low Frequency Sound Exposure. *PLOS ONE* 8(10): e78825. https://doi.org/10.1371/journal.pone.0078825.

Solé, M., P. Sigray, M. Lenoir, M. Van Der Schaar, E. Lalander, and M. André. 2017. Offshore exposure experiments on cuttlefish indicate received sound pressure and particle motion levels associated with acoustic trauma. *Scientific Reports* 7: 45899. https://doi.org/10.1038/srep45899.

Song, J., D.A. Mann, P.A. Cott, B.W. Hanna, and A.N. Popper. 2008. The inner ears of northern Canadian freshwater fishes following exposure to seismic air gun sounds. *Journal of the Acoustical Society of America* 124(2): 1360-1366. https://doi.org/10.1121/1.2946702.

Soria, M., P. Freon, and F. Gerlotto. 1996. Analysis of vessel influence on spatial behaviour of fish schools using a multi-beam sonar and consequences for biomass estimates by echo-sounder. *ICES Journal of Marine Science* 53: 453-458.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene, Jr., D. Kastak, D.R. Ketten, J.H. Miller, et al. 2007. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. *Aquatic Mammals* 33(4): 411-521. https://doi.org/10.1080/09524622.2008.9753846.

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

Tavolga, W.N. and J. Wodinsky. 1963. Auditory capacities in fishes: pure tone thresholds in nine species of marine teleosts. *Bulletin of the American Museum of Natural History* 126: 177-240.

Tennessen, J.B. and S.E. Parks. 2016. Acoustic propagation modeling indicates vocal compensation in noise improves communication range for North Atlantic right whales. *Endangered Species Research* 30: 225-237. https://doi.org/10.3354/esr00738.

Terhune, J.M., R.E.A. Stewart, and K. Ronald. 1979. Influence of vessel noises on underwater vocal activity of harp seals. *Canadian Journal of Zoology* 57(6): 1337-1338. https://doi.org/10.1139/z79-170.

Tsujii, K., T. Akamatsu, R. Okamoto, K. Mori, Y. Mitani, and N. Umeda. 2018. Change in singing behavior of humpback whales caused by shipping noise. *PLOS ONE* 13(10): e0204112. https://doi.org/10.1371/journal.pone.0204112.

Tubelli, A.A., A. Zosuls, D.R. Ketten, and D.C. Mountain. 2012. Prediction of a mysticete audiogram via finite element analysis of the middle ear. *In* Popper, A.N. and A.D. Hawkins (eds.). *The Effects of Noise on Aquatic Life*. Volume 730. Springer, New York. pp 57-59. https://doi.org/10.1007/978-1-4419-7311-5_12.

Vabø, R., K. Olsen, and I. Huse. 2002. The effect of vessel avoidance of wintering Norwegian spring spawning herring. *Fisheries Research* 58(1): 59-77. https://doi.org/10.1016/S0165-7836(01)00360-5.

Van Parijs, S.M. and P.J. Corkeron. 2001. Vocalizations and behaviour of Pacific humpback dolphins *Sousa chinensis*. *Ethology* 107(8): 701-716. https://doi.org/10.1046/j.1439-0310.2001.00714.x.

Vasconcelos, R.O., M.C.P. Amorim, and F. Ladich. 2007. Effects of ship noise on the detectability of communication signals in the Lusitanian toadfish. *Journal of Experimental Biology* 210(12): 2104-2112. http://jeb.biologists.org/content/jexbio/210/12/2104.full.pdf.

Wale, M.A., S.D. Simpson, and A.N. Radford. 2013. Size-dependent physiological responses of shore crabs to single and repeated playback of ship noise. *Biology Letters* 9(2). https://doi.org/10.1098/rsbl.2012.1194.

Ward, W.D. 1997. Effects of high-intensity sound. (Chapter 119) *In* Crocker, M.J. (ed.). *Encyclopedia of acoustics*. Volume III. John Wiley and Sons, New York. pp 1497-1507. https://doi.org/10.1002/9780470172537.ch119.

Wartzok, D. and D.R. Ketten. 1999. Marine Mammal Sensory Systems. (Chapter 4) *In* Reynolds, J. and S. Rommel (eds.). *Biology of Marine Mammals*. Smithsonian Institution Press, Washington, DC. pp 117-175.

Wensveen, P.J., P.H. Kvadsheim, F.-P.A. Lam, A.M. von Benda-Beckmann, L.D. Sivle, F. Visser, C. Curé, P.L. Tyack, and P.J.O. Miller. 2017. Lack of behavioural responses of humpback whales (*Megaptera novaeangliae*) indicate limited effectiveness of sonar mitigation. *The Journal of Experimental Biology* 220(22): 4150-4161. https://jeb.biologists.org/content/jexbio/220/22/4150.full.pdf.

Wenz, G.M. 1962. Acoustic Ambient Noise in the Ocean: Spectra and Sources. *Journal of the Acoustical Society of America* 34(12): 1936-1956. https://doi.org/10.1121/1.1909155.

Wever, E.G., P.N. Herman, J.A. Simmons, and D.R. Hertzler. 1969. Hearing in the blackfooted penguin, Pheniscus demersus, as represented by cochlear potentials. *Proceedings of the National Academy of Sciences of the United States of America*. Volume 63(3). pp 676-680. https://doi.org/10.1073/pnas.63.3.676.

Williams, R., A.W. Trites, and D.E. Bain. 2002. Behavioural reponses of killer whales (*Orcinus orca*) to whale-watching boats: Opportunistics observations and experimental approaches. *Journal of Zoology* 256: 255-270. https://doi.org/10.1017/S0952836902000298.

Williams, R., C. Erbe, E. Ashe, A. Beerman, and J. Smith. 2014. Severity of killer whale behavioral responses to ship noise: A dose–response study. *Marine Pollution Bulletin* 79(1-2): 254-260. https://doi.org/10.1016/j.marpolbul.2013.12.004.

Wysocki, L.E., J.P. Dittami, and F. Ladich. 2006. Ship noise and cortisol secretion in European freshwater fishes. *Biological Conservation* 128(4): 501-508. https://doi.org/10.1016/j.biocon.2005.10.020.

Zelick, R., D. Mann, and A.N. Popper. 1999. Acoustic communication in fishes and frogs. *In* Fay, R.R. and A.N. Popper (eds.). *Comparative Hearing: Fish and Amphibians* Springer-Verlag, New York. pp 363-411. https://doi.org/10.1007/978-1-4612-0533-3_9.

# Appendix A. Physical Characteristics Of Underwater Sound

Sound is always present in the underwater environment. It is naturally caused by biological sources such as whales, fish, and invertebrates (e.g., snapping shrimp) and by meteorological and oceanographical sources (such as rain, wind driven waves, and currents). The existing sound in an environment can be summed up as the ambient sound or soundscape. While the term 'sound' is objective, the term 'noise' can be considered as the 'unwanted' sound, i.e., sound that has an impact on a receptor. Anthropogenic sound is emitted by almost all activities at sea, either intentional (e.g., an echosounder) or as a by-product (e.g., shipping). Assessing the impact of anthropogenic underwater noise on marine receptors requires an understanding of the basic physical principles of underwater sound. The following subsections provide a brief overview of the most important aspects and introduces the most relevant terms and metrics.

## A.1. Sound Characteristics

Sound is a physical phenomenon consisting of minute vibrations that travel through a supporting medium, such as air or water. When the surface of a vibrating object (sound source) moves forward into the medium, it compresses the surrounding molecules, thereby creating a region of higher pressure. As the surface then moves back toward and past its neutral position, the molecules of the surrounding medium expand back and a region of lower pressure results. These cycles are called compressions and rarefactions, respectively (see Figure A-1).

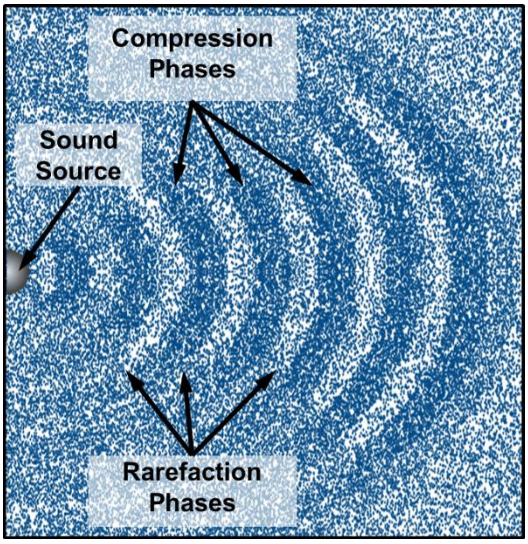


Figure A-1. Compression and rarefaction phases of a travelling sound wave.

The successive compressions and rarefactions result in sound waves. The speed at which these compressions and rarefactions travel away from the source depends on the compressibility and density of the medium and defines the speed of sound in that medium. Sound waves travel much faster in water than in air.

Sound is generally described in terms of frequency (or pitch), intensity, and temporal properties (e.g., short or long in duration, impulsive and non-impulsive). The following text provides a general description of these terms. For more details, there are several publications and books that provide detailed overviews of underwater acoustics, such as Richardson et al. (1995) and Au and Hastings (2008b), and some internet sources such as the Discovery of Sound in the Sea (DOSITS 2019), which is a highly recommended source of information on the subject.

Frequency is a measure of how many times the crest of a sound pressure wave passes a fixed point over the duration of a second; it is measured in Hertz (Hz). Some mysticetes (baleen whales) produce

and may hear sounds below 20 Hz, while odontocetes (toothed whales) produce and hear sounds at frequencies much higher (up to 180 kHz for some species).

Sound intensity is defined as the acoustic power per unit area. The intensity, power, and energy of a sound wave are proportional to the average of the squared pressure. Measurement instruments and most receivers (humans, animals) sense changes in pressure, which is measured in Pascals (Pa). While pressure changes due to sound waves can be measured in Pascals, they are more commonly expressed in decibels (dB). The decibel is a logarithmic scale that is based on the ratio of the sound pressure relative to a standard reference pressure. The logarithmic decibel scale is used to allow comparison of extremely large sound pressure differences between sources.

Different standard reference pressures are used for airborne sounds and underwater sounds. The airborne standard pressure reference is $p_{ref(air)}$ = 20 micropascals (μPa), while the underwater standard reference pressure is $p_{ref(water)}$ = 1 μPa. The formula used to convert a pressure p measured in micropascals to sound pressure level *P* measured in dB is $P = 20 \log10 [p/p_{ref}]$. Because of the logarithmic nature of the decibel scale, sound levels cannot be added or subtracted directly [If a sound's pressure is doubled, its sound level increases by 6 dB, regardless of the initial sound level].

## A.2. Impulsive Sounds versus Non-impulsive Sounds

Impulsive and non-impulsive sounds are primarily distinguished by their temporal pattern: Impulsive or 'pulsed' sounds can be described as discrete (single pulses) and sometimes intermittent sounds (multiple pulses) produced by sources such as airguns and pile driving. These sounds, sometimes also termed transients, are typically brief signals consisting of high peak sound pressure with a rapid rise time and a rapid decay (NIOSH 1998).

Non-impulsive sounds, which can be intermittent or continuous, produced by sound sources such as ships and pumps. Non-impulsive sounds are longer than impulsive ones and usually do not have the high peak sound pressure and rapid rise/decay time that impulsive sounds do (NIOSH 1998). However, especially in respect to their auditory effects, the term non-impulsive does not imply long duration signals.

## A.3. Particle Motion

A sound wave can be detected underwater and classified by the pressure fluctuation (compression and rarefaction of the supporting medium). However, when pressure and density change, the particles that comprise the media also move (Martin et al. 2016, Nedelec et al. 2016). Pressure and particle motion, the two components of sound, serve as input to the sensory systems in marine animals.

Different species (or taxa) developed sensors for either one of these sound components, and some are sensitive to both: Many fish species and all invertebrate species studied so far do not have hearing organs that detect pressure differences due to sound pressure waves. Instead, they use receptors that sense particle motion in the water column to detect sound; the relevant exposure metric for most fish and all invertebrates is therefore particle motion.

There is no regulatory guidance, however, with respect to setting criteria for particle motion impact. Few particle motion measurements have been collected in conditions typically encountered in monitoring situations. This is due in part to limitations in the available instrumentation and a general lack of experience in recording this quantity.

## A.4. Acoustic Metrics

Three metrics are commonly used for analysing underwater sound propagation and evaluating underwater sound impacts on marine wildlife: peak pressure (PK), sound pressure level (SPL), and sound exposure level (SEL). Terminology in this field should refer to the ISO standard International Organization for Standardization (2017). For impulsive sources, SPL is gradually being supplemented or replaced by fast time-weighted average SPL.

Figure A-2 shows a representation of a sinusoidal (single frequency) pressure wave to illustrate the various metrics. The amplitude of the pressure is shown along the vertical axis, and time is shown along the horizontal axis. The pressure of the wave fluctuates around the neutral point. The peak pressure is the absolute value of the maximum variation from the neutral position of a wave oscillation; therefore, it can result from either a compression or a rarefaction. The peak-to-peak sound pressure is the difference between the maximum and minimum pressures. The average amplitude is the average of absolute value of pressure over the period of interest.

The rms amplitude is a type of average determined by squaring all of the amplitudes over the period of interest, determining the mean of the squared values, and then taking the square root of this mean. The rms amplitude of an impulsive signal will vary significantly depending on the length of the period of interest.

SEL is a metric related to the sound energy per area received over time, though it does not have energy units; it is proportional to the square of the sound pressure and the time over which a sound is received.

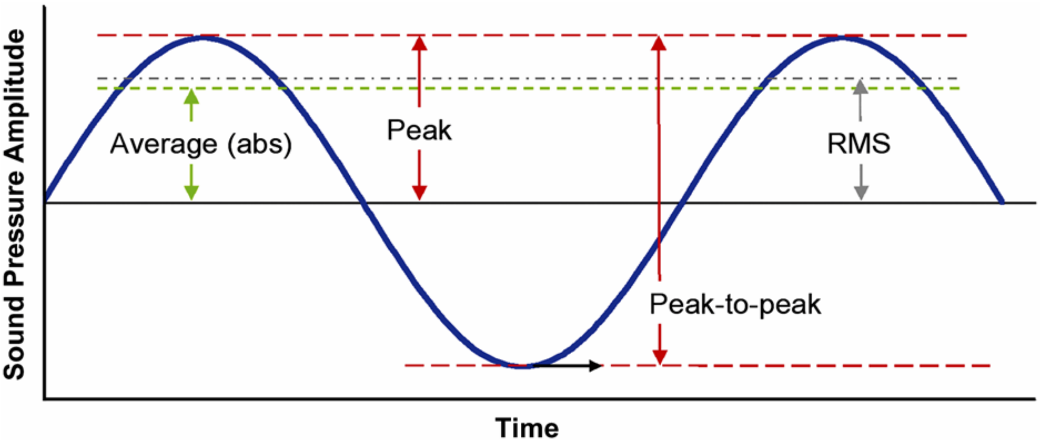


Figure A-2. Sound level metrics.

The publication of ISO 18405 Underwater Acoustics – Terminology (ISO 2017) provided a dictionary of underwater bioacoustics (previous standards: IEC 1994, ANSI 2013). This report follows the definitions and conventions of ISO (2017) unless directly referring to metrics used in published references. The US NMFS issued a Technical Guidance document that provides acoustic thresholds for the onset of PTS and TTS in marine mammal hearing for all sound sources (NMFS 2018).

The NMFS Guidance recommends the use of a dual criteria for assessing injurious exposures, including a peak (unweighted/flat) sound pressure level metric PK ($L_{pk}$) and a cumulative sound exposure level $SEL_{cum}$ ($SEL_{24h}$) metric with frequency weighting. Following the ISO standard, the $L_{pk}$ as used by NMFS is denoted as PK in this report. The $SEL_{cum}$ metric as used by NMFS describes the sound energy received by a receptor over 24 hours. Accordingly, following the ISO standard, this will be denoted as $SEL_{24h}$ in this report (Table A-1).

Table A-1. Acoustic metrics used in this report as compared to other publications.

| Metric | ISO (2017)/This report | Other publications | NMFS (2018) |
|---|---|---|---|
| Sound Pressure Level | SPL | $SPL_{rms}$, $SPL_{RMS}$ | Not available |
| Peak Pressure | PK | $SPL_{pk}$ | PK |
| Cumulative Sound Exposure Level | $SEL_{24h}$ | $SEL_{cum}$ | $SEL_{cum}$ |

Sources of underwater noise, such as ship propellers or marine mammal calls, generate radiating sound waves whose intensity generally decays with distance from the source. The reduction in sound level measured in decibels that results from propagation of sound away from an acoustic source is called propagation loss (PL) or transmission loss (TL). The loudness or intensity of a noise source is

quantified in terms of the source level (SL), which is the sound level referenced to some fixed distance from a noise source. The standard reference distance for underwater sound is 1 m. By convention, transmission loss is quoted in units of dB and underwater acoustic source levels are specified in units of dB re 1 μPa.

## A.5. Underwater Soundscapes

The background sound levels that comprise the ocean soundscape result from the contributions of many natural and anthropogenic sources (Figure A-3); depending on the sound source, they are collectively summarised as environmental (meteorological, geological or biological) or anthropogenic sounds. Meteorological causes of underwater sound are predominantly wind, rain, and storms. Wind-generated sound in the ocean is well studied (e.g., Wenz 1962, Ross 1976), and surf sound is an important contributor to nearshore soundscapes. Precipitation is a commonly occurring sound source, with frequencies typically concentrated above 500 Hz. At low frequencies (<100 Hz), earthquakes, mass subsea land/fault movement, and other seismic activities are part of the soundscape.

Biological sources of sound are diverse. Invertebrates, such as snapping shrimp, are a significant source of sound in shallow waters and at higher frequencies (Cato 1992, Richardson et al. 1995). Snapping shrimp can increase background sound levels by a factor of 10 (20 dB) in the 500 Hz to 20 kHz frequency band (Hildebrand 2009). Many fish species are known to produce sounds, either individually or in spawning aggregations and choruses. Chorusing fish can temporarily elevate the background sound levels by greater than tenfold in the 100 and 2000 Hz frequency band (Cato 1992, Zelick et al. 1999). The best documented biological contributors to the ocean soundscape are marine mammals. All studied cetacean and pinniped species produce sounds ranging in frequency from ~8 Hz for blue whale (*Balaenoptera musculus*) and fin whale (*B. physalus*) vocalizations to 150 kHz for some porpoise and dolphin vocalizations (Richardson et al. 1995). Baleen whale sounds can double background sound levels within their frequency bands and persist for extended periods of time (McDonald et al. 2008).

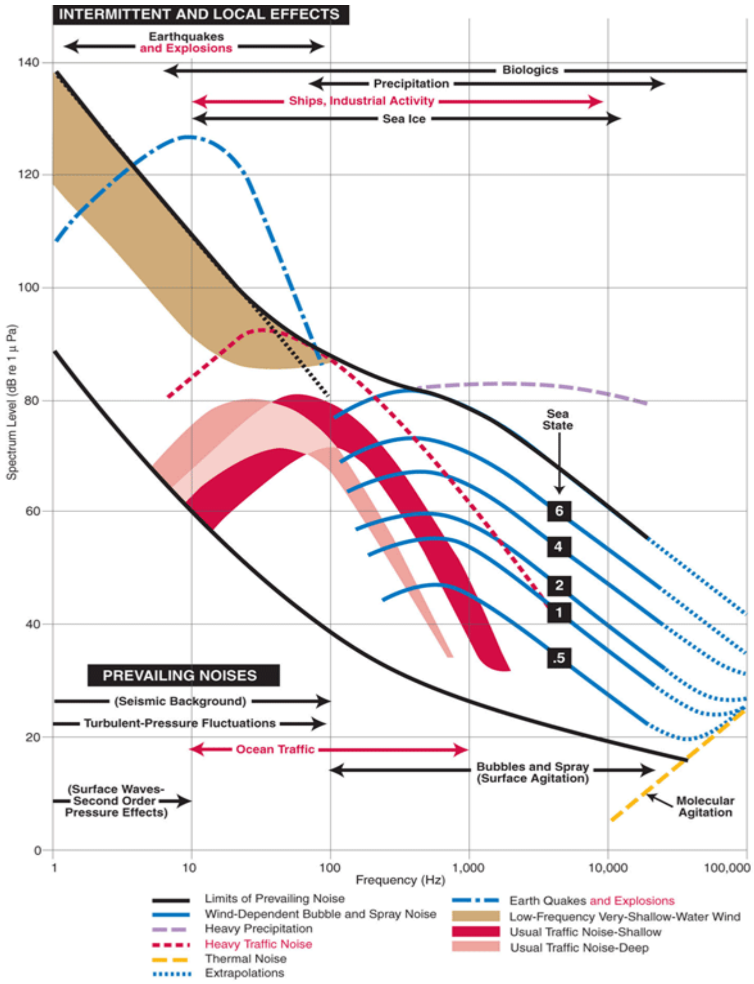


Figure A-3. Wenz curves describing pressure spectral density levels of marine ambient sound from weather, wind, geologic activity, and commercial shipping (NRC 2003, adopted from Wenz 1962).

Anthropogenic (human-generated) sound can be a by-product of vessel operations, such as engine sound radiating through vessel hulls and cavitating propulsion systems, or it can be a product of active acoustic data collection with seismic surveys, military sonar, and depth sounding as the main contributors. Marine construction projects often involve nearshore blasting and pile driving that can produce high levels of impulsive-type noise. The contribution of anthropogenic sources to the ocean soundscape has increased from the 1950s to 2010, largely driven by greater maritime shipping traffic (Ross 1976, Andrew et al. 2011). Recent trends suggest that global sound levels or levelling off or potentially decreasing in some areas (Andrew et al. 2011, Miksis-Olds and Nichols 2016). Oil and gas exploration with seismic airguns, marine pile driving and oil and gas production platforms elevate sound levels over radii of 10 to 1000 km when present (Bailey et al. 2010, Miksis-Olds and Nichols 2016, Delarue et al. 2018).The extent of seismic survey sounds has increased substantially following the expansion of oil and gas exploration into deep water, and seismic sounds can now be detected across ocean basins (Nieukirk et al. 2004).

# Appendix B. Documented Noise-Induced Impacts

## B.1. Marine Mammals

### B.1.1. Acoustic Masking and Compensation Strategies

As the noise emitted at the Gas Import Jetty peaks in the low frequencies, acoustic masking is most likely to occur for low-frequency specialist species such as mysticetes (i.e., baleen whales) and otariid pinnipeds. Mysticetes produce and use sound at the frequencies from <10 Hz to 24 kHz, and otariid vocalizations have been measured between 80 Hz and 8 kHz (Southall et al. 2019).

Marine mammals can reduce the effects of masking by various active and passive mechanisms, so-called masking-release mechanisms (Erbe et al. 2016b). They may increase the amplitude of their calls (referred to as the Lombard effect) or change spectral and temporal properties of vocalizations such as frequency content (Parks et al. 2010, Hotchkin and Parks 2013). Bottlenose dolphins (*Tursiops truncatus*) produced more whistles when boats approached (Buckstaff 2004) and emitted lower frequency and longer whistles when interacting with dolphin-watching boats, particularly during foraging activities (May-Collado and Quiñones-Lebrón 2014). Furthermore, Luís et al. (2014) discovered that the mean overall call rates decreased significantly in the presence of operating vessels. These changes in call emission rates and temporary shifts in whistles characteristics may be a vocal response to the proximity of operating vessels, facilitating communication in this busy noisy estuary. Similarly, high-speed ferry noise has been demonstrated to have implications for harbour porpoise (Hermannsen et al. 2014). For killer whales (*Orcinus orca*), an increased source level and vocalization duration has been reported in the presence of ship noise levels above 98 dB re 1 mPa rms (1–40 kHz) (Foote et al. 2004, Holt et al. 2009, Holt et al. 2011). Studies show North Atlantic right whales (*Eubalaena glacialis*) produced calls with a higher average fundamental frequency and lowered their call rate in high noise conditions (Parks et al. 2007a, Parks et al. 2009), whereas blue whales have been recorded increasing their discrete audible calls during a seismic survey (Di Iorio and Clark 2009) and when ship sounds were nearby (Melcon et al. 2012).

Grey whales (*Eschrichtius robustus*) have a limited repertoire of low-frequency (40–4000 Hz) vocalizations, which overlap with vessel noise (Dahlheim et al. 1984, Moore and Ljungblad 2012, Dahlheim and Castellote 2016, Burnham et al. 2018). In the presence of ships and boats, grey whales increased their vocalization rate, and at times of increased outboard engine noise, received levels from grey whales were higher (interpreted as an increase in source levels; Dahlheim 1987, Dahlheim and Castellote 2016).

Humpback whales (*Megaptera novaeangliae*) in Glacier Bay National Park, AK, United States of America, are prone to high noise exposures from tourism vessels. They have been shown to increase the amplitude of their vocalizations by 0.8 dB for every 1.0 dB increase in ambient noise, while also vocalizing less frequently (Frankel and Gabriele 2017, Fournet et al. 2018). Similarly, singing individuals near Chichi-jima Island ceased singing after a passenger-cargo vessel passed within 1400 m (Tsujii et al. 2018).

### B.1.2. Behavioural Impacts

With regard to non-impulsive sounds such as those produced by ships, the review by Southall et al. (2007) found no or limited responses by low-frequency cetaceans to non-impulsive sound at received levels up to 120 dB re 1 µPa, but an increasing probability of avoidance and other behavioural responses beginning at 120 to 160 dB re 1 µPa.

In relation to high-frequency cetaceans, in the Bay of Fundy, Nova Scotia, Polacheck and Thorpe (1990) noted that harbour porpoises, which are high-frequency cetaceans, tended to swim away from approaching vessels. Off the western coast of North America, Barlow (1988) observed that harbour porpoises within 1 km of a survey vessel moved rapidly out of its path.

Cuvier's beaked whales responded to ship sounds by decreasing their vocalisations when they attempted to catch prey (Aguilar de Soto et al. 2006). Foraging changes were observed in Blainville's beaked whales (*Mesoplodon densirostris*) when they were exposed to vessel noise (Pirotta et al. 2012).

Groups of Pacific humpback dolphins (*Sousa chinensis*) that contained mother-calf pairs increased their rate of whistling after a boat transited the area (Van Parijs and Corkeron 2001). The authors postulated that vessel sounds disrupted group cohesion, especially between mother-calf pairs, requiring them to re-established by vocal contact after boat noise masked their communication.

Lesage et al. (1999) revealed that belugas reduced their overall call rate in the presence of vessels but increased the emission and repetition of specific calls and shifted to higher frequency bands.

In response to high levels of boat traffic, killer whales increased the duration (Foote et al. 2004) or the amplitude (Holt et al. 2009) of their calls.

Marley et al. (2017) found that Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in Fremantle Inner Harbour (WA) significantly increased their average movement speeds in high vessel densities but only for some activity states. Behavioural budgets also changed in the presence of vessels, with animals spending more time travelling and less time resting or socialising.

Killer whales showed changes in behaviour in response to vessel noise (i.e., less foraging and increased surface-active behaviour), respiration, and swim speed and direction occurred at received levels above 130 dB re 1 mPa rms (0.01–50 kHz) (Williams et al. 2002, Lusseau et al. 2009, Noren et al. 2009, Williams et al. 2014).

Humpback whales off the Australian east coast exhibited great variation in behavioural responses to seismic survey vessels with the airguns turned off. While no behavioural change was seen in some trials, others revealed a decrease in dive duration, travel speed, and the number of breaches (Dunlop et al. 2015, Dunlop 2016, Dunlop et al. 2017a, Dunlop et al. 2017b, Dunlop et al. 2018). Most humpback whales did not respond to sonar vessels with the sonar turned off (Sivle et al. 2016, Wensveen et al. 2017). Tsujii et al. (2018) found that humpback whales moved away from large vessels, while others noted changes in respiratory behaviour (Baker and Herman, 1989)(Frankel and Clark 2002) and a cessation of foraging activities (Blair et al. 2016). The large number of studies on humpback whales and the resulting variety of documented responses demonstrate that context affects behaviour.

Conversely, North Atlantic right whales show no behavioural response to ship noise at all, or at least not to received levels of 132–142 dB re 1 mPa rms from large ships passing within 1 nm distance, nor to received levels of 129–139 dB re 1 mPa rms (main energy between 50 and 500 Hz) from ship noise playback (Nowacek et al. 2004).

Cetaceans avoid stationary sound sources when the received sounds are strong, but not when the sounds are barely audible (Richardson et al. 1995). Whales seem most responsive when the sound level is increasing or when a noise source first starts up, as when migrating whales are swimming toward a noise source. Some cetaceans enter areas that are strongly ensonified by stationary sound sources and may even (partially) habituate to non-impulsive noise, i.e., not display any behavioural responses to the noise exposure. The radius of strong behavioural responses (such as avoidance) around stationary sound sources seems considerably smaller than the radius of audibility, assuming that mammals can usually hear sounds whose levels exceed the background level in the corresponding band.

A study using acoustic tags that record sound and behaviour concurrently showed that harbour and grey seals were exposed to vessel noise 2.2–20.5% of their time at sea (Mikkelsen et al. 2019). In response to vessel noise, a tagged seal changed its diving behaviour, switching quickly from a dive ascent to descent (Mikkelsen et al. 2019). This observation agrees with descriptions of changes in diving reported from a juvenile northern elephant seals (*Mirounga angustirostris*) (Fletcher et al. 1996, Burgess et al. 1998).

### B.1.3. Physical Impacts/Injury

Noise-induced physical impacts from exposure to non-impulsive sound have not been directly observed or measured in free-ranging marine mammals. A number of studies have been conducted on marine mammals in controlled conditions to investigate noise-induced threshold shift phenomena. The experiments have focused on measuring TTS[3] exposed to intense tones and band-limited noise (but not the vessel noise) with various sound pressure levels, frequencies, durations, and temporal patterns. These studies have been performed with dolphins and belugas, and a harbour porpoise exposed to tones with durations ranging from 1 s to 1 h. Most of these studies employed non-impulsive exposures, though four studies used intermittent tones (Mooney et al. 2009, Finneran et al. 2010, Kastelein et al. 2014, Kastelein et al. 2015). Tonal signals may be used to represent the effects of military sonars, fish finders, depth sounders, and other sources emitting steady-state, narrowband signals. The studies showed that the temporal pattern of noise exposure affects the resulting threshold shift and for intermittent noise, the quiet periods between noise exposures allow some recovery of hearing compared to noise that is continuously present with the same total SEL (Ward 1997). For continuous exposures with the same SEL but different durations, the exposure with the longer duration will tend to produce more TTS.

## B.2. Fish

Boat noise represents a chronic source of harassment for fish species (Popper 2003), whose communication is mainly based on low-frequency sound signals (Ladich and Myrberg 2006, Myrberg and Lugli 2006). Recent studies show that boat noise can induce endocrine stress response (Wysocki et al. 2006), diminish hearing ability, and mask intra-specific relevant signals in exposed fish species (Scholik and Yan 2002, Amoser et al. 2004, Vasconcelos et al. 2007, Codarin et al. 2009). In addition, vessel noise can provoke short-term changes in the spatial position and group structure of pelagic fish in the water column (Buerkle 1974, Olsen et al. 1983, Schwarz and Greer 1984, Engås et al. 1995, Soria et al. 1996, Vabø et al. 2002, Mitson and Knudsen 2003, Ona et al. 2007, Sarà et al. 2007).

Fish can respond to approaching vessels by diving towards the seafloor or by moving horizontally out of the vessel’s path, with reactions often initiated well before the vessel reaches the fish (Ona et al. 2007, Berthe and Lecchini 2016). The avoidance of vessels by fish has been linked to the high levels of infrasonic and low-frequency noise (>10 to 1000 Hz) emitted by the ships. Accordingly, it was suggested that silent ships have a higher chance of encountering more fish than noisier ones (De Robertis et al. 2010). This assumption was initially contradicted when two research vessels were compared with regard to their effect on schooling herring (Ona et al. 2007). The authors found that the reaction initiated by the silent vessel was stronger and more prolonged than the one initiated by the conventional vessel. In a comment to this publication, Sand et al. (2008) pointed out that fish are highly sensitive to particle acceleration and that the cue, in this case, may have been low-frequency particle acceleration caused by displacement of water by the moving hull in the near field of the vessel. This fact would explain the stronger response to the larger, noise-reduced vessel in the study by (Ona et al. 2007), which would have displaced more water as it approached.

Nedelec et al. (2016) investigated the response of reef-associated fish by exposing them in their natural environment to playback of motorboat noise. They found that juvenile fish increased hiding and ventilation rate after a short-term boat noise playback, but responses diminished after long-term playback thus indicating habituation to sound exposure over longer durations. These results were corroborated by Holmes et al. (2017) who also observed short-term behavioural changes in juvenile reef fish after exposure to boat noise as well as desensitisation over longer exposure periods.

A single study reported temporary threshold shift caused by exposure to vessel noise: Scholik and Yan (2001) exposed fathead minnows (*Pimephales promelas*) for two hours to sound playback recorded from small boats at a level of 142 dB re 1 µPa. They measured noise-induced threshold shift (NITS) of 7.8–13.5 dB at frequencies between 1–2 kHz, the most sensitive hearing range of this species.

[3] No PTS has been performed on marine mammals.

## B.3. Invertebrates

In a field experiment, Nedelec et al. (2014) investigated the effect of long-term exposure to continuous noise on the development and survival of the early life stages of the sea hare (*Stylocheilus striatus*). They found that in comparison to a control experiment with ambient-noise playback, the exposure to 12-h playbacks of small boat-noise stopped development of nudibranch embryos by 21% and increased the mortality of the remaining nudibranch larvae by 22%.

Several tank-based experiments investigated the physiological and behavioural effects of sound exposure on marine invertebrates. The sound generated by tidal and wind turbines was found to delay the time to metamorphosis between larval stages in estuarine crabs (Pine et al. 2012). Celi et al. (2013) documented statistically significant variations in haemato-immunological parameters as well as a reduction in agonistic behaviour in red swamp crayfish (*Procambarus clarkii*) after constant exposure to frequency sweeps over a duration of 30 min; the signals covered a frequency range between 0.1–25 kHz and reached a peak amplitude 148 dB re 1 µPa at 12 kHz. Shore crabs (*Carcinus maenas*) experiencing repeated ship-noise playback showed initial stress responses (Wale et al. 2013). On first exposure, the animals consumed more oxygen, indicating a higher metabolic rate. Filicotto et al. (2016) examined the effects of recorded boat noise on the behaviour and biochemistry of the common prawn (*Palaemon serratus*). The exposure elicited changes in locomotor patterns and caused physiological and behavioural effects which the authors identified as stress-related responses. Mooney et al. (2016) tested unconditioned behavioural responses to tonal signals in squid (*Doryteuthis pealeii*). The reactions elicited by sound exposure from 80 Hz to 1 kHz ranged from inking and jetting to body pattern changes and fin movements. Animals responded to the lowest sound levels in the 200–400 Hz range.

André et al. (2011) and Solé et al. (2013) provide evidence of acoustic trauma in two cephalopod species (*Sepia officinalis, Octopus vulgaris, Loligo vulgaris* and *Illex condietii*) which they exposed (under water) for 2 h to low-frequency sweeps between 50–400 Hz (1 s duration) generated by an in-air speaker. The received level at the animals' position was 157 dB re 1 µPa with peak levels (unspecified) up to 175 dB re 1 µPa. Both studies report permanent and substantial morphological and structural alterations of the sensory hair cells of the statocysts following noise-exposure with no indication of recovery. In a more recent experiment, Solé et al. (2017) exposed common cuttlefish (*Sepia officinalis*) to tonal sweeps between 100–400 Hz in a controlled exposure experiments in open water. Their results show a clear statistical relationship between the cellular damage detected in the sensory cells of the individuals exposed to the sound sweeps and the distance to the sound source. The authors measured and report the particle motion and pressure of the signals received by the animals, but due to the signal type (frequency sweep), they can only provide the maximum received levels or an estimate thereof, respectively; the maximal particle motion level was 0.7 $ms^{-2}$ observed at 1 m depth, the pressure reached levels of 139–142 dB re $1µPa^2$. The sound pressure levels reported are only slightly higher than the hearing threshold determined for longfin squid (*Loligo pealeii*), another decapodiforme cephalopod, measured by Mooney et al. (2010). The maximum particle motion (reported in terms of particle acceleration) reported by Solé et al. (2017) is in the same order of magnitude as the behaviourally thresholds measured at 100 Hz by (Packard et al. 1990) using a standing wave acoustic tube.

Many marine invertebrates are permanently, or at least sporadically, in contact with bottom sediment. The sediment, however, does not follow exactly, or at all, the movement of the surrounding water. Therefore, exposure to underwater sound will result is in a relative movement between the body of these animals and the oscillating water column. Accordingly, marine invertebrates face a different situation and perception from free-swimming or neutrally buoyant animals such as demersal or pelagic fish or marine mammals. In a discussion of the pressure related as well as the particle motion related sensitivity in marine invertebrates, it is therefore important to also consider the propagation of vibration through the ground. For benthic organisms, it is likely that this type of vibration is of similar if not greater importance than the water-borne vibration or even the compressional component of a sound (Roberts and Elliott 2017). The published scientific information on vibration sensitivity in marine invertebrates is extremely scarce (Roberts et al. 2015, Roberts et al. 2016). Most information on vibration sensitivity has been being derived from semi-terrestrial species known to use vibration in mating behaviour (Aicher and Tautz 1990). Only a small number of studies have indicated reception of vibration and behavioural responses in bivalves, which include the closure of the syphons and, in more

active molluscs, movement away from the substrate (Mosher 1972, Ellers 1995, Kastelein 2008). Nevertheless, to date, there is no convincing evidence for any significant effects induced by non-impulsive noise in benthic invertebrates.

Moreover, given the rapid attenuation of vibrational signals beyond the near field of a sound source (Morley et al. 2014), it is unlikely that these stimuli are causing more than behavioural effects (such as flight or retraction) or physiological (e.g., stress) responses.

## B.4. Avifauna

Stemp (1985; as cited in LGL (2012)) conducted observations on the effects of impulsive sounds generated by a seismic exploration on seabirds and did not observe any negative effects. (2003) (as cited in LGL (2012)) investigated the effect of near shore seismic surveys on moulting long-tailed ducks in the Beaufort Sea, Alaska, and also failed to detect any negative effects. Furthermore, they noted that seismic (i.e., impulsive) activity did not appear to change the diving intensity of the ducks significantly.

THIS PAGE HAS BEEN INTENTIONALLY LEFT BLANK