9.10 Underwater noise / ocean sound

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State of Knowledge of the "Underwater noise / ocean sound" attribute: Good / established but incomplete – general agreement, but limited data/studies

Part A—Attribute and method

A1. How does the attribute relate to ecological integrity or human health?

Underneath the ocean's surface is an environment filled with noise generated from natural sources (i.e., plate tectonics, under sea volcanoes, hydrothermal vents), climatic events (i.e., ice, waves, storms, rain, wind) and marine fauna undertaking every day biological activities (i.e., communication, orientation, foraging, predator interactions, reproduction) [1-4]. As sound propagates differently in water compared to air, underwater noise can be detected several kilometres from the source, much further and faster than would be possible with vision or other senses [1]. However, underwater noise propagation is also complex in that transmission is affected differently in deep water versus shallow water, in cold water versus more temperate waters, in channels or canyons versus flat, homogenous seafloors, and in silty versus clear water [1, 3].

The efficiency of sound transmission through water means most marine fauna use underwater noise as their primary sense for most aspects of their lives [1- 4]. For example, several invertebrate and fish species rely on natural underwater sound cues from reefs or rocky shores to guide larval stages to suitable habitats for settlement. Other species like blue whales communicate with conspecifics across whole ocean basins using low frequency underwater vocalisations. The range of hearing capabilities in marine animals dictates their potential responses to different underwater sounds while making them vulnerability to impacts from different sources of underwater noise [2]. For these reasons, changes in ambient (or background) noise or particular sound frequencies can be a hinderance for marine fauna that are reliant on sound for survival. A sound can only be detected if the received level of the sound is equal or exceeds a detection threshold, usually the ambient noise level [1-4]. Hence, a health ecosystem is dependent on its organisms being able to detect and react to important underwater sounds [4].

Marine fauna likely cope with naturally occurring large , but short duration, variations in ambient noise levels and the distances over which sound is effective [3]. However, elevated ambient noise levels caused by an increase in anthropogenically generated underwater noise can prevent or interfere with the detection of sounds important to marine fauna. Termed underwater noise pollution, the detrimental effects (acute) of increased human-generated underwater noise on the marine environment is a well-studied but more data is needed on longer-term chronic effects [1-5].

A2. What is the evidence of impact on (a) ecological integrity ~~or (b) human health~~? What is the spatial extent and magnitude of degradation?

Strong international evidence recognises the increasing adverse effects that underwater noise levels are having on marine resources and ecosystems (ecological integrity) [2-4]. Based on this growing evidence, anthropogenic underwater noise is now recognised as a concern by international organisations, industries and regulatory agencies around the world [6-11].

Adverse effects to marine fauna associated with increases in underwater noise include reduced detection, behavioural responses (e.g., changes in surfacing or diving patterns), auditory masking (e.g., interruptions in type or timing of vocalisations) and possible auditory injury (e.g., auditory threshold shifts and stress) [2-5, 12]. Acute effects that are associated with high impact sounds (i.e., seismic surveys, pile driving, underwater explosions) can have immediate effects on nearby individual animals over limited distances (frequency dependent). More chronic effects from less intense, wide-spread sounds of longer duration (primarily shipping traffic) can affect individuals as well as populations. Known as noise-dependent or physiological stress, research suggest this latter effect is the greater impact of underwater noise pollution as it can lead to negative consequences for whole ecosystems [2, 4, 13].

A3. What has been the pace and trajectory of change in this attribute, and what do we expect in the future 10 - 30 years under the status quo? Are impacts reversible or irreversible (within a generation)?

Most international literature reports that the ocean has become louder by an average of 3-4 dB* per decade since the 1960 [2-5), although recent research suggests the current trend may be slowing to 1-2 dB per decade. This increase is attributed mainly to an exponential increase in maritime traffic since the end of World War II [14-16], specifically commercial shipping, which accounts for up to 90% of current internationally traded goods [17], but also includes fishing, military fleets, tourism and transport fleets.

Future estimates suggest that with the current rate of growth in ship traffic and economic trading, ambient noise is projected to continue to rise globally [16]. However, several international initiatives are forcing rapid developments towards quieter, more efficient propulsion technology such as electric or hybrid systems for new ships (see question C2(v)) [18]. At the same time, noise abatement technology (i.e., bubble curtains) and noise threshold limits for construction are continuing to be refined and implemented in the United States and several European countries to mitigate and / or manage other anthropogenic noise pollution [13, 19].

The Covid-19 pandemic gave us a rare opportunity to study the impact of reducing shipping and recreational traffic on the global soundscape [20-21]. While the results of this relatively short-term 'experiment' are not consistent [21], the data demonstrate that when underwater noise pollution is decreased, listening and communication distances are immediately improved [20]. For example, in some parts of the ocean, a vocalising whale would have been audible twice as far away during the pandemic relative to 2019. Whether the wider biological and ecological consequences of long-term, elevated underwater soundscapes are as reversible at the individual or population level has yet to be fully tested.

* It is important to note that the decibel scale is logarithmic, which means an increase of 3 dB represents a doubling of intensity.

A4-(i) What monitoring is currently done and how is it reported? (e.g., is there a standard, and how consistently is it used, who is monitoring for what purpose)? Is there a consensus on the most appropriate measurement method?

As far as we are aware, there is no routine or long-term monitoring of underwater noise levels within Aotearoa New Zealand waters. The majority of monitoring done with Aotearoa New Zealand waters is highly localised (i.e., specific port or bay) and short-term (i.e., several months, very few more than one year) with most underwater noise monitoring undertaken by industry for resource consent or RMA applications and / or university student projects.

Several international governments and regulatory agencies are continuing to research, review and revise appropriate standards and methods (including units) for measuring a variety of different underwater noise components; general soundscape levels, ship noise limits, and adverse hearing and behavioural threshold limits for marine fauna [13, 19, 22-24]. There are currently no agreed upon national guidelines or standards used for underwater noise in Aotearoa New Zealand. The exception is a section in the Auckland Unitary Plan that has policies relating to the management of underwater noise from high-impact construction activities (i.e., pile-driving or blasting) and its effects on marine mammals [25]. Most Aotearoa New Zealand ports undertaking infrastructure upgrades are currently voluntarily adhering to the United States' NOAA standards for pile-driving and construction activities as part of their resource consent condition requirements [19, 22-23].

A4-(ii) Are there any implementation issues such as accessing privately owned land to collect repeat samples for regulatory informing purposes?

Aotearoa New Zealand presently has several real-time monitoring buoys operating throughout coastal waters [26-28], however, none of these current systems monitor underwater noise levels. While several real-time, telemetered systems have been designed and successfully trialled internationally and nationally, the cost and complexity of sending large amounts of continuous digital underwater noise data (live or stored) over months or years make this method presently unaffordable. Hence, the greatest issue restricting wide-spread monitoring is the cost of sending and storing large data files.

Another consideration when placing and leaving scientific recording gear in the marine environment (for short or long periods of time) is that it always involves a moderate level of risk, potential for loss of gear (and the data) either due to natural causes (i.e., water leak, mooring shifted or lost in storm) or human-related ones (i.e., trawled by commercial or moved, stolen by recreational fisheries).

Finally and perhaps most importantly, Aotearoa New Zealand currently lacks trained and experienced acousticians to process and analyse underwater noise data to the expected international standards.

A4-(iii) What are the costs associated with monitoring the attribute? This includes up-front costs to set up for monitoring (e.g., purchase of equipment) and on-going operational costs (e.g., analysis of samples).

Standard underwater noise monitoring in Aotearoa New Zealand is currently undertaken using a stand-alone, purpose-built mooring with 1 or 2 passive acoustic recording devices (i.e., noise levels are recorded and stored) attached close to the seafloor. Designed and built in Aotearoa, the *SoundTrap* recorder costs between $4,500 and $5,500 USD. With the cost of a suitably insulated frame to hold the recorder and mooring floats, ropes and anchor gear, an initial deployment will cost a total of approximately $10,000 to $15,000 NZD (depending on location and recovery needs). Autonomous recorders, like *SoundTraps*, can record and archive approximately 3-6 months of underwater noise data using SD cards, depending on the location and duty cycle.

As a single recorder can store up to 5TB of audio data over one deployment, AI-aided software is a necessity in auditing the data for the various sounds of interest. Even with purpose-built algorithms for automated auditing and processing, each day of data collected can take between three and four days to process and analyses on a consumer-grade computer. Parallelisation and GPU arrays can substantially improve this processing time. Data processing costs are in addition to the hardware.

A real-time option for monitoring underwater noise includes placing an integrated hydrophone onto an existing coastal monitoring buoy. A new purpose-built monitoring buoy costs approximately $30,000 to $200,000 (depending on size, processing, storage and sending capabilities). However, integrating and sending noise data can be costly depending on the type and intervals of data collected and the level of on-board processing needed. Often edge processing and AI is used, whereby the acoustic data are processed inside the buoy itself, transmitting only small data payloads containing detection data as they occur, or sound pressure level statistics over predefined time periods. These payloads are transmitted to the cloud, where further processing can occur as required.

An alternative to moored devices would be a cabled hydrophone (or hydrophone array) from a land-based station. This setup would only be applicable at locations in which the hydrophone could be regularly supervised and maintained, and in which the hydrophone was stationary and well-protected but deep enough to avoid noise contamination (i.e., rocky shore nearby). Cable laying can also be expensive and require relays when the cable exceeds 700-750m to maintain the integrity of the hydrophone's data cable. With the on-board processing occurring on land, cabled systems can have the advantage of being powered via mains supply or ethernet in some circumstances, which permits long-term, even permanent, placements.

A5. Are there examples of this being monitored by Iwi/Māori? If so, by who and how?

We are not aware of any specific underwater sound related monitoring being carried out by representatives of iwi/hapū/rūnanga.

There are mātanga moana (Māori expertise in marine knowledge) who have long monitored tohorā (whales) and their wider ecosystems and are just beginning to engage with science researchers on local projects. Collaboration and partnership in this space would lend itself to understanding mātauranga and the range of variables that mātanga incorporate in their assessment of estuarine and coastal health.

A6. Are there known correlations or relationships between this attribute and other attribute(s), and what are the nature of these relationships?

The state of water quality (i.e., turbidity, type of sediments) can have minimal or indirect effects on underwater sound. However, such factors mainly affect the speed of sound rather than pressure levels.

Part B—Current state and allocation options

B1. What is the current state of the attribute?

The current state of underwater noise levels in Aotearoa New Zealand is only partially understood at a national scale. Sporadic sampling has been undertaken within most of our ports and industrial coastal areas, which allows for relative comparisons of current underwater noise levels [20, 29]. Additional underwater noise data from protected bays to open coastal zones also exist through one-off studies by different universities or institutes [30]. However, as there are no national or regulatory requirements for the collection of underwater noise data, there is no coordinated, standardised data collections or network of existing monitoring efforts.

We are aware that the Royal New Zealand navy has an array of hydrophones off Great Barrier Island, starting in 1961 [31-32], to monitor sounds and movements in eastern, North Island waters. To the best of our knowledge, these data are not available for public use, but could represent an important long-term monitoring database that would help quantify the current state of underwater noise levels in our northern coastal waters.

B2. Are there known natural reference states described for New Zealand that could inform management or allocation options?

There are no currently described reference state(s) for underwater noise levels in Aotearoa New Zealand coastal waters, with the possible exception of the inaccessible, long-term naval monitoring database. However, it is possible that underwater noise data exists on representative habitats within our coastal waters (i.e., isolated fiords, rocky shore reefs, surf breaks) that represent a natural state [30]. The Covid lockdown gave us the opportunity to glimpse what the ‘natural soundscape’ of some of our ports (Auckland, Lyttelton, and Picton) might have been previously relative to recorded noise levels both before and post-lockdown [20, 33].

B3. Are there any existing numeric or narrative bands described for this attribute? Are there any levels used in other jurisdictions that could inform bands? (e.g., US EPA, Biodiversity Convention, ANZECC, Regional Council set limit)

There are currently no attribute bands, standards, or thresholds for underwear noise levels in Aotearoa New Zealand. The two exceptions are narrative management objectives and policies in the Auckland Unitary Plan for high-impact construction activities (i.e., pile-driving or blasting) and its effects on marine fauna [25]. The Department of Conservation has an industry wide voluntarily code of conduct to minimise any effects of seismic operation noise on marine mammals in Aotearoa water [34].

There are several overseas narrative standards and numeric thresholds for assessing potential impacts of different underwater noise components that have been developed by international organisations and regulatory agencies [13, 19, 22-24]. High-impact or impulsive noise (i.e., pile driving, seismic surveys) tend to be discrete and are generally controlled through a consent or regulatory process. For instance, to determine at what distance predicted noise levels could cause any physical impairment or injury (i.e., permanent or temporary hearing threshold shifts) to marine mammal species, the United States' National Oceanic and Atmospheric Administration (NOAA) developed relevant underwater acoustic thresholds based on established functional hearing groups to distinguish between different marine mammal species [19]. Appropriate sound level thresholds for behavioural disturbance of marine mammals from high-impact noise sources are currently being assessed and revised overseas [22-23]. In the interim, a two-tiered approach in which a lower behavioural responses threshold is used for impulse noise levels with more moderate responses at higher sound levels of all species are being used overseas studies [24, 35].

Numeric hearing thresholds are also available for non-impulsive sounds, but usually applied to similar construction activities (i.e., dredging, increase in construction traffic) rather than regular shipping traffic. Behavioural response and auditory masking ranges are based on a continuous noise approach known as dose-response curves [22-24, 35]. This approach estimates the probability of a response occurring at different noise levels (i.e., distances from the source) and can be species-specific where data are available. The only legislation globally that directly addresses chronic underwater noise pollution (primarily shipping) and requires that noises levels do not adversely affect marine ecosystems is the European Union's Descriptor 11 of the Marine Strategy Framework Directive (MSFD) developed in 2008 [13]. In 2021, the EU added a narrative action to reduce underwater noise pollution in its waters. A preliminary indicator for this initiative aims at tracking low frequency ambient noise level using annual average sound levels across three different frequency bands (63Hz, 125Hz and 2000Hz bands) within a specified affected area [13, 36].

B4. Are there any known thresholds or tipping points that relate to specific effects on ecological integrity ~~or human health~~?

As noted in answer to B3, underwater noise thresholds have been developed overseas for several marine fauna (particularly marine mammals and some fish) based on their hearing and vocalisation capabilities. Thresholds have been developed mainly for two types of noise - continuous and impulse. Thresholds are provided to protect marine fauna against permanent (PTS; i.e., injury, mortality) and temporary (TTS: i.e., injury, discomfort) hearing shifts, which are considered more acute and relate to discrete, high-impact noises (i.e., pile driving, seismic surveys). But both PTS and TTS thresholds have been developed for continuous noises (i.e., dredging) as well. Several preliminary behavioural responses and masking thresholds have been proposed, but they are not yet species-specific, instead focusing on dose-exposure risk. Internationally, there are currently no agreed upon tipping points or thresholds for underwater noise pollution levels that distinguish a health ecosystem from an impacted one. However, international and national research is underway into the use of acoustic indices as proxies for monitoring marine biodiversity with habitats [37-38] as well as sound impact mapping [39].

B5. Are there lag times and legacy effects? What are the nature of these and how do they impact state and trend assessment? Furthermore, are there any naturally occurring processes, including long-term cycles, that may influence the state and trend assessments?

In terms of high-impact underwater noise, hearing and physiological effects are generally immediate and site-dependent, similar to a point source effect. However, the chronic effects of longer-term construction projects and /or busy shipping areas on individuals and their populations are more difficult to assess due to potential generational lags (i.e., reproductive impacts) and natural variations in density / abundance of some marine fauna, masking survivorship or emigration impacts. In addition, marine fauna's lagged responses to the more pronounced effects of large-scale climate drivers (i.e., marine heatwaves) potentially conceal chronic noise pollution effects [29].

Potential legacy effects relate mainly to the pace at which underwater noise monitoring technology has evolved over the past two decades. Prior to the 2000s, sound files were still recorded from reels on to tapes and cassette, potentially affecting the sound quality. In addition, historical noise data was limited to low and medium frequencies, again, due to technological limits. Hence, the use of historical datasets can involve lots of complex adjustments and calibrations.

B6. What tikanga Māori and mātauranga Māori could inform bands or allocation options? How? For example, by contributing to defining minimally disturbed conditions, or unacceptable degradation.

Based on our limited knowledge, we understand mātauranga Māori considers sound to be an important connector between the land and the water. For example, species on land (e.g., kauri trees) share a connection to a species in the water (e.g., parāoa - sperm whales) through sounds /songs.

Part C—Management levers and context

C1. What is the relationship between the state of the environment and stresses on that state? Can this relationship be quantified?

The relationships between underwater noise levels and natural sources as well as climatic and daily events are well studied with generalised spectra curves available [1]. However these sources, while very noisy at times, are transient, lasting minutes to days. The propagation of underwater noise generated from discrete anthropogenic activities (such as pile-driving and seismic surveys) have also been well documented, and with location-specific data (i.e., seafloor sediment composition, depth, stratification and temperature), can be modelled and predicted [19, 22-23]. Hence, why there are several applicable guidelines and thresholds for these types of activities (see B3).

In relation to marine shipping traffic, underwater noise levels increase linearly with an increase in the number of ship present, noting however that decibels are logarithmic. However, this relationship is not always clear as not all ships are the same, the increase in general noise pollution along a busy port or channel will vary across different frequencies depending on the size, weight and type of population of the ships present. The impact of shipping noise is continuous and travels over long distances, at the same time noise levels also change as individual marine ships come and go. As a result, annual average sound pressure levels are proposed to be considered against a representative condition (i.e., 'good noise' year based on long-term data) with the aim of an overall spatial reduction percentage for a particular area i.e., Hauraki Gulf) [13,39].

C2. Are there interventions/mechanisms being used to affect this attribute? What evidence is there to show that they are/are not being implemented and being effective?

C2-(i). Local government driven

The Auckland Unitary Plan is the only local government example of policies aimed at limit or reducing underwater noise levels in relation to high-impact activities on marine fauna. However, no specific interventions are recommended or required [25].

Most underwater noise management or mitigation measures come through resource consent conditions, either offered by the client or enforced through the local regulator. As a result, this process provides considerable inconsistencies and uncertainty for both operators and regulators. To our knowledge, only one port infrastructure project has monitored, analysed and reviewed the efficacy of their underwater noise intervention and mitigation measures in regard to marine mammals [29]. This work found that enforced shutdowns based on TTS, requirements for qualified observers, and daylight limits for pile driving helped reduce shorter-term impacts. The review also recommended additional measures were warranted to reduce noise production at the source (e.g., bubble curtains). The project was not able to conclusively determine if longer-term declines in dolphin detections were due solely to the construction projects or in conjunction with other climate factors (e.g., simultaneous marine heatwave).

C2-(ii). Central government driven

While section 16 of the RMA mentions noise, it is not specific to underwater noise and is rarely mentioned in resource consent cases.

The Department of Conservation's national code of conduct to minimise effects of seismic operation noise on marine mammals has been reviewed and revised internationally to ensure efficacy [34].

C2-(iii). Iwi/hapū driven

We are not aware of interventions/mechanisms being used by iwi/hapū/rūnanga to directly affect this attribute.

C2-(iv). NGO, community driven

With advice from researchers, the shipping industry and Ports of Auckland developed a voluntary transit protocol to minimise Bryde's whale collisions in the Hauraki Gulf region [40-41]. By limiting speed for all commercial ships travelling within the Gulf to 10 knots (and reducing noise generation at the same time), the estimated probability of a lethal ship strike with Bryde's whales has reduced from 51% to 16% [42]. Unfortunately, the reduction in underwater noise levels was not quantified.

Bubble curtain technology to reduce noise levels generated from pile-driving was also trialled by KiwiRail for up-coming infrastructure upgrades at ferry terminals in both Wellington and Picton. Similar to overseas studies, preliminary results demonstrated large reduction in middle and higher frequency ranges, which overlap with several marine mammal species [43]. However, more work in needed to reduce lower frequency noise levels, ranges that affect whale and some fish species [4].

C2-(v). Internationally driven

In addition to the large amount of work being undertaken by international organisations to monitor, reduce and mitigate underwater noise as described in B3, other overseas ports have also implemented voluntary slow down protocols for shipping traffic in their areas [44-45] while passenger ferries servicing large cities are now actively monitoring for marine fauna [45].

Maersk Shipping and universities are researching how ship design changes affect underwater noise production while the company retrofitted one of their ship classes to carry more containers [46]. They found a reduction up to 5dB, likely due to changes in the propeller and bow design. The International Maritime Organization (IMO) recently revised the guidelines for the reduction of noise emissions from shipping, while also taking into account technical innovations and adaptations in shipbuilding [18].

Part D—Impact analysis

D1. What would be the environmental/human health impacts of not managing this attribute?

Changes in the attribute state affect ecological integrity as described in A1. Not managing underwater noise levels will lead to continued displacement of soniferous fish and mammal species from preferred coastal / inshore habitats and eventual avoidance by more migratory species, particular noise sensitive life stages of vertebrates and invertebrates [1-3]. For those species with restricted home-ranges and unable to move away from areas with increasing noise levels (i.e., ports, marina, shipping channels, oil / gas fields), increased chronic ecological stress at a regional and population level may eventually affect reproductive and survival capabilities [2-4]. Such impacts are greatest for non-migrating, taonga and indigenous species, such as Hector's and Maui dolphins and southern right whales, but also important iconic Aotearoa New Zealand ecosystems / habitats.

D2. Where and on who would the economic impacts likely be felt? (e.g., Horticulture in Hawke's Bay, Electricity generation, Housing availability and supply in Auckland)

Shipping is the largest contributor to underwater noise levels [1-5, 14-16] yet restricting commercial shipping speeds within Aotearoa New Zealand waters equates to longer shipping times and costs that are passed on to the industry, ports and eventually Aotearoa New Zealand taxpayers. However, as noted from Covid pandemic research, slowing shipping speeds and limiting recreational boats can have a significant reduction in the amount of underwater noise produced in our shipping channels [20]

Slowing shipping speeds and lowering noise levels also has an important secondary advantage of mitigating the risk of ship collision with whales and other large marine fauna [40]. The voluntary transit protocol to minimise Bryde's whale collisions initiated in 2013 between the shipping industry and the Ports of Auckland for the Hauraki Gulf region is a noteworthy Aotearoa New Zealand example [41]. As discussed in answer to C2(v), other overseas ports have successfully undertaken similar initiatives to reduce shipping noise effects even in light of potential economic impacts [44-45].

D3. How will this attribute be affected by climate change? What will that require in terms of management response to mitigate this?

Overseas researchers [16, 49] trying to understand the potential effects that climate change might have on ocean noise levels note that the 2022 IPCC assessment of climate change impacts [48] does not acknowledge any impacts of climate change on the ocean soundscape. In general, climate driven increases in the frequency and intensity of storm events, windier and / or wetter seasons may generally increase ambient noise levels within most habitats, but these effects might be moderated by the countering effects of raising ocean temperatures and decreasing ocean pH, that tend to increase the speed at which underwater noise travels [2, 49-52]. Simulation modelling predicts that some northern oceans will be up to 7dB noisier while locations in the Pacific and Southern Oceans are expected to be quieter by the next century (based on the sound field of a single ship) [16]. Drivers of these effects are mainly stratification, and to a lesser extent absorption, due to the creation or disappearance of sound ducts that will affect sound speeds and propagation distances at various depths differently [16, 53].

Future changes in sound propagation have the potential to significantly affect those marine fauna that rely on specialised auditory systems, such as marine mammals, however, such implications have not been investigated. In addition, the performance of anthropogenic acoustic sensor systems, on which maritime organisations such as naval military depend, will also likely be substantially affected [54]. The only current mitigation or management actions to reduce such effects are tied to those associated with reducing climate change. However, an overall reduction in shipping traffic and any increased efficiencies in furthering noise reduction technologies will help slow or reduce these impacts.

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