Styles Group
Underwater Acoustics

UNDERWATER NOISE EFFECTS ON THE MARINE ENVIRONMENT

AKAROA WHARF REDEVELOPMENT

PREPARED FOR

Christchurch City Council

DATE

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Assessment prepared by Styles Group for Christchurch City Council.

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Executive summary

Christchurch City Council has engaged Styles Group to undertake an underwater acoustic assessment to inform the resource consent application to rebuild the Akaroa Wharf.

This report describes the modelling of the underwater acoustics that has been undertaken to inform the effects on the marine environment. It describes the methods and outputs of the underwater noise modelling and compares them with recognised international guidelines for noise effects in marine species.

This information has then been used to inform the marine ecology and marine mammal impact assessment by the Cawthron Institute. This report does not provide any discussion of effects associated with underwater noise but instead establishes an information basis for Cawthron to establish those effects and appropriate mitigation to inform the application for resource consent.

Noise criteria

We have adopted the thresholds set out in the marine mammal acoustic technical guidance (revised in 2024) from the National Marine Fisheries Service of the U.S. Department of Commerce. This guidance has been extensively used around New Zealand and the world for underwater noise assessments. In the absence of specific guidance on underwater noise effects criteria in New Zealand, the adoption of overseas standards and peer-reviewed research is common and considered appropriate in the Akaroa Harbour Basin context.

For fish, we relied on the 2014 American National Standards Institute (ANSI) accredited guidelines for injuries that could lead to fatality and hearing loss. Those are the two noise-related impacts that current research can consistently and reliably link to negative effects on an individual or population net fitness.

Types of noise thresholds and species assessed

Auditory injury (including permanent threshold shift (PTS)), temporary threshold shift (TTS), risk of various behavioural responses, auditory masking and overall audibility were assessed (i.e., modelled) for a range of species. Threshold shifts are changes in hearing thresholds following some noise exposure and can either be temporary (i.e., return to normal hearing after a period of time) or permanent (i.e., hearing never returns). Specifically, Hector's dolphins and other delphinid species, baleen whales, New Zealand fur seals and leopard seals were investigated.

Fishes were assessed as two key groups: fish with swim bladders and fish without swim bladders. The distinction between these groups was made because the effects thresholds differ between them. The assessment was done in the context of 3 months of ambient sound data recorded within the Akaroa Harbour Basin.

The underwater noise modelling was undertaken for 710mm steel casing piles, as the largest pile being driven and in the deepest water. The effects ranges for all other pile types and smaller sizes (such as the timber piles) will be within the stated ranges below.

Results for marine mammals

The modelling suggests that there is a risk for auditory injury through PTS occurring for Hector's dolphins (up to 209m), other dolphin species (within 15m), leopard seals (85m) and baleen whales (112m), such as humpback whales, during the percussive piling with no mitigation. There is also a risk of TTS for all marine mammal species investigated within a maximum range of 1,593m (for Hector's dolphins) and a minimum range of 91m (for other delphinid species, including orca). New Zealand fur seals will be at risk of TTS to some degree within 175m from an unmitigated percussive piling source. Leopard seals will be at risk of TTS onset within 307m.

Temporary behavioural changes in marine mammals can be expected from the percussive piling. For cetaceans, at least 10% of exposed individuals could be expected to respond to the piling noise within 502m, while 50% of individuals will respond within 80m. Low severity behavioural changes in pinnipeds may occur within 5,000m from the piling. Moderate behavioural changes in pinnipeds can be expected within 1,478m of the unmitigated percussive piling.

Some degree of auditory masking effects may occur across the harbour to Anchorage Bay (~5,000m) for all marine mammal species. For Hector's dolphins, at least 50% of their active listening space may be reduced when 1,336m away from the piling source. Within 208m from the unmitigated piling, more than 75% of their active listening space may be reduced. For other dolphin species, 50% listening space reduction may occur within 1,101m – which is smaller than for NZ fur seals (1,985m). Baleen whales, however, show the greatest susceptibility to substantial auditory masking over large ranges, with over 50% reduction in listening range occurring across the harbour, over 5 km.

Results for fish & kororā

The modelling suggests that fishes with swim bladders risk recoverable injury if within 66m of percussive piling. Fishes without swim bladders may be exposed to that same risk of injury within 28m of the full-power percussive piling. Risk for the potential onset of TTS in all fishes (regardless of their anatomy) may occur within a conservative 23m of the full-power percussive piling. These distances assume minimal movement of fishes during their exposure to piling noise.

For kororā, auditory injury or hearing loss effects were unable to be modelled, due to lack of thresholds. However, based on the most recent audiogram data, masking effects can be expected. For example, 50% reduction in kororā listening space may occur within 436m, without noise mitigation.

Overall Conclusion

The redevelopment of the Akaroa Wharf will expose marine mammals, penguins and fish to acoustic-related disturbances that are either physiological, auditory or behavioural. Mitigation will be required to reduce the spatial extent of the more concerning effects to an appropriate level, namely temporary thresholds shift (TTS). This is particularly relevant for Hector's dolphins. There are number of potentially effective mitigation options that are discussed in this report.

1.0 Introduction

This report has been prepared for CCC as part of the application to rebuild Akaroa Wharf in Akaroa (**the wharf**). Our assessment has been undertaken to inform the effects of the application on marine mammals and fishes. Discussions of the effects in the context of the site are therefore not contained in this report, but instead are discussed in the ecological assessments.

The purpose and scope of this underwater noise assessment is to:

i. Model the underwater piling noise associated with the proposed project.

ii. To assess the potential extent of hearing threshold shifts (both permanent and temporary) in marine mammals and fishes.

iii. To assess the potential extent of masking risk, behavioural effects and general acoustic footprint.

2.0 The proposal

The reconstruction of the wharf will include constructing a new wharf structure 185m long and 8m wide, located 1.5 – 2.5m to the north of the existing wharf. The proposed works include:

- Installation of 44-55 steel-encased concrete piles (710mm diameter) for the main wharf, which will be driving in to the underlying basalt. Driving methods to include a combination of vibratory, bore and percussive piling. Installation of fender piles (timber) into the seabed, but not into the basalt.
- Installation of floating pontoons that will involve 12-16 steel piles (710mm diameter) being driven.
- Installation of 18 timber construction piles between the wharf and the Black Cat and Blue Pearl buildings to provide support during construction.

To facilitate construction, a small loading ramp will be built on the southern side of the Akaroa boat ramp. This will involve 2-4 steel piles (610mm diameter) to be driven along the southern side of the existing boat ramp to aide barge loading and unloading. The seaward approach to the loading ramp will also require dredging to allow for barge access, extending 90m from the shoreline and 30m wide. Approximately 1500m^3 of seabed will be dredged using a mechanical excavator (backhoe dredging) from a barge, the shore at low tide, or a combination of both.

From an underwater noise perspective, the proposed percussive piling of 710mm steel piles poses the highest risk of effects to marine life without mitigation.

A full description of the project is provided in the AEE.

2.1 Potential noise receivers

Cawthron has identified several marine mammal species as likely occurring inside French Bay and greater Akaroa Harbour (Pavanato & Clement (2023)). Specifically:

- Hector's dolphins (year-round residents).
- New Zealand fur seals (year-round residents).
- Leopard seals (frequent visitors).
- Killer whales (frequent visitors).
- Humpback whales (seasonal migrants).
- Southern right whales (seasonal migrants).
- Antarctic blue whales (seasonal migrants).
- Pygmy blue whales (seasonal migrants).

Under the provisions of the 2024 *Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 3.0)* from the U.S. National Marine Fisheries Service (NMFS), these species can be divided into one of five functional hearing groups.

3.0 Underwater noise and effects modelling

Underwater noise modelling of the proposed piling was undertaken from the end of the existing wharf structure. This was to account for the furthest location offshore that percussive piling of the 710mm steel piles will take place (**Figure 1**). The furthest location was chosen due to being in deeper water where noise will be able to propagate further. This represents an appropriate 'worst case' envelope for the propagation of noise.

Appendix C sets out the methodology for the underwater noise and effects modelling, including details on the source levels, propagation model, environmental inputs, and effects thresholds.

The key aspects of the modelling are:

- Wideband empirical source level data from 800mm steel piles were used. A reference spectrum was taken as a maximum from 674 piles over varying ranges during the Lyttelton Port Company's cruise berth construction project and adjusted to match the broadband source levels.
- The empirical broadband source level data were obtained from seafloor-mounted (<15m depths) recorders at 55, 100, 200, 500 and 1000m from a steel pile being driven. The data were chosen from sites with similar water depths, seabed morphology and water temperatures. Specifically:

- Measurements were undertaken while the 800mm steel casing piles (18m length) was driven 2.96m (consolidated sediment >10m below seabed) with 509 blows using a Junttan 6/8S (6T mode) impact hammer and Kobelco CKE 1800 crane from the barge Leonora.

- The noise model incorporates bathymetry, sound speed, frequency dependencies, and seafloor reflectivity. The required environmental parameters were provided by Land Information New Zealand (LINZ), Environment Cantebury (ECan) and reports by NIWA and the University of Canterbury.
- An additional 2.7m was added to the bathymetry to simulate MHWS. This was to assess the worst-case scenario, when lower frequencies are better able to propagate in deeper water.
- Two propagation algorithms were used: the parabolic equation method (RAMGeo from AcTUP) and the range-dependent energy flux (EF) (Weston et al. 1971, 1976). The EF algorithm is computationally efficient over range-dependent scenarios (Farcas et al. 2020). As such, very high-resolution models can used to investigate a range of scenarios, in short time frames. It has also been validated in a range of environments (such as in ship noise models (Farcas et al. 2020) or around shallow water fish farms (Findlay et al. 2021) and can produce very good propagation loss predictions (Sertlek & Ainslie 2013; 2014). While caution is needed, its use in modelling pile-driving noise has also been undertaken (for example de Jong et al. (2019); Wood (2016)) and presents several advantages for piling in shallow waters.
- The EF model's limitations are that it presents depth-averaged propagation losses (i.e., it has no depth-dependence) and assumes isovelocity sound channel (Wood 2016). However, for shallow water piling scenarios, the lack of depth-dependence circumvents the issue of identifying a single source point depth and sound speed profiles are often near isovelocity (Wood 2016).
- Passive acoustic monitoring (**PAM**) was undertaken using static autonomous recorders (ST600STD and ST300HF SoundTraps) between 22 June and 18 September 2023. Those recordings were processed to establish baseline ambient sound pressure levels.
- The noise models, composite audiograms (NMFS 2024) and PAM data were used to assess PTS, TTS, listening space reductions (**LSR**) and behavioural zones for all species when exposed to piling noise.

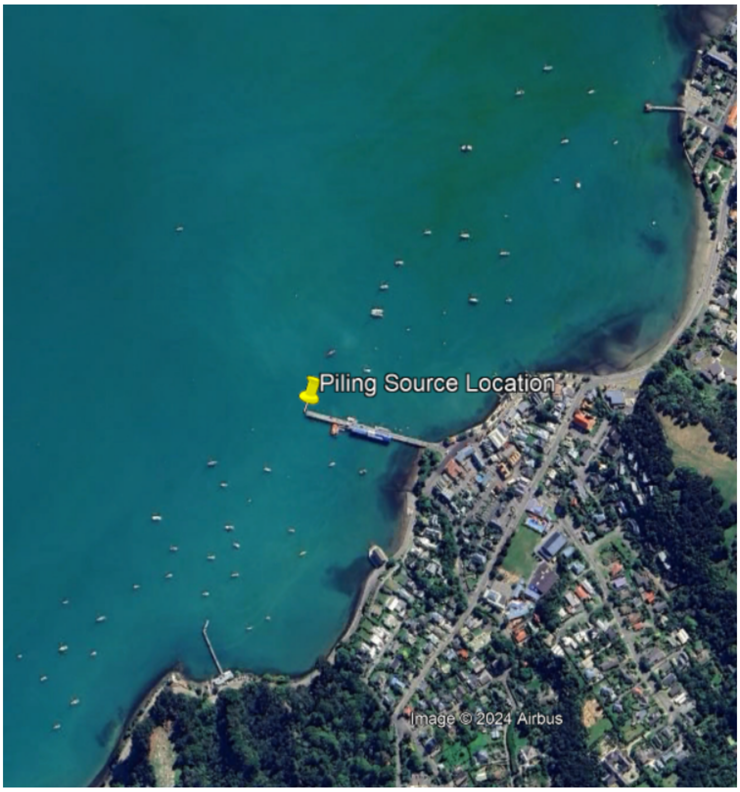

Figure 1 Source location used in the modelling.

4.0 Results: Marine Mammals

This section sets out the noise effects ranges during the percussive piling, providing ranges for:

- Potential onset of permanent threshold shift (**PTS**).
- Potential onset of temporary threshold shift (**TTS**).
- Distances at which animal listening spaces are reduced by 75%, 50%, 25% and 0% (LSRs).
- Distances at which risk for behavioural responses can be expected.
- Distance within which audibility of the percussive piling activity would be possible.

Appendix D provides maps of the sound field and impact zone maps.

4.1 Permanent and temporary threshold shifts

In this case, the cumulative SEL ($L_{E24\text{-}hr}$) levels were above the peak (L_{pk}) levels for all functional hearing groups investigated. The $L_{E24\text{-}hr}$ levels were therefore used to assess threshold shift ranges.

Table 1 and **2** below summarises the ranges within which permanent and temporary threshold shifts, respectively, in various species can be expected, in the absence of mitigation.

Table 1: Ranges (in metres) for the potential onset of permanent threshold shift (PTS) for the five functional hearing groups of cetaceans, during peak summer and winter seasons.

Species	Winter (SST = 7.5°C)*	Summer (SST = 16.5°C)*
Hector's Dolphins (VHF)	209m	189m
Baleen Whales (LF)	112m	75m
Other delphinids (HF)	15m	13m
Leopard Seals (PCW)	85m	45m
Fur Seals (OCW)	16m	15m

* Sea surface temperature, SST.

Table 2: Ranges for the potential onset of temporary threshold shift (TTS) for the five functional hearing groups of cetaceans.

Species	Winter (SST = 7.5°C)	Summer (SST = 16.5°C)
Hector's Dolphins (VHF)	1,593m	1,458m
Baleen Whales (LF)	329m	210m
Other delphinids (HF)	91m	48m
Leopard Seals (PCW)	307m	197m
Fur Seals (OCW)	175m	138m

4.2 Behavioural effects

Table 3 shows the distances within which behavioural effects thresholds are exceeded as absent of mitigation. Because sound propagation is further during the colder water temperatures, distances are reported for winter to give the worst-case scenario.

Table 3: Distances at which the potential onset of behavioural responses may occur from the percussive piling.
The threshold values, their origin, and meaning are provided in the methods, contained in Appendix C.

Species	**Effect**	
	10% of individuals likely to respond	**50% of individuals likely to respond**
All species: cetaceans	502m	80m
	Low severity responses*	**Moderate severity responses****
All species: pinnipeds	5,000m***	1,478m

* Such as alert behaviours, minor changes to swimming speeds, dive profiles or directions, changes to respiration rates, or minor cessation or modification of vocalisations (Southall et al. 2017, Table 4).
** Such as prolonged changes to swimming speeds, dive profiles, or directions, moderate shifts in distributions, prolonged cessation or modification of vocalisations (Southall et al. 2017, Table 4).
*** Across harbour to Anchorage Bay (approximately 5000m away).

4.3 Auditory masking

Table 4 shows the distances within which auditory masking effects can occur, during the winter months as absent of mitigation.

Table 4: Distances at which 75, 50, 25 and 0% listening space reduction (LSR) occurs for each of the species of interest.

Species	**Critical Distance (m)**			
	75% LSR	**50% LSR**	**25% LSR**	**0%LSR**
Hector's dolphins (VHF)	208m	1,336m	5,000m*	5,000m*
Other delphinids (HF)	138m	1,101m	5,000m*	5,000m*

Table 4: Distances at which 75, 50, 25 and 0% listening space reduction (LSR) occurs for each of the species of interest.

Leopard Seals (PCW)	754m	4,164m	5,000m*	5,000m*
Fur Seals (OCW)	162m	1,985m	5,000m*	5,000m*
Baleen whales (LF)	1,377m	5,000m*	5,000m*	5,000m*

*LSR >30% across harbour opposite French Bay (approximately 5,000m away).

4.4 Audibility

The piling noise is expected to be audible across the harbour to Anchorage Bay near Wainui Wharf (approximately 5km).

5.0 Results: Fishes

For fishes, the L_{pk} were above the $L_{E\text{-}24hr}$ and were therefore relied upon for determining the critical ranges for injury. The TTS effects were smaller than injury ranges due to the threshold for TTS in the ANSI guidance[1] being based on L_E only. Please note, these are in the absence of mitigation.

Table 5: Ranges for the potential onset of noise impacts from the percussive piling in fishes, based on the ANSI-Accredited guideline thresholds (Popper et al. 2014).
Note: TTS threshold is based on the cumulative SEL model, while injury is the Lpk.

Species	Critical Range (m)
Injury (including recoverable and fatal) in fishes without swim bladders (particle motion detection)*	28m
Injury (including recoverable and fatal) in fishes with swim bladders (particle motion and pressure detection)*	66m
TTS (All fishes)**	23m

* *Lpk* thresholds for fatal and recoverable injuries are the same and therefore grouped together in this assessment.
** The *SELcum* thresholds are the same for all fish-groups and therefore grouped together in this assessment.

[1] See Appendix C for details on the ANSI guidance for fishes and its use in this assessment.

6.0 Korora/Little penguin

Table 5 shows the distances within which auditory masking effects can occur for little penguins, based on the audiogram from Wei & Erbe (2024), without mitigation.

Table 5: Distances at which 75, 50, 25 and 0% listening space reduction (LSR) occurs for each of the species of interest.

	Critical Distance (m)			
	75% LSR	**50% LSR**	**25% LSR**	**0%LSR**
Little penguins	N/A	436m	2,146m	5,000m*

*LSR >7% across harbour opposite French Bay (approximately 5,000m away).

The piling noise is expected to be audible across the harbour to Anchorage Bay near Wainui Wharf (approximately 5km).

7.0 Mitigation

The underwater noise modelling identifies that a large shut down and marine mammal observation zone is required to protect Hector's dolphins from TTS onset risk. It is our understanding[2] that marine mammal observers are generally unable to effectively monitor for dolphins beyond 300m. Therefore, noise mitigation is required to reduce that shut down zone to a maximum of 300m. This can be validated via a noise limit of a VHF weighted cumulative SEL ($L_{E24\text{-}hr}$) limit of 144 dB re 1 μPa^2•s at 300m.

There are several options that could be used to comply with a VHF-weighted $L_{E24\text{-}hr}$ 144dB at 300m, either by conditioning the piling operation itself or reducing the amount of noise entering the marine environment. For example:

- Using vibratory and bore piling methods to drive the steel casing piles. While longer driving durations, the amount of radiated noise from the source is substantially less than percussive piling[3]. Furthermore, the TTS thresholds for Hector's dolphins when exposed to continuous noise sources is 17 dB higher than for impulsive signals.
- Limiting the number of piles per day to be driven. This reduces the $L_{E\text{-}24hr}$ levels per day, as the total sound energy entering the marine environment is capped daily.

[2] After personal comms with the project's marine mammal specialist, Dr Deanna Clement.

[3] see Findlay et al. (2023) for example of how longer sound exposure duration from quieter sources can have lower noise effects for moving/stationary sources/receivers.

- Limiting the hammer energy, either through limiting the maximum hammer energy and/or using a sacrificial timber dolly.
- Single or double bubble curtains. This technology reduces the amount of noise energy entering the environment beyond the immediate area.

Hector's dolphins are the most at risk and are therefore afforded the largest shut-down zones; by protecting Hector's dolphins, all other species can be further protected.

The relationship between percussive piling duration (as function of hammer strikes) and TTS onset ranges (i.e., would-be shut down zones) are provided in **Figure 2** and **Table 6**.

If driven using vibratory and bore piling methods (see Appendix C for model methods and assumptions used), the TTS onset range for Hector's dolphin is approximately 400 – 550m (220m average) (**Figure 3**)

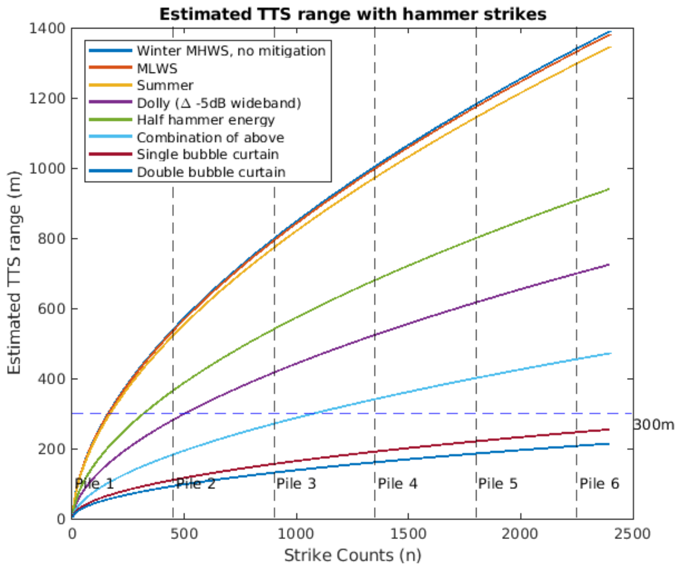

Figure 2 Relationship between modelled TTS onset range with hammer strikes during various operational conditions.

"Combination of above" means the TTS onset range while piling at half hammer energy (~50kJ) and a timber dolly during MLWS in summer.

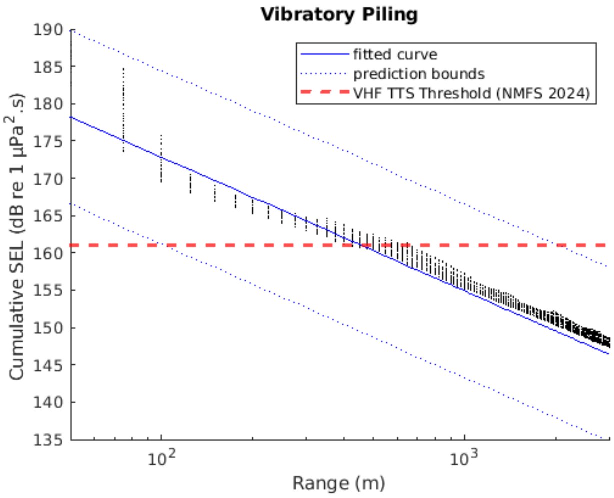

Figure 3: Modelled noise (cumulative SEL, dB re 1 μPa^2•s) from a vibratory-driven 680mm steel casing pile (representing the 710mm piles) at Akaroa wharf with range (metres). The red dotted line represents the TTS onset level (cumulative SEL, dB) for Hector's dolphins, which occurs within ~450m from the piling source.

Table 6: Possible changes to the estimated TTS ranges (shut-down zones) under various piling operations.

Strategy	Mean TTS range (shut-down zone)
Unmitigated	1389
Summer months only (16.5°C)	1346
Restrict piling operations to 2 hours either side of MLWS	1382
50% reduction in hammer energy	942
Timber dolly	726
Combination	473
Single bubble curtain	256
Double bubble curtain	216
Vibratory & bore piling only	450

8.0 Conclusion

The reconstruction of the Akaroa wharf will expose marine mammals to acoustic-related disturbances that are either physiological or behavioural. Mitigation is required to reduce the spatial extent of the more concerning effects, namely temporary threshold shift. This is particularly relevant for Hector's dolphins for which there is a potential risk of TTS onset beyond 1km from the unmitigated percussive piling of 710mm steel casing piles. There are number of potentially effective mitigation options that can reduce that TTS onset range an appropriate one whereby an effective MMOZ can be achieved.

9.0 References

de Jong, C., Binnerts, B., Prior, M., Colin, M., Ainslie, M., Mulder, I., Hartstra, I. 2019. Update of the Aquarius models for marine pile driving sound predictions. Technical report from TNO. Report No. TNO 2018 R11671.

Farcas, A., Powell, C.F., Brookes, K.L., Merchant, N.D. 2020. Validated shipping noise maps of the Northeast Atlantic. *Science of the Total Environment* 735: 139509.

Findlay, C.R., Aleynik, D., Farcas, A., Merchant, N.D., Risch, D., Wilson, B. 2021. Auditory impairment from acoustic seal deterrents predicted for harbour porpoises in a marine protected area. *Journal of Applied Ecology* 58: 1631-1642.

Findlay, C.R., Rojano-Doñate, L., Tougaard, J., Johnson, M., Madsen, P.T. 2023. Small reductions in cargo vessel speed substantially reduce noise impacts to marine mammals. *Science Advances* 9(25): eadf2987.

National Marine Fisheries Service (NMFS). 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 thresholds shifts. U.S. Dept. of Commerce, NOAA. NOAA Technical Memorandum NMFS-OPR-59.

Pavanato H, Clement D. 2023. Re-establishment and extension of Akaroa Wharf: assessment of environmental effects on marine mammals. Nelson: Cawthron Institute. Cawthron Report No. 3989. Prepared for Christchurch City Council.

Sertlek, O., Ainslie, M.A. 2013. Propagation loss model comparisons on selected Scenarios from the Weston memorial workshop, UAC2013, 441-447.

Sertlek, O., Ainsliem, M.A. 2014. A depth-dependent formula for shallow water propagation. *Journal of the Acoustical Society of America* 136: 573-582.

Wei, C., Erbe, C. 2024. Sound reception and hearing capabilities in the Little Penguin (*Eudyptula minor*): first predicted in-air and underwater audiograms. *Royal Society Open Science* 11: 240593.

Weston, D.E. 1971. Intensity-range relations in oceanographic acoustics. *Journal of Sound and Vibration* 18: 271–287.

Weston, D.E. 1976. Propagation in water with uniform sound velocity but variable-depth lossy bottom. *Journal of Sound and Vibration* 47(4): 473-483.

Wood, M.A. 2016. Modelling and preduction of acoustic disturbances from off-shore piling. Ph.D. Thesis, University of Southampton.

Appendix A Glossary of terms

Acoustic waveguide	A medium or structure that guides sound waves by restricting the wave movement in one of more dimensions, resulting in the efficient transmission of the sound wave.
Ambient sound	Ambient sound is the total of all noise within a given environment, comprising a composite of sounds from sources near and far.
Biologically important signal	An acoustic signal that, once detected and perceived, provides the receiving animal some information that is important to its survival and/or reproductive output.
Critical band	The frequency band of sound, contained within a broadband noise spectrum, that contains the energy equal to that of a pure tone centred in the critical band and just audible in the presence of broadband noise (Erbe et al. 2016).
dB (decibel)	The basic measurement unit of sound. The logarithmic unit used to describe the ratio between the measured sound pressure level and a reference level of 1 micropascals (0 dB) (or 20 micropascals for airborne sound).
Detector	A detector is a computer program that automatically detects the presence or absence of a particular signal that the algorithm is trained to detect.
Halocline	A strong change in salinity in a body of water with depth, where the salinity is markedly different above and below the layer in which the salinity change occurs.
Power spectral density (PSD)	The dB level of the power spectrum, presented every 1 Hz.
Permanent Threshold Shift (PTS)	An increase in the threshold of hearing (i.e. the minimum sound intensity required for the receiver to detect a signal) at a specific frequency that does not return to its pre-exposure level over time., i.e., it is permanently altered.
Sub-lethal	Sub-lethal effects are biological (including ecological), physiological or behavioural effects on individuals that survive exposure to the invasive noise.
Sound pressure level (SPL)	The logarithmic unit used to describe the ratio between the measured sound pressure level and a reference level of 1 micropascals (0 dB) (or 20 micropascals for airborne sound). Unless stated otherwise, the SPL refers to the root-mean-square (rms) sound pressure.
Soundscape	Similar to ambient sound, the acoustic soundscape is the sum of multiple sound sources arriving at a receiver (whether animal or hydrophone).
SoundTrap (ST)	An autonomous underwater acoustic logger used in marine science research from Ocean Instruments New Zealand.
Sound exposure level	The dB level of the time integral of the squared pressure over the duration of the sound event, expressed as dB re 1 $\mu Pa^2 \cdot s$.
Source level	The sound pressure level transmitted by a point-like source that would be measured at 1 metre distance and expressed as dB re 1 µPa @ 1m.
Temporary Threshold shift (TTS)	An increase in the threshold of hearing (i.e. the minimum sound intensity required for the receiver to detect a signal) at a specific frequency that returns to its pre-exposure level over time.

Appendix B Existing soundscape

Marine mammals, fish and invertebrates depend on underwater sound for their survival. It plays a vital role in many life processes, such as (but not limited to) maintaining group cohesion while navigating turbid coastal waters, communication between group members, locating prey during foraging, mediating reproductive behaviours and avoiding predation (Duarte et al. 2021). Their ability to communicate and perceive biologically important sounds are directly related to the surrounding acoustic environment as signals must be audible over the background soundscape within some critical bandwidth. Coastal activities, including pile-driving, dredging, shipping, boating, drilling etc, can cause ambient noise levels across a very wide frequency range to rise to the point where marine animals are unable to detect signals that are critical to them. This masking effect can induce a range of sub-lethal impacts, from increased stress hormones and behavioural responses to total habitat avoidance and exclusion (Southall et al. 2007, 2019; Nowacek et al. 2007; Duarte et al. 2021). Underwater noise pollution can therefore degrade marine habitats within and around sites where nearshore or offshore activities take place.

However, the degree/extent of habitat degradation is not equal between areas/environments/regions because the physical environment changes. Generally, noise effects only occur if the invading noise source is audible (audibility being a function of both the ambient soundscape and hearing thresholds of a listener). Therefore, to properly assess the maximum spatial extent of possible acoustic disturbance for marine mammals, the ambient soundscape must be understood and incorporated into assessments.

Autonomous recorders where therefore deployed at two sites to provide data on the current soundscape of the area.

Methodology

Monitoring sites and data acquisition

In many harbours and productive coastal areas, ambient sound levels and spectra can vary over relatively short distances (Pine et al. 2015; Radford et al. 2010). It is therefore necessary to monitor areas not only near the activity itself, but also more distant habitats where the anthropogenic noise can propagate into. Autonomous recorders were therefore set up within and outside French Bay.

SoundTrap 300HF and 600STD recorders were deployed between 22 June and 18 September 2023 within and outside French Bay (**Figure 4**). The ST600 was programmed to operate on a 50% duty cycle (5min every 10min) at 192kHz. Two ST300HF recorders were deployed on the same mooring, programmed to run on alternating duty cycles (i.e., both recorders operated on a 5min recording every 10min duty cycle, but one started on the hour, while the second recorder started 5min later). This allowed for a longer continuous monitoring period, while providing sampling redundancy and a backup recorder should one experience a technical fault.

The hydrophone component of the SoundTrap recorders was calibrated by the manufacturer. Field-calibration checks before the initial deployment were undertaken using a calibrated piston phone (GRAS Type 42AA, SPL 114 dB re 20 µPa, nominal frequency range 250 Hz), and calibrated (using a Brüel & Kjaer Type 4231 Sound Calibrator) sound level meter (Brüel & Kjaer 2250 Type 1 SLM with a Brüel & Kjaer ½ inch condenser microphone Type 4189) and specialist acoustic software.

The primary rationale for the ambient soundscape monitoring was to understand the existing sound levels, the effects on weather on ambient sound and general vessel activity (including AIS and non-AIS broadcasting vessels) occurring in and around the French Bay. Monitoring for Hector's dolphin vocalisations (or other cetacean species) was not a primary aim due to their presence being well known and understood before hydrophones were deployed. Notwithstanding, however, the ST300HF recorders were set with a 288 kHz sampling rate to provide some presence data should it be useful to the project's marine ecologists.

Figure 4 Map showing the locations (AH = Akaroa Harbour, AHFB = Akaroa Harbour French Bay) of the two SoundTrap recorders deployed between 22 June and 18 September 2023.

Weather data

Hourly wind speeds (m/s) and direction were obtained using NIWA's CliFlo database (**Figure 5**). The weather station was located 45m above sea level (Akaroa EWS (Agent number 36593, [-43.8094 172.9657]) and was selected as the closest station to the hydrophone sites with reasonable exposure.

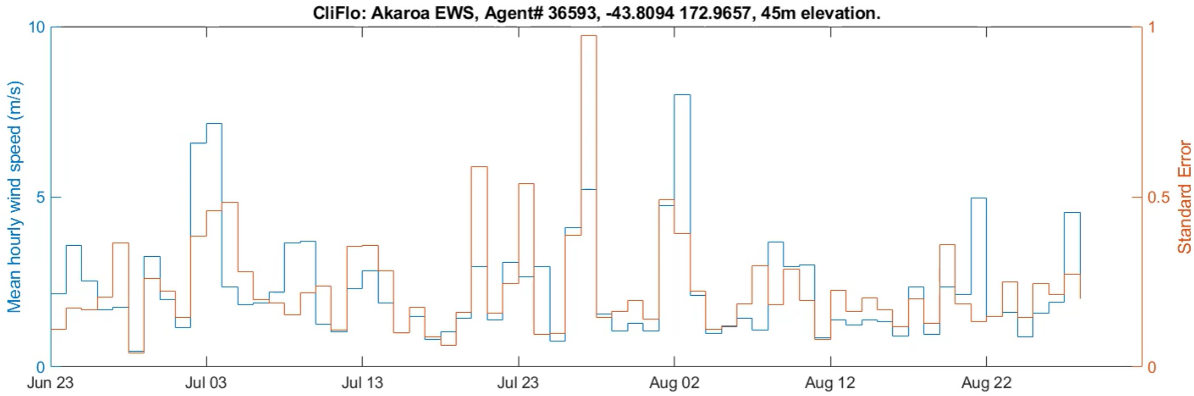

Figure 5 Snapshot of hourly wind speeds per day from CliFlo over the acoustic monitoring.

Data analysis

Ambient sound data were analysed following the methods in Pine et al. (2021) but summarized below.

Every 60sec of acoustic data was used to determine power spectral densities (PSDs, 1-sec FFT Hamming window sizes, 50% overlap, 60s averaging), producing a long-term spectral average (LTSA) spectrogram for the site. Wideband sound pressure levels (SPLs) (10Hz – 144 kHz for the ST300HFs; 10Hz – 96 kHz for the ST600), and decidecade bands were calculated from the LTSAs. This generated a single power spectrum, decidecade spectrum and SPL sample for every 60sec (maximum 5 samples per recording, and 30 samples per hour based on the 50% duty cycle). Time-stamped hourly averages were then calculated. Daytime periods were defined as the time between sunrise and sunset times for the hydrophone site. Data were then sorted into nine different wind-speed categories to represent each Beaufort Scale (BS), following Wenz (1962).

Vessel activity within and around French Bay was quantified as general presence and individual pass-by events that were identifiable from their closest-point-of-approach (CPA)[4] were characterised using the maximum received SPL (1-sec average, Lmax) and Leq over the complete pass-by. Pass-by events were defined by the start/end times when the received SPL between 1 and 5 kHz exceeded 10dB above the ambient noise floor without the vessel noise. Noise floors were based on the moving average in between vessel detections within successive audio files. Vessel presence was determined in the recording using a vessel noise detector (see Pine et al. 2021 for more details).

Hector's dolphin echolocation clicks were detected from the recordings using a specific dolphin detector (see Clement et al 2022). Detection events were defined as the time between the first

[4] The CPA was not always recorded due to the recorder's duty cycle, but presence was logged.

and last detected echolocation signal that is within 20 minutes of the previous echolocation click. For example, if one detection was made at 10:00hrs and another at 10:10hrs, that would count as the same detection event (lasting 10min). However, if no echolocation signals were detected within 20min of the last (i.e., at 10:10hrs), that the detection event is concluded, and the duration would be 10min.

All detectors were created using artificial neural networks and described in either Pine et al. (2021) (vessels) or Clement et al. (2022) (Hector's dolphins).

Results & discussion

The ambient soundscape of Akaroa Harbour was found to have a considerable geophonic component, with little influence from anthropogenic noise when compared to other New Zealand harbours, such as Lyttelton (**Figure 6, 7**). The area is also quiet, with wideband SPLs (10Hz – 24kHz) dropping to ~86 dB re 1 µPa and ~95 dB re 1 µPa during the night and day, respectively (**Figure 8, 9**).

Hourly mean SPLs as low as 89 dB_{rms} re 1 µPa (5^{th} percentile level between 10Hz and 144 kHz, between 22 June and 28 August 2023) were registered from either monitoring site (**Figures 10, 11**). Cumulative distribution plots of the hourly-averaged SPLs revealed narrow percentile ranges at both sites, of approximately 18 dB_{rms} re 1 µPa (**Figure 6, 7**).

Between June and August 2023, wind was the primary driver of sound levels within and around French Bay (**Figure 12, 13, Table 7**). Wind speeds greater than 11 km h^{-1} (BF 2) caused ambient sound between 100Hz and 70 kHz (averaged of all 1-hr samples over the whole deployment) to increase approximately 2dB at both monitoring sites (**Figure 14 and 15**). Above 30 km h^{-1} (BF 4), SPLs above 30Hz increased in the shallower French Bay, while at the more exposed Akaroa Harbour site, the whole spectrum increased in amplitude above 11 km h^{-1} (BF 2). Below 6 km h^{-1}, wind speed had no effect on sound levels.

Vessel activity was relatively low around French Bay, with 229 instances of vessels causing >10dB increases to the 1-sec averaged SPLs. Pass by events lasted between 19 and 186 seconds, reaching Lmax levels between 86 dB (distant vessel near harbour entrance) and 153 dB_{rms} re 1 µPa and Leq levels between 100 and 147 dB_{rms} re 1 µPa.

There were 85 detection events recorded over 66.69 days of recording (the length of time the ST300HF recorders lasted). The mean detection positive minutes within all detection events were 3, while the max was 4. It is important that the duty cycle of 5min/10min meant the maximum DPM in a recording was 5, and therefore no conclusions about vocal activities can be made or inferred beyond presence.

The times for all detection events for Hector's dolphins are provided in Appendix E. Vessel pass-by detections are provided in Appendix F.

Table 7: Relationship between ambient sound levels (10Hz – 96kHz (Akaroa Harbour), 10Hz – 144 kHz (French Bay), Beaufort Scale and wind speed.

Beaufort Scale	Wind Speeds (km/h)	Wideband ambient sound level (hourly averages)	
		Akaroa Harbour	French Bay
0	0 – 2	94.43	93.21
1	2.01 – 6	96.72	92.76
2	6.01 – 11	100.10	96.67
3	11.01 – 18	102.25	99.84
4	18.01 – 30	105.94	103.71
5	30.01 – 39	106.74	106.36
6	39.01 – 50	-	-
7	50.01 – 61	-	-
8	61.01 – 74	-	-

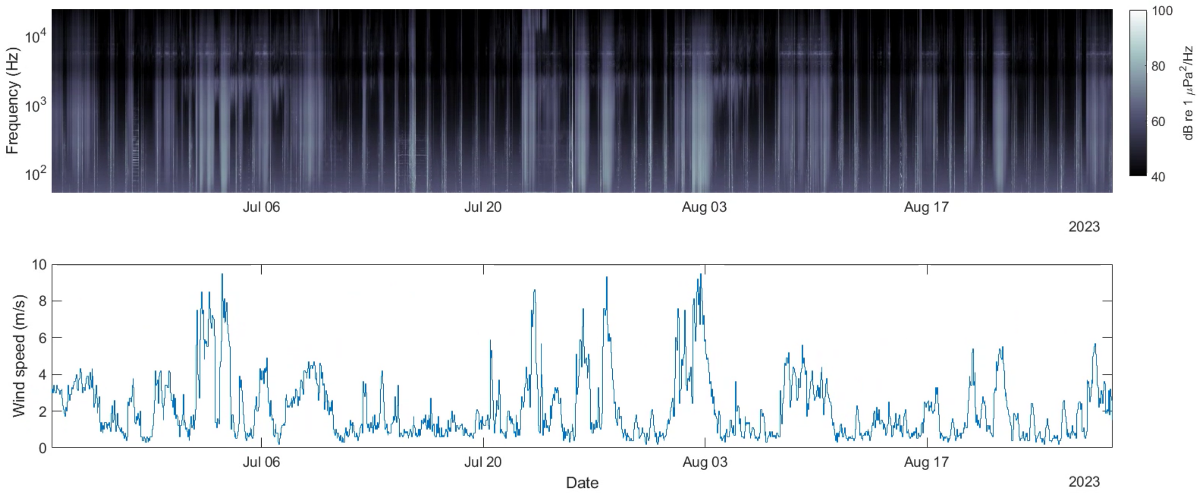

Figure 6 Spectrogram from within French Bay (AHFB01 site) between 22 June and 29 August 2023 (top panel) and hourly averaged wind speeds from nearest weather station operated by NIWA (bottom panel).

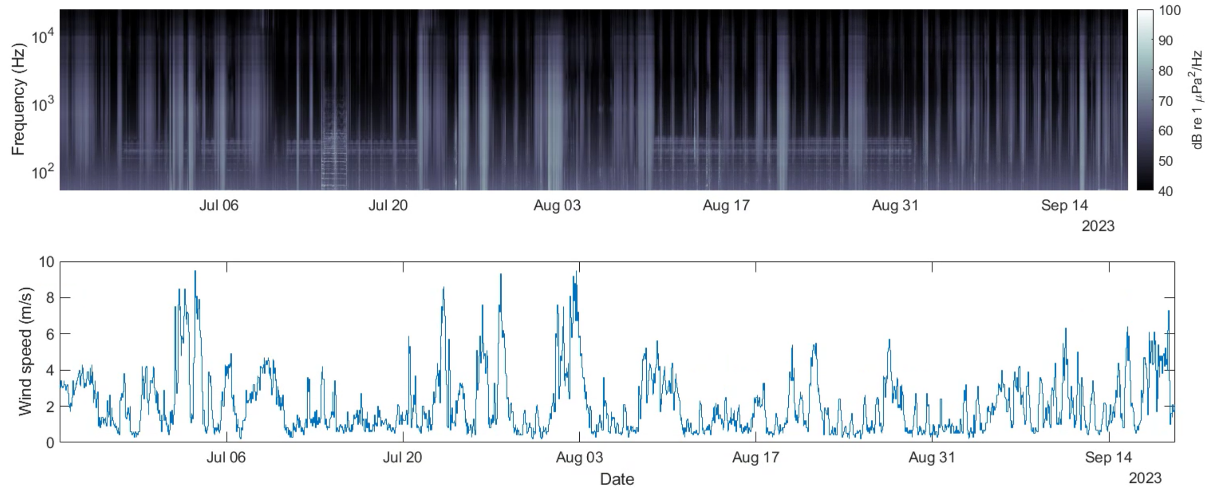

Figure 7 Spectrogram from within Akaroa Harbour (AH01 site) between 22 June and 29 August 2023 (top panel) and hourly averaged wind speeds from nearest weather station operated by NIWA (bottom panel).

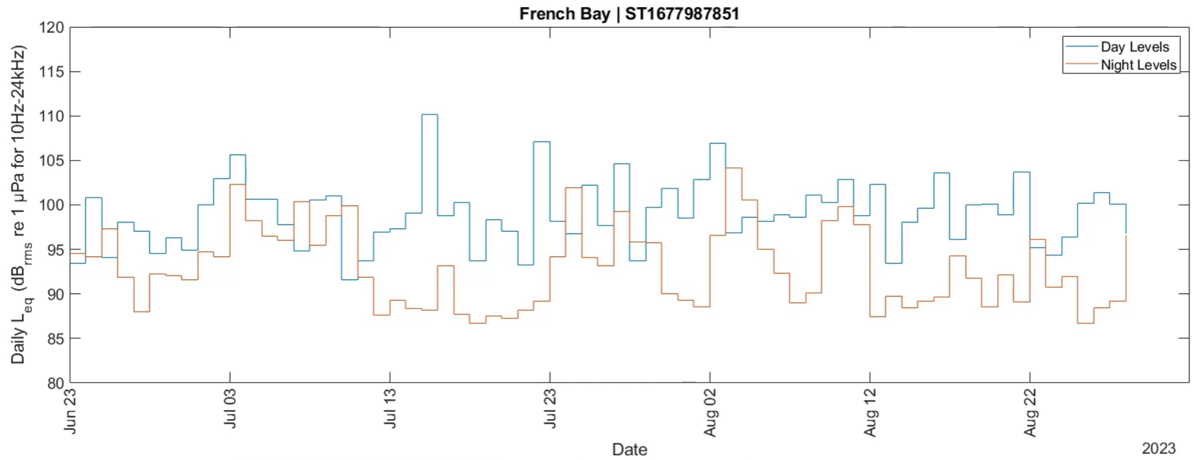

Figure 8 Daily sound pressure levels (Leq, dB_{rms} re 1 µPa), averaged over day and night time periods (based on sunset/sunset times), from within French Bay (AHFB01 site).

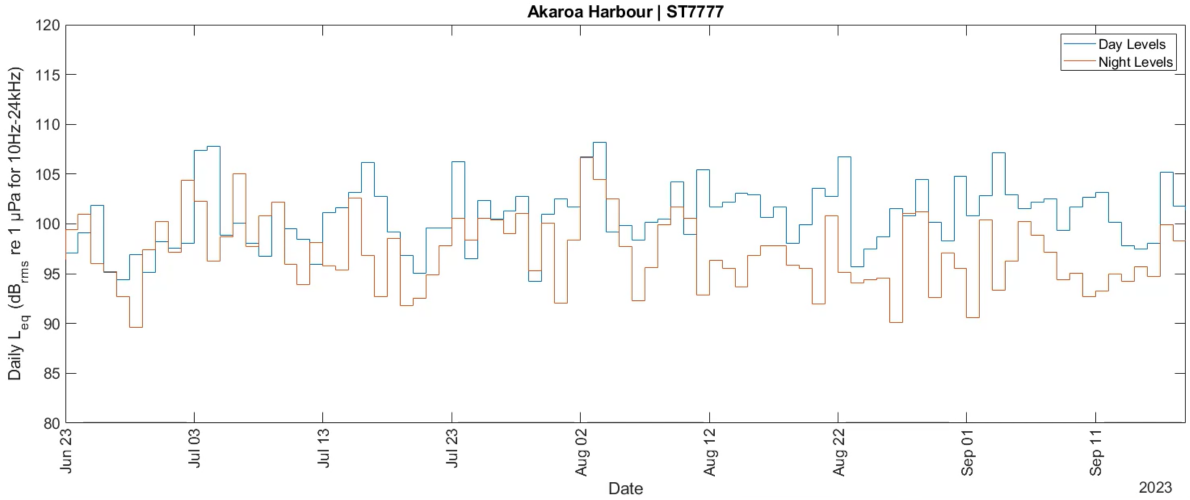

Figure 9 Daily sound pressure levels (Leq, dB_{rms} re 1 µPa), averaged over day and night time periods (based on sunset/sunset times), from within Akaroa Harbour (AH01 site).

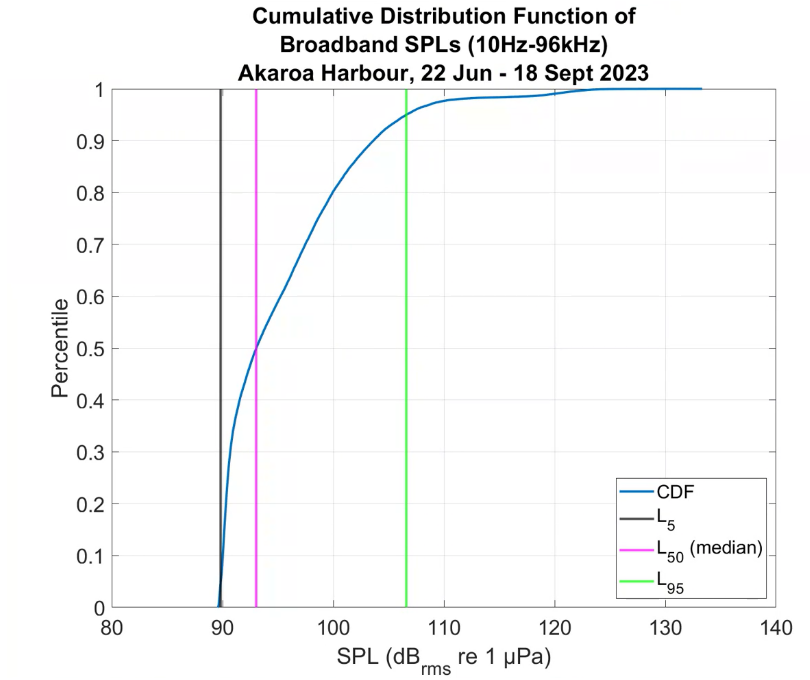

Figure 10 Statistical variance (5th, 50th and 95th percentiles) in wideband sound pressure levels (SPLs) within Akaroa Harbour (AH01 site).

L5 = 89.8 dB re 1 µPa; L50 = 93.1 dB re 1 µPa; L95 = 106.6 dB re 1 µPa.

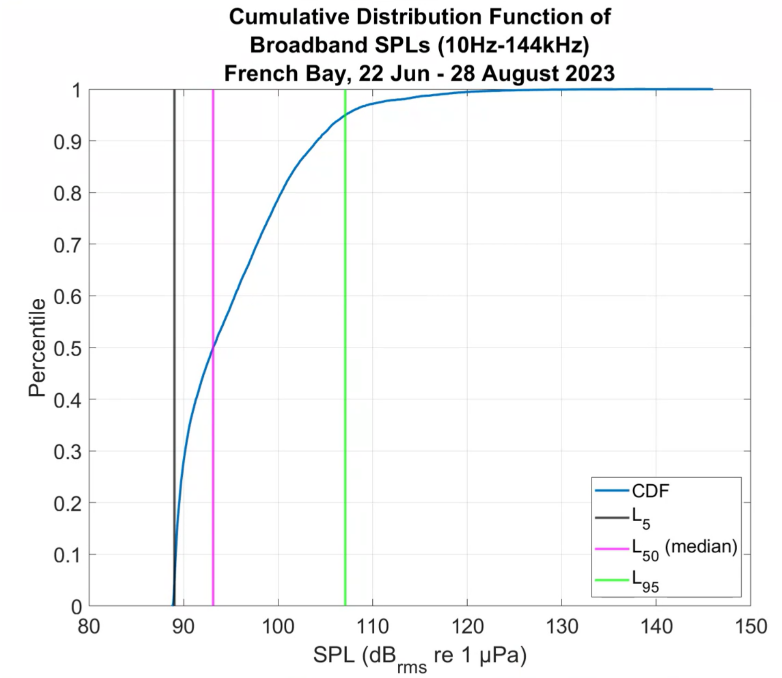

Figure 11 Statistical variance (5th, 50th and 95th percentiles) in wideband sound pressure levels (SPLs) within French Bay (AHFB01 site).

L5 = 89.0 dB re 1 μPa; L50 = 93.1 dB re 1 μPa; L95 = 107.1 dB re 1 μPa.

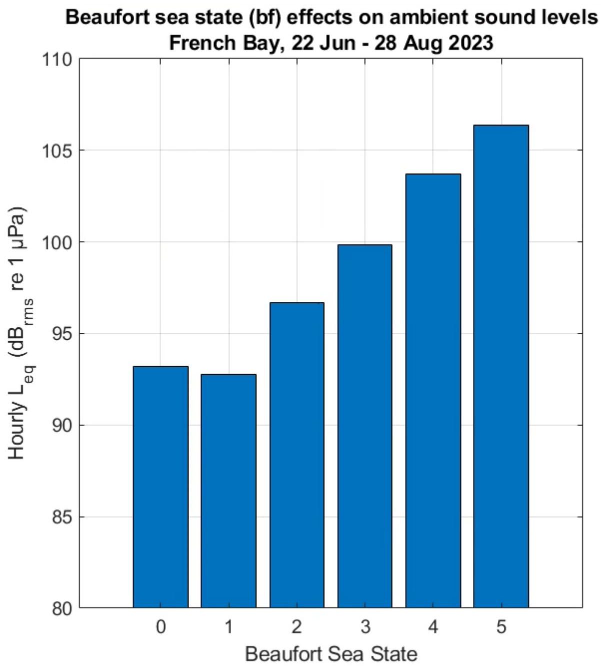

Figure 12 Hourly Leq (dB re 1 μPa) levels for different Beaufort Scale sea states within French Bay (AHFB01 site).

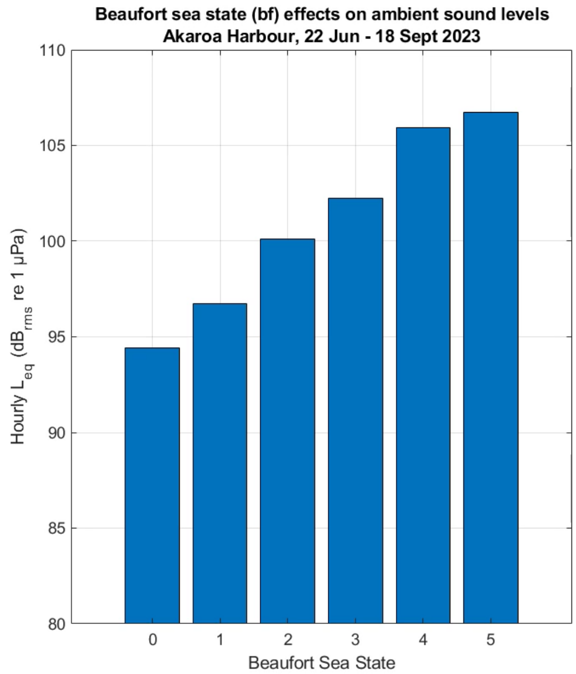

Figure 13 Hourly Leq (dB re 1 µPa) levels for different Beaufort Scale sea states within Akaroa Harbour (AH01 site).

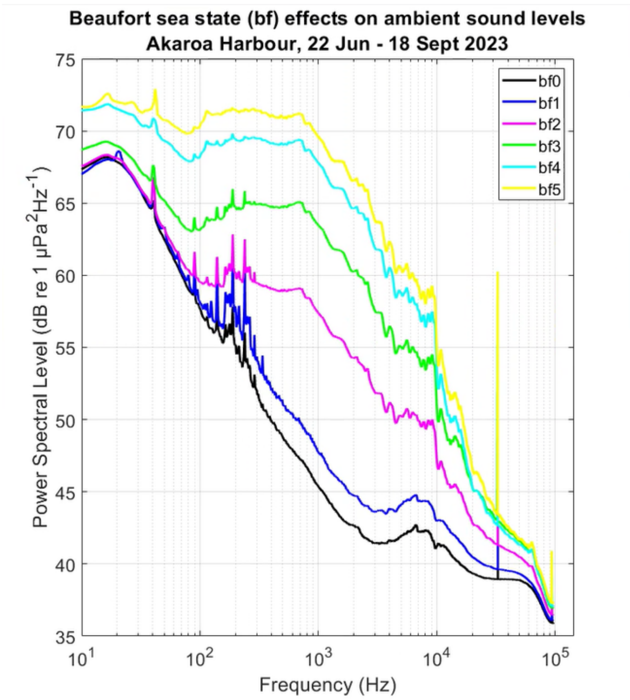

Figure 14 Noise spectrum between 10Hz and 96kHz for each Beaufort Scale (bf) from within the seafloor-mounted SoundTrap in Akaroa Harbour (AH01 site).

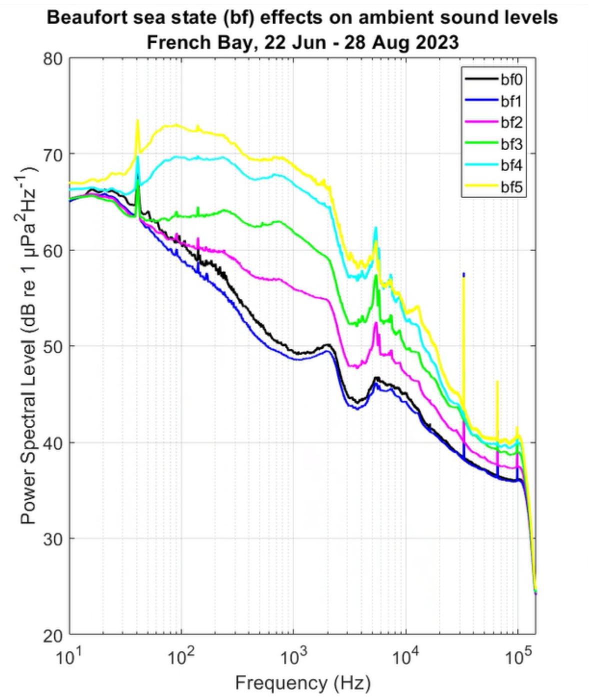

Figure 15 Noise spectrum between 10Hz and 96kHz for each Beaufort Scale (bf) from within the seafloor-mounted SoundTrap in French Bay (AHFB01 site).

Literature cited

Clement, D., Pavanato, H., Pine, M.K. 2022. LPC's cruise berth project – marine mammal research report. Prepared for Lyttelton Port Company Ltd. Cawthron Report No. 3820.

Duarte CM, Chapuis L, Collin SP, Costa DP, Devassy RP, Eguiluz VM, Erbe C, Gordon TAC, Halpern BS, Harding HR, Havlik MN, Meekan M, Merchant N, Miksis-Olds JL, Parsons M, Predragovic M, Radford An, Radford CA, Simpson SD, Slabbekoorn H, Staaterman E, Van Opzeeland IC, Winderen J, Zhang X, Juanes F. 2021. The soundscape of the Anthropocene ocean. *Science*. 371, eaba4658.

Merchant ND, Fristrup KM, Johnson MP, Tyack PL, Witt MJ, Blondel P, Parks SE. 2015. Measuring acoustic habitats. *Methods in Ecology and Evolution* 6(3): 257-265.

Nowacek, DP, Thorne LH, Johnston DW., Tyack PL. 2007. Responses of cetaceans to anthropogenic noise. *Mammal Review* 37(2): 81-115.

Pine, M.K, Radford, C.A., Jeffs, A.G. 2015. Eavesdropping on the Kaipara Harbour: characterising underwater soundscapes within a seagrass bed and subtidal mudflat. *New Zealand Journal of Marine and Freshwater Research* 49(2): 247-258.

Pine, M.K., Wilson, L., Jeffs, A.G., McWhinnie, L., Juanes, F., Scuderi, A., Radford, C.A. 2021. A gulf in lockdown: how an enforced ban on recreational vessels increased dolphin and fish communication ranges. *Global Change Biology* 27: 4839-4848.

Radford, C.A., Stanley, J.A., Tindle, C.T., Montgomery, J.C. 2010. Localised coastal habitats have distinct underwater sound signatures. *Marine Ecology Progress Series* 401: 21-29.

Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J., Gentry, R.L., Greene, C.R., Kastak, D., Ketten, D.R., Miller, J.H., Nachtigall, P.E., Richardson, W.J., Thomas, J.A., Tyack, P.L. 2007. Marine mammal noise exposure criteria. *Aquatic Mammals*, 33(4): 411-522.

Southall, B.L., Finneran, J.J., Reichmuth, C., Nachtigall, P.E., Ketten, D.R., Bowles, A.E., Ellison, W.T., Nowacek, D.P., Tyack, P.L. 2019. Marine mammal noise exposure criteria: updated scientific recommendations for residual hearing effects. *Aquatic Mammals* 45(2): 125-232.

Wenz GM. 1962. Acoustic ambient noise in the ocean: spectra and sources. *Journal of the Acoustical Society of America* 34(12):1936-1956.

Appendix C Methodology: underwater noise modelling

Sound sources

A range of pile sizes will be used, from the smaller ~350mm timber piles and larger concrete and steel casing piles up to 710mm. The modelling was therefore based on the larger steel casing piles. This is because steel casing piles can produce higher frequencies than timber or concrete filled steel piles, which Hector's dolphins will be sensitive to.

The broadband source levels for the percussive piling were based on measurements of

- 800mm steel casing pile (18m length) being driven 2.96m (from 6.99m to 9.85m) with 509 blows into consolidated sediment.
- Hammer energies ranged from 12.9 kJ (for first 66 blows) to 34.4 kJ beyond 9.7m depth (the final 65 blows) due to the harder ground.
- The piles were driven using a Junttan 6/8S (6T mode) impact hammer and Kobelco CKE 1800 crane from the barge Leonora.

Sound data were recorded from an array of calibrated SoundTrap recorders between 50m and 1000m and were recording continuously over several hours. For each of those locations, individual pulses (in this case the 509 blows) were detected using an impulse signal detector designed to identify impulsive signals in long-term passive acoustic monitoring datasets (based on that by Pine et al. 2020). The detector was customised specifically for the percussive piling being measured and the receiving environment. Detector outputs include full scale received spectrum of individual pulses over the T90 duration[5] (thereby encompassing any hammer bounces and range-dependent multipaths). Frequency-dependent received SPLs where then back-calculated using the energy-flux numerical model (Wilson et al. 2023) and PE model (below 1.2kHz) and adjusted to match the shape of a reference source spectrum to control for any underestimates of frequencies below 1kHz (a possibility when measuring source levels in very shallow waters). The reference spectrum used was the maximum decidecade band levels from over 300,000 hammer blows 674 steel piles (between 710mm and 910mm) being driven in 20m of water.

The percussive piling was assessed based on the 24hr cumulative sound exposure and peak levels. The cumulative SEL source levels were calculated based on 2400 strikes per day. This is an overestimate (by ~2x) based on the seafloor sediments expected at the piling locations

[5] The T90 duration is the time interval within which the cumulative energy rises from 5% to 95%, thereby containing 90% of the energy.

and the relatively shallow drive-depths. However, it was doubled to account for any underestimates of the single strike SELs in the lower frequencies.

Single strike SEL was defined as

$$SEL = L90 + 10 \times 10Log_{10} + 0.458\, dB \qquad \text{(eq.1)}$$

The 0.458 dB is to account for the lost energy either side of the 5% and 95% during the T90 calculation (i.e. 10×Log_{10}(0.9) = 0.458 dB).

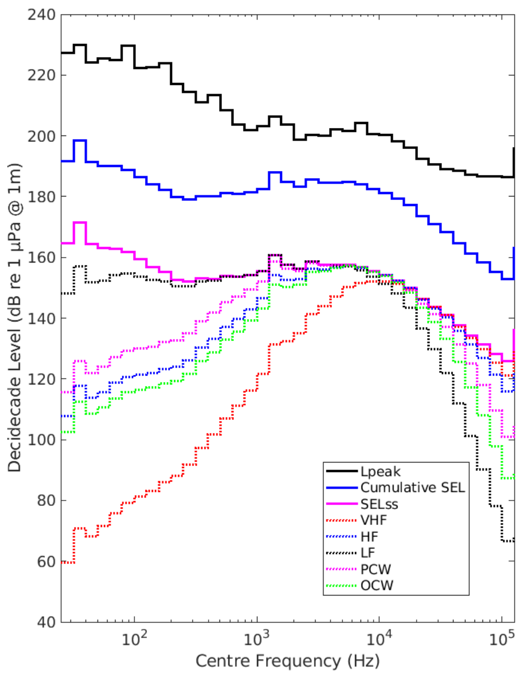

Figure 16 Source spectrum of the piling methods used in the modelling. The Lpeak is the peak levels, SELss the single-strike sound exposure level calculated over the T90 duration (average over 509 pulses).

Wideband source levels: Lpeak = 237, selcum = 208, selss = 177.

Bathymetry

Sound propagation within coastal waters typically follows a normal mode whereby a sound wave of a particular wavelength moves sinusoidally through an acoustic waveguide (i.e., the water column or seafloor) (Jensen 2011). However, sound propagation in shallow water is highly influenced by boundary effects and the extent of those effects is related to water depth, as well as the seafloor and surface roughness. Bathymetry data is therefore critical for range-dependent propagation modelling.

The bathymetry dataset, surveyed in 2021, was provided by LINZ/ECAN with a 5m gridded resolution (**Figure 18**). This is the most up-to-date bathymetry available. Due to the shallow depths within French Bay, 2.7m was added to the bathymetry to represent a high tide and more favourable propagation conditions for lower frequencies.

Sea-floor composition

The composition of the seafloor and sediments has a direct influence on the sound propagation as part of the ocean acoustic medium. Sediment type and seafloor roughness also influences the boundary effects through sound absorption, reflectivity, and changes to compression wave velocities. These factors mean that the sound field at any given location from the sound source can depend on the changes in the seafloor compositions and geoacoustic properties. These factors can also mean the arrival times between the signal's multi-paths can also vary (which is also highly influenced by bathymetry). For waterborne signals, the surface layer of the seabed is more important but for ground-borne signals (both of which are present in pile-driving), the depth of the sediment layers is also of some relevance, as the compression wave 'leaks' into the adjacent water column. This leakage, however, is not a significant contributor to the received noise levels by marine animals within the water column with no contact with the seabed.

In this case, the depth of the sediment layer was set as infinite as vibrocore sediment samples in the area have not been undertaken. Therefore, the seafloor composition was incorporated into the model essentially as coarse 2D transects.

A map showing the locations of sediment areas is shown in **Figure 18** and **19.**

Sound speed profiles

The speed of sound underwater is predominately dependent on temperature, density (salinity) and depth. We understand that stratification of the water column around the study site does not occur because there is sufficient mixing to prevent salinity wedges. We have therefore assumed iso-velocity in the sound speed, which is an assumption in the energy-flux numerical models.

Sea surface temperature (SST), water densities, salinity data were therefore incorporated into the model. Both summer and winter seasons (see **Table 8**) were modelled to test for any substantial seasonal effects to the sound propagation.

A simplified equation from Medwin & Clay (1998) was used to calculate the sound speed.

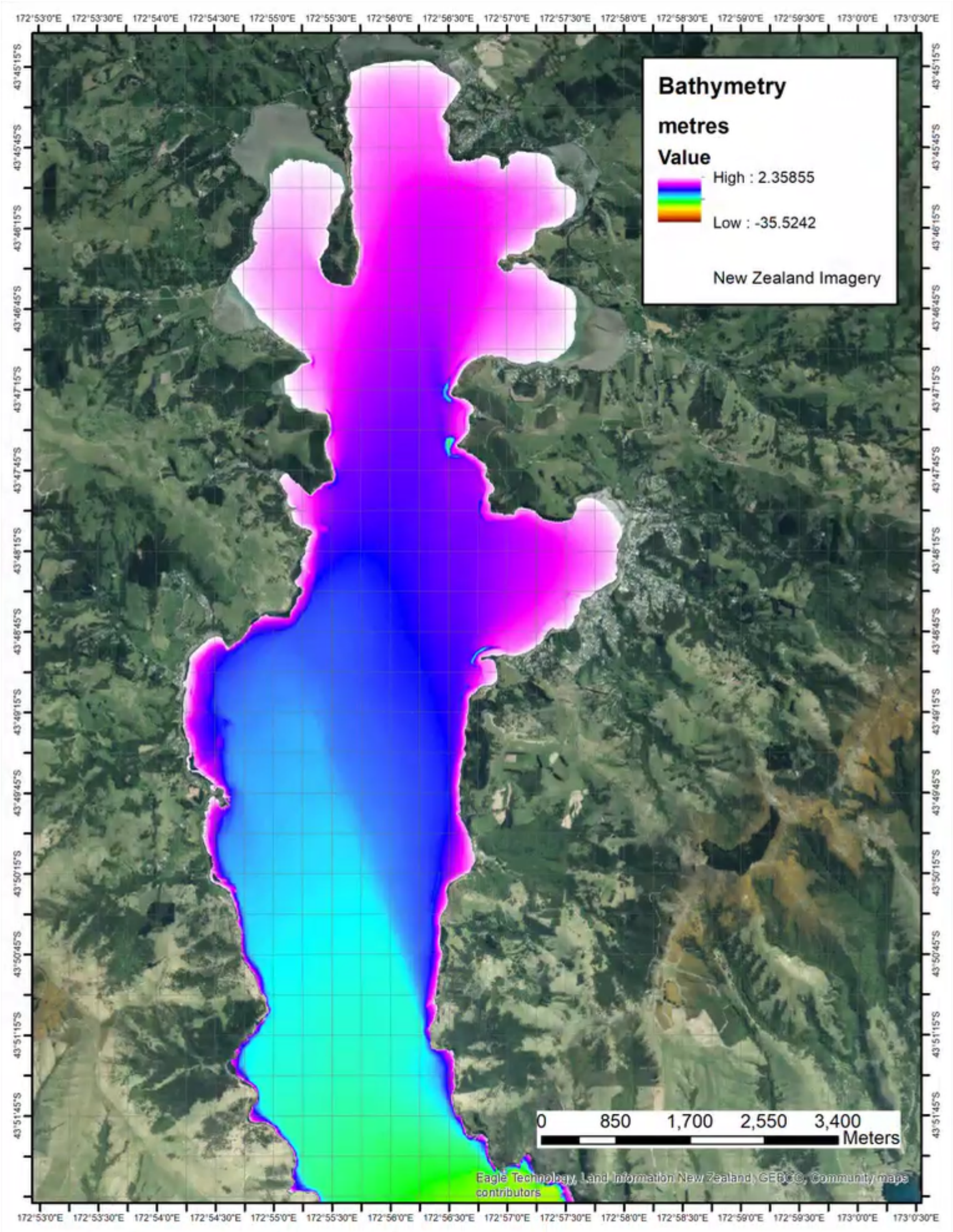

Figure 17 Map of the bathymetry raster used in the acoustic model.

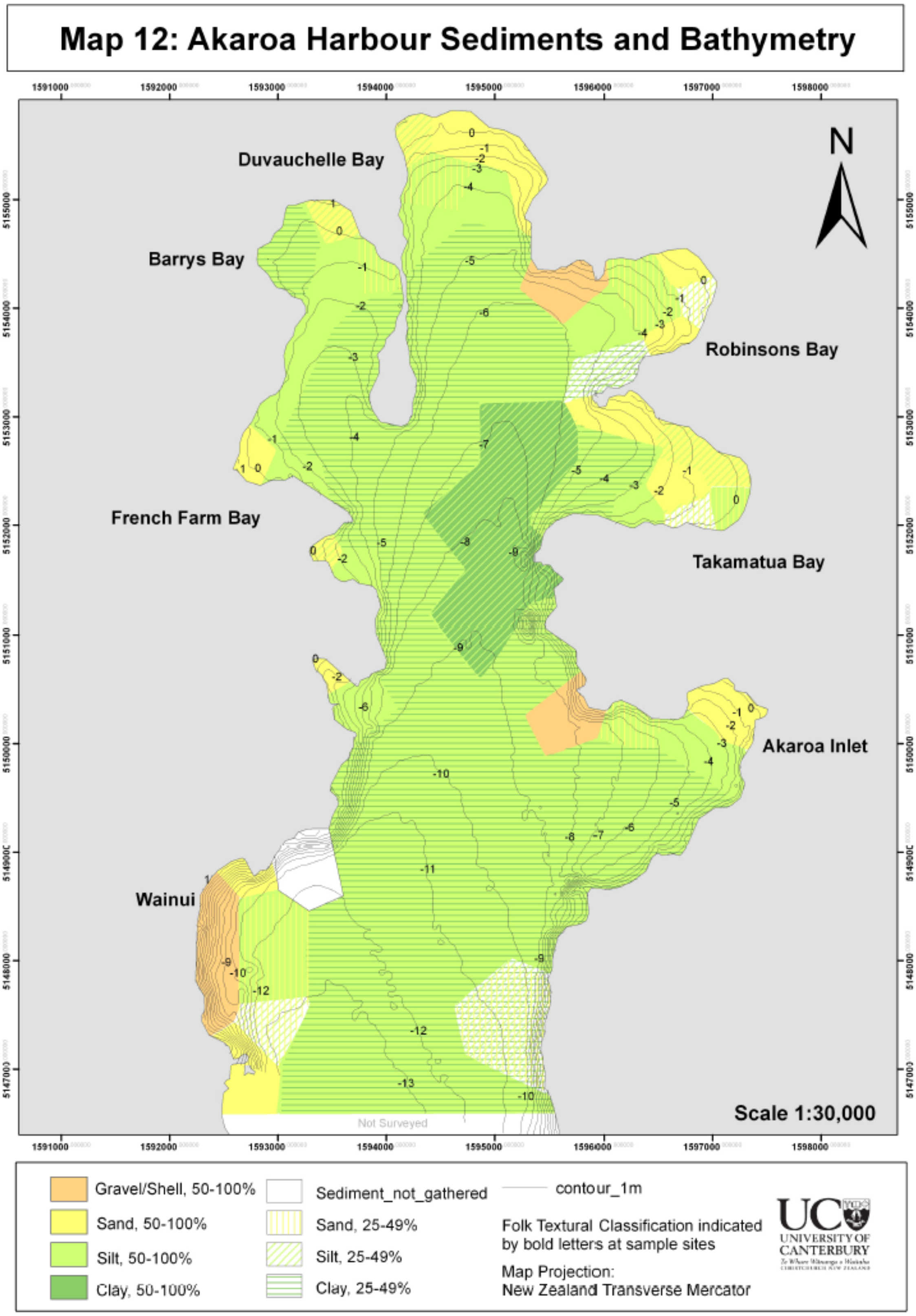

Figure 18: Map of the seabed sediments.

Figure taken directly from Hart et al. (2009).

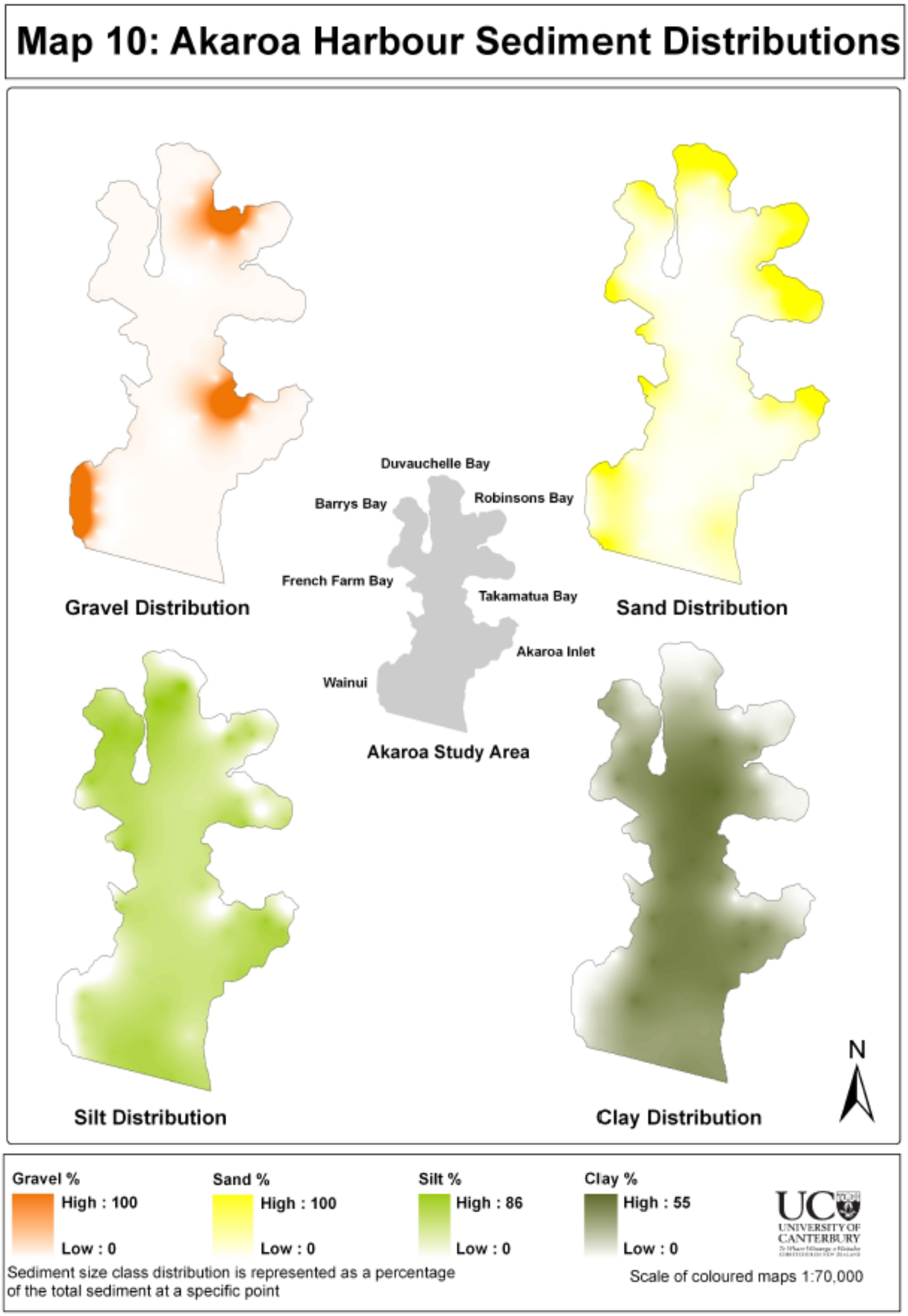

Figure 19 Map of the seabed sediment distributions.

Figure taken directly from Hart et al. (2009).

Range-dependent propagation model

The underwater noise modelling was simply defined as:

$$SPL_{freq}(R) = SL_{freq} - PL_{freq}(R) \text{ (eq.2)}$$

where SPL_{freq} at distance *R* was the predicted sound pressure level for some frequency bandwidth, SL_{freq} was the source level at that frequency band and PL_{freq} was the propagation loss over R for that frequency band.

The propagation loss (PL) was calculated using the energy flux model (Weston 1971,1976), for frequencies above 1.2kHz, and PE below 1.2kHz. The input parameters are provided in **Table 8** below.

Energy flux numerical models demonstrate very fast computational rates, allowing for very high-resolution outputs in range-dependent scenarios. International uptake of these models for piling noise has been widespread. Simplified energy flux models are 2D models that divide the propagation pathway into four regions at increasing distances from the source and are identified as regions *A, B, C* and *D* (Wood, 2016):

- Region A is spherical spreading out to half the water's depth from the source;
- Region B is a channel where shallower critical grazing angles are reflected from the seabed but absorbed at higher critical angles;
- Region C uses mode-stripping with high grazing angles or higher modes are attenuated; and
- Region D is single-model propagation.

The energy flux/PE codes were run along 10km transects for 360 radials from the piling source with values extracted from the underlying bathymetry raster layers every 10m (as shown in **Figure 17**) and manually generated transects for sediment types (from **Figures 18, 19**). Those resulted in 3D arrays for which the PL was calculated along the second dimension to produce a new 3D array of PL values. Linear interpolation and nearest neighbour extrapolation were then used to convert the PL arrays into a 2D map for that specific frequency and stored in a structural array. The range-dependent PL were then summed over their respective decidecade bands to produce a representative PL map for a specific band. The decidecade bands were chosen for the modelling as they are often used to represent the critical bandwidths in marine mammals[6] (Erbe et al., 2016; Pine et al. 2018).

The specific input parameters for the model are summarised in **Table 8**.

[6] This is done when the true critical bandwidths are unknown for the species of concern.

Table 8: Input parameters for the acoustic model.

	Model independent variables
Bathymetry	10m resolution, down-sampled from 5m ASCII raster. Additional 2.7m added to depths to simulate high tides.
Model independent variables	360 radials; 10km per radial; 10m range steps.
3D array to 2D grid conversion	Natural neighbour interpolation with nearest neighbour extrapolation.
	Model dependent variables
PE	RAMGeo implementation (**AcTUP**), 5 padé terms. 3 frequencies either side of decidecade centre frequency (Fc). Fc = [25 31.6 40 50 63 80 120 125 160 200 250 315 400 500 630 800 1000 1200].
Range-dependant Weston's energy flux	3 frequencies either side of decidecade centre frequency (Fc). Fc = [1600 2000 2500 3200 4000 5000 6300 8000 10000 12500 16000 20000 25000 32000 40000 50000 64000 80000 100000 125000]
	Sediments
Sediment types	Gravel/Shell: ρ 2000kg/m^3, c_p 1800m/s, α_p 0.6 dB/λ. Sand: ρ 1950kg/m^3, c_p 1725m/s, α_p 0.8 dB/λ. Silt: ρ 1700kg/m^3, c_p 1650m/s, α_p 1.0 dB/λ. Clay: ρ 1500kg/m^3, c_p 1500m/s, α_p 0.2 dB/λ.
	Water column
Sea temperature	Winter: 7.5°C; Summer: 16.5°C (NIWA 2014).
Water density	Winter: 1026.56 kg/m^3; Summer: 1024.86 kg/m^3 (NIWA 2014)
Salinity	34 psu (NIWA 2014).

Effects modelling for marine mammals

The overall objective of the acoustic modelling is to provide the acoustic footprint of the noisiest activities to inform an assessment of the potential impacts on marine animals. The physiological effects (PTS/TTS) reported below are the two most serious effects that can directly impact an animal's net fitness.

Permanent and temporary threshold shifts

When a receiver is exposed to high noise levels over an extended period, the cells within the inner ear being to fatigue and become less sensitive. Therefore, a change in the animal receiver's hearing threshold occurs, and the degree at which those thresholds change is referred to as a threshold shift. If hearing returns to normal after a certain time post-exposure, the threshold shift is temporary (termed temporary threshold shift, TTS), but if not, then it is referred to as permanent threshold shift (PTS)[7]. The type and amount of threshold shift depends on the duration of noise, rise times, duty cycles, sound pressure levels within the listener's critical bandwidths (i.e., the spectral composition of the noise) and, of course, the overall energy.

The noise criteria used for the establishment of PTS and TTS radii was from NMFS (2024). Consequently, the various hearing groups are named VHF, HF, LF cetaceans and PCW, OCW for pinnipeds in water in this report. These are simply reclassed functional hearing groups, essentially shifting MF to HF, and HF to a new group, VHF (very high frequency) (**Table 9**). The 2024 update to the NMFS guidance also includes new M-weighting functions, revised TTS/PTS thresholds and refers to PTS as Auditory Injury (AUD INJ).

Because these updated functions, classes and thresholds are based on the latest science, we have adopted those functional hearing groups and thresholds in our assessment.

Table 9: Nomenclature of functional hearing groups between NMFS (2018) and NMFS (2024).

NMFS (2018)	NMFS (2024)	Species
High-frequency (HF) cetaceans	Very high-frequency (VHF) cetaceans.	NBHF odontocetes: Hector's dolphins, porpoises.
Mid-frequency (MF) cetaceans	High-frequency (HF) cetaceans. .	General odontocetes not NBHF: Killer whales, bottlenose dolphins, common dolphins, dusky dolphins.

[7] Classed as Auditory Injury (AUD INJ) in NMFS (2024).

Table 9: Nomenclature of functional hearing groups between NMFS (2018) and NMFS (2024).

Low-frequency (LF) cetaceans	Low-frequency (LF) cetaceans.	Baleen whales.
Phocid pinnipeds (PW) underwater	Phocid carnivores (PW) in water.	True seals.
Otariid pinnipeds (OW) underwater	Other marine carnivores (OW) in water.	Sea lions & fur seals.

For percussive piling, NMFS (2024) prescribes criteria for the potential onset of either PTS or TTS effects in both peak pressure (L_{pk}) or cumulative sound exposure level ($L_{E\text{-}24hr}$) (termed a duel-metric threshold), whichever is the highest (**Table 10**). The $L_{E\text{-}24hr}$ metric is commonly used for assessing impulsive signals as it can incorporate the energy from multiple pulses and the overall exposure required for an animal receiver to be at risk of TTS/PTS onset. The number of pulses and delay between them, for each pile (in the case of percussive piling) can therefore be incorporated when calculating the $L_{E\text{-}24hr}$, unlike for the L_{pk}. In the case of multiple pulse sources, such as percussive piling, the dual metric is particularly relevant as sometimes the $L_{E\text{-}24hr}$ values can be higher than L_{pk} levels for some marine mammal functional hearing groups, and therefore both must be considered.

Unlike the L_{pk}, the SEL criteria are to be cumulative over a 24-hr period and are M-weighted.

For the percussive piling, the $L_{E\text{-}24hr}$ was calculated by adding $10\text{Log}_{10}(n)$ to the single-strike SEL, where n=2400 strikes, to the modelled single strike SEL.

Table 10: NMFS (2024) auditory threshold criteria for impulsive signals, for the functional hearing groups.

Functional Hearing Group	TTS Threshold		PTS Threshold	
	$L_{E\text{-}24hr}$ (weighted)	L_{pk} (unweighted)	$L_{E\text{-}24hr}$ (weighted)	L_{pk} (unweighted)
LF	168	216	183	222
HF	178	224	193	230
VHF	144	196	159	202
OCW	170	224	185	230
PCW	168	217	183	223

Behavioural responses: cetaceans

There is a substantial amount of literature on marine mammals, fish and invertebrates responding to underwater noise. Those include direct evidence-based studies, opportunistic studies or observational studies that have been summarized in several reviews (for example, Richardson et al. 1995; Hildebrand 2005; NRC 2005; MMC 2007; Nowacek et al. 2007; Weilgart 2007; NAS 2017; Southall et al. 2019). Behavioural effects are highly varied and may include changes in swimming behaviours (directions and speeds), diving behaviours (duration, depths, surface intervals), time spent on the surface, respiration rates, fleeting noise sources and changes to vocalisations. Predicting specific zones within which some behavioural effect can be expected is the most difficult noise effect to quantify. This is because behavioural effects are extremely contextual and depends on species, location and temporal aspects (see Ellison et al. 2012; Gomez et al. 2016 for reviews on the issue of context dependency on marine mammal behaviour).

Consequently, there are no widely accepted regulatory guidance yet (though much work is being done, including recent updated reviews (Southall et al. 2021)). The only interim guidance for behaivoural response to noise is the step function approach, whereby a 140 dB or 160 dB re 1 µPa threshold for impulsive noise is applied. However, these numerical thresholds were based on few sample sizes and for specific noise sources, such as offshore drilling. Consequently, they have not experienced wide-spread uptake (Gomez et al. 2016). One of the issues of using a single noise threshold for behavioural response is that the data currently available are not very comparable (Nowacek et al. 2007; Southall et al. 2007; Eillison et al 2012; Gomez et al 2016). There is a limited relationship between the severity of a behavioural response and the received sound pressure level from an anthropogenic noise source (Gomez et al 2016). As such, the application of a simplistic noise threshold should be avoided when possible, and instead take on a more tailored approach for the specific species in the target area (Faulker et al. 2018).

Recent studies assess behavioural zones based on the probability of occurrence using dose-response curves specific for the species of interest (for example, Joy et al. 2019). Dose-response curves show the relationship between the probability of a behavioural effect occurring at a given level of noise exposure (Joy et al. 2019). The dose-response formulas have been used by the U.S. Navy (US Navy 2008, 2012) and the scientific community for several years, primarily for sonar, among other transducers, and explosions or airgun pulses.

Species-specific dose-response curves for percussive piling driving, however, have not been explicitly calculated and the U.S. Navy continues to recommend the existing NMFS risk criteria for the onset of behavioural responses from impact pile driving (160 dB_{rms} re 1 µPa[8]).

[8] Root mean square (rms) calculation for impact piling is based on the duration of the pulse defined by 90% of the cumulative energy in the impulse.

Therefore, in the absence of specific dose-response curves for percussive piling, the step function threshold of 160 dB_{rms} re 1 µPa continues to be used.

Extensive reviews show most marine mammals respond to impulsive noise of varying levels between 140 and 180 dB_{rms} re 1 µPa, including large whales (Malme et al. 1983, 1984; HESS 1999; Southall et al. 2007; Woods et al. 2012). Probabilistic metrics applied at 10%, 50% and 90% of exposed individuals having behavioural responses have been assumed above M-weighted levels of 140, 160 and 180 dB_{rms} re 1 µPa, respectively (Woods et al. 2012).

Considering no general consensus on behavioural threshold for percussive piling, the unweighted 140 and 160 dB_{rms} re 1 µPa step function thresholds have been used in this assessment. Being unweighted, they are more conservative, especially for Hector's dolphins.

Behavioural responses: pinnipeds

Dose-response curves for pinnipeds exposed to percussive piling are not available and remain a research question. Data for leopard seals, NZ sea lions and fur seals are not available and therefore the step function approach was used and applied to all three species. Southall et al. (2007) reviews studies showing pinnipeds responding to continuous noise, with individuals shown to react above 120 dB_{rms} re 1 µPa (Southall severity score 3[9]. Above 130 dB_{rms} re 1 µPa, the behavioural responses reviewed by Southall et al. (2007, 2019) are more moderate[10]. These unweighted thresholds were used to determine the potential onset for low and moderate severity behavioural responses in pinnipeds within Akaroa Harbour.

Auditory masking

Several species of marine mammals and fish are known to have hearing ranges that overlap with low-frequency anthropogenic noise – such as vessels or machinery such as renewable energy devices. For example, bottlenose dolphins (*Tursiops truncates*) and common dolphins (*Delphinus delphis*) have shown hearing sensitivities to signals as low as 100 Hz, while killer whales (*Orcinus orca*) show sensitivity down to 500 Hz (Hall & Johnson 1972; Popov & Klishin 1998; Szymanski et al. 1999). Therefore, auditory masking - the interference of a biologically important signal (such as vocalisations from conspecifics or predator/prey etc) by an unimportant noise that prevents the listener from properly perceiving the signal (Erbe 2008) – is expected to occur (Pine et al. 2019). Piling has the potential to interfere with an animal's ability to perceive their natural acoustic environment (Erbe et al. 2016; Popov & Klishin 1998). The inclusion of auditory masking in underwater noise effects assessments is best practice

[9] Such as alert behaviours, minor changes to swimming speeds, dive profiles or directions, changes to respiration rates, or minor cessation or modification of vocalisations (Southall et al. 2017, Table 4).

[10] Such as prolonged changes to swimming speeds, dive profiles, or directions, moderate shifts in distributions, prolonged cessation or modification of vocalisations (Southall et al. 2017, Table 4).

because behavioural effects generally occur at moderate levels of masking and thus understanding the spatial limits of masking is important (Pine et al. 2019).

We assessed auditory masking for marine mammals by quantifying the reduction in an animal's listening space. An animal's listening space is the immediate area (volume of ocean) surrounding it within which it can detect and perceive a biologically important signal. The listening space method was used instead of sonar equations in this case because the call structures of all the species of interest at the source are not well understood, while the listening space method is more sensitive to changes in the existing sound environment (Pine et al. 2018).

As an animal receiver moves through the area while the pile-driving is underway, the animal's listening space will decrease to a new, smaller listening space. The difference between the original and the smaller listening space under masking conditions is termed the listening space reduction (**LSR**).

The method for calculating the LSR is fully described by Pine et al. (2018) who define the LSR as:

$$LSR = 100\left(1 - 10^{-2\frac{\Delta}{N}}\right) \text{ (eq.3)}$$

where *N* is the frequency-dependent N_{PL} slope coefficient (set at 15 + α_f) and Δ is the difference between the perceived base ambient noise level NL_1 and anthropogenic noise level NL_2 at a given distance (NL_2 was the modelled sound pressure levels/SELs of the percussive piling). The ambient noise levels were taken from the passive acoustic monitoring (as described in Appendix B). It is important to note that NL_1, being the perceived base ambient noise level, is the maximum of the listener's hearing threshold (audiogram value) and the ambient level inside a critical band, approximated herein by 1/3 octave bands (Erbe et al. 2016; Pine et al. 2018). Audiogram values for little penguins were taken from Wei & Erbe (2024), while the various marine mammal species in Akaroa Harbour were based on composite audiograms (see NMFS (2024) for details). Composite audiograms for each 1 Hz over the complete modelled bandwidth were calculated using:

$$T(f) = T_0 + A\,Log_{10}\left(1 + \frac{F_1}{f}\right) + \left(\frac{f}{F_2}\right)^B$$

where $T(f)$ is the auditory threshold at frequency f, and T_0, F_1, F_2, A, and B are fitting parameters provided by NMFS (2024).

The N_{PL} slope coefficient was calculated by curve fitting the empirical N_{PL} of each 1/3 octave band between 32 Hz and 32 kHz over a distance that represented the listener's maximum listening range under natural sound conditions. This was done using a simplified sonar equation without signal gain (to increase conservativeness):

$$\Delta L_{SE} = SL - PL - NL_1 - \Delta L_{DT}$$

where signal excess (ΔL_{SE}) is set to zero to indicate detection onset, NL_1 was the 5th percentile ambient noise level and ΔL_{DT} was the detection threshold (conservatively set at 10 dB for (Clark et al. 2009; Kastelein et al. 2013; Putland et al. 2017; Pine et al. 2018; Pine et al 2019)). This was done because the N_{PL} slope can have some range-dependence.

The empirical source levels, ambient levels and audiograms are provided in **Figure 20**.

The LSR was then calculated for each decidecade band at each depth step – resulting in an LSR map for each band. Those maps were then overlaid on top of each other (forming a 3D matrix) and averaged through layers to provide an overall 2D LSR map for the project area (Pine et al. 2018).

It is important to note the three important assumptions applied to the auditory masking model: (1) the listener exhibits omnidirectional hearing; (2) the sound propagation field is omnidirectional; and (3) no masking release mechanisms occurred. The exclusion of masking release is an important assumption as it means the results are likely to be conservative (i.e., has the potential to overstate true masking).

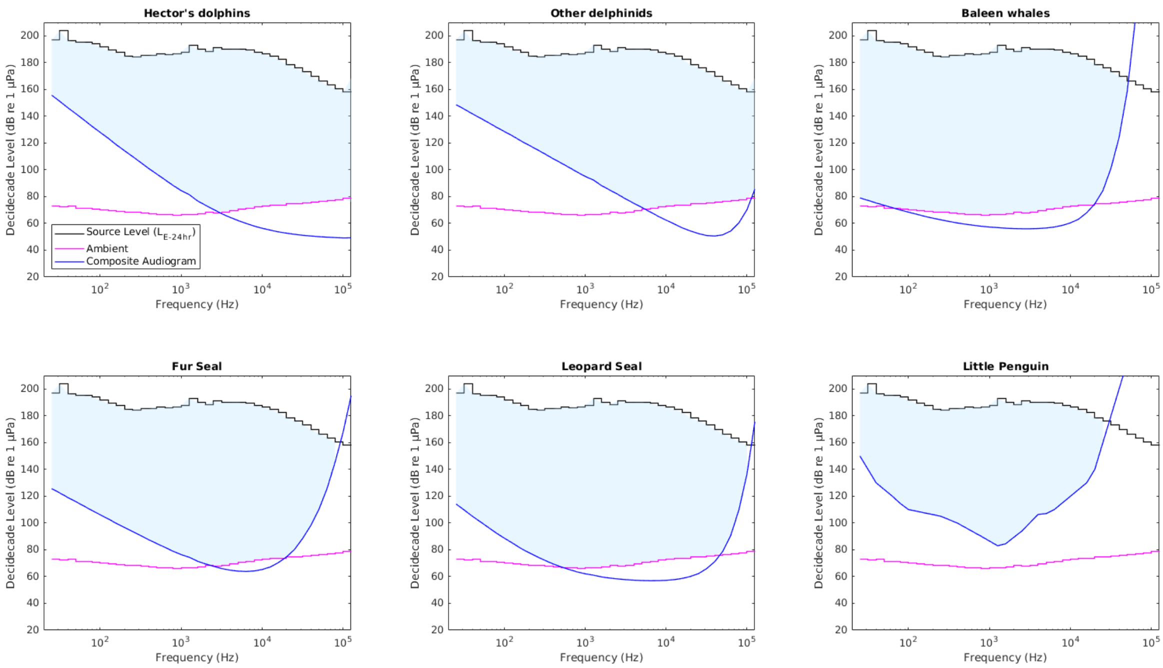

Figure 20 Decidecade band source levels, median ambient sound levels measured between 22 June and 18 Sept 2023 within Akaroa Harbour (AH01 site) and NMFS (2024) composite audiograms for different species (each of the NMFS functional hearing groups). The blue shading represents the area used as NL1 in the LSR equation and the larger the area, the more sensitive a listener is to masking effects.

Marine fauna has evolved in a naturally noisy environment, with many natural sources (such as waves and conspecific or heterospecific vocalisations etc) acting as effective maskers

(Radford et al. 2014). Taxa have therefore evolved to counteract naturally occurring maskers, ensuring their vocalisations can be detected by a listener in a range of environments. Anti-masking strategies by the sender are predominately altering the call's characteristics, such as increasing call amplitude (Lombard effects), changing the spectral characteristics of the call (such as lowering or raising the fundamental or peak frequencies) to reduce spectral overlap, or altering the temporal dynamics of the call, such as increasing call rates or repetition (Radford et al. 2014; Erbe et al. 2016). There may also be repeating information at multiple frequencies within a call's harmonics (such as in some fish calls, graded structures in dolphin vocalisations and whale calls). In addition, masking release at the listener may occur when the call and masking noise are coming from different direction (termed spatial release from masking) or when the masking noise is amplitude modulated over a bandwidth much wider than the critical band of the listener (termed comodulation masking release) (Erbe et al. 2016). All these masking release mechanisms have been documented in marine mammals and fish, and thus the importance of this assumption.

Audibility ranges

In order for any noise effect to occur, the noise has to first be audible to a receiver. It is important to note, however, that simply detecting a noise source does not equate to an effect occurring. Notwithstanding, the limits of audibility do provide us a maximum area within which the risk of any effect occurring is theoretically greater than 1 %. By calculating the limits of audibility for each of the species of concern, it allows regulatory bodies to better understand the acoustic footprint of the proposed piling for particular species or groups.

A conservative approach was taken – detection thresholds, auditory gain functions and directivity of hearing sensitivities have been left out of the calculations because they are unknown for the species of concern. Masking release mechanisms have also been left out for the same reason. The key assumption, therefore, is that detectability of the anthropogenic noise is omnidirectional[11] and directly relates to the difference between the ambient sound level, the anthropogenic noise and hearing thresholds at each critical band.

Effects modelling for fishes

Fish and invertebrates can be negatively impacted by anthropogenic noise, just as marine mammals. However, unlike marine mammals who have statutory protections in several countries, noise exposure criteria for fish are far more varied in their usefulness (Hawkins & Popper 2017). Data that establishes the expected severity of a certain effect following the exposure to some pressure levels are scarce. One of the only peer-reviewed guidance for the

[11] Also assumed in peer reviewed scientific publications, such as Pine et al. 2016; Pine et al. 2018; Pine et al. 2019; Putland et al. 2017; Stanley et al. 2018.

potential onset of noise effects (from a range of sources, including pile-driving) on fishes that has experienced some uptake internationally is the ANSI-accredited guidance from Popper et al. (2014). That guidance does provide useful guidelines (within the limitations and constraints) in gauging the spatial extent of potential impact. For percussive pile-driving, the criteria for various fish-groups are provided as decibel ranges.

While thresholds are a good starting point, noise criteria for fishes should consider the biological significance of sound exposure (Hawkins et al. 2020). The biological significance of the sound exposure relates to whether the animal experiences an adverse effect in its life, i.e., is the invasive noise likely to cause significant physical, chemical or biological responses that have real consequences for the net fitness of the individual or population (Hawkins et al. 2020). The only effect that can currently be directly linked to such an impact is mortality or severe injury that eventually may be fatal. Other biologically significant effects include PTS, TTS, sub-lethal injuries, behavioural and auditory masking but the relationship between the severity of those effects and exposure to noise is data deficient and still a research question (Hawkins et al. 2020). Notwithstanding, hearing loss (either permanent or temporary) is an impact that can impact an individual's net fitness because their perception of predators can be inhibited. We have therefore considered TTS risk in fishes from the percussive piling. Thresholds for the potential onset of TTS in fishes are provided in the ANSI-accredited guidelines. It is important to note those TTS guidelines were based on seismic airgun pulses and no data are available for TTS effects on fish from percussive pile-driving. The TTS thresholds are, therefore, considered conservative based on the shock wave from airgun pulses being higher energy, rise times and duration (through reverberation) than from percussive piling.

Multiple studies have been published that present noise exposure data and effects on fishes, but they suffer from a wide range of laboratory conditions, experimental methods, species and conclusions. Given the wide range of thresholds between research studies and the most recent review paper by Hawkins et al. (2020) maintaining the current state of knowledge does not alter the recommended thresholds within the ANSI-accredited guidance, we have adopted that guidance.

The ANSI-accredited thresholds used in this assessment are presented in **Table 11** below.

Table 11: ANSI-accredited threshold criteria for mortality, recoverable injury and TTS (Popper et al. 2014)

Type of Fish	Mortality & potentially fatal injury	Recoverable injury*	TTS
No swim bladder (particle motion detection)	219 dB SEL_{cum} or 213 dB Lpk	216 dB SEL_{cum} or 213 dB Lpk	186 dB SEL_{cum}

Table 11: ANSI-accredited threshold criteria for mortality, recoverable injury and TTS (Popper et al. 2014)

Swim bladder is not involved in hearing (particle motion detection)	210 dB SEL_{cum} or 207 dB Lpk	203 dB SEL_{cum} or 207 dB Lpk	186 dB SEL_{cum}
Swim bladder involved in hearing (primarily pressure detection)	207 dB SEL_{cum} or 207 dB Lpk	203 dB SEL_{cum} or 207 dB Lpk	186 dB SEL_{cum}

*It is important to note that recoverable injury was deemed possible in controlled laboratory conditions therefore do not consider the fact some recoverable injuries could lead indirectly to mortality or reducing an animal's net fitness, even if temporarily (Popper et al. 2014).

10.0 Mitigation

Due to large TTS onset ranges associated with the pile-driving, mitigation will be required to reduce the impact zone to one that is more manageable. Methods to achieve this for pile-driving generally fall into two areas:

1. Operationally. These methods mitigate sound exposure to animals/environments by changing piling methods. For example, slow starts, restricted hammer strikes per day, timing activity to certain tidal levels, etc.
2. Reducing underwater radiated noise. These methods mitigate sound exposure on animals by reducing the radiated noise from the immediate area around the source. For example, timber dollys, bubble curtains, restricting hammer energies, etc.

10.1 Calculating TTS onset ranges under varying piling conditions

TTS onset ranges depend on varying hammer strike energy, pile diameter, ram weights and water depths. While the dependency of each of those variables can theoretically be isolated, it is a combination of factors that determine the true level of underwater radiated noise, and therefore TTS onset range.

Theoretical analysis of how varying piling conditions could influence the TTS onset range for Hector's dolphins was undertaken. The aim of the calculations was not to define actual mitigated TTS ranges for the purposes of prescribing a set of mitigation conditions but provide decision makers an understanding of what the applicant could do to comply with a conditioned TTS range limit (through an observed noise limit).

Several mitigation options have been investigated to demonstrate possible methods for reducing observation/shutdown zones for Hector's dolphins based on TTS onset ranges.

Specific options included:

- Favouring vibratory and bore piling methods instead of percussive piling.
- Restricting the number of piles per day that are driven into the seabed.
- Reducing hammer strike energy.
- Sacrificial timber dollies for steel piles.
- Bubble curtains (single and double).
- Tidal and seasonal timing.

10.1.1 Vibratory methods

Favouring vibratory and bore piling methods over percussive driving will result in a much smaller shut down zone. To demonstrate the potential benefits of vibratory piling methods, the same propagation loss models were applied to measurements of a 680mm steel casing pile (18m long) being driven into consolidated sediments (**Figure 21**). The subject pile was driven using an ICE 44/50 vibratory hammer and Kobelco CKE1800 crane from a barge.

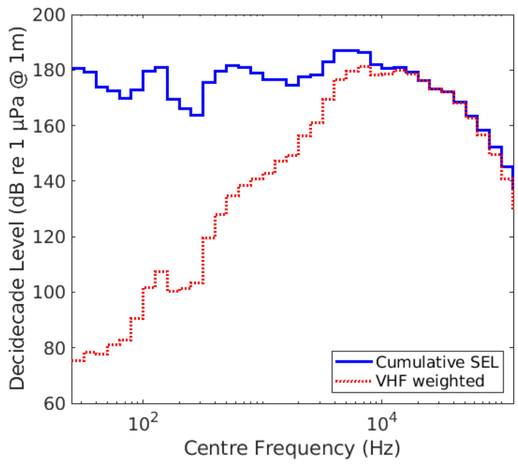

Figure 21 Decidecade band source levels used to model vibratory piling.

Wideband SPL @ 1m = 195 dB_{rms} re 1 µPa; VHF weighted SPL @ 1m = 188 dB re 1 µPa.

10.1.2 Reducing strike energy

Reductions in the hammer strike energy directly leads to less acoustic energy radiated from the impacted pile. A simple TTS onset model that assumes linear dependence of the sound energy on the strike energy can be calculated using:

$$\Delta L_E = 10 \times Log_{10}\left(\frac{E_i}{E_0}\right) \text{ (eq.4)}$$

where ΔL_E is the difference in the sound exposure level from some reference strike energy, E_0, and the scaled energy, E_i (von Pein et al. 2022) (**Figure 21**). Recent research shows discrepancies in ΔL_E from assuming a linear relationship between sound energy and strike energy, when in reality it is non-linear, to be minor (von Pein et al. 2022).

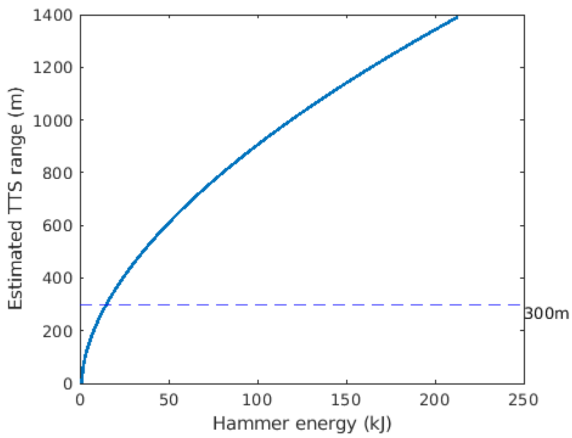

Figure 22 Relationship between strike energy and TTS onset range. Unmitigated piling noise could achieve 300m onset range if limiting 10kJ hammer energy

10.1.3 Bubble curtains

Air bubble curtains are commonly used internationally due to their simplicity in their application and effectiveness at reducing noise (Tsouvalas & Metrikine 2016). Due to strict underwater noise limits in certain countries, such as Germany, there has been much research into the effectiveness of air bubble curtains, and various types exist.

For this project, single and double bubble curtains may be a preferred configuration. They consist of rising air bubbles around the pile being driven, forming a curtain of various thickness (Tsouvalas & Metrikine 2016, Würsig et al. 2000). For low frequencies, such as when driving large piles, they work by causing a substantial disruption in the acoustic impedance, thanks to changes in density of the seawater and bubble medium (Tsouvalas & Metrikine 2016).

The effectiveness of bubble curtains has some frequency-dependence, whereby the rate, size and placement of bubble curtains has varying effects on the noise attenuation achieved. For example, when the sound energy being emitted from the pile is more concentrated around the resonance frequency of the bubbles (such as smaller piles with higher frequency components), the sound absorption of the bubble curtain itself is most important, and therefore the bubble characteristics (diameter, rates, etc) are important (Tsouvalas & Metrikine 2016).

The specific configuration of a bubble curtain cannot be directly modelled due to too many unknown variables. Instead, a general approach has been undertaken based on the wideband insertion losses stated by the German Federal Maritime and Hydrographic Agency **(BSH)** and adjusting for frequency-dependence using published spectra (Bellmann 2014).

The BSH claims wideband insertion losses (ΔSEL, dB) between 11 and 15 dB for single bubble curtains (>0.3 $m^3/(min*m)$) and 14 and 18 dB for double bubble curtains in waters shallower than 25m[12]. These were used in our assessment because no peer-reviewed published acoustic data on smaller bubble curtains being used on typical coastal piles (600-980mm diameter steel casing piles) in New Zealand are available. Furthermore, a wideband insertion loss of 11dB and 14dB for single and double bubble curtains, respectively, are most likely conservative.

The frequency-dependence was calculated based on the averaged insertion loss in decidecade bands between 12.5Hz and 16kHz for a big bubble curtain (BBC) emitting 0.15 – 0.32 $m^3/min*m$ around a 1.2m diameter pile and ~800kJ hammer energy (Bellmann 2014, **Figure 23**). The data were standardized using:

$$SIL_f = IL_f \times \left(\frac{IL_f}{max(|IL_{f,1..n}|)}\right) \quad \text{(eq.5)}$$

where the standardized insertion loss, SIL_f, for i frequency (f) was a ratio of the i^{th} insertion loss for that frequency, IL_f, to the maximum of all frequency-dependent insertion losses measured by Bellmann (2014) (**Figure 23**). The frequency dependence measured by Bellmann (2014) was commensurate with other published spectra (such as Dähne et al. 2017). The standardized *SIL* values were then scaled, in linear space, between zero (i.e., no attenuation achieved by the bubble curtain) to some maximum loss across all frequencies (11 or 14 dB for single or double bubble curtains, respectively). This resulted in a frequency-dependent insertion loss curve that could be applied to the unmitigated SEL models, where $\Delta L_{E,f}$ is the insertion loss, in dB, for frequency, f (**Figure 23**):

$$\Delta L_{E,f} = 10 \times Log_{10}\left(\frac{SIL_{f,i} - min(SIL_f)}{\max(SIL_f) - \min(SIL_f)} \times \left(10^{\left(\frac{Attn}{10}\right)} - 0\right)\right), \text{ where } \Delta L_{E,f}(\Delta L_{E,f} < 0) = 0 \quad \text{(eq.6)}$$

$\Delta L_{E,f}$ is subtracted from the unmitigated received SELs to represent either single bubble curtains (when *Attn* = 11 dB) or double bubble curtains (*Attn* = 14 dB).

This method assumes:

- Zero attenuation in SELs is achieved for decidecade bands below 100Hz and above 25kHz, with a 50% roll-off rate applied to bands below 500Hz and above 25kHz (see **Figure 23**).
- The same frequency-dependence for single and double bubble curtains.

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12 https://www.bsh.de/EN/TOPICS/Offshore/Environmental_assessments/Underwater_sound/_Module/Karussell/_documents/Artikel_Gr_Blasenschleier.html Accessed Nov 2023.

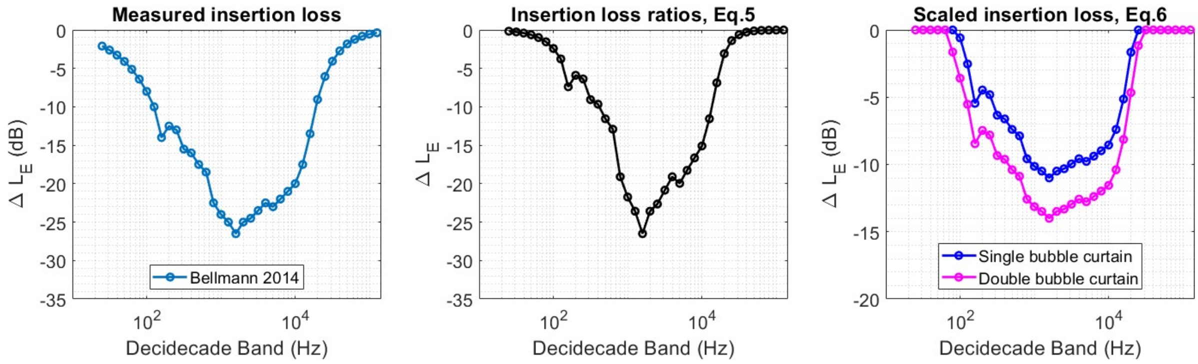

Figure 23 Frequency-dependent insertion losses assumed for single and double bubble curtains.

The left panel is the reproduced insertion losses from Bellmann (2014). The middle panel shows the insertion loss ratios based on the Bellmann (2014) data (from eq. 5). The right panel shows the insertion losses applied to the noise modelling to represent noise fields beyond a single or double bubble curtain (from eq. 6)

Literature cited

Bellmann, M.A. 2014. Overview of existing noise mitigation systems for reducing pile-driving noise. Internoise 2014 Conference, 16-19 November 2014.

Clark CW., Ellison WT., Southall BL., et al. 2009. Acoustic masking in marine ecosystems: intuitions, analysis, and implication. *Marine Ecology Progress Series* 395, 201–222. https://doi.org/10.3354/meps08402.

Cranford TW., Krysl P. 2015. Fin whale sound reception mechanisms: skull vibration enables low-frequency hearing. *PLoS One* 10, 1–18.

Dähne, M., Tougaard, J., Carstensen, J., Rose, A., Nabe-Nielsen, J. 2017. Bubble curtains attenuate noise from offshore wind farm construction and reduce temporary habitat loss for harbour porpoises. *Marine Ecology Progress Series* 580: 221-237.

Ellison WT., Southall BL., Clark CW., Frankel AS. 2012. A new context-based approach to assess marine mammal behavioral responses to anthropogenic sounds. *Conservation Biology* 26:21−28

Erbe C. 2008. Critical ratios of beluga whales (Delphinapterus leucas) and masked signal duration. *Journal of the Acoustical Society of America* 124(4): 2216-2223.

Erbe C., Reichmuth C., Cunningham K., Lucke K., Dooling R. 2016. Communication masking in marine mammals: a review and research strategy. *Marine Pollution Bulletin* 103: 15–38.

Faulkner RC., Farcas A., Merchant ND. 2018. Guiding principles for assessing the impact of underwater noise. *Journal of Applied Ecology* 55:2531-2536.

Farcas, A., Powell, C.F., Brookes, K.L., Merchant, N.D. 2020. Validated shipping noise maps of the Northeast Atlantic. *Science of the Total Environment* 735: 139509.

Findlay, C.R., Aleynik, D., Farcas, A., Merchant, N.D., Risch, D., Wilson, B. 2021. Auditory impairment from acoustic seal deterrents predicted for harbour porpoises in a marine protected area. *Journal of Applied Ecology* 58: 1631-1642.

Gomez C., Lawson JW., Wright AJ, et al. 2016. A systematic review on the behavioural responses of wild marine mammals to noise: the disparity between science and policy. *Canadian Journal of Zoology* 94: 801-819.

Hall JD., Johnson SC. 1972. Auditory thresholds of a killer whale *Orcinus orca*. Journal of the *Acoustical Society of America* 51:515.

Hart, D.E., Todd, D.J., Nation T.E., McWilliams, Z.A. 2019. Upper Akaroa Harbour seabed bathymetry and soft sediments: a baseline mapping study. Technical Report from University of Canterbury for Environment Canterbury. Report No. 09/44.

Hawkins, A.N., Johnson, C., Popper, A.N. (2020). How to set sound exposure criteria for fishes. *The Journal of the Acoustical Society of America* 147(3): 1762-1777.

Hawkins, A.D., Popper, A.N. (2017). A sound approach to assessing the impact of underwater noise on marine fishes and invertebrates. *ICES Journal of Marine Science* 74(3): 634-651.

High Energy Seismic Survey Team (HESS). 1999. High Energy Seismic Survey Review Process and Interim Operational Guidelines for Marine Surveys Offshore Southern California. The California State Lands Commission and The United States Minerals Management Service.

Hildebrand JA. 2005. Impacts of anthropogenic sound. In: Reynolds JE III, Perrin WF, Reeves RR, et al (eds) Marine Mammal Research: Conservation Beyond Crisis. Johns Hopkins University Press, Baltimore, Md. pp 101-124.

Jensen FB., Kuperman WA., Porter MB., Schmidt H. 2011. Computational Ocean Acoustics. Springer, New York.

Joy R., Tollit D., Wood J. et al. 2019. Potential benefits of vessel slowdowns on endangered southern resident killer whales. *Frontiers in Marine Science* 6:344.

Kastelein, R.A., van Heerden, D., Gransier, R., Hoek, L., 2013. Behavioral responses of a harbor porpoise (Phocoena phocoena) to playbacks of broadband pile driving sounds. *Marine Environmental Research* 92: 206–214.

Malme, C. I., Miles, P. R., Clark, C. W., Tyak, P., & Bird, J. E. 1983. Investigations of the Potential Effects of Underwater Noise from Petroleum Industry Activities on Migrating Gray Whale Behavior. MMS Report No. 5366: U.S. Department of the Interior.

Malme, C. I., Miles, P. R., Clark, C. W., Tyak, P., & Bird, J. E. 1984. Investigation of the potential effects of underwater noise from petroleum industry activities on migrating gray whale behavior. MMS Report No. 5586: U.S. Department of the Interior.

Medwin, H., Clay, C.S. 1998. Fundamentals of Acoustical Oceanography. Academic Press, San Diego, CA.

MMC (Marine Mammal Commission). 2007. Marine Mammals and Noise: A Sound Approach to Research and Management. MMC. (12 December 2011).

NAS (National Academy of Sciences). 2017. Approaches to understanding the cumulative effects of stressors on marine mammals. Washington, DC: The National Academies Press. https://doi.org/10.17226/23479

National Marine Fisheries Service (NMFS). 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 thresholds shifts. U.S. Dept. of Commerce, NOAA. NOAA Technical Memorandum NMFS-OPR-59.

Nedwell JR., Edwards B., Tumpenny AWH., Gordon J. 2004. Fish and marine mammal audiograms: a summary of available information. Subacoustech Ltd, Southampton.

National Institute of Water and Atmospheric Research (NIWA). 2014. Akaroa Harbour modelling report: Akaroa wastewater project. Technical report for CH2M Beca Ltd. NIWA Report No. HAM2014-027.

National Marine Fisheries Service (NMFS). 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 thresholds shifts. U.S. Dept. of Commerce, NOAA. NOAA Technical Memorandum NMFS-OPR-59.

Nowacek, DP., Thorne LH,, Johnston DW., Tyack PL. 2007. Responses of cetaceans to anthropogenic noise. *Mammal Review* 37(2): 81-115.

NRC (National Research Council). 2005. Marine mammal populations and ocean noise: determining when noise causes biologically significant events. National Academy Press, Washington, DC.

Pine MK., Hannay DE., Insley SJ., Halliday WD. 2018. Assessing vessel slowdown for reducing auditory masking for marine mammals and fish of the western Canadian Arctic. *Marine Pollution Bulletin* 135: 290-302.

Pine MK., Schmitt P., Culloch RM., et al. 2019. Providing ecological context to anthropogenic subsea noise: assessing listening space reductions of marine mammals from tidal energy devices. *Renewable and Sustainable Energy Reviews* 103: 49-57.

Pine MK., Nikolich K., Martin B., Morris C., Juanes F. 2020. Assessing auditory masking for management of underwater anthropogenic noise. *Journal of the Acoustical Society of America* 147(5): 3408-3417.

Popper, A.N., Hawkins, A.D., Fay, R.R. 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. Report No. ASA S3/SC1.4 TR-2014.

Popov VV., Klishin VO. 1998. EEG study of hearing in the common dolphin, Delphinus delphis. *Aquatic Mammals* 24:13–20.

Putland RL., Merchant ND., Farcas A., Radford CA. 2017. Vessel noise cuts down communication space for vocalizing fish and marine mammals. *Global Change Biology* 24(4): 1-14.

Radford, A. N., Kerridge, E., and Simpson, S. D. 2014. Acoustic communication in a noisy world: Can fish compete with anthropogenic noise? *Behavioural Ecology* 25: 1022–1030.

Reine, K.J., Clarke, D., Dickerson, C. 2014. Characterization of underwater sounds produced by hydraulic and mechanical dredging operations. *Journal of the Acoustical Society of America* 135(6): 3280-3294.

Richardson WJ., Greene CR., Jr, Malme CI., et al. 1995. Marine mammals and noise. Academic Press, San Diego, CA. 576 pp.

Robinson, S.P. 2015 Dredging Sound Measurements. WODA Workshop presentation. 26 March 2015, Paris.

Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J., Gentry, R.L., Greene, C.R., Kastak, D., Ketten, D.R., Miller, J.H., Nachtigall, P.E., Richardson, W.J., Thomas, J.A., Tyack, P.L. 2007. Marine mammal noise exposure criteria. *Aquatic Mammals*, 33(4): 411-522.

Southall, B.L., Finneran, J.J., Reichmuth, C., Nachtigall, P.E., Ketten, D.R., Bowles, A.E., Ellison, W.T., Nowacek, D.P., Tyack, P.L. 2019. Marine mammal noise exposure criteria: updated scientific recommendations for residual hearing effects. *Aquatic Mammals* 45(2): 125-232.

Southall, B.L., Nowacek, D.P., Bowles, A.E., Senigaglia, V., Bejder, L., Tyack, P.L. 2021. Marine mammal noise exposure criteria: assessing the severity of marine mammal behavioural responses to human noise. *Aquatic Mammals* 47(5): 421-464.

Szymanski MD., Bain DE., Kiehl K., et al. 1999. Killer whale (Orcinus orca) hearing: auditory brainstem response and behavioral audiograms. *Journal of the Acoustical Society of America* 106:1134–41. https://doi.org/10.1121/1.427121.

Tonkin & Taylor Ltd. 2016. Marsden Point Refinery - Crude Freight Project. April 2016, report number 30488.1000.

Tsouvalas, A., Metrikine, A.V. 2016. Noise reduction by the application of an air-bubble curtain in offshore pile driving. *Journal of Sound and Vibration* 371: 150-170.

US Navy. 2008. Southern California Range Complex Environmental Impact Statement/Overseas Environmental Impact Statement. Washington, DC: United States Department of the Navy.

US Navy. 2012. Atlantic Fleet Training and Testing EIR/OEIS: Draft Version. Washington, DC: United States Department of the Navy.

von Pein, J., Lippert, T., Lippert, S., von Estorff, O. 2022. Scaling laws for unmitigated pile driving: dependence of underwater noise on strike energy, pile diameter, ram weight, and water depth. *Applied Acoustics* 198: 108986.

Wei, C., Erbe, C. 2024. Sound reception and hearing capabilities in the Little Penguin (*Eudyptula minor*): first predicted in-air and underwater audiograms. *Royal Society Open Science* 11: 240593.

Weilgart LS. 2007. The impacts of anthropogenic ocean noise on cetaceans and implications for management. *Canadian Journal of Zoology* 85: 1091-1116.

Weston, D.E. (1971). Intensity-range relations in oceanographic acoustics. *Journal of Sound and Vibration* 18: 271–287.

Weston, D.E. (1976). Propagation in water with uniform sound velocity but variable-depth lossy bottom. *Journal of Sound and Vibration* 47(4): 473-483.

Wilson, L., Constantine, R., Pine, M.K., Farcas, A., Radford, C.A. 2023. Impact of small boat sound on the listening space of *Pempheris adspersa*, *Forsterygion lapillum*, *Alpheus richardsoni* and *Ovalipes catharus*. *Scientific Reports* 13: 7007.

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

Wood, M.A. (2016). Modelling and preduction of acoustic disturbances from off-shore piling. Ph.D. Thesis, University of Southamptom.

Würsig, B., Greene, C.R., Jefferson, T.A. 2000. Development of an air bubble curtain to reduce underwater noise of percussive piling, *Marine Environmental Research* 49:79–93.

Appendix D Noise maps and effects contours

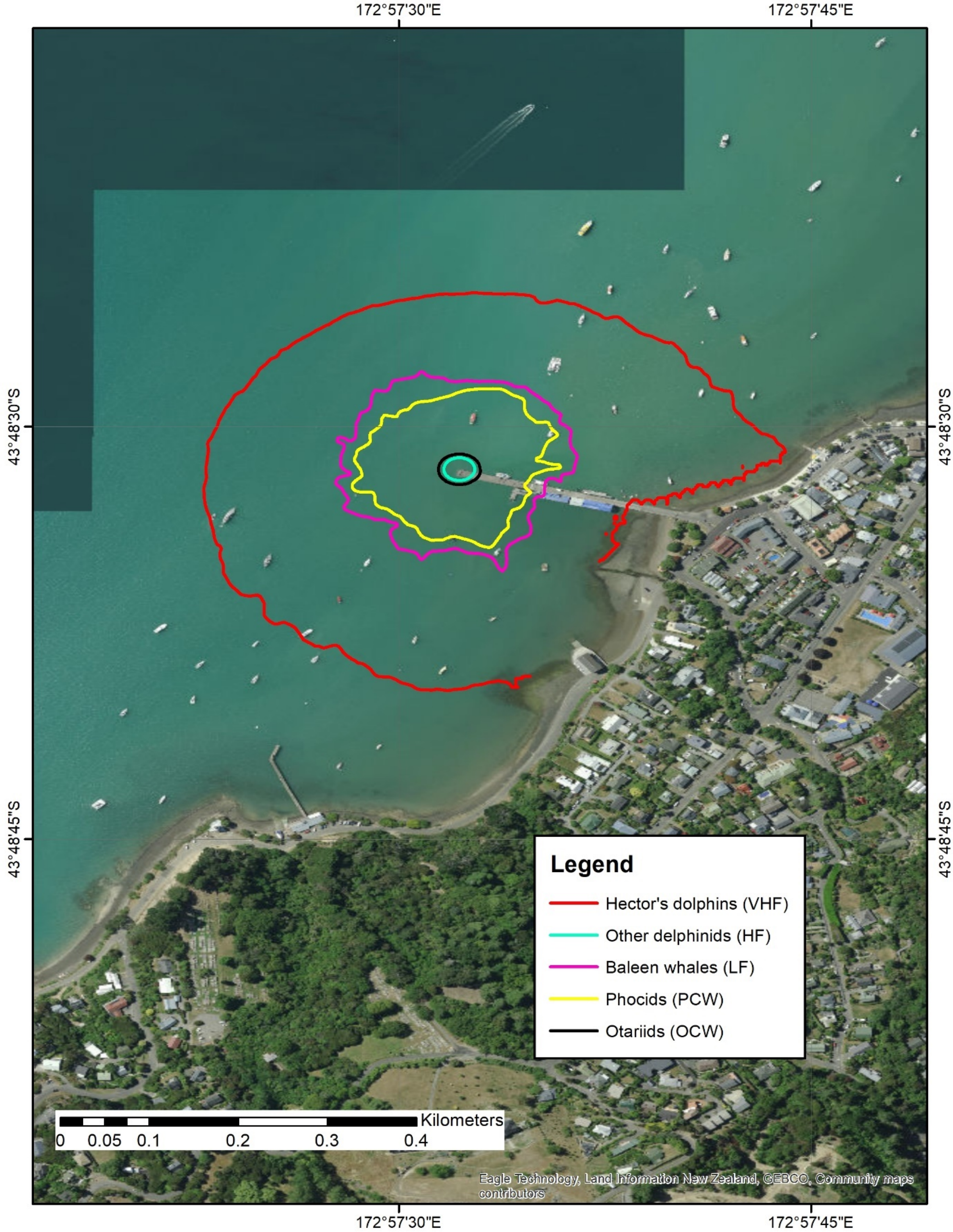

Figure 24 Contours showing the ranges within which the potential onset of permanent threshold shift (PTS) for each functional hearing group of marine mammals from the percussive piling.

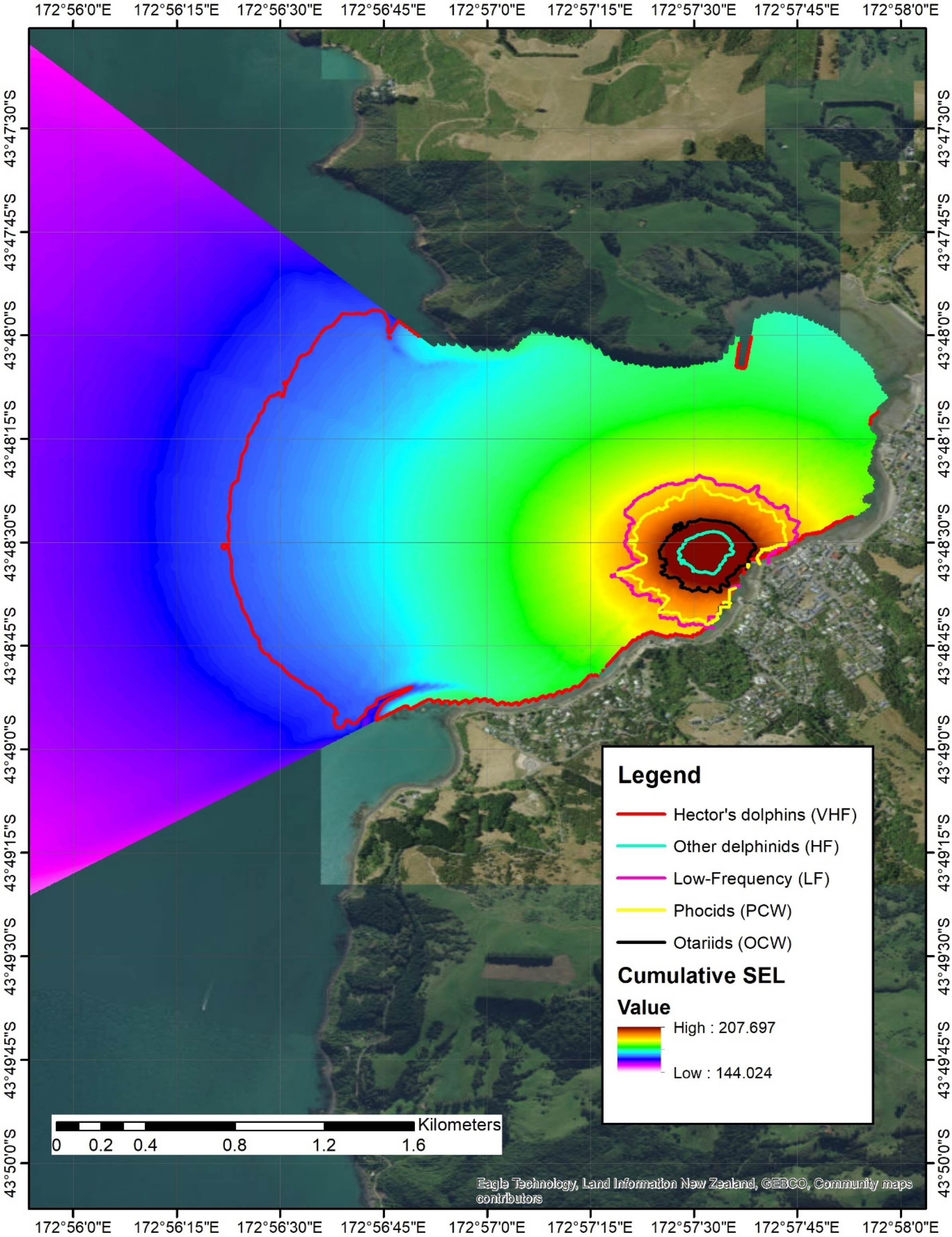

Figure 25 Contours showing the ranges within which the potential onset of temporary threshold shift (TTS) for each functional hearing group of marine mammals from the percussive piling. The colour map represents the unweighted cumulative sound exposure levels, $L_{E\text{-}24hr}$.

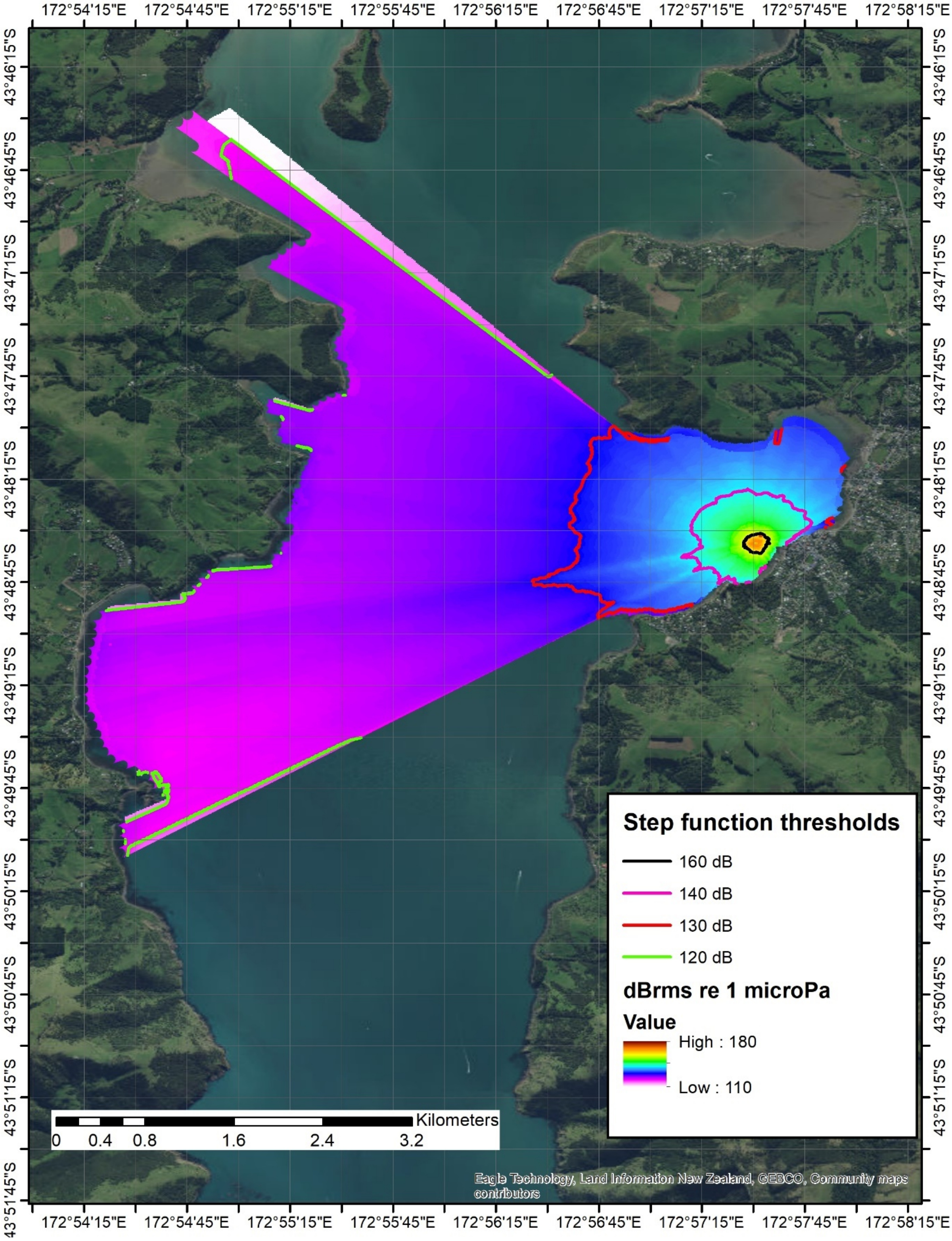

Figure 26 Contours showing the ranges within which the potential onset of behavioural responses from the percussive piling may occur for marine mammals. The colour map represents the unweighted root-mean-squared (RMS) levels.

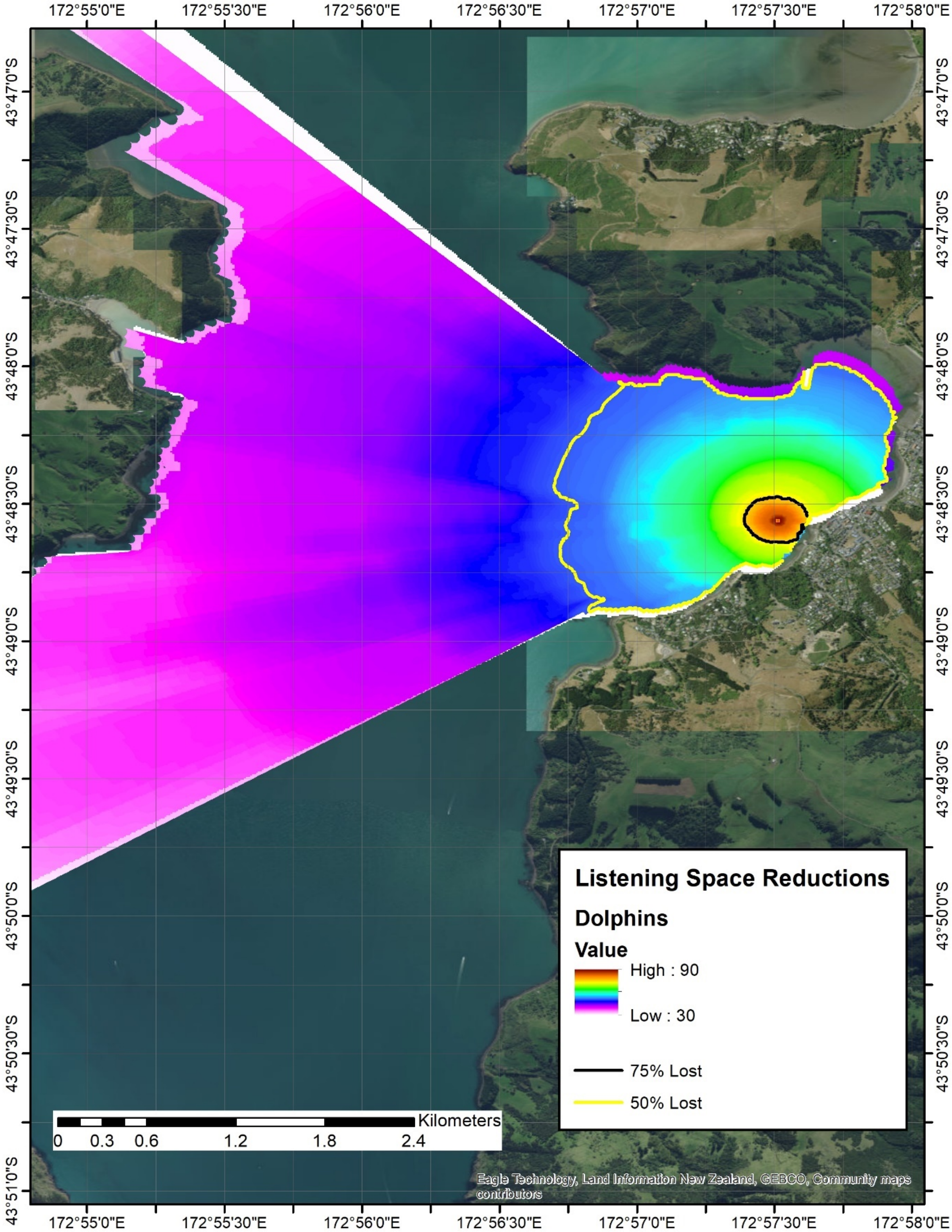

Figure 27 Map showing the extent of listening space reductions (LSR, %) for dolphin species (excl. Hector's dolphins and killer whales) during the percussive piling.

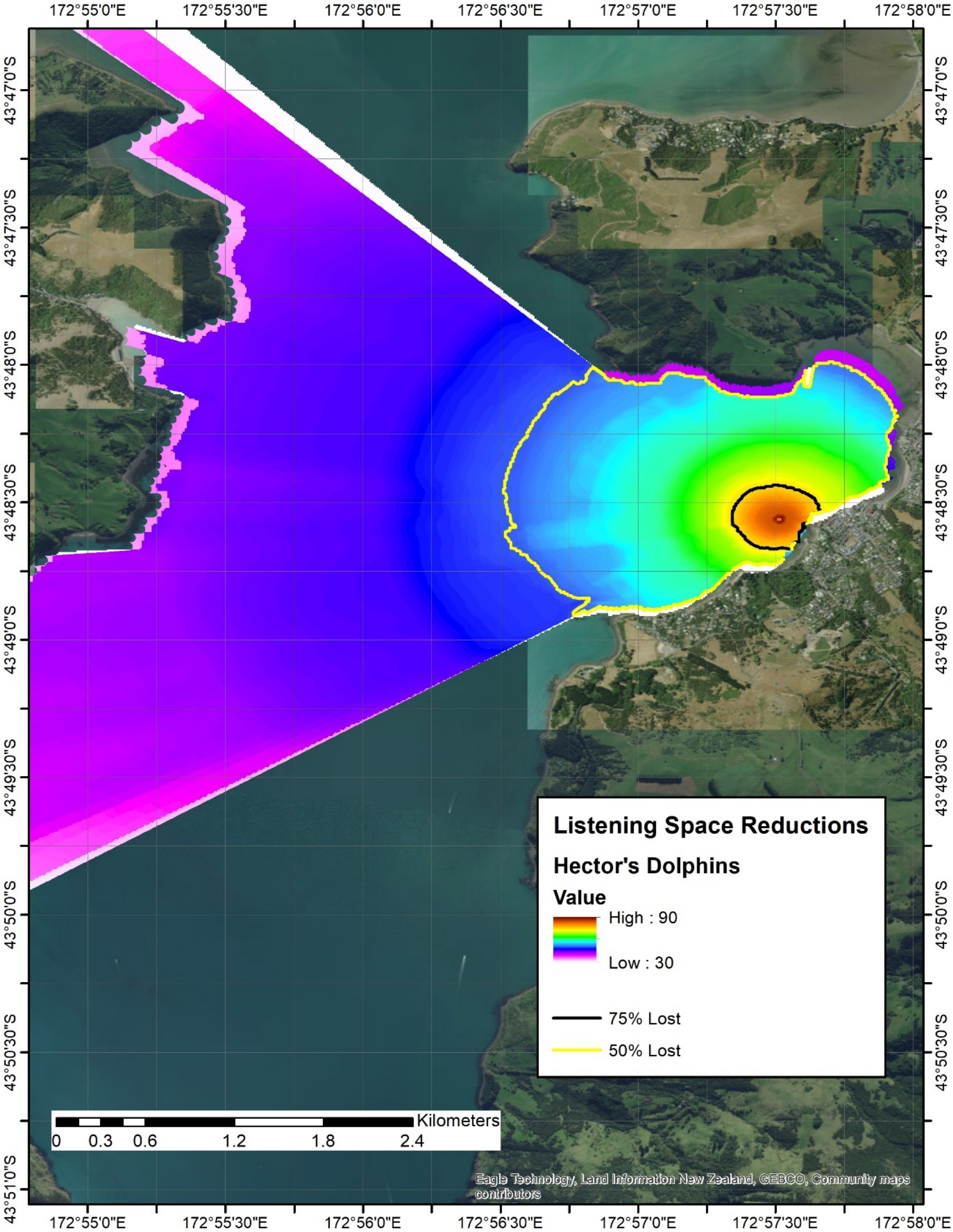

Figure 28 Map showing the extent of listening space reductions (LSR, %) for Hector's dolphin during the percussive piling.

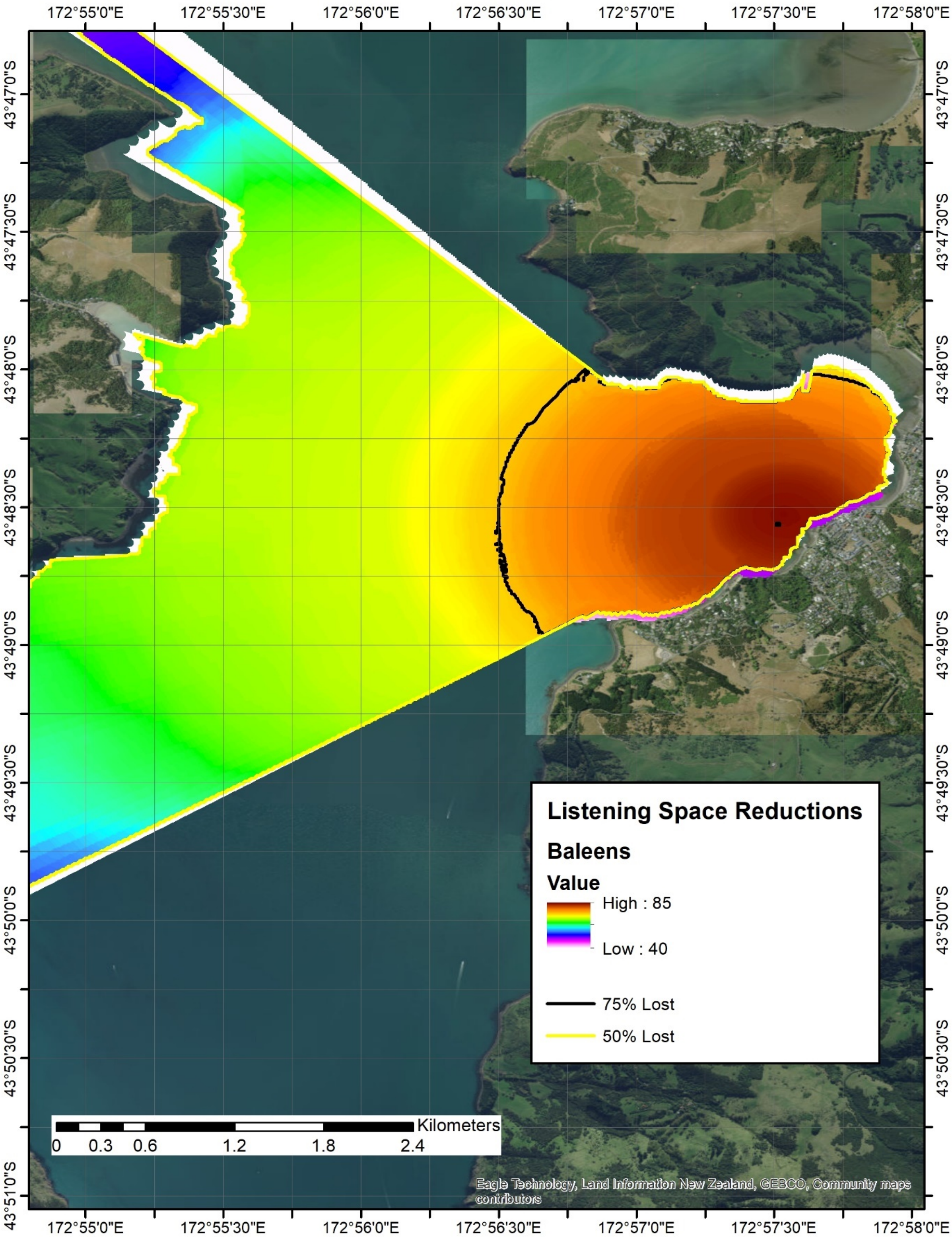

Figure 29 Map showing the extent of listening space reductions (LSR, %) for baleen whales during the percussive piling.

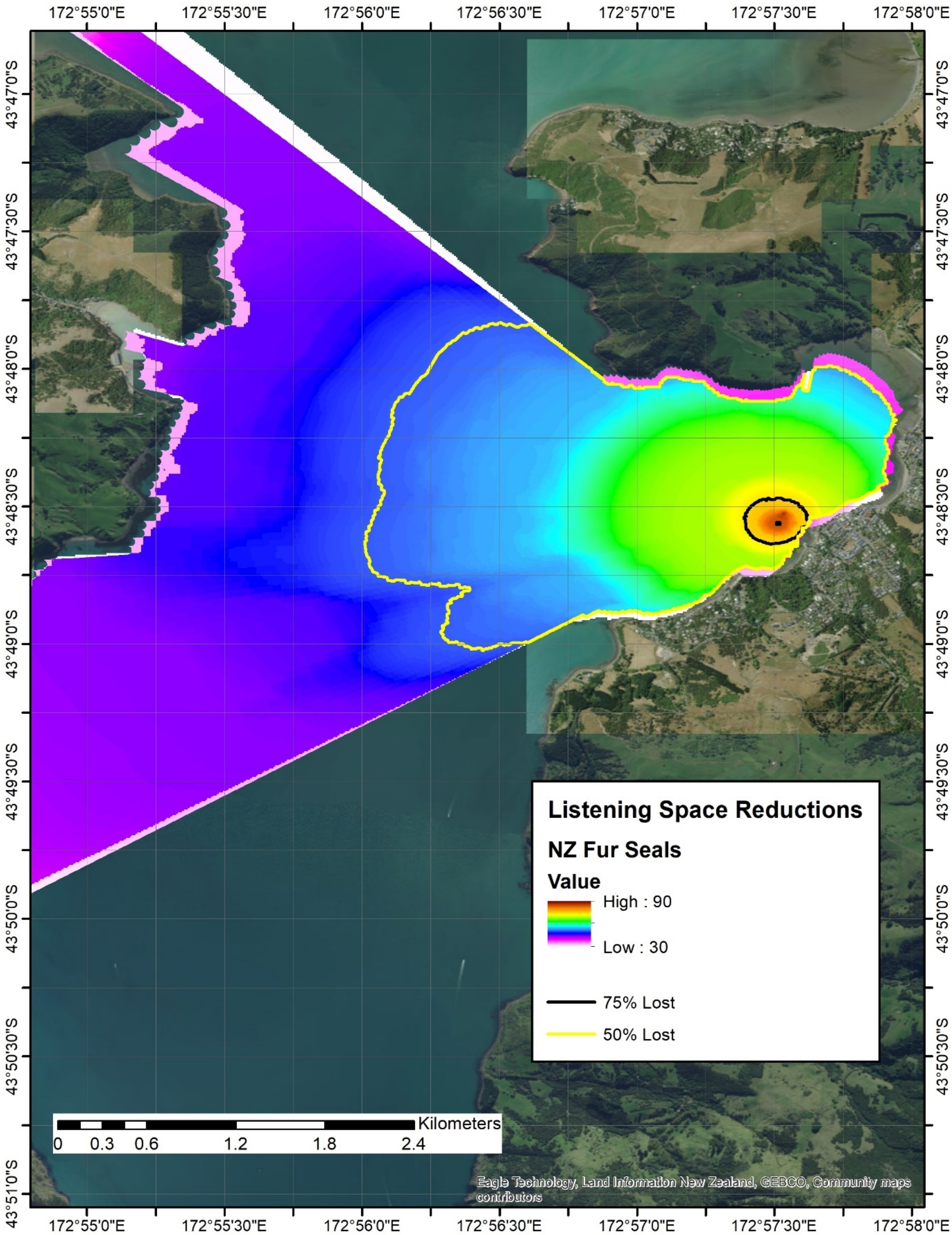

Figure 30 Map showing the extent of listening space reductions (LSR, %) for NZ fur seals during the percussive piling.

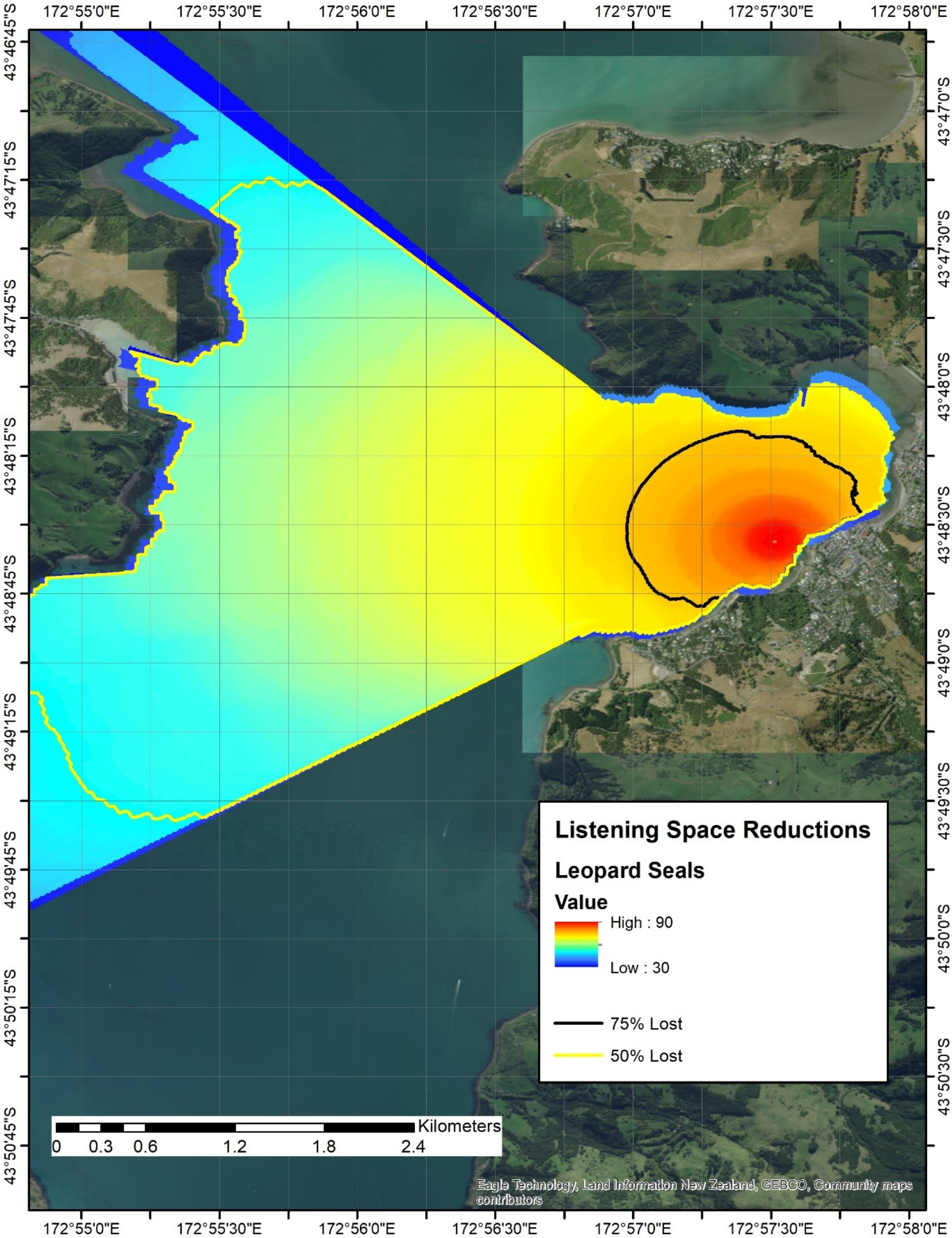

Figure 31 Map showing the extent of listening space reductions (LSR, %) for leopard seals during the percussive piling.

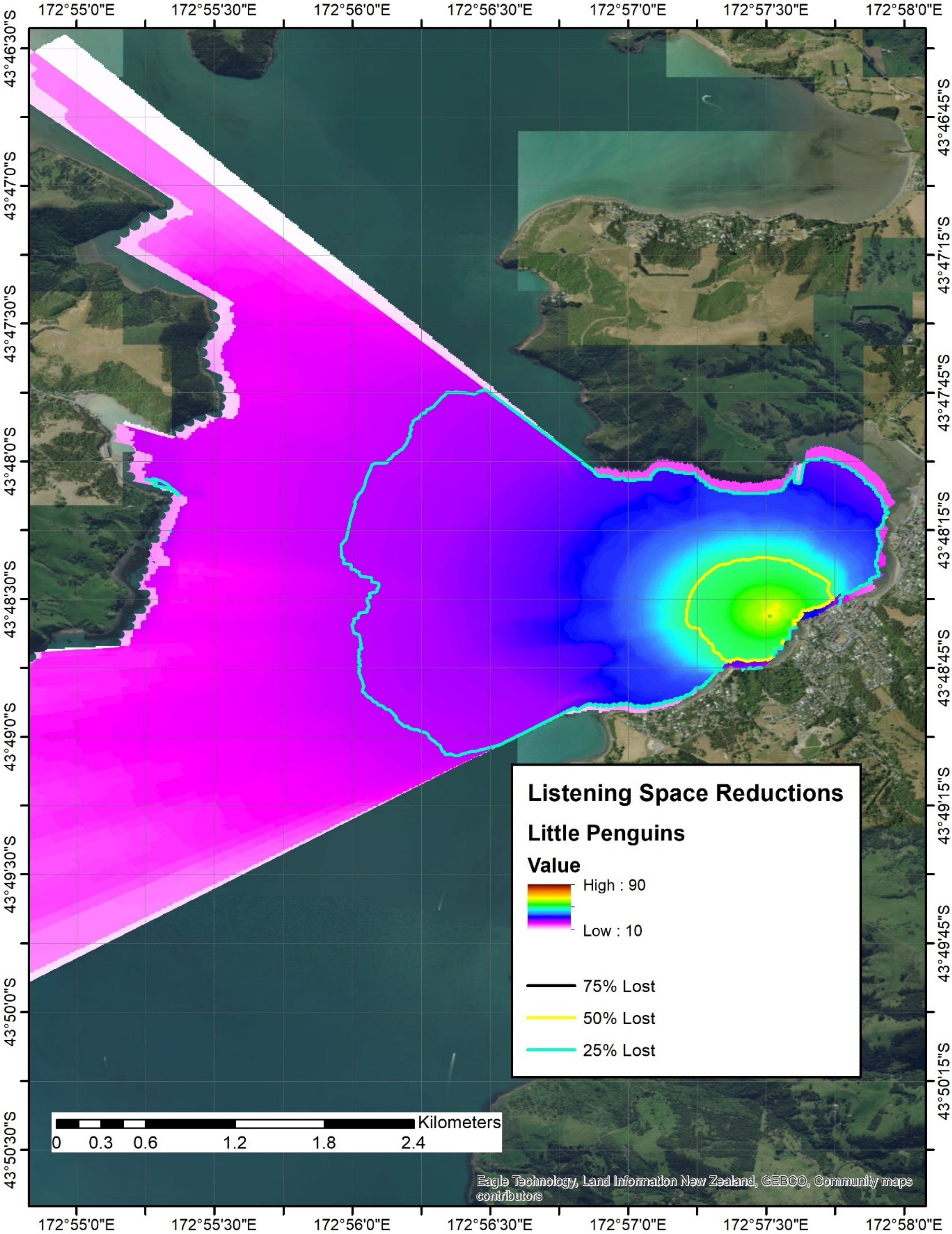

Figure 32 Map showing the extent of listening space reductions (LSR, %) for little penguins during the percussive piling.

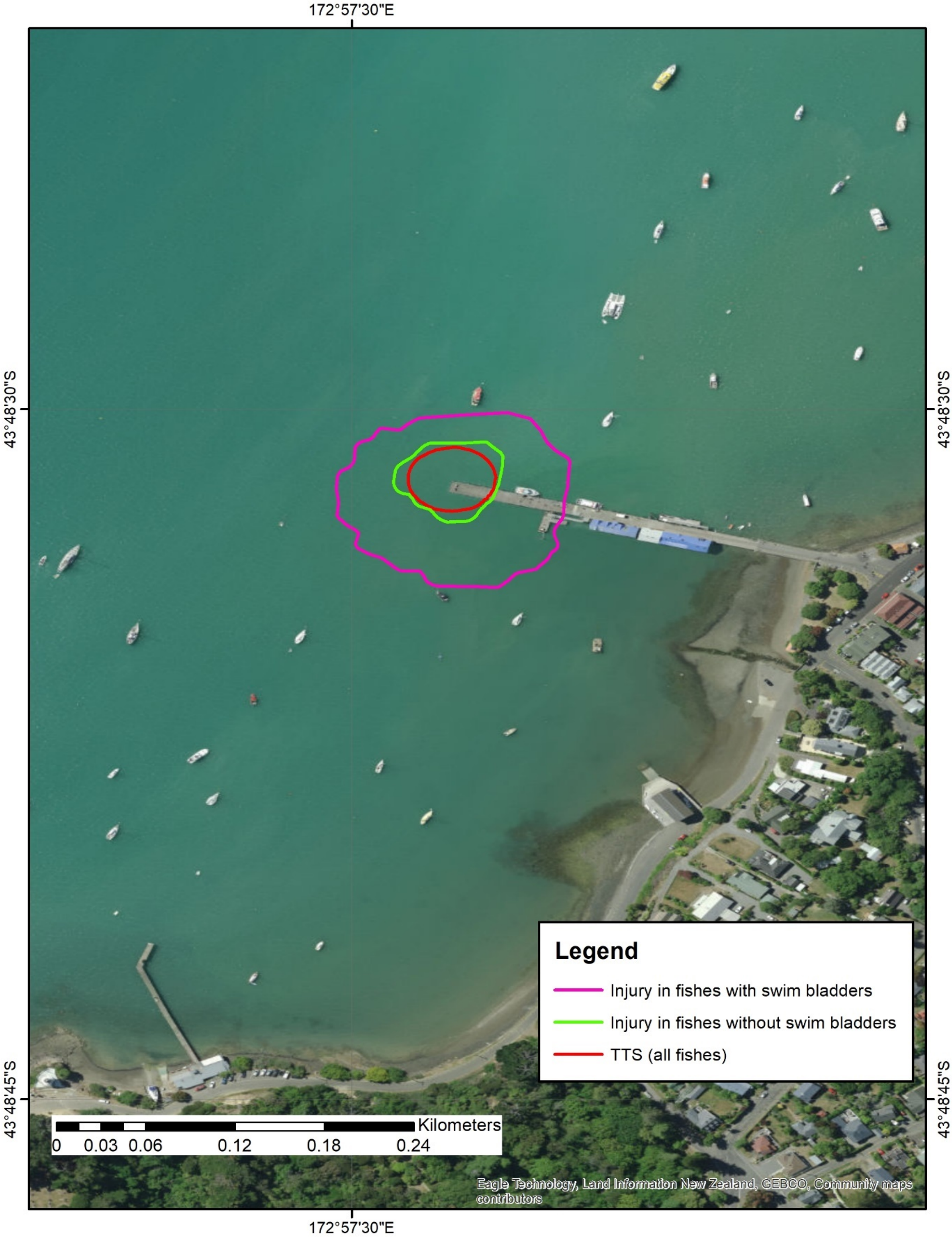

Figure 33 Contours showing the ranges within which there is a risk of potential injury (incl. recoverable & fatal injuries) or temporary threshold shift (TTS) in fishes during percussive piling.

Appendix E Hector’s dolphin acoustic detection events

List of detection events from the SoundTrap 300HF recorder inside French Bay, Akaroa. The acoustic sampling effort comprises 66.98 days (between 22 June and 28 August 2023). The ST300HF recorder was operating on a low duty cycle. This was because the recorder was sampling the ambient soundscape for the effects monitoring, rather than specifically marine mammal monitoring.

The list below details 85 detection events. Detection events are defined as the time between the first vocalisation detected and the last vocalisation detected that is within 20 minutes of the previous detection. For example, if one detection was made at 10:00hrs, and then again at 10:10hrs, that would count as the same detection event. However, if no vocalisation is detected within 20mins of the last (i.e., by 10:20hrs), then that would conclude that detection event.

Detection Event		Duration	
Start	End	Detection Positive Minutes	Group
23/06/2023 12:47	23/06/2023 12:49	02	Hectors
24/06/2023 7:45	24/06/2023 7:46	01	Hectors
25/06/2023 7:45	25/06/2023 7:49	04	Hectors
25/06/2023 8:15	25/06/2023 8:16	01	Hectors
26/06/2023 4:46	26/06/2023 4:47	01	Hectors
26/06/2023 7:45	26/06/2023 7:49	04	Hectors
26/06/2023 8:16	26/06/2023 8:19	03	Hectors
28/06/2023 22:45	28/06/2023 22:48	03	Hectors
29/06/2023 3:47	29/06/2023 3:49	02	Hectors
29/06/2023 8:15	29/06/2023 8:16	01	Hectors
1/07/2023 0:15	1/07/2023 0:17	02	Hectors
2/07/2023 4:49	2/07/2023 4:50	01	Hectors
6/07/2023 8:19	6/07/2023 8:20	01	Hectors
7/07/2023 14:45	7/07/2023 14:46	01	Hectors
7/07/2023 23:17	7/07/2023 23:19	02	Hectors
8/07/2023 15:15	8/07/2023 15:19	04	Hectors
9/07/2023 12:17	9/07/2023 12:18	01	Hectors
10/07/2023 7:15	10/07/2023 7:19	04	Hectors
11/07/2023 11:48	11/07/2023 11:49	01	Hectors
15/07/2023 9:15	15/07/2023 9:19	04	Hectors
16/07/2023 12:47	16/07/2023 12:48	01	Hectors
19/07/2023 4:46	19/07/2023 4:47	01	Hectors
20/07/2023 11:45	20/07/2023 11:49	04	Hectors
20/07/2023 13:49	20/07/2023 13:50	01	Hectors
22/07/2023 8:48	22/07/2023 8:49	01	Hectors
24/07/2023 10:18	24/07/2023 10:19	01	Hectors
24/07/2023 13:15	24/07/2023 13:18	03	Hectors

25/07/2023 6:45	25/07/2023 6:46	01	Hectors
25/07/2023 13:47	25/07/2023 13:49	02	Hectors
28/07/2023 9:15	28/07/2023 9:16	01	Hectors
29/07/2023 22:47	29/07/2023 22:49	02	Hectors
1/08/2023 2:16	1/08/2023 2:19	03	Hectors
1/08/2023 11:45	1/08/2023 11:49	04	Hectors
1/08/2023 12:49	1/08/2023 12:50	01	Hectors
1/08/2023 19:45	1/08/2023 19:49	04	Hectors
1/08/2023 23:15	1/08/2023 23:19	04	Hectors
2/08/2023 0:15	2/08/2023 0:16	01	Hectors
2/08/2023 10:15	2/08/2023 10:16	01	Hectors
7/08/2023 4:45	7/08/2023 4:49	04	Hectors
7/08/2023 5:15	7/08/2023 5:19	04	Hectors
7/08/2023 14:47	7/08/2023 14:48	01	Hectors
7/08/2023 17:15	7/08/2023 17:16	01	Hectors
7/08/2023 20:17	7/08/2023 20:19	02	Hectors
8/08/2023 1:15	8/08/2023 1:18	03	Hectors
8/08/2023 7:15	8/08/2023 7:17	02	Hectors
8/08/2023 7:45	8/08/2023 7:47	02	Hectors
8/08/2023 11:15	8/08/2023 11:19	04	Hectors
8/08/2023 22:45	8/08/2023 22:47	02	Hectors
9/08/2023 0:17	9/08/2023 0:19	02	Hectors
10/08/2023 22:18	10/08/2023 22:19	01	Hectors
10/08/2023 22:47	10/08/2023 22:49	02	Hectors
11/08/2023 4:45	11/08/2023 4:46	01	Hectors
14/08/2023 15:15	14/08/2023 15:19	04	Hectors
16/08/2023 12:45	16/08/2023 12:46	01	Hectors
16/08/2023 21:16	16/08/2023 21:17	01	Hectors
16/08/2023 21:47	16/08/2023 21:48	01	Hectors
17/08/2023 4:45	17/08/2023 4:47	02	Hectors
17/08/2023 12:15	17/08/2023 12:17	02	Hectors
17/08/2023 12:45	17/08/2023 12:46	01	Hectors
19/08/2023 16:15	19/08/2023 16:19	04	Hectors
20/08/2023 7:15	20/08/2023 7:19	04	Hectors
21/08/2023 4:17	21/08/2023 4:18	01	Hectors
21/08/2023 4:45	21/08/2023 4:49	04	Hectors
21/08/2023 19:45	21/08/2023 19:48	03	Hectors
22/08/2023 0:15	22/08/2023 0:19	04	Hectors
22/08/2023 0:46	22/08/2023 0:47	01	Hectors
22/08/2023 1:46	22/08/2023 1:49	03	Hectors
22/08/2023 10:45	22/08/2023 10:46	01	Hectors
22/08/2023 12:48	22/08/2023 12:49	01	Hectors
22/08/2023 14:45	22/08/2023 14:49	04	Hectors

23/08/2023 15:49	23/08/2023 15:50	01	Hectors
24/08/2023 1:15	24/08/2023 1:16	01	Hectors
24/08/2023 5:16	24/08/2023 5:17	01	Hectors
24/08/2023 11:15	24/08/2023 11:19	04	Hectors
24/08/2023 11:46	24/08/2023 11:48	02	Hectors
25/08/2023 13:15	25/08/2023 13:16	01	Hectors
26/08/2023 12:18	26/08/2023 12:19	01	Hectors
26/08/2023 17:15	26/08/2023 17:16	01	Hectors
27/08/2023 2:46	27/08/2023 2:47	01	Hectors
27/08/2023 3:15	27/08/2023 3:16	01	Hectors
27/08/2023 3:47	27/08/2023 3:49	02	Hectors
27/08/2023 8:18	27/08/2023 8:19	01	Hectors
27/08/2023 9:18	27/08/2023 9:19	01	Hectors
27/08/2023 13:46	27/08/2023 13:49	03	Hectors
27/08/2023 14:15	27/08/2023 14:18	03	Hectors

Appendix F Vessel noise levels

These vessel detection events comprise complete vessel passbys that exceeded a 10dB SNR threshold for longer than 10 seconds, after being detected by the machine learning. The recorder operated on a 50% duty cycle (5min recordings every 10min), which meant the vessel had to pass the hydrophone within 5min for the received noise levels from the vessel to be logged. If a vessel was approaching the hydrophone but failed to pass it before the end the of 5min recording, it would not be measured.

DateTime	Passby Duration	Lmax (dB re 1 µPa)	Leq (dB re 1 µPa)
24/06/2023 16:19	42 sec	126.0794	118.2192
28/06/2023 6:01	19 sec	111.3351	106.7216
29/06/2023 11:26	38 sec	124.2096	118.4585
1/07/2023 14:01	83 sec	119.3506	114.3593
4/07/2023 11:40	121 sec	125.9453	118.9283
5/07/2023 15:30	52 sec	134.7327	125.3462
10/07/2023 15:26	55 sec	124.0742	116.3418
10/07/2023 15:28	76 sec	123.843	114.3015
11/07/2023 8:50	85 sec	128.869	119.9292
11/07/2023 11:27	114 sec	117.2531	110.2725
11/07/2023 11:37	32 sec	103.999	100.3046
14/07/2023 13:31	54 sec	118.0744	113.5155
14/07/2023 14:07	43 sec	133.1526	124.1202
14/07/2023 15:48	52 sec	113.9608	110.8231
15/07/2023 7:00	83 sec	118.5766	110.1577
15/07/2023 8:01	71 sec	130.1279	120.2777
15/07/2023 8:48	76 sec	122.7707	116.6609
15/07/2023 10:57	59 sec	126.0978	119.1143
15/07/2023 10:58	67 sec	138.0935	127.5411
15/07/2023 11:28	42 sec	127.6812	121.362
15/07/2023 11:40	34 sec	116.5893	112.9368
15/07/2023 12:11	37 sec	122.6723	116.2954
15/07/2023 12:21	24 sec	121.944	115.9484
15/07/2023 12:48	55 sec	120.5261	116.3408
15/07/2023 13:20	53 sec	129.0833	120.8709
15/07/2023 13:41	55 sec	116.5237	112.4144
15/07/2023 14:17	73 sec	126.1571	118.4
15/07/2023 14:29	78 sec	125.9663	119.4216
15/07/2023 14:47	70 sec	116.357	109.8699
15/07/2023 15:19	50 sec	127.3653	120.5092
15/07/2023 15:41	66 sec	125.243	112.6425
15/07/2023 17:41	55 sec	115.384	109.3234

16/07/2023 8:11	78 sec	152.3569	133.3132
16/07/2023 9:27	42 sec	107.9818	105.5271
16/07/2023 10:29	70 sec	125.8308	118.5704
16/07/2023 12:41	28 sec	119.7741	114.665
16/07/2023 14:08	108 sec	128.2055	119.4012
17/07/2023 13:37	87 sec	121.3968	115.2516
17/07/2023 14:19	48 sec	114.8176	110.4711
17/07/2023 14:51	44 sec	113.197	109.3782
18/07/2023 7:58	84 sec	120.481	114.2682
18/07/2023 13:59	128 sec	132.9083	122.8341
18/07/2023 14:49	77 sec	119.0434	112.7841
18/07/2023 15:17	40 sec	111.2389	107.6774
19/07/2023 8:10	34 sec	115.9244	108.0149
19/07/2023 8:10	31 sec	114.5751	108.3973
21/07/2023 11:06	42 sec	118.9466	113.1422
21/07/2023 11:09	91 sec	124.9493	118.1732
21/07/2023 11:10	33 sec	90.13063	118.0991
21/07/2023 11:10	33 sec	116.5029	118.0991
25/07/2023 13:09	64 sec	98.60228	110.573
25/07/2023 13:09	64 sec	105.5846	110.573
25/07/2023 13:10	58 sec	116.3145	108.461
25/07/2023 13:27	68 sec	123.9669	117.5025
25/07/2023 13:31	23 sec	123.6347	114.8758
25/07/2023 13:36	25 sec	126.4851	120.3195
25/07/2023 13:41	42 sec	123.3472	116.672
25/07/2023 14:47	35 sec	121.459	114.1077
25/07/2023 15:16	84 sec	112.1983	107.6081
25/07/2023 15:18	45 sec	110.712	106.2307
25/07/2023 15:19	34 sec	105.8217	102.1702
29/07/2023 10:36	39 sec	106.9708	102.5734
29/07/2023 11:07	61 sec	116.1483	106.6176
29/07/2023 12:51	115 sec	113.1246	107.2779
29/07/2023 16:20	87 sec	127.2756	117.9185
29/07/2023 16:49	71 sec	116.3407	111.8073
30/07/2023 7:08	82 sec	121.5437	115.2389
30/07/2023 7:57	51 sec	125.185	119.6554
30/07/2023 8:00	57 sec	123.2845	116.7212
30/07/2023 10:49	95 sec	128.1299	118.8809
30/07/2023 10:59	46 sec	144.5791	132.0663
30/07/2023 12:09	73 sec	129.6025	120.4438
30/07/2023 13:08	49 sec	137.7034	125.921
31/07/2023 7:01	52 sec	110.3439	102.3296
31/07/2023 10:50	38 sec	110.3224	107.2156

31/07/2023 10:50	36 sec	110.5002	107.6307
5/08/2023 11:48	87 sec	140.7027	125.6421
5/08/2023 11:48	34 sec	118.7521	109.0692
5/08/2023 13:08	72 sec	112.6222	106.1707
5/08/2023 15:41	30 sec	133.665	108.8717
6/08/2023 9:18	74 sec	107.3082	102.7993
6/08/2023 10:50	86 sec	113.5748	107.5697
6/08/2023 12:29	88 sec	126.4308	117.9944
7/08/2023 9:38	85 sec	120.5481	115.5181
7/08/2023 12:39	38 sec	119.171	114.1277
7/08/2023 12:50	44 sec	113.1872	106.8611
8/08/2023 11:19	64 sec	127.9458	123.0017
8/08/2023 15:16	75 sec	120.0882	109.8624
8/08/2023 16:20	50 sec	112.0615	107.0621
8/08/2023 16:51	84 sec	134.9752	124.9891
9/08/2023 12:31	28 sec	109.2579	106.5053
10/08/2023 12:27	53 sec	135.9583	128.2389
11/08/2023 13:37	51 sec	125.0849	119.7157
11/08/2023 13:47	83 sec	122.7892	115.9438
11/08/2023 14:49	94 sec	125.2468	117.9737
11/08/2023 14:59	98 sec	137.9041	124.4108
11/08/2023 15:08	92 sec	124.4392	113.9135
11/08/2023 16:58	120 sec	134.7425	121.7819
12/08/2023 7:38	51 sec	112.338	108.5168
12/08/2023 7:38	53 sec	120.1534	111.0986
12/08/2023 7:39	30 sec	120.1401	111.4115
12/08/2023 7:39	34 sec	114.1522	108.9415
12/08/2023 7:48	109 sec	127.3946	118.1369
12/08/2023 10:47	36 sec	128.4399	123.0906
12/08/2023 12:39	57 sec	117.4274	111.4931
12/08/2023 13:00	97 sec	135.097	125.5152
12/08/2023 13:41	19 sec	128.0853	120.3554
12/08/2023 14:09	86 sec	120.5893	113.7874
13/08/2023 7:21	42 sec	107.2794	103.1585
13/08/2023 10:01	68 sec	116.7221	110.8761
13/08/2023 10:09	80 sec	123.7983	116.9198
13/08/2023 10:49	55 sec	112.5381	108.9447
13/08/2023 10:49	30 sec	112.6639	109.5989
13/08/2023 10:50	106 sec	113.833	110.4941
13/08/2023 13:40	186 sec	114.802	110.4637
13/08/2023 13:59	75 sec	129.895	121.3216
14/08/2023 10:06	37 sec	115.614	109.7807
14/08/2023 10:51	94 sec	114.2223	109.7921

14/08/2023 12:36	21 sec	111.3036	109.1259
15/08/2023 12:37	159 sec	124.385	113.1133
15/08/2023 15:26	67 sec	106.3811	102.5885
16/08/2023 9:27	60 sec	116.8957	113.0227
18/08/2023 7:30	82 sec	123.1829	116.2547
18/08/2023 7:48	102 sec	117.5433	110.9845
18/08/2023 7:57	87 sec	133.6728	124.055
18/08/2023 9:41	112 sec	110.0242	105.1431
18/08/2023 9:46	37 sec	129.2911	123.3351
18/08/2023 9:47	69 sec	105.8347	108.6255
18/08/2023 9:47	69 sec	105.5945	108.6255
18/08/2023 16:08	118 sec	115.8089	108.929
19/08/2023 10:50	162 sec	113.1607	108.8035
20/08/2023 10:50	74 sec	113.0478	109.5132
20/08/2023 10:51	50 sec	112.3277	109.2019
20/08/2023 16:50	84 sec	127.7195	121.0148
20/08/2023 17:39	79 sec	127.781	118.6374
22/08/2023 11:40	31 sec	105.7286	102.3322
23/08/2023 11:50	33 sec	106.9243	101.3692
23/08/2023 15:26	55 sec	112.7918	109.378
24/08/2023 10:56	64 sec	129.2816	122.2967
24/08/2023 12:38	182 sec	115.0308	110.5909
24/08/2023 15:26	153 sec	113.6504	108.0443
24/08/2023 15:29	42 sec	107.6416	103.1227
24/08/2023 17:00	76 sec	120.1631	112.9466
25/08/2023 7:21	86 sec	141.755	129.1125
25/08/2023 12:16	37 sec	126.2047	118.6252
25/08/2023 13:29	110 sec	137.2212	125.4149
25/08/2023 17:40	93 sec	120.4785	112.8797
26/08/2023 10:58	59 sec	125.3487	118.0899
30/08/2023 14:00	57 sec	135.8678	123.8197
30/08/2023 17:18	108 sec	127.6037	117.5327
31/08/2023 10:40	103 sec	118.1239	112.0838
31/08/2023 12:50	122 sec	112.1851	107.5469
31/08/2023 13:08	93 sec	128.3118	116.0219
31/08/2023 13:37	52 sec	108.6526	101.7224
1/09/2023 8:20	73 sec	121.9484	116.1034
1/09/2023 14:49	99 sec	129.9391	119.625
1/09/2023 16:37	88 sec	112.9658	106.9951
1/09/2023 16:49	49 sec	131.266	119.787
2/09/2023 5:57	74 sec	120.7332	114.6997
2/09/2023 6:10	73 sec	129.2666	121.2843
2/09/2023 6:31	53 sec	108.3033	104.4944

2/09/2023 7:09	73 sec	134.8959	125.6017
2/09/2023 7:18	54 sec	117.1107	113.7755
2/09/2023 7:29	70 sec	118.5149	113.7902
2/09/2023 7:41	89 sec	142.8109	129.436
2/09/2023 7:48	50 sec	153.1327	130.9613
2/09/2023 7:51	58 sec	129.7325	122.3617
2/09/2023 8:09	73 sec	122.7236	117.3777
2/09/2023 10:20	73 sec	122.4083	116.5055
2/09/2023 12:50	53 sec	133.9359	125.2669
2/09/2023 13:01	45 sec	144.5778	131.2434
2/09/2023 13:31	53 sec	122.1439	116.1273
2/09/2023 14:00	54 sec	140.6712	130.6882
2/09/2023 14:07	55 sec	142.4375	130.88
2/09/2023 14:27	31 sec	125.7143	120.1923
2/09/2023 14:29	51 sec	145.7778	132.4832
2/09/2023 14:31	23 sec	133.8168	126.3185
2/09/2023 14:38	51 sec	124.1628	120.9124
2/09/2023 15:07	49 sec	128.6221	120.548
2/09/2023 17:11	19 sec	120.8774	115.0535
3/09/2023 7:19	77 sec	125.7314	119.1701
3/09/2023 8:17	42 sec	114.0182	109.5557
3/09/2023 9:17	90 sec	130.6811	124.3484
3/09/2023 9:20	60 sec	133.9756	123.3008
3/09/2023 9:56	89 sec	110.8698	105.8389
3/09/2023 9:58	110 sec	105.0788	99.79442
3/09/2023 10:19	78 sec	114.694	110.5911
3/09/2023 10:50	62 sec	137.1683	127.227
3/09/2023 11:10	39 sec	109.7177	104.7831
3/09/2023 11:11	37 sec	110.6844	105.0609
3/09/2023 11:37	57 sec	143.9601	128.3598
3/09/2023 11:39	53 sec	122.6667	115.0219
3/09/2023 12:39	37 sec	119.5389	113.1934
3/09/2023 15:07	44 sec	135.2704	126.7314
3/09/2023 15:09	50 sec	135.3392	126.2223
3/09/2023 15:10	47 sec	131.2637	122.6811
6/09/2023 10:07	64 sec	120.9636	114.1972
7/09/2023 7:20	86 sec	112.9959	108.1486
7/09/2023 15:50	47 sec	121.7425	115.0926
8/09/2023 8:29	56 sec	143.1739	130.1144
9/09/2023 8:30	60 sec	125.2742	118.0734
9/09/2023 12:51	25 sec	128.4576	122.1639
9/09/2023 13:37	51 sec	136.758	127.5509
9/09/2023 14:18	53 sec	144.9449	130.3553

12/09/2023 16:39	66 sec	127.7857	120.5619
13/09/2023 14:41	79 sec	115.4052	107.9671
16/09/2023 9:10	57 sec	106.4617	103.404
16/09/2023 10:19	83 sec	127.0609	118.4186
16/09/2023 10:29	78 sec	125.7795	117.0865
16/09/2023 13:31	38 sec	118.8809	113.0142
19/09/2023 9:56	24 sec	134.5962	127.4776