



UNDERWATER NOISE EFFECTS: PAKIRI SAND EXTRACTION

MANGAWHAI-PAKIRI COAST

PREPARED FOR
McCallum Brothers Limited

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Executive Summary

Styles Group has been engaged by McCallum Brothers Limited (MBL) to undertake an acoustic assessment of the proposed resource consent renewal for extracting sand in the Mangawhai – Pakiri embayment. This report describes the modelling of the underwater dredging noise effects that been undertaken in order for the Cawthron Institute to complete their assessment of the potential for dredging noise to adversely affect marine mammals. Thus, it is important to note that the effects concluded to potentially occur from the consent renewal are not discussed in this report but rather contained entirely within the report from Cawthron. An assessment on airborne noise effects is provided in a separate report.

The current resource consent granted in May 2006 allows MBL to extract up to 76,000 m³ per year from the inshore area between Mangawhai and Pakiri using both a stationary dredge as well the mobile trail-suction hopper dredge (TSHD) *Coastal Carrier*. The application for the renewal of the current consent, however, does have two changes: (1) the cessation of the use of a stationary dredger and instead relying entirely on a TSHD; and (2) decommissioning of the *Coastal Carrier* for the newly-built *William Fraser*. The *William Fraser* has now completed her sea-trials and incorporates the latest industry advances that make the new vessel much more efficient than the 1968 *Coastal Carrier*. There is also extensive isolation of the engine mounts, and hull insulation that reduce the on-board noise emissions from the vessel into the water column. Therefore, the main noise sources associated with the activity will be the draghead making contact with the seafloor, the water jetting and the movement of the sand slurry up the pipe to the hopper (which is also largely the case for the *Coastal Carrier*). We have therefore based our assessment on the loudest operational stage (active dredging). Since the *Coastal Carrier* has now been decommissioned and the consent renewal will use only the new *William Fraser*, our assessment is primarily based on the *William Fraser* only. However, we have measured the noise levels of both the *Coastal Carrier* and *William Fraser* and have provided data on the *Coastal Carrier* as an appendix. Briefly, those data show the *William Fraser* is approximately 2 dB quieter than the *Coastal Carrier*.

Section F2.18.2 Objective of the Auckland Unitary Plan (Operative in Part) pertains to the health and well-being of marine fauna, and this assessment considered the noise effects on invertebrates, fish and marine mammals. However, given the physical properties of the dredging noise in this case and differing hearing mechanisms between the different phylums or classes, the potential noise effects on invertebrates and fishes are not expected to be greater than those predicted for marine mammals. Therefore, the effects modelling was undertaken specifically for marine mammals, with effects radii on fishes and invertebrates being inside those of the marine mammals.

Nine marine mammal species have been identified within the area, five of which (the more common species) were focused on. Those five were common dolphins, bottlenose dolphins, killer whales, Bryde's whales and NZ fur seals. Of those species, three functional hearing groups have been identified: low-frequency (LF) cetaceans, mid-frequency (MF) cetaceans and Otariid pinnipeds (OW).

In order to assess potential noise effects on those species, two data needs were identified: (1) understanding the existing soundscape; and (2) understanding the source levels and true propagation coefficients of the *William Fraser* inside the current consent area. These investigations were completed between March and June 2019, with two passive acoustic monitoring arrays being deployed inside the southern consent area off Pakiri, and a single measurement array (containing 6 SoundTrap recorders) used to investigate the noise levels of the *William Fraser* and propagation losses (used to adjust the acoustic models herein). Those data revealed a typical soundscape for an open coastal area (with sounds from fish and marine mammals, snapping shrimp, vessels, dredging and weather (wind and waves), generating daily sound pressure levels between 96 and 111 dB re 1 μ Pa) and dredging noise levels below those from larger TSHDs previously assessed in New Zealand waters (average source level of the *William Fraser* approximately 168 dB re 1 μ Pa @ 1m).

Predicted noise emissions from the TSHD *William Fraser* were evaluated in terms of critical distances for which injury (PTS, where hearing sensitivities do not return to normal following noise exposure), temporary threshold shifts (TTS, whereby hearing sensitivities do return to pre-exposure thresholds after a period of time following noise exposure), risk of behavioural effects (as a percentage over range), and auditory masking (whereby noise interferes with a biologically-important signal that marine mammals rely on). The key methods used to assess those effects were the safe distance method, dose-response calculations, listening space reductions (LSRs) and generalised sonar equations.

Injury (PTS) from the sand extraction activities using the TSHD *William Fraser* is not expected to occur at any stage of the dredging within the consented area, for any species. Temporary threshold shifts are also not expected to occur for any species beyond 1m from the proposed TSHDs. These findings are based on the source levels and subsequent exposure levels being below the 2018 NMFS thresholds for PTS and TTS beyond 1m.

Audibility of the dredging noise from the *William Fraser* is calculated to be within 3.6km, beyond which, acoustic disturbance is theoretically not possible. Based on the measured ambient sound levels and published hearing thresholds for the species listed above, there is a risk of auditory masking and behavioural effects occurring at a limited range from the *William Fraser*. There is also a risk of auditory masking for fish; however they are substantially smaller than for the marine mammals. The risk for moderate behavioural responses (defined as those moderate or extensive changes in swimming speeds, direction and/or diving behaviours, cessation of vocalisations for a moderate or extended period, and/or avoidance of the area) was less extensive than low behavioural responses (defined as minor changes in respiration rates, swimming speeds and direction). For example, the 50% probability of a moderate behavioural response in the delphinids was 5m compared to 57m for a low response. Those ranges extend to 54m and 97m, respectively, for a 25% probability of risk.

The degree of auditory masking (and spatial extent) was highest for fur seals (maximum of 83% reduction in the available listening space (i.e. the volume of ocean surrounding an animal within which a biologically-important sound can be detected) within 15m of the TSHD, followed by Bryde's whales (maximum of 72% LSR), then bottlenose/common dolphins and

killer whales (67% LSR). The spatial extent of any masking (i.e. greater than 1% LSR) was highest for fur seals, followed by killer whales, bottlenose/common dolphins, then Bryde's whales.

Generally, the noise effects from the newly constructed *William Fraser* are lower than for the older *Coastal Carrier*. For example, behavioural effects start within 309 and 1.96km from the *Coastal Carrier*, but between 617m and 1.44km from the *William Fraser*. Similarly, an overall decrease of 7.55 – 8.86% in the auditory masking effects zone was seen for the *William Fraser* (auditory masking effects seen within 2.78 – 3.5km from the *Coastal Carrier* compared to 2.57 and 3.19km from the *William Fraser*). No risk of hearing temporary threshold shifts beyond 1m from the *Coastal Carrier*, based on the empirical data, and no risk of PTS was found.

1.0 Introduction

1.1 Background

Styles Group has been engaged by McCallum Brothers Ltd (MBL) to undertake an underwater acoustic assessment for the resource consent renewal pertaining to the sand extraction in the Mangawhai – Pakiri embayment. The current coastal permits, granted in May 2006, allow MBL to extract sand up to 76,000 m³ per year from the inshore area as shown in Figure 1. All extraction activities rely on dredging using mainly a single trail-suction hopper dredger (TSHD) that then transports the pumped sand slurry directly to MBL depot at the Ports of Auckland. There is therefore no offshore disposal as is sometimes associated with marine dredging. The existing coastal permits allow MBL to use a stationary dredge as well as the TSHD, which they occasionally use.

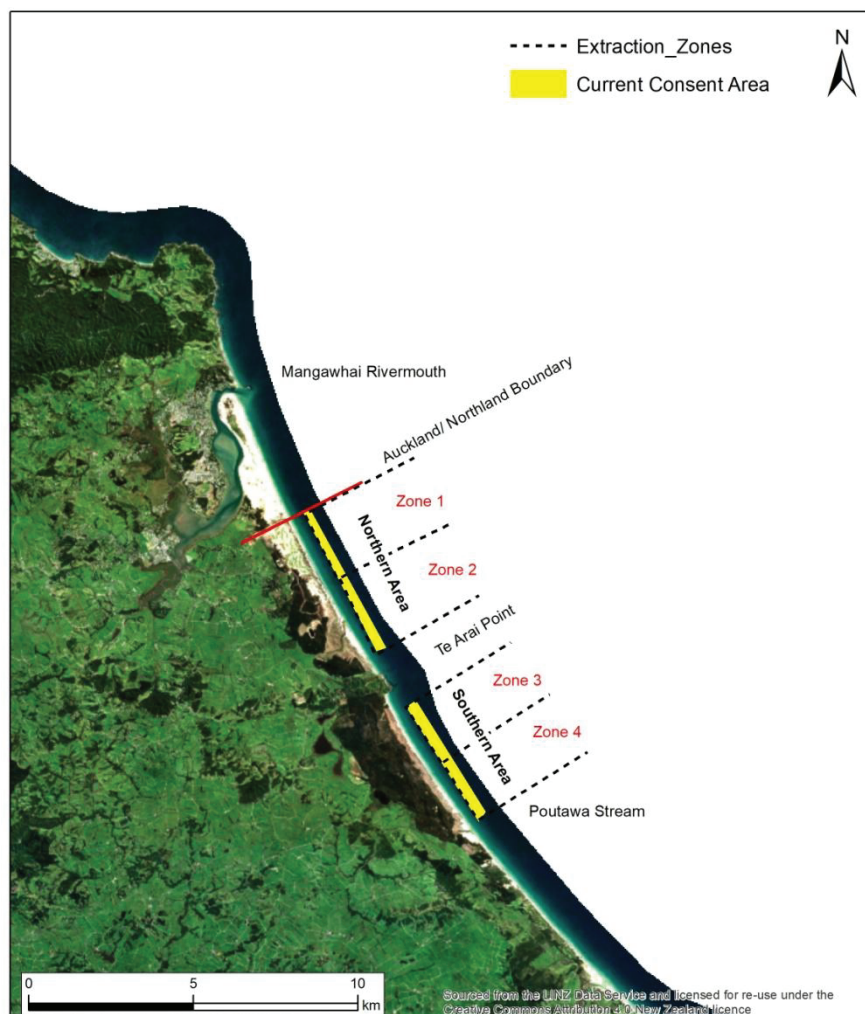


Figure 1: Current and renewal consent areas of MBL.

The current proposal that this assessment pertains to relates to the renewal of their existing coastal permit. Notwithstanding, MBL do propose a number of changes to the current dredging operation for this renewal application. Those include (1) cessation of the use of a stationary dredger and instead relying entirely on a TSHD; and (2) the commissioning of the purpose-built *William Fraser* – a newly-constructed TSHD built specifically for MBL – to replace the older *Coastal Carrier* TSHD. These changes are expected to reduce potential environment effects based on the industry advances built into the *William Fraser*.

A full description of the proposed activity is provided in the Description of Activity¹.

There is a growing body of evidence to suggest that loud anthropogenic noise, of similar intensity and bandwidths to dredging noise may have adverse effects on a range of marine taxa, including marine mammals (Williams et al. 2016). Noise emissions from TSHDs have in the past been characterised as a potential source of acoustic disturbance in marine mammal species (Todd et al. 2014). During a typical production cycle, sources of noise vary between dredgers, as well of course between dredger types (CEDA 2011, WODA 2013). Typical noise sources from operating TSHDs include noise from the propellers, inboard pumps, engines, the draghead and the underwater pipe used to transport the aggregate from the draghead to the hopper (WODA 2013).

1.2 Potential Noise Receivers

Section F2.18.2 *Objective* of the Auckland Unitary Plan states:

- 1) *Underwater noise from identified activities is managed to maintain the health and well-being of marine fauna and users of the coastal environment.*

Section F2.18.3(3) within F2.18.3 *Policies* of the Auckland Unitary Plan states:

- 3) *Enable the generation of underwater noise where that noise is associated with the following activities:*
 - a) *the operational requirements of vessels;*
 - b) *construction or operation of marine and port activities, marine and port facilities, marina activities, marine and port accessory structures and services, maritime passenger facilities an dredging, that do not involve underwater blasting, impact and vibratory piling, or marine seismic surveys; and*
 - c) *sonar not including marine seismic surveys.*

Marine dredging for mineral extraction falls under Activity A28 in Table F2.19.4 and is the identified activity that Section F2.18.2 relates to.

¹ Description of activity document from Jacobs dated December 2019

In this case, the identified potential noise receivers are those marine fauna expected to be present in the area at some time during the dredging operations – namely marine mammals, fish and invertebrates.

Notwithstanding, however, the potential noise effects from the proposed renewal of this application are not expected to be greater for invertebrate and fish species, than for marine mammals². Thus, the underwater acoustic modelling undertaken for this report has been performed specifically for marine mammals. A total of nine marine mammal species have been identified as species potentially affected, due to their presence in the area (whether frequent, seasonal, or infrequent) (Deanna & Johnston 2019). However, of those, four species are considered to be more likely affected based on their presence in the area being most common. Those are common dolphins (*Delphinus delphis*), bottlenose dolphins (*Tursiops truncatus*), killer whales (*Orcinus orca*) and Bryde's whales (*Balaenoptera edeni*). Underwater noise effects modelling have therefore been undertaken on each of those species. With respect to their bio-acoustics, these species also share similarities with the other species less frequent in the area, and therefore focusing on the most common species can be considered as an appropriate proxy for those (including those data-deficient ones). We have also assessed potential noise effects on New Zealand fur seals (*Arctocephalus forsteri*), as they do not share similar hearing physiologies or effects criteria to the four cetacean species listed above.

1.3 Scope of this Assessment

The scope of this assessment was to model the underwater dredging noise to assess the potential extent for which dredging noise may induce hearing threshold shifts (both permanent and temporary), behavioural responses and auditory masking in marine mammals. We did consider fishes as well, however the effects on fishes were less sensitive to the most pervasive component of dredging noise and were, therefore, not worse than those expected for the marine mammals. Noise effects on fish have therefore not been mapped. This acoustic report is targeted at aiding the assessment of effects on marine mammals (provided in Clement & Johnston 2019) by providing the critical distances for which the potential onset of noise effects may occur for the species of concern. As such, discussion of the results from the acoustic modelling and impact zones in the context of literature and the relevant objectives and policies of the Auckland Unitary Plan, as well as recommended monitoring and mitigation, is not included herein. Instead, they are provided as part of the assessment of effects on marine mammals (Deanna & Johnston 2019).

² This is because fish and invertebrates show a high degree of sensitivity to particle motion which propagate over shorter distances compared to the pressure wave (i.e. the pressure component that marine mammals are more sensitive to), and no direct evidence of tissue damage in invertebrates and fish exists over the same distances as for marine mammals.

2.0 The Existing Underwater Soundscape

Marine mammals (as well as fish and marine invertebrates) depend on underwater sound for critical life processes. These processes include, but are not limited to, keeping group members together while navigating turbid coastal waters, communication between family members, locating prey during feeding, mediating mating behaviours, and avoiding predation (Montgomery et al., 2006; Popper et al., 2001; Radford et al., 2007; Richardson and Thomson, 1995; Slabbekoorn et al., 2010; Stanley et al., 2010). Their ability to communicate and sense their environment using sound is therefore linked to the ambient sound environment; whereby the biologically-important signal must be audible over the background sound level within some critical bandwidth. Coastal activities, including pile driving, dredging, shipping, drilling, etc, can cause ambient sound levels over wide frequency bandwidths to rise – to the point where biologically-important signals for marine mammals can be masked, leading to increased stress and sub-lethal behavioural responses (Southall et al. 2007; Nowacek et al. 2007). Underwater noise pollution can therefore degrade marine mammal habitats within sites where offshore activities take place.

Notwithstanding, the extent of which possible effects may occur is not always homogenous across sites or regions but vary according to the physical environment. Generally, noise effects can only occur if the invading noise source is audible (audibility being a function of both the ambient sound levels and hearing thresholds of the listener). Therefore, in order to properly assess the spatial extent of possible acoustic disturbances, the ambient soundscape must be fully considered and incorporated into the effects modelling (in the context of the species' hearing thresholds).

2.1 Methodology

2.1.1 Study Site and Recorders

To characterise the ambient soundscape within the area, we deployed four SoundTrap 300HF recorders (two arrays, providing sampling redundancy) off the northern end of Pakiri Beach (Figure 2). That area was chosen due to dredging operations occurring nearer Mangawhai. The sampling rates were at 96 kHz, while the click detectors operated at the full sampling rate of 576 kHz. The arrays were deployed along the 30m depth contour between 19 March and 25 April 2019, and then again between 9 May and 10 June 2019.

The hydrophone component of the SoundTrap recorders was calibrated by the manufacturer and field-calibration checks before and after deployments were undertaken using a calibrated piston phone (GRASS Type 42AA, SPL 114 dB re 20 µPa, nominal frequency 250 Hz), a 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. Electronic calibration of the recorder component was done at the start of every recording event by comparing a set of automated tones of known frequency and voltage amplitude to the full-scale response level provided by the manufacturer for the appropriate gain setting, and verified using the piston phone.



Figure 2: Google Earth image showing the locations of the two hydrophone arrays used to characterise the existing soundscape.

The two arrays were identical for sampling redundancy reasons.

2.1.2 Overview of Analysis Procedure

The sound pressure levels (*SPLs*), daily in-band sound energy contributions (as a percentage), power spectral densities (*PSDs*), and third octave band levels (*TOLs*) were calculated, along with the statistical variation. The *PSD* data were plotted as long-term spectral averages (*LTSA*). *LTSA* plots are useful in allowing large time series data to be viewed and analysed in a more efficient way. In total, 3,318 sound files were generated and viewing all those files as individual spectrograms would be near impossible. *LTSA* plots provide the means to compress the data and view all recordings as a whole, revealing an overview of the spectrum for the monitoring period. The .WAV files were uploaded to PAMScan's file directory and restructured into 1-min time-bins. Acoustic analyses were then undertaken on each minute and the 1-min time averaging was then applied (generating the time-averaged data for the *LTSA*). The statistical analyses of the *PSDs* (percentile levels (1st, 5th, 25th, 50th, 75th, 90th and 99th percentiles) and spectral probability densities) and *TOLs* (boxplots) were then performed and plotted. Bandpass filters for four bandwidths (10 – 100 Hz, 100 – 1000 Hz, 1 – 10 kHz and 10 – 32 kHz) were then applied to the raw waveform for each 1 minute of data. The bandpass filtered 1-min L_{eqs} were then calculated for each time-bin, generating a single mean value for each time bin and frequency bandwidth. The *SPL* data were then batch processed by individual days (each 1-min bin was time stamped, determined by the file name of each recording) and averaged over each day (so a single mean value for each day was obtained). The in-band energy contributions of each frequency

band were calculated at the same time as the daily L_{eqs} , except an additional algorithm was used that took the daily acoustic energy in each frequency band, compared it to the total energy in the whole bandwidth, then multiplied it by 100 to generate a percentage. The results were plotted for the whole monitoring period, showing the change in each day.

2.2 Results: The Existing Soundscape

All figures in this section are provided in Appendix B, and referenced as such.

The relative broadband (10 Hz – 48 kHz) daily *SPLs* varied by approximately 15 dB re 1 μ Pa (between 96 dB re 1 μ Pa (on 25 March) and 111 dB re 1 μ Pa (on 14 April) over the survey period and are provided in Figure 18. The hourly broadband *SPLs* are provided in Figure 19, and do show dawn and dusk choruses (typical of nearshore habitats (Pine 2013)). Broken down into smaller bandwidths, the bands between 100 Hz and 10 kHz showed similar trends to the broadband levels. Unlike busy harbours, the *SPLs* below 100 Hz were generally lower than the 1 – 10 kHz band, reflecting the fewer vessels in the study area.

The relative in-band daily *SPL* contributions over the survey period are also provided Figure 20. The relative in-band daily *SPL* contributions were generally higher for the lower frequency band 100 – 1000 Hz, followed by the mid-frequency band 1 – 10 kHz. This did differ on occasion, with inclement weather (as particularly evident in the *LTSA* data, Figure 21) increasing levels below 100 Hz (Figure 20).

The *LTSA* plot is provided in Figure 21. The *LTSA* plot reveals similar trends to the in-band contributions, but at a much finer frequency resolution (every 1 Hz). Figure 22 and 23 respectively show the statistical plots for the *PSD* and *TOL* data from the whole survey period (between March and June 2019). These plots are useful for showing the variation in the decibel levels for each frequency or frequency band, as well as the corresponding spectral probabilities. This descriptive statistical analysis revealed considerable variation in the frequency-dependent sound levels. Generally, the ambient noise floor (represented by the 1st and 5th percentiles in the *PSD* data, Figure 22) shows a shallow slope with no distinct rises between 500 and 2000 Hz – which is typical of a sandy bottom habitat with limited vessel traffic (Radford et al. 2010). The higher percentiles (the 95th and 99th percentiles and represented the more transient events) do reflect the presence of vessels (also seen in the *LTSA* data) but have limited influence on the averaged and median sound levels.

Overall, the ambient soundscape is typical of a sandy beach habitat that is not inside or near a busy harbour.

3.0 Marine Mammal Detections

3.1 Data analysis

Automated detectors and classifiers for marine mammal vocalisations were run through all acoustic data from the northern array. The detectors were focused on dolphins (species

unidentifiable beyond a broadband click species, i.e. bottlenose and common dolphins) and whales (baleen whales, assumed to be Bryde's whales based on their resident status within the Hauraki Gulf and time of the year during which this study took place).

Dolphins were detected in the acoustic dataset based on their echolocation clicks and whistles using PAMGuard³ (Figure 3, Putland 2017). Detection data from the on-board click detector in the SoundTrap 300HF units were also processed in PAMGuard, as well as the .WAV snippets. Snapping shrimp were a prevalent source of false positives in the detection data and so positive detections were only logged when a train source was identified and manually verified by assessing the waveform, spectrum, Wigner plot, *PSD* and in some cases, playing back the edited audio file itself. Once a true positive was confirmed, the start time, end time and duration of that detection event were logged, as well as the minimum inter-click interval (to determine the presence of foraging buzzes, and thus foraging activity). A single detection event was defined as the time between the first and last confirmed vocalisation (either echolocation clicks or whistles) after no vocalisations were detected for more than 30min followings the last detection (Pine et al. 2017).

Whale vocalisations were detected using a custom-written detector similar to that described by Hendricks et al. (2018), but modified for the Mangawhai – Pakiri region. The detector first runs through an adaptive entropy band detector, then runs an additional algorithm based on the spectrogram itself to confirm the presence and location of a whale's call within the recording. The detector worked by breaking the signal into 10-second windows and performing the processing in each window with 50% overlap. Using an optimised-sized Hann window, the entropy in each window was calculated and compared those to a dynamic threshold based on the background entropy after being scaled for the variance per unit of time. When the entropy dropped below the set threshold, the program indexed the number of successful triggers and flagged the detection when the number of successive triggers reached the required minimum (Hendricks et al. 2018). The start and end times were then extracted and a 120 second spectrogram around the detection was generated and saved as a .PNG image for reference. Those spectrograms were then binarised based on adaptive thresholds inside a predetermined window to identify the call's contours for cross-correlation with known calls. If the contours of the detection met the required criteria, the .PNG was moved to a new directory for quick manual verification.

³ PAMGuard is an open source software designed specifically for bioacoustic analyses of passive acoustic data and the detection and classification of marine mammal vocalisations. It is the most commonly used software for passive acoustic monitoring of marine mammals worldwide. See www.pamguard.org

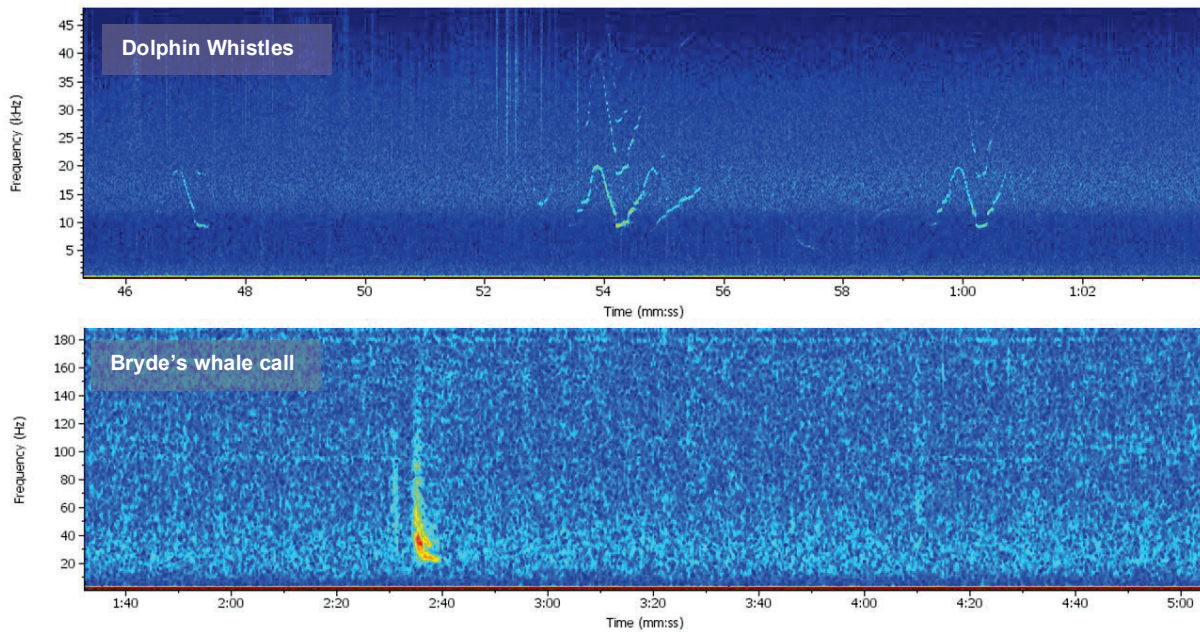


Figure 3: Spectrogram showing examples of detected dolphin whistles (lower end of echolocation clicks also visible between 52 and 54 seconds) (Top Panel); and a single Bryde’s whale call (Bottom Panel).

3.2 Results: Marine Mammal Detections

A total of 64 detection events (comprising of thousands of echolocation clicks spanning 22hr 24min) of dolphins (either bottlenose or common dolphins) were confirmed, while 477 Bryde’s whale calls were detected over the 69 recording days (Figure 4). Of the 64 dolphin detection events, 36% of them contained feeding buzzes. A summary of dolphin detections are provided in Table 1 and the activity plots (including foraging activity) are provided Figures’ 5 through 7.

Table 1: Durations of the dolphin detection events

Median (h:mm:ss)	Average (h:mm:ss)	Min (h:mm:ss)	Max (h:mm:ss)
0:12:00	0:20:22	0:03:00	1:36:00

Bryde’s whale vocalisations were detected at least once during 25 days out of the 69 day deployment (i.e. 36% of all days monitored contained at least 1 whale call).

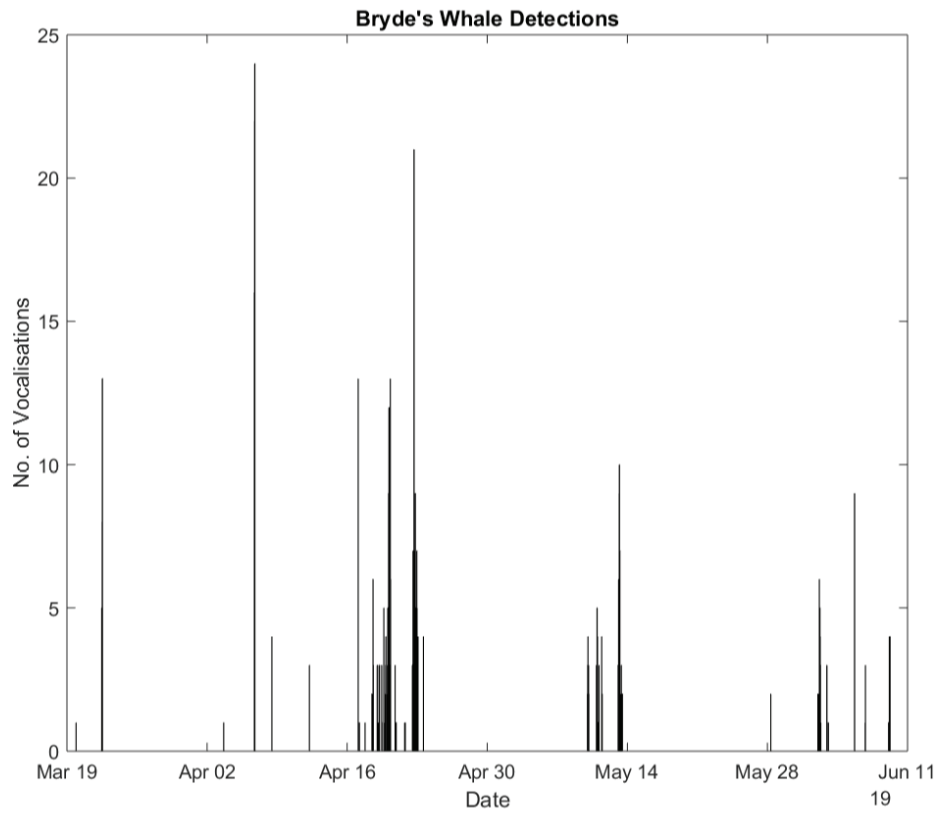


Figure 4: Acoustic detections of Bryde's whales during the monitoring period.

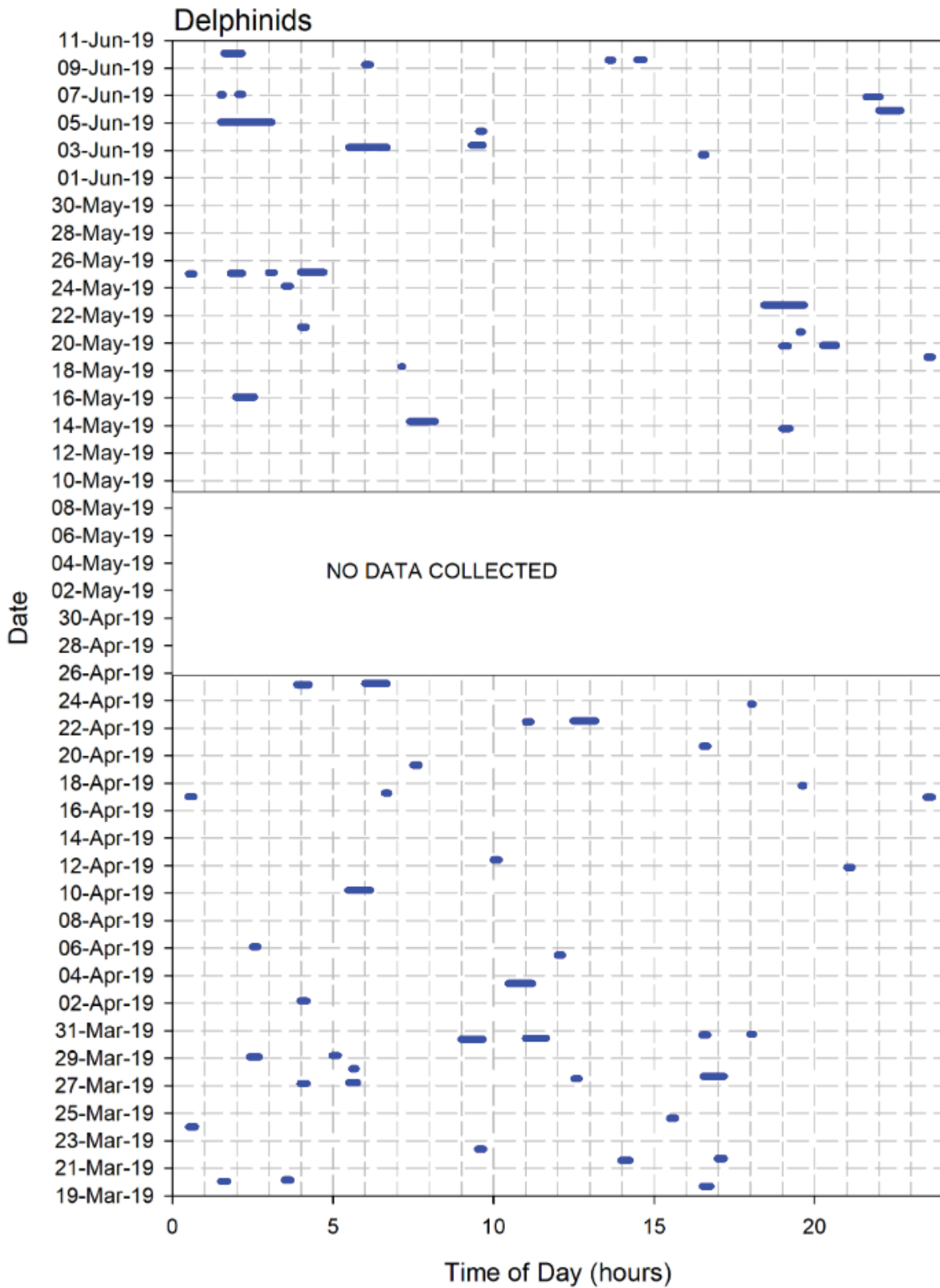


Figure 5: Actograms showing bottlenose/common dolphins during the monitoring period.

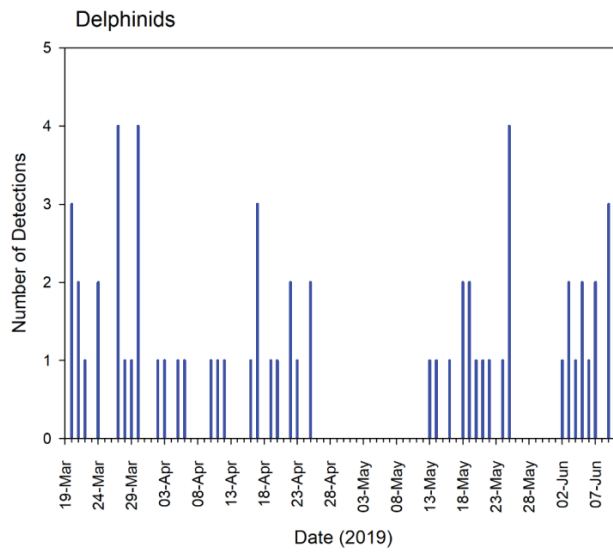


Figure 6: Number of acoustic detections of bottlenose/common dolphins per day over the monitoring period.

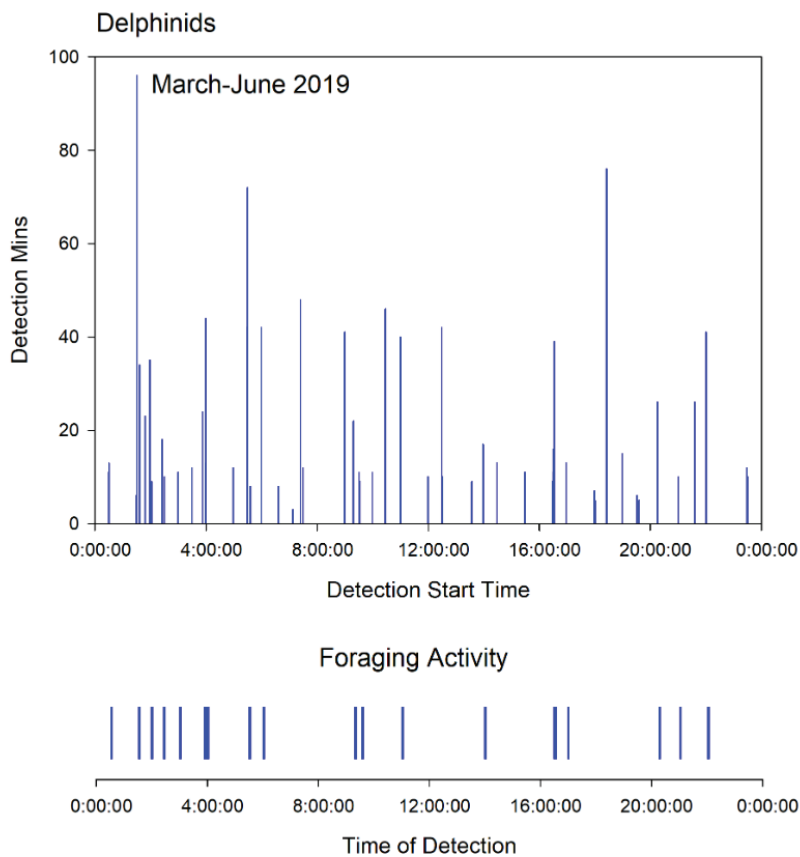


Figure 7: Plots showing detection durations of bottlenose/common dolphins (presented as detection minutes) (top panel) and occurrence of feeding buzzes (bottom panel) over the day.

These data have not been time averaged, but are the actual durations overlaid for the monitoring period

4.0 Noise Modelling: Methodology

The overall approach to the underwater noise modelling undertaken in this project is given **Figure 8**. Each component is described below.

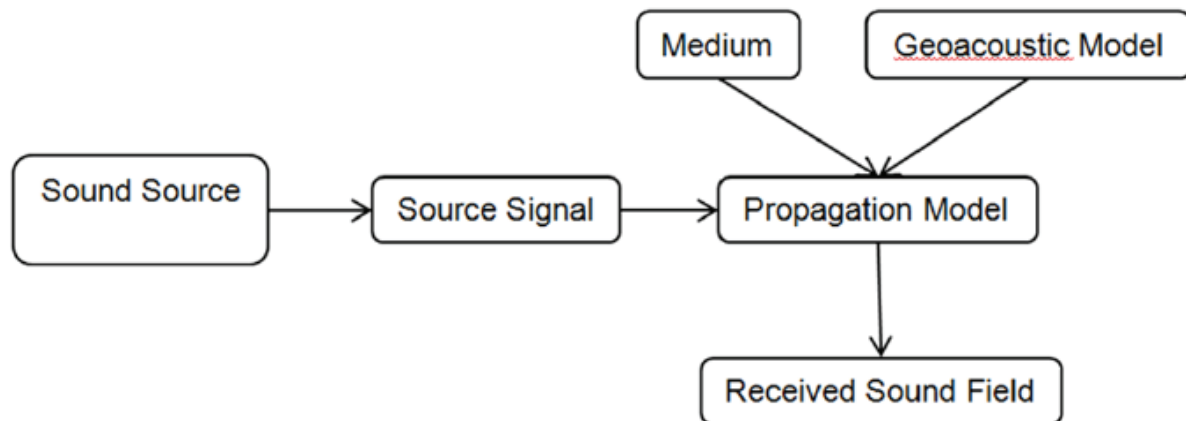


Figure 8: Flow diagram showing the overall approach to the acoustic modelling.

Each box represents a key component to the model environment described below.

4.1 The Modelled Area

The modelling was undertaken within and around the existing sand extraction operations within the northern consenting area (please refer to Figure 1). The northern area within which the dredging was modelled was defined by the Pakiri inshore extraction consent coordinates (provided in Appendix B). The modelling was not repeated in the southern consented area because the environment and input data are the same.

4.2 Sound Source: the TSHDs

The current sand extraction operations have primarily involved the use of the TSHD *Coastal Carrier* (IMO# 6910154, 630 gross tonnage). However, the *Coastal Carrier* was recently decommissioned in October 2019 and the newly built *William Fraser* replaced it (Figure 9). For comparative reasons, details of these two TSHDs, including their operating characteristics, are provided in Table 2.

Since the older *Coastal Carrier* has been decommissioned, should the consent renewal be granted, the *William Fraser* will be continue to be used. Therefore, our underwater noise assessment is based primarily on the *William Fraser* only. However, the *Coastal Carrier* was measured in June 2019 to gain an understanding the older vessel to compare with the newer *William Fraser* and the effects modelling were undertaken on both vessels. The data and results of the modelling of the *Coastal Carrier* are provided in Appendix F.

Since the *William Fraser* is operational in the area (under existing resource consent(s)), our underwater noise assessment is able to consider the actual dredger that will be used under the new consent.



Figure 9: Photographs of the two trail-suction hopper dredgers (TSHDs) used by MBL.
The *Coastal Carrier* was decommissioned October 2019 and the *William Fraser* has replaced it.

Table 2: Summary table comparing the different dredging vessels that will be used by MBL.

	<i>Coastal Carrier</i>	<i>William Fraser</i>
Length	56.65 m	68 m
Beam	12 m	16 m
Deck Size	28m x 10 m	43m x 10 m
Hopper Capacity	460 m ³	900 m ³
Loaded Draft	2.8m	4.2 m
Vessel extraction speed	1.2 knots	1.5 – 2 knots
Draghead Width	1.2 m	1.5 m

	<i>Coastal Carrier</i>	<i>William Fraser</i>
Sand pump capacity	300 mm	400 mm
Sand screen size	2.5 mm	2.5 mm
Dredging characteristics		
Width of extraction trench	Average 1.2 m	Average 1.5 m
Depth of extraction trench	Average 0.15 m	Average 65 mm
Extraction trench shape	Trapezoidal	Trapezoidal
Volume required to be extracted from seabed to fill hopper	1100 m ³	1560 m ³
Length of extraction track needed to fill hopper	6 km	Up to 15 km
Time to fill hopper	3 – 4 hrs	4 – 5 hrs
Number of trips in 30 consecutive days for 15,000 m ³ limit	33 trips	17 trips

While the size the two TSHDs that will be used are similar, the key difference with the newly built *William Fraser* is that it uses water jetting and has greater acoustic and vibration isolation. The pump size of the *William Fraser* is slightly larger (400mm), as well as the vessel's engine size, but both are much more efficient and comply with the latest environmental and occupational health and safety (OSH) standards. These advances in industry practice allow for the dredging operations to be far more efficient and quieter, and thus are expected to limit the potential noise effects compared to the much older *Coastal Carrier* (built in 1968). For example, the number of trips in 30 consecutive days to reach the 15,000m³ limit decreases from 33 trips with the *Coastal Carrier* to 17 trips with the *William Fraser*. Therefore, the newer *William Fraser* operates far less than the *Coastal Carrier*, which reduces the overall risk of potential noise effects on marine mammals. Furthermore, the improved acoustic isolation of the engine means less engine noise should transfer into the water column through the hull.

4.3 Sound Source Characterisation: The *William Fraser*

Underwater noise measurements of the *William Fraser* were undertaken on the 28th November 2019, during fine weather conditions (variable 10 knot breeze, sea state zero and no swell). A measurement array was deployed that consisted of six SoundTrap 202STD recorders (Ocean Instruments Ltd, Auckland, New Zealand) (Figure 10). The hydrophones

were calibrated using the same method described in Section 2.1.1 *Study Sites and Recorders* and operated continuously.

The array was deployed the morning of the 28th of November, and each hydrophone was bottom-mounted along the 30m (the inner hydrophones, ST 1, 2, 3, and 4) and 35m (ST 5, and 6) contours. The hydrophones were set at 3 m above the seafloor, with a subsurface float (2 L volume) set a further 2 m above the hydrophone. This was done to ensure the subsurface float was far enough away so to not contaminate the measurements. The differing depths between the inner and outer hydrophones are not expected to cause any differences in the noise levels recorded in this case. The rationale for the outer hydrophones was to simultaneously record the noise emissions of the *William Fraser* at two distances that were in-line of each other to further investigate the empirical frequency dependent propagation loss. The inner hydrophones (ST 1,2,3,4) were placed between 200 and 300m apart, while the outer ones were placed 400m away to the east from ST 2 and 3 (the middle of the inner 'line') (Figure 10). This shape of the array effectively allowed for four replicates as the TSHD passed the array (whilst actively dredging, i.e. draghead down with pump and generator operating), for multiple bearings. The vessel operated as normal, with no issues reported. Once it passed, the vessel continued north for approximately 1.4 km after passing the last hydrophone of the array (ST1), before turning around and passing the array again, southbound. The TSHD followed the 30m contour, as per the offshore consent owned by Kaipara Ltd but operated by MBL.

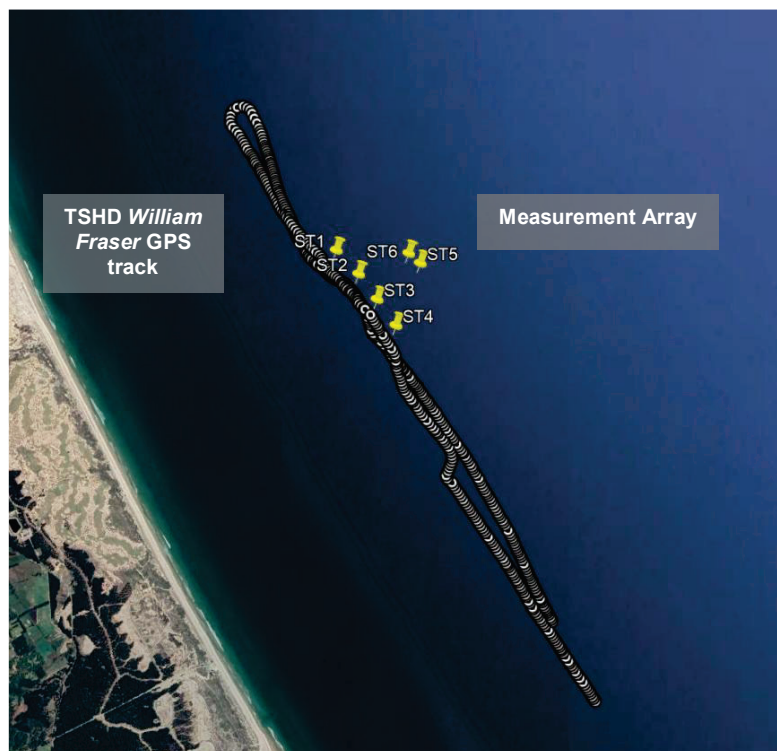


Figure 10: Google Earth image showing the GPS track of the TSHD *William Fraser* in relation to the measurement (hydrophone) array (ST1 through 6) on 28 November 2019 in fine weather conditions.

The vessel was tracked using a Garmin Map62 GPS unit, logging the vessels' position in relation to the array every few seconds (with an error of 3m). The same GPS unit was used to mark the GPS positions of each of the hydrophones, and those were used to calculate the horizontal distances between the vessel and hydrophones for every 10 seconds (since the *SPL* data was averaged over a 10 second period).

During the measurements, the research vessel left the area but remained 10 km away. The times when other vessels were visible anywhere were recorded and checked against the hydrophone data to ensure no contamination. In addition, bespoke vessel detectors were used to ensure no vessel noise was confounding the results. If there was any contamination (i.e. another vessel was detectable on the hydrophone (using both power spectra and detection of modulation of noise methods), those data were excluded from the analysis (Figure 11).

4.3.1 Data analysis

Time-series of the recorded power spectral densities (*PSDs*) were calculated and plotted to examine the quality of the data from all six hydrophones. The received third octave band levels (*TOLs*) were also calculated and plotted, providing the frequency-dependent sound pressure levels that were used to represent the critical bandwidths of cetaceans in the effects modelling (Erbe et al. 2016; Pine et al. 2018).

The *PSDs* and *TOLs* were calculated using a 1-sec Hamming window and 50% overlap with 10-sec averaging. The broadband (10Hz – 48 kHz) *SPLs*, as 1-sec and 10-sec averages, were calculated for each horizontal distance between the TSHD *William Fraser's* GPS position and the respective hydrophone position. This analysis was performed using the Haversine formula, after the source and receivers latitude and longitude coordinates' were time-synced.

It is important to note that the Haversine formula assumes the earth to be a perfect sphere, however the distances between the *William Fraser* and all hydrophones were inside 3.1km, the margin of error from assuming a perfect sphere is trivial. For each distance, the 10 second *SPLs* (both broadband *SPLs* and *TOLs*) were plotted (and can be viewed as an animation through time), showing the fine-scale variations in the received sound pressures over distance as the TSHD passed the array. These data were also used to compare the propagation modelling and improve its performance using an empirical *PL* coefficient, similar to that undertaken by Pine et al. (2014).

For the purposes of the underwater noise modelling, the received sound pressures measured at the *William Fraser's* closest point of approach (CPA) to each hydrophone (Figure 11) while actively dredging were back-calculated to a reference distance of 1 metre. This was done using the published sound propagation formulas by Pine et al. (2014) but modifying the spreading coefficient based on the empirical data collected in this study (see Figure 33 in Appendix F). The overall source spectra used in the effects modelling was the averaged spectra over the 4 closest hydrophones (thus 8 replicates – 4 hydrophones, two passes of the TSHD each).

Only the source spectra of the *William Fraser* was used in the effects modelling due to the decommissioning of the *Coastal Carrier* in October 2019, however both spectra are provided in Figure 12 for comparison.

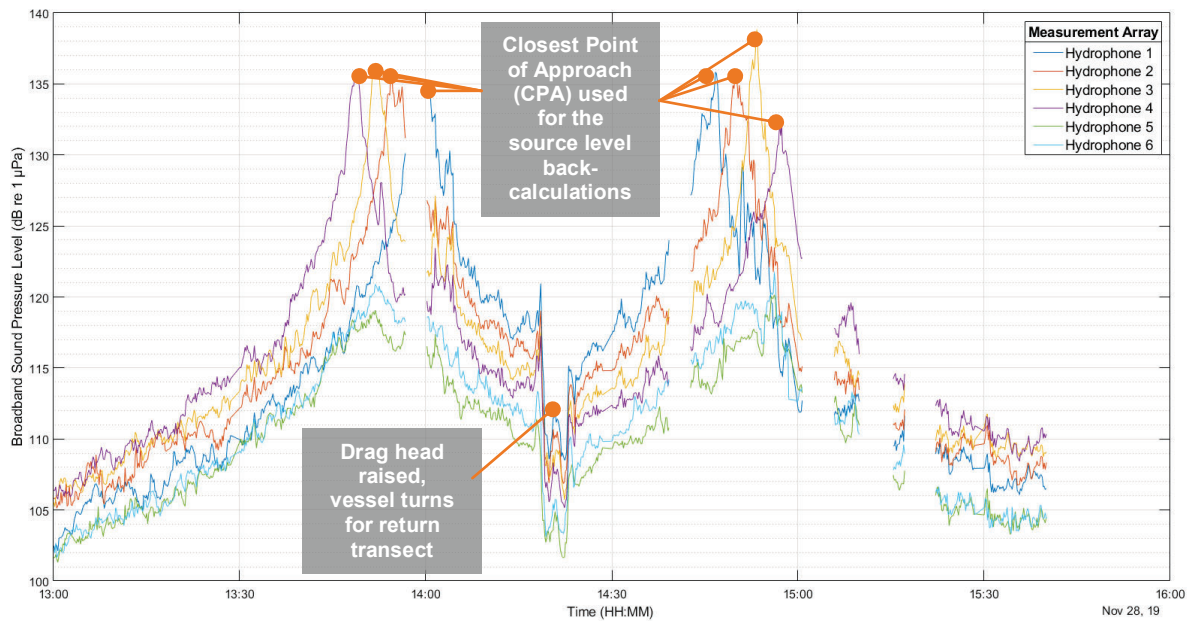


Figure 11: Measured SPLs from the inner hydrophones (ST 1, 2, 3, 4) as the *William Fraser* moves through the northern consent area, actively dredging, passing the measurement array.

Data containing contaminating vessel noise (extraneous) were removed from the analysis

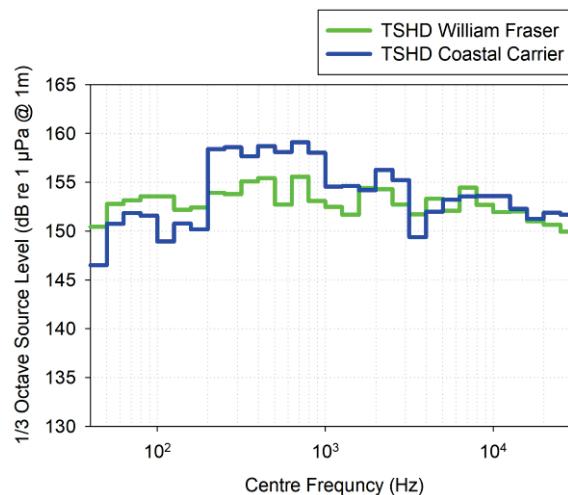


Figure 12: Averaged 1/3 octave source spectrum for the two TSHD vessels used by MBL.

Note the *Coastal Carrier* was decommissioned October 2019 and will not be used in the new consent. The *Coastal Carrier's* spectrum is provided for comparative purposes only and was measured on the 28th June 2019 using the same methods described in Section 4.3 *Sound Source Characterisation*. The underwater noise modelling and effects results for the *Coastal Carrier* are provided in Appendix F.

4.4 Bathymetry

Sound propagation in shallow water typically follows a normal mode whereby a sound wave of a particular frequency moves sinusoidally through an acoustic waveguide (i.e. the water column of seafloor) (Jensen et al. 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 for the acoustic modelling within this project were those obtained by MBL and the National Institute of Water and Atmosphere (NIWA 2016). The NIWA dataset was region-wide, while the bathymetry provide by MBL was of the consent area only. The two datasets were overlaid and the MBL bathymetry was relied upon in the consent area based on being the more recent dataset (since dredging that has occurred over the past few years and the depths within the consenting area may differ to the NIWA dataset). The bathymetry from NIWA was obtained using multibeam and single beam sounding lines spaced 50-120m apart. The bathymetry from MBL was obtained using side-scan sonar and multibeam sounding lines spaced an average of 30m apart (that decreased as depth reduced the further inshore the bathymetric survey was undertaken). This is the most comprehensive digitised bathymetry data available for the Mangawhai – Pakiri region and was uploaded directly to the acoustic model platform (Figure 13).

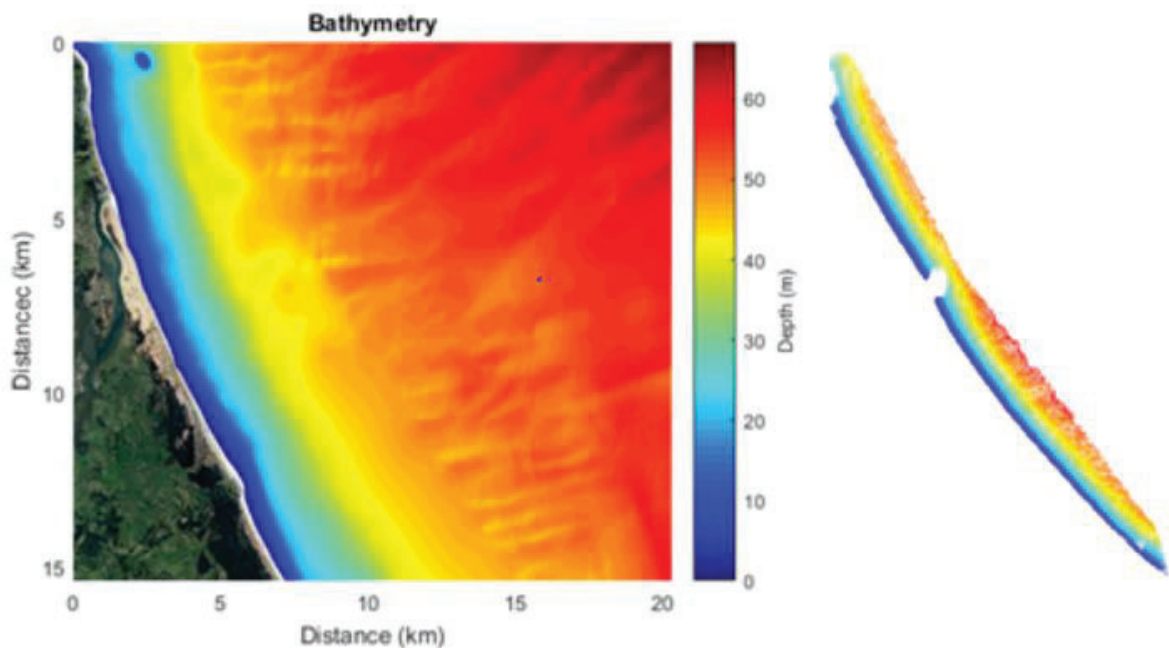


Figure 13: Bathymetry rasters used in the acoustic modelling.

The left raster is from the NIWA dataset, while the right raster is the MBL dataset from 2019. The two were used together to cover the region. Note the colour bar on the left raster does not correspond to the MBL raster.

4.5 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, sound speed changes and reflections. These factors mean that the sound field at any given location from the sound source can be highly variable due to changes in the seafloor composition and geo-acoustic properties. The seafloor composition within the existing consent area is well understood, with a range of comprehensive studies having been undertaken. Information on the seafloor composition within the modelled area has been obtained by MBL at many locations from Mangawhai to south Pakiri during 2011 and 2017 (Figure 14). Those data were uploaded to the model platform and the sediments outside the consent area were based on hydrographic charts.



Figure 14: Google Earth image showing the locations of sediment samples from 2011 and 2017 used in the acoustic modelling.

The geo-acoustic properties for different sediment types that were used in the modelling are provided in Table 2.

Table 2: Geo-acoustic properties for various sediment types within the project area.

Sediment Type	Density (kg/m³)	Compressional wave velocity (m/s)	Absorption (dB / lambda)
Sand-silt-clay	1600	1560	0.20
Sand-silt	1700	1605	1.0
Silty sand	1800	1650	1.1
Very fine sand	1900	1680	1
Fine sand	1950	1725	0.8
Coarse sand	2000	1800	0.9
Gravel	2000	1800	0.6

4.6 Sound Speed Profiles

The speed of sound underwater is dependent on the temperature, density (salinity) and depth. Within the Hauraki Gulf, sea surface temperatures vary between summer and winter months, with significant mixing down to 40m depth occurring during the winter months (Zeldis 2013). The absence of this mixing during the summer months gives way to the development of a thermocline (a layer in which there is a steep temperature gradient) and halocline (a layer in which there is a steep salinity gradient) which causes a change in sound speeds with depth. While long term sea surface data from various locations around the Hauraki Gulf (including near the project area) is available, long-term (i.e. spanning seasons) thermocline and halocline data for the Mangawhai – Pakiri area is not available⁴. Information on the thermocline and halocline depths for the acoustic modelling has therefore been from a proxy location within the outer Hauraki Gulf of similar depths and hydrology to Pakiri (Zeldis 2013). Based on these similarities, we expect the thermocline and halocline differences between Pakiri and the proxy location to be negligible in terms of sound speed effects and we therefore consider the assumption to be appropriate. The use of environmental data from nearby proxy locations has occurred in many published scientific investigations, both abroad and within New Zealand, when specific data in the study’s location is unavailable. Please refer to Appendix D for the plots showing the thermoclines and haloclines that were used to calculate the sound speed profiles (provided in Figure 15).

⁴ CTD cast data is available from December 2019 and these were compared with the proxy data with good agreement.

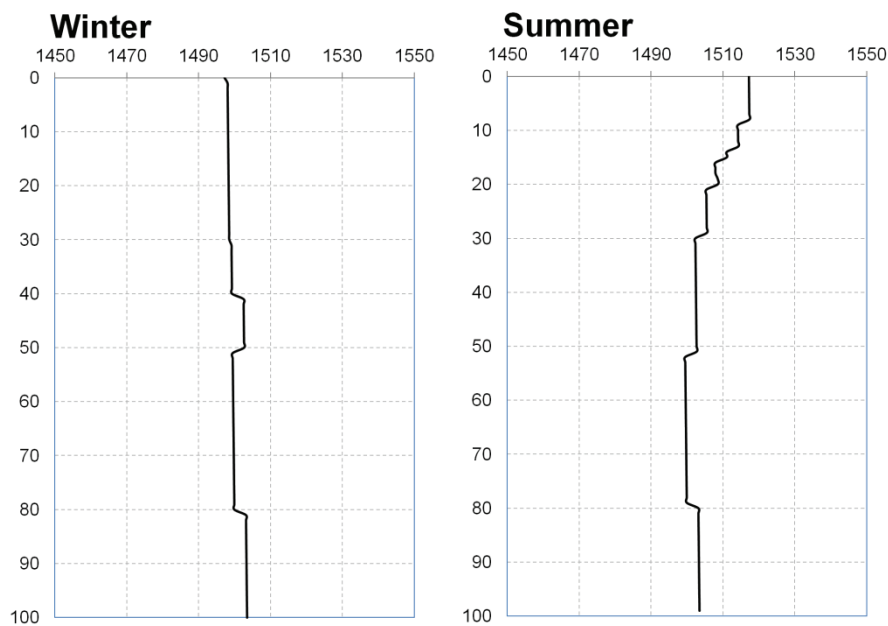


Figure 15: Sound speed profiles calculated for the project area.

Depths (y-axis) are in metres below the surface and sound speeds (x-axis) are metres per second.

4.7 Propagation Modelling

The underwater noise modelling was simply defined as:

$$SPL_{freq}(R) = SL_{freq} - PL_{freq}(R)$$

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 distance R for that frequency band. The propagation loss (PL) was determined using a combination of range dependent parabolic equation (PE) and ray trace (RT) models in dBSea, for frequencies below and above 1.4 kHz, respectively, for 180 radials over a 10m grid with 0.5 m depth resolution. Since the ray trace model is based on Snell's Law, it is applicable if a signal's wavelength is much less than the layer in which it is propagating. Therefore, ray tracing was only applied for frequencies above 1.4 kHz (based on the halocline depth during the summer (due to the density change either side of the halocline) and the depth during the winter model, as no halocline is present). The PL for three frequencies within each 1/3 octave band between centre frequencies 50 Hz and 32 kHz were calculated and then averaged within each 1/3 octave bandwidth to represent the PL for a specific band. Third octave bands were chosen for the modelling as they are often used to represent the critical bandwidths of marine mammal hearing⁵ (Erbe et al. 2016; Pine et al. 2018).

⁵ This is done when the true critical bandwidths are unknown for the species of concern.

The validity of the acoustic model was tested by comparing the modelled *PL* coefficients for each 1/3 octave bandwidth with the empirical data collected from the *William Fraser and Coastal Carrier*. There was good agreement between the modelled and the empirical data, and the results are provided in Appendix G.

4.8 Effects Modelling for Marine Mammals

The overall aim of the acoustic modelling is to provide the acoustic footprint of the dredging works in order to inform an assessment of the potential impacts on marine mammals⁶. It is important to note that these impacts are discussed in the assessment of effects on marine mammals (please refer to [Clement & Johnston 2019](#)) and not in this report. We have provided advice to the Cawthron Institute regarding underwater noise effects and, for conciseness, those impacts and recommendations are not discussed herein. However, the methods used to reach those noise effects conclusions and recommendations are provided herein, as well as an overview of the key results.

The potential noise effects, and severity, depend on the distance between the source and receiver, with injury (permanent threshold shifts, PTS) occurring close to the source, followed by temporary threshold shift (TTS), behavioural responses and auditory masking. PTS effects are not expected for the consent renewable because the source levels of the TSHD were too low.

4.8.1 Temporary Threshold Shifts

When a receiver is exposed to high noise levels over an extended period of time, the cells within the inner ear begin to fatigue and become less sensitive. Therefore, a change in the 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 TTS), but if not, then it is referred to as PTS. The amount of threshold shift depends on the duration of noise, rise times, duty cycles, sound pressure levels within the receiver's critical bandwidths' (i.e. the spectral composition of the noise) and, of course, the overall energy.

Some exposure guidelines for hearing effects (TTS/PTS) prescribe a cumulative sound exposure level threshold, which relates to the amount of time (for example a 24-hour period, as is the case with [NMFS \(2018\)](#)) that the noise source is present (after M-weighting the noise):

$$SEL_{cum} = SPL + 10 \log_{10}(\text{duration of exposure (seconds)})$$

where SEL_{cum} is the cumulative sound exposure level, assuming a constant received *SPL* with no temporal variability over space and time ([NMFS 2018](#)). However, if one was to assume a stationary (or very slow moving) receiver (i.e. a marine mammal) and a moving source at a constant speed and direction (typical of TSHDs actively dredging), then the

⁶ Noise effects on fish and invertebrates are well inside the zones for marine mammals, and therefore not explicitly stated herein.

actual exposure will vary over space and time (i.e. the rate at which exposure increases will be the greatest when the receiver is closest to the TSHD and decrease with increasing range as either the TSHD or receiver moves away). Thus, if the problem is addressed from the perspective of the marine mammal, then the simple SEL_{cum} equation above does not reflect reality particularly well. In this case, the approach for assessing potential noise impacts on marine life is the *safe distance*, R_0 , method⁷. This concept is also provided within NOAA’s technical guidance stating that it “allows one to determine the distance the receiver would have to remain in order to not exceed some predetermined exposure threshold”. The safe distance method accounts for the source velocity, spectrum, duty cycle, and is independent to the exposure duration (i.e. suitable for moving sources, whether continuous or impulsive). The safe distance method was calculated using the same equation from [Sivle et al. \(2014\)](#), but expressed in a simpler manner:

$$R_0 = \frac{\pi}{E_0 v} SD$$

where S is the source factor, D is the duty cycle, v is the transit speed and E_0 is the exposure threshold⁸ (NMFS 2018). A key assumption to this method is that the sound source is simple – i.e. the source moves at a constant speed and in a constant direction (such as that of a TSHD actively dredging). Since the exposure thresholds for TTS used herein as those from the NMFS (2018) guidance (Table 3), the source levels of the *William Fraser* were M-weighted. This was done for every 1 Hz, and then recombined to generate the broadband source level used for the TTS zone calculations. Previous research undertaken by Cawthron Institute has identified nine different species of marine mammals within or near the current project area (Clements & Johnston 2019). Among those nine species, four functional hearing groups were identified: low-frequency and mid-frequency cetaceans and otarrid pinnipeds.

Table 3: NMFS (2018) auditory threshold criteria for a non-impulsive noise source for the functional hearing groups relevant to this consent application.

Functional Hearing Group	Functional Hearing Range		Non-Impulsive Noise	
	f_1 (kHz)	f_2 (kHz)	TTS Threshold (SEL*, weighted)	PTS Threshold (SEL*, weighted)
LF	0.2	19	179	199
MF	8.8	110	178	198
OW	0.94	25	199	219

* Cumulative sound exposure level.

⁷ First described by Sivle et al. (2014) and described in the 2018 Revisions to the Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2) from NOAA, April 2018.

⁸ As a pressure value of the NMFS 2018 thresholds.

4.8.2 Behavioural Responses

There is a substantial amount of literature on the behavioural effects of noise on marine mammals – either direct evidence-based studies, opportunistic studies, or observations – that have been summarised in several reviews (for example [Richardson et al. 1995](#); [Hildebrand 2005](#); [NRC 2005](#); [MMC 2007](#); [Nowacek et al. 2007](#); [Weilgart 2007](#); [NAS 2017](#)). Behavioural effects are highly varied and may include changes in swimming behaviours (directions and speeds), diving behaviours (durations, depths, surface intervals), time spent on the surface, respiration rates, fleeing the noise source and changes to vocalisations. Predicting the zones within which behavioural effects may be seen is the most difficult noise effect to quantify due their dependency on the context, species and location (see [Ellison et al. 2012](#); [Gomez et al. 2016](#) for reviews on the issue of context dependency on marine mammal behaviour).

There is no widely-accepted regulatory guidance on behavioural effects currently in existence – it is still a research problem. The only preliminary guidance in existence for behavioural responses is a single unweighted decibel value of 120 dB_{rms} re 1 µPa (from the National Oceanic and Atmospheric Administration (NOAA)), but it has not had a wide-spread uptake ([Gomez et al. 2016](#)). One of the issues of using a single noise threshold for behavioural responses is that the data currently available are not very comparable ([Nowacek et al. 2007](#); [Southall et al. 2007](#); [Ellison et al. 2012](#); [Gomez et al. 2016](#)) with limited relationships between the severity of the behavioural response and the received level of underwater noise ([Gomez et al. 2016](#)).

Some underwater noise assessments in New Zealand still consider the 120 dB_{rms} re 1 µPa contour, stating the reason being it's the only measure of behavioural effects on marine mammals. However, because of the uncertainty in assessing the risk of behavioural effects within and between species (based on the highly contextual nature of behavioural effects), the application of a simplistic noise threshold value for behaviours should be avoided ([Faulker et al. 2018](#)). Recent scientific research assesses behavioural zones based on the probability of occurrence using dose-response curves specific for the species of interest ([Joy et al. 2019](#)). Dose-response curves show the relationship between the probabilities 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 US Navy ([US Navy 2008, 2012](#)) and the scientific community for a number of years – primarily for impulsive signals. However, a recent scientific investigation from the Sea Mammal Research Unit (SMRU), JASCO Applied Sciences and the Ports of Vancouver in British Columbia, Canada, has been published that provides a specific dose-response function and thresholds for southern resident killer whales and a continuous noise source ([Joy et al. 2019](#)). The thresholds used make use of the most up-to-date data for killer whales and behavioural effects (specifically those effects classed as low⁹ or moderate¹⁰ (respectively a Southall severity score of 2-3 and 4-6 ([Southall et al.](#)

⁹ Low behavioural responses are defined as minor changes in respiration rates, swimming speeds and direction ([Joy et al. 2019](#)).

¹⁰ Moderate behavioural responses are defined as moderate to extensive changes in swimming speeds, direction and/or diving behaviours, moderate or prolonged cessation of vocalisations, and/or avoidance ([Joy et al. 2019](#)).

2007)). Briefly explained, the researchers took empirical studies on killer whales and noise (42 studies in total) and correlated the estimated received noise levels with the behavioural response type (i.e. the Southall severity scores from Southall et al. 2007) to get a regression curve (linear relationship). From there, the researchers calculated two received levels that corresponded to the 50% probability of either a low or moderate behavioural response occurring and used those to generate the dose-response curve for killer whales. The dose-response curve in this assessment was calculated using:

$$R = \frac{1 - \left(\frac{L - B}{K}\right)^{-A}}{1 - \left(\frac{L - B}{K}\right)^{-2A}}$$

where R was the risk from 0 to 1 (i.e. the probability of an effect occurring) at the noise level L , B was the basement received level (RL) at which the risk of an effect occurring is so low it does not warrant calculating, K was the RL increment above B at which there is 50% risk and A was a transition sharpness parameter (Joy et al. 2019). The RL at which there was a 50% risk of an effect was set at 129.5 (for a low response (Southall severity 2.5)) and 137.2 dB re 1 μ Pa (for a moderate response (Southall severity 5)) (Joy et al. 2019).

Since this method was based on more accurate data (and a killer whale, which is a species that can occur in the Mangawhai – Pakiri area, with hearing biology similar to other delphinids), we applied the same method and assumptions to our data. However, we altered the basement received level, B , to be the averaged 1-min SPL of ambient noise over our 69 day monitoring period. This provided a conservative baseline level specifically related to Pakiri that is more useful and scientifically based than the unweighted threshold level of 120 dB_{rms} re 1 μ Pa for all marine mammals.

For Bryde's whales, however, the RL at which there was a 50% risk of a low behavioural response was set a 120 dB re 1 μ Pa (since that level was the lowest at which bowhead whales, another mystecete species and one of the only whales with estimated levels of exposure (from continuous noise) linked to a certain behavioural response (Southall et al 2007). This is conservative. No assessment for moderate behavioural effects for Bryde's whales was done because we do not know what such a threshold would look like and is therefore too speculative to be meaningful. The same basement levels and transition sharpness values were applied for Bryde's whales as for the odontocetes (represented by the killer whales and bottlenose dolphins).

4.8.3 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 (Pine et al. 2016; Putland et al. 2018) or machinery such as renewable energy devices (Pine et al. 2019). For example, bottlenose dolphins (*Tursiops truncatus*) 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). Therefore, dredging noise (along with other anthropogenic noise sources commonly seen in coastal waters), 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 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 a species 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 the species of interest at the source are poorly understood, while the listening space method is more sensitive to changes in the existing sound environment (Pine et al. 2018). Those changes could be better modelled by the computer using the empirical data outlined in Section 2.0 and 3.0 above. As the anthropogenic noise source (in this case, the *William Fraser*) approaches an animal (or vice versa), 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:

$$LSR = 100 \left(1 - 10^{-\frac{\Delta}{N}} \right)$$

where *N* is the frequency-dependent *PL* slope coefficient and Δ is the difference between the perceived base ambient noise level NL_1 and TSHD noise level NL_2 at a given distance (NL_2 was the modelled sound pressure levels, as described in Section 4.6 *Propagation Modelling*). The ambient noise levels were those described in Section 2.0 *The Existing Underwater Soundscape*. 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 bottlenose dolphins and killer whales (reconstructed from Nedwell et al. 2004) were used to estimate hearing thresholds in each critical band. There are no audiograms available for the New Zealand fur seal or Bryde’s whale. Consequently, a Northern fur seal (*Callorhinus ursinus*) audiogram (Nedwell et al. 2004) and modelled audiogram for the fin whale (Cranford & Krysl 2015) were used herein. The use of modelled audiograms do require special care when used, as they are based on the structure of the skull and no true hearing data is available (as AEP experiments, or behavioural audiograms, are not able to be done on mytcecetes). However, their use in scientific studies is done when no other data exists – as is the case with this assessment.

The *PL* slope coefficient was calculated by curve fitting the empirical *PL*s of each 1/3 octave band between 50 Hz and 32 kHz (using the same data collected as described in Section

4.2.2 *Data Analysis*) over a distance that represented the listener's maximum listening range under natural sound conditions (the ground-truthed *PL* model was also used for those distances beyond a few kilometres). This was done using a simplified sonar equation without signal gain (to increase conservativeness):

$$SE = SL - PL - NL_1 - DT$$

where signal excess (*SE*) is set to zero to indicate detection onset, NL_1 was the 5th percentile ambient noise level and *DT* was the detection threshold (conservatively set at 10 dB for common dolphins (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 *PL* slope can have some range-dependence.

The empirical source levels, ambient levels and audiograms are provided in Figure 16.

The *LSR* was then calculated for each 1/3 octave 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 across 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). Marine fauna have evolved in a naturally noisy environment, with many natural sources (such as waves and conspecific or heterospecific vocalisations etc) active as effective maskers (Radford et al. 2014). It therefore stands to reason that they have evolved to counteract naturally occurring maskers, ensuring their vocalisations can be detected by a listener over ambient noise levels. 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 particular assumption.

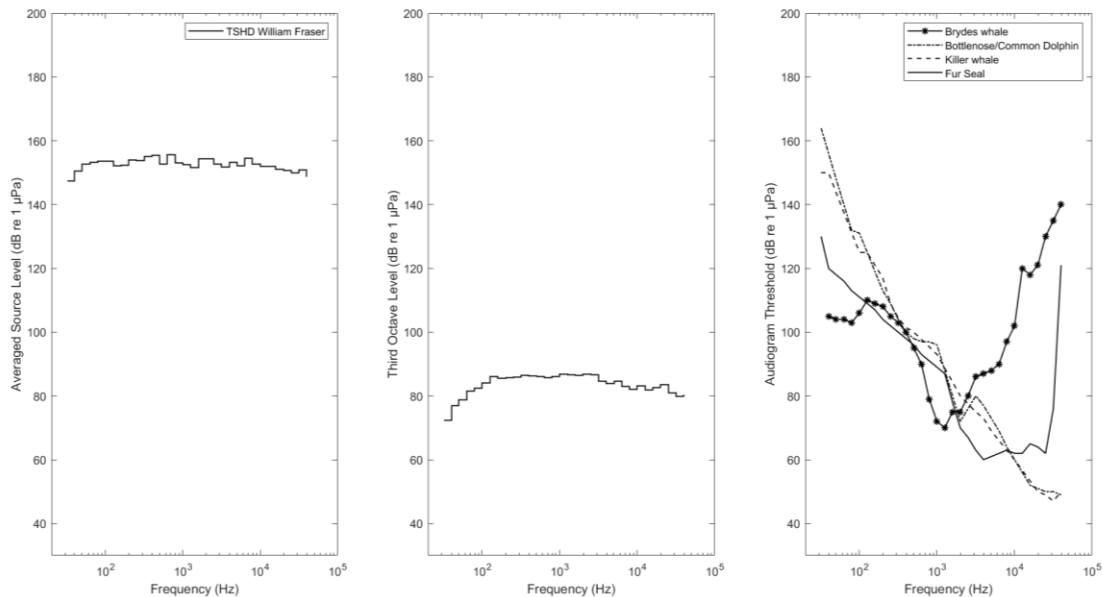


Figure 16: 1/3 Octave source level for the *William Fraser* (left panel), median 1/3 octave ambient sound levels measured between March and June 2019 (middle panel) and species audiograms (right panel) reproduced from [Nedwell et al. 2004](#).

4.8.4 Audibility Ranges

In order for any noise effects to occur, the noise has to first be audible to a receiver. It is important to note, however, that just by 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 dredging for particular species or groups.

Audibility limits were calculated based on the hearing sensitivities of killer whales, common dolphins, bottlenose dolphins and New Zealand fur seals (approximated based on the Northern fur seal, being the closest phylogenetic relative to the NZ fur seal for which audiogram studies have been undertaken), in the context of the ambient soundscape. 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 dredging noise is omnidirectional¹¹ and directly relates to the difference between the ambient sound level, the dredging noise and hearing thresholds at each critical band.

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](#)).

5.0 Noise Modelling: Results

5.1 Seasonal Variation in the Acoustic Propagation

The propagation of sound levels did show variation between summer and winter months, with the warmer surface temperatures and shallow thermocline increasing the propagation of dredging noise (Figure 17).

Spring and autumn months are expected to be within these two seasonal extremes, and thus not specifically investigated herein. The noise effects modelling were therefore performed during summer conditions, being the more conservative of the two seasons.

5.2 Noise Effects

5.2.1 Temporary Threshold Shifts

During full dredging conditions (pump on, draghead down and loading the hopper), the TSHD *William Fraser* is not expected to induce a TTS beyond 1m distance due to the M-weighted source levels being below the required sound exposure level thresholds¹².

5.2.2 Behavioural Effects

Behavioural effects can be expected to occur within limited ranges from the TSHD. The specific distances at which there is a 75% chance for some behavioural effect to occur (whether low or moderate in severity) is 16m for dolphin species and 134m for Bryde's whales. A 50% probability of some behavioural effect occurring is restricted within 57m and 215m for dolphins and Bryde's whales, respectively. Based on the baseline noise conditions that we measured between March and June 2019, the risk of behavioural effects occurring beyond 617m and 1440m (respectively for dolphins and Bryde's whales) are not expected.

¹² Those thresholds being the [NMFS \(2018\)](#) thresholds for LF- MF- and OW functional hearing groups.

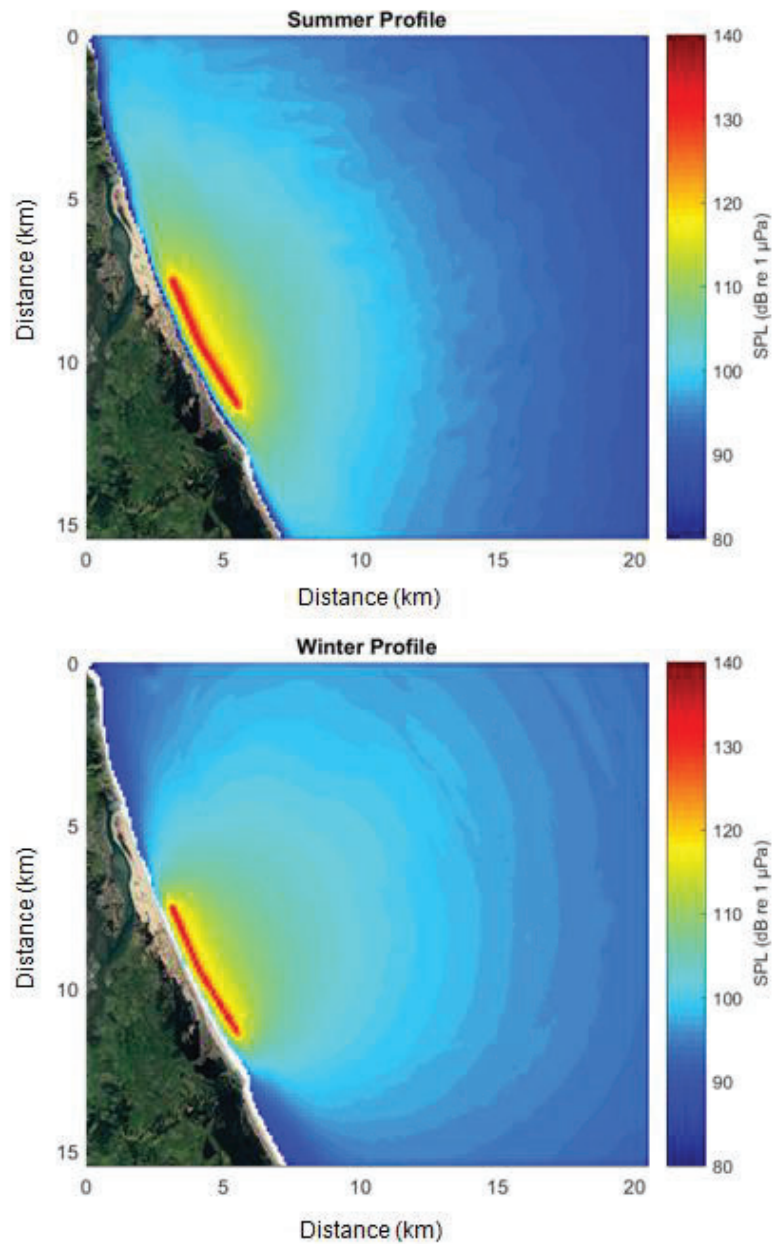


Figure 17: Comparative sound fields (broadband (10Hz – 48 kHz) un-weighted sound pressure levels) for a single measurement sample of the TSHD during summer and winter sound speed profiles and surface roughness.

All noise effects modelling were based on the more conservative summer profile.

Table 4: Distances at which 75, 50, 25 and 0% risk of low and moderate behavioural responses for each of the species of interest.

Species	Behavioural Response	Risk isopeth (m)			
		75%	50%	25%	0%
Killer Whale	Low (minor changes in respiration rates, swimming speeds/direction)	16	57	97	617
Bottlenose Dolphin					
Common Dolphin	Moderate (moderate to extensive changes in swimming speeds/direction and/or diving behaviours, moderate or prolonged cessation of vocalisations, and/or avoidance)	NA	5	54	205
Bryde's Whale					
Bryde's Whale	Low (minor changes in respiration rates, swimming speeds/direction)	134	215	394	1440

5.2.3 Auditory Masking

Auditory masking effects, and the extent of such, varied between species, and are provided in Table 5. Higher masking impacts, in terms of *LSR*, were seen for fur seals and Bryde's whales – the two species more sensitive to low frequencies – with averaged *LSRs* exceeding 80% and 75% within 15m, respectively. The spatial extent of any masking effects also occurred over longer distances for seals compared to cetacean listeners.

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

Species	Distance from the TSHD			
	75% LSR	50% LSR	25% LSR	0% LSR
Killer whale	NA	673	2206	3108
Bottlenose/Common dolphin	NA	558	2108	2878
Bryde's whale	5	86	1716	2572
Fur seal	14	896	2221	3188

5.2.4 Audibility Limits

The limits of audibility for each of the species of interest are provided in Table 6. The audibility limit for Bryde's whales is expected to be smallest, followed by bottlenose/common dolphins, fur seals and then killer whales. This is expected, based on the hearing thresholds of each species and the *William Fraser's* spectrum. It is important to note, however, is that

the audibility limits (like the *LSR* metric) is the averaged audibility limit over several critical bands for each species¹³.

Table 6: Distances within which audibility is likely.

Species	Audibility radius (m)
Killer whale	3593
Bottlenose/Common dolphin	3501
Bryde's whale	2668
Fur seal	3535

6.0 Summary

Styles Group has been engaged by MBL to undertake underwater noise effects modelling of the sand extraction operations associated with the consent renewal. Noise effects on fishes were considered and concluded to be lesser than those for marine mammals and therefore not outlined in the results.

Changes to marine mammals' hearing thresholds (PTS/TTS), risk of behavioural effects, auditory masking and general audibility were assessed. As expected, audibility of the dredging noise occurred over the greatest distances for all species (approximately 2.7km for Bryde's whales, 3.5km for fur seals and bottlenose/common dolphins and 3.6km for killer whales), followed by auditory masking effects (starting within 2.57 – 3.19km) and behavioural effects (starting within 617m and 1.44km). No risk of hearing temporary threshold shifts beyond 1m from the TSHD was found, based on the empirical data collected from the actively dredging *William Fraser*. No risk of PTS for all species was found.

These effects zones are smaller for the *William Fraser* than for the *Coastal Carrier* (see Appendix F).

7.0 Literature Cited

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¹³ Similar to the *LSR* method as outlined in [Pine et al. 2018 and 2019](#).

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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.
$L_{eq(t)}$ (dB)	The equivalent sound pressure level with the same energy content as the measured varying acoustic signal over a sample period (t). The preferred metric for sound levels that vary over time because it takes into account the total sound energy over the time period of interest.
Power spectral density (PSD)	The dB level of the power spectrum, presented every 1 Hz.
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 $1 \mu\text{Pa}^2 \cdot \text{s}$.
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 $1 \mu\text{Pa}$ @ 1m.
Temporary Threshold shift	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.

Thermocline

A sudden change in temperature in a body of water with depth, where the temperature is markedly different above and below the layer in which this temperature change occurs.

Appendix B Pakiri Inshore Extraction Consent Co-ordinates

21 November 2008

PAKIRI INSHORE EXTRACTION CONSENTS CO-ORDINATES

NZMS260

WGS 1984

1. Te Arai Beach northern inner co-ordinate

R08 566 637 36° 06' 57.6590"S 174° 37' 19.5485"E

2. Te Arai Beach northern outer co-ordinate

R08 568 638 36° 06' 54.2918"S 174° 37' 27.4673"E

3. Te Arai Beach southern inner co-ordinate

R08 588 595 36° 09' 12.5178"S 174° 38' 50.7365"E

4. Te Arai Beach southern outer co-ordinate

R08 591 596 36° 09' 09.0862"S 174° 39' 02.6574"E

5. Pakiri Beach northern inner co-ordinate

R08 597 578 36° 10' 07.0919"S 174° 39' 28.0517"E

6. Pakiri Beach northern outer co-ordinate

R08 600 580 36° 10' 00.4157"S 174° 39' 39.8967"E

7. Pakiri Beach southern inner co-ordinate

R08 619 543 36° 11' 59.2187"S 174° 40' 58.8115"E

8. Pakiri Beach southern outer co-ordinate

R08 621 546 36° 11' 49.3605"S 174° 41' 06.5785"E

Appendix C Soundscape Characterisation Results

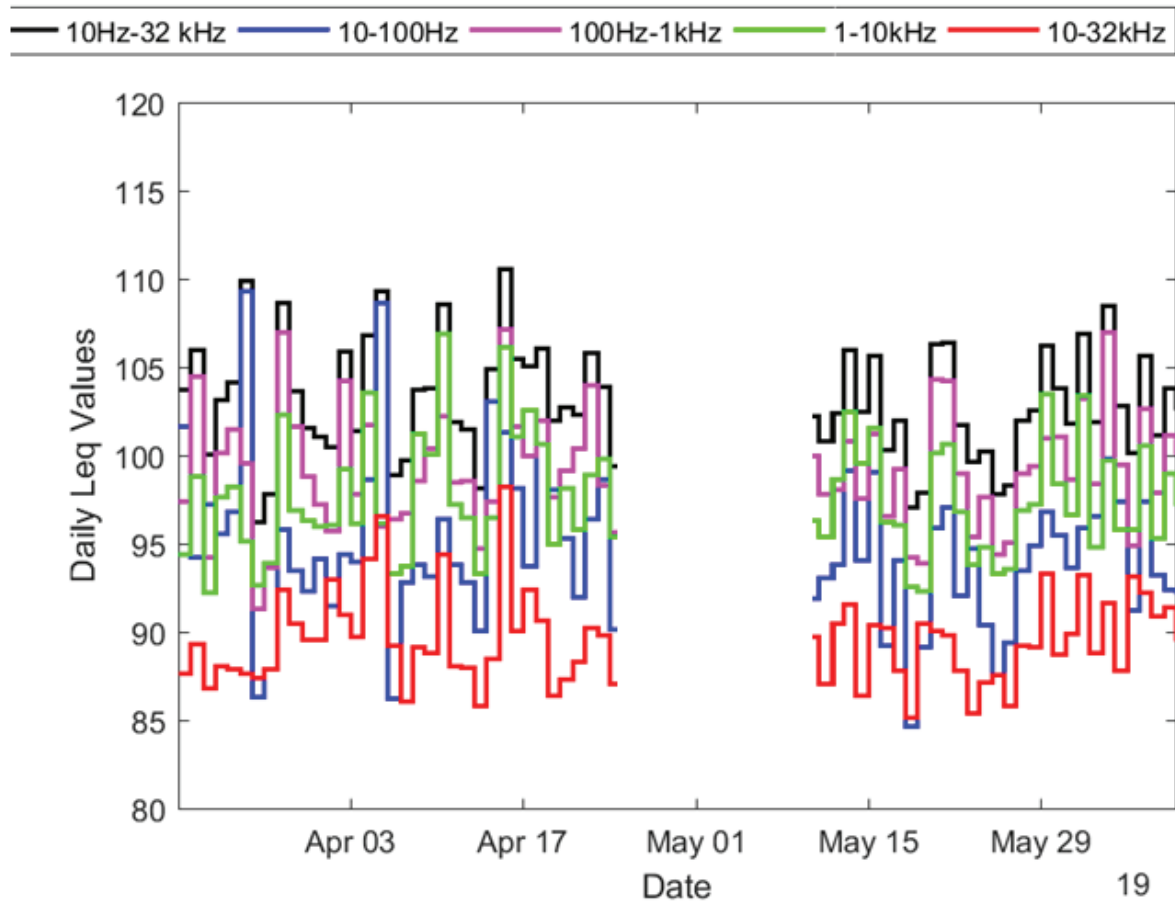


Figure 18 Daily sound pressure levels (presented as daily Leq values, dB re 1 μ Pa) measured within the southern consent area off northern Pakiri Beach between May and June 2019.

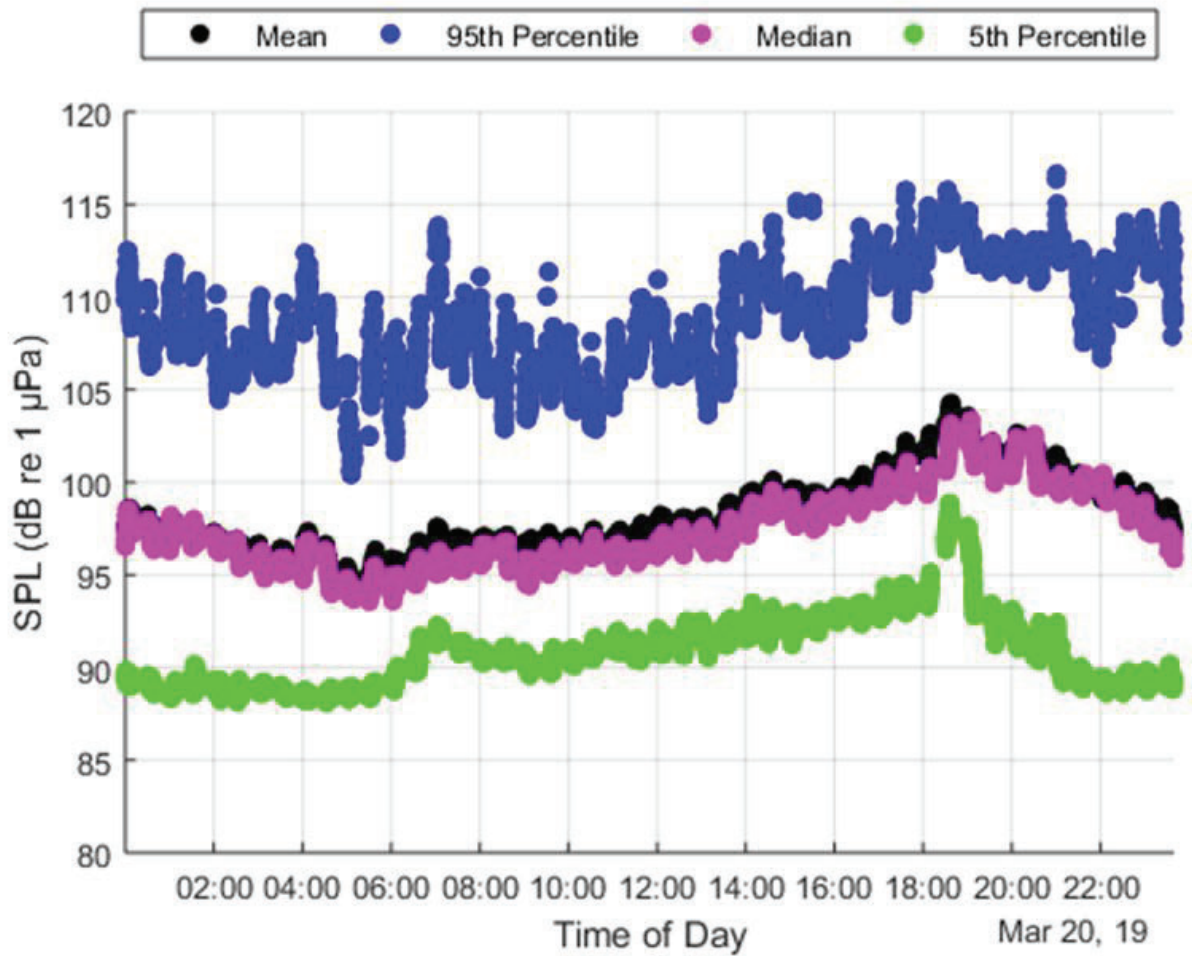


Figure 19 Descriptive statistics of the sound pressures levels over each 24 hour period between March and June 2019. Each data point represents the 1-min *Leq*.

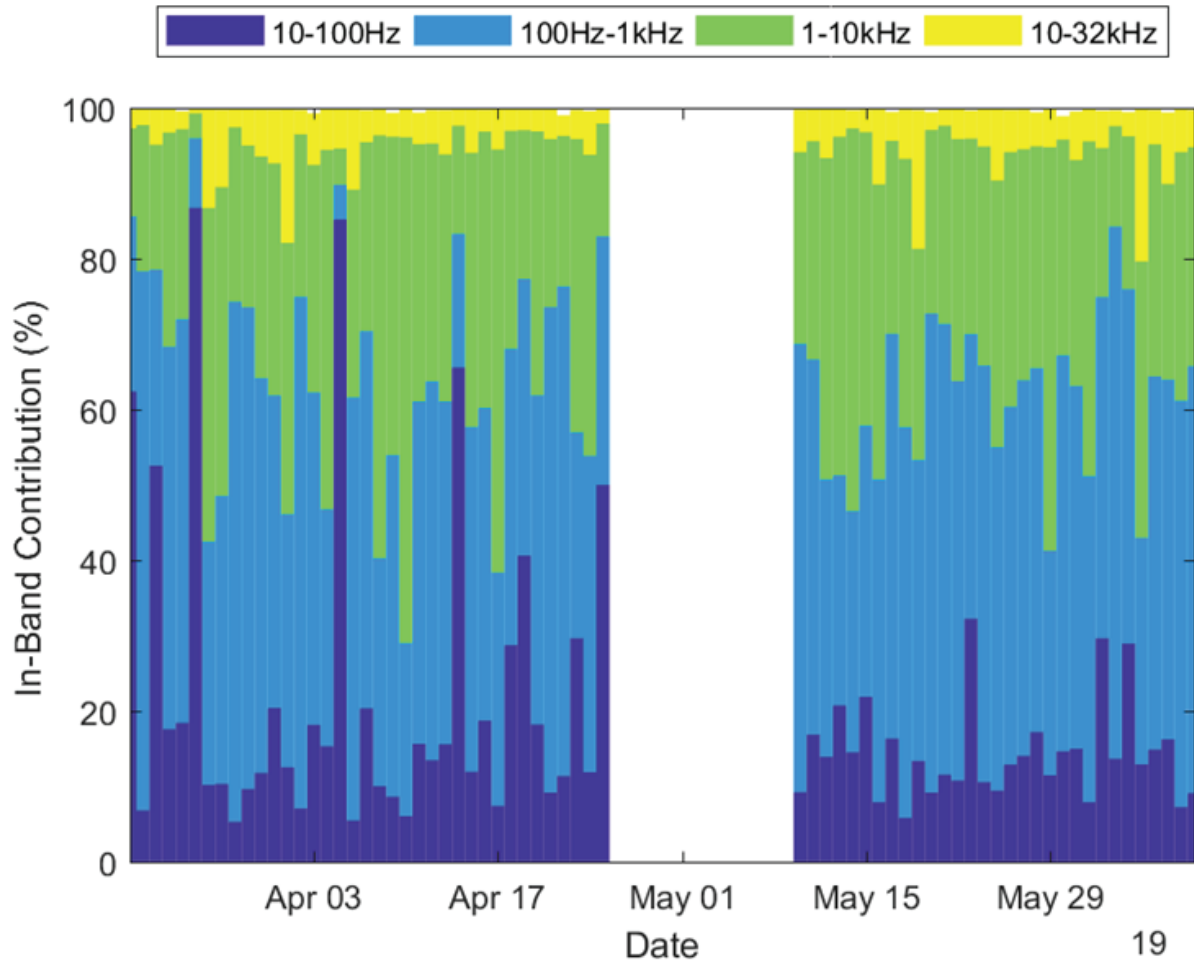


Figure 20 Daily in-band contributions (%) per day.

The in-band contribution shows the percentage contribution of each frequency band to the total broadband energy for each 24 hour period.

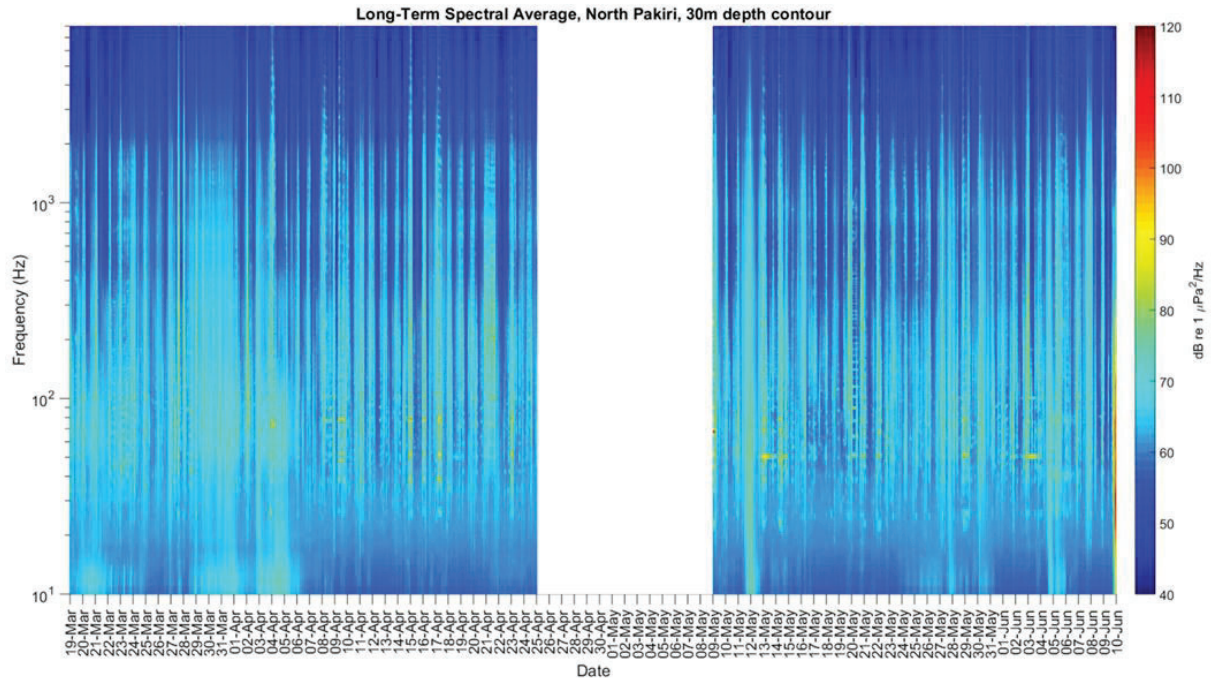


Figure 21 Long term spectral average (LTSA) of the power spectral density (PSD, dB re 1 $\mu\text{Pa}^2/\text{Hz}$) over the monitoring period. No data were collected between the 25 April and 09 May.

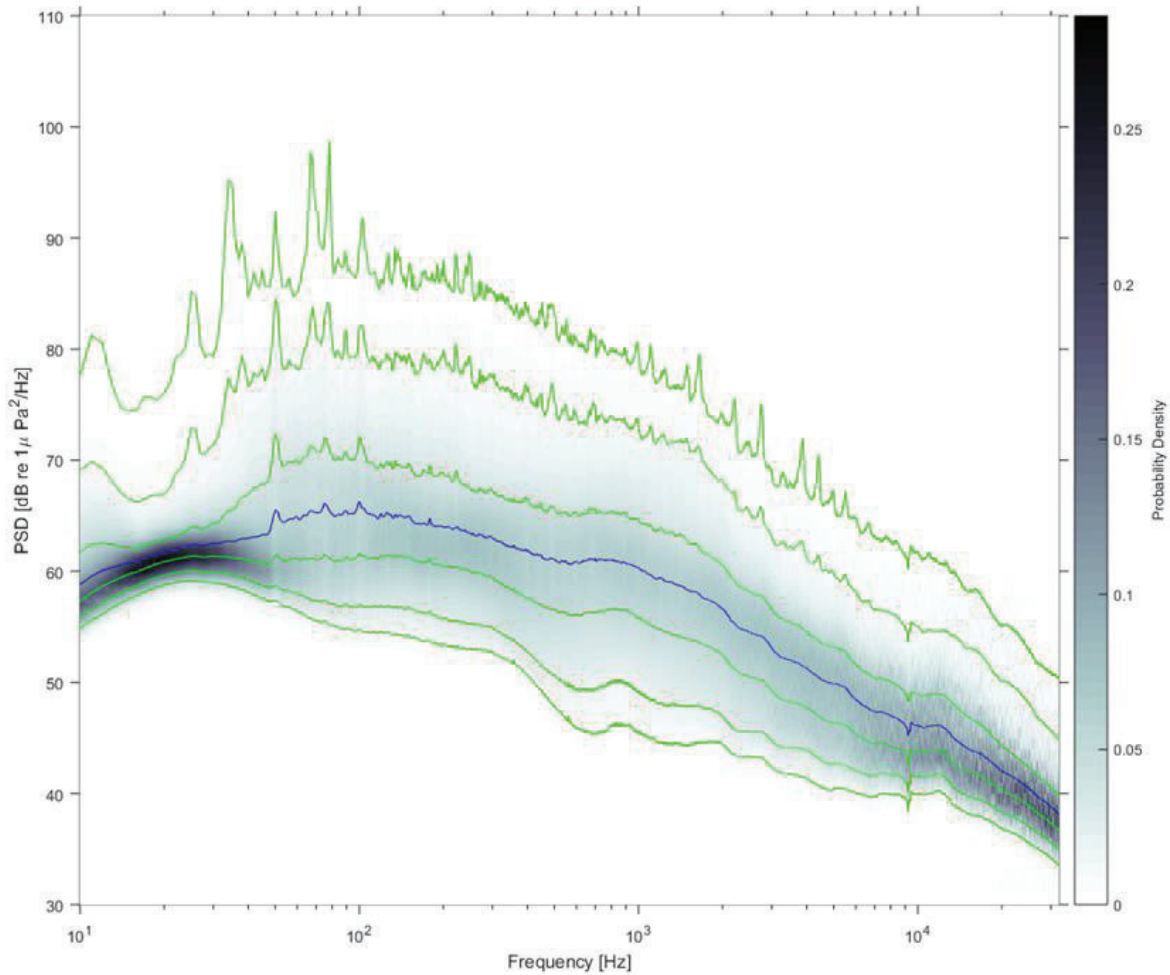


Figure 22 Plots showing the variation in power spectral densities (*PSD*, dB re 1 $\mu\text{Pa}^2/\text{Hz}$) and the spectral probability density for the monitoring period.

The blue line represented the median (50th percentile) levels, while the green lines, starting at the top line, represent the 99th, 95th, 75th, 25th, 5th and 1st percentile levels. The colour bar presents the spectral probability density from 10 Hz to 32 kHz. These plots were generated using the LTSA data shown in Figure 21.

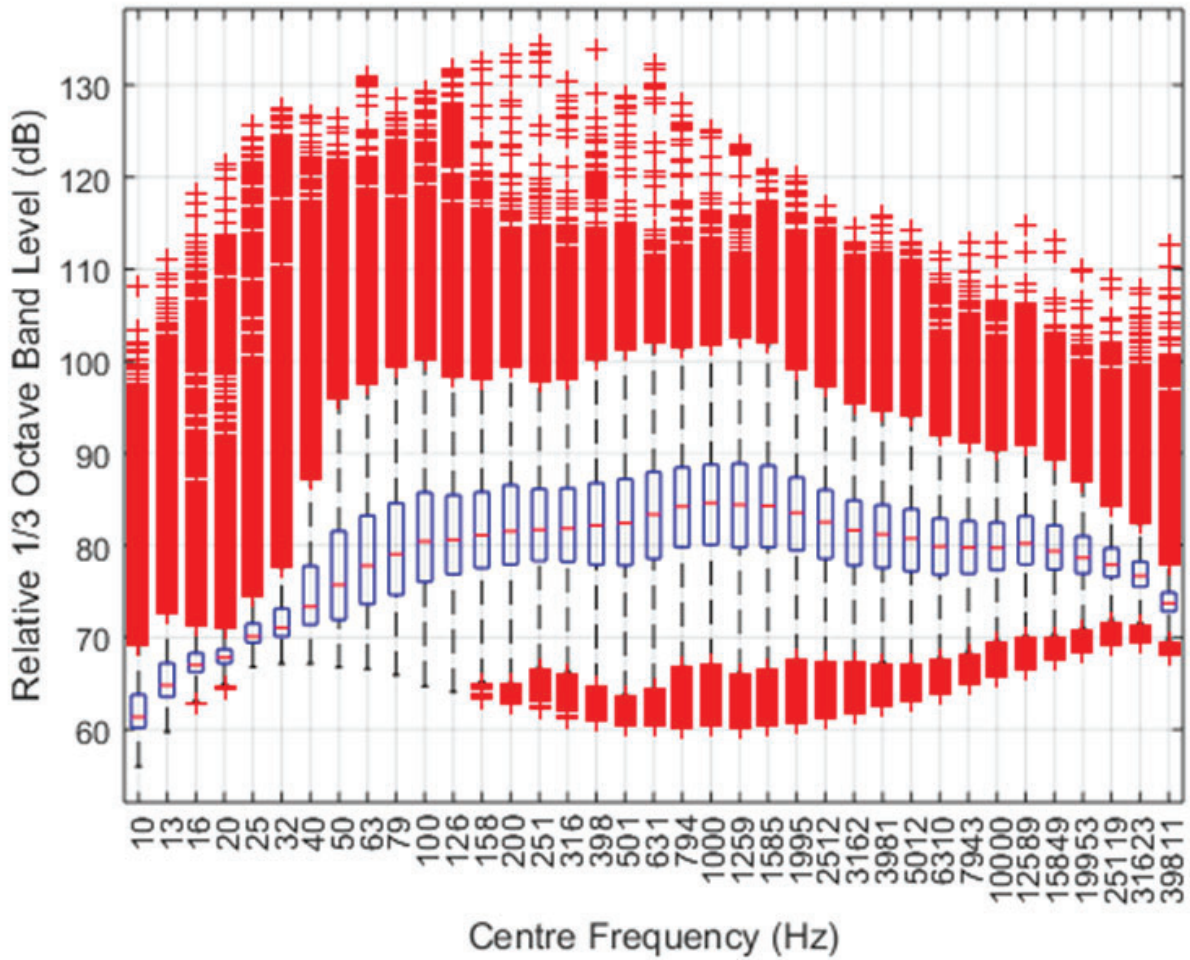


Figure 23 Boxplot showing the variation in the 1/3 octave band levels (dB re 1 μ Pa) for the monitoring period.

The plot was generated from the 1-min averages in each 1/3 octave band for each day of the monitoring period.

Appendix D Temperature and Salinity Data

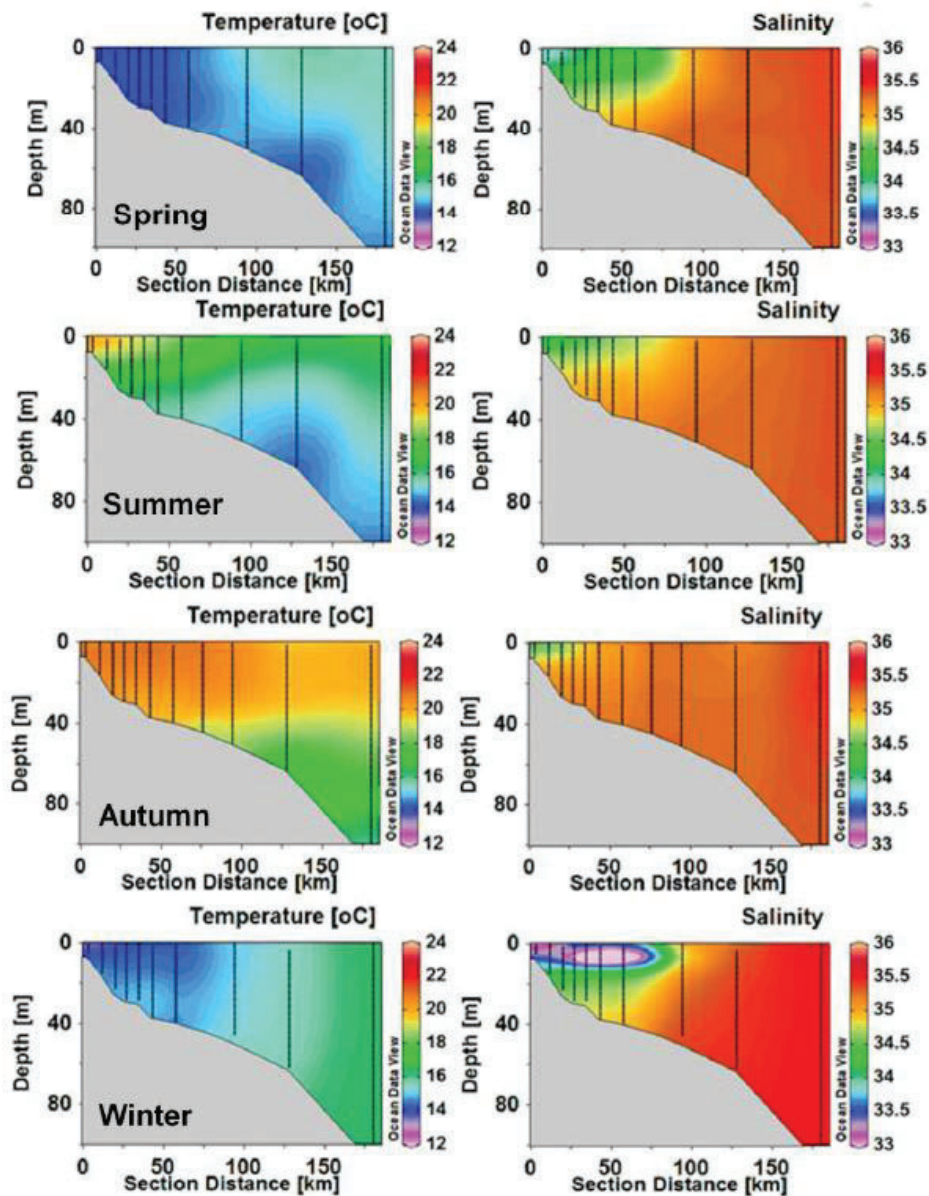


Figure 24: Thermo- and halocline depths used to calculate the sound speed profiles.

These figures have been taken directly from Zeldis (2013) and were measured from within the Hauraki Gulf off Coromandel.

Appendix E Underwater Noise Effects Modelling Results: The *William Fraser*

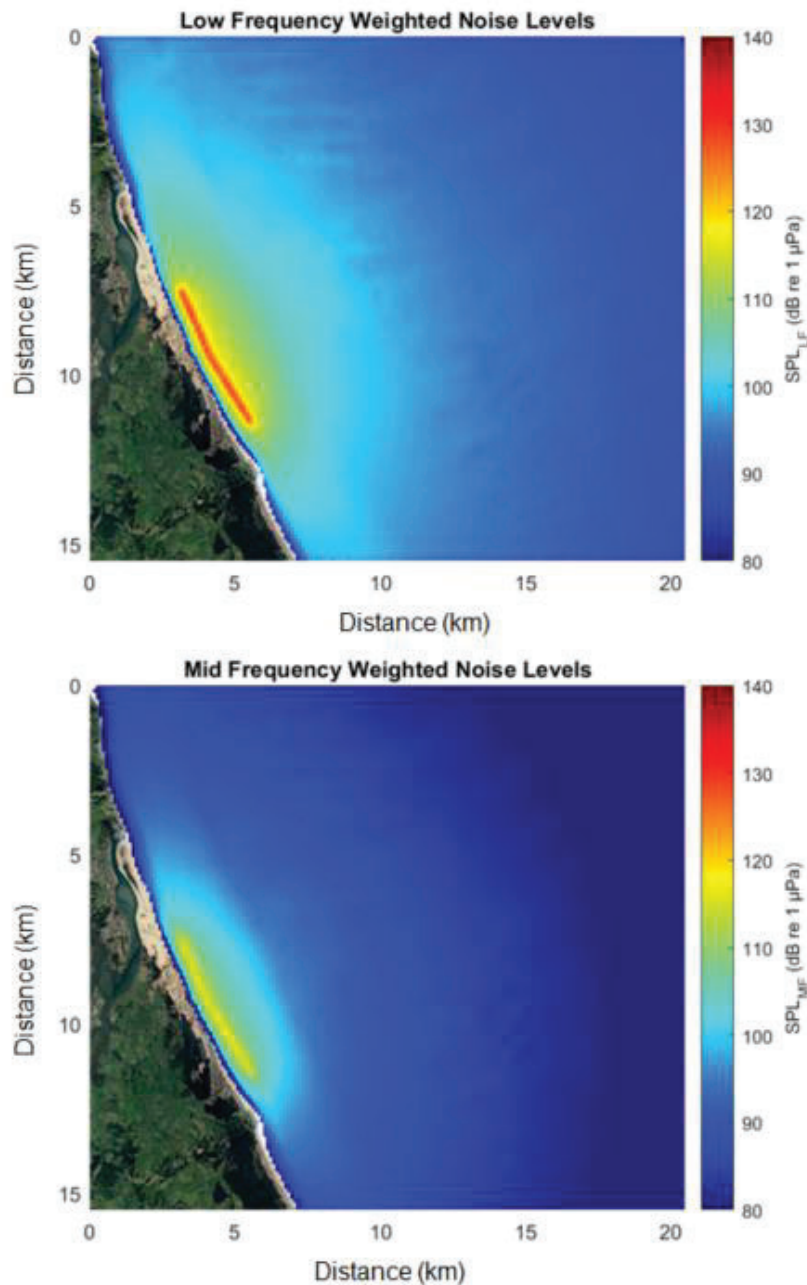


Figure 25: Modelled broadband (10Hz – 38 kHz) sound pressure levels for low-frequency and mid-frequency functional hearing groups for the TSHD *William Fraser* under full dredging conditions (pump on, draghead down, vessel underway and hopper being loaded).

Note the plots above show an entire dredge transect over multiple hours and is not the acoustic footprint or effect at a single point in time (as provided in Section 5.0).

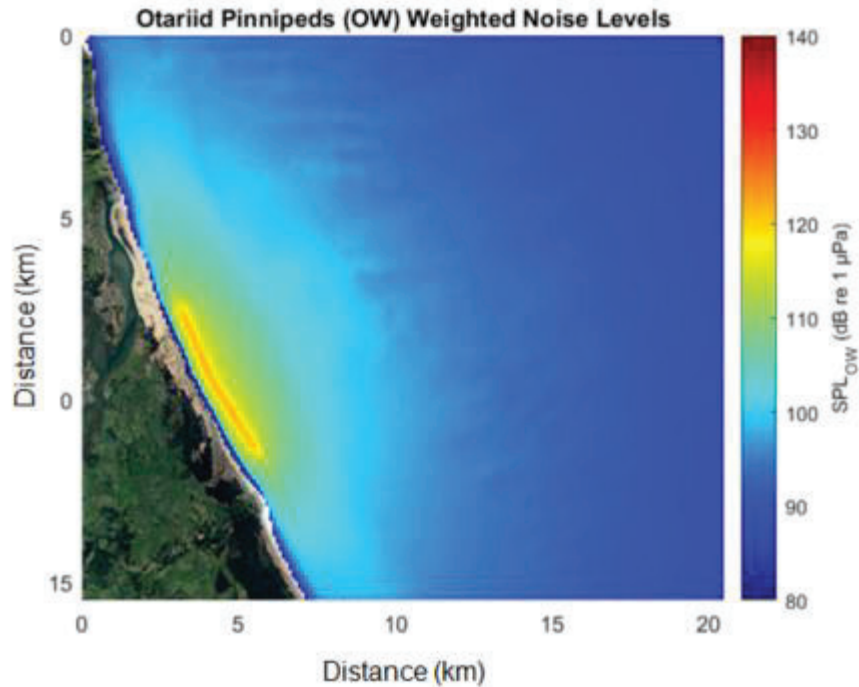


Figure 26: Modelled broadband (10Hz – 38 kHz) sound pressure levels for otariid pinniped functional hearing group for the TSHD *William Fraser* under full dredging conditions (pump on, draghead down, vessel underway and hopper being loaded).

Note the plots above show an entire dredge transect over multiple hours and is not the acoustic footprint or effect at a single point in time (as provided in Section 5.0).

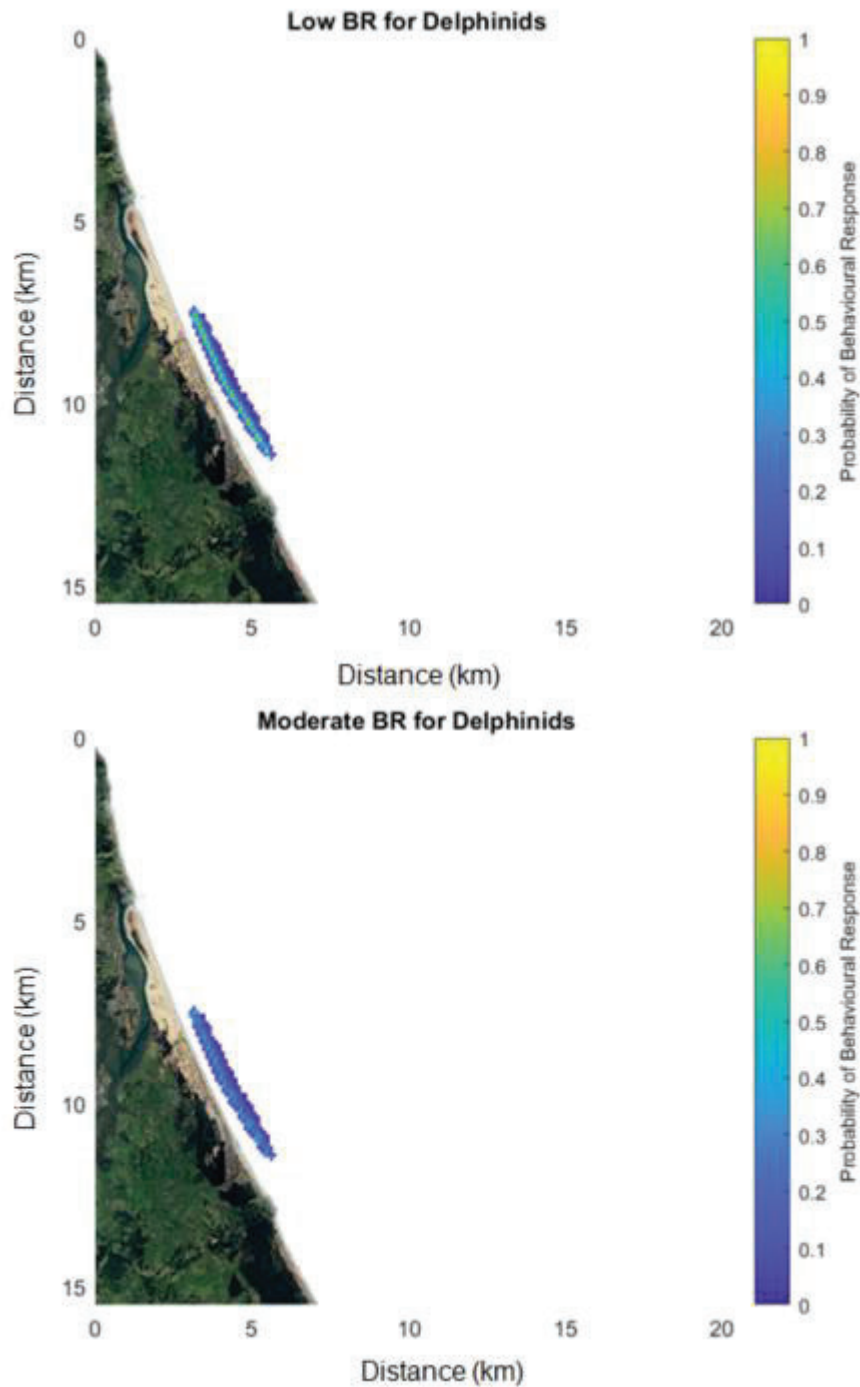


Figure 27: Low and moderate behavioural response risk (top and bottom panels, respectively) for dolphin species (either bottlenose or common dolphins) for the TSHD *William Fraser* under full dredging (pump on, draghead down, vessel underway and hopper being loaded).

Note the plots above show an entire dredge transect over multiple hours and is not the acoustic footprint or effect at a single point in time (as provided in Section 5.0).

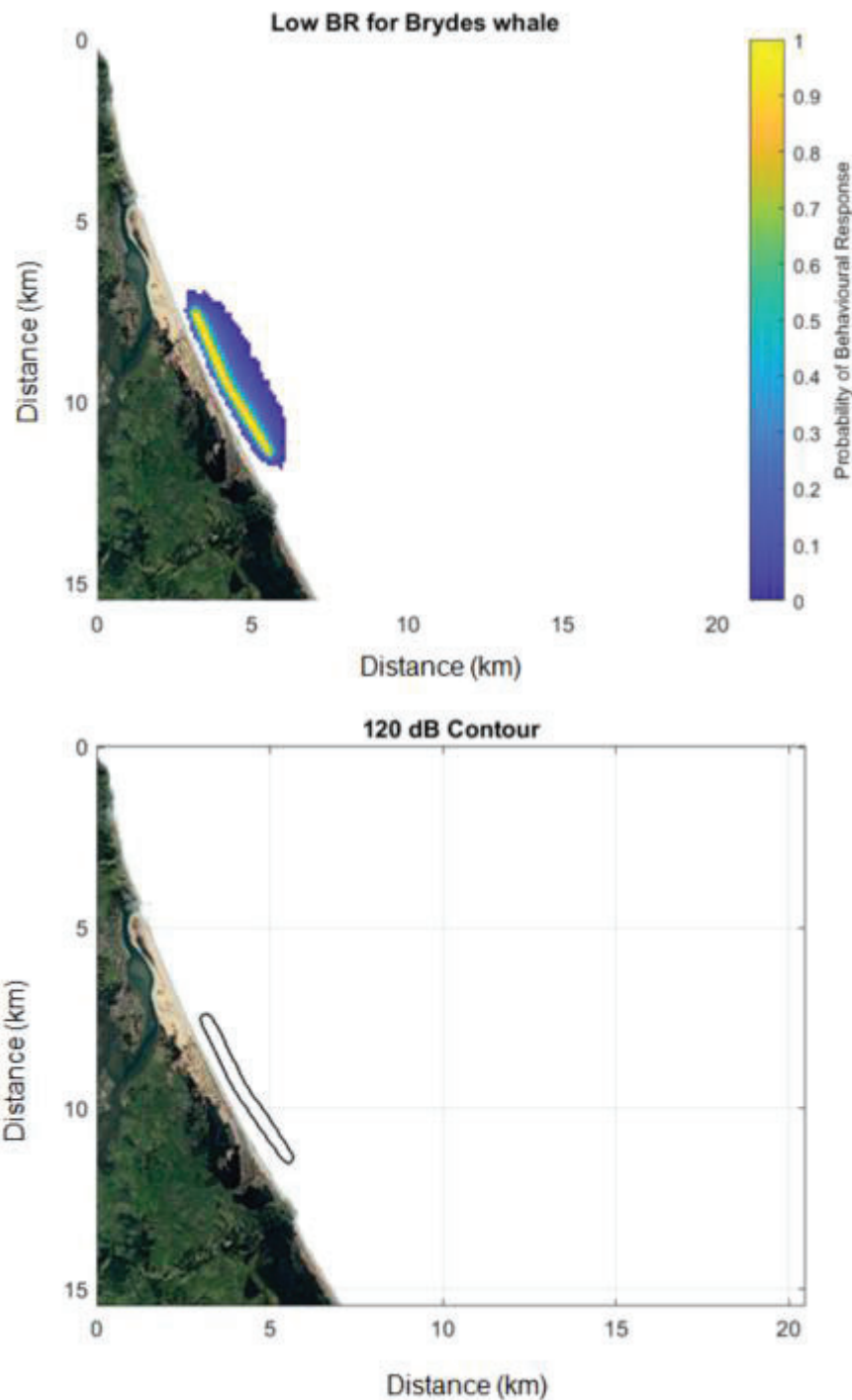


Figure 28: Low behavioural response risk for Bryde’s whales (top panel) and the 120 dB re 1 μ Pa contour for comparison (bottom panel) for the TSHD *William Fraser* under full dredging (pump on, draghead down, vessel underway and hopper being loaded).

The dose-response formulas used to generate the probability of risk in Bryde’s whales was based on a 50% risk occurring at that 120 dB re 1 μ Pa threshold as a conservative measure.

Note the plots above show an entire dredge transect over multiple hours and is not the acoustic footprint or effect at a single point in time (as provided in Section 5.0).

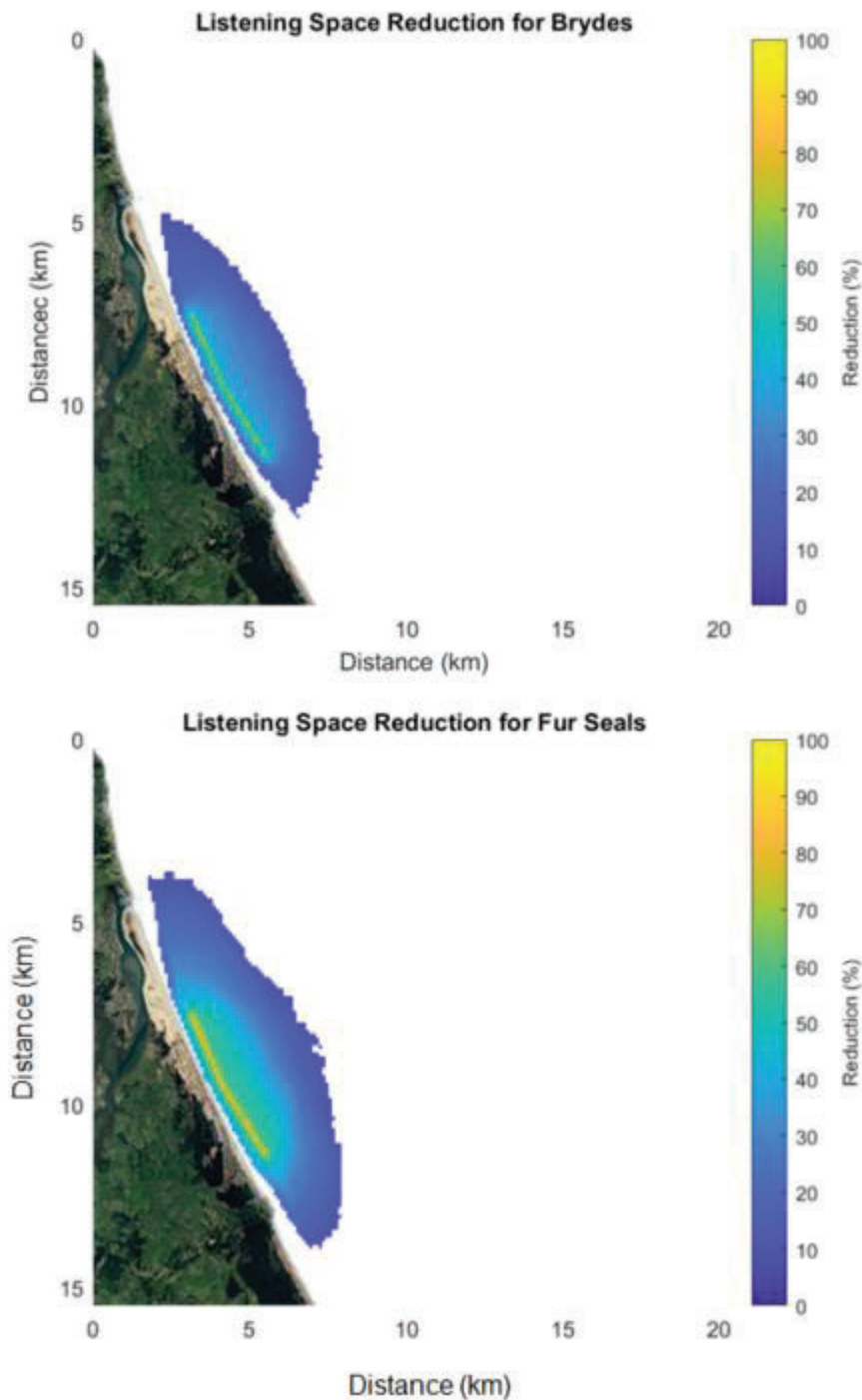


Figure 29: Plots showing the spatial extent of LSRs for Bryde’s whales and fur seals for the TSHD *William Fraser* under full dredging (pump on, draghead down, vessel underway and hopper being loaded).

Note the plots above show an entire dredge transect over multiple hours and is not the acoustic footprint or effect at a single point in time (as provided in Section 5.0).

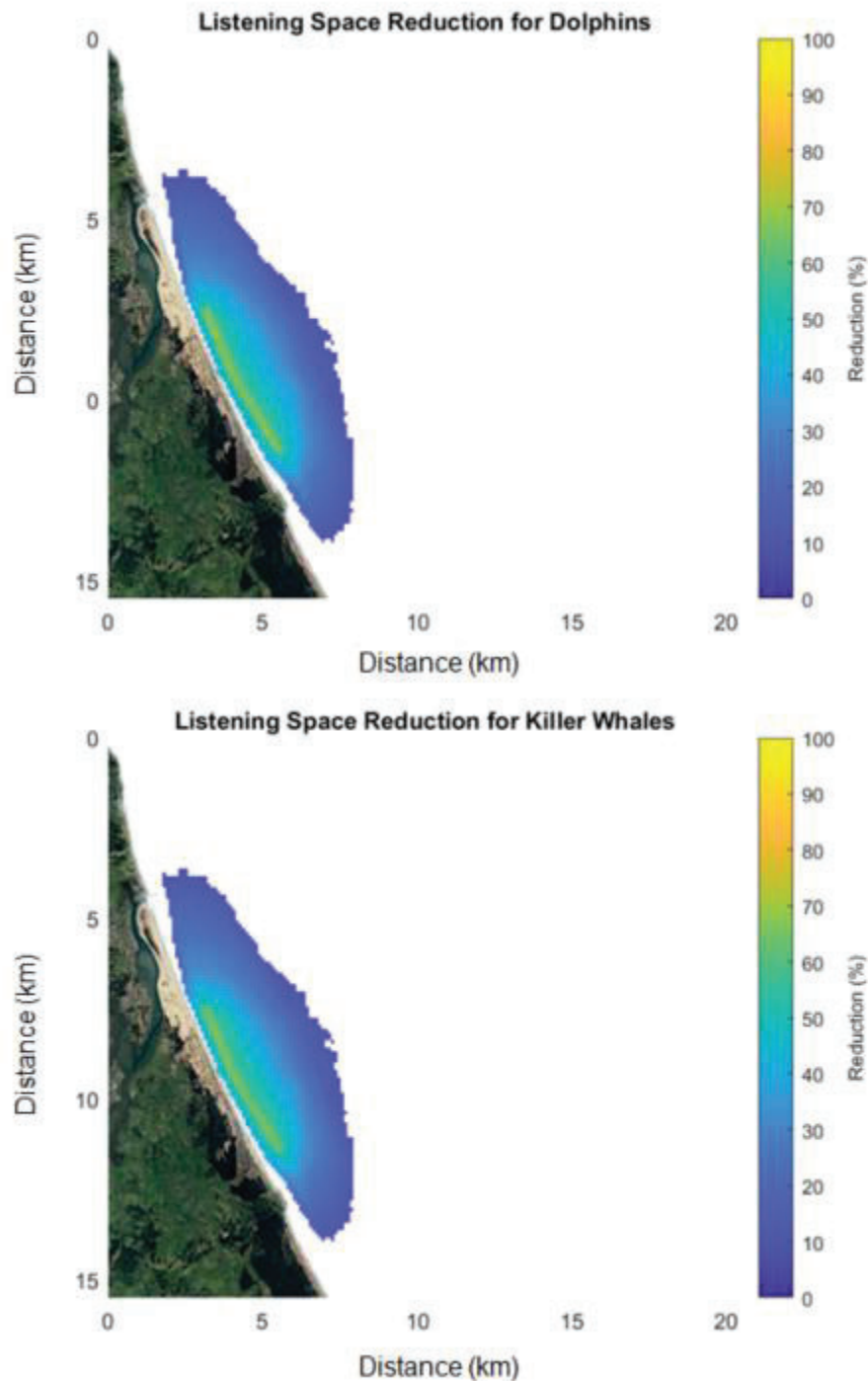


Figure 30: Plots showing the spatial extent of *LSRs* for dolphins (bottlenose/common dolphins) and killer whales for the TSHD *William Fraser* under full dredging (pump on, draghead down, vessel underway and hopper being loaded).

Note the plots above show an entire dredge transect over multiple hours and is not the acoustic footprint or effect at a single point in time (as provided in Section 5.0).

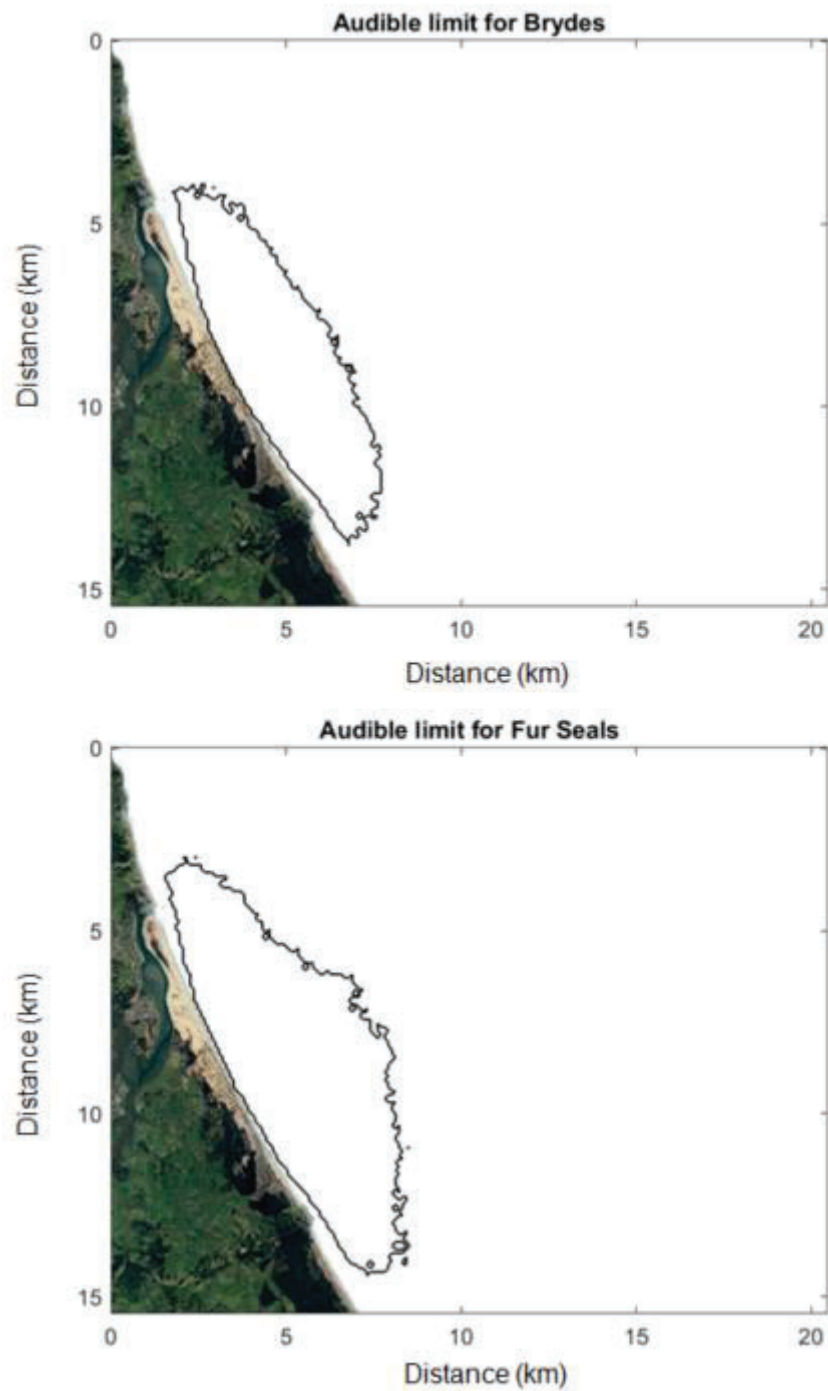


Figure 31: Plots showing the audibility limits for Bryde’s whales and fur seals for the TSHD *William Fraser* under full dredging (pump on, draghead down, vessel underway and hopper being loaded).

Note the plots above show an entire dredge transect over multiple hours and is not the acoustic footprint or effect at a single point in time (as provided in Section 5.0).

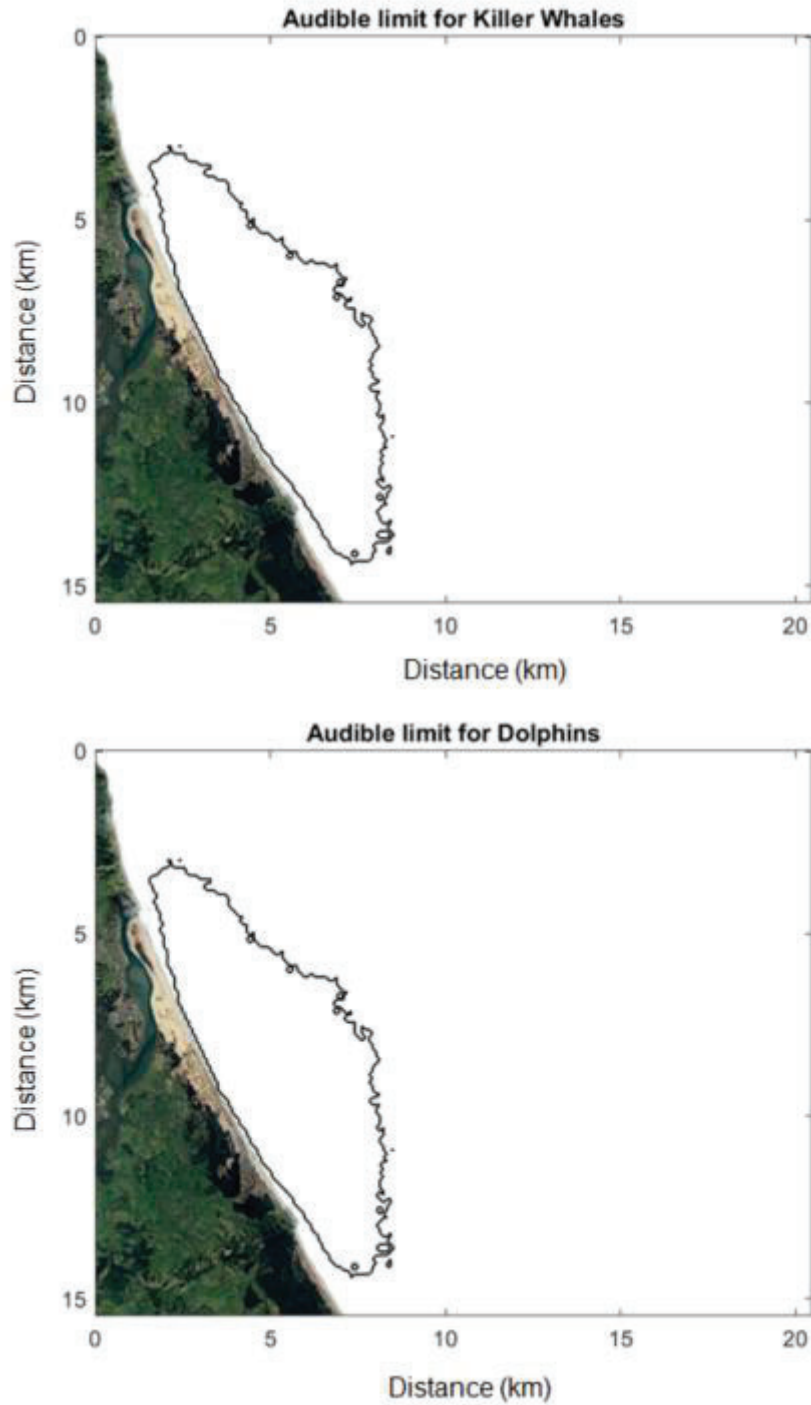


Figure 32: Plots showing the audibility limits for killer whales and dolphins (bottlenose/common dolphins) for the TSHD *William Fraser* under full dredging (pump on, draghead down, vessel underway and hopper being loaded).

Note the plots above show an entire dredge transect over multiple hours and is not the acoustic footprint or effect at a single point in time (as provided in Section 5.0).

Appendix F Underwater Noise Effects Modelling Results: The Coastal Carrier

Underwater noise measurements of the *Coastal Carrier* were undertaken on the 10th June 2019, during fine weather conditions (variable 10 knot breeze, sea state zero and no swell). The equipment used and methods for measurement and data analysis were identical those used for the *William Fraser*, as described in Section 4.3 *Sound Source Characterisation*. The hydrophones were calibrated using the same method described in Section 2.1.1 *Study Sites and Recorders* and operated continuously.

The vessel operated as normal, with no issues reported. Once it passed, the vessel continued north for approximately 1.3 km after passing the last hydrophone of the array (ST1), before turning around and passing the array again, southbound (Figure 33). The *Coastal Carrier* followed the 30m contour.

If there was any contamination (i.e. another vessel was detectable on the hydrophone (using both power spectra and detection of modulation of noise methods), those data were excluded from the analysis (Figure 34).

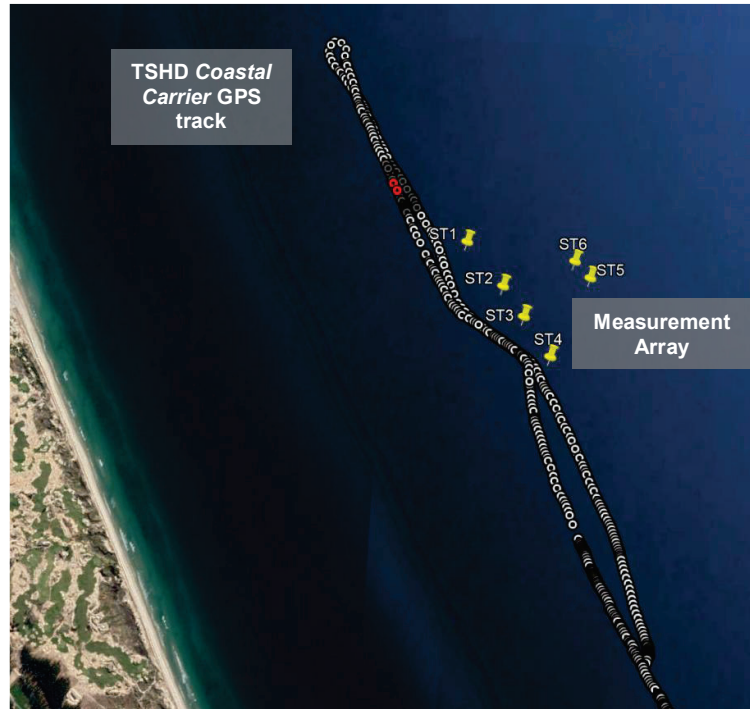


Figure 33: Google Earth image showing the GPS track of the *Coastal Carrier* in relation to the measurement (hydrophone) array (ST1 through 6) on 10 June 2019 in fine weather conditions

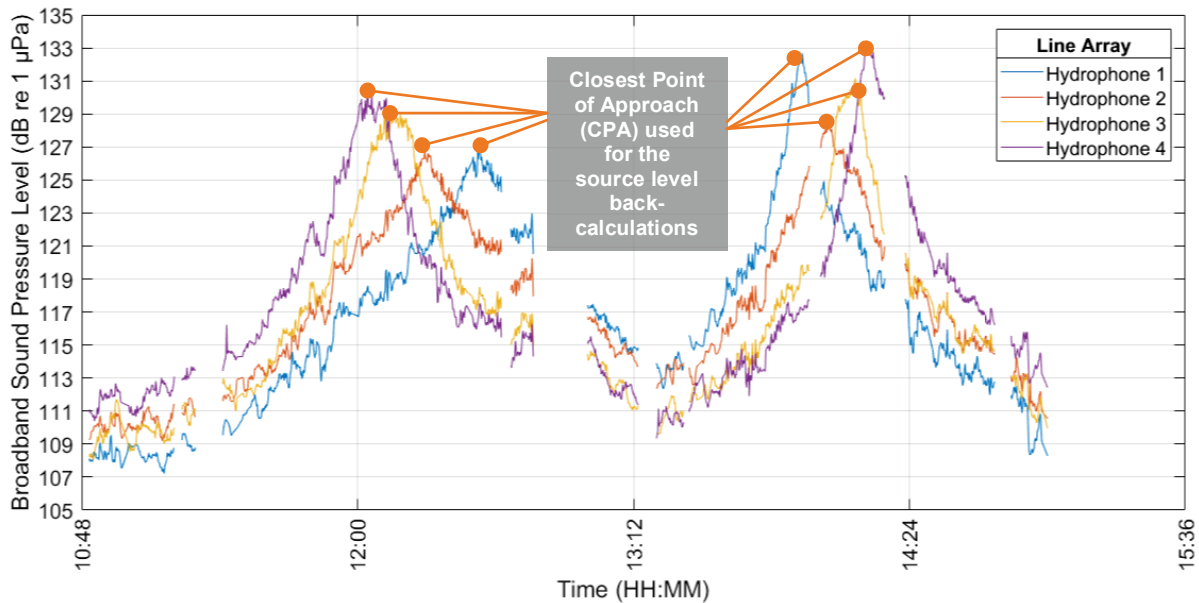


Figure 34: Measured SPLs from the inner hydrophones (ST 1, 2, 3, 4) as the Coastal Carrier moves through the northern consent area, actively dredging, passing the measurement array.

Data containing contaminating vessel noise (extraneous) were removed from the analysis

The underwater noise effects modelling were repeated for the *Coastal Carrier* using the same methods as described in Section 4.4 through Section 4.8.

During full dredging conditions (pump on, draghead down and loading the hopper), the TSHD *Coastal Carrier* is not expected to induce a TTS beyond 1 m distance due to the M-weighted source levels being below the required sound exposure level thresholds¹⁴.

Behavioural effects can be expected to occur within limited ranges from the *Coastal Carrier* (provided in Table AF1). The specific distances at which there is a 75% chance for some behavioural effect to occur (whether low or moderate in severity) is 28m for dolphin species and 178m for Bryde’s whales. A 50% probability of some behavioural effect occurring is restricted within 78m and 309m for dolphins and Bryde’s whales, respectively. Based on the baseline noise conditions that we measured between March and June 2019, the risk of behavioural effects occurring beyond 823m and 1955m (respectively for dolphins and Bryde’s whales) are not expected.

¹⁴ Those thresholds being the NMFS (2018) thresholds for LF- MF- and PW functional hearing groups.

Table AF1: Distances at which 75, 50, 25 and 0% risk of low and moderate behavioural responses for each of the species of interest.

Species	Behavioural Response	Risk isopeth (m)			
		75%	50%	25%	0%
Killer Whale	Low (minor changes in respiration rates, swimming speeds/direction)	28	78	148	823
Bottlenose Dolphin					
Common Dolphin	Moderate (moderate to extensive changes in swimming speeds/direction and/or diving behaviours, moderate or prolonged cessation of vocalisations, and/or avoidance)	NA	11	68	309
Bryde's Whale					
	Low (minor changes in respiration rates, swimming speeds/direction)	178	309	639	1955

Auditory masking effects, and the extent of such, varied between species, and are provided in Table AF2. Higher masking impacts, in terms of *LSR*, were seen for fur seals and Bryde's whales – the two species more sensitive to low frequencies – with averaged *LSRs* exceeding 80% and 75% within 20m, respectively. The spatial extent of any masking effects also occurred over longer distances for seals compared to cetacean listeners.

Table AF2: Distances at which 75, 50, 25 and 0% listening space reduction (*LSR*) occurs for each of the species of interest.

Species	Distance from the TSHD			
	75% LSR	50% LSR	25% LSR	0% LSR
Killer whale	NA	977	2212	3386
Bottlenose/Common dolphin	67	926	2264	3396
Bryde's whale	43	103	1955	2778
Fur seal	52	1235	2470	3499

The limits of audibility for each of the species of interest are provided in Table AF3. The audibility limit for Bryde’s whales are expected to be largest, followed by fur seals, then the dolphin species. This is expected, based on the hearing thresholds of each species. It is important to note, however, is that the audibility limits (like the *LSR* metric) is the averaged audibility limit over several critical bands for each species¹⁵.

Table AF3: Distances within which audibility is possible.

Species	Audibility radius (m)
Killer whale	3396
Bottlenose/Common dolphin	3436
Bryde’s whale	3602
Fur seal	3499

Generally, the noise effects from the newly constructed *William Fraser* are lower than for the older *Coastal Carrier*. For example, behavioural effects start within 309 and 1.96km from the *Coastal Carrier*, but between 617m and 1.44km from the *William Fraser*. Similarly, an overall decrease of 7.55 – 8.86% in the auditory masking effects zone was seen for the *William Fraser* (auditory masking effects seen within 2.78 – 3.5km from the *Coastal Carrier* compared to 2.57 and 3.19km from the *William Fraser*). No risk of hearing temporary threshold shifts beyond 1m from the *Coastal Carrier*, based on the empirical data, and no risk of PTS was found.

The complete modelling results for comparison with the *William Fraser* are provided below.

¹⁵ Similar to the *LSR* method as outlined in [Pine e t al. 2018 and 2019](#).

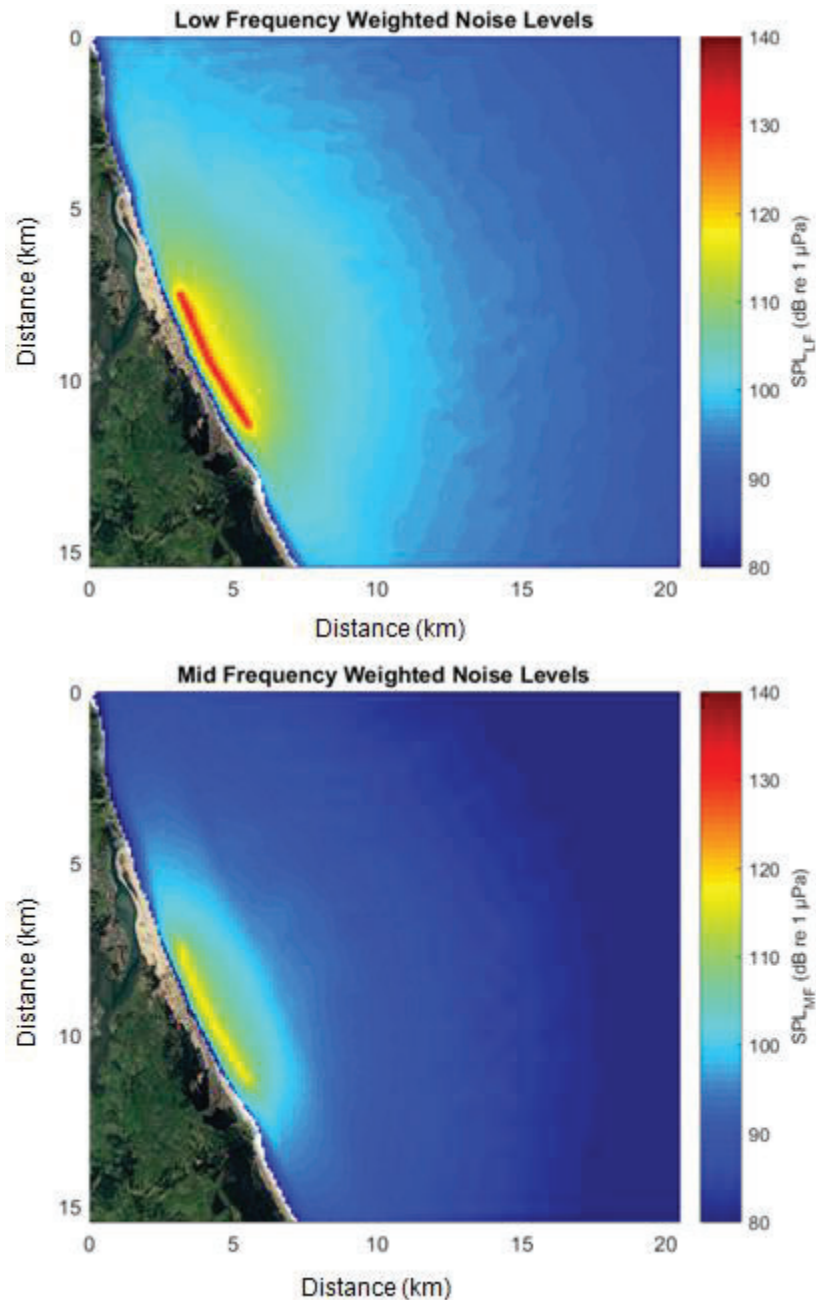


Figure 35: Modelled broadband (10Hz – 38 kHz) sound pressure levels for low-frequency and mid-frequency functional hearing groups for the TSHD *Coastal Carrier* under full dredging conditions (pump on, draghead down, vessel underway and hopper being loaded).

Note the plots above show an entire dredge transect over multiple hours and is not the acoustic footprint or effect at a single point in time (as provided in Appendix F above).

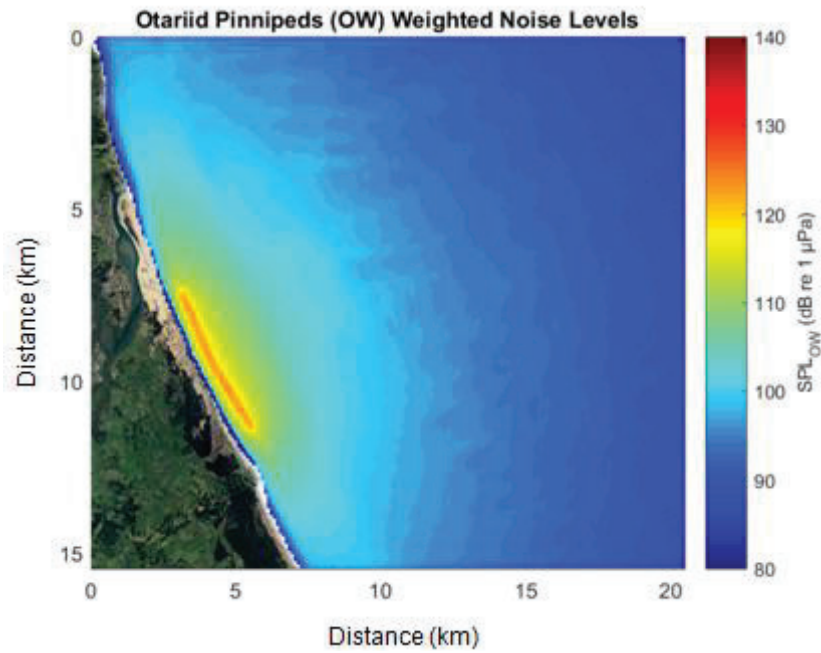


Figure 36: Modelled broadband (10Hz – 38 kHz) sound pressure levels for the otariid pinniped functional hearing group for the TSHD *Coastal Carrier* under full dredging conditions (pump on, draghead down, vessel underway and hopper being loaded).

Note the plots above show an entire dredge transect over multiple hours and is not the acoustic footprint or effect at a single point in time (as provided in Appendix F above).

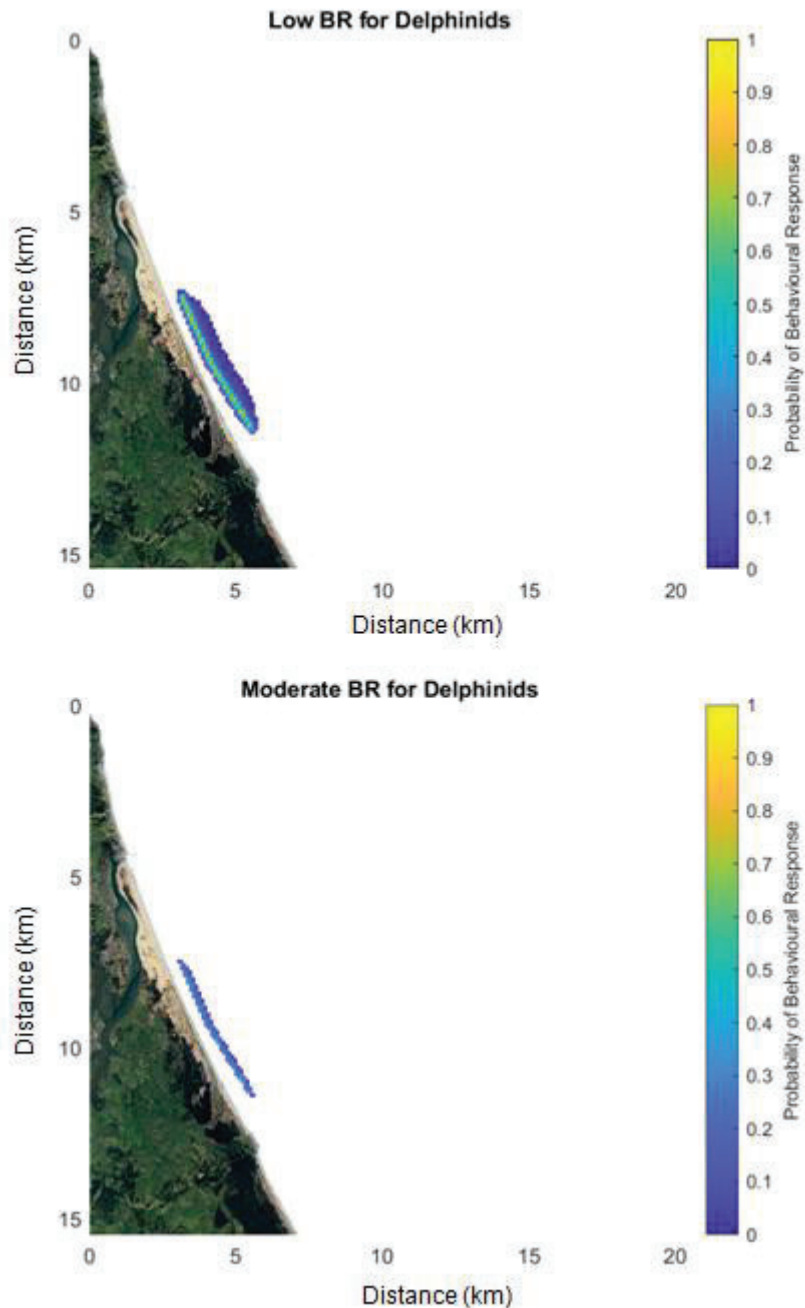


Figure 37: Low and moderate behavioural response risk (top and bottom panels, respectively) for dolphin species (either bottlenose or common dolphins) for the TSHD *Coastal Carrier* under full dredging (pump on, draghead down, vessel underway and hopper being loaded).

Note the plots above show an entire dredge transect over multiple hours and is not the acoustic footprint or effect at a single point in time (as provided in Appendix F above).

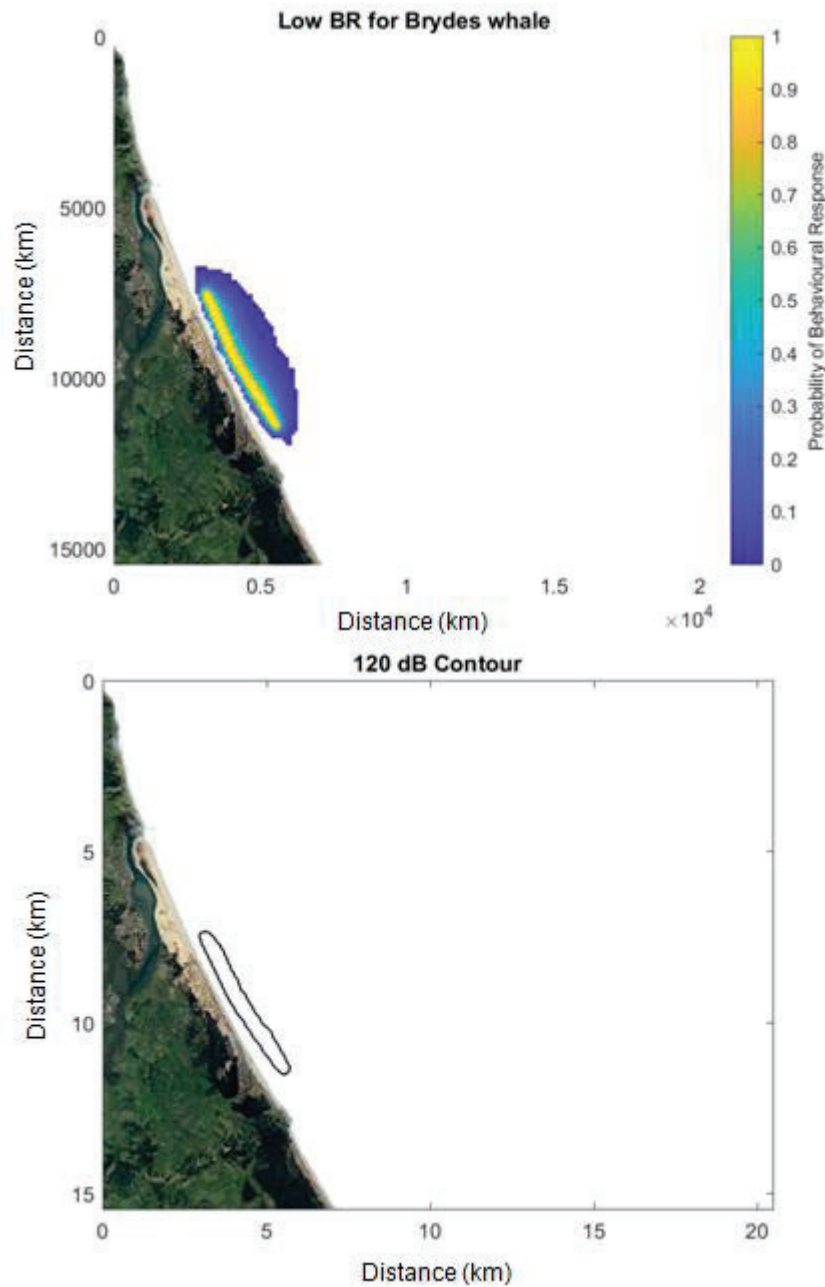


Figure 38: Low behavioural response risk for Bryde’s whales (top panel) and the 120 dB re 1 μ Pa contour for comparison (bottom panel) for the TSHD *Coastal Carrier* under full dredging (pump on, draghead down, vessel underway and hopper being loaded).

The dose-response formulas used to generate the probability of risk in Bryde’s whales was based on a 50% risk occurring at that 120 dB re 1 μ Pa threshold as a conservative measure.

Note the plots above show an entire dredge transect over multiple hours and is not the acoustic footprint or effect at a single point in time (as provided in Appendix F above).

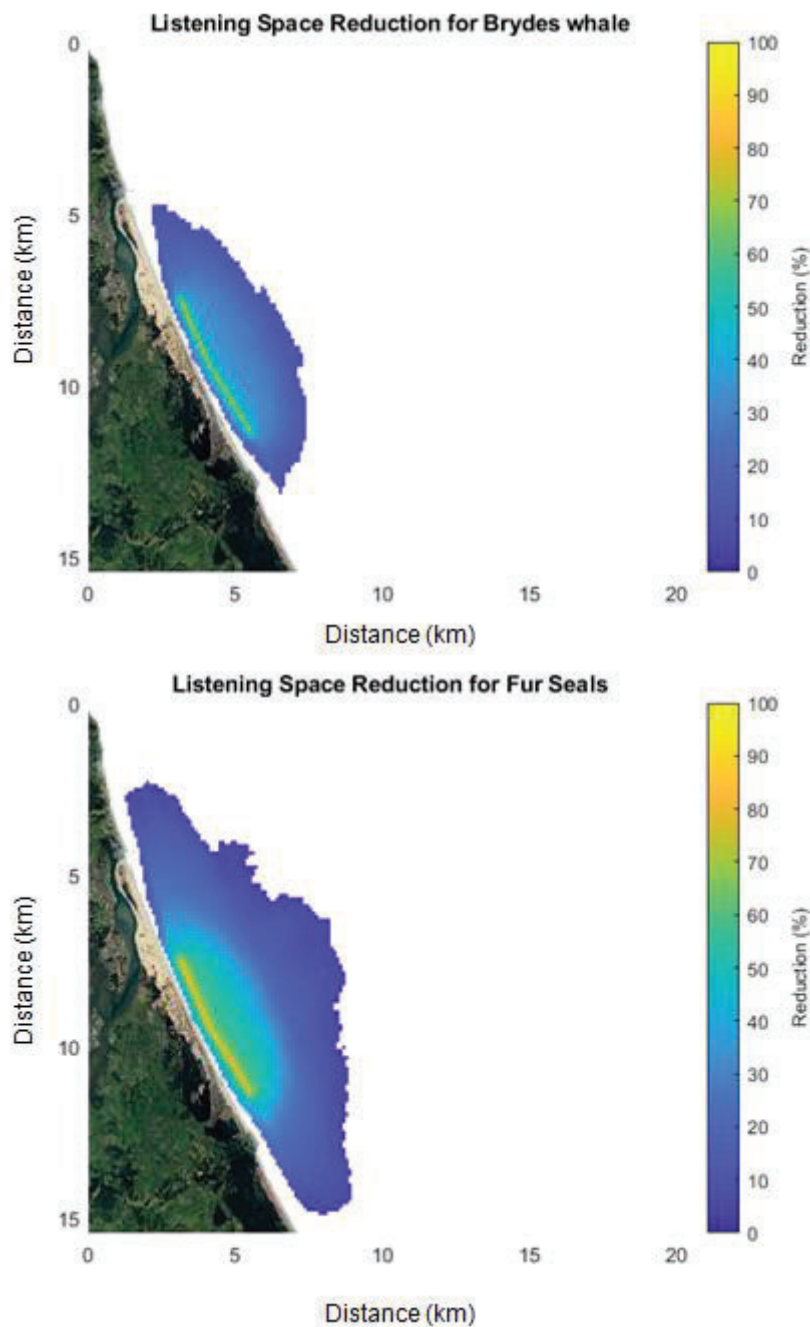


Figure 39: Plots showing the spatial extent of *LSRs* for Bryde’s whales and fur seals for the TSHD *Coastal Carrier* under full dredging (pump on, draghead down, vessel underway and hopper being loaded).

Note the plots above show an entire dredge transect over multiple hours and is not the acoustic footprint or effect at a single point in time (as provided in Appendix F above).

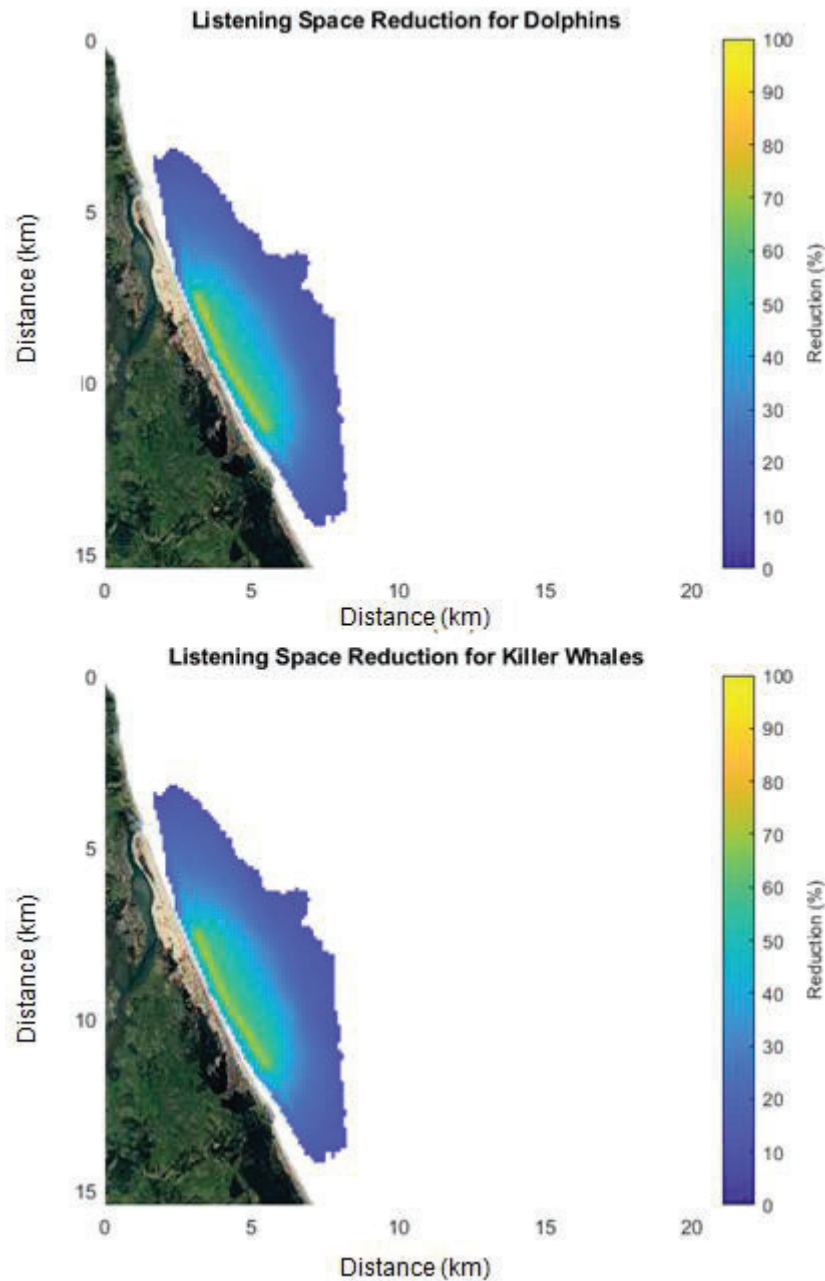


Figure 40: Plots showing the spatial extent of *LSRs* for dolphins (bottlenose/common dolphins) and killer whales for the TSHD *Coastal Carrier* under full dredging (pump on, draghead down, vessel underway and hopper being loaded).

Note the plots above show an entire dredge transect over multiple hours and is not the acoustic footprint or effect at a single point in time (as provided in Appendix F above).

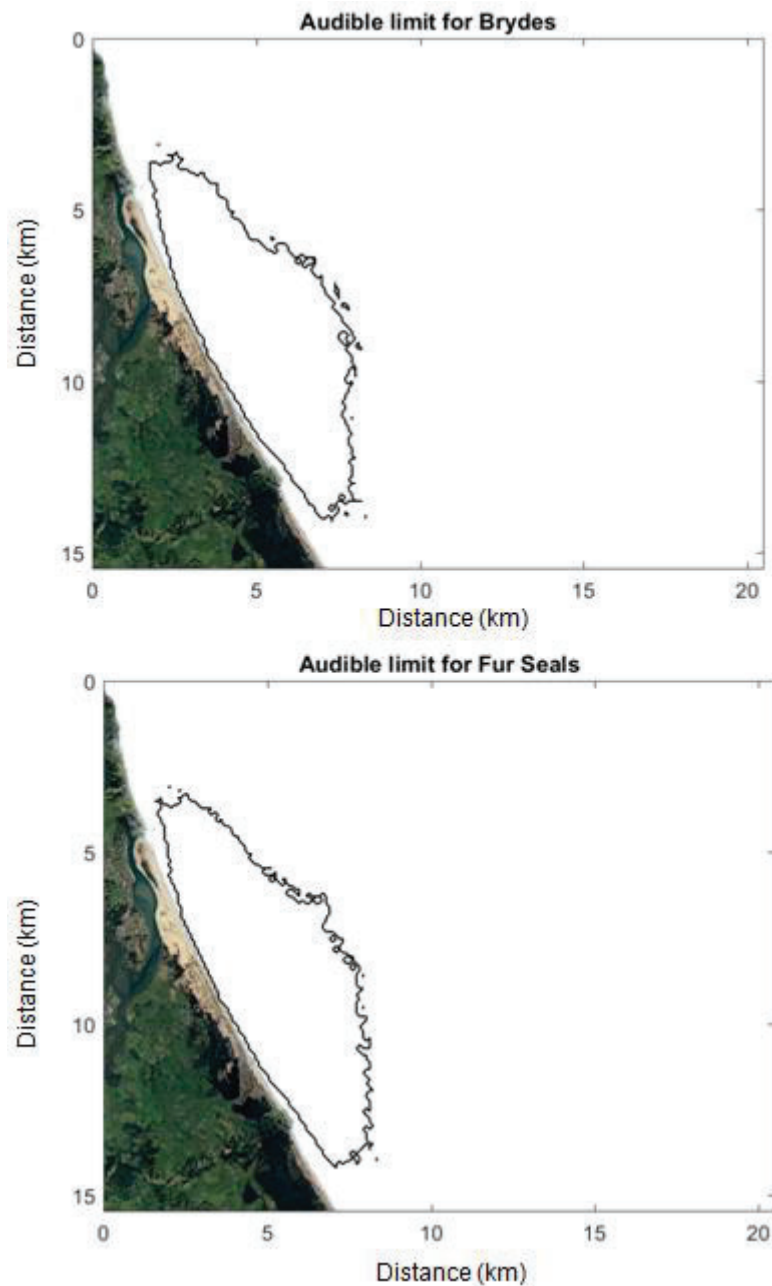


Figure 41: Plots showing the audibility limits for Bryde’s whales and fur seals for the TSHD Coastal Carrier under full dredging (pump on, draghead down, vessel underway and hopper being loaded).

Note the plots above show an entire dredge transect over multiple hours and is not the acoustic footprint or effect at a single point in time (as provided in Appendix F above).

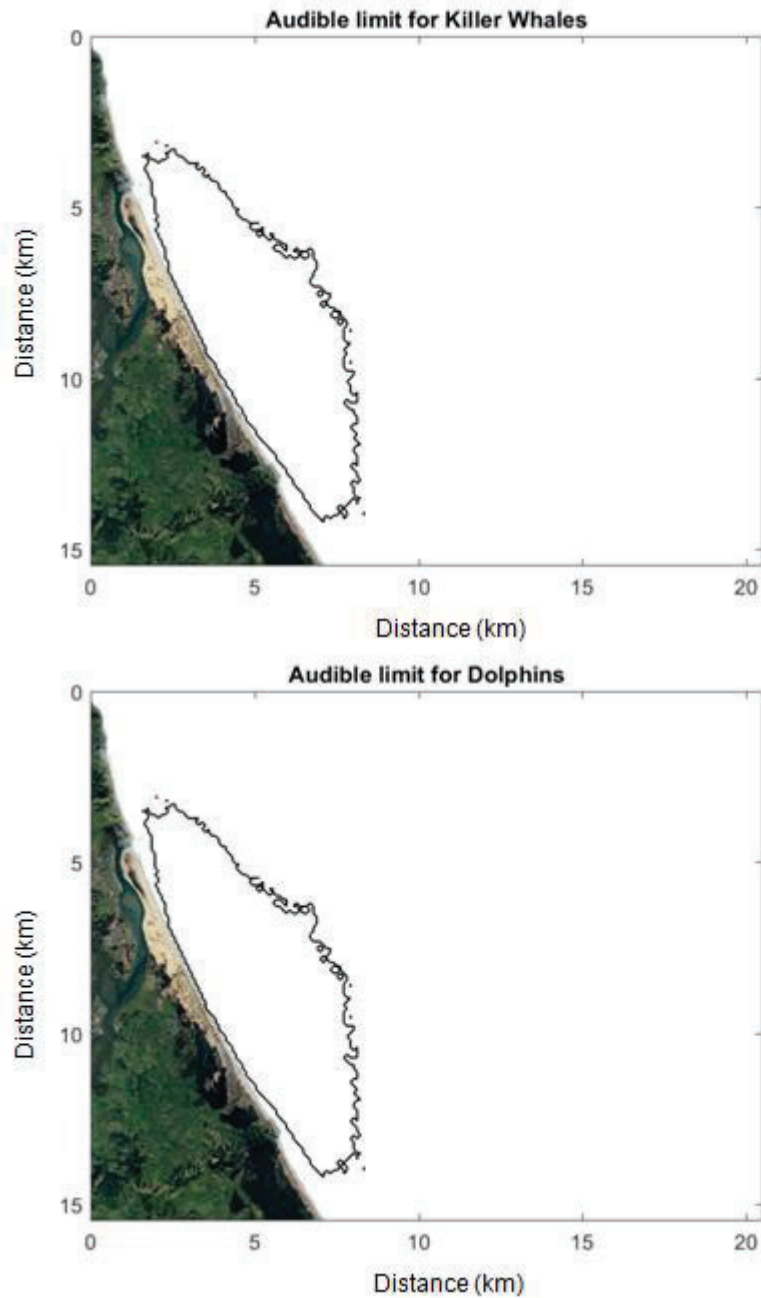


Figure 42: Plots showing the audibility limits for killer whales and dolphins (bottlenose/common dolphins) for the TSHD *Coastal Carrier* under full dredging (pump on, draghead down, vessel underway and hopper being loaded).

Note the plots above show an entire dredge transect over multiple hours and is not the acoustic footprint or effect at a single point in time (as provided in Appendix F above).

Appendix G Model Ground-Truthing

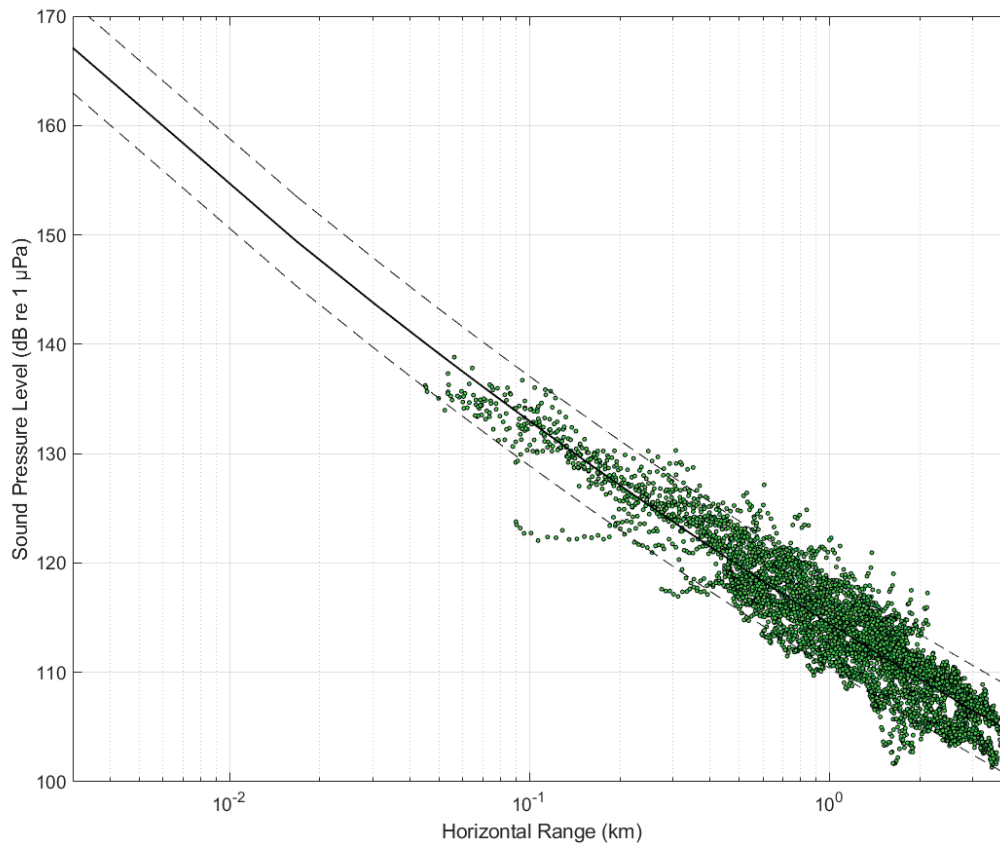


Figure 43: Curve-fitted data (and 90% confidence interval) from each of the six hydrophones in the measurement array. Each data point is the 10-second averaged SPL (10Hz – 48kHz) as the TSHD *William Fraser* operated in the northern consent area on 28 November 2019.

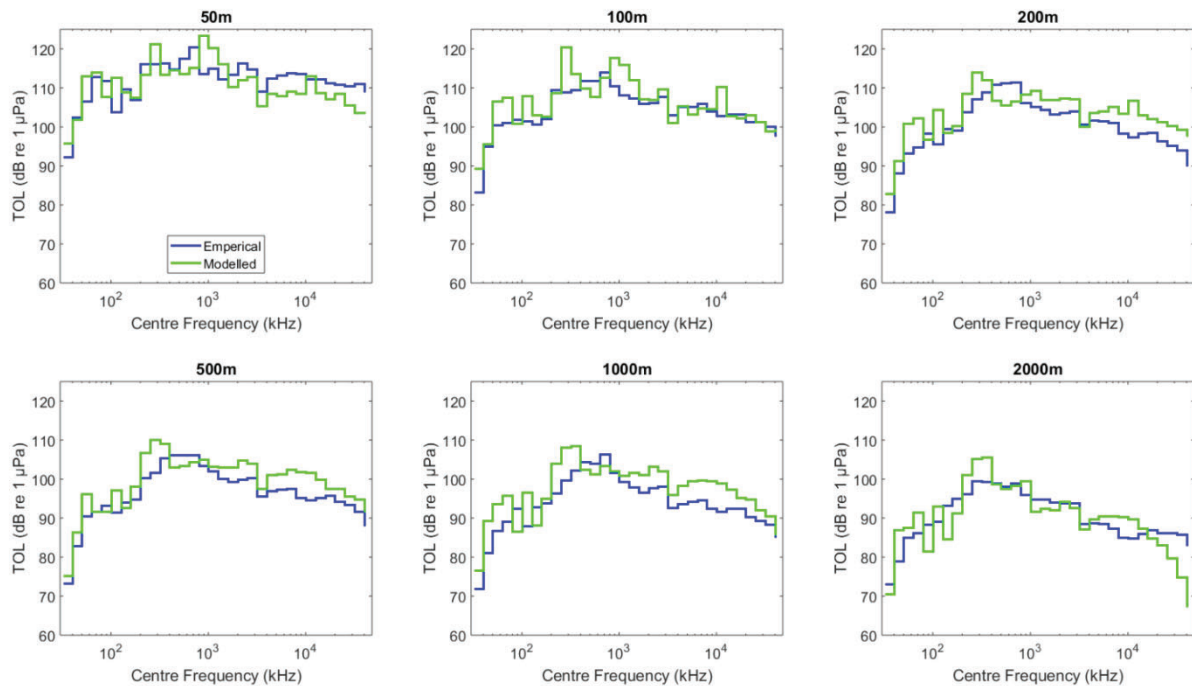


Figure 44: Modelled 1/3 octave sound pressures at various ranges compared to the empirical data.

The modelled levels incorporate the area-specific coefficient determined from the curve-fitted data for each three frequencies within a 1/3 octave band. This was based on the *Coastal Carrier* because the outputs are related to the frequency-dependent propagation loss only, which is independent to the type of dredger (given the modelled area is unchanged).