Compliance Monitoring Certified

Auckland Council

Date: 02/09/2021
CST60082321
Certifier: Sian Farrell
Related conditions: C24A
Revision: A

MARSHALL DAY Acoustics

KENNEDY POINT: LITTLE BLUE PENGUINS AND CONSTRUCTION NOISE

Rp 002 r04 2016226A | 19 August 2021

MARSHALL DAY Acoustics
Level 2, 5 Willeston Street
PO Box 25442
Wellington 6140 New Zealand
T: +64 4 499 3016
www.marshallday.com

Project: **KENNEDY POINT PILING**

Prepared for: **Kennedy Point Boatharbour Limited**
5 Auburn Street
Takapuna
Auckland 0622

Attention: **Kitt Littlejohn**

Report No.: **Rp 002 r04 2016226A**

Document Control

Status:	Rev:	Comments	Date:	Author:	Reviewer:
Issued	-	For ecologist	16-07-21	V. Warren B. Lawrence	C. Fitzgerald
Issued	01	For ecologist	26-07-21	V. Warren B. Lawrence	C. Fitzgerald
Issued	02	For ecologist	09-08-21	V. Warren B. Lawrence	-
Issued	03	For ecologist	09-08-21	B. Lawrence	C. Fitzgerald
Issued	04	For ecologist	19-08-21	V. Warren B. Lawrence	C. Fitzgerald

1.0 SUMMARY

Marshall Day Acoustics has been engaged to predict noise emissions, underwater and in-air, from wharf construction works at Kennedy Point, and to assess the potential effects the noise emissions may have on a nearby population of little blue penguins/kororā (*Eudyptula minor*).

We have undertaken a literature review of the current understanding of penguin hearing and their possible noise sensitivity. On-site, noise will be generated by various construction activities, with vibro-piling likely to be the loudest noise emitter. Our findings are:

- There is no specific guidance or thresholds for noise effects on kororā. We have therefore relied on studies on other penguin species, but we note that this data is also generally inconclusive – particularly regarding behavioural response. Little specific information can be determined beyond confirming that penguins are likely to be sensitive to noise at the frequencies produced by construction activities and may show behavioural responses to loud and/or continuous noise levels.
- Our measurements show that piling noise levels are well below the thresholds for hearing injury in birds, so there is no risk of kororā hearing impairment.
- The key threshold of relevance is therefore behavioural response. Our review of literature in relation to the project environment concluded that behavioural responses are likely to occur as a result of airborne noise levels around 80 dB $L_{Aeq(1s)}$, and underwater noise levels around 100-120 dB re 1µPa RMS or a signal noise ratio of 10 dB above ambient. However, behavioural effects could occur at lower levels which are not clearly defined. We recommend that these thresholds are used as a guide, with all practicable measures made to mitigate sound levels as much as possible.

We have measured construction noise on-site, and calculated the potential effects zones in-air and underwater using penguin hearing sensitivity thresholds obtained from the literature review. In summary:

Airborne noise:

- There is no risk of temporary or permanent hearing damage from drilling or vibro-piling
- Both drilling and vibro driving of the closest piles (12m) were measured to be 79 dB $L_{Aeq(1s)}$ at the breakwater, which is just below the 80 dB $L_{Aeq(1s)}$ threshold for behavioural response. Other sources such as engine noise and movement of tracked equipment were below 75 dB L_{Aeq} for the closest piles.
- We recommend the implementation of effective source screening for both drilling and vibro piling, which could achieve a 3 – 5 decibels reduction in source level. Other sound sources on-site, such as generator, excavators and cranes, should be screened as far as practicable.

Underwater noise:

- The ambient underwater noise levels at the proposed construction site are already close to or above the behavioural response threshold of penguins as a result of Sealink ferry and other permitted vessel movements, and natural sources including snapping shrimp.
- Vibro piling, drilling, engine noise and movement of tracked equipment all produced underwater noise at relatively low levels. The loudest was vibro piling, which was at the behavioural response onset threshold (SNR = 10 dB) at a distance of around 100m from the pile. Other sources, including drilling and engine noise, contributed less than 10dB to the ambient noise level over the frequencies of interest at 45m from the equipment.

A glossary of acoustic terminology is included in Appendix A.

A summary of our noise measurements of the drilling and vibro piling is included in Appendix B.

2.0 INTRODUCTION

Marshall Day Acoustics (MDA) has been engaged to carry out an acoustic assessment of wharf construction works required for the construction of Kennedy Point Marina, Waiheke Island, in relation to the population of little blue penguins/kororā (*Eudyptula minor*) that inhabit the adjacent breakwater.

Kororā are classified as 'at risk, declining' in the New Zealand Threat Classification[1]. Policy 11 (Indigenous biological diversity) of the New Zealand Coastal Policy Statement 2010 requires the avoidance of adverse effects on indigenous taxa listed as threatened or at risk. This noise assessment therefore focuses specifically on kororā.

Kennedy Point Marina is proposed west of the existing car ferry terminal on Donald Bruce Road, Surfdale, Waiheke Island. An artist's impression of the development is reproduced in Figure 1 below.

Figure 1: Artist's impression of Kennedy Point Marina. Breakwater with known kororā colony circled red.

The proposed marina features approximately 186 berths, up to 19 pile moorings and 30 public day berths; two floating wave attenuators, floating pontoons, pier and wharf; office, storage and visitor facilities, clubroom, up to 72 car parks and berth access.

Here, we have focused on drilling and pile-driving as these activities are expected to be the loudest sound emitting activities associated with the construction. We understand that impact piling will not be undertaken during the wharf construction.

Kororā are known to nest within the breakwater adjacent to the proposed marina development. Penguins are amphibious, spending time on land and underwater. For other species, such as marine mammals, guidelines for assessing the physiological impacts of anthropogenic (human-made) sound are defined and widely accepted (for example, NOAA Guidelines[2]). In the case of marine mammals, the NOAA Guidelines are a US statute that is accepted as current best practice in New Zealand. Unfortunately, similar guidelines are not yet defined for penguins. Accordingly, we have conducted a literature review of the current state of understanding of penguin hearing and noise effects.

---

[1] https://www.doc.govt.nz/globalassets/documents/science-and-technical/nztcs19entire.pdf

[2] National Oceanic and Atmospheric Administration: *'Technical Guidance for Assessing the Effects on Anthropogenic Sound on Marine Mammal Hearing'* (April 2018).

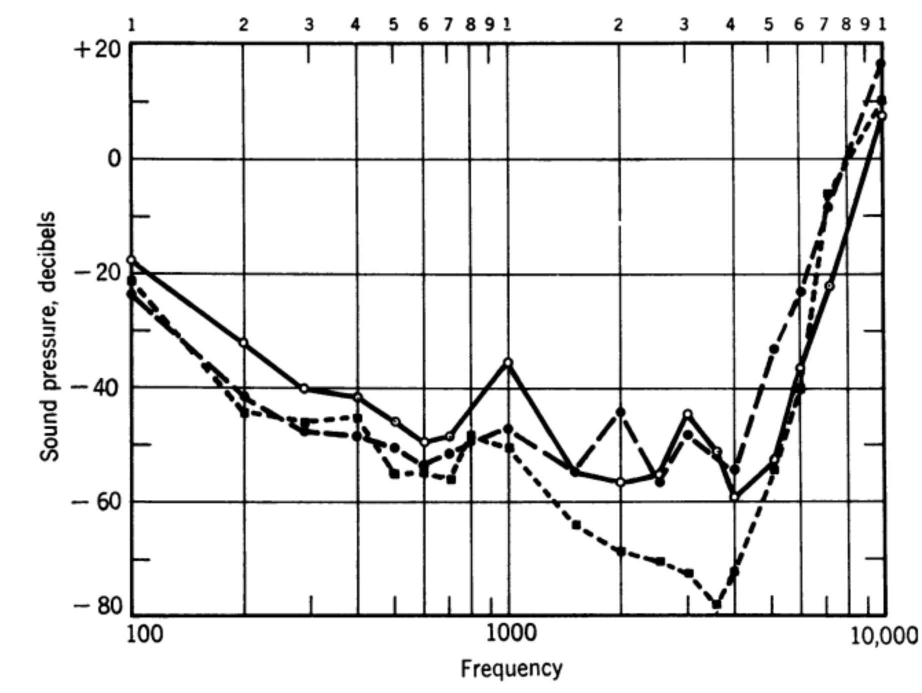
3.0 LITERATURE REVIEW

We have conducted a review of available literature on penguin hearing and their responses to noise to understand the potential effects of construction noise on the nearby kororā population.

There have been relatively few studies on the hearing abilities of penguins, and our research was unable to uncover any specifics pertaining to kororā hearing. Nonetheless, we have reviewed the available literature on penguin hearing in general as the best relevant information.

Hearing ability is determined by the frequencies that a species has the capability to hear, in addition to their sensitivity across those frequencies. Figure 2, from a 1969 paper[3], illustrates the sensitivity curves of three Blackfooted penguins (*Spheniscus demersus*) and shows that they are most sensitive to sounds between 600 and 4,000 Hz. Above and below this frequency range, sound needs to be at a louder level in order for the penguins to hear it, within the limits of their capabilities (i.e., they probably can't hear sounds at extremely high or extremely low frequencies, no matter how loud they are). These sensitivity curves are supported by the frequency range of penguin vocalisations: around 500 to 2,000 Hz fundamental frequencies for king (*Aptenodytes patagonicus*), macaroni (*Eudyptes chrysolophus*) and gentoo (*Pygoscelis papua*) penguins underwater[4], and below 1000 Hz to 5,500 Hz in air, for kororā specifically[5]. In general, an animal's hearing is most sensitive at the frequencies produced by its own species.

Figure 2. Sensitivity curves for three Blackfooted penguins. Frequency units = Hz. From Wever *et al.*, 1969



[3] 'Hearing in the blackfooted penguin, *Spheniscus demersus*, as represented by the cochlear potentials.' Wever *et al.*, 1969. https://www.pnas.org/content/pnas/63/3/676.full.pdf

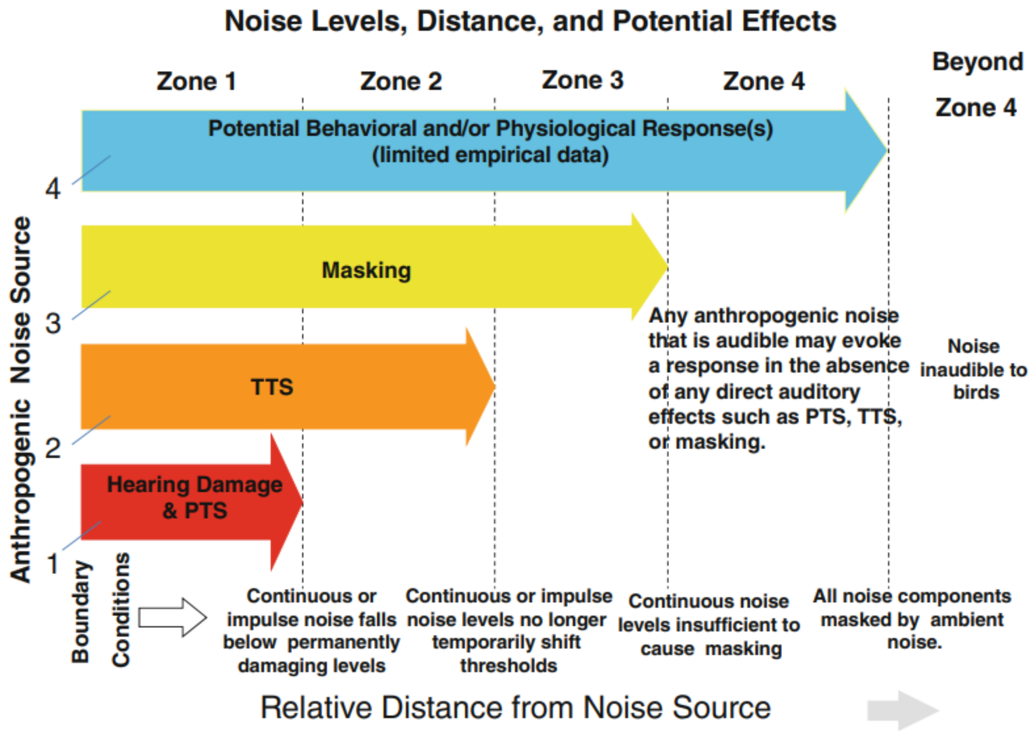
[4] 'First evidence of underwater vocalisations in hunting penguins.' Thiebault *et al.*, 2019. https://peerj.com/articles/8240/

[5] 'Heart rate changes reveal that little blue penguin chicks (*Eudyptula minor*) can use vocal signatures to discriminate familiar from unfamiliar chicks.' Nakagawa *et al.* 2001. https://www.jstor.org/stable/4601951

When an individual can hear a noise, there are several ways in which it could be affected, depending upon how loud the noise is, and how sensitive the animal is to it. Figure 3 (sourced from Dooling and Therrien, 2012[6]) illustrates:

- PTS (Zone 1): When the sound is loudest (when the noise source is close to the receiver), there is a potential for hearing damage and permanent threshold shift (PTS), which occurs when the ear anatomy is exposed to such high levels of sound that it is no longer able to hear quiet sounds.
- TTS (Zone 2): When the sound source is a little further away, and therefore not as loud, a temporary threshold shift (TTS) can occur where the ear is temporarily unable to hear quiet sounds following exposure, but the hearing recovers over time.
- Masking (Zone 3): Occurs when the sound source is not loud enough to cause hearing damage (permanent or temporary), but the sound is loud enough to disguise other sounds that are biologically important (e.g., sounds from predators, prey or other individuals).
- Behavioural Response (Zone 4): Can occur when the sound is audible but does not cause damage or masking – i.e., a notable change in behaviour due to the sound exposure. Behavioural responses may be context-specific (e.g., animals may be more easily disturbed during their breeding season), and some individual animals may be more affected than other.

Figure 3. Effect zones arising from exposure to noise, with respect to distance. From Dooling and Therrien, 2012.



Sound propagates more effectively underwater than in air. As kororā spend time above and below water, we have reviewed the literature for both of these scenarios.

[6] 'Hearing in Birds: What Changes from Air to Water.' a chapter by Dooling and Therrien 2012, from the book 'Effects of Noise on Aquatic Life.' Popper and Hawkins 2012.

3.1 Penguins and Airborne Noise

3.1.1 PTS and TTS

In air, continuous noise levels above 110 dBA SPL, or a single impulsive sound over 140 dB SPL, can lead to PTS in diving birds (Zone 1, Figure 3)[6]. TTS can occur at continuous noise exposure levels above 90 – 95 dBA SPL (Zone 2, Figure 3)[6].

3.1.2 Masking and Behavioural Response

Penguins are vulnerable to direct masking of their sounds (Zone 3, Figure 3) in air as they utilise auditory cues above water to identify other penguins[7]. This has been shown in kororā specifically[8]. The hearing threshold (i.e. the level at which sound becomes audible) of penguins in air is unknown (Zone 4, Figure 3), and will vary across frequencies (refer Section 3.0). When a sound is audible, it can potentially generate behavioural responses (Zone 4, Figure 3). Some studies have examined the behavioural responses of penguins to noise (Zone 4, Figure 3), and we review these below.

Concert Noise and Captive Fiordland Penguins in Melbourne Zoo

Captive Fiordland penguins/tawaki (*Eudyptes pachyrhynchus*) have been noted to exhibit significant behavioural changes during music concerts nearby Melbourne Zoo[9]. This study considered penguin behaviour before, during and after the concert. During concerts, penguins were noted to spend more time surface swimming and diving and less time interacting with their habitat than usual. Noise levels inside the penguin enclosure were not reported. This captive scenario may not be relevant to wild penguins, and it should be noted that behaviour changes were also noted in the 'before concert' period when the number of visitors to the penguin enclosure was higher than average. It is difficult to determine whether the reported behavioural responses were due to noise, or other factors, and in combination with uncertainty about the received level of the sound, we have chosen to exclude this data from our consideration.

Predator/Penguin Sound Playbacks and Australian Little Blue Penguins in Colony

Across all species, behavioural responses can be context specific. The behavioural responses of Australian little blue penguins were examined in relation to controlled predator and penguin sound playbacks.[10] The study found that little blue penguins exhibited lesser behavioural responses to sound disturbance when they lived in a fairly undisturbed colony with many penguin neighbours. Little blue penguins that lived in a smaller colony that was regularly disturbed displayed greater behavioural responses to the sound playbacks. This indicated that the penguins that were regularly disturbed did not habituate to all types of disturbance, and their reactions may have been due to lower response thresholds as a result of consistently high levels of stress.

[7] 'Measuring in-air and underwater hearing in seabirds.' a chapter by Crowell 2016, from the book 'Effects of Noise on Aquatic Life II.' Popper and Hawkins 2016. https://www.jstor.org/stable/4601951

[8] 'Heart rate changes reveal that little blue penguin chicks (*Eudyptula minor*) can use vocal signatures to discriminate familiar from unfamiliar chicks.' Nakagawa et al 2001.

[9] 'A preliminary study investigating the impact of musical concerts on the behavior of captive Fiordland penguins (*Eudyptes pachyrhynchus*) and collared peccaries (*Pecari tajacu*).' Fanning *et al*., 2020 https://www.mdpi.com/2076-2615/10/11/2035/htm

[10] 'Behavioural and heart rate responses to stressors in two populations of Little Penguins that differ in levels of human disturbance and predation risk.' Schaefer & Colombelli-Negrel, 2021. https://onlinelibrary.wiley.com/doi/abs/10.1111/ibi.12925

Overhead Aircraft Noise and King Penguins, South Georgia

King penguins (*Aptenodytes patagonicus*) on South Georgia exhibited significant behavioural responses to overhead aircraft and helicopters[11]. Unfortunately, in this instance, it is difficult to determine whether the reported behavioural responses were due to the sound levels produced by the aircraft or merely due to an object flying overhead, which may be analogous to a predatory bird, thereby initiating a predator response from the penguins. Indeed, the cause of behavioural responses can be difficult to pinpoint, and may result from cumulative aspects (e.g. the sound AND the overhead object). Nonetheless, this study provides sound levels at which behavioural responses occurred, which are some of the few available at the present time.

In the study[11], background sound levels in the penguin colony ranged from 65 – 70 dB L_{Aeq}. During aircraft over-flights, maximum 1 second L_{Aeq} levels ranged from 67 – 83 dB L_{Aeq}. Evidently, some of the over-flights that reportedly caused behavioural responses resulted in lower sound levels than the ambient level of background noise at other times. Indeed, two of the over-flights that generated behavioural responses did not materially elevate the ambient background environment, indicating that the penguins were not merely responding to noise. Similarly, at Kennedy Point Marina, disturbance will arise from various sources in addition to noise: people on site, movement and activity from large plant vehicles, boat movements, deliveries, and other activities.

Given the lack of other studies and clear acoustical information from which to draw conclusions, we conclude that the potential onset of behavioural responses are likely to occur at noise levels around 80 dB L_{Aeq}, but could occur at lower levels which are not clearly defined. We note that king penguins have surface nests as opposed to burrows, so their responses may not be directly comparable to kororā in burrows.

3.2 Penguins and Underwater Noise

3.2.1 PTS and TTS

To the best of our knowledge, the underwater sound levels that cause PTS (Zone 1, Figure 3) and TTS (Zone 2, Figure 3) in penguins are not known.

3.2.2 Masking and Behavioural Response

Penguins are sensitive to sound underwater as they utilise vocalisations at sea for group formation and during hunting[4]. Given that penguins rely on auditory cues to communicate, they may be particularly vulnerable to masking (Zone 3, Figure 3). Studies on other diving birds, such as cormorants, have revealed that they can hear sounds that are above 70 – 75 dB re 1µPa underwater [12]. Once a sound is audible, it has the potential to lead to behavioural responses.

Exploratory Seismic Survey Noise and African Penguins

African penguins (*Spheniscus demersus*) fitted with GPS trackers showed strong avoidance behaviour of a seismic survey occurring in their preferred foraging area[13]. Seismic surveying for sub-sediment oil and gas resources generates loud, impulsive sounds that propagate well in the marine environment. In this case, the seismic survey fired 169 airgun shots per hour and operated 24 hours per day. When the seismic survey was in operation, penguins from a nearby colony chose to forage in less preferred areas that were further away, therefore expending more energy than usual. Once the sound from

---

[11] 'Short-term responses of king penguins *Aptenodytes patagonicus* to helicopter disturbance at South Georgia.' Hughes *et al*., 2008. https://link.springer.com/article/10.1007/s00300-008-0492-2

[12] 'Great cormorants (*Phalacrocorax carbo*) can detect auditory cues while diving.' Hansen *et al*., 2017. https://link.springer.com/article/10.1007%2Fs00114-017-1467-3

[13] 'Avoidance of seismic survey activities by penguins.' Pichegru *et al*., 2017. https://www.nature.com/articles/s41598-017-16569-x

the seismic survey had ceased, the penguins returned to their preferred feeding area. The sound levels received by the free-ranging penguins was not recorded, and would have varied with distance from the survey itself. This study demonstrates that penguins respond negatively to loud impulsive underwater sound sources, although it should be noted that the planned piling methodologies at Kennedy Point Marina produce continuous sound, not impulsive sound.

Underwater Sound Playbacks and Captive Gentoo Penguins

In a 2020 study, underwater sound playbacks were made to Gentoo penguins in a tank[14]. The playback signals were broadband, 200 – 6,000 Hz, with 100ms ramp-up, 500ms signal and 100ms ramp-down. The source levels of the signals ranged from 100 - 120 dB re 1µPa RMS @ 1m, and were received by penguins at 0.4 – 1.5 m from the source leading to a ±3 dB variation from the source level. The 100 dB re 1µPa RMS had poor signal to noise ratio above the ambient level of the tank, and 12.5% of trials resulted in a minor behavioural response. Clear behavioural responses and startle responses occurred when the signal source level reached 110 dB re 1µPa RMS. At a source level of 120 dB re 1µPa RMS, 87.5% of penguins reacted to the underwater signal. 75% of the trials at 120 dB re 1µPa RMS resulted in a clear behavioural response or startle response. This study utilised a short, loud signal that likely surprised the swimming penguins. Such a signal is not comparable to the continuous stable sound levels produced by drilling, generator noise, or vibro, bored or screw piling. Nonetheless, there is a lack of more pertinent response data. Here, we consider the absolute response values of 110 – 120 dB re 1µPa RMS, and signal-to-noise ratio (SNR) of 10 – 20 dB re 1µPa RMS, in the context of the underwater environment at Kennedy Point Marina. The SNR must be considered only across the relevant frequencies i.e., the 200 – 6,000 Hz signal, which was designed to target the frequencies that penguins perceive most sensitively.

3.3 Summary

The reviewed literature indicated that penguins are sensitive to sound both in-air and underwater. The current state of understanding does not extend to the hearing abilities of little blue penguins specifically, nor have we been able to find references pertaining to the response thresholds of little blue penguins. We have reviewed the available literature relating to noise response thresholds of other penguin species and compared the descriptions of the acoustic environments in the literature to that of Kennedy Point to determine appropriate effect thresholds for behavioural response.

Our recommended thresholds for this project are summarised in Table 1. They must be considered with their respective caveats discussed above.

Table 1. Suggested effects thresholds for penguins – refer to preceding text for relevant caveats

Effect Zone (Figure 3)	**In-Air**	**Underwater**
PTS (Zone 1)	Above 110 dBA SPL (footnote 6) Single blast of 140 dB SPL (footnote 6)	Unknown
TTS (Zone 2)	90 – 95 dBA SPL continuous sound (footnote 6)	Unknown
Behavioural response observed (Zone 3)	80 dB $L_{Aeq(1s)}$ (footnote 11)	Approximately 110 - 120 dB re 1µPa RMS (footnote 14), <u>or</u> 10 – 20 dB re 1µPa RMS above ambient levels in 200 – 6,000 Hz frequency band (footnote 14)
Audible (Zone 4)	Unknown	Above 70 dB re 1µPa RMS (footnote 12)

[14] ‘Gentoo penguins (*Pygoscelis papua*) react to underwater sounds.’ Sorensen *et al*., 2020. https://royalsocietypublishing.org/doi/10.1098/rsos.191988

Note that due to variation in both reference pressure level and the properties of the medium (air vs water), underwater noise levels appear significantly higher than those typical in airborne environments. Thus, there is no direct relationship between sound levels expressed as decibels (dB), in air and underwater, and they should not be compared directly.

The available literature reviewed reported penguin responses to sound that was generally short, and/or impulsive. Such sounds may have generated startle or surprise responses in the penguins that occurred in addition to, or instead of, responses to the noise itself. Drilling and vibro-piling are continuous noise sources that should not generate such startle responses. However, in the absence of other reference information, we have proceeded with these thresholds as a guide.

In the following sections, we consider these suggested effects thresholds in relation to predicted and measured sound levels of piling activities at the Kennedy Point Marina construction site.

4.0 AMBIENT NOISE ENVIRONMENT

4.1 Airborne Noise Environment

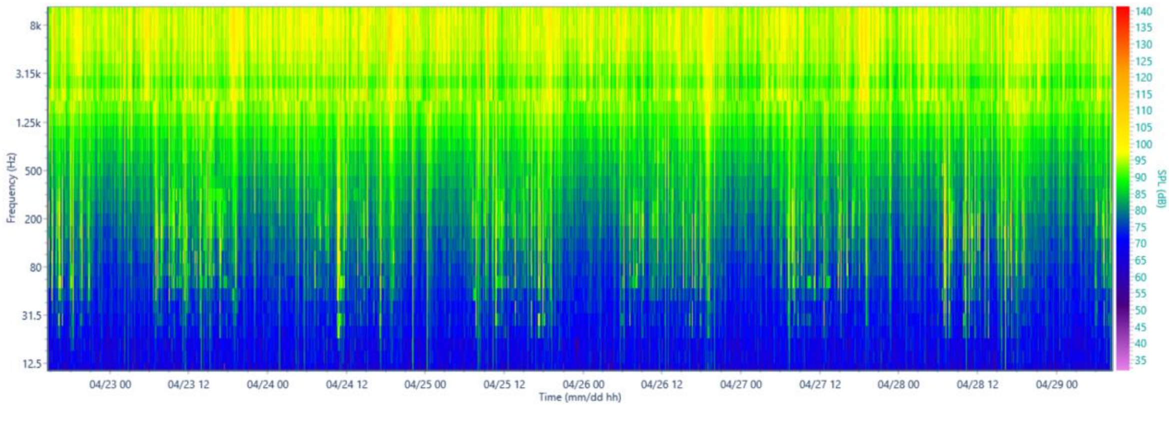
In April 2016, we measured airborne noise levels over a 7-day period at the reserve beyond the beach, around 100m from the breakwater. The average noise levels were 56 dB L_{Aeq} (ambient) and 46 dB L_{A90} (background) during the day, and 48 dB L_{Aeq} and 38 dB L_{A90} at night. The measured levels fluctuated over the survey period but were typical of a coastal environment. This monitoring location was in a quieter environment than the breakwater due to being away from the road leading to the ferry terminal.

Notable noise sources near the breakwater include heavy vehicles accessing the wharf (typical sound power levels of 100 – 103 dB L_{WA}) and the Sealink ferry (sound power level of 103 dB L_{WA}). We measured noise levels at the breakwater of up to 74 dB $L_{Aeq(1\ second)}$ during truck pass-bys during our site visit on 2 August 2021 (findings summarised in Appendix B).

4.2 Underwater Noise Environment

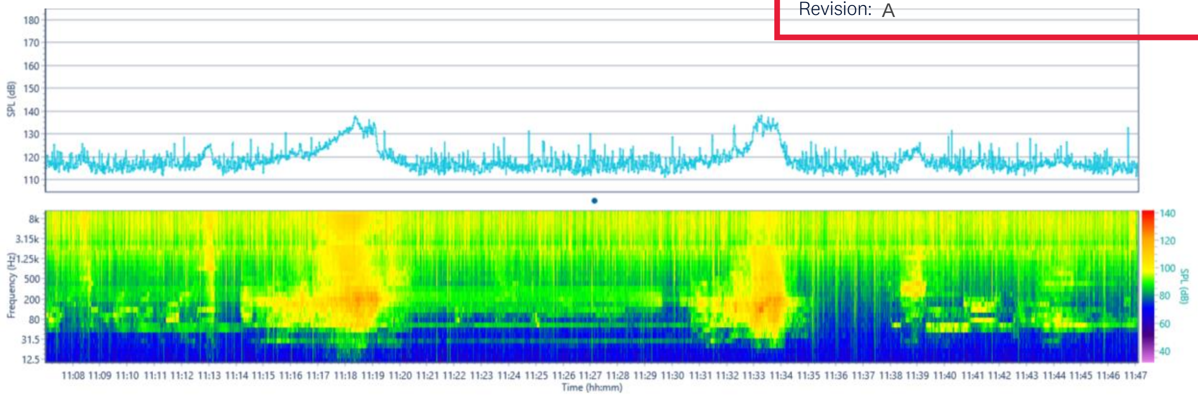
Ambient underwater noise levels near the breakwater were recorded continuously from 22 – 29 April 2016. Full details of the recordings are provided in our Acoustic Assessment report[15]. Figure 4 is a spectrogram of the full week of recording. This figure shows the domination of the soundscape by snapping shrimp, particularly at frequencies above 500 Hz. Below 500 Hz, sound levels were higher during the day compared to night-time. The ambient underwater noise level fluctuated with low frequency noise contributions from scheduled ferries and recreational boat movements (Figure 5).

Figure 4. Spectrogram of the underwater ambient data recorded 22-29 April 2016



[15] 'Kennedy Point Marina Acoustic Assessment', Marshall Day Acoustics, dated 20 February 2017

Figure 5. Spectrogram illustrating the arrival and departure of the Sealink ferry, 23 April 2016

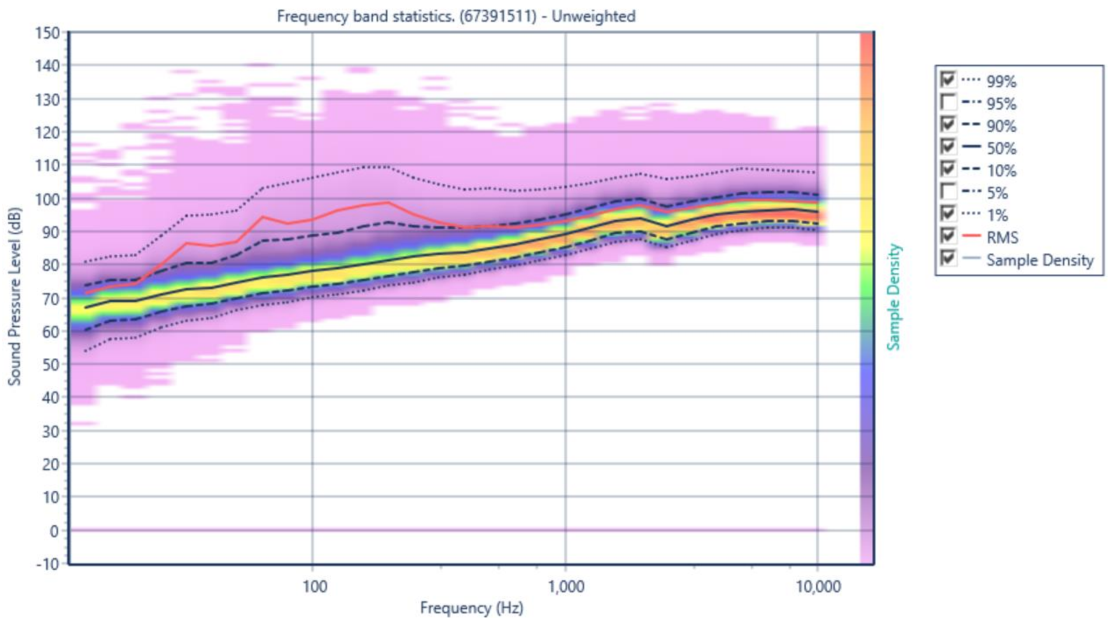


Across the recording period, the overall root-mean-squared (RMS level) was 107 dB re. 1µPa between 200Hz and 6kHz (weighted for the penguin hearing sensitivity range), while the broadband unweighted RMS level was 110 dB re. 1µPa (filtered to remove self-noise from the recording equipment below 10 Hz). The broadband RMS level is similar to those reported from other soundscape recordings in the inner-Hauraki Gulf environment[16].

The broadband daytime (7am to 7pm) RMS level was approximately 111 dB re. 1µPa, while the night-time (7pm to 7am) RMS level was approximately 109 dB re. 1µPa.

Figure 6 illustrates the spectral probability density of the data recorded across the full week in April 2016. The RMS (red line) is raised between 50-200 Hz; the main frequencies contributed by boat noise. The drop in sound pressure level across all percentiles around 2kHz is an artefact due to a performance anomaly in the recording equipment.

Figure 6. Spectral probability density of all data recorded 22-29 April 2016



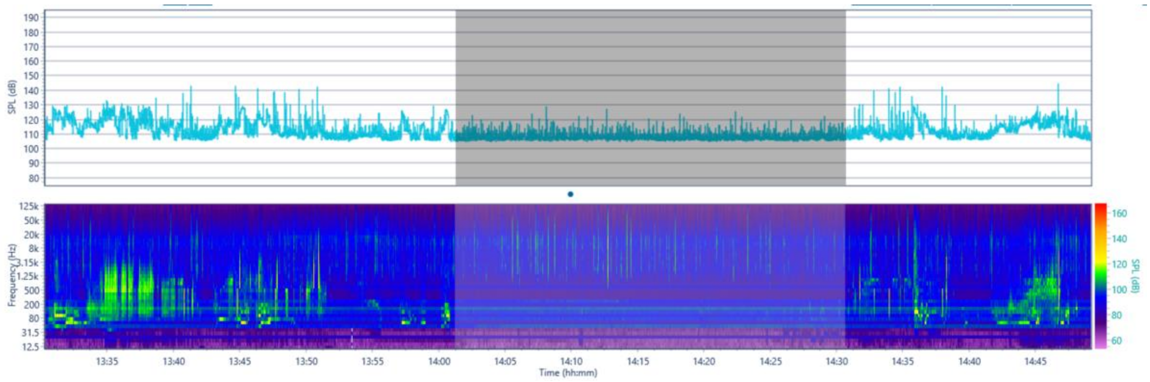
The underwater noise environment was also measured during our 2 August 2021 survey (summarised in Appendix B). The ambient environment was recorded during periods between construction activities. Figure 7 shows a highlighted section of ambient underwater noise. During this

16 'Exploring spatial and temporal trends in the soundscape of an ecologically significant embayment.' Putland, Constantine and Radford, 2017. https://www.nature.com/articles/s41598-017-06347-0

period, the RMS level in the penguin hearing range (200Hz to 6000 Hz) was 105 dB re. 1µPa, with a broadband unweighted RMS level of 109 dB re. 1µPa (filtered to remove self-noise from the recording equipment below 10 Hz). These ambient levels are very similar to the ambient noise levels recorded in 2016.

It should be noted that the existing ambient underwater environment in the penguin hearing range is approximately 3-5 dB below the penguin behavioural response threshold of 110-120 dB re 1µPa RMS suggested by the literature review.

Figure 7. Sound pressure level trace (upper) and spectrogram (lower) of ambient underwater noise (highlighted section) between construction activities recorded in August 2021



5.0 CONSTRUCTION NOISE SOURCES

Noise arising from pile-driving is likely to be the loudest construction activity. We have been advised that two piling methodologies are under consideration for the wharf: vibro driving the pile casings and drilling out the inside of the casings to depth. The following sections provide noise information for these methodologies based on our site measurements on 2 August 2021[17].

The general sound of engine noise (generators/power packs as well as excavator and crane engines) will also be key contributors to airborne sound levels; their sound emissions are considered below.

All noise levels have been filtered to only include 200 – 6,000 Hz in accordance with the penguin hearing range specified in Table 1.

5.1 Vibro Piling

Vibro piling is a widely used pile driving method. A vibrating hammer is positioned on the top of the pile using a crane, which then vibrates the pile to 'loosen' the soil particles and drive the pile under its own weight. A diesel generator powers the vibro hammer. It is common to vibro drive the pile until it will not go in any further (known as 'refusal') to create a seal. The purpose of this so that water cannot enter the pile casing. The inside of the pile is then drilled out to the required depth and filled with concrete and reinforcing.

Noise from vibro piling is mostly due to the pile and vibro hammer but also has appreciable contribution from the generator powering the vibro hammer. It generates relatively loud low to mid frequency noise continuously while the vibro hammer is on. High noise levels can be generated if the steel pile is in contact with the pile gate, but this can be avoided/mitigated.

The hammer is typically operated for 3 – 5 minutes then turned off so alignment of the pile can be checked. It can take around 30 minutes on average to drive a pile with the hammer operating around two thirds of the time.

In August 2021, we measured noise from vibro piling a 'test pile' that was driven for around 10 minutes for the purpose of obtaining noise data. We consider this data to be representative of the main noise sources associated with this methodology (the vibro hammer and power pack). We will be undertaking additional measurements to verify during installation of the next full pile to verify these levels but do not expect that the results will change.

The source levels based on our measurements are as follows (including engine noise):

Airborne noise levels: 106 dB L_{WA} (80 dB L_{Aeq} at 12m)

Underwater source levels: 119 – 121 dB re. 1µPa rms at 45m
116 dB re. 1µPa rms at 105m

Ground Vibration: Not perceptible at 12m (i.e., < 0.3mm/s PPV)

Noise barriers on the barge screening the power pack from the breakwater is predicted to reduce noise levels by around 3 decibels.

5.2 Drilling

Drilling involves an excavator or crane-mounted drill rig, which drills out the inside of a pile casing that has been installed with a vibro hammer. The primary noise source is the diesel engine on the crane/generator which drives the drill and the whining noise from the drill attachment.

During drilling, high noise levels can be generated when the spoil is removed by shaking the drill, but this is be avoided or at least significantly mitigated by removing the spoil with a shovel. We also note that the kelly bar can slip on the drill during drilling, but this can be mitigated with the installation of a

[17] Detailed in our letter 'Lt 006 R01 2016226A BL - Little Blue Penguins - Piling Measurements', dated 5 August 2021

section of rubber between the drill shaft and pile casing to create a seal which minimised noise from breaking out of the top of the pile. We have also been informed from the drilling team that this is generally preventable through careful operation of the drill rig.

The source levels based on our measurements are as follows (including engine noise):

Airborne noise levels: 106 dB L_{WA} (80 dB L_{Aeq} at 12m)

Underwater source levels: 110 – 112 dB re. 1µPa rms at 60m.

Ground Vibration: Negligible/undetectable

Noise barriers attached to the side of the barge/pile gates which block line of sight to the drill head and spoil bin is predicted to provide a reduction of 3 – 5 decibels. Similarly, noise barriers blocking line of sight to generators and other noise sources are also predicted to provide a reduction of 3 – 5 decibels.

5.3 Engine Noise

Most construction equipment is powered by large diesel engines. This includes the excavator with drill attachment, tracked crane on the equipment barge, and the vibro hammer power pack. Noise from these engines is a notable part of the noise emissions from the site both in air and underwater.

The source levels based on our underwater noise measurements and airborne noise data from measurements of comparable equipment are as follows (engine noise only):

Airborne noise levels[18]: 93 – 103 dB L_{WA} (up to 80 dB L_{Aeq} at 8m)

Underwater source levels: 106 – 116 dB re. 1µPa rms at 35 – 45m.

Ground Vibration: Negligible/undetectable

As discussed above in the vibro piling and drilling sections, shielding of engines is predicted to achieve a 3 – 5 decibel reduction in airborne noise levels received at the breakwater.

5.4 Movement of Tracked Equipment

Movement of the crane on the equipment barge and excavator on the jack up barge also generated airborne and underwater noise.

The source levels based on our measurements and are as follows:

Airborne noise levels: 99 dB L_{WA} (up to 80 dB L_{Aeq} at 5m)

Underwater source levels: 109 – 114 dB re. 1µPa rms at 35 – 45m.

Ground Vibration: Negligible/undetectable

6.0 AIRBORNE NOISE ASSESSMENT

6.1 Predicted Airborne Noise Levels

We have predicted airborne noise levels from the proposed construction methodologies based on our August 2021 measurements.

The rock armouring of the breakwater and any soft sediment inside penguin burrows may attenuate sound, meaning that received noise levels inside the burrows may be slightly lower than those outside. However, given the uncertainty, we have conservatively assumed no attenuation from the rock armouring.

[18] Airborne noise levels were not measured specifically for these equipment items during our August 2021 site visit. Therefore we have used data from measurements of comparable equipment on other projects

Typical set-back distances for each piling methodology are presented in Table 2.

Table 2. Received sound levels (dB L_{Aeq}) per piling methodology, per set-back distance (excluding barriers)

Distance (m)	Vibro-piling	Drilling	Engine noise	Tracked equipment moving
10	81	81	78	74
15	77	77	74	70
20	75	75	72	68
25	73	73	70	66
30	71	71	68	64
40	68	68	65	61
50	66	66	63	59

If engines and/or generators of construction machinery can be shielded, then noise levels at the receiver can be reduced by approximately 3 – 5 decibels.

Installing noise barriers at the breakwater to block line of sight from the penguin burrows to the construction activities is predicted to provide an additional 5 decibel reduction in received noise level. With these barriers and the localised source screening mentioned above, an overall reduction of 10 decibels could be achieved.

6.2 Airborne Noise Levels in Relation to Kororā Thresholds

6.2.1 PTS and TTS

All predicted and measured airborne noise levels were below the penguin PTS and TTS thresholds in the breakwater area.

6.2.2 Behavioural Response

Our review of literature in relation to the project environment concluded that the potential onset of behavioural responses is likely to occur at noise levels around 80 dB $L_{Aeq(1s)}$ but could occur at lower levels which are not clearly defined. We therefore recommended that 80 dB $L_{Aeq(1s)}$ is the appropriate behavioural response threshold in this context.

Once the loud bangs from the slipping kelly bar were resolved (refer footnote 17), the sound levels arising from drilling at the closest pile location were 79 dB L_{Aeq} at a distance of 12m from the pile. This is just below our recommended behavioural response threshold. Noise barriers on the side of the jack up barge blocking line of sight to the drill head are predicted to provide a further 3 – 5 decibel reduction.

Our measurements demonstrated that vibro piling sound levels were also 79 dB L_{Aeq} at 12m distance. Noise levels could be further reduced by around 3 decibels with noise barriers screening the vibro powerpack on the barge.

Engine noise and the movement of tracked equipment at the closest point to the breakwater also resulted in sound levels less than 80 dB L_{Aeq} at the breakwater.

7.0 UNDERWATER NOISE ASSESSMENT

7.1 Underwater Noise Levels from Construction Activities in Relation to Kororā Thresholds

As noted above, the existing ambient underwater environment excluding any construction related sources in the penguin hearing range (200 Hz to 6000 Hz) is approximately 3 – 5 dB below the penguin behavioural response threshold of 110 – 120 dB re 1µPa RMS suggested by the literature review.

We have therefore considered the construction noise in the context of a signal to noise ratio (SNR) of 10 – 20 decibels above the ambient environment for behavioural response, based on the literature review (refer Section 3.3).

As discussed in Section 4.2, the ambient underwater noise environment averaged 105 – 107 dB re 1µPa RMS within the penguin hearing bandwidth. From our measurements, we can determine the following:

- Vibro piling is at a level of 119 – 121 dB re 1µPa RMS at a distance of 45m. This value results in a SNR of 13 – 15 dB.
- Vibro piling is at a level of 116 dB re 1µPa RMS at a distance of 105m (11 decibels above ambient). This is approximately at the SNR = 10 dB threshold, which is the level for the potential onset of underwater behavioural responses, based on our literature review.
- Drilling is at a level of 110 – 112 dB re 1µPa RMS at a distance of 45m. This results in an SNR of 5 dB, which is below the level at which the potential onset of behavioural responses may occur.
- Engine noise and moving tracked equipment generated noise levels of up to 114 - 116 dB re 1µPa RMS at distances of 35 – 45m during noisy periods. This is approximately at the SNR = 10 dB threshold, which is the potential onset of underwater behavioural response.

The construction site is situated in very shallow water (less than 10m, and tidal), where sound propagation is complex and variable. As such, we do not consider that it is appropriate to ascertain source levels (sound level @1m), or to extrapolate the exact areas over which sound levels are raised by construction activities. That said, each individual activity (vibro piling, drilling and engine noise) was at or below the 10 dB SNR threshold in our recordings at 105m distance. We therefore propose that the underwater penguin effect zone (for behavioural response) is approximately 100m radius from the piling location, and this could be reduced by effective underwater noise mitigation, such as bubble curtaining.

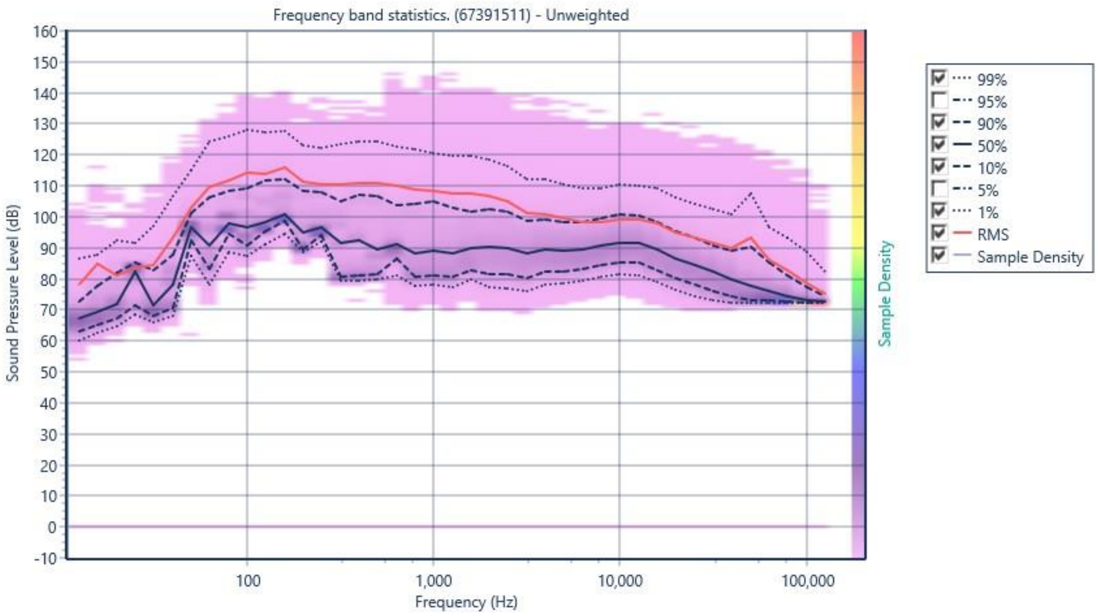
7.2 Comparison with Vessel Movements

We have also compared the construction activities to vessel movements, which are not necessarily associated with the construction activity. In summary, vessel movements were measured to be significantly louder than the construction works and above the SNR = 10 dB behavioural response threshold:

- Noise levels from what appeared to be small vessels ranged from 110 – 128 dB re 1µPa RMS, and larger noisier vessels ranged from 114 – 135 dB re 1µPa RMS. The distance from the vessels to the hydrophones is not known.
- Analysis of the 2016 underwater noise data (refer Section 4.2) showed that the Sealink ferry generated received noise levels of up to 130 dB re 1µPa RMS. The vessel was estimated to have been at 100 – 200m from the measurement location.

Figure 8 illustrates the spectral probability density of all sound contributors recorded on-site on 2 August 2021. Compared to Figure 6 (spectral probability density of ambient levels recorded in 2016), overall sound levels were approximately 10-20 dB higher in August 2021 as a result of construction activities and increased vessel activity. As per the 2016 data, sound was raised in the 50-200 Hz band due to vessel movements. Vibro piling contributed sound below 1000 Hz, and generator noise was generally below 500 Hz (refer Figure 9 in Appendix B).

Figure 8. Spectral probability density of all data recorded on-site on 2 August 2021



8.0 NOISE MITIGATION OPTIONS

As kororā are likely to be sensitive to noise both in-air and underwater, our overarching advice is to maximise noise mitigation to ensure that noise levels are as low as practicable.

The following mitigation is currently being implemented and is important to ensure the relevant zones are not larger than presented in this assessment:

- Remove spoil from the coring barrel using a shovel instead of shaking the barrel with the excavator which causes loud banging noises
- Install a section of rubber between the drill shaft and pile casing to create a seal which minimises noise from breaking out of the top of the pile.
- Ensuring the operator of the drill rig is appropriately briefed on noise sensitivity and taking due care to minimise banging.
- Avoid steel on steel contact between the pile casing and pile gate when vibro driving using rubber or a similar material on potential areas of contact.

The following sections provides guidance for further mitigation options to reduce in-air and underwater noise levels. In doing so, effect zones can be reduced in size, and behavioural responses may be less, or avoided. In our experience, these are effective mitigation options to mitigate noise emissions and manage noise effects.

8.1 General Mitigation Recommendations

8.1.1 Pile during periods of least disturbance

The project ecologist, Dr Leigh Bull, has advised that outside of the breeding (July to December) and moulting (December to April) seasons kororā are rarely on land during the day as they forage offshore during daylight hours[19]. These daytime periods, when penguins are likely to be away from their burrows, provide a window of opportunity when acoustic disturbance to the penguins may be minimised.

8.1.2 Observers and shut-down procedures

Current practice to manage noise effects is to utilise observers to monitor the effect zones, and shut down piling activities if a sensitive animal (i.e. a kororā) is sighted inside the zones. The behavioural response zones from piling without additional mitigation may be impractical to manage due to their size, therefore additional mitigation would be required to reduce the size of the effect zones.

8.1.3 Modify piling rates

The methodology can be revised to reduce cumulative sound exposure. This could involve:

- Limiting the number of piles installed per day.
- Limiting the duration of vibro piling by prioritising screw piling.
- Minimising vibro piling by drilling out the pile to depth once a seal has been achieved.

8.1.4 Verification measurements

Verification measurements are key to ensuring noise emissions are controlled.

Our assessments are based on measurements of similar piling rigs to the proposed systems and the underwater noise model produces conservative zones. This generally means that on-site verification measurements reveal that the zones are smaller than predicted.

However, in some cases, the zones can be larger. This can be the result of mitigation not working effectively (e.g. noise barriers not functioning/installed correctly), a louder rig is used, or the piling rates are higher than anticipated.

On-site verification 'closes the loop' that ensures the mitigation and management measures are appropriate and effective.

8.2 Mitigation Recommendations for Noise In-Air

8.2.1 Noise barriers

Noise barriers can be used to shield a receiver (i.e. penguins) from a noise source (i.e. piling). They should be installed prior to works commencing and maintained throughout the works. We propose that noise barriers could be erected on the piling rig itself, perhaps in addition to further noise barriers which could be erected on structures between the piling and the breakwater. With localised screening at the source, and barriers at the receiving location, we predict a noise reduction of approximately 10 decibels could be achieved.

Where practicable, the following guidelines should be applied in designing and installing temporary noise barriers:

- The panels should have a minimum surface mass of 6.5 kg/m^2. Suitable panels include 12 mm plywood or the following proprietary 'noise curtains': proprietary
  - Hushtec 'Premium Series Noise Barrier' (www.duraflex.co.nz)
  - Soundbuffer 'Performance Acoustic Curtain' (soundbuffer.co.nz)
  - Safesmart 'Acoustic Curtain 6.5kg/m^2' (www.safesmartaccess.co.nz)

[19] 'BM210282_002_Kennedy_Point_marina_LBP_monitoring__management_plan_RevB_20210615 CLEAN' by Dr Leigh Bull, dated 15 June 2021.

- o Alternatives should be approved by a suitably qualified and experienced acoustic specialist
- The panels should block line-of-sight between source and receiver.
- The panels should be abutted, battened or overlapped to provide a continuous screen without gaps at the bottom or between panels.
- Barriers should be positioned as close as practicable to the noise source. A site hoarding at the boundary may not be effective for all receivers.

8.2.2 Piling shroud

Sailmakers provide a custom vinyl shroud for piling rigs, used to control dust (http://sailmakers.co.nz/cll-drill-surround/). With the option to be constructed from 1800gsm vinyl, and deployment/retraction via a winch mounted on top of the piling rig head, this shroud may provide noise mitigation for the shaft.

8.3 Mitigation Recommendations for Noise Underwater

8.3.1 Bubble curtain

A ‘curtain’ formed by freely rising bubbles produced by air which is compressed and injected from a tube that surrounds the pile source. The density difference between air and water, as well as the bubble size and shape, help to scatter and absorb sound energy.

A proprietary bubble curtain example is the Canadian Pond bubble curtain (https://canadianpond.ca/en/), which can be sourced from EcoNets (https://econetsaustralia.com/)

We have worked on another piling project in New Zealand where bubble curtain mitigation reduced high frequency sound (>500 Hz) arising from impact piling by up to 20 decibels (see also Bellman 2014[20]).

8.3.2 Isolation casing

Pile driving is undertaken within a larger steel tube casing resting on the seabed. This can reduce the noise transmitted directly into the surrounding water. More effective casings systems can include a bubble curtain between the pile and shell casing for enhanced absorption.

[20] ‘Overview of existing noise mitigation systems for reducing pile-driving noise.’ Bellman 2014. https://www.acoustics.asn.au/conference_proceedings/INTERNOISE2014/papers/p358.pdf

APPENDIX A GLOSSARY OF TERMINOLOGY

Noise	A sound that is unwanted by, or distracting to, the receiver.
dB	Decibel (dB) is the unit of sound level. Expressed as a logarithmic ratio of sound pressure (P) relative to a reference pressure (Pr), where dB = 20 x log(P/Pr). The convention is a reference pressure of Pr = 20 μPa in air.
dBA	The unit of sound level which has its frequency characteristics modified by a filter (A-weighted) to more closely approximate the frequency bias of the human ear. A-weighting is used in airborne acoustics.
$L_{Aeq\ (t)}$	The equivalent continuous (time-averaged) A-weighted sound level commonly referred to as the average level. The suffix (t) represents the period, e.g. (8 h) would represent a period of 8 hours, (15 min) would represent a period of 15 minutes and (2200-0700) would represent a measurement time between 10 pm and 7 am.
L_{AFmax}	The A-weighted maximum noise level. The highest noise level which occurs during the measurement period.
NZS 6803:1999	New Zealand Standard NZS 6803: 1999 "Acoustics - Construction Noise"
Underwater noise	A sound that is unwanted by, or distracting to, the receiver underwater.
L_{peak}	The peak instantaneous pressure level (un-weighted).
L_{50}	The noise level equalled or exceeded for 50% of the measurement period. This is commonly referred to as the median noise level.
L_{10}	The noise level equalled or exceeded for 90% of the measurement period. This is commonly referred to as the background noise level.
RMS	Root Mean Square (RMS) is the equivalent continuous (time-averaged) sound level commonly referred to as the average level (period matches the event duration).
SEL	Sound exposure level (SEL) is the total sound energy of an event, normalised to an average sound level over one second. It is the time-integrated, sound-pressure-squared level. SEL is typically used to compare transient sound events having different time durations, pressure levels and temporal characteristics.
SEL_{cum}	The SEL_{cum} is the 'cumulative' sound energy of all events in a 24-hour period, normalised to an average sound level over one second.
TTS	Temporary Threshold Shift (TTS) is the temporary loss of hearing caused by sound exposure. The duration of TTS varies depending on the nature of the stimulus, but there is generally recovery of full hearing over time. TTS in humans can be likened to the 'muffled' effect on hearing after being exposed to high noise levels such as at a concert. The effect eventually goes away, but the longer the exposure, the longer the threshold shift lasts. Eventually, the TTS becomes permanent (PTS).
PTS	Permanent Threshold Shift (PTS) is the permanent loss of hearing caused by acoustic trauma. PTS results in irreversible damage to the sensory hair cells of the ear.

APPENDIX B ON-SITE PILING MEASUREMENT

To validate and add context to our noise level predictions, on 2 August 2021 we visited the Kennedy Point Marina and measured the sound emissions from vibro driving a test pile, and from a drilling rig. The full results are reported in a results letter (refer footnote 17). In summary:

- Airborne noise levels from the excavator mounted drill rig were 2 decibels lower than predicted. This was likely due to the prediction being based on a larger crane mounted drill rig. Noise levels at mean high water spring (or lower) on the breakwater during drilling were 79 dB L_{Aeq} at a distance of 12m from the pile.
- The drilling rig produced some loud bangs due to the kelly bar on the drill end slipping while drilling. The banging occurred intermittently at approximately one-minute intervals. Noise levels from the bangs received at the breakwater were up to 95 dB $L_{Aeq(1sec)}$ for brief periods. This was resolved on-site with the following measures:
    - Ensuring the operator of the drill rig is appropriately briefed on noise sensitivity and taking due care to minimise banging.
    - Installation of a section of rubber between the drill shaft and pile casing to create a seal which minimised noise from breaking out of the top of the pile. This measure was demonstrated to be effective during our site measurements.
- Airborne noise levels from the vibro rig were 7 decibels lower than predicted. This could have been due to the deep soft sediments having a dampening effect (over 8m of mud below the seafloor). Noise levels were 79 dB L_{Aeq} at 12m from the test pile.
- Underwater, noise from the whining of the drill was faintly audible in the recording but did not affect the overall measured ambient levels. The measured levels range from 110 – 112 dB re. 1µPa rms at 60m.
- Underwater noise levels from the vibro piling were also significantly lower than predicted. The measured levels range from 119 – 121 dB re. 1µPa rms at 45m and 116 dB re. 1µPa rms at 105m.
- Other sources such as engines (excavator, generators, vibro power packs) and movement of track equipment on the barges also generated noticeable noise levels underwater. The measured levels ranged from 106 – 116 dB re. 1µPa rms at 35 – 45m for the engines, and 109 – 114 dB re. 1µPa rms at 35 – 45m for the tracked equipment.

Noise from the vibro rig was difficult to isolate from the ambient environment and vessel movements as shown by the figure below. The generator noise was from the vibro hammer power pack on the barge.

Figure 9. Underwater noise recording of vibro piling from 45m distance