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LPC'S CRUISE BERTH PROJECT - MARINE MAMMAL RESEARCH REPORT

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LPC'S CRUISE BERTH PROJECT - MARINE MAMMAL RESEARCH REPORT

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Prepared for Lyttelton Port Company Ltd

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EXECUTIVE SUMMARY

Whakaraupō / Lyttelton Harbour is part of the Banks Peninsula Marine Mammal Sanctuary and home to the nationally vulnerable Hector's dolphin. Lyttelton Port Company Limited (LPC) has recently completed two large-scale infrastructure projects in the harbour: the Channel Deepening Project completed in 2018 and the Cruise Berth Project completed in 2020. LPC undertook a five-year monitoring programme, as part of the management plans associated with these projects, to assess the potential underwater noise effects from these construction activities on local Hector's dolphins. In addition, there are two complementary reports on the underwater sound levels produced from the Cruise Berth construction related to the verification of propagation models (Tonkin & Taylor, in press) and hearing threshold zones (Pine 2022).

LPC's monitoring programme gathered underwater acoustic occurrence information on Hector's dolphins (and other marine mammals) throughout the inner, middle and outer regions of Lyttelton Harbour (see map below) between January 2017 and April 2021. This wider-scale view allowed a more informed understanding of how Hector's dolphin presence and behaviour varied throughout the harbour prior to, during and after the completion of the construction projects.

Within this monitoring period, additional information was gathered on the background underwater noise levels and dolphin detections (acoustic and visual) within the inner harbour region during the Cruise Berth construction periods. Both dolphin detections and underwater noise data were analysed and modelled in several ways to assess potential effects of the Cruise Berth pile-driving activity on local Hector's dolphins. This report synthesises and summarises the results of the marine mammal acoustic and visual monitoring carried out in association with the Cruise Berth Project only.

Effects of pile-driving noise

Several different lines of evidence demonstrated that pile-driving noise had a short-lived negative influence on Hector's dolphin visiting the Port and regions of Lyttelton Harbour up to approximately 2 km from the construction area. Model results found that as hammer piling-driving noise increased, very gradual declines in dolphin detections occurred nearest the Port. These declines were greater in spring and / or summer than in the colder months, despite increased piling activity over the autumn and winter period.

Both visual and acoustic data suggest dolphins appear to be responding behaviourally to an increase in piling noise levels by temporarily shifting away from the piling exposed areas. The low number of project shut-downs due to marine mammal presence near piling operations over the 14-months of piling activity also confirm that ramping up and stand-by mitigation procedures were successful in allowing dolphins time to move away from the area before normal piling operations began. However, once piling ceased for the day, dolphins moved back into inner harbour waters, being generally observed within an hour, and acoustic evidence suggested detections were back to pre-piling levels within several days.

Harbour-wide evidence suggested that a longer-term decline in dolphin CPOD detections took place starting in 2019, and as of the end of 2020, had not returned to pre-2017 / 2018 levels. Given the timing of these declines and the shorter-term effects, the evidence suggests that ongoing disturbance from construction activities may have been a factor in some animals choosing not to venture as far into the harbour as they might have previously, while others may have put off even entering the harbour. However, this study was not able to conclusively determine if these longer-term declines in detections were due solely to the two construction projects or in conjunction with other factors. The resulting models are not exhaustive and do not consider all possible factors that might influence the dolphins. In particular, the model does not include other larger-scale climate or environmental drivers that also affect the wider Banks Peninsula (e.g. winter 2020 / 2021 droughts) and / or the east coast South Island population of Hector’s dolphins (e.g. marine heatwave 2017 / 2018).

Noise regulations

A review of received noise levels at each of the three inner harbour moorings confirmed that these moorings lie beyond the TTS zone as predicted by Humpheson (2018) and confirmed in the complementary sound report by Pine (2022). Impact hammer-piling activity was most intense over the autumn months of April / May 2019, and at lower, but elevated intensities over winter months while vibro piling activity was more consistent across the construction period. This timing partially coincides with the advice of experts in the Te Awaparahi Bay Wharf Consent hearings to carry out the most intense piling activity over winter when fewer dolphins enter the harbour.

Based on the verified noise levels, the designated Marine Mammal Observation Zone (MMOZ) proved to be an effective measure at an adequate distance for limiting the exposure of Hector’s dolphins to pile-driving noise. Statistical comparisons suggested that dolphins were actively avoiding the MMOZ area when piling was underway, and with the relatively low number of shut-downs (n = 15), these results highlight the success of other management procedures associated with the MMOZ (i.e. ramping up, soft-starts, stand-bys). Post-piling visual observations and acoustic detections provided evidence that dolphins returned to the inner harbour region and MMOZ within one hour after piling ceased and back closer to pre-piling levels after several days.

There were several sightings by marine mammal observers (MMOs) of Hector’s dolphins inside the inner Port region (opposite side of the reclaimed rock wall bund to which piles were being driven) while piling was underway. While the expert acoustic advice at the time suggested that underwater noise would be considerably limited in these areas, further verification is warranted if any other pile-driving activities are to be undertaken around the Port entrance area in the future.

Comparisons between both acoustic methods and between visual and acoustic methods determined that a combination of monitoring methods (real-time and passive) are necessary with any future Port developments. Real-time methods are necessary to enforce immediate protective measures, such as shut-downs or stand-bys, while passive methods are

necessary to ensure mitigation and management conditions were being adhered to and the effects on the animals monitored. The importance of using MMOs that are well-trained and experienced was highlighted by these results. In addition, these comparisons confirmed that background noise (such as pile driving) did not negatively affect or prevent the passive recorders' capacity to detect dolphins.

Recommendations

Overall, these results indicate that currently planned pile-driving programmes within Lyttelton Harbour (i.e. Te Awaparahi Bay Wharf), due to their larger proposed scale, size and duration, will require additional mitigation to reduce pile-driving noise to a similar or lower level of localised impacts (i.e. behavioural) demonstrated in the Cruise Berth project, while avoiding longer term impacts. LPC managers are encouraged to review the various parameters associated with the Cruise Berth pile-driving activities that generated the greatest or more intense noise levels (e.g. pile size and type, hammer type and frequent, power setting and bottom type). Understanding what operational aspects are contributing the most to the resulting noise would help with developing possible options and alternatives for future mitigation.

Several mitigation measures used in the Cruise Berth construction are recommended for future piling projects based on the results from this study. In addition, the use of bubble curtains needs to be re-considered given their recent and successful use at reducing pile-driving noise levels in Wellington Harbour projects. This report makes several other recommendations on monitoring design, methods and requirements, the use of marine mammal observers and other operational control measures based on the results of this study.

The locations of the various underwater acoustic moorings and regions used to monitor marine mammals in Lyttelton Harbour from 2017 to 2021.

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1. INTRODUCTION

Whakaraupō / Lyttelton Harbour is part of the Banks Peninsula Marine Mammal Sanctuary and home to the Hector's dolphin, a nationally vulnerable New Zealand dolphin species. Within this harbour, Lyttelton Port Company Ltd (LPC) has recently completed two large-scale infrastructure projects within the last five years—the Channel Deepening Project and the Cruise Berth Project. As part of the management plans associated with these projects, monitoring data were collected on Hector's dolphin and other marine mammals within the harbour and associated with the project works.

One of the primary goals of this monitoring programme was to collect data on the potential underwater noise effects from Port construction activities on local Hector's dolphins. Hector's dolphin is one of the few species that can be easily acoustically distinguished from other dolphin species due to the high-frequency sounds they produce relative to the more broadband clicks used by other dolphin species. As such, the monitoring programme relied on underwater acoustic data collection methods to monitor Hector's dolphins, comparing detections before, during and after the completion of the two projects. Various mitigation and management control measures were also implemented during these two projects to ensure any potential adverse effects were reduced to the greatest extent practicable (Enviser 2018). The overall effectiveness of these various measures at meeting their intended goals (as defined in the associated management plans) was reviewed and assessed as part of the monitoring programme.

The Cawthron Institute (Cawthron) and Styles Group were contracted by LPC to undertake an analysis of the underwater acoustic and visual sighting data associated with the monitoring programme of these two projects. This report synthesises and summarises the results of marine mammal acoustic and visual monitoring carried out in association with the Cruise Berth Project only. A second, complementary report on the underwater sound levels produced from the Cruise Berth construction, as well as the verification of propagation models and marine mammals hearing threshold zones, is included in Pine (2022). In addition, a third summary report reviewing the marine mammal monitoring data associated with the Channel Deepening Project will be forthcoming.

1.1. Project background

1.1.1. Cruise Berth construction

Construction of the Cruise Berth involved six main piling components (Table 1). Commencing in December 2018, initial piling activity was concentrated on temporary, on-land piling works through the former reclaimed breakwaters and a pinning wall (just below the low-tide line) designed to stabilise the Eastern Mole for further construction. The in-water portions of the piling activity did not start until March 2019 and continued at varying intervals both daily and monthly until December 2019. The final stage of piling involved the bollard construction on the wharf structure itself during the first few months of 2020 (Table 1).

Only one piling rig operated at one time on the site and only in daylight hours. Due to the welding, pile pitching and repositioning of the equipment, actual hydraulic hammering was limited to at most 6 hours/day, but more likely, occurred intermittently over 2–4 hours within a day. Additional details on these construction components and piling methods can be found in Appendix 1.

Table 1. Cruise Berth wharf construction piling components and timeframes.

Piling phase	Description	Construction timeframe
1	Crane support piles (on land)	July - October 2018
2	Pinning wall	December 2018–February 2019
3	Eastern and Western Bollard Structures	February 2019-June 2019
4	Main wharf piling	April 2019–December 2019
5	Land Restraint Piles (LRP)	January 2020–February 2020
6	Platform piles	February 2020

1.1.2. Construction monitoring programme

In New Zealand, the monitoring of marine mammals in conjunction with coastal development projects, such as piling driving activity, has only been recently implemented by ports in the last five or more years. As the Cruise Berth extension was one of the first large-scale coastal development projects in New Zealand to employ both dedicated observers (visual) and passive underwater acoustic methods, the efficacy of these methods needs to be examined and reviewed.

Using dedicated observers to watch for marine mammals within a designated area is a proven method used worldwide for such projects. One of the main advantages of having an experienced observer on site watching for marine mammals is their ability to detect animals in real-time and then immediately undertake the necessary mitigation actions. However, observers' ability to reliably detect animals from the surface is inversely correlated with sighting and visibility conditions (e.g. turbidity, wind levels or fog). Poor sighting conditions can unnecessarily delay construction activities as reliable observations are not possible. In addition, the limited range over which observers can accurately detect marine mammals is highly dependent on the species of concern (i.e. 300 m up to 1 km) and is often a criticism highlighted in consent hearings (e.g. Dawson 2017b).

Other remote monitoring alternatives include underwater acoustic or camera systems and aerial drone monitoring. The advantage of using remote acoustic monitoring methods is the ability to continuously monitor the presence of marine mammals both day and night and when sea conditions are not favourable for visual sighting work. The disadvantages are that such methods can be limited in their spatial detection range for some species (e.g. within a few hundred metres of acoustic recorders) and the method cannot assess if marine mammals are truly absent (i.e., they may be present but not vocalising and so are not detected). While these remote acoustic monitoring options can be monitored in real-time (live streaming detections following onboard processing, etc.) rather than passively (stored and collected at later date), previous technology constraints limited the Cruise Berth project to passive underwater acoustic monitoring only. In addition, acoustic moorings could not be placed on or within the shut-down boundary for this project due to the vicinity of the Port’s shipping channel which limited the spatial coverage of acoustic monitoring.

1.2. Scope

The main aims of this report include:

- assessing any trends in Hector’s dolphin detections (acoustic and visual) with and without pile-driving activities
- modelling any pile-driving effects on dolphin detection and recovery of Hector’s dolphin
- comparing dolphin detections between acoustic and visual datasets to assess their monitoring effectiveness for this type of marine development
- investigating any regulation violations or consent exceedances by project activities
- highlighting the important key learnings that will be applicable to the planning and development of the Te Awaparahi Bay Wharf project plan in regard to its possible effects on Hector’s dolphins
- providing any further recommendations of advice for future piling projects.

2. MONITORING METHODS

2.1. Acoustic detection methods

Passive acoustic monitoring for the occurrence of Hector's dolphin and other marine mammals was undertaken using two different instruments: 1) continuous porpoise detectors or CPODs developed by Chelonia Ltd and 2) SoundTrap ST300 HF (ST) acoustic recorders made by Ocean Instruments NZ Ltd.

2.1.1. Acoustic mooring set-up

Eight separate moorings with acoustic recorders attached were deployed throughout the full monitoring period. All acoustic moorings had a single CPOD attached while four of the moorings also had a ST recorder attached. Each mooring was attached to the bottom substrate with a plough anchor with a separate five metres of 1.27 cm chain to help prevent movement and facilitate retrieval, if necessary. Each CPOD was positioned along a rope attached to a surface float to help it remain vertical and approximately 3–5 m off the bottom. When both instruments were used on the same mooring, CPODs were positioned closest to the bottom and STs were located approximately a metre above on the line. A diagrammatic representation of the mooring configuration is shown in Figure 1.

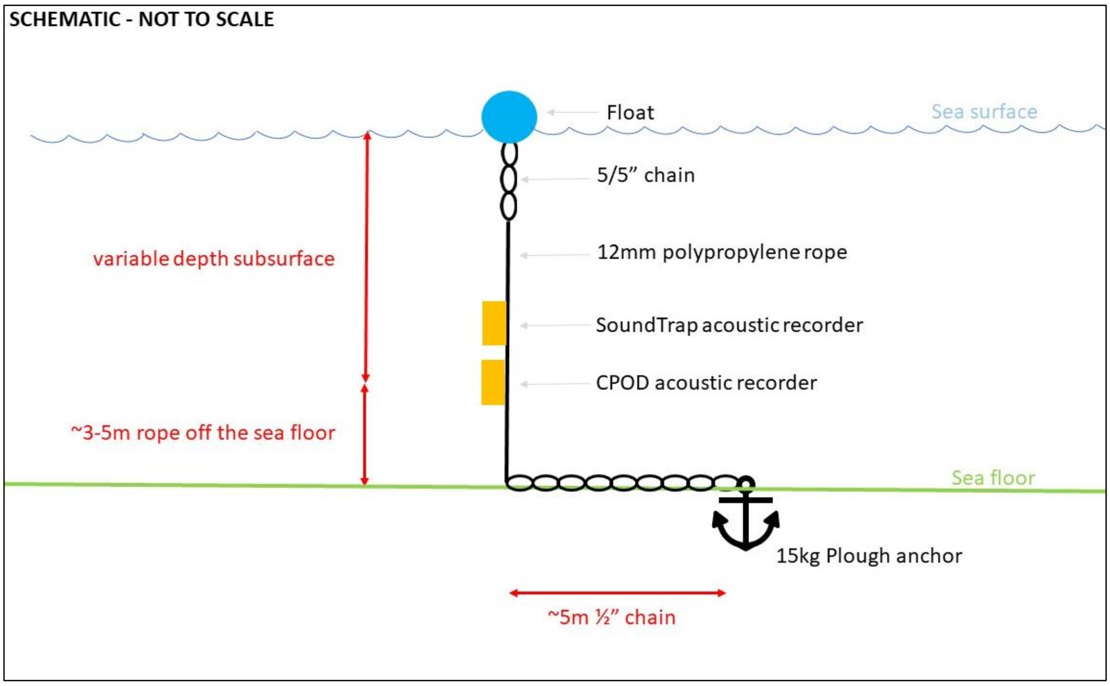

Figure 1. Diagrammatic representation of the moorings with CPOD and SoundTrap acoustic recording units.

2.1.2. Deployment locations and timeframes

The monitoring programme gathered acoustic occurrence information on Hector's dolphins (and other marine mammals) throughout the inner, middle and outer regions of Lyttelton Harbour (Figure 2). This wider-scale view allowed a more informed understanding of how Hector's dolphin acoustic occurrence varied throughout the Harbour prior to, during and after the completion of the two construction projects.

Four moorings with only CPODs attached were initially deployed starting in January 2017 (Table 2) to gather baseline detection data on marine mammals for the Channel Deepening Project. The first two moorings (MM1 and MM2) were located within middle regions of Lyttelton Harbour while the other two (MM3 and MM4) were located at the Lyttelton Heads or outside of the Harbour (Figure 2, Table 2). These locations were chosen primarily based on the proposed acoustic monitoring needs of Hector's dolphins in relations to the Channel Deepening Project, which was mostly working in the channel and near the dredge disposal grounds (Clement 2016).

Additional inner harbour CPOD moorings (MM5 to MM8) were deployed in January 2018 (Figure 2). In August 2018, STs were added to MM2 (middle harbour) as well as inner harbour moorings MM5 to MM7 (Table 2). These moorings were located near the Port and at varying distances from the Cruise Berth construction to monitor pile-driving sound levels and Hector's dolphin presence simultaneously.

CPODs and ST were permanently removed starting in May 2020 and finishing in March / April 2021.

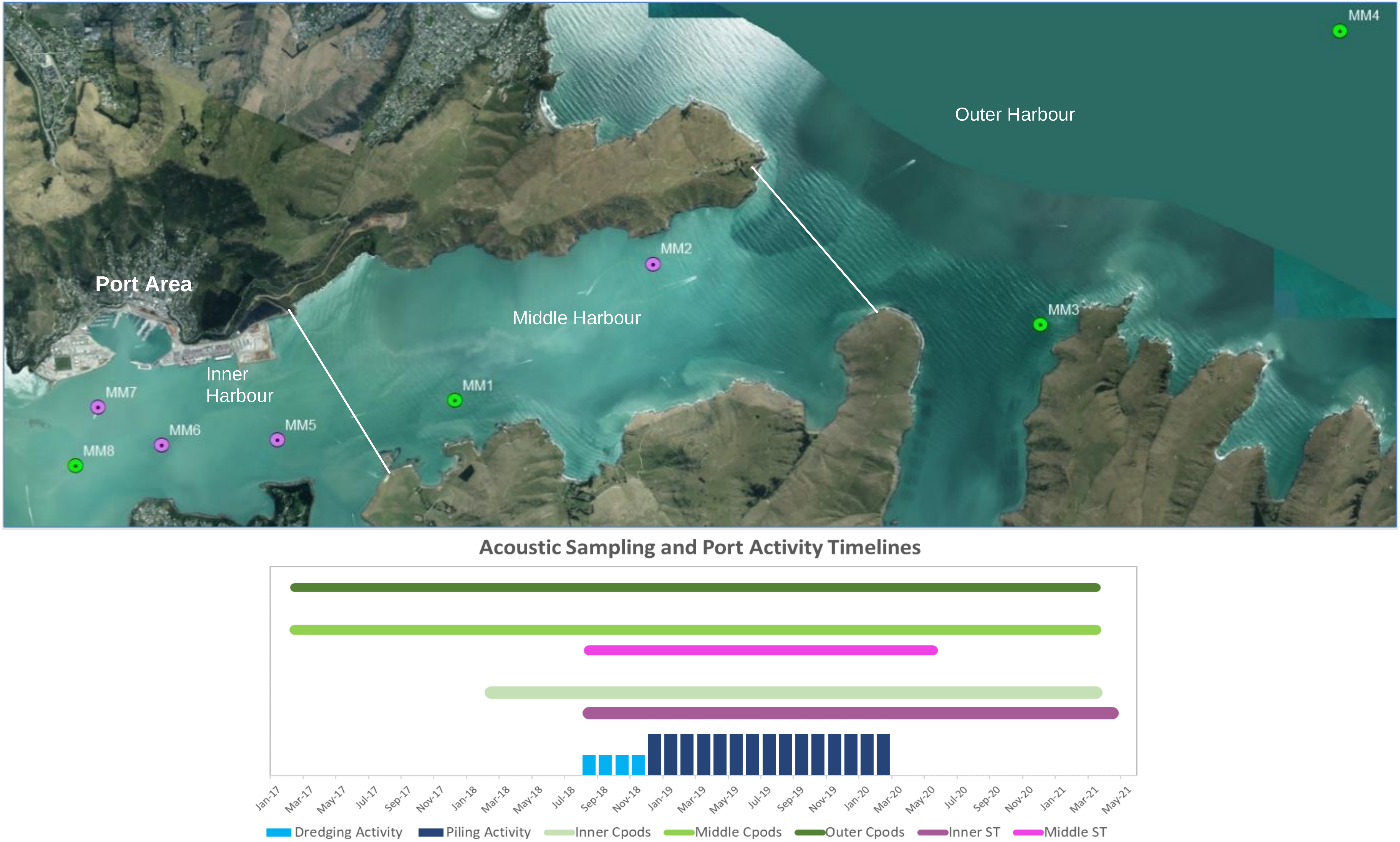

Figure 2. The locations of the various underwater acoustic moorings used to monitor marine mammals in Lyttelton Harbour from 2017 to 2021. The schematic timeline below the map indicates the dates of mooring deployments alongside the Port's two main development projects—Cruise Berth construction (piling activity–navy blue) and Channel Deepening Project (dredging activity–light blue). Purple lines represent SoundTrap + CPOD moorings while green lines represent CPOD-only moorings.

Table 2. The deployment dates and locations of the various underwater acoustic moorings used to monitor marine mammals in Lyttelton Harbour from 2017 to 2021 along with the different types of acoustic recorder. Distance to Cruise Berth is the distance from the centre point of the new berth to the various mooring locations.

Mooring Site	Harbour Location	Acoustic recorder	Distance to Cruise Berth (km)	Monitoring Start	Monitoring End
MM1	Middle	CPOD	3.62	January 2017	March 2021
MM2	Middle	CPOD SoundTrap	6.05	January 2017 July 2018	December 2020 May 2020
MM3	Outer	CPOD	10.41	January 2017	March 2021
MM4	Outer	CPOD	14.44	January 2017	August 2020
MM5	Inner	CPOD SoundTrap	1.75	January 2018 August 2018	March 2021 April 2021
MM6	Inner	CPOD SoundTrap	0.935	January 2018 August 2018	May 2020 May 2020
MM7	Inner	CPOD SoundTrap	0.710	January 2018 August 2018	March 2021 June 2020
MM8	Inner	CPOD	1.42	January 2018	May 2020

2.1.3. CPOD data processing

The CPOD acoustic recorders were installed at sites MM1 through MM4 initially, and later at sites MM5 through MM8 (Table 2). CPOD recorders continuously listen for sounds characteristic of Hector’s dolphin clicks and make a data entry at that time. Detailed explanations on how CPOD data were processed and their performance checked can be found in earlier acoustic reports (i.e. Pine 2020; Appendix 2).

Following all checks and scans, the initial KERNO classifier followed by the GENERC encounter classifiers were applied to the data. The purpose of these classifiers was to determine which clicks were from a train source (i.e. a dolphin) with the subsequent GENERC classifier being applied to improve the discrimination of Hector’s dolphins from other species and noise. A sub-sample (n = 100) of the filtered click trains where then manually validated to cross-check performance.

Only high and medium quality clicks were selected for further analysis. The main parameter used to quantify spatio-temporal variation in dolphin clicks near each monitoring site was Detection Positive Minutes (DPM). The DPM is the number of minutes that contained at least one dolphin click train across an hour (see Appendix 2 for more details).

2.1.4. SoundTrap data processing

ST acoustic recorders differed from CPODs in that they ran on a 33% duty cycle (5 min recordings every 15 min) that stored full spectrum data (digitised as .WAV files with a 288 kHz sampling rate), rather than continuously ‘listening’ for particular sounds and recording events. This duty cycle was used to extend battery life, optimise memory and improve data handling efficiency (Pine 2017).

From the ST recordings, several aspects of Lyttelton Harbour’s soundscape were summarised for exploration and further analysis, including:

- one-second received Sound Pressure Levels root-mean-square (SPL_{rms})[1]
- pile-driving noise, from both vibratory and hammer or percussive piling
- Hector’s dolphin echolocation clicks to quantify dolphin presence.

Because of the large amount of data (greater than 100,000 hours of acoustic data), a series of automated detectors and classifiers was required. Visual sighting data recorded from marine mammal observers (MMOs, see Section 2.2) were used to help direct the data processing of these acoustic datasets in the initial stages. For example, the MMO sighting data were used to focus the deep learning (a type a machine learning that uses artificial neural networks to learn features in data for recognition) to specific time periods of dolphin presence, which greatly improved the performance of the echolocation click detectors in the initial stages of detector development (see Appendix 2 for more details).

One-sec averaged SPLs

The 1-sec time-averaged SPLs were processed for every deployment for each ST using code that was adapted from Merchant et al. (2015), but specifically written for this project. In summary, individual .wav files were broken into 1-sec bins (no overlap) and the broadband (10Hz to 48 kHz) SPL of that 1-sec window was calculated. The signal processing and equations for the SPL calculations follow that by Merchant et al. (2015).

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[1] The term RMS = root mean square or mean squared pressure. RMS levels are often used for the assessment of continuous noise sources. The averaged square pressure is measured across some defined time window that encompasses the signal.

Pile-driving noise

Pile-driving noise, both from vibratory and percussive (hammer piling) methods, was analysed based on the piling records from the MMOs and LPC contractor work logs. A combined pile-driving dataset was created that listed all start / end times of piling activity, the drive method (vibratory or percussive), and the pile number that was being driven.

Vibratory piling, being continuous, was processed using 1-sec SPLs for the whole duration that a single pile was being driven. Descriptive statistics were then calculated for each pile number, and the logarithmic means (the RMS) were retained for further analysis.

For the percussive hammer piling, only the pulse of the hammer strike was analysed. This was completed using a pulse detector on the combined pile-driving dataset. The pulse detector extracted the broadband (10Hz to 48 kHz) RMS sound pressure over the T90 duration (L90), the single-strike sound exposure level (SELss) and the peak sound level (Lpeak). As with vibratory piling, the program also calculated the full-scale power spectrum of each pulse, the third octave levels and the M-weighted spectrum.

The L90 and SELss are time-dependent metrics in that they are calculated over the pulse's duration. The result, therefore, reflects the average (for the L90) or total amount of sound energy (for the SELss) that the receiver is exposed to over that duration. The exact start and end times of each pulse is difficult to accurately determine in recordings that also contain ambient noise. Therefore, the duration of the pulse, T, is often defined as the interval in which the cumulative energy rises from 5% to 95%, therefore containing 90% of the energy. That interval is referred to as the T90 duration and the L90 was calculated over that T90 duration. The SELss, being the total energy contained in the single pulse, was defined as:

$$\mathrm{SEL_{ss}} = \mathrm{L90} + 10 \times \mathrm{Log_{10}(T90)} + 0.458\ \mathrm{dB}.$$

The 0.458 dB constant was an energy ratio to account for the lost energy either side of the 5% and 95% during the T90 calculation (i.e., $10 \times \mathrm{Log_{10}}(0.9) = 0.458$ dB).

The SELss, from each hammer strike detected inside the start / end time of the piling positive minutes for each hour ($\mathrm{PPM_{1hr}}$), were then cumulatively added inside each hour to produce a measured cumulative SEL value (SELcum) based on the actual received sound pressures. Because the SoundTraps were operating at a 33% duty cycle, the SELcum had to be adjusted according to the actual amount of time that piling occurred in that hour (i.e., $\mathrm{SELcum_{1hr}}$). For example, if piling occurred for 60 mins (i.e., $\mathrm{PPM_{1hr}} = 60$), with only 20 min of that hour was actually recorded (since the ST recorded four 5-min recordings every 15 mins in that same 60 min period), then the calculated SELcum would be missing 40 min of piling activity. Therefore, to control for this, an adjustment was necessary to obtain the actual $\mathrm{SELcum_{1hr}}$.

A series of assumptions were tested to identify the most conservative, yet representative, calculation adjustment to obtain the SELcum_{1hr}. These were

- Assume the exact same piling activity measured, and those received levels, happened for all unknown minutes[2].
- Calculate the average number of strikes that occurred in all 5-min recordings with piling noise, over the complete monitoring period, and then use that average strike rate, along with the average single-strike SEL for the hour in question, for all the unknown minutes.
- Calculate the busiest 30-sec of piling and assume that rate continues for the unknown minutes before recording starts again (15 min later).

The assumption found to be most reasonable, and conservative, was to base the adjustment on the average strike rate per recording (calculated over the duration of entire piling period) and then multiply that by the number of unknown minutes. By doing so meant that:

- Soft-starts that occur in some recordings will not be repeated in subsequent piling minutes without recordings (i.e. unknown minutes); and
- Irregular piling behaviour is not carried forward. For example, if the PPM is 10 but only the last 1 minute of the 5-min recording contained piling noise, then that 4-min delay would not be carried forward, or repeated, in the subsequent 5-min period, as the strike rate is not based on only 1-min.

The SEL adjustment for each hour was defined as:

$$SEL\_adj_i = SELss_i + 10\ Log_{10}\left(n\ \frac{strike\ count\ per\ recording}{recording\ length\ (min)}\right)$$

where SELss_i is the average single-strike SEL for hour *i*, and *n* is the number of unknown minutes in the PPM_{1hr}. For example, if the PPM_{1hr} was 15 minutes, then 5 minutes will have been recorded and the remaining 10 minutes would be unknown (based on the 5 min every 15 min duty cycle). Those 10 unknown minutes are *n*. An average of 105 strikes per 5-min recording was assumed, after plotting the histogram (with bin size of 3) of hammer strikes detected inside each 5-min recording for the whole monitoring period (Figure 3).

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[2] Unknown minutes are those minutes between the SoundTrap recording periods when the recorder was not recording .WAV files.

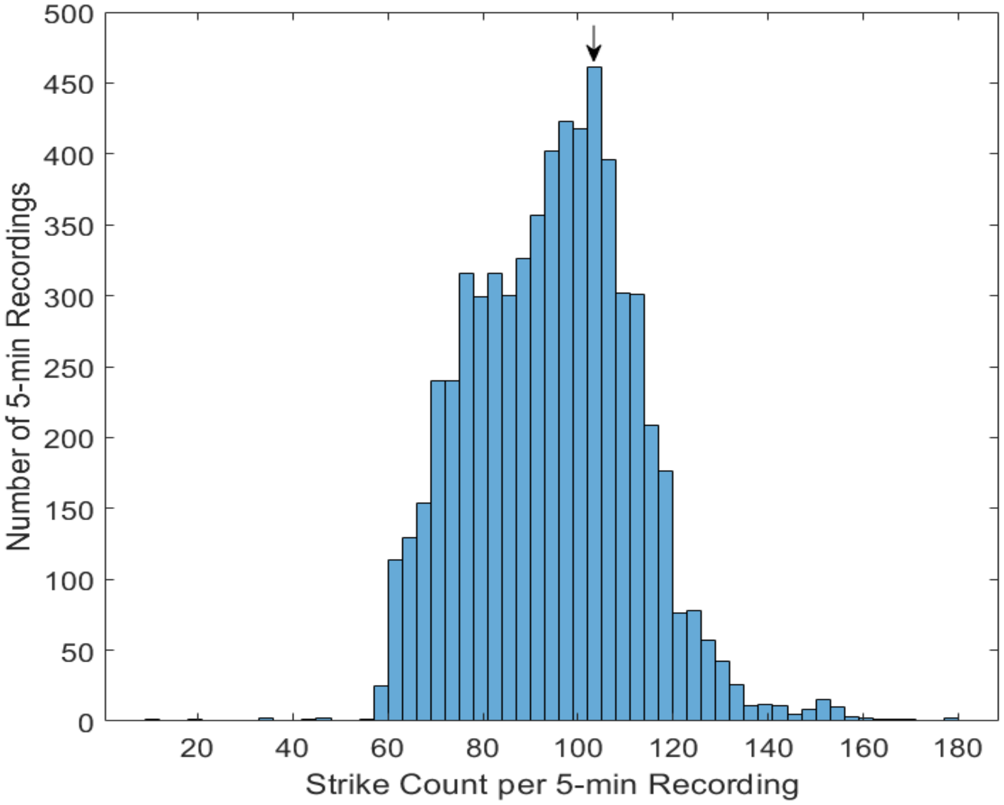

Figure 3. Distribution of hammer strikes per 5-min recording between Jan and Dec 2019. The black arrow represents the average strike rate, *n*, used for the SELcum_{1hr} adjustments.

The adjustment was then added to the measured SELcum for the known minutes to obtain the representative SELcum for the whole hour, SELcum_{1hr}. This was done using:

$$SELcum_{1hr} = 10\ Log_{10}\left(10^{\left(\frac{SELcum_i}{10}\right)} + 10^{\left(\frac{SEL\_adj_i}{10}\right)}\right)$$

where SELcum_i is the measured SELcum for that i^{th} hour and SEL_adj_i is the adjustment previously calculated for the same i^{th} hour.

Figure 4 demonstrates an example of the SEL adjustment calculation using the above equations. In the figure, (A) represents the portion of time for which piling activity was measured in the recordings (i.e., the known minutes), while (B) represents the time when the piling activity was occurring but not being measured due to falling outside the ST's duty cycle (i.e., the unknown minutes). The PPM_{1hr} value was 11 mins and the average single-strike SEL for all strikes measured inside the same hour as the PPM_{1hr} was 148 dB re 1 µPa2·s [3]. Of the 11 mins within the PPM_{1hr}, 5 mins were measured (because the recording time was 5 mins), but the remaining 6 mins were unknown because the recorder did not restart until 15 mins. The true cumulative SEL

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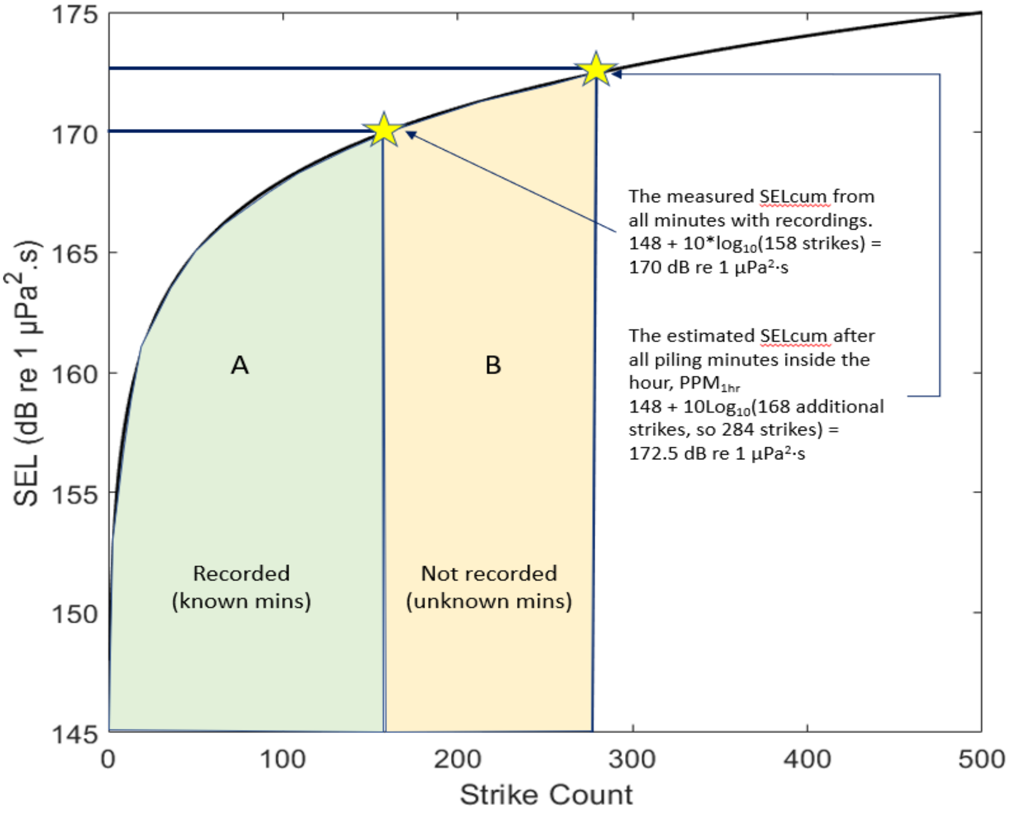
[3] The term 'dB re 1 µPa2·s' represents the sound pressure level that has been back calculated to a standardised distance of one metre distance from the source and is often known as source level.

estimate for the hour, therefore, requires the yellow section of the plot (B) to be added to the green section of the plot (A). Therefore, assuming the averaged strike rate of 21 strikes per minute (105 strikes per 5 mins recording divided by 5 mins from Figure 3), the adjustment would be 148 dB re 1 µPa2·s + 10Log10 (21 strikes × 6 mins) = 169 dB re 1 µPa2·s. This adjustment was then added to the measured SEL value of 170 dB re 1 µPa2·s (start at top of the green section) after converting into pressure: 10^ (170/10) + 10^ (169/10) = 172.5 dB re 1 µPa2·s. This method provides the same result as if the complete strike count was assumed, i.e., 148 + 10Log10 (158+126 strikes) = 172.5 dB re 1 µPa2·s.



The measured SELcum from all minutes with recordings. 148 + 10*$\log_{10}$(158 strikes) = 170 dB re 1 µPa^2·s

The estimated SELcum after all piling minutes inside the hour, PPM_{1hr} 148 + 10Log_{10}(168 additional strikes, so 284 strikes) = 172.5 dB re 1 µPa^2·s

Figure 4. Schematic plot showing how the SEL adjustment was calculated and applied. The relationship between the duty cycle SELcum and the adjusted SELcum_{1hr} for the whole hour, as described in Figure 4, is further explored in Appendix 3.

Hector's dolphin echolocation clicks

ST recorders at sites MM2, MM5, MM6, and MM7 were all processed for Hector's dolphin echolocation clicks. Unlike the CPODs, the ST digitalised recordings (.wav files) were downloaded and the audio files were processed using machine learning techniques.

The overall process for the Hector's dolphin echolocation detectors is summarised in Figure 5 and detailed further in Appendix A2.2. These techniques were the most efficient method for processing over 100,000 hours of audio data from the four sites collected between 2018 and 2021.

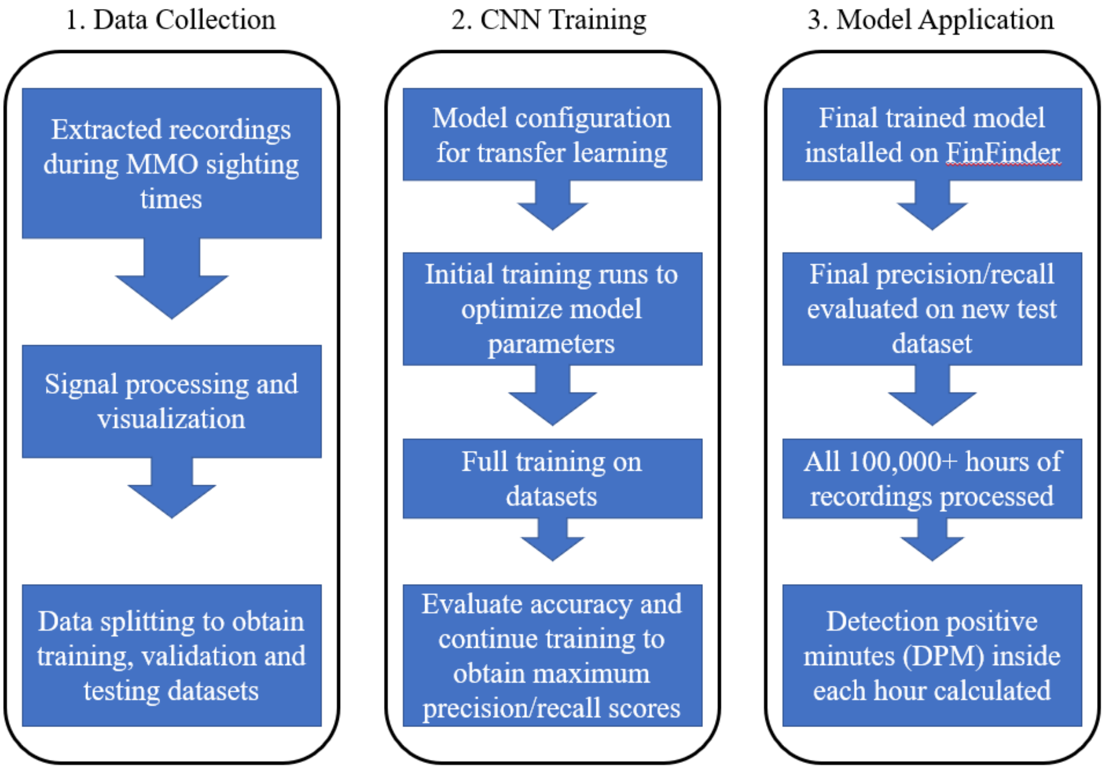


Figure 5. Schematic drawing of the data processing steps used for Hector's dolphin detector development, using a convoluted neural network (CNN). FinFinder is an acoustic analysis software for marine mammal detections and classifications written by M. Pine at Styles Group Acoustics.

2.2. Visual detection methods

As detailed in the Marine Mammal Management Plan (MMMP) for the LPC Cruise Berth Project (Enviser 2018), a key part of mitigation was establishing a safety / shut-down zone around the work area to minimise any risk of hearing impairment or injury (i.e. temporary or permanent hearing threshold shifts: TTS, PTS) to marine mammals from pile-driving activities. A shut-down zone of approximately 450 m radius from the site, known as the marine mammal observation zone (MMOZ), was monitored by an experienced marine mammal observer[4] (MMO). The MMO focused mainly on the MMOZ but scanning also took place beyond the zone and up to 1 km radius from the site, when visibility allowed. MMO observations were made from an elevated 2.6 m high platform near the piling rig to enable a better vantage point of the MMOZ and wider construction sites. The specific protocols and standard operation procedures of the MMOZ / MMO can be found in the MMMP (Enviser 2018). Below, the data and methods used by the MMO to record visual sighting data are briefly summarised.

The role of the MMO was to scan the water's surface and coastal shoreline within and around the MMOZ and wider construction area for the presence of fur seals, dolphins or whales. MMOs were on continuous watch at least 30 mins prior to, during and following any pile-driving activities (which took place during daylight hours only).

The observer(s) had two general duties:

1. to detect, record and report the presence of marine mammals within the wider operational area
2. to enforce the management plan control measures, including documenting any action taken (if necessary).

All marine mammal sightings were logged with details including date / time, number of animals, their location (distance, bearing), piling activity (type, duration and pile number) and general descriptions of the species and their behaviour. Records were also kept of all delayed start-up or enforced shut-downs due to presence of marine mammals within the MMOZ. Details of shut down events were captured on the sighting forms.

MMO watches took place intermittently and as required from 7 December 2018 to 5 February 2020, whenever pile-driving (vibro or hammer) activity was underway.

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[4] All MMOs on the project were contracted and trained by Blue Planet Marine (https://blueplanetmarine.com/). MMOs attended and passed a Department of Conservation (DOC) approved MMO training course in accordance with the code of conduct developed by DOC ('Code of Conduct for Minimising Acoustic Disturbance to Marine Mammals from Seismic Survey Operations') and modified for pile-driving operations.

3. STATISTICAL ANALYSIS

3.1. CPOD data analyses

3.1.1. Detection trends

As discussed in Section 2.1.3, verified dolphin detections were classified into the number of minutes that contained detections, as Detection Positive Minutes per hour (DPM). This collated dataset was then explored in order to visualise how DPMs vary temporally (monthly, per season and year) and spatially (per site). As the number of recording days differed between instruments and across years, the mean number of detections per hour are given for relative comparisons in detection rates.

As CPOD data were collected over the baseline piling period (prior to December 2018), they were used for comparisons in dolphin detections across years, seasons and sites. For this, a linear model was used to evaluate a potential annual trend in DPM per day and across mooring sites. To obtain comparable estimates across years that included all seasons, data from 2020 and 2021 were removed. Due to the non-normality of the residuals when using a linear model (i.e., considering a normal distribution of the residuals), a generalised linear model (GLM) assuming a negative binomial distribution was used (Dobson & Barnett 2018).

3.2. SoundTrap data analyses

3.2.1. Detection trends

Similar to CPOD methods, ST recordings of dolphin clicks were interpreted as acoustic detections and summarised as the number of minutes that contained clicks, named Detection Positive Minutes per duty cycle hour (DPM). As with CPOD data, ST data were explored in order to visualise how dolphin clicks vary temporally (monthly, per season and year) and spatially (per site).

3.2.2. Modelling

To evaluate the potential effect of increased noise (i.e. ambient and / or piling noise) on ST dolphin detections, a general and a fine-scale approach were adopted, and for both approaches, random effects models, also known as mixed models, were used (Zuur et al. 2019). Random effects models allow the modelling of correlated data within the context of generalised linear models (GLMM) or generalised additive models (GAMM) as the predictor can be described in terms of random effects in addition to fixed effects (Bolker et al. 2009). This class of models is particularly interesting in the current analyses, as ST DPM per duty cycle hour is an autocorrelated variable as we expect that the number of detections in a given hour is similar to the number of ST detections in adjacent hours within a day. In the GLMM framework, the random effects were described as an autoregressive structure of order 1 (AR1), which considers correlations between data points to be highest between adjacent times, and a systematically decreasing correlation with increasing distance between time points (Zuur et al. 2019). For example, the number of ST dolphin detections are potentially more similar between 9am and 10am than between 10am and 6pm.

Due to the moorings being deployed at different times of the year, the ST data were first truncated to standardise the data to the same time periods for further analysis. For the models, ST data between September 2018 and May 2020 were used, which allowed for seasonal comparison among years. General GLMMs were then fit to data to reflect how dolphin detections varied in regard to piling variables (pile-driving and ambient noise), spatio-temporal variables (site, year and season) and environmental variables with potential to affect underwater noise (i.e. wind speed, wind direction, or rainfall accumulation) or with potential ecological effect (i.e. temperature, Table 3).

To look at a finer scale, following the approach adopted by Leunissen et al. (2019), generalised additive models (Wood 2017) were then fit to detection data for hours in which percussive piling (hammer) only occurred, i.e. from December 2018 to February 2020, excluding data from mooring site MM2 as piling noise was negligible in that location as was the case in Leunissen et al. (2019). The difference between our approach and Leunissen et al. (2019) is that we used generalised additive mixed models (GAMMs) to account for the hourly nested observations within a particular day. The GAM / GAMM framework use smooth functions to estimate the relationship between the response variable and covariates, allowing us to investigate covariate effects that are beyond linear.

To evaluate the piling noise effect isolated from other sources of noise (e.g. vessel traffic), the cumulative sound exposure level ($SELcum_{1hr}$) of the piling pulses was used instead of ambient noise in the fine-scale models (Table 3). Models were fitted separately for each mooring site to evaluate possible site-specific behaviour of DPM per duty cycle hour with $SELcum_{1hr}$ (Appendix 3). Environmental and spatial variables, except year, were also considered in the fine-scale models to ensure all other potential effects on detections were included.

Before fitting both the general and fine-scale models, the numerical predictor variables were standardised to avoid convergence issues and to yield comparable effects among them. Collinearity between predictors was also addressed, and if present, correlated variables were not included in the same model. The random effect was defined to account for DPM variability among hours within a day. By incorporating hour variability, we account for potential autocorrelation among DPM measures and improve our ability to describe how fixed effects relate to outcomes.

For both the general and fine-scale models, the response variable DPM was assumed to have a negative binomial distribution. A Poisson distribution was also considered in preliminary analyses, however, data overdispersion was identified as the DPM variance was greater the mean.

Table 3. Fixed effects included in the general linear models (GLMM) and fine-scale generalised additive models (GAMM) with the potential to affect detection positive minutes (DPM) per duty cycle hour as recorded with ST recorders.

Variable	**Type**	**Description**	**Data source**
Piling			
Ambient noise	numerical	Sound pressure levels (SPL) averaged over a duty cycle hour (regardless of construction activity)	SoundTraps
Hourly cumulative sound exposure level ($SELcum_{1hr}$)	continuous	Sum of energy from all hammer strikes within each unique hour, measured in dB re 1 µPa^2·s	SoundTraps
Pile driving	dummy	'1' denoting hours with pile-driving and '0' denoting absence of pile-driving[5]	LPC & MMO
Spatio-temporal			
Site	factor	Moorings in which STs are located – MM2, MM5, MM6 and MM7	
Year	factor	2018, 2019, 2020	
Season	factor	Spring (September, October, November), summer (December, January, February), autumn (March, April, May) and winter (June, July, August)	
Environmental			
Wind speed	continuous	Measured every minute at two stations, averaged over an hour between both locations, measured in km/h	LPC
Wind direction	continuous	Measured every minute at two stations, averaged over an hour between both locations, measured in km/h	LPC
Temperature	continuous	Measured every 30 minutes off Rapaki Bay and Pile Bay, averaged between both locations, measured in Celsius degrees	ECAN
Rainfall accumulation	continuous	Measured every 10 minutes at two stations, averaged over an hour between both locations, measured in mm	LPC

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[5] Piling positive minutes (PPM) were originally used as calculated from the MMO's and contractors' log of piling time and strike numbers for each pile driven. However, the effect of PPM and a simpler '0' and '1' approach had same effect in models. Hence, we adopted the simpler 0 / 1 approach to avoid any uncertainty associated with the piling log.

Models were fitted using the *glmmTMB* (Brooks et al. 2017) and *mgcv* (Wood 2017) packages available in R (R Core Team 2021). Model selection was performed by fitting a global model (i.e. containing all predictor variables) and then dropping one variable each time. Whenever remaining explanatory variables had a negligible effect (i.e., p-value < 0.05 or GAM smooth functions virtually zero), two or more variables were dropped in the next model fit. Competing models were compared on the basis of the Akaike information criteria (AIC, Akaike 1973), following recommendations of Burnham and Anderson (2002). The global models (i.e. models with all available variables) are given in Table 4.

Table 4. Explanatory variables used in the models for the general dataset (2018 - 2020), and for the reduced dataset comprising the hours when piling was undertaken (December 2018 to February 2020).

Approach	**Fixed effects**
General	Ambient noise + Pile-driving + Site + Season + Year + Wind speed + Wind direction + Temperature + Rainfall
Fine scale	SELcum_{1hr} + Season + Wind speed + Wind direction + Temperature + Rainfall

3.2.3. Short-term recovery rates

To assess short-term effects of pile-driving activity on Hector's dolphins, the 'recovery rate' or amount of time that it took for dolphin detections to return to 'pre-piling' detection levels was assessed. For this analysis, pre-piling behaviour does not refer to normal, undisturbed behaviour in which the animals have not been exposed to any pile driving activity. Instead, pre-piling behaviour refers to the behaviour of animals that have not been exposed to any piling activity for at least 48 hours.

The 2019 pile-driving construction period was searched for any specific time intervals in which DPM was recorded at least 48 hours before and after a piling session with no piling activity during those before or after time periods. This would correspond to a situation where, for example, piling ceased at 6 pm on Friday, then returned at 7 am on Monday for few hours in the morning and once finished, no further piling occurred until after Wednesday afternoon.

Once those time periods were identified per mooring site (MM7, MM6, MM5 and MM2), the ST DPM per duty cycle hour from all four moorings were analysed separately to determine if and how long dolphin detections took to return to the mean levels recorded just prior to the piling event. In order to evaluate the hypothesis of potential movement between inner and mid-harbour mooring sites (e.g. were dolphins moving from the proximities of pile-driving noise source (inner harbour) to mid- or outer harbour sites?), data on MM2 was also analysed.

Generalised additive models (GAMs) were used to fit DPM per duty cycle hour data as a function of time representing pre-piling hourly intervals (48 hours before pile driving), during pile driving ('0 hour'), and post-piling hourly intervals (48 hours after pile driving ceased). Similarly to the approach adopted for the fine-scale models (see 3.2.2 Modelling for details), DPM per duty cycle hour was assumed to have a negative binomial distribution, and it was modelled as a unique function of time pre-, during and post- piling. The fitted smooth terms were visually analysed in order to access whether DPM per duty cycle hour returned to pre-piling levels.

3.3. Visual sighting data analysis

3.3.1. Detection trends

Visual sighting data were initially explored to look for detection distance trends over various temporal scales (month and per season). As visual surveys were undertaken as part of the mitigation during the Cruise Berth construction period to protect animals against acoustic noise effects, no visual surveys were undertaken prior to or after the construction period itself (December 2018 to February 2020).

3.3.2. Method comparisons

Visual sighting data were also used to help examine the various pros and cons of the different acoustic sampling methods. While the sighting data were limited to a narrower distance radius around construction works and to daylight hours only, a visual sighting was still viewed as definitive evidence of Hector’s dolphin presence in the area. This confirmation is not always possible with acoustic data as dolphins may be physically present, but they are not detected acoustically (i.e. false absence) due to distance from the recorder or lack of vocalising.

A sub-set of those MMO sightings that occurred close enough to the inner moorings (MM6 and MM7) to record an acoustic detection was first collated in ArcGIS. Using the initial GPS-position estimates of the sightings, only those sightings that were within 300 m radius[6] of either MM7 or MM6 were selected. This ‘test dataset’ was then used to match and compare CPOD and ST acoustic method capabilities at detecting the presence of a known Hector’s dolphin sightings.

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[6] A collaboration study of TPOD (an earlier version of CPODs) detection distances by Rayment et al. (2009) found that the highest detection rates occurred within the first 100 m and declined quickly past 300 m with no acoustic detections recorded past 500 m. These distances are comparable to other overseas studies on acoustically similar species to Hector’s dolphin, including harbour porpoise (Tougaard et al. 2006) and finless porpoises (Jefferson et al. 2002).

Both CPOD and ST acoustic datasets (.wav files) were manually inspected for dolphin clicks that were produced from up to 1 hour before the start time of a sighting to up to 1 hour after the end time of each sighting (based on the MMO sighting logs and test dataset). Custom code was then used to annotate those visual sightings that contained acoustic detections and those without acoustic detections. This comparison was used for both CPOD and ST datasets and ran separately at the inner harbour moorings, MM6 and MM7, closest to the Port and visual sighting locations.

The matched datasets were then used to investigate a hypothesis that Hector’s dolphin may react behaviourally to the increase in underwater noise from pile-driving activities by clicking less or not at all. A similar example would be when people attend a loud music concert, friends generally do not attempt to have long or complex conversations as others are not able to hear them while the music is playing. Using X^2 test, we aimed to test: 1) which acoustic method (CPOD or ST) performed better and 2) any potential differences across methods with and without piling activity underway.

4. RESULTS AND DISCUSSION

4.1. Trends in dolphin detections

4.1.1. Harbour-wide annual detections - CPOD data

The Cruise Berth construction period coincided with the full 2019 calendar year. For comparative purposes, the mean numbers of Hector's dolphin detection positive minutes (DPMs) per hour recorded over each year of the project are listed in Table 5 for each of the CPOD moorings. A harbour-wide gradient in DPMs rates was evident across all moorings, all sampling years and most seasons (Table 5, Figure 6–7, Appendix 4). In general, mean DPM rates are lowest near the Port (MM6, MM7 and MM8) and gradually increased from these inner harbour locations into middle harbour regions (MM5, MM1 and MM2). This gradient of increased mean DPM rates continued towards the harbour heads and into outer harbour areas with the greatest detections rates consistently reported at MM3 and then MM4 (Table 5). This harbour-wide gradient in detections was expected based on several decades of previous boat-based Hector's dolphin surveys in Lyttelton Harbour and other harbours / bays around the wider Banks Peninsula region by the University of Otago (e.g. Brough et al. 2014, 2018).

Overall, outer and middle mooring sites (MM1 to MM4) recorded greater CPOD detection rates prior to 2019 (Table 5). According to mooring-specific GLM results, the annual mean DPM per day declined at all moorings (MM4, MM3, MM2 and MM1) during 2017–2020 (Figures 6–7, Table 6).

Over the same period, the inner harbour site CPOD detection rates varied less annually across baseline, piling and / or post-piling sampling years (Figures 6–7, Table 5). Mooring-specific GLM results indicated declines in mean DPM per day at MM5, and increase at MM6, MM7 and MM8 during 2018–2020 (Table 7).

Table 5. Mean dolphin detection positive minutes per hour by each CPOD mooring over the different sampling years. Standard errors are in brackets and sample sizes are underneath. Red and blue text represents the lowest and highest mean detection positive minutes by year, respectively. Note the table is laid out to mimic the order in which mooring were placed from outer harbour regions (top of the table) to innermost harbour regions (bottom of the table) and across the different sampling periods—baseline, piling and post-piling (left to right). *denotes years in which a full year of sampling was not undertaken (see Table 2).

Mooring	**Baseline Period**		**Piling Period**	**Post-Piling Period**	
Location	*2017*	*2018*	*2019*	*2020*	*2021*
Outer Harbour					
MM4	5.76 *(0.11)* *40,547*	6.29 *(0.11)* *51,861*	5.01 *(0.09)* *40,887*	* 3.11 *(0.09)* *13,439*	
MM3	**7.35** *(0.13)* *51,535*	**7.65** *(0.13)* *55,682*	**6.07** *(0.11)* *46,019*	**5.97** *(0.11)* *49,360*	* **7.48** *(0.230)* *14,028*
Middle Harbour					
MM2	6.32 *(0.13)* *39,380*	4.35 *(0.09)* *35,837*	3.35 *(0.08)* *27,347*	2.69 *(0.07)* *21,748*	
MM1	4.12 *(0.08)* *30,590*	3.59 *(0.08)* *29,553*	2.46 *(0.06)* *20,133*	1.28 *(0.04)* *10,348*	* 1.39 *(0.12)* *1,832*
Inner Harbour					
MM5		1.45 *(0.05)* *7,541*	1.33 *(0.05)* *8,915*	1.01 *(0.03)* *8,239*	* 0.93 *(0.07)* *1,740*
MM6		1.02 *(0.04)* *7,540*	1.20 *(0.04)* *9,096*	* 1.03 *(0.05)* *3,382*	
MM7		**0.30** *(0.02)* *2,098*	**0.43** *(0.02)* *3,323*	0.71 *(0.03)* *5,880*	* **0.40** *(0.04)* *742*
MM8		0.61 *(0.03)* *4,708*	0.75 *(0.03)* *6,141*	* **0.54** *(0.04)* *1,773*	

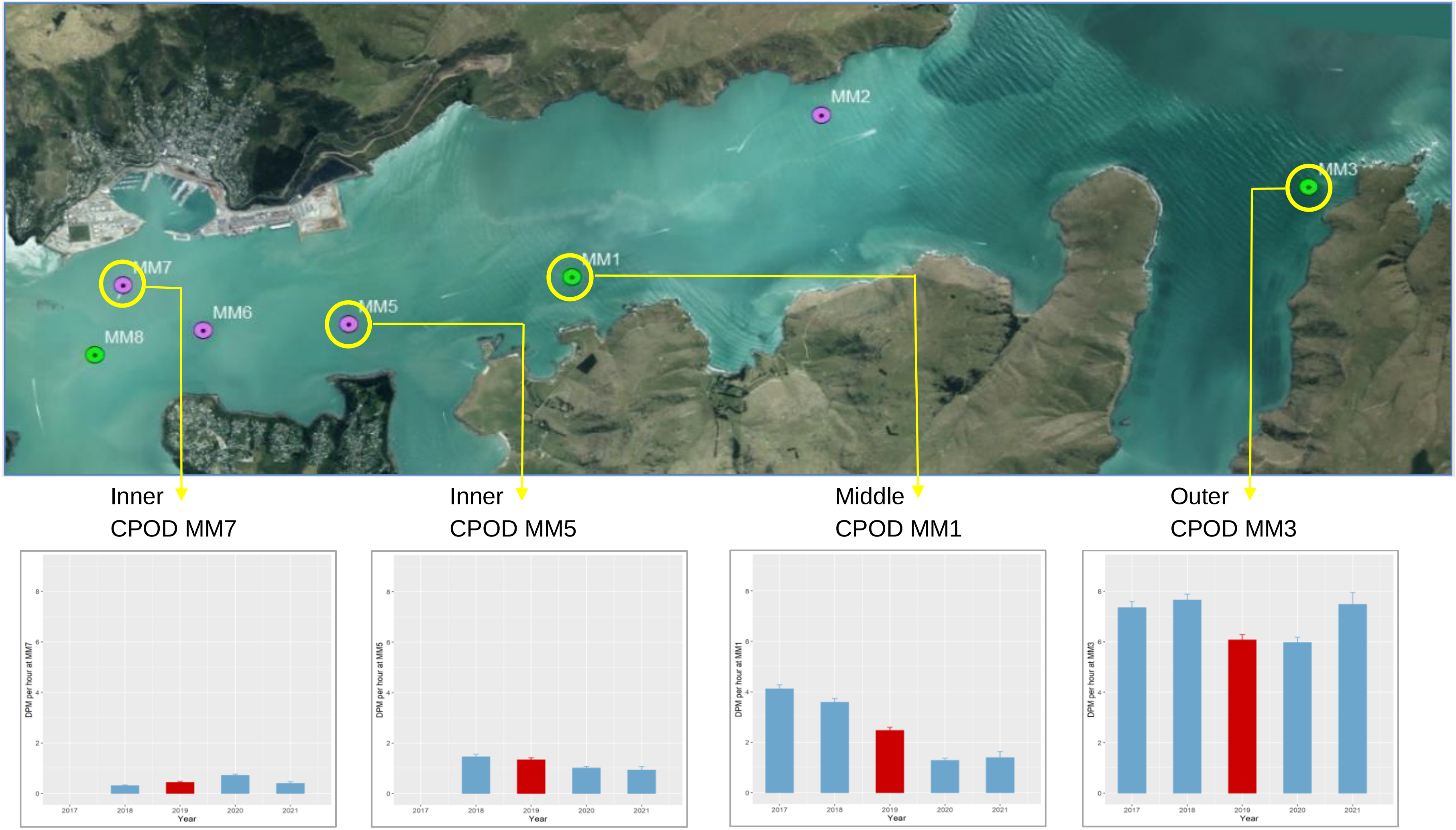

Figure 6. Visual comparison of the gradient in mean annual CPOD DPM per hour from the inner moorings near the Port (left) out towards the outer harbour moorings at Lyttelton Heads (right). The red bars denote 2019—the piling period. Note that the x- and y-axis scale are the same across all figures.

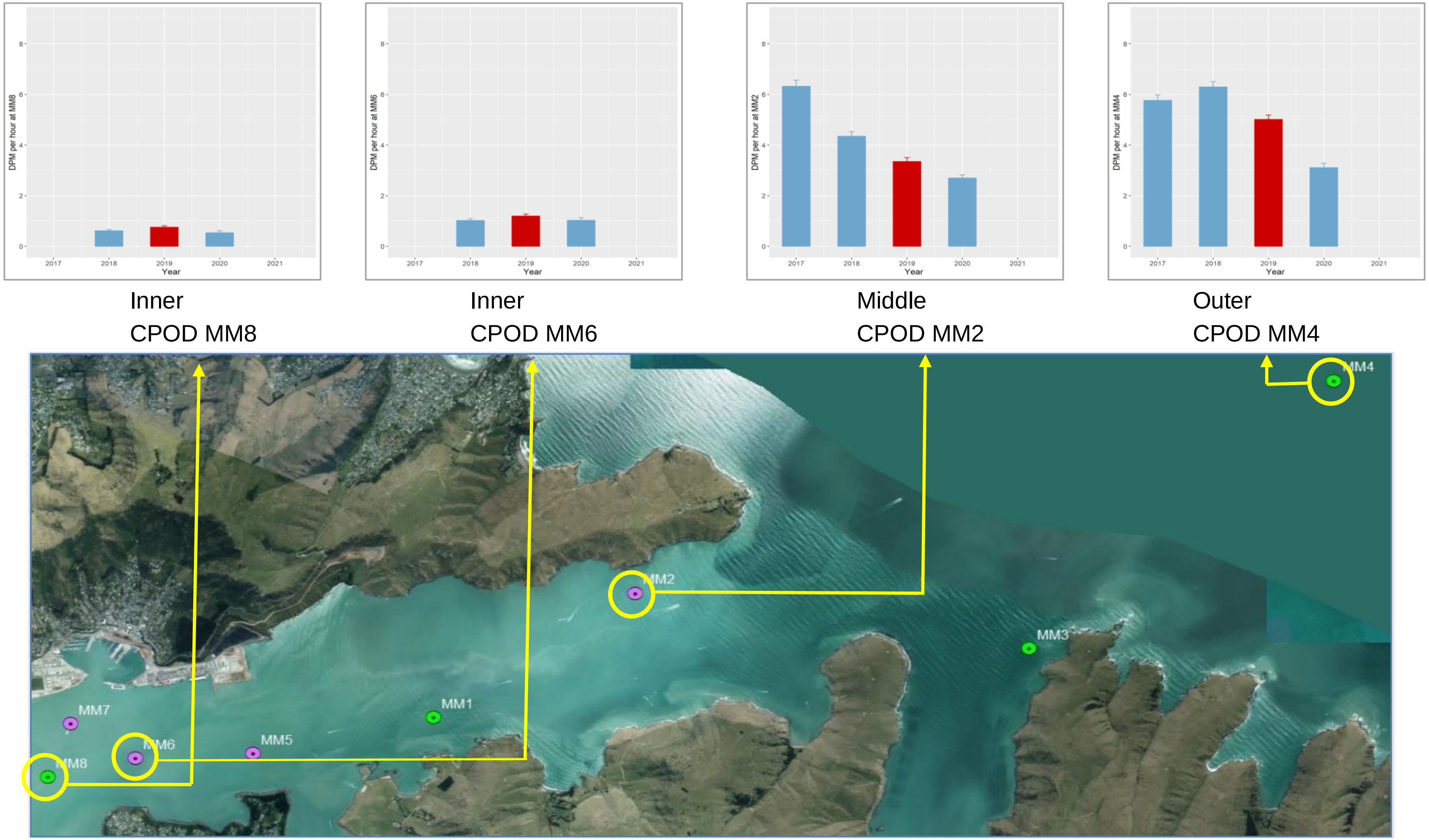

Figure 7. Visual comparison of the gradient in mean annual CPOD DPM per hour from the inner moorings near the Port (left) out towards the outer harbour moorings at Lyttelton Heads (right). The red bars denote 2019—the piling period. Note that the x- and y-axis scale are the same across all figures.

Table 6. Results of generalised linear models fit to CPOD dolphin detection positive minutes (DPM) per hour at sites MM4, MM3, MM2, and MM1 during 2017–2020. For each predictor in the model, the point estimate (logarithmic scale), standard error (SE), test statistic (z-value), and p-value are given. The intercept refers to the baseline DPM per hour at MM4 on the logarithmic scale. Positive estimates refer to positive effects on DPM on the logarithmic scale, and negative estimates to negative effects on the logarithmic scale. P-values highlighted in bold represent strong evidence for an effect.

Variables	**Estimate**	**SE**	**Statistic**	**P-value**
Intercept	5.23	0.07	72.25	**< 0.001**
Year	-0.19	0.03	-6.57	**< 0.001**
Site: MM3	0.04	0.10	0.41	0.685
Site: MM2	-0.01	0.10	-0.12	0.901
Site: MM1	-0.14	0.10	-1.40	0.161
Year:MM3	0.10	0.04	2.61	**0.009**
Year:MM2	-0.09	0.04	-2.46	**0.014**
Year:MM1	-0.20	0.04	-5.47	**< 0.001**

Table 7. Results of GLM fit to CPOD dolphin detection positive minutes (DPM) per hour at sites MM5, MM6, MM7, and MM8 between 2018-2020. For each predictor in the model, the point estimate (logarithmic scale), standard error (SE), test statistic (z-value), and p-value are given. The intercept refers to the baseline DPM per hour at MM5 on the logarithmic scale. Positive estimates refer to positive effects on DPM on the logarithmic scale, and negative estimates to negative effects on the logarithmic scale. P-values highlighted in bold represent strong evidence for an effect.

Variables	**Estimate**	**SE**	**Statistic**	**P-value**
Intercept	3.95	0.18	22.52	**< 0.001**
Year	-0.19	0.05	-3.55	**< 0.001**
Site: MM6	-0.79	0.25	-3.17	**0.002**
Site: MM7	-2.87	0.24	-12.00	**< 0.001**
Site: MM8	-1.18	0.25	-4.72	**< 0.001**
Year: MM6	0.22	0.08	2.69	**0.007**
Year: MM7	0.62	0.07	8.32	**< 0.001**
Year: MM8	0.18	0.08	2.16	**0.031**

4.1.2. Harbour-wide seasonal detections - CPOD data

Hector's dolphins are known for a distinct seasonal signal in their distribution patterns. The most pronounced seasonal variability in CPOD detections was present in the outermost sites (MM2 to MM4; Figure 8; Appendix A5). The DPM rates were generally highest in summer and lowest over winter months as expected (e.g. Clement 2018; Brough et al. 2014).

While there was less variance in detection rates within the innermost sites (MM5 to MM8), a reduced seasonal signal was still apparent some years at MM5 and within middle harbour point MM1 (Figure 9). Appendix 5 features the seasonal and monthly data of each mooring in more detail.

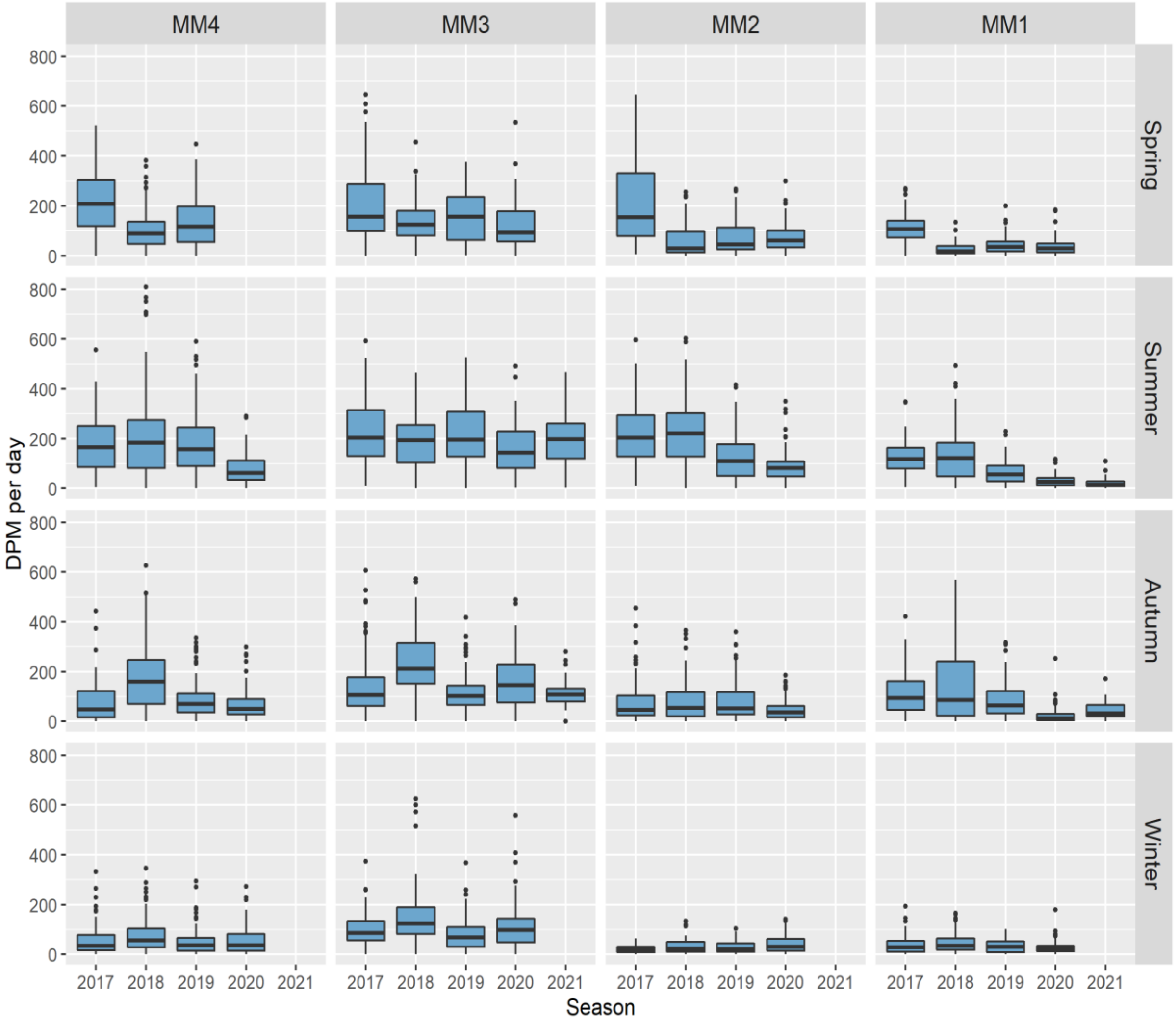

Figure 8. Boxplots of annual CPOD detection positive minutes (DPM) per day (sum of DPM per hour over 24 hours) summarised by **outer and mid mooring sites**, season and year. The boxes indicate the 25th and 75th percentiles, the horizontal bold lines indicate the 50th percentile (median), the vertical lines indicate the maximum values, and the dots indicate the outliers.

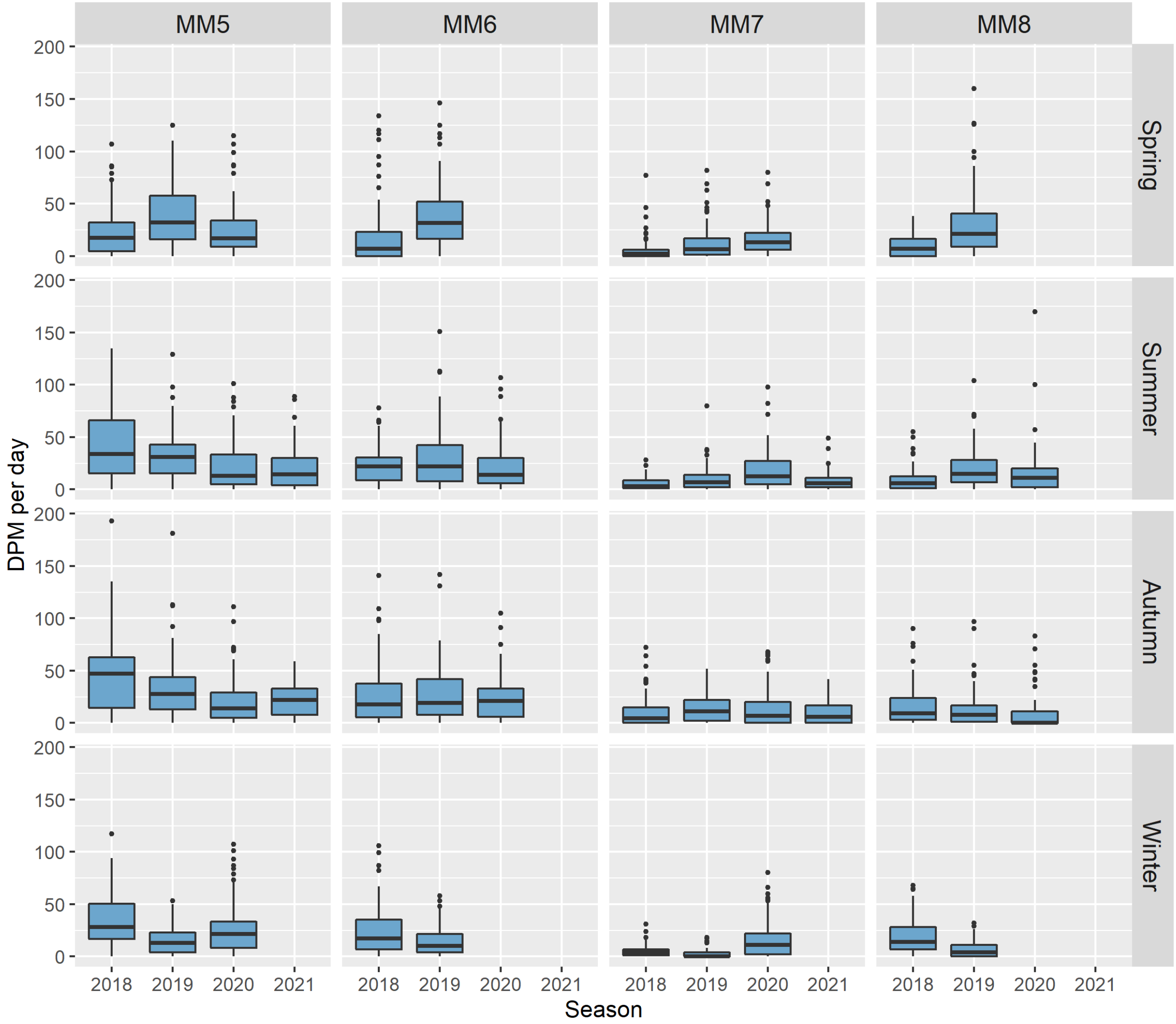

Figure 9. Boxplots of annual CPOD detection positive minutes (DPM) per day (sum of DPM per hour over 24 hours) summarised by **inner mooring sites**, season and year. The boxes indicate the 25th and 75th percentiles, the horizontal bold lines indicate the 50th percentile (median), the vertical lines indicate the maximum values, and the dots indicate the outliers. Note the y-axis scale differences to Figure 8.

4.1.3. Inner harbour acoustic detections

The data collected with SoundTraps (ST) recorders do not provide the same full baseline coverage as CPOD data as they were not deployed until later winter / early spring 2018, and mainly on inner harbour moorings, with some removed earlier than CPODs (see Table 2). In addition, ST recorders were on a duty cycle not a continuous listening cycle like CPODs. Hence, the mean number of Hector's dolphin detection positive minutes per duty cycle hour (DPM) recorded by year are listed in Table 8 for information purposes only.

The goal with ST moorings was to capture information on underwater noise levels and dolphin detections simultaneously over the piling-driving period near the construction site to assess any subsequent effects. In general, greater DPMs were recorded during the months of December and March / April across all years relative to the other sampling months, indicating the presence of a seasonal signal (Figure 10). As with CPOD data, seasonal trends in DPM rates were more pronounced at the middle harbour site (MM2) and reduced at those inner harbour sites closest to the Port (Figure 10). At a finer scale, dolphin detection rates were highly variable between days but with some general trends apparent between seasons and sampling years (Figures 11–12).

Table 8. Mean, standard error (in brackets), and sample size of dolphin detection positive minutes per duty cycle hour for each SoundTrap mooring over the different sampling years. * denotes those years in which a full year of sampling was not undertaken (see Table 2).

Mooring Location	**Baseline Period**	**Piling period**	**Post-Piling Period**	
	2018	*2019*	*2020*	*2021*
Middle Harbour				
MM2	* 3.60 *(0.08)* *10,613*	3.19 *(0.06)* *19,296*	* 4.97 *(0.09)* *14,251*	
Inner Harbour				
MM5	* 2.08 *(0.05)* *7,358*	1.84 *(0.04)* *13,660*	1.78 *(0.04)* *9,240*	* 1.44 *(0.05)* 3,119
MM6	* 2.73 *(0.07)* *8,126*	1.60 *(0.03)* *10,033*	* 1.71 *(0.05)* *4,749*	
MM7	* 1.10 *(0.04)* *2,844*	0.79 *(0.02)* *5,695*	* 1.02 *(0.04)* *2,861*	

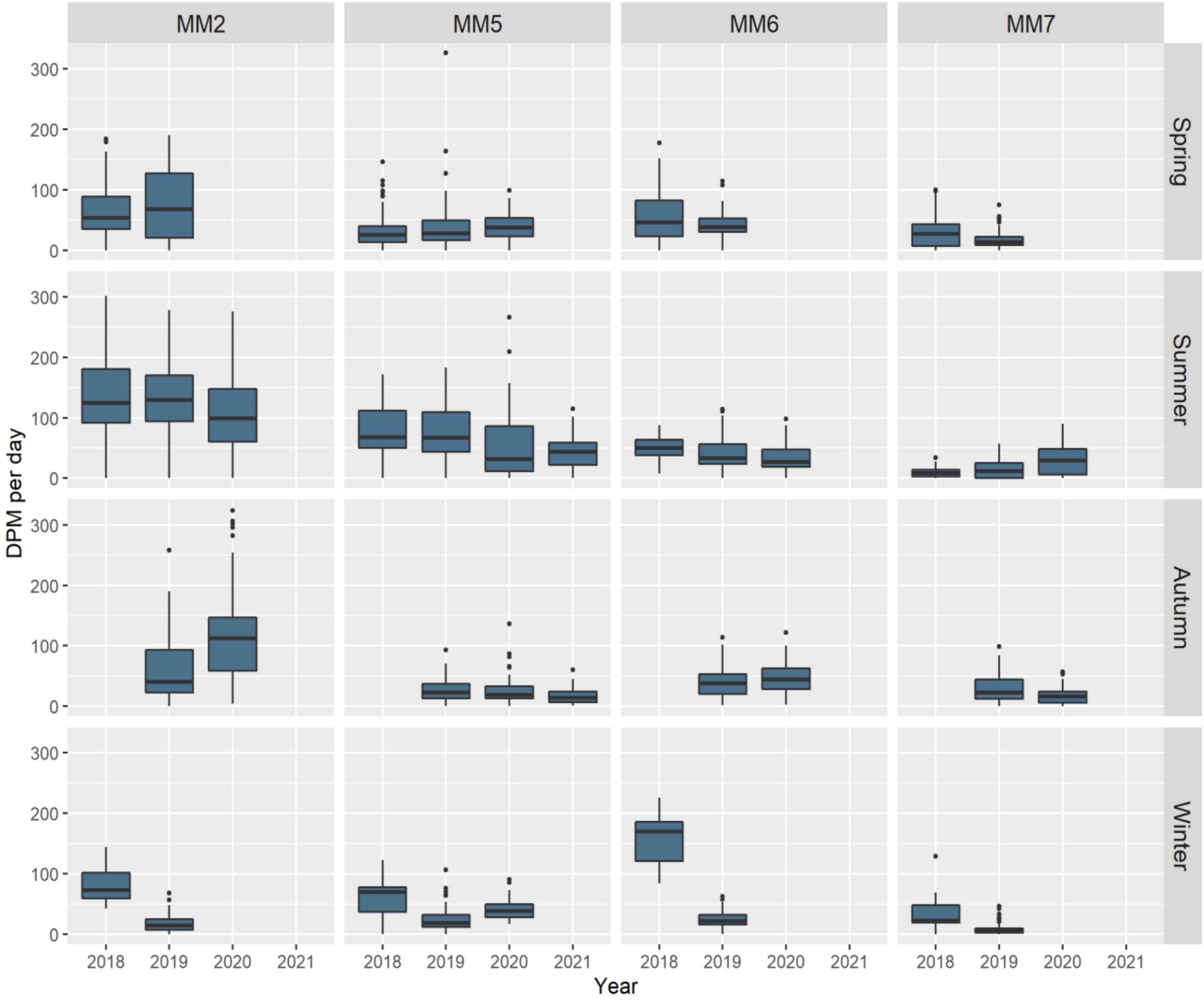

Figure 10. Boxplot of annual SoundTrap detection positive minutes (DPM) per day (sum of DPM per duty cycle hour over 24 hours) summarised by season, year and site. The boxes indicate the 25th and 75th percentiles, the horizontal bold lines indicate the 50th percentile or median, the vertical lines indicate the maximum values, and the dots indicate the outliers.

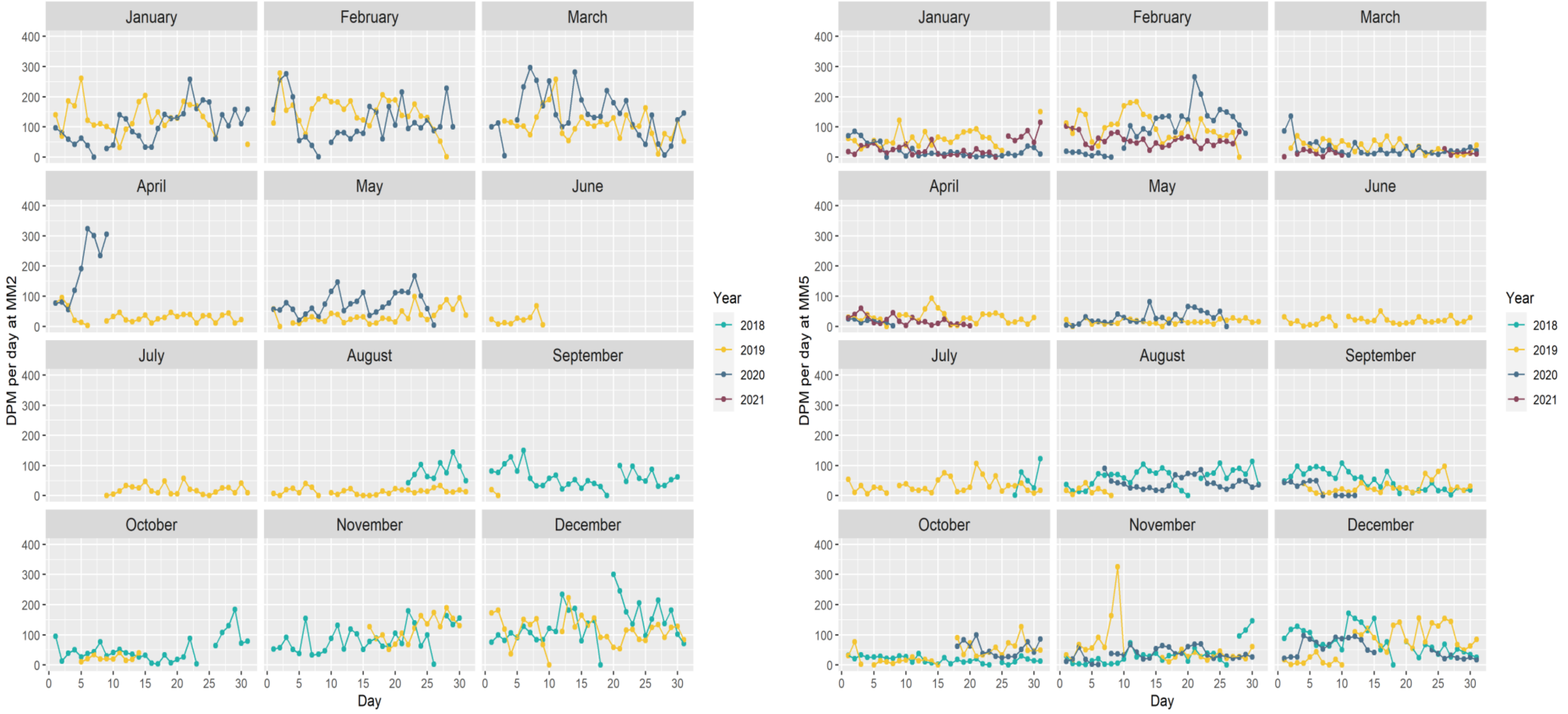

Figure 11. SoundTrap DPM per day (sum of DPM per duty cycle hour over 24 hours) at **MM2** (left figures) and **MM5** (right figures). MM2 is located in the mid- to outer regions of the harbour while MM5 is located within the inner harbour region. The different years are represented by the different colours as indicated in the legend.

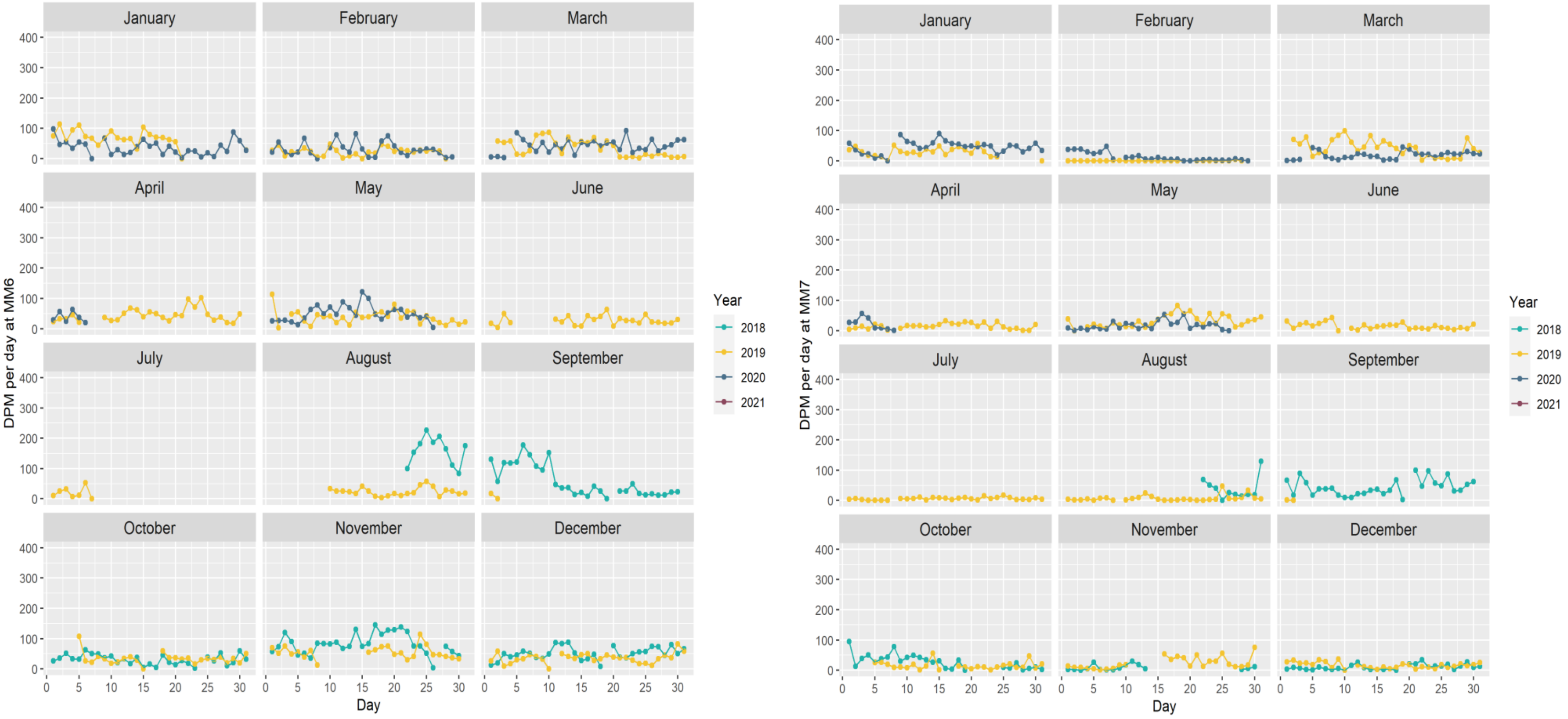

Figure 12. SoundTrap DPM per day (sum of DPM per duty cycle hour over 24 hours), month, and year at **MM6** (left figures) and **MM7** (right figures), both of which are located in the inner harbour. The different years are represented by the different colours as indicated in the legend.

4.2. Piling effects

To investigate the effect piling driving activities may have on Hector's dolphin, only ST detections[7] were used in models as these instruments recorded and stored the actual sound levels at the moorings when dolphins were and were not present. CPOD data, while collected over a much longer sampling period, only recorded when a dolphin was detected with no associated underwater noise levels. Hence, the possible effects of pile driving activity on noise levels could not be modelled with CPOD data.

4.2.1. General model results

The general model took into consideration the spatial-temporal variables examined in previous sections (e.g. season, year) as well as all piling activity (e.g. vibro and hammer, including periods without any activity) and other influential environmental conditions that might affect dolphin detections (e.g. wind speed, rainfall). There was evidence that water temperature was correlated with both season and year (Spearman's correlation test = -0.51 and 0.37, $p < 0.001$), therefore these variables were not combined into a single model. Instead, global models were fitted with these predictors separately, and on the basis of AIC, the global model containing season and year was selected (ΔAIC = 816.55). The rank of models based on AIC is given in Table 9. The lowest AIC model among competing models contained all predictors (global model); Models 2, 3 and 4 had similar weight while Model 3 was the least parameterised. Therefore, following the parsimony principle (Burnham & Anderson 2002), Model 3 was selected to carry out further inference. Models excluding site, season and ambient noise were the least favourable in this order, suggesting that these predictors were important drivers of DPM variability.

Model 3 estimates are given in Table 10. The estimates and respective standard errors are given in the logarithmic scale, and they are given in comparison to a baseline (intercept) that refers to the DPM per duty cycle hour at MM2, in spring, and in 2018. On the logarithmic scale, there was very strong indication of a negative effect of pile-driving ($p < 0.001$), ambient noise ($p < 0.001$), and wind speed ($p = 0.006$) on DPM per duty cycle hour (Table 10). There was also evidence that DPM was greater at site MM2 compared to all others ($p < 0.001$) and in summer compared to all other seasons ($p < 0.001$), while at its lowest in winter ($p < 0.001$). Through a multi-year comparison, the evidence also points to a smaller DPM in 2019 compared to 2018 and 2020.

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[7] SoundTraps are only deployed on the middle harbour mooring - MM2 and all inner harbour moorings (MM5 - MM7) with the exception of MM8.

Table 9. Summary of competing general models (GLMMs) fit to SoundTrap DPM per duty cycle hour . ∆AIC is the relative difference in AIC values compared with the top ranked model. The fixed effects column shows the explanatory variables that were excluded from the model; global means that all explanatory variables were included in the model. The preferred model is in bold.

Rank	Fixed effects	AIC	∆AIC	Log-likelihood
1	- Rainfall	158774.9	0.00	-79371.5
2	Global	158776.5	1.60	-79371.3
3	**- Rainfall and wind direction**	158777.4	2.47	-79373.7
4	- Wind direction	158778.7	3.73	-79373.3
5	- Wind speed	158782.8	7.85	-79375.4
6	- Year	158795.3	20.38	-79382.7
7	- Pile-driving	158817.3	42.33	-79392.6
8	- Ambient noise	158876.9	102.01	-79422.5
9	- Season	159678.9	903.93	-79825.4
10	- Site	161668.5	2893.60	-80820.3

Table 10. Results of general Model 3 (excluding rainfall and wind direction) fit to dolphin detection positive minutes (DPM) per duty cycle hour recorded from STs. The intercept refers to the baseline represented by DPM per duty cycle hour at MM2, spring, 2018. The estimate (logarithmic scale), standard error (SE), test statistic (z-value), and p-value are given for each predicator. Positive estimates refer to positive effects on DPM on the logarithmic scale, and negative estimates to negative effects on the logarithmic scale. P-values highlighted in bold represent strong evidence for an effect.

Variables	Estimate	SE	Statistic	P-value
Intercept	1.36	0.03	46.23	**< 0.001**
Pile-driving	-0.28	0.04	-6.34	**< 0.001**
Ambient noise	-0.10	0.01	-10.11	**< 0.001**
Site: MM5	-0.67	0.02	-28.74	**< 0.001**
Site: MM6	-0.70	0.02	-28.84	**< 0.001**
Site: MM7	-1.40	0.03	-54.73	**< 0.001**
Season: Summer	0.20	0.03	7.99	**< 0.001**
Season: Autumn	-0.07	0.03	-2.36	**0.019**
Season: Winter	-0.81	0.03	-23.28	**< 0.001**
Year: 2019	-0.12	0.03	-4.50	**< 0.001**
Year: 2020	-0.06	0.03	-1.86	0.063
Wind speed	-0.03	0.01	-2.74	**0.006**

The expected DPM per duty cycle hours in the original scale are obtained as $\exp(intercept + variable\ estimate)$. For example:

- Expected DPM without pile-driving (intercept): $\exp(intercept) = \exp(1.36) = 3.90$
- Expected DPM with pile-driving: $\exp(intercept + pile - driving\ estimate) = \exp(1.36 - 0.28) = 2.94$
- Expected DPM at MM2 (intercept): $\exp(intercept) = \exp(1.36) = 3.90$
- Expected DPM at MM5: $\exp(intercept + site\ MM5\ estimate) = \exp(1.36 - 0.67) = 1.99$
- Expected DPM at MM6: $\exp(intercept + site\ MM6\ estimate) = \exp(1.36 - 0.70) = 1.93$
- Expected DPM at MM7: $\exp(intercept + site\ MM7\ estimate) = \exp(1.36 - 1.40) = 0.96$.

4.2.2. Fine-scale model results

The fine-scale model focused solely on the effects of hammer-pile driving on ST detection positive minutes (DPM) per duty cycle hour per site between December 2018 and February 2020. These models took into consideration other potential factors that might affect detection rates while piling was underway (e.g. environmental and temporal variables), with the exception of year as basically pilling was underway mostly in 2019. Initial trials showed high variability in noise response among sites; hence, separate models were fitted for the three inner most harbour mooring sites (MM5, MM6 and MM7). MM2 was excluded as pile-driving noise (i.e. SELcum_{1h}) was negligible at this location, similar to the findings of Leunissen et al. (2019). Note that the total number of models fitted per site can vary due to the potential negligible effect of some explanatory variables, which were dropped in the next model fit (see details in Section 3.2.2 Modelling).

Site MM5

As in the general dataset, correlation between temperature and season was identified (Spearman's correlation test = -0.66, $p < 0.001$); therefore, these variables were not combined into a single model. Instead, global models were fitted with these predictors separately, and on the basis of AIC, the global model containing temperature was selected (ΔAIC = -2.26). Note that a smooth term was fitted to temperature, while season was treated as a factor variable, and therefore, each level of season (summer, autumn, spring, or winter) would have an associated parametric coefficient.

The rank of models based on AIC is given in Table 11. The first six models in Table 11 had similar support; hence, the inference model was chosen as the smallest AIC and least equal parameterised model among them, which was the model excluding wind direction and wind speed (Model 1). The fine-scale models that excluded cumulative SEL, temperature, and the model with rainfall, wind direction and speed combined were the least favourable in this order, suggesting that these predictors, or their combination, were important drivers of DPM variability at MM5.

Table 11. Summary of competing fine-scale models (GAMMs) fit to dolphin detection positive minutes per duty cycle hour at **MM5**. ∆AIC is the relative difference in AIC values compared to the top ranked model. The fixed effects column shows the explanatory variables excluded from the model; global means that all explanatory variables were included in the model. The preferred model is in bold.

Rank	**Fixed effects**	**AIC**	**∆AIC**	**Log-likelihood**
1	**- Wind direction and wind speed**	**1280.6**	**0.00**	**-618.52**
2	- Wind speed	1282.3	1.66	-618.70
3	- Wind direction	1282.4	1.78	-618.43
4	- Rainfall and wind direction	1283.6	2.92	-620.29
5	Global	1284.2	3.58	-618.63
6	- Rainfall and wind speed	1284.6	3.91	-620.48
7	- Rainfall	1291.3	10.62	-620.04
8	- Temperature	1297.4	16.73	-617.38
10	- Rainfall, wind direction and speed	1317.0	36.40	-632.54
11	- SELcum_{1hr}	1333.3	52.66	-640.22

Cumulative SEL, water temperature and rainfall were described as smooth terms in Model 1 (Figure 13). Smooth terms describe a non-linear relationship between the response variable and covariates. Hence, instead of looking at the model's single estimate as in a GLM (see details in Section 4.2.1 General model results), we can visually interpret the smooth curves. A relationship close to linear was estimated for all the three explanatory variables, with DPM per duty cycle hour decreasing with SELcum_{1hr}, and increasing with water temperature and rainfall. Although rainfall was included as an explanatory variable in the model, its effect was highly variable as can be seen by its wide confidence interval (Figure 13, bottom-left graph).

The random effects term accounts for the hourly variation in DPM across days. Model results consider the random effects term to be somewhat important, which means that part of the model variance came from daily variability (Table 12). For comparison purposes, the random effects variance at MM6 and MM7 are also presented in Table 12.

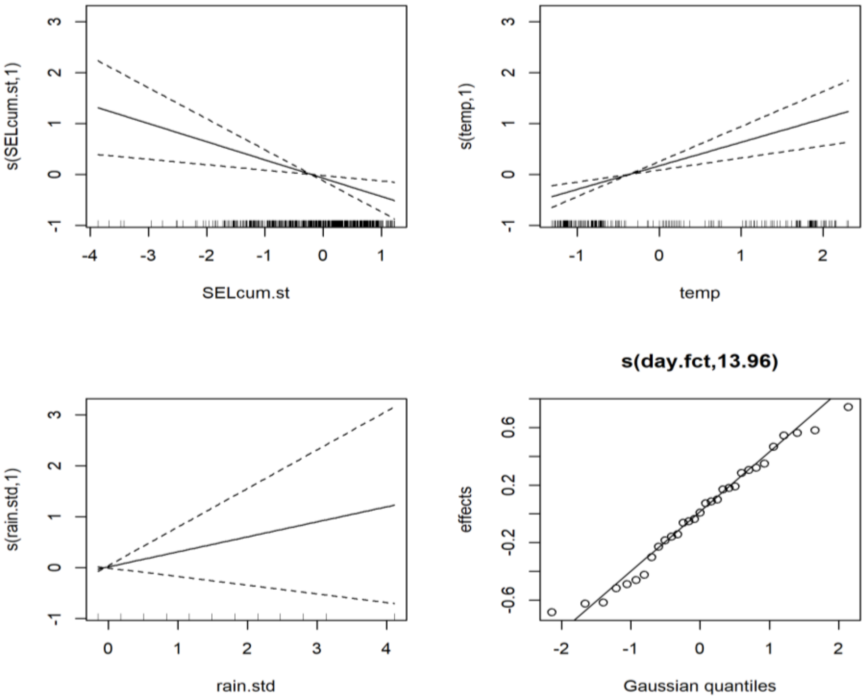

Figure 13. Smooth terms of Model 1 for **site MM5** including the effects of cumulative SEL (SELcum.st), temperature (temp), and rainfall (rain.std) on detection positive minutes per duty cycle hour (y-axis). The Gaussian quantiles of random effects are also shown (right-bottom graph). The solid lines are the estimates, and the dashed lines are the 95% confidence interval. The explanatory variables were standardised before fitting the model; hence, their range in the graphs are not the original values.

Table 12. Random effects (day) summary of fine-scale models (GAMMs) fit to dolphin detection positive minutes per duty cycle hour for MM5, MM6 and MM7.

Site	Variance	SD
MM5	0.344	0.586
MM6	0.025	0.157
MM7	0.000	0.003

The SELcum$_{1hr}$ smooth term of Model 1 shows the predicted effect of cumulative SEL on DPM per duty cycle hour for four distinct temperatures (10 °C, 13 °C, 16 °C and 19 °C), and a negligible rainfall rate (mean hourly rainfall for the period was 0.004 mm). These temperatures were chosen to reflect minimum, maximum, and in between temperatures in the inner and mid harbour, and are representative of seasonal temperatures (winter: 10 °C, autumn: 13 °C, spring: 16 °C, summer: 19 °C).

Predictions at MM5 indicated a general linear negative response to piling noise from 110 dB to 175 dB. The decline was particularly noticeable in higher temperatures (16 °C and 19 °C), corresponding to spring and summer (Figure 14).

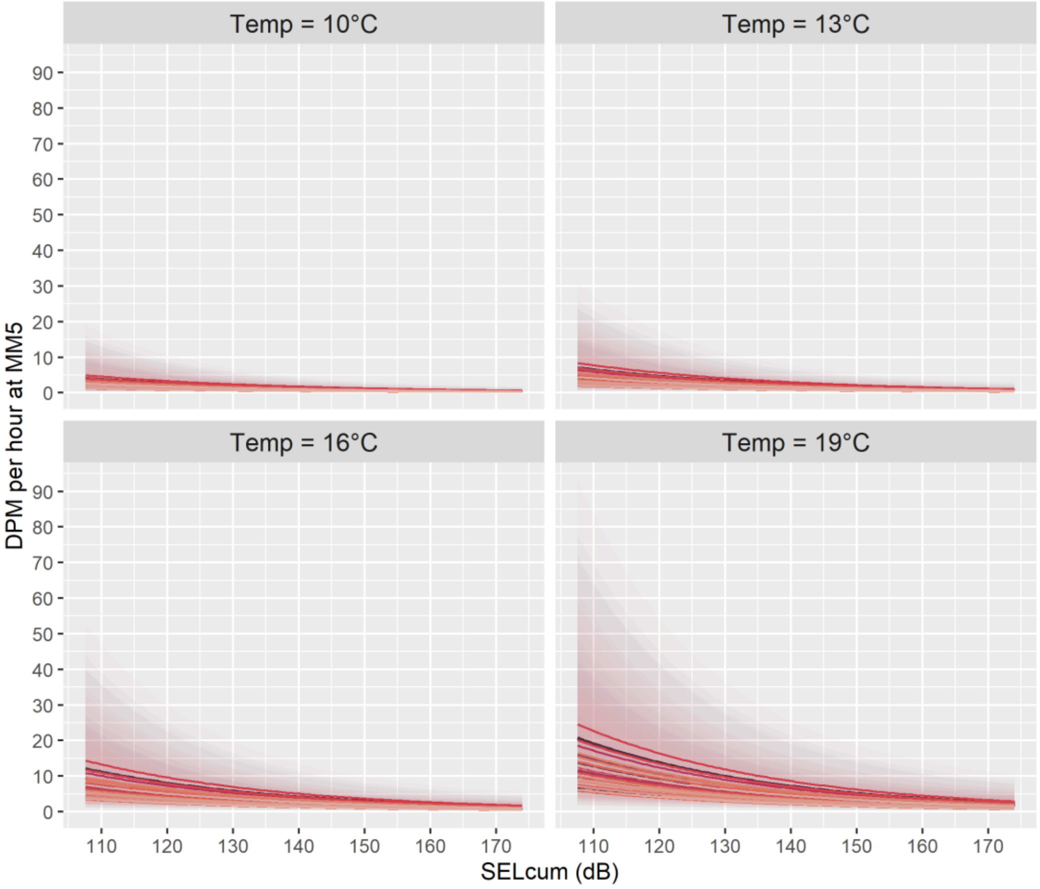

Figure 14. The predicted effect of cumulative sound exposure level ($SELcum_{1hr}$) on detection positive minutes (DPM) per duty cycle hour at **site MM5** across different temperatures. The bold lines represent the different random effects (days), and the shaded coloured areas represent their 95% confidence interval.

Site MM6

As in the general dataset, correlation between water temperature and season was identified (Spearman’s correlation test = -0.89, $p < 0.001$), and like MM5, the global model containing temperature was selected (ΔAIC = -3.56). The rank of models based on AIC is given in Table 13. The first four models in Table 13 had similar support; hence, the inference model was chosen as the smallest AIC and least parameterised model among them, which was the model excluding wind direction and rainfall (Model 1). Models excluding cumulative SEL, wind speed, and temperature were the least favourable in this order, suggesting these predictors were important drivers of MM6 DPM variability.

Table 13. Summary of competing fine-scale models (GAMMs) fit to dolphin detection positive minutes per duty cycle hour at **MM6.** ∆AIC is the relative difference in AIC values compared with the top ranked model. The fixed effects column shows the explanatory variables that were excluded from the model; global means that all explanatory variables were included in the model. The preferred model is in bold.

Rank	Fixed effects	AIC	∆AIC	Log-likelihood
1	**- Wind direction and rainfall**	**937.8**	**0.00**	**-457.76**
2	- Wind direction	939.7	1.89	-457.81
3	- Rainfall	940.5	2.79	-456.99
4	Global	942.6	4.82	-457.00
5	- Temperature	950.1	12.29	-461.93
6	- Wind speed	952.2	14.41	-464.67
7	- SELcum_{1hr}	968.1	30.38	-471.12

Cumulative SEL, temperature and wind speed were described as smooth terms in Model 1 (Figure 15). A relationship close to linear was estimated for wind speed, with DPM per duty cycle hour decreasing with wind speed. The effects of cumulative SEL and temperature were less linear, but generally pointed to a decrease and increase in DPM per duty cycle hour, respectively. A peak in DPM per duty cycle hour was estimated for temperatures around 16 °C, corresponding to spring temperatures.

The random effects term accounts for the hourly variation in DPM across days. Model results consider the random effects term was somewhat important, but not as much as at site MM5 (Table 12).

From the SELcum_{1hr} smooth term of Model 1, Figure 16 shows the predicted effect of cumulative SEL on DPM per duty cycle hour for four distinct temperatures (10°C, 13°C, 16°C and 19°C), and the mean wind speed at site MM6 (10 km/h). These predictions indicated a gradual linear negative response to piling noise from 110 dB to 175 dB, noticeable in temperatures ranging from 13 to 19°C, particularly in spring (16 °C).

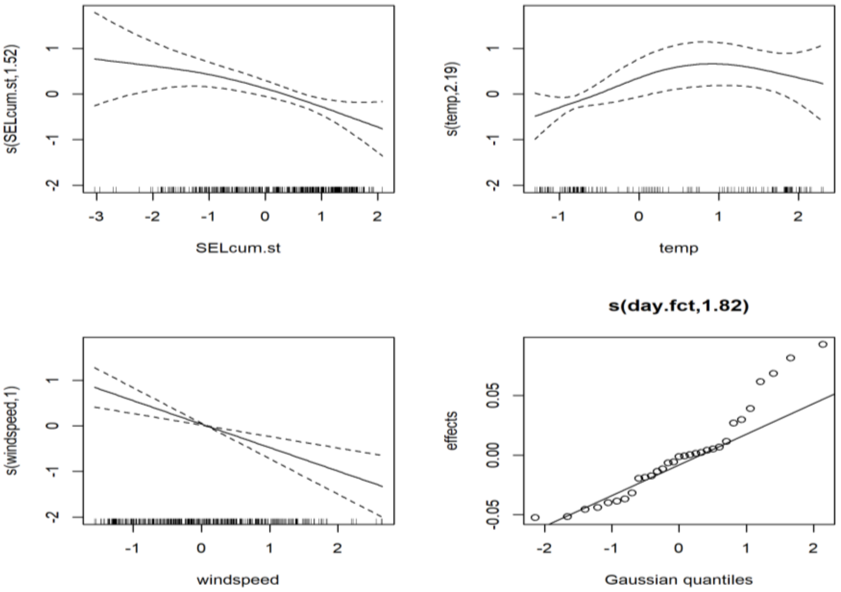

Figure 15. Smooth terms of Model 1 for **site MM6** including the effects of cumulative SEL (SELcum.st), temperature (temp), and wind speed (windspeed) on DPM per duty cycle hour (y-axis).The Gaussian quantiles of random effects are also shown (right-bottom graph). The solid lines are the estimates, and the dashed lines are the 95% confidence interval. The explanatory variables were standardised before fitting the model, hence their range in the graphs are not the original values.

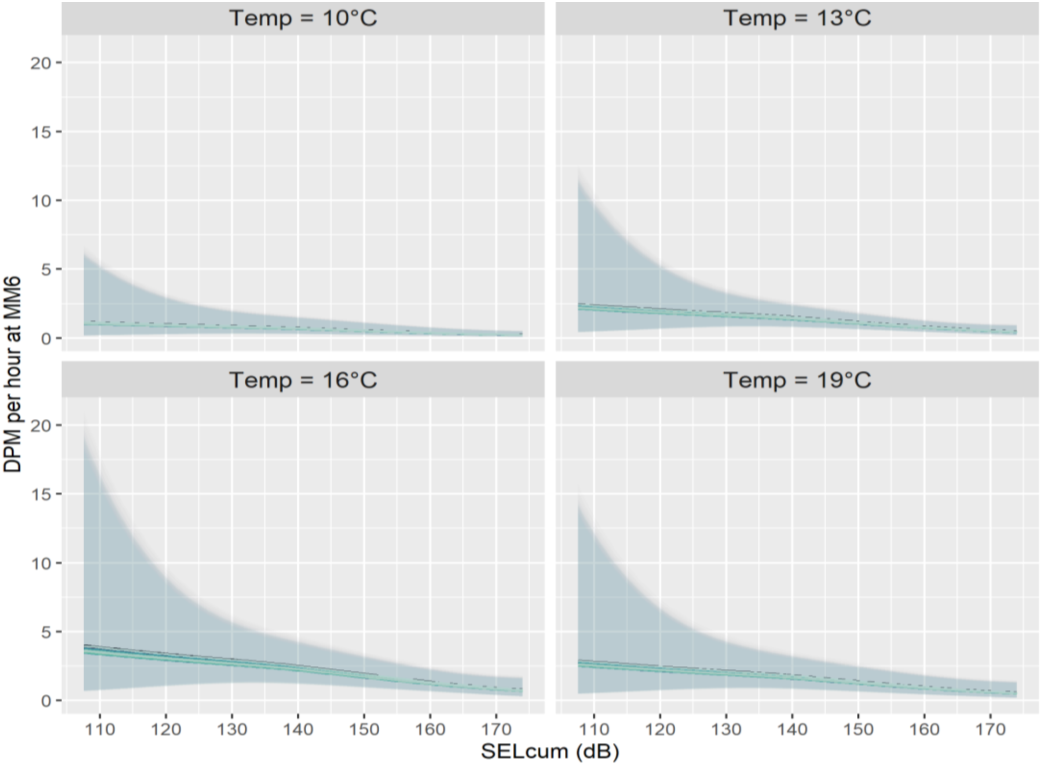

Figure 16. The predicted effect of cumulative sound exposure level (SELcum$_{1hr}$) on detection positive minutes (DPM) per duty cycle hour at **site MM6** across different temperatures. The bold lines represent the different random effects (days), and the shaded coloured areas represent their 95% confidence interval.

Site MM7

As in the general dataset, correlation between temperature and season was identified (Spearman's correlation test = -0.92, $p < 0.001$), and like MM5 and MM6, the global model containing temperature was selected (∆AIC = -6.32). The rank of models based on AIC is given in Table 14. The first four models in Table 14 had similar support, hence the inference model was chosen as the smallest AIC and least parameterised model among them, which was the model excluding wind direction, wind speed and rainfall (Model 1). Models excluding cumulative SEL and temperature were the least favourable in this order, suggesting these predictors were important drivers of DPM variability at MM7.

Table 14 Summary of competing fine-scale models (GAMMs) fit to dolphin detection positive minutes per duty cycle hour at **MM7**. ∆AIC is the relative difference in AIC values compared with the top ranked model. The fixed effects column shows the explanatory variables that were excluded from the model; global means that all explanatory variables were included in the model. The preferred model is in bold.

Rank	Fixed effects	AIC	∆AIC	Log-likelihood
1	**- Wind direction, speed, and rainfall**	**489.0**	**0.00**	**-236.60**
2	- Wind direction and speed	489.6	0.61	-235.94
3	- Wind speed and rainfall	489.9	0.89	-236.00
4	- Wind direction and rainfall	490.4	1.41	-235.28
5	- Wind speed	491.7	2.64	-236.02
6	- Wind direction	492.0	3.02	-235.12
7	- Rainfall	492.5	3.45	-235.20
8	- Global	493.8	4.79	-234.95
9	- Temperature	504.9	15.83	-243.49
10	- $\text{SELcum}_{1\text{hr}}$	606.5	117.46	-295.22

Cumulative SEL and temperature were described as smooth terms in Model 1 (Figure 17). The effect of temperature was not linear, pointing to an increase in DPM per duty cycle hour with peak around 17 °C, corresponding to spring, followed by a decrease at higher temperatures up to 20 °C.

The random effects term accounts for the hourly variation in DPM across days. Model results consider the random effects term was very small and negligible (Table 12); this can be seen by the single lines in Figure 18, which means that the DPM was invariant across days. From the smooth term of Model 1 (i.e., SELcum$_{1hr}$), Figure 18 shows the predicted effect of cumulative SEL on DPM per duty cycle hour for the four distinct temperatures that indicated a very small overall decline in DPM as piling noise increased that is only apparent in spring (around temperatures of 16 °C).

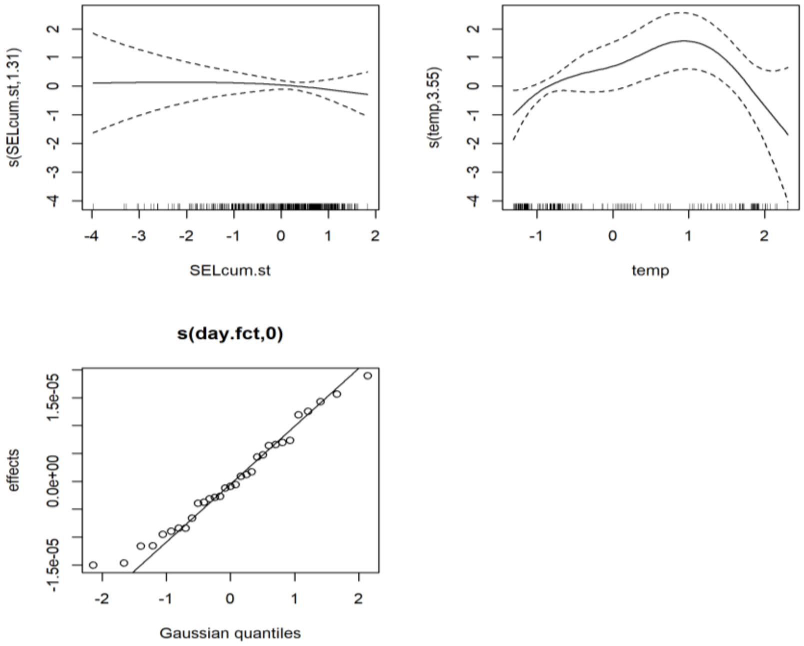

Figure 17. Smooth terms of Model 1 for **site MM7** including the effects of cumulative SEL (SELcum.st), and temperature (temp) on detection positive minutes per duty cycle hour (y-axis). The Gaussian quantiles of random effects are also shown (left-bottom graph). The solid lines are the estimates, and the dashed lines are the 95% confidence interval. The explanatory variables were standardised before fitting the model, hence their range in the graphs are not the original values.

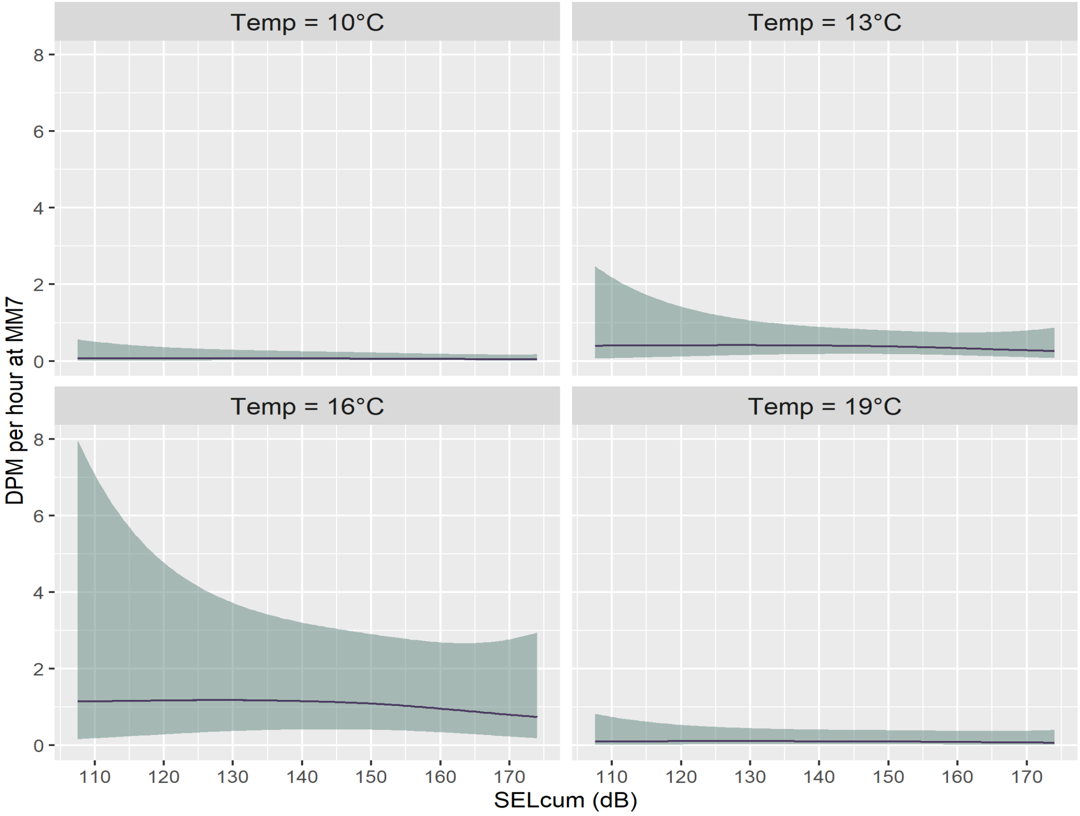

Figure 18. The predicted effect of cumulative sound exposure level (SELcum$_{1hr}$) on detection positive minutes (DPM) per duty cycle hour at **site MM7** across different temperatures. The bold lines represent the different random effects, and the shaded coloured areas represent their 95% confidence interval. Due to the very small variance of the random effects, the lines and 95% CI strongly overlap.

4.2.3. Model summary

Between the general and fine-scale models, we were able to investigate the potential effects of pile-driving noise and other variables on dolphin ST detections. The findings from the fine-scale models show that, while DPM per duty cycle hour decreased with increasing noise from pile-driving at all mooring sites, a response gradient can be inferred with the noise response becoming greater as we move from the innermost (MM7) to the outermost site (MM5). Temperature (or season) was one of the most important explanatory variables to describe variability at DPM per duty cycle hour in all mooring sites, while wind speed or direction and rain seemed to explain the remaining variability on the data.

4.2.4. Short term recovery rates

The longer-term 'recovery' rate of Hector's dolphins after the Cruise Berth construction as a whole was reviewed in Section 4.1 by looking at trends in annual and seasonal CPOD detection rates collected across Lyttelton Harbour and outside regions. In the section, the number of hours that it took for dolphin detections to return to 'pre-piling'[8] detection levels were examined to understand possible shorter-term effects of pile-driving activity on dolphins at inner harbour sites (MM5 to MM7) using ST data only. The mid-harbour site, MM2, was also examined for evidence of change in detection rates, with potential to reflect short-term dolphin movements to or from inner harbour regions.

Between 1,199 and 1,436 sampling periods (i.e. DPM per duty cycle hour) at inner (MM5 to MM7) and mid-harbour (MM2) mooring sites were found in which there was no piling activity, neither vibro or hammer, for the 48 hours immediately prior to and immediately after the cessation of a particular pile-driving event (Figure 19 to Figure 22, Figure 23 to Figure 26). Based on these sample periods, GAMs were fitted to DPM per duty cycle hour data separately for each mooring site in order to see whether DPM per duty cycle hour returned back to pre-piling rates [9]. Results suggest that DPM per duty cycle hour did not return to pre-piling levels within 48 hours after piling activity ceased, with no evidence of associated increases in DPM per duty cycle hour at either MM5 or MM2 (i.e. no support for animals being displaced from inner regions and moving towards the harbour entrance; Figure 27). At MM6 and MM7, DPM rates seem to be reaching pre-piling levels after 48 hours, while recovery at MM5 and MM2 seem to be slower (Figure 27). These short-term recovery time periods are of similar lengths to those reported by Leunissen et al.'s (2019) study.

These results align with those of the fine-scale models in which dolphin detections at MM5 had a more pronounced response to piling noise than the very subtle and more temporary responses at MM7, the mooring closest to the Port and the noise source. These results may be due to the bathymetric characteristics around MM7, as it sat on a semi-plateau next to the newly dredged shipping channel. Pine's (2022) propagation model demonstrated that pile-driving noise tended to funnel along the shipping channel and away from habitats directly across from the Cruise Berth location. See Pine's (2022) figures 14 and 15 for further details.

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[8] For this analysis, pre-piling behaviour does not refer to normal, undisturbed behaviour in which the animals have not been exposed to any pile driving activity. Instead, pre-piling behaviour refers to the behaviour of an animals that have not been exposed to any piling activity for at least 48 hours.

[9] No other explanatory variables, such as season or time of day, were used in these GAM models for this report.

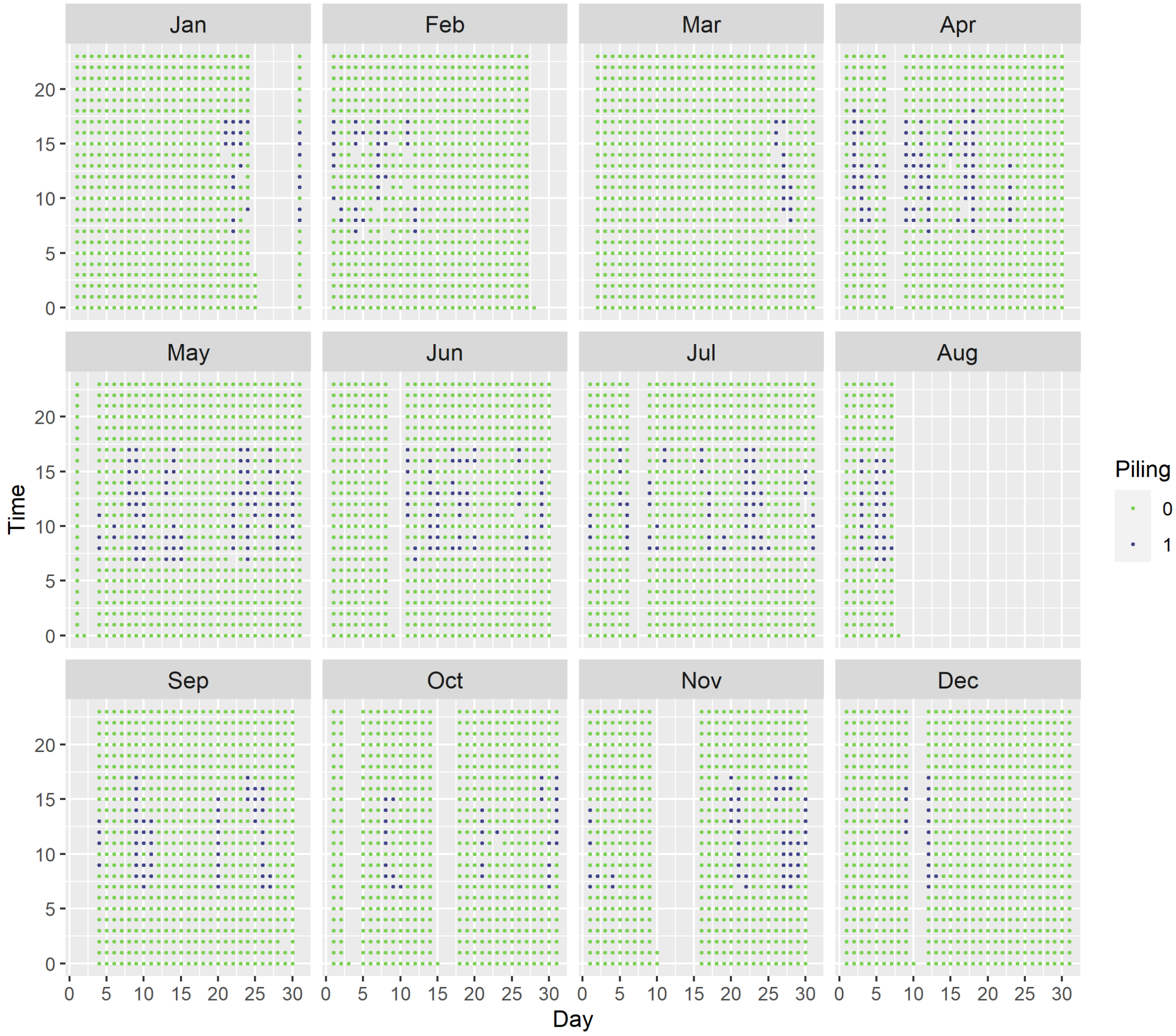

Figure 19. Dates and times at which pile driving (hammer or vibro) was underway as represented by the purple dots, and dates and times at which there was no pile driving (green dots) at **MM5** in 2019.

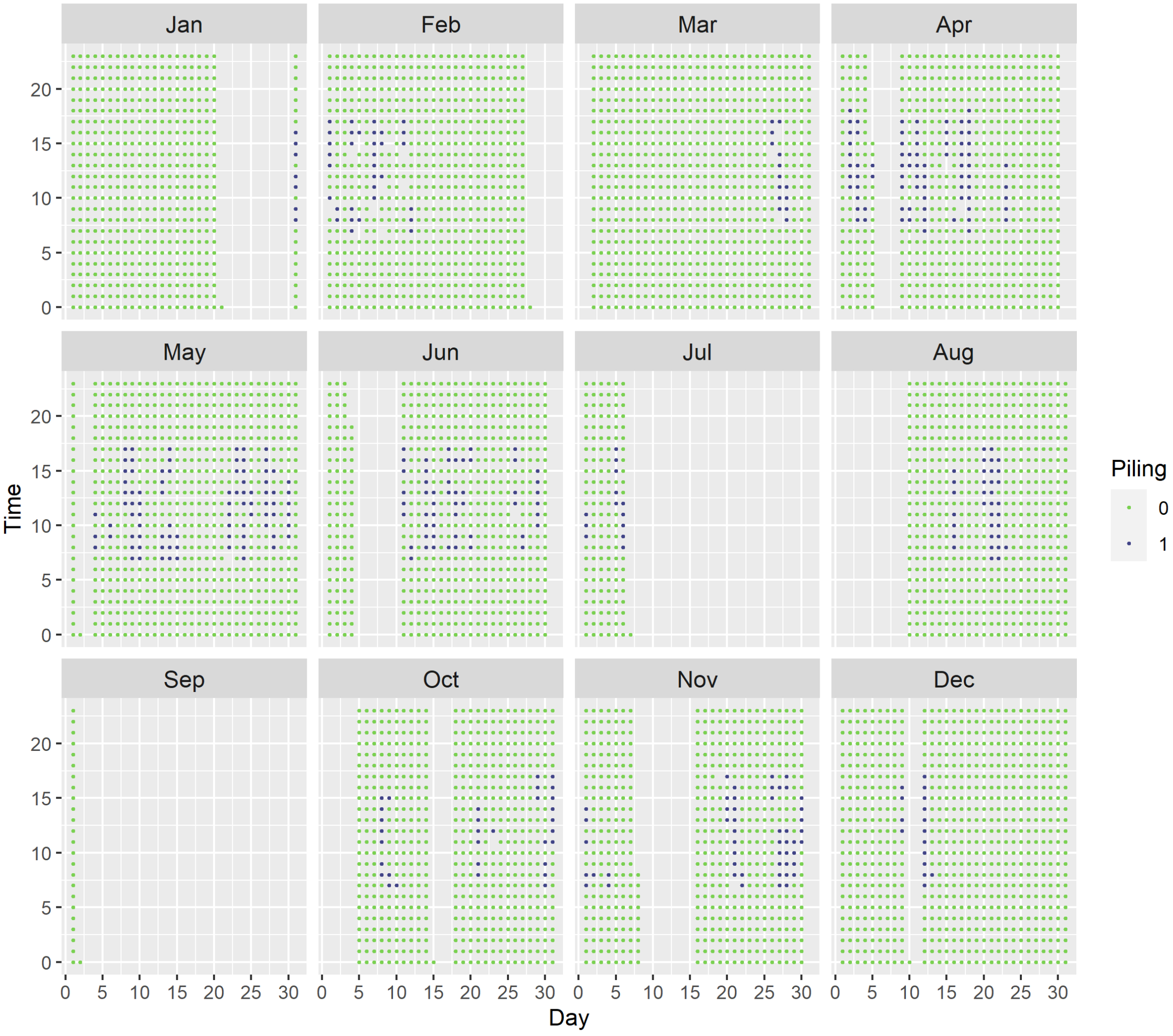

Figure 20. Dates and times at which pile driving (hammer or vibro) was underway as represented by the purple dots, and dates and times at which there was no pile driving (green dots) at **MM6** in 2019.

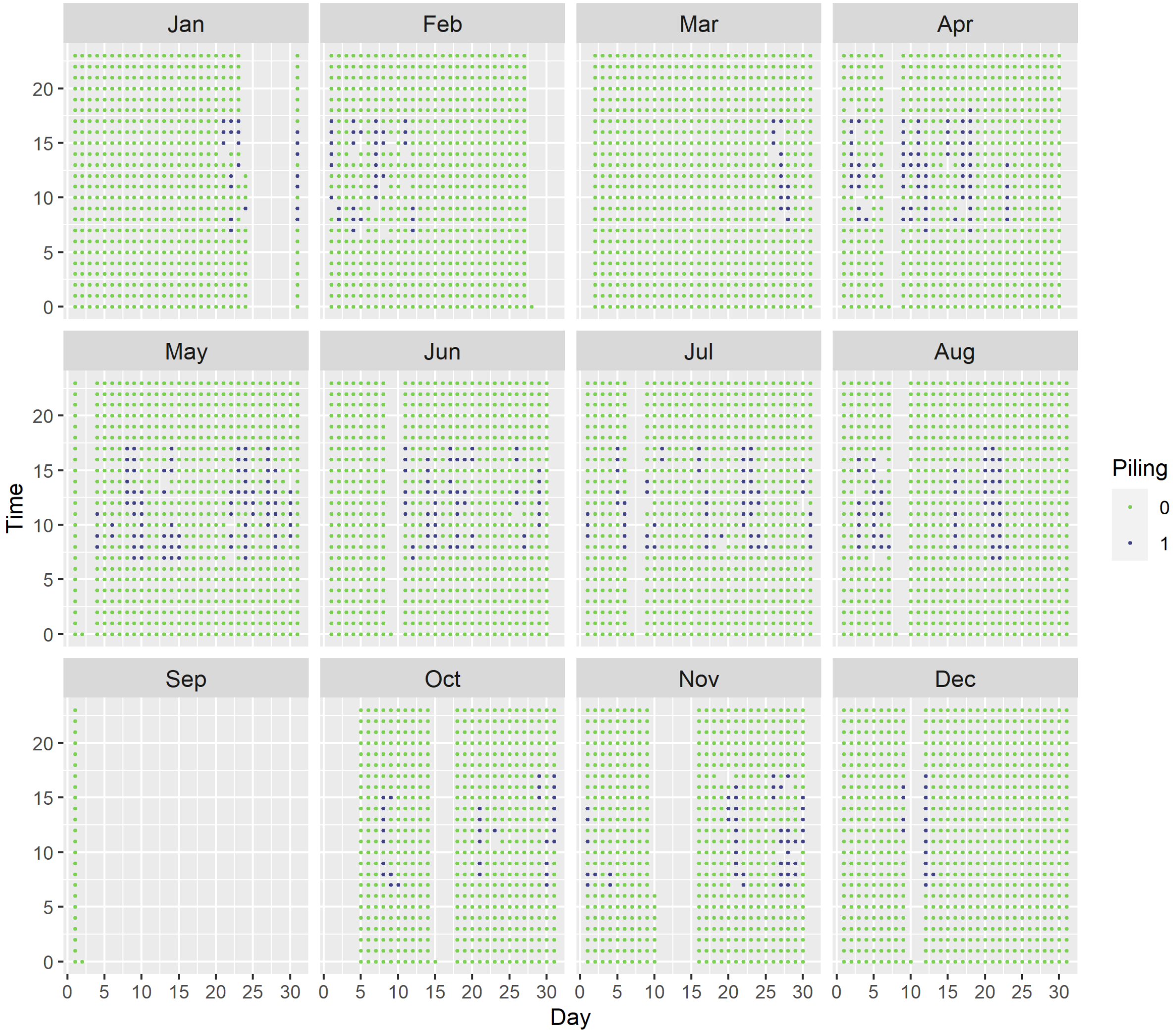

Figure 21. Dates and times at which pile driving (hammer or vibro) was underway as represented by the purple dots, and dates and times at which there was no pile driving (green dots) at **MM7** in 2019.

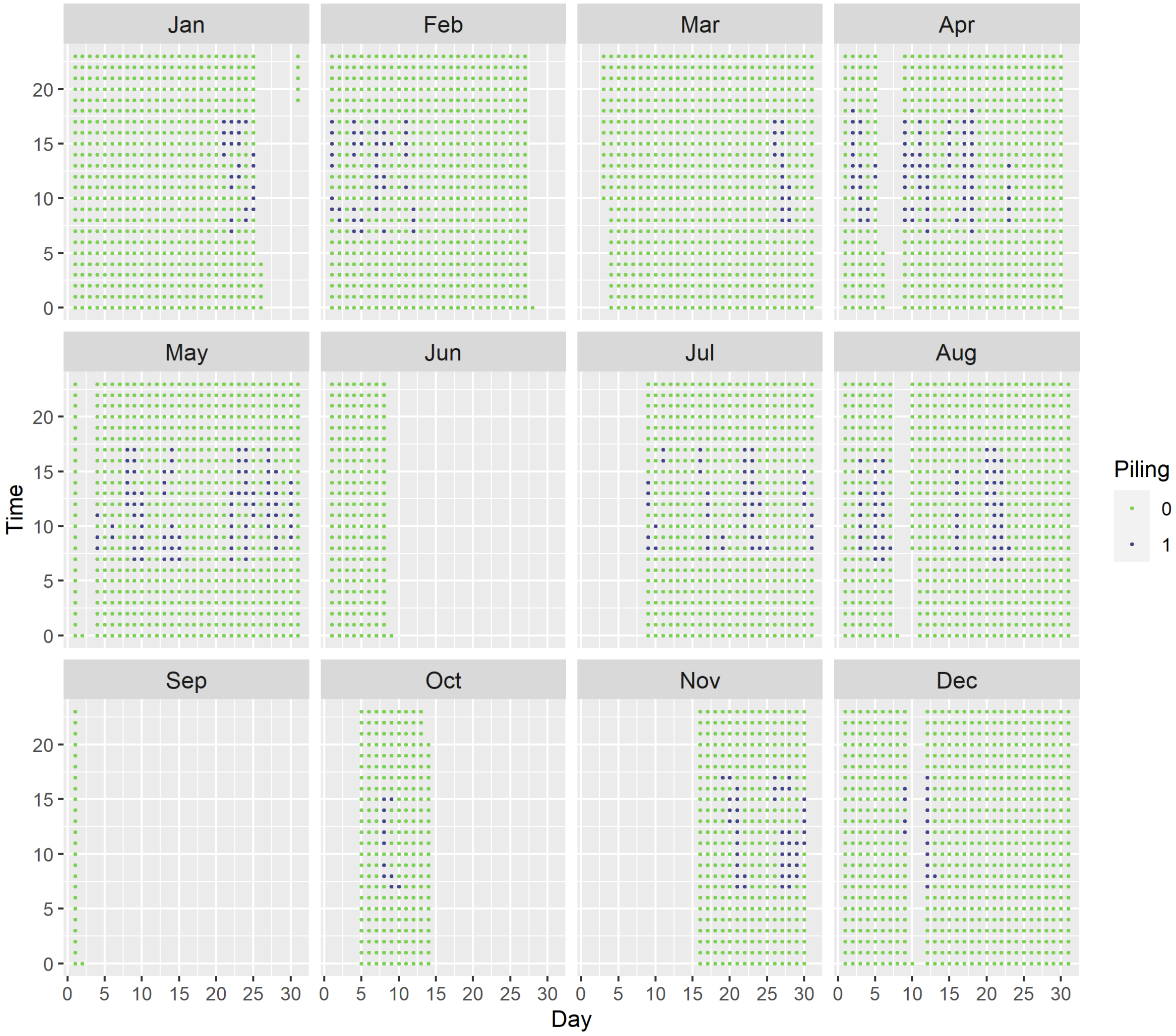

Figure 22. Dates and times at which pile driving (hammer or vibro) was underway as represented by the purple dots, and dates and times at which there was no pile driving (green dots) at **MM2** in 2019.

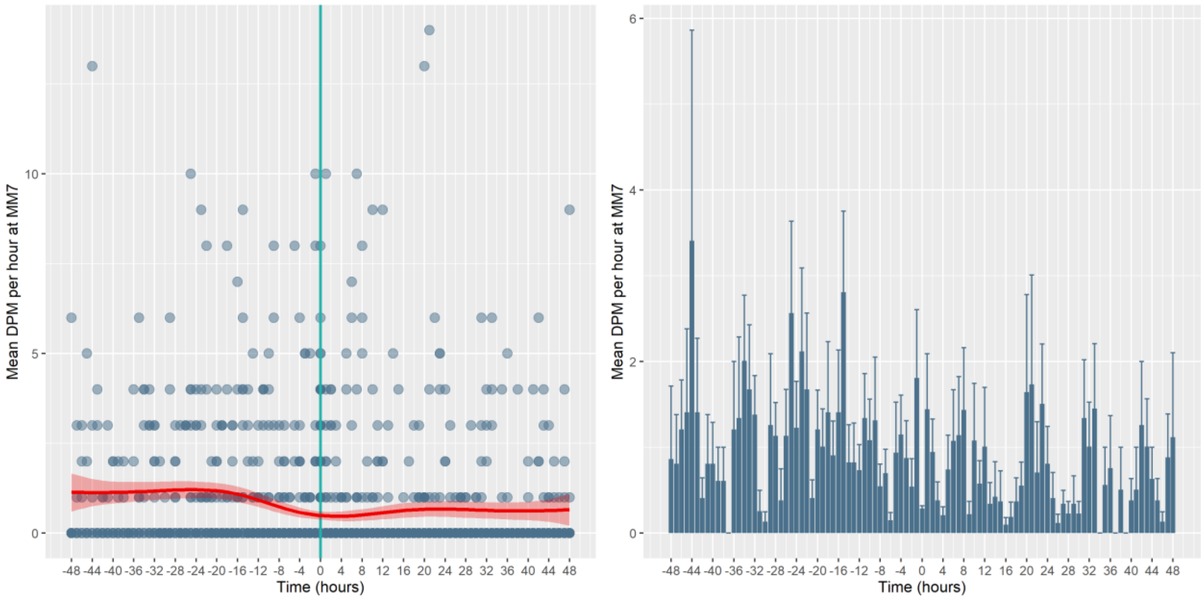

Figure 23. Mean detection positive minutes (DPM) per duty cycle hour for 48 hours before and after a piling event at **MM7**. Zero corresponds to time in which piling was underway. The different levels of transparency on the left panel represent the DPM overlap, and the red curve represents a smoothing adjustment for the data. The error bars on the right panel represent the standard error.

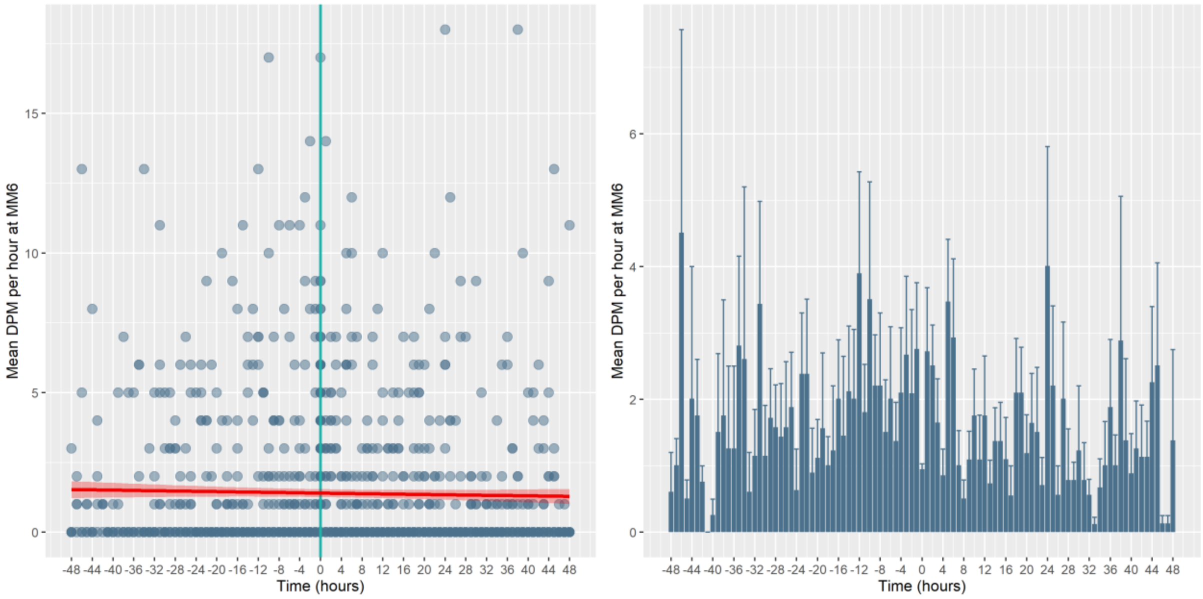

Figure 24. Mean detection positive minutes (DPM) per duty cycle hour for 48 hours before and after a piling event at **MM6**. Zero corresponds to time in which piling was underway. The different levels of transparency on the left panel represent the DPM overlap, and the red curve represents a smoothing adjustment for the data. The error bars on the right panel represent the standard error.

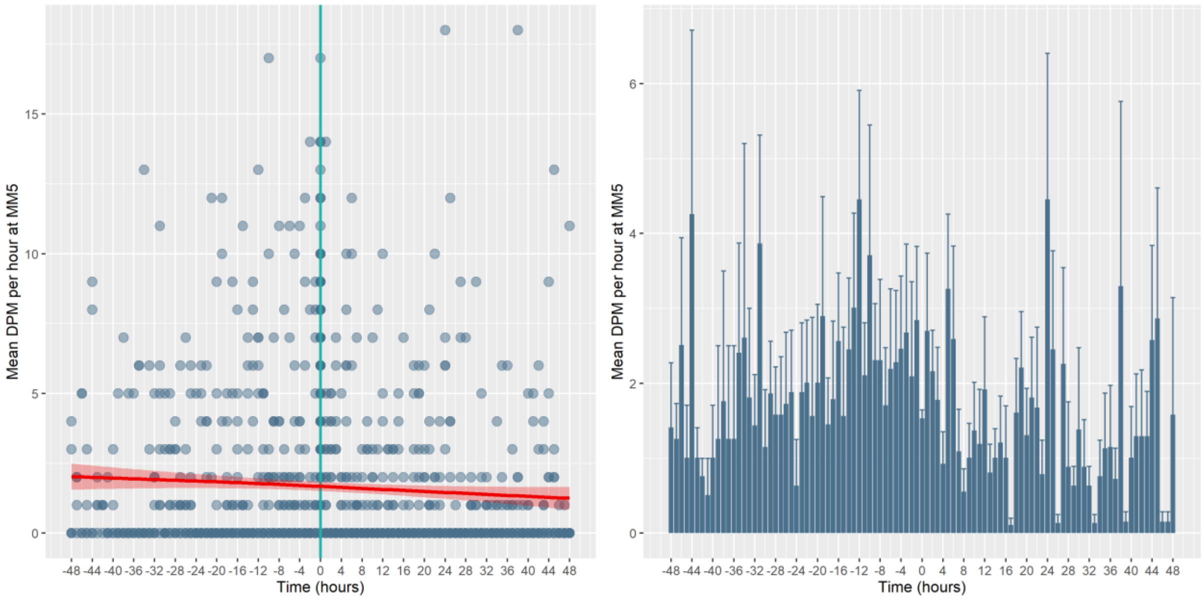

Figure 25. Mean detection positive minutes (DPM) per duty cycle hour for 48 hours before and after a piling event at **MM5**. Zero corresponds to time in which piling was underway. The different levels of transparency on the left panel represent the DPM overlap, and the red curve represents a smoothing adjustment for the data. The error bars on the right panel represent the standard error.

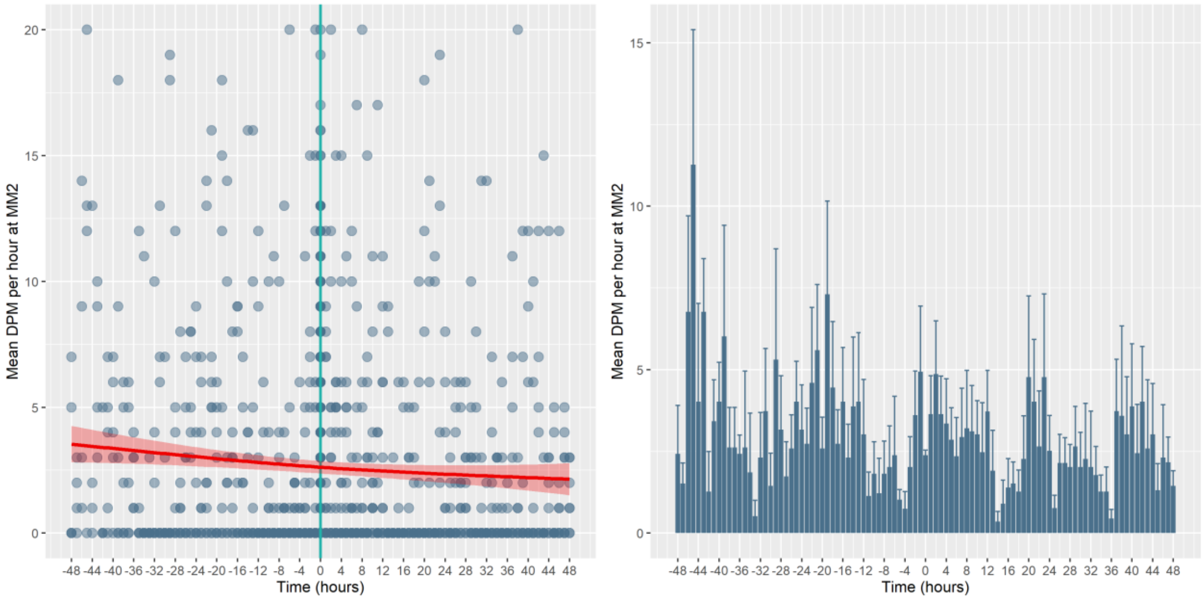

Figure 26. Mean detection positive minutes (DPM) per duty cycle hour for 48 hours before and after a piling event at **MM2**. Zero corresponds to time in which piling was underway. The different levels of transparency on the left panel represent the DPM overlap, and the red curve represents a smoothing adjustment for the data. The error bars on the right panel represent the standard error.

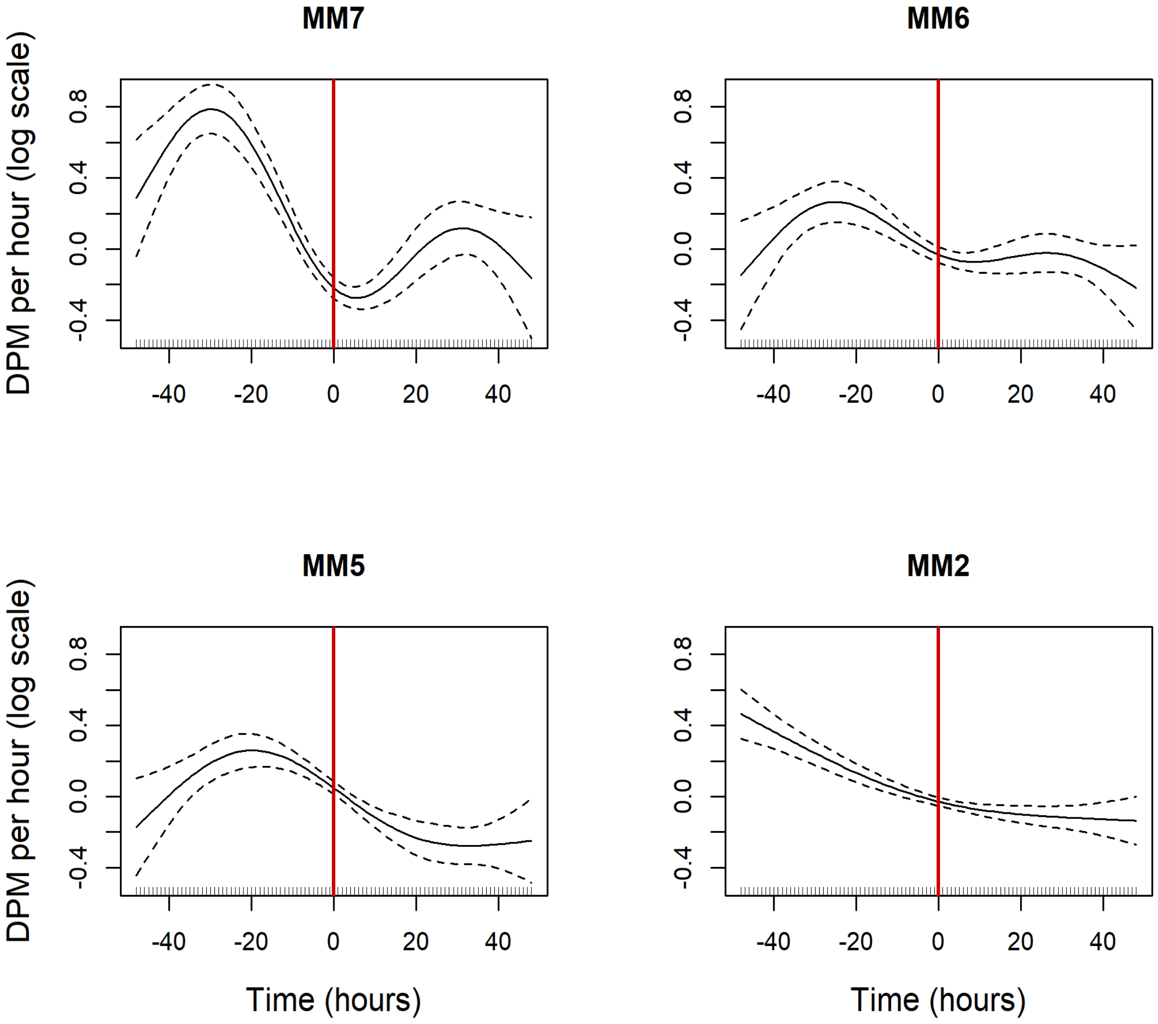

Figure 27. Smooth terms of GAMs fitted separately for each mooring site (MM7, MM6, MM5 and MM2) evaluating the detection positive minutes (DPM) per duty cycle hour 48 hours pre, response during pile driving (‘0 hour’, vertical red line), and 48 hours post pile-driving events. The solid curves are the estimates, and the dashed lines are the 95% confidence interval.

4.3. Regulation violations or exceedances

Underwater ambient noise and percussive (hammer) piling noise collected by the ST recorders helped ground-truth some noise assumptions and verify noise source data that were used in the original Cruise Berth acoustic models (Humpheson 2018) with actual data. Comparing the predicted noise levels with a subset of the ST data are detailed in the Tonkin & Taylor (2022) report, while the efficiency of the MMOZ in protecting dolphins against TTS is being investigated by Styles Group Acoustics.

For the purposes of this report, a brief summary of piling noise and activity over the relevant monitoring periods is given, while mainly focusing on any exceedances or violations associated with piling activity as noted by the MMOs.

4.3.1. Pile-driving activity

The total amount of pile-driving activity per month, summarised as piling positive minutes (PPM) using the piling logs completed by contractors, were compared across the entire Cruise Berth construction period from 7 December 2018 to 5 February 2020. As highlighted in Figure 28, hammer-piling activity was most intense over the autumn months of April / May 2019, and continued at lower, but still elevated, intensities over winter months (through to August 2019) relative to the rest of the year(s). Hammer pile-driving activity was generally lower over some summer months but piling activity took place over two consecutive Decembers (2018, 2019) and Januarys (2019, 2020). At the same time, vibro piling activity was more consistent across the construction period, except for the more intensive activity over the first three months of the project (Figure 28).

Figure 29 highlights that there is a visual indication that mean noise levels[10] were greater over winter and spring 2018, particularly at the MM2 mooring. This period coincides with the capital dredging project (end August to mid-November 2018), the channel of which passes close to MM2 while the dredger vessel itself would be transiting past the other moorings on a daily basis. From 2019 onwards, the range of daily ambient levels was fairly consistent across the mooring sites varying between means of 108 dB (SD = 12.3) at MM7 in autumn and 113 dB (SD = 8.32) at MM5 in spring, although there appeared to be a declining trend in mean levels through to 2020. This trend is likely due to the completion of the Cruise Berth project just prior to the decrease in shipping activity associated with New Zealand's COVID-lockdown.

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[10] These noise levels include all underwater noise occurring near the moorings including normal shipping, recreational boating, effects of wind or rain as well as the two construction projects (dredging and piling activity). These levels are an average / mean for the entire day and include both daytime and nighttime noises.

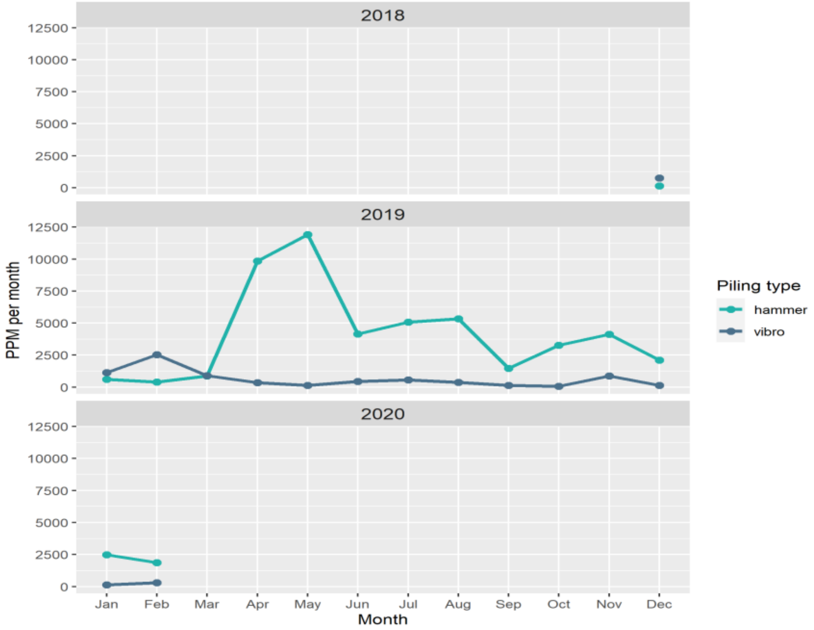

Figure 28. Sum of piling positive minutes (PPM) per month and piling type (hammer or vibro) during piling operations that took place between December 2018 and February 2020.

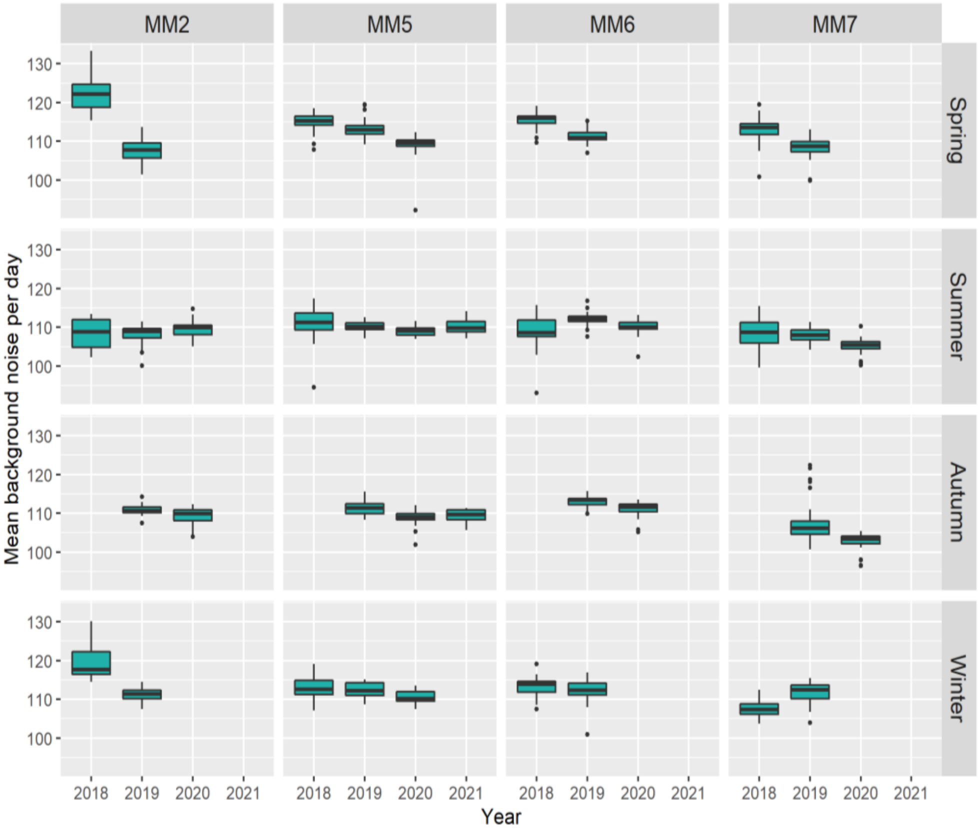

Figure 29. Mean ambient noise per day (SPL) per year across seasons and sites (MM2, MM5, MM6 and MM7). The boxes indicate the 25th and 75th percentiles, the horizontal bold lines indicate the 50th percentile or median, the vertical lines indicate the minimum and maximum values, and the dots indicate the outliers.

Further review of the maximum cumulative SEL levels received per hour at each of the three inner harbour moorings confirmed that these moorings lie beyond the TTS zone (SELcum_{1hr} = 180 dB re 1 µPa^2·s) as predicated by Humpheson (2018) and confirmed in the upcoming report by Pine (2022; Figure 30). In the Te Awaparahi Bay Wharf Consent hearing, experts discussed basing thresholds for noise on the Kastelein et al. (2015) study in which they proposed a TTS for harbour porpoises based on their response to an average received single strike unweighted SEL of 146 dB re 1 µPa^2·s over one hour. This information was wrongly interpreted by the experts and the panel as equating to a TTS threshold. Since the hearing, the NOAA (2018) Noise Guidelines have been released. These guidelines used the Kastelein et al. (2015) data to recommend an appropriate TTS threshold for high-frequency cetaceans, such as harbour porpoise and Hector's dolphin, of $\mathrm{SELcum}_{\underline{24hr}}$ of 140 dB re 1 µPa^2·s, which is equivalent to a $\mathrm{SELcum}_{\underline{1hr}}$ of 180 dB re 1 µPa^2·s.

However, Figure 31 demonstrates that the maximum single-strike sound exposure level (SEL) per day at these moorings reached or exceeded the 133 dB behavioural threshold level discussed at the Te Awaparahi Bay Wharf Consent Hearing, which is often associated with harbour porpoises (Kastelein et al. 2013) and was discussed in relation to Hector's dolphins. The closest moorings (MM7and MM6) recorded the loudest maximum single-strikes from hammer-pile driving more over the autumn and winter months, corresponding to the increase in piling activity over these time periods (Figure 28).

While exploring these data, we found that MM7 recorded lower mean ambient levels at times, despite being located only approximately 700 m from the Port, while MM6 (200 m further away) consistently recorded greater noise levels out of the three inner moorings (Figures 30 and 31). These differences in the received levels of noise at the various moorings are explained further in the separate underwater noise summary report (Pine 2022) but are likely attributed to the configuration of the dredged swing basin in this region.

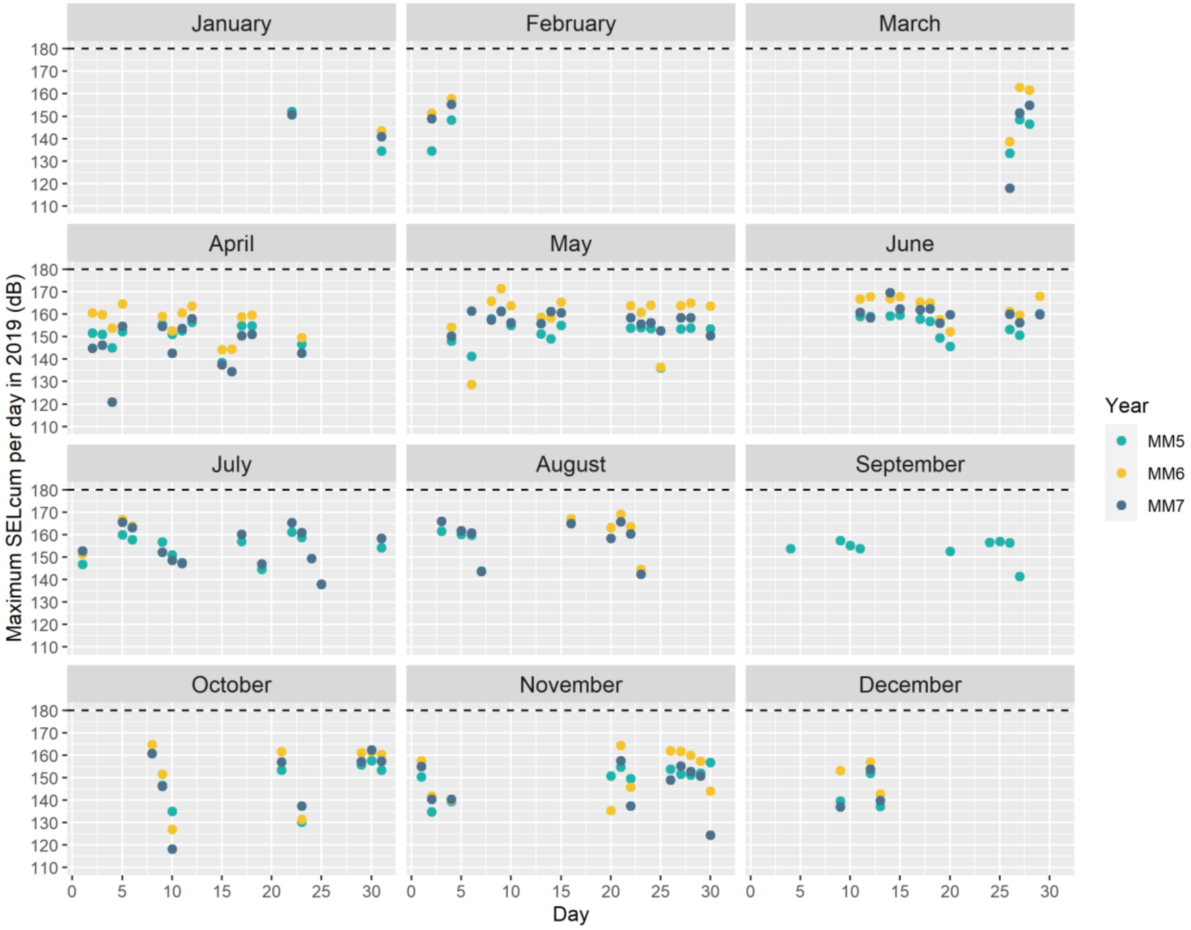

Figure 30. Maximum cumulative sound exposure level (SELcum$_{1hr}$) per day, month and site (MM5, MM6 and MM7) in 2019, all of which are in the inner harbour. The dashed line shows the TTS threshold (SELcum$_{1hr}$ = 180 dB re 1 µPa^2·s).

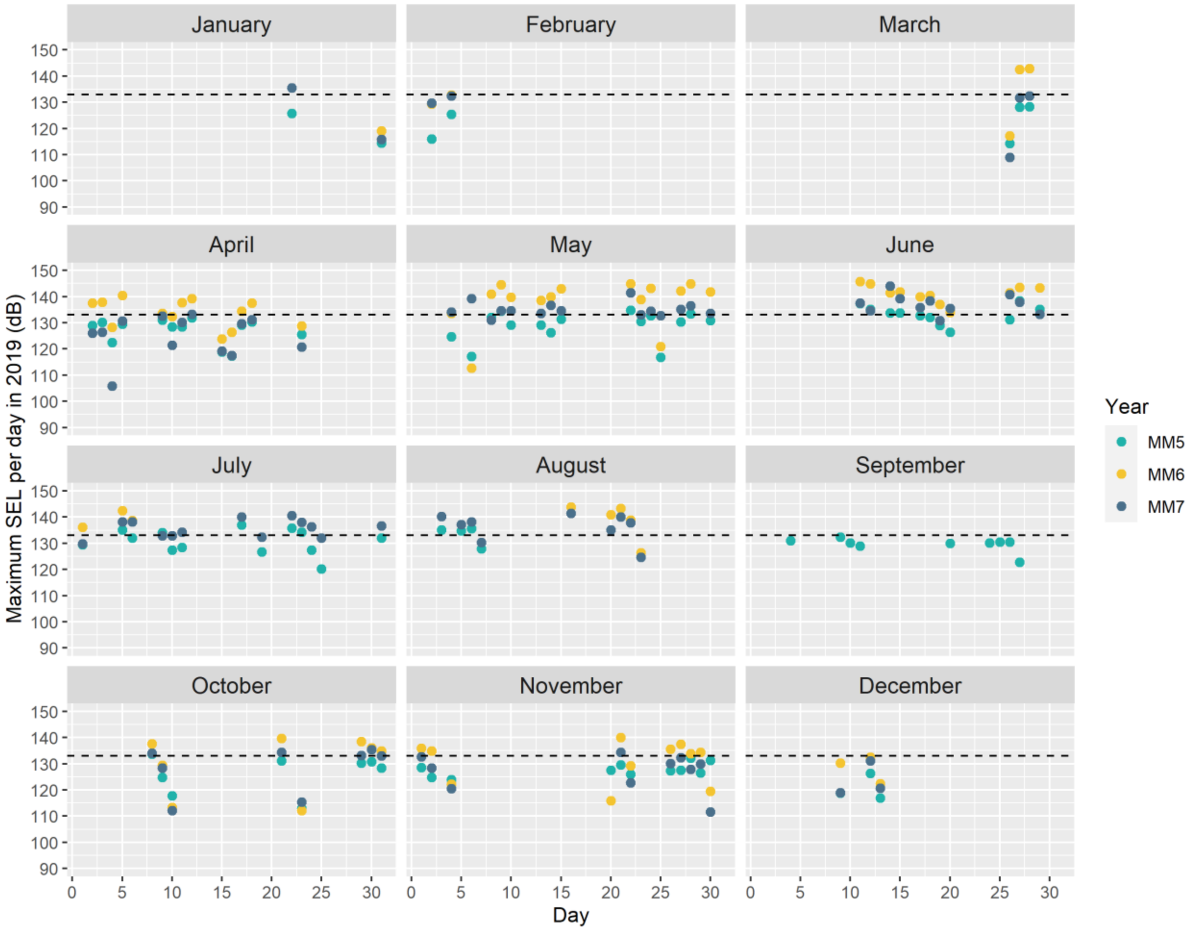

Figure 31. Maximum single-strike sound exposure level (SEL) per day, month and site (MM5, MM6 and MM7) in 2019, all of which are in the inner and mid harbour. The dashed line shows the behavioural threshold (SEL = 133 dB re 1 µPa^2·s).

4.3.2. Inner Harbour visual detections

LPC contracted Blue Planet Marine to provide suitably trained and experienced marine mammal observers (MMOs) to independently monitor within and around the 450 m Marine Mammal Observation Zone (MMOZ) for any marine mammals while pile-driving activity was underway. MMOs monitored piling activity (vibro, hammer or both) over 243 days (approximately 1,836 hours of watches) between 7 December 2018 and 5 February 2020 during daylight hours only. Over this time, 424 visual sightings of Hector’s dolphins and two visual sightings of fur seals were recorded within the MMOZ and / or the wider construction and harbour area (Figure 32). Some of these sightings may be repeat observations of the same animal or groups of animals over the course of the same day.

The distances of sightings from the MMO’s location varied from 25 m to just over 2.4 km away with over half of all sightings less than 600 m from the MMO (Figure 33). This gradual decline in sightings with distance away from the MMO is as expected and falls within the range of likely distances for land-based surveys on Hector's dolphins (e.g. Martinez 2010).

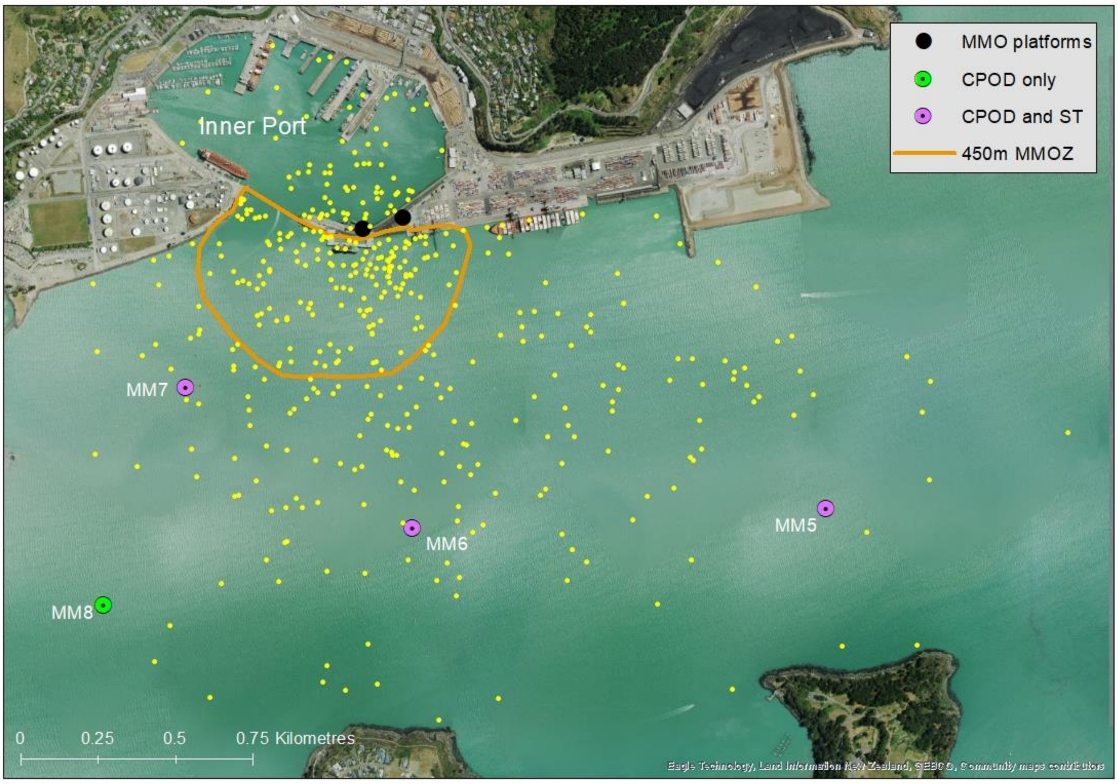

Figure 32. The locations of Hector's dolphin sightings (yellow circles) recorded by Marine Mammal Observers (MMO) during pre-, during and post-pilings watches between 7 December 2018 and 5 February 2020. The location of the Marine Mammal Observation Zone (MMOZ) and acoustic moorings (CPOD only and CPOD+ST) are given for context.

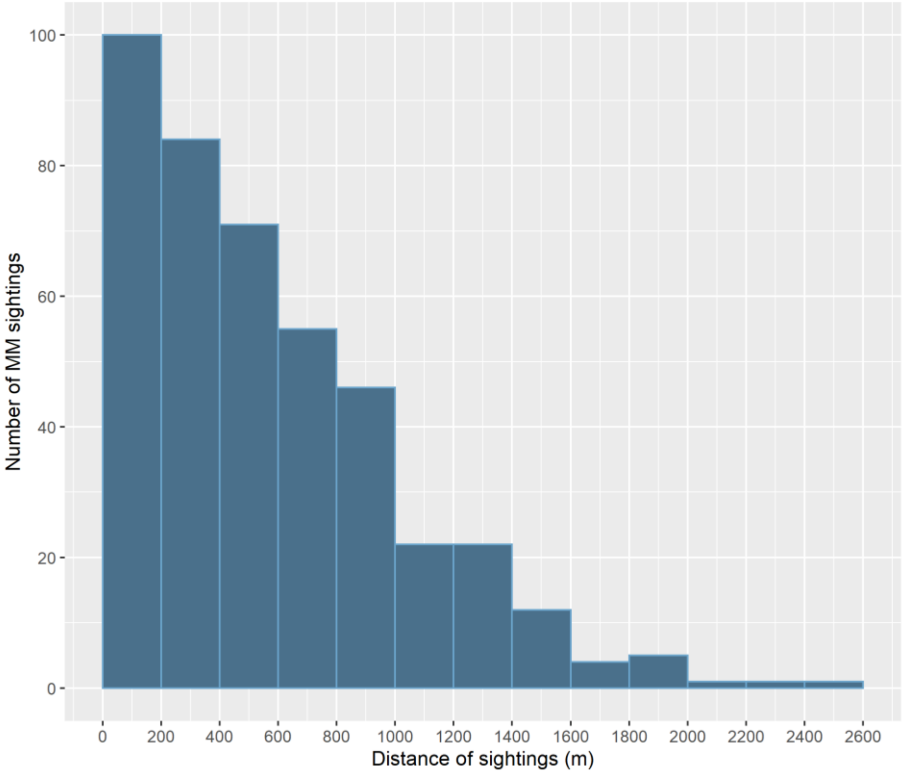

Figure 33. The number of Hector's dolphin sightings by MMOs categorised into their approximate distance (metres) from the location of the MMO viewing platform.

Figure 34 and Figure 35 show that visual sighting rates of Hector's dolphin were greater over the summer months, particularly December and January, than winter months despite greater effort (i.e. more MMO watches) over the colder months (see Appendix 6 for seasonal sighting maps). This result aligns with the acoustic data as described above (Sections 4.1.1 and 4.1.3) as well with previous information on Hector's dolphin seasonal movements and distribution patterns in the region (e.g. Clement 2018).

Sighting rates were also slightly higher in the mornings prior to noon than in afternoon hours (Table 15). Lower but similar sighting rates occurred in early morning (before 8am) and early evening (after 6 pm) hours. The majority of MMO watches tended to occur between 10 am and 2 pm, but we note that these hours likely reflect normal construction routes (i.e. Daily Toolbox meetings, mandatory breaks, etc.) and were also constrained to good sighting conditions within daylight hours.

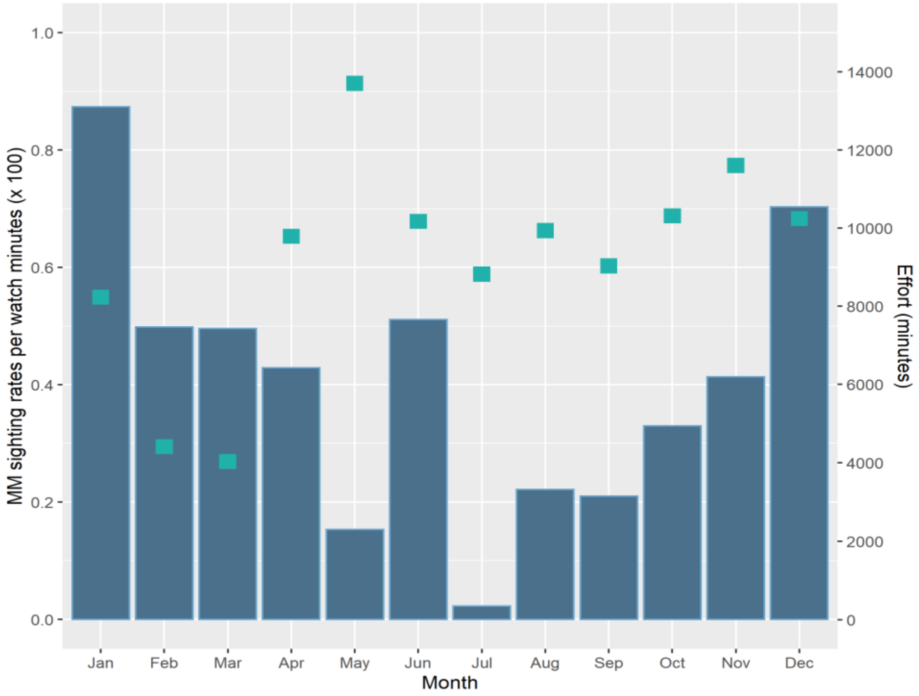

Figure 34. Monthly marine mammal sighting rates (blue bars) represent the proportion of MMO watch (in minutes) that reported a visual sighting. Sighting numbers were standardised for unequal effort (total minutes of MMO watches that occurred during each month – green squares) between 7 December 2018 and 5 February 2020.

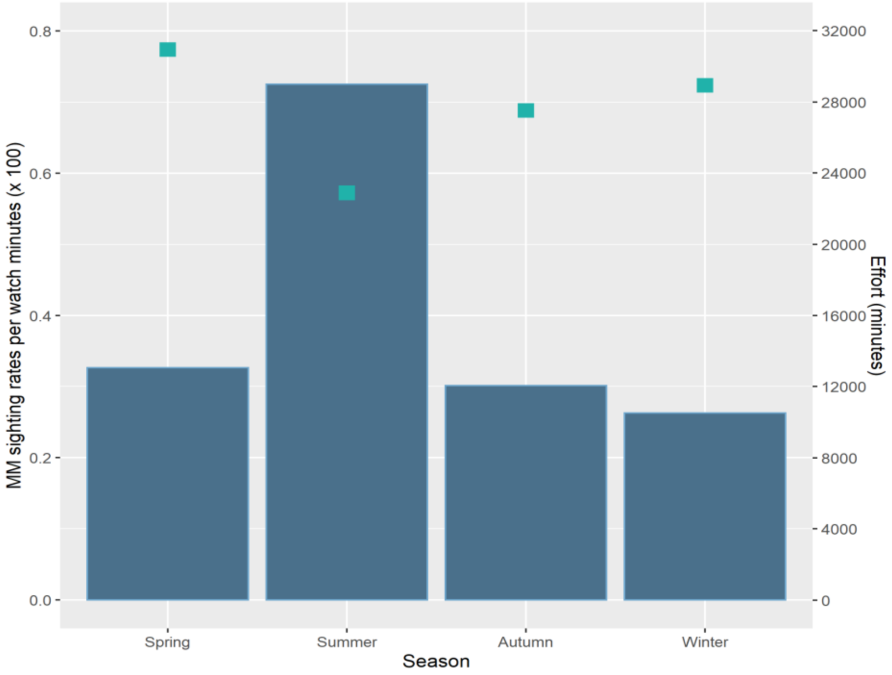

Figure 35. Marine mammal sighting rates (blue bars) across seasons representing the proportion of MMO watch (in minutes) that reported a visual sighting. Sighting numbers were standardised for unequal effort (total minutes of MMO watches that occurred during each season – green squares) between 7 December 2018 and 5 February 2020.

Table 15. Total number of MMO sightings and watches recorded prior and up to the indicated time period. Sighting rate represents the number of sightings standardised by the number of watches undertaken over the same time period between 7 December 2018 and 5 February 2020.

Time of Day	MMO Sightings	MMO watches	Sighting Rate
8:00	33	281	0.12
10:00	112	613	0.18
12:00	98	568	0.17
14:00	75	615	0.12
16:00	67	498	0.13
19:00	41	384	0.11

4.3.3. MMO control measures

A key part of the control measures put in place by LPC and the contractors for the Cruise Berth construction was having a dedicated and experienced MMO on continuous watch throughout any pile-driving operations. The main purpose of MMOs was to visually monitor the MMOZ (~450 m), as well as scan the wider area of the port / harbour up to 1 km radius from the source (when possible), for any signs of marine mammal presence before, during and after pile-driving operations (Enviser 2018). Depending on the stage of piling operations, several mitigation actions were undertaken by the MMO and / or contractors when a marine mammal(s) was sighted in or near to the MMOZ (see Table 16, Enviser 2018).

Pile-driving activities (vibro, hammer or both) and the associated MMO watches took place over 243 days between 7 December 2018 and 5 February 2020. Of the 426 observations of marine mammals made by MMOs, 356 sightings were made in conjunction with piling activity (pre-start survey, during piling or post-observation survey; Table 16). The remaining sightings were made on days when piling was scheduled but subsequently cancelled or from opportunistic surveys undertaken between piling days.

MMO surveys

The vast majority (greater than 78%) of MMO sightings were recorded during pre-start surveys (Table 16). The greater number of sightings associated with pre-start surveys than other stages is not unexpected given surveys took place at least 30 minutes prior to the first piling activity commencing for the day and / or after any breaks in piling that lasted more than 30 minutes (Enviser 2018). Approximately 1,163 pre-start surveys took place across the entire construction period. The purpose of these surveys was to ensure that if any marine mammals were present or moving into the MMOZ, piling activity would be delayed avoiding any adverse effects on animals' hearing. Overall, the number of visual detections was significantly lower when pile-driving was underway relative to the number of detections in the absence of any piling activity (proportion = 0.77, $X^2 = 127.44$, $p < 0.001$).

Table 16. The number of Hector's dolphin sightings reported by MMOs that occurred within the different piling stages and the subsequent mitigation actions that followed. Further descriptions of the different piling stages can be found in the Appendix 7.

		Subsequent Mitigation Action			
Piling Stage	**Total Sightings**	*Delayed starts*	*Shut downs*	*Stand-by*	*Nothing required*
Pre-start	280	66	3	20	191
Soft-start	14	1	5	0	8
Stand-by	2	n/a	0	1	1
Shut-downs	1	n/a	n/a	n/a	1
Normal ops	19	1	4	0	14
Hammer ops	8	n/a	2	0	6
Vibro ops	2	n/a	1	0	1
Post observation	30	n/a	n/a	n/a	30
Total Sightings	356	68	15	21	252

Shut-downs

Over the entire piling stages of the Cruise Berth construction, only 15 full shutdowns were necessary due to animals entering or appearing in the MMOZ (Table 16). Six of these shutdowns occurred in December or January while the rest were spread across the other months. A large proportion of the shutdowns (n = 10) occurred in the mid-to late afternoon hours (approximately 3 pm or later) with the earliest shut down occurring mid-morning around 10 am. There were two instances of two shutdowns occurring on the same day but no instances of shutdowns occurring on consecutive days. As a result, no adjustments to the MMOZ boundaries were warranted during the duration of the project.

The 'Nothing Required' mitigation option occurred when a sighting was observed within one piling stage (i.e. pre-survey, soft-start, post-observation) and continued in that same stage (Table 16). There are also several instances in which a dolphin was observed within the inner Port region on the opposite side of the reclaimed rock wall bund to which piles were being driven (n = 70 sightings; Figure 32). Approximately 10 of these sightings occurred while piling was underway (i.e. normal, hammer, vibro).

Acoustic experts advised LPC that the rock wall bund would considerably limit any underwater noise from the piling penetrating through and into the inner Port area. As a result, MMOs were required to track these animals but no further mitigations took place while they remained within the protections of the inner Port. If, and when, an animal decided to move to the entrance and out of the inner Port, a delay, stand-by or shutdown of piling activity was called until the animal was safely out of the MMOZ (n = 15 of the 70 sightings).

Post-observational surveys

Several sightings (n = 30) were made during post-observation surveys when the MMO was asked to continue scanning the MMOZ for at least 30 minutes or more once piling activity ceased for the day, and if weather and daylight conditions allowed (Table 16). Only one post-observation survey could be undertaken on any given piling day and approximately 195 surveys were completed.

Approximately 70% of all post-observational sightings occurred within 30 minutes of the last pile-driving activity ceasing with the mean time to the first post-piling sighting being 36 minutes (Figure 36). While sighting distances varied from between 80 m to over 1.6 km from the MMO, 60% of sightings were within 500 m and 83% were observed within 1 km. Except for six, all sightings were reported in the afternoon or early evening, when most post-observational surveys were undertaken.

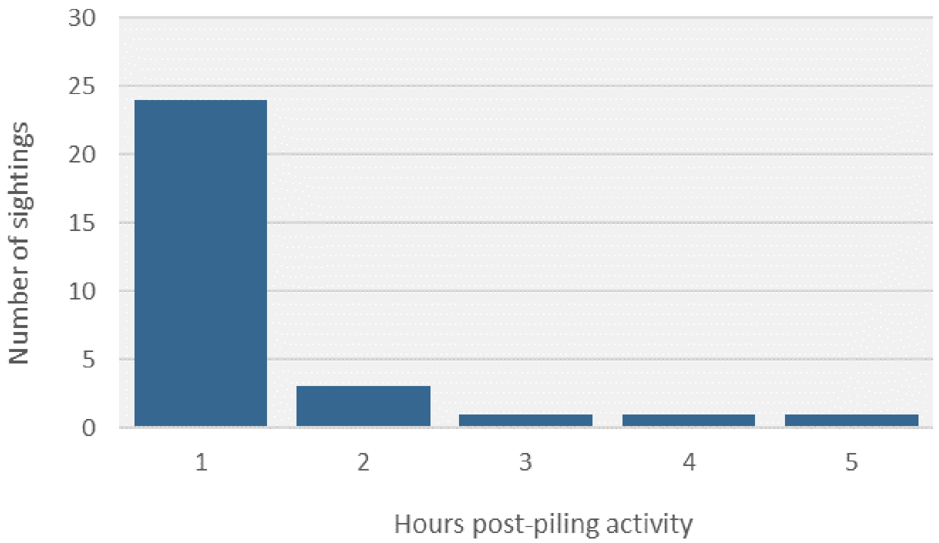

Figure 36. The number of post-observation sightings of Hector's dolphins according to time (hour) after any piling activities ceased (n = 30).

Missed violations - MMO vs acoustic detections

The inner harbour moorings were not positioned close enough to the MMOZ to be able to accurately assess how often Hector’s dolphins may have been missed within the shut-down zone by the MMO on watch (i.e. acoustically but not visually detected), constituting a missed shut-down violation. Instead, the days in which pile-driving activities and MMO watches occurred were reviewed to determine if there were any instances where acoustic detections were recorded but no MMO sightings were reported. While towards the edge of the MMOs expected visual detection range, the two closest moorings, MM6 (~935 m away) and MM7 (~710 m away), were reviewed.

With the exception of May, July, August, November and December 2019, there were fewer than three days a month in which acoustic moorings detected dolphins when MMOs did not report dolphins present in the inner harbour area. Four of these five months did not have the primary MMO on duty for all or most of the sampling month.

Table 17. The total number of days each sampling month that acoustic moorings (MM6 and MM7) detected a dolphin present when watching MMOs did not between December 2018 and February 2020. For comparative purposes, the total number of days in which MMOs undertook at least one watch and the associated days in which visual sightings occurred are listed with the MMO on duty for most of each month. NA = ST data were not available.

Month and Year	**MMO Sighting Days**	**MMO Watch Days**	**MM6 ✓ Acoustic ☒ Visual**	**MM7 ✓ Acoustic ☒ Visual**	**MMO on duty**
December 2018	10	11	1	1	primary
January 2019	19	21	1	0	primary
February 2019	8	9	1	NA	primary
March 2019	9	9	0	0	primary
April 2019	19	20	1	0	primary
May 2019	15	25	9	9	secondary
June 2019	19	22	2	2	primary
July 2019	6	24	3	17	secondary
August 2019	13	23	8	7	primary
September 2019	13	20	NA	NA	primary & secondary
October 2019	16	23	3	3	primary & secondary
November 2019	17	24	4	5	primary & secondary
December 2019	6	10	4	4	primary & secondary
February 2020	0	1	1	1	secondary

4.4. Comparisons between detection datasets

We attempted to match each MMO visual sighting to a corresponding acoustic detection(s) from the two most-inner harbour moorings (MM6 and MM7) to assess detection capabilities between the ST and CPOD methods. Further details of this matching process are in the methods, but the assumption was that a Hector's dolphin sighted by MMOs within 300 m of a corresponding mooring (either MM6 or MM7) would likely move close enough to register an acoustic detection if vocalising (e.g. Rayment et al. 2009)[11]. It was assumed that 'missed' matches occurred for one of two reasons: 1) the dolphin(s) did not swim near enough or directly at that particular acoustic mooring for an acoustic detection to be recorded, or 2) the dolphin(s) did not vocalise while near the mooring. We note that differences in the total number of matched visual detections between the two moorings is due to time periods where the acoustic devices were full, stopped working or being replaced and not available to match.

Overall, the FinFinder detectors, used on the ST recordings, had a greater matching rate to visual sightings than the auto-detectors of the CPODs (Figure 37). The FinFinder detectors were able to detect 69% of all visual detections while the CPOD method detected only 35%, despite the STs having a shorter duty cycle. These results indicate that STs produce data that can be processed with a higher degree of sensitivity in these monitoring situations, or at least with Hector's dolphins, than CPODs.

By matching visual with acoustic detections, we also attempted to test for any differing effect that pile-driving activities might have on the acoustic recorders' ability to detect dolphin clicks. At both mooring sites, there was no statistical indication of differences in the proportions of matched detections between pile / no pile activities across the two acoustic methods (Table 18, Figure 38 and Figure 39). While these results supported the adequacy of acoustic recorders as monitoring tools for these construction activities, they should not be interpreted as conclusive given the relatively small sample size ($n_{MM7} = 45$, $n_{MM6} = 40$).

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[11] A collaboration study of TPOD (an earlier version of CPODs) detection distances by Rayment et al. (2009) found that the highest detection rates occurred within the first 100 m and declined quickly past 300 m with no acoustic detections recorded past 500 m. These distances are comparable to other overseas studies on acoustically similar species to Hector's dolphin, including harbour porpoises (Tougaard et al. 2006) and finless porpoises (Jefferson et al. 2002).

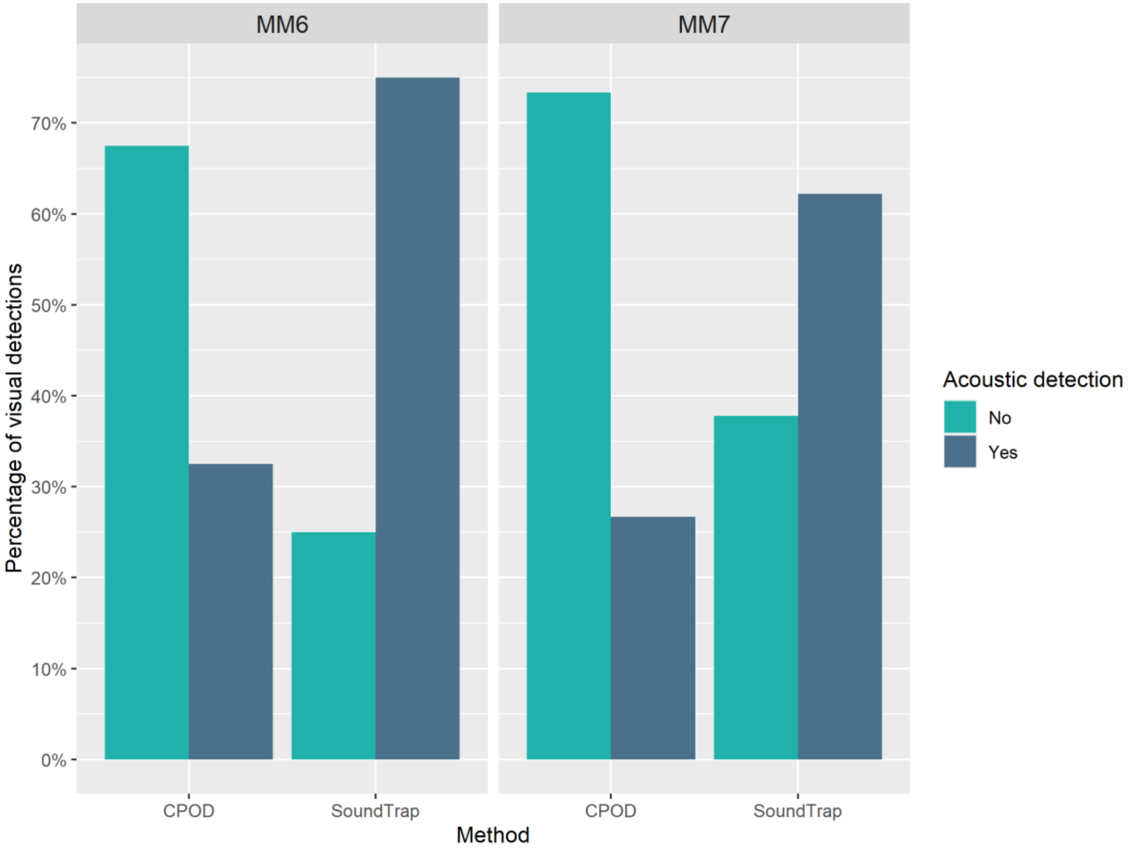

Figure 37. Percentage of visual detections compared with acoustic detections by method (CPOD's auto-detector or FinFinder with SoundTrap data) at MM6 and MM7. The different colours represent those visual detections that matched with acoustic detections (blue) or those that were not detected (green).

Table 18. Summary of X^2 tests for the proportion of acoustic detections of each method (CPOD/SoundTrap) between pile / no pile activities, showing test statistics and p-value for mooring sites MM7 and MM6 and for both acoustic methods, CPOD and SoundTrap.

Site	Acoustic detector	Sample size	X^2 statistics	P-value
MM7	CPOD	45	0.29	0.59
MM7	SoundTrap	45	0.82	0.37
MM6	CPOD	40	1.28	0.41
MM6	SoundTrap	40	0.06	1.00

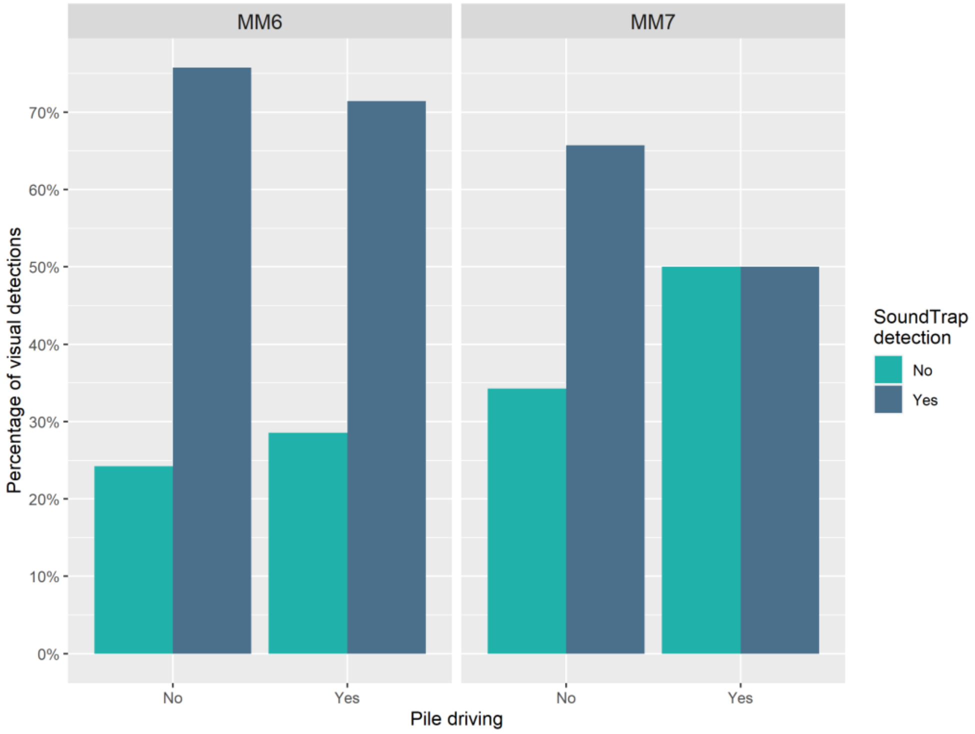

Figure 38. Percentage of visual detections recorded in association with pile-driving activity (yes/no) at MM6 and MM7. The different colours represent whether the visual detections were matched (blue) or not matched (green) with the SoundTrap acoustic detections.

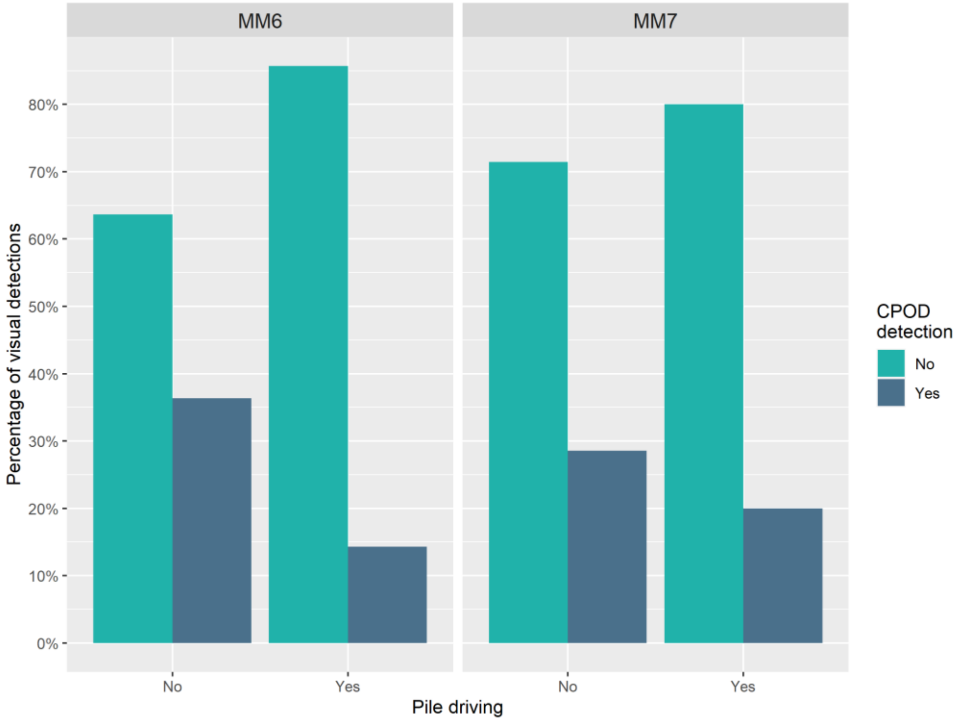

Figure 39. Percentage of visual detections recorded in association with pile-driving activity (yes/no). The different colours represent whether the visual detections were matched (blue) or not matched (green) with the CPOD acoustic detections.

5. SUMMARY OF FINDINGS

As acoustic mooring locations were spread across most of Lyttelton Harbour, LPC's monitoring programme was able to monitor changes in the harbour-wide use of Hector's dolphin prior to any port construction developments, during construction and for a period after the construction was complete. In general, several harbour-wide trends in Hector's dolphin occurrence were evident prior to any construction activity and remained consistent throughout the monitoring period. These trends include a clear pattern of decreasing dolphin CPOD detections from outside the harbour (MM4 and MM3) into middle regions (MM2 and MM1) and near the Port (MM5 to MM8), which remained noticeable across all sampling years and seasons. The well-known seasonal movement of Hector's dolphins (e.g. increased detections over warm months and decreased in cooler months) was also apparent in outer and middle region. While seasonal patterns were detectable within inner harbour sites, these trends were diminished compared to other harbour regions, and instead, dolphin presence remained at a consistently low level across the years. As a whole, these results provide clear evidence confirming previous boat-based findings suggesting a similar seasonal and spatial gradient in Hector's dolphin use of Lyttelton Harbour (Brough et al. 2014, 2018; Clement 2018).

The monitoring programme also indicated a general decline in annual CPOD detection rates of Hector's dolphins at outer and mid-harbour sites occurring across the longer-term sampling period from 2017 to 2020. These sites recorded greater detection rates prior to 2019, when a general decline occurred across through to 2020. Over a similar period (2018–2020), CPOD annual detection rates in one out of the three inner harbour mooring sites (MM5), followed the same trend, although not as pronounced or as variable. Detection rates closest to the Port (MM6 to MM8) demonstrated evidence of a general increase in detections over the sampling years.

Both general and finer-scale models were used to investigate how pile-driving activity may have affected inner harbour (and MM2) detection trends, as these were the only moorings that also collected simultaneously noise levels with ST recorders (September 2018 to May 2020). The general model found that out of the main factors considered, pile driving (i.e. hours with or without vibro and hammer), wind speed and ambient noise levels were all associated with a decrease in dolphin ST detections at inner harbour moorings and that in general, DPMs decreased over the 2019 construction period.

The finer-scale models looked more closely at hammer-pile driving at each inner harbour site only, noting that MM2 was excluded due to negligible hammer piling-specific noise at that location. Site-specific model results implied that dolphin ST detections declined linearly with an increase in hammer-piling noise, as measured by cumulative SEL per hour. DPM decreases within the inner most moorings (MM6 and MM7) were very slight to non-existent, while MM5 (closer to mid-harbour) predictions indicated more noticeable declines in DPMs with increases in hammer-piling noise. All three models suggested these noise effects were greater on DPMs during the warmer temperatures of spring, and at MM5, also in summer.

Short-term recovery analyses per mooring were then used to assess how long decreases in detections lasted in between various pile-driving events. None of the ST acoustic moorings had detection rates returning to pre-piling levels after 48 hours. However, the innermost moorings, MM7 and MM6, showed signs of faster recovery than MM5 and MM2. An important caveat of these model results is that the effects of time of day and season have not been included and may have an influence on short-term recovery rates between the various moorings. Pine's (2022) sound propagation model demonstrated that the newly dredged shipping channel tended to funnel much of the pile-driving related noise along the channel and away from areas directly across the harbour from the Cruise Berth site. Hence, dolphins visiting areas around MM7, and to a lesser extent MM6, may have been exposed to more reduced levels of pile driving noise than expected at these locations (see Section 4.2.2) and perhaps, returned sooner. At the same time, dolphins that occurred closer to the middle harbour regions (MM5 and MM2) may have simply chosen not to travel further into the harbour, due to the ongoing noise within the channel, and left the harbour instead.

5.1.1. Long-term findings

While the ST findings from inner harbour moorings suggested localised and shorter term (several days) behavioural level reactions to pile-driving activity, the longer-term CPOD data indicated a harbour-wide decline in dolphin presence around the same time as the construction projects began. This decline may suggest that (i) the construction of the Cruise Berth and / or Channel Deepening projects has had a larger regional effect on the portion of the Banks Peninsula population that use Lyttelton Harbour, and this effect has persisted past their completion; (ii) there were several large-scale climate[12] and marine temperatures drivers[13] affecting fluctuations in the Banks Peninsula regional population of Hector's dolphin; or (iii) both Port construction projects and climate drivers combined affected dolphins that may regularly visit Lyttelton Harbour. This report is unable to distinguish between these possible explanations. Further information and analyses are needed to clarify the main influence(s) of the decline and its longer-term persistence.

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[12] The variability of New Zealand's climate and marine temperatures are dependent on three main factors (NIWA 2011, MfE 2008): 1) **El Niño/Southern Oscillation cycle (ENSO/SOI)** - Quasi-periodic climate patterns of prolonged differences in surface temperatures of the Pacific Ocean that occur approximately every five years, characterised by temperature cycles of warming (El Niño) or cooling (La Niña) of the surface waters in the tropical eastern Pacific Ocean, also known as the Southern Oscillation Index or SOI; 2) **Interdecadal Pacific Oscillation (IPO)** - Longer-term cycles of 15-30 years that affects sea-surface temperature (SST) and sea-level pressure patterns within both the north and south Pacific Ocean; and 3) **Climate change** - Warming temperatures due to increasing greenhouse gases.

[13] New Zealand experienced one of its first large-scale marine heatwaves in the spring of 2017 that lasted through much of 2018 (NIWA 2018). This event had notable effects on Lyttelton Harbour intertidal species that likely had several latent ecosystem effects (S. Montie, PhD student, University of Canterbury, unpublish. data 22 Nov 2022).

5.2. Noise regulations and control measures

5.2.1. Noise levels

While noise levels recorded at the various moorings did not exceed temporary hearing thresholds (TTS), the noise levels at which harbour porpoises begin to demonstrate behavioural responses (~133dB) were regularly reached and exceeded. Behavioural responses of marine mammals to noise disturbance can vary from minor changes in direction, breathing or vocalisation rates to abandonment or avoidance of impacted waters. In this study, there was little or no evidence of piling noise affecting the acoustic recorders' ability to detect dolphins (i.e. due to background noise) nor that dolphins seen by the MMOs were silent (i.e. not echolocating) when pile driving was underway (see 5.3 Method comparisons below). There was also no evidence of dolphins abandoning regions of the harbour or even an associated displacement from inner harbour regions towards the middle or outer regions when piling was underway, as found by Leunissen et al. (2019). Instead, the inner harbour detection rates suggested that dolphins temporarily move from these regions while piling was underway and gradually returned closer to the Port area once piling ceases. The bathymetry and associated propagation of the pile driving noise within the dredged shipping channel, as discussed in the previous section, may help explain the spatial differences in these behavioural reactions of the animals.

Noise monitoring results over the 14 months of construction activity found that the amount of pile-driving activity, and in particular, hammer driving, was more intense over late autumn 2019 and over most of the winter 2019 months. In the Te Awaparahi Bay Wharf Consent hearings, experts agreed that if piling activity needed to take place, the best period was considered to be winter when fewer Hector's dolphins entered Lyttelton Harbour. The mainly winter timing of the most intense piling activity and noise levels within behavioural response ranges (rather than hearing injury ranges) might also help explain why these behavioural reactions were more localised in their impacts on dolphin detections.

As noted in earlier sections, annual trends in dolphin CPOD detections during 2020 and some of 2021 were mixed and showed varying levels of recovery towards earlier 2017 and 2018 levels. Overseas studies have noted that the duration of noise disturbances may be an important factor in the extent of behavioural reactions of species and among individual animals (Southall et al. 2007; Bailey et al. 2010). The construction of the Cruise Berth spanned two summer seasons (December 2018 to February 2019, and December 2019 to February 2020). Model results demonstrated that Hector's dolphins appear to be more sensitive to pile-driving noise over the warmer months of spring and summer. The decline in these longer-term trends suggest that the ongoing disturbance from construction activities may have been a factor for some animals choosing not to venture as far into the harbour as they might have previously while others may have foregone even entering the harbour.

5.2.2. MMOs

Designated MMOs were employed to monitor the 450-m wide Marine Mammal Observation Zone (MMOZ) associated with any pile-driving construction activity. Seasonal trends in the MMO sightings of Hector's dolphin aligned well with acoustic detection trends suggesting no unknown biases in piling operations were present and affecting MMOs' monitoring capabilities.

MMOs had several different regulatory options available to protect any animal sighted near or within the MMOZ when pile driving was about to begin or was already underway. MMO watches resulted in approximately 68 delayed starts, 21 stand-bys and 15 shut-downs over the 243 days in which pile driving occurred. Statistical comparisons between the number of visual sightings reported with and without pile-driving activity suggested that dolphins were actively avoiding the MMOZ area when piling was underway. With the relatively low number of shut-downs, these results may highlight the success of ramping up procedures in which the hammer is gradually brought up to full power over a 10 minute period, allowing dolphins time to move away from the piling impact area prior to normal operations. Once piling ceased, MMOs generally sighted dolphins back in the inner harbour region (up to 1.6 km) almost immediately and with the majority of post-observational sightings occurring within 36 minutes, was similar to the inner harbour acoustic mooring findings.

5.3. Method comparisons

Comparisons between sampling methods suggested STs provided data of higher sensitivity to echolocation clicks for these monitoring situations or at least with Hector's dolphins, than with the auto-detection method of CPODs. STs produce .wav files that can be processed using more sophisticated software, such as FinFinder. An additional advantage of using STs over CPODs was the ability to collect simultaneous noise and dolphin detections data in order to understand the levels of noise animals were experiencing.

This study was not able to fully test the efficiency of acoustic versus visual methods due to the distance at which acoustic moorings were spaced from the MMOs and the correspondingly small sampling size. Yet, the advantages of using MMOs were obvious in this case as no other real-time dolphin detection methods were available at the time of consent. Even if real-time acoustic monitoring had been available, the inability to place acoustics moorings in the vicinity of the MMOZ would have prohibited their use for the Cruise Berth construction.

By employing different detections methods, this was one of the few studies capable of testing how pile-driving noise might affect acoustic recorders' ability to detect Hector's dolphin echolocation clicks. In this case, the visual sightings were used as proof of dolphins' presence in which the ability of acoustic methods to detect them was tested, both in the presence and absence of pile-driving noise. Although sampling sizes were low, this is the first study to show statistical evidence that when Hector's dolphins were present as reported by MMOs, they were detectable acoustically (DPMs) at similar rates whether or not pile-driving activities were underway.

5.4. Key learnings and recommendations

5.4.1. Noise verification

A large number of MMO sightings (n = 70) reported Hector's dolphins within the inner Port region on the opposite side of the reclaimed rock wall bund to which piles were being driven for the Cruise Berth. Expert acoustic advice at the time suggested that, due to the rock wall bund, underwater noise from piling activities would be considerably limited in its ability to penetrate into inner Port areas. This study has not been able to verify or examine noise levels within inner Port regions as no underwater noise recordings were undertaken in this region. Given the number of dolphins sighted in inner harbour region, further verification is warranted if any other pile-driving activities are to be undertaken around the Port entrance area in the future.

Similar advice was given in regard to 'pin piles' and on-land piling works (through the former reclaimed breakwaters) and just below the low-tide line. While some MMO watches were undertaken and corresponding underwater acoustic noise recorded, this study was unable to look at or verify the noise levels associated with these activities due to inadequate piling activity logs and mismatches between MMO pile numbering system and those of the sub-contractor. Having a well-kept piling record log (date, pile number and type, piling method and duration) that is in good agreement with the MMOs is key to being able to accurately find and isolate individual pile-driving noise data in which to verify noise levels. Alternatively, a separate noise assessment could be carried out when these types of piles are being driving and the actual noise levels recorded in situ over several days.

5.4.2. Post-construction data

This study was unable to fully assess whether longer-term trends in Hector's dolphin acoustic detections have recovered to previous baseline (2017–2018) levels once pile driving and other construction activity ceased. While several of the moorings did gather underwater noise and dolphin acoustic detections post-construction (i.e. February 2020 to March 2021), most did not include a full calendar year of data or were pulled out mid-season. In addition, and as expected, recorder failures occurred throughout the sampling years with several vital months and / or seasons lost at certain locations.

Hence, annual and seasonal comparisons were more difficult after February 2020 due to the lack of adequate data samples collected over similar time periods or significant data gaps due to the COVID-19 pandemic. Future monitoring programmes need to consider the full pre-, during and post-time periods carefully when designing such monitoring programmes as the post-data are often the most vital. These programmes need to consider the temporal aspects of the species being protected rather than just construction periods; in this case, the seasonal aspects of Hector's dolphin are extremely important as they influence their expected use of harbour waters.

Another important factor to consider for future monitoring programmes is the value of processing, analysing and reviewing the underwater acoustic and dolphin detection data as they are gathered. Understanding the pre-construction trends as the construction projects were underway would have helped establish the level of post-construction monitoring necessary to more thoroughly test variations in trends.

5.4.3. Mitigation recommendations

With the data collected from LPC's monitoring programme, this study was able to verify that the short-term effects of pile driving within inner harbour waters were potentially short-lived in their duration. Dolphins' behavioural reactions suggested they were more sensitive to pile-driving noises in summer / spring than during autumn / winter months.

As such, any future construction projects within Lyttelton Harbour that might involve pile-driving activities should look to emulate several of the operational restrictions and control measures used in the Cruise Berth construction, particularly the following:

- similar or smaller sized and types of piles
- similar or smaller piling rig and hammers
- only one piling rig operating at any one time
- piling activities restricted to daylight hour operations only
- hydraulic hammering limited to at most 6 hours / day
- restrict the most intense piling activities to the colder months of the year (preferably winter months)
- suitably-sized MMOZ monitored by a designated and dedicated, independent MMO with previous experience and training.

It is worth LPC managers also reviewing the various parameters associated with those pile-driving activities that generated the greatest or more intense noise levels (e.g., pile size and type, hammer type and frequency, power setting and bottom type). Understanding what operational aspects are contributing the most to the resulting noise would help with developing possible options and alternatives for mitigation.

However, given the shortcomings of the post-construction data and lack of other regional population information, this study could not conclusively determine if longer-term declines in Hector’s dolphin detections throughout the harbour, and even outside of it, were due to the two construction projects or arose in conjunction with other factors. Given the possible effects that the duration of continued noise disturbance can have on the wider regional population of Hector’s dolphins and the proposed size and scale of future pile-driving programmes (i.e. Te Awaparahi Bay Wharf), further mitigation will be warranted to reduce and keep pile-driving noise levels to an acceptable level.

The most obvious mitigation measure for LPC to explore is the use of bubble curtains. This option was raised in planning discussions with the Cruise Berth construction and considered at that time unfeasible. Since then, Centre Port (Wellington) has employed bubble curtain technology in association with a few different pile-driving projects with considerable success (i.e. achieved necessary noise reduction levels). The authors of this report feel that bubble curtains should become a standard mitigation tool for all future pile-driving projects in areas with marine mammals present.

The second recommendation would be to limit pile-driving projects to less than a 12-month duration, unless monitoring data can demonstrate no adverse effects on Hector’s dolphin detection trends and continue to undertake the most intensive piling components over the winter months.

5.4.4. Monitoring recommendations

Monitoring recommendations based on these results would be to use a similar combination of monitoring methods (real-time and passive) with any future Port developments. Real-time methods are necessary to enforce immediate protective measures, such as shut-downs or stand-bys. These findings also emphasise the importance of using MMOs that are well-trained, experienced and interested in the project to ensure the best results. However, passive methods, in particular STs for the collection of underwater noise, are also necessary to ensure other mitigation and management conditions were being adhered to, operations are continuing as expected and the effects on the animals are regularly monitored.

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Vision Environment (Australia) was responsible for retrieving, deploying and maintaining the acoustic moorings for the duration of the monitoring programme along with LPC staff. Lesley Douglas of Blue Planet Marine trained and oversaw all the MMOs used on the project, of which Maryjane Waru went above and beyond the call of duty as an MMO. HEB Construction were also critical in implementing and monitoring the MMOZ and working with the MMOs to ensure the safety of Hector's dolphins during the project.

Finally, Crystal Lenky (LPC) has been instrumental in moving the analyses of the monitoring programme forward and organising all the datasets and necessary information. Melanie Burns of Environment Canterbury (ECAN) supplied the rain, temperature, and wind data used in the general models. Jessica Schattschneider, Paula Casanovas and Simon Childerhouse (Cawthron) all provided useful advice and help with this report.

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8. APPENDICES

Appendix 1. Description of pile-driving works

A1.1. Main components

Construction of the Cruise Berth involved three main components, including temporary works to enable access to the site for construction equipment.

A1.1.1. Temporary works piling

Prior to starting the piling for wharf construction, 187 support piles were driven to make the land stable enough to withstand the weight of the construction equipment. Two phases of piling were required; the first was on-land and provided support for the main piling crane. These crane support piles, with a concrete capping beam and connecting steel tie rods, ran in two parallel rows running along the Eastern Mole. The seaward piles are larger (710 mm diameter) and longer (15 m) compared to the Inner Harbour side (610 mm diameter and 6-10 m long).

The second phase involved a ‘pinning wall’ on the seaward slope of the Eastern Mole, just below the low tide line. This pinning wall was designed to stabilise the Eastern Mole during construction works and consisted of 79 piles (810 mm diameter and 39 m long). While these piles were considered as temporary in terms of the design process, they were not removed at completion of the works.

A1.1.2. On-land bollard piling

The bow and stern lines from the cruise vessels affix to on-land bollard structures, one for the bow and one for the stern. Each bollard structure comprises two parallel rows of 22 piles (914 mm in diameter and 15 m long) with a concrete capping beam and connecting steel tie rods. In total, approximately 90 piles were required for the bollard structures.

A1.1.3. Main wharf piling

Construction of the main wharf required driving approximately 64 piles, 914 mm in diameter and driven to depths of approximately 60–70 m. A concrete deck was cast atop the piles. The main wharf is tied back to the Breakwater by means of land restraint structures, which have a piled wall at the rear of the structure containing 18 x 900 mm diameter casings driven to 11 m below ground level. The lines platform at the western end of the site consists of 2 x 900 mm driven to approximately 36 m.

A1.2. Piling methodology

Whilst there were slight differences in the detail of how each phase was installed, the overall piling methodology was the same for all phases. The steps were as follows:

- A pre-fabricated pile gate (to hold and guide the piles) was positioned on site. Small H piles (or tubular piles) may have been driven (using vibro methods) to hold the pile gate in place.
- A pile was pitched in the pile gate using a specialised excavator.
- The main piling rig used a vibro-piling method to drive this pile as far as possible.
- The pitching and vibro-piling were continued until the pile gate was full; the pile gate was designed for four piles.
- The piling head was then changed to a hydraulic hammer and all piles were driven to their design depth.
- For the deeper piles (20 m+), additional pile sections were welded onto the already driven piles. Once welded, hydraulic hammering of these extended piles continued.
- Once the desired pile depth was reached, the gate was removed and the piles were cut to the desired height.
- The equipment then repositioned to the next set of piles and the above was repeated.

Appendix 2. Acoustic method – additional information

A2.1. CPOD data processing

Every 1–2 months, the SD cards and batteries in the CPODs were replaced. The data were uploaded to cpod.exe software (Chelonia Ltd, UK) and scanned for any metadata warnings, the maximum click count per minute, patterns in the time-series and the overall spectra to determine possible contamination issues via tides, weather events, vessels, and non-target biological sources (such as snapping shrimp). An example of a time-series is provided in Figure A2.1.

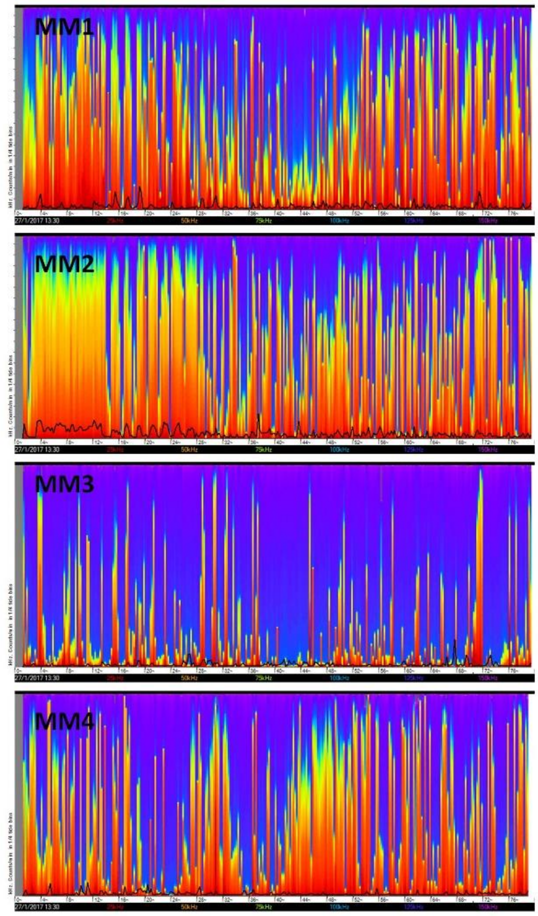
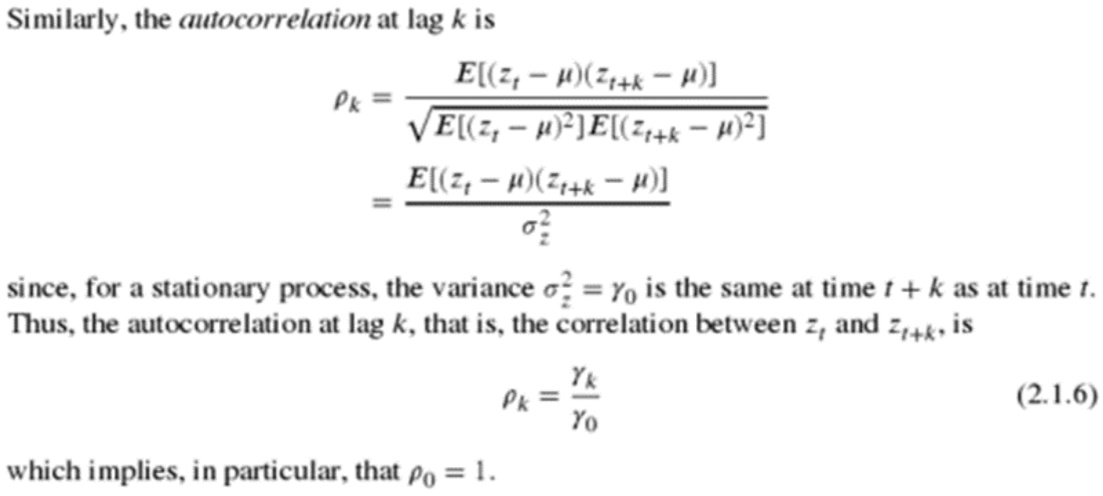


Figure A2.1 Time series of the raw data before any filters were applied. These plots depict the entire first deployment for sites MM1 to MM4, with the deployment day along the x-axis. The y-axis is the number of unfiltered clicks that were logged (shown by the black line plot overlaying the colour spectrum) and the colour spectrum represents frequency (from below 25 kHz (red) to 150 kHz (pink)). Incoherence between time series plots from each monitoring site and the absence of any cyclic patterns in the unfiltered clicks show minimal tidal interference from currents on the performance of the units but high levels of low frequencies at the shallower sites MM1 and MM2 compared to the deeper MM3 and MM4 sites.

Following all checks, autocorrelation (the correlation between data points of the same variable based on related factors) in the DPM metric was assessed to determine the most appropriate time-interval during the analyses. This was done using the 1-min DPM counts and following the formula for the autocorrelation at lag k from Box et al. (2016) as follows:



Similarly, the *autocorrelation* at lag k is

$$\rho_k = \frac{E[(z_t - \mu)(z_{t+k} - \mu)]}{\sqrt{E[(z_t - \mu)^2]E[(z_{t+k} - \mu)^2]}} = \frac{E[(z_t - \mu)(z_{t+k} - \mu)]}{\sigma_z^2}$$

since, for a stationary process, the variance $\sigma_z^2 = \gamma_0$ is the same at time $t + k$ as at time t. Thus, the autocorrelation at lag k, that is, the correlation between z_t and z_{t+k}, is

$$\rho_k = \frac{\gamma_k}{\gamma_0} \qquad (2.1.6)$$

which implies, in particular, that $\rho_0 = 1$.

With the number of values for the lag series limited to 1,000 of the number of bins (Tollit et al. 2011), values were then plotted in a correlogram with the horizontal limits[14] representing the approximate 0.05 *p*-values. Since the resulting autocorrelation was observed up to 29 minutes across all sites, the DPM per duty cycle hour was the shortest time interval used for statistical analyses.

A2.2. SoundTrap data processing

Unlike the CPODs, the ST produced audio files that were processed using machine learning techniques, followed by a series of detection and classification steps. Machine learning allows computers to perform complex tasks and learn from experience with real-world data. The overall process for the Hector's dolphin echolocation detectors, as outlined in Figure 5 (Section 2.1.4), involved the following steps:

- collect the data
- configure the network (transfer learning)
- train the network
- validate the network
- test the network and repeat training on larger datasets, as required
- apply the network to complete dataset using the detector software.

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[14] Set using ±1.96*(2/sqrt(N))*ones(1,2)

A2.2.1. ST data selection

The data used in the deep learning was pulled from the sound files using the MMO sighting times as a general guide. The MMO sighting times were used because they were the known times when dolphins were present, thereby directing us to the most likely times echolocation clicks would be detected.

Audio files that were recorded by the ST 1-hour either side of the MMO's sighting start and end time were extracted and inserted into unique directories, labelled according to the sighting number. This was done for the four sites in the MMO's visual range (MM5, MM6, and MM7) and MM2 in the middle harbour region as a control.

Once extracted, those audio files were processed into 60-sec spectrograms (using a 9774-sample Hanning window, 50% overlap, plotted for frequencies 50–144 kHz (288 kHz sampling rate). Those 60-sec spectrograms were then manually inspected for Hector's dolphin echolocation clicks (example in Figure A2.2).

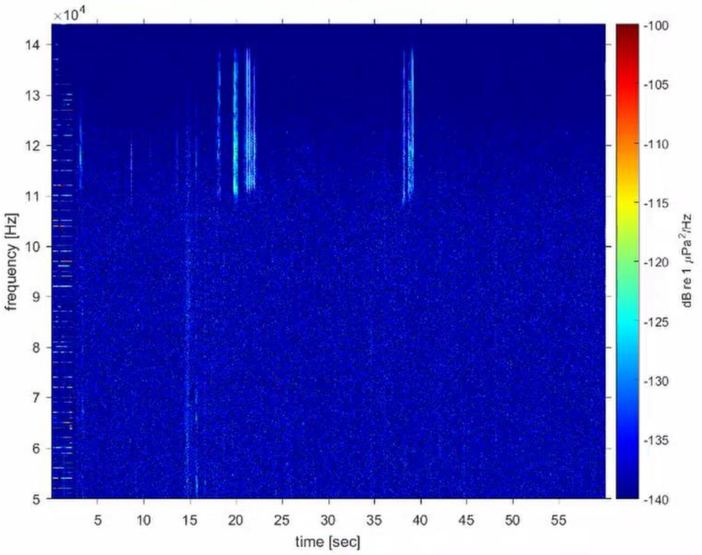

Figure A2.2 Example of 60-sec spectrogram showing Hector's dolphin echolocation clicks.

Spectrograms with Hector's dolphin echolocation clicks where isolated and the datetime stamps were used to extract the audio file behind the spectrogram. Those audio files were then reprocessed but for 2-sec spectrograms, following the methods in Buchanan et al. (2021). Those 2-sec spectrograms where then separated as Positives (i.e., Hector's dolphin echolocation clicks present in the spectrogram) and Negatives (i.e., no echolocation clicks present, only noise). These spectrograms were used as the training datasets. The axis labels were removed as they were redundant information in the CNN training (Figure A2.3). In total, 4,534 positive spectrograms and 4,534 negative spectrograms were used to start the CNN model training.

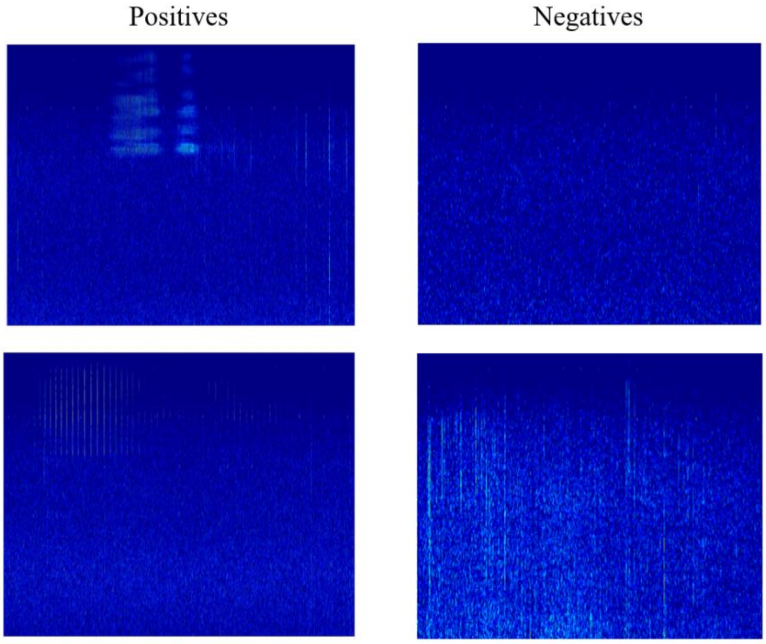

Figure A2.3 Examples of 2-sec spectrograms, generating using a 512 sample Hanning window with 50% overlap, used in the CNN model training. The left panel represents the Positive category (i.e., Hector's dolphin clicks), and the right panel represents the Negative category (i.e., no dolphin clicks present, only noise).

A2.2.2. CNN model configuration for transfer learning

CNN models were the primary artificial neural network used based on research by Buchanan et al. (2021). After comparing different CNN models, Buchanan et al. (2021) found ResNet-18 to be most effective at detecting dolphin echolocation clicks.

ResNet-18 is a current state-of-the-art model for image classification, achieving over 97% accuracy for dolphin echolocation clicks (Buchanan et al. 2021). However, for our purposes, the model required reconfiguration:

- We added a function before the model's first layer (the input layer) that automatically resizes spectrograms of any size to the required 224 × 224 pixels but maintained the multi-channel expectation.
- The last learnable layer (fully connected layer) and classification output layers were adapted for our class probabilities, loss values and predicted labels. This involved replacing the fully connected and classification layers with ones that reflect our two classification classes (Positive or Negative). The learning rate factors for the weights and biases were set at 10.
- The weights of the first four layers were frozen, so to maintain their weights and not update the parameters of those layers. By doing so, the training does not need to recompute the gradients of the frozen layers and therefore, speeds up the training. It can also help in preventing overfitting due to smaller training datasets.

- Data augmentation was applied to the training datasets so to help prevent overfitting.

A2.2.3. Train the network

Three datasets were used for the network training:

- **Training dataset**: this was made up of 80% of all training images and is used to train the CNN. This set is used by the model to find the most optimal values of weights and biases during training.
- **Validation dataset**: this was made up of 20% of all training images and is used during training to fine-tune the CNN's parameters. Because we used early stopping rather than a set number of epochs, the validation dataset is also used to determine when to stop training.
- **Test dataset**: this is not actually used during the training but is used to test the performance of the network after training is complete. This dataset is one that the model has not seen before.

With the reconfigured model completed, the training options were set as:

- Mini batch size = 100.
- Validation frequency = 1 per epoch.
- Adam optimizer.
- Early stopping was used to determine maximum epochs, by setting validation patience at 10 and recall of best model until that point.
- Initial learning rate = 1e-6.
- Gradient decay factor = 0.01.
- Mini batches randomly shuffled after each epoch.
- Training was scaled up using GPU arrays.

At various stages during the model's development, gradient-weighted class activation mapping (Grad-CAM) was the primary method used to visualize the model's focus within spectrograms.

Because the CNN training method is stochastic, it was repeated five times with the mean accuracy and standard deviations evaluated. The network's accuracy was calculated using

$$Accuracy = 100 \times \frac{TP + TN}{TP + TN + FP + FN} \%$$

where TP, TN, FP and FN were true positives, true negatives, false positives and false negatives, respectively (Buchanan et al. 2021). This equation was applicable because the datasets were balanced.

Once a test accuracy greater than 95 percent was achieved, the training options were considered appropriate, and further training consisted of building a greater training dataset to improve the false positive scores. Subsets of the data from random times throughout the year were run through the trained model, and the outputs were manually checked. All false positives were then flagged as *Negatives*, while true positives were added to the *Positives* class in the training dataset. This was repeated (took 8 repeats) until the model's test accuracy increased to over 98%, signalling that the detector was very well suited for Lyttelton Harbour's soundscape. The final training dataset consisted of 10,000 Positives and 10,000 Negatives from random periods during 2019 and 2020.

The final model was evaluated using precision/recall method (Halliday et al. 2020),

$$Precision = \frac{TP}{TP + FP}$$

$$Recall = \frac{TP}{TP + FN}$$

Precision measured how often the model correctly identified echolocation clicks, while recall measured how often echolocation clicks were missed. A new test dataset, not used during any previous tests or training, was used to calculate precision, and recall of the final model. This was done separately to gain confidence before being used on all 100,000+ hours of data.

A2.2.4. Model application

The final model was then integrated into *FinFinder* detector software[15] to be run on all deployments across all sites. The overall detector included the signal loading, pre-processing, filtering and image generation before being classified and results recorded. Outputs included Raven Pro selection tables of each detection as well as the classified spectrograms, probability scores and detection tables.

To compare against CPOD performance, the ST detections were summarised as DPM per duty cycle hour, written to .CSV files.

A2.2.5. Model performance

The model performed very well at detecting Hector's dolphin echolocation clicks (see Table A2.1), and the Grad-CAM outputs consistently showed the model focusing on the correct area of spectrograms that contained clicks (Figure A2.4).

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[15] FinFinder is a detection and classification software written by Matt Pine (Styles Group Acoustics).

Table A2.1 Performance metrics for the echolocation click detector.

Development Stage	**Metrics Used**	
	Validation Accuracy (%)	*Test Accuracy (%)*
At final training	98.41 ± 0.78	97.91 ± 0.61
	Precision	*Recall*
At final model	0.975	0.992

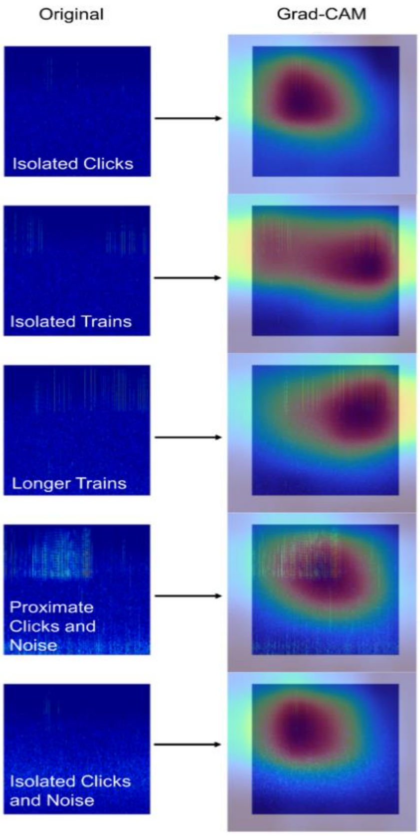

Figure A2.4 Visualisations of the detector model classifications. The left panel shows example of echolocation clicks, while the right panel show the most important area in the spectrogram that the model uses to detect the echolocation clicks.

References

Box GEP, Jenkins GM, Reinsel GC 2016. Time Series Analysis: Forecasting and Control. 5th ed. Englewood Cliffs, NJ: Prentice Hall, pg 25.

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Halliday WD, Pine MK, Mouy X, Kortsalo P, Hilliard RC, Insley SJ 2020. The coastal Arctic marine soundscape near Ulukhaktok, Northwest Territories, Canada. Polar Biology 43: 623-636.

Tollit D, Wood J, Broome J, Redden A 2011. Detection of marine mammals and effects monitoring at the NSPI (OpenHydro) turbine site in the Minas Passage during 2010. SMRU Consulting Ltd & Acadia University (SMRU Rpt # NA0410BOF, Acadia Publication # 101).

Appendix 3. Comparison between SELcum and SELcum$_{1hr}$

To determine the potential varying effect that the duty cycle SELcum and the adjusted SELcum$_{1hr}$ for the whole hour (as described in Figure 4) might have on fine scale model results, the two parameters were plotted against each other (Figure A3.1). The resulting relationship is relatively linear after SELcum = 130 dB, while there is a tendency of the adjusted SELcum$_{1h}$ to be greater than the duty cycle SELcum at lower decibel levels. Hence, we considered that the adjusted SELcum$_{1h}$ represented the more conservative, or worst-case, scenario and for this report, decided to use it in the individual mooring models.

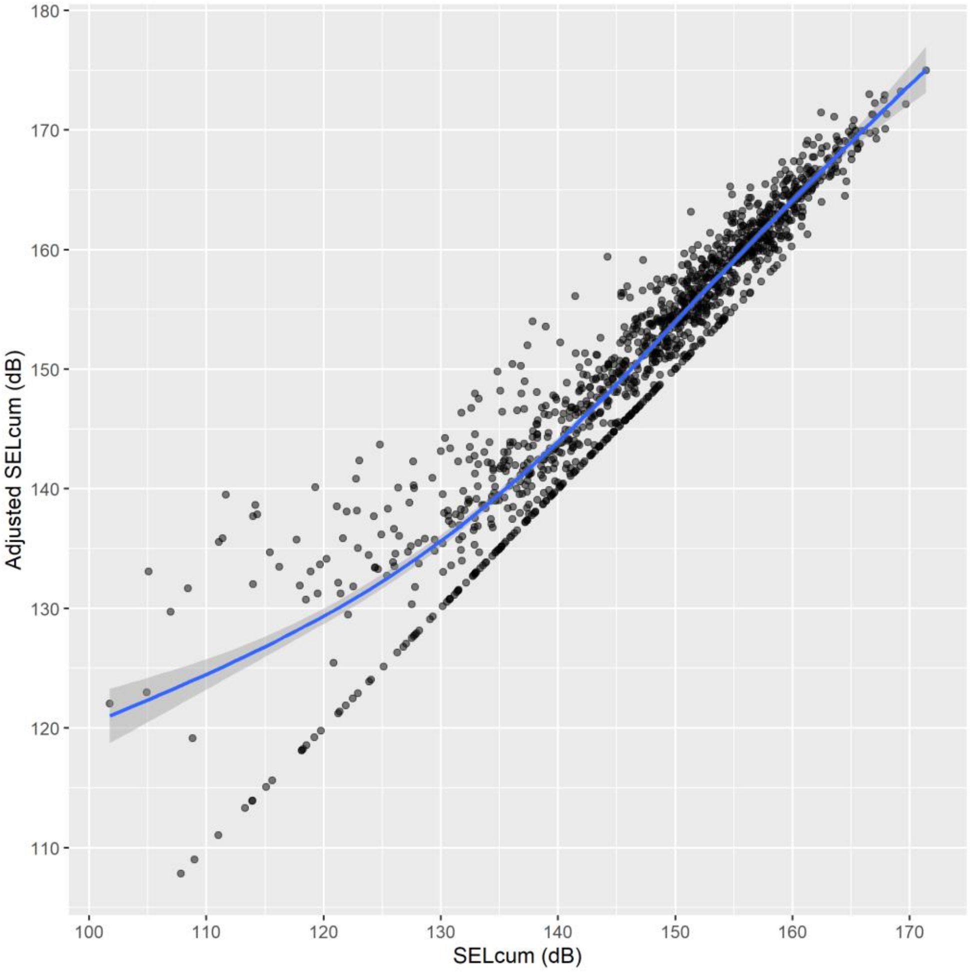

Figure A3.1. The relationship between SELcum (x-axis) and adjusted SELcum$_{1hr}$ (y-axis).

Appendix 4. Daily CPOD detection trends by mooring

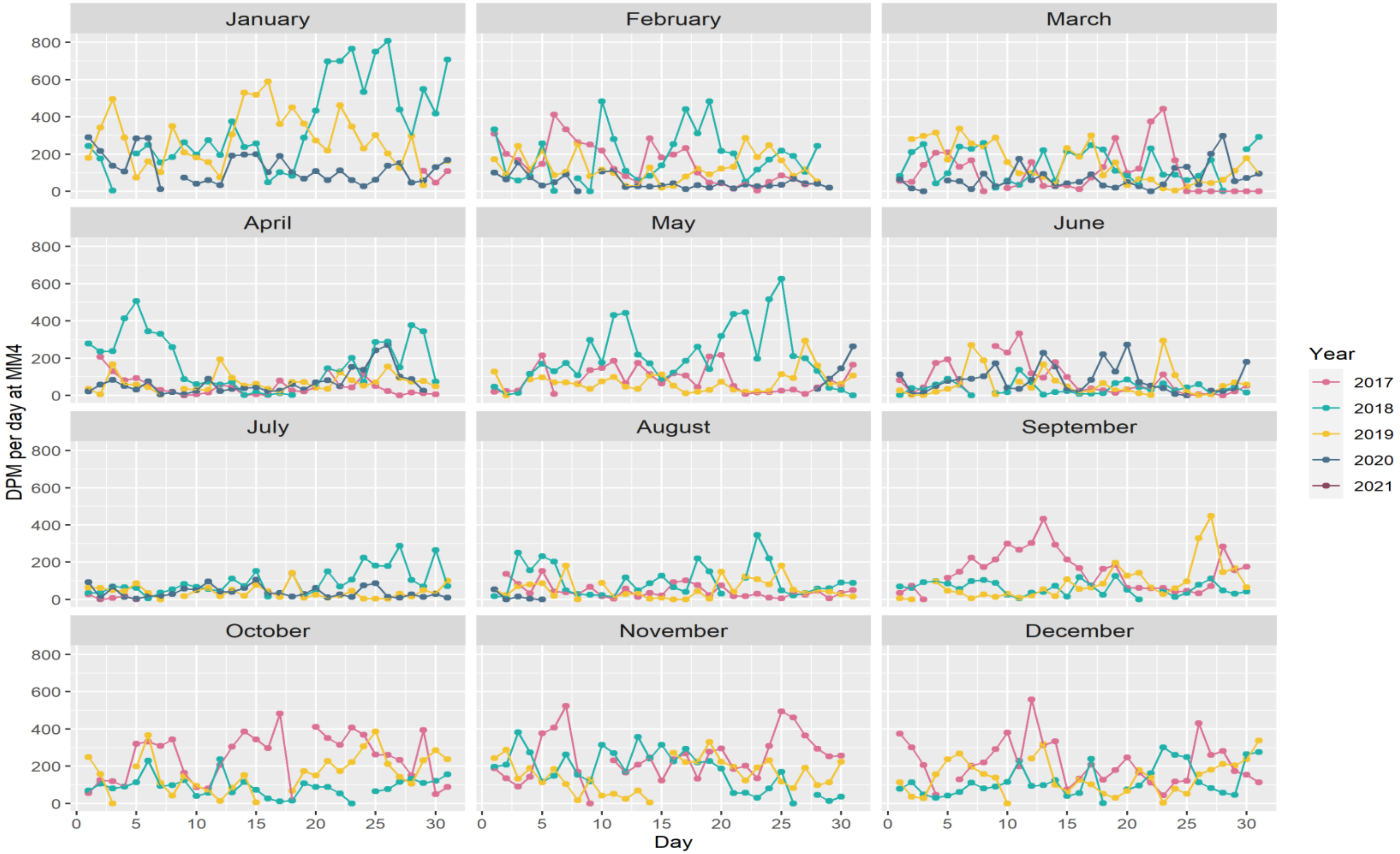

Figure A4.1. CPOD DPM per day (sum of DPM per hour over 24 hours) at **MM4**, which is located outside of the harbour. The different years are represented by the different colours as indicated in the legend.

Figure A4.2. CPOD DPM per day (sum of DPM per hour over 24 hours) at **MM3**, which is located at the entrance to the harbour. The different years are represented by the different colours as indicated in the legend.

Figure A4.3. CPOD DPM per day (sum of DPM per hour over 24 hours) at **MM2**, which is located at inside the harbour and near the north head / entrance. The different years are represented by the different colours as indicated in the legend.

Figure A4.4 CPOD DPM per day (sum of DPM per hour over 24 hours) at **MM1**, which is located in middle regions of the harbour. The different years are represented by the different colours as indicated in the legend.

Figure A4.5 CPOD DPM per day (sum of DPM per hour over 24 hours) at **MM5**, which is located in the inner regions of the harbour. The different years are represented by the different colours as indicated in the legend.

Figure A4.6. CPOD DPM per day (sum of DPM per hour over 24 hours) at **MM6**, which is located in inner regions of the harbour near the Port. The different years are represented by the different colours as indicated in the legend.

Figure A4.7. CPOD DPM per day (sum of DPM per hour over 24 hours) at **MM7**, which is located in inner regions of the harbour near the Port. The different years are represented by the different colours as indicated in the legend.

Figure A4.8. CPOD DPM per day (sum of DPM per hour over 24 hours) at **MM8**, which is located in inner regions of the harbour near the Port. The different years are represented by the different colours as indicated in the legend.

Appendix 5. Seasonal trends for CPOD detection data

The following figures display monthly CPOD detections for each mooring across all years collected.

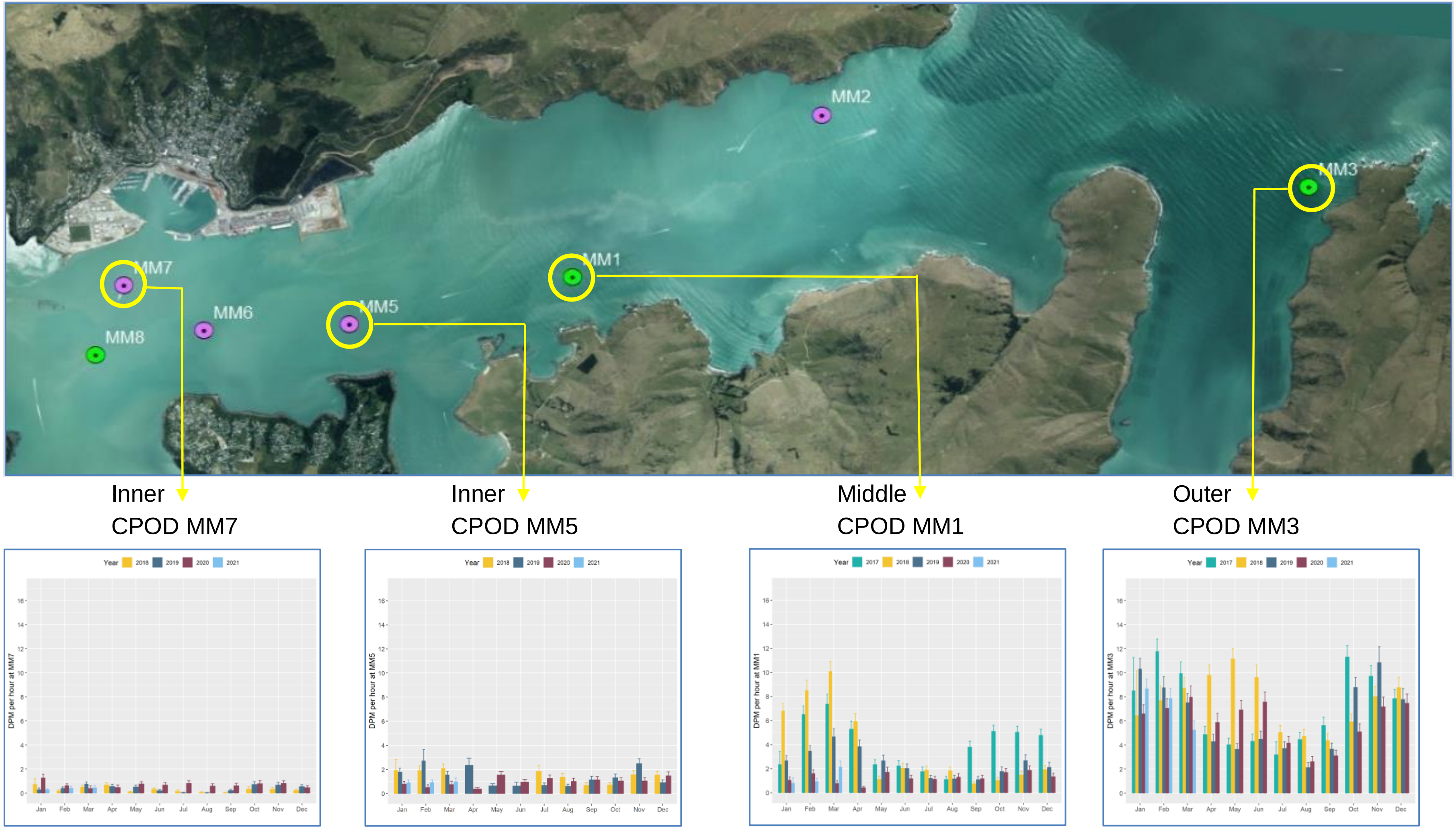

Figure A5.1 Visual comparison of season trends in mean annual CPOD DPM per hour from the inner moorings near the Port (left) out towards the outer harbour moorings at Lyttelton Heads (right). Note that the x- and y-axis scale are the same across all figures.

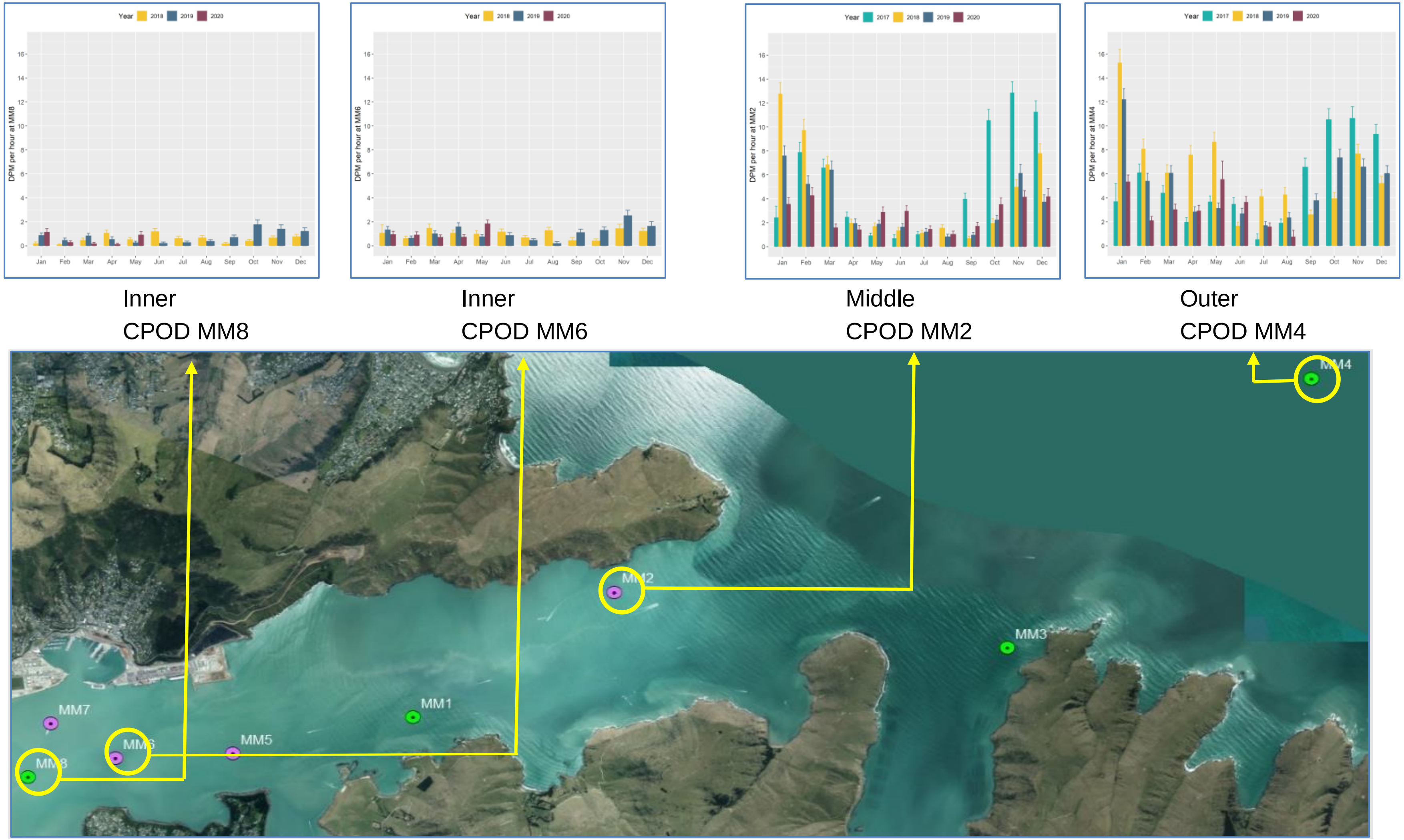

Figure A5.2. Visual comparison of the seasonal trends in mean annual CPOD DPM per hour from the inner moorings near the Port (left) out towards the outer harbour moorings at Lyttelton Heads (right). Note that the x- and y-axis scale are the same across all figures.

Appendix 6. MMO Sighting data by season

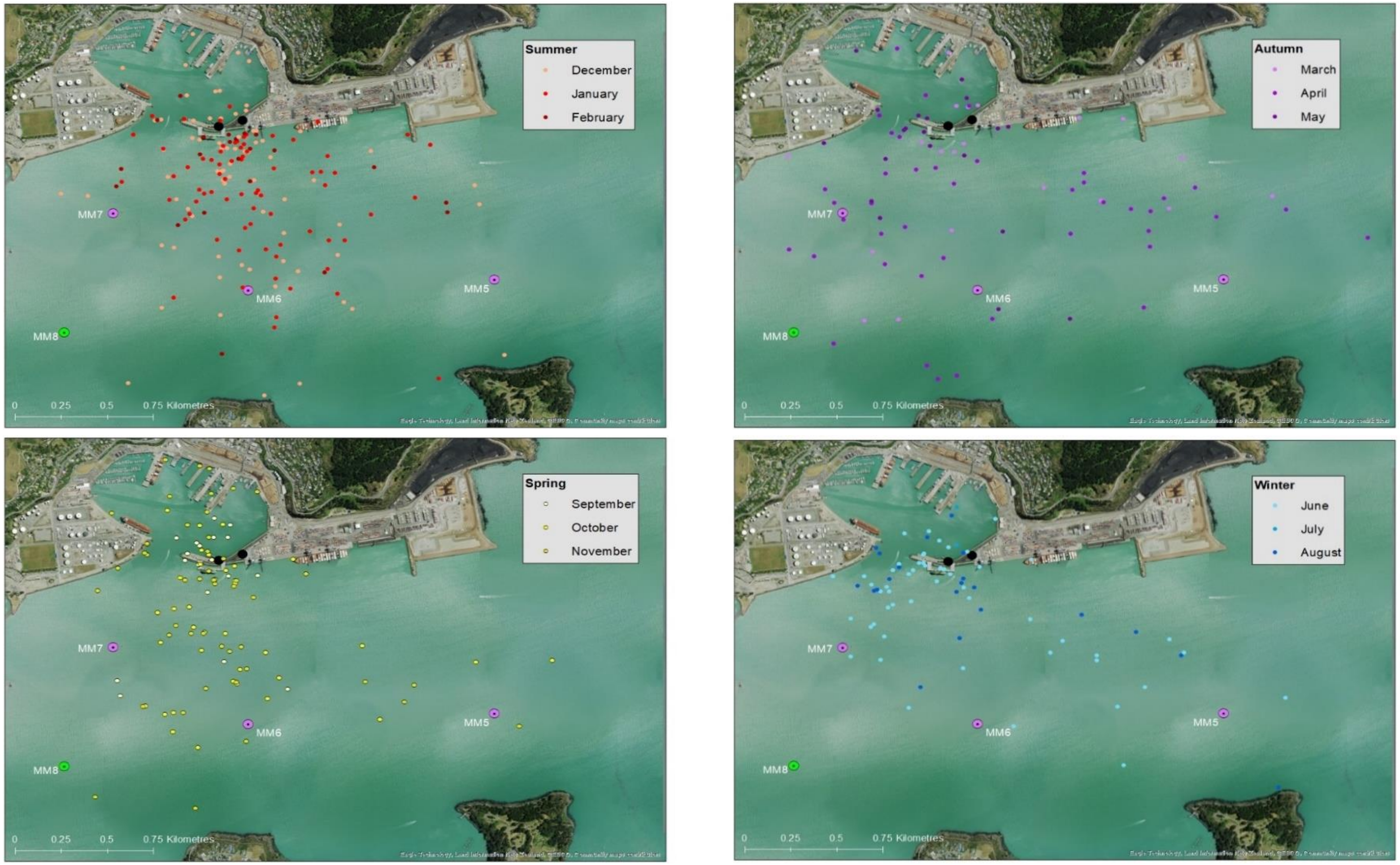

Figure A6.1 The locations of seasonal sightings of Hector's dolphin recorded by Marine Mammal Observers (MMO) during pre-, during and post-pilings watches between 7 December 2018 and 5 February 2020.

Appendix 7. MMO piling stage descriptions and procedures

Standard operation procedures (SOP) that were undertaken by MMOs and contractors during piling activities to protect against any TTS effects included pre-start, soft start, normal operation, stand-by operation, shut-down procedures and post-piling observation.

Pre-start procedure – Potential marine mammal presence should be visually monitored by the MMO(s) for at least 30 minutes before the commencement of the soft start procedure. Particular focus should be put on the MMOZ but scanning should take place beyond the zone and up to 1 km radius from the source where visibility allows. Observations should be made from the piling rig or a better vantage point if possible (i.e. in the absence of a high vantage point, a large observation zone may require an additional vessel as sufficient observation platform).

Soft start procedure – If marine mammals have not been sighted within or are likely to enter the MMOZ during the pre-start procedure, the soft start procedure may commence in which the piling impact energy is gradually increased over a 10 minute time period. The soft start procedure should also be used after long breaks of more than 30 minutes in piling activity and visual observations have ceased. Visual observations for marine mammals within the MMOZ should be maintained by the MMO(s) throughout soft starts. The soft start procedure may alert marine mammals to the presence of the piling rig and enable animals to move away to distances where injury is unlikely.

In some instances, such as pile testing which requires immediate full energy, soft starts will not be possible. Testing situations will only occur in optimal visibility conditions when the designated MMO shall ensure that the exclusion zone has been closely monitored for 30 mins and that no mammals have been present in that period.

Normal operation procedure – If marine mammals have not been sighted within or are not likely to enter the MMOZ during the soft start procedure, piling may start at full impact energy. MMO(s) should continuously undertake visual observations during piling activities and shut-down periods. After breaks longer than 30 mins in piling activity and visual observations or were hampered by poor visibility, the pre-start procedure should be used.

Stand-by operations procedure – If a marine mammal is sighted near the observation zone during the soft start or normal operation procedures, the operator of the piling rig should be placed on stand-by ready to shut down the piling rig. The MMO(s) should continuously monitor the marine mammal in sight.

Shut-down procedure – If a marine mammal is sighted within or about to enter the shut-down zone, the piling activity should be stopped immediately. If a shut-down procedure occurred and marine mammals have been observed to move outside the observation zone, or 30 minutes have lapsed since the last marine mammal sighting, then piling activities should recommence using the soft start procedure. If marine mammals are detected in the observation zone and poor visibility sets in, operations should switch to poor visibility procedures.

Post-piling observations – The MMO(s) should maintain a watch of the MMOZ (and beyond) for at least 1 hour after pile-driving activity has ceased (or as long as daylight allows). In particular, observers are looking for any indication of marine mammal presence in the wider vicinity to evaluate the duration of effect that piling activities might be having.

Poor visibility procedure – Poor visibility is defined as sea fog (on the water surface), winds greater than 20 knots and / or rain or sun glare that obstructs more than 50% of MMOZ. If these any of these conditions occurs to an extent that makes it too difficult for the MMO to visually inspect the MMOZ for marine mammals, then piling activities should be postponed until conditions improve. If the MMOZ is prone to strong sea chop or afternoon sea breezes (i.e. wind greater than 20 knots), and does not adversely affect piling operations, an additional MMO should be employed at a second observation location to ensure adequate coverage of the MMOZ. If, during periods of intermittent poor visibility, there are more than three shut-downs due to marine mammals within the MMOZ, piling activities should be stopped for the remainder of the day.