Burrard Inlet underwater noise study: 2021 final report

ECHO Program study summary

This study was undertaken for the Vancouver Fraser Port Authority-led Enhancing Cetacean Habitat and Observation (ECHO) Program and project partner Tsleil-Waututh Nation, with financial support from Transport Canada. Building upon monitoring efforts in Burrard Inlet in 2019 and 2020, this project set out to monitor underwater noise and cetacean presence (whales, dolphins, and porpoise) in Burrard Inlet, a key waterway for commercial shipping, port-related activities, and the transportation of passengers by sea and air. This document summarizes the study's overarching questions and describes the study's methods, key findings, and conclusions.

What questions was the study trying to answer?

The third year of the Burrard Inlet underwater noise study sought to evaluate longer-term trends in total ambient noise and marine mammal presence, as well as evaluating the following specific questions:

- What is the source level of a bulker at anchor in English Bay?
- Was there a measurable difference in underwater ambient noise at a site near the cruise ship terminal between a season with cruise traffic (2019) and one without cruise traffic (2021)?

Who conducted the project?

SMRU Consulting North America (SMRU) was awarded the contract for the 2019 monitoring program and was retained by Vancouver Fraser Port Authority to continue monitoring though 2020 and 2021. Underwater noise levels measured by Ocean Networks Canada (ONC) at the Brockton Point cabled observatory were also analyzed by SMRU, to take advantage of this new station commissioned by ONC and Tsleil-Waututh Nation in 2021.

What methods were used?

Acoustic data were collected over approximately one year between February 2021 and February 2022, using bottom-mounted SoundTrap hydrophone recorders deployed in four locations in the inner and outer harbour: English Bay, Burrard West 2, Burrard East and Indian Arm. The SoundTrap hydrophones recorded acoustic data at an effective frequency range of 48 kHz, on a seven-minute on seven-minute off, 50% duty cycle. An IC Listen HF1951 hydrophone collected data continuously at an effective frequency range of 25 kHz at the ONC station (see Figure 1). In addition, a SoundTrap hydrophone was deployed on a short-term (~2 month) basis to collect ambient measurements at Burrard West 1, the location closest to the cruise terminal.

Power Spectral Density (PSD) and sound pressure level (SPL) were calculated for every minute of data. Broadband, decade band and 1/3-octave band levels were analyzed on monthly, daily and hourly time scales. L50 (median), Leq (mean) and L5 were chosen as exceedance percentiles for SPL reporting. High frequency echolocation clicks and lower frequency marine mammal calls were identified in the SoundTrap data using PAMGuard software, focusing on identification of harbour porpoise, killer whales, and other cetaceans

The source level of a bulker at anchor in English Bay was conducted using the portable Coastal Acoustic Buoy (CAB) measurement system. Two CABs were deployed; one within 100 m of the stern of the vessel and another unit was deployed ~400 m from the bow. Each CAB was equipped with two Reson TC4014 hydrophones, deployed at 10 m and 20 m depth. All hydrophones collected acoustic recordings at an effective frequency of 125 kHz.

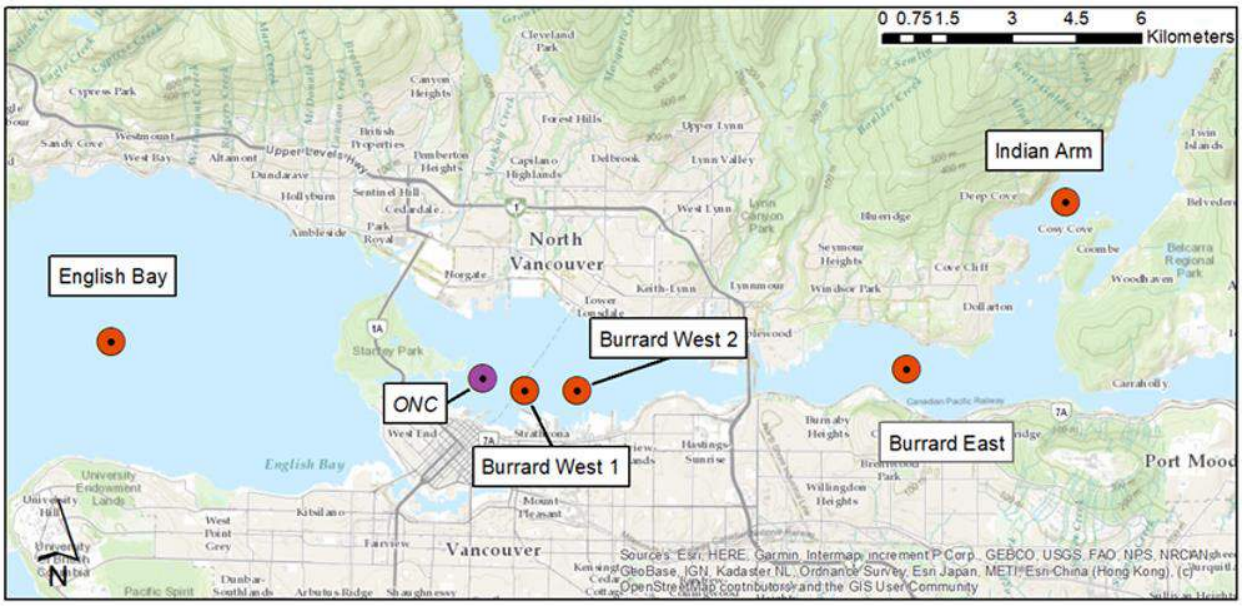

Figure 1: Burrard Inlet monitoring locations
Source: SMRU Consulting North America

What were the key findings?

The main findings of the 2021 Burrard Inlet underwater noise study are summarized as follows:

- The relative broadband noise levels between sites remained consistent to 2019, with the Burrard West location being the loudest and the Indian Arm location being the quietest.
- Average sound levels at each location show little change between years, albeit with some month-to-month variation. The English Bay location showed the most consistency in sound levels over time.
- Readings at the ONC hydrophone were consistent month-to-month but indicated a quieter profile than that of nearby Burrard West locations. This may be due to the difference in location, proximity to the SeaBus, equipment or processing, which will be evaluated over the coming years.
- Received sound levels at Burrard East were higher in 2020 than in 2019, however 2021 was the lowest of all three years. This location also saw greater fluctuations in peak noise levels, and increased sound levels during the daytime indicative of frequent vessel passes proximate to the hydrophone.
- Burrard East also saw an increase in noise levels in the summer months in both 2019 and 2020, likely attributed to increased recreational vessel traffic; however, due to high current flow noise during the first deployment (February to May) this same trend could not be confirmed in 2021.
- Due to high currents at the time of measurement, broadband levels of the bulker at anchor could not be accurately determined; however, the lower frequency peaks showed similar levels to measurements of a containership at berth made in 2019.
- Due to equipment difficulties, comparison of ambient noise levels at the Burrard 2 location between 2019 and 2021 (with and without cruise traffic) was delayed until the shoulder season of September and October. The ambient noise levels were quieter overall in 2021 when compared to 2019.
- The vast majority of acoustic detections of harbour porpoise occur in English Bay. In 2021, acoustic detections of porpoise occurred on 144 days at this location. This is a significant increase from harbour porpoise detections in 2019 (57) and in 2020 (107).
- There were 12 days of acoustic detections of killer whales in 2021, and only four days with visual observations. Of those 12 days, three were confirmed Southern Resident killer whales, five were confirmed to be Northern Resident killer whales, the remaining four were Biggs or unconfimed ecotype. This is the first documented presence of Northern Residents killer whales in Burrard Inlet.

Conclusions and next steps

Passive acoustic monitoring was successful in capturing total ambient noise and detecting the presence of killer whales and porpoise in Burrard Inlet. Noise levels at the English Bay hydrophone remained quite consistent over all metrics measured and represents an excellent location for monitoring trends over time. Due to the global pandemic, two of the last three years have abnormal vessel traffic patterns, including a lack of cruise vessels. Results indicate the lack of cruise vessels reduce ambient noise levels at Burrard West 1 even during the shoulder of the cruise season.

Acoustic detections of killer whales were consistent between 2019 and 2020 but increased in 2021, with five days of Northern Resident killer whales detected in the inner harbour for the first time. Bigg's killer whales are more likely to be visually observed than heard on hydrophones, and resident killer whales, being more vocal, are more likely to be acoustically detected.

The number of days harbour porpoise were detected was nearly 30% higher in 2021 than in 2020 which was nearly double that of 2019, although no specific cause for this can be determined from the data.

The port authority commits to continued investigation of underwater noise sources in the region and to working with stakeholders to reduce their contribution to underwater noise. Monitoring of underwater noise levels and cetacean presence in Burrard Inlet is already underway at two locations for 2022 and is expected to continue for the next several years.

Burrard Inlet Underwater Noise Characterization: 2021 Final Report

Prepared for the Vancouver Fraser Port Authority and the Tsleil-Waututh Nation

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Burrard Inlet Underwater Noise Characterization: 2021 Final Report

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Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 Background

The Enhancing Cetacean Habitat and Observation (ECHO) Program, led by Vancouver Fraser Port Authority (VFPA) focuses on underwater noise monitoring, research, and mitigation efforts in areas most used by targeted cetacean species, such as the Strait of Georgia and Haro Strait. Burrard Inlet, which is used extensively for shipping and other port-related activities, is also frequented by a variety of marine mammals (including multiple species of cetacean) and other noise-sensitive marine species. The VFPA and project partner Tsleil-Waututh Nation are interested in a better characterization of noise levels and cetacean presence in Burrard Inlet. This project was therefore initiated to conduct passive acoustic monitoring (PAM) in Burrard Inlet and the adjacent waters of English Bay and Indian Arm.

An initial year of PAM was conducted at five locations in Burrard Inlet in 2019 (SMRU Consulting, 2019). A second year of PAM monitoring began in 2020, this time focused at only two locations in the inner- and outer-harbor (SMRU Consulting, 2020). The monitoring project continued into a third year beginning in February 2021 at four, year-round locations and one short-term location matching the five sites from the initial project year, shown in Figure 1. Ocean Networks Canada contributed an additional cabled listening station to the monitoring program starting in January 2021. This hydrophone was also located within Burrard Inlet (Figure 1).

In addition to ECHO's long-term monitoring objectives, this project supports the objectives of Tsleil-Waututh Nation's Cumulative Effects Monitoring Initiative which aims to understand long-term ecosystem impacts to Burrard Inlet and inform management and restoration to restore the health of the Inlet to a productive, diverse, and robust ecosystem where biodiversity persists; healthy, wild marine foods can be harvested; water quality is clean and safe, and sensitive habitats are plentiful.

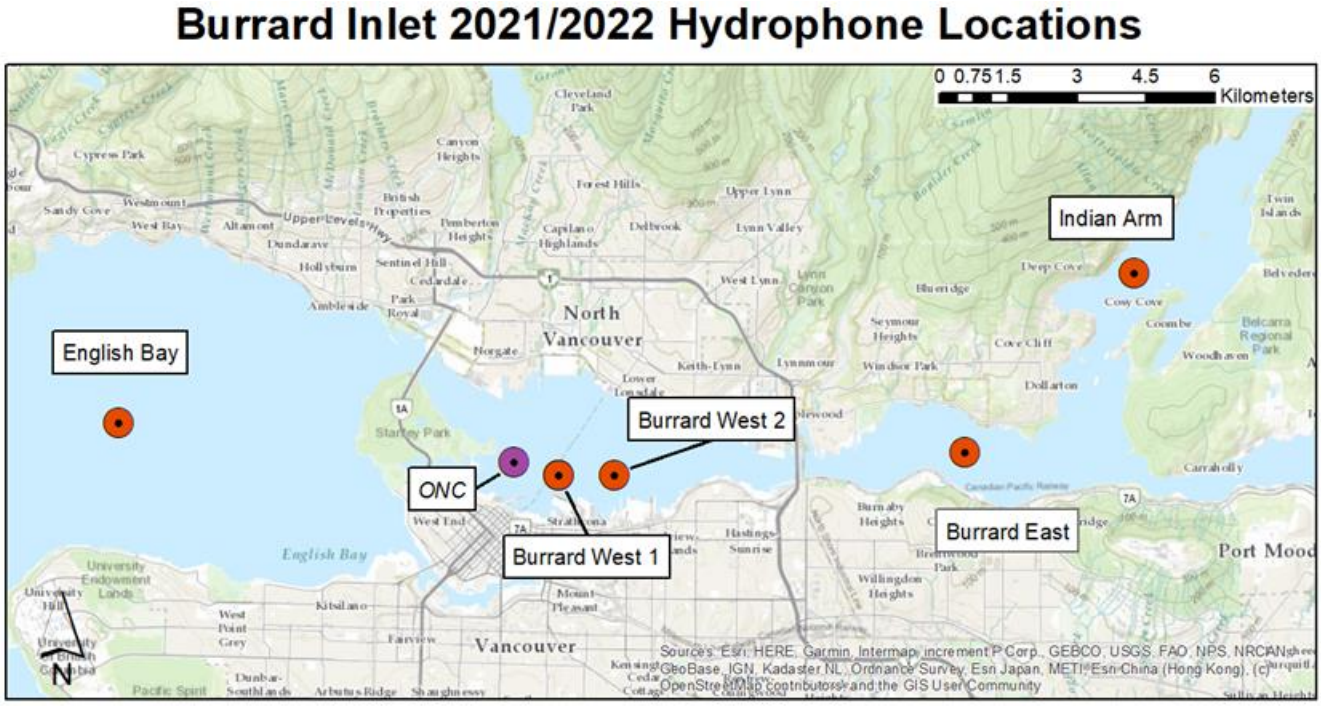


Figure 1. Map of five SoundTrap deployment locations plus the cabled node provided by Ocean Networks Canada (see Table 1 for location names and coordinates).

1.2 Project Objectives

Based on the interests of the ECHO Program and the Tsleil-Waututh Nation, the following project objectives were identified for 2021:

1) **Characterize underwater noise levels within Burrard Inlet both spatially and temporally over the course of a year.**

The ECHO Program has provided high level guidance on analytical methods that have been adopted by this study and are reported here. The standardised noise level metrics reported are consistent with those used by the European Union under the Marine Strategy Framework Directive.

While the noise monitoring equipment used in past project years has been effective, some design improvements were identified and subsequently incorporated to maximize efficiency of materials, durability, and ease of recovery.

2) **Characterize underwater noise levels at the Burrard West 1 site and compare with 2019**

For 2021, it was decided not to monitor continuously at Burrard West 1 (Figure 1) due to its proximity to the Seabus, the ONC node and the Burrard West 2 location. However, this location is closest to the

cruise ship terminal in Burrard Inlet. Due to COVID-19, there were again no cruise ships present within Burrard Inlet in 2021. This set up a natural experiment whereby a three-month deployment during 2021 could be compared with the equivalent period during 2019, when cruise ships were last present. Our standard noise metrics were calculated for the 2019 and 2021 periods to compare ambient noise levels between years when the cruise ships were and were not present.

3) Characterize source levels of a bulker at anchor.

Previous noise characterization efforts have monitored the collective noise generated by numerous underwater sound sources in Burrard Inlet. There was additional interest from both the VFPA and Tsleil-Waututh Nation in the noise generated by a single bulker at anchor to complement source levels measurements of other port-related activities completed in 2019 (SMRU Consulting, 2019). Source level characterization follows ANSI/ASA S12.64-2009 standard Grade C (Survey Method) as closely as possible, with exception of the depth of the hydrophone which would not meet the standard due to depth restrictions in Burrard Inlet.

4) Monitor for the presence of cetaceans in Burrard Inlet using PAM.

The VFPA and Tsleil-Waututh Nation have an interest in understanding seasonal and spatial cetacean presence within Burrard Inlet. Given recent sightings and technological capability to discriminate across species, killer whales and porpoise were the focus of this effort. These observations will contribute to building a 3-year dataset of porpoise and killer whale presence, which is clearly a valuable addition to on-going visual observation programs.

2 Methods

The Methods and Results section are divided by the objectives identified above. The reporting period for this report begins February 19th, 2021 and ends on January 31st, 2022. Any data collected beyond this end date will be included in next year's reporting.

2.1 Characterize Underwater Noise Levels

This report includes spectrum levels in monthly spectrograms and power spectral density (PSD) exceedance plots. Sound pressure levels (SPLs) using broadband, decade-band, and one-third octave bands were reported and investigated on monthly, diurnal, and weekly cycles using a variety of plots. SPLs are described in the form of exceedance percentiles including median (L_{50}), and the arithmetic mean (L_{eq}) of the squared sound pressure. This metric is recommended by the European Union's Marine Strategy Framework Directive as an environmental indicator to assess trends in ambient noise caused by anthropogenic sources (Dekeling *et al.*, 2014). Merchant *et al.* (2016) reviewed multiple metrics and concluded that environmental indicators of anthropogenic noise should use exceedance percentiles to ensure statistical robustness and recommended high exceedance metrics (L_{10} or L_5) as being an appropriate metric for tracking levels of anthropogenic noise in the marine environment. Consequently, this study has focused reporting of underwater noise levels using L_{50}, L_{eq} and L_5.

To measure underwater sound levels, four Ocean Instruments SoundTraps (models ST300HF and ST600HF) were deployed in Burrard Inlet to record sound levels. SoundTrap locations mirrored the 2019 project year to continue building a baseline dataset throughout the Inlet. Sites included English Bay, Burrard West 2, Burrard East and Indian Arm (Table 1, Figure 1). The Burrard West 1 site was also deployed for part of the year in order to do a comparison of noise levels between years when cruise ships were and were not present. Data were also collected at the Ocean Networks Canada (ONC)/TWN cabled observatory site near Brockton Point (Figure 1).

The mooring system and recovery were re-designed for 2021 to simplify deployment and retrieval of hydrophones from the sea floor (Figure 2). The new design allows for the anchor to be retrieved instead of leaving it behind and replacing it for each instance. The system features an anchor that holds the unit in place on the seafloor, an acoustic release that houses a coiled rope for retrieval, a suspension line to which the hydrophone is attached, and a trawl float to keep the hydrophone upright in the water column. This design, allowed for the removal of additional mooring weights, but also eliminate numerous exterior components which may have contributed to unwanted noise (i.e., chains and clamps). This allows for an overall cleaner and more accurate recording of the ambient noise environment.

Deployment required manually lowering the hydrophone package via a long line to ensure desired placement on the seafloor. Communication with the unit was then verified before releasing the deployment line. Retrieval of the hydrophones required transiting to the deployment location and sending an authorization signal to the acoustic release. This allowed the hydrophone unit to float to the surface while remaining attached to the mooring weights via the recovery rope contained in the

rope bucket. Once the float was on the surface, it was hauled on board and the line attached to the mooring weight was pulled in using a winch.

The Ocean Networks Canada cabled hydrophone consists of an Ocean Sonics icListen HF Hydrophone 'smart hydrophone' attached to a 'bottom lander' style mooring unit on the seafloor. Data from the ONC hydrophone was provided for January 2021 through to October 2021. The remaining 2021 data from this node was not available from ONC at the time of reporting. Data for this location were provided with calibration curves from 10- 51,200 Hz. The hydrophone had a flat response over the majority of the frequency range but dropped >4 dB at frequencies higher than 50kHz. For frequencies above the maximum calibration value extending to the Nyquist frequency (51.5-64kHz), the reported calibration at the maximum calibration frequency was used.

The systems were deployed and retrieved as noted in Table 2. Hydrophone locations and depths are provided in Table 1 and hydrophone settings can be found in Table 3.

Table 1. Latitude and longitude of SoundTraps deployed in for the 2021 project year.

SoundTrap Hydrophone Location	Latitude (N)	Longitude (W)	Water depth
English Bay	49.304	123.233	55 m
Burrard West 1	49.293	123.103	30 m
Burrard West 2	49.291	123.081	37 m
Burrard East	49.296	122.982	61 m
Indian Arm	49.334	122.921	69 m

Table 2. SoundTrap deployment and retrieval dates.

Deployment Number	Deployment Date	Recovery Date	Deployment Duration (days)
1	February 19th, 2021	June 1st, 2021	102
2	June 4th, 2021	August 23rd, 2021	80
3	August 26th, 2021	November 22nd, 2021	88
4	November 25th, 2021	February 7th, 2022	74
Burrard West 1	September 23rd,2021	November 12th,2021	50

All deployed hydrophones were retrieved, marking the second consecutive year of this monitoring program without the loss of a hydrophone. While all hydrophones were retrieved, one acoustic release was damaged beyond repair in June 2021 due to an insecure watertight fitting. During the first recovery at the Burrard East location, half of a rope bucket and mooring weight were also lost due to a snag which prevented the bucket from being recovered under the limitations of the lifting system aboard the Tsleil-Waututh vessel *Say Nuth Khaw Yum*. This incident occurred at the Burrard East location, which has had issues in past project years with snagged lines from debris and currents in the area. For this reason, after the first deployment, a 'rope-less' design was used for the remainder of the project year to avoid further losses. The rope-less design did however necessitate a return to the practice of leaving anchor weights on the seafloor during recovery. This alternative design is shown in Figure 3.

The short-term deployment at Burrard West 1 was recovered September 23rd and spot-checked for data quality. In this process it was discovered that no data had been collected at that site due to improper setup. The instrument was refurbished in the field and redployed the same day and set to record continuously for the remainder of the deployment.

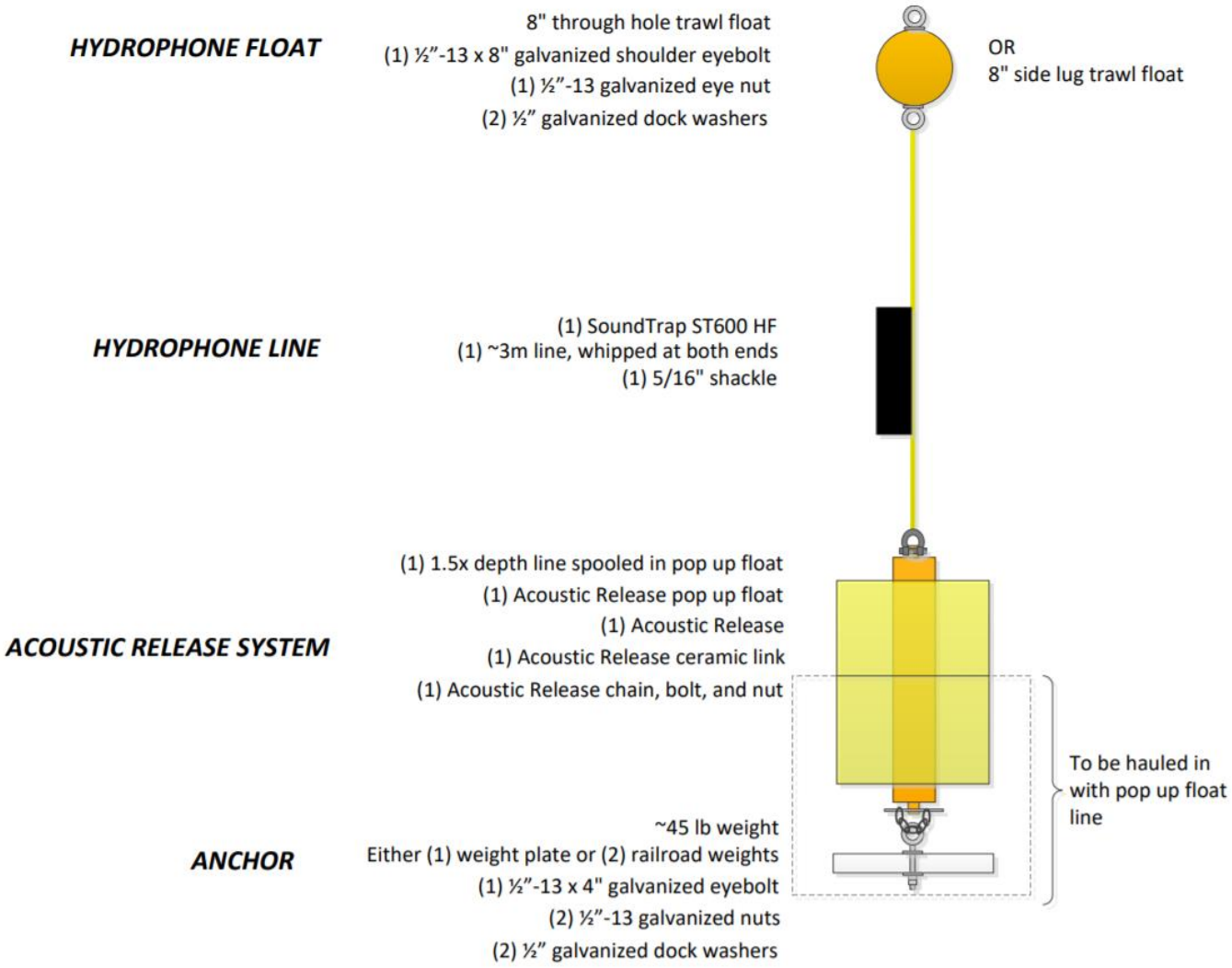


Figure 2. Schematic of SoundTrap hydrophone and EdgeTech acoustic release deployment method.

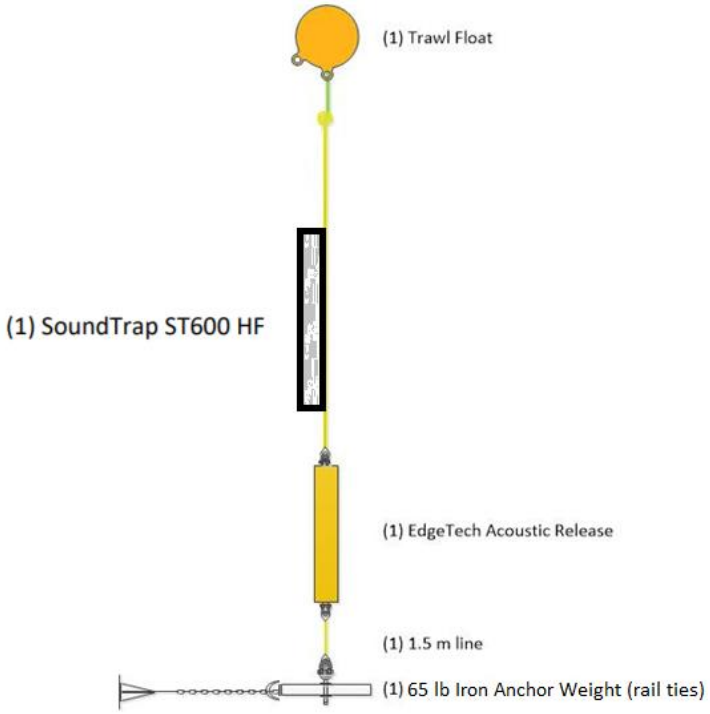


Figure 3. Schematic of 'rope-less' deployment method used at the Burrard East location.

Table 3. SoundTrap settings used for the 2021 project year.

Site	Gain	Sample Rate (kHz)	Duty Cycle	Detectors	Detector threshold (dB)
English Bay	High (~172 dB max)	96	50% (7 minutes)	Click Detector	16
Burrard West 1	Low (~184 dB max)	96	100% (continuous)	Click Detector	16
Burrard West 2	Low (~184 dB max)	96	50% (7 minutes)	Click Detector	16
Burrard East	High (~172 dB max)	96	50% (7 minutes)	Click Detector	16
Indian Arm	High (~172 dB max)	96	50% (7 minutes)	Click Detector	16
ONC	Flat frequency response 10Hz-51kHz 169dB	128	Continuous	None	NA

Custom MATLAB scripts based on Merchant *et al.* (2015) were used to calculate median PSD, SPL (in broadband, decade band and one-third octave bands) for every minute of data. These results were then used to calculate monthly, daily, and hourly results (SMRU Consulting 2019). L_{eq} (arithmetic mean), L_5 (level that is exceeded 5% of the time), and L_{50} (level that is exceeded 50% of the time) for each site are also reported.

2.1.1 Ancillary Analysis

Ancillary data were used to contextualize and interpret trends and patterns in noise levels. AIS data for the wider Burrard Inlet area were purchased to use as covariate data in noise analyses. The 2-dimensional area within 3 km of each hydrophone was calculated using GIS (Table 4). This range was selected to encompass the bulk of noise contributions from the relatively slow-moving commercial vessels transiting the area. Data from the ONC node was not included in the analysis as the first several months did not meet our data quality standards.

Table 4. Marine area within 3 km of each hydrophone location

Location	**Area (km^2)**
1) Burrard West 1	11.76
2) Burrard West 2	11.74
3) Burrard East	8.60
4) Indian Arm	10.59
5) English Bay	27.89

Hourly vessel density was calculated based on AIS transmissions and area associated with each hydrophone location (Table 4). AIS data were partitioned into a) Class A vessels, as defined by AIS, moving at least one knot of speed and b) all Class A vessels including those that were moored or anchored. For each hour of each deployment day and location the number of AIS transmissions detected within 3 km of each hydrophone were calculated and divided by the total marine area represented in the 3 km range. This value is referred to as signal density and was correlated against the median hourly broadband and decade bands at each location. This approach builds on results initially reported in 2019 for the relationship between vessel presence and ambient noise levels through Burrard Inlet.

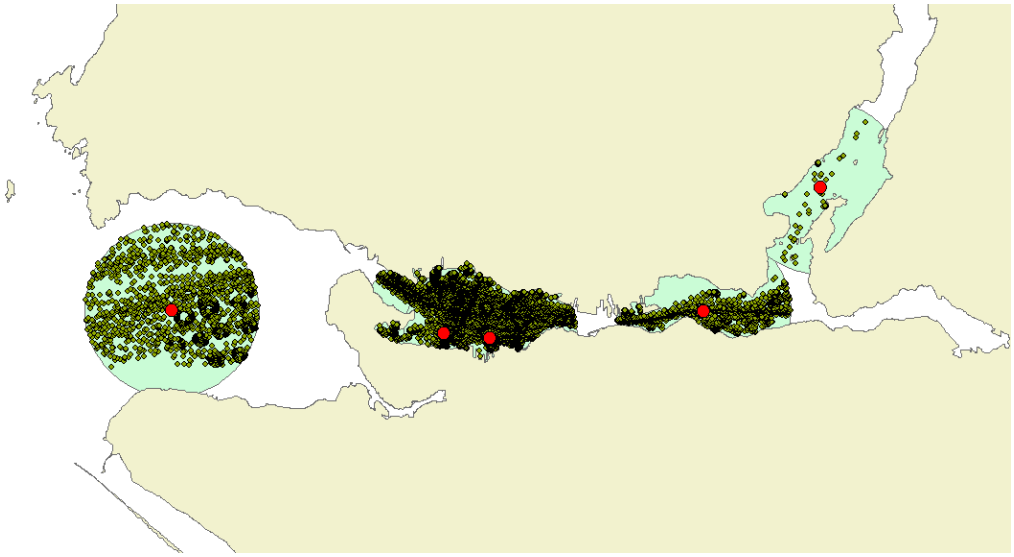


Figure 4. AIS data selection and area calculation. The two-dimensional survey area (light green) within 3 km of each deployment location (red points). Green points indicate AIS locations within the survey area of each deployment location during a single month.

Weather statistics (https://www.weatherstats.ca/) provided data on daily rainfall (mm) and average wind speeds (km/h) for the Vancouver area. These were plotted to compare monthly trends and a visual inspection of monthly spectrograms was undertaken for the top ten rainiest and windiest days to assess potential patterns in SPLs associated with high wind. Daily rainfall and average winds were thus correlated against daily SPLs (1-10 kHz). Choice of which frequency band to best detect the covariate effect patterns was based on Wenz (1962) curve data for each environmental factor.

2.2 Burrard West 1 2019/2021 Comparison

Due to the global COVID-19 pandemic, cruise ships have been prevented from berthing in Vancouver harbor since 2020. This represented a natural experiment to investigate how the presence of cruise ships impacted noise levels near the previously documented Burrard West 1 site. To achieve this goal, a SoundTrap was deployed at the Burrard West 1 site as part of the second deployment. However, due to an inappropriate sensitivity setting on the click detectors the data collected period during this deployment was cut short and partially compromised. The click detection sensitivity issue was resolved and the Burrard West 1 location was redeployed as part of the third deployment. However, a mid-deployment check on the instrument revealed that the system had failed to record. The unit was refurbished in the field and set to record continuously for the remainder of the deployment.

Two forms of analysis were used to compare noise levels at this location between 2019 and 2021. First, decade band calculations including 5^{th}, 25^{th}, 50^{th}, 75^{th}, and 95^{th} noise level percentiles were calculated for both the portion of September included in the data and the whole of October. Second,

third octave levels from the entire deployment at this location were compared to levels across the same dates in the 2019 dataset.

2.3 Bulker at Anchor

Source level measurements of a bulker at anchor were made on September 22, 2021. The length of the selected vessel was approximately 180 m. The fore and aft drafts were 7.2 m and 9.8 m respectively. Measurements were made following ANSI standard S12.64-2009 as closely as possible. The standard identifies three measurement configurations (A, B and C) the first two of which denote three hydrophones deployed vertically in the water column and the third which requires only one hydrophone. In this work an intermediate approach was utilized, deploying two hydrophones vertically in the water column. The vessel reported a single generator running throughout the measurement period.

Two Coastal Acoustic Buoys (CABs) were deployed in the vicinity of the bulker at anchor. One unit was deployed within 100 m of the stern of the vessel and another unit was deployed ~400 m from the bow of the vessel. Each CAB was equipped with two Reson TC4014 hydrophones. One was deployed at 10 m depth and the second at 20 m depth. All hydrophones collected acoustic recordings at 250 kHz sample rate. Both units were equipped with GPS antenna to monitor their drift with tidal currents. Continuous AIS data were also collected from the vessel while in the field to monitor the distance between the vessel and the CABs. CAB units were employed at 19:23 UTC and recovered at 22:35 UCT resulting in 191 minutes of data collection.

2.4 Cetacean Presence Using PAM

PAMGuard V2.02.01 software (www.pamguard.org) was used to detect potential echolocation clicks and calls from marine mammals in the SoundTrap data. Detections were validated by a trained analyst using PAMGuard Viewer Mode and Audacity software. During this process, the analyst identified acoustic events for killer whales. Acoustic events are defined as a period of calling with no more than a 30 min separation between successive calls. This process was done for both echolocation clicks and whistle contours.

PAMGuard Viewer Mode was used to identify and log cetacean events. All events indicated by strong whistle contours were validated by a human listener using PAMGuard playback mode or via Audacity when signals were less audible. In addition, common signal patterns and a random selection of lower probability tonal detections were reviewed. Furthermore, for days with known killer whale visual observations, all tonal detections identified by the Whistle and Moan detector were reviewed for the presence of killer whale vocalizations. Visual sightings data were obtained from the Wild Ocean Whale Society (https://whalesanddolphinsbc.com/) as well as a search of press releases from the study period including online news publications and social media.

2.4.1 Echolocation Clicks

Odontocetes produce a variety of sounds including impulsive signals used for communication and echolocation. Porpoises produce narrowband high frequency clicks centered at ~120 kHz. A typical click waveform and spectrum are shown in Figure 5. Capturing these signals can provide logistical challenges as continuously recording at these high sample rates drains data storage and battery power more quickly than continuously recording at lower sample rates.

To address this capacity issue, SoundTraps are equipped with an onboard 'click detector' capable of monitoring for impulsive sounds. When impulsive sounds are detected, a high frequency (fs = 576 kHz) recording is triggered capturing a 'snipit' of the wave form. Snipits are referred to as 'click detections' by the manufacturer regardless of the source of the impulse.

PAMGuard software was used to identify click detections in the frequency range and duration representative of harbor porpoise. Porpoise detection parameters were set with a 0.22 milliseconds (ms) duration, a peak frequency range between 100-125 kHz, and a control band of 40-90 kHz. The control band is a reference against which the energy in the peak band is compared. In doing so, broadband clicks containing uniform energy across multiple frequencies are identified as non-porpoise clicks. A threshold of 6 dB was set to ensure detection of high or moderate probability porpoise detections while limiting false positive detection.

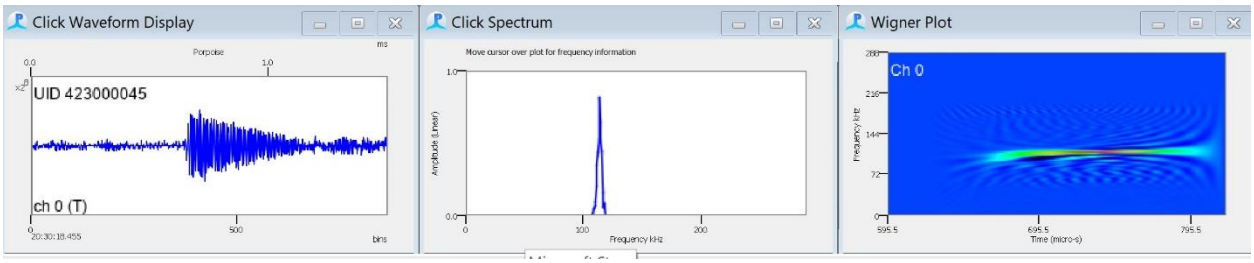


Figure 5. A typical porpoise echolocation click. Click Waveform Display, Click Spectrum and Wigner Plot displayed using PAMGuard software.

2.4.2 Whistles and Moans

Tonal sounds are produced by a variety of marine mammals including both odontocetes (whistles) and mysticetes (moans). These lower frequency calls are captured in the continuous recordings and detected by tonal contour tracking software. The 'whistle and moan' detector was run on the recordings over the frequency range of 800 Hz to 30 kHz. The sensitivity threshold was set to 6 dB above background to ensure a high rate of marine mammal detections (SMRU Consulting, 2018).

All whistle and moan detections were visually scanned for the presence of killer whales. Where killer whales could be confirmed in the recordings, events were annotated. Killer whale calls were also reviewed by Dr. Jason Wood (an experienced acoustic analyst with 15 years of relevant experience) to determine the ecotype (Resident or Bigg's/Transient).

3 Results

3.1 Underwater Noise Levels

Between the five hydrophone locations monitored by SMRU Consulting, a combined total of 1,290 days of PAM data were collected in this project cycle (February 19th, 2021 through to February 7th, 2022). In addition to the hydrophones deployed by SMRU Consulting, an additional 225 days of data were processed from the ONC node. There were 2 periods of data loss during the project year:

- During the second deployment, erroneous click detector settings (within the manufacturer's standard default) caused newly acquired hydrophones to overload and restart recordings. This resulted in 35 days of data loss at English Bay, 54 days at Burrard West 1, 57 days at Burrard West 2, 39 days at Burrard East and 44 days at Indian Arm.

- During the third deployment, data corruption during transfer resulted in the loss of 20 days of data at English Bay. Additionally, an incorrect deployment of the Burrard West 1 hydrophone resulted in the loss of 28 days of data. This error was corrected, an additional deployment undertaken, and the duty cycle was increased to 100% to make up for the lack of recordings in the previous deployment.

- The ONC data contained numerous outages in April, June, August, and September. Most outages (Table 5) were less than a week with the exception of a storm event in April which resulted in maintenance on the system.

Table 5. ONC Data outages.

Month	Data Duration (days)
April	1
June	26
August	29
September	17

- ONC data were also contaminated by continuous pump noise from an associated CTD sampling device. Additionally, an onboard acoustic Doppler current profiler (ADCP) resulted in narrowband noise at 23, 27, and 50 kHz (Figure 6).

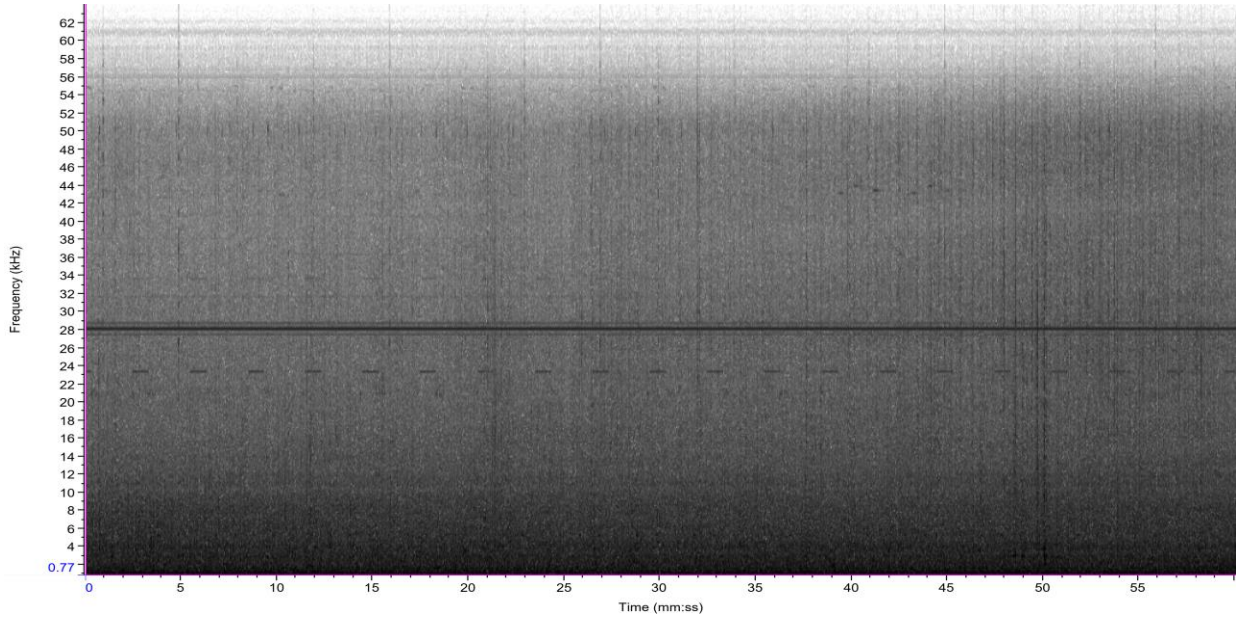


Figure 6. Example 1-minute spectrograms (1024 FFT, 50% overlap, Hann window) from the icListen hydrophone at the ONC node (128 kHz fs). Note linear frequency scale. White area at top of spectrogram indicates non-flat response above 50kHz. Horizontal banding indicates noise from associated sensors (ADCP) not present in data from the SoundTraps.

Table 6. SoundTrap data start and data end dates. Acoustic data were collected across 353 deployment days in total.

Deployment Number	Location	Data start date	Data end date	Data duration (days)
1	English Bay	February 19th, 2021	June 1st, 2021	102
	Burrard West 2	February 19th, 2021	June 1st, 2021	102
	Burrard East	February 19th, 2021	June 1st, 2021	102
	Indian Arm	February 19th, 2021	June 1st, 2021	102
2	English Bay	June 4th, 2021	July 19th, 2021	46
	Burrard West 1	June 7th, 2021	June 30th, 2021	24
	Burrard West 2	June 4th, 2021	June 27th, 2021	24
	Burrard East	June 4th, 2021	July 15th, 2021	42
	Indian Arm	June 4th, 2021	July 10th, 2021	37
3	English Bay	August 26th, 2021	November 3rd, 2021	89
	Burrard West 1	September 22nd, 2021	November 13th, 2021	53
	Burrard West 2	August 26th, 2021	November 22nd, 2021	89
	Burrard East	August 26th, 2021	November 22nd, 2021	89
	Indian Arm	August 26th, 2021	November 22nd, 2021	89
4	English Bay	November 25th, 2021	February 7th, 2022*	75
	Burrard West 2	November 25th, 2021	February 7th, 2022*	75
	Burrard East	November 25th, 2021	February 7th, 2022*	75
	Indian Arm	November 25th, 2021	February 7th, 2022*	75
-	ONC	January 1st, 2021	October 25th, 2021	225
				1515
** = Data collected beyond the reporting period (Jan 31st, 2022) will be included in next year's report.*				

3.1.1 Inter-Annual Sound Levels

Monthly averages for each at each of the sites for all months are shown in (Table 7). Because some months contained two weeks or fewer of data, two metrics are presented. The first (2021a) includes all data collected in this project year and the second (2021b) excluded incomplete months and months at Burrard East where high flow noise was present (see Section 3.1.2).

Overall monthly averages showed some variation across the three years that data were collected (Table 7), most notably Burrard East. Between site differences continued to exceed 30 dB.

- At English Bay the L_{50}, L_{eq}, and L_5 were relatively consistent between years (all within 1 dB re 1µPa). 2021 was the highest amplitude year by all three metrics.

- Burrard West 2 showed little variation in L_{50} between 2019 and 2021. Both L_{eq} and L_5 showed reductions in noise. L_{eq} decreased by 1.0 dB re 1µPa while L_5 showed a drop of 1.7 dB re 1µPa from 2019. Overall, this site remains the loudest, as expected given its location directly adjacent to major port operations.

- Burrard East displayed the greatest variation across years of any site in the study. L_{50} was the lowest reported yet, decreasing by 1.9 dB re 1µPa from 2019 measured value. Both L_{eq} and L_5 showed reductions from 2020 levels but remained above 2019 levels. L_{eq} increased by 0.8 dB re 1µPa over 2019 levels. L_5 increased by 0.2 dB re 1µPa over the same period.

- Indian Arm remained as the quietest overall site by all metrics. While L_{50} was reduced by 0.8 dB re 1µPa, L_{eq} matched 2019 levels and L_5 showed an increase of 0.8 dB re 1µPa.

- The ONC listening station was comparable in broadband L_{50}, L_{eq} and L_5 to the English Bay site, despite being in the inner harbor.

Table 7. Average monthly broadband SPL (median (L_{50}), mean (Leq) and L_5 in dB re 1µPa) by location for 2019, 2020 (where available) and 2021 project years.

	L_{50}				**L_{eq}**				**L_5**			
Location	**2019**	**2020**	**2021a**	**2021b**	**2019**	**2020**	**2021a**	**2021b**	**2019**	**2020**	**2021a**	**2021b**
English Bay	121.0	120.8	*121.4*	**121.2**	124.6	124.6	*125.4*	**125.3**	128.4	128.2	*128.7*	**128.6**
Burrard West 1	129.1	-	-	**-**	135.4	-	-	**-**	141.0	-	-	**-**
Burrard West 2	131.4	-	*131.0*	**131.5**	134.8	-	*133.4*	**133.8**	139.1	-	*136.2*	**137.4**
Burrard East	110.8	115.9	*113.2*	**108.9**	124.1	126.6	*131.1*	**124.9**	129.4	132.4	*135.1*	**129.6**

Indian Arm	100.0	-	*99.5*	**99.2**	113.4	-	*114.3*	**113.4**	118.3	-	*119.9*	**119.1**
ONC Node	-	-	*119.5*	***119.1***	-	-	*124.0*	***124.0***	-	-	*128.7*	***128.4***

3.1.2 Ambient Sound Levels Over Time

Probability distributions for all five sites are shown for 2019 in Figure 7 and the four long-term 2021 sites as well as ONC data are shown in Figure 8. In both years, pre-and post COVID-19, Indian Arm remained the quietest overall location with low frequency (<1kHz) noise rarely exceeding 120 dB re 1µPa. Burrard West 1 and 2 were also consistently the highest amplitude sites measured in both years. Despite being close enough to the SeaBus to pick up the diel trend associated with the transit schedule (3.1.4), median noise levels from the ONC site were consistently lower than the Burrard West 1 and 2 sites from 2019 and 2020, respectively. However, noise levels distributions at nearly all locations excluding the Burrard West sites (where SeaBus noise remained constant), widened in 2021 compared to 2019. Data from the ONC node showed a bimodal distribution in noise levels consistent with the Burrard West 1 site in 2019, likely indicative of the SeaBus schedule.

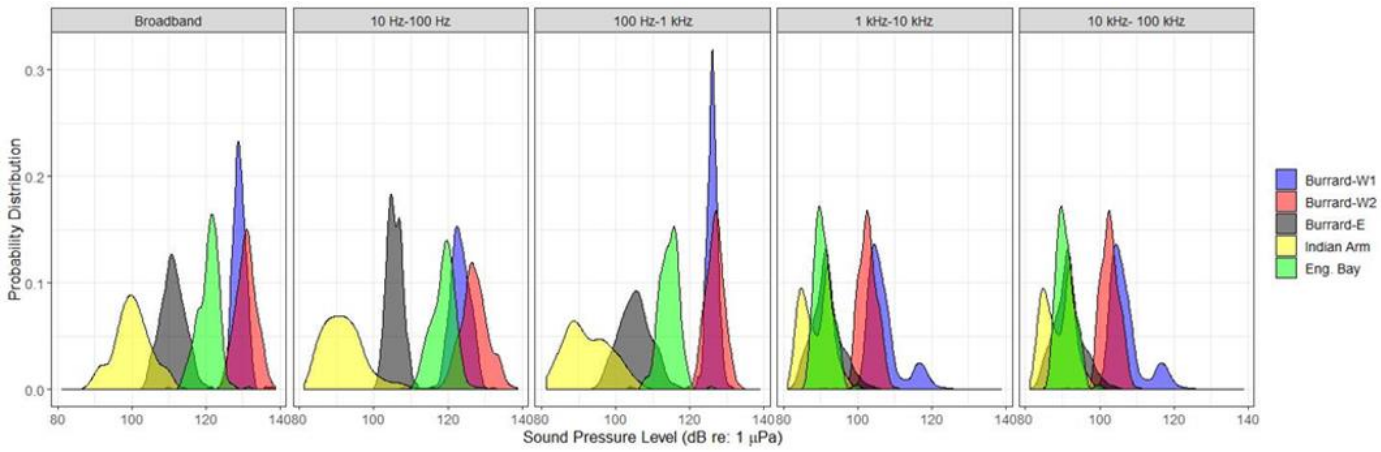


Figure 7. Probability distribution of median (L_{50}) monthly SPL (dB re 1µPa) at each location for broadband and decade frequency bands in 2019.

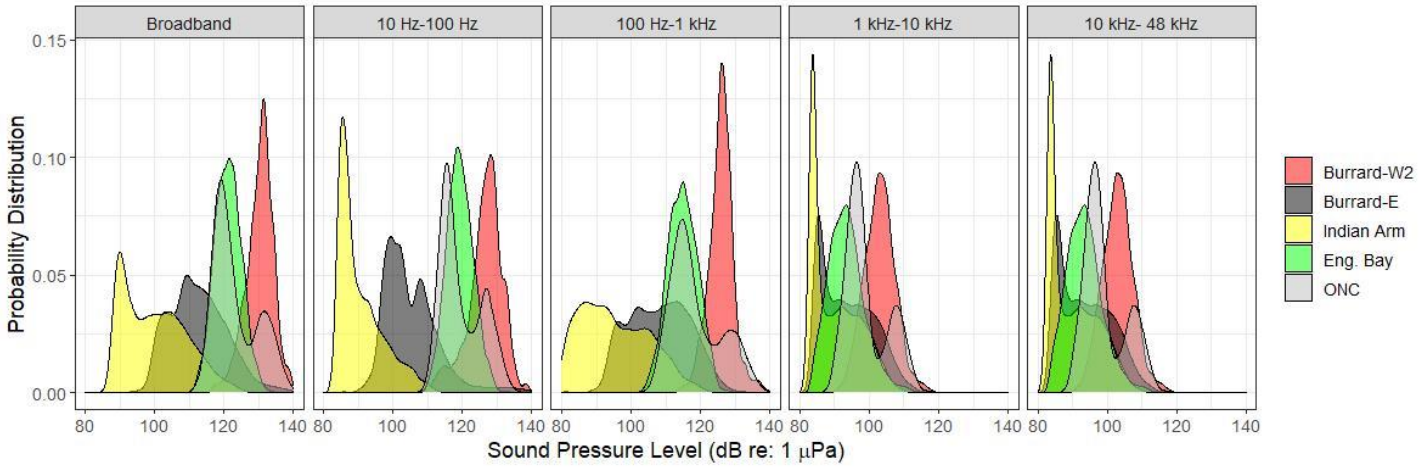


Figure 8. Probability distribution of median (L_{50}) monthly SPL (dB re 1µPa) at each location for broadband and decade frequency bands in 2021. Note Jan-April data excluded from ONC site due to self noise.

Monthly descriptive statistics by location are provided in Table 8. Where less than 14 days of data are available, these months are indicated by an asterisk and were removed from the modified annual value reported in Table 7. At the English Bay location, monthly median broadband L_{50} throughout the year were generally in line with previous observed levels with the exception being November through to February. Noise levels in these months displayed a notable increase, peaking at 125.7 dB re 1µPa in January 2022. These were also the four loudest months recorded in English Bay since the program began (Table 8, Figure 10, Figure 15).

The first deployment at the Burrard East location indicated substantive flow noise associated with high current velocities. This was evidenced by the fact that the monthly broadband L_5 and L_{eq} values were substantially higher than the median values, suggesting brief yet loud sounds (Table 8, Figure 11, Figure 16). This finding was further supported by the anomalous peak in the daily diel trends occurring between 4 and 8 am (Section 3.1.4), coinciding with peak tides during this time of the year.

Visual inspection of the LTSA plots for Burrard East revealed elevated periods of noise, as indicated by bright-red bands in the lower frequencies in Figure 22. While initially suspected to be industrial noise, a closer inspection of these elevated noise periods revealed otherwise. This was based on two findings: a) the noise was only present in the 10-100 Hz frequency range b) the cyclical, repetitive nature of these periods aligned very closely with tidal cycles throughout the month, as shown in Figure 9. Raw audio files from these time periods were also examined and confirmed to not be related to industrial activity. Elevated periods of noise in previous reporting have not shown these same patterns and it is not believed that similar flow noise contaminated previous deployments at this location.

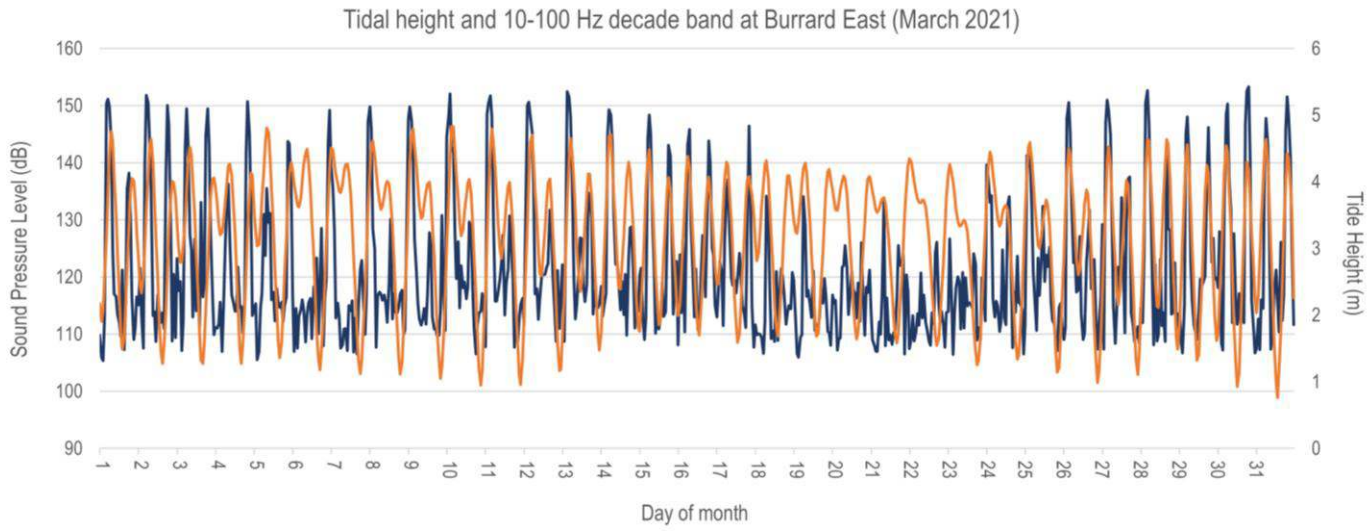


Figure 9. Tidal height (orange) measured at Port Moody and 10-100 Hz noise levels (blue) at Burrard East in the month of March 2021. As tidal height peaks, noise levels tend to increase, particularly on the largest of flood tides.

Given these findings, the noise levels at Burrard East in the months of February, March, April, and May 2021 appear to be biased by effects of the changing tide. Data from these months have been highlighted in the annual and interannual plots below and were excluded from the calculation of annual noise levels at this site in the adjusted value reported in Table 7.

Accordingly, monthly median broadband levels (L_{50}) were highest from February through May 2021, with a maximum of 118.6 dB re 1µPa in March (Table 8). After re-deployment broadband (L_{50}) values dropped by ~10 dB, never peaking above a monthly median of 111.6 dB re 1µPa for the remainder of the project year. The minimum monthly median broadband L_{50} was 106.9 dB re 1µPa and occurred in December.

Monthly median broadband L_{50} were highest at Burrard West 2 in all months of the year. Burrard West 2 peaked in June 2021 at 134.4 dB re 1µPa which was the highest monthly broadband L_{50} recorded at all sites throughout the year. The lowest monthly median broadband L_{50} was 123.1 dB re 1µPa in August 2021. (Table 8, Figure 12, Figure 17).

Indian Arm monthly median broadband L_{50} was highest in May 2021 (101.7 dB re 1µPa) and lowest in February 2022 (92.9 dB re 1µPa). Monthly broadband values were very similar to the 2019 project year although the minimum in February 2022 was the lowest recorded so far, 3.3 dB re 1µPa lower than the previous minimum. Like Burrard East, monthly broadband L_5 and L_{eq} values here were elevated when compared to the median values (Table 8, Figure 13, Figure 18).

The ONC listening station recorded relatively constant monthly median broadband L_{50} throughout the year other than a brief spike in April 2021 to a maximum of 122.1 dB re 1µPa. The lowest value was

returned the following month in May (118.4 dB re 1µPa) (Table 8, Figure 19). Monthly median broadband levels are provided for each location as well as 2019 and 2021 in Figure 14.

Table 8. Monthly median (L_{50}), mean (Leq), and L_5 broadband SPL (dB re 1µPa) by location. Monthly L_{50} SPL are also provided for each decade band. Locations with an asterisk (*) represent partial months of data associated with data loss or deployment dates.

Location	Month	L_{50}, Broadband	L_{50}, 0.01-0.1 kHz	L_{50}, 0.1-1 kHz	L_{50}, 1-10 kHz	L_{50}, 10-48 kHz	L_{eq}, Broadband	L_5, Broadband
English Bay	Feb*	119.2	117.6	112.9	104.8	92.7	123.7	126.7
	Mar	119.9	118.0	113.8	105.2	91.7	125.1	128.0
	Apr	119.0	117.1	113.1	105.5	91.7	124.5	127.0
	May	118.2	116.5	111.4	102.7	91.0	124.2	127.2
	Jun	120.1	118.4	112.9	103.3	88.6	123.5	128.0
	Jul	119.0	117.2	113.1	102.1	89.2	122.4	126.2
	Aug*	119.9	117.6	112.8	109.1	93.4	125.2	129.1
	Sep	121.0	119.2	114.7	105.2	93.8	126.2	129.6
	Oct	122.3	120.3	116.3	107.5	96.3	126.4	130.6
	Nov*	124.3	121.9	119.4	109.2	98.8	125.5	128.7
	Dec	124.5	122.9	117.9	109.2	94.8	126.9	129.3
	Jan	125.7	123.6	120.1	112.0	96.6	128.1	131.3
Burrard East	Feb**	116.8	111.2	111.7	103.2	94.4	138.6	142.1
	Mar**	118.6	112.5	113.1	102.0	93.2	139.2	145.0
	Apr**	118.4	112.1	113.1	103.7	92.9	138.0	142.5
	May**	117.7	111.8	112.9	105.7	93.0	133.5	138.0
	Jun	109.7	102.8	105.9	102.0	91.0	125.0	130.6
	Jul	109.5	103.4	105.5	102.5	90.1	124.0	129.9
	Aug*	111.6	100.6	108.6	104.2	91.9	125.2	131.2
	Sep	110.3	100.8	106.9	102.4	93.1	124.9	130.5
	Oct	108.5	98.7	105.2	100.0	92.7	124.1	129.3
	Nov	108.8	99.9	104.9	100.6	94.3	124.2	129.5
	Dec	106.9	98.5	101.5	98.9	90.5	123.9	128.0
	Jan	108.5	100.6	104.1	100.9	91.5	127.8	129.1

** = Less than 14 days data available*

*** = Periods biased by flow noise*

Location	Month	L_{50}, Broadband	L_{50},	L_{50},	L_{50}, 1-10	L_{50}, 10-48	L_{eq}, Broadband	L_5, Broadband

			0.01-0.1 kHz	0.1-1 kHz	kHz	kHz		
Burrard West 2	Feb*	134.5	130.8	130.0	126.1	102.9	136.5	139.5
	Mar	132.4	128.2	127.8	122.5	102.9	135.0	139.5
	Apr	131.4	127.9	126.7	123.1	102.9	134.0	137.9
	May	130.6	127.0	126.2	121.5	102.6	134.0	138.2
	Jun	134.4	132.7	128.3	122.9	104.3	135.7	138.1
	Jul	-	-	-	-	-	-	-
	Aug*	123.1	114.5	121.3	112.6	99.3	128.1	131.7
	Sep	127.2	123.5	123.2	116.5	102.2	130.3	133.8
	Oct	131.9	128.3	127.4	123.6	104.2	133.7	137.0
	Nov	131.0	127.6	126.0	122.7	102.9	132.8	137.2
	Dec	128.2	124.2	124.1	119.4	101.8	131.4	135.0
	Jan	130.8	128.0	125.5	121.2	105.1	132.8	136.2
Indian Arm	Feb*	98.6	86.7	89.5	89.8	89.6	111.2	116.8
	Mar	97.3	86.7	90.1	90.6	86.7	112.0	117.3
	Apr	100.8	90.8	94.6	93.3	88.3	114.7	120.9
	May	101.7	90.3	97.2	95.4	88.4	116.5	123.3
	Jun	100.1	89.5	95.5	93.9	86.6	118.1	123.7
	Jul*	101.1	91.5	96.9	94.5	86.2	117.0	123.9
	Aug*	100.8	91.1	96.9	93.2	85.1	119.4	124.7
	Sep	100.2	89.3	94.3	92.9	87.5	115.4	121.6
	Oct	98.2	86.2	91.0	90.9	89.2	112.6	118.0
	Nov	99.3	85.8	91.8	93.1	90.3	110.4	115.1
	Dec	97.0	87.5	90.2	88.8	86.5	108.6	112.9
	Jan	97.2	88.0	90.7	89.0	85.8	109.3	114.2

** = Less than 14 days data available*

Location	Month	L_{50}, Broadband	L_{50}, 0.01-0.1 kHz	L_{50}, 0.1-1 kHz	L_{50}, 1-10 kHz	L_{50}, 10-48 kHz	L_{eq}, Broadband	L_5, Broadband
ONC/TWN	Feb	119.9	116.9	114.1	108.3	97.3	124.8	129.0
	Mar	119.4	116.0	114.3	107.9	96.6	123.7	128.3
	Apr*	122.1	119.4	114.4	108.9	96.7	125.3	130.8
	May	118.4	113.6	113.9	108.2	95.3	123.3	128.0
	Jun	119.1	114.8	114.6	108.7	94.6	124.1	128.5
	Jul	118.4	114.1	114.0	108.1	93.7	123.2	128.3
	Aug	118.1	114.2	113.2	107.5	93.7	122.9	127.8
	Sep	118.8	114.9	114.1	108.3	95.9	123.1	127.7
	Oct	120.5	117.5	115.4	108.9	96.5	124.9	129.1

** = Less than 14 days data available*

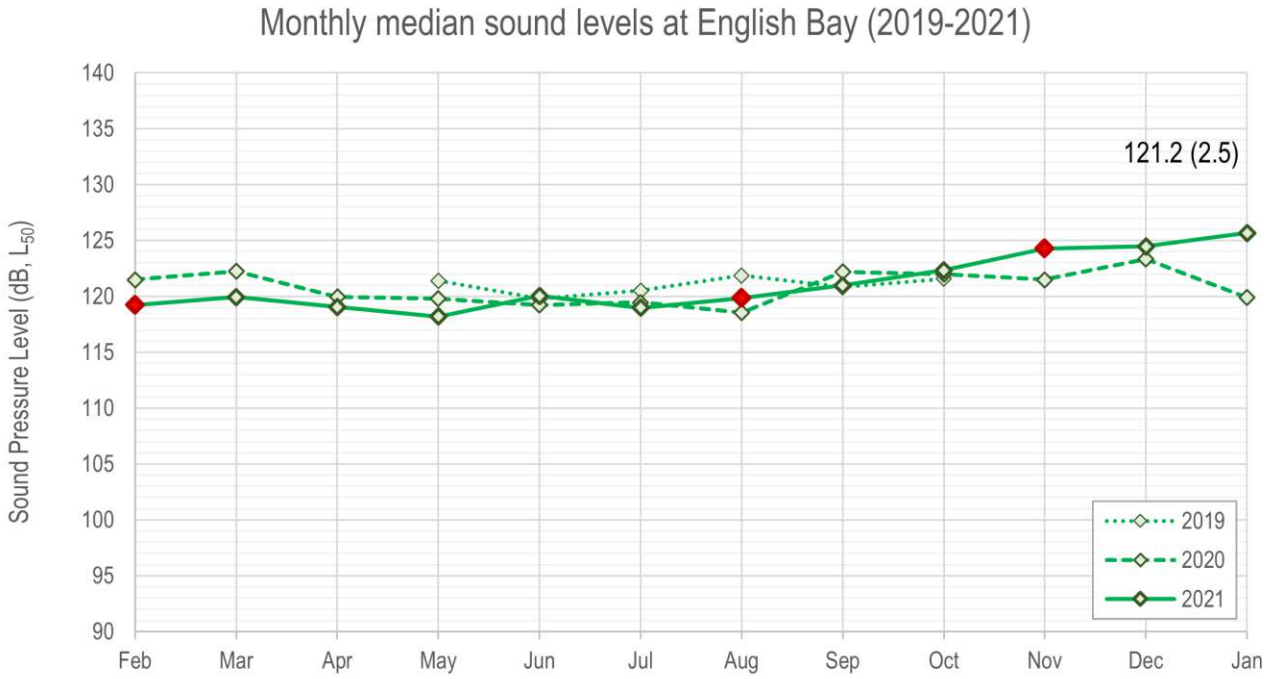


Figure 10. Median (L_{50}) broadband monthly SPL (dB re 1µPa) at English Bay across all project years. Red data points indicate months for which fewer than 14 days of data were available. Adjusted average values for the 2021 project year with standard deviation is provided to the right of the monthly trend.

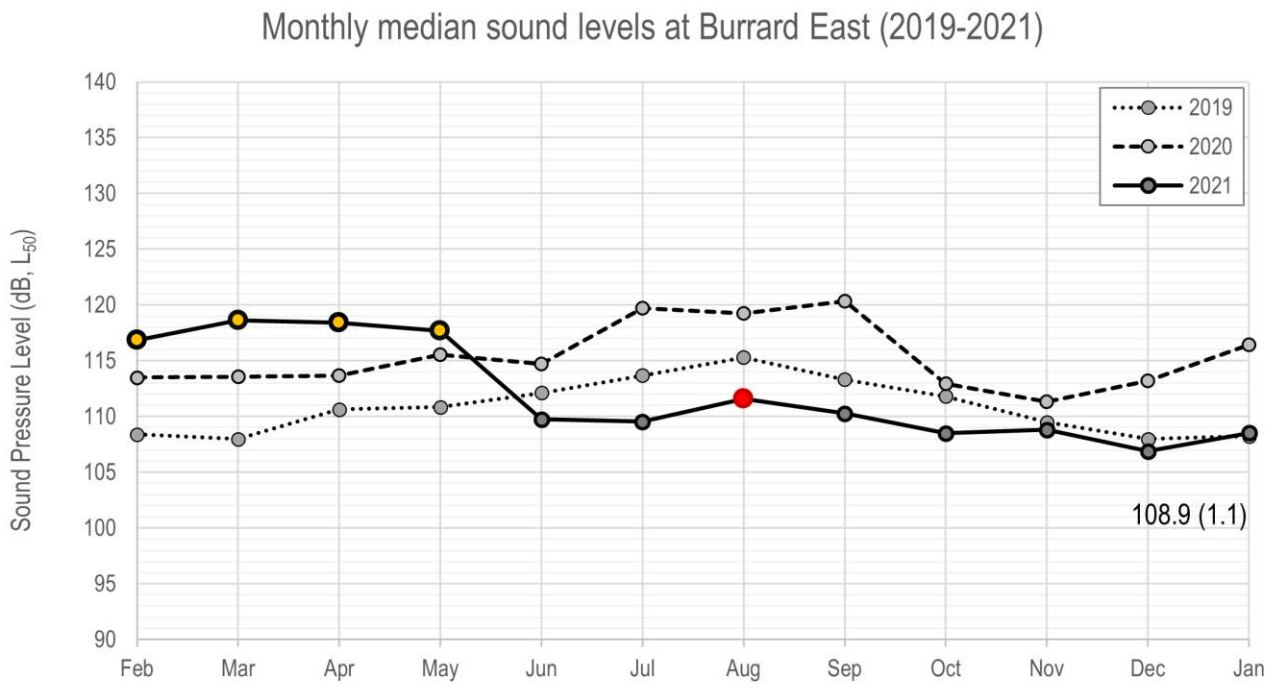


Figure 11. Median (L_{50}) broadband monthly SPL (dB re 1µPa) at Burrard East across all project years. Yellow data points indicate months biased by current velocity affects (February through May) and red data points indicate months for which fewer than 14 days of data were available. Adjusted average values for the 2021 project year with standard deviation is provided to the right of the monthly trend.

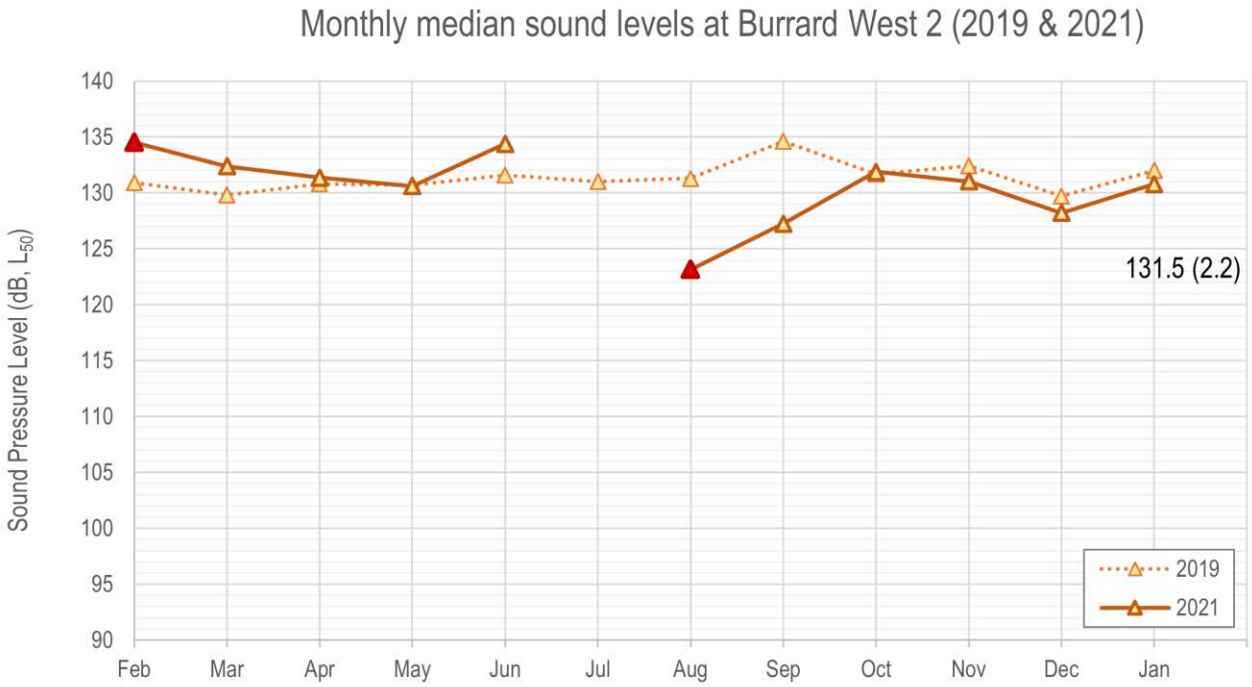


Figure 12. Median (L_{50}) broadband monthly SPL (dB re 1µPa) at Burrard West 2 across all project years. Red data points indicate months for which fewer than 14 days of data were available. July data missing due to erroneous click detector setting. Adjusted average values for the 2021 project year with standard deviation is provided to the right of the monthly trend.

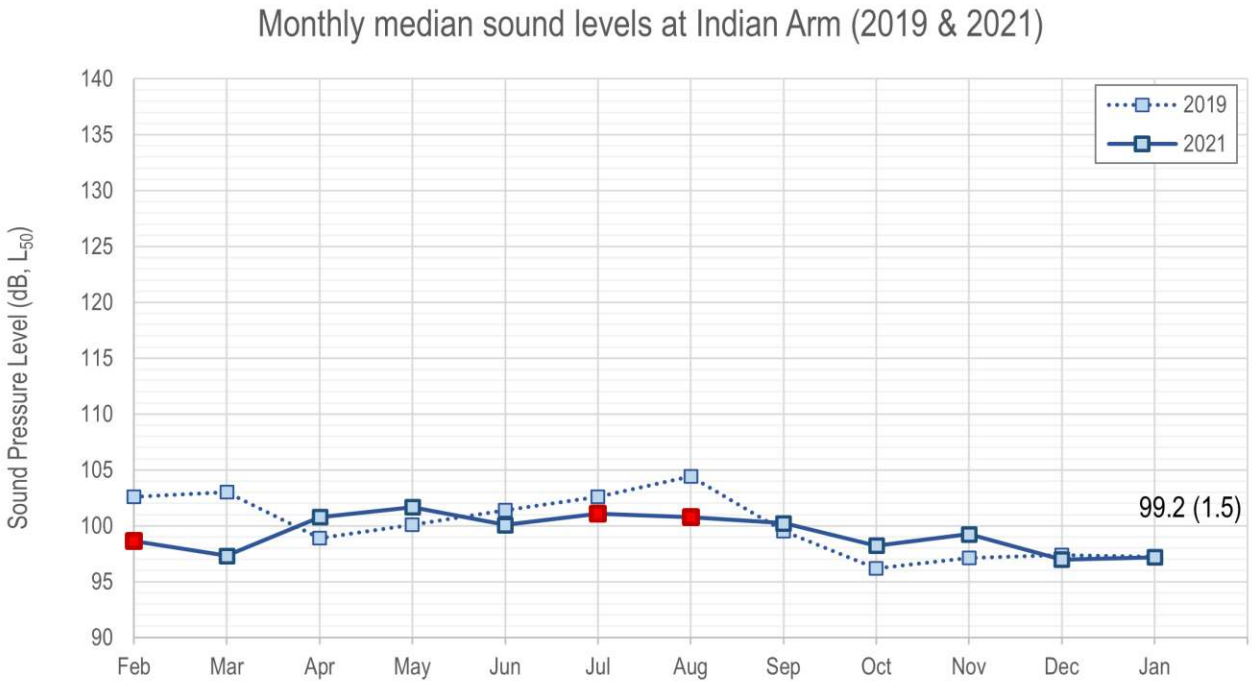


Figure 13. Median (L_{50}) broadband monthly SPL (dB re 1µPa) at Indian Arm across all project years. Red data points indicate months for which fewer than 14 days of data were available. Adjusted average values for the 2021 project year with standard deviation is provided to the right of the monthly trend.

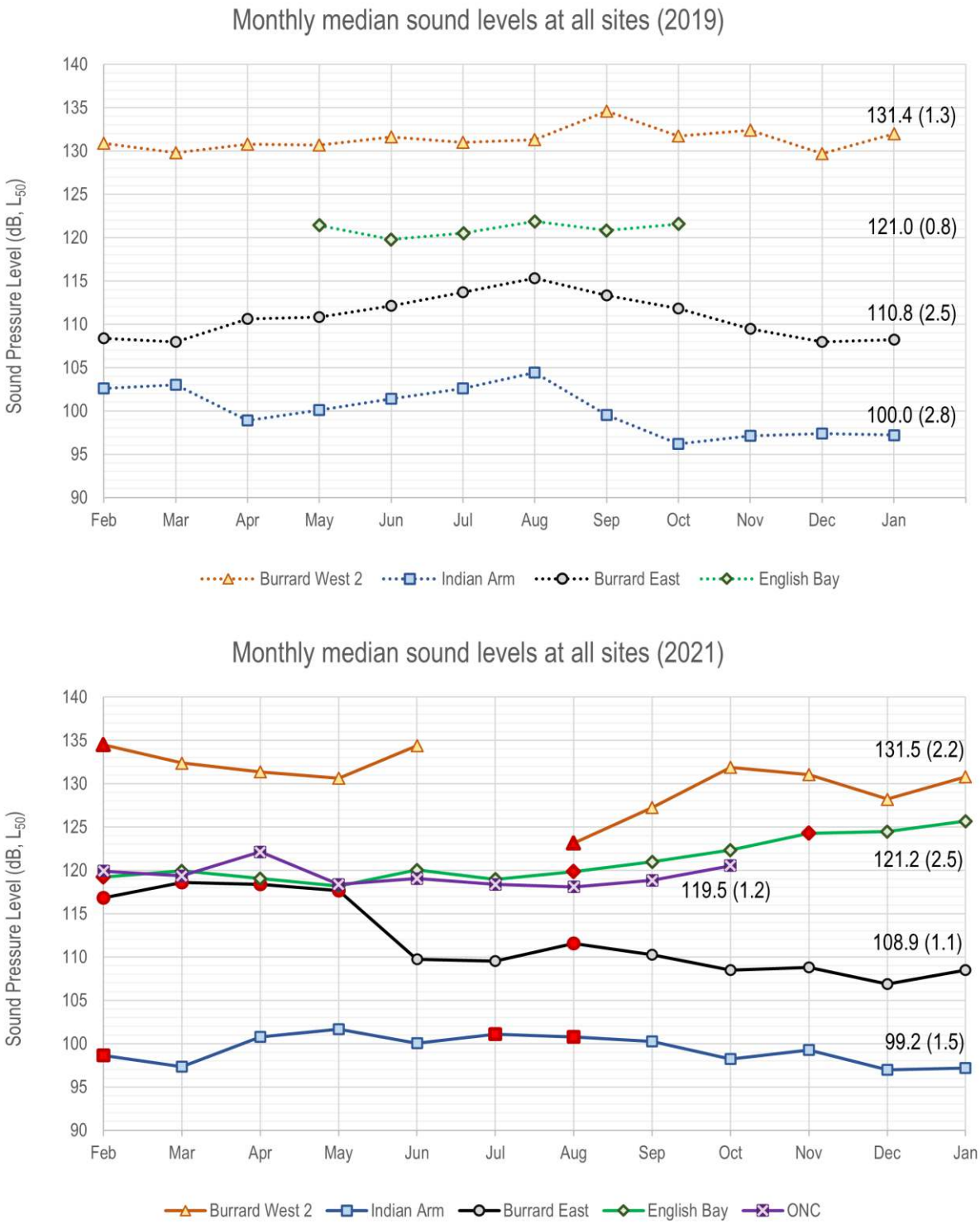


Figure 14. Median (L_{50}) broadband monthly SPL (dB re 1µPa) at each location for the 2019 (top) and 2021 (bottom) project year. Red data points indicate months for which fewer than 14 days of data were available. July data missing at Burrard West 2 due to erroneous click detector setting. Adjusted average values for the 2021 project year with standard deviation is provided to the right of the monthly trend.

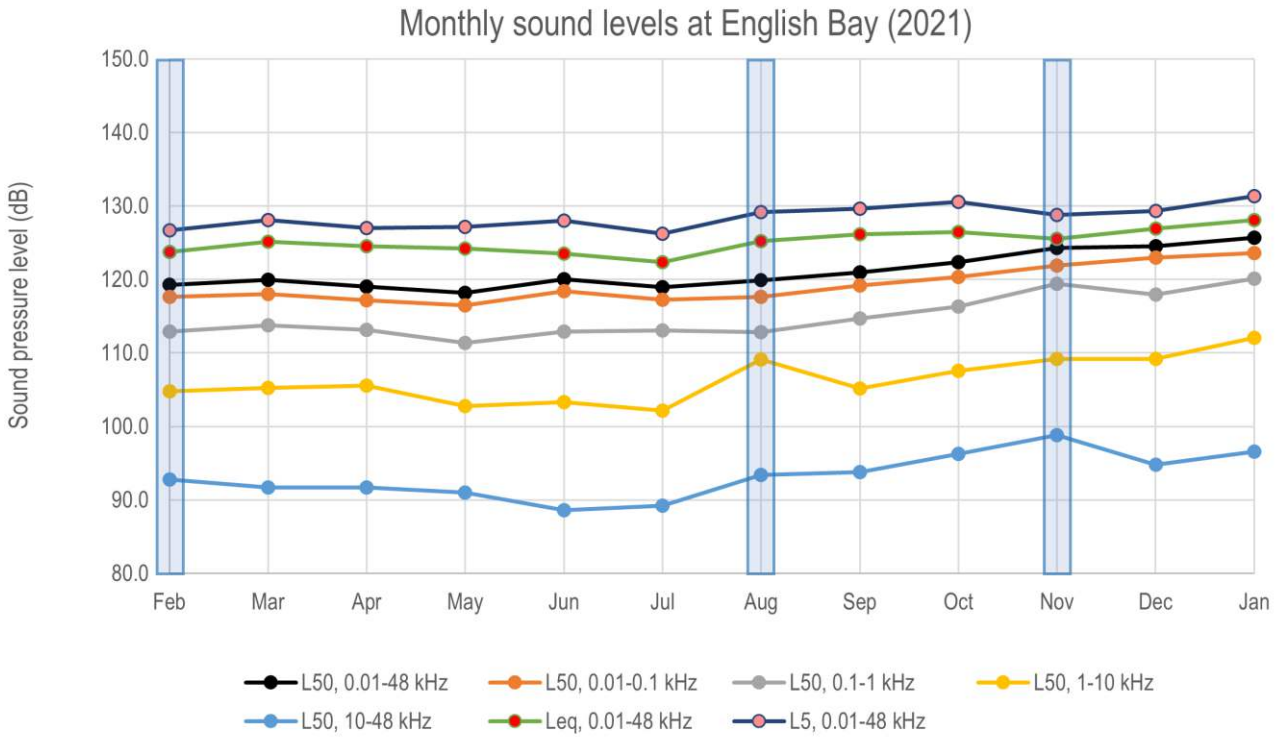


Figure 15. English Bay broadband median (L_{50}), mean (L_{eq}) and L_5 and median (L_{50}) decade band monthly SPL (dB re 1µPa). Boxes indicate months for which fewer than 14 days of data were available.

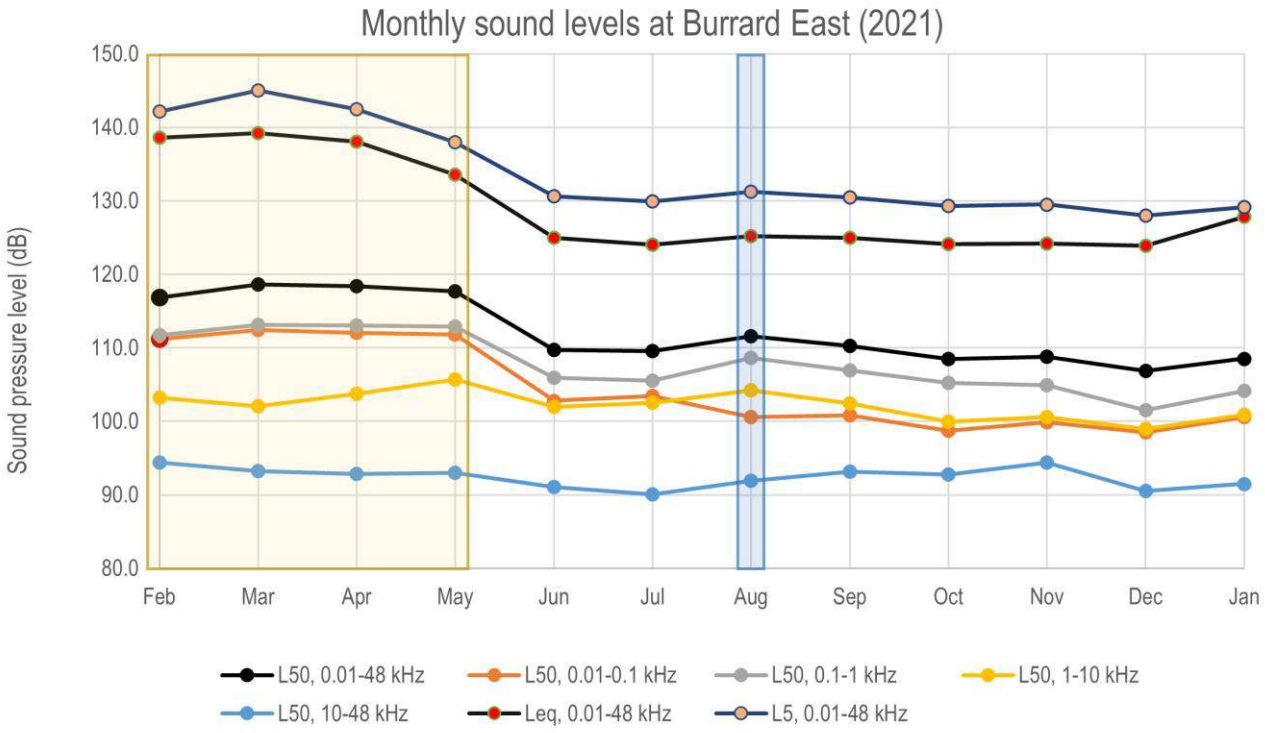


Figure 16. Burrard East broadband median (L_{50}), mean (L_{eq}) and L_5 and median (L_{50}) decade band monthly SPL (dB re 1µPa). The yellow box indicates months biased by flow noise and the blue box indicates the month for which fewer than 14 days of data were available.

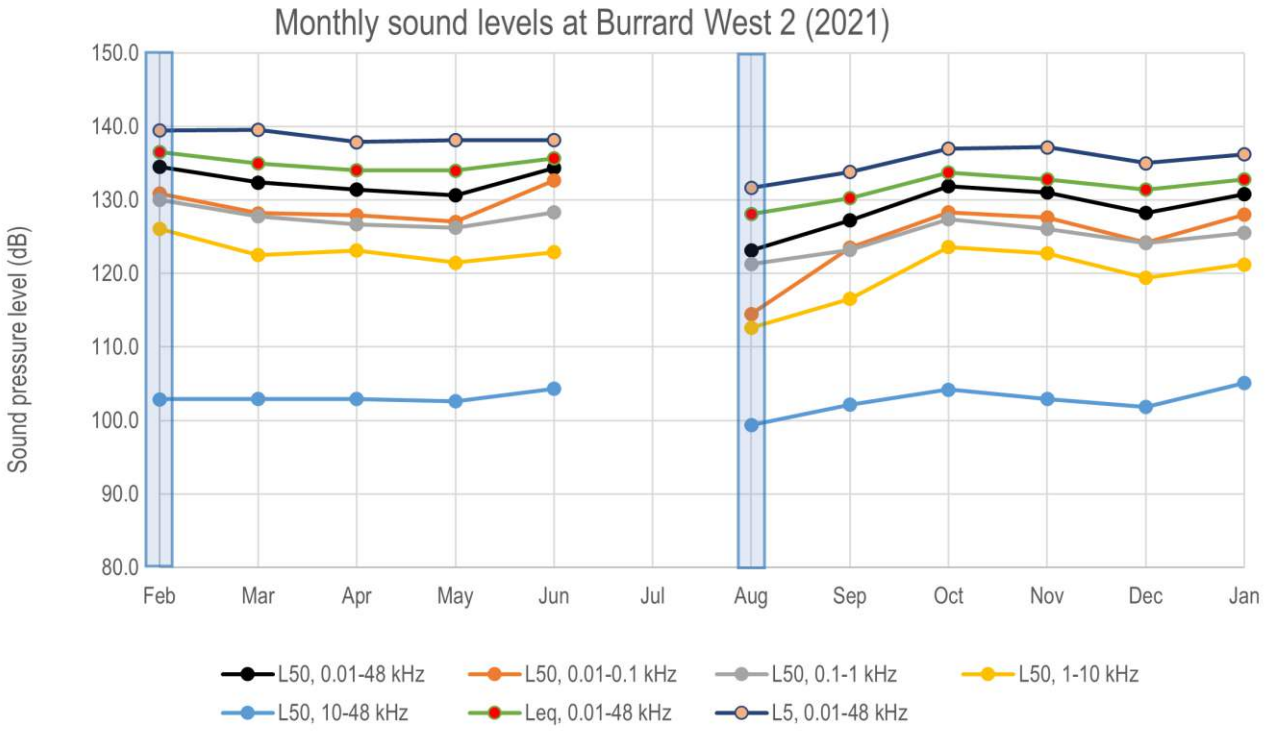


Figure 17. Burrard West 2 broadband median (L_{50}), mean (L_{eq}) and L_5 and median (L_{50}) decade band monthly SPL (dB re 1µPa). Boxes indicate months for which fewer than 14 days of data were available. July data missing due to erroneous click detector setting.

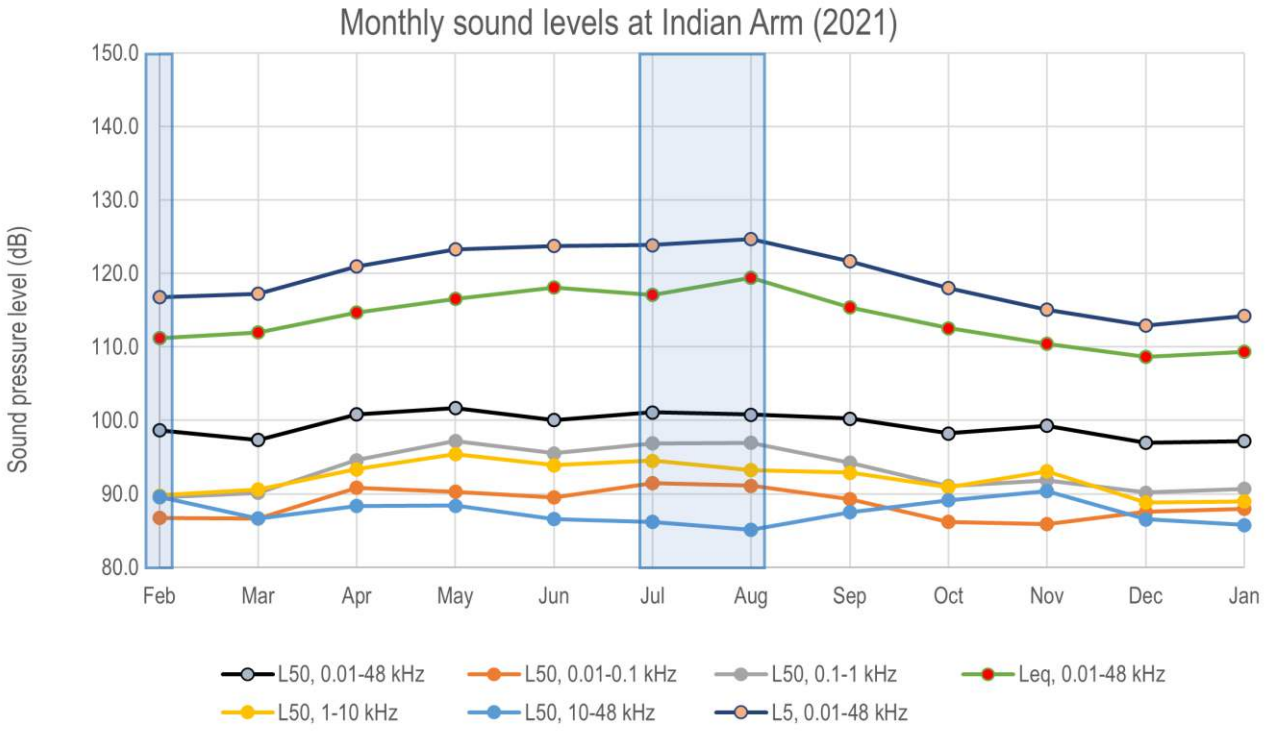


Figure 18. Indian Arm broadband median (L_{50}), mean (L_{eq}) and L_5 and median (L_{50}) decade band monthly SPL (dB re 1µPa). Boxes indicate months for which fewer than 14 days of data were available.

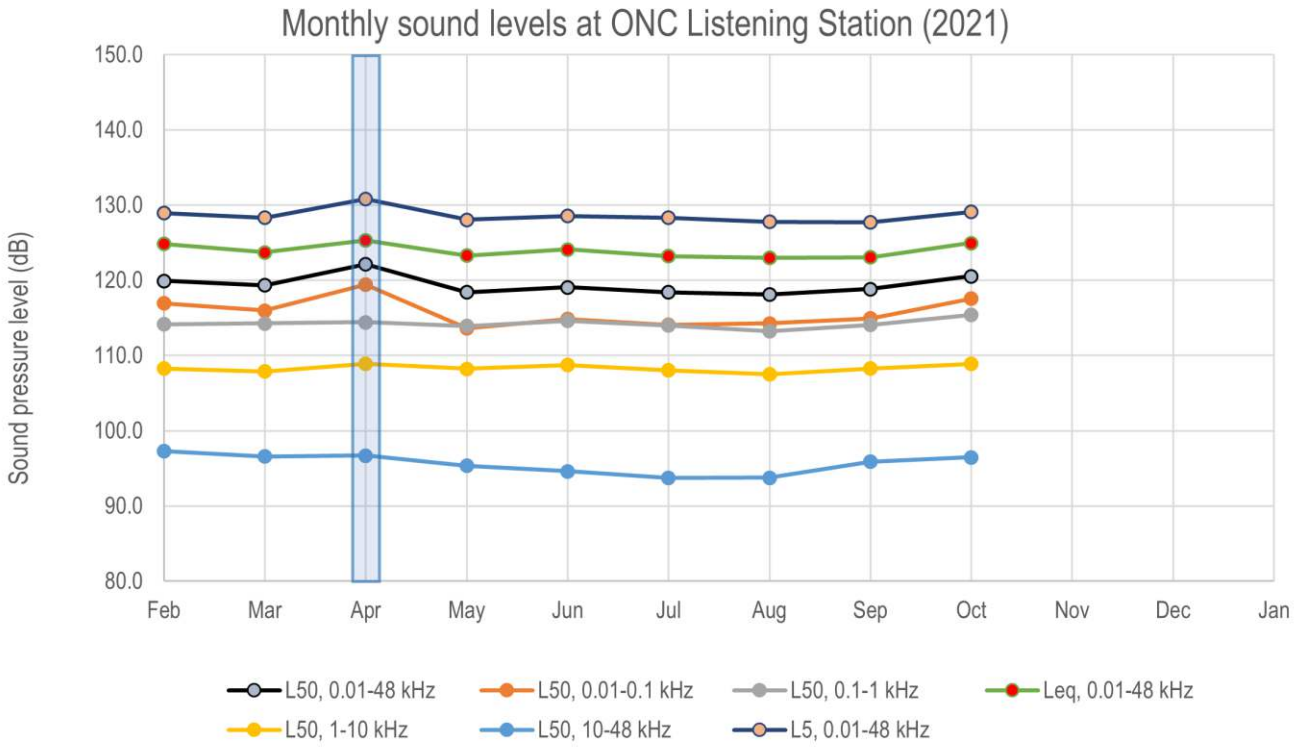


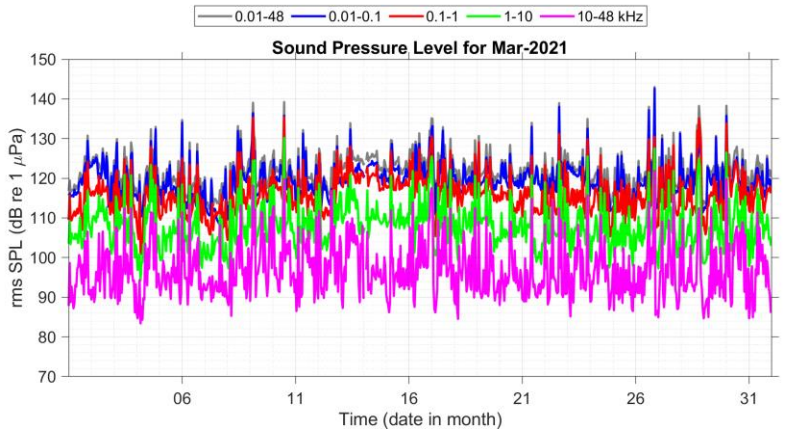
Figure 19. Ocean Networks Canada cabled listening station broadband median (L_{50}), mean (L_{eq}) and L_5 and median (L_{50}) decade band monthly SPL (dB re 1µPa). Box indicates month for which fewer than 14 days of data were available.

3.1.3 Monthly One-Third Octave SPLs and PSDs

Example decade band and Long-Term Spectrogram Average (LTSA) levels are shown in Figure 20 through Figure 24 for all sites. LTSAs are time averaged spectrograms for viewing acoustic data over weeks, months or years. The months of March and September were selected as no deployments or recoveries took place during those periods. Evidence of flow noise associated with high tidal current, especially in the 1st decade band, near the Burrard East site is present in the LTSA and the decade band plots in March but is not present in September (Figure 22).

Monthly plots of data from the ONC node indicate presence of the water sampling pump as well as the daily trends associated with the SeaBus schedule (Figure 24). The presence of self noise from additional sensors including the CTD and ADCP at this location are present in the noise level statistics and 1/3rd octave levels, as indicated by peaks in their respective frequencies (Figure 29).

English Bay (March)



English Bay (September)

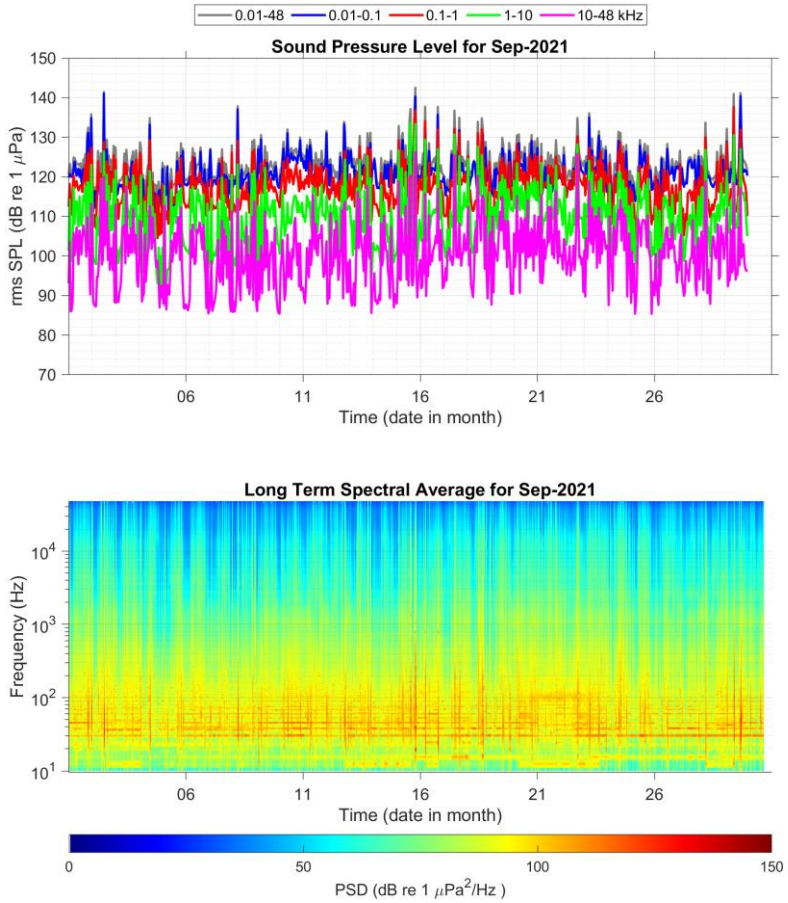


Figure 20. Decade band sound pressure levels (SPL, top panel) and long-term spectrograms for two representative months (March and September) at one hour resolution for the English Bay deployment site.

Burrard West 2 (March)

Burrard West 2 (September)

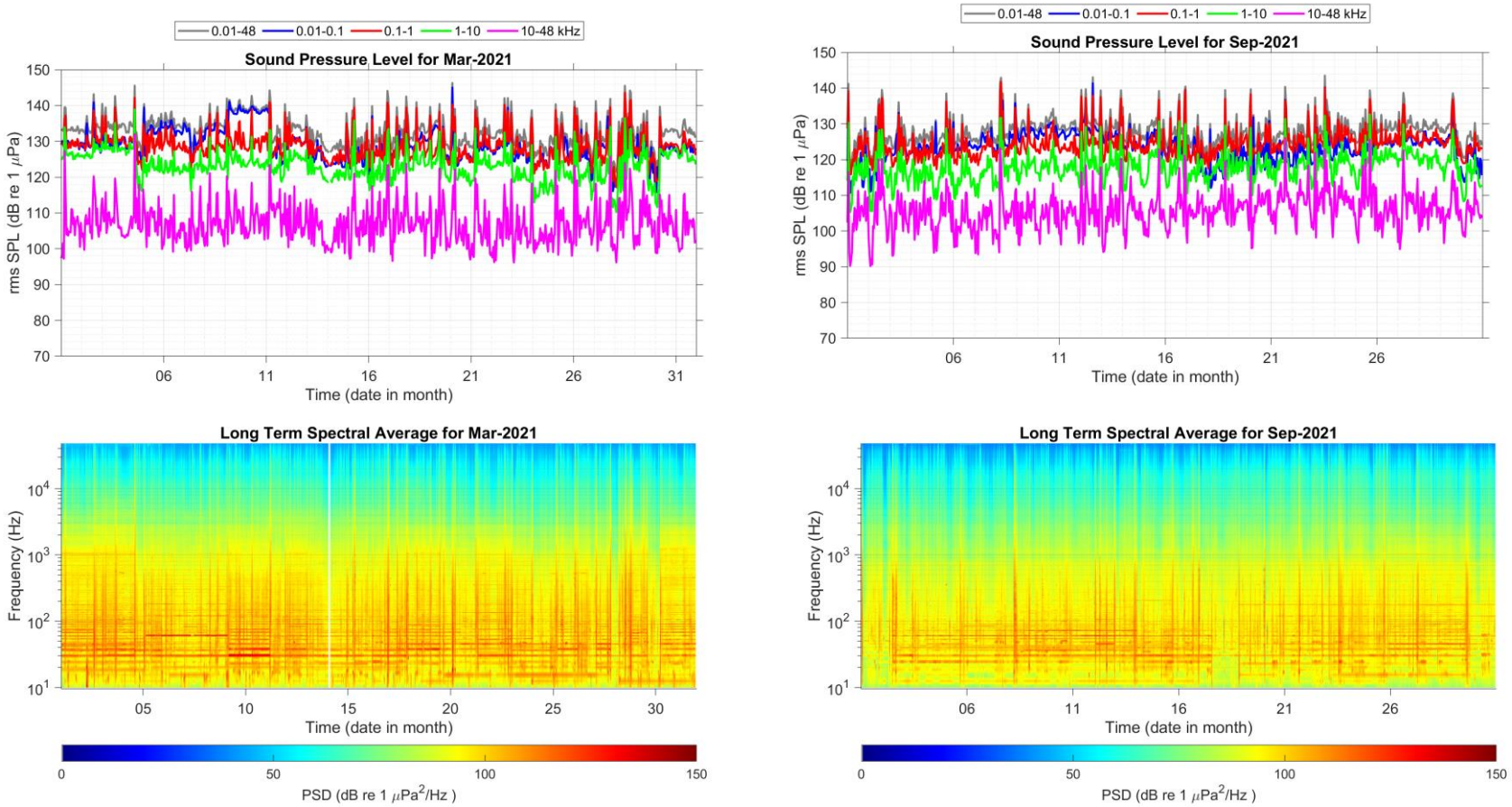
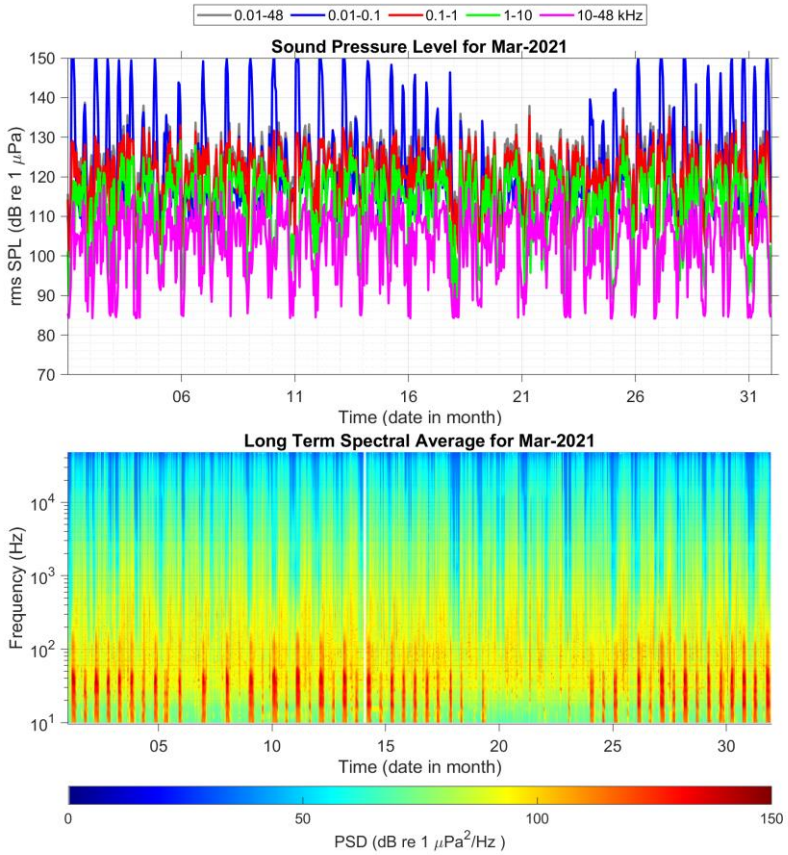


Figure 21. Decade band sound pressure levels (SPL, top panel) and long-term spectrograms for two representative months (March and September) at one hour resolution for the Burrard West 2 deployment site.

Burrard East (March)



Burrard East (September)

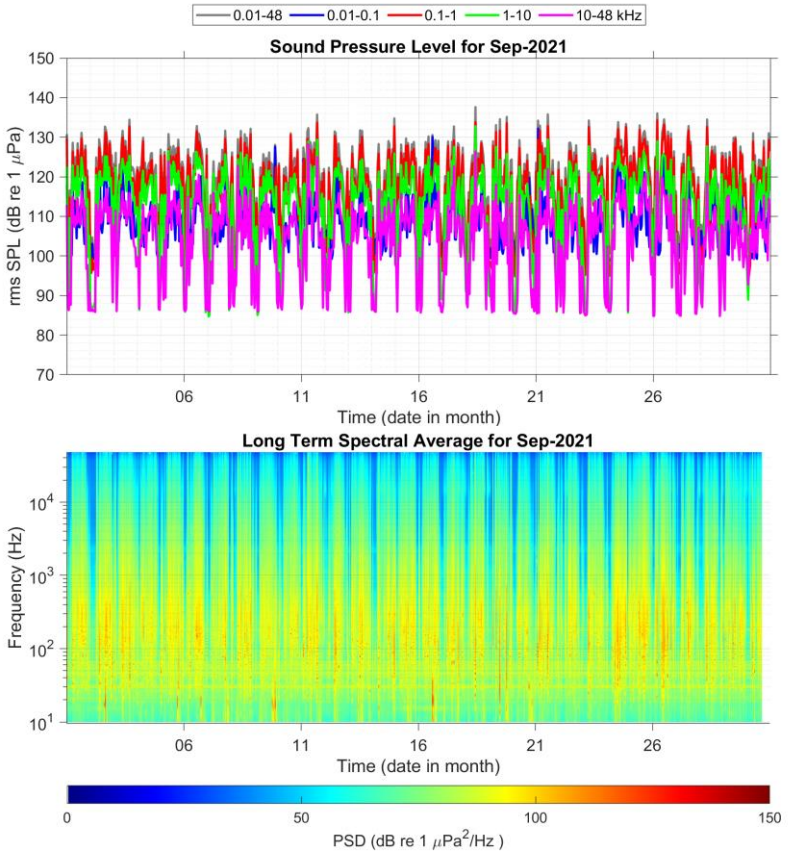
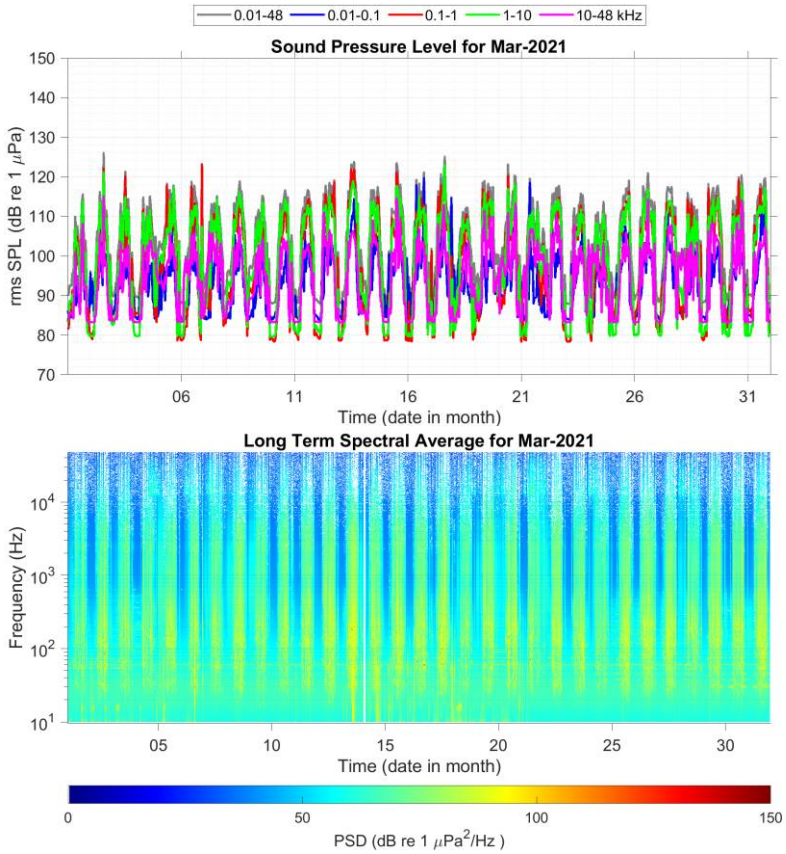


Figure 22. Decade band sound pressure levels (SPL, top panel) and long-term spectrograms for two representative months (March and September) at one hour resolution for the Burrard East deployment site.

Indian Arm (March)



Indian Arm (September)

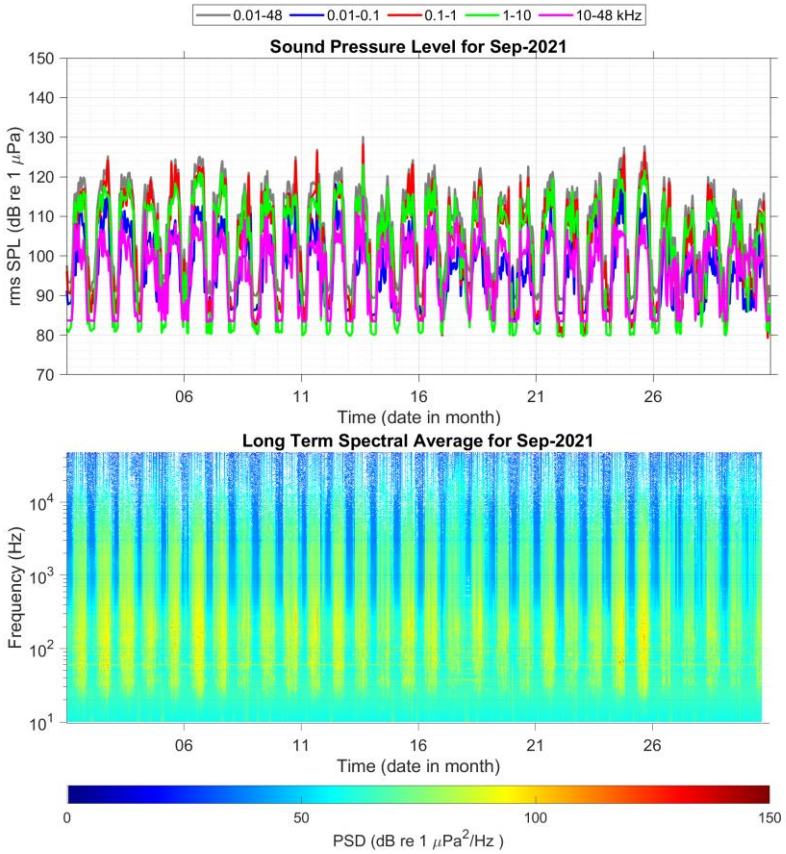
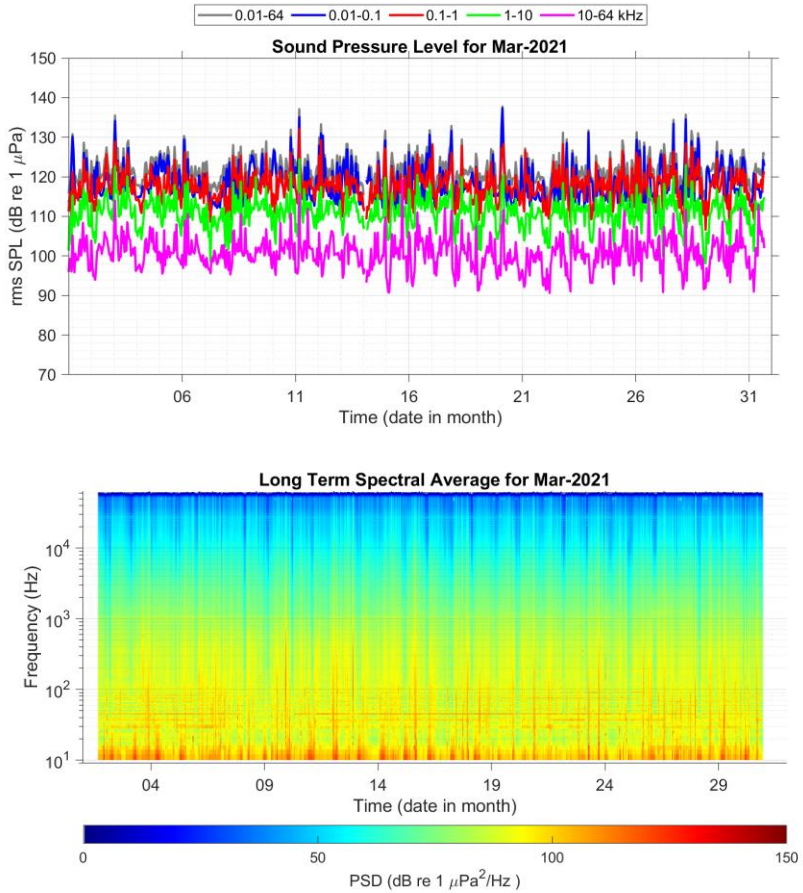


Figure 23. Decade band sound pressure levels (SPL, top panel) and long-term spectrograms for two representative months (March and September) at one hour resolution for the Indian Arm deployment site.

ONC Node (March)



ONC Node (September)

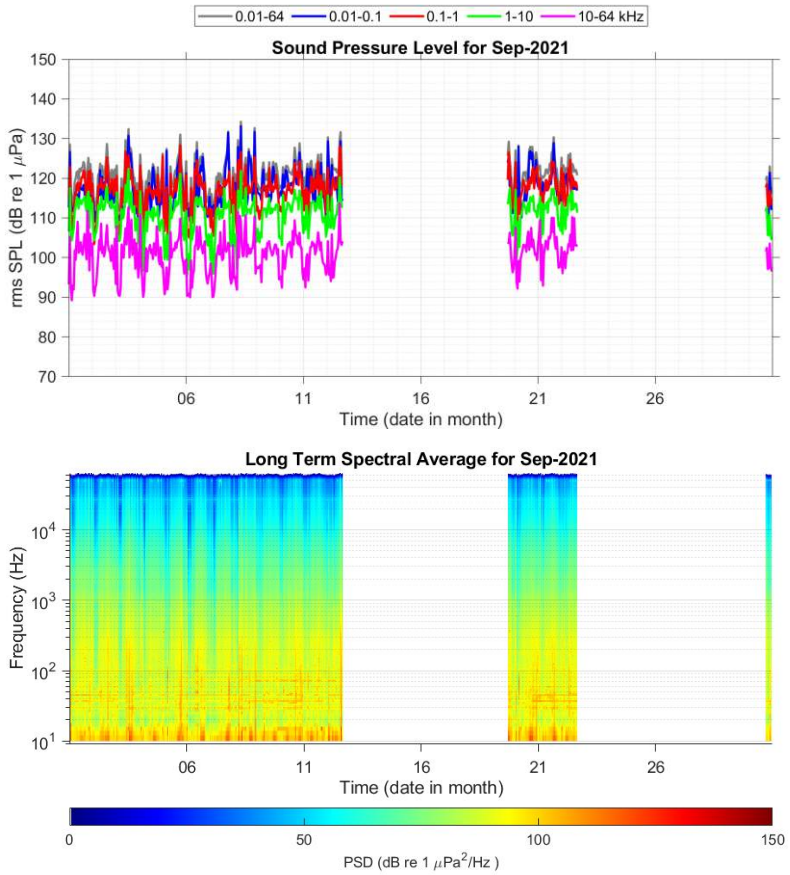


Figure 24. Decade band sound pressure levels (SPL, top panel) and long-term spectrograms for two representative months (March and September) at one hour resolution for the ONC node.

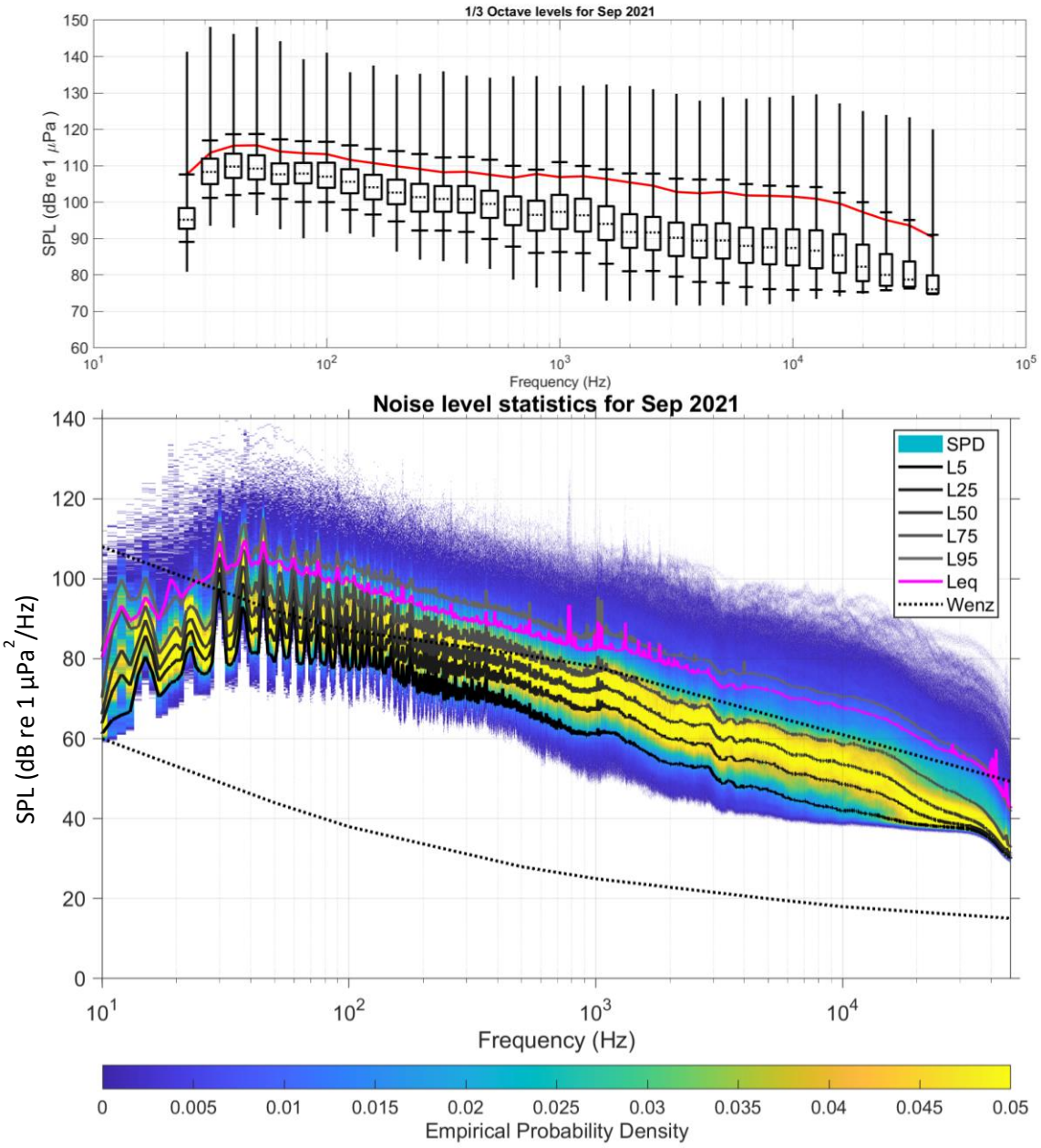


Figure 25. One minute power spectral density percentiles (lower panel) and third octave band distributions (upper panel) for September 2021 at English Bay. Red line indicates mean RMS level in each third octave bin, vertical extents represent the minimum and maximum values recorded, 'whisker' edges represent the 5th and 95th percentiles, box edges represent 25th and 75th percentiles and dashed lines represent median noise levels.

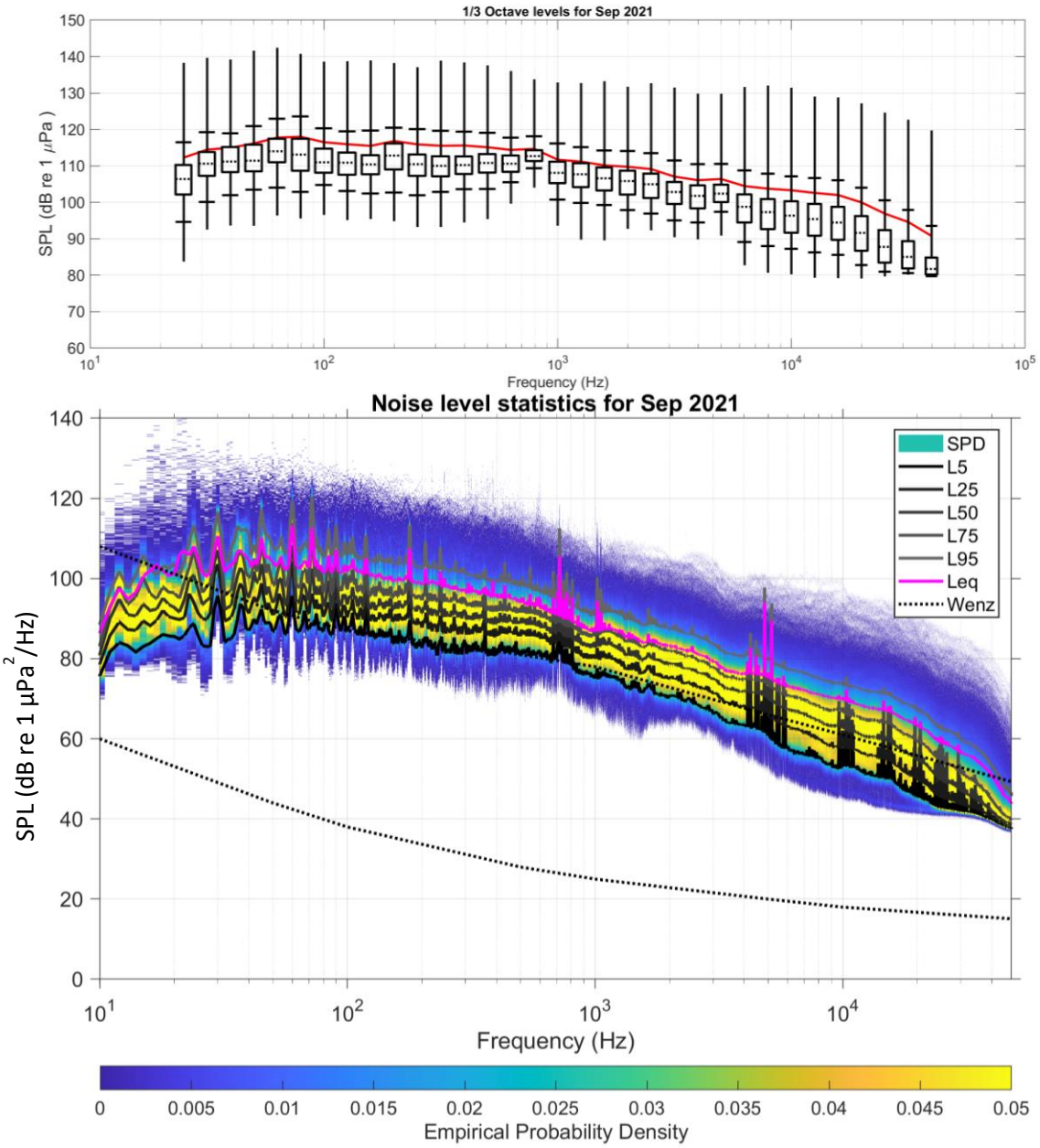


Figure 26. One minute power spectral density percentiles (lower panel) and third octave band distributions (upper panel) for September 2021 at Burrard West 2. Red line indicates mean RMS level in each third octave bin, vertical extents represent the minimum and maximum values recorded, 'whisker' edges represent the 5th and 95th percentiles, box edges represent 25th and 75th percentiles and dashed lines represent median noise levels.

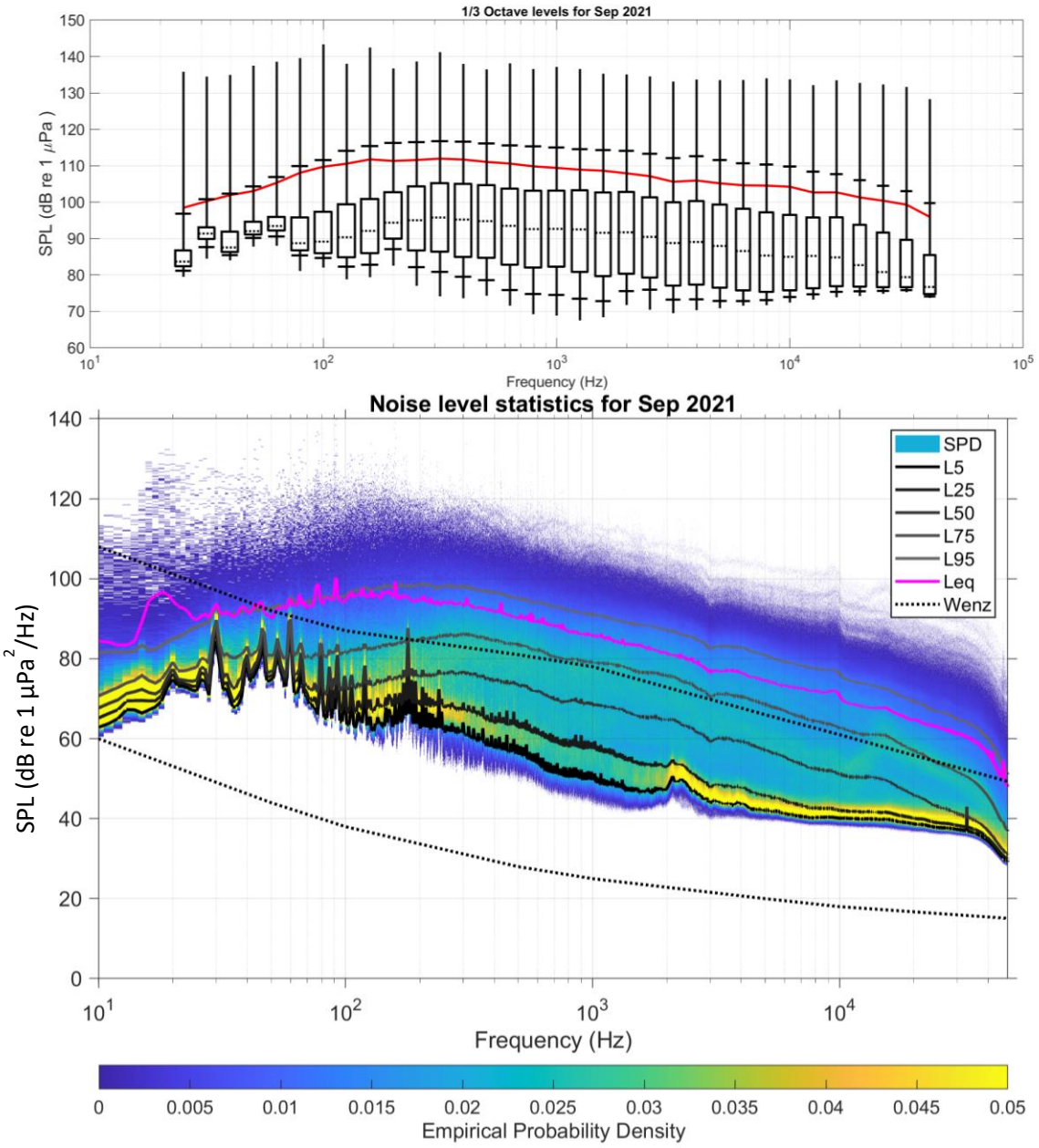


Figure 27. One minute power spectral density percentiles (lower panel) and third octave band distributions (upper panel) for September 2021 at Burrard East. Red line indicates mean RMS level in each third octave bin, vertical extents represent the minimum and maximum values recorded, 'whisker' edges represent the 5th and 95th percentiles, box edges represent 25th and 75th percentiles and dashed lines represent median noise levels.

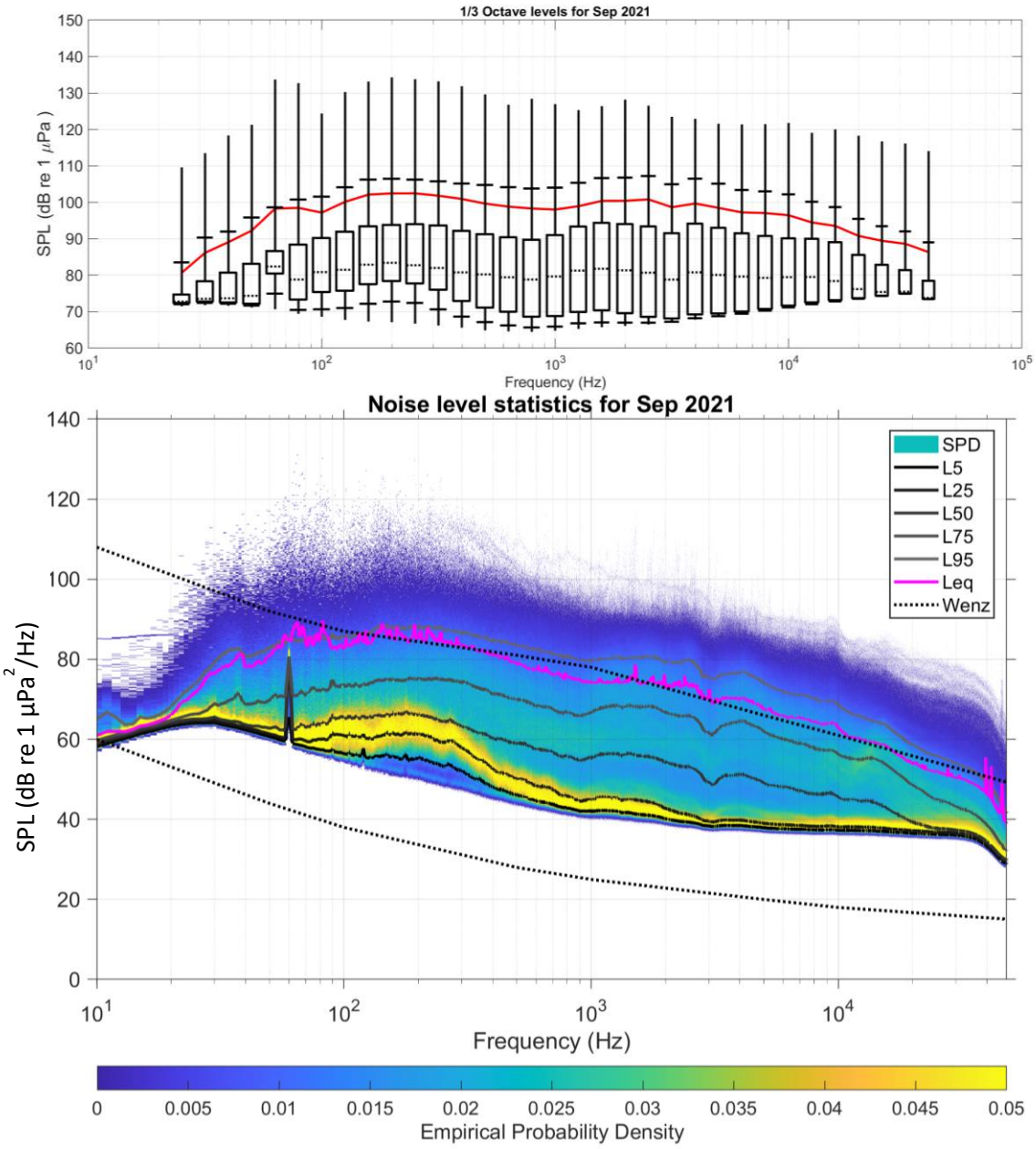


Figure 28. One minute power spectral density percentiles (lower panel) and third octave band distributions (upper panel) for September 2021 at Indian Arm. Red line indicates mean RMS level in each third octave bin, vertical extents represent the minimum and maximum values recorded, 'whisker' edges represent the 5th and 95th percentiles, box edges represent 25th and 75th percentiles and dashed lines represent median noise levels.

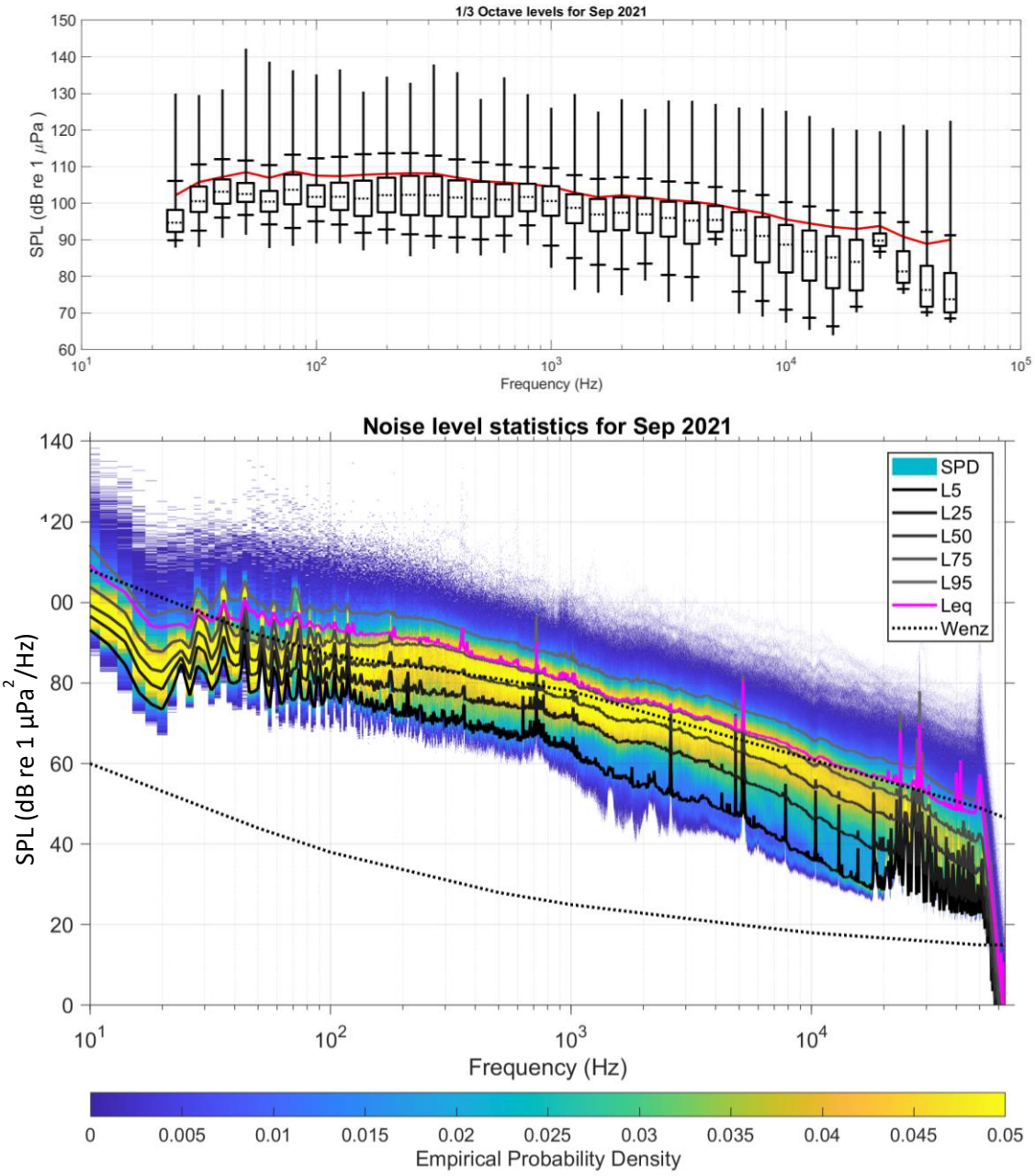


Figure 29. One minute power spectral density percentiles (lower panel) and third octave band distributions (upper panel) for September 2021 at the ONC node. Red line indicates mean RMS level in each third octave bin, vertical extents represent the minimum and maximum values recorded, 'whisker' edges represent the 5th and 95th percentiles, box edges represent 25th and 75th percentiles and dashed lines represent median noise levels.

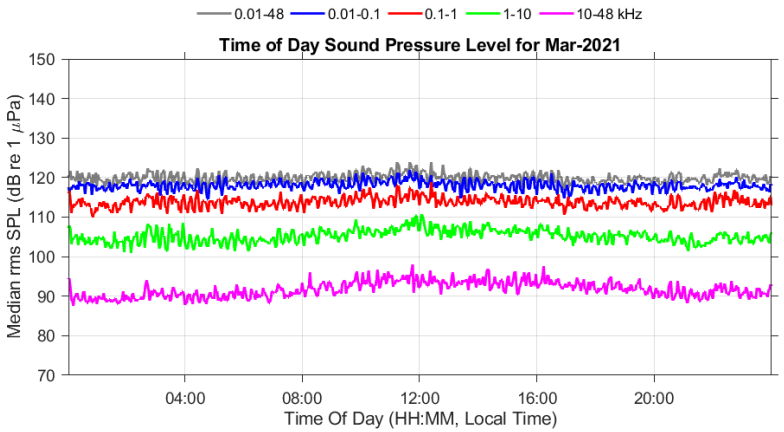
3.1.4 Diurnal Rhythm

Diel plots for each of the five locations with year-long deployments are shown in Figure 30 through Figure 34.

Diel plots, spectrograms and days of the week analyses highlighted several observations. The hydrophones at both ONC and Burrard West 2 picked up diel noise trends believed to be related to the SeaBus. At the Burrard East location, a diel trend consistent with increased vessel traffic during daylight hours was observed. In addition, during the first deployment a strong peak in broadband and lower decade band frequencies not previously observed occurred between 5 and 7 am local time. This was consistent with flow noise associated with high current velocities during the morning high tides during this time of the year.

Diel trends consistent with increased daytime vessel traffic were also evident in English Bay. However, these were limited in scope compared with Indian Arm for which noise levels in the highest decade band increase by greater than 20 dB during daylight hours. Noise levels during the night at Indian Arm drop to ~80-90 dB re 1µPa depending on the decade band, highlighting low levels of anthropogenic noise at this location.

English Bay (March)



English Bay (September)

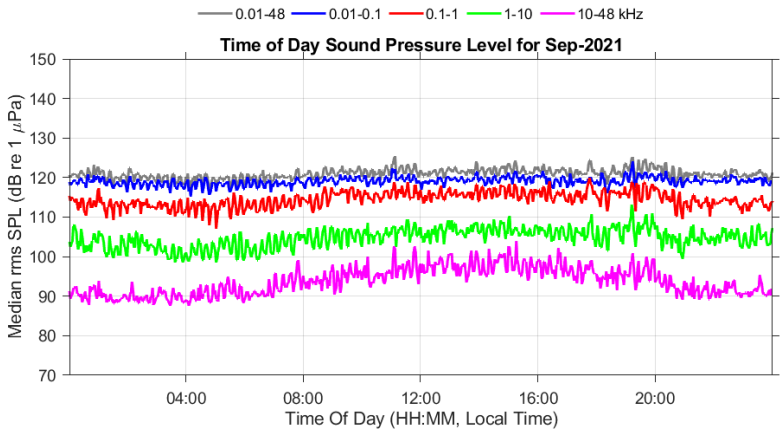
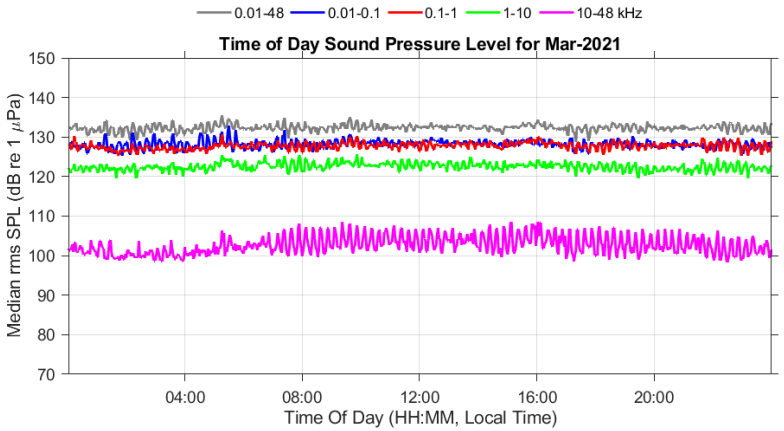


Figure 30. Decade band sound pressure levels by time of day at English Bay for two representative months.

Burrard West 2 (March)



Burrard West 2 (September)

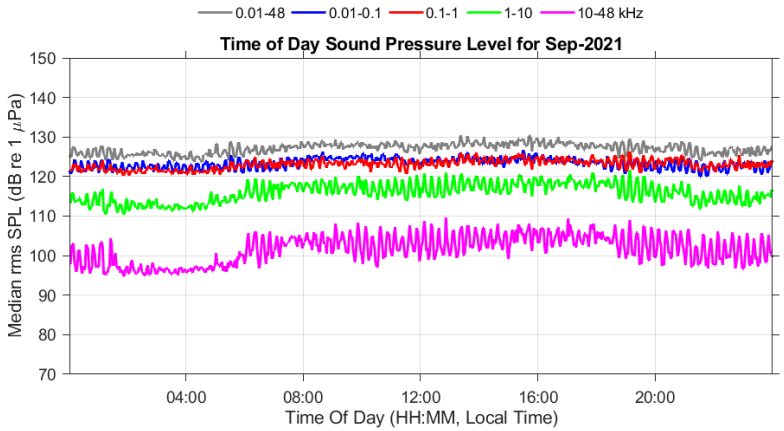
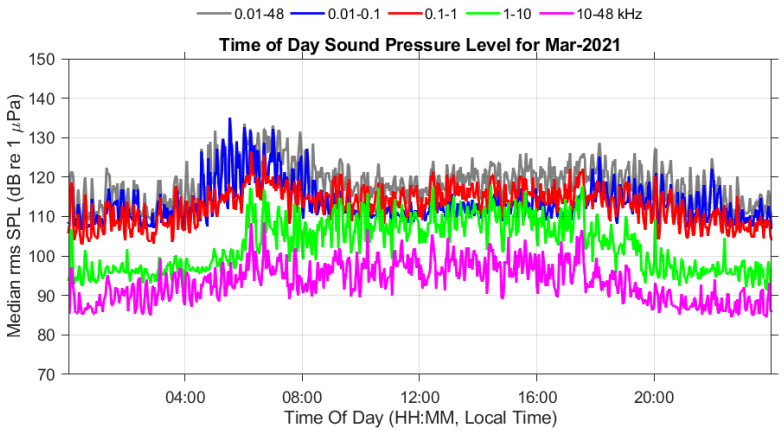


Figure 31. Decade band sound pressure levels by time of day at Burrard West 2 for two representative months.

Burrard East (March)



Burrard East (September)

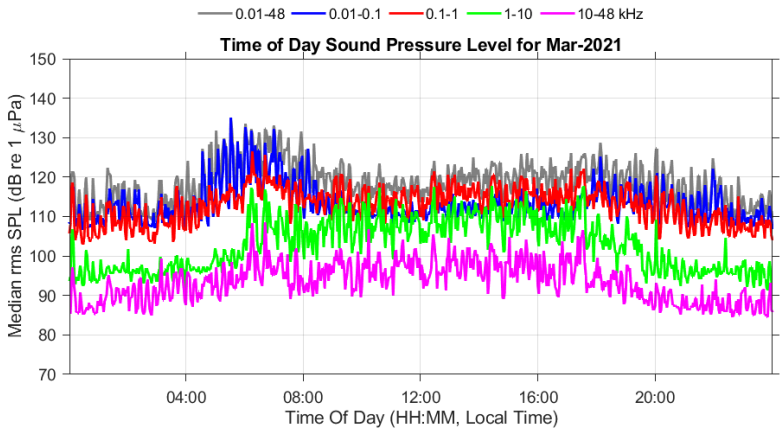
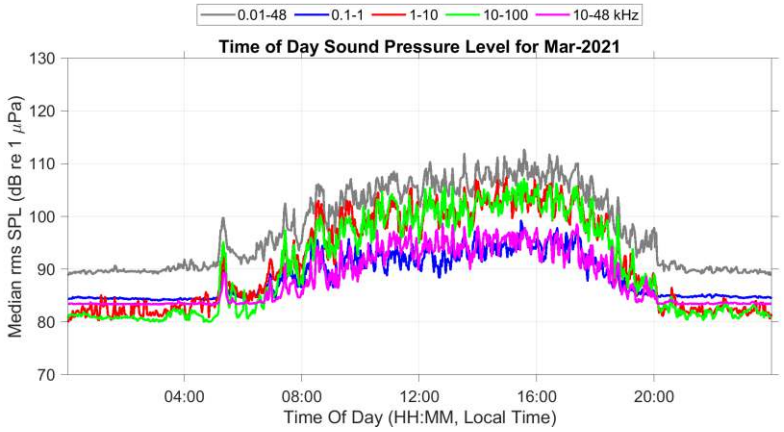


Figure 32. Decade band sound pressure levels by time of day at Burrard East for two representative months.

Indian Arm (March)



Indian Arm (September)

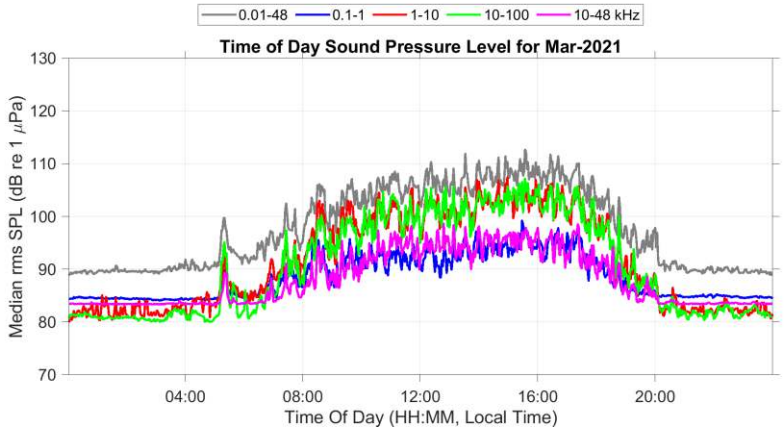
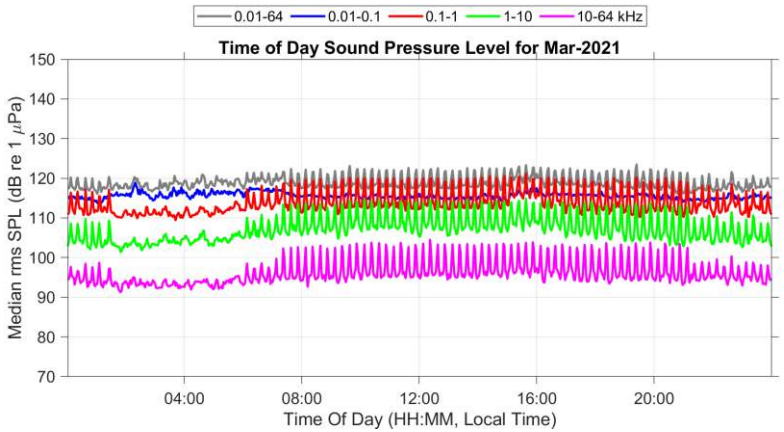


Figure 33. Decade band sound pressure levels by time of day at Indian Arm for two representative months.

ONC (March)



ONC (September)

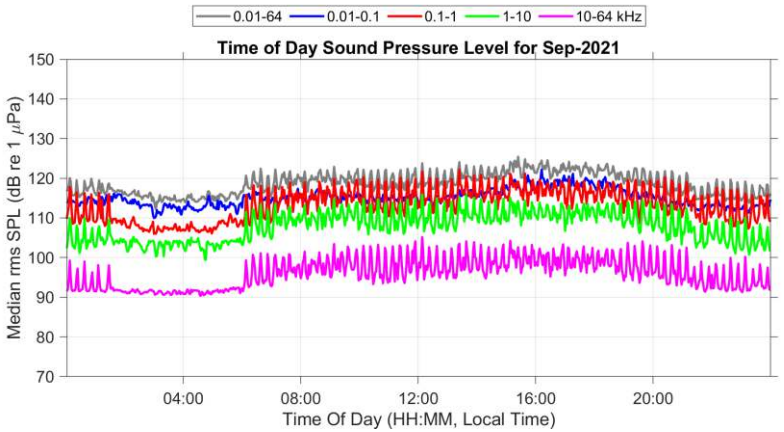


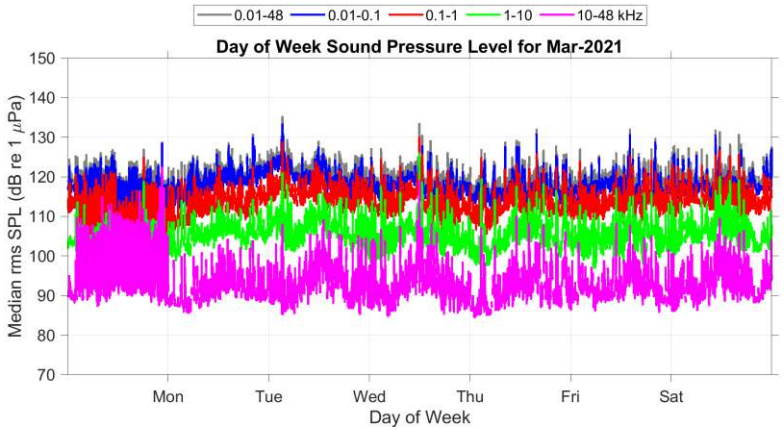
Figure 34. Decade band sound pressure levels by time of day at the ONC node for two representative months.

3.1.5 Weekly Rhythm

Plots showing weekly patterns are provided for March and for September at each year-long deployment location. Most notably, these plots re-highlight the diurnal patterns described in the previous section, but several other features are of interest:

- In March at the English Bay site, there is a clear peak in the upper decade on Sundays.
- In March, at Burrard West, there is a weak trend for lower noise levels over the weekends.
- In March at Burrard East the low frequency spikes from tidal current velocity are again very evident but absent in September.
- In both example months (March and September) at the Indian Arm site there is weak evidence for higher SPLs Friday through Sundays.

English Bay (March)



English Bay (September)

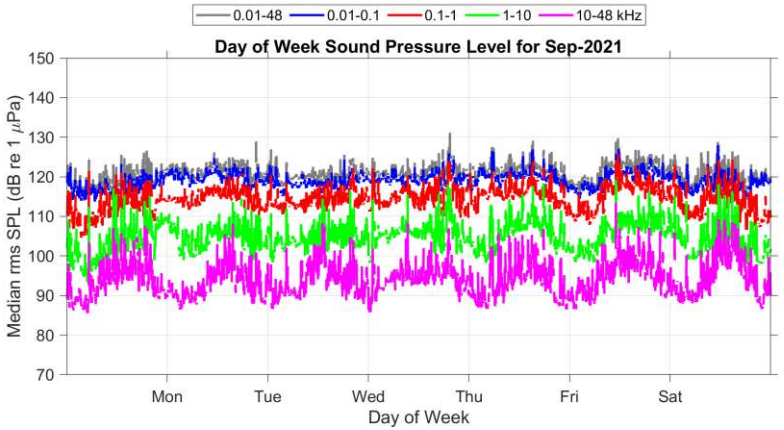
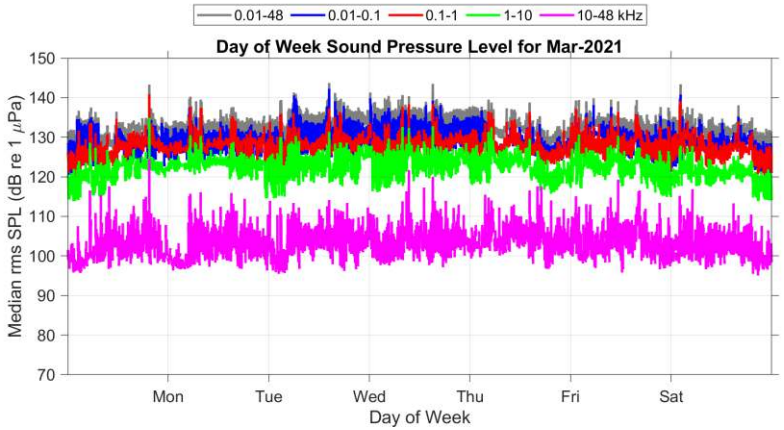


Figure 35. Decade band sound pressure levels by day of week for March and September 2021 at English Bay.

Burrard West 2 (March)



Burrard West 2 (September)

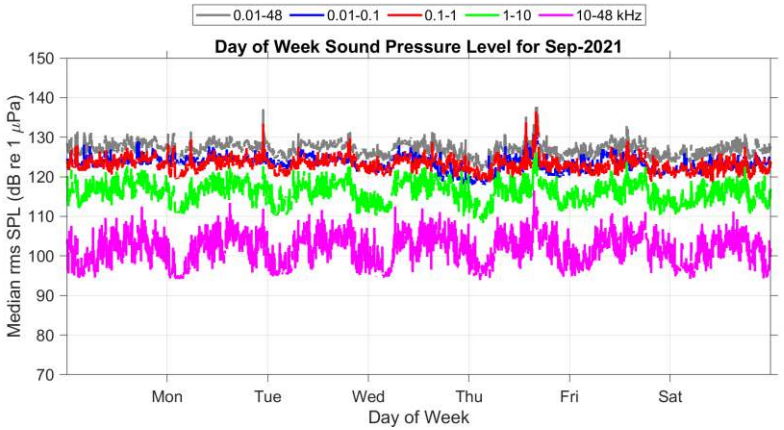
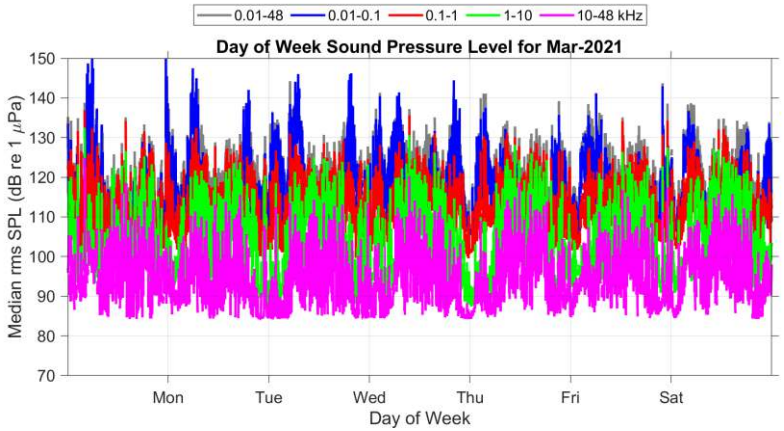


Figure 36. Decade band sound pressure levels by day of week for March and September 2021 at Burrard West 2.

Burrard East (March)



Burrard East (September)

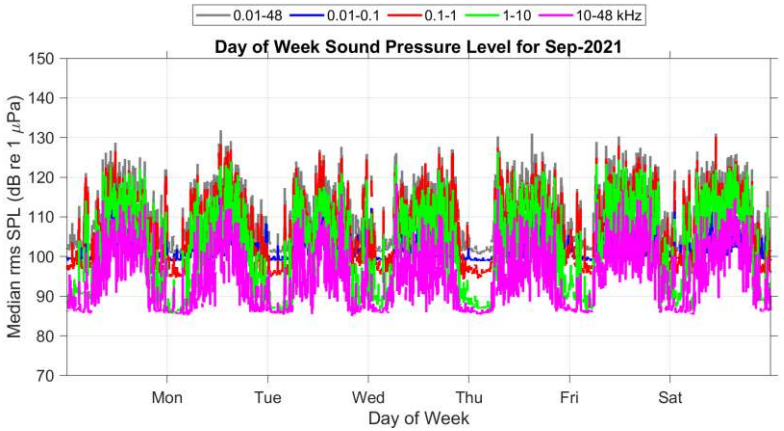
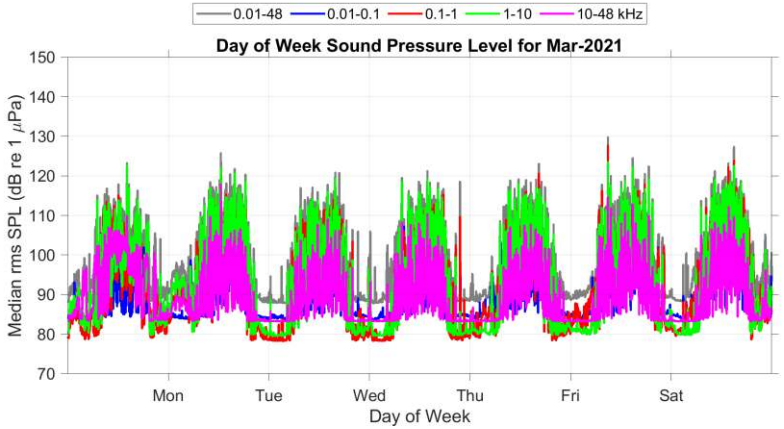


Figure 37. Decade band sound pressure levels by day of week for March and September 2021 at Burrard East.

Indian Arm (March)



Indian Arm (September)

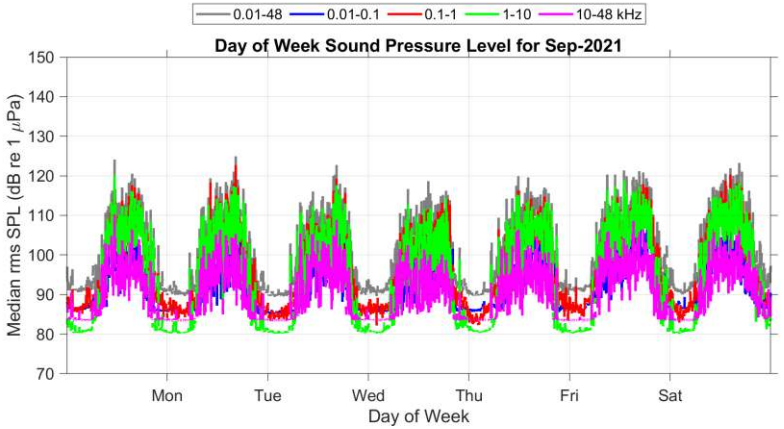
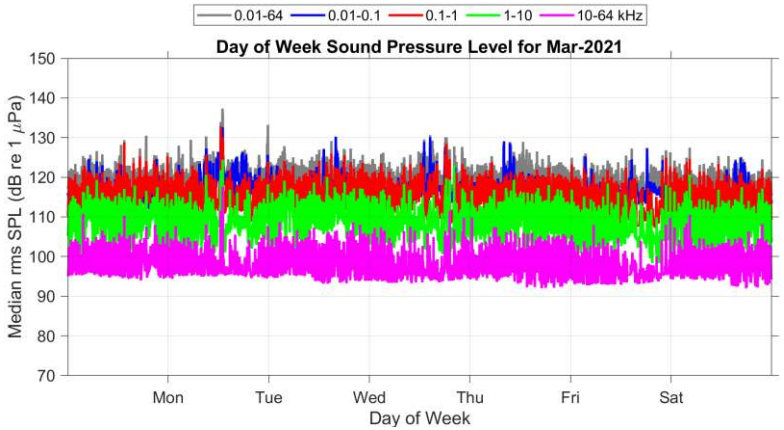


Figure 38. Decade band sound pressure levels by day of week for March and September 2021 at Indian Arm.

ONC (March)



ONC (September)

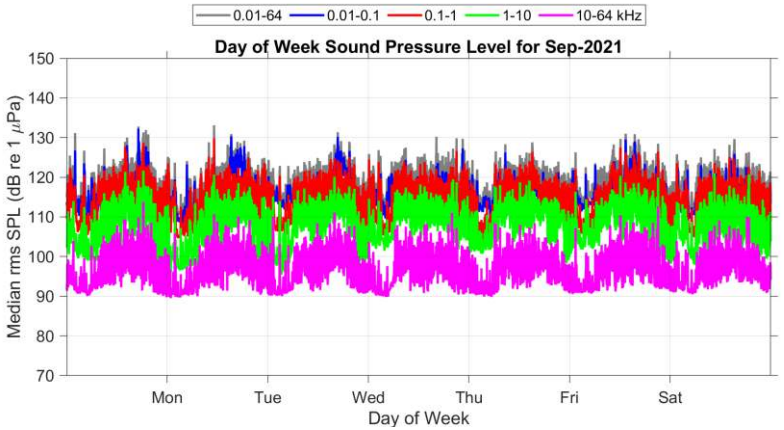


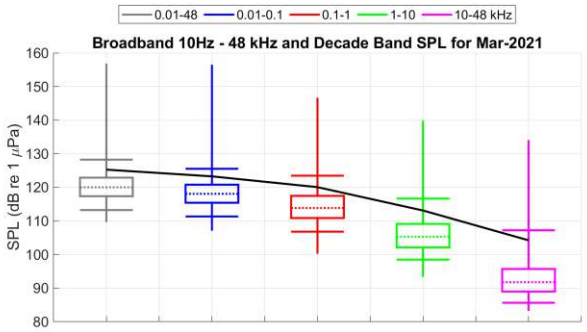
Figure 39. Decade band sound pressure levels by day of week for March and September 2021 at the ONC Node

3.1.6 SPL Box Plots

SPL box plots help identify trends and variability within and across locations. March and September are selected again for display.

- Burrard East was the only site to show notable variability across months. The 10-100 Hz decade band showed a noise level drop after the month of May when current velocity issues ceased, consistent with the drop in overall noise levels.
- There was minimal variability at other sites throughout the project.
- At most sites there was a clear trend in noise levels across decade bands, with lower levels at higher frequencies. A significant portion of underwater noise in the study area is from shipping, which is dominant in lower frequencies, and the higher frequency components of this sound are attenuated more rapidly.
- It is notable that at the Indian Arm site, high frequency noise levels that occur mainly during the day are relatively elevated compared to the other decade bands. It is likely that the limited industrial activity and shipping traffic, together with the known small boat activity close to the mooring, is responsible for this result.

English Bay (March)



English Bay (September)

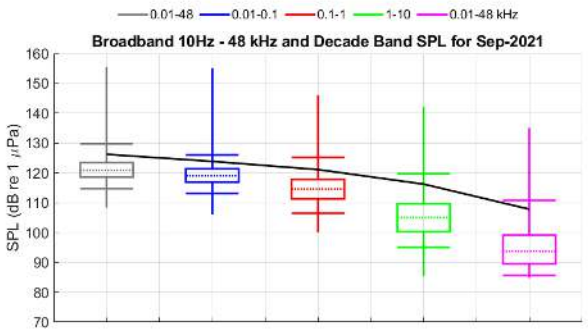
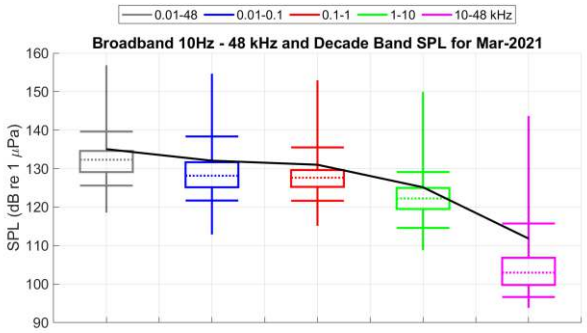


Figure 40. Box plot of broadband and decade band noise levels for March and September 2021 at English Bay.

Burrard West 2 (March)



Burrard West 2 (September)

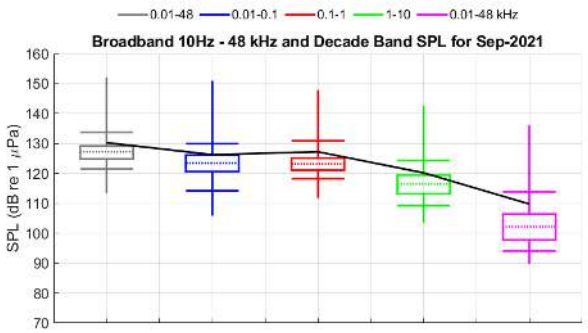
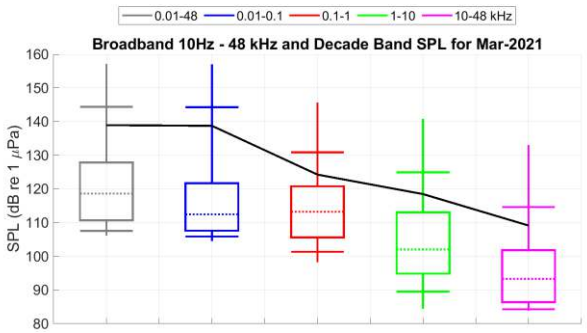


Figure 41. Box plot of broadband and decade band noise levels for March and September 2021 at Burrard West 2.

Burrard East (March)



Burrard East (September)

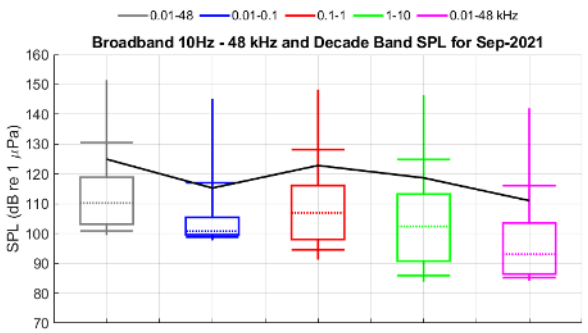
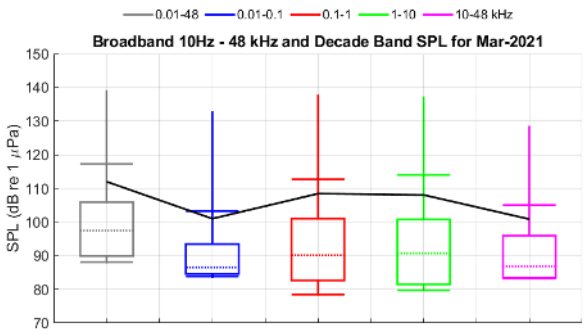


Figure 42. Box plot of broadband and decade band noise levels for March and September 2021 at Burrard East.

Indian Arm (March)



Indian Arm (September)

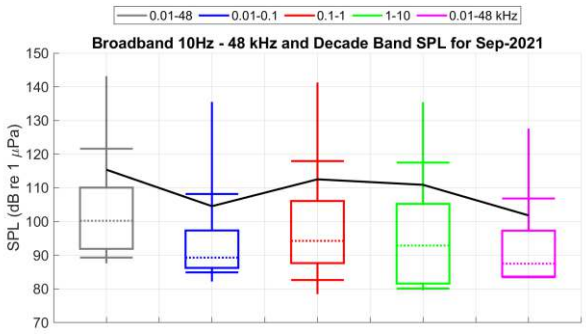
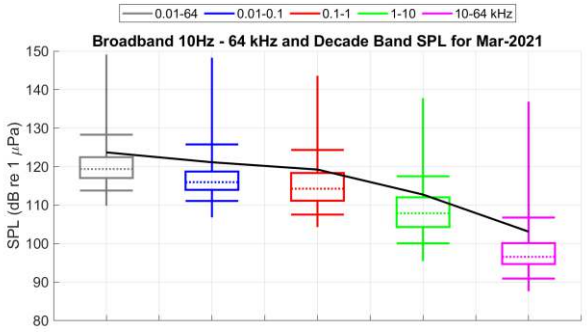


Figure 43. Box plot of broadband and decade band noise levels for March and September 2021 at Indian Arm.

ONC (March)



ONC (September)

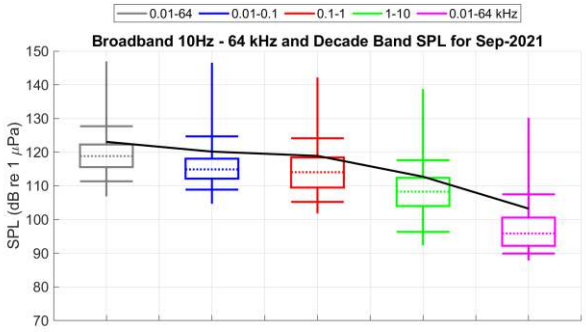


Figure 44. Box plot of broadband and decade band noise levels for March and September 2021 at the ONC Node.

3.1.7 Ancillary Data

Consistent with previous years, visual inspection of monthly spectrograms for the top ten rainiest and windiest days showed no clear patterns in ambient noise intensity compared to other time periods at the Indian Arm location. Indian Arm SPL (1-10 kHz) at daily scales were plotted with both daily rainfall and average wind speed. Given that Indian Arm is the quietest location, and no clear impact of rain or wind was detected, it is reasonable to conclude that these environmental factors are not major contributors to long term trends in ambient noise observed throughout the Inlet.

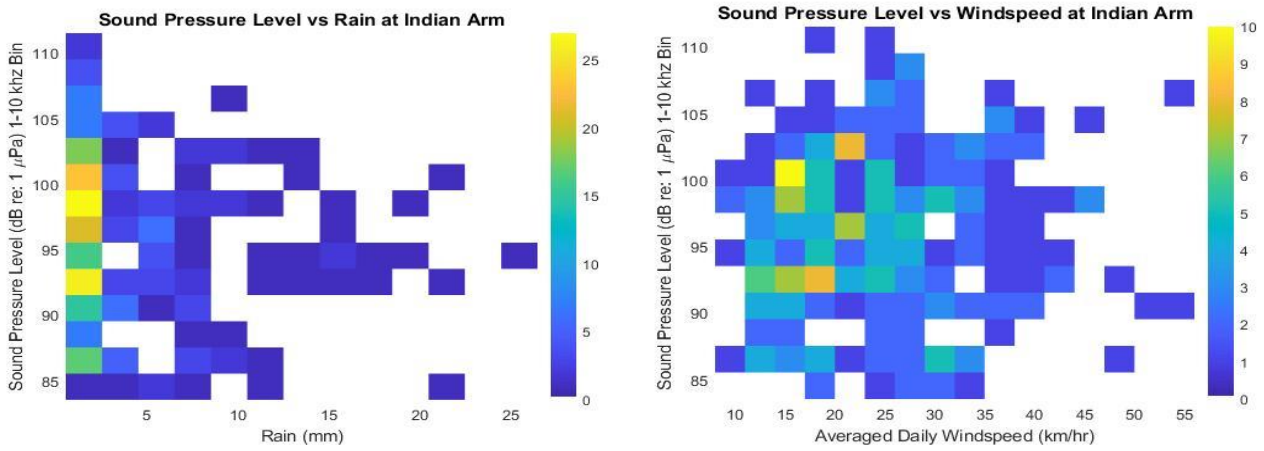


Figure 45. Left panel, Indian Arm SPL (10-64 kHz) versus daily rainfall (mm) and (right panel) average wind speed (km/h). Color scale indicates number of observations at each bin location.

3.1.7.1 Vessel Density

Hourly AIS signal densities are shown in (Figure 46). The upper panel depicts vessels moving > 1 knot and the lower panel includes both moving and non-moving vessels transmitting AIS. Highest signal densities were observed at Burrard West 2, followed closely by Burrard East. Lowest densities are observed at Indian Arm, followed by English Bay. Both these locations had lower variability across days, compared with the Burrard Inlet locations. Vessel density at the ONC site was not evaluated due to uncertainty pertaining to when and to what degree the pump noise affected the data quality at that location. Burrard West 1 was excluded in the analysis due to the short-term deployment.

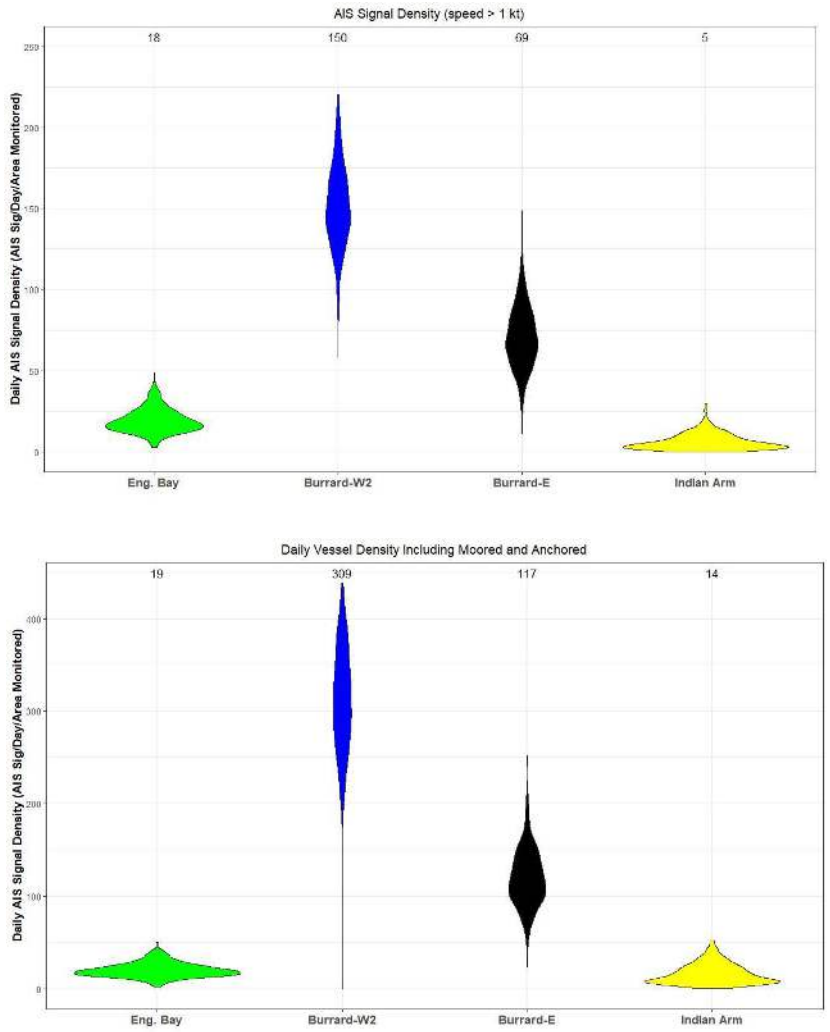


Figure 46. Daily AIS signal densities by location based on AIS data (Class A) within 3 km of each hydrophone. Panels depict moving vessels only (top) and all vessels (bottom) including moored, anchored, and vessels travelling < 1 knot. Median AIS densities are provided at the top of each plot.

Figure 47 shows the relationship between ambient noise levels plotted against the AIS moving vessel density at that time. Data in this figure constitute a representative sample of the >135,000 datapoints in this analysis. Consistent with the 2019 results, strong correlations were observed between SPL and moving vessel density estimates, especially at broadband and mid frequencies (<10 kHz). Thus, there is a strong positive relationship between moving vessel density and SPL with higher vessel density leading to higher SPL. The trend between SPL and vessel density was less strong at the English Bay location where broadband and the lowest decade band showed no relationship between SPL and vessel density. This is likely because of the combination of a large area monitored at this site (Table 4) and the higher number of anchored vessels contributing to the background sound pressure levels.

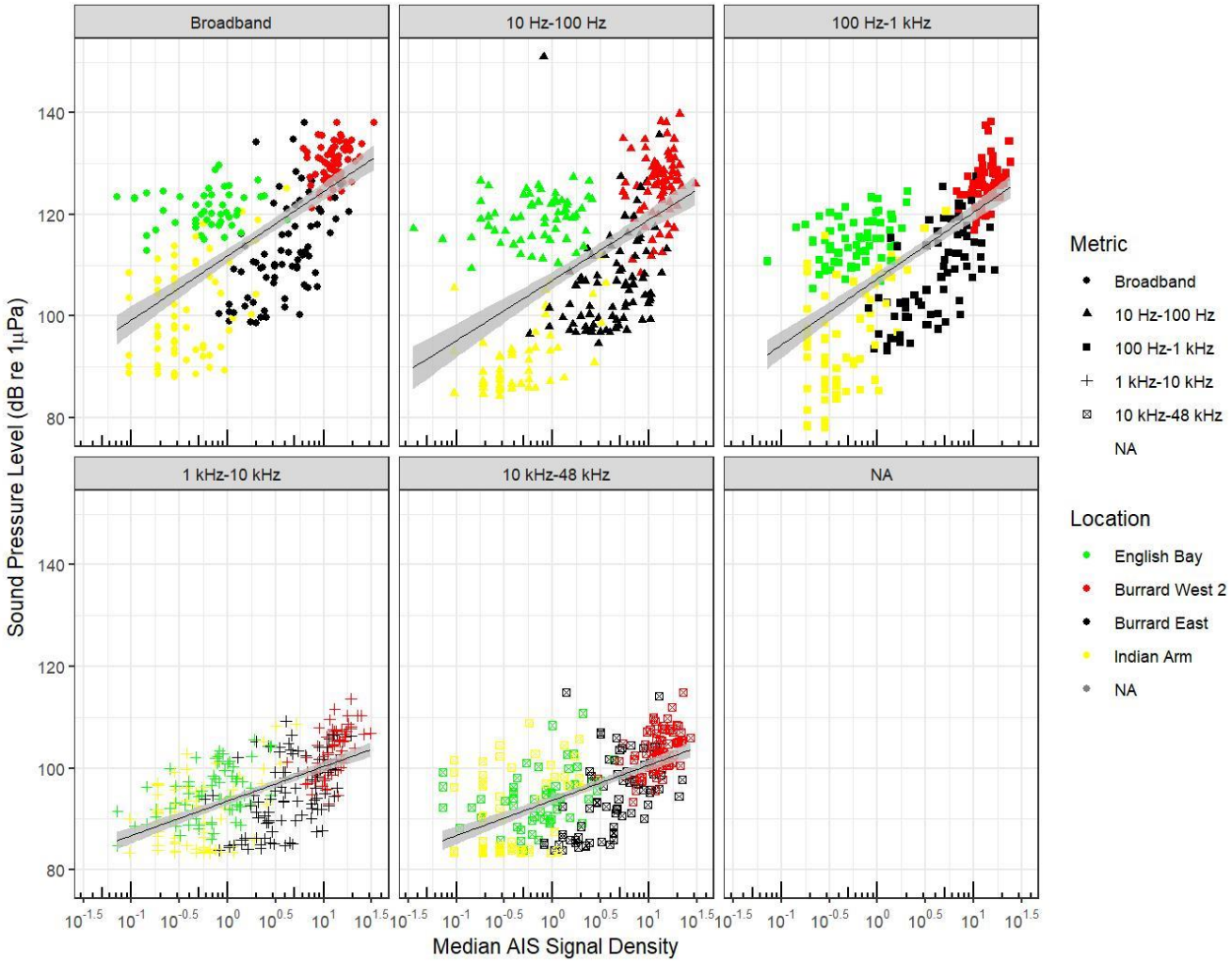


Figure 47. Relationship between moving vessel density per hour and SPL for broadband and decade band values at each location.

3.2 Burrard West 1 2019/2021 Comparison

The intent of the Burrard West 1 installation was comparison of underwater noise levels when cruise ships were present (2019) and not present due to the pandemic (2021). Due to technical failure of the Burrard West 1 hydrophone in the June-September deployment, the data period evaluated covered the end of the cruise ship season. To confirm the presence of cruise ships in the 2019 data, AIS data was used to identify the number of cruise ships within 3 km of the Burrard West 1 site for each day of the comparison period. While there were more cruise ships present in the beginning of the analysis period, there was at least one cruise ship present during every day of September and 19 days in October (Table 9). Only one day in November contained cruise ships and as such November 2nd through the 13th were not included in the analysis and monthly comparisons considered only September and October.

Table 9. Number of cruise ships within 3km of the Burrard West 1 site for each day of the comparison period.

September Date	Number of Cruise Ships	October Date	Number of Cruise Ships	November Date	Number of Cruise Ships
2019-09-23	4	2019-10-01	4	2019-11-01	1
2019-09-24	3	2019-10-02	1	2019-11-02	0
2019-09-25	5	2019-10-03	1	2019-11-03	0
2019-09-26	4	2019-10-04	1	2019-11-04	0
2019-09-27	3	2019-10-05	1	2019-11-05	0
2019-09-28	2	2019-10-06	2	2019-11-06	0
2019-09-29	6	2019-10-07	4	2019-11-07	0
2019-09-30	8	2019-10-08	4	2019-11-08	0
		2019-10-09	2	2019-11-09	0
		2019-10-10	0	2019-11-10	0
		2019-10-11	0	2019-11-11	0
		2019-10-12	0	2019-11-12	0
		2019-10-13	2	2019-11-13	0
		2019-10-14	2		
		2019-10-15	1		
		2019-10-16	1		
		2019-10-17	1		
		2019-10-18	1		
		2019-10-19	0		
		2019-10-20	0		
		2019-10-21	1		
		2019-10-22	1		
		2019-10-23	1		
		2019-10-24	1		
		2019-10-25	1		

		2019-10-26	0		
		2019-10-27	0		
		2019-10-28	0		
		2019-10-29	0		
		2019-10-30	0		
		2019-10-31	0		

The Burrard West 1 location is near to where cruise ships berth in the Port of Vancouver as well as the SeaBus terminal. To evaluate differences in ambient noise levels with (2019) and without (2021) cruise ship presence, decade band comparisons for ambient sound levels are shown in Table 10. As per section 2.2, the data were sub-sampled to include only data from September 23 – November 1. The 2019 values were subtracted from the 2021 values; thus, negative values represent decreases in ambient noise levels during the period without cruise ships.

Table 10. Descriptive statistics for the 2019 and 2021 noise levels at the Burrard West 1 location for the partial month of September and all of October. Shades of red indicate scale of decrease from 2019 to 2021. Shades of blue indicate scale of increase from 2019 to 2021.

	September						**October**					
	2019						**2019**					
Percentiles (%)	*5*	*25*	*50*	*75*	*95*	*Leq*	*5*	*25*	*50*	*75*	*95*	*Leq*
Broadband	123.2	127.4	130.7	134.7	142.4	137.2	122.4	126.6	130.1	134.2	142.7	137.3
10-100 Hz	119.4	123.6	126.2	128.6	135.5	131.5	118.0	121.7	124.9	128.4	138.4	133.6
100 Hz -1 kHz	118.3	123.2	127.6	132.0	140.2	134.6	118.9	123.0	126.7	130.9	139.5	133.7
1-10 kHz	106.4	112.7	119.3	124.9	133.2	127.6	108.0	112.9	118.6	123.8	133.5	127.6
10-48 kHz	93.9	100.2	109.4	118.5	129.3	125.0	93.2	98.6	108.1	117.4	128.0	123.0
	2021						**2021**					
Percentiles (%)	*5*	*25*	*50*	*75*	*95*	*Leq*	*5*	*25*	*50*	*75*	*95*	*Leq*
Broadband	121.1	125.0	128.5	133.1	140.7	134.5	124.2	126.9	129.2	132.9	140.4	135.0
10-100 Hz	115.3	120.4	122.8	126.2	132.2	128.4	119.5	122.3	124.2	126.3	131.8	129.6
100 Hz -1 kHz	117.6	122.0	125.8	130.6	138.5	132.0	120.6	123.7	126.5	130.6	138.4	132.3
1-10 kHz	107.7	113.5	119.1	124.8	133.9	126.8	112.4	115.7	119.7	124.6	133.2	126.6
10-48 kHz	95.3	100.9	108.6	117.0	127.8	120.4	94.5	100.3	107.4	115.2	126.3	119.1
	September Changes						**October Changes**					
Percentiles (%)	*5*	*25*	*50*	*75*	*95*	*Leq*	*5*	*25*	*50*	*75*	*95*	*Leq*
Broadband	-2.1	-2.4	-2.2	-1.6	-1.7	-2.6	1.8	0.3	-1.0	-1.3	-2.2	-2.4
10-100 Hz	-4.2	-3.2	-3.4	-2.5	-3.3	-3.1	1.5	0.6	-0.7	-2.2	-6.5	-4.0
100 Hz -1 kHz	-0.7	-1.2	-1.7	-1.4	-1.7	-2.7	1.7	0.7	-0.3	-0.3	-1.0	-1.4
1-10 kHz	1.3	0.8	-0.2	-0.1	0.7	-0.8	4.4	2.8	1.1	0.9	-0.3	-1.1
10-48 kHz	1.4	0.7	-0.8	-1.5	-1.5	-4.5	1.3	1.7	-0.7	-2.3	-1.7	-3.9

In general, there was a trend of decreasing noise levels in 2021 compared to 2019 at L_{50} and greater percentiles, as well as L_{eq} values. Decreases were also more likely in September than October and at broadband and the first two decade bands. It is plausible that the decreases in decade-band noise levels in 2021 were partly attributable to the lack of cruise ships in the area, particularly those with high-frequency anti-fouling devices installed (SMRU Consulting, 2019). However, it could also have been attributable to local construction conditions or other sources unrelated to cruise ship presence.

Third-octave plots for the entire comparison period are shown in Figure 48. These plots indicate lower overall noise levels in bands <500 Hz and a considerable (~10 dB) decrease in ambient noise levels within the frequency range of the antifouling device (20-30 kHz bands). However, data from nearly all deployments in the 2019 study experienced a roll-off in sound levels around 500 Hz. The suspected cause of the 500 Hz roll-off was not conclusive but was present in all 2019 recording. Thus, for lower frequencies determining the cause of the decrease between years is a challenge and firm conclusions in these band are not possible.

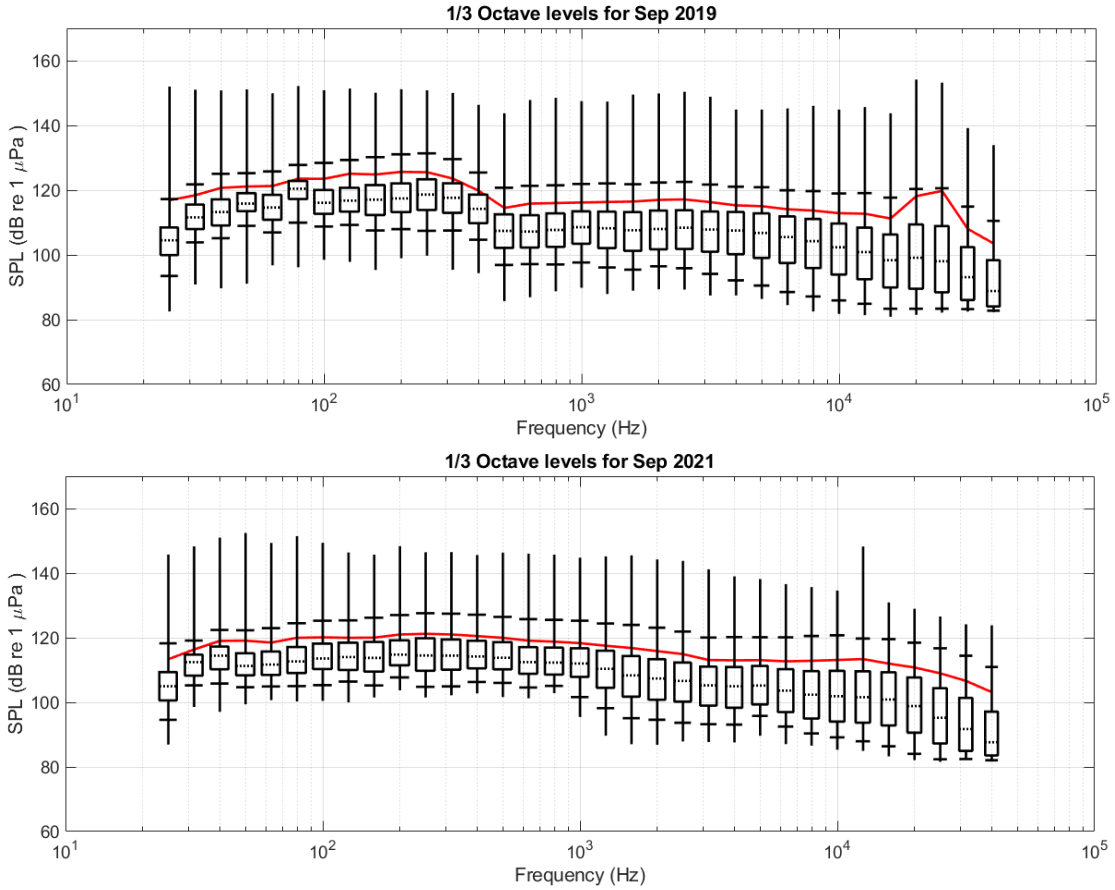


Figure 48. Third-octave sound levels at the Burrard West 1 site measured between September 23rd and November 1st in 2019 (top) and 2021 (bottom). Red line indicates mean RMS level in each third octave bin, vertical extents represent the minimum and maximum values recorded, 'whisker' edges represent the 5th and 95th percentiles, box edges represent 25thand 75th percentiles and dashed lines represent median noise levels.

3.3 Bulker at Anchor

A bulker at anchor in English Bay was measured as per the methodology described in Section 2.3. The recording period commenced at approximately 19:00:00 UTC and ceased at 23:00:00 UTC. During this period currents were higher than expected and the resulting data needed to be trimmed to exclude flow noise. The final analysis therefore included data from the period between 19:30 and 19:59 UTC only. Broadband received levels for all four hydrophones are shown in Figure 49. Despite extensive data cleaning and several hours of data collection, values below 100 Hz showed evidence of flow noise, and as such should be considered as representative levels only.

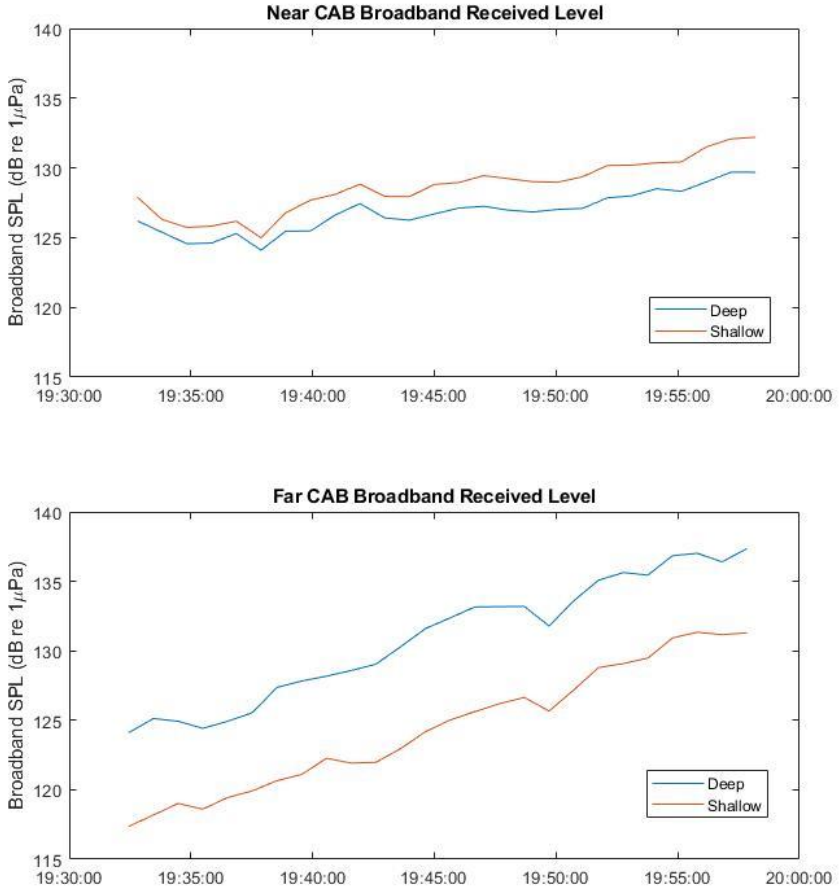


Figure 49. Broadband received levels for the CABs deployed 'near' to (top panel) and 'far' from (lower panel) the bulker.

Received levels at the two 'far' hydrophones differed by 10 dB due to heavy current in the water column. Visual inspection of the data indicated that the deeper hydrophone experienced considerably

more flow noise than the shallower hydrophone. For this reason, only data from the shallower hydrophone were included. As per ANSI standards, data from the 'near' hydrophone CABs were averaged. The distance between the near CAB, as calculated with the GPS on the CAB, and the bulker varied between 87-171 m. However, measurements taken with a digital range finder during the deployment indicated a minimum range of 30 meters between the vessel and the CAB. The discrepancy was most likely caused by uncertainty about where on the ~180m vessel the AIS beacon was located. To account for this, all ranges were adjusted downward by 57 m.

Third octave source levels associated with the vessel were calculated based on the ANSI standard are shown in Figure 50. Broadband source levels are not reported due to concerns about flow noise.

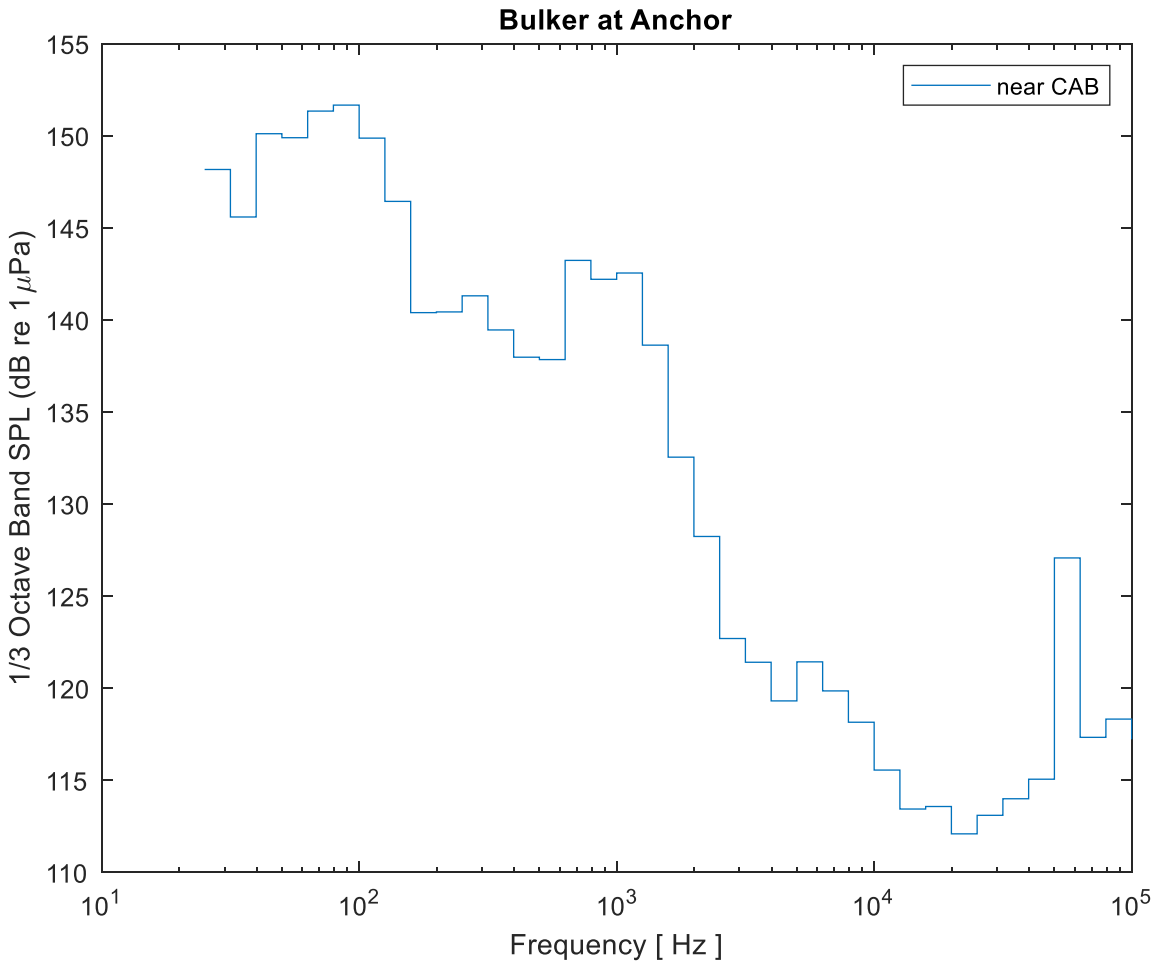


Figure 50. Third octave source levels for the bulker at anchor.

One-third octave source levels of the bulker at anchor were broadly comparable to levels recorded for the containership measured in the in 2019 study (SMRU Consulting, 2019). Source levels in the 500 Hz- 1.5 kHz range were between 140 and 145 dB for the bulker and in the same range when the containership was on (140 dB) and off (145 dB) shore power.

3.4 Cetacean Presence Using PAM

A summary of all cetacean detections is provided in Table 11. An example of a PAM-detected harbor porpoise (*Phocoena phocoena*) click train from English Bay is provided in Figure 51. Harbor porpoise were detected at English Bay in all months of the year where data was available. The spring months began with moderate porpoise activity similar to the previous project cycle. The fall and winter months showed the greatest number of porpoise detections. In fact, these are the highest numbers recorded yet in the program (Figure 52).

A total of 144 porpoise days were recorded at English Bay and again this location recorded the most activity. The other remaining three sites recorded a total of 18 porpoise days (7 at Burrard East, 8 at Burrard West 2, and 3 at Indian Arm).

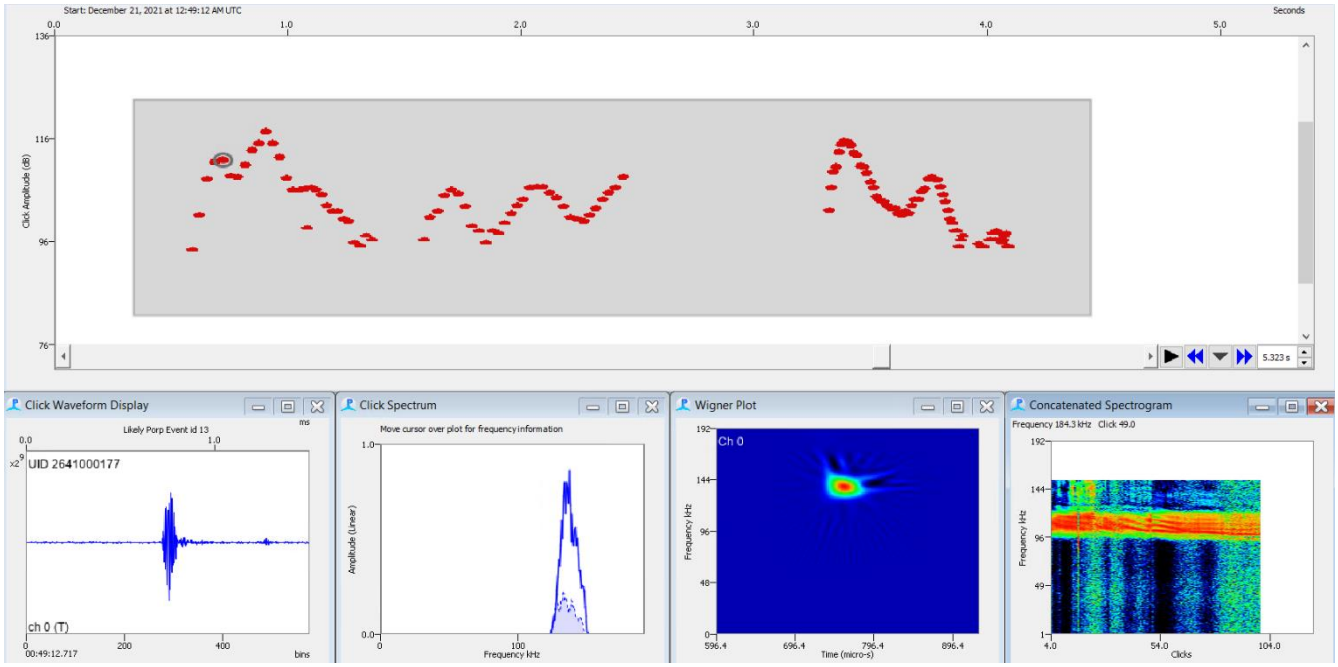


Figure 51. Example of a porpoise detection event using PAMGuard software. The top panel shows trend in amplitude (y-axis) as animals sweep past the hydrophone. Lower panels provide click diagnostics including (left to right) waveform, click spectrum, Wigner plot and concatenated spectrogram.

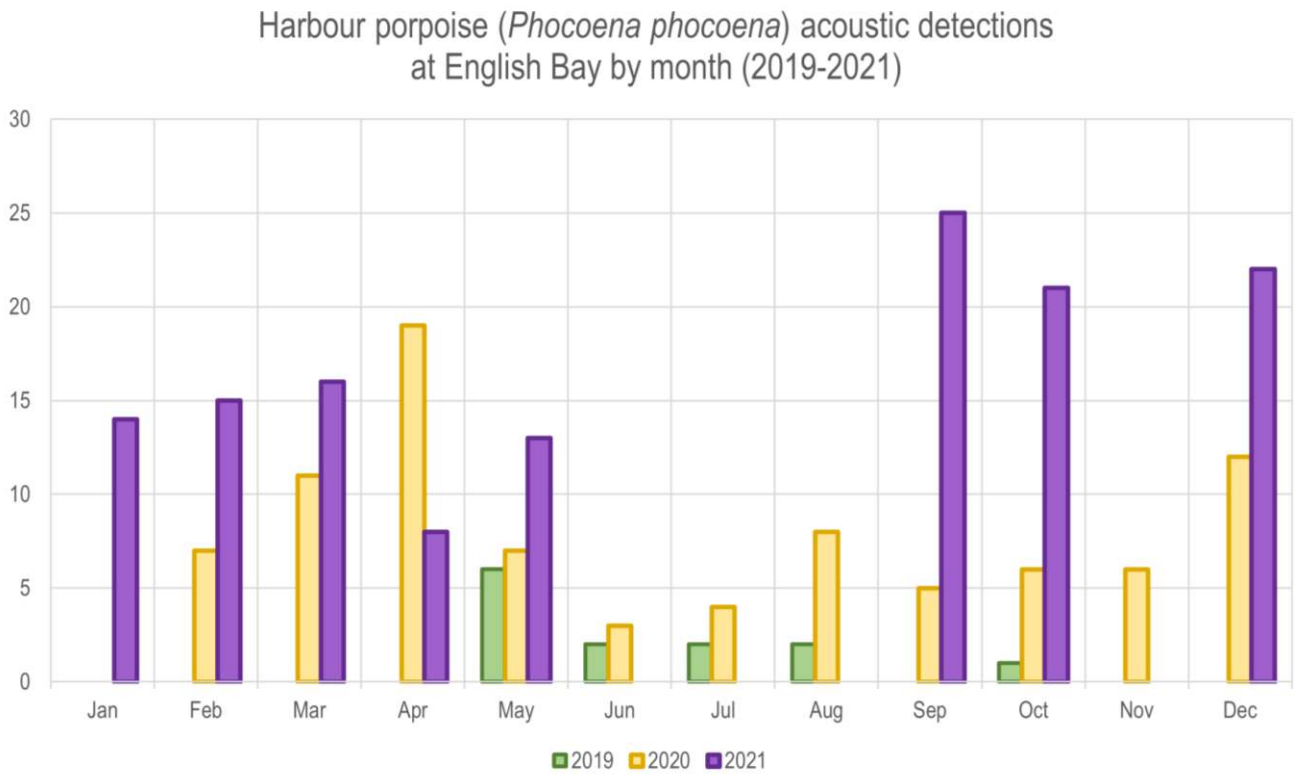


Figure 52. Harbor porpoise detections for 2021 showed a distinctly different pattern than the previous year, with the highest numbers recorded in the in fall and winter months. Note that months without bars indicate months with no data available, not a lack of porpoise.

Table 11. Marine mammal detection results for this project year (beginning February 2021). Both PAMGuard 'Whistle and Moan' detector and SoundTrap Click detector results are presented. Locations with an (*) represent partial months of data associated with data loss or deployment dates.

Site	Month	# Probable Days – *Clicks (Porpoise)*	# Probable Days – Whistles (other cetaceans)
English Bay	February 2021*	8	1
	March 2021	16	2
	April 2021	8	0
	May 2021	13	0
	June 2021	*No data*	0
	July 2021	*No data*	1
	August 2021*	*No data*	*No data*
	September 2021	25	0
	October 2021	23	0
	November 2021*	4*	0
	December 2021	22	1
	January 2022	18	3
	February 2022	7	2
	Year Total	***144***	***10***
** = incomplete data*			
Burrard East	February 2021*	0	0
	March 2021	2	0
	April 2021	1	0
	May 2021	0	0
	June 2021	*No data*	0
	July 2021	*No data*	0
	August 2021*	*No data*	*No data*
	September 2021	0	0
	October 2021	1	0
	November 2021	0	0
	December 2021	1	0
	January 2022	2	0
	February 2022	0	0
	Year Total	***7***	***0***

Site	Month	# Probable Days – *Clicks (Porpoise)*	# Probable Days – Whistles (other cetaceans)
Burrard West 2	February 2021*	1	0
	March 2021	2	0
	April 2021	0	0
	May 2021	3	0
	June 2021	*No data*	0
	July 2021	*No data*	*No data*
	August 2021*	*No data*	*No data*
	September 2021	*2*	0
	October 2021	0	0
	November 2021	0	0
	December 2021	0	0
	January 2022	0	0
	February 2022	0	1
	Year Total	***8***	***1***
Indian Arm	February 2021*	0	0
	March 2021	1	0
	April 2021	0	0
	May 2021	0	0
	June 2021	*No data*	0
	July 2021*	*No data*	0
	August 2021*	*No data*	*No data*
	September 2021	0	1
	October 2021	0	0
	November 2021	1	0
	December 2021	0	0
	January 2022	1	0
	February 2022	0	1
	Year Total	***3***	***2***

Visual sightings of killer whales are provided in Table 12. One of these visual sightings was also detected acoustically. Killer whale acoustic detections were confirmed on 12 separate days, during all four hydrophone deployments. A summary of detections is provided in Table 13. Most detections occurred at the English Bay site (10), while Burrard West 2 and Indian Arm recorded one and two events respectively. This year was the first time during this monitoring program that a detection was recorded at Indian Arm. The longest event lasted one hour and fifty-eight minutes while the shortest was less than one minute.

Three different killer whale ecotypes were detected during this project year. For the first time in this monitoring program, Northern Resident Killer Whales (NRKW) were identified. These detections occurred in January and February 2022, and their presence was captured on the English Bay, Burrard West 2 and Indian Arm hydrophones, providing a unique insight into their movement. Other ecotypes included Southern Resident Killer Whales (SRKW) and transient killer whales (also known as Bigg's ecotype). One killer whale event on March 2nd, 2021 could not be identified due the high noise and faint calls. SRKW were identified in spring, summer, and winter months for a total of three separate events. Transients were identified in fall and winter months making two visits. The NRKW event recorded on February 7th, 2022 produced an extremely clear recording of Northern Resident vocalizations due to very low background noise in Indian Arm during nighttime hours (Figure 53).

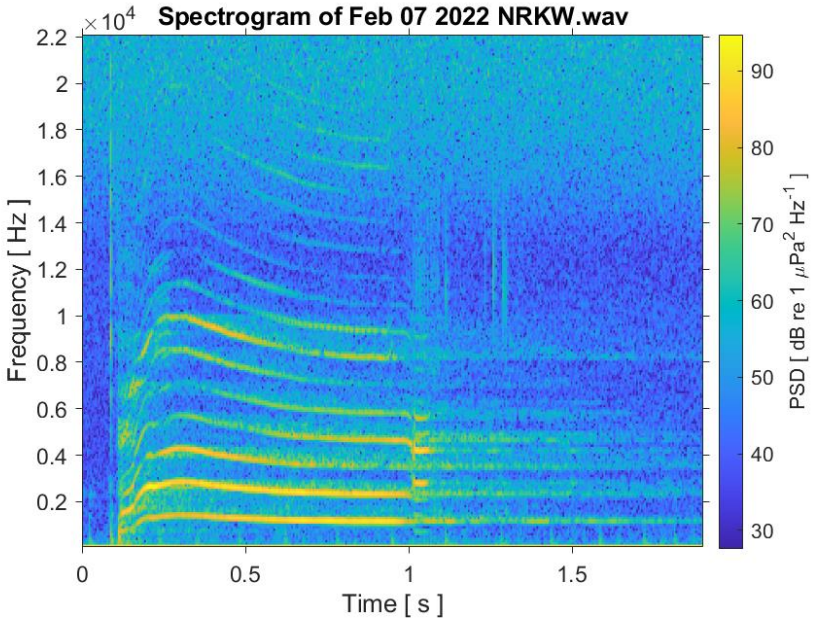


Figure 53. Northern Resident killer whale call recorded on February 7th, 2022 at the Indian Arm site.

Table 12. Observed visual sightings of killer whales in Burrard Inlet. A single visual sighting was also detected in the acoustic recordings.

Date	Time (Local)	Notes/comments	PAM Detection?
2021-07-30	20:00	5-6 Biggs Orca heading north-east between Bowen Island and West Vancouver	No
2021-10-10	16:00	2 Orca swimming near Coal Harbor seaplane docks	No
2021-11-29	2:00 PM	5-6 Orca swimming near Brockton Point, heading towards Coal Harbor	No
2022-01-25	11:00 AM	12 Orca in Burrard Inlet heading towards Indian Arm	Yes

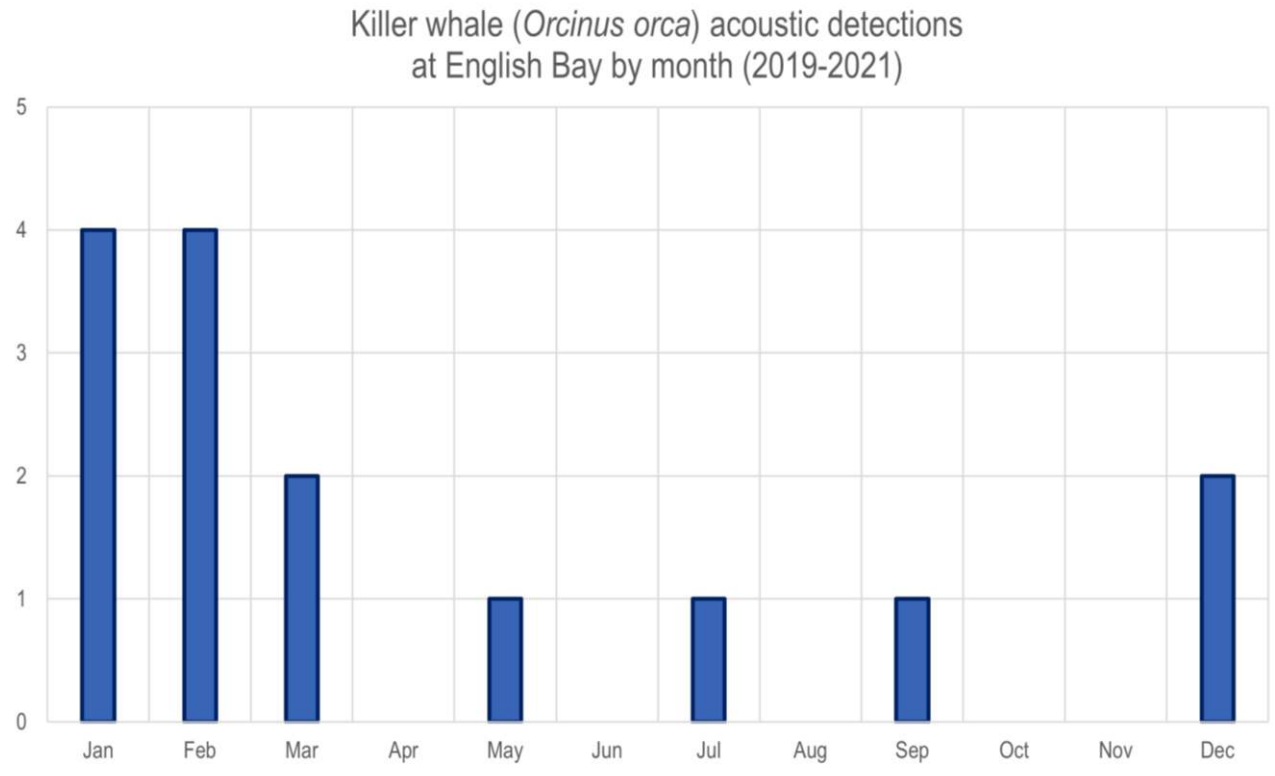


Figure 54. Cumulative killer whale events by month at English Bay from three years of PAM data collection. Winter months show the greatest number of detections.

Table 13. Acoustic detection of killer whales for the project year.

Deployment Number	Location	Date	Start time of recording (local)	End time of recording (local)	Event Duration (min)	Ecotype
1	English Bay	February 20th, 2021	4:04 AM	4:05 AM	01:00	Transient
1	English Bay	March 2nd, 2021	10:54 AM	11:10 AM	16:00	Unknown
1	English Bay	March 13th, 2021	9:49 PM	12:39 AM	**170:00**	SRKW
2	English Bay	July 17th, 2021	12:01 AM	12:21 AM	20:00	SRKW
3	Indian Arm	September 2nd, 2021	8:44 PM	8:46 PM	02:00	Probable Transient
4	English Bay	December 21st, 2021	9:11 PM	9:16 PM	05:00	SRKW
4	English Bay	January 24th, 2022	9:37 PM	10:05 PM	28:00	Probable NRKW
4	English Bay	January 26th, 2022	6:12 PM	6:25 PM	13:00	NRKW
4	English Bay	January 30th, 2022	5:15 PM	5:31 PM	16:00	NRKW
4	English Bay	Feb 5th, 2022	9:47 PM	11:45 AM	**118:00**	NRKW
4	English Bay	Feb 6th, 2022	7:43 PM	7:45 PM	02:00	NRKW
4	Burrard West 2	Feb 6th, 2022	9:37 PM	9:53 PM	16:00	NRKW
4	Indian Arm	Feb 7th, 2022	12:50AM	2:25 AM	**95:00**	NRKW

4 Discussion

This report represents the third continuous year of acoustic monitoring in Burrard Inlet. This year, four of the original five sites measured in Year 1 of the study were chosen to provide year-round acoustic monitoring. The fifth site (Burrard West 1) was monitored only from September to November and a new site in Burrard Inlet was deployed in 2021 by ONC and assessed for this report. Moorings were adapted and improved in this year and 100% recovery of hydrophones achieved. Between the five SoundTrap hydrophones deployed by SMRU, a total of 1,290 days of monitoring data was collected, despite some loss of data due to technical data-related and manufacturer issues.

Inter-site differences in median SPL continued to exceed 30 dB, with the site at Burrard West 1, (close to the SeaBus route) having the highest noise levels. The lowest levels were recorded at Indian Arm, which has minimal industrial activity and is the only site with an annual average median SPL under 100 dB re 1µPa. Comparison of SPL metrics with data collected in previous years, highlighted no significant differences, except for Burrard East, where median broadband levels varied by more than 5 dB across years with 2020 being the loudest.

Industrial noise may have continued to contribute to noise levels outside of the February-May period, as seen in previous project years. Tidally induced flow noise near the Burrard East deployment site are the likely cause of elevated noise levels in the first deployment. Upon inspection of the raw audio files, this noise is a continuous (non-pulsed), very low frequency rumbling sound. This phenomenon can be seen in the long-term spectrograms indicated by bright red in the lower frequencies (Figure 22).

Periods of excess noise that were indicated by the relationship of 10-100 Hz noise levels and tidal cycles were unique to the first deployment of the Burrard East unit in the 2021 project year. Other deployments (in this year and previous years) have not shown similar patterns, which lead to the exclusion of this data in reporting. The Burrard East site had previously been identified as being in a region of Burrard Inlet which experiences very fast tidal currents, and visual evidence of upwelling has been noted by SMRU and TWN crews working in the area.

This was the first year including data from the ONC node and, like many startup monitoring systems, there were numerous challenges processing and interpreting acoustic data from this location. The system did not appear to have a flat frequency response above 48 kHz and calibration information at these higher frequencies was not provided. Therefore, values above 48 kHz are considered suspect. Additionally, other sampling instruments at this node resulted in considerable self-noise. Intermittent broadband noise associated with CTD pumps was present as were narrowband sounds attributable to the ADCP. Even so, within the comparison range of the SoundTrap (10 Hz – 48 kHz) the robust metrics chosen allowed for the exploration of daily, monthly, and annual trends. The values of each were relatively consistent with what was recorded at the Burrard West 1 Location previously and in this document. Furthermore, the low sensitivity above 50 kHz meant that broadband comparisons were likely comparable to the 48 kHz recordings made by the SoundTrap. However, future analyses of these data should exclude frequencies outside of the flat response of this hydrophone.

Increased daytime noise levels were visible at the English Bay, Burrard East, and Indian Arm locations. These increases were most visible in the highest decade bands consistent with small vessel traffic. Investigations of data from the Burrard West 2, Burrard West 1 and ONC hydrophones on the daily scale predominantly indicated the presence of SeaBus noise. As the only non-operational period of the SeaBus coincides with nighttime hours, any daily increase in noise associated with recreational vessels near these locations are difficult to differentiate. There were no overt, easily describable, weekly rhythms in the data. However, a very marginal weekly rhythm may be present at the Burrard West 2 site which showed a slight decrease on weekends, possibly related to lower rates of industrial activity during these periods. Indian Arm showed the opposite trend, with weak evidence of an increase in noise on Saturdays and Sundays. This may be caused by an increase in recreational boating activity on the weekends. However, confirming the presence of these trends would require a more advanced statistical approach outside of the scope of this report. If present, determining whether the source of increased daytime activity was recreational vessels could involve a small boat detector as has been implemented at the Lime Kiln location (SMRU Consulting, 2019).

The comparison of sound levels near the cruise ship terminal between 2019 and 2021 took place in September and October which is the shoulder of the cruise ship season. To ensure a fair comparison between periods with and without cruise ships, AIS data from 2019 was used to confirm the presence of vessels in the 2019 dataset and all data past the November 1, when the last cruise ship was in port were truncated. Even in the shoulder season, the analysis indicated a small but appreciable decrease in overall ambient noise between the comparison periods. This was especially prominent in the upper octaves where the lack of anti-fouling devices during the 2021 survey period was clear. However, in both years the noise regime was dominated by noise from the SeaBus. Thus, except for the acoustic antifouling device, the overall impact of the exclusion of cruise ships from that location was relatively small, especially considering the overall median broadband noise levels were >118 dB.

Porpoise monitoring in 2021 showed a substantial increase over the previous year despite the fact that data were missing for 3.5 months from English Bay. This suggests that the increase in porpoise activity versus the previous project cycle is even greater than reported here. The highest number of porpoise click detections occurred from September to December. This differed from the previous project cycle where the lowest activity of the year was recorded in the winter months. Reasons for this change could be related to prey availability or may simply indicate a wider hydrophone network is needed to achieve better sampling of local populations. Continuation of porpoise monitoring at English Bay is recommended to further investigate any possible trends.

Killer whale detections this year were the greatest since this monitoring program began. There were twelve detection positive days in 2021 vs. four in 2020 and just two in 2019. This was also the first year where there were more acoustic detections of killer whales than visual detections, which signifies the value of an acoustic monitoring program in addition to visual sightings. The majority of killer whale acoustic detections that have occurred since the program began have been in the winter months, from December through March, with only three detections outside of this period. This is particularly notable as this is the opposite of what would be expected based on historical visual sightings of all killer whales ecotypes in the Salish Sea, which indicates the peak season is typically April-September (Shields *et al.*, 2018). For the second year in a row, Southern Resident Killer Whale (SRKW) were confirmed in the month of December. In the previous project year, a detection occurred

on December 25th, 2020 and this year SRKW were recorded on December 21st, 2021. While this is only two data points, it may indicate some level of seasonality in SRKW and should continue to be monitored in future years.

Of particular note during this monitoring year was the detection of Northern Resident Killer Whales (NRKW) between January 24th, 2022 and February 7th, 2022. NRKW are typically sighted in the inside waters between northern Vancouver Island and mainland British Columbia but have been documented as far south as Washington State on the outer coast (Olesiuk *et al.*, 2005). Their population is estimated to be around 300 individuals. This acoustic detection represents movement near the southern extent of their range and outside of what would be traditionally be considered critical habitat for the ecotype, albeit out of season with the salmon runs on which they typically feed (Sato *et al.*, 2021). Dr. John Ford and Candice Emmons at NOAA confirmed the calls to be that of the A-Clan of NRKW, one of three clans in the ecotype.

5 Acknowledgements

We gratefully acknowledge funding from the ECHO Program of the Vancouver Fraser Port Authority and the Tsleil-Waututh Nation. Scheduling and coordinating this project with numerous groups would not have been possible without Krista Trounce and Derek White of the Vancouver Fraser Port Authority. Spencer Taft and Graham Nicolas of the Tsleil-Waututh Nation along with their entire crew were instrumental in deployment and retrieval of hydrophones. We are extremely grateful for the able assistance provided in the field by Rod MacVicar who filled in the gaps on short notice when needed. We thank John Ford, Candice Emmons, Jeanne Hyde and Jen Wladichuck for help in identifying NRKW calls.

Appendix

Appendix 1. English Bay, monthly SPL (dB re 1µPa) by study month for each broadband and decade frequency band metric. Months with incomplete data are indicated by an asterisk.

Location	*SPL Metric*	*Month*	*0.01-48 kHz*	*0.01-0.1 kHz*	*0.1-1 kHz*	*1-10 kHz*	*10-48 kHz*
English Bay	**Min**	Feb 2021*	113.5	112.0	104.0	94.6	84.4
	L_{95}	Feb 2021*	115.7	114.0	108.3	99.5	86.1
	L_{75}	Feb 2021*	117.4	115.8	111.0	102.2	89.6
	L_{50}	Feb 2021*	119.2	117.6	112.9	104.8	92.7
	L_{25}	Feb 2021*	121.4	119.8	114.9	107.4	96.2
	L_{5}	Feb 2021*	126.7	124.7	120.8	113.6	104.1
	Max	Feb 2021*	147.4	145.6	142.3	138.1	131.5
	Mean	Feb 2021*	123.7	121.9	118.0	111.3	103.4
English Bay	**Min**	Mar 2021	109.7	107.1	100.2	93.3	83.2
	L_{95}	Mar 2021	113.3	111.4	106.9	98.5	85.6
	L_{75}	Mar 2021	117.3	115.4	110.8	102.2	88.9
	L_{50}	Mar 2021	119.9	118.0	113.8	105.2	91.7
	L_{25}	Mar 2021	122.8	120.7	117.4	109.0	95.7
	L_{5}	Mar 2021	128.0	125.4	123.3	116.4	107.0
	Max	Mar 2021	156.8	156.5	146.7	139.8	134.0
	Mean	Mar 2021	125.1	123.1	119.9	112.9	104.1
English Bay	**Min**	Apr 2021	110.0	108.1	102.1	93.6	83.2
	L_{95}	Apr 2021	114.3	112.6	106.6	98.6	85.3
	L_{75}	Apr 2021	116.8	114.8	110.7	102.6	88.4
	L_{50}	Apr 2021	119.0	117.1	113.1	105.5	91.7
	L_{25}	Apr 2021	121.7	119.6	115.7	108.8	95.9
	L_{5}	Apr 2021	127.0	124.6	122.3	115.6	105.5
	Max	Apr 2021	152.9	152.2	147.0	140.8	134.5
	Mean	Apr 2021	124.5	122.2	119.6	113.9	104.4
English Bay	**Min**	May 2021	107.1	105.9	99.3	89.2	82.7
	L_{95}	May 2021	112.6	110.8	105.5	95.8	84.1
	L_{75}	May 2021	115.7	113.8	108.8	99.4	87.4
	L_{50}	May 2021	118.2	116.5	111.4	102.7	91.0
	L_{25}	May 2021	121.4	119.5	114.9	107.6	96.0
	L_{5}	May 2021	127.2	124.5	122.3	116.3	106.7
	Max	May 2021	154.0	152.4	147.6	142.9	138.2
	Mean	May 2021	124.2	121.9	119.1	113.4	105.5

Location	*SPL Metric*	*Month*	*0.01-48 kHz*	*0.01-0.1 kHz*	*0.1-1 kHz*	*1-10 kHz*	*10-48 kHz*
English Bay	**Min**	Jun 2021	111.4	109.4	102.4	88.2	83.1
	L_{95}	Jun 2021	115.4	113.8	107.4	95.0	83.7
	L_{75}	Jun 2021	117.9	116.3	110.3	99.6	85.7
	L_{50}	Jun 2021	120.1	118.4	112.9	103.3	88.6
	L_{25}	Jun 2021	122.9	121.3	116.1	107.3	93.7
	L_{5}	Jun 2021	128.0	126.6	122.1	115.1	104.8
	Max	Jun 2021	147.0	146.4	140.7	137.8	135.8
	Mean	Jun 2021	123.5	121.9	117.7	110.8	101.7
English Bay	**Min**	Jul 2021	110.0	109.2	101.6	87.1	83.1
	L_{95}	Jul 2021	115.4	113.8	108.3	94.6	83.9
	L_{75}	Jul 2021	117.3	115.6	110.8	99.6	86.7
	L_{50}	Jul 2021	119.0	117.2	113.1	102.1	89.2
	L_{25}	Jul 2021	121.2	119.1	115.9	105.2	92.9
	L_{5}	Jul 2021	126.2	123.9	121.7	112.3	102.9
	Max	Jul 2021	149.7	149.6	142.0	138.4	131.7
	Mean	Jul 2021	122.4	120.4	117.2	109.9	101.4
English Bay	**Min**	Aug 2021*	111.3	110.0	103.4	94.9	85.0
	L_{95}	Aug 2021*	114.6	113.0	106.7	97.7	85.6
	L_{75}	Aug 2021*	117.9	115.8	109.8	103.5	88.4
	L_{50}	Aug 2021*	119.9	117.6	112.8	109.1	93.4
	L_{25}	Aug 2021*	122.0	119.5	116.6	113.1	99.3
	L_{5}	Aug 2021*	129.1	123.7	123.9	124.1	109.1
	Max	Aug 2021*	152.6	142.7	146.2	150.6	137.5
	Mean	Aug 2021*	125.2	120.8	119.7	120.6	107.4
English Bay	**Min**	Sep 2021	108.4	106.0	100.2	85.4	84.8
	L_{95}	Sep 2021	114.8	113.2	106.6	95.2	85.7
	L_{75}	Sep 2021	118.7	117.0	111.3	100.5	89.5
	L_{50}	Sep 2021	121.0	119.2	114.7	105.2	93.8
	L_{25}	Sep 2021	123.5	121.4	117.8	110.0	99.2
	L_{5}	Sep 2021	129.6	125.9	125.1	119.5	110.6
	Max	Sep 2021	155.5	155.2	146.1	142.2	135.1
	Mean	Sep 2021	126.2	123.8	121.0	116.2	107.7
English Bay	**Min**	Oct 2021	114.7	112.9	105.4	95.1	85.6
	L_{95}	Oct 2021	118.2	116.3	111.4	102.0	88.9
	L_{75}	Oct 2021	120.4	118.5	114.3	105.1	92.9
	L_{50}	Oct 2021	122.3	120.3	116.3	107.5	96.3
	L_{25}	Oct 2021	124.5	122.5	118.8	110.7	100.7
	L_{5}	Oct 2021	130.6	128.1	124.7	118.4	110.0
	Max	Oct 2021	151.3	149.6	148.7	145.0	141.7
	Mean	Oct 2021	126.4	124.3	121.1	115.6	108.4

Location	*SPL Metric*	*Month*	*0.01-48 kHz*	*0.01-0.1 kHz*	*0.1-1 kHz*	*1-10 kHz*	*10-48 kHz*
English Bay	**Min**	Nov 2021*	119.2	116.7	112.0	93.4	87.8
	L_{95}	Nov 2021*	120.8	118.5	115.3	97.4	92.0
	L_{75}	Nov 2021*	122.9	120.6	117.6	106.3	96.1
	L_{50}	Nov 2021*	124.3	121.9	119.4	109.2	98.8
	L_{25}	Nov 2021*	125.7	123.2	121.3	112.3	101.7
	L_{5}	Nov 2021*	128.7	125.3	125.9	117.9	106.1
	Max	Nov 2021*	144.1	139.5	141.6	138.0	127.3
	Mean	Nov 2021*	125.5	122.7	121.7	113.3	103.0
English Bay	**Min**	Dec 2021	116.1	115.2	108.0	94.8	85.7
	L_{95}	Dec 2021	120.7	119.0	113.5	103.2	89.0
	L_{75}	Dec 2021	122.7	121.2	115.7	106.2	92.0
	L_{50}	Dec 2021	124.5	122.9	117.9	109.2	94.8
	L_{25}	Dec 2021	126.2	124.7	120.0	112.3	99.0
	L_{5}	Dec 2021	129.3	127.4	124.5	118.4	107.7
	Max	Dec 2021	152.9	151.3	148.5	141.3	135.9
	Mean	Dec 2021	126.9	125.1	121.4	114.3	104.6
English Bay	**Min**	Jan 2022	116.7	113.2	107.9	95.8	85.4
	L_{95}	Jan 2022	120.3	117.6	114.3	104.7	89.6
	L_{75}	Jan 2022	123.1	121.1	117.7	108.2	93.3
	L_{50}	Jan 2022	125.7	123.6	120.1	112.0	96.6
	L_{25}	Jan 2022	128.1	126.2	122.4	115.1	102.1
	L_{5}	Jan 2022	131.3	129.8	125.6	118.7	110.7
	Max	Jan 2022	153.9	148.2	150.0	148.2	142.0
	Mean	Jan 2022	128.1	126.0	122.8	116.5	107.9

Appendix 2. Burrard West 2, monthly SPL (dB re 1µPa) by study month for each broadband and decade frequency band metric. Months with incomplete data are indicated by an asterisk.

Location	*SPL Metric*	*Month*	*0.01-48 kHz*	*0.01-0.1 kHz*	*0.1-1 kHz*	*1-10 kHz*	*10-48 kHz*
Burrard West 2	**Min**	Feb 2021*	129.3	123.2	123.5	117.8	96.1
	L_{95}	Feb 2021*	131.7	125.9	125.9	120.1	98.2
	L_{75}	Feb 2021*	133.0	128.9	128.6	125.1	100.6
	L_{50}	Feb 2021*	134.5	130.8	130.0	126.1	102.9
	L_{25}	Feb 2021*	135.7	132.8	131.9	127.6	106.3
	L_{5}	Feb 2021*	139.5	136.1	136.3	129.9	116.3
	Max	Feb 2021*	158.4	153.0	154.9	152.5	150.8
	Mean	Feb 2021*	136.5	132.7	132.9	128.1	118.1
Burrard West 2	**Min**	Mar 2021	118.6	112.9	115.1	108.8	93.8
	L_{95}	Mar 2021	125.7	121.9	121.8	114.8	96.7
	L_{75}	Mar 2021	129.3	125.3	125.4	119.7	99.7
	L_{50}	Mar 2021	132.4	128.2	127.8	122.5	102.9
	L_{25}	Mar 2021	134.5	131.4	129.6	125.3	106.8
	L_{5}	Mar 2021	139.5	138.3	135.4	129.0	115.7
	Max	Mar 2021	156.8	154.7	152.9	149.9	143.7
	Mean	Mar 2021	135.0	131.9	131.0	125.3	111.9
Burrard West 2	**Min**	Apr 2021	119.3	113.4	116.8	110.4	93.4
	L_{95}	Apr 2021	125.5	119.7	121.9	116.1	96.7
	L_{75}	Apr 2021	129.4	125.7	125.1	121.0	99.7
	L_{50}	Apr 2021	131.4	127.9	126.7	123.1	102.9
	L_{25}	Apr 2021	133.2	130.1	128.4	124.5	106.9
	L_{5}	Apr 2021	137.9	133.4	135.3	128.5	114.7
	Max	Apr 2021	155.8	155.0	151.7	146.6	139.8
	Mean	Apr 2021	134.0	130.3	130.5	125.1	111.5
Burrard West 2	**Min**	May 2021	120.2	113.8	115.3	109.5	93.4
	L_{95}	May 2021	125.1	120.3	120.8	115.7	95.7
	L_{75}	May 2021	128.8	124.8	124.6	119.3	98.9
	L_{50}	May 2021	130.6	127.0	126.2	121.5	102.6
	L_{25}	May 2021	132.4	129.5	128.1	123.6	107.3
	L_{5}	May 2021	138.2	133.8	135.4	128.8	115.7
	Max	May 2021	158.2	156.7	153.2	151.6	146.3
	Mean	May 2021	134.0	130.1	130.6	125.0	113.5

Location	*SPL Metric*	*Month*	*0.01-48 kHz*	*0.01-0.1 kHz*	*0.1-1 kHz*	*1-10 kHz*	*10-48 kHz*
Burrard West 2	**Min**	Jun 2021	93.2	85.1	80.8	85.7	91.0
	L_{95}	Jun 2021	124.7	118.2	122.2	114.0	97.4
	L_{75}	Jun 2021	133.0	130.3	126.9	121.5	100.6
	L_{50}	Jun 2021	134.4	132.7	128.3	122.9	104.3
	L_{25}	Jun 2021	135.6	133.9	129.6	124.4	108.6
	L_{5}	Jun 2021	138.1	135.9	134.2	127.8	114.8
	Max	Jun 2021	161.5	160.4	155.9	152.4	145.2
	Mean	Jun 2021	135.7	133.2	131.0	125.4	113.1
Burrard West 2	**Min**	Jul 2021	-	-	-	-	-
	L_{95}	Jul 2021	-	-	-	-	-
	L_{75}	Jul 2021	-	-	-	-	-
	L_{50}	Jul 2021	-	-	-	-	-
	L_{25}	Jul 2021	-	-	-	-	-
	L_{5}	Jul 2021	-	-	-	-	-
	Max	Jul 2021	-	-	-	-	-
	Mean	Jul 2021	-	-	-	-	-
Burrard West 2	**Min**	Aug 2021*	115.6	106.0	112.5	100.1	90.9
	L_{95}	Aug 2021*	117.0	110.2	114.4	103.7	92.3
	L_{75}	Aug 2021*	119.9	112.5	117.8	108.7	94.9
	L_{50}	Aug 2021*	123.1	114.5	121.3	112.6	99.3
	L_{25}	Aug 2021*	125.9	117.4	124.4	116.7	103.8
	L_{5}	Aug 2021*	131.7	125.4	130.1	122.4	111.5
	Max	Aug 2021*	152.3	150.2	147.8	144.5	141.4
	Mean	Aug 2021*	128.1	122.9	125.8	117.9	109.2
Burrard West 2	**Min**	Sep 2021	113.3	105.9	111.8	103.5	89.7
	L_{95}	Sep 2021	121.5	114.2	118.2	109.2	94.0
	L_{75}	Sep 2021	124.8	120.6	121.1	113.2	97.8
	L_{50}	Sep 2021	127.2	123.5	123.2	116.5	102.2
	L_{25}	Sep 2021	129.2	126.1	125.1	119.4	106.4
	L_{5}	Sep 2021	133.8	129.9	130.9	124.3	113.8
	Max	Sep 2021	152.2	151.0	147.9	142.5	136.1
	Mean	Sep 2021	130.3	126.3	127.2	120.2	109.8
Burrard West 2	**Min**	Oct 2021	120.3	113.0	118.9	106.0	92.1
	L_{95}	Oct 2021	128.6	124.4	124.0	119.5	96.5
	L_{75}	Oct 2021	130.4	126.6	125.9	122.1	100.5
	L_{50}	Oct 2021	131.9	128.3	127.4	123.6	104.2
	L_{25}	Oct 2021	133.7	130.9	128.7	124.9	107.7
	L_{5}	Oct 2021	137.0	133.5	133.9	127.7	114.8
	Max	Oct 2021	152.8	150.7	150.6	146.0	142.8
	Mean	Oct 2021	133.7	130.2	129.9	125.0	111.7

Location	*SPL Metric*	*Month*	*0.01-48 kHz*	*0.01-0.1 kHz*	*0.1-1 kHz*	*1-10 kHz*	*10-48 kHz*
Burrard West 2	**Min**	Nov 2021	121.0	116.5	116.0	109.8	91.3
	L_{95}	Nov 2021	124.1	120.2	120.1	114.2	95.2
	L_{75}	Nov 2021	129.5	125.6	124.6	119.4	98.8
	L_{50}	Nov 2021	131.0	127.6	126.0	122.7	102.9
	L_{25}	Nov 2021	132.1	129.0	127.5	124.2	106.6
	L_{5}	Nov 2021	137.2	134.2	132.7	127.1	113.5
	Max	Nov 2021	154.0	153.8	149.7	145.0	134.9
	Mean	Nov 2021	132.8	129.5	128.8	123.8	109.8
Burrard West 2	**Min**	Dec 2021	112.4	106.8	108.7	103.0	89.8
	L_{95}	Dec 2021	119.5	112.9	116.7	109.7	93.8
	L_{75}	Dec 2021	125.1	120.3	121.2	115.5	97.6
	L_{50}	Dec 2021	128.2	124.2	124.1	119.4	101.8
	L_{25}	Dec 2021	130.6	126.8	126.5	123.2	105.7
	L_{5}	Dec 2021	135.0	130.3	132.2	127.3	113.6
	Max	Dec 2021	155.1	148.8	152.0	147.8	144.2
	Mean	Dec 2021	131.4	126.7	128.4	123.0	110.7
Burrard West 2	**Min**	Jan 2022	115.9	110.4	113.1	106.8	90.4
	L_{95}	Jan 2022	125.8	122.3	121.2	114.7	94.6
	L_{75}	Jan 2022	128.4	125.0	123.9	118.6	100.0
	L_{50}	Jan 2022	130.8	128.0	125.5	121.2	105.1
	L_{25}	Jan 2022	132.4	129.9	127.2	123.1	109.0
	L_{5}	Jan 2022	136.2	132.6	133.1	126.8	114.7
	Max	Jan 2022	159.0	157.1	153.1	147.7	141.1
	Mean	Jan 2022	132.8	129.5	128.9	123.4	111.4

Appendix 3. Burrard East, monthly SPL (dB re 1µPa) by study month for each broadband and decade frequency band metric. Months with incomplete or data biased by flow noise are indicated by an asterisk.

Location	*SPL Metric*	*Month*	*0.01-48 kHz*	*0.01-0.1 kHz*	*0.1-1 kHz*	*1-10 kHz*	*10-48 kHz*
Burrard East	**Min**	Feb 2021*	105.7	104.3	97.8	88.1	83.8
	L_{95}	Feb 2021*	107.5	105.8	100.4	90.9	84.1
	L_{75}	Feb 2021*	110.9	107.9	104.8	95.7	86.4
	L_{50}	Feb 2021*	116.8	111.2	111.7	103.2	94.4
	L_{25}	Feb 2021*	126.1	119.2	119.9	113.1	102.0
	L_{5}	Feb 2021*	142.1	141.5	130.3	124.7	114.7
	Max	Feb 2021*	157.1	157.0	145.9	139.1	132.9
	Mean	Feb 2021*	138.6	138.4	123.9	118.4	108.9
Burrard East	**Min**	Mar 2021*	105.9	104.5	98.2	84.4	83.8
	L_{95}	Mar 2021*	107.5	105.8	101.2	89.5	84.3
	L_{75}	Mar 2021*	110.6	107.6	105.5	94.8	86.3
	L_{50}	Mar 2021*	118.6	112.5	113.1	102.0	93.2
	L_{25}	Mar 2021*	128.0	121.9	120.7	112.9	101.8
	L_{5}	Mar 2021*	145.0	144.9	130.9	124.8	114.5
	Max	Mar 2021*	157.1	157.0	145.6	140.8	133.0
	Mean	Mar 2021*	139.2	139.0	124.2	118.3	109.0
Burrard East	**Min**	Apr 2021*	106.3	104.4	97.1	85.2	83.8
	L_{95}	Apr 2021*	108.0	106.4	100.7	88.4	84.6
	L_{75}	Apr 2021*	110.8	108.1	105.0	93.6	85.9
	L_{50}	Apr 2021*	118.4	112.1	113.1	103.7	92.9
	L_{25}	Apr 2021*	127.2	120.7	120.5	114.2	102.5
	L_{5}	Apr 2021*	142.5	142.2	130.9	125.5	114.9
	Max	Apr 2021*	157.4	157.3	145.0	140.9	135.0
	Mean	Apr 2021*	138.0	137.8	124.2	118.9	109.1
Burrard East	**Min**	May 2021*	106.4	105.4	96.7	86.3	83.9
	L_{95}	May 2021*	108.3	107.1	100.3	88.8	84.7
	L_{75}	May 2021*	111.1	108.8	104.5	94.1	85.8
	L_{50}	May 2021*	117.7	111.8	112.9	105.7	93.0
	L_{25}	May 2021*	125.4	117.8	120.8	116.4	104.2
	L_{5}	May 2021*	138.0	135.2	130.0	126.5	116.2
	Max	May 2021*	156.5	156.5	146.4	142.4	136.4
	Mean	May 2021*	133.5	132.8	123.8	119.8	110.0

Location	*SPL Metric*	*Month*	*0.01-48 kHz*	*0.01-0.1 kHz*	*0.1-1 kHz*	*1-10 kHz*	*10-48 kHz*
Burrard East	**Min**	Jun 2021	87.8	83.3	78.5	79.5	83.6
	L_{95}	Jun 2021	102.2	100.6	94.4	86.3	85.0
	L_{75}	Jun 2021	104.3	101.7	98.5	93.1	85.8
	L_{50}	Jun 2021	109.7	102.8	105.9	102.0	91.0
	L_{25}	Jun 2021	118.5	106.4	115.3	112.8	102.7
	L_{5}	Jun 2021	130.6	118.3	127.5	125.5	116.7
	Max	Jun 2021	152.6	147.3	149.4	146.0	143.2
	Mean	Jun 2021	125.0	117.0	122.2	119.3	111.6
Burrard East	**Min**	Jul 2021	100.2	99.1	91.7	83.9	84.5
	L_{95}	Jul 2021	102.8	101.3	93.6	85.5	85.0
	L_{75}	Jul 2021	104.7	102.4	98.1	92.8	85.7
	L_{50}	Jul 2021	109.5	103.4	105.5	102.5	90.1
	L_{25}	Jul 2021	118.2	106.1	114.8	113.5	103.1
	L_{5}	Jul 2021	129.9	115.8	126.7	125.5	116.7
	Max	Jul 2021	149.0	140.5	147.5	142.2	141.0
	Mean	Jul 2021	124.0	113.0	121.4	119.1	111.2
Burrard East	**Min**	Aug 2021*	100.0	97.8	92.7	84.3	85.0
	L_{95}	Aug 2021*	101.0	98.8	94.8	88.2	85.8
	L_{75}	Aug 2021*	103.5	99.4	99.4	91.5	86.7
	L_{50}	Aug 2021*	111.6	100.6	108.6	104.2	91.9
	L_{25}	Aug 2021*	120.4	106.0	117.7	115.0	104.6
	L_{5}	Aug 2021*	131.2	116.3	128.8	125.8	116.8
	Max	Aug 2021*	147.7	137.6	146.1	140.7	132.4
	Mean	Aug 2021*	125.2	113.0	123.3	119.3	110.4
Burrard East	**Min**	Sep 2021	99.5	97.7	91.2	83.8	84.2
	L_{95}	Sep 2021	100.9	98.8	94.6	85.9	85.2
	L_{75}	Sep 2021	103.1	99.6	98.1	90.8	86.5
	L_{50}	Sep 2021	110.3	100.8	106.9	102.4	93.1
	L_{25}	Sep 2021	118.9	105.5	116.1	113.2	103.6
	L_{5}	Sep 2021	130.5	117.0	128.1	124.8	116.1
	Max	Sep 2021	151.5	145.2	148.3	146.4	142.0
	Mean	Sep 2021	124.9	115.3	122.8	118.7	111.0
Burrard East	**Min**	Oct 2021	94.0	91.2	86.3	82.9	83.7
	L_{95}	Oct 2021	97.9	93.6	91.3	86.4	84.2
	L_{75}	Oct 2021	102.0	96.9	97.1	92.7	86.1
	L_{50}	Oct 2021	108.5	98.7	105.2	100.0	92.7
	L_{25}	Oct 2021	116.9	104.1	114.8	109.9	101.4
	L_{5}	Oct 2021	129.3	116.8	127.2	123.1	114.2
	Max	Oct 2021	153.3	149.7	150.5	141.2	134.9
	Mean	Oct 2021	124.1	115.5	122.2	117.0	108.7

Location	*SPL Metric*	*Month*	*0.01-48 kHz*	*0.01-0.1 kHz*	*0.1-1 kHz*	*1-10 kHz*	*10-48 kHz*
Burrard East	**Min**	Nov 2021	98.3	96.4	90.8	82.2	83.6
	L_{95}	Nov 2021	99.9	97.3	93.4	87.5	84.0
	L_{75}	Nov 2021	103.1	98.4	97.3	94.0	86.7
	L_{50}	Nov 2021	108.8	99.9	104.9	100.6	94.3
	L_{25}	Nov 2021	117.0	105.4	115.1	109.5	102.5
	L_{5}	Nov 2021	129.5	117.6	127.6	122.6	113.7
	Max	Nov 2021	156.3	150.0	153.8	148.4	143.2
	Mean	Nov 2021	124.2	115.8	122.4	116.7	109.2
Burrard East	**Min**	Dec 2021	94.9	89.7	89.5	85.0	83.5
	L_{95}	Dec 2021	98.9	94.2	93.2	88.7	83.9
	L_{75}	Dec 2021	101.4	96.7	95.7	93.4	85.7
	L_{50}	Dec 2021	106.9	98.5	101.5	98.9	90.5
	L_{25}	Dec 2021	115.2	104.7	112.5	108.4	99.3
	L_{5}	Dec 2021	128.0	116.4	125.7	121.7	112.2
	Max	Dec 2021	153.6	153.6	149.4	146.4	139.3
	Mean	Dec 2021	123.9	118.1	121.0	116.4	108.6
Burrard East	**Min**	Jan 2022	97.3	95.3	89.5	86.2	83.4
	L_{95}	Jan 2022	99.8	96.2	94.0	90.9	83.8
	L_{75}	Jan 2022	103.7	97.4	98.1	95.5	85.3
	L_{50}	Jan 2022	108.5	100.6	104.1	100.9	91.5
	L_{25}	Jan 2022	116.9	105.4	114.1	110.3	101.0
	L_{5}	Jan 2022	129.1	117.7	126.4	122.4	113.0
	Max	Jan 2022	159.6	159.6	146.9	140.3	133.6
	Mean	Jan 2022	127.8	126.3	121.1	116.3	108.1

Appendix 4. Indian Arm, monthly SPL (dB re 1µPa) by study month for each broadband and decade frequency band metric. Months with incomplete data are indicated by an asterisk.

Location	*SPL Metric*	*Month*	*0.01-48 kHz*	*0.01-0.1 kHz*	*0.1-1 kHz*	*1-10 kHz*	*10-48 kHz*
Indian Arm	**Min**	Feb 2021*	87.6	83.1	78.2	79.5	83.2
	L_{95}	Feb 2021*	88.3	84.0	78.7	79.8	83.2
	L_{75}	Feb 2021*	91.3	84.6	83.6	81.6	83.6
	L_{50}	Feb 2021*	98.6	86.7	89.5	89.8	89.6
	L_{25}	Feb 2021*	106.0	95.2	100.6	99.7	97.1
	L_{5}	Feb 2021*	116.8	104.4	113.2	112.8	105.1
	Max	Feb 2021*	133.7	124.6	133.5	129.3	124.1
	Mean	Feb 2021*	111.2	98.6	108.2	106.7	100.0
Indian Arm	**Min**	Mar 2021	87.7	83.3	78.1	79.5	83.2
	L_{95}	Mar 2021	88.1	83.9	78.5	79.7	83.2
	L_{75}	Mar 2021	90.0	84.6	83.0	81.5	83.4
	L_{50}	Mar 2021	97.3	86.7	90.1	90.6	86.7
	L_{25}	Mar 2021	105.9	93.5	101.1	100.8	95.7
	L_{5}	Mar 2021	117.3	103.3	112.7	114.0	105.0
	Max	Mar 2021	139.2	132.9	137.9	137.3	128.6
	Mean	Mar 2021	112.0	101.1	108.4	108.0	100.8
Indian Arm	**Min**	Apr 2021	87.7	83.5	78.2	79.5	83.2
	L_{95}	Apr 2021	88.7	84.1	80.8	79.9	83.3
	L_{75}	Apr 2021	91.8	85.0	87.4	82.0	83.5
	L_{50}	Apr 2021	100.8	90.8	94.6	93.3	88.3
	L_{25}	Apr 2021	110.7	97.8	106.5	105.9	98.2
	L_{5}	Apr 2021	120.9	107.5	116.8	117.8	107.1
	Max	Apr 2021	142.3	134.4	142.1	133.4	130.7
	Mean	Apr 2021	114.7	102.8	111.3	110.9	102.2
Indian Arm	**Min**	May 2021	87.9	83.3	78.3	79.6	83.3
	L_{95}	May 2021	88.7	84.0	81.5	79.9	83.3
	L_{75}	May 2021	92.8	85.0	89.5	81.3	83.5
	L_{50}	May 2021	101.7	90.3	97.2	95.4	88.4
	L_{25}	May 2021	113.2	100.1	108.9	109.1	99.2
	L_{5}	May 2021	123.3	110.5	119.2	119.6	109.4
	Max	May 2021	137.6	135.2	137.3	135.0	127.5
	Mean	May 2021	116.5	106.1	113.0	112.7	103.6

Location	*SPL Metric*	*Month*	*0.01-48 kHz*	*0.01-0.1 kHz*	*0.1-1 kHz*	*1-10 kHz*	*10-48 kHz*
Indian Arm	**Min**	Jun 2021	87.6	82.5	77.7	79.5	83.7
	L_{95}	Jun 2021	89.2	84.6	80.7	80.0	83.9
	L_{75}	Jun 2021	93.2	86.3	89.4	81.7	84.0
	L_{50}	Jun 2021	100.1	89.5	95.5	93.9	86.6
	L_{25}	Jun 2021	112.0	98.7	107.7	107.5	97.6
	L_{5}	Jun 2021	123.7	109.9	119.3	120.2	109.5
	Max	Jun 2021	148.3	140.9	142.3	147.2	134.8
	Mean	Jun 2021	118.1	110.2	114.2	113.9	103.9
Indian Arm	**Min**	Jul 2021*	87.9	83.0	78.3	79.7	83.8
	L_{95}	Jul 2021*	88.8	84.0	80.6	80.0	83.9
	L_{75}	Jul 2021*	90.7	84.9	86.6	80.6	84.0
	L_{50}	Jul 2021*	101.1	91.5	96.9	94.5	86.2
	L_{25}	Jul 2021*	113.6	101.2	109.0	109.4	100.7
	L_{5}	Jul 2021*	123.9	110.7	119.6	120.5	111.6
	Max	Jul 2021*	140.5	129.0	136.0	136.9	134.5
	Mean	Jul 2021*	117.0	105.1	113.1	113.6	106.2
Indian Arm	**Min**	Aug 2021*	87.2	82.3	77.2	79.1	83.3
	L_{95}	Aug 2021*	89.1	86.4	77.7	79.2	83.3
	L_{75}	Aug 2021*	93.6	88.0	90.3	81.6	83.6
	L_{50}	Aug 2021*	100.8	91.1	96.9	93.2	85.1
	L_{25}	Aug 2021*	113.5	100.6	109.8	108.4	95.8
	L_{5}	Aug 2021*	124.7	112.2	121.6	119.4	106.3
	Max	Aug 2021*	142.2	140.1	138.6	138.2	130.4
	Mean	Aug 2021*	119.4	114.3	115.8	113.1	102.7
Indian Arm	**Min**	Sep 2021	87.6	82.2	78.4	79.6	83.4
	L_{95}	Sep 2021	89.3	84.9	82.6	80.1	83.5
	L_{75}	Sep 2021	91.9	86.2	87.7	81.6	83.7
	L_{50}	Sep 2021	100.2	89.3	94.3	92.9	87.5
	L_{25}	Sep 2021	110.1	97.4	106.1	105.2	97.3
	L_{5}	Sep 2021	121.6	108.2	118.0	117.5	106.8
	Max	Sep 2021	143.1	135.5	141.3	135.4	127.6
	Mean	Sep 2021	115.4	104.6	112.5	110.9	101.8
Indian Arm	**Min**	Oct 2021	87.9	83.6	77.7	79.3	83.3
	L_{95}	Oct 2021	88.4	84.3	78.4	79.5	83.4
	L_{75}	Oct 2021	90.4	85.1	83.9	81.4	83.7
	L_{50}	Oct 2021	98.2	86.2	91.0	90.9	89.2
	L_{25}	Oct 2021	106.2	93.2	101.8	99.9	97.5
	L_{5}	Oct 2021	118.0	103.7	114.6	113.8	106.3
	Max	Oct 2021	137.8	136.0	133.5	134.0	130.9
	Mean	Oct 2021	112.6	100.9	109.4	108.2	101.8

Location	*SPL Metric*	*Month*	*0.01-48 kHz*	*0.01-0.1 kHz*	*0.1-1 kHz*	*1-10 kHz*	*10-48 kHz*
Indian Arm	**Min**	Nov 2021	87.5	83.0	77.5	79.2	83.3
	L_{95}	Nov 2021	88.2	84.0	78.5	79.5	83.4
	L_{75}	Nov 2021	90.9	84.7	83.8	82.5	84.1
	L_{50}	Nov 2021	99.3	85.8	91.8	93.1	90.3
	L_{25}	Nov 2021	105.2	90.6	99.8	100.1	97.3
	L_{5}	Nov 2021	115.1	100.6	112.0	110.6	105.5
	Max	Nov 2021	136.1	129.2	134.9	129.6	126.6
	Mean	Nov 2021	110.4	97.5	107.4	105.9	100.4
Indian Arm	**Min**	Dec 2021	87.4	82.2	77.6	79.3	83.3
	L_{95}	Dec 2021	88.8	83.3	78.5	79.6	83.3
	L_{75}	Dec 2021	90.7	86.3	83.3	81.8	83.5
	L_{50}	Dec 2021	97.0	87.5	90.2	88.8	86.5
	L_{25}	Dec 2021	103.3	92.3	97.7	97.4	94.2
	L_{5}	Dec 2021	112.9	102.5	110.3	108.6	103.2
	Max	Dec 2021	137.2	129.8	136.2	130.2	122.0
	Mean	Dec 2021	108.6	97.4	105.7	104.0	97.5
Indian Arm	**Min**	Jan 2022	87.8	83.4	77.5	79.2	83.2
	L_{95}	Jan 2022	89.1	85.2	78.9	79.6	83.3
	L_{75}	Jan 2022	90.9	86.6	84.3	81.4	83.5
	L_{50}	Jan 2022	97.2	88.0	90.7	89.0	85.8
	L_{25}	Jan 2022	104.0	94.2	98.8	96.5	93.3
	L_{5}	Jan 2022	114.2	106.4	111.6	109.1	102.6
	Max	Jan 2022	137.3	131.9	132.1	134.0	130.9
	Mean	Jan 2022	109.3	99.9	106.4	104.3	97.6

Appendix 5. Ocean Networks Canada/Tsleil-Waututh Nation cabled listening station, monthly SPL (dB re 1µPa) by study month for each broadband and decade frequency band metric. Months with incomplete data are indicated by an asterisk.

Location	*SPL Metric*	*Month*	*0.01-48 kHz*	*0.01-0.1 kHz*	*0.1-1 kHz*	*1-10 kHz*	*10-48 kHz*
ONC	**Min**	Feb 2021	109.2	106.7	100.6	95.9	89.5
	L_{95}	Feb 2021	113.6	110.9	107.0	100.1	92.0
	L_{75}	Feb 2021	117.5	114.3	110.6	104.7	94.7
	L_{50}	Feb 2021	119.9	116.9	114.1	108.3	97.3
	L_{25}	Feb 2021	122.9	119.3	118.6	112.7	100.3
	L_{5}	Feb 2021	129.0	126.8	124.2	118.3	106.9
	Max	Feb 2021	151.9	151.7	147.2	138.5	131.1
	Mean	Feb 2021	124.8	122.7	119.7	113.4	103.0
ONC	**Min**	Mar 2021	109.8	106.8	104.3	95.4	87.6
	L_{95}	Mar 2021	113.8	111.1	107.5	100.1	90.9
	L_{75}	Mar 2021	117.0	114.0	111.1	104.3	94.7
	L_{50}	Mar 2021	119.4	116.0	114.3	107.9	96.6
	L_{25}	Mar 2021	122.5	118.7	118.3	112.0	100.1
	L_{5}	Mar 2021	128.3	125.8	124.3	117.5	106.8
	Max	Mar 2021	149.1	148.3	143.6	137.8	136.9
	Mean	Mar 2021	123.7	121.1	119.2	112.7	103.1
ONC	**Min**	Apr 2021*	113.6	111.3	107.3	101.5	91.8
	L_{95}	Apr 2021*	115.8	112.1	108.4	103.7	93.0
	L_{75}	Apr 2021*	118.7	115.9	111.1	105.8	94.1
	L_{50}	Apr 2021*	122.1	119.4	114.4	108.9	96.7
	L_{25}	Apr 2021*	125.1	123.2	119.1	113.2	101.9
	L_{5}	Apr 2021*	130.8	128.3	125.8	119.1	109.3
	Max	Apr 2021*	139.8	139.3	134.7	128.3	125.2
	Mean	Apr 2021*	125.3	123.3	119.9	113.8	105.6
ONC	**Min**	May 2021	107.0	102.7	99.6	93.4	86.4
	L_{95}	May 2021	111.7	109.0	105.8	98.4	88.8
	L_{75}	May 2021	115.1	111.5	109.7	104.4	92.0
	L_{50}	May 2021	118.4	113.6	113.9	108.2	95.3
	L_{25}	May 2021	122.2	117.2	118.3	112.4	100.1
	L_{5}	May 2021	128.0	125.5	124.0	117.8	107.0
	Max	May 2021	150.8	150.7	144.4	136.0	136.6
	Mean	May 2021	123.3	120.5	119.0	112.9	102.9

Location	*SPL Metric*	*Month*	*0.01-48 kHz*	*0.01-0.1 kHz*	*0.1-1 kHz*	*1-10 kHz*	*10-48 kHz*
ONC	**Min**	Jun 2021	109.0	106.9	102.0	94.7	86.6
	L_{95}	Jun 2021	112.9	110.4	107.4	100.1	88.1
	L_{75}	Jun 2021	116.1	112.8	110.8	104.7	90.4
	L_{50}	Jun 2021	119.1	114.8	114.6	108.7	94.6
	L_{25}	Jun 2021	122.6	117.8	118.8	112.7	99.9
	L_{5}	Jun 2021	128.5	126.0	124.5	118.0	107.3
	Max	Jun 2021	156.8	156.5	147.8	140.6	134.7
	Mean	Jun 2021	124.1	121.5	119.6	113.5	103.5
ONC	**Min**	Jul 2021	106.4	104.0	99.6	93.7	87.4
	L_{95}	Jul 2021	111.8	108.9	105.7	99.0	88.6
	L_{75}	Jul 2021	115.3	111.9	110.0	103.9	90.1
	L_{50}	Jul 2021	118.4	114.1	114.0	108.1	93.7
	L_{25}	Jul 2021	122.2	117.2	118.3	112.3	99.0
	L_{5}	Jul 2021	128.3	125.8	124.2	117.9	107.0
	Max	Jul 2021	151.1	151.1	142.3	136.2	131.2
	Mean	Jul 2021	123.2	120.4	118.9	112.8	102.4
ONC	**Min**	Aug 2021	103.2	98.8	98.2	92.1	87.0
	L_{95}	Aug 2021	111.2	108.6	103.8	98.2	88.6
	L_{75}	Aug 2021	114.9	111.9	108.5	103.0	90.2
	L_{50}	Aug 2021	118.1	114.2	113.2	107.5	93.7
	L_{25}	Aug 2021	121.7	117.2	118.0	111.9	99.0
	L_{5}	Aug 2021	127.8	124.8	123.9	117.8	107.0
	Max	Aug 2021	152.8	152.0	148.8	140.2	138.7
	Mean	Aug 2021	122.9	119.9	118.9	112.8	103.6
ONC	**Min**	Sep 2021	106.9	104.7	101.8	92.3	87.8
	L_{95}	Sep 2021	111.4	108.9	105.2	96.3	89.9
	L_{75}	Sep 2021	115.6	112.1	109.5	104.0	92.2
	L_{50}	Sep 2021	118.8	114.9	114.1	108.3	95.9
	L_{25}	Sep 2021	122.3	118.1	118.4	112.4	100.6
	L_{5}	Sep 2021	127.7	124.7	124.1	117.6	107.5
	Max	Sep 2021	146.9	146.6	142.2	138.7	130.2
	Mean	Sep 2021	123.1	120.2	118.9	112.7	103.3
ONC	**Min**	Oct 2021	108.0	115.6	118.4	120.5	123.5
	L_{95}	Oct 2021	105.8	112.7	115.4	117.5	120.0
	L_{75}	Oct 2021	101.4	109.3	112.4	115.4	119.1
	L_{50}	Oct 2021	94.3	101.7	105.6	108.9	112.3
	L_{25}	Oct 2021	90.7	92.4	94.0	96.5	100.4
	L_{5}	Oct 2021	108.0	115.6	118.4	120.5	123.5
	Max	Oct 2021	105.8	112.7	115.4	117.5	120.0
	Mean	Oct 2021	101.4	109.3	112.4	115.4	119.1

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