Burrard Inlet underwater noise study: 2022 final report

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 through to 2021, 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 fourth year of the Burrard Inlet underwater noise study sought to monitor ambient noise and marine mammal presence to inform future evaluation of longer-term trends.

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 each year since, including 2022.

What methods were used?

Acoustic data were collected over approximately one year using bottom-mounted SoundTrap hydrophone recorders deployed in two locations in English Bay and Burrard East. 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. Data collection from the Ocean Networks Canada (ONC) location at Brockton point while planned for 2022 was not available at the time of this report. The system was offline from January 2022 until October 2022.
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 final report appended to this document is based on the calendar year of January 2022 to December 2022.

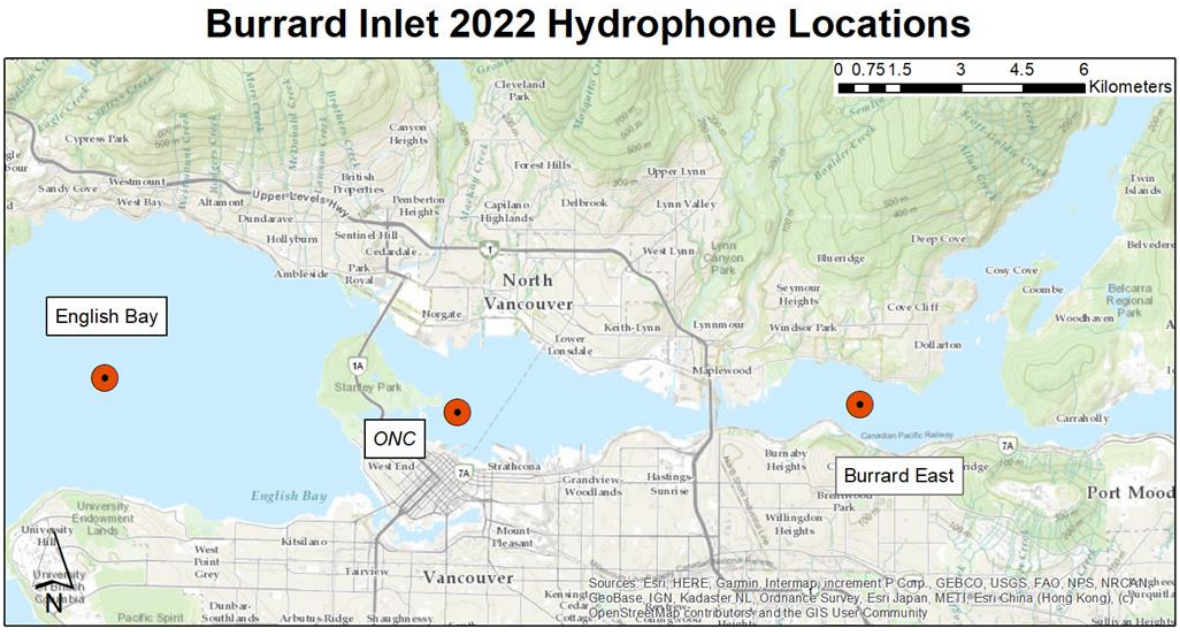


Figure 1: Burrard Inlet monitoring locations 2022
Source: SMRU Consulting North America

What were the key findings?

The main findings of the 2022 Burrard Inlet underwater noise study are summarized as follows:

- The deployments in 2022 once again had 100% instrument recovery and at total of 614 days of monitoring data between the two SMRU-deployed hydrophones. Due to a flooded hydrophone, data was lost at the Burrard East location from February 10 to May 17, 2022.
- Due to equipment failure from December 2021 until October 2022, data from the ONC observatory was not available for this report.
- 2022 saw higher monthly amplitude noise levels at the L_{eq} (mean), L_{50} (median) and L_5 (loudest 5%) when compared to 2021 ranging from 3.3 to 5.7dB.
- The L_{50} monthly (median) sound levels were once again higher at English Bay than at Burrard East. While comparable, the L_{eq} (mean) and L_5 (loudest 5%) levels were slightly higher at Burrard East than English Bay. This was presumed to be due to higher tidal flow and closer proximity to vessel traffic at the Burrard East location.
- Daily variation, with higher sound levels during daytime conditions, was clearly visible at the Burrard East location, but sound levels were consistent at the English Bay location over the course of a day.
- Harbour porpoise acoustic detections in English Bay have continued to rise year-over-year, totaling 254 unique detections in 2022.
- There were 15 days of acoustic detections of killer whales in the 2022 calendar year, compared to only 7 in the 2021 calendar year and 1 in the 11 months monitored in the 2020 calendar year. Additionally, there were four days in 2022 with visual observations of killer whales.
- Acoustic detections included northern (month/year) and southern (months/year) resident killer whales and Transient/Bigg's killer whales.

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.

Acoustic detections of killer whales and harbour porpoises continue to rise year over year with northern and southern resident and Biggs killer whales all acoustically detected in 2022. At the English Bay hydrophone, harbour porpoise also continue to show increases in detections.

The port authority intends to continue to collect data through 2023 and undertake a review of longer-term trends at the conclusion of the fifth year of acoustic data collection in Burrard Inlet.

Burrard Inlet Underwater Noise Characterization: 2022 Final Report

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

SMRU Consulting North America

815D Spring St. Unit 1
Friday Harbor, WA 98250
USA

604 – 55 Water Street
Vancouver, BC V6B 1A1
Canada

Burrard Inlet Underwater Noise Characterization: 2022 Final Report

March 2023

Prepared by SMRU Consulting NA

Authors:

Jason Wood, PhD
Managing Director

Natasha Hardy, PhD
Senior Research Scientist

Kaitlin Palmer, PhD
Senior Research Scientist

Alex Harris, MSc
Research Scientist

Madalina Matei, MSc,
Project Scientist

Rachel Charish, MSc
Project Scientist

Meadhbh Quinn, MSc
Project Scientist

Dominic Tollit, PhD
Principal Scientist

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.

SMRU Consulting has conducted PAM monitoring of Burrard Inlet, on behalf of the ECHO Program, continuously since 2019 (SMRU Consulting, 2019). The monitoring plan alternates between five-location and two-location years. For the initial deployment year in 2019, SMRU Consulting monitored at five locations in Burrard Inlet. For the 2020 deployment, the two sites selected were an inner harbour location (Burrard East) and an outer harbour location (English Bay). The year 2021 marked a return to five sites matching the initial project year, with four year-round locations and one short-term deployment along with evaluation of acoustic data from a hydrophone near Brockton Point collected by Ocean Networks Canada (ONC) in collaboration with project partner Tsleil-Waututh Nation. Finally, in 2022, monitoring continued for a fourth consecutive year at two locations matching the 2020 sites (Figure 1) (SMRU Consulting, 2020). Unfortunately, in 2022, data from the Brockton Point observatory was not available and as such is excluded from this report.

In addition to ECHO's long-term monitoring objectives, this project supports the objectives of Tsleil-Waututh Nation's Cumulative Effects Monitoring Initiative. This initiative 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 SoundTrap deployment locations plus the cabled node operated 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 2022:

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 in 2021, and carried forward to 2022 monitoring, to maximize efficiency of materials, durability, and ease of recovery.

2) **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 4-year dataset of porpoise and killer whale presence, which is clearly a valuable addition to on-going opportunistic visual observations.

2 Methods

The Methods and Results sections are divided by the objectives identified above. The reporting period for this report begins January 1st, 2022 and ends on December 31st, 2022. We note that this differs from the reporting period of February 19th, 2021 to January 31st, 2022 for the previous report (SMRU Consulting, 2021). Any data from January 1st 2023 collected from the last 2022 deployment and until December 31st 2023, 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, two Ocean Instruments SoundTraps (model ST600 HF) were deployed in Burrard Inlet to record sound levels at the English Bay and Burrard East locations (Table 1, Figure 1). SoundTrap locations mirrored the 2020 project year to continue building a baseline dataset throughout the Inlet (Table 1, Figure 1).

The mooring system and recovery were re-designed in 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 eliminated numerous exterior components which could have contributed to unwanted noise (i.e., clamps and other metallic components). The 2022 deployments continued to utilize the same mooring and recovery system.

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 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. We highlight that to complete the time series for this year's reporting period of January 1st to December 31st, 2022, we use 38 days of data from January 1st until February 7th from the November 25th, 2021, deployment described in the previous report.

Table 1. Latitude and longitude of SoundTraps deployed in for the 2022 project year.

SoundTrap Hydrophone Location	Latitude (N)	Longitude (W)	Water depth
English Bay	49.304	123.233	55 m
Burrard East	49.296	122.982	61 m

Table 2. SoundTrap deployment and retrieval dates for the 2022 project year.

Deployment Number	Deployment Date	Recovery Date	Deployment Duration (days)
*	November 25th, 2021 (using from January 1st, 2022)	February 7th, 2022	38 (used for 2022)
1	February 10th, 2022	May 17th, 2022	97
2	May 19th (Burrard East) May 24th, 2022 (English Bay)	August 9th, 2022	78—83**
3	August 12th, 2022	November 28th, 2022	109
4	December 1st, 2022	January 10th, 2023	41

*Note that to complete the time series for this year's reporting period we use 38 days from the deployment which began in November 2021
** 78 days of data were collected for Burrard East and 83 days of data were collected for English Bay. The gap between deployments was due to a weather delay.

All deployed hydrophones were retrieved, marking the third consecutive year of this monitoring program without the loss of a hydrophone, and the second consecutive year without hydrophone anchor loss. However, during the first deployment (February 10th to May 17th, 2022, Table 2), the hydrophone deployed at the Burrard East site was found to have flooded upon retrieval. The unit was highly pressurized upon opening and about 1/3rd full of sea water and sediment. As a result, the hydrophone did not recover any usable data for the 97 days during which it was deployed, affecting data collection at Burrard East from for the beginning of 2022. Complete data collection was successful from all other deployments.

Also, during the recovery of the first deployment at the Burrard East location for 2021, half a rope bucket and mooring weight were 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*. The Burrard East location had issues in past project years with snagged lines from debris and currents in the area. For this reason, a 'rope-less' design remains in use in 2022 at Burrard East to prevent further losses (Figure 3). The rope-less design has necessitated a return to the practice of leaving anchor weights on the seafloor during recovery at this location.

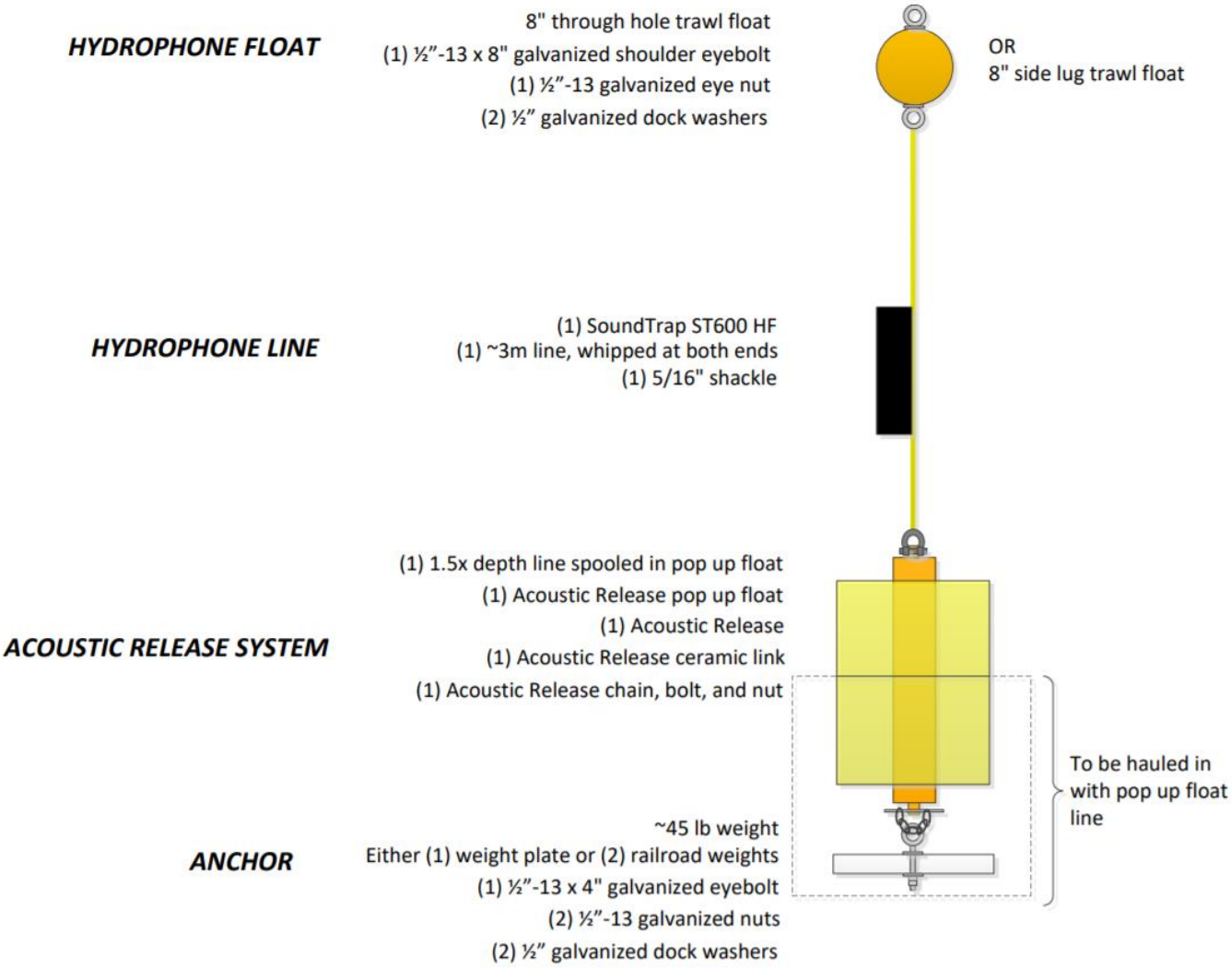


Figure 2. Schematic of SoundTrap hydrophone and EdgeTech acoustic release deployment method.

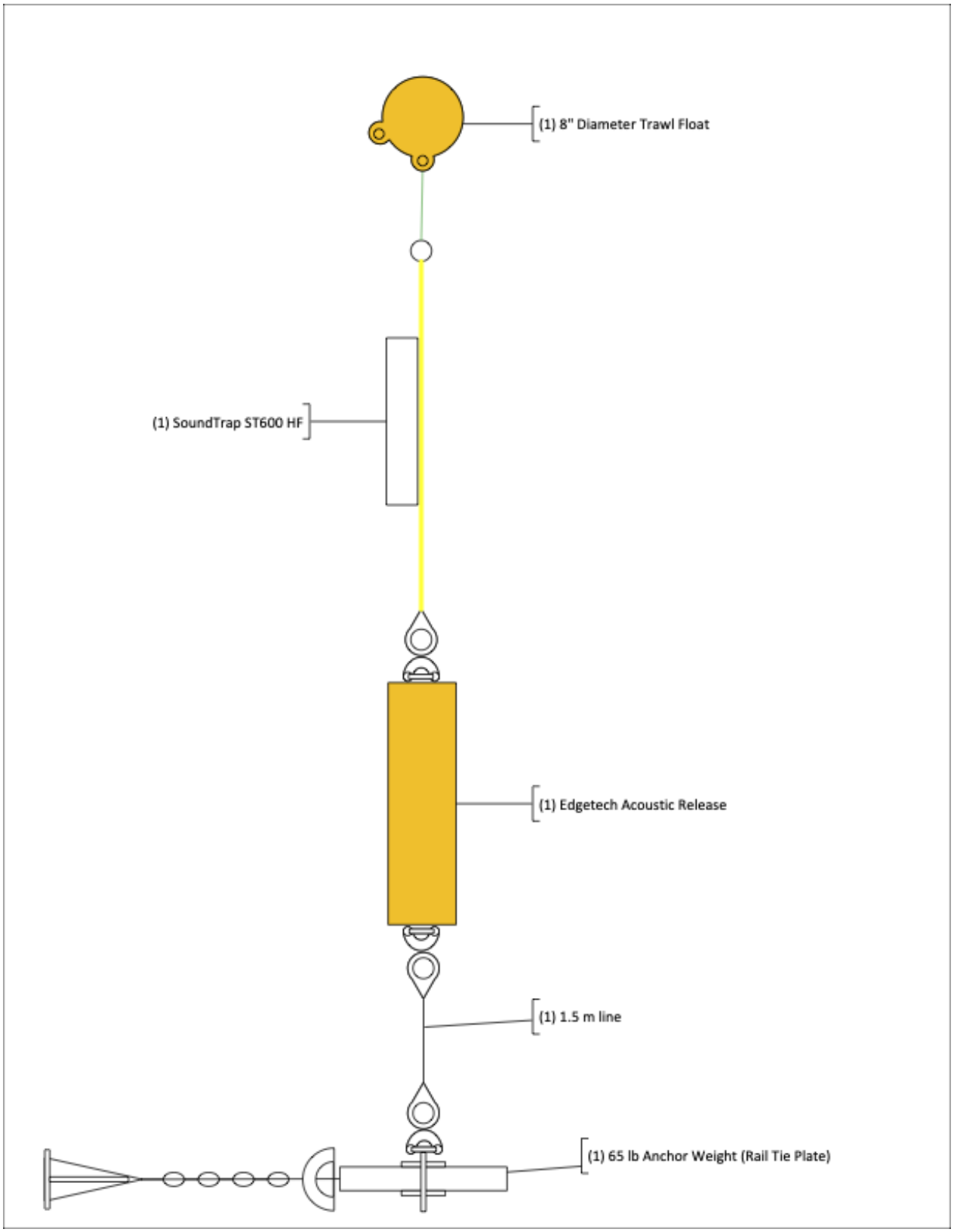


Figure 3. Schematic of 'rope-less' deployment method used at the Burrard East location.

Table 3. SoundTrap settings used for the 2022 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 East	High (~172 dB max)	96	50% (7 minutes)	Click Detector*	16

*Further details regarding the click detector are provided in section 2.2.1.

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; SMRU Consulting, 2019). 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 received during the 2022 monitoring period and therefore not included in analyses.

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

Location	Area (km^2)
Burrard East	8.60
English Bay	27.89

Daily vessel abundance 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 vessels moving at least one knot of speed and b) all Class A vessels including those moving at speeds below 1 knot, such as when moored or anchored. For each deployment day and location, the total number of individual AIS transmissions detected within 3 km of each hydrophone were calculated. This value is referred to as signal density in this report and is illustrated 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 (green) within 3 km of each deployment location (red points). Yellow points indicate AIS locations within the survey area of each deployment location during a single representative month (September).

2.2 Cetacean Presence Using PAM

PAMGuard V2.02.05 software (www.pamguard.org) was used to detect potential echolocation clicks and calls from marine mammals in the SoundTrap data. Detections were validated by trained analysts using PAMGuard Viewer Mode, which was used to identify and log cetacean events. During this process, the analysts identified echolocation clicks and acoustic events for porpoises and killer whales. Acoustic events are defined as a period of calling with no more than a 30 min separation between successive calls.

2.2.1 Echolocation Clicks

Odontocetes produce a variety of sounds including impulsive signals called echolocation clicks, which are used for communication and echolocation. Echolocation clicks are short in duration and broad in frequency. Echolocation clicks are used by odontocetes to scan their surroundings by listening to the echoes coming from reflected objects, prey, or the sea floor. The echolocation clicks of killer whales can have a bandwidth of up to 100 kHz whereas harbour porpoises (*Phocoena phocoena*) produce clicks with most of the energy concentrated between 100 and 150 kHz (see Figure 5 for an example).

The sampling frequency required to fully capture these signals (exceeding 300,000 samples per second) provides logistical challenges because continuously recording at 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. These acoustic recorders usually sample the sound field at a rate of 96 kHz but when impulsive sounds are detected, a high frequency recording is triggered (sampling at a

frequency of 576 kHz), thus capturing a 'snipit' of the waveform. Snipits are referred to as 'click detections' by the manufacturer regardless of the source of the impulse.

The bioacoustics software PAMGuard has built-in click detection modules designed to capture these brief, impulsive sounds from acoustic data as well as data importing modules for clicks already detected by SoundTraps. For monitoring the acoustic presence of harbor porpoises, the SoundTrap click detections were imported into PAMGuard Viewer Mode and run through a classifier to identify clicks of frequency and duration representative of this species. Porpoise classification parameters were set to 0.22 ms duration, peak frequency range of 100—125 kHz, and a control band of 40—90 kHz. The search and integration band had a lower range of 40 kHz, while peak frequency was set to 110—125 kHz. A threshold of 6 dB was set to ensure detection of high or moderate probability porpoise detections while limiting false positive detections.

There was a discrepancy in the overall number of click detections classified as porpoise between English Bay and, depending on the year, the other three monitored sites (Burrard East, Burrard West, and Indian Arm), with greater detection counts at the former site. This led to the selection of a location-specific detection count threshold for the fine-scale inspection of the PAM data, with the same threshold applied across years for each location (SMRU Consulting, 2019, 2020, 2021). This threshold was applied to the number of clicks classified as porpoise within each recording period of 7-minutes. All recording periods where likely porpoise detector counts exceeded a set threshold (100 for English Bay or 10 for the other three sites) were manually verified for the presence of porpoise echolocation click trains. When a series of clicks resembling those of porpoises were identified, the corresponding day was marked as 'detection positive' and the review restarted from the next calendar day.

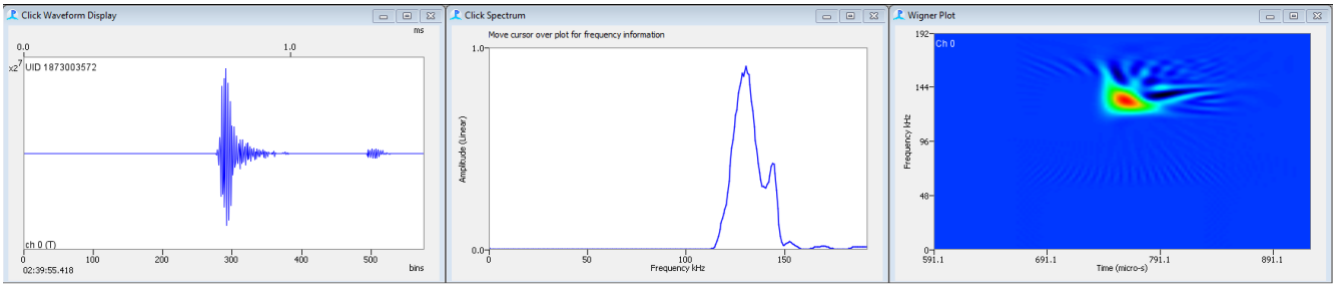


Figure 5. A typical porpoise echolocation click. Click Waveform Display, Click Spectrum and Wigner Plot displayed using PAMGuard software.

2.2.2 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.

PAMGuard was used to detect these tonal vocalisations of marine mammals using the 'whistle and moan' detector. This detector identifies groups of pixels on a spectrogram display which are likely to correspond to tonal, narrow-band acoustic signals such as dolphin whistles. The whistle and moan detector was run using the following parameters: frequency range of 0.8 to 24 kHz, sensitivity threshold of 6 dB above background noise levels, minimum signal duration of 10 time slices (measured as Fast Fourier Transform bins), and a minimum total pixel area of 20 pixels. Additionally, the type of connection between pixels was set to 'Connect 8' in PAMGuard, meaning that any of the 8 adjacent pixels surrounding a target pixel with a signal-to-noise ratio exceeding 6 dB could be joined on the spectrogram using both sides and diagonals. This renders the detection more accurate than the 'Connect 4' setting of this detector, where only the four pixels connected to the sides of the target pixel can be joined. PAMGuard Viewer was used to verify and log cetacean events. Events were first identified using a scrolling spectrogram and the spectrogram annotation module was used to mark the start and end times of cetacean acoustic events. A PAMGuard functionality called "Scroll Arrows" was used to move between whistle and moan detections without the need to manually move the cursor to find the next detection. All high and moderate probability events were validated by a human listener and killer whale acoustic call catalogues were used to identify the possible ecotype of the detected vocalisations.

Click detections were analyzed on a detection positive day level, such that once one confirmed echolocation click train was identified, analysis moved to the next day. 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 (a senior acoustic analyst with 15 years of relevant experience) to determine the ecotype (Resident or Bigg's/Transient). Furthermore, visual sightings data were obtained from a key word search of press releases from the study period including online news publications and social media. 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.

3 Results

3.1 Underwater Noise Levels

Between the two hydrophone locations monitored by SMRU Consulting in 2022, a combined total of 614 days of PAM data were collected in this project cycle (January 1st to December 31st, 2022) (Table 5). There was one period of data loss during the project year. During the first deployment in 2022 (February 10th to May 17th, 2022), the hydrophone at Burrard East flooded and no data was recoverable. As a result, 97 days of data were lost and for February – May 2022, no noise levels could be analyzed, and no cetacean detections could be processed for the Burrard East site.

Table 5. 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)
2021-4	English Bay	January 1st, 2022 (from 25th November 2021 deployment)	February 7th, 2022	38
	Burrard East	January 1st, 2022 (from 25th November 2021 deployment)	February 7th, 2022	38
2022-1	English Bay	February 10th, 2022	May 17th, 2022	97
	Burrard East	NA	NA	NA
2022-2	English Bay	May 24th, 2022	August 9th, 2022	78
	Burrard East	May 19th, 2022	August 9th, 2022	83
2022-3	English Bay	August 12th, 2022	November 28th, 2022	109
	Burrard East	August 12th, 2022	November 28th, 2022	109
2022-4	English Bay	December 1st, 2022	December 31st, 2022	31
	Burrard East	December 1st, 2022	December 31st, 2022	31
				614

3.1.1 Inter-Annual Sound Levels

Annual averages at each of the sites are shown in
Table 6. The averages for 2021 excludes incomplete months and months at Burrard East where high flow noise was present. The average for 2022 for Burrard East excludes missing data from February to May.

Table 6. Average annual broadband SPL (median (L50), mean (Leq) and L5 in dB re 1µPa) by location for 2019, 2020, 2021 and 2022 project years.

	L_{50}				L_{eq}				L_5			
Location	**2019**	**2020**	**2021**	**2022**	**2019**	**2020**	**2021**	**2022**	**2019**	**2020**	**2021a**	**2022**
English Bay	121.0	120.8	121.2	**124.5**	124.6	124.6	125.3	**128.7**	128.4	128.2	128.6	**132.4**
Burrard West 1	129.1	-	-	**-**	135.4	-	-	**-**	141.0	-	-	**-**
Burrard West 2	131.4	-	131.5	**-**	134.8	-	133.8	**-**	139.1	-	137.4	**-**
Burrard East	110.8	115.9	108.9	**114.6**	124.1	126.6	124.9	**129**	129.4	132.4	129.6	**134.5**
Indian Arm	100.0	-	99.2	**-**	113.4	-	113.4	**-**	118.3	-	119.1	**-**
ONC Node	-	-	119.1	**-**	-	-	124.0	**-**	-	-	128.4	**-**

3.1.2 Ambient Sound Levels Over Time

Probability distributions for both sites are shown for 2022 in Figure 6. Burrard East was characterised by a lower amplitude, broader distribution of median hourly broadband L_{50} from 100 dB and not exceeding 125 dB re 1µPa. At English Bay we observed a higher amplitude median hourly broadband L_{50} from 110 dB and up to 140 dB re 1µPa. This pattern was more pronounced for the 10—100 Hz decade band, and similar to broadband for the 100—1k Hz decade band. Noise level distributions were narrower at 1k—10k and 10k—100k Hz decade bands, with median hourly SPLs not exceeding 120 dB re 1µPa.

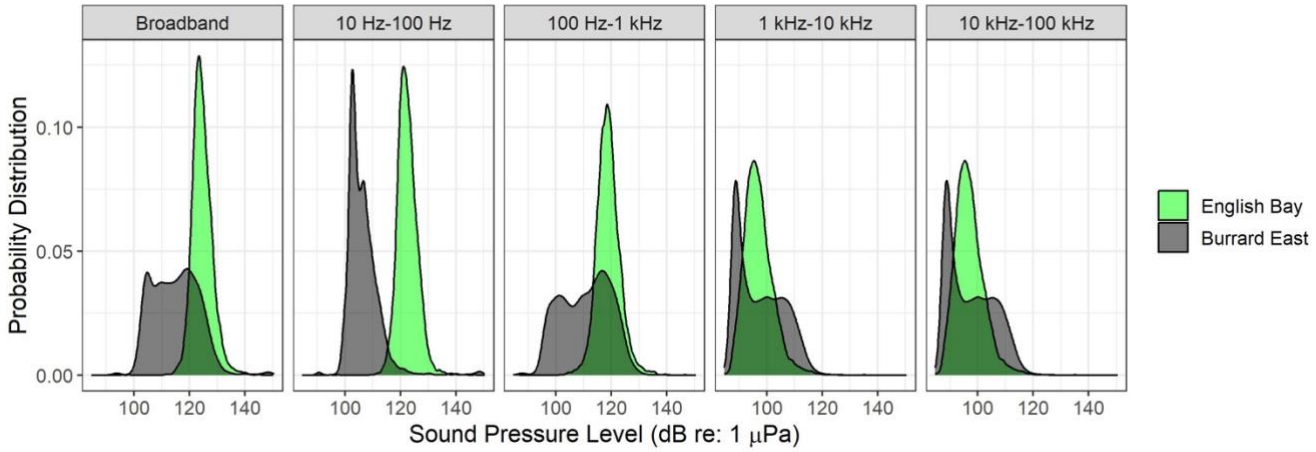


Figure 6. Probability distribution of median (L_{50}) hourly SPL (dB re 1µPa) at each location for broadband and decade frequency bands in 2022.

Monthly descriptive statistics by location are provided in Table 7. Where less than 14 days of data are available, these months are indicated by a single asterisk and were removed from the modified annual value reported in Table 7. Data gaps due to the hydrophone deployment and retrieval schedule are indicated by a single asterisk in Table 7, and data gaps due to equipment failure are indicated by a double asterisk. At the English Bay location, 2022 was the noisiest year in terms of monthly median broadband L50 compared to all other years on record. The trend at Burrard East was less clear due to the data gap between January – May 2022. Averaging the results throughout the year, English Bay had a higher monthly median broadband L50 than Burrard East (124.5 dB re 1µPa vs 114.6 re 1µPa), again with the caveat that four months of the year were missing from the Burrard East dataset (Table 7).

The highest monthly median (L50) decade band values were in the 0.01—0.1 kHz decade band at English Bay, whereas at Burrard East the 0.1—1 kHz decade band was highest. Monthly median broadband levels are provided for each location and year monitored in Figure 7 through Figure 8. Figure 9 displays are a comparison between locations for the 2022 project year, and Figure 10 through Figure 11 provide additional information on the sound pressure levels for each decade band.

Table 7. 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	Jan	125.7	123.6	120.1	112.0	96.6	128.1	131.3
	Feb*	123.4	120.6	119.3	108.3	97.2	127.8	131.2
	Mar	124.3	122.3	118.7	109.5	96.0	127.9	131.4
	Apr	122.6	120.7	117.1	108.1	95.6	127.0	130.8
	May	122.7	120.3	117.7	109.3	98.1	128.0	131.8
	Jun	124.7	122.5	119.2	109.6	97.6	127.8	131.6
	Jul	125.5	123.4	119.6	109.7	98.6	131.2	135.8
	Aug*	123.8	121.7	118.3	107.2	94.1	128.2	131.8
	Sep	123.6	121.5	118.2	107.9	95.1	128.0	131.4
	Oct	125.6	123.7	119.6	111.8	96.7	130.2	132.6
	Nov*	125.2	122.6	120.2	112.4	98.1	129.1	132.3
	Dec	127.0	125.3	120.5	112.3	97.5	131.0	137.0
Burrard East	Jan**							
	Feb**							
	Mar**							
	Apr**							
	May*	114.7	104.7	110.9	106.1	95.6	128.2	133.6
	Jun	116.5	105.4	113.2	109.4	98.8	130.1	134.3
	Jul	117.3	105.9	114.2	110.7	99.2	128.1	133.9
	Aug*	116.8	105.3	113.9	109.3	98.4	128.9	134.8
	Sep	115.4	104.9	112.2	107.8	96.4	128.6	134.7
	Oct	112.0	103.9	107.9	103.4	94.4	126.5	132.2
	Nov*	109.6	103	104.6	100.6	92	125.7	130.7
	Dec	114.3	108.7	109.2	104.4	95.0	135.9	141.9

** = Data gaps associated with deployment and retrievals.*
*** = Data loss resulting from equipment failure.*

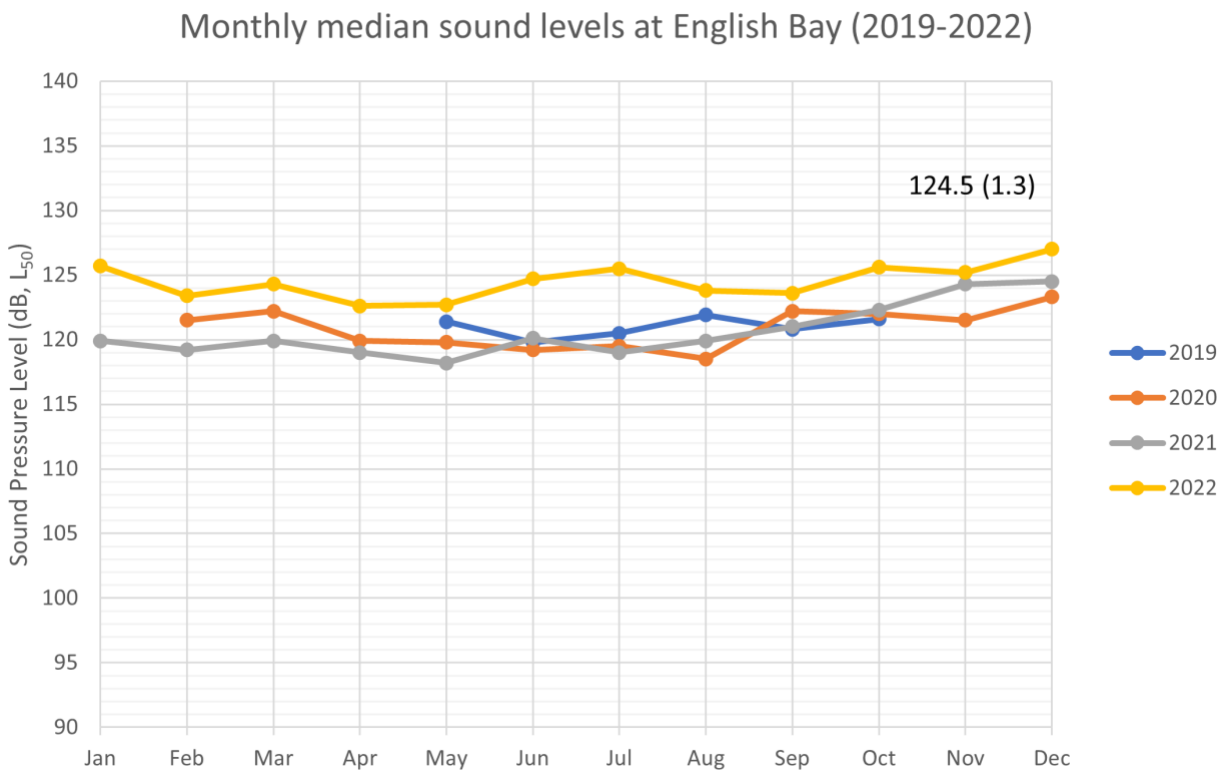


Figure 7. Median (L_{50}) broadband monthly SPL (dB re 1µPa) at English Bay across all project years. Adjusted average values for the 2022 project year with standard deviation are provided above and to the right of the monthly trend lines.

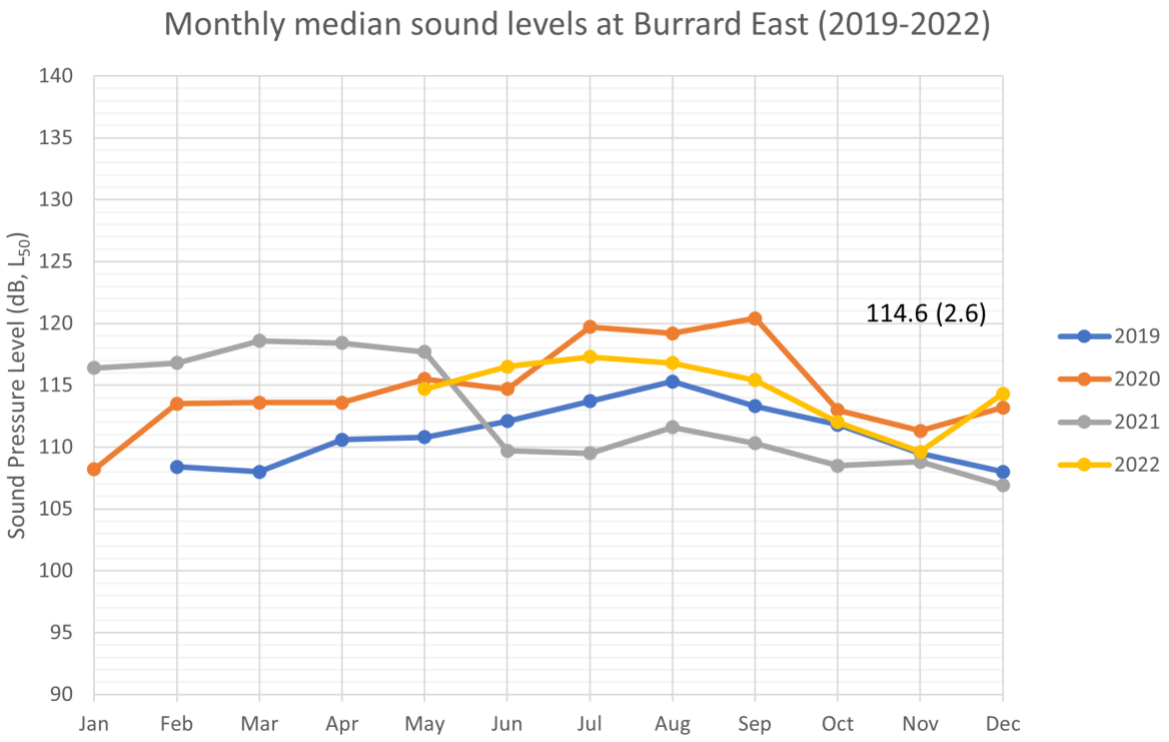


Figure 8. Median (L_{50}) broadband monthly SPL (dB re 1µPa) at Burrard East across all project years. Full months of data were unavailable for January – May 2022 at the Burrard East location due to equipment failure. Adjusted average values for the 2022 project year with standard deviation are provided above and to the right of the monthly trend lines.

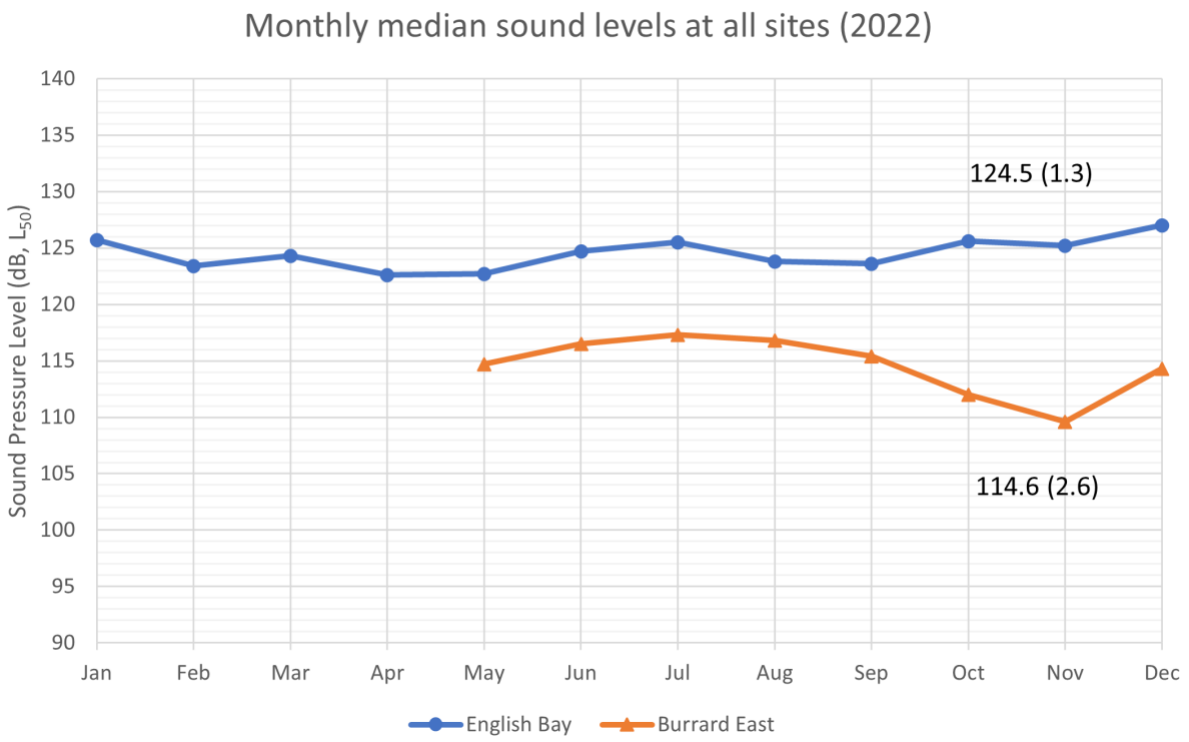


Figure 9. Median (L_{50}) broadband monthly SPL (dB re 1µPa) at both locations, English Bay and Burrard East, for the 2022 project year. Full months of data were unavailable for January – May 2022 at the Burrard East location due to equipment failure. Adjusted average values for the 2022 project year with standard deviation are provided to the right of the monthly trend.

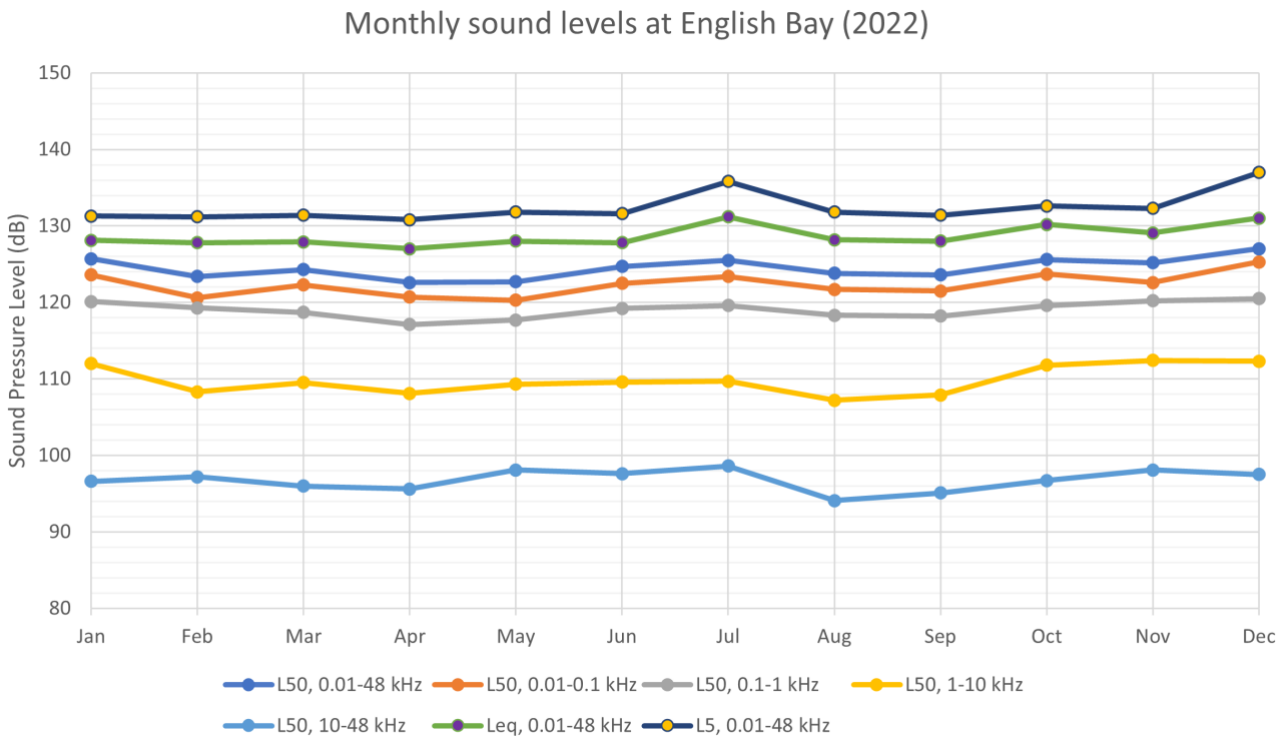


Figure 10. English Bay broadband median (L_{50}), mean (L_{eq}) and L_5 and median (L_{50}) decade band monthly SPL (dB re 1µPa).

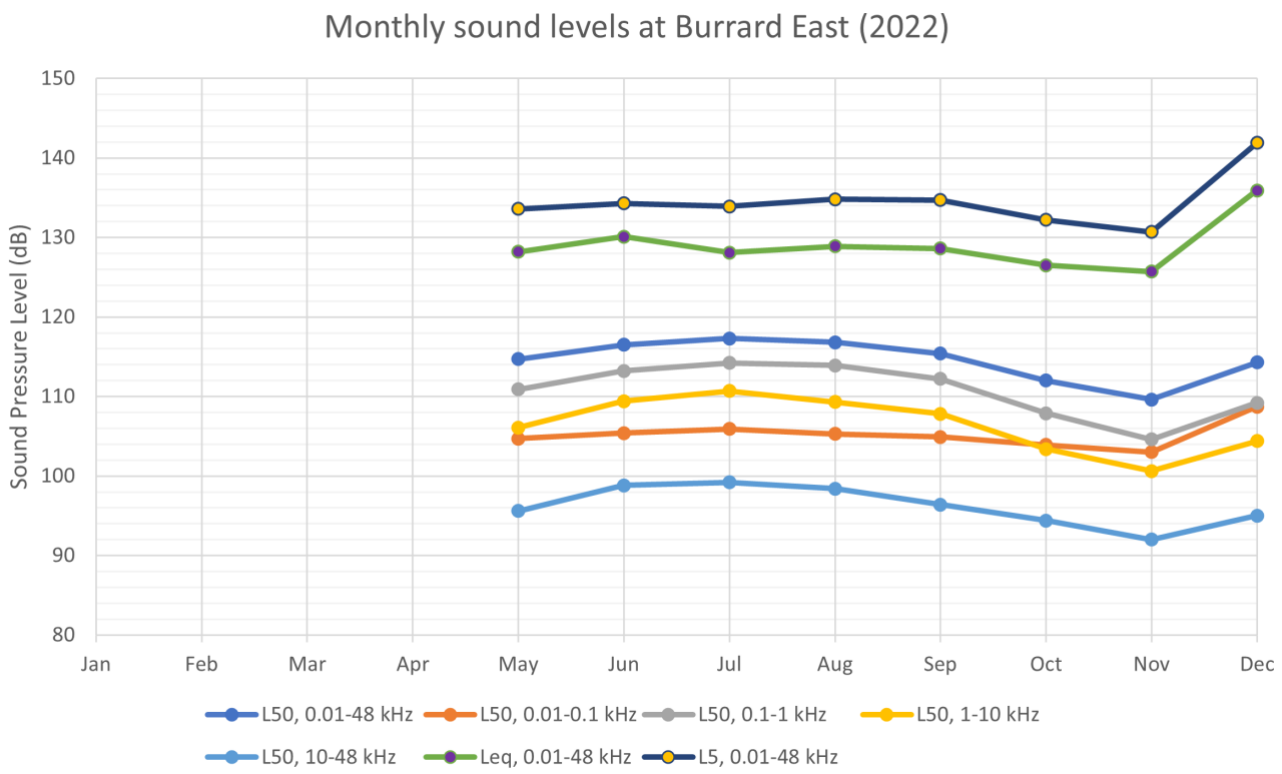


Figure 11. Burrard East broadband median (L_{50}), mean (L_{eq}) and L_5 and median (L_{50}) decade band monthly SPL (dB re 1µPa).

3.1.3 Monthly One-Third Octave SPLs and PSDs

Example decade band and Long-Term Spectrogram Average (LTSA) levels are shown in Figure 12 through Figure 17 for all sites. LTSAs are time averaged spectrograms, useful for viewing acoustic data over weeks, months or years. The months of June and September were selected for evaluation here, as no deployments or recoveries took place during those periods.

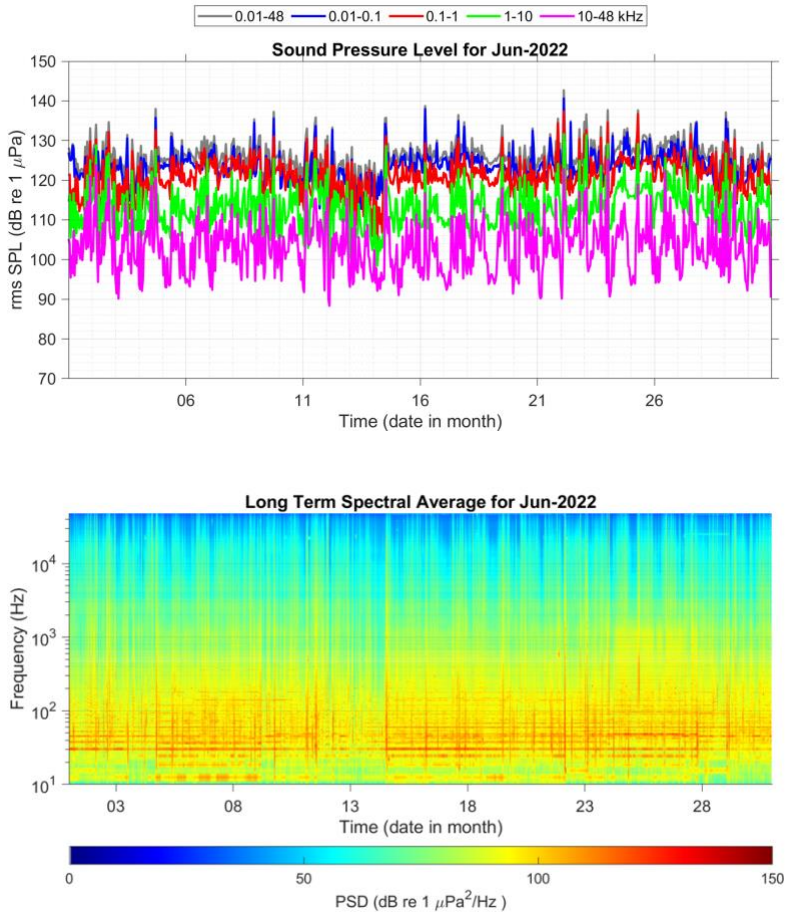
At both the English Bay and Burrard East sites, the highest noise levels tended to occur at lower frequencies. At English Bay, the highest noise levels generally occurred below 500 Hz in both June and September 2022, whereas at Burrard East the spread of energy was broader with higher noise levels still detectable up to 1 kHz.

- The median broadband sound pressure level (L_{50}) was 124.7 dB re 1µPa at English Bay throughout the month of June, and 123.6 dB re 1µP throughout the month of September.

- The median broadband sound pressure level (L_{50}) was 116.5 dB re 1µPa at Burrard East throughout the month of June, and 115.4 dB re 1µPa throughout the month of September.

The LTSA for the Burrard East site revealed periods of increased noise (>140 dB re 1µPa) below 0.1 kHz between June 16th and 18th inclusive (Figure 13 and Figure 16). Tidal heights during this period exceeded 5 m (https://www.tides.gc.ca). A similar but fainter pattern was observed again at the Burrard East site between the 6th and 12th of September. The pattern was a repeating phenomenon observed on the LTSA plots of various months at Burrard East. Manual inspection of the Burrard East audio files revealed that these short-term periods of increased noise result mainly from tidal flow noise with a contribution from vessel noise at times.

English Bay (June)



English Bay (September)

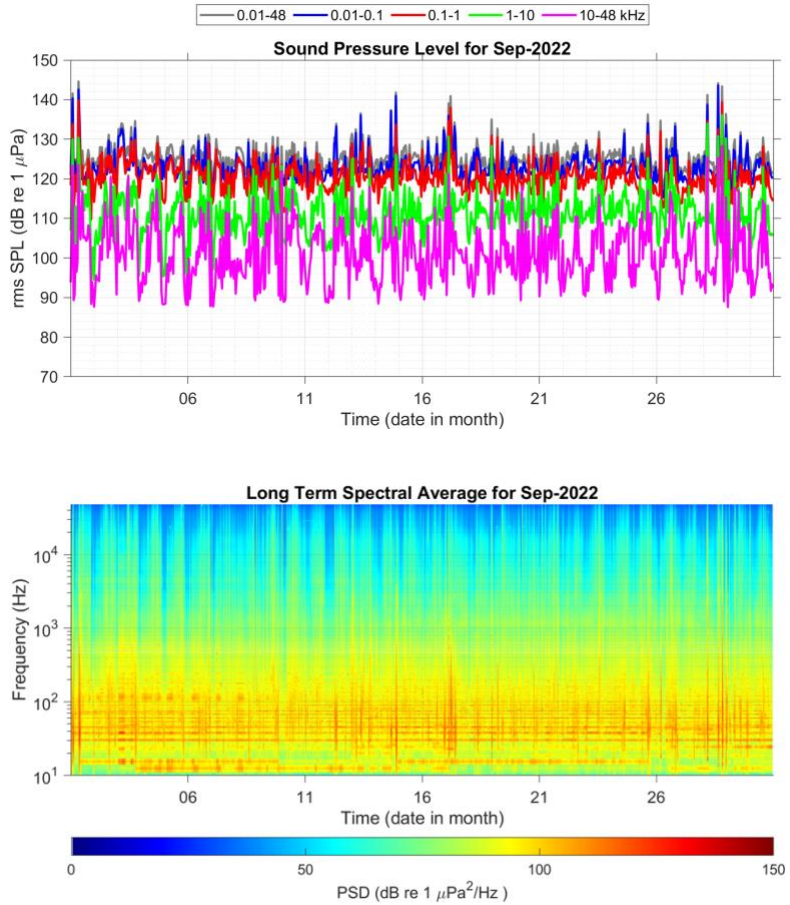


Figure 12. Decade band sound pressure levels (SPL, top panel) and long-term spectrograms for two representative months (June and September) at one hour resolution for the English Bay deployment site.

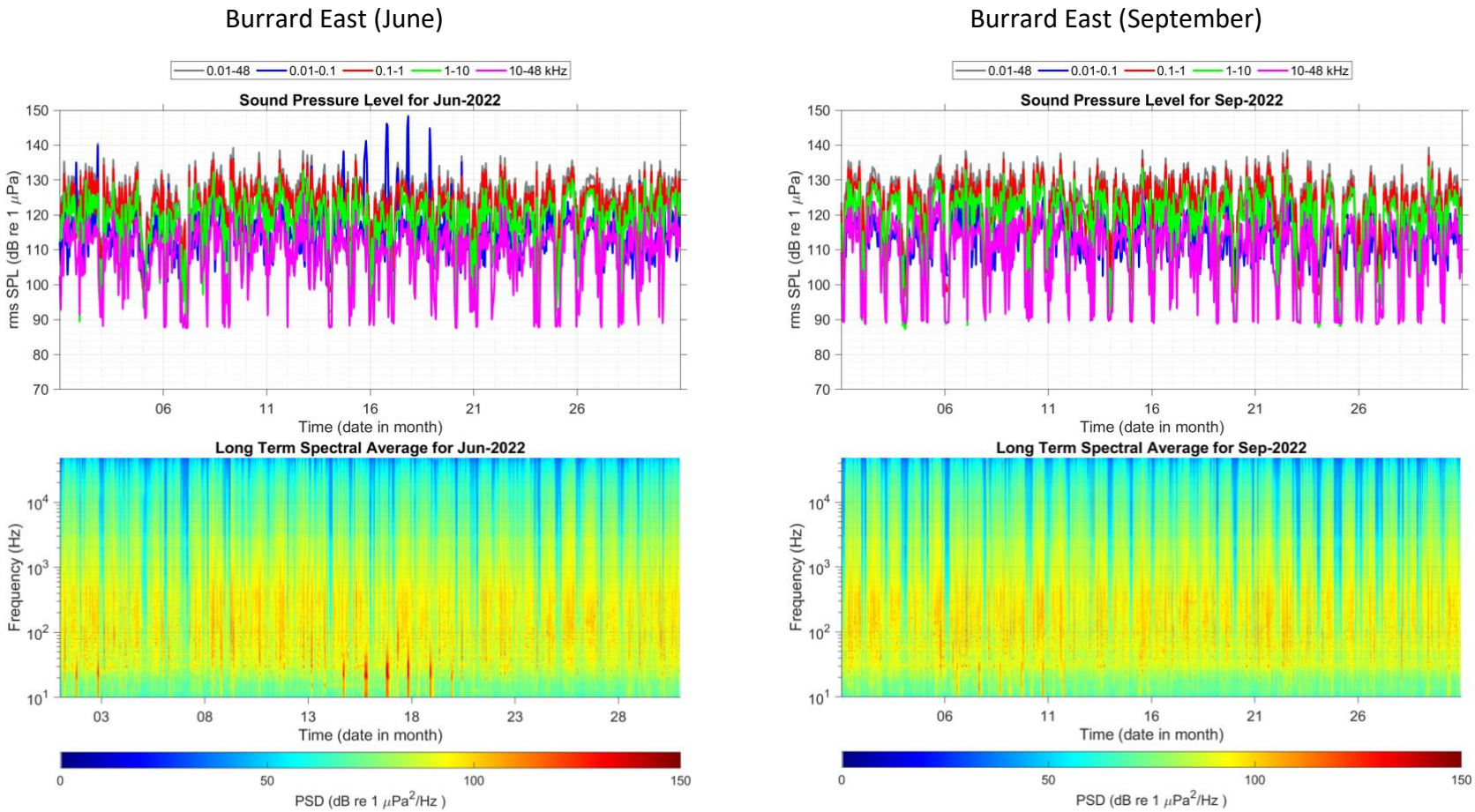


Figure 13. Decade band sound pressure levels (SPL, top panel) and long-term spectrograms for two representative months (June and September) at one hour resolution for the Burrard East deployment site.

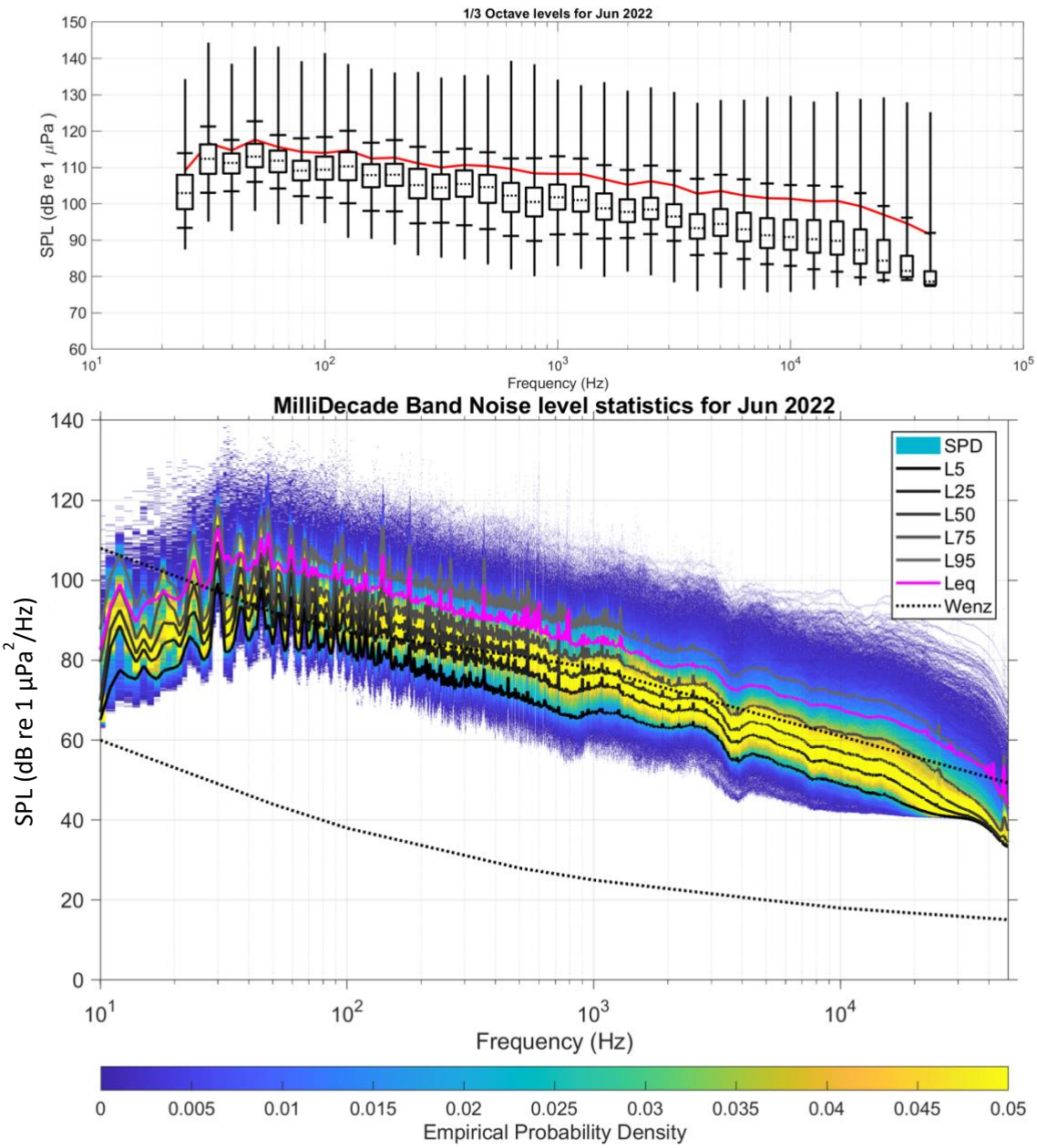


Figure 14. One minute power spectral density percentiles (lower panel) and third octave band distributions (upper panel) for June 2022 at English Bay. Red line indicates root mean square (RMS) sound pressure level in each third octave bin. Boxplots illustrate the distribution of SPL data, whereby whiskers represent the minimum and maximum values recorded, fences truncate the whiskers and represent the 5th and 95th percentiles, box edges represent the 25th and 75th percentiles and dashed lines within the box represent median noise levels.

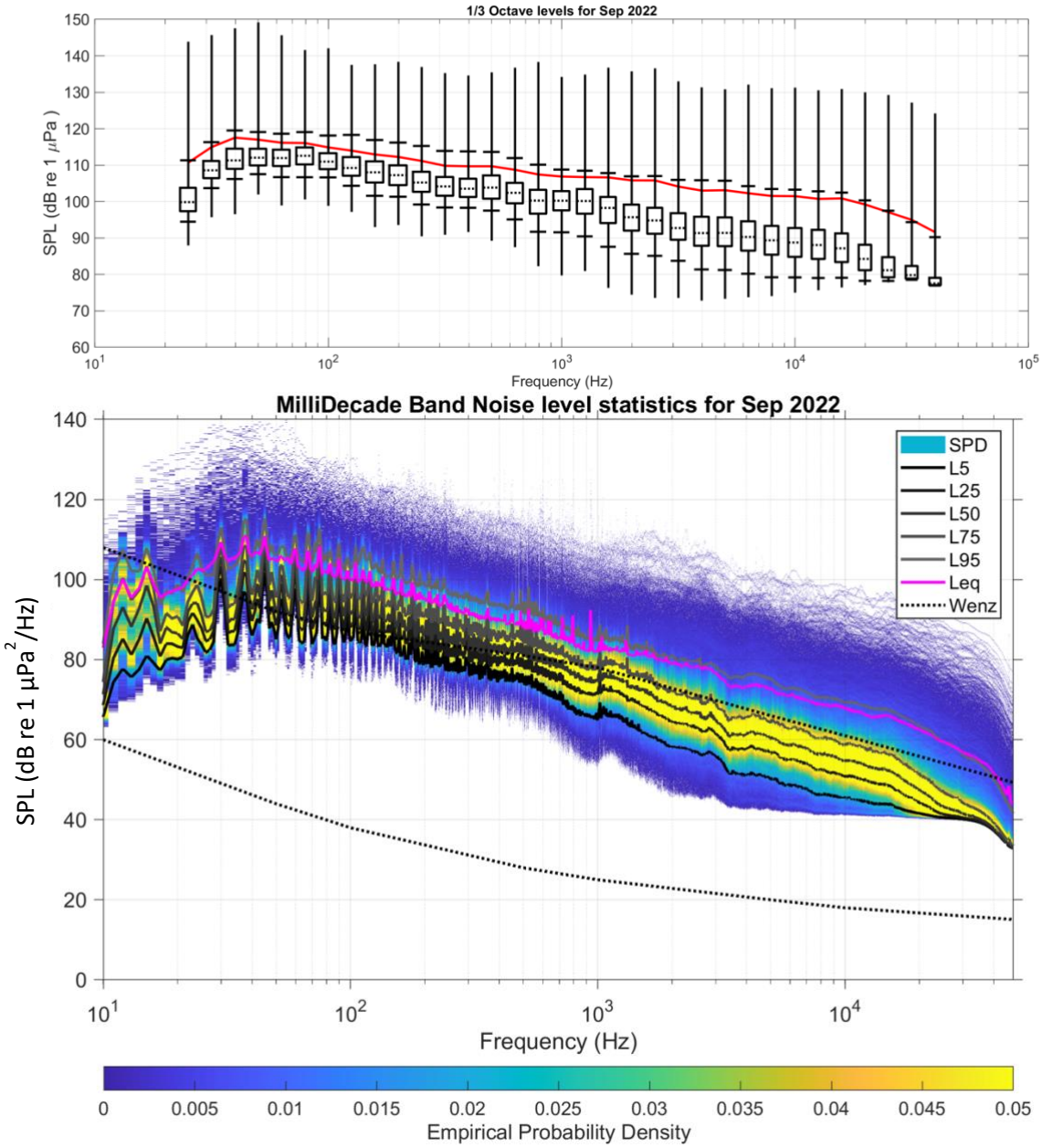


Figure 15. One minute power spectral density percentiles (lower panel) and third octave band distributions (upper panel) for September 2022 at English Bay. Red line indicates RMS sound pressure level in each third octave bin. Boxplots illustrate the distribution of SPL data, whereby whiskers represent the minimum and maximum values recorded, fences truncate the whiskers and represent the 5th and 95th percentiles, box edges represent the 25th and 75th percentiles and dashed lines within the box represent median noise levels.

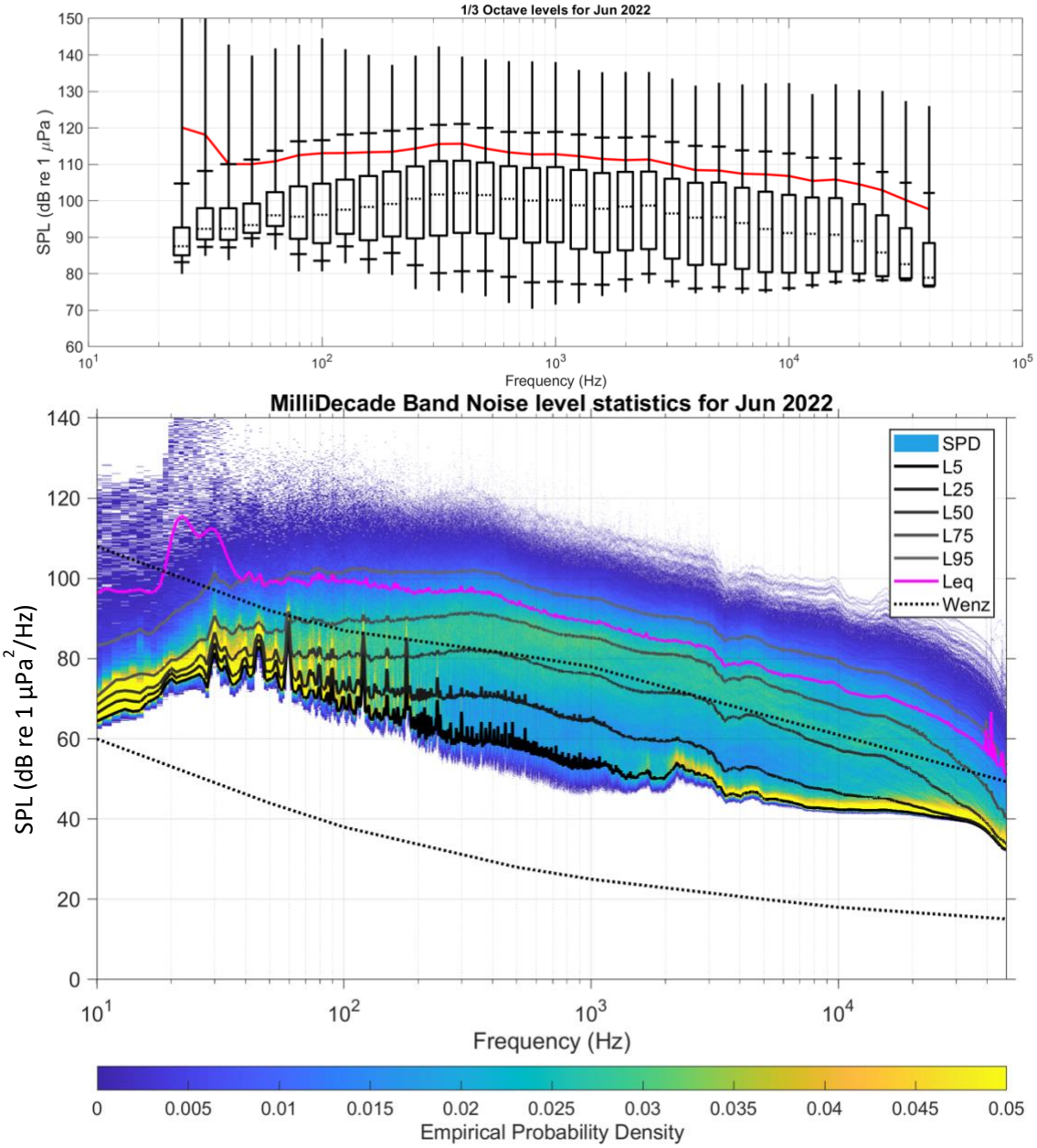


Figure 16. One minute power spectral density percentiles (lower panel) and third octave band distributions (upper panel) for June 2022 at Burrard East. Red line indicates RMS level in each third octave bin. Boxplots illustrate the distribution of SPL data, whereby whiskers represent the minimum and maximum values recorded, fences truncate the whiskers and represent the 5th and 95th percentiles, box edges represent the 25th and 75th percentiles and dashed lines within the box represent median noise levels.

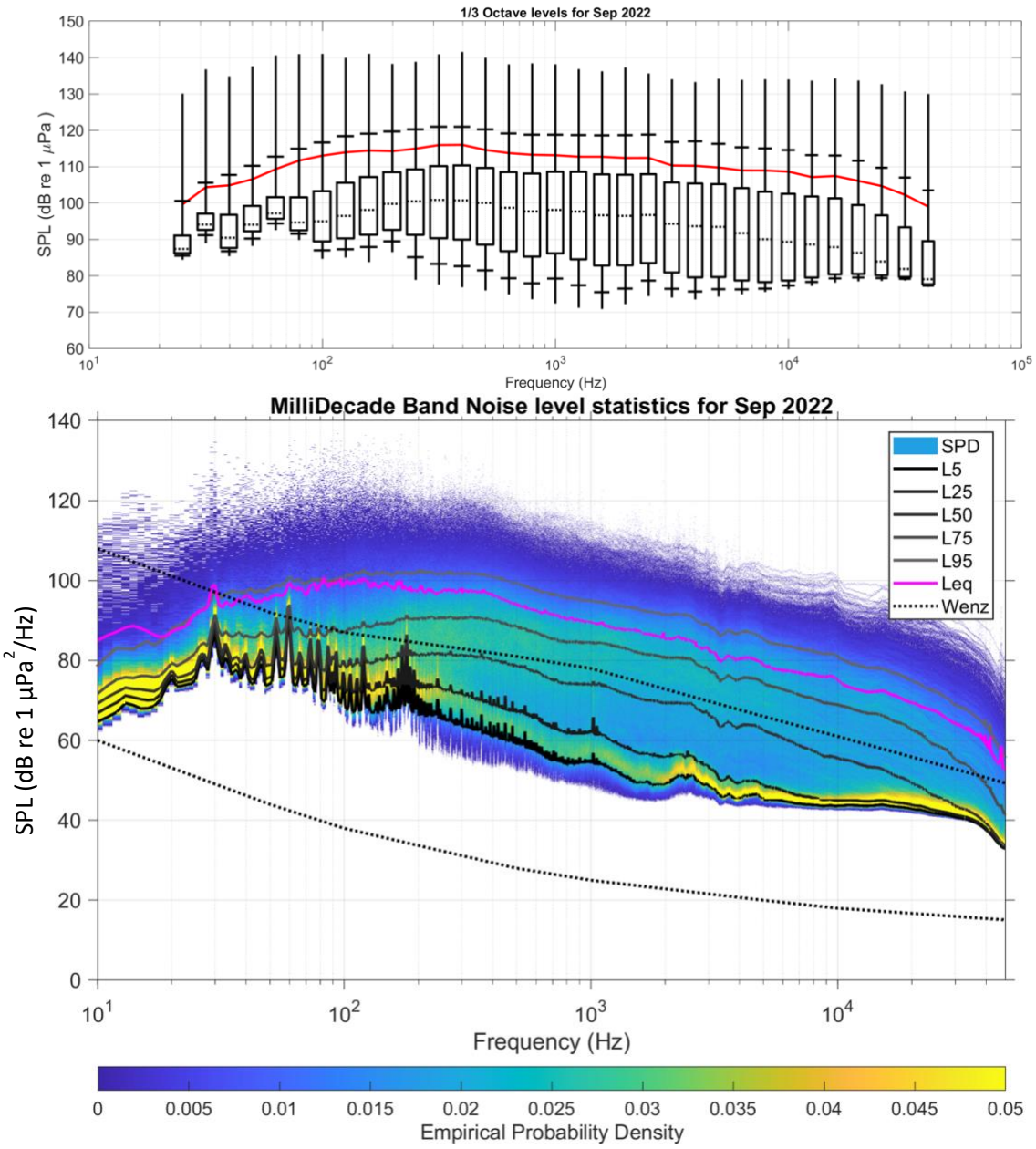


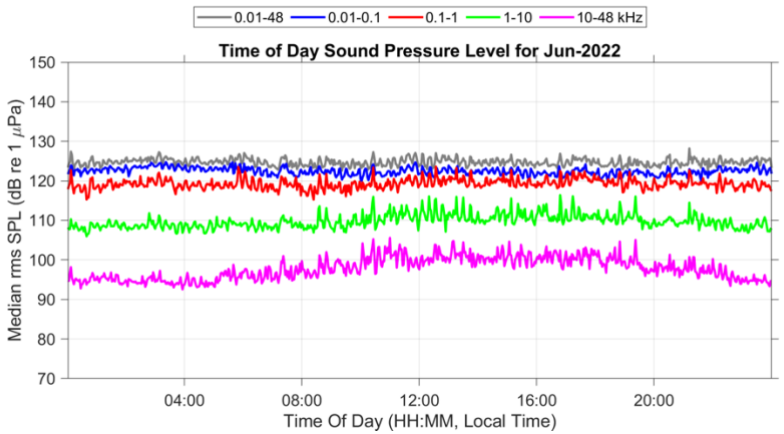
Figure 17. One minute power spectral density percentiles (lower panel) and third octave band distributions (upper panel) for September 2022 at Burrard East. Red line indicates RMS level in each third octave bin. Boxplots illustrate the distribution of SPL data, whereby whiskers represent the minimum and maximum values recorded, fences truncate the whiskers and represent the 5th and 95th percentiles, box edges represent the 25th and 75th percentiles and dashed lines within the box represent median noise levels.

3.1.4 Diurnal Rhythm

Average diurnal variation in noise levels are visualised at both sampling locations and for two representative months of the year, June and September (Figure 18 through Figure 19).

Burrard East continues to exhibit a far more pronounced diurnal trend than English Bay. The broadband noise levels at Burrard East are ~20 dB higher during daylight hours. The noise levels in all decade bands at the Burrard East location rise at approximately 06:00 (Local Time) and stay elevated into the evening. During the summer months, the evening drop-off in noise is gradual after 20:00, whereas by September an abrupt decrease in noise can be observed at approximately 20:00. This is consistent with the change in day length and time of sunset.

English Bay (June)



English Bay (September)

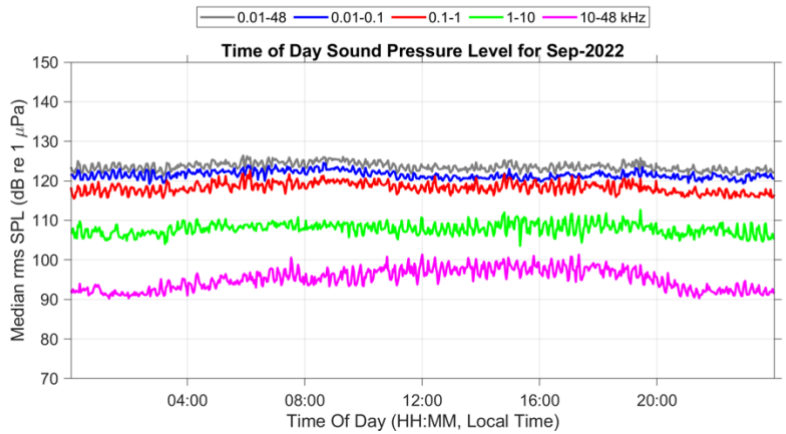
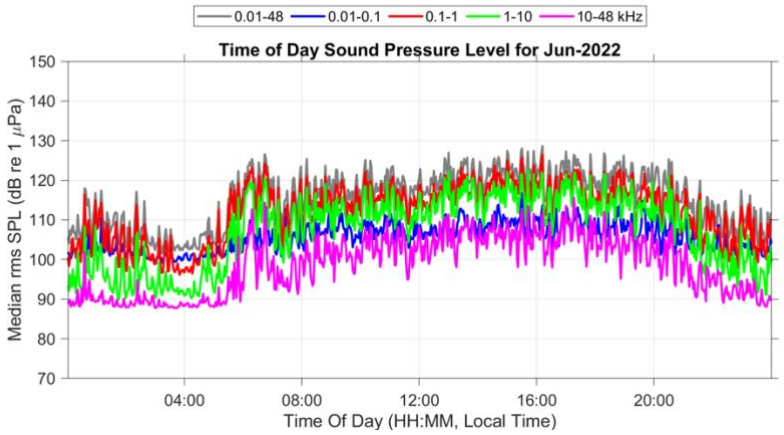


Figure 18. Decade band sound pressure levels by time of day at English Bay for two representative months.

Burrard East (June)



Burrard East (September)

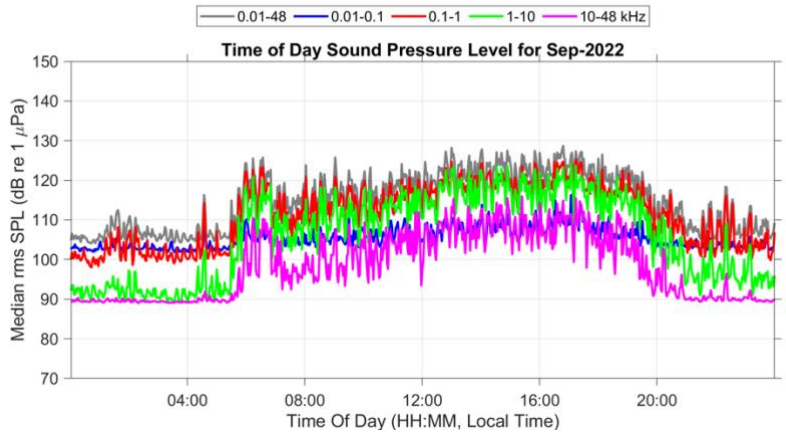


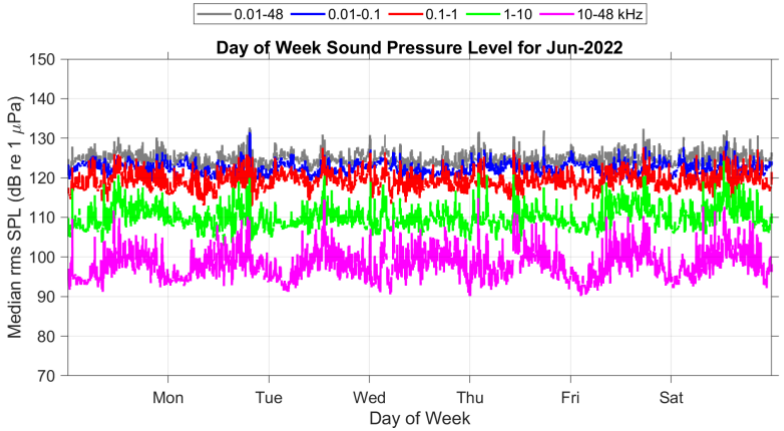
Figure 19. Average daily decade band sound pressure levels by time of day at Burrard East for two representative months.

3.1.5 Weekly Rhythm

Average weekly variation in noise levels are visualised at both sampling locations and for two representative months of the year, June and September (Figure 20 through to Figure 21). Notably, these plots re-highlight the diurnal patterns described in the previous section and confirm these patterns over a weekly time-span. Additionally, several other features are of interest:

- Very little variation exists between weekday and weekend noise levels at the Burrard East and English Bay locations.
- At English Bay during the month of September, there appears to be a very slight trend towards higher noise levels on Saturdays in the third and fourth decade bands. This was not observed consistently throughout the year.

English Bay (June)



English Bay (September)

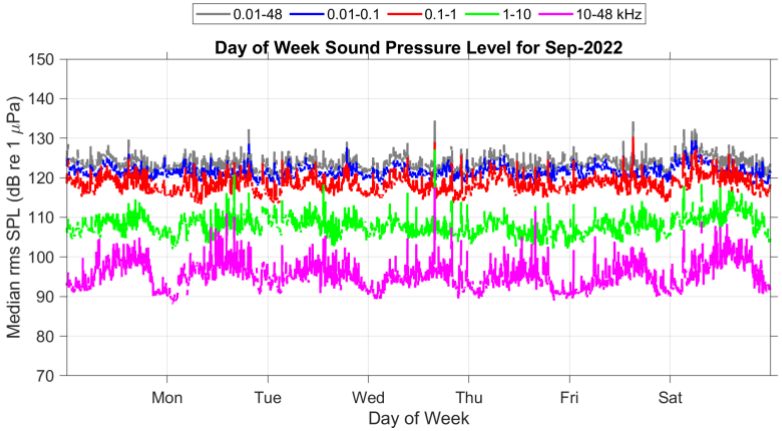
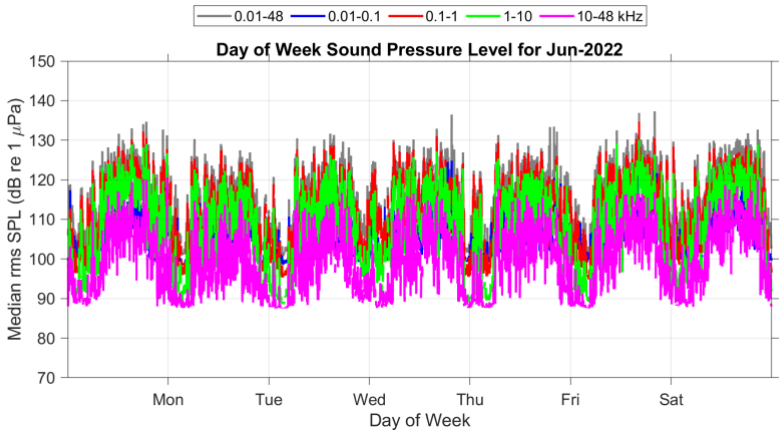


Figure 20. Decade band sound pressure levels by day of week for June and September 2022 at English Bay.

Burrard East (June)



Burrard East (September)

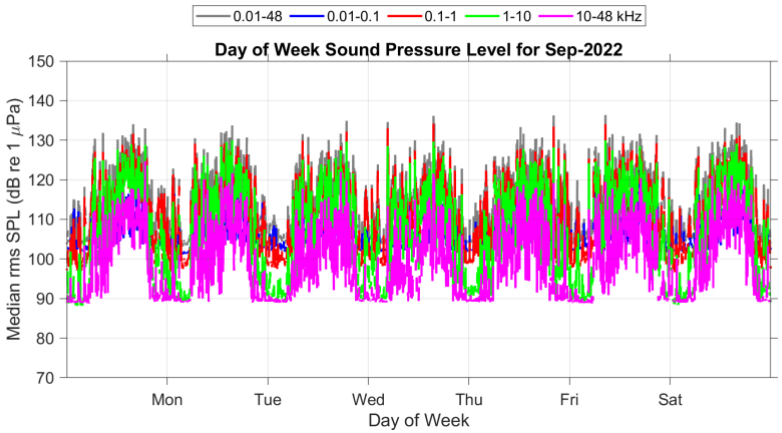


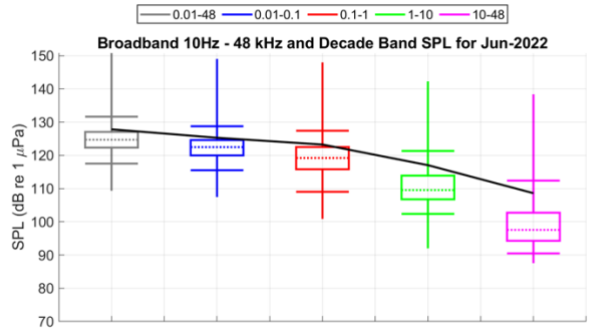
Figure 21. Decade band sound pressure levels by day of week for June and September 2022 at Burrard East.

3.1.6 SPL Variability

SPL trends and variability across locations are visualised using box plots. June and September are selected again for display (Figure 22 and Figure 23).

- In English Bay, the highest noise levels are observed in the first decade band (0.01—1 kHz), which is consistent with low frequency shipping noise.
- At Burrard East, the highest noise levels are observed in the second decade band (0.1—1 kHz) and we observe a wider variation in noise levels at this location than English Bay, and a larger contribution from higher-frequency noise sources.

English Bay (June)



English Bay (September)

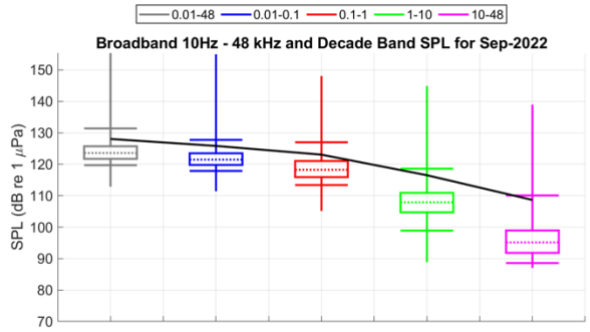
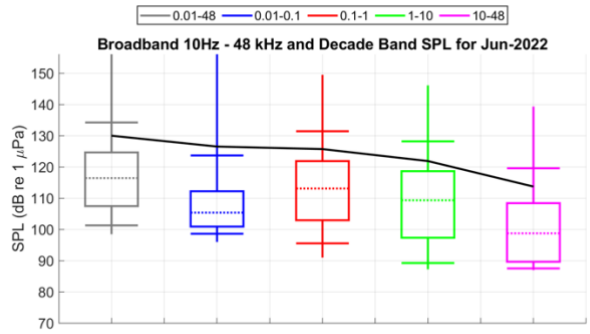


Figure 22. Box plot of broadband and decade band noise levels for June and September 2022 at English Bay.

Burrard East (June)



Burrard East (September)

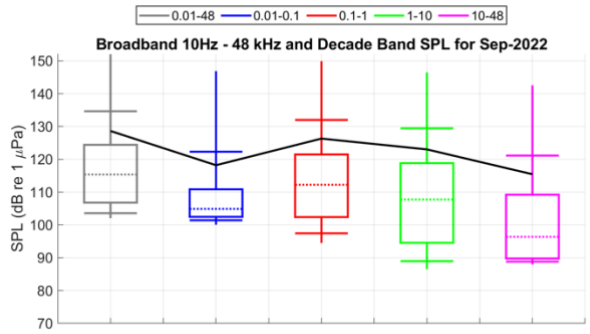


Figure 23. Box plot of broadband and decade band noise levels for June and September 2022 at Burrard East.

3.1.7 Ancillary Data

3.1.7.1 Vessel Density

The range in daily AIS-based based vessel abundances are shown in Figure 24 and in reference to the locations and total areas described in Table 4. The upper panel depicts vessels moving > 1 knot and the lower panel includes both moving and non-moving vessels transmitting AIS. For moving vessels, observed vessel speeds based on AIS data ranged from over 1 to 14 knots, with a small percentage of vessels doing from 14 up to 43.2 knots such as Search and Research (SAR), large pleasure craft and military operations. The number of moving vessels per day ranged from 5–55 with a median of 31 per day for Burrard East, and from 9–141 with a median of 52 for English Bay. When including stationary vessels, daily total counts ranged from 7–59 with a median of 35 for Burrard East and 20–149 with a median of 61 for English Bay.

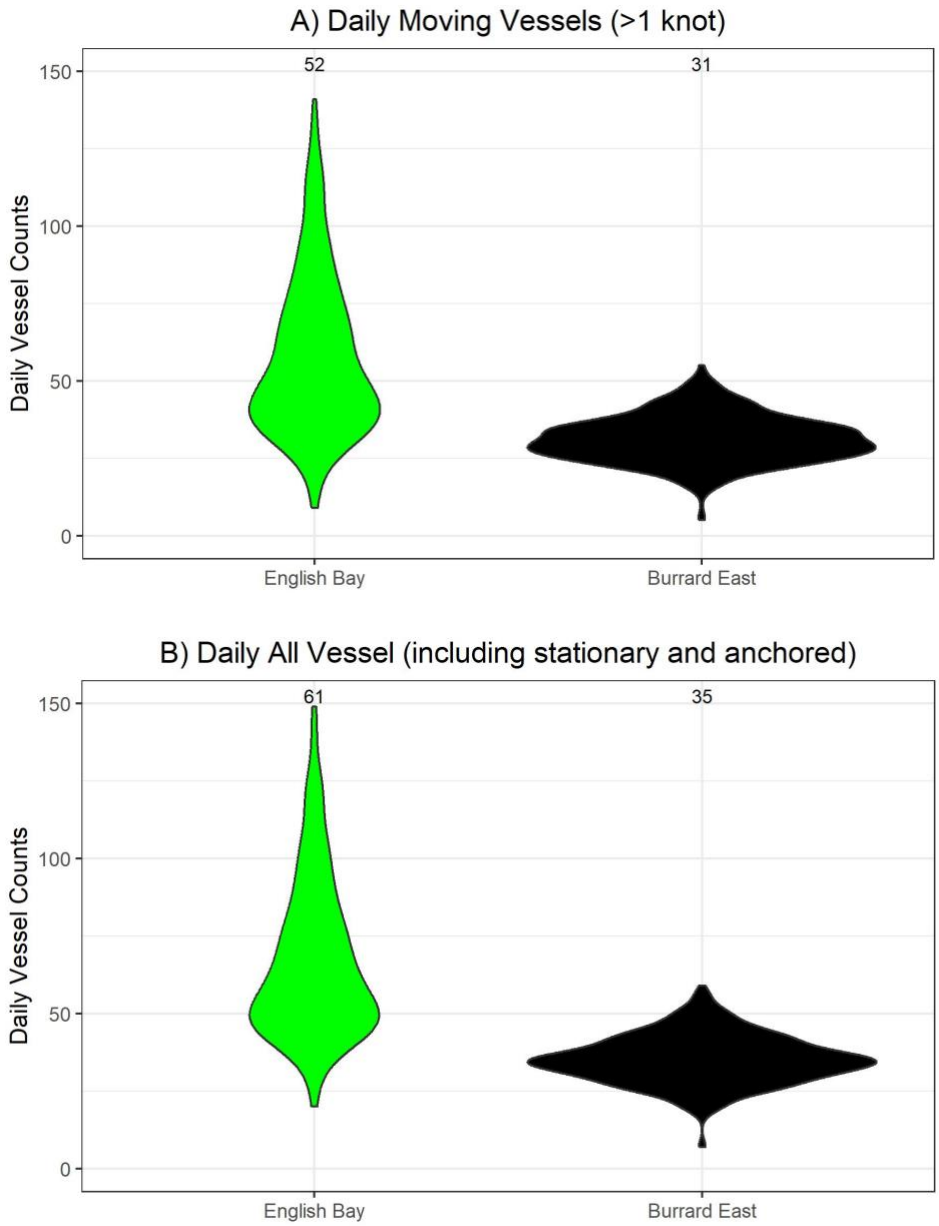


Figure 24. Daily vessel abundance (counts) by location based on AIS data (Class A) within 3 km of each hydrophone. Top panel depicts signal density for moving vessels only (> 1 knot). Median vessel abundances are provided at the top of each plot.

The relationship between hourly ambient noise levels plotted against the AIS-based moving vessel abundance for the same time is illustrated in Figure 25. We observe a positive relationship between increasing daily, moving vessel abundance and sound pressure levels at broadband and low frequencies (10–1000 Hz) at English Bay and Burrard East, while this relationship is not visible at higher frequencies (> 1000 Hz) (Figure 25).

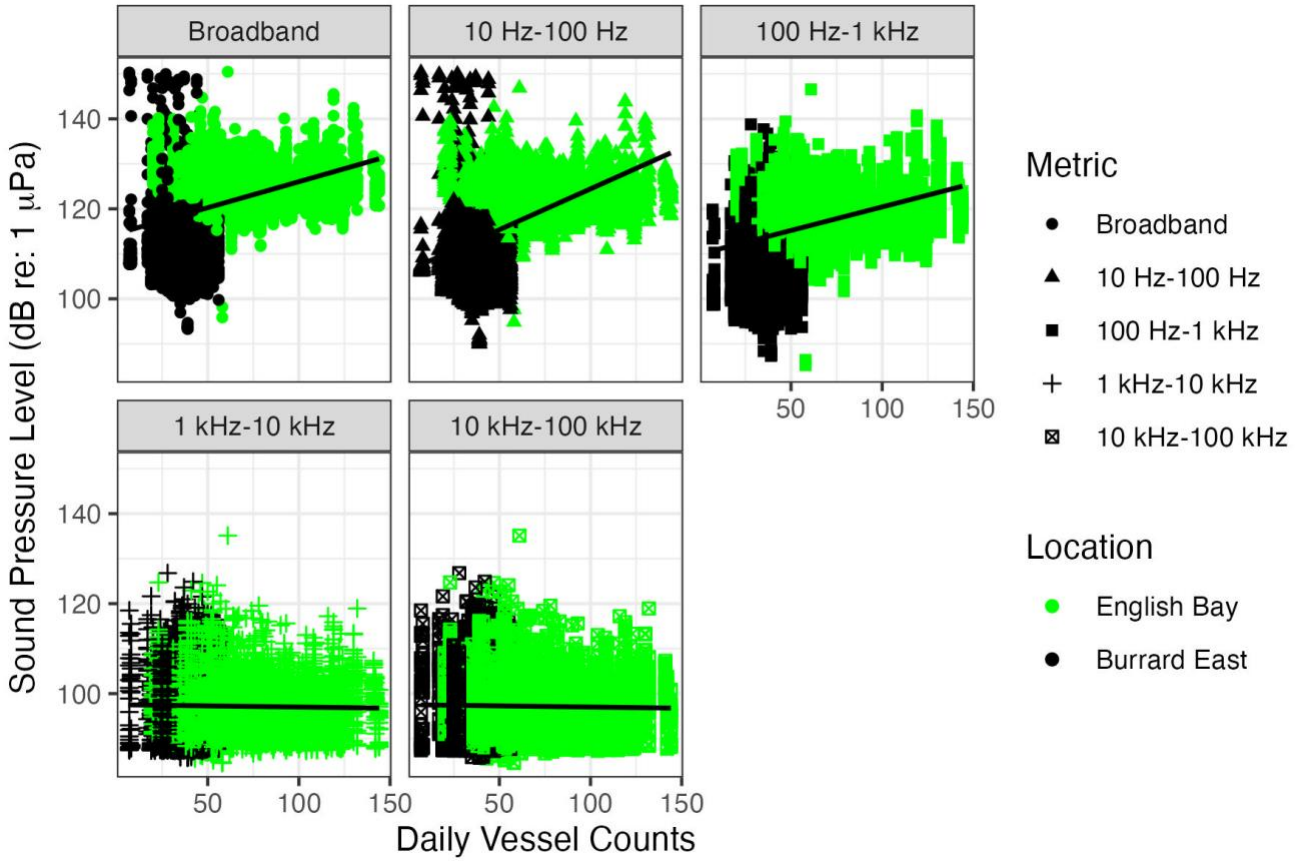


Figure 25. Relationship between moving vessel abundance (counts) per day and hourly sound pressure levels per day for broadband and decade band values at each location.

3.2 Cetacean Presence Using PAM

A summary of all cetacean detections is provided in Table 8. An example of a PAM-detected harbor porpoise (*Phocoena phocoena*) click train from English Bay is provided in Figure 26. Harbor porpoises 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 reporting cycle (February 19th 2021 – January 31st 2022). 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 27) and continue the trend of increased detections year over year since the monitoring program was initiated. A total of 254 porpoise days were recorded at English Bay and as per previous years, this location recorded the most activity. A total of 3 porpoise days were recorded in Burrard East, 2 in January and 1 in December.

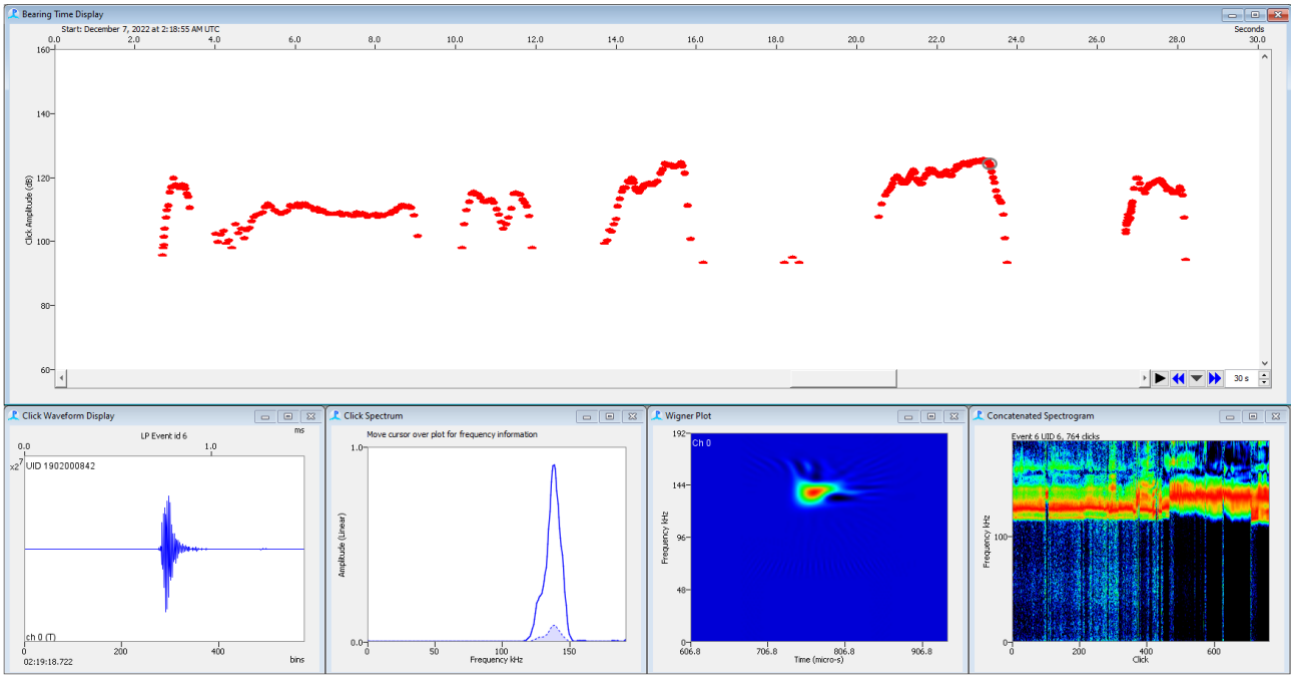


Figure 26. Example of a porpoise detection event using PAMGuard software. The top panel shows trend in amplitude (y-axis) as animals sweep past the hydrophone. Lower panels provide click diagnostics including (left to right) waveform, click spectrum, Wigner plot and concatenated spectrogram.

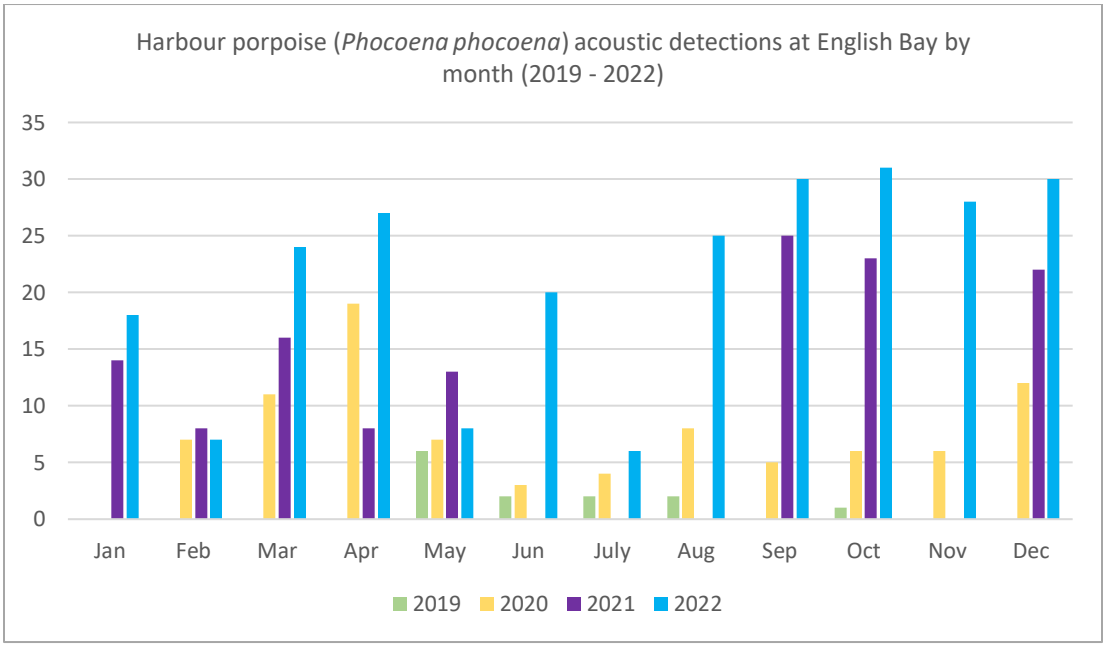


Figure 27. Harbor porpoise detection positive days for 2022 showed a similar pattern to the previous year, with the highest numbers recorded in the fall and winter months. Note that months without coloured bars indicate months with no data available, not a lack of porpoise detections.

Table 8. Marine mammal detection results for this project year (beginning January 2022). 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***	***# Positive Days – Clicks (Porpoise)***	***# Positive Days – Whistles (other cetaceans)***
English Bay	January 2022	18	3
	February 2022	7	2*
	March 2022	24	0
	April 2022	27	0
	May 2022	8	0
	June 2022	20	0
	July 2022	6*	0
	August 2022	25	2*
	September 2022	30	1
	October 2022	31	1
	November 2022	28	2*
	December 2022	30	3
	Year Total	***254***	***14***
Burrard East	January 2022	2	-
	February 2022	-	-
	March 2022	-	-
	April 2022	-	-
	May 2022	-	-
	June 2022	0	0
	July 2022	0	0
	August 2022	0	1**
	September 2022	0	0
	October 2022	0	0
	November 2022	0	0*
	December 2022	1	0
	Year Total	***3***	***1***
Burrard West 2	January 2022	0	0
	February 2022	0	1
	Year Total	***0***	***1***
Indian Arm	January 2022	1	0
	February 2022	0	1
	Year Total	***1***	***1***

- Indicates periods without data
* Reduced coverage from corrupted click files or data gaps associated with deployment and retrievals
** Indicates an unknown delphinid whistle

Killer whale acoustic detections were confirmed on 15 separate days in 2022 (Table 8 and Table 9). On one day (6th February 2022), two detections were made first at English Bay followed by Burrard West (Table 9). One detection was recorded at Indian Arm, and all 13 remaining detections occurred at English Bay (Table 9). The longest event lasted one hour and eleven minutes while the shortest was one minute. A summary of acoustic detection events in 2022 is provided in Table 9 and the total number of killer whale acoustic detection events by month are illustrated for Burrard Inlet (across all sites) for four years of PAM data collection (Figure 28), there are therefore 16 killer whale detection events (described in Table 9) illustrated in this figure that occurred on 15 individual days across Burrard Inlet in 2022. These results are illustrated alongside the total killer whale detection events for previous years of monitoring from 2019–2021 (SMRU Consulting, 2019, 2020, 2021). There was also one delphinid whistle recorded at the Burrard East site which could not be classified as a killer whale vocalisation, but was recorded as a detection positive event included for cetaceans (Table 8).

Three different killer whale ecotypes were detected during this project year (Table 9). For the first time in this monitoring program, Northern Resident Killer Whales (NRKW) were identified in seven detection events. 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. It should be noted that the detections at Burrard West 2 and Indian arm locations were presented in the 2021 annual report (SMRU Consulting, 2022) – and as these locations were not part of the 2022 monitoring program, detections at these two locations were not monitored beyond February 2022. One of the NRKW events 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 29).

Other ecotypes included transient killer whales (also known as Bigg's ecotype) and Southern Resident Killer Whales (SRKW). Three killer whale detection events on August 27th and 31st, and September 11th 2022, could not be identified to ecotype as the calls were too faint. Transients were identified during one event on November 17th, 2022, and SRKW were identified in October, November, and December for a total of five separate events.

Visual sightings of killer whales are provided in Table 10. None of these visual sightings were detected acoustically.

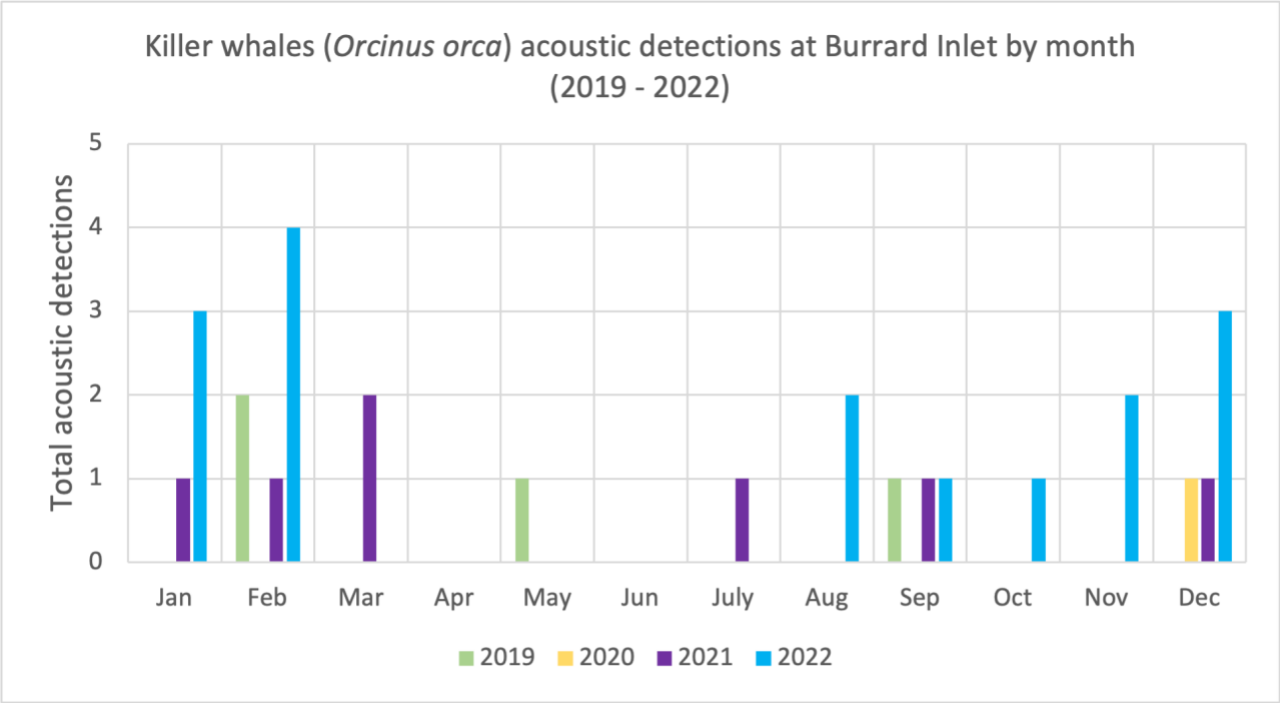


Figure 28. Total number of killer whale acoustic detection events by month for the Burrard Inlet as a whole, including all sampling locations within each year of monitoring and across locations monitored for four years of PAM data collection.

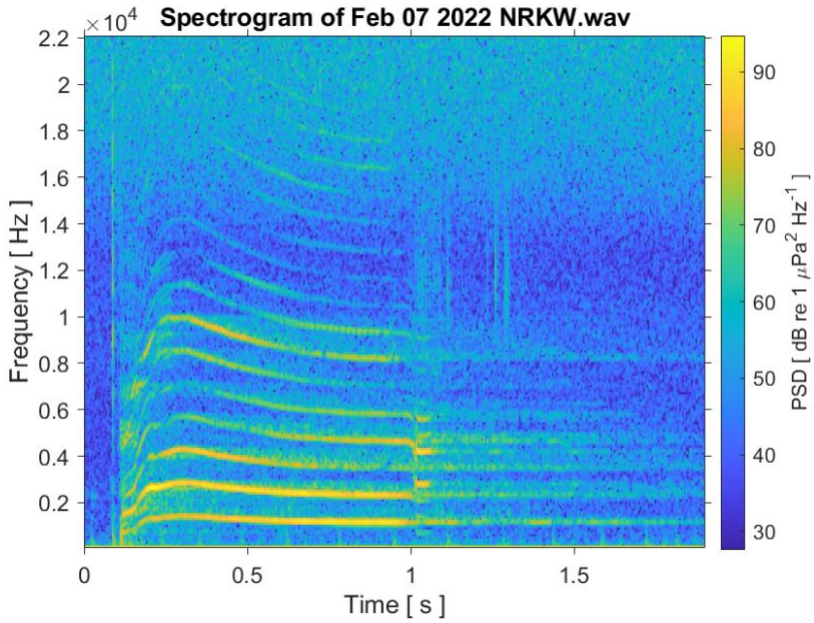


Figure 29. Northern Resident killer whale call recorded on February 7th, 2022, at the Indian Arm site.

Table 9. Acoustic detection of killer whales for the project year (Jan – Dec 22).

Deployment Number	Location	Date	Start time of recording (local)	End time of recording (local)	Event Duration (min)	Ecotype
4-2021	English Bay	24-01-22	21:37	22:05	00:28:00	Probable NRKW
4-2021	English Bay	26-01-22	18:12	18:25	00:13:00	NRKW
4-2021	English Bay	30-01-22	17:15	17:31	00:16:00	NRKW
4-2021	English Bay	5-02-22	09:47	11:45	01:02:00	NRKW
4-2021	English Bay	6-02-22	19:43	19:45	00:02:00	NRKW
4-2021	Burrard West 2	6-02-22	21:37	21:53	00:16:00	NRKW
4-2021	Indian Arm	7-02-22	00:50	02:25	01:35:00	NRKW
3-2022	English Bay	27-08-22	13:17	13:18	0:01:00	Possible KW
3-2022	English Bay	31-08-22	08:55	09:00	0:05:00	KW Unknown Ecotype
3-2022	English Bay	11-09-22	12:08	12:10	0:02:00	KW Unknown Ecotype
3-2022	English Bay	10-10-22	15:56	16:21	0:24:00	SRKW
3-2022	English Bay	17-11-22	02:10	02:13	00:03:00	Transient
3-2022	English Bay	20-11-22	19:51	21:02	1:11:00	SRKW
4-2022	English Bay	4-12-22	23:22	00:30	1:08:00	SRKW
4-2022	English Bay	14-12-22	04:45	04:52	0:07:00	SRKW
4-2022	English Bay	15-12-22	15:03	15:31	0:28:00	SRKW

Table 10. Observed visual sightings of killer whales in Burrard Inlet.

Date	Time (Local)	Notes/comments	PAM Detection?
2022-01-18	Unknown	6 killer whales swimming near Eagle Island, West Vancouver (potentially T90s)	No
2022-01-25	09:00	5-7 Biggs Killer whales swimming near Cates Park (T86As, T124Ds and T117A)	No
2022-06-15	Unknown	3 Biggs Killer whales (T65A, T65A5, T65A2) swimming near Point Atkinson	No
2022-08-16	18:00	Unidentified number of Killer whales (ecotype unknown)	No

Discussion

This report represents the fourth continuous year of acoustic monitoring in Burrard Inlet. In 2022, a reduced site selection corresponding to the same two sites measured in Year 2 (SMRU Consulting, 2020) of the study were selected for year-round acoustic monitoring, out of the five total monitored by SMRU in alternate years (SMRU Consulting, 2021). ONC did not provide any data from its cabled observatory site for additional ambient noise characterisation during this project year. SMRU moorings were adapted and improved in 2021, and 100% recovery of hydrophones was achieved for a second consecutive year. Between the two SoundTrap hydrophones deployed by SMRU, a total of 614 days of monitoring data was collected, despite loss of data during the first deployment at Burrard East due to a flooded hydrophone.

Overall, 2022 recorded the highest amplitudes in terms of annual averaged mean (L_{eq}), median (L_{50}), and 5th percentile loudest (L_5) broadband sound pressure levels, with increases in SPL of 3.3 to 5.7 dB re 1µPa across both sites monitored and key metrics reported. These higher annual average values in comparison to 2021 were more pronounced at Burrard East for 2022, however significant data gaps between January – May 2022 render uncertain if the trend would have been dampened by potentially quieter months, as happened early in 2020, or further enhanced if the earlier months of 2022 were louder months, as happened in 2021 at this location. SPL levels in English Bay were consistently higher in 2022 compared to 2021. This could have been caused by higher vessel usage of this area, hydrophone deployments closer to one of the anchorage sites, increased use of the anchorage sites, or even a change in vessel type using these anchorages. These trends will be more fully investigated in 2023 when we analyze longer term trends in more detail.

Throughout the year, higher monthly median (L_{50}) broadband SPLs were recorded at English Bay (124.5 dB re 1µPa) compared to Burrard East (114.6 re 1µPa), but higher mean (L_{eq}) and L_5 broadband sound pressure levels at Burrard East compared to English Bay, with the caveat of missing data at Burrard East early in 2022. Notably, during the period of recorded data, Burrard East location experienced several very high amplitude periods in the data (> 140 dB re 1µPa) while remaining the

generally quieter site. This pattern can be explained by Burrard East being a more constricted area which results in the hydrophone being ensonified by a smaller area (which likely caused lower average amplitude SPL). The constricted nature of Burrard East also causes ships to transit closer to the hydrophone, which may cause higher peak SPL values than at English Bay. In contrast, the English Bay location is open but further from the transit lane for vessels. This results in higher average SPL but lower L_5 SPL.

A distinguishing feature of the Burrard East location is the heavy contribution that tidal flow noise makes to the soundscape. Repeated cycles of low-frequency noise can be observed on the Burrard East long term spectral averages in certain months throughout the year, but especially in December 2022, and are consistent with periods of increased tidal flow accompanied by a smaller contribution from vessel traffic. Such a period occurred early in the year in 2021.

When comparing between the two sites, English Bay continues to have a soundscape that is dominated by low frequency noise, in the 0.01—0.1 kHz kHz decade band, whereas at Burrard East the 0.1—1 kHz and 1—10 kHz decade bands were higher based on monthly median (L_{50}) SPLs. At both locations, the higher decade bands contributed less noise, and in particular the 10—48 kHz decade band had the lowest monthly median (L_{50}) values between 90—100 dB re 1µPa at both locations. Comparatively, English Bay was generally higher amplitude than Burrard East in the lower decade bands (0.01—10 kHz), but in the 10—48 kHz the two sites had similar noise levels.

Across months, generally higher median sound pressure levels were observed in summer months (June—August 2022) and again in winter (January and December 2022). However, noise levels were lower for the summer and fall periods at the Burrard East location than in the previous year (SMRU Consulting, 2021). There were no clear weekly rhythms in the data, similar to past years of monitoring at these and other sites in Burrard Inlet (SMRU Consulting, 2021). At both the English Bay and Burrard East locations, the noise levels were comparable between weekdays and weekends. At English Bay during the month of September, there appears to be a very slight trend towards higher noise levels on Saturdays in the third (1—10 kHz) and fourth (10—48 kHz) decade bands. This was not observed consistently throughout the year.

Diurnal patterns were the most evident temporal effects specifically for the Burrard East location. At Burrard East, there is a clear rise in noise levels at approximately 06:00 (Local Time) and noise levels are sustained until 20:00. During the summertime (June – August), noise levels decreased gradually after 20:00. By September, when the local sunset times occurred between 19:54—18:52, the decrease in noise is abrupt at 20:00. The English Bay location had only a very minor increase in noise levels during daytime hours. Previous years of monitoring have identified increased daytime noise levels at Burrard East, and especially Indian Arm, with again very little diurnal change in noise levels at English Bay. This lack of diurnal change at English Bay, in spite of significant recreational boat activity in that area, is due to the consistent use of English Bay for passage and anchoring of large ships.

Higher total daily AIS-based vessel abundances were observed at English Bay (ranging from 9—141, and median 52 moving vessels daily) compared to Burrard East (ranging from 5—55, and median 31 moving vessels daily). This pattern was observed for both moving and non-moving vessels but with higher variability across days at English Bay due to a broader range in AIS-based vessel counts. This is

consistent with the results of English Bay being the noisier site, especially at broadband sound pressure levels and lower frequency decade bands (<10 kHz). This is consistent with past observations of a positive relationship between increasing AIS vessel density values and increasing sound pressure levels in these noise level metrics.

Substantially greater presence of both killer whales and porpoises were observed in 2022 in comparison to previous years, with an increasing trend with each year of monitoring, even though data were missing for January through May at Burrard East. However, detection data were not always available for all months in all years monitored, including 2022. These trends will be further assessed while considering effort (i.e. data gaps) in our next multi-year trend analyses for Burrard Inlet through 2023.

In 2022, the highest number of porpoise click detections occurred from September to December, when porpoise echolocation clicks were detected during each day of these months at English Bay. A similar trend was observed in 2021, although the absence of data from the summer of 2021 prevents more detailed comparisons. This trend differed from 2020 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.

For killer whales, there were 15 acoustic detection positive days in 2022, 7 in 2021, 1 in 2020 and 4 in 2019 (SMRU Consulting, 2019, 2020, 2021). 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, as part of the final deployment for the 2021 report. These additional data provide a unique insight into their movement (SMRU Consulting, 2021). 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. These acoustic detections represent movement near the southern extent of their range and outside of what would 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.

In addition to the acoustic detections recorded as part of the monitoring period, there were 4 visual observations of killer whales reported within Burrard Inlet, 3 of which were reported to be transients and one was an unknown ecotype. The time of these visual detections were compared to the acoustic detections within the dataset, however, there were no simultaneous detections which may be due to the reduced vocal activity of the transient ecotype. Transient killer whales hunt marine mammals and emit pulsed calls less frequently than resident killer whales, as their prey's hearing ability is within the frequency of killer whale vocal communication (Deecke et al. 2005). Thus, there is a greater cost for vocalizing as potential prey may detect their presence and respond with anti-predator behavior. To avoid detection, transients utilize a foraging strategy of stealth, acoustic crypsis and passive listening

(Barrett-Lennard et al. 1996) which increases hunting success, however, this means they are difficult to detect using PAM. This is reflected within the acoustic detection results where only one transient call was positively identified on November 17th, 2022. However, many of the Southern Resident detections were captured during late evening and night-time hours with 9 out of the 15 detection positive days containing events which started after 5pm and ended before 7am. This further emphasizes the usefulness and importance of PAM for tracking the acoustic presence of this ecotype.

When assessing the data cumulatively from 2019 to 2022, killer whales have been detected in all months of the year except April and June. There may be a slight seasonal trend indicating more detections in the winter months, from December through March, however, these data need to be evaluated with effort correction, considering the number of days the hydrophones were functional. This is in contrast to historical visual sightings of all killer whale ecotypes in the Salish Sea which indicated that the peak season is typically April – September (Shields et al. 2018). For the third year in a row, Southern Resident Killer Whale (SRKW) were detected during the month of December. During this monitoring period, SRKW were detected during three separate events in December, one of which was an hour and 8 minutes long. This indicates some level of seasonality but more data from subsequent reporting periods are required to provide more insights into seasonal trends of killer whale ecotypes within this area.

4 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 Derek White and Krista Trounce of the Vancouver Fraser Port Authority. Haley Crozier and Graham Nicolas of the Tsleil-Waututh Nation along with their entire crew were instrumental in deployment and retrieval of hydrophones. 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 data gaps associated with hydrophone deployments and retrievals are marked with 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**	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	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	148.2	142.0
	Mean	Jan 2022	128.1	126	122.8	116.5	107.9
English Bay	**Min**	Feb 2022*	91.3	88.6	82	81	84.6
	L_{95}	Feb 2022*	119.3	116.8	113.2	99.4	89.7
	L_{75}	Feb 2022*	121.6	119	116.2	105.8	93.8
	L_{50}	Feb 2022*	123.4	120.6	119.3	108.3	97.2
	L_{25}	Feb 2022*	125.7	122.9	122	111.8	101.5
	L_5	Feb 2022*	131.2	127.9	127.1	121.1	109.4
	Max	Feb 2022*	155.9	152.5	152	147	149.2
	Mean	Feb 2022*	127.8	125.1	123.5	116.8	110.7
English Bay	**Min**	Mar 2022	111.4	110.6	101.8	90.7	84.9
	L_{95}	Mar 2022	118.1	116.2	111	100.6	89.1
	L_{75}	Mar 2022	121.8	120	116	106.4	93
	L_{50}	Mar 2022	124.3	122.3	118.7	109.5	95.9
	L_{25}	Mar 2022	127.6	125.1	122.7	114.5	100.1
	L_5	Mar 2022	131.4	129.4	126.7	121.5	108.6
	Max	Mar 2022	157.3	156.7	147.8	144.6	137.8
	Mean	Mar 2022	127.9	125.6	122.8	117	107.5
English Bay	**Min**	Apr 2022	113.5	110.8	105.2	96.1	85.7
	L_{95}	Apr 2022	118.3	116.1	111.4	102.6	88.7
	L_{75}	Apr 2022	120.6	118.7	114.7	105.7	92.4
	L_{50}	Apr 2022	122.6	120.7	117.1	108.1	95.6
	L_{25}	Apr 2022	125.1	123.1	119.5	111	100.4
	L_5	Apr 2022	130.8	128.5	125.7	120.5	109.6
	Max	Apr 2022	154.3	154.2	148.7	146	139.5
	Mean	Apr 2022	127	125	121.7	115.5	107

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**	May 2022*	113.9	112.5	105	96.3	87.1
	L_{95}	May 2022*	117.4	115.6	109.9	102.5	90.2
	L_{75}	May 2022*	120.6	118.4	114.5	106	94.3
	L_{50}	May 2022*	122.7	120.3	117.7	109.3	98.1
	L_{25}	May 2022*	125.5	123.1	120.8	113	102.9
	L_5	May 2022*	131.8	128.5	127.8	121.4	111.4
	Max	May 2022*	159.9	159	151.8	147.4	137.8
	Mean	May 2022*	127.9	125.6	123.1	116.8	107.8
English Bay	**Min**	Jun 2022	109.3	107.5	100.9	92	87.6
	L_{95}	Jun 2022	117.5	115.5	109	102.4	90.5
	L_{75}	Jun 2022	122.3	120	115.8	106.8	94.3
	L_{50}	Jun 2022	124.7	122.5	119.2	109.5	97.6
	L_{25}	Jun 2022	127.1	124.6	122.5	113.9	102.7
	L_5	Jun 2022	131.6	128.7	127.4	121.3	112.4
	Max	Jun 2022	150.8	149	148	142.3	138.4
	Mean	Jun 2022	127.8	125.3	123.3	117	108.6
English Bay	**Min**	Jul 2022	113.9	113.1	103	87.1	87.6
	L_{95}	Jul 2022	120.1	118.6	113	100.3	89.5
	L_{75}	Jul 2022	122.8	121	116.1	106.3	94.2
	L_{50}	Jul 2022	125.5	123.4	119.6	109.7	98.6
	L_{25}	Jul 2022	129.1	126.4	124.8	114.7	103.8
	L_5	Jul 2022	135.8	132.2	132.2	124.2	113.3
	Max	Jul 2022	157.1	156.6	150.2	143.4	138.7
	Mean	Jul 2022	131.2	128.8	126.7	118.9	110.4
English Bay	**Min**	Aug 2022*	115.1	113.8	106.6	86.6	86.9
	L_{95}	Aug 2022*	118.9	117	112.4	96	87.9
	L_{75}	Aug 2022*	121.8	119.7	116	103.5	90.9
	L_{50}	Aug 2022*	123.8	121.7	118.3	107.2	94.1
	L_{25}	Aug 2022*	126.1	123.8	121	111.1	98.2
	L_5	Aug 2022 *	131.8	128.7	127.4	120	110.3
	Max	Aug 2022*	154.6	154.5	148.8	144.3	140.1
	Mean	Aug 2022*	128.2	125.9	123.4	117	108.9
English Bay	**Min**	Sep 2022	112.9	111.4	105.2	88.8	87
	L_{95}	Sep 2022	119.7	117.9	113.4	98.9	88.6
	L_{75}	Sep 2022	121.7	119.8	115.9	104.7	91.8
	L_{50}	Sep 2022	123.6	121.5	118.2	107.9	95.1
	L_{25}	Sep 2022	125.7	123.5	121	110.9	98.9
	L_5	Sep 2022	131.4	127.7	127	118.6	110.1
	Max	Sep 2022	155.3	155	148.1	144.9	138.9
	Mean	Sep 2022	128	125.8	123	116.5	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***
English Bay	**Min**	Oct 2022	113.6	111.5	106.8	95.5	87.6
	L_{95}	Oct 2022	120.5	118.8	113.5	102.1	90.2
	L_{75}	Oct 2022	123.2	121.2	117	107.5	93.5
	L_{50}	Oct 2022	125.6	123.7	119.6	111.8	96.7
	L_{25}	Oct 2022	128	126.2	122.2	115.4	101.4
	L_5	Oct 2022	132.6	129.9	127.8	123.1	112.2
	Max	Oct 2022	163.1	162.9	150.5	146.7	139.7
	Mean	Oct 2022	130.2	128.4	124.2	118.6	109.2
English Bay	**Min**	Nov 2022	117.2	115.1	108.8	98	87.7
	L_{95}	Nov 2022	121	118.9	113.4	104.8	90.3
	L_{75}	Nov 2022	123.3	120.9	117.8	109.3	94
	L_{50}	Nov 2022	125.2	122.6	120.2	112.4	98.1
	L_{25}	Nov 2022	127.5	124.8	123	115.3	103.7
	L_5	Nov 2022	132.3	129	128.3	121.4	113.5
	Max	Nov 2022	157.1	153.7	153.6	151.6	146.2
	Mean	Nov 2022	129.1	126.4	124.5	119	111.3
English Bay	**Min**	Dec 2022	116.1	114.5	109.3	99.4	87.5
	L_{95}	Dec 2022	122.4	120.6	115	106.1	90
	L_{75}	Dec 2022	124.7	123.1	117.4	109.1	92.9
	L_{50}	Dec 2022	127	125.3	120.5	112.3	97.5
	L_{25}	Dec 2022	130.4	127.9	125.4	119.3	102.6
	L_5	Dec 2022	137	134.2	132.1	128.1	113.2
	Max	Dec 2022	156	154.7	149.9	147.7	142
	Mean	Dec 2022	131	128.7	125.9	121.3	110.8

Appendix 2. Burrard East, monthly SPL (dB re 1µPa) by study month for each broadband and decade frequency band metric. Months with data gaps associated with hydrophone deployments and retrievals are marked with 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**	May 2022*	92.5	89.6	81.5	81.9	85.8
	L_{95}	May 2022*	99.8	98.3	91.3	86.1	85.9
	L_{75}	May 2022*	105.2	100.6	99.8	94.1	88.3
	L_{50}	May 2022*	114.7	104.7	110.9	106.1	95.6
	L_{25}	May 2022*	123.9	111.7	120.9	117.5	106.6
	L_5	May 2022*	133.6	123.1	130.9	127.5	118.5
	Max	May 2022*	152.5	152.5	146.9	145.4	141
	Mean	May 2022*	128.2	122.8	125.1	121.3	112.9
Burrard East	**Min**	Jun 2022	98.5	96.1	91.1	87.3	87.1
	L_{95}	Jun 2022	101.4	98.7	95.6	89.3	87.6
	L_{75}	Jun 2022	107.5	101	103	97.4	89.7
	L_{50}	Jun 2022	116.5	105.4	113.2	109.4	98.8
	L_{25}	Jun 2022	124.7	112.3	121.9	118.7	108.5
	L_5	Jun 2022	134.3	123.7	131.5	128.3	119.6
	Max	Jun 2022	156.1	156.1	149.5	146.2	139.4
	Mean	Jun 2022	130.1	126.6	125.8	122	113.8
Burrard East	**Min**	Jul 2022	100.6	98	94	87.6	86.9
	L_{95}	Jul 2022	102.3	99.7	96.5	89.3	87.7
	L_{75}	Jul 2022	108.3	101.7	104.2	98.5	89.8
	L_{50}	Jul 2022	117.3	105.9	114.2	110.7	99.2
	L_{25}	Jul 2022	125.2	112.3	122.2	119.7	110
	L_5	Jul 2022	133.9	122.8	131.1	128.5	120
	Max	Jul 2022	153.7	153.7	149.9	146.5	140.6
	Mean	Jul 2022	128.1	120.8	125.3	122.1	114.2
Burrard East	**Min**	Aug 2022*	93.9	92.1	84	82.7	85.9
	L_{95}	Aug 2022*	104.1	100.7	98.8	88.3	88.5
	L_{75}	Aug 2022*	107.3	102.9	103.6	94.4	89.8
	L_{50}	Aug 2022*	116.8	105.3	113.9	109.3	98.4
	L_{25}	Aug 2022*	125.3	111.8	122.3	119.5	110.3
	L_5	Aug 2022*	134.8	123.2	132.4	129.5	121.1
	Max	Aug 2022*	154.6	150.8	153.3	145.4	152.5
	Mean	Aug 2022*	128.9	119.7	126.5	122.8	116.5

Location	***SPL Metric***	***Month***	***0.01-48 kHz***	***0.01-0.1 kHz***	***0.1-1 kHz***	***1-10 kHz***	***10-48 kHz***
Burrard East	**Min**	Sep 2022	102.1	100.1	94.5	86.5	88
	L_{95}	Sep 2022	103.6	101.4	97.5	89	88.8
	L_{75}	Sep 2022	106.8	102.5	102.4	94.6	89.8
	L_{50}	Sep 2022	115.4	104.9	112.2	107.8	96.4
	L_{25}	Sep 2022	124.4	110.9	121.5	118.8	109.2
	L_{5}	Sep 2022	134.7	122.3	132	129.5	121.1
	Max	Sep 2022	152	146.9	149.9	146.5	142.6
	Mean	Sep 2022	128.6	118.2	126.3	123	115.5
Burrard East	**Min**	Oct 2022	102.2	100.4	94.4	87	87.4
	L_{95}	Oct 2022	103.2	101.5	95.9	88.8	87.9
	L_{75}	Oct 2022	105.6	102.5	99.7	93.6	88.7
	L_{50}	Oct 2022	112	103.9	107.9	103.4	94.4
	L_{25}	Oct 2022	120.6	108.6	117.9	114.4	105.6
	L_{5}	Oct 2022	132.2	119.5	129.6	127.1	118.7
	Max	Oct 2022	152.4	148.1	149.4	146.4	139.8
	Mean	Oct 2022	126.5	116.9	124.1	120.7	113.1
Burrard East	**Min**	Nov 2022*	102.3	100.3	94.2	86.8	87.1
	L_{95}	Nov 2022*	103.3	101.6	95.8	89.9	87.4
	L_{75}	Nov 2022*	104.9	102.2	98.2	94.4	88.2
	L_{50}	Nov 2022*	109.6	103	104.6	100.6	92
	L_{25}	Nov 2022*	117.7	106.5	115.2	110.8	102
	L_{5}	Nov 2022*	130.7	117.9	128.2	125.2	116.2
	Max	Nov 2022*	152.8	145.5	150.1	146.5	139.9
	Mean	Nov 2022*	125.7	115.2	123.6	119.7	111.8
Burrard East	**Min**	Dec 2022	106.5	104.8	97.9	89.7	86.9
	L_{95}	Dec 2022	107.7	105.9	100.1	93.7	87.6
	L_{75}	Dec 2022	109.7	107	103.2	97.9	88.9
	L_{50}	Dec 2022	114.3	108.7	109.2	104.4	95
	L_{25}	Dec 2022	124.4	115.8	119.1	114.6	105.2
	L_{5}	Dec 2022	141.9	139.7	130.4	126.3	118.6
	Max	Dec 2022	153.5	153.5	147.7	144.2	150.7
	Mean	Dec 2022	135.9	135.3	124.4	120.2	121.3

References

Dekeling, R., Tasker, M., Van der Graaf, A., Ainslie, M., Andersson, M., André, M., Borsani, J., Brensing, K., Castellote, M., and Cronin, D. (**2014**). "Monitoring Guidance for Underwater Noise in European Seas, Part II: Monitoring Guidance Specifications. A guidance document within the Common Implementation Strategy for the Marine Strategy Framework Directive by MSFD Technical Subgroup on Underwater Noise. JRC Scientific and Policy " Report EUR 26555 EN Publications Office of the European Union, Luxembourg, DOI:10.2788/27158.

Merchant, N. D., Brookes, K. L., Faulkner, R. C., Bicknell, A. W., Godley, B. J., and Witt, M. J. (**2016**). "Underwater noise levels in UK waters," Sci. Rep **6**, 1-10

Merchant, N. D., Fristrup, K. M., Johnson, M. P., Tyack, P. L., Witt, M. J., Blondel, P., and Parks, S. E. (**2015**). "Measuring acoustic habitats," Methods Ecol. Evol. **6**, 257-265

Olesiuk, P. F., Ellis, G. M., and Ford, J. K. (**2005**). *Life history and population dynamics of northern resident killer whales (Orcinus orca) in British Columbia* (Canadian Science Advisory Secretariat Nanaimo, BC, Canada).

Sato, M., Trites, A. W., and Gauthier, S. (**2021**). "Southern resident killer whales encounter higher prey densities than northern resident killer whales during summer," Canadian Journal of Fisheries and Aquatic Sciences **78**, 1732-1743

Shields, M. W., Hysong-Shimazu, S., Shields, J. C., and Woodruff, J. (**2018**). "Increased presence of mammal-eating killer whales in the Salish Sea with implications for predator-prey dynamics," PeerJ **6**, e6062

SMRU Consulting (**2019**). "ECHO Slowdown 2018: Ambient Noise and SRKW Acoustic Detections Report. Prepared on behalf of the Vancouver Fraser Port Authority".

SMRU Consulting (**2020**). "Burrard Inlet Underwater Noise Characterization: 2020 Final Report Prepared on behalf of the Vancouver Fraser Port Authority".

SMRU Consulting (**2021**). "Burrard Inlet Underwater Noise Characterization: 2020 Final Report Prepared on behalf of the Vancouver Fraser Port Authority and Tseil-Waututh Nation".