# Burrard Inlet underwater noise study: 2020 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 to learn more about underwater noise and cetacean presence in Burrard Inlet.

Building upon the 2019 monitoring project in Burrard Inlet, this project set out to monitor underwater noise and the presence of cetaceans (whales, dolphins and porpoise) in Burrard Inlet, a marine mammal habitat and a key waterway for commercial shipping, port-related activities, and passenger transportation.

This document summarizes the project question and describes the methods, key findings, and conclusions.

## What questions was the study trying to answer?

The second year of the Burrard Inlet underwater noise study sought to evaluate longer-term trends in total ambient noise and marine mammal presence, while building upon the results from 2019.

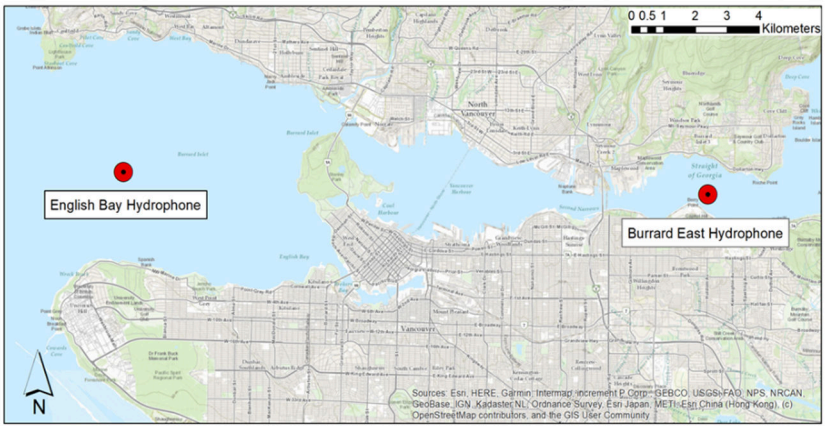
## Who conducted the project?

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 at fewer sampling locations.

## What methods were used?

Bottom-mounted SoundTrap hydrophone recorders were deployed in two locations in the inner and outer harbour: one at Burrard Inlet East near the Tsleil-Waututh Nation reserve lands and Burnaby petroleum terminals, and one in English Bay between anchorages 1 and 3. Acoustic data were collected over approximately one year between February 2020 and February 2021. The figure below shows the approximate locations of the hydrophone deployments.

**Burrard Inlet 2020 Hydrophone Locations**




*Source: SMRU Consulting North America*

The SoundTraps hydrophones recorded acoustic data at a rate of 96 kHz (for an effective frequency range of 48 kHz), on a seven-minute, 50% duty cycle. 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. $L_{50}$ (median), $L_{eq}$ (mean) and $L_5$ 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.

## What were the key findings?

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

- Over the course of the year, the English Bay location had a higher median broadband noise level of 120.8 dB re 1µPa, compared to that of the Burrard East location at 115.9 dB re 1µPa.
- The English Bay location saw limited variability in sound pressure levels when looking at monthly, weekly or daily patterns, and noise levels were very similar in 2020 when compared to 2019.
- Received sound levels at Burrard East were higher in 2020 than those measured in 2019. This location also saw greater fluctuations in peak noise levels, and increased sound levels during the daytime. This is indicative of frequent vessel passes proximate to the hydrophone during the day.
- Burrard East also saw an increase in noise levels in the summer months in both 2019 and 2020, which may be attributed to increased recreational vessel traffic.
- During the one-year monitoring period, Bigg's (or Transient) killer whales were visually observed in the study area on nine (9) days, with corresponding acoustic detections on only one of those days. Southern resident killer whales (SRKWs) were acoustically detected on two occasions, at the English Bay hydrophone in December 2020 and January 2021.
- Acoustic detections of porpoise occurred on 107 days, with the vast majority of these detected at the English Bay location. This is a significant increase from harbour porpoise detections in 2019. There were no detections of other cetaceans.

## 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, 2020 was a unique year in all aspects, and observed increases in noise metrics at the Burrard East location may be reflective of changes in port activities as well as increased recreational vessel traffic during this time.

Acoustic detections of killer whales were fairly consistent between 2019 and 2020, with Bigg's killer whales being visually observed far more often than they were heard on the hydrophones. Southern resident killer whales were detected by the English Bay hydrophone on two occasions during the winter months in 2020, but not detected in the summer. The number of days harbour porpoise were detected in 2020 was nearly double that of 2019, although no specific cause for this can be determined from the data.

The ECHO Program and project partner Tsleil-Waututh Nation recognize the importance of better understanding and reducing underwater noise both in Burrard Inlet and the region as a whole. 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 four locations for 2021, and is expected to continue for the next several years.

# Burrard Inlet Underwater Noise Characterization: 2020 Final Report

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

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# Burrard Inlet Underwater Noise Characterization: 2020 Final Report

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# 1 Introduction

## 1.1 Background

The Enhancing Cetacean Habitat and Observation (ECHO) Program, led by Vancouver Fraser Port Authority (VFPA) had previously focused underwater noise monitoring, research, and mitigation efforts in areas most used by cetaceans, such as the Strait of Georgia and Haro Strait. However, Burrard Inlet, which is used extensively for shipping and other port-related activities, is also frequented by some marine mammals 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. An initial year of PAM was conducted at five locations in Burrard Inlet in 2019 (SMRU Consulting 2019). This current project extended the PAM efforts for another year (2020) at two locations in Burrard Inlet.

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 important habitats are plentiful.

## 1.2 Project Objectives

Based on the interests of the ECHO Program and the Tsleil-Waututh Nation, the following project objectives were identified for 2020:

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. These noise level metrics are consistent with those used by the European Union under the Marine Strategy Framework Directive.

2) **Characterize source levels of a bulk carrier at anchorage.**

   Due to the closure of the Canada – US border relating to COVID-19, we were unable to deploy Coastal Acoustic Buoys to measure source levels of a bulk carrier ship at anchorage. We are planning to carry out this work in the 2021-2022 cycle as this project continues. This project objective is not discussed further in the report.

**3) Evaluate the presence of cetaceans in Burrard Inlet using PAM.**

The VFPA and Tsleil-Waututh Nation have an interest in understanding cetacean presence within Burrard Inlet. Given recent sightings, killer whales and porpoise were the focus of this effort.

# 2 Methods

The methods and results section are divided by the objectives identified above.

## 2.1 Characterize Underwater Noise Levels

This report includes spectrum levels in monthly spectrograms and power spectral density (PSD) exceedance plots. We also report sound pressure levels (SPLs) using broadband, decade-band, and one-third octave bands and investigate 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 (the metric 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 also 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, SoundTrap autonomous recorders (http://www.oceaninstruments.co.nz/SoundTrap-300/) were deployed in two locations around Burrard Inlet (Figure 1). The hydrophone module included the hydrophone fastened vertically in a floatation collar attached to an anchor weight. This setup was attached to an acoustic release with a trawl float and anchor weight via a float line ~2 times the water depth for retrieval (Figure 2). Deployments involved manually lowering the hydrophone package via the float line, then manually lowering the acoustic release module via a separate line. Manually lowering each module ensured desired placement on the seafloor. Communications with the acoustic release were then verified.

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

All deployed hydrophones were eventually recovered, although some required extra effort to retrieve. The hydrophone at the Burrard East location failed to come to the surface after the initial deployment. An ROV was deployed to recover the instrument without success. It was later reported to have washed up on a construction site closer to the mouth of the inlet. A later deployment successfully recovered the acoustic release but the line connecting the instruments had been cut. The ROV was again used to recover the hydrophone. This effort was successful.

Table 1. SoundTrap deployment and retrieval dates. Acoustic data were collected across 374 deployment days in total.

| Deployment Number | Deployment Date | Retrieval Date | Deployment Duration (days) |
|---|---|---|---|
| **1** | Feb 1st, 2020 | May 11th, 2020 | 101 |
| **2** | May 15th, 2020 | August 24th, 2020* | 102 |
| **3** | August 28th, 2020 | December 7th, 2020** | 102 |
| **4** | December 10th, 2020 | February 16th, 2021 | 69 |

* Burrard East unit found on November 20th, 2020
** Burrard East unit recovered via ROV search on January 14th, 2020

Table 2. Latitude and longitude of SoundTraps deployed in Burrard Inlet and English Bay (See Figure 1).

| SoundTrap Hydrophone Location | Latitude (N) | Longitude (W) | Water depth |
|---|---|---|---|
| English Bay | 49.304 | 123.233 | 55 m |
| Burrard East | 49.296 | 122.982 | 65 m |

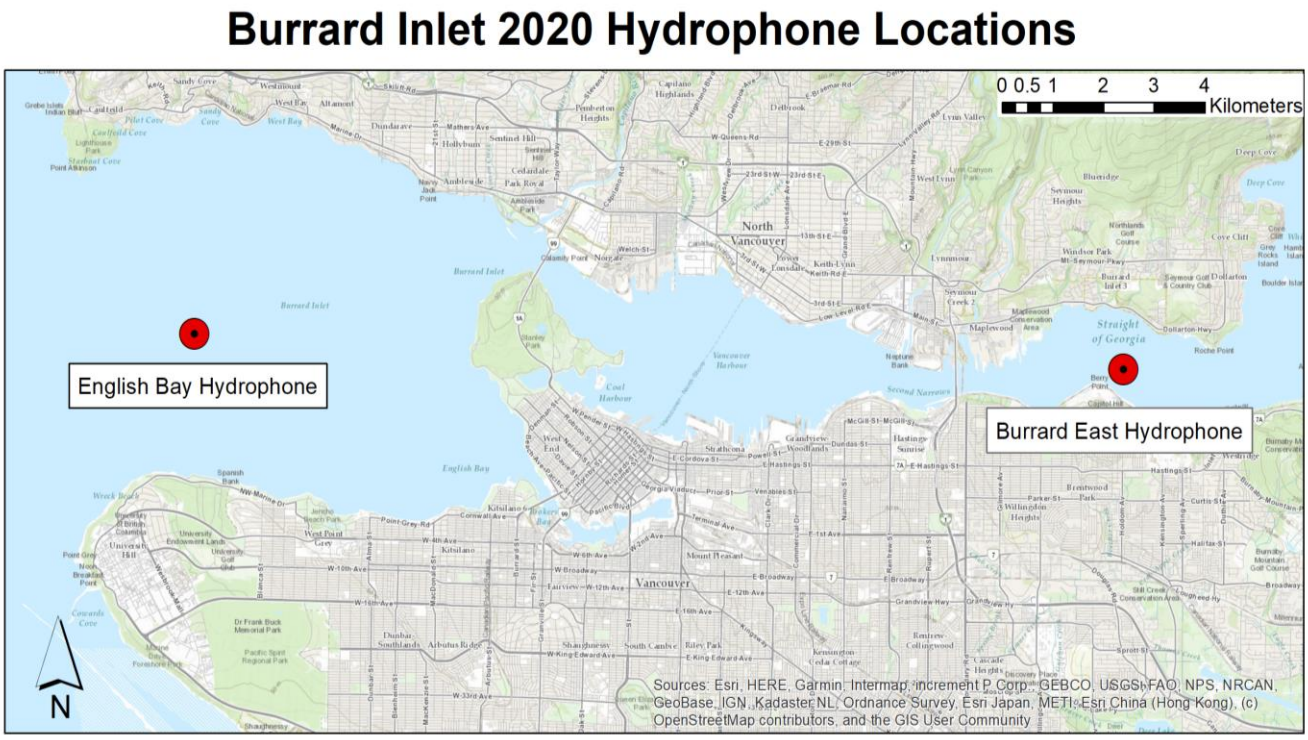



Figure 1. Map of two SoundTrap deployment locations (see Table 2 for location names and coordinates).

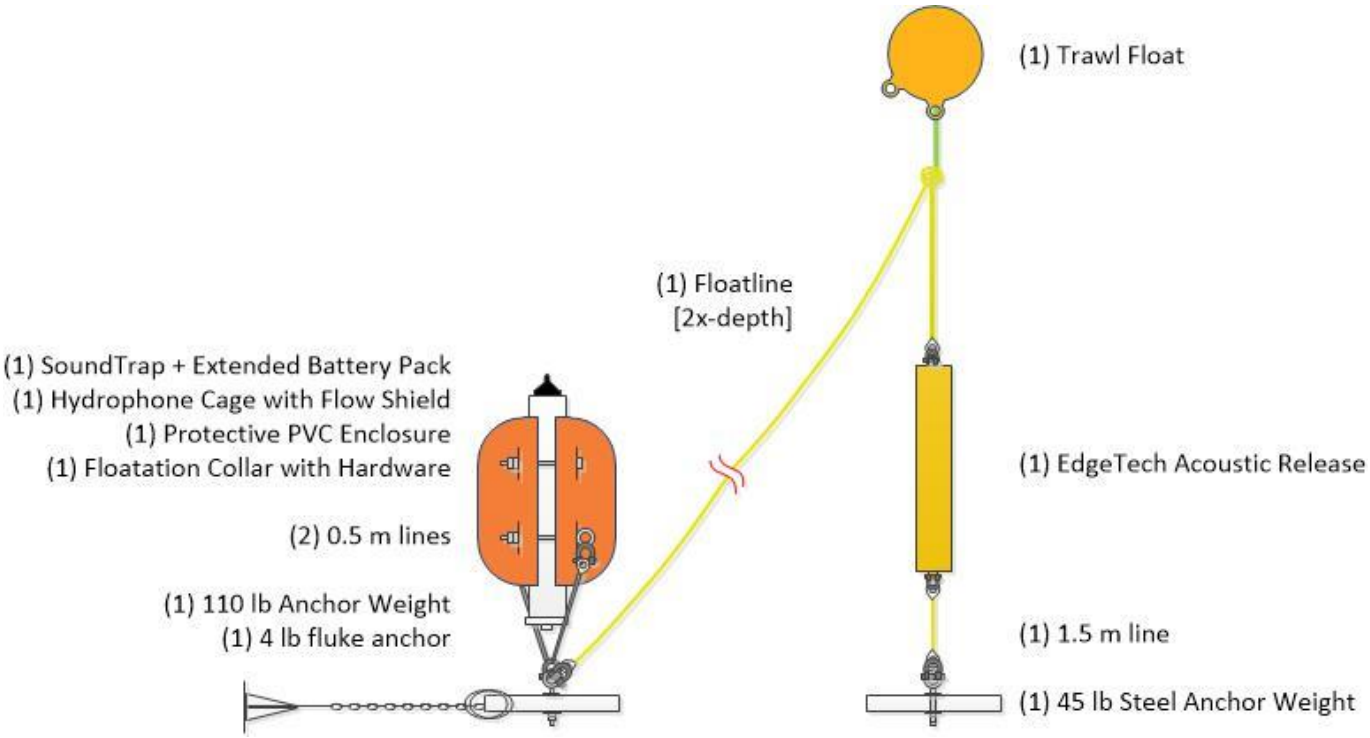



Figure 2. Schematic of SoundTrap hydrophone and EdgeTech acoustic release deployment method.

Table 3. SoundTrap settings used for each deployment. Settings remained the same for the duration of the project year.

| Site | High Pass Filter | Preamp Gain | Sample Rate (kHz) | Duty Cycle | Detector | Detector threshold (dB) |
|---|---|---|---|---|---|---|
| English Bay | Off | High (~172 dB max) | 96 | 50% (7 min on/off) | Click Detector | 16 |
| Burrard East | Off | High (~172 dB max) | 96 | 50% (7 min on/off) | Click Detector | 16 |

Custom Matlab scripts based on Merchant et al. (2014) 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 (see SMRU Consulting 2019). We also report $L_{eq}$ (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.

## 2.2 Cetacean Presence Using PAM

PAMGuard V2.00.16 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 (https://www.audacityteam.org/).

During this process, the analysist created acoustic events consisting of all calls occurring with less than 30-minute inter-call interval. This process was done for both echolocation clicks and whistles contours.

PAMGuard Viewer Mode was used to identify and log cetacean events. All high and moderate probability events 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 flagged by the Whistle and Moan detector were reviewed. Visual sighting data were obtained from the Wild Ocean Whale Society (https://whalesanddolphinsbc.com/) as well as a search of press releases from the study period.

### 2.2.1 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 3. Capturing these signals can provide logistical challenges as continuously recording at these high sample rates drains storage and energy resources more quickly than continuously recording at lower sample rates.

To address this capacity issue, SoundTraps are provisioned with an onboard 'click detector' capable of monitoring for impulsive sounds. When impulsive sounds are detected, a high frequency (fs = 300 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 to 0.22 milliseconds (ms) duration, peak frequency range between 100-125 kHz, and the control band of 40-90 kHz. A 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 detection.

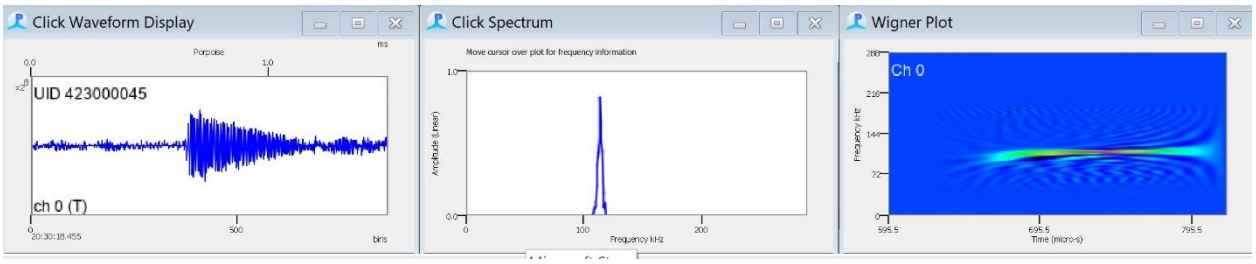



Figure 3. A typical porpoise click: Click Waveform Display, Click Spectrum and Wigner Plot displayed using PAMGuard software.

### 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. The 'whistle and moan' detector was run on the 96 kHz continuous recordings over the frequency range of 800 Hz to 30 kHz. The sensitivity threshold was set to 5 dB to ensure that marine mammal calls were not missed (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 the SMRU team to determine the ecotype (Southern Resident or Bigg's/Transient).

## 2.3 Ancillary data

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. Vessel density based on AIS transmissions was compiled for each day within a 3 km radius of each hydrophone location. This range was selected to encompass the bulk of noise contributions from the relatively slow-moving commercial vessels transiting the area. The data set was partitioned using AIS data into a) Class A vessels moving at least one knot of speed and b) all Class A vessels including those that were moored or anchored. For each day we calculated the number of AIS transmissions detected within 3 km of each hydrophone and divided that value by the total marine area represented in the 3 km range. This value is referred to as signal density and was correlated with $L_{50}$, $L_{eq}$ and $L_5$ SPLs.

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. Daily rainfall and average winds were thus correlated against daily SPLs (1-10 kHz) and the SoundTraps internal tilt recorder's data were used as a proxy for current speed to assess potential current flow noise effects. A correlation analysis comparing hourly SPLs (10-100 Hz) and tilt angle was therefore undertaken. Choice of optimal frequency band to detect covariate effect patterns was based on Wenz (1962) curve data for each environmental factor.

# 3 Results

## 3.1 Underwater Noise Levels

A total of 374 days of PAM data were collected in this project cycle (February 1st, 2020 through to February 16th, 2021). There was a small data loss of approximately 8 hours length at Burrard East on April 2nd, 2020. Aside from this brief audio drop-out, audio was recorded continuously throughout the deployment periods.

### 3.1.1 Ambient Sound Over Time

Overall monthly averages showed some variation between 2019 and 2020 for both sites. At English Bay the $L_{50}$ and $L_5$ were relatively constant between years and $L_{eq}$ was identical to the 2019 value. The Burrard East location showed a 5.1 dB increase in $L_{50}$ between 2019 and 2020, a 3 dB increase in $L_5$ and an increase of 2.5 dB $L_{eq}$ (Table 4).

Table 4. Average monthly broadband SPL (median ($L_{50}$), mean ($L_{eq}$) and $L_5$ in dB re 1µPa) by location for 2019 and 2020.

| | $L_{50}$ | | $L_{eq}$ | | $L_5$ | |
|---|---|---|---|---|---|---|
| **Location** | **2019** | **2020** | **2019** | **2020** | **2019** | **2020** |
| English Bay | 121.0 | 120.8 | 124.6 | 124.6 | 128.4 | 128.2 |
| Burrard East | 110.8 | 115.9 | 124.1 | 126.6 | 129.4 | 132.4 |

Noise level distributions from the entirety of 2020 for the two sites are shown in Figure 4. As with 2019, median noise level distribution was higher at English Bay in the low frequency decade bands and similar in between the sites in the upper two decade bands. Burrard East had a wider distribution of noise levels than English Bay.

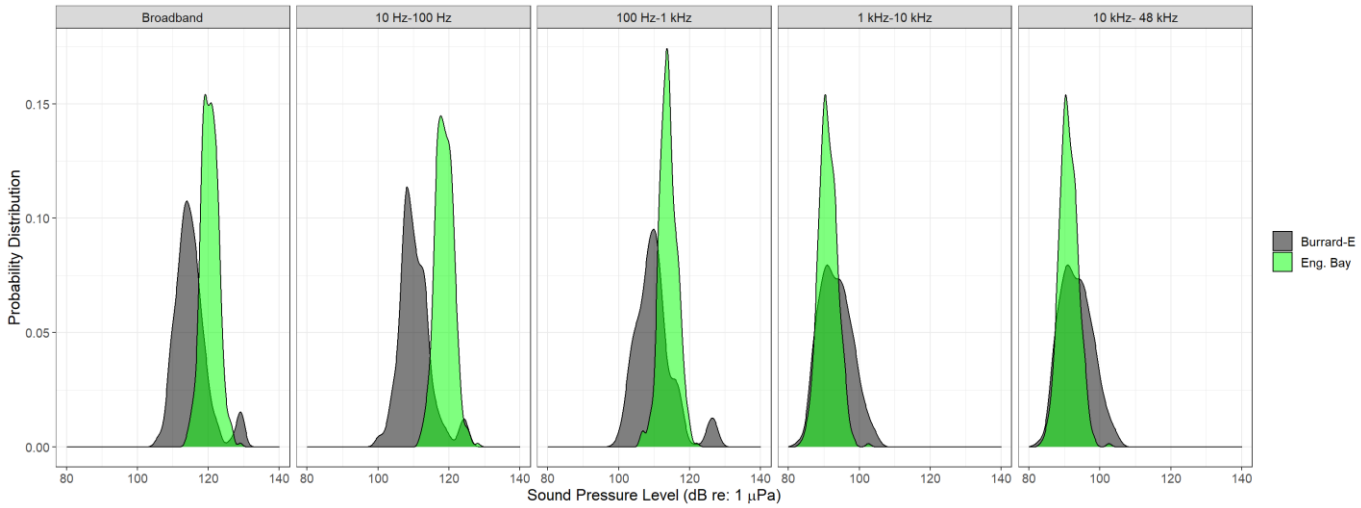



Figure 4. Probability distribution of median ($L_{50}$) monthly SPL (dB re 1µPa) at each location for broadband and decade frequency bands.

Monthly median broadband $L_{50}$ were highest at English Bay ($L_{50}$ = 120.8 dB re 1µPa ± 1.5 S.D.). English Bay peaked in December 2020 (123.3 dB re 1µPa) with a minimum in August 2020 (118.5 dB re 1µPa) while remaining somewhat steady throughout the project year. August and September were the only two months where Burrard East had higher amplitude than English Bay (Table 5).

Burrard East displayed a lower monthly median broadband SPL with higher degree of variability ($L_{50}$ = 115.8 dB re 1µPa ± 2.9 S.D.). This site showed a marked increase in $L_{50}$ levels through the months of July, August, and September, averaging 119.9 dB re 1µPa in these months versus 114.2 dB re 1µPa throughout the rest of the year. Burrard East displayed a notable increase in the 1-10 kHz decade band in the month of September.

Table 5. Monthly median ($L_{50}$), mean ($L_{eq}$), and $L_5$ broadband SPL (dB re 1µPa) by location. Monthly $L_{50}$ SPL are also provided for each decade band.

| 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 | 121.5 | 119.7 | 115.3 | 104.9 | 94.0 | 125.8 | 130.0 |
| | Mar | 122.2 | 120.4 | 115.0 | 107.2 | 91.5 | 124.7 | 127.9 |
| | Apr | 119.9 | 117.9 | 114.4 | 104.4 | 90.2 | 123.2 | 127.0 |
| | May | 119.8 | 117.6 | 114.5 | 106.1 | 92.1 | 123.1 | 127.0 |
| | Jun | 119.2 | 117.2 | 112.6 | 107.0 | 93.2 | 122.7 | 126.8 |
| | Jul | 119.5 | 117.6 | 112.6 | 103.9 | 90.5 | 124.0 | 126.5 |
| | Aug | 118.5 | 117.2 | 112.2 | 99.7 | 89.8 | 122.4 | 126.4 |
| | Sep | 122.2 | 120.2 | 116.4 | 104.3 | 89.9 | 125.8 | 129.1 |
| | Oct | 122.0 | 120.6 | 114.6 | 101.4 | 89.2 | 126.6 | 131.4 |
| | Nov | 121.5 | 120.1 | 114.7 | 100.2 | 90.6 | 125.4 | 128.6 |
| | Dec | 123.3 | 121.8 | 115.6 | 102.8 | 87.1 | 126.0 | 130.3 |
| | Jan | 119.9 | 118.0 | 113.7 | 105.8 | 92.3 | 124.4 | 127.2 |
| | Feb | 119.8 | 118.5 | 112.1 | 100.1 | 89.5 | 124.3 | 126.3 |
| **Burrard East** | Feb | 113.5 | 107.0 | 109.8 | 103.1 | 94.0 | 125.9 | 131.7 |
| | Mar | 113.6 | 106.5 | 109.6 | 102.2 | 92.5 | 125.4 | 131.3 |
| | Apr | 113.6 | 111.0 | 107.0 | 99.5 | 89.9 | 125.6 | 131.6 |
| | May | 115.5 | 112.0 | 110.1 | 102.7 | 91.7 | 126.2 | 132.3 |
| | Jun | 114.7 | 109.2 | 110.1 | 104.7 | 92.5 | 125.2 | 131.2 |
| | Jul | 119.7 | 114.0 | 115.9 | 108.0 | 94.6 | 126.5 | 132.3 |
| | Aug | 119.2 | 113.5 | 115.2 | 107.9 | 95.1 | 126.6 | 132.7 |
| | Sep | 120.4 | 111.2 | 116.1 | 113.7 | 96.0 | 128.2 | 132.1 |
| | Oct | 113.0 | 108.6 | 109.0 | 102.5 | 93.4 | 126.7 | 131.3 |
| | Nov | 111.3 | 108.3 | 106.0 | 100.0 | 92.6 | 123.5 | 127.9 |
| | Dec | 113.2 | 110.5 | 107.0 | 99.6 | 94.9 | 127.5 | 134.5 |
| | Jan | 116.4 | 112.8 | 110.3 | 102.2 | 93.4 | 128.5 | 135.3 |
| | Feb | 115.9 | 112.1 | 109.4 | 101.2 | 92.4 | 128.5 | 134.7 |

Monthly broadband $L_{50}$ values are shown in Figure 5 for both sites in 2019 and 2020. Throughout the study, monthly median values were relatively consistent at the English Bay location. A slight reduction in median SPL was observed from April through August 2020, increased in September through December, returning to average levels in January and February 2021.

Values at Burrard East were lower than the English Bay location between February and June 2020 but increased sharply in July, remaining elevated throughout the summer, and decreasing again in October 2020. Burrard East recorded higher monthly broadband $L_{50}$ than English Bay during July and August. In 2020, monthly broadband $L_{50}$ SPL at the Burrard East site were higher than those documented in 2019 for every month of the year. At English Bay, monthly broadband $L_{50}$ SPL in 2020 were marginally lower than those documented in 2019 for the months of May through August but increased over those recorded in 2019 for the months of September and October.

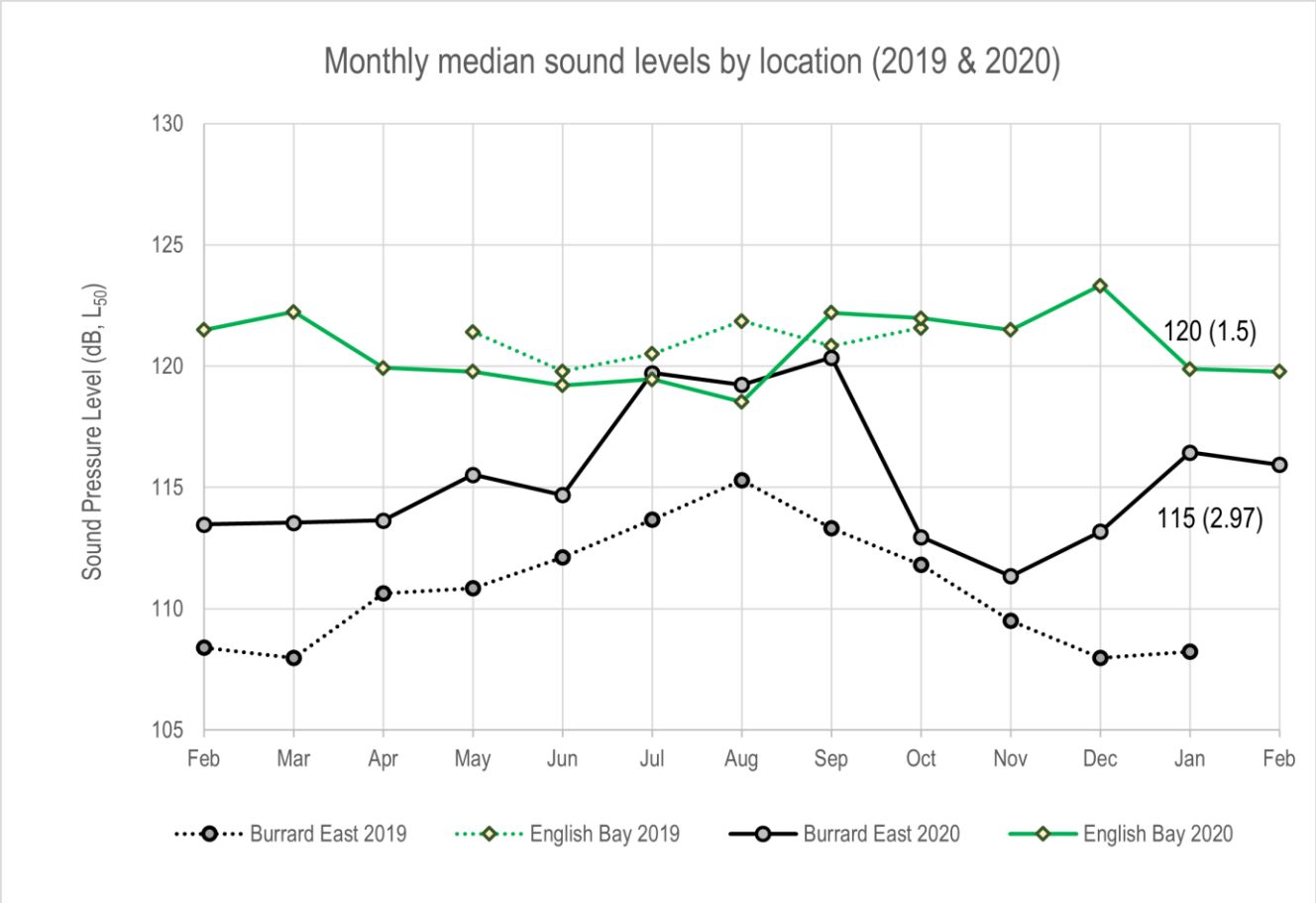



Figure 5. Median ($L_{50}$) broadband monthly SPL (dB re 1µPa) at each location (previous project year's results are indicated by dashed lines). Average values for the year with standard deviations are provided to the right of each monthly trend.

SPL for key broadband and decade frequency bands are provided in Table 5 for each month and location. Complete monthly SPL results are provided in the Appendix. Electronic copies of all one-third octave levels by month and location have been provided to VFPA. See Figure 5 through Figure 7 for monthly trends at each location.

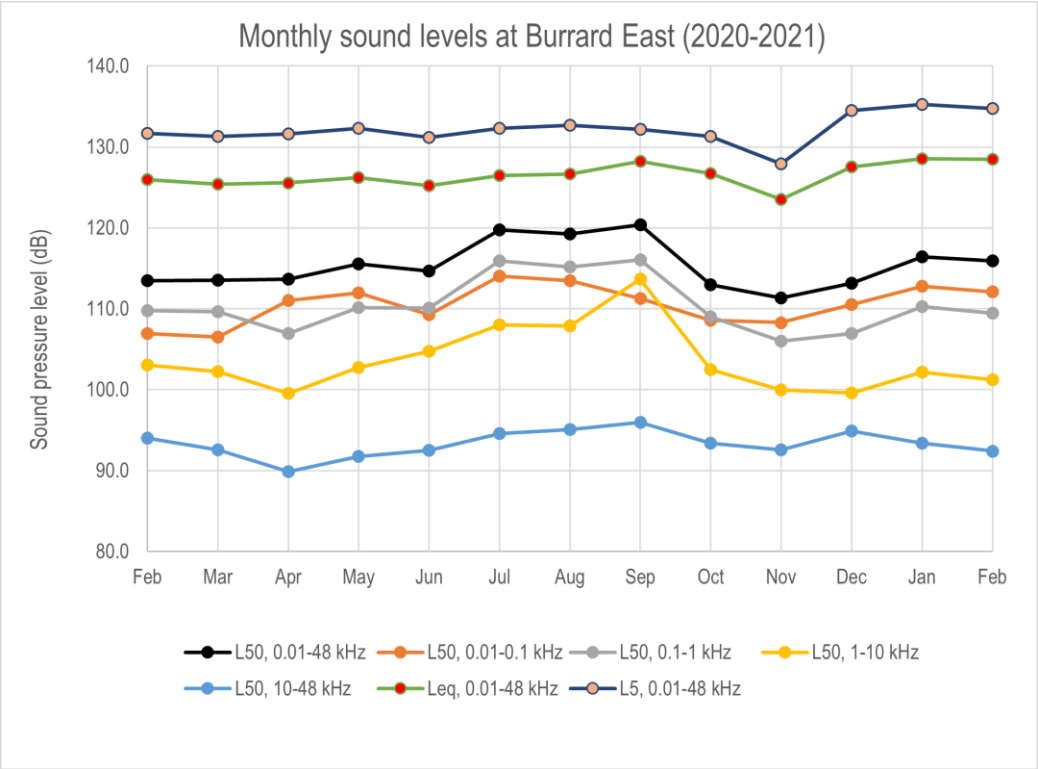



Figure 6. Burrard East broadband median ($L_{50}$), mean ($L_{eq}$) and $L_5$ and median ($L_{50}$) decade band monthly SPL (dB re 1µPa).

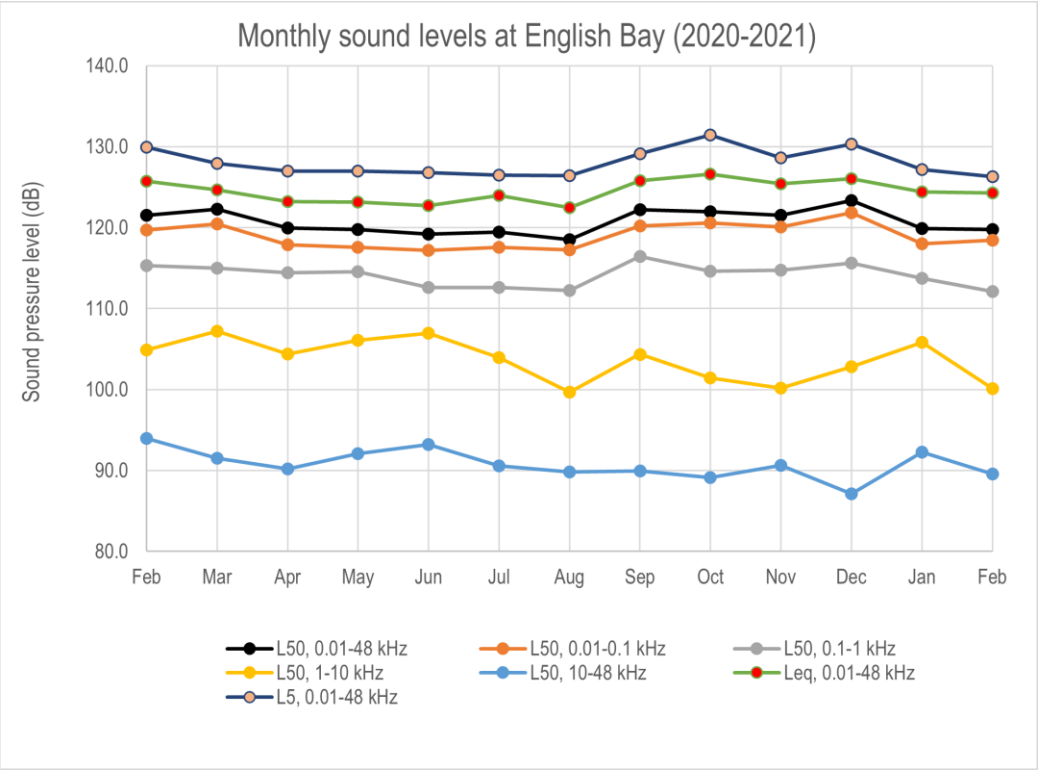



Figure 7. English Bay broadband median ($L_{50}$), mean ($L_{eq}$) and L5 and median ($L_{50}$) decade band monthly SPL (dB re 1µPa).

Investigation of the raw acoustic data indicated impact pile driving activities (
Figure 8) recorded by the Burrard East location while English Bay low-frequency noise stemmed largely from ship engines in transit and idling. English Bay showed greater average $L_{50}$ values in the 100-1000 Hz band, while the average $L_{eq}$ and SPL Max levels were greater at Burrard East.

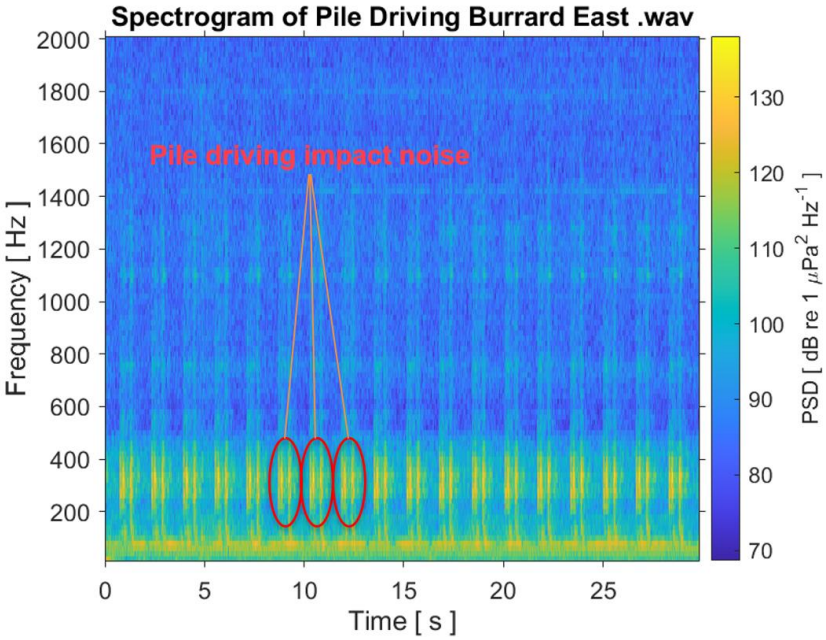



Figure 8 – Spectrogram of pile driving impact noise recorded at the Burrard East hydrophone in April 2020.

### 3.1.2 Monthly and One-Third Octave SPLs with PSD plots

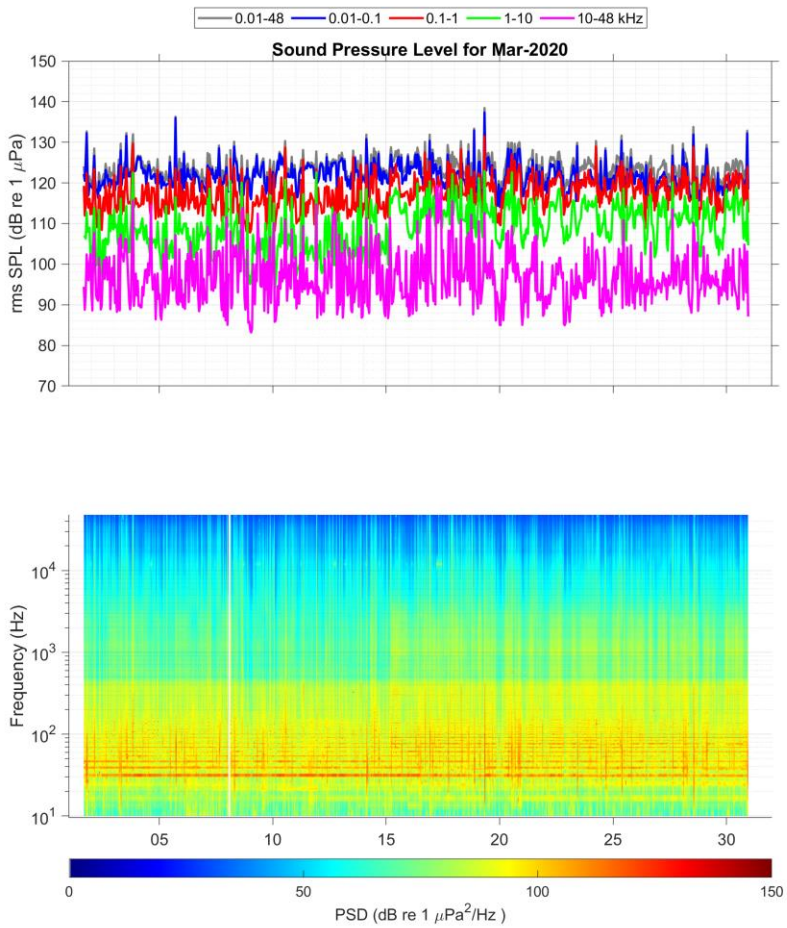
Monthly SPLs and spectrograms for March (Figure 9) and August (Figure 10) are shown for Burrard East and English Bay locations. Two consecutive months of June and July (Figure 11) at English Bay have also been selected to illustrate several clear patterns across the larger time frame.

- A notable band of energy between 30-300 Hz can be observed at both sites, highlighting where the majority of underwater noise falls on the frequency spectrum.
- Consistent tones between 30-100 Hz are present at both locations, but particularly at English Bay.
- Several periods of low-frequency (> 30 Hz) noise in the daytime hours.

Monthly Power Spectral Density (PSD) exceedance plots for March and August at Burrard East and English Bay (Figure 12 through Figure 15) display the following patterns.

- Strong oscillations in PSD between 30-100 Hz, with continued weaker oscillations beyond 200 Hz at both sites.
- A clear reduction in intensity at ~ 400 Hz was present in the data for both locations.
- Noise appears to be more evenly distributed at all octaves in the summer months, while leaning toward the lower frequencies in the winter months.

English Bay (March)




Burrard East (March)

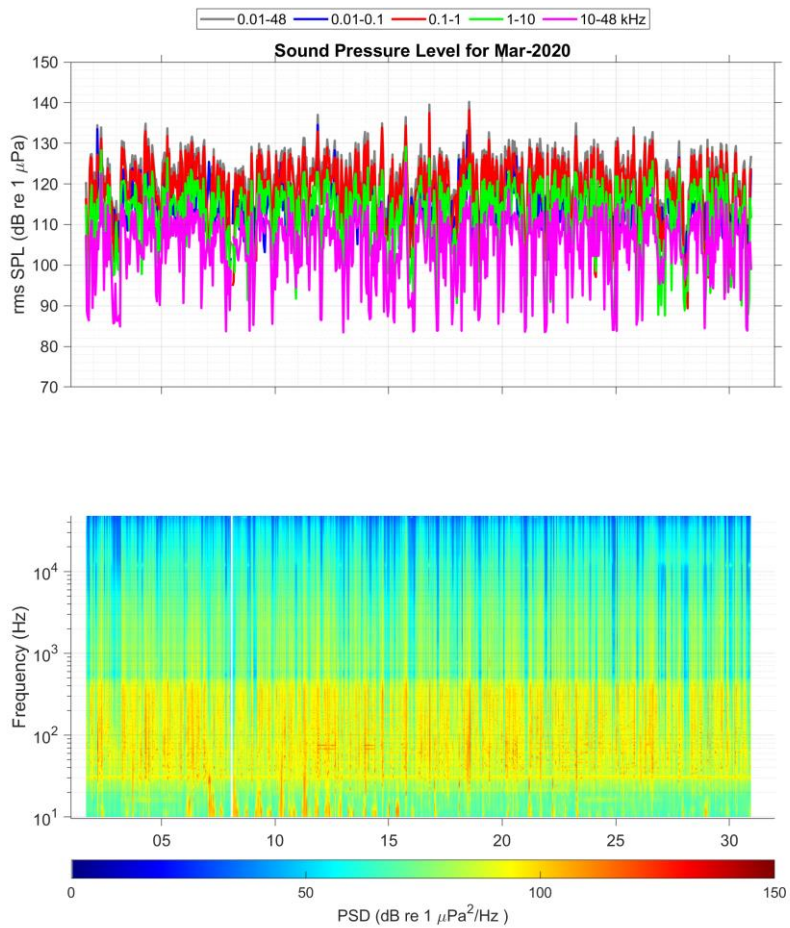
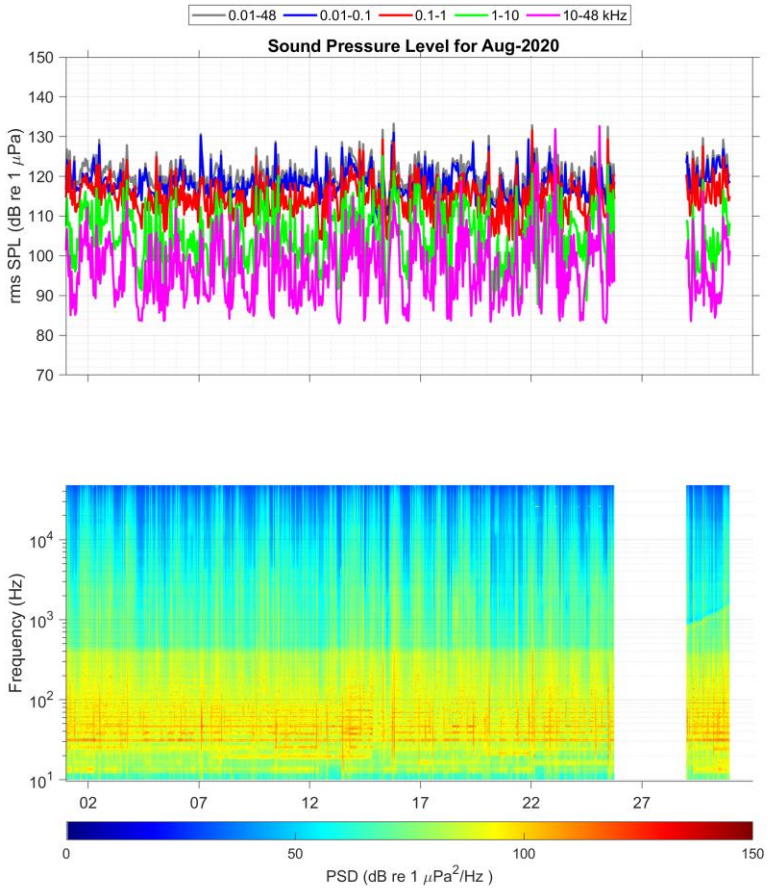



Figure 9. March broadband (10 Hz – 48 kHz) and decade band SPL (top panel) and spectrogram (bottom panel) by location. Plots are at 1-hour resolution.

English Bay (August)




Burrard East (August)

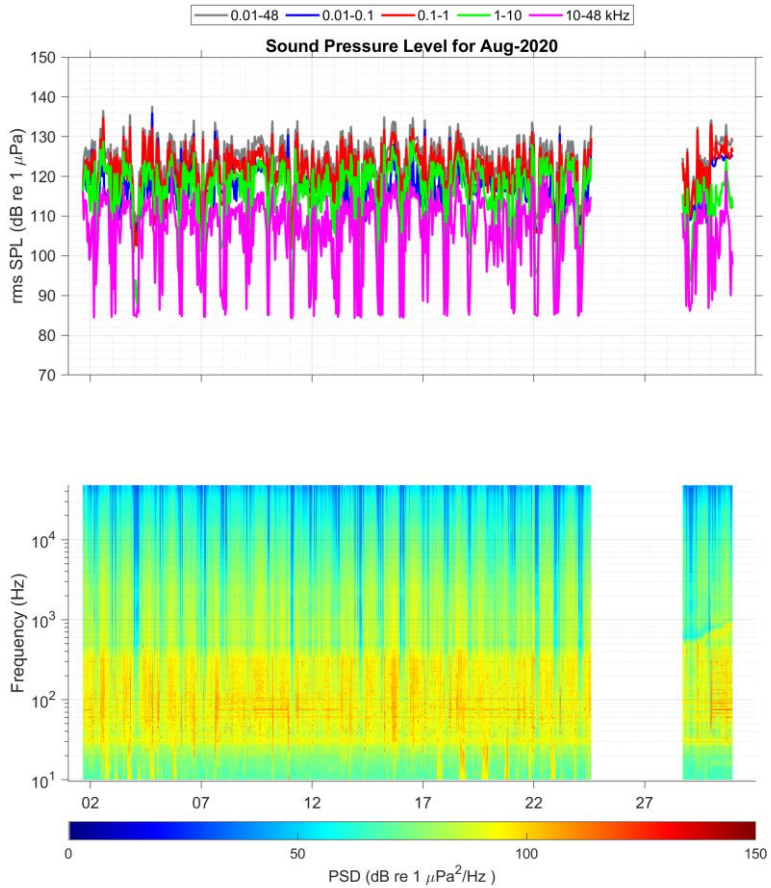
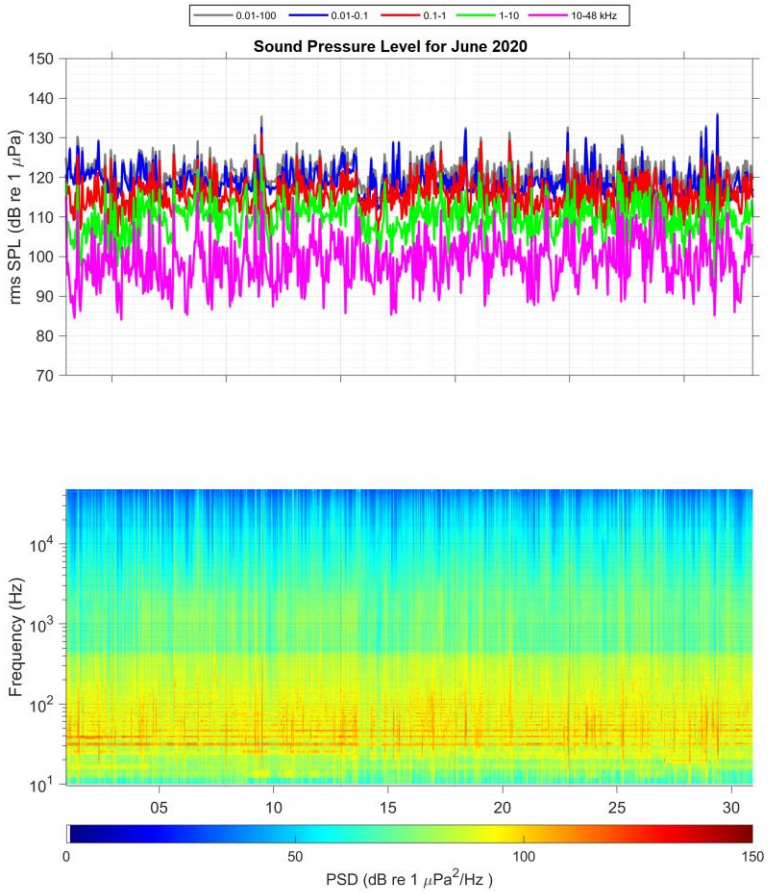



Figure 10. August broadband (10 Hz – 48 kHz) and decade band SPL (top panel) and spectrogram (bottom panel) by location. Plots are at 1-hour resolution. Data gaps represent deployment and recovery days.

English Bay (June)




English Bay (July)

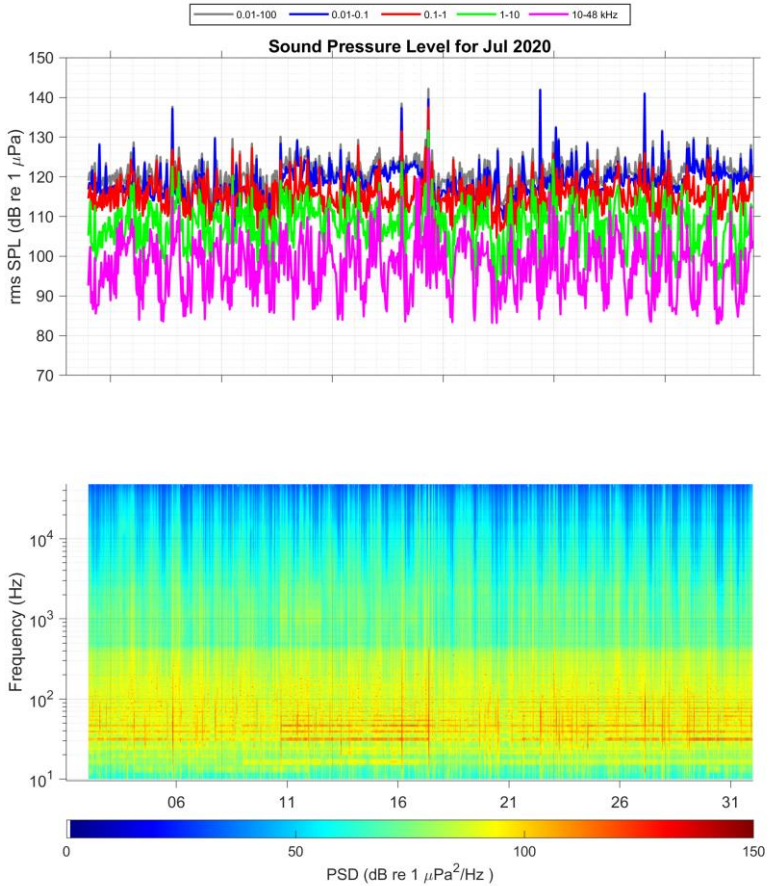



Figure 11. June and July English Bay broadband (10 Hz – 48 kHz) and decade band SPL (top panel) and spectrogram (bottom panel). Plots are at 1-hour resolution.

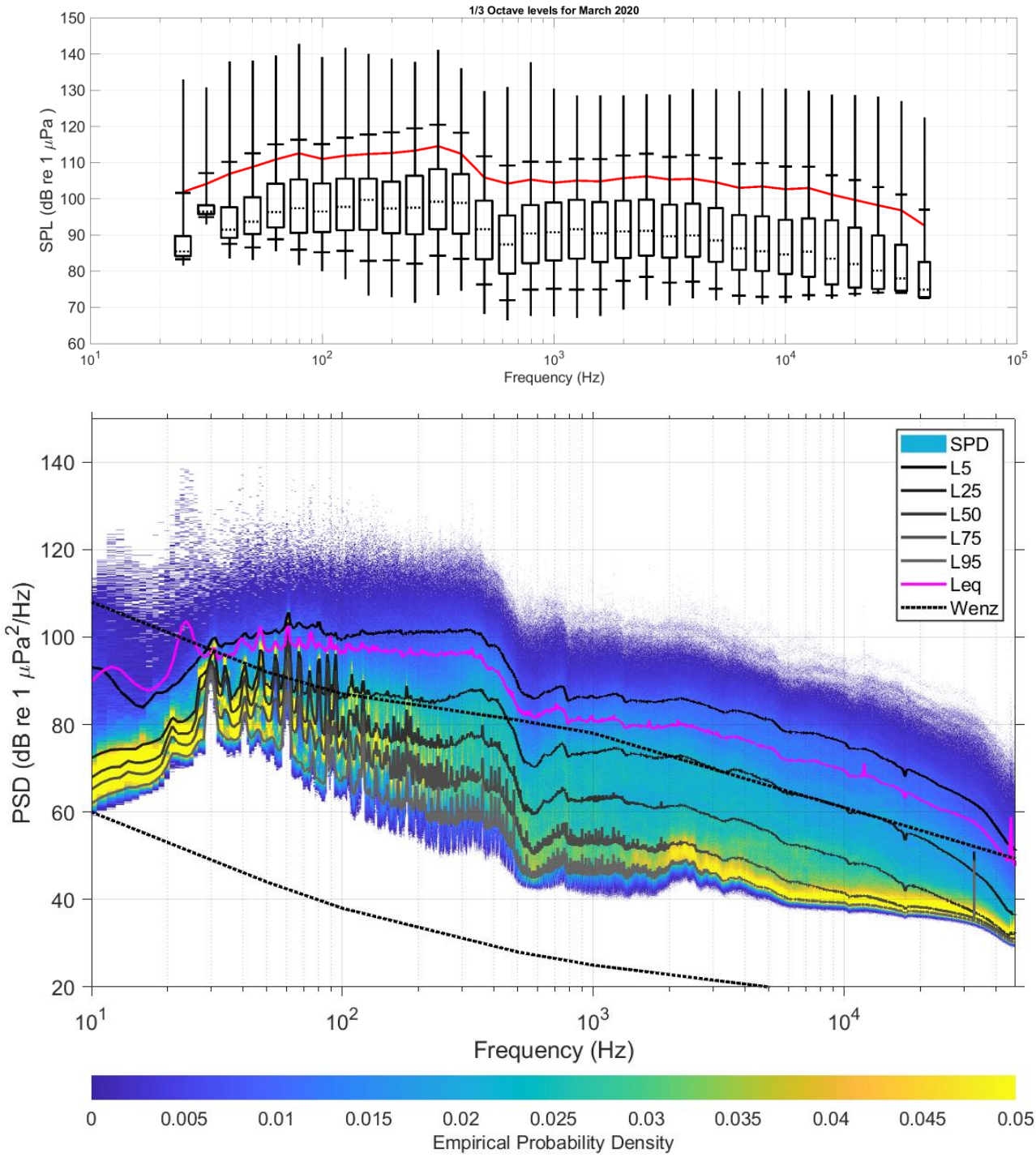



Figure 12. Burrard East (March), percentiles of 1-minute one-third octave band levels (top). Red line is rms mean ($L_{eq}$). Percentiles of 1-minute PSD levels (bottom).

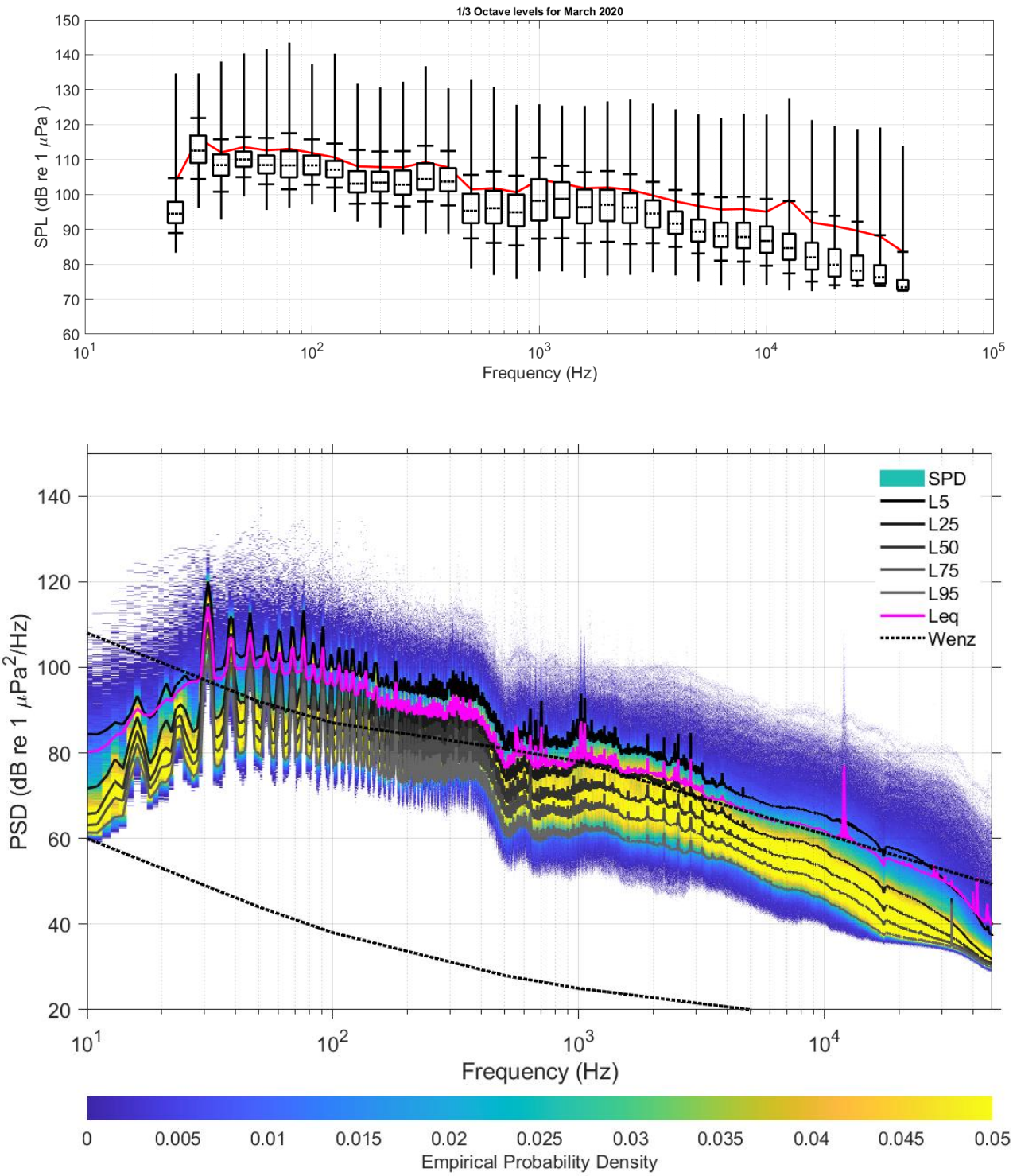



Figure 13. English Bay (March), percentiles of 1-minute one-third octave band levels (top). Red line is rms mean ($L_{eq}$). Percentiles of 1-minute PSD levels (bottom).

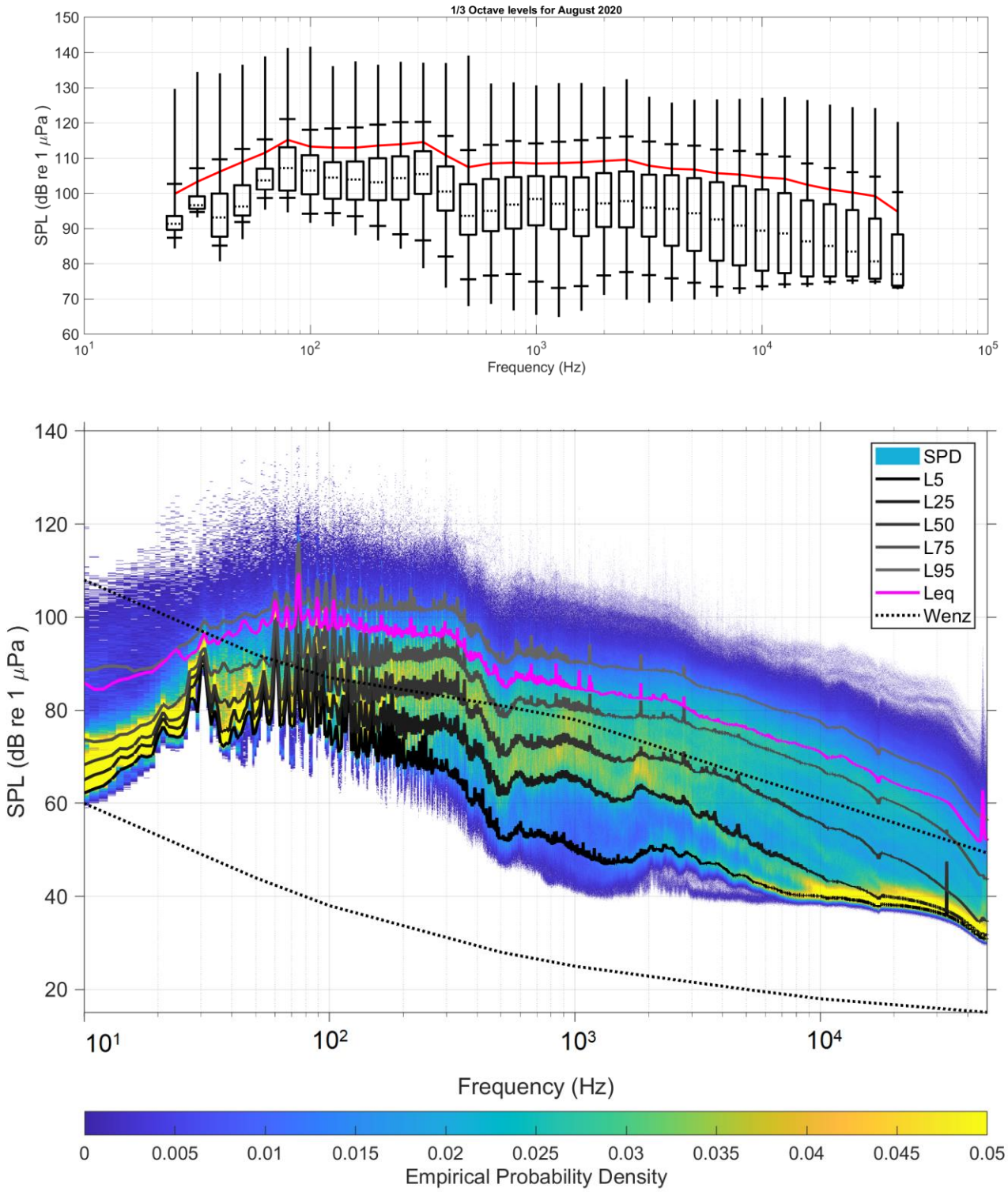



Figure 14. Burrard East (August), percentiles of 1-minute one-third octave band levels (top). Red line is rms mean ($L_{eq}$). Percentiles of 1-minute PSD levels (bottom).

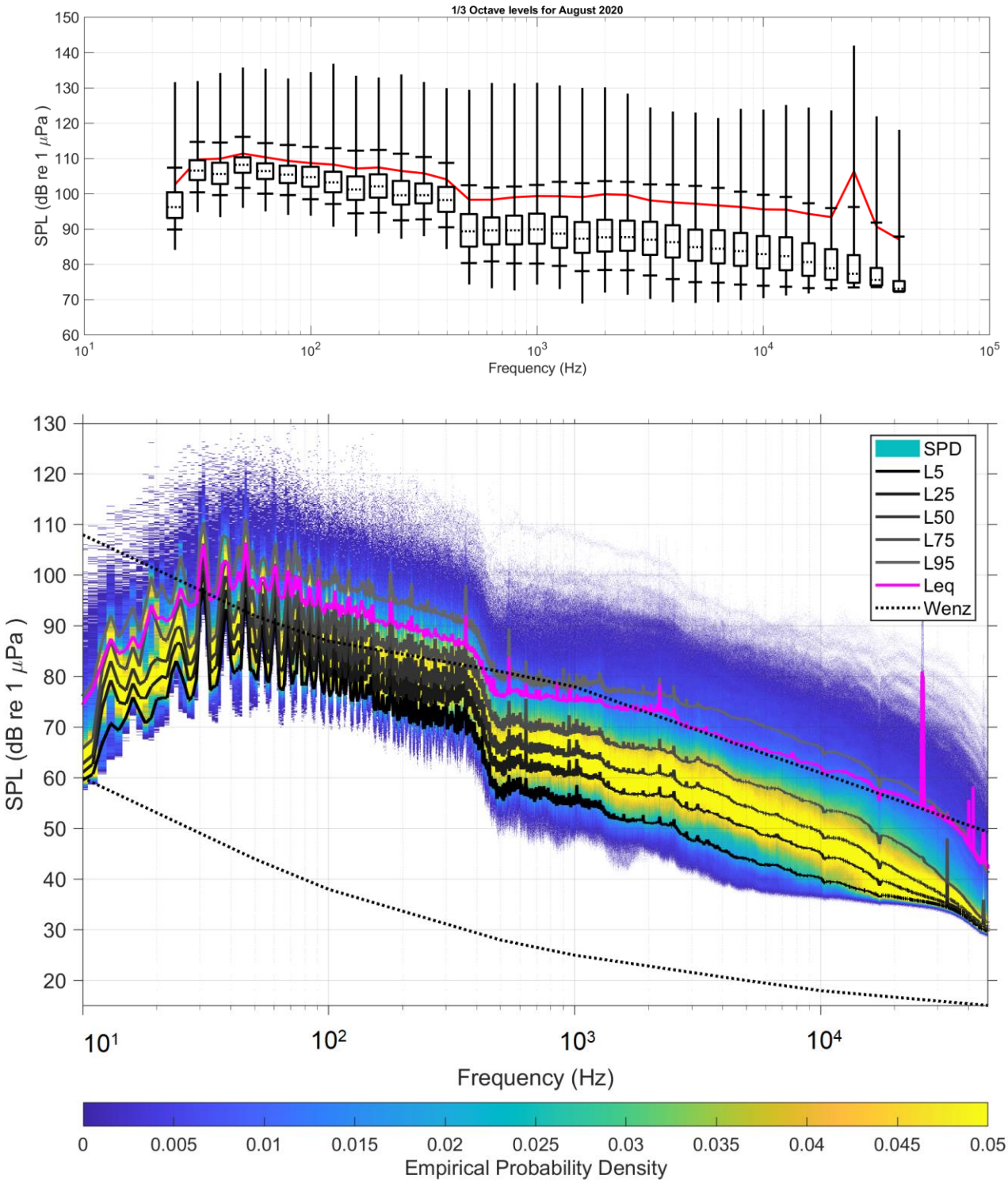


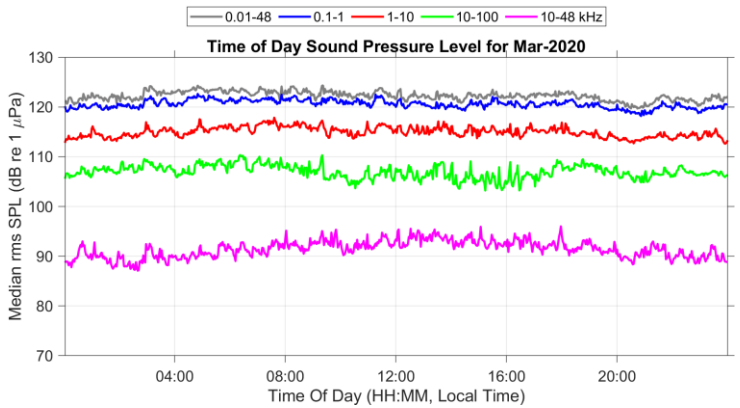

Figure 15. English Bay (August), percentiles of 1-minute one-third octave band levels (top). Red line is rms mean ($L_{eq}$). Percentiles of 1-minute PSD levels (bottom).

### 3.1.3 Diurnal Rhythm

Plots showing diurnal patterns are provided for March (Figure 16) and August (Figure 17) at both locations. Based on these plots we find the following patterns:

- Clear differences in the time of day patterns can be seen between the two sites.
    - Burrard East displays a marked increase in noise levels at all frequencies during the hours of 6:00am and 10:00pm.
    - English Bay tends is flatter throughout the 24-hour period, indicating consistent noise levels throughout both the day and the night.
    - These trends were present throughout the project year.
- In the summer months, English Bay displayed a more difference between day and night versus the winter, spring and fall.
- This pattern was also observed at Burrard East, where the day/night differences were exaggerated in the summer months.

English Bay (March)




Burrard East (March)

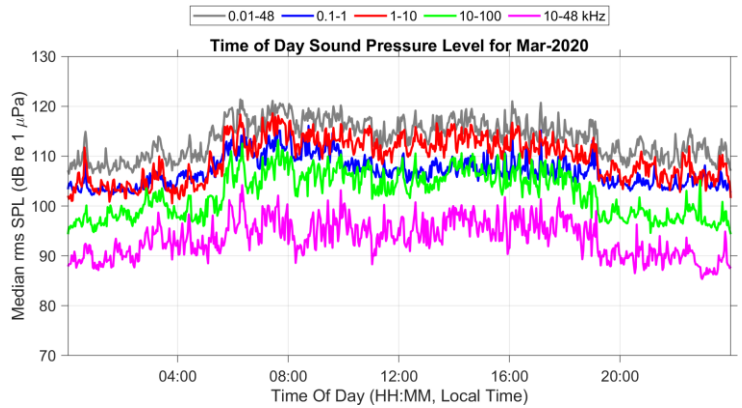
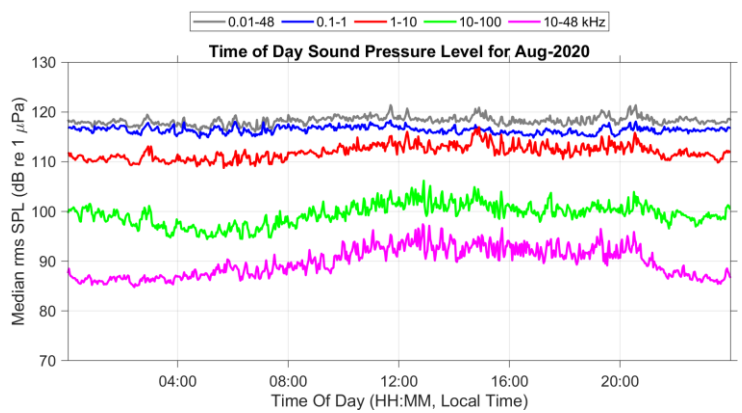



Figure 16. Median SPL across the month of March for each hour of day by location.

English Bay (August)




Burrard East (August)

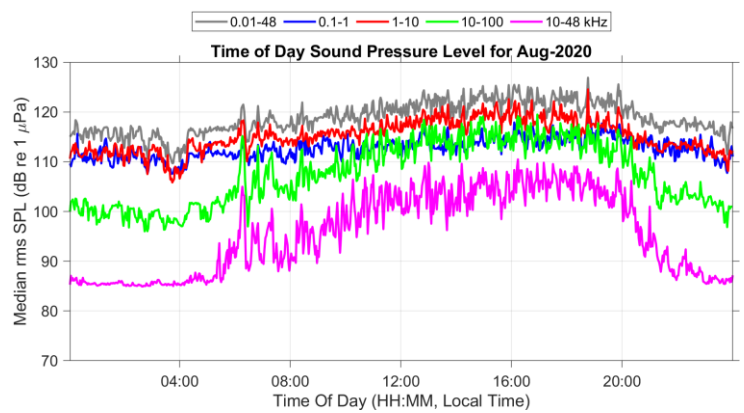


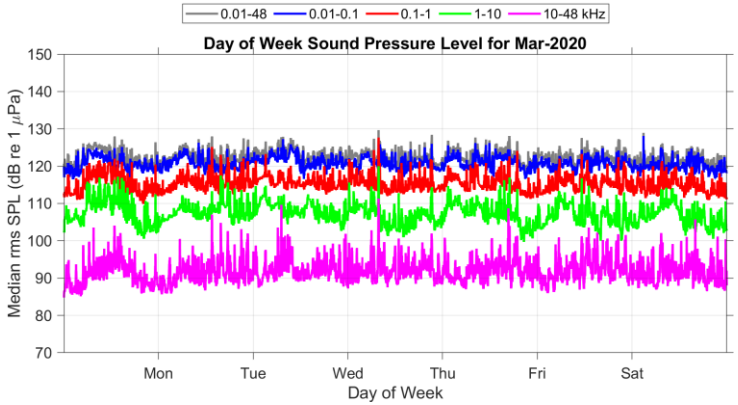

Figure 17. Median SPL across the month of August for each hour of day by location.

### 3.1.4 Weekly Rhythm

Plots showing weekly patterns are provided for March (Figure 18) and for August (Figure 19) at each location. Based on these plots we find the following patterns:

- Weekly rhythm is more apparent at Burrard East than at English Bay.
- Weekly rhythm was most clear in the summer months versus other seasons.
- September at Burrard East shows elevated levels of low- and mid-frequency (1-10,000 Hz) noise on Tuesdays, Wednesdays and Fridays (
- Figure 20).

English Bay (March)




Burrard East (March)

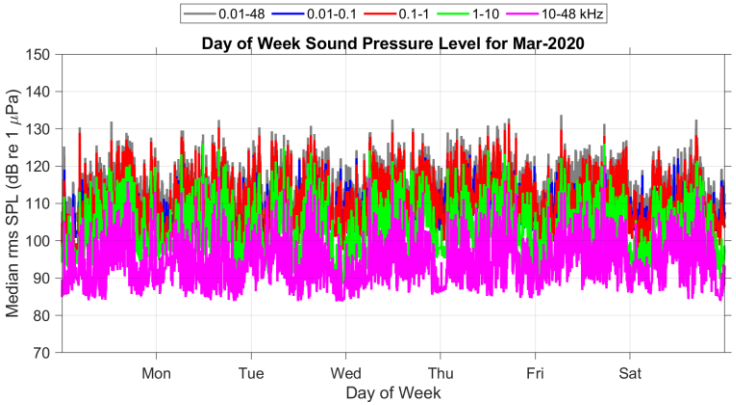
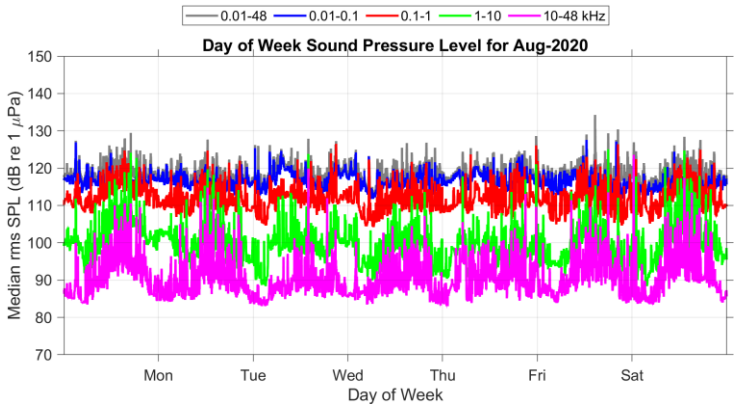



Figure 18. Median SPL across the month of March for each day of the week by location.

English Bay (August)




Burrard East (August)

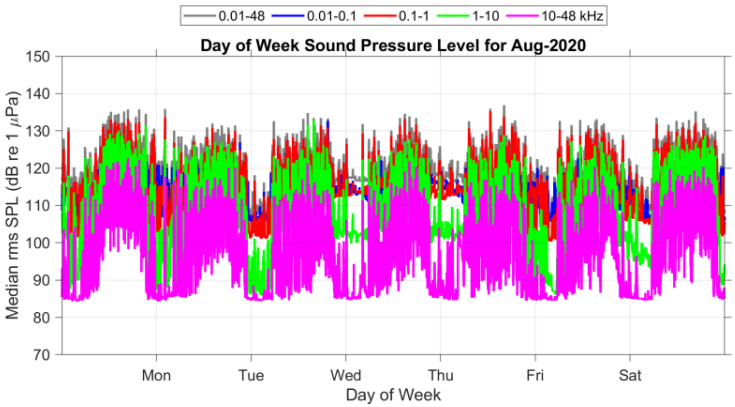
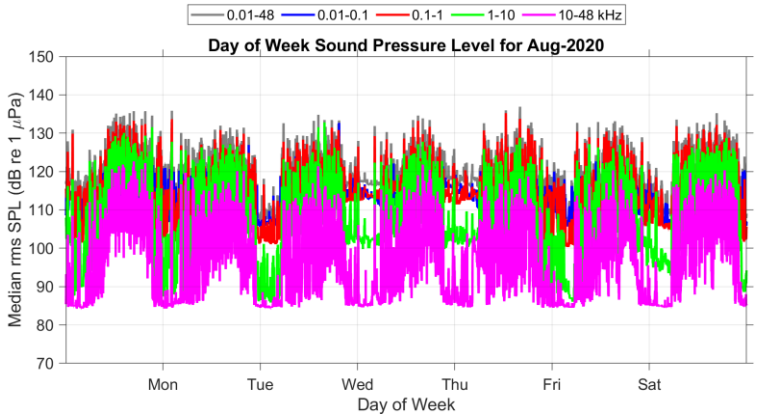



Figure 19. Median SPL across the month of August for each day of the week by location.

Burrard East (August)




Burrard East (September)

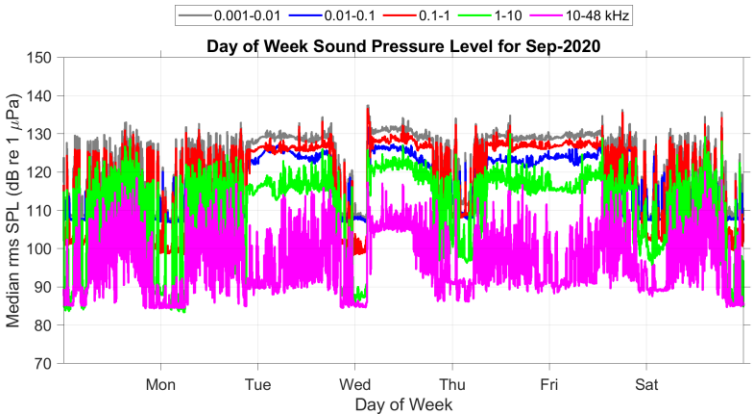


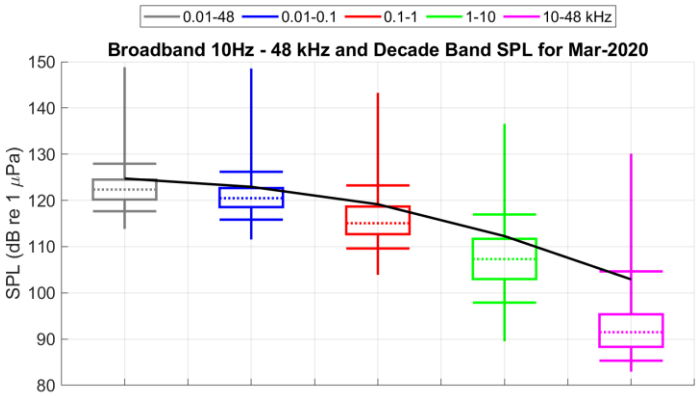

Figure 20. Comparison of Burrard East median SPL for August versus September. September was the only month at Burrard East which displayed elevated low and mid-range noise overnight. This was inconsistent with the rest of the project year.

### 3.1.5 SPL Box Plots

SPL box plots helped identify trends and variability within and across locations. March and August are selected again for display (Figure 21 and **Error! Reference source not found.**). Burrard East showed a consistent dip in the 10-100 Hz decade band throughout all months of the project when compared with English Bay.

There was minimal variability at both sites throughout the project. The exception was August at English Bay which indicated an increase in higher frequency noise (10-48 kHz) for the month.

English Bay (March)




Burrard East (March)

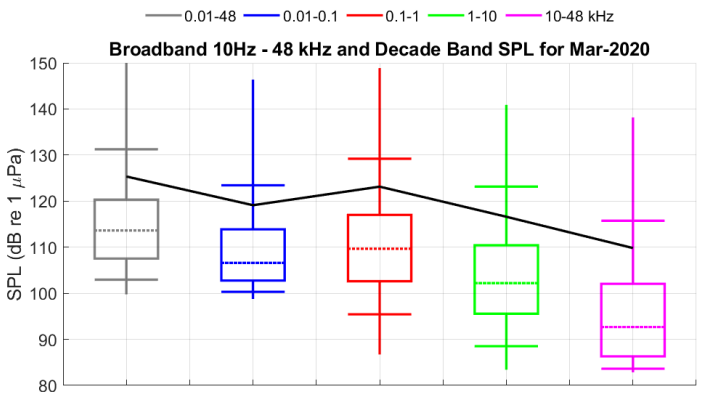
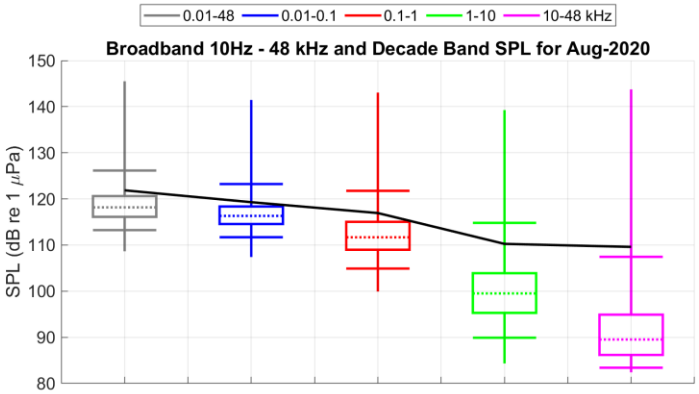



Figure 21. Boxplots of broadband (10 Hz – 48 kHz) and decade frequency band SPL March 2020 by location. The black lines are the $L_{eq}$.

English Bay (August)




Burrard East (August)

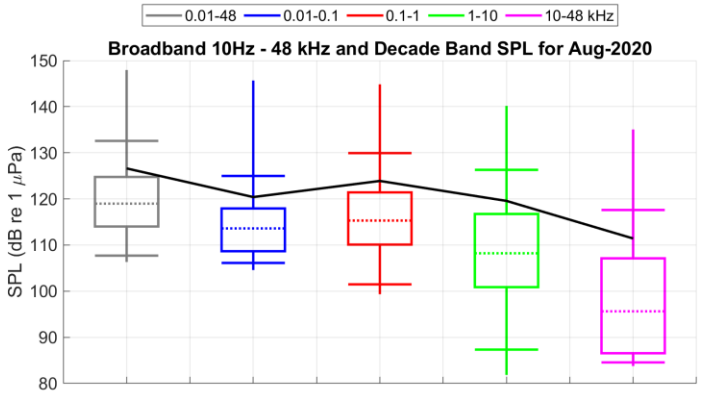



Figure 22. Boxplots of broadband (10 Hz – 48 kHz) and decade frequency band SPL August 2020 by location. The black lines are the $L_{eq}$.

### 3.1.6 Ancillary Data

#### *3.1.6.1 Vessel Density*

Violin plots (Figure 23) depict daily vessel density by location based on AIS data within 3 km of each hydrophone. As with 2019, higher vessel densities were observed at Burrard East than English Bay. The variability in vessel traffic was considerably higher at the Burrard East site.

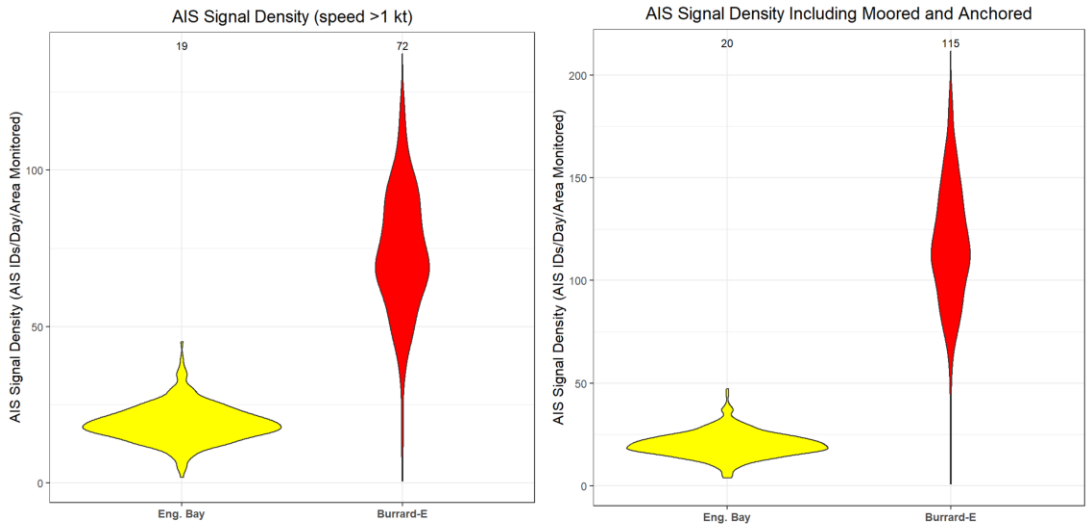
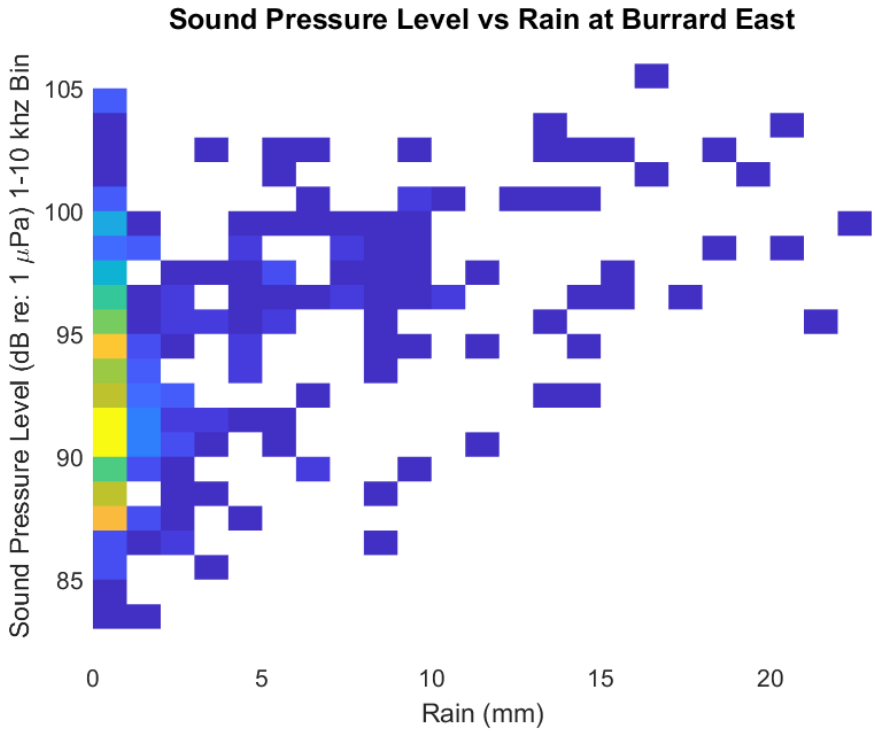



Figure 23. Daily AIS signal densities by location based on AIS data (Class A) within 3 km of each hydrophone. Panels depict moving vessels only (left) and all vessels (right) including moored, anchored, and vessels travelling < 1 knot. Median AIS densities are provided at the top of each plot.

#### *3.1.6.2 Currents, Wind and Rain*

As with 2019, visual inspection of monthly spectrograms for the top ten rainiest and windiest days in 2020 showed no clear patterns in ambient noise intensity compared to other time periods at the Burrard East location (Figure 24). Burrard East SPL (1-10 kHz) at daily scales were plotted with both daily rainfall and average wind speed. While no robust patterns were observed (Figure 24), SPL's below 85 dB were not recorded when the average daily rainfall exceeded 3 mm. Given that Burrard East was the lower SPL 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 and seasonal patterns at English Bay under current conditions. However, it should be noted that shallower locations within English Bay (not measured in this study), where sound associated with surface action is closer to the instrument, would likely show a stronger relationship between environmental factors and ambient noise levels.



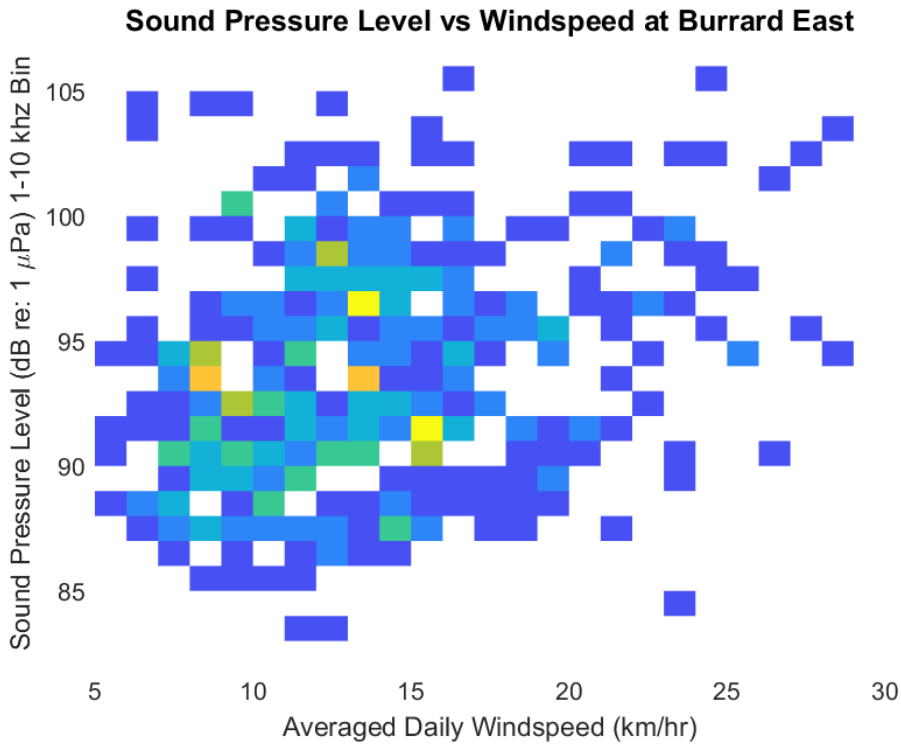




Figure 24. Burrard East SPL (10-48 kHz) versus daily rainfall (mm) and average wind speed (km/h). Color scale indicates number of observations.

SoundTrap internal tilt recorder documents the pitch, angle and roll of the instrument. Tilt angle was considered a proxy for current speed as the instrument is vertical when no current is present and tilted as increasing current forces the tethered instrument downward. Tilt angles were correlated with SPLs (10-100 Hz) at the Burrard East location where stronger currents were expected. No relationship was found between noise levels in the 10-100 Hz band and tilt angles at this location.

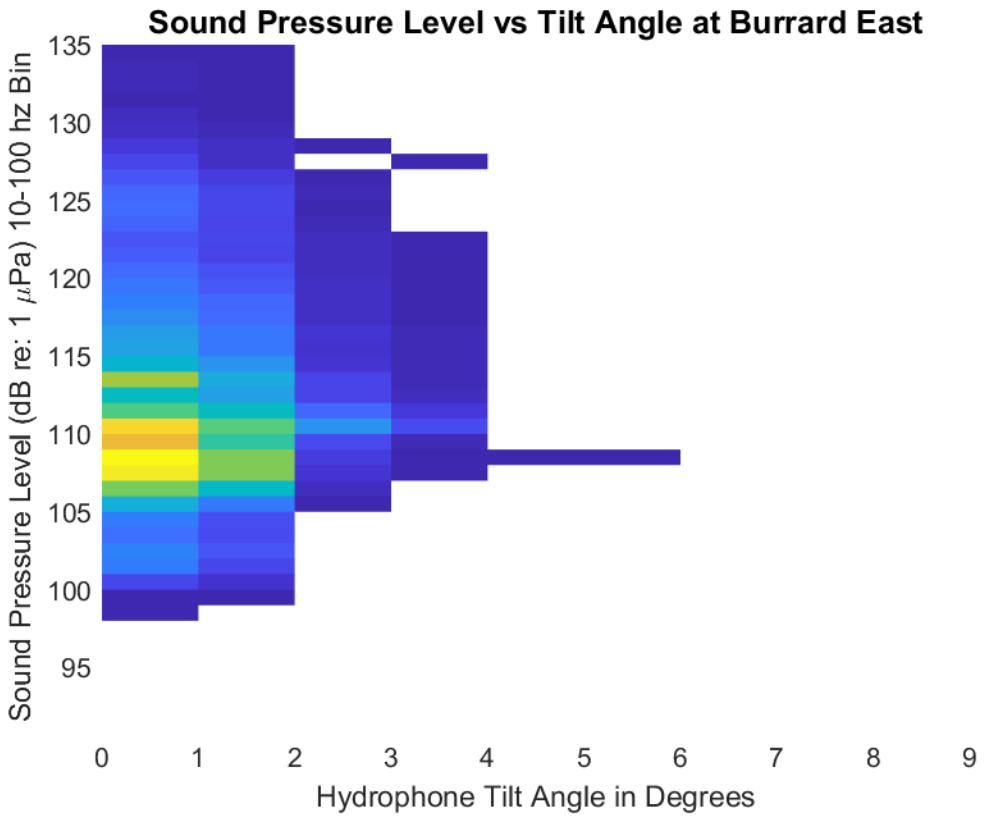



Figure 25. Burrard East SPL (10-100 Hz) versus SoundTrap tilt angle (considered a proxy for current speed). Color scale indicates number of observations.

## 3.2 Cetacean Presence Using PAM

A summary of all cetacean detections is provided in Table 6. Harbour porpoise (*Phocoena phocoena*) were detected at English Bay in all months of the year. The project year began with higher porpoise activity in winter and spring, then during summer and fall months fewer encounters followed. Activity began to increase again in December through the end of the project cycle (Figure 26). Only 4 detection days could be confirmed at Burrard East during the project, while a total of 107 days were confirmed at English Bay. An example of a detected harbour porpoise click train is provided in Figure 27.

Table 6. Marine mammal detection results for this project year (beginning February 2020). Both PAMGuard 'Whistle and Moan' detector and SoundTrap Click detector results are presented.

| Site | Month | # Probable Days – *Clicks (Porpoise)* | # Probable Days – Whistles (other cetaceans) |
|---|---|---|---|
| ***English Bay*** | February 2020 | 7 | 0 |
| | March 2020 | 11 | 0 |
| | April 2020 | 19 | 0 |
| | May 2020 | 7 | 0 |
| | June 2020 | 3 | 0 |
| | July 2020 | 4 | 0 |
| | August 2020 | 8 | 0 |
| | September 2020 | 5 | 0 |
| | October 2020 | 6 | 0 |
| | November 2020 | 6 | 0 |
| | December 2020 | 12 | 1 |
| | January 2021 | 14 | 1 |
| | February 2021 | 5 | 1 |
| | ***Year Total*** | ***107*** | ***3*** |
| | | | |
| ***Burrard East*** | February 2020 | 0 | 0 |
| | March 2020 | 0 | 0 |
| | April 2020 | 1 | 0 |
| | May 2020 | 0 | 0 |
| | June 2020 | 0 | 0 |
| | July 2020 | 0 | 0 |
| | August 2020 | 1 | 0 |
| | September 2020 | 0 | 0 |
| | October 2020 | 0 | 0 |
| | November 2020 | 0 | 0 |
| | December 2020 | 0 | 0 |
| | January 2021 | 2 | 0 |
| | February 2021 | 0 | 0 |
| | ***Year Total*** | ***4*** | ***0*** |

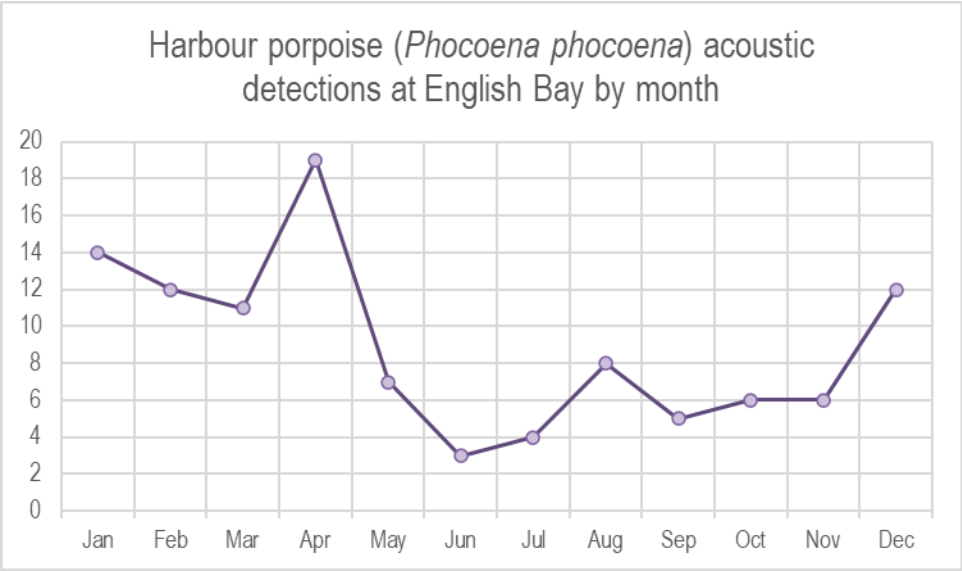



Figure 26 - Harbour porpoise detections peaked in the winter and spring while showing lower numbers in the summer and fall. February observations were combined in the above chart.

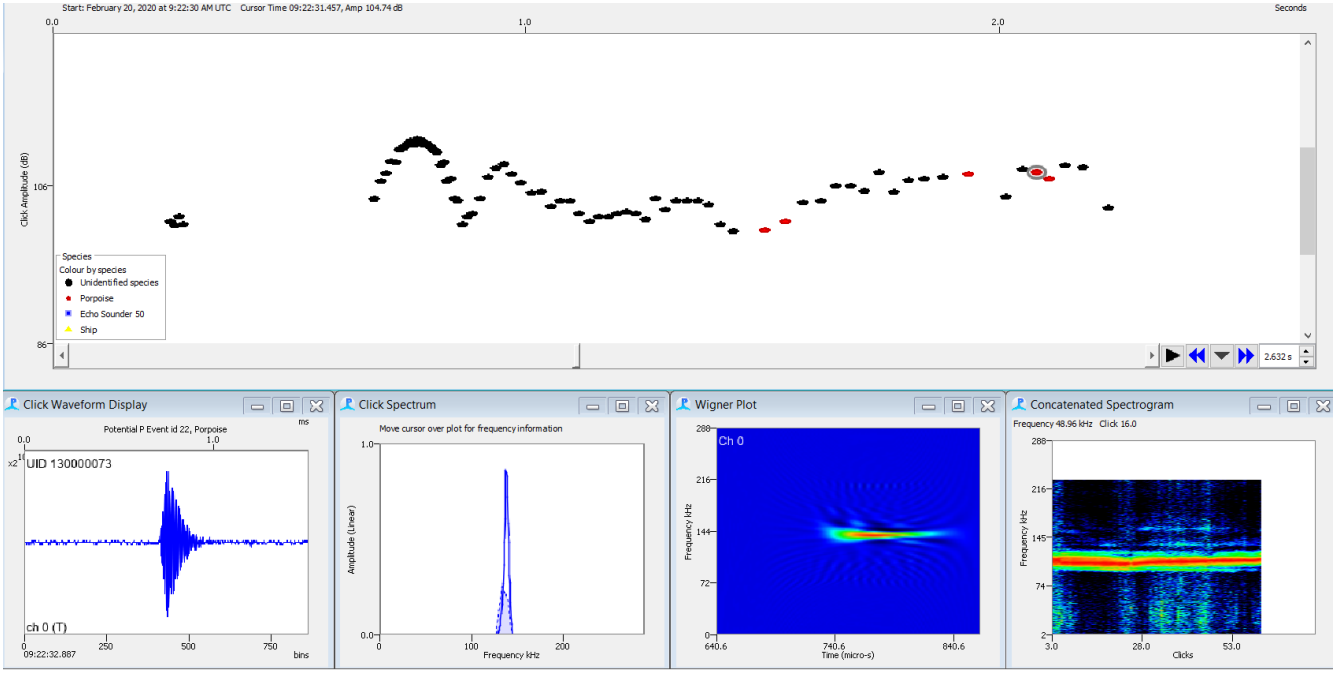



Figure 27. Example of a porpoise detection event using PAMGuard software. Top panel shows trend in amplitude (y-axis) as animals sweep past the hydrophone. Lower panels provide click diagnostics including (left to right) waveform, click spectrum, Wigner plot and concatenated spectrogram.

Visual sightings of killer whales are provided in Table 7. Only one of these visual sightings was also detected acoustically at English Bay. Killer whale acoustic detections were confirmed on 3 separate days, all during the last hydrophone deployment. A summary of detections is provided in Table 8. All detections occurred at the English Bay site. The longest event lasted 49 minutes while the shortest was only 3 minutes.

After review by the SMRU team, it was determined that two of the killer whale detection events were Southern Resident killer whales (December 2020 and January 2021 events) while the third was Bigg's ecotype (February 2021 event).

No humpback whale or dolphin detections were confirmed during the project year.

Table 7. Observed visual sightings of killer whales. Acoustic detections by location are provided in the final columns. One visual sighting was detected in the acoustic recordings.

| Date | Time (Local) | Notes/comments | Burrard East | English Bay |
|---|---|---|---|---|
| **2020-03-29** | 00:30 | 4-5 Biggs Orca foraging, heading east just north of Wall Street in Vancouver | N | N |
| **2020-05-03** | 13:00 | 3-4 Biggs Orca heading north-west off Eagle Harbour, West Vancouver | N | N |
| **2020-05-17** | 18:30 | 4 Biggs Orca travelling, heading east off Point Atkinson at West Vancouver | N | N |
| **2020-06-17** | ~19:00 | 3-4 Orca seen near Whytecliff Park. Ecotype unknown | N | N |
| **2020-07-13** | 06:06 | 1 Biggs Orca heading north at False Creek | N | N |
| **2020-08-09** | ~10:00 | 3 Orca seen near Batchelor Bay. Ecotype unknown | N | N |
| **2020-09-10** | 16:00 | 3 Biggs Orca heading north mid-channel, near the marine park at Barnet | N | N |
| **2020-12-03** | 22:40 | 3 Biggs Orca travelling, heading south off Grebe Islets | N | N |
| **2021-02-14** | ~15:00 | 3 Biggs Orca seen Whytecliff Park | N | Y |

Table 8. Acoustic detection of killer whales for the project year.

| Deployment Number | Location | Dates | Start time of recording (local) | End time of recording (local) | Event Duration | Ecotype |
|---|---|---|---|---|---|---|
| 4 | English Bay | December 25th, 2020 | 4:52 PM | 5:41 PM | 49:00 min | SRKW |
| 4 | English Bay | January 25th, 2021 | 2:18 AM | 2:25 AM | 7:00 min | SRKW |
| 4 | English Bay | February 14th, 2020 | 1:06 AM | 1:09 AM | 3:00 min | Bigg's |

# 4 Discussion

This report represents the second continuous year of acoustic monitoring in Burrard Inlet. This year, two of the original five sites measured in Year 1 of the study were chosen to provide acoustic monitoring. The English Bay site was chosen as it was closest to the Straight of Georgia and to offshore noise regimes including remote vessel traffic and regional weather events. The choice to repeat monitoring at the Burrard East site represented a compromise between the need to provide spatial coverage of the inlet, cover ecologically and culturally important habitat, and measure noise regimes representative of activity withing the inlet excluding the SeaBus which dominated noise regimes at the western locations. Furthermore, in late 2020, Oceans Network Canada installed a cabled hydrophone based on the Eastern side of Stanley Park and commenced acoustically monitoring habitat that was previously covered by the Burrard West locations in 2019. Last, in 2019 the Indian Arm location documented the quietest noise levels, but the data were not representative of the traffic and noise throughout the majority of the inlet.

The Burrard East site was closer to construction activity, while the English Bay site was closer to the anchorage of numerous large cargo vessels. Both sources tend to generate noise in the lower frequencies (100 Hz to 1000 Hz). English Bay showed greater average $L_{50}$ values in the 100-1,000 Hz band, while the average $L_{eq}$ and SPL Max levels were greater at Burrard East. The weekly and diel trends in the noise levels at these locations provide some insight into the ambient noise contributors. At English Bay, the noise levels were fairly consistent across the 24-hour period whereas strong increases in noise during daylight hours at the Burrard East site are indicative of vessel activity.

Median broadband $L_{50}$ levels at Burrard East showed a notable increase in the months of July, August, and September. These trends were also present in the previous year's data (though more pronounced in 2020) and can likely be attributed to increases in vessel traffic during these months.

It goes without saying that 2020 was a novel year. In addition to the global COVID-19 pandemic, local rail blockades certainly had an impact on anthropogenic noise within and around Burrard Inlet. Our results show a complex relationship in ambient noise levels between 2019 those 2020. Unlike other areas that have seen a decrease in noise levels associated with the 'anthropause' of COVID-19 (Dugald and Barcaly 2020), noise levels at the monitoring stations in the Burrard Inlet did not show a consistent decrease in ambient noise. Though the broadband $L_{50}$ data from the English Bay site indicated marginal month-to-month decreases at the start of the pandemic, this decrease was small and potentially explained by other covariates. Moreover, there were large and consistent increases in month-to-month broadband $L_{50}$ noise levels at the Burrard East location.

While we did not deploy any instruments in the Inner Harbour in 2020, we expect there may have been a marked decrease in noise in that area compared to 2019, as we previously found that the SeaBus dominated the immediately local soundscape. However, in early 2020, the SeaBus schedule was reduced by 50% due to COVID-19 precautions, likely causing reduced ambient noise levels.

The majority of porpoise detections occurred at English Bay, with only a few detections at Burrard East. At the Burrard East location, harbour porpoise were detected in April, August, and January indicating that they likely use the area but in limited numbers compared to English Bay. The peak in acoustic detections in April roughly corresponds with the spawning of Pacific Herring (*Clupea pallasii*) thus it is possible that animals are exploiting this local resource (Hay, 1985) though we cannot confirm this correlation is meaningful with these data alone.

These findings contrast with the results from the 2019 report that indicated a higher proportion of days with porpoise detections at Burrard East than English Bay. Multiple factors could account for this change. The trend could represent biological shift in site usage between years, while noting review and validation was performed by different observers, a known source of variability when identifying high-frequency species from clicks alone.

The timing of visual and acoustic killer whale detections differed considerably and there was only one overlap during the February 2021 event. This could be explained by three primary factors. First, visual observation is only useful in daylight hours (which are shorter in the winter months). All three of the recorded killer whale acoustic encounters occurred after sunset. Second, the SoundTraps were deployed on a 50% duty cycle, meaning some audio detection opportunities may have been missed. Bigg's (transient) killer whales tend to vocalise less than Southern Residents (Deecke et al., 2005), making them harder to detect with passive acoustic monitoring. Finally, ambient noise may simply have been too high to make additional detections possible.

Of particular note are the two detections of Southern Resident killer whales on December 25$^{th}$ 2020 and January 25$^{th}$ 2021. Visual sightings of Southern Residents are considerably rare in this region and little is known of the winter behaviour of SRKW (Zamon, 2007). In the 2019 project year, killer whales were detected on three separate days. Two of these were determined to be Bigg's (February 11$^{th}$ 2019 and May 31$^{st}$ 2019) and the other was SRKW (September 23$^{rd}$, 2019). This detection set further demonstrates the value of passive acoustic monitoring in Burrard Inlet to generate a broader dataset of killer whale (and other cetacean) encounters.

# 5 Conclusions

- A second year of continuous monitoring within Burrard Inlet was successful, with all hydrophones recovered and a near-continuous dataset collected for the entire project year.
    - Two of the original five monitored in 2019 were monitored in 2020, Burrard East and English Bay.
- Noise levels at these locations showed a complex relationship with those measured in 2019 with both increases and decreases in noise level metrics observed.
    - All month-to-month broadband $L_{50}$ values at Burrard East were higher in 2020 than 2019.
    - Month-to-month $L_{50}$ values at English Bay were largely similar between 2019 and 2020 with 2019 levels slightly higher than 2020 from May through August and the reverse in September and October.
- The English Bay site recorded the highest annual broadband $L_{50}$ SPL at 120.8 dB re 1µPa through the project year. The English Bay $L_5$ level was 128.2 dB re 1µPa.
    - The English Bay $L_{50}$ level was down 0.2 dB re 1µPa from 2019. The $L_5$ level was also down 0.2 dB re 1µPa from 2019.
- Burrard East recorded 115.9 dB re 1µPa annual broadband $L_{50}$ SPL. Burrard East recorded the highest $L_5$ exceedance at 132.4 dB re 1µPa.
    - The $L_{50}$ and $L_5$ values at Burrard East were up 5.1 dB re 1µPa and 2.5 dB re 1µPa relative to 2019, respectively.
- Both sites exhibited diurnal and weekly rhythm, but these effects were far more pronounced at Burrard East. This was likely driven by a higher proportion of vessel traffic transiting through this site. These effects increased notably in the summer months (July, August, September).
- As with 2019, The annual average broadband $L_{50}$ SPL was higher at English Bay than Burrard East. However, the broadband $L_5$ (associated with transient sounds) at Burrard East was higher than English Bay in both 2019 and 2020.
- Harbour porpoise (*Phocoena phocoena*) were detected in all months of the study year at English Bay for a total of 107 days. Porpoise were only detected 4 times throughout the project year at Burrard East in April 2020, August 2020 and January 2021.
- Killer whales (*Orcinus orca*) were detected 3 times during the project year, in December 2020 (SRKW), January 2021 (SRKW) and February 2021 (Biggs). All detections occurred at English Bay. Total encounter time was less than one hour.

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# Appendix

Appendix 1. Burrard East, monthly SPL (dB re 1µPa) by study month for each broadband and decade frequency band metric.

| ***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 2020 | 93.4 | 89.1 | 87.4 | 85.2 | 82.8 |
| | **$L_{95}$** | Feb 2020 | 103.3 | 101.0 | 95.3 | 90.5 | 83.4 |
| | **$L_{75}$** | Feb 2020 | 107.5 | 103.1 | 101.7 | 96.4 | 86.3 |
| | **$L_{50}$** | Feb 2020 | 113.5 | 107.0 | 109.8 | 103.1 | 94.0 |
| | **$L_{25}$** | Feb 2020 | 120.7 | 113.1 | 117.8 | 111.6 | 103.0 |
| | **$L_{5}$** | Feb 2020 | 131.7 | 123.6 | 129.7 | 123.2 | 115.7 |
| | **Max** | Feb 2020 | 151.7 | 148.0 | 149.8 | 140.1 | 133.2 |
| | **Mean** | Feb 2020 | 125.9 | 119.6 | 123.8 | 117.1 | 110.1 |
| Burrard East | **Min** | Mar 2020 | 99.8 | 98.8 | 86.7 | 83.4 | 82.8 |
| | **$L_{95}$** | Mar 2020 | 102.9 | 100.3 | 95.6 | 88.5 | 83.6 |
| | **$L_{75}$** | Mar 2020 | 107.4 | 102.7 | 102.5 | 95.5 | 86.2 |
| | **$L_{50}$** | Mar 2020 | 113.6 | 106.5 | 109.6 | 102.2 | 92.6 |
| | **$L_{25}$** | Mar 2020 | 120.3 | 113.8 | 117.0 | 110.5 | 102.1 |
| | **$L_{5}$** | Mar 2020 | 131.3 | 123.4 | 129.3 | 123.2 | 115.9 |
| | **Max** | Mar 2020 | 150.9 | 146.4 | 148.9 | 140.9 | 138.2 |
| | **Mean** | Mar 2020 | 125.4 | 119.0 | 123.2 | 116.8 | 109.9 |
| Burrard East | **Min** | Apr 2020 | 100.6 | 98.7 | 86.9 | 82.7 | 83.2 |
| | **$L_{95}$** | Apr 2020 | 103.7 | 101.9 | 93.6 | 85.5 | 83.8 |
| | **$L_{75}$** | Apr 2020 | 110.2 | 107.1 | 101.1 | 90.6 | 84.7 |
| | **$L_{50}$** | Apr 2020 | 113.6 | 111.0 | 107.0 | 99.5 | 89.9 |
| | **$L_{25}$** | Apr 2020 | 119.9 | 113.6 | 115.9 | 110.4 | 101.0 |
| | **$L_{5}$** | Apr 2020 | 131.6 | 123.4 | 129.4 | 123.6 | 115.4 |
| | **Max** | Apr 2020 | 148.6 | 144.5 | 146.2 | 143.1 | 136.6 |
| | **Mean** | Apr 2020 | 125.6 | 119.4 | 123.3 | 117.1 | 109.7 |
| Burrard East | **Min** | May 2020 | 110.4 | 109.6 | 100.3 | 82.3 | 83.5 |
| | **$L_{95}$** | May 2020 | 111.3 | 110.5 | 102.0 | 87.0 | 84.0 |
| | **$L_{75}$** | May 2020 | 112.2 | 111.1 | 104.0 | 92.7 | 85.1 |
| | **$L_{50}$** | May 2020 | 115.6 | 112.0 | 110.1 | 102.7 | 91.8 |
| | **$L_{25}$** | May 2020 | 121.9 | 115.3 | 118.4 | 113.2 | 103.2 |
| | **$L_{5}$** | May 2020 | 132.3 | 123.8 | 130.1 | 124.8 | 116.8 |
| | **Max** | May 2020 | 147.4 | 145.0 | 146.5 | 138.9 | 132.9 |
| | **Mean** | May 2020 | 126.2 | 119.4 | 124.0 | 118.2 | 110.7 |

| *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** | Jun 2020 | 105.2 | 103.6 | 98.5 | 84.3 | 83.2 |
| | **$L_{95}$** | Jun 2020 | 106.5 | 105.0 | 100.3 | 86.4 | 83.8 |
| | **$L_{75}$** | Jun 2020 | 109.2 | 106.4 | 102.8 | 92.9 | 85.0 |
| | **$L_{50}$** | Jun 2020 | 114.7 | 109.2 | 110.1 | 104.7 | 92.5 |
| | **$L_{25}$** | Jun 2020 | 121.4 | 114.4 | 117.9 | 114.0 | 103.2 |
| | **$L_5$** | Jun 2020 | 131.2 | 123.0 | 128.5 | 125.1 | 116.5 |
| | **Max** | Jun 2020 | 150.3 | 149.4 | 144.8 | 139.6 | 134.9 |
| | **Mean** | Jun 2020 | 125.2 | 118.6 | 122.6 | 118.3 | 110.2 |
| Burrard East | **Min** | Jul 2020 | 104.3 | 102.3 | 97.0 | 82.2 | 82.9 |
| | **$L_{95}$** | Jul 2020 | 106.7 | 104.7 | 100.5 | 88.3 | 83.9 |
| | **$L_{75}$** | Jul 2020 | 113.4 | 107.9 | 108.9 | 101.3 | 85.9 |
| | **$L_{50}$** | Jul 2020 | 119.7 | 114.1 | 115.9 | 108.0 | 94.6 |
| | **$L_{25}$** | Jul 2020 | 124.0 | 118.4 | 120.7 | 116.6 | 105.9 |
| | **$L_5$** | Jul 2020 | 132.3 | 123.9 | 129.6 | 126.4 | 117.2 |
| | **Max** | Jul 2020 | 150.1 | 148.9 | 147.7 | 142.0 | 137.0 |
| | **Mean** | Jul 2020 | 126.5 | 120.2 | 123.7 | 119.6 | 111.0 |
| Burrard East | **Min** | Aug 2020 | 106.6 | 104.8 | 99.4 | 84.0 | 83.9 |
| | **$L_{95}$** | Aug 2020 | 107.9 | 106.3 | 101.6 | 88.2 | 84.7 |
| | **$L_{75}$** | Aug 2020 | 114.0 | 108.6 | 110.1 | 100.9 | 86.7 |
| | **$L_{50}$** | Aug 2020 | 119.7 | 113.6 | 116.3 | 108.2 | 95.6 |
| | **$L_{25}$** | Aug 2020 | 124.8 | 118.9 | 121.5 | 116.8 | 107.1 |
| | **$L_5$** | Aug 2020 | 132.5 | 124.6 | 129.9 | 126.0 | 117.4 |
| | **Max** | Aug 2020 | 147.8 | 145.6 | 144.7 | 139.8 | 134.8 |
| | **Mean** | Aug 2020 | 126.7 | 120.5 | 124.0 | 119.3 | 111.3 |
| Burrard East | **Min** | Sep 2020 | 105.8 | 104.3 | 96.3 | 80.9 | 83.6 |
| | **$L_{95}$** | Sep 2020 | 107.8 | 106.6 | 99.0 | 85.7 | 84.8 |
| | **$L_{75}$** | Sep 2020 | 110.5 | 107.8 | 104.7 | 98.8 | 89.1 |
| | **$L_{50}$** | Sep 2020 | 120.4 | 111.3 | 116.1 | 113.7 | 96.0 |
| | **$L_{25}$** | Sep 2020 | 129.3 | 124.1 | 126.8 | 118.6 | 104.8 |
| | **$L_5$** | Sep 2020 | 132.2 | 126.9 | 130.1 | 123.8 | 113.6 |
| | **Max** | Sep 2020 | 154.7 | 152.3 | 150.4 | 142.8 | 135.5 |
| | **Mean** | Sep 2020 | 128.2 | 122.4 | 126.0 | 119.1 | 109.0 |
| Burrard East | **Min** | Oct 2020 | 106.0 | 102.3 | 97.1 | 81.2 | 83.2 |
| | **$L_{95}$** | Oct 2020 | 107.8 | 105.7 | 100.5 | 86.9 | 84.7 |
| | **$L_{75}$** | Oct 2020 | 109.8 | 107.4 | 103.7 | 95.3 | 86.6 |
| | **$L_{50}$** | Oct 2020 | 113.0 | 108.6 | 109.0 | 102.5 | 93.4 |
| | **$L_{25}$** | Oct 2020 | 122.9 | 114.0 | 120.4 | 115.1 | 103.5 |
| | **$L_5$** | Oct 2020 | 131.3 | 125.6 | 129.4 | 123.4 | 113.4 |
| | **Max** | Oct 2020 | 152.0 | 147.0 | 151.4 | 149.0 | 142.2 |
| | **Mean** | Oct 2020 | 126.7 | 119.5 | 124.8 | 118.4 | 109.5 |

| *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** | Nov 2020 | 105.5 | 103.7 | 98.7 | **80.3** | 83.0 |
| | **$L_{95}$** | Nov 2020 | 107.7 | 106.1 | 101.1 | 86.5 | 83.8 |
| | **$L_{75}$** | Nov 2020 | 109.0 | 107.1 | 103.2 | 92.3 | 85.9 |
| | **$L_{50}$** | Nov 2020 | 111.3 | 108.3 | 106.0 | 100.0 | 92.6 |
| | **$L_{25}$** | Nov 2020 | 116.5 | 110.3 | 112.1 | 109.1 | 101.7 |
| | **$L_{5}$** | Nov 2020 | 127.9 | 118.0 | 126.1 | 121.3 | 111.5 |
| | **Max** | Nov 2020 | 152.4 | 144.1 | 151.2 | 144.7 | 136.5 |
| | **Mean** | Nov 2020 | 123.5 | 115.1 | 121.7 | 116.1 | 107.4 |
| Burrard East | **Min** | Dec 2020 | 95.6 | 92.7 | 91.4 | 80.7 | 82.4 |
| | **$L_{95}$** | Dec 2020 | 109.6 | 108.0 | 102.2 | 88.9 | 85.3 |
| | **$L_{75}$** | Dec 2020 | 110.8 | 109.0 | 103.9 | 93.6 | 86.7 |
| | **$L_{50}$** | Dec 2020 | 113.2 | 110.5 | 107.0 | 99.7 | 94.9 |
| | **$L_{25}$** | Dec 2020 | 121.3 | 115.3 | 116.1 | 109.4 | 103.2 |
| | **$L_{5}$** | Dec 2020 | 134.5 | 130.9 | 128.7 | 123.5 | 115.5 |
| | **Max** | Dec 2020 | 149.1 | 145.9 | 146.7 | 143.2 | 136.7 |
| | **Mean** | Dec 2020 | 127.5 | 123.9 | 123.7 | 118.4 | 110.8 |
| Burrard East | **Min** | Jan 2021 | 109.7 | 108.5 | 100.9 | 88.4 | 85.5 |
| | **$L_{95}$** | Jan 2021 | 111.0 | 109.7 | 103.1 | 92.2 | 85.8 |
| | **$L_{75}$** | Jan 2021 | 112.3 | 110.6 | 105.3 | 95.8 | 87.1 |
| | **$L_{50}$** | Jan 2021 | 116.4 | 112.8 | 110.3 | 102.2 | 93.4 |
| | **$L_{25}$** | Jan 2021 | 124.0 | 118.3 | 118.9 | 112.1 | 103.3 |
| | **$L_{5}$** | Jan 2021 | 135.3 | 131.4 | 130.5 | 125.3 | 116.6 |
| | **Max** | Jan 2021 | 149.5 | 147.5 | 147.1 | 143.3 | 137.9 |
| | **Mean** | Jan 2021 | 128.5 | 124.7 | 125.0 | 119.5 | 111.7 |
| Burrard East | **Min** | Feb 2021 | 105.5 | 104.5 | 96.8 | 89.2 | 82.8 |
| | **$L_{95}$** | Feb 2021 | 109.1 | 108.1 | 101.2 | 91.0 | 85.6 |
| | **$L_{75}$** | Feb 2021 | 111.7 | 110.0 | 105.0 | 94.0 | 86.5 |
| | **$L_{50}$** | Feb 2021 | 115.9 | 112.1 | 109.5 | 101.2 | 92.4 |
| | **$L_{25}$** | Feb 2021 | 124.6 | 118.6 | 119.2 | 111.6 | 103.1 |
| | **$L_{5}$** | Feb 2021 | 134.7 | 131.9 | 130.3 | 124.7 | 116.0 |
| | **Max** | Feb 2021 | 151.2 | 147.0 | 148.3 | 141.4 | 133.4 |
| | **Mean** | Feb 2021 | 128.5 | 124.6 | 125.0 | 119.3 | 111.0 |

Appendix 2. English Bay, monthly SPL (dB re 1µPa) by study month for each broadband and decade frequency band metric.

| ***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 2020 | 112.80 | 110.69 | 103.53 | 90.67 | 82.97 |
| | **$L_{95}$** | Feb 2020 | 116.59 | 115.01 | 109.46 | 97.92 | 86.31 |
| | **$L_{75}$** | Feb 2020 | 119.27 | 117.53 | 113.03 | 101.54 | 90.28 |
| | **$L_{50}$** | Feb 2020 | 121.49 | 119.69 | 115.29 | 104.86 | 93.95 |
| | **$L_{25}$** | Feb 2020 | 124.16 | 122.18 | 118.63 | 108.54 | 98.87 |
| | **$L_{5}$** | Feb 2020 | 129.95 | 127.48 | 125.24 | 115.78 | 108.86 |
| | **Max** | Feb 2020 | 151.74 | 149.75 | 150.82 | 138.78 | 134.53 |
| | **Mean** | Feb 2020 | 125.75 | 123.35 | 121.41 | 112.95 | 105.05 |
| English Bay | **Min** | Mar 2020 | 113.84 | 111.55 | 103.90 | 89.51 | 82.95 |
| | **$L_{95}$** | Mar 2020 | 117.65 | 115.85 | 109.55 | 97.95 | 85.33 |
| | **$L_{75}$** | Mar 2020 | 120.14 | 118.52 | 112.64 | 102.94 | 88.30 |
| | **$L_{50}$** | Mar 2020 | 122.24 | 120.42 | 114.96 | 107.22 | 91.51 |
| | **$L_{25}$** | Mar 2020 | 124.45 | 122.57 | 118.58 | 111.54 | 95.41 |
| | **$L_{5}$** | Mar 2020 | 127.92 | 126.15 | 123.23 | 116.89 | 104.74 |
| | **Max** | Mar 2020 | 148.82 | 148.53 | 143.28 | 136.57 | 130.12 |
| | **Mean** | Mar 2020 | 124.66 | 122.85 | 119.13 | 112.18 | 102.82 |
| English Bay | **Min** | Apr 2020 | 107.35 | 105.64 | 98.46 | 83.96 | 82.54 |
| | **$L_{95}$** | Apr 2020 | 113.55 | 111.89 | 106.62 | 94.33 | 83.72 |
| | **$L_{75}$** | Apr 2020 | 117.46 | 115.59 | 111.54 | 100.55 | 86.80 |
| | **$L_{50}$** | Apr 2020 | 119.93 | 117.90 | 114.42 | 104.40 | 90.18 |
| | **$L_{25}$** | Apr 2020 | 122.65 | 120.46 | 117.33 | 109.07 | 94.20 |
| | **$L_{5}$** | Apr 2020 | 126.96 | 124.65 | 122.58 | 114.83 | 104.37 |
| | **Max** | Apr 2020 | 148.72 | 148.11 | 141.35 | 135.57 | 128.30 |
| | **Mean** | Apr 2020 | 123.24 | 121.09 | 118.45 | 110.55 | 100.72 |
| English Bay | **Min** | May 2020 | 112.09 | 109.62 | 104.63 | 92.55 | 83.08 |
| | **$L_{95}$** | May 2020 | 115.75 | 113.38 | 109.19 | 99.68 | 85.14 |
| | **$L_{75}$** | May 2020 | 118.17 | 115.76 | 112.47 | 103.48 | 88.36 |
| | **$L_{50}$** | May 2020 | 119.78 | 117.56 | 114.53 | 106.08 | 92.11 |
| | **$L_{25}$** | May 2020 | 121.98 | 119.72 | 116.89 | 108.97 | 97.42 |
| | **$L_{5}$** | May 2020 | 126.96 | 124.20 | 122.78 | 115.28 | 106.26 |
| | **Max** | May 2020 | 146.61 | 145.88 | 141.71 | 135.77 | 129.34 |
| | **Mean** | May 2020 | 123.15 | 120.78 | 118.50 | 111.53 | 102.63 |

| *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 2020 | 109.92 | 108.50 | 99.65 | 89.75 | 82.85 |
| | **$L_{95}$** | Jun 2020 | 114.78 | 113.17 | 106.11 | 99.12 | 85.41 |
| | **$L_{75}$** | Jun 2020 | 117.36 | 115.54 | 110.30 | 103.84 | 89.40 |
| | **$L_{50}$** | Jun 2020 | 119.14 | 117.20 | 112.60 | 106.97 | 93.18 |
| | **$L_{25}$** | Jun 2020 | 121.23 | 119.01 | 115.62 | 110.17 | 98.23 |
| | **$L_{5}$** | Jun 2020 | 126.81 | 123.89 | 122.28 | 116.13 | 107.26 |
| | **Max** | Jun 2020 | 147.80 | 146.56 | 144.09 | 138.75 | 131.02 |
| | **Mean** | Jun 2020 | 122.74 | 120.48 | 117.64 | 112.08 | 103.45 |
| English Bay | **Min** | Jul 2020 | 108.42 | 105.63 | 98.24 | 86.53 | 82.48 |
| | **$L_{95}$** | Jul 2020 | 113.26 | 111.37 | 106.09 | 94.40 | 83.64 |
| | **$L_{75}$** | Jul 2020 | 116.88 | 114.78 | 110.23 | 99.69 | 86.74 |
| | **$L_{50}$** | Jul 2020 | 119.45 | 117.55 | 112.58 | 103.92 | 90.54 |
| | **$L_{25}$** | Jul 2020 | 121.89 | 120.19 | 115.37 | 108.20 | 96.13 |
| | **$L_{5}$** | Jul 2020 | 126.46 | 124.13 | 122.08 | 115.68 | 106.52 |
| | **Max** | Jul 2020 | 156.38 | 156.36 | 146.56 | 141.30 | 136.99 |
| | **Mean** | Jul 2020 | 123.97 | 122.28 | 117.99 | 111.73 | 104.57 |
| English Bay | **Min** | Aug 2020 | 110.40 | 108.94 | 102.16 | 84.94 | 82.75 |
| | **$L_{95}$** | Aug 2020 | 114.27 | 112.70 | 106.30 | 90.19 | 83.79 |
| | **$L_{75}$** | Aug 2020 | 116.96 | 115.47 | 109.80 | 95.71 | 86.51 |
| | **$L_{50}$** | Aug 2020 | 118.95 | 117.22 | 112.22 | 99.68 | 89.80 |
| | **$L_{25}$** | Aug 2020 | 121.31 | 119.28 | 115.46 | 104.00 | 95.01 |
| | **$L_{5}$** | Aug 2020 | 126.77 | 123.89 | 122.35 | 114.70 | 107.43 |
| | **Max** | Aug 2020 | 145.49 | 141.16 | 143.13 | 138.96 | 143.03 |
| | **Mean** | Aug 2020 | 122.43 | 119.98 | 117.48 | 110.25 | 109.19 |
| English Bay | **Min** | Sep 2020 | 113.10 | 110.84 | 104.32 | 85.29 | 82.32 |
| | **$L_{95}$** | Sep 2020 | 116.58 | 114.63 | 110.71 | 93.58 | 83.88 |
| | **$L_{75}$** | Sep 2020 | 119.79 | 117.94 | 113.82 | 99.66 | 86.94 |
| | **$L_{50}$** | Sep 2020 | 122.20 | 120.20 | 116.43 | 104.35 | 89.92 |
| | **$L_{25}$** | Sep 2020 | 124.78 | 122.71 | 119.53 | 110.80 | 94.94 |
| | **$L_{5}$** | Sep 2020 | 129.10 | 126.62 | 124.83 | 119.39 | 105.58 |
| | **Max** | Sep 2020 | **158.50** | 156.18 | 153.71 | 147.28 | 137.50 |
| | **Mean** | Sep 2020 | 125.77 | 123.55 | 120.94 | 113.82 | 105.13 |
| English Bay | **Min** | Oct 2020 | 112.72 | 111.82 | 103.92 | 86.51 | 82.56 |
| | **$L_{95}$** | Oct 2020 | 117.06 | 115.94 | 108.94 | 92.14 | 83.79 |
| | **$L_{75}$** | Oct 2020 | 119.61 | 118.33 | 112.33 | 97.08 | 86.43 |
| | **$L_{50}$** | Oct 2020 | 121.98 | 120.56 | 114.62 | 101.42 | 89.16 |
| | **$L_{25}$** | Oct 2020 | 124.95 | 123.73 | 117.57 | 106.41 | 93.55 |
| | **$L_{5}$** | Oct 2020 | 131.45 | 130.44 | 124.24 | 115.51 | 103.37 |
| | **Max** | Oct 2020 | 157.20 | 156.85 | 143.71 | 141.45 | 135.77 |
| | **Mean** | Oct 2020 | 126.63 | 125.40 | 119.84 | 111.71 | 104.08 |

| *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 2020 | 112.47 | 111.34 | 103.79 | 85.14 | 82.41 |
| | **$L_{95}$** | Nov 2020 | 117.18 | 115.74 | 109.49 | 93.07 | 83.52 |
| | **$L_{75}$** | Nov 2020 | 119.68 | 118.36 | 112.35 | 97.17 | 86.50 |
| | **$L_{50}$** | Nov 2020 | 121.49 | 120.09 | 114.75 | 100.20 | 90.64 |
| | **$L_{25}$** | Nov 2020 | 123.51 | 122.14 | 117.41 | 103.89 | 95.32 |
| | **$L_{5}$** | Nov 2020 | 128.63 | 126.49 | 123.86 | 113.15 | 103.57 |
| | **Max** | Nov 2020 | 153.99 | 153.87 | 148.19 | 142.08 | 139.99 |
| | **Mean** | Nov 2020 | 125.44 | 123.71 | 119.80 | 112.05 | 105.92 |
| English Bay | **Min** | Dec 2020 | 94.93 | 92.12 | 89.16 | **78.96** | 82.13 |
| | **$L_{95}$** | Dec 2020 | 117.72 | 116.46 | 108.12 | 89.37 | 82.89 |
| | **$L_{75}$** | Dec 2020 | 120.49 | 119.15 | 113.22 | 99.53 | 84.29 |
| | **$L_{50}$** | Dec 2020 | 123.32 | 121.83 | 115.61 | 102.82 | 87.13 |
| | **$L_{25}$** | Dec 2020 | 126.31 | 125.15 | 118.66 | 106.49 | 91.31 |
| | **$L_{5}$** | Dec 2020 | 130.29 | 128.57 | 124.44 | 114.51 | 102.64 |
| | **Max** | Dec 2020 | 145.44 | 144.67 | 139.96 | 133.14 | 128.19 |
| | **Mean** | Dec 2020 | 126.01 | 124.70 | 119.57 | 109.99 | 101.88 |
| English Bay | **Min** | Jan 2021 | 108.94 | 108.12 | 98.47 | 88.01 | 82.38 |
| | **$L_{95}$** | Jan 2021 | 114.82 | 113.25 | 107.99 | 96.79 | 84.61 |
| | **$L_{75}$** | Jan 2021 | 117.85 | 115.87 | 111.58 | 102.21 | 88.75 |
| | **$L_{50}$** | Jan 2021 | 119.88 | 118.02 | 113.73 | 105.80 | 92.29 |
| | **$L_{25}$** | Jan 2021 | 122.18 | 120.26 | 116.24 | 109.64 | 96.28 |
| | **$L_{5}$** | Jan 2021 | 127.16 | 124.93 | 121.98 | 115.30 | 104.63 |
| | **Max** | Jan 2021 | 151.85 | 151.27 | 145.70 | 141.95 | 133.95 |
| | **Mean** | Jan 2021 | 124.39 | 122.41 | 118.98 | 112.97 | 104.14 |
| English Bay | **Min** | Feb 2021 | 109.90 | 108.30 | 102.76 | 87.55 | 82.50 |
| | **$L_{95}$** | Feb 2021 | 113.93 | 112.59 | 106.66 | 93.23 | 83.63 |
| | **$L_{75}$** | Feb 2021 | 117.53 | 116.28 | 109.97 | 96.92 | 85.88 |
| | **$L_{50}$** | Feb 2021 | 119.78 | 118.47 | 112.10 | 100.12 | 89.54 |
| | **$L_{25}$** | Feb 2021 | 121.88 | 120.52 | 115.30 | 104.99 | 94.35 |
| | **$L_{5}$** | Feb 2021 | 126.30 | 124.52 | 120.43 | 111.68 | 103.20 |
| | **Max** | Feb 2021 | 151.69 | 151.61 | 144.07 | 138.80 | 129.81 |
| | **Mean** | Feb 2021 | 124.28 | 122.93 | 117.86 | 109.86 | 101.73 |