Underwater Noise Assessment

Phase II Monitoring and Reporting - Quarterly Report

Port of Seattle

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Revision Record

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Executive Summary

The Port of Seattle (Port) has begun implementing an Underwater Noise Assessment Program to begin to characterize the regional soundscape in the waters surrounding, and on approach to, its operational area in Elliott Bay. The program's overall goal is to understand and reduce noise impacts on marine species while supporting sustainable maritime operations as part of the Port's Underwater Noise Mitigation and Management Plan (UNMMP). The Underwater Noise Assessment Program aims to build an acoustic database and establish a baseline understanding of the underwater noise soundscape, which can be used to set realistic, measurable reduction targets. The data to support the program goals will be collected over a two-year monitoring period via hydrophones at two separate but complementary offshore locations near Jack Block Park and the Seattle Aquarium Pier 59.

The hydrophones were deployed mid July 2025. This quarterly report summarizes the findings and contributions to the ambient noise level from the two monitoring stations referenced as SJBL-01 (Jack Block Park) and SAQU-01 (Seattle Aquarium) since deployment. All monitoring data is reported on a monthly basis to provide a consistent format for review and comparison. August represents the first full month of recorded data included in this report.

Key Observations for this reporting period are as follows:

- **Ambient Noise Levels**
  - SAQU-01 recorded consistently higher broadband noise (median ~130 dB re 1 µPa) than SJBL-01 (~120 dB re 1 µPa).
  - Low-frequency bands (10–1000 Hz) dominated both sites, driven by vessel traffic and propeller cavitation.
  - High-frequency spikes (>10,000 Hz) occurred intermittently, linked to SONAR/echosounder use.
- **Temporal Patterns**
  - Noise peaked during daytime (5 AM–10 PM) and Fridays, correlating with vessel schedules.
  - SAQU-01 exhibited a louder, more uniform soundscape; SJBL-01 was quieter but more variable.
- **Marine Mammal Detections**
  - Automated detectors logged Harbor Seal, California Sea Lion, and Killer Whale vocalizations.
  - These detections may indicate species presence but require validation for definitive presence and behavioral interpretation.
- **Environmental**
  - Environmental noise was minimal during this reporting period and is not included in this quarter's report. Weather conditions were mild and clear, resulting in negligible environmental noise contribution.

- **AIS Vessel Traffic**
    - SAQU-01 detected 404 unique vessels and SJBL-01 detected 256 unique vessels. There was essentially continuous AIS-equipped vessel presence in the area of each monitoring location during the duration of the survey.
    - Passenger vessel schedules strongly influenced diurnal noise trends.
- **Anthropogenic Sources**
    - Propeller cavitation and active SONAR/echosounder systems were confirmed as major contributors to variability.

Overall, Elliott Bay's underwater soundscape shows spatial and temporal variability, with the station near Seattle Aquarium representing a consistently louder environment. These conditions may influence marine mammal exposure and behavior, underscoring the need for continued monitoring and potential mitigation strategies.

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Acronyms and Abbreviations

μPa	micro-Pascal
AIS	Automatic Identification System
ANSI	American National Standards Institute
CPA	closest point of approach
dB	decibel
Hz	Hertz
HF	High Frequency
ISO	International Organization for Standardization
LF	Low frequency
LTSA	Long-Term Spectral Average
MF	Medium Frequency
ms	milliseconds
s	seconds
SAQU-01	SLR Seattle Aquarium
SJBL-01	SLR Jack Block Park site
SLR	SLR International Corporation
SPD	Spectral Probability Density
SPL	Sound Pressure Level

1.0 Introduction

SLR Consulting was contracted by the Port of Seattle to monitor and collect underwater noise data within Elliott Bay and prepare quarterly reports as part of the Port of Seattle's (Port's) Underwater Noise Assessment Program. This program supports the Port's commitment to environmental stewardship and its goal of advancing its Green Marine certification by evaluating underwater noise levels associated with Port operations and identifying opportunities to reduce impacts on marine species.

Underwater noise monitoring is conducted using two cabled underwater monitoring stations (SJBL-01 and SAQU-01), which have been operational since July 16, 2025 (see Figure 1). Each station is equipped with a calibrated smart hydrophone, the icListen model SJ9-ETH, from Ocean Sonics, and records at a sampling frequency of 128,000 Hz. The stations are located offshore of Jack Block Park and the Seattle Aquarium (see Table 1).

Table 1: Underwater monitoring station, hydrophone, location, and water depth

Station	Hydrophone	Serial Number	Location Site	Latitude (N)	Longitude (W)	Water Depth (feet)
SJBL-01	icListen SJ9-ETH	6976	Jack Block Park	47°35’09.2”	122°22’06.2”	~65
SAQU-01	icListen SJ9-ETH	6977	Seattle Aquarium	47°36’25.8”	122°20’38.5”	~65

This report summarizes the data for August 2025, the first full month of recorded data since the system's deployment. This first quarterly report represents the initial dataset for this study and includes a very limited sample size for analysis. Any findings or conclusions in this document should be considered in that context. Future quarterly reports will include up to four months of validated monthly data, providing a clear and consistent format for review and facilitating easier comparisons. Due to the necessary processing and validation steps that follow data collection, there is a lag between data collection, processing, and reporting.

Environmental noise, noise due to rain and wave action, was minimal during this period and is not included in this report, as weather conditions were mild and clear. This approach will be adjusted as the program evolves, and more data becomes available for analysis.

1.1 Methodology

The methodology outlines how underwater noise data were collected, processed, and analyzed to ensure consistency with international standards. It describes the acoustic metrics applied, including sound pressure level calculations, and explains the classification of frequency bands used to interpret the soundscape. The section also details the formats used for presenting results and specifies how Automatic Identification System (AIS) vessel data and marine mammal detections were integrated into the analysis. Together, these methods provide a structured framework for evaluating underwater noise and its potential ecological implications.

Figure 1: Hydrophone Station Deployment Locations

1.2 Report Schedule

The analysis was conducted over a calendar month period for August 2025. Table 2 lists the report schedule for the monitoring period analyzed in this report.

Table 2: Report schedule for the recording period analyzed

Month start	Month end	Weeks reported
1 August 2025 00:00 UTC	1 September 2025 00:00 UTC	Sun 3 Aug to Sat 9 Aug Sun 10 Aug to Sat 16 Aug Sun 17 Aug to Sat 23 Aug Sun 24 Aug to Sat 30 Aug

2.0 Ambient Noise

Underwater noise measurements during the monitoring period reveal patterns across frequency bands and time. The analysis focuses on sound pressure levels at both monitoring stations, identifying dominant sources such as vessel traffic and propeller cavitation, and highlighting variations by day and hour. These observations establish the baseline soundscape for Elliott Bay.

2.1 Jack Block Park

The SPL box plot for the monitoring period shows distinct patterns across frequency bands (see Figure B-1 and Table B-1). Lower and upper Low-frequency (LF) decade bands exhibited the highest variability, with median SPLs of approximately 108 dB and 118 dB, respectively. The lower LF decade band displayed the widest range, extending from 91 dB to above 135 dB, consistent with contributions from vessel traffic and other anthropogenic sources. Mid-frequency (MF) and high-frequency (HF) decade bands were generally quieter, with medians ranging from 112 to 113 dB, although sporadic outliers exceeded 130 dB. The broadband noise level was highest overall, with a median of nearly 120 dB.

The spectral probability density plot for the monitoring period (see Figure B-2) indicates that an average noise level (L_{eq}) starts at approximately 80 dB at 10 Hz, reaches around 90 dB between 200 and 400 Hz, and gradually declines with increasing frequency. The L_{50} (median) curve follows a similar trend, indicating that LF noise dominates the soundscape, likely due to vessel traffic and other anthropogenic sources. At MF and HF decade bands, noise levels decrease substantially. However, L_5 (upper percentile) and a notable peak at 20 kHz suggest intermittent high noise level events, consistent with the operation of HF active systems (such as SONARs/echosounders) during the analysis period. The probability density shading confirms that most acoustic energy is concentrated in the LF decade band, with sporadic samples exceeding the 120 dB noise level.

The weekly LTSA plots (see Figures B-3 to B-6) illustrate temporal and spectral variations in underwater sound levels over the four weeks of the monitoring period, spanning the frequency range of 10 Hz to 64,000 Hz. Over all weeks, the lower and upper LF decade bands remain consistently high, with noise levels frequently reaching 100 dB, reflecting persistent contributions from vessel traffic and other anthropogenic sources. Distinct vertical decade bands of elevated noise levels appear regularly, indicating repeated transient events such as passing ships. Periodically, vertical noise bands with lower noise levels are consistent with nighttime. At the HF decade band, most periods exhibit relatively lower noise levels; however, intermittent spikes and tonal features are evident, particularly during the first and third weeks, indicating the operation of SONAR/echosounder systems. These tonal signals appear as narrowband, high-intensity lines extending across time, consistent with active acoustic sources. Overall, the spectrograms confirm a soundscape dominated by LF noise with episodic HF activity.

Radial charts for the weekly (7-day) monitoring period (see Figure B-7) show clear temporal patterns in underwater noise levels across frequency bands. Day-of-week trends indicate that LF decade bands peak on Fridays, with average levels ranging from 110 to 119 dB, consistent with increased vessel activity on Fridays. The MF decade band has two peak days, Wednesday and Friday, with average noise levels of 113 dB. The HF decade band also exhibits significant increases on Friday, with average noise levels of 115 dB, suggesting intermittent use of SONAR. Overall, broadband noise levels can reach up to 121 dB on Fridays.

Hourly patterns (see Figure B-8) reveal that broadband noise is highest during daytime hours (5 AM–10 PM). LF decade bands tend to exhibit daytime spikes at 3 PM. Meanwhile, MF and HF decade bands exhibit occasional daytime spikes, further supporting the presence of active acoustic sources. Nighttime noise levels remain lower across all frequency decade bands, indicating a reduction in anthropogenic activity. These patterns confirm a soundscape dominated by daytime vessel traffic, with episodic HF decade band activity linked to SONAR operations.

2.2 Seattle Aquarium

Underwater noise levels recorded during August 2025 at SAQU-01 show that the LF decade bands exhibited the highest median SPL, approximately between 126 and 127 dB (see Figure B-9 and Table B-2). The lower LF decade-band showed the greatest variability, with values ranging from approximately 101 dB to nearly 147 dB. The upper LF band also exhibited high levels, with several outliers exceeding 140 dB. The MF and HF decade bands were quieter, with a median level of around 118 dB; however, numerous outliers exceeded 140 dB, and some in the HF decade band reached nearly 150 dB, indicating intermittent high-level events. The broadband noise level had a median of approximately 130 dB, reflecting substantial acoustic energy across the spectrum. The presence of multiple high-frequency outliers suggests that one or more high-frequency SONAR systems were active during the analysis period, contributing to variability in the HF decade band.

The spectral probability density plot for the entire monitoring period at SAQU-01 (see Figure B-10) indicates that the average spectrum (L_{eq}) starts at approximately 95 dB at 10 Hz, increases to over 100 dB between 50 and 100 Hz, with multiple outliers exceeding 120 dB along the LF decade band. L_{eq} tends to decrease gradually with increasing frequency; however, numerous sharp peaks, influenced by the L_{95} percentile, are observed in the MF decade band, suggesting the constant presence of intermittent or tonal sources of underwater noise during the August 2025 monitoring period. These tonal sources, between 1000–5000 Hz, may indicate vessel machinery tones or communication signals. These sources are not constant but occur frequently enough to influence the 95th percentile. The occasional high peak of the L_5 percentile at 20,000 Hz is consistent with survey operations or vessel transits using SONAR/echosounders.

The weekly LTSA plots (Figures B-11 to B-14) at Site SAQU-01 show that LF noise levels remain consistently high, with levels frequently reaching 110 dB, indicating persistent vessel traffic and other anthropogenic sources. Regular vertical bands of high noise level that appear throughout the system represent repeated transient events such as passing ships. Periodically, vertical bands with lower noise levels are consistent with nighttime. Above 10,000 Hz, the LTSA plots show relatively low energy; however, narrowband, distinct tonal signals at 20,000 Hz, which can last several hours and repeat once or twice a week, are consistent with active HF SONAR/echosounders used by commercial and recreational vessels. Overall, the LTSA confirms a louder soundscape than the one found at SJBL-01.

Radial charts for site SAQU-01 (Figure B-16) reveal clear temporal trends in underwater noise levels across frequency bands. Day-of-week patterns indicate that Friday is the noisiest day in the upper LF, MF, and HF decade bands, with peak levels ranging from 119 to 125 dB. The LF decade band peaks on Tuesday, reaching a level of 124 dB. Notable peaks are observed in the broadband on Fridays and Mondays; coincidentally, intermittent SONAR/echo sounder activity was detected twice, on Mondays and Fridays, during the August 2025 monitoring period.

Hourly patterns at site SAQU-01 (Figure B-17) reveal that the maximum broadband noise (>128 dB) peaks during the day and early evening (5 AM–10 PM). In contrast, the HF decade band exhibits peak noise levels (>123 dB) only during the day and within a shorter timeframe (5:00 AM-10:00 PM), further supporting the presence of active noise sources in the early morning (around 5:00 AM). Nighttime levels remain lower across all decade-bands, indicating a reduction in anthropogenic activity.

3.0 Marine Mammal Detections

Acoustic monitoring detected vocalizations from harbor seals, killer whales, and California sea lions. The data provides insight into species presence and activity patterns within the study area, supporting efforts to understand how marine mammals interact with underwater noise.

3.1 Detection Algorithm

An automated Whistle and Moan detector developed by PAMGuard (Gillespie et al, 2013) was used to detect any tonal vocalization from pinniped moans and odontocete whistles such as Harbor Seal (*Phoca vitulina*), California Sea Lion (*Zalophus californianus*), and Killer Whale (*Orcinus orca*).

Detection is a multi-stage process, the main steps being:

1. Computation of a spectrogram from raw audio data
2. Processing of the spectrogram to remove noise (especially clicks)
3. Thresholding to create a binary map of regions above the threshold
4. Connecting regions of the binary map to create sounds
5. Breaking and then rejoining branches of complex regions (for instance, if two whistles cross).

Table 3 shows the main settings of the Whistle and Moan detector PAMGuard algorithm used to detect the tonal sounds encountered during the monitoring period.

Table 3: Whistle & Moan Detector Settings

Marine Mammal Species	Sample Rate (Hz)	FFT Length	Frequency Resolution (Hz)	Time Resolution (ms)	Minimum Tonal Duration (s)	Bandpass Filter (Hz)
Harbor Seal	4000	4096	0.98	1024	≥0.5	250-2000
California Sea Lion	8000	2048	3.91	256	0.2 – 0.5	500-4000
Killer Whale	64,000	2048	31.25	32	0.3 – 0.5	1000–20,000
FFT length refers to the number of points used in the Fast Fourier Transform (FFT) when converting a time-domain signal into its frequency-domain representation.						

3.2 Relative Vocalization Detections by Species

The acoustic data were processed to detect the tonal sounds of marine fauna. This section presents the results of data collected from 1 to 31 August 2025. The total number of vocalizations is subject to review and quality control due to high levels of vessel noise and low signal-to-noise (SNR) ratio. These detections may represent the presence of the species during this monitoring period.

3.2.1 Harbor Seal

Harbor Seal vocalizations were detected from the automated detectors at SJBL-01 and SAQU-01 from 1 to 31 August 2025. Figure 2 shows the proportion of detections by species for this period.

3.2.2 California Sea Lion

California Sea Lion vocalizations were detected from the automated detectors at SJBL-01 and SAQU-01 from 1 to 31 August 2025. Figure 3 shows the proportion of detections by species for this period.

3.2.3 Killer Whale

Killer whale vocalizations were detected from the automated detectors at SJBL-01 and SAQU-01 from 1 to 31 August 2025. Figure 4 shows the proportion of detections by species for this period.

3.2.4 Relative Vocalization Detections by Species

Figure 5 shows the proportion of detected vocalizations by an automated Whistle and Moan detector algorithm during the monitoring period of August 2025 at each station. The chart is divided into three categories:

- Harbor Seal (blue): represents the largest proportion at 62.8% (SJBL-01) and 69.6% (SAQU-01), indicating that most of the vocalizations detected were from Harbor seals.
- California Sea Lion (red): Makes up 37.2% (SJBL-01) and 29.8% (SAQU-01), reflecting a small contribution compared to the other species.
- Killer Whale (green): Accounts for 0% (SJBL-01) and 0.6% (SAQU-01), showing a low likelihood presence of killer whale vocalizations. These detections coincide with the 20,000 Hz tone of the echosounder, which masks the most automatic detections and makes it difficult to validate, as shown in Figure 4.

Figure 2: Count detections of Harbor Seal calls at SJBL-01 (top) and SAQU-01 (bottom)

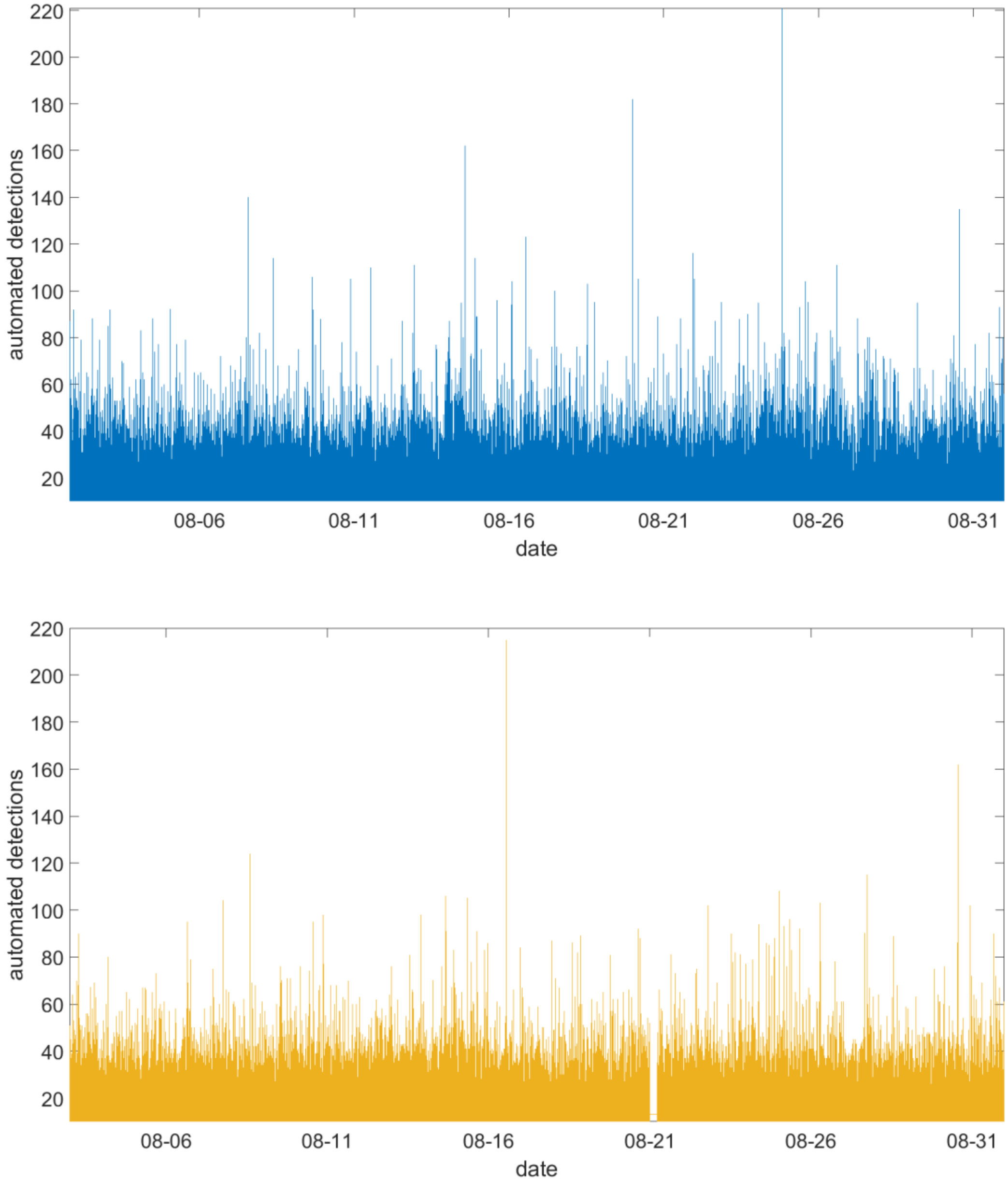
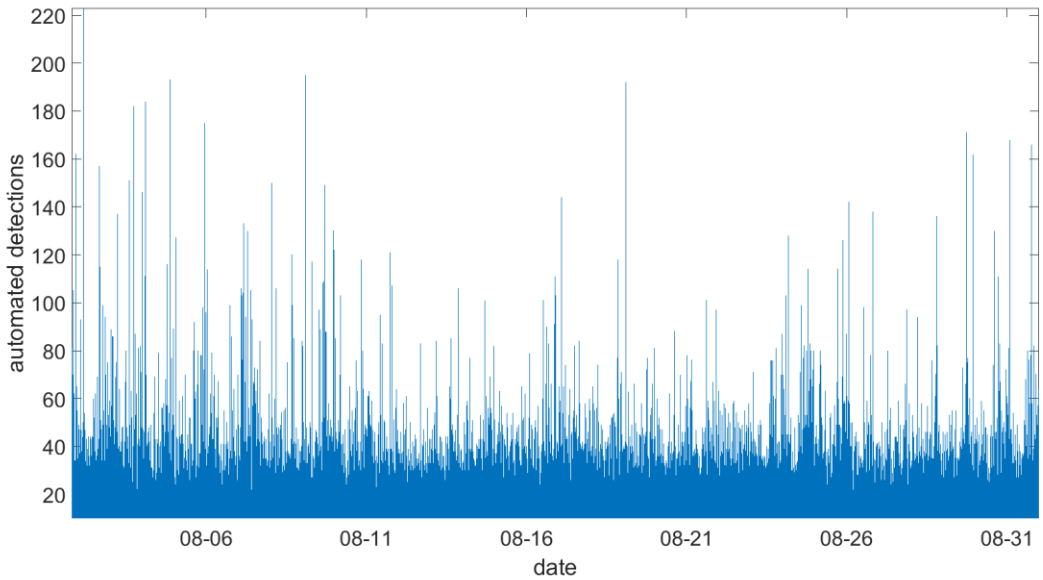


Figure 3: Count detections of C. Sea Lion calls at SJBL-01 (top) and SAQU-01 (bottom)



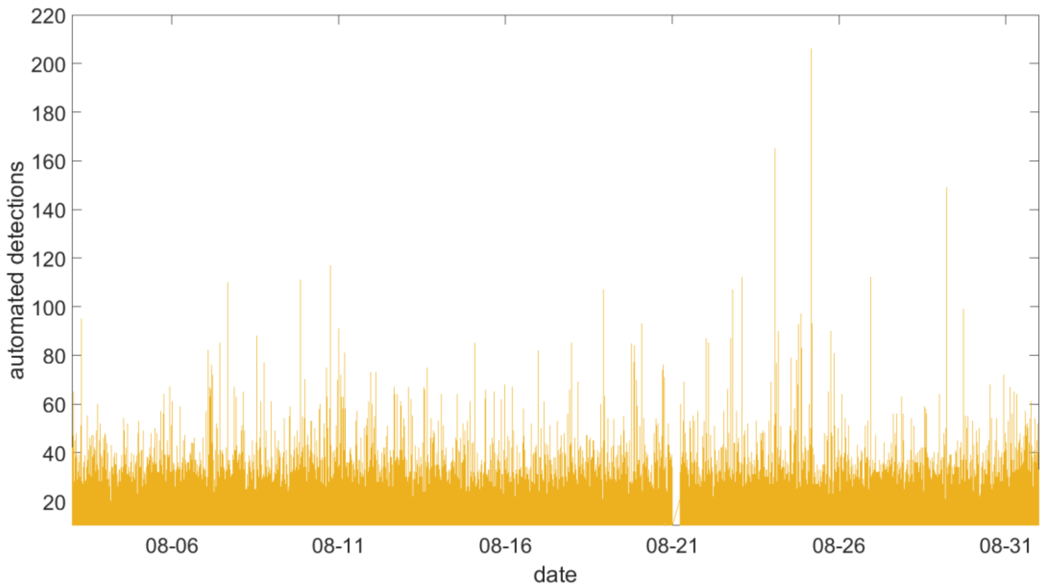


Figure 4: Count detections of Killer Whale calls at SAQU-01 (top) and spectrogram view (bottom) at 00:33 hrs – UTC time, Aug 4

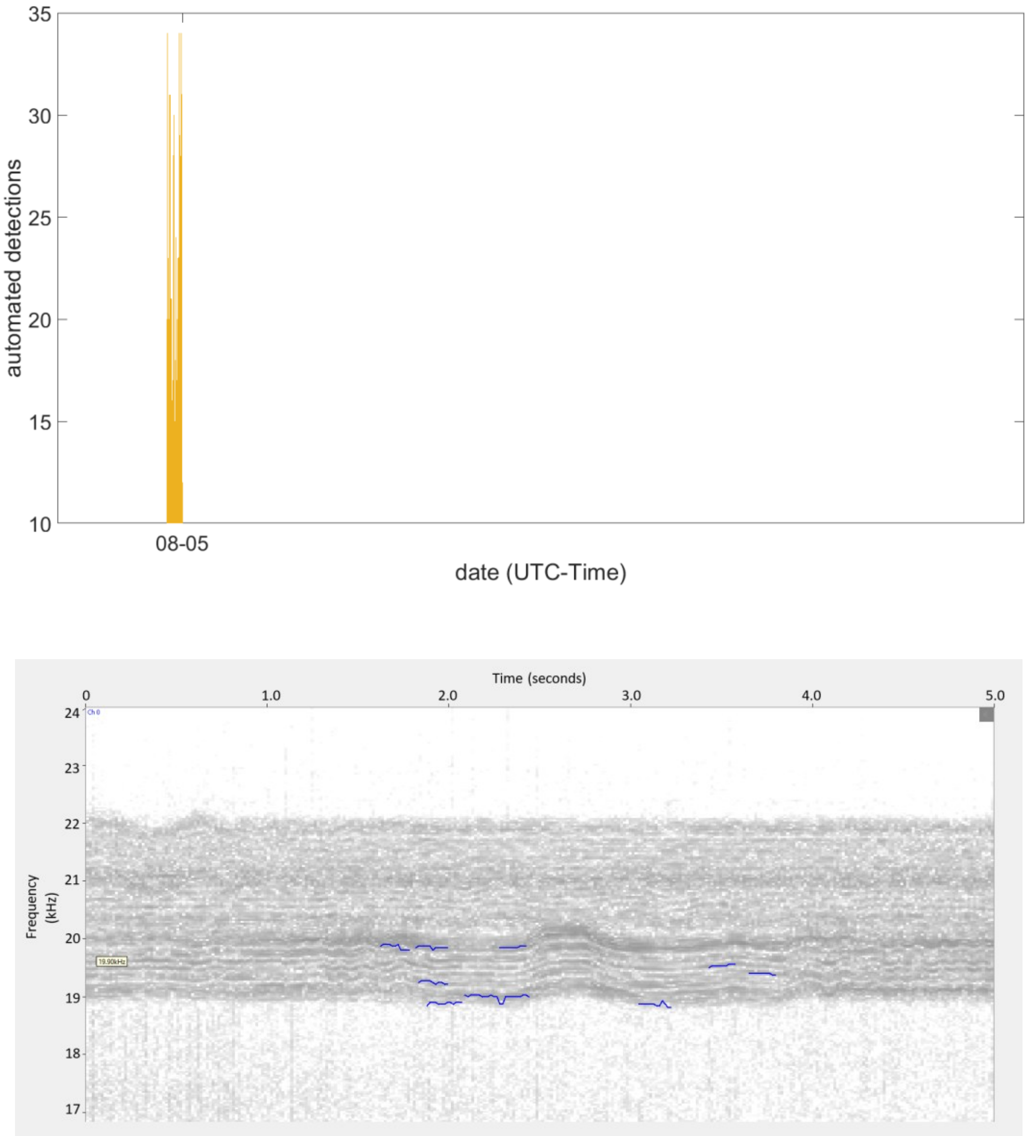
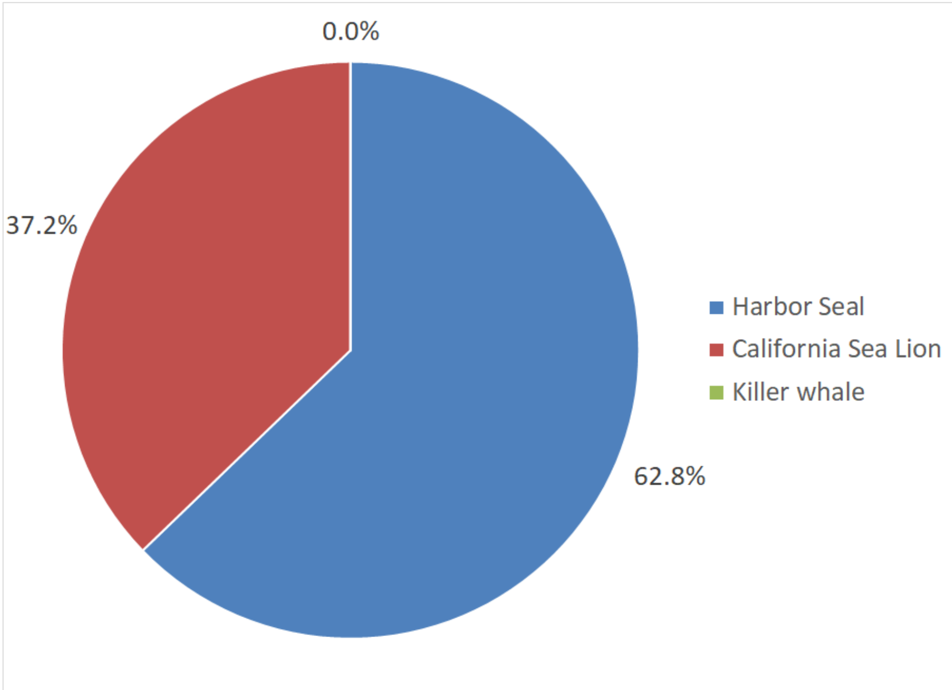
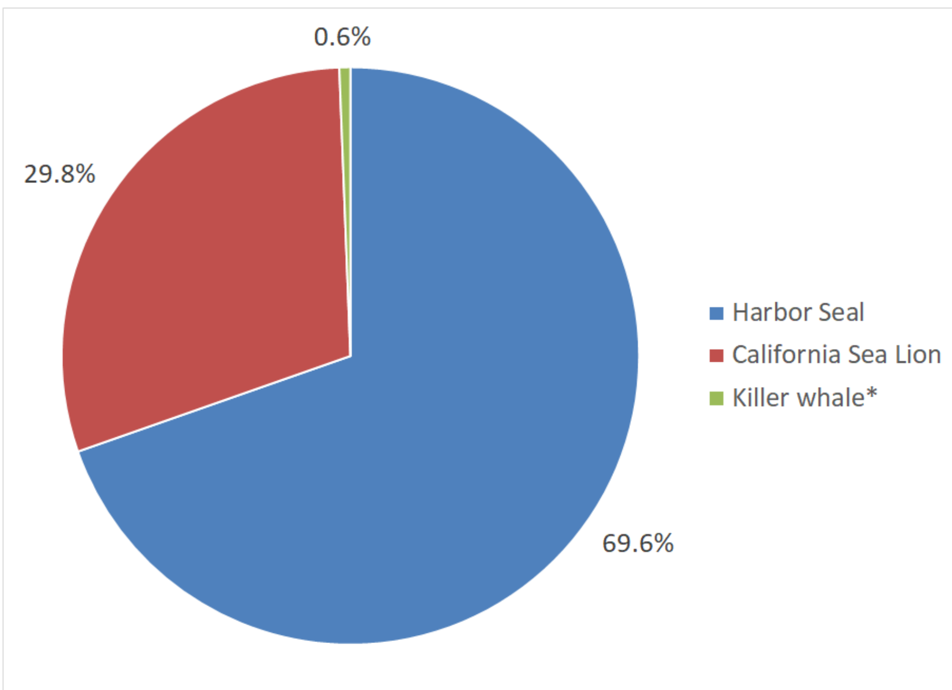


Figure 5: Relative vocalization detections by species during the entire monitoring period SJBL-01 (top) and SAQU-01[1] (bottom)





[1] The vocalization detection of Killer whale coincides with the echosounder and may not reflect actual presence of killer whales (see Figure 4).

4.0 Environmental

Environmental noise was minimal during this reporting period and is not included in this quarter's report. Weather conditions were mild and clear, resulting in negligible environmental noise contribution.

5.0 AIS Data Analysis

AIS tracking data offers a detailed view of vessel traffic near the monitoring stations. The analysis includes vessel counts, classifications, and temporal trends, linking vessel activity to observed acoustic patterns and identifying key contributors to underwater noise.

AIS data was collected across two zones (see Figure 6), one centered on Jack Block Park (SJBL-01) and the other on the Seattle Aquarium (SAQU-01), every 15 seconds across the monitoring period. Quantitative vessel presence (and subsequent variation over time) within each zone was determined using a 5-minute moving average and classification by vessel class (e.g. Passenger). Both underwater monitoring stations show a persistent presence of vessels equipped with AIS transponders (see Figure 7).

Figure 8 shows only vessels classified as Passenger by AIS data, with a distinct daily schedule visible most clearly at SJBL-01 and attributed to local ferry traffic (and associated operational hours). This trend is also visible at SAQU-01; however, multiple routes and schedules likely overlap and intersect throughout the operational day.

A breakdown of unique vessels detected during the monitoring period by vessel class is shown in Table 4. SAQU-01 detected over 400 unique vessels, while approximately 250 were detected in the vicinity of SJBL-01.

Figure 6: AIS Data Collection Zones

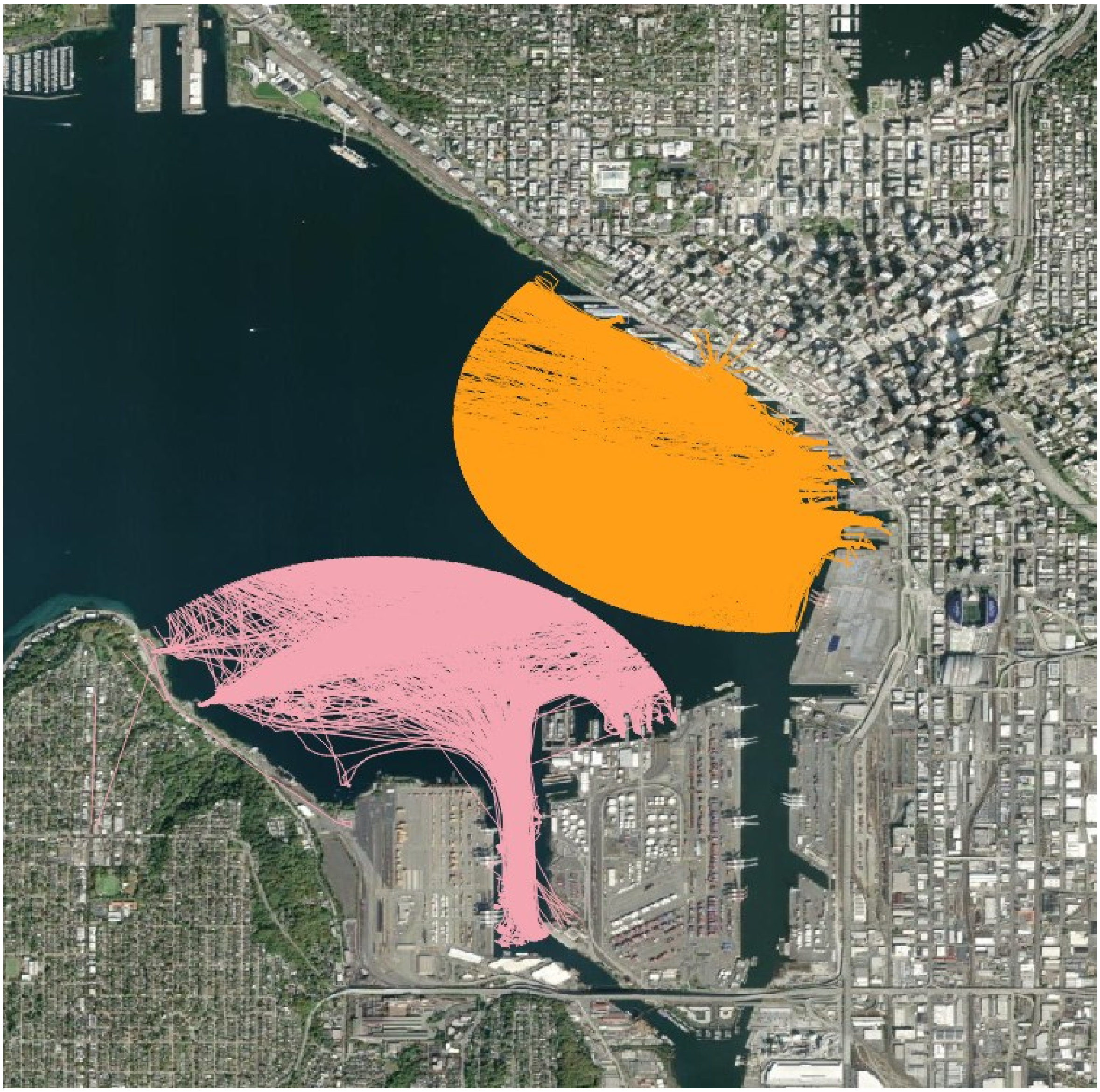
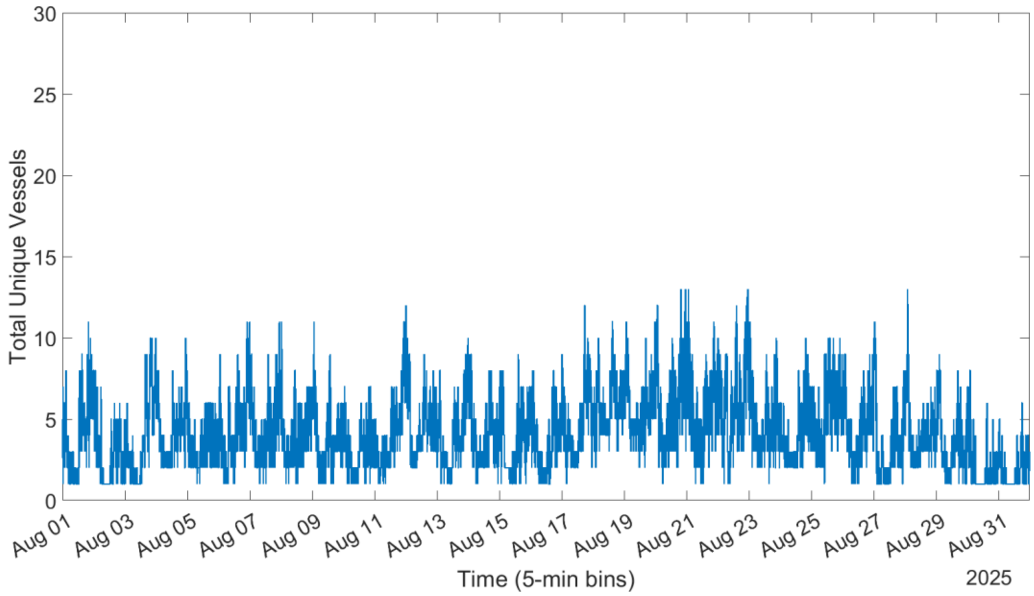


Figure 7: AIS Overall Vessel Presence at SJBL-01 (top) and SAQU-01 (bottom)



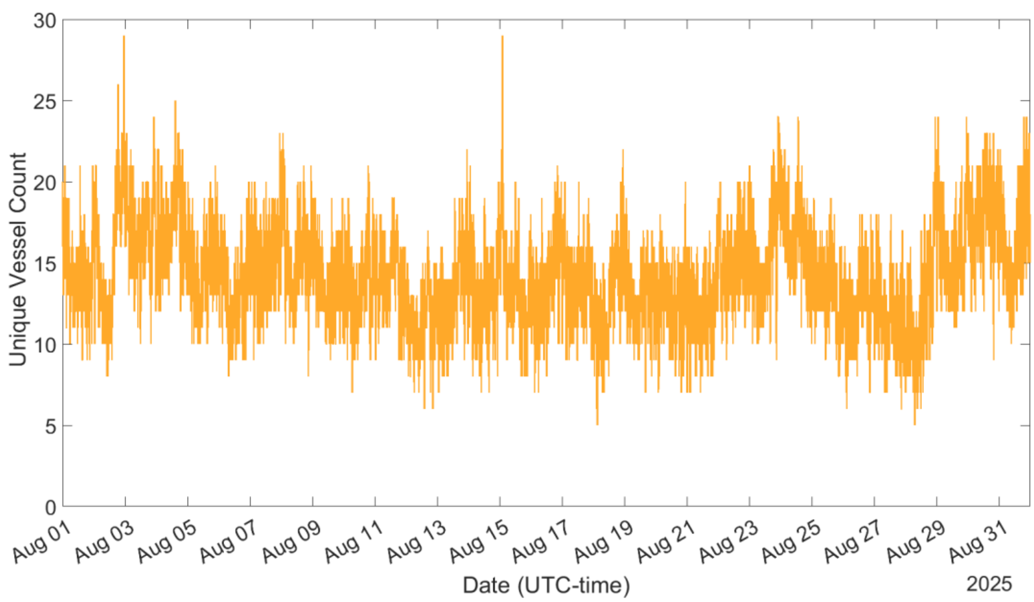


Figure 8: AIS Passenger Vessel Presence at SJBL-01 (top) and SAQU-01 (bottom)

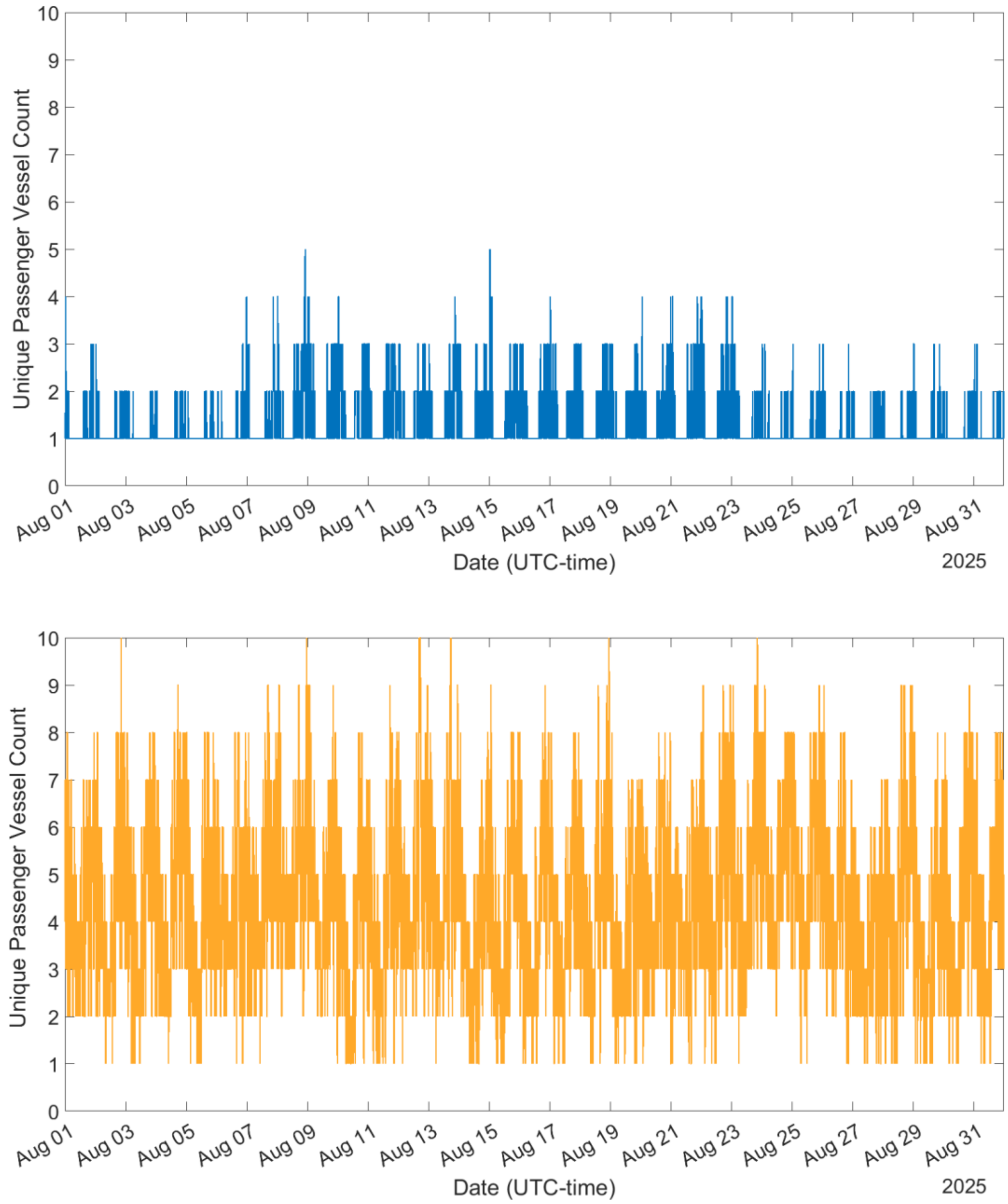


Table 4: AIS Unique Vessel Detections by Class (August 2025)

Vessel Class	Unique Detections (SJBL-01)	Unique Detections (SAQU-01)
Tug/Towing vessel	84	36
Cargo ship	21	30
Tanker	1	0
Passenger ship	18	24
Pleasure craft	16	60
Fishing vessel	5	2
High-speed craft	5	7
Sailing vessel	5	17
Search and Rescue	5	8
Pilot vessel	2	1
Port tender	1	1
Law enforcement vessel	1	1
Unknown/Undefined	92	217
Total	**256**	**404**

6.0 Other Anthropogenic Noise Sources

Beyond vessel traffic, additional human activities influence underwater sound levels. Propeller cavitation and active SONAR or echosounder systems were identified as significant contributors, with acoustic signatures that vary in frequency and intensity.

6.1 Propeller Cavitation from a Vessel

The spectrogram in Figure 9 captures a vessel pass-by event characterized by strong low-frequency tonal noise (engine/propeller) and broadband energy, with clear Doppler effects and peak intensity at the closest point of approach (CPA).

- Left Panel (10–1000 Hz): This grayscale spectrogram highlights low-frequency components typical of vessel noise. The horizontal bright line around 500 Hz suggests a dominant tonal component, likely from the vessel's engine or propeller. The diagonal streaks radiating outward indicate Doppler shifts as the vessel approaches and then moves away, consistent with a pass-by or transit event.
- Right Panel (1000–40,000 Hz): This color spectrogram (blue-green-yellow scale) emphasizes higher-frequency content. Most energy is concentrated below 10,000 Hz, with a bright region near the center of the time axis, marking the CPA. The green/yellow intensity at low frequencies confirms the presence of strong tonal and broadband noise during CPA, while the fading blue areas before and afterwards indicate reduced energy as the vessel moves away.

6.2 Active SONAR/Echosounder

The spectrogram in Figure 10 captures a high-frequency active SONAR/echosounder signal at approximately 20 kHz, characterized by a strong, stable tonal component and possible harmonics, consistent with continuous or pulsed operation of an ultrasonic acoustic source.

- Upper Panel (Spectrogram): A strong, continuous horizontal band is visible around 20 kHz, highlighted in green/yellow, indicating a persistent tonal signal from the SONAR/echosounder. This is typical of active acoustic systems and ultrasonic systems transmitting at a fixed frequency. Additional weaker bands above and below suggest harmonics or sideband energy. The color intensity (green/yellow) reflects high sound pressure levels compared to the surrounding blue background noise.
- Lower Panel (FFT Plot): The frequency-domain representation confirms a dominant peak centered near 20 kHz, with noticeable amplitude variations over time. Smaller peaks may correspond to harmonics or other system-related tones.

Figure 9: Acoustic signature of a vessel passing over SJBL-01 (00:30 hrs – UTC time, Aug 1) with LF-10-1000 Hz (top) and HF-1000-40,000 Hz (bottom) depicted

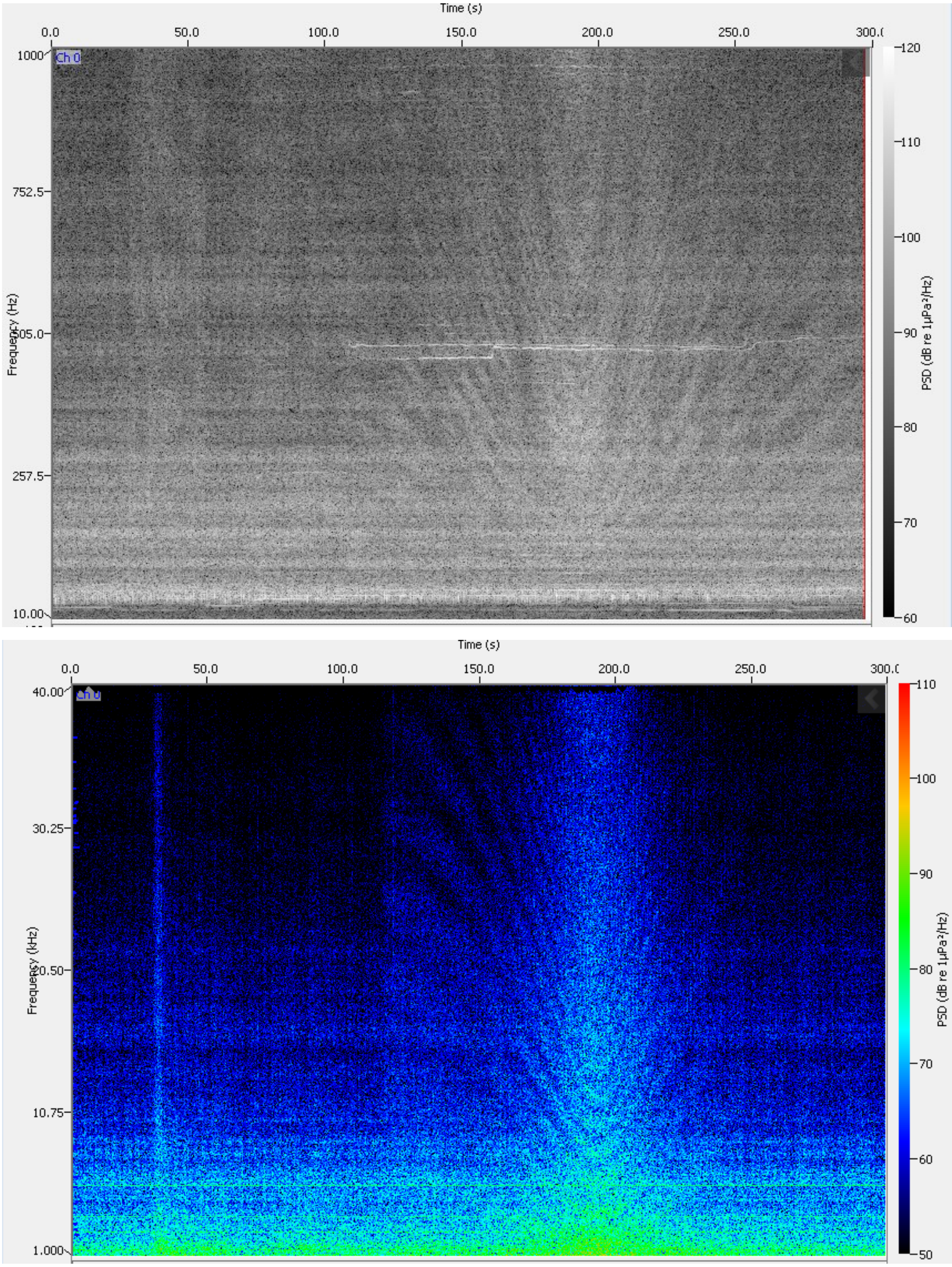
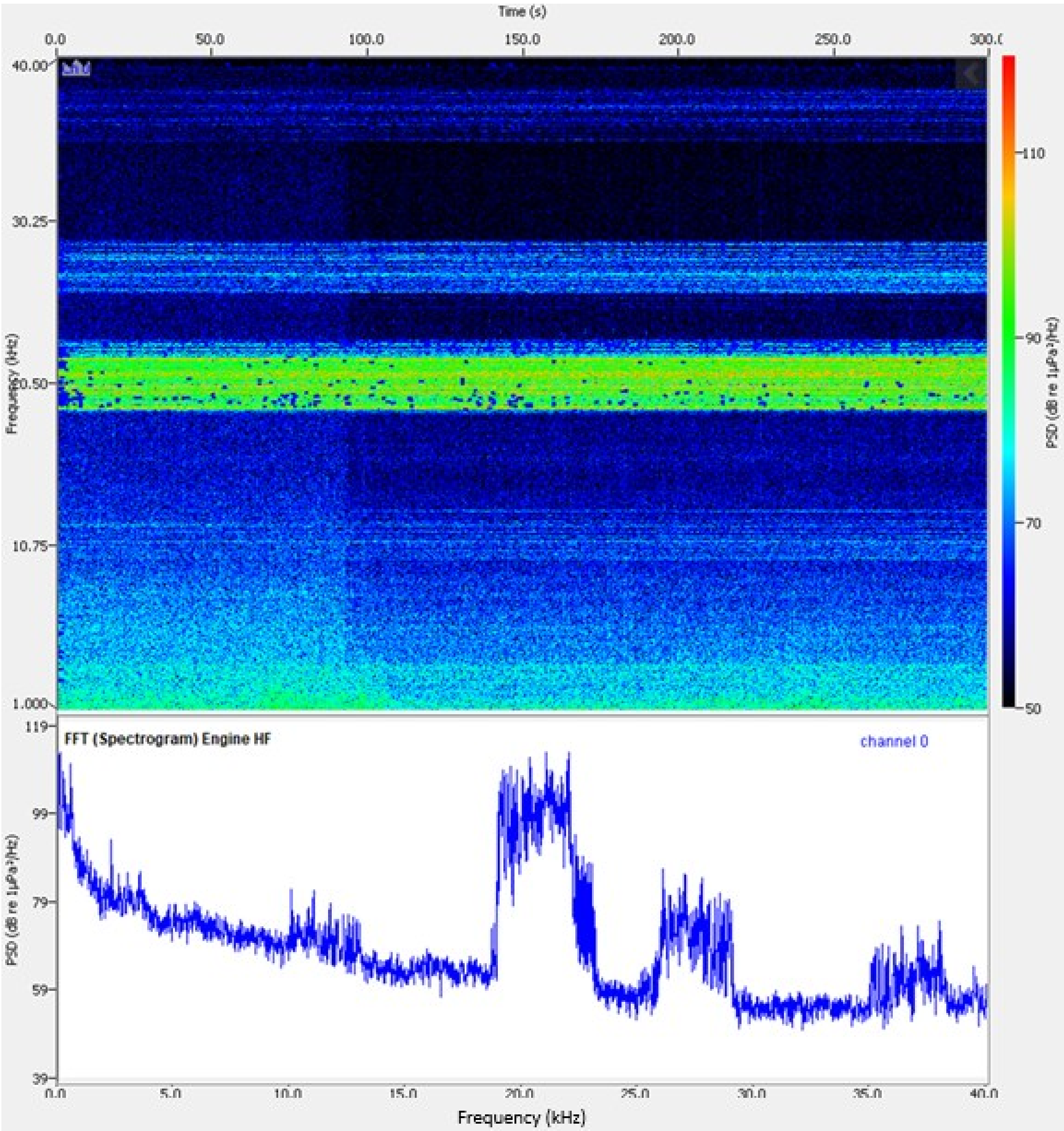


Figure 10: Acoustic signature of active SONAR/echosounder (20 kHz) detected by SAQU-01 (13:00 hrs – UTC time, Aug 4) with spectrogram (top) and PSD-(bottom)



7.0 Discussion

Overall ambient noise levels typically range from as low as 80 dB re 1 µPa for the LF and MF bands (10-10,000 Hz) in areas with little ship movement and calm sea surface conditions, to as high as 120 dB re 1 µPa for the LF and MF bands (10-10,000 Hz) in areas with moderate to heavy remote maritime traffic and medium to strong wind conditions (Wenz 1962).

A comparison of ambient noise between SJBL-01 and SAQU-01 during August 2025 reveals notable differences in both magnitude and variability. SAQU-01 consistently recorded higher noise levels across all frequency bands, with the LF band (10–100 Hz) showing the largest difference of 10–20 dB. This suggests that greater contributions from vessel traffic and propeller cavitation occur near SAQU-01.

Broadband noise was also elevated at SAQU-01, with a median level of 129.9 dB, compared to 120.0 dB at SJBL-01. Peak sound pressure levels were high at both sites, but SAQU-01 reached 146 dB, slightly higher than SJBL-01, indicating stronger anthropogenic influences near SAQU-01.

Despite higher overall levels, SAQU-01 exhibited lower variability, particularly in the MF and HF brands, suggesting a more stable and predictable noise environment. In contrast, SJBL-01 showed greater fluctuations, likely due to intermittent sources such as passing ships or episodic SONAR operations. Spectral patterns further highlight these differences. SAQU-01 displayed a smooth decline from around 100 Hz upward, creating a relatively uniform soundscape. SJBL-01, however, showed pronounced dips and peaks between 20–200 Hz and again around 1–10 kHz, indicating a more dynamic and variable acoustic environment. In summary, SAQU-01 represents consistently louder and more uniform soundscape, while SJBL-01 is quieter but more variable.

AIS transponder data is used to correlate vessel presence with changes in underwater noise levels and is collected within the vicinity of each hydrophone. This data also provides insight into the class distribution of local vessel traffic (e.g., Passenger, Tanker, Cargo, Fishing), the number of unique vessels, and operational parameters such as vessel speed and overall length, which previous studies have shown to influence underwater radiated noise levels.

The presence of vessels equipped with AIS transponders is nearly continuous in the vicinity of SJBL-01 (~2 vessels minimum at any given time) and SAQU-01 (~10 vessels minimum at any given time). At SAQU-01, up to 29 unique vessels were identified in the vicinity of the monitoring station within a 5-minute period on multiple dates, particularly approaching weekend periods in the summer. The number of unique vessels in the vicinity of SJBL-01 is fewer, with a peak of 13 unique vessels on multiple dates. It should be noted that the number of unique vessel detections is not indicative of the actual number of transits past each monitoring station; rather, it is an indicator of general traffic density and variation in vessels operating in the area. Clear, diurnal patterns in underwater noise, particularly within the LF decade band, correspond most closely to the presence of passenger vessels near SJBL-01, which is indicative of the daily/weekly schedules of nearby Ferries.

These differences reflect local vessel activity patterns and may have implications for the exposure of marine fauna to noise, especially for common species such as harbor seals, which are expected to be frequently present in the area.

Regards,

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8.0 References

American National Standards Institute (ANSI) and Acoustical Society of America (ASA). S1.1-2013 (R2020). American National Standard: Measurement of Sound Pressure Levels in Air. NY, USA. https://webstore.ansi.org/standards/asa/ansiasas12013r2020

Gillespie, D., Caillat, M., Gordon, J., and White, P. 2013. "Automatic detection and classification of odontocete whistles," The Journal of the Acoustical Society of America, 134, 2427-2437.

International Organization for Standardization (ISO). 2022. ISO 18405:2017. Underwater acoustics – Terminology. Geneva. https://www.iso.org/standard/62406.html.

International Organization for Standardization (ISO). 2023. ISO 80000-3:2019 Quantities and units – Part 3: Space and time. https://www.iso.org/standard/64974.html

Wenz, G.M. 1962. Acoustic Ambient Noise in the Ocean: Spectra and Sources. *Journal of the Acoustical Society of America* 34(12): 1936-1956. https://doi.org/10.1121/1.1909155.

Appendix A Fundamentals of Underwater Acoustics, Metrics, and Plot formats

Underwater Noise Assessment

Phase II Monitoring and Reporting - Quarterly Report

Port of Seattle

SLR Project No.: 119.000032.00001

January 9, 2026

A.1 Fundamental Concepts of Underwater Noise

Sound is a form of energy made by vibrations. When an object vibrates, it causes the fluid particles around it to move. These particles collide with nearby particles, and this continues until they run out of energy.

In underwater acoustics, the word sound is used to describe all the pressure waves that are generated in an underwater medium. Sound waves propagate as alternate phases of compression and rarefaction. Compression occurs when molecules are pressed together. Rarefaction is just the opposite; molecules are allowed to expand.

A **tonal** or tone refers to a signal or component that is dominated by one or a few discrete frequencies, rather than spread across a wide range of frequencies like broadband noise.

A **harmonic** is a frequency component that is an integer multiple of a fundamental frequency. Harmonics often appear in periodic signals like machinery vibrations or propeller noise in underwater acoustics. If the fundamental propeller noise tone is 10 Hz, then harmonics are will appear at 20 Hz, 30 Hz, 40 Hz, and so on.

A.1.1 Frequency Band Classifications

Frequency is measured in hertz (Hz), which represents cycles per second. In underwater acoustics, frequency bands are generally categorized based on their propagation characteristics, absorption, and typical applications. Frequency bands refer to ranges of frequencies within the electromagnetic or acoustic spectrum that are grouped for classification and analysis. In acoustics (like underwater noise monitoring), these bands help organize sound energy into manageable segments for interpretation.

A **decade** band refers to a frequency range where the upper limit is ten times greater than the lower limit. In signal processing, it is common to group frequencies into logarithmic rather than linear intervals.

Broadband frequency refers to a wide range of frequencies rather than a narrow or single frequency band. Broadband signals are often used for high-resolution imaging to exploit frequency diversity and reduce noise at specific frequencies.

An **octave band** is a range of frequencies where the highest frequency is twice the lowest frequency. It is a way to group frequencies for analysis, especially in acoustics and noise measurement. A 1/3 octave scale contains finer resolution (see Table B-3 and Table B-4).

The frequency band classification shown below is widely accepted and serves as a reference for the analyzed data in this report.

Table A-1: Frequency Band Classifications

Frequency Band	Decade Bands (Hz)	Anthropogenic Noise
LF- Low frequency	10-100 (lower) 100-1000 (upper)	Propeller cavitation noise from vessels often dominates below 1000 Hz
MF - Medium Frequency	1000-10,000	Pumps, generators, and other machinery can produce tonal components in the 1,000 -10,000 Hz band.
HF - High Frequency	10,000-64,000	Predominant for active sources such as SONAR/echosounders
Broadband	50-64,000	All above

A.2 Underwater Noise Metrics

This analysis incorporates, where possible, recent updates to internationally recognized standards for acoustic terminology and metrics, including American National Standards Institute (ANSI) ANSI S1.13-2013 and International Organization for Standardization (ISO) 18405:2017 and ISO 80000-3:2019. These standards provide consistent definitions and alignment with the best practices in marine noise assessment.

Sound pressure level (SPL) is the primary metric used to indicate the amplitude level of sound at a specific location in space and is a scalar quantity. The level is dependent on the location and distance at which the sound is observed relative to a sound source. Sound pressure is measured in Pascals (Pa) but can be computed in decibels (dB). A standard reference pressure is used to compare sound levels given in decibels to one another. In underwater acoustics, the traditional standard reference pressure (p_o) is 1 micro-Pascal (μPa), leading to the use of the unit dB re 1 μPa, which represents a decibel referenced to a pressure of 1 μPa.

The following acoustic metrics are most commonly applied in this report:

- **zero-to-peak SPL ($L_{p,pk}$, dB re 1 μPa)** measures the maximum instantaneous signal's amplitude without considering time in a stated frequency band. It is used to assess potential permanent or temporary injuries in the hearing of marine mammals, as well as mortality or injuries in fish and sea turtles exposed to impulsive sound.
- **root-mean-square SPL ($L_{p,rms}$, dB re 1 μPa**) is essentially an average intensity over a given amount of time and, therefore, not an instantaneous pressure. This type of metric can be used to assess potential behavioral disturbance in marine mammals from impulsive and non-impulsive sound exposure. It is also used to assess mortality or injury in fish and sea turtles exposed to non-impulsive sound.
- **equivalent continuous sound level (L_{eq}, dB re 1 μPa**), is a measure used to describe the average sound energy over a specified period, taking into account fluctuations in noise levels.

By applying ANSI and ISO standards, this report ensures that underwater noise metrics are calculated using globally accepted methodologies, supporting scientific rigor and facilitating comparison with other marine acoustic studies.

A.3 Plots Format

Results are shown using visual formats that make patterns in underwater noise easier to interpret. Box plots summarize sound levels across frequency bands, spectral plots show how energy is distributed, and long-term averages highlight trends over time. Radial charts illustrate daily and weekly patterns, while AIS and marine mammal data are displayed in time-series and pie charts for quick comparison.

A.3.1 Ambient Noise

The ambient noise results for this monitoring period are presented in four different formats:

The **SPL box plot** is a summary of the broadband and decade-band statistics of SPL (1-minute) over the month analysis period. Each plot shows the median sound pressure level (center line), the interquartile range (box), and the minimum and maximum values (whiskers). This format provides a quick visual comparison of typical noise levels and variability across frequency bands and monitoring sites. By highlighting both central tendencies and extremes, box plots make it easier to identify patterns, assess variability, and compare conditions without reviewing large datasets. A table of values accompanies each plot for reference.

The **Spectral Probability Density (SPD) plot** illustrates the distribution of underwater sound energy across different frequencies. To create this plot, the acoustic data is divided into 1-second segments, and each segment is processed using a Hanning-windowed spectra with 50% overlap. The Hanning window tapers the edges of each segment to reduce distortion in the frequency analysis (called spectral leakage), while overlapping segments ensure smoother transitions and better time resolution. These 1-second spectra are then averaged into 1-minute periods for stability and clarity.

The 1-minute averages are displayed at the 5th, 50th, and 95th percentile levels, referred to as L_5, L_{50}, and L_{95}, respectively. According to the ANSI standard, L_5 is the sound level exceeded only 5% of the time (typically the highest value), L_{95} represents the level exceeded 95% of the time (the quieter end), and the L_{50} is commonly referred to as the median. The frequency range is displayed logarithmically and spans the most important acoustic bandwidth of the recordings.

The **Long-Term Spectral Average (LTSA) plot** is a visual representation of the signal's frequency content over time. The LTSA plot is used to visualize how the spectral density of a signal evolves through the recording period. It spans most of the acoustic bandwidth of the recording (from 10 Hz to 55,000 Hz). The icListen hydrophones have a nominal frequency range of 64,000 Hz. However, they incorporate an anti-aliasing filter that suppresses frequencies above approximately 55,000 Hz. This means the LTSA only displays the usable portion of the signal or frequencies that were recorded accurately without being suppressed. Using LTSA helps identify trends and anomalies in noise levels across the full frequency range over extended periods.

A **Radial chart**, also known as a spider chart, is a two-dimensional chart used to display multivariate data with all axes originating from a common center point. These plots have been adjusted to reflect local time.

A.3.2 AIS Data

AIS is a maritime tracking system that uses transponders on vessels to broadcast real-time information such as position, speed, and heading. This data is collected via satellite and terrestrial receivers, providing a detailed record of vessel movements within the monitoring area. AIS data for this monitoring period has been analyzed to quantify vessel activity as it relates to underwater noise monitoring.

The results are presented as a **time series histogram of vessel counts**, showing frequency and density of vessel presence at very fine temporal resolution (5-minute bins).

A.3.3 Marine Mammal Detections

Marine mammal detections are based on automated acoustic monitoring, which identifies species-specific vocalizations recorded during the monitoring period. These detections provide insight into species presence and activity patterns within the study area, supporting correlation with underwater noise levels.

The marine mammal detections for this monitoring period are presented in two formats:

- Pie charts show counts and proportions of automatic vocalization detections by species.
- Time-series graphs display the 1-minute occurrence for each species for the entire monitoring period. All graphs are in UTC time unless otherwise indicated.

Appendix B Ambient Noise Figures and Tables

Underwater Noise Assessment

Phase II Monitoring and Reporting - Quarterly Report

Port of Seattle

SLR Project No.: 119.000032.00001

January 9, 2026

B.1 Jack Block Park (SJBL-01)

Figure B-1: Summary of the SPL box plot (broadband and decade-band) for SJBL-01 over the entire monitoring period (August 2025)

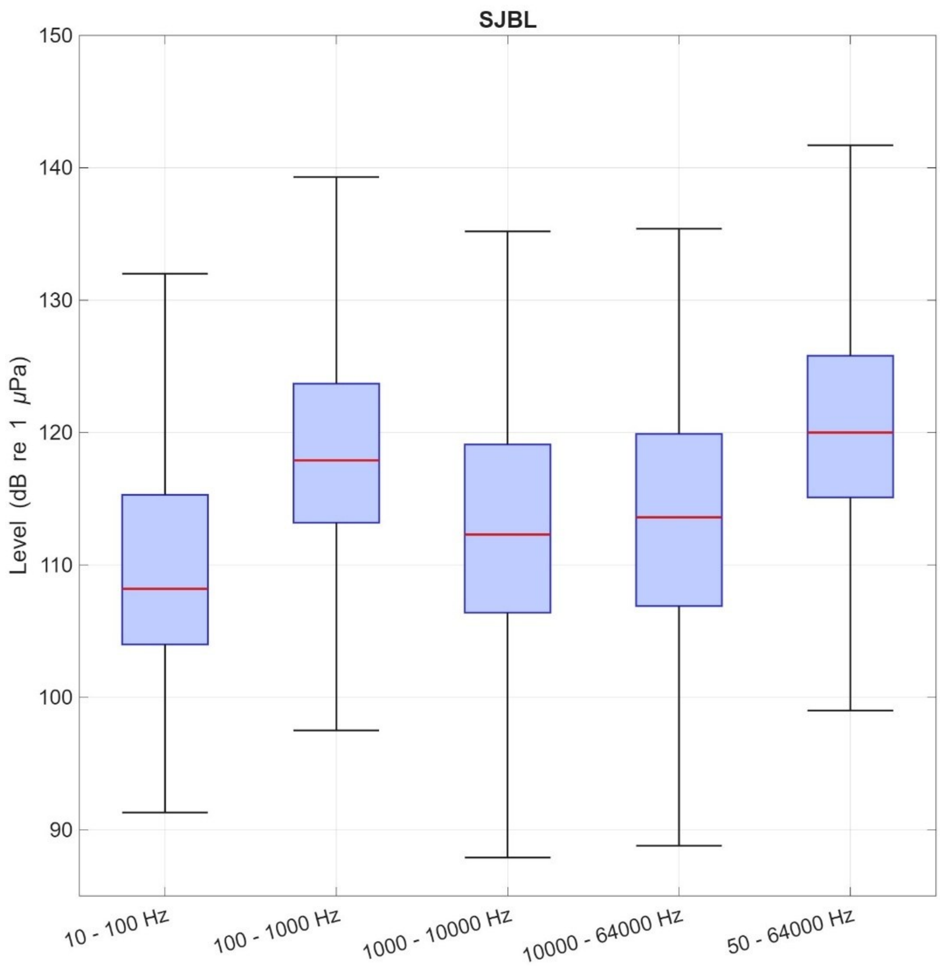


Table B-1: Summary of the SPL box plot (values) for SJBL-01 over the entire monitoring period (August 2025)

Decade-band	Minimum	Q1	Median	Q3	Maximum	IQR
10 - 100 Hz	91.3	104.0	108.2	115.3	132.0	11.3
100 - 1000 Hz	97.5	113.2	117.9	123.7	139.3	10.5
1000 - 10000 Hz	87.9	106.4	112.3	119.1	135.2	12.7
10000 - 64000 Hz	88.8	106.9	113.6	119.9	135.4	13.0
50 - 64000 Hz	99.0	115.1	120.0	125.8	141.7	10.7

Figure B-2: Spectral probability density plot of SJBL-01 over the entire monitoring period (August 2025)

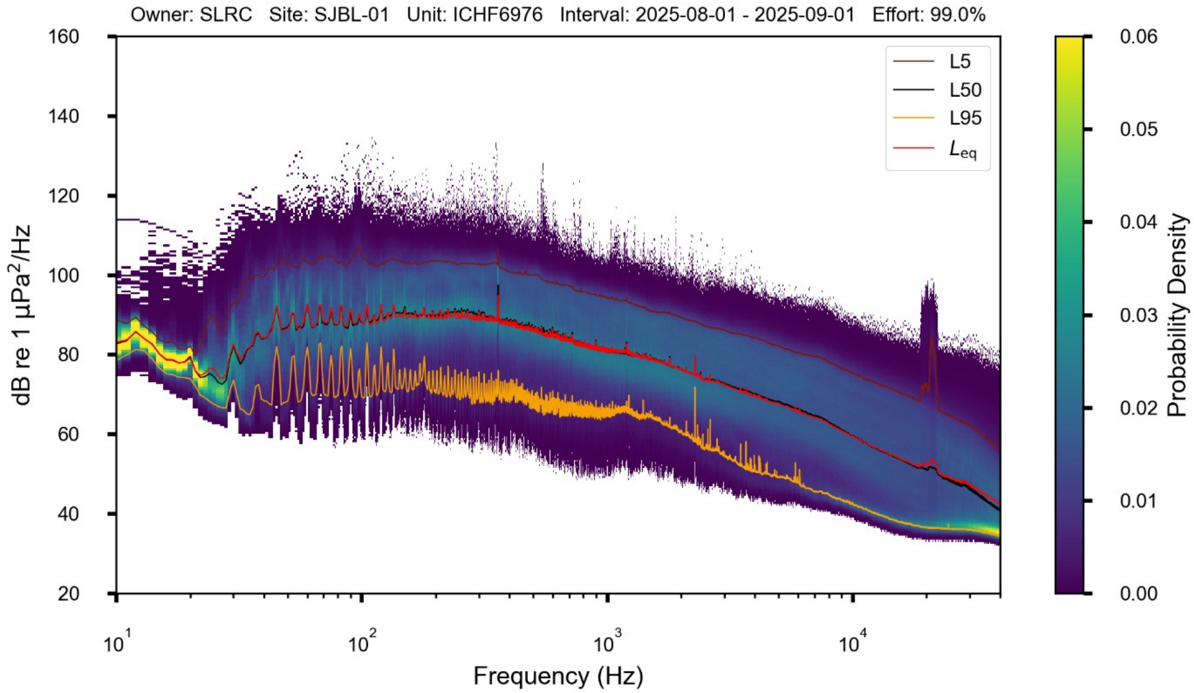


Figure B-3: Weekly LTSA for SJBL-01 over the entire first week of the monitoring period (August 2025)

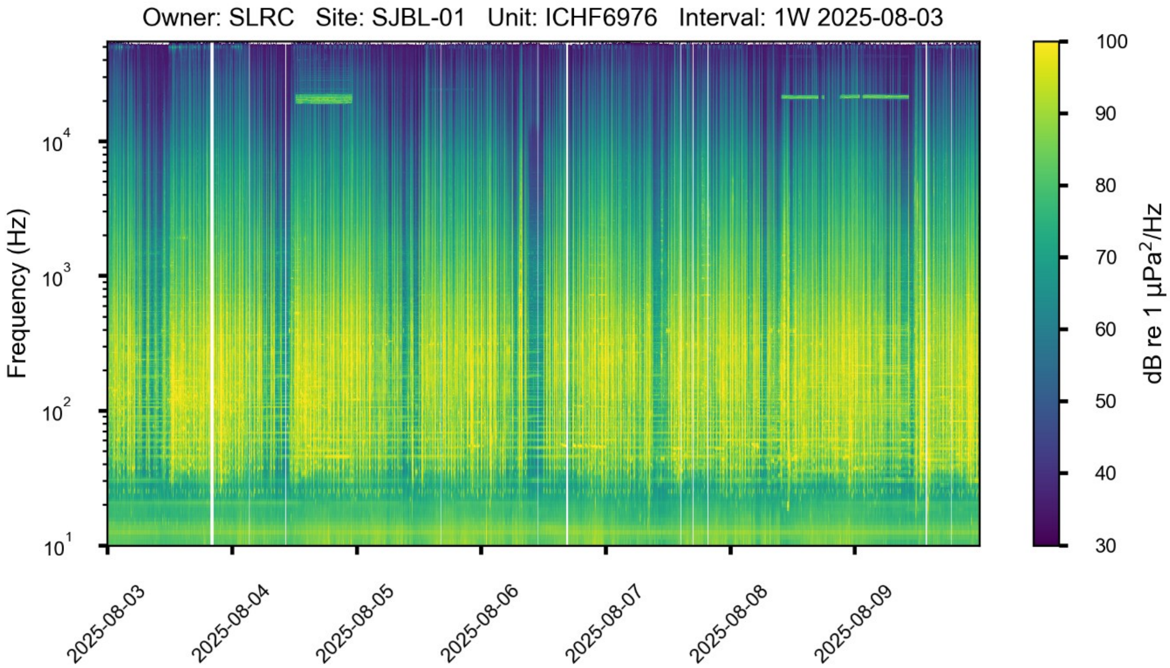


Figure B-4: Weekly LTSA for SJBL-01 over the entire second week of the monitoring period (August 2025)

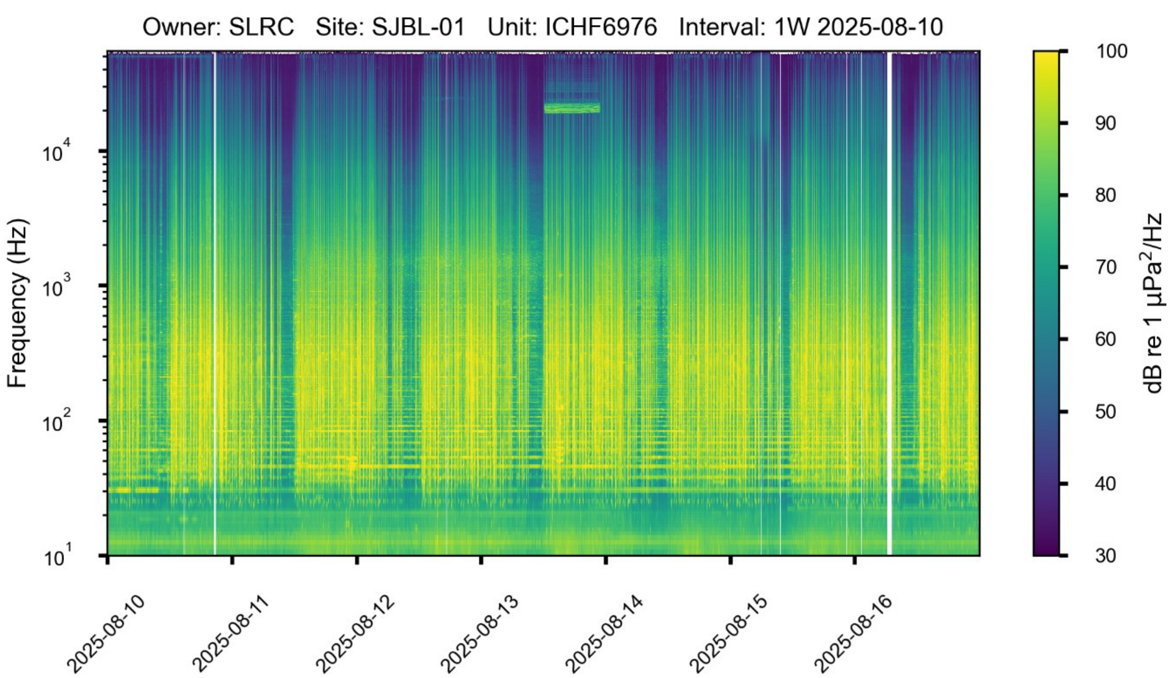


Figure B-5: Weekly LTSA for SJBL-01 over the entire third week of the monitoring period (August 2025)

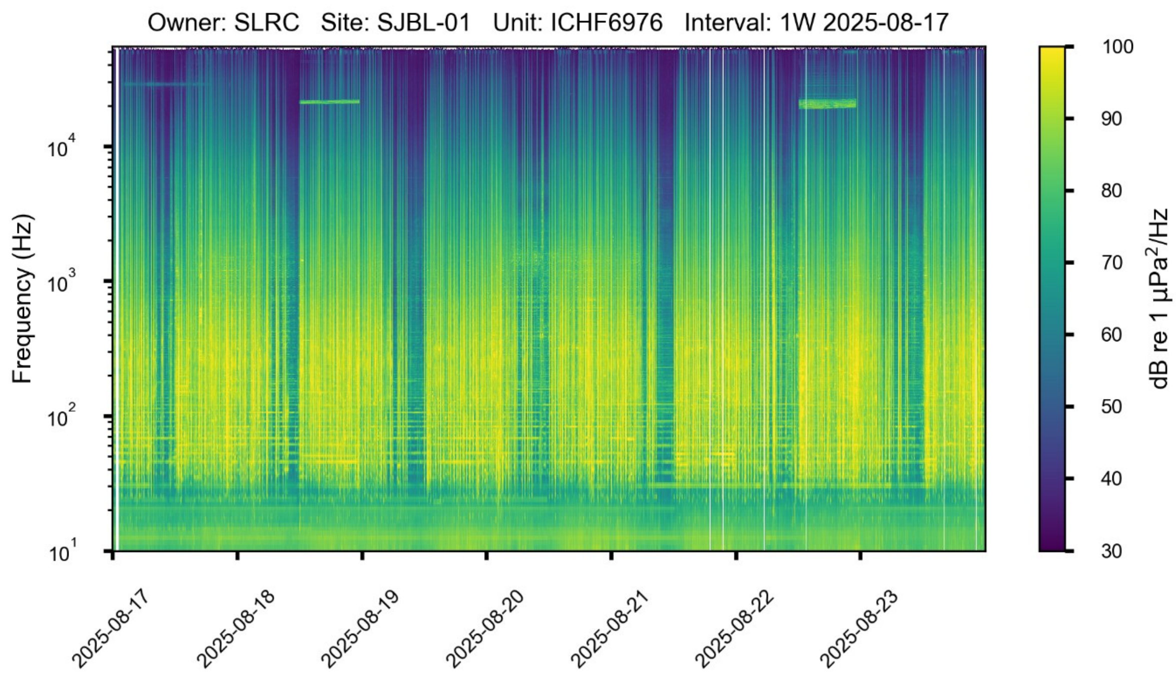


Figure B-6: Weekly LTSA for SJBL-01 over the entire fourth week of the monitoring period (August 2025)

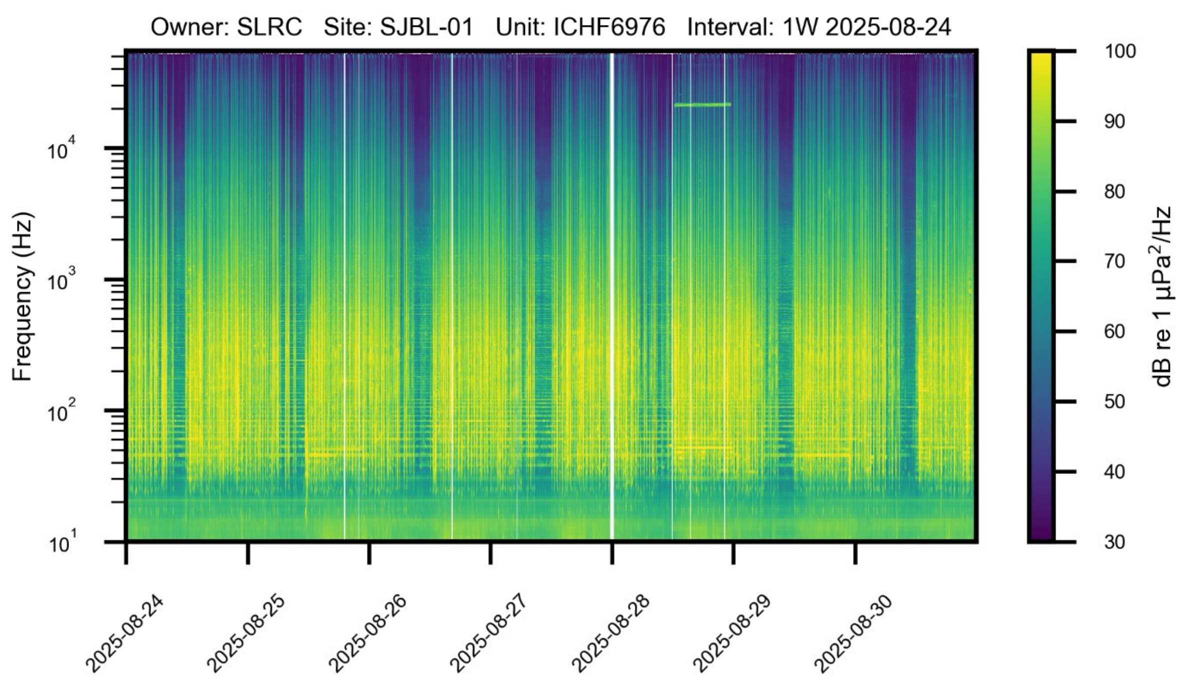


Figure B-7: Representative radial charts for SJBL-01 of the seven day-of-week pattern for each decade-band of the monitoring period (August 2025)

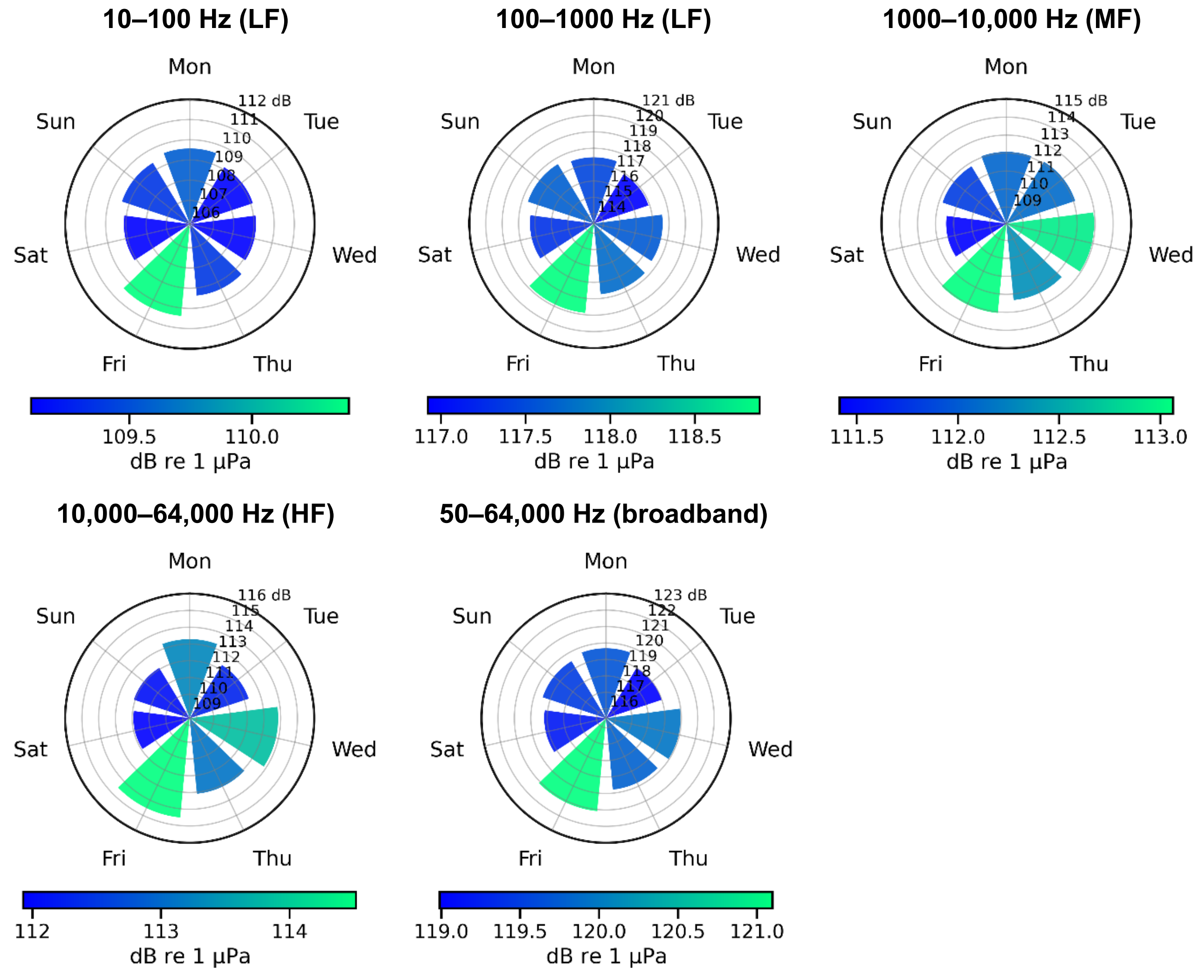
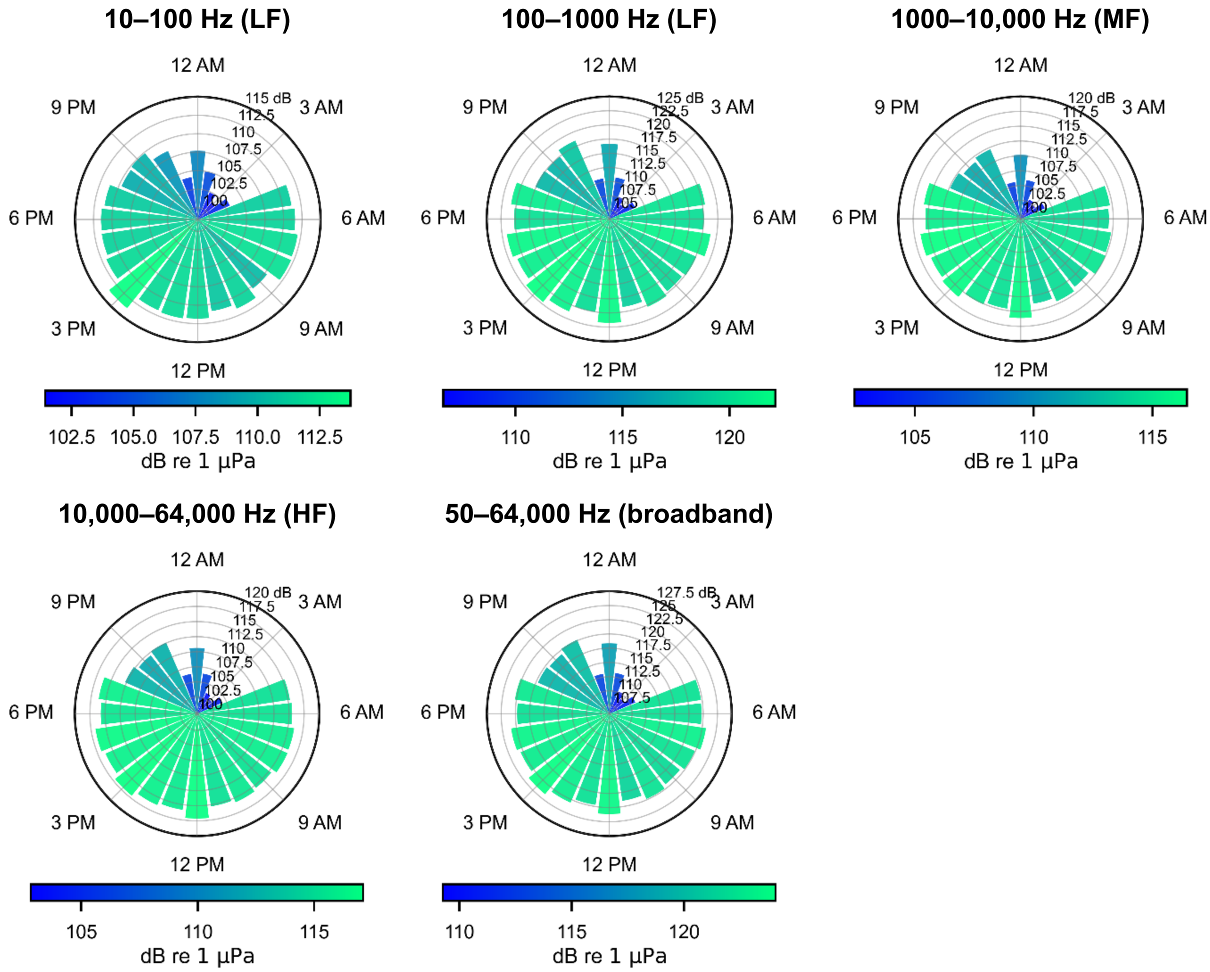


Figure B-8: Representative radial charts for SJBL-01 of the 24-hour pattern for each decade-band of the monitoring period (August 2025)



B.2 Seattle Aquarium (SAQU-01)

Figure B-9: Summary of the SPL box plot (broadband and decade-band) for SAQU-01 over the entire monitoring period (August 2025)

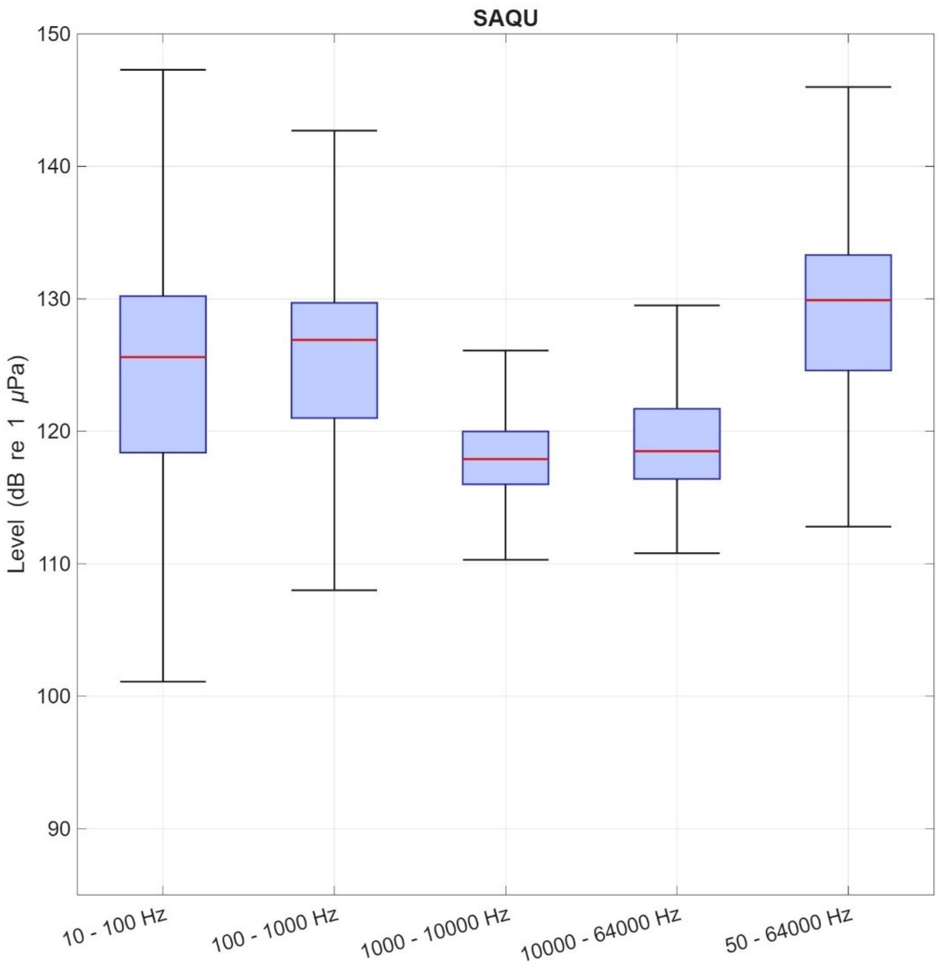


Table B-2: Summary of the SPL box plot (values) for SAQU-01 over the entire monitoring period (August 2025)

Decade-band	Minimum	Q1	Median	Q3	Maximum	IQR
10 - 100 Hz	101.0	118.4	125.6	130.2	147.3	11.8
100 - 1000 Hz	108.0	121.0	126.9	129.7	142.7	8.7
1000 - 10000 Hz	110.3	116.0	117.9	120.0	126.1	4.1
10000 - 64000 Hz	110.8	116.4	118.5	121.7	129.5	5.2
50 - 64000 Hz	112.8	124.6	129.9	133.3	146.0	8.7

Figure B-10: Spectral probability density plot of SAQU-01 over the entire monitoring period (August 2025)

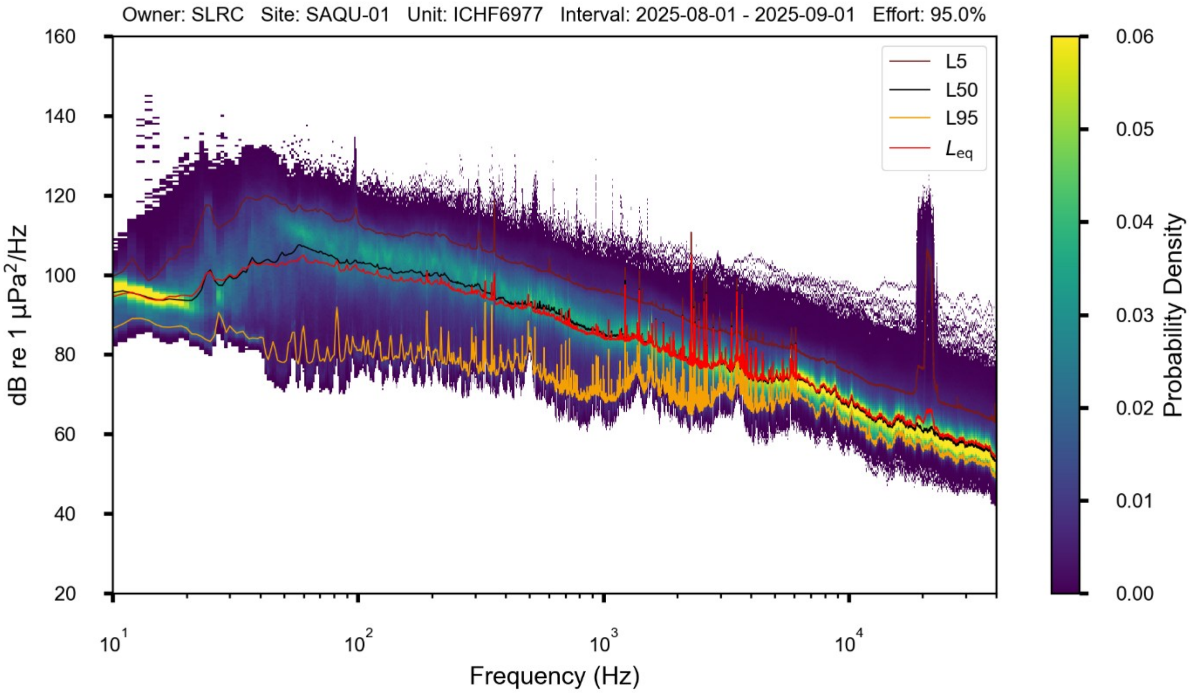


Figure B-11: Weekly LTSA for SAQU-01 over the entire first week of the monitoring period (August 2025)

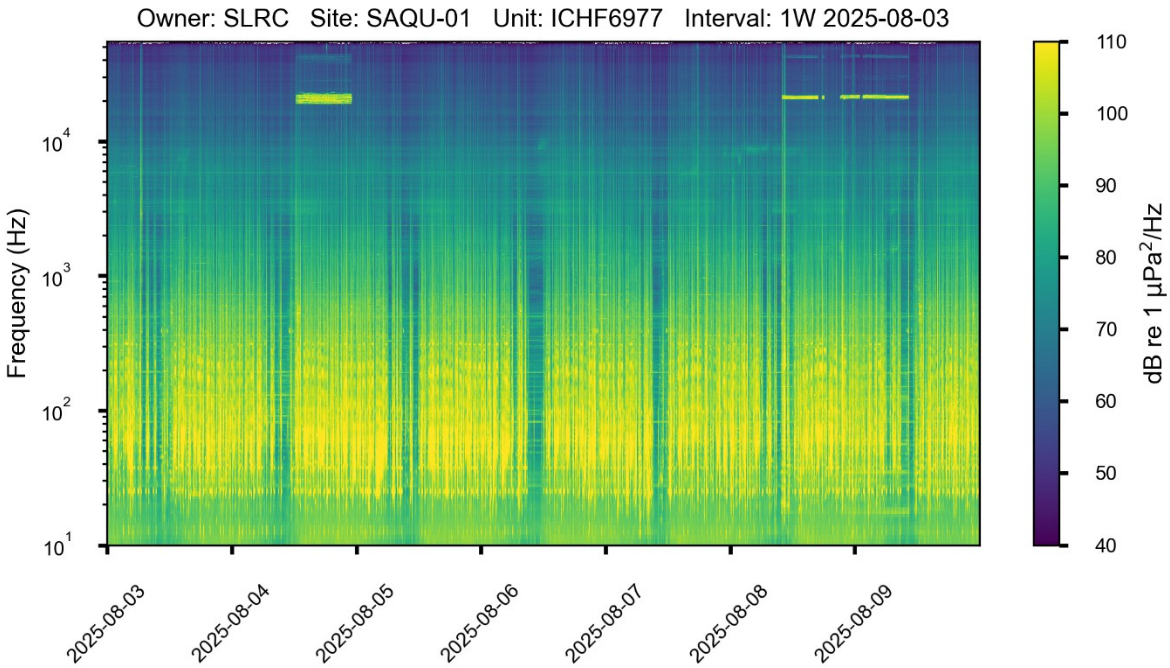


Figure B-12: Weekly LTSA for SAQU-01 over the entire second week of the monitoring period (August 2025)

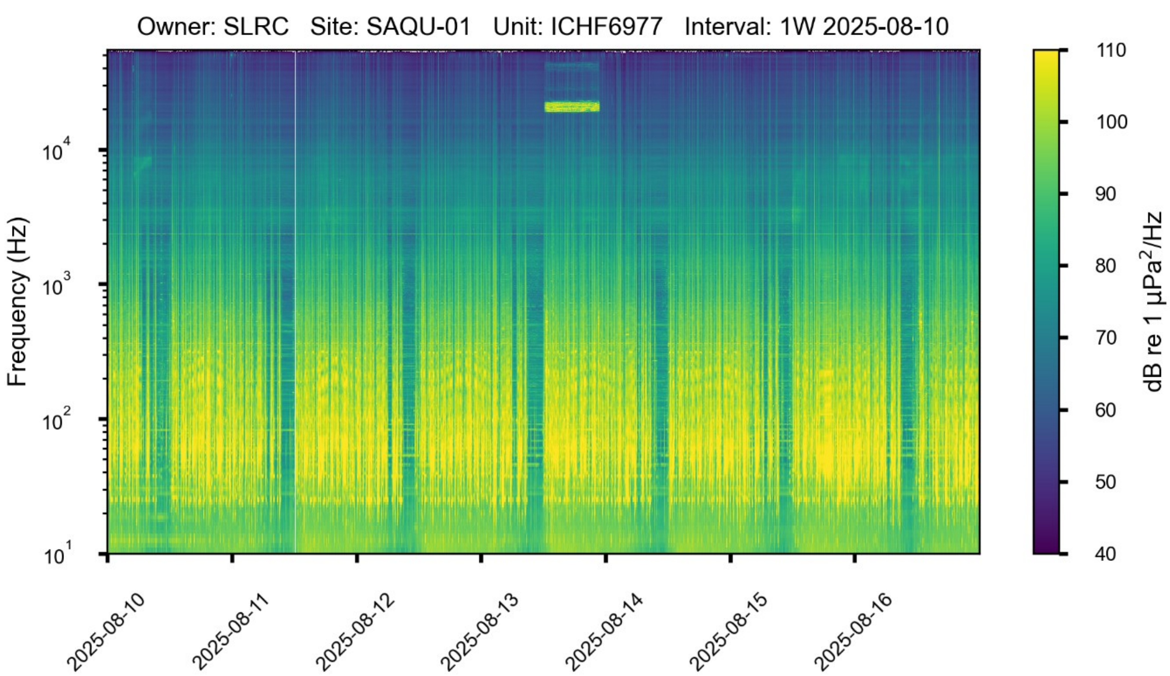


Figure B-13: Weekly LTSA for SAQU-01 over the entire third week of the monitoring period (August 2025)

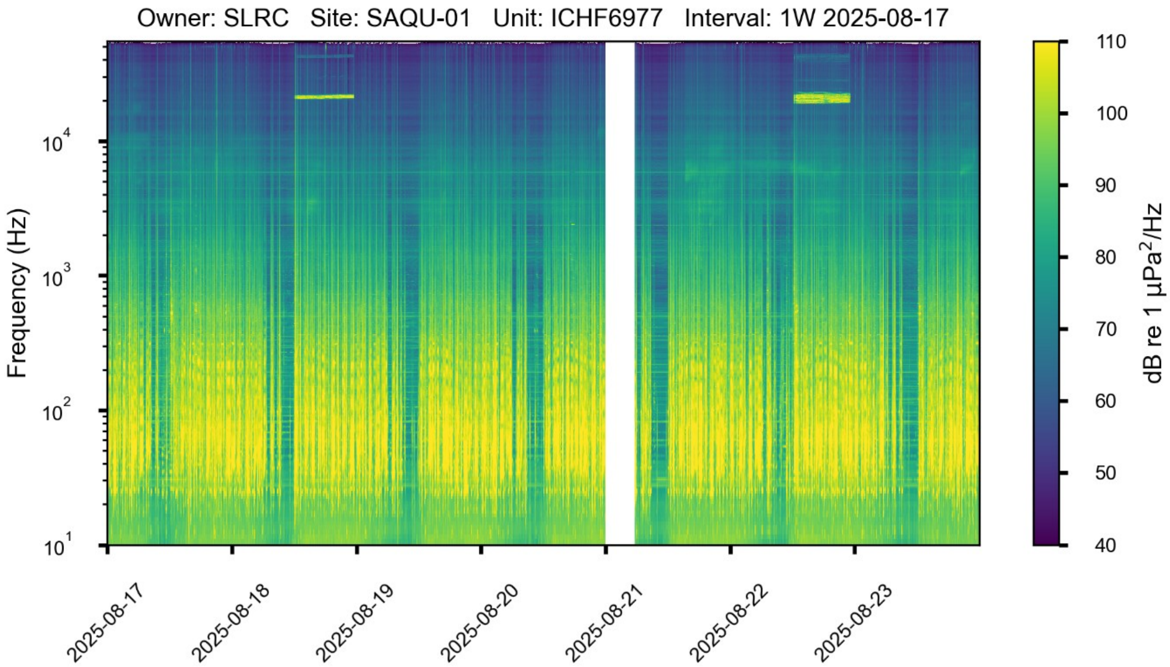


Figure B-14: Weekly LTSA for SAQU-01 over the entire fourth week of the monitoring period (August 2025)

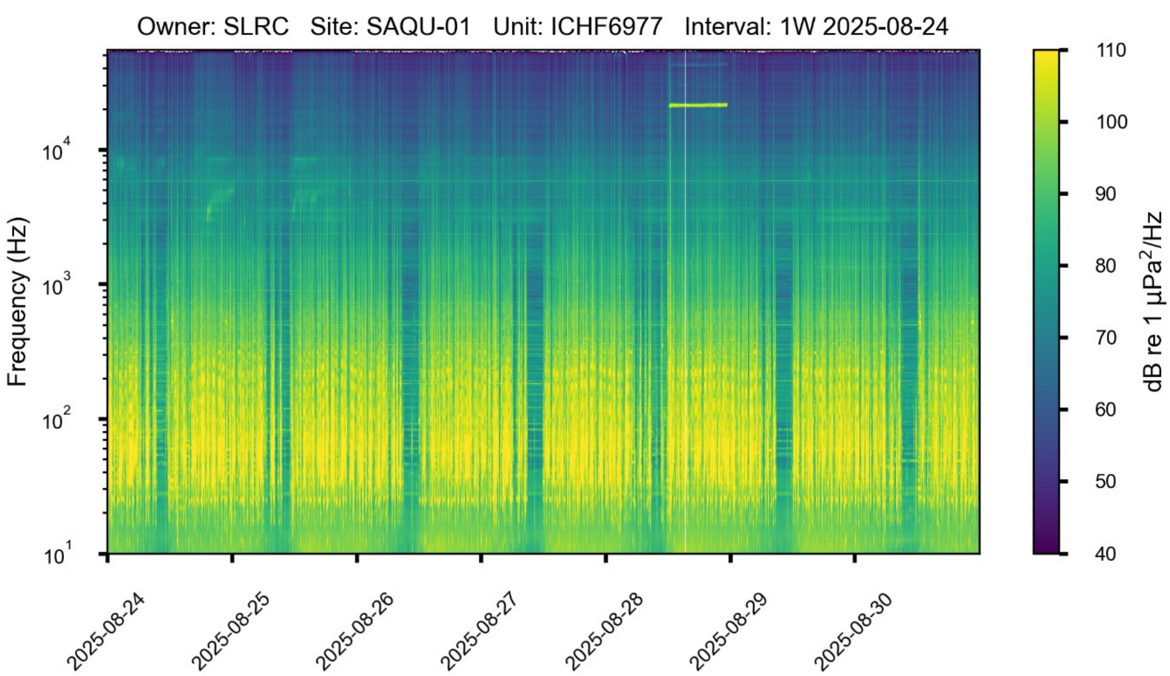


Figure B-15: Representative radial charts for SAQU-01 of the seven day-of-week pattern for each decade-band of the monitoring period (August 2025)

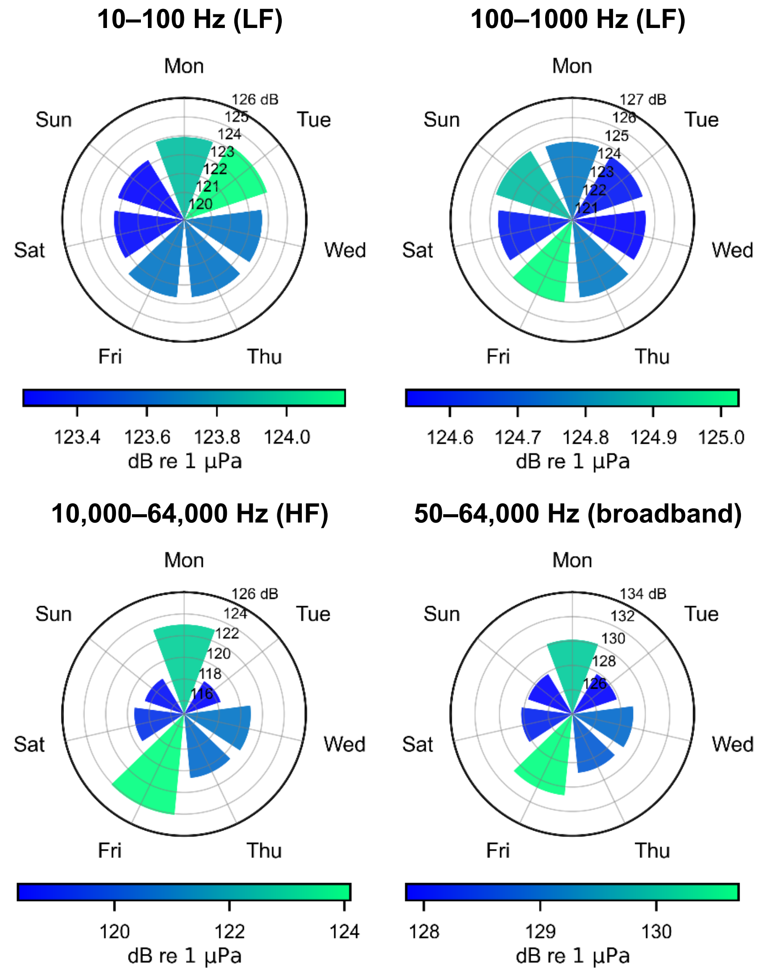
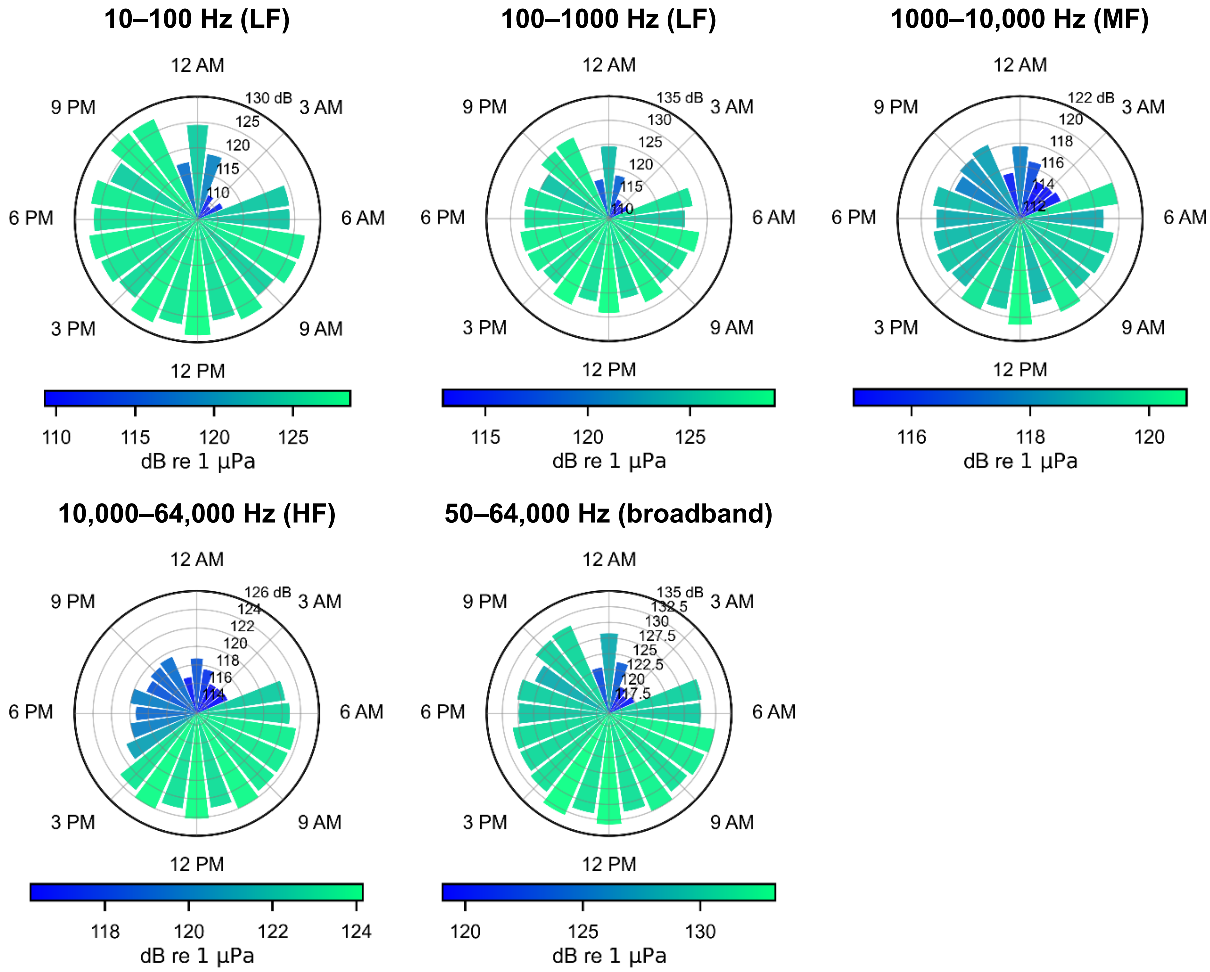


Figure B-16: Representative radial charts for SAQU-01 of the 24-hour pattern for each decade-band of the monitoring period (August 2025)



B.3 Comparison of ambient noise levels

Figure B-17: Comparison of ambient noise levels ($_{Leq}$) of the two underwater monitoring stations throughout the monitoring period (August 2025)

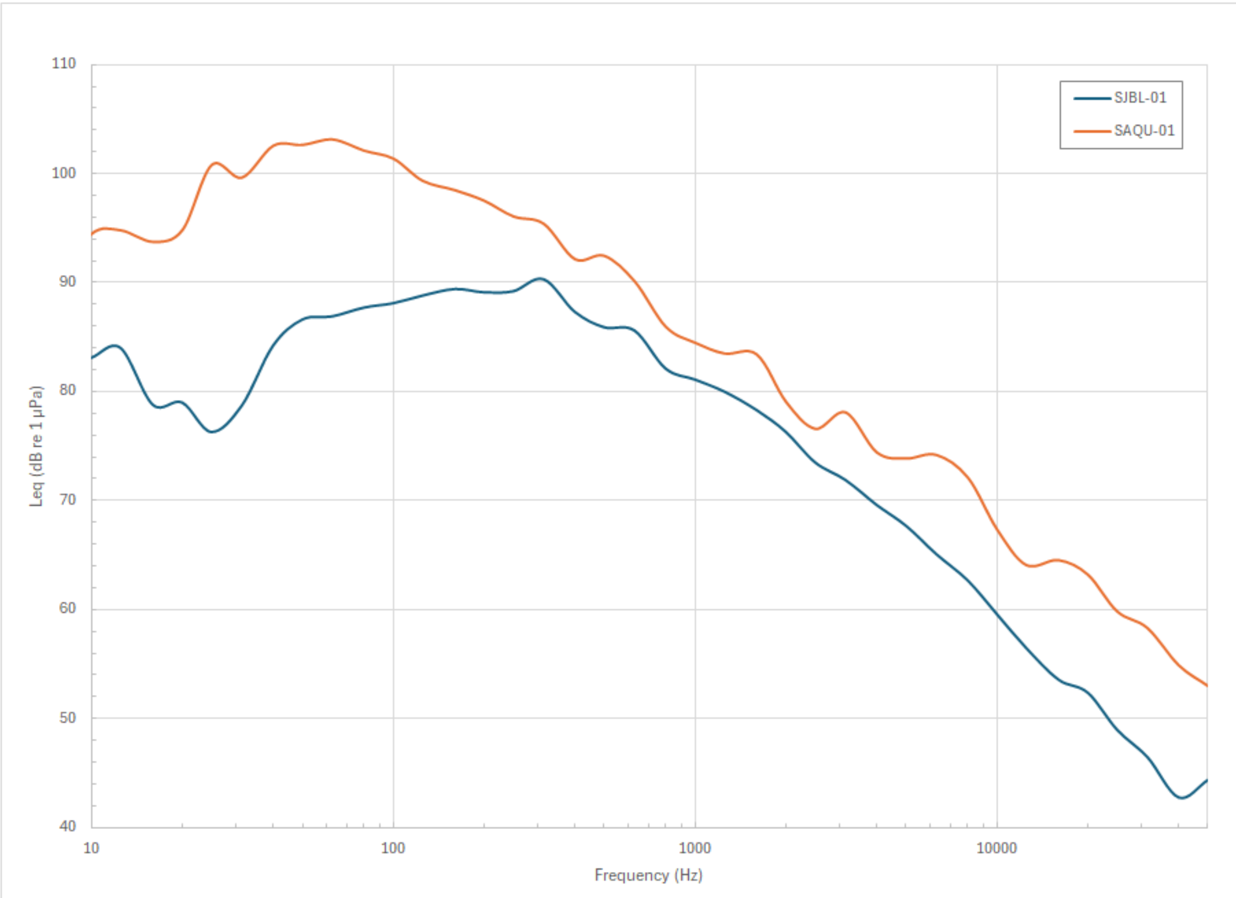


Table B-3: L_{eq} (1-min SPL) for the 1/3 octave band center frequencies of SJBL-01 for the monitoring period (August 2025)

1/3 Octave Band (Hz)	L_{eq} dB re 1 µPa	1/3 Octave Band (Hz)	L_{eq} dB re 1 µPa
10	83.1	800	82.1
12.5	84.0	1000	81.1
16	78.8	1250	80.0
20	79.0	1600	78.3
25	76.3	2000	76.3
31.5	78.7	2500	73.5
40	84.2	3150	71.9
50	86.6	4000	69.6
63	86.9	5000	67.7
80	87.7	6300	65.1
100	88.1	8000	62.7
125	88.8	10000	59.6
160	89.4	12500	56.5
200	89.1	16000	53.6
250	89.2	20000	52.4
315	90.3	25000	49.0
400	87.3	31500	46.5
500	85.9	40000	42.8
630	85.6	50000	44.4

Table B-4: L_{eq} (1-min SPL) for the 1/3 octave band center frequencies of SAQU-01 for the monitoring period (August 2025)

1/3 Octave Band (Hz)	L_{eq} dB re 1 µPa	1/3 Octave Band (Hz)	L_{eq} dB re 1 µPa
10	94.5	800	86.0
12.5	94.8	1000	84.5
16	93.8	1250	83.5
20	94.9	1600	83.4
25	100.8	2000	79.1
31.5	99.7	2500	76.6
40	102.6	3150	78.1
50	102.7	4000	74.4
63	103.2	5000	73.9
80	102.2	6300	74.2
100	101.4	8000	72.2
125	99.4	10000	67.4
160	98.5	12500	64.1
200	97.6	16000	64.6
250	96.1	20000	63.2
315	95.4	25000	59.9
400	92.2	31500	58.3
500	92.5	40000	54.9
630	90.1	50000	53.0

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