ECHO Program
Study Summary

Underwater Listening Station in the Strait of Georgia

The Enhancing Cetacean Habitat and Observation (ECHO) Program, in partnership with Transport Canada, commissioned a project to explore the feasibility of a real-time, continuous underwater listening station (ULS) for measuring ship underwater acoustic source levels, ambient noise, and marine mammal detections in the Strait of Georgia.

This summary document was prepared to describe why the project was conducted, its key findings and conclusions, and how the results are planned to be used by the ECHO Program to help manage the impact of shipping activities on at-risk whales throughout the southern coast of British Columbia.

What questions was the study trying to answer?

Endangered Southern Resident Killer Whales (SRKW) and other at-risk whale species frequent the Strait of Georgia, which also hosts commercial and recreational vessel activities. Underwater noise from vessels combines to increase ambient noise levels and can interfere with the ability of whales to feed and communicate. In order to better understand the different source levels of the vessels calling to the Port of Vancouver, the ECHO Program instigated a feasibility project to answer the following questions:

- Is a real-time, automated system for accurately measuring vessel source levels feasible?
- What are the source levels of different vessels calling to the Port of Vancouver?
- What are the ambient noise conditions in the Strait of Georgia, proximate to the Port of Vancouver?
- When are specific marine mammals present in the area?

The underwater listening station in the Strait of Georgia captures noise levels of vessels calling to the Port of Vancouver.

Who conducted the project?

Ocean Networks Canada (ONC) and JASCO Applied Sciences (JASCO) are project partners along with Vancouver Fraser Port Authority and Transport Canada. The ULS utilizes the existing seafloor infrastructure of ONC's VENUS Observatory which provides power and data transmission. JASCO was selected as a project partner based on their expertise in the measurement and analysis of underwater noise. Both ONC and JASCO have provided in-kind contribution of time and equipment to the project.

What methods were used?

In the first year of operation, the Underwater Listening Station (ULS) utilized two acoustic (hydrophone) arrays under the inbound shipping lane on the approach to the Port of Vancouver, cabled to the ONC VENUS East Node site. The station was deployed on September 14, 2015 and redeployed as a single array on October 7, 2016. Continuous recording of underwater noise was conducted, with this data processed to provide near real-time vessel acoustic source level reports and marine mammal detections using JASCO software products. On a monthly basis reports on lunar monthly, weekly and daily ambient noise levels were provided.

What were the key findings?

Vessel Source Levels

- The system was successful in providing near real-time measurement and analysis of vessel source levels, with the first year dataset containing more than 1,000 valid measurements.
- The loudest recorded vessel was a bulker in the >200m length class, with a broadband radiated noise level of 201.2 dB re 1 μPa at 1 m.
- The quietest vessel recorded was a naval vessel with a radiated noise level of 161.0 dB re 1 μPa at 1 m.
- The commercial vessel class with the highest mean radiated noise level was the container ship >200m length class, with a mean level of 190.5 dB re 1 μPa at 1 m.
- The commercial vessel with the quiet mean radiated noise level was the tug <50m length class with a mean level of 179.5 dB re 1 μPa at 1 m.

Ambient Noise

- Underwater noise energy levels are "high" between about 30 Hz and 200 Hz with respect to open ocean, high traffic conditions (Wentz curves), due to the constrained geography in the Strait of Georgia.
- The ambient noise showed a dominant hourly cycle from 5 AM to 11 PM daily. Daily fluctuations in sound were evident, with lower noise levels observed between midnight and 4:00 AM, and spikes attributable to regularly scheduled transits (such as ferries).

Marine Mammal Detections

- Marine mammal detectors were focused on identifying killer whale (*Orcinus orca*), humpback whale (*Megaptera novaeangliae*) and Pacific white-sided dolphin (*Lagenorhynchus obliquidens*).
- The number of detections do not reflect the number of individuals, as non-vocalizing individuals could be present or an individual can make multiple calls.
- Killer whale detections were primarily recorded in September & October, 2015 and April to October, 2016 with peak detections observed in September 2015 and August 2016. Few killer whale detections were recorded between November 2015 and March 2016.
- Humpback whale vocalizations were detected in October, November and December, 2015, with the highest detection numbers observed in December of 2015.
- Pacific white-sided dolphins were not detected in the first year of operation.

Conclusions and next steps

The results of this study furthered the ECHO Program's understanding of current ambient noise conditions, vessel source levels from different vessel types (e.g., tugs, bulk carriers, container ships, cruise ships, ferries) and marine mammal presence in the Strait of Georgia. The ECHO Program is using this knowledge to better understand vessel characteristics that may contribute to underwater noise, and to help focus management efforts and inform the development of vessel noise reduction and monitoring programs. The ULS was redeployed in October, 2016 for a second year of data collection.

Please note: Proprietary information has been redacted from report appendices.

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18 December 2016

Year 1 Project Final Report on the Vancouver Fraser Port Authority Strait of Georgia Underwater Listening Station

Prepared for the Vancouver Fraser Port Authority
Enhancing Cetacean Habitat and Observation (ECHO) Program

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1 Executive summary

The Underwater Listening Station (ULS) is funded by Transport Canada, the Vancouver Fraser Port Authority (VFPA) ECHO Program and received in kind contributions from Ocean Networks Canada (ONC) and JASCO Applied Sciences (JASCO). The objective is to explore the feasibility of an underwater listening station for the purpose of measuring ship underwater acoustic source levels and ambient noise within the jurisdictional waters of the Vancouver Fraser Port Authority. The listening station is designed to allow the majority of vessels visiting the Port to have underwater acoustic measurements made without impacting their schedules. This approach allows for continuous measurements of vessel noise over time, possibly enabling a vessel quieting incentive program to be implemented at VFPA. In addition to monitoring vessel underwater noise, the listening station is also designed to record ambient noise data in the Strait of Georgia and assess vocalizing marine mammal detections in the area.

The Year 1 ULS feasibility project utilized two tetrahedral acoustic arrays under the inbound shipping lane at the ONC VENUS East Node site, deployed in 14 September of 2015 and removed in 07 October 2016. Each array can provide ship source level, ambient noise and marine mammal vocalization data individually. The system is designed to approximate as closely as possible the ANSI/ASA S12.64-2009/Part 1 standard on the Quantities and Procedures for Description and Measurement of Underwater Sound from Ships – Part 1: General Requirements, grade C.

The ULS acoustic data can be affected by the VENUS observatory going offline for maintenance, equipment failures and redactions for national security reasons. The ULS data was redacted for 1094 hours (11.7% of the project) and the system was offline for a total of 103 hours (1.1% of the project). Changes in the military redaction procedures were implemented at the end of August 2016 and the redaction impact dropped to zero for the last two months of the project.

As expected for a busy, confined coastal waterway, the monthly mean ambient underwater noise levels at the ULS have been consistently high since September 2015 relative to open ocean, high shipping traffic reference levels (Wenz, 1962). In all months, the ULS data has a 10 to 20 dB difference between the mean and median sound pressure level (SPL) which indicates that a significant portion of the acoustic energy is produced by short duration, high intensity sound sources consistent with a heavily trafficked waterway.

Vessels with daily scheduled transits of the Strait of Georgia create spikes in the average daily SPL plots. The magnitude (7 to 15 dB) and continuity of the spikes in the daily SPL data throughout the project year highlight the impact of the daily scheduled vessel transits on the soundscape of the Strait of Georgia. In the mean hourly root mean square (rms) SPL monthly plots, most vessels generate 10 dB spikes however, large (15 to 30 dB) spikes occasionally occur. The large spikes are always associated with vessels radiating strongly in the 10 to 30 Hz frequency bands and likely passing close to the ULS.

Fish-like calls were detected in all months except December with the peak number of calls occurring in June. Humpback vocalizations were only detected in the months of Oct, Nov and Dec, with maximum detections recorded in the month of December. Killer whale detections were primarily recorded between the months of April to October, with peak detections recorded in August 2016 and September 2015. Significantly lower to no killer whale detections were recorded between the months of Nov and March. Pacific white-sided dolphin vocalizations were not detected in Year 1.

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Automated vessel underwater noise level measurements, approximating the ANSI standard criteria, were generated for 1002 vessel transits out of the 1807 detected vessels in the shipping lane. Vessel transits were rejected if the vessel transited outside the defined measurement corridor, turned or accelerated inside the measurement corridor, or if there was noise from other nearby vessels at time of measurement. The Year 1 dataset contains more than twice the number of compliant measurements than any other vessel noise study ever undertaken. The goal of obtaining 100 valid vessel measurements per class, for ranking vessels by class, has not yet been achieved for every vessel class. It is hoped that the year 2 ULS feasibility extension project (array redeployed from Oct 2016 to Oct 2017) will allow several more of the vessel classes to achieve more than 100 vessel measurements and allow the vessel ranking system to be implemented for the most utilized classes.

During the project the loudest two vessels were in the bulker >200m class with broadband radiated noise levels (RNL) of 201.2 and 200.8 dB re 1 μPa at 1 m. The quietest vessel was a Naval vessel with a RNL of 161.0 dB re 1 μPa at 1 m. The class with the highest mean RNL was the container ship >200m class, with a mean RNL of 190.5 dB re 1 μPa at 1 m. Some vessels with multiple passes showed a positive correlation of RNL to vessel speed. Other vessels showed a poor correlation with speed indicating there are other factors which may be important to RNLs such as vessel loading (depth of propeller) or variable pitch versus fixed pitch propellers.

We had hoped to characterize acoustic performance changes associated with hull cleaning of several vessels during this feasibility study. The hull cleaning technology was unfortunately not available during the project, so the effect of hull cleaning on vessel underwater radiated noise could not be assessed.

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2 Project overview

The underwater listening station is funded by Transport Canada, the Vancouver Fraser Port Authority (VFPA) ECHO Program and received in kind contributions from Ocean Networks Canada (ONC) and JASCO Applied Sciences (JASCO). The objective is to explore the feasibility of an underwater listening station for measuring ship underwater acoustic source levels and ambient noise within the jurisdictional waters of the Vancouver Fraser Port Authority. The listening station is designed to allow the majority of vessels visiting the Port to have underwater acoustic measurements made without impacting their schedules. This approach allows for continuous measurements of vessel noise over time, possibly enabling a vessel quieting incentive program to be implemented at the Port of Vancouver. In addition to monitoring vessel underwater noise, the listening station is also designed to record ambient noise data in the Strait of Georgia and assess vocalizing marine mammal presence in the area.

Two tetrahedral acoustic arrays, shown in Figure 2.1, were deployed under the inbound shipping lane at the ONC VENUS East Node site, shown in Figure 2.2, in September of 2015. Each array can provide ship source level (RNL, MSL, range to vessel, time of closest point of approach (CPA), and MSL depth), ambient noise and marine mammal presence data individually. The system is designed to approximate as closely as possible the ANSI/ASA S12.64-2009/Part 1 standard on the Quantities and Procedures for Description and Measurement of Underwater Sound from Ships – Part 1: General Requirements, grade C. Approximating the standard will allow the best possible ship source levels to be measured in the approaches to VFPA. There are some deviations from the standard due to the depth limitations of the Strait of Georgia, the bottom mounted configuration of the arrays and a single pass of each vessel. These deviations are necessary to operate in the local waters and avoid affecting shipping schedules. To provide the best possible accuracy, each array was deployed with an acoustic projector to perform daily calibration verifications of the hydrophones and regional vessel operators and BC Coast Pilots were engaged to seek their participation in accurately transiting vessels past the listening station. A shore based automatic identification system (AIS) is used to identify and track vessels, and ONC environmental data is used to support the source level assessments performed by the JASCO software.

Data from ONC sensors and the two JASCO AMAR Observer hydrophone systems were collected from 15 September 2015 to 07 October 2016. During this time, JASCO has worked continuously on the development of software to automate their existing vessel measurement systems, which were normally applied manually. The automated system is capable of choosing valid vessel passes, analyzing the corresponding acoustic data, and providing the ability to automatically generate reports.

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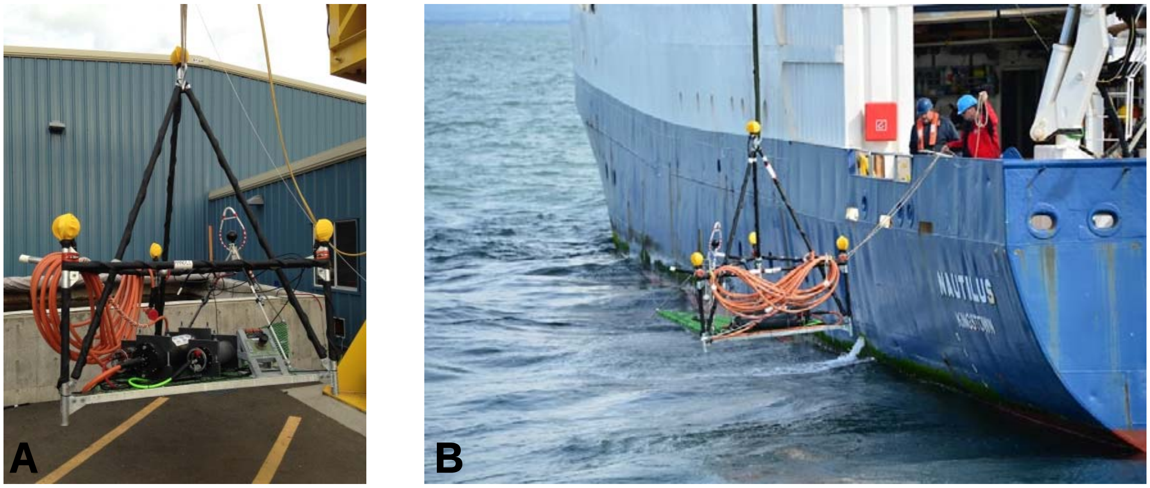
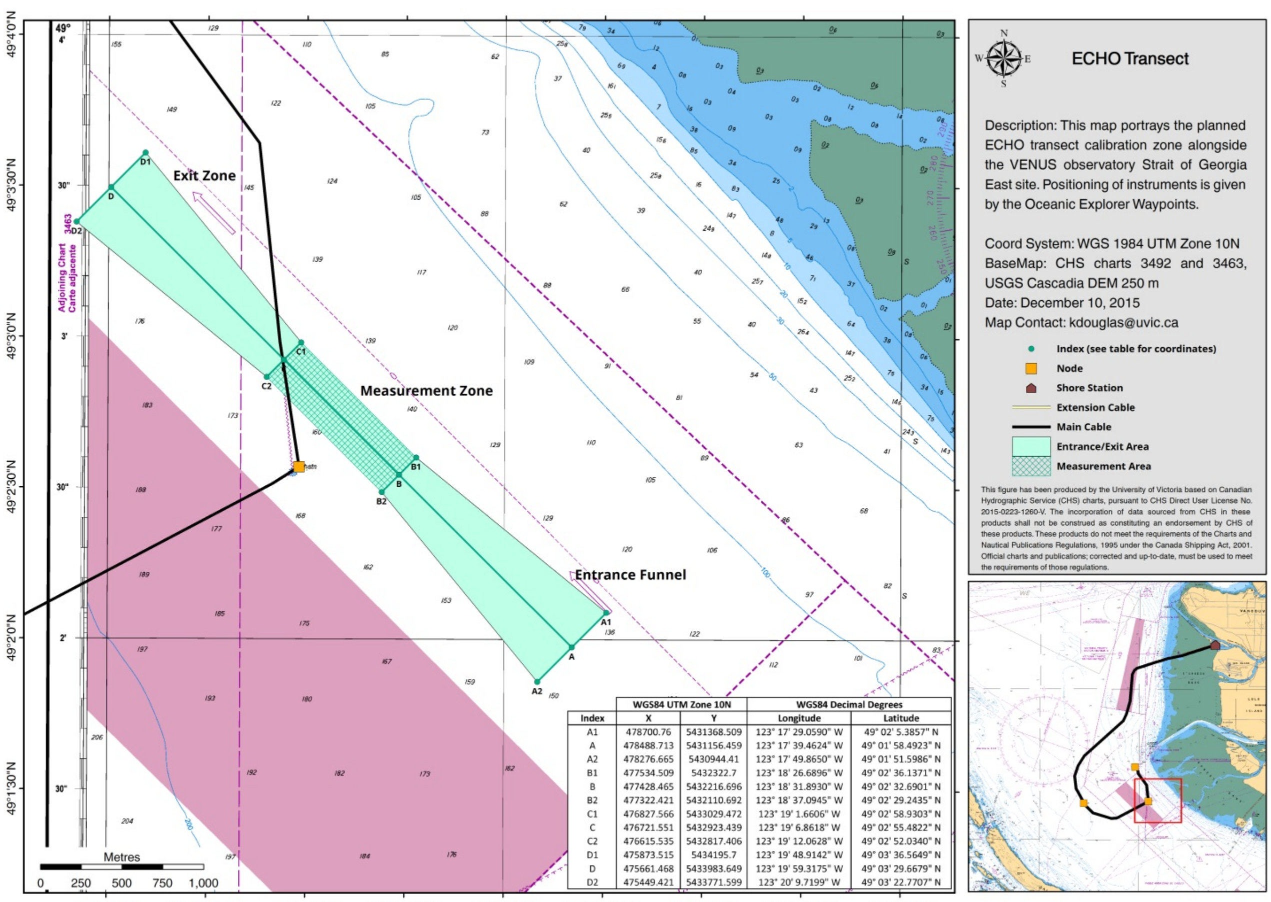


Figure 2.1 A) Tank test of tetrahedral array 1 with projector tripod hooked on array in the deployment and recovery position, B) Array 2 and projector being deployed to the sea floor, 15 Sept. 2015.



	WGS84 UTM Zone 10N		WGS84 Decimal Degrees	
Index	X	Y	Longitude	Latitude
A1	478700.76	5431368.509	123° 17' 29.0590" W	49° 02' 5.3857" N
A	478488.713	5431156.459	123° 17' 39.4624" W	49° 01' 58.4923" N
A2	478276.665	5430944.41	123° 17' 49.8650" W	49° 01' 51.5986" N
B1	477534.509	5432322.7	123° 18' 26.6896" W	49° 02' 36.1371" N
B	477428.465	5432216.696	123° 18' 31.8930" W	49° 02' 32.6901" N
B2	477322.421	5432110.692	123° 18' 37.0945" W	49° 02' 29.2435" N
C1	476827.566	5433029.472	123° 19' 1.6606" W	49° 02' 58.9303" N
C	476721.551	5432923.439	123° 19' 6.8618" W	49° 02' 55.4822" N
C2	476615.535	5432817.406	123° 19' 12.0628" W	49° 02' 52.0340" N
D1	475873.515	5434195.7	123° 19' 48.9142" W	49° 03' 36.5649" N
D	475661.468	5433983.649	123° 19' 59.3175" W	49° 03' 29.6679" N
D2	475449.421	5433771.599	123° 20' 9.7199" W	49° 03' 22.7707" N

Figure 2.2 VENUS observatory East Node site and vessel transit corridor for the Vancouver Fraser Port Authority ECHO Program underwater listening station.

2.1 System Performance

The system performance is assessed for time offline and time redacted. Since the offline and redacted time has the greatest impact on the ambient noise reports, the system performance numbers, shown in Table 2.1, are reported with respect to lunar month. As shown in Figure 2.1 the ULS data was redacted for 1094 hours (11.7% of the project) and the system was offline for a total of 103 hours (1.1% of the project).

Table 2.1 System performance by lunar month since 26 Sep 2016.

Lunar Month			Redactions					Offline				
Duration [hrs]	Start	Stop	Start	Stop	Duration [hrs]	Total [hrs]	Total [%]	Start	Stop	Duration [hrs]	Total [hrs]	Total [%]
284.630	21:33 14Sep15	18:11 26Sep15	21:33 14Sep15 16:41 21Sep15	23:54 16Sep15 18:11 26Sep15	50.3 121.5	171.8	60.4%			0.0	0.0	0.0%
708.733	18:11 26Sep15	06:55 26Oct15	15:16 30Sep15 15:06 01Oct15 18:36 14Oct15 15:11 15Oct15 14:46 16Oct15	21:46 30Sep15 19:51 01Oct15 22:31 14Oct15 21:21 15Oct15 19:31 16Oct15	6.5 4.7 3.9 6.2 4.8	26.1	3.7%				0.0	0.0%
708.733	06:55 26Oct15	19:39 24Nov15	17:08 28Oct15 16:21 04Nov15 18:01 13Nov15 08:16 17Nov15 16:16 18Nov15 16:21 20Nov15	23:06 03Nov15 20:01 04Nov15 00:36 14Nov15 11:41 17Nov15 22:06 18Nov15 21:21 20Nov15	150.0 3.7 6.6 3.4 5.8 5.0	174.5	24.6%				0.0	0.0%
708.733	19:39 24Nov15	08:23 24Dec15	22:32 30Nov15	00:42 01Dec15	2.2	2.2	0.3%	22:41 27Nov15	02:17 28Nov15	3.6	3.6	0.5%
708.733	08:23 24Dec15	21:07 22Jan16	14:00 13Jan16 16:30 14Jan16	15:15 13Jan16 04:20 15Jan16	1.2 11.8	13.1	1.8%	03:21 11Jan16	06:45 11Jan16	3.4	3.4	0.5%
708.733	21:07 22Jan16	09:51 21Feb16	13:46 10Feb16 17:46 16Feb16 20:01 17Feb16	23:06 10Feb16 19:31 17Feb16 14:56 20Feb16	9.3 25.8 66.9	102.0	14.4%	19:31 17Feb16	20:01 17Feb16	0.5	0.5	0.1%
708.733	09:51 21Feb16	22:35 21Mar16	16:36 23Feb16 16:16 25Feb16 09:37 05Mar16 16:26 10Mar16	00:46 24Feb16 02:43 27Feb16 01:42 10Mar16 00:06 15Mar16	8.2 34.5 112.1 103.7	258.4	36.5%	07:28 02Mar16 01:47 10Mar16	09:37 05Mar16 16:26 10Mar16	74.1 14.6	88.8	12.5%
708.733	22:35 21Mar16	11:19 20Apr16	15:17 29Mar16 08:22 12Apr16 06:17 13Apr16 07:27 14Apr16 08:42 15Apr16 15:57 18Apr16 04:52 19Apr16	21:22 29Mar16 17:07 12Apr16 05:47 14Apr16 19:57 14Apr16 19:32 15Apr16 20:32 18Apr16 00:42 20Apr16	6.1 8.7 23.5 12.5 10.8 4.6 19.8	86.1	12.1%	20:37 18Apr16	03:37 19Apr16	7.0	7.0	1.0%
708.733	11:19 20Apr16	00:02 20May16	12:57 20Apr16 14:12 21Apr16 16:57 22Apr16	03:12 21Apr16 01:02 22Apr16 19:57 22Apr16	14.3 10.8 3.0	28.1	4.0%			0.0	0.0	0.0%
708.733	00:02 20May16	12:46 18Jun16	18:24 12Jul16 15:54 15Jul16 15:39 17Jul16	00:09 14Jul16 00:59 16Jul16 22:24 17Jul16	29.8 9.1 6.8	45.6	6.4%			0.0	0.0	0.0%
708.733	12:46 18Jun16	01:30 18Jul16	19:31 09Aug16 15:17 10Aug16	00:06 10Aug16 13:14 16Aug16	4.6 142	146.5	20.7%			0.0	0.0	0.0%
708.733	01:30 18Jul16	14:14 16Aug16	19:31 09Aug16 15:17 10Aug16	00:06 10Aug16 13:14 16Aug16	4.6 142	146.5	20.7%			0.0	0.0	0.0%
708.733	14:14 16Aug16	02:58 15Sep16			0.0	0.0	0.0%			0.0	0.0	0.0%
525.018	02:58 15Sep16	07Oct16			0.0	0.0	0.0%			0.0	0.0	0.0%

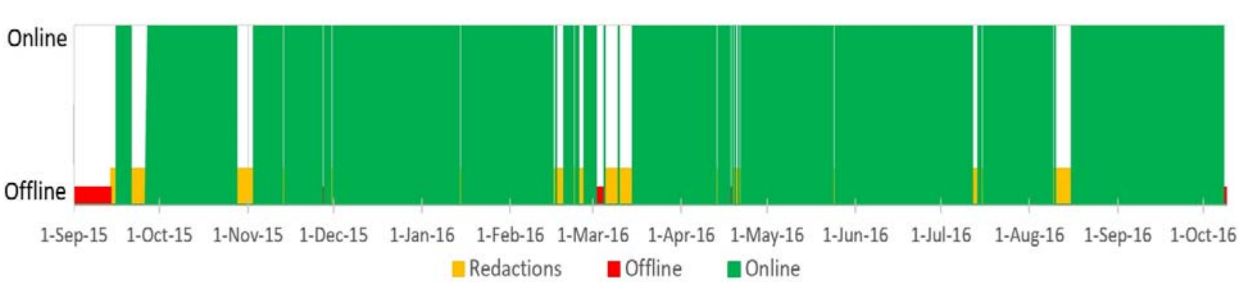


Figure 2.3 ULS status during the project.

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The severity of the redactions lead to discussions with the Canadian Forces several times during the feasibility project time period. The Canadian Forces have made significant changes in policy to reduce the number and duration of the redactions. This includes declassifying the acoustic signatures of some classes of warships and redacting only during tests instead of during the entire presence of a vessel at the Canadian Forces Maritime Test and Evaluation Range (CFMTER). The Canadian Forces have agreed to capture the full acoustic bandwidth data during a redaction period and post-process the data so that as much data as possible can be returned to ONC. This data could then be included in the ambient noise reporting after being reprocessed by JASCO's PAMView software. The Canadian Forces have agreed to allow real time reporting of redaction events to VFPA so any impacts on vessel measurement projects can have an immediate assessment by VFPA. The Canadian Forces will also assess specific ECHO program research project schedules, given sufficient warning via ONC, and determine if there are scheduling conflicts.

A failure of the data diversion switch accounted for 85 % of the system offline time. This was the first failure of the switch in ten years. Three days were needed to obtain the parts and bring in personnel to access the secure area of the shore station to make the repair. The military are assessing procedures to have personnel with the appropriate clearances available to address potential future failures.

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3 Ambient noise measurement

Ambient noise measurements are made to assess the acoustic energy underwater from all acoustic sources: anthropogenic, marine fauna, weather, currents and geophysical sources. Ambient noise analysis is one of many methods to assess the health of an ecosystem and the anthropogenic impact on it.

An ambient noise report is generated for each synodic lunar month (29 days, 12 hours, 44 minutes). The ECHO Acoustic Technical Committee recommended the lunar month reporting period, to address the cyclical variation of tidal currents which could introduce non-acoustic noise into the measurements; the hope is that the tidal currents averaged over the cycle will be more consistent than if the averaging period is not synchronized with the cycle.

Within each report the ambient noise is assessed in three time formats; lunar monthly, weekly and daily. The lunar monthly ambient noise assessment is correlated to the tidal cycle discussed above. Assessments of ambient noise on a weekly period are suited to evaluating anthropogenic noise sources since this timing is more correlated with human work and recreation cycles. The assessment of the daily ambient noise highlights diurnal patterns such as day/night and daily scheduled vessel movements.

Ambient noise reports for each lunar month of Year 1 are provided as Appendix A.1 to this report.

3.1 Interpreting the ambient noise report

This section is a generic description of the ambient noise report. Page 1 of the ambient noise report shows the reporting schedule of each lunar month and week assessed in the report. Page 2 is a textual identification of the ambient noise reporting period and a description of the various presentation formats used in the report. Examples of the data graphics on Pages 3 to 8 of the ambient noise report are shown in Figures 3.1 and 3.2.

The first graphic on Page 3 of the ambient noise report, the broadband and decade band SPL versus time plots, shows the hourly variability of the ambient noise over the lunar month. The broadband plot is the total SPL for the frequency range of 10 Hz to 32 kHz. The four decade band plots show the contribution to the SPL from the 10 to 100 Hz, 100 to 1000 Hz, 1 to 10 kHz, and 10 to 32 kHz bands, respectively. During a redaction event all acoustic data below 4 kHz are filtered out to protect acoustic signatures with national security implications. During these events the SPL values in the 10 to 100 and 100 to 1000Hz bands will become undetectable and drop off the charts in the report. The SPL values in the 1 to 10 kHz and 10 Hz to 32 kHz bands will show marked decreases of roughly 10 to 15 dB and the 10 kHz to 32 kHz band will remain unaffected.

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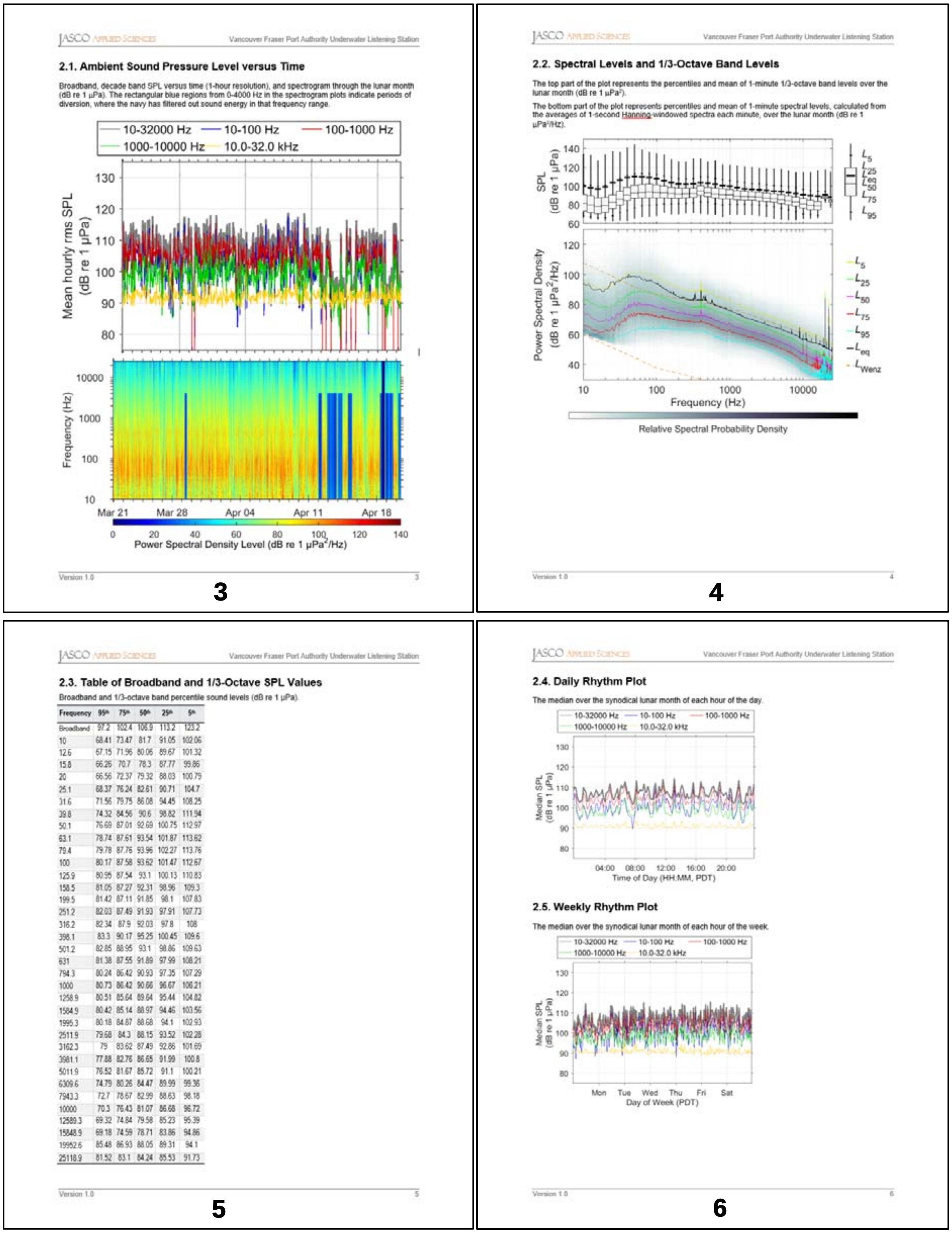

Frequency	95th	75th	50th	25th	5th
Broadband	97.2	102.4	106.9	113.2	123.2
10	68.41	73.47	81.7	91.05	102.06
12.6	67.15	71.96	80.06	89.67	101.32
15.8	66.26	70.7	78.3	87.77	99.86
20	66.56	72.37	79.32	88.03	100.79
25.1	68.37	76.24	82.61	90.71	104.7
31.6	71.56	79.75	86.08	94.45	108.25
39.8	74.32	84.56	90.6	98.82	111.94
50.1	76.69	87.01	92.69	100.75	112.97
63.1	78.74	87.61	93.54	101.87	113.62
79.4	79.78	87.76	93.96	102.27	113.76
100	80.17	87.58	93.62	101.47	112.67
125.9	80.95	87.54	93.1	100.13	110.83
158.5	81.05	87.27	92.31	98.96	109.3
199.5	81.42	87.11	91.85	98.1	107.83
251.2	82.03	87.49	91.93	97.91	107.73
316.2	82.34	87.9	92.03	97.8	108
398.1	83.3	90.17	95.25	100.45	109.6
501.2	82.85	88.95	93.1	98.86	109.63
631	81.38	87.55	91.89	97.99	108.21
794.3	80.24	86.42	90.93	97.35	107.29
1000	80.73	86.42	90.66	96.67	106.21
1258.9	80.51	85.64	89.64	95.44	104.82
1584.9	80.42	85.14	88.97	94.46	103.56
1995.3	80.18	84.87	88.68	94.1	102.93
2511.9	79.68	84.3	88.15	93.52	102.28
3162.3	79	83.62	87.49	92.86	101.69
3981.1	77.88	82.76	86.65	91.99	100.8
5011.9	76.52	81.67	85.72	91.1	100.21
6309.6	74.79	80.26	84.47	89.99	99.36
7943.3	72.7	78.67	82.99	88.63	98.18
10000	70.3	76.43	81.07	86.68	96.72
12589.3	69.32	74.84	79.58	85.23	95.39
15848.9	69.18	74.59	78.71	83.86	94.86
19952.6	85.48	86.93	88.05	89.31	94.1
25118.9	81.52	83.1	84.24	85.53	91.73

Figure 3.1 Pages 3 to 6 of an example ambient noise report.

The second graphic on Page 3 of the ambient noise report, the spectrogram for the lunar month, shows the power spectral density variability on an hourly basis. The low power spikes in blue reaching up to 4

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kHz are indicative of the same redactions described in the preceding paragraph. The dark blue band extending from 0 to 25 kHz is indicative of a data gap due to maintenance or system failures. Occasionally 6 hour cyclic power variations in the 10 to 20 Hz range can be seen and are generally related to tidal flow noise, though earthquake noise can sometimes be seen in this frequency range as well.

The plots on Page 4 of the ambient noise report show the 1/3-octave band levels and spectral levels for the lunar month. The 5th (L_5), 25th (L_{25}), 50th (L_{50}), 75th (L_{75}), and 95th (L_{95}) percentile levels are computed from 1 minute SPL averages throughout the lunar month. The L_{50} values are commonly referred to as the median. The percentiles represent the percentage of time the ambient noise is greater than the SPL (in dB) at that frequency over the course of the lunar month. Therefore, L_5 values represent sound levels exceeded during the highest 5% of time. Spikes in the L_5 plot are indicative of high intensity short duration tones likely from a particularly noisy vessel. Spikes in the L_{95} plot are indicative of persistent tonals and may indicate systematic contamination of the environment, such as nearby pumps or noisy electrical power supplies. The mean levels (L_{eq}) are also shown on the plots. The mean level is the average SPL computed in the linear domain. Very high intensity but short duration sounds such as vessel transits affect the mean level whereas the median level (L_{50}) tends to minimize transient signals and enhance the visibility of long duration sound levels. Since vessels typically emit intense underwater noise at low frequencies, the mean level will normally be far above the median at low frequencies in areas with significant vessel traffic. The shaded region of the spectral plot shows the relative spectral probability density. The darker the shading the more time is spent at that power level during the lunar month. The spectral probability density is an excellent tool to identify modes in the ambient noise. An example of a site with two acoustic noise modes would be a site near an anchorage where one mode of ambient noise levels would be with no ship at anchor and another mode would be the ambient noise condition while a ship is at the anchorage. The orange dashed lines (L_{Wenz}), shown on the lower figure on page 4 of the ambient report, represent the quiet and loud open ocean noise levels as reported by Wenz (1962). The Wenz limits are often used by acousticians to provide a relative perspective for the spectral levels reported. The quiet Wenz limit indicates zero sea state, no shipping and no biological noise. The loud Wenz limit indicates severe weather and heavy shipping.

Page 5 of the ambient noise report contains a tabular presentation of the 1/3-octave band and broadband results.

The daily rhythm plot on Page 6 of the ambient noise report shows the lunar monthly median SPL for each 5 minute period of the local day. This is used to identify daily repeating sound levels. The medians are plotted for broadband noise as well as the contribution from the four decadal frequency bands. Plotting the daily cadences can reveal patterns associated with human activity such as ferries or other regular vessel passages.

The weekly rhythm plot on Page 6 of the ambient noise report is similar to the daily rhythm plot but the median SPL is presented for each 5 minute period of a 7 day week. Plotting the weekly cadences can reveal patterns associated with human activity that varies according to a weekly schedule.

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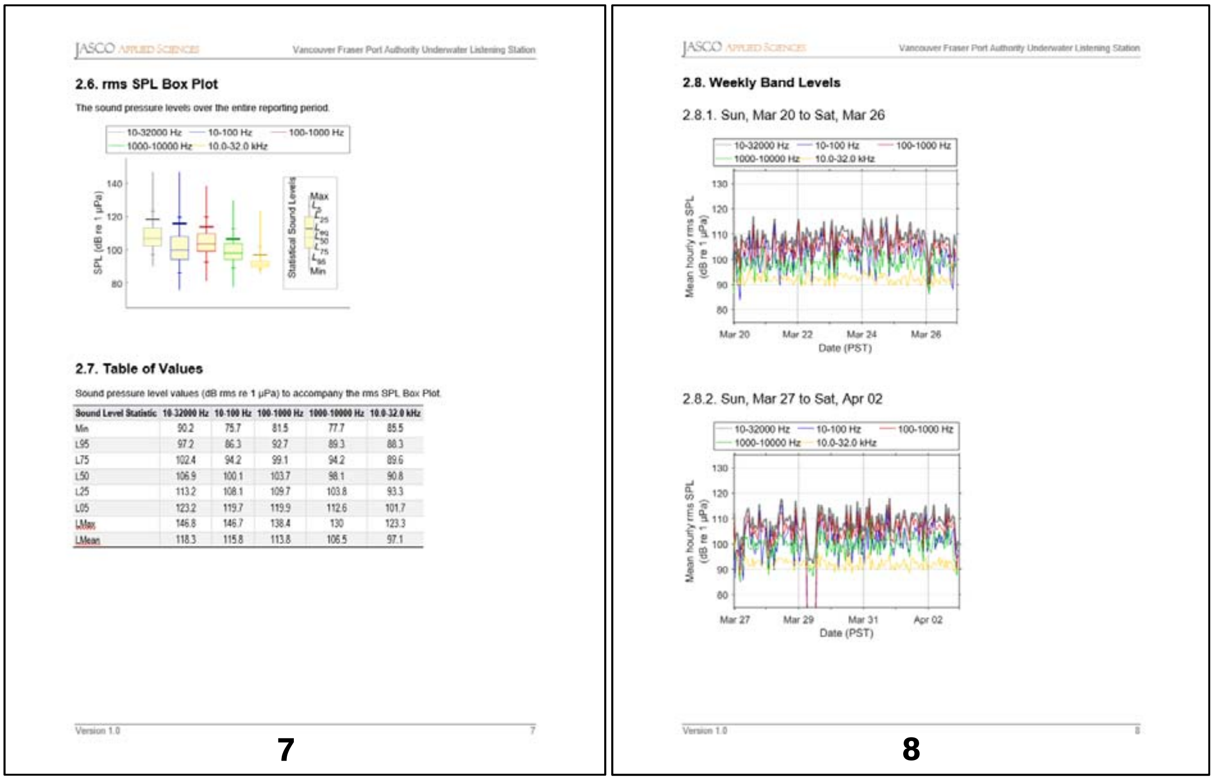
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2.6. rms SPL Box Plot

The sound pressure levels over the entire reporting period.

2.7. Table of Values

Sound pressure level values (dB rms re 1 µPa) to accompany the rms SPL Box Plot.

Sound Level Statistic	10-32000 Hz	10-100 Hz	100-1000 Hz	1000-10000 Hz	10.0-32.0 kHz
Min	90.2	75.7	81.5	77.7	85.5
L95	97.2	86.3	92.7	89.3	88.3
L75	102.4	94.2	99.1	94.2	89.6
L50	106.9	100.1	103.7	98.1	90.8
L25	113.2	108.1	109.7	103.8	93.3
L05	123.2	119.7	119.9	112.6	101.7
LMax	146.8	146.7	138.4	130	123.3
LMean	118.3	115.8	113.8	106.5	97.1

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2.8. Weekly Band Levels

2.8.1. Sun, Mar 20 to Sat, Mar 26

2.8.2. Sun, Mar 27 to Sat, Apr 02

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Figure 3.2 Pages 7 and 8 of an example ambient noise report.

Page 7 of the ambient noise report contains an rms SPL box plot of the noise for the broadband and decadal bands. A table of the specific values is also included.

Note that the data presented in pages 4, 5, 6, and 7 of the ambient noise reports does not include the redacted periods. Including the redacted data in the reports causes large negative biases in the data below 4 kHz.

Pages 8 and beyond of the report show the broadband and decadal band SPLs for each of the individual weeks of the lunar month. There may be two or three pages of these weekly band level plots. As shown in the page 8 example, there are occasional drops in the weekly band level plots, these are due to redactions in the data.

3.2 Summary of the ambient noise reports

The automated ambient noise reports for the Year 1 feasibility project are attached as Appendix A.1. Figures 3.3, 3.4 and 3.5 show the yearly trends of the 95th, 50th and 5th percentiles respectively.

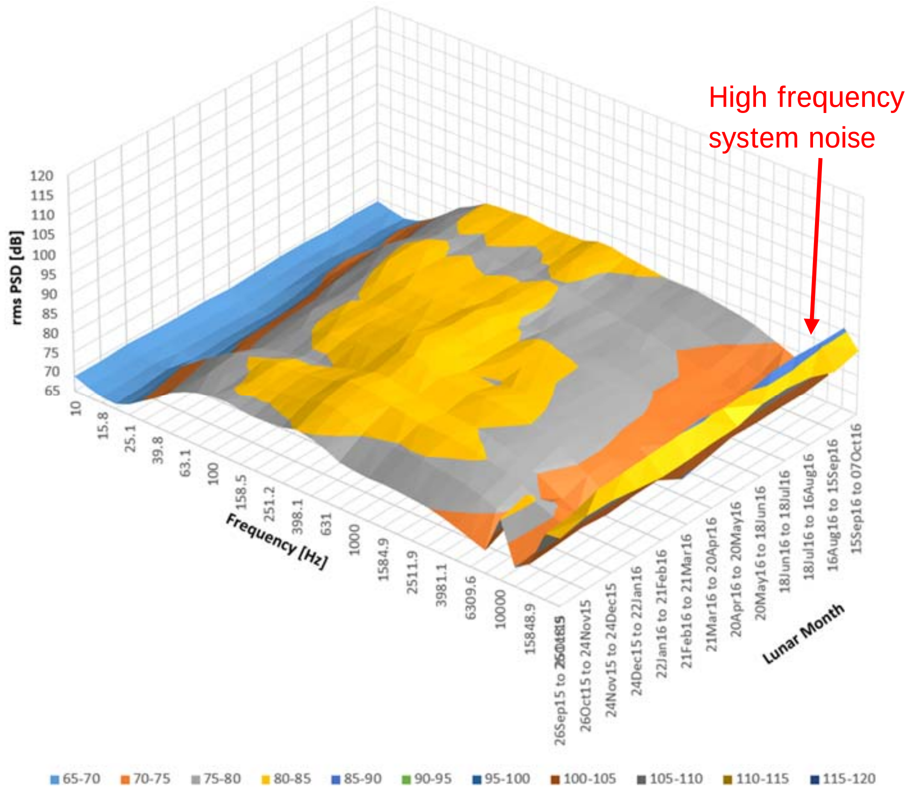

Figure 3.3 Underwater Listening Station 95th percentile trend.

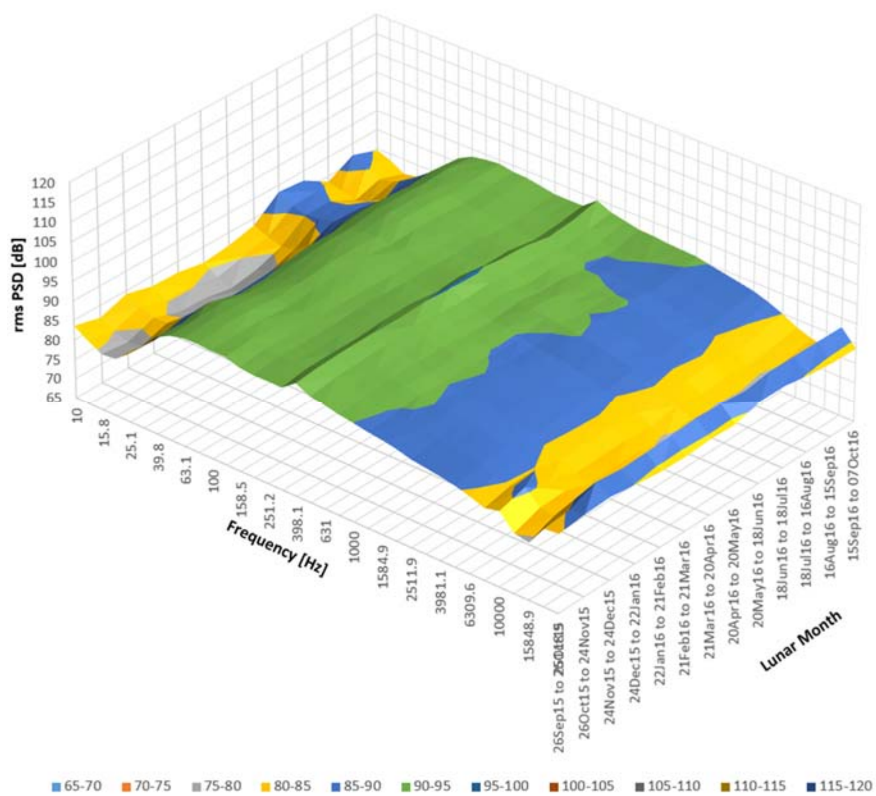

Figure 3.4 Underwater Listening Station 50th percentile trend

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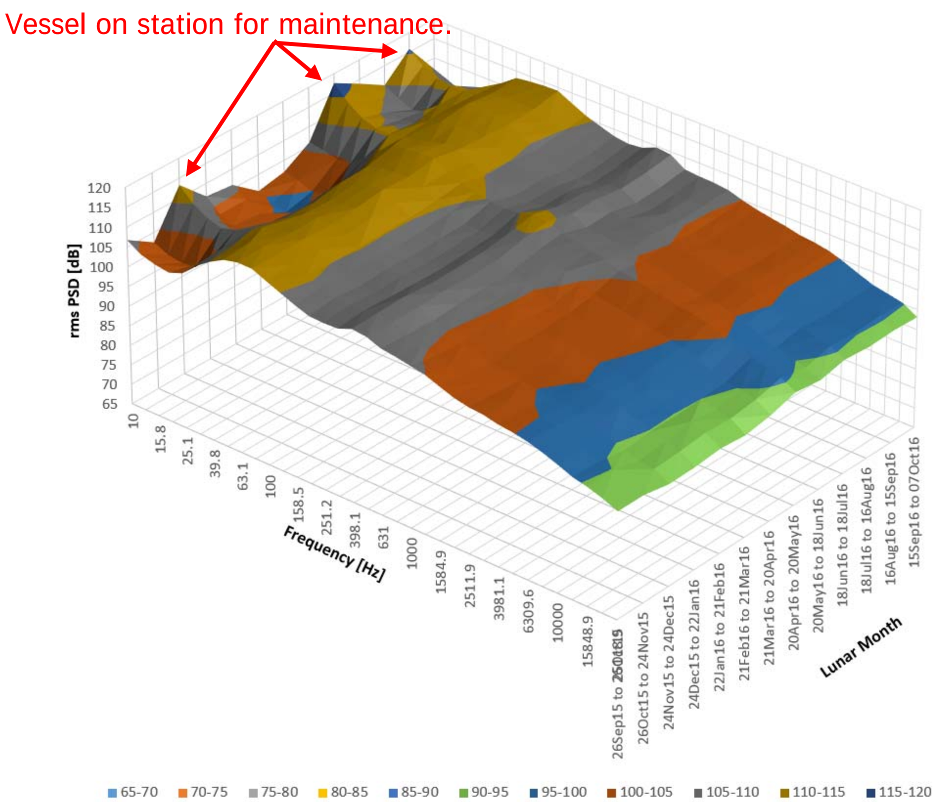

Figure 3.5 Underwater Listening Station 5th percentile trend

As expected for a busy, confined, coastal waterway the L_{eq} underwater sound levels above 30 Hz, as shown on page 4 in the ambient noise reports, are high with respect to the Wenz open ocean, high shipping traffic, reference level. The monthly mean levels, L_{eq}, exceed the median levels, L_{50}, by 10 to 20 dB indicating significant high intensity short duration sound sources, which is also consistent with a heavily trafficked waterway.

The daily rhythm plots in the monthly reports show SPL peaks at specific times each day. These are attributable to vessels which make scheduled transits at the same time every day. The magnitude (7 to 15 dB) and continuity of the spikes in the daily SPL data throughout the project year highlight the impact of the daily scheduled vessel transits on the soundscape of the Strait of Georgia.

Most vessels passing the ULS generate 10 dB spikes in the mean hourly rms SPL plots (page 3 of the reports) for each month however, large (15 to 30 dB) spikes occasionally occur. The large spikes are associated with vessels radiating strongly in the 10 to 30 Hz frequency bands. At locations further away from the shipping lanes than the ULS, these spikes will be of lower amplitude above nominal ambient levels but of longer duration. Also, lower frequency vessel sounds will be attenuated more rapidly than mid-frequency sounds (i.e. >100 Hz) due to the dipole radiation pattern caused by the Lloyd mirror effect.

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4 Marine fauna detections

The marine fauna detection assessment summarizes automatic-detections of marine fauna vocalizations made at the underwater listening station. This will help analysts assess the habitat usage with respect to time. Automatic detectors have been developed for killer whale, humpback whale, pacific white sided dolphin and fish-like sounds. The fish-like sounds in the north east Pacific are not well understood by the scientific community. As a result, the fish-like sound detection data has a higher uncertainty than that of the marine mammal detection data.

Random portions of the PAMView automatic detection and classification results are manually vetted prior to generation of the monthly marine fauna reports. All monthly reports for Year 1 are attached as Appendix A.2. During the Year 1 feasibility project, extensive manual classification vetting ensured the marine mammal report was accurate and false positive detections were used to help improve the classifier software.

4.1 Interpreting the marine fauna report

Example plots from the marine fauna report are shown in Figure 4.1. The pie chart in Figure 4.1-A shows the relative number of vocalizations by fauna for the month.

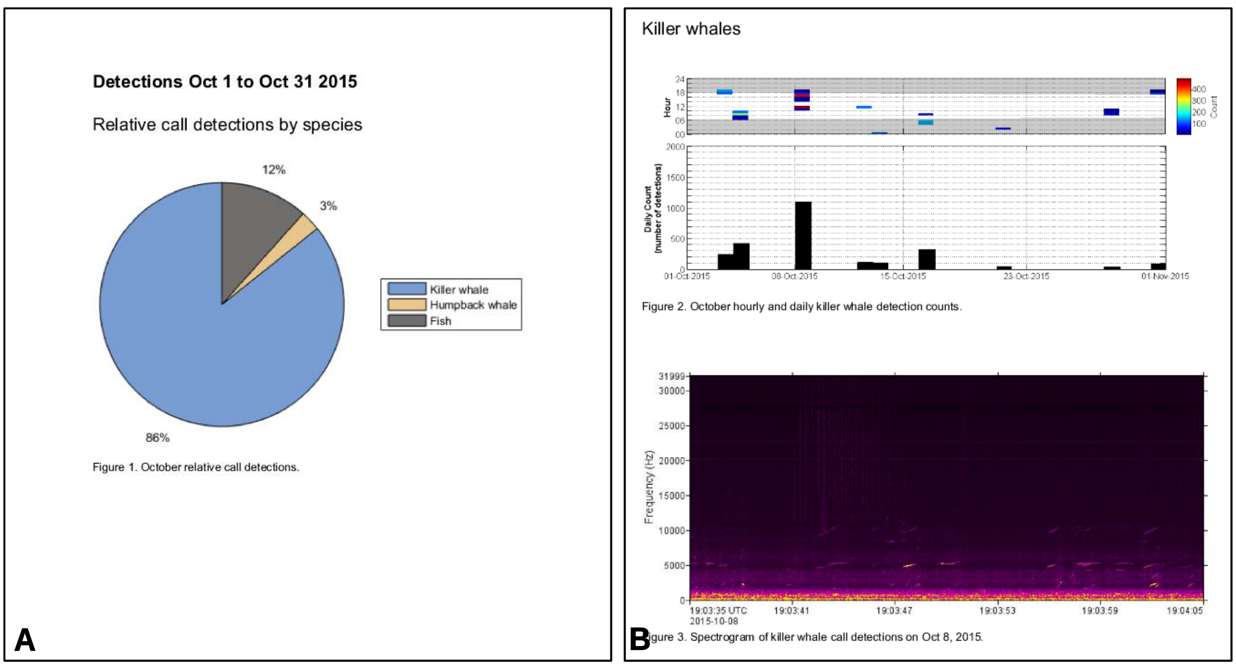

Figure 4.1 Example plots from the marine mammal report A) Pie chart of relative detections by fauna for the month, B) species specific plots including; time of day of the detections, histogram of detections per day, and an example spectrogram showing a typical vocalization.

Figure 4.1-B shows the species specific plots. The top plot is the time of day when the detections occurred for that species. This plot allows the reader to assess the diurnal patterns of the vocalizations. The middle plot is a histogram of the number of detections per day for the month for the species. The bottom plot is a representative spectrogram for the species to show how the vocalizations vary with frequency and intensity in time. These three plots are duplicated for each species detected that month.

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4.2 Summary of the marine fauna reports

Table 4.1 shows the total number of vocalization detections per month by species or type. These detections were automatically detected by JASCO Applied Sciences' PAMView software and then reviewed by JASCO analysts to remove false positive detections. Note that an individual animal can make many vocalizations in a short period of time. Each grunt, call and echolocation click is treated as an individual detection. Thus the number of detections does not equate to the number of animals detected. For example, the high number of humpback whale detections in December 2015 occurred almost entirely within a 5-day period. It is likely that a small number of individuals account for these vocalizations.

Table 4.1 – Number of vocalizations detected per month by species or type.

Month	Fish-like sounds		Humpback whale		Killer whale		Pacific white sided dolphin	
	Number of detections	Days with detections	Number of detections	Days with detections	Number of detections	Days with detections	Number of detections	Days with detections
Sep-15	14	1/10	0	0/10	3091	5/10	0	0/10
Oct-15	342	16/31	79	1/31	2526	9/31	0	0/31
Nov-15	219	12/30	12	1/30	0	0/30	0	0/30
Dec-15	0	0/31	3670	8/31	111	4/31	0	0/31
Jan-16	120	8/31	0	0/31	0	0/31	0	0/31
Feb-16	218	13/29	0	0/29	17	1/29	0	0/29
Mar-16	118	3/31	0	0/31	0	0/31	0	0/31
Apr-16	444	11/30	0	0/30	148	5/30	0	0/30
May-16	1652	19/31	0	0/31	338	7/31	0	0/31
Jun-16	2517	29/30	0	0/30	1053	8/30	0	0/30
Jul-16	1059	17/31	0	0/31	464	9/31	0	0/31
Aug-16	1090	17/31	0	0/31	3333	16/31	0	0/31
Sep-16	481	14/30	0	0/30	2027	10/30	0	0/30

Figure 4.2 Marine fauna vocalization detections during Year 1 of the project. A) The number of days in the calendar month with vocalizations. B) Number of fish-like vocalizations per month. C) Number of humpback whale vocalizations per month. D) Number of killer whale vocalizations per month.

Fish-like calls were detected in all months except December with the peak number of calls occurring in June. There were 8274 fish-like calls detected and they occurred in 160 of the 376 days.

Humpback vocalizations were only detected in the months of Oct, Nov and Dec, with maximum detections recorded in the month of December. There were 3761 humpback whale vocalizations detected and they occurred in 10 of the 376 days.

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Killer whale detections were primarily recorded between the months of April to October, with peak detections recorded in August 2016 and September 2015. Significantly lower to no killer whale detections were recorded between the months of Nov and March. There were 13108 killer whale vocalizations detected and they occurred in 74 of the 376 days.

No pacific white sided dolphin vocalizations were detected in Year 1.

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5 Vessel underwater acoustic source levels

Vessels emit sound underwater while they are operating. Some of this noise is generated by systems operating on, or within, the vessel but typically most of the sound energy is produced by the propulsion system. As marine traffic levels increase, sound levels underwater increase correspondingly, particularly for low frequency (10-50 Hz) sound[1]. The underwater acoustic energy caused by vessel traffic can stress marine life by interfering with sounds used by fauna for social, reproductive, navigation, predator avoidance and feeding. The extent to which underwater noise impacts marine mammals, fish and invertebrates is generally poorly understood. However, the impact likely varies between species and depends on the nature of the sounds produced (i.e. frequency distribution, duration, and temporal structure). These characteristics are influenced by vessel class; for example, small vessels typically generate lower overall sound levels than larger vessels but may produce higher sound levels at high frequencies. The vessel classes considered in the ULS project are outlined in Appendix A.3

5.1 Vessel source level measurements

The Underwater Listening Station project generates automatic vessel source level reports when a vessel transits accurately through the listening station measurement zone shown in figure 2.2. Examples of the automated reports are provided in Appendix A.4. Manual reports, containing additional information, were provided for specific vessels as requested by VFPA, examples are shown in Appendix A.5.

Source level measurements are made as close as possible to the ANSI/ASA S12.64-2009/Part 1 standard on the Quantities and Procedures for Description and Measurement of Underwater Sound from Ships – Part 1: General Requirements, grade C. Deviations from the standard include the water depth versus vessel length which is constrained by the 170 m water depth, bottom mounted hydrophones due to the strong currents in the Strait of Georgia, and the calculation of monopole source levels (MSL) in addition to the standard radiated noise levels (RNL) of the standard, and the measurement of a single pass (port aspect) of the vessel past the ULS. The single pass measurement results from the requirement to not impede the vessel schedule.

The vessels are tracked by Automatic Identification System (AIS) reports from the vessel. If the vessel travels through the transit corridor at a constant speed, and there are no nearby acoustic noise sources the received sound levels of the vessel will be measured at the closest point of approach (CPA) of the vessel to the ULS. The acoustic measurement is integrated over a time corresponding to ± 30º off the port beam of the vessel. This is done to average the constructive and destructive interference of the sea surface and bottom acoustic reflections. Once the acoustic received level is recorded at the hydrophone a correction is applied to compensate for the transmission losses due to the range of the vessel from the hydrophone. The corrected acoustic level is the vessel RNL normalized to 1 m from the acoustic centre of the vessel. The software also computes the vessel acoustic centre depth from the Lloyd mirror pattern and calculates the MSL for the vessel.

The most common reason for failing to generate a vessel source level report was that a vessel transited outside the defined measurement corridor. Other reasons for reporting failures included turning or

[1] Mark A. McDonald, DRD, John A. Hildebrand, Sean M. Wiggins, and DRD, *Increases in deep ocean ambient noise in the Northeast Pacific west of San Nicolas Island, California*, The Journal of the Acoustical Society of America 2006 120:2, 711-718

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accelerating inside the measurement corridor, and interference of noise from other nearby vessels at time of measurement.

5.2 ULS Vessel classes

For the purposes of this report, **vessel type** will refer to vessel categories defined by the Maritime Mobile Service Identity (MMSI), Marine Traffic designations or AIS and **ULS vessel class** will refer to the VFPA ULS grouping of vessels by similar cargo, length, and displacement.

Since there is little scientific evidence on what constitutes an acceptable threshold for noise levels from anthropogenic sources such as vessels, the underwater listening station project within the ECHO Program is intending to use a relative ranking for each vessel by comparing the vessel's source level to other vessels in its ULS vessel class that have been measured by the underwater listening station. This requires careful classification of vessels to provide a fair comparison. Based on the data collected to date, the minimum number of measured vessels within each ULS vessel class has been revised to 100. The number of classes should be low to allow sufficient vessel numbers in each ULS vessel class. There are presently 27 ULS vessel classes which can be reported however, only 16 classes obtained valid vessel transits during Year 1. As more data is obtained in future phases of the ULS project the ULS vessel classification may be revised. A detailed description of the present classification scheme is detailed in Appendix A.3.

At this stage of the project we are coming close to having sufficient vessel data in five ULS vessel classes (bulkers <200m, bulkers >200m, container ships >200m, ferries >50m, and tugs <50m) to establish the relative rankings required to perform relative assessments of a vessel's performance. The ULS vessel class indicators are shortly due to be enabled in the automated source level reports for classes that have acquired enough measurements. As more data are obtained, the remaining ULS vessel class ranking indicators will be enabled.

5.3 Interpreting the vessel underwater acoustic source level reports

An example source level report, generated by JASCO's PortListen software, is shown in Figure 5.1. There are two pages to the report. Page 1 identifies the vessel, provides key measurement parameters, shows the measured source levels and shows the ranking of the vessel within its ULS vessel class. Since VFPA may send individual reports to ship owners, Page 2 provides an explanation of the report and additional environmental data useful to experts evaluating the ship's measurements.

As identified on Page 1 of the report, the vessel information is derived from the AIS data transmitted by the ship. This information is constant for the vessel. The ULS vessel class is derived from the AIS data and grouped according to the scheme detailed in Appendix A.3.

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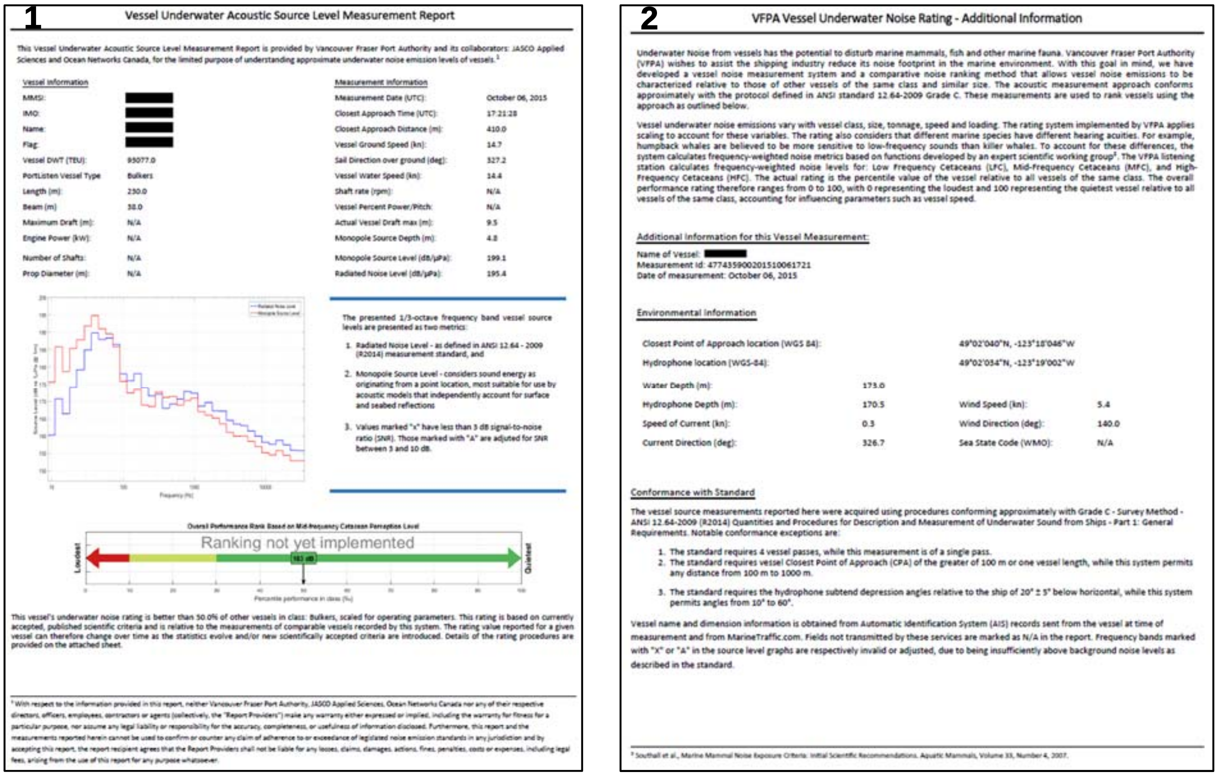

1 Vessel Underwater Acoustic Source Level Measurement Report

This Vessel Underwater Acoustic Source Level Measurement Report is provided by Vancouver Fraser Port Authority and its collaborators: JASCO Applied Sciences and Ocean Networks Canada, for the limited purpose of understanding approximate underwater noise emission levels of vessels.[1]

Vessel information		Measurement information	
MMSI:	[redacted]	Measurement Date (UTC):	October 06, 2015
IMO:	[redacted]	Closest Approach Time (UTC):	17:21:28
Name:	[redacted]	Closest Approach Distance (m):	410.0
Flag:	[redacted]	Vessel Ground Speed (kn):	14.7
Vessel DWT (TEU):	95077.0	Sail Direction over ground (deg):	327.2
PortListen Vessel Type	Bulkers	Vessel Water Speed (kn):	14.4
Length (m):	230.0	Shaft rate (rpm):	N/A
Beam (m)	38.0	Vessel Percent Power/Pitch:	N/A
Maximum Draft (m):	N/A	Actual Vessel Draft max (m):	9.5
Engine Power (kW):	N/A	Monopole Source Depth (m):	4.8
Number of Shafts:	N/A	Monopole Source Level (dB/µPa):	199.1
Prop Diameter (m):	N/A	Radiated Noise Level (dB/µPa):	195.4

The presented 1/3-octave frequency band vessel source levels are presented as two metrics:

1. Radiated Noise Level - as defined in ANSI 12.64 - 2009 (R2014) measurement standard, and
2. Monopole Source Level - considers sound energy as originating from a point location, most suitable for use by acoustic models that independently account for surface and seabed reflections
3. Values marked "x" have less than 3 dB signal-to-noise ratio (SNR). Those marked with "A" are adjuted for SNR between 3 and 10 dB.

This vessel's underwater noise rating is better than 50.0% of other vessels in class: Bulkers, scaled for operating parameters. This rating is based on currently accepted, published scientific criteria and is relative to the measurements of comparable vessels recorded by this system. The rating value reported for a given vessel can therefore change over time as the statistics evolve and/or new scientifically accepted criteria are introduced. Details of the rating procedures are provided on the attached sheet.

[1] With respect to the information provided in this report, neither Vancouver Fraser Port Authority, JASCO Applied Sciences, Ocean Networks Canada nor any of their respective directors, officers, employees, contractors or agents (collectively, the "Report Providers") make any warranty either expressed or implied, including the warranty for fitness for a particular purpose, nor assume any legal liability or responsibility for the accuracy, completeness, or usefulness of information disclosed. Furthermore, this report and the measurements reported herein cannot be used to confirm or counter any claim of adherence to or exceedance of legislated noise emission standards in any jurisdiction and by accepting this report, the report recipient agrees that the Report Providers shall not be liable for any losses, claims, damages, actions, fines, penalties, costs or expenses, including legal fees, arising from the use of this report for any purpose whatsoever.

2 VFPA Vessel Underwater Noise Rating - Additional Information

Underwater Noise from vessels has the potential to disturb marine mammals, fish and other marine fauna. Vancouver Fraser Port Authority (VFPA) wishes to assist the shipping industry reduce its noise footprint in the marine environment. With this goal in mind, we have developed a vessel noise measurement system and a comparative noise ranking method that allows vessel noise emissions to be characterized relative to those of other vessels of the same class and similar size. The acoustic measurement approach conforms approximately with the protocol defined in ANSI standard 12.64-2009 Grade C. These measurements are used to rank vessels using the approach as outlined below.

Vessel underwater noise emissions vary with vessel class, size, tonnage, speed and loading. The rating system implemented by VFPA applies scaling to account for these variables. The rating also considers that different marine species have different hearing acuities. For example, humpback whales are believed to be more sensitive to low-frequency sounds than killer whales. To account for these differences, the system calculates frequency-weighted noise metrics based on functions developed by an expert scientific working group[2]. The VFPA listening station calculates frequency-weighted noise levels for: Low Frequency Cetaceans (LFC), Mid-Frequency Cetaceans (MFC), and High-Frequency Cetaceans (HFC). The actual rating is the percentile value of the vessel relative to all vessels of the same class. The overall performance rating therefore ranges from 0 to 100, with 0 representing the loudest and 100 representing the quietest vessel relative to all vessels of the same class, accounting for influencing parameters such as vessel speed.

Additional Information for this Vessel Measurement:

Name of Vessel: [redacted]
Measurement Id: 477435900201510061721
Date of measurement: October 06, 2015

Environmental Information

Closest Point of Approach location (WGS 84):		49°02'040"N, -123°18'046"W	
Hydrophone location (WGS-84):		49°02'034"N, -123°19'002"W	
Water Depth (m):	173.0		
Hydrophone Depth (m):	170.5	Wind Speed (kn):	5.4
Speed of Current (kn):	0.3	Wind Direction (deg):	140.0
Current Direction (deg):	326.7	Sea State Code (WMO):	N/A

Conformance with Standard

The vessel source measurements reported here were acquired using procedures conforming approximately with Grade C - Survey Method - ANSI 12.64-2009 (R2014) Quantities and Procedures for Description and Measurement of Underwater Sound from Ships - Part 1: General Requirements. Notable conformance exceptions are:

1. The standard requires 4 vessel passes, while this measurement is of a single pass.
2. The standard requires vessel Closest Point of Approach (CPA) of the greater of 100 m or one vessel length, while this system permits any distance from 100 m to 1000 m.
3. The standard requires the hydrophone subtend depression angles relative to the ship of 20° ± 5° below horizontal, while this system permits angles from 10° to 60°.

Vessel name and dimension information is obtained from Automatic Identification System (AIS) records sent from the vessel at time of measurement and from MarineTraffic.com. Fields not transmitted by these services are marked as N/A in the report. Frequency bands marked with "X" or "A" in the source level graphs are respectively invalid or adjusted, due to being insufficiently above background noise levels as described in the standard.

[2] Southall et al., Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. Aquatic Mammals, Volume 33, Number 4, 2007.

Figure 5.1 Example two-page ship source level report.

The measurement information provided on Page 1 of the report contains information about the vessel and the underwater listening station measurements which are unique to that measurement event. Variations in the vessel's configuration and operation at the time of the measurement can have a large effect on the vessel source level. The closest point of approach (CPA) is the time at which the vessel was closest to the hydrophone array. The vessel ground speed is determined from the AIS data and the acoustic record using a cepstrogram method that measures the rate of change of the Lloyd mirror interference pattern. The sail direction is the heading of the vessel during the time of the measurement. The in-water speed (of the vessel) is derived from the ground speed and the sea surface current. The propeller shaft rate, power and draft are obtained from the AIS data transmitted from the vessel, when broadcast. The monopole depth is calculated from the acoustic data, also using a cepstrogram method, and represents the depth below the sea surface of the acoustic centre of the vessel. Knowing the depth of the acoustic centre of the vessel allows acousticians to accurately model the effect of acoustic reflections from the sea surface and bottom. The ***monopole source level*** is the broadband underwater acoustic energy level radiated from the acoustic center of the vessel before it interacts with its surface-reflected signal. The ***radiated noise level*** is the measured broadband underwater acoustic energy level as defined by the ANSI 12.64-2009 (R2014) standard, and is modulated by the constructive and destructive interference from surface and bottom reflections.

The source level plot on Page 1 of the source level report, shows both the radiated noise level and monopole source level measurements of the vessel. The acoustic energy is presented in 1/3- octave frequency bands from 10 Hz to 32 kHz. The logarithmic frequency scale of the horizontal axis makes the frequency bin sizes appear to be of equal size. The vertical scale of the plot is the RNL or MSL in decibels (dB) which is a logarithmic expression related to the acoustic intensity. The source level is calculated

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from the ratio of the measured RMS acoustic pressure (p) and a reference RMS acoustic pressure (p_o) of 1 µPa using the formula $SL_{dB} = 20 \log(p/p_o)$. A three dB increase in source level represents twice the acoustic power (under the assumption that power is proportional to p^2); a 10 dB increase is 10 times the acoustic power; 20 dB is 100 times and 30 dB is 1000 times the power. Logarithmic scales are used since acoustic pressures commonly vary over many orders of magnitude and are often difficult to represent in linear plots. The logarithmic decibel scale allows a wide range of amplitudes to be plotted on a single graph. The logarithmic scale in both intensity and frequency also better reflects the way human (and likely marine mammal) hearing perceives acoustic intensity.

An X in a frequency bin on the source level plot of Figure 5.1 indicates that the background noise in that frequency bin was within 3 dB of the measured value, and consequently too high to allow accurate processing of a source level for that frequency band. High background noise can be caused by other vessels in the area, marine mammal vocalizations, waves and rain. The ANSI standard requires application of this 3 dB criterion. Bands marked with an "A" have ambient noise levels between 3 and 10 dB less than the measurement. These bands have had their values adjusted according to the method prescribed by the standard. The unmarked frequency bins meet the signal to noise requirement for ANSI standard accuracy.

The vessel noise emission level rating is a method developed for the Vancouver Fraser Port Authority, by JASCO Applied Sciences and Ocean Networks Canada, to characterize a vessel's source level relative to other vessels of the same ULS vessel class. The underlying acoustic source level measurement conforms approximately with the protocol outlined in ANSI standard 12.64-2009 Grade C. Vessel underwater noise emissions vary with vessel class, size, tonnage, speed and loading. The rating considers that different marine species have different hearing acuities. For example, humpback whales are believed to be more sensitive to low-frequency (e.g. less than 1 kHz) sounds than killer whales. To account for these differences, the system calculates a frequency-scaled noise metric based on functions developed by an expert scientific working group (Southall, 2007)[2]. The vessel rating system provides a noise rating based on the scaling functions specified for mid-frequency cetaceans, such as the endangered southern resident killer whales. The vessel rating number in dB is the cetacean frequency band weighted SPL of the measured vessel.

An overall performance ranking is calculated as the vessel's broadband weighted SPL as a percentile relative to other vessels in the ULS vessel class. There was insufficient class data at the time of reporting to accurately produce this ranking so the indicator is labelled 'not enough data'. The ranking analysis results will be implemented for some of the classes in Year 2 of the feasibility study as more data becomes available.

The additional environmental information section on Page 2 is intended for acousticians performing detailed analysis and comparisons of the vessel source level measurements.

5.4 Summary of the vessel source level reports for year one

There were 1002 valid vessel transits past the ULS during Year 1 of the ULS project, 317 of which were piloted vessels. Of the 27 ULS classes, 16 classes had one or more valid vessel transits. The valid vessel

[2] Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene, Jr., D. Kastak, D.R. Ketten, J.H. Miller, et al. 2007. Marine mammal noise exposure criteria: Initial scientific recommendations. Aquatic Mammals 33(4): 411-521.

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transits for each vessel are presented, with the broadband RNL and MSL measurements, in Appendix A.4. The number of valid vessel transits per day past the ULS for all vessels and for piloted vessels is shown in Figure 5.2. The data gaps correspond to military redactions and system maintenance.

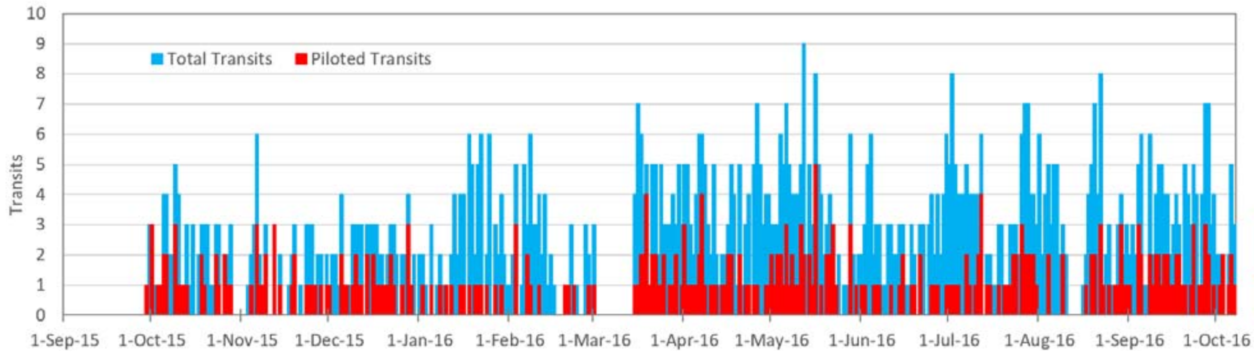

Figure 5.2 Valid transits over the ULS.

A summary of the Radiated Noise Level range, in dB re 1uPa @ 1m, and the number of transits by ULS vessel class is presented in Table 5.1.

Table 5.1 Radiated Noise Level range and number of ULS transits by ULS class for the feasibility study.

Max RNL (dB)	Average RNL (dB)	Min RNL (dB)	Number transits	Vessel class
198.3	186.9	169.1	113	Bulkers <200
201.2	188.4	177.6	87	Bulkers >200
186.7	182.2	174.0	5	Container Ship <200
199.6	190.5	181.6	74	Container Ship >200
195.9	186.6	173.0	586	Ferry >50
191.6	180.9	173.3	5	Fishing Vessel
175.9	174.9	173.8	2	Government/Research
185.9	185.9	185.9	1	LNG Carrier
161.0	161.0	161.0	1	Naval Vessel
189.9	182.3	174.6	5	Other
190.7	181.9	175.3	7	Passenger >100
168.3	168.3	168.3	1	Recreational Vessel
200.4	187.3	180.5	27	Tanker
185.4	179.5	170.4	79	Tug <50
189.5	186.0	183.7	6	Tug >50
192.4	186.4	178.1	3	Vehicle Carrier

The majority of vessel measurements were in the ferry >50m class. The large number of ferry transits, 586, was accumulated by 9 vessels over the first year of the project. Three quarters of the ferry transits were attributable to two vessels. A summary of the RNL range, in dB re 1uPa @ 1m, and the number of transits by vessel for the Ferry > 50m class is presented in Table 5.2.

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Table 5.2 Radiated Noise Level range and number of ULS transits for the ferry class for the Year 1 feasibility study.

Max RNL (dB)	Average RNL (dB)	Min RNL (dB)	Number transits	Vessel
190.9	185.3	176.0	25	Ferry A
192.1	184.7	180.1	221	Ferry B1
186.6	184.6	183.4	9	Ferry B2
194.2	191.8	187.9	4	Ferry C
184.6	184.6	184.6	1	Ferry D
190.2	185.8	177.9	9	Ferry E
180.2	180.2	180.2	1	Ferry F
188.8	184.5	177.0	41	Ferry G
195.9	189.0	183.0	237	Ferry H1
194.9	191.3	187.9	26	Ferry H2
174.8	173.9	173.0	11	Ferry I
191.9	191.9	191.9	1	Ferry J

Representative vessel source level reports are included in Appendix A.4. The reports included in the appendix are composed of the loudest and quietest vessel in each class. To rank a vessel within it's class requires a statistically sufficient data set within each class as a baseline. The baseline objective for the project was 100 vessels in each class. As shown in Table 5.1 only the ferry >50m and bulker <200m classes exceeded the 100-measurement mark. Unfortunately, the bulk of the ferry class measurements were obtained from only two vessels, and 9 vessels in total. The baseline for the ferry class is representative of this specific location however, the low number of vessels is considered an insufficient baseline to represent ferries at other locations within the Salish sea. The Year 2 extension project for the ULS will help to accumulate sufficient measurements in each class.

Figure 5.3 shows the RNL data by class for the vessels with valid measurements. The class order is listed by increasing mean RNL values (the red cross). The boxes represent the 25th to 75th percentile levels and the whiskers represent the minimum and maximum range of the RNL for the class. Figure 5.3 shows the range of measurements without scaling for speed or other operational factors which contribute to the variability in source levels.

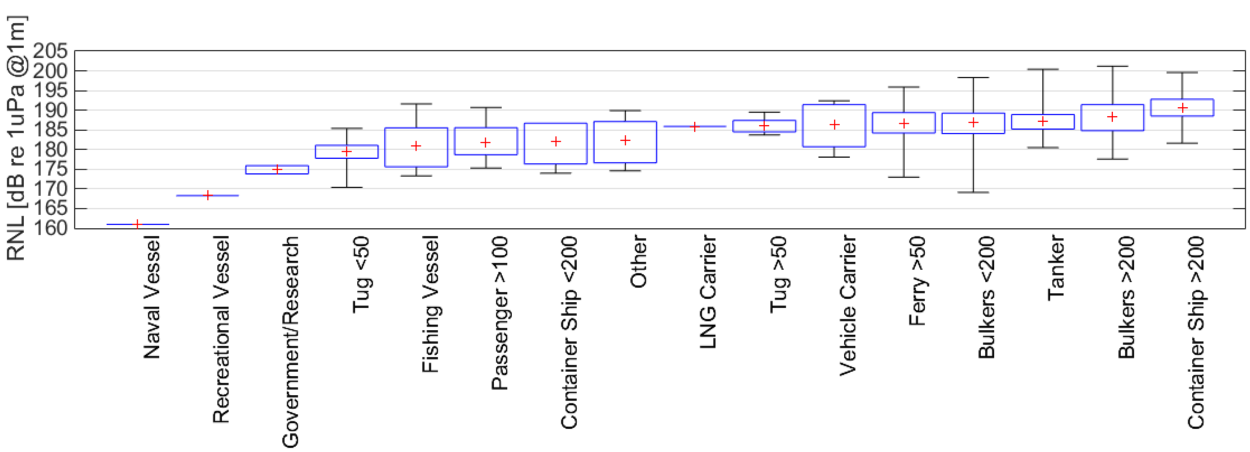

Figure 5.3 Vessel monopole source level (MSL) range by class. The red cross is the mean, box represents the 25th to 75th percentiles and the whiskers represent the minimum to maximum range for the class.

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During the project the loudest two vessels were in the bulker >200m class with broadband radiated noise levels (RNL) of 201.2 and 200.8 dB re 1 μPa at 1 m. The quietest vessel was a Naval vessel with a RNL of 161.0 dB re 1 μPa at 1 m. The class with the highest mean RNL was the container ship >200m class, with a mean RNL of 190.5 dB re 1 μPa at 1 m.

In the bulk carrier <200m class, one vessel was 6.4 dB quieter than any other vessel in it's class. This is likely due to the much slower transit speed, 6.6 knots, compared to the other vessels. If this vessel is to be considered an outlier, then the minimum RNL for the class is 175.5 dB and the class range is very comparable to the bulk carrier >200m class.

The ferries >50m class has a wide source level range. Figure 5.4 shows the radiated noise levels plotted versus speed over ground for several ferries. Ferries B1 and B2 are the same ferry model and ferries H1 and H2 are the same ferry model. Ferries E, and G show a strong correlation with speed. Ferries A, B1, B2, H1, H2, and I do not show a strong correlation to speed. For ferries A, B1, B2, H1, and H2, it is likely there is another factor such as vessel loading (which changes the vessel propeller depth which in turn affects cavitation) or fixed versus variable pitch propellers. The B ferry model is roughly 10 dB quieter at 19 knots than the H model.

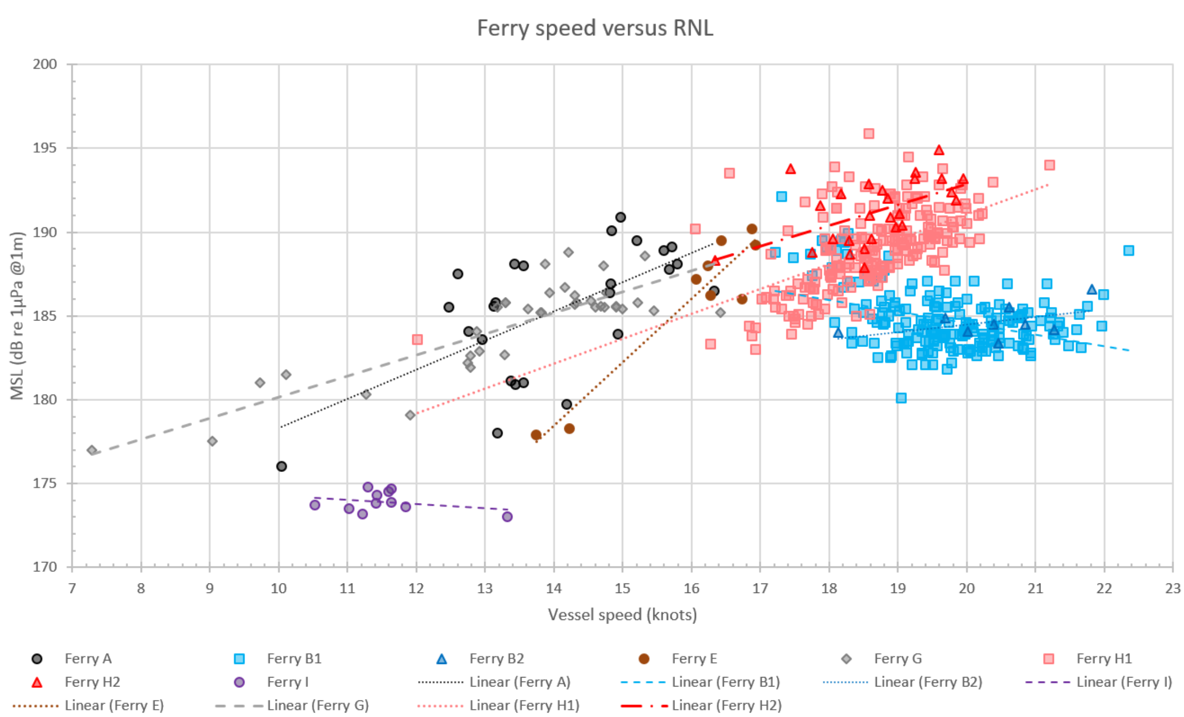

Figure 5.4 Ferry radiated noise levels versus speed in water

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6 Hull cleaning acoustic summary

The underwater listening station project proposed to undertake acoustic assessments of vessels participating in an ECHO Program hull cleaning project. Ten (10) manually processed vessel source level reports were to be produced for specified vessels before and after hull cleaning in VFPA jurisdiction. However, the technology for performing the hull cleaning is behind schedule for deployment. As a result, the acoustic project deliverables were modified to provide a manual assessment of three vessels. All three vessels were measured in March of 2016. The remaining 7 manual ship source level reports will be held in reserve until the hull cleaning technology becomes operational. The three manual vessel source level reports are included in Appendix A.5.