Protecting SRKW Foraging Hotspots: Acoustics Report

Prepared for San Juan County

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Protecting SRKW Foraging Hotspots: Acoustics Report

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Executive Summary

In support of the San Juan County's efforts to protect Southern Resident killer whale hotspots, SMRU Consulting deployed Coastal Acoustic Buoys at four paired locations between Cattle Point and Pile Point in the summers of 2019 and 2020 to measure ambient noise levels inside and outside of the County's voluntary No-Go Zone as well as acoustically detect Southern Residents. A total of 200 days of acoustic data (63 days in 2019 and 137 day in 2020) were collected for this project. Southern Residents were detected in the study area for a total of 24.73 hours over 13 days in 2019 and 42.60 hours over 20 days in 2020. These numbers are similar to Southern Resident detections at Lime Kiln during the same monitoring periods, suggesting that both areas constitute Southern Resident hotspots.

The strong tidal currents between Cattle Point and Pile Point proved a challenge to data collection and analysis. Flow noise from currents is focused at frequencies below 100 Hz and boat noise tends to be focused between 100 and 1,000 Hz. We therefore focused our analysis and reporting in the 100-1,000 Hz decade band. In addition to ambient noise analyses, we ran an acoustic boat detector and a 50 kHz detector to identify periods when boats were present and depth sounders/fish finders were being used. Based on the difference in these detectors, they roughly differentiate between transiting boats and those engaged in trolling. To tease apart different drivers of ambient noise in the study area, we focused on seven different factors: 1) the No-Go Zone, 2) location, 3) day vs night, 4) weekend vs midweek, 5) holiday weekends, 6) year, and 7) commercial fish openings.

In the study area and including all the data, we found median (L_{50}) sound pressure levels to be 103.0 dB re 1µ in the 100-1,000 Hz band. Median (L_{50}) levels were 0.7 dB lower inside the No-Go Zone compared to outside the No-Go Zone. When focused on high amplitude periods (L_5), there was a 3.4 dB drop when comparing inside to outside the No-Go Zone. Whether this drop is due to boaters avoiding the No-Go Zone on purpose is not known. Boat use at the four locations varied with the location nearest Pile Point having the most boat detections and highest L_5 value, suggesting this area is used heavily by transiting boats. The center two locations (nearest to Eagle Cove and Grannie's Cove) are used more heavily by boats that are assumed to be trolling. The fourth location, closest to Cattle Point had lower levels of boat and 50 kHz detections but is still heavily used by boats.

Based on analyses of day vs night, weekend vs midweek and holiday weekend, we can clearly state that the areas monitored are highly influenced by boat noise. Daytime noise levels in the 100-1,000 Hz band are 2.8 to 8.9 dB higher for L_{50} and L_5 values, respectively. Weekends add 0.4 to 1.6 dB and Holiday weekends 2.2 to 7.1 dB to ambient noise levels at the L_{50} and L_5 values, respectively, and in the 100-1,000 Hz band. From this we can infer that boats are significant contributors to this soundscape and that the more boats present, the higher the sound pressure levels.

Since the study spanned a 'typical' summer (2019) and a 'Covid' summer, we compared data across years. The summer of 2020 had L_{50} values 0.4 dB and L_5 values 5.8 dB higher than 2019. Anecdotal evidence suggests this was driven by more boats in 2020 when the Canadian border was closed, and a boat holiday was perceived as 'Covid safe'.

Intriguingly, commercial fish openings lead to a decrease in boat and 50 kHz detections as well as a reduction of 1.8 and 4.1 dB in the L_{50} and L_5 values in the 100-1,000 Hz band. It is not clear why this is the case although it should be noted that we included all commercial and Tribal fish openings which include very different fishing activities (e.g., purse seining, gill netting).

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List of Acronyms

CAB	Coastal Acoustic Buoy
CDF Plots	Exceedance cumulative distribution function
ECHO Program	Enhancing Cetacean Habitat and Observations Program
LTSA	Long Term Spectrogram Average
NFWF	National Fish and Wildlife Foundation
PSD	Power Spectral Density
SPL	Sound Pressure Level
SRKW	Southern Resident killer whale

1 Introduction

The San Juan County Environmental Resources Department secured funding from NFWF to protect Southern Resident killer whale (SRKW) foraging hot spots on the west coast of San Juan Island WA. This project is implementing a model engagement strategy to protect these areas. Through scientifically sound methods and a socially acceptable process, the community will help define defensible Chinook and SRKW refuge area(s). The core summer critical habitat of the endangered SRKW is located in the heart of the Salish Sea, a distinction held in high regard by the local community and the Coast Salish tribes that call the San Juan Islands home. The west coast of San Juan Island is one of the primary migratory corridors for returning Fraser River Chinook, known to make up a majority of the SRKW's diet in the Summer/Fall, and is also a location of intense acoustic disturbance, vessel presence, and harvest (prey removal) during the Summer and early Fall season. This report covers the acoustic monitoring aspect of this project.

The goal of this portion of the County led project was to conduct acoustic monitoring in the Cattle Point to Pile Point area during the summers of 2019 and 2020 to measure SRKW and vessel presence in the area.

2 Methods

Acoustic monitoring was conducted at four paired locations during the summer months of 2019 and 2020. The locations were chosen to sample ambient noise and detect Southern Resident killer whales (SRKW) between Cattle Point and Pile Point. Each site was paired such that one hydrophone was located inside the San Juan County voluntary No-Go zone and one hydrophone was located outside the No-Go zone (Figure 1; Table 1). A total of nine deployments were conducted in the summer of 2019 and 2020 (Table 2).

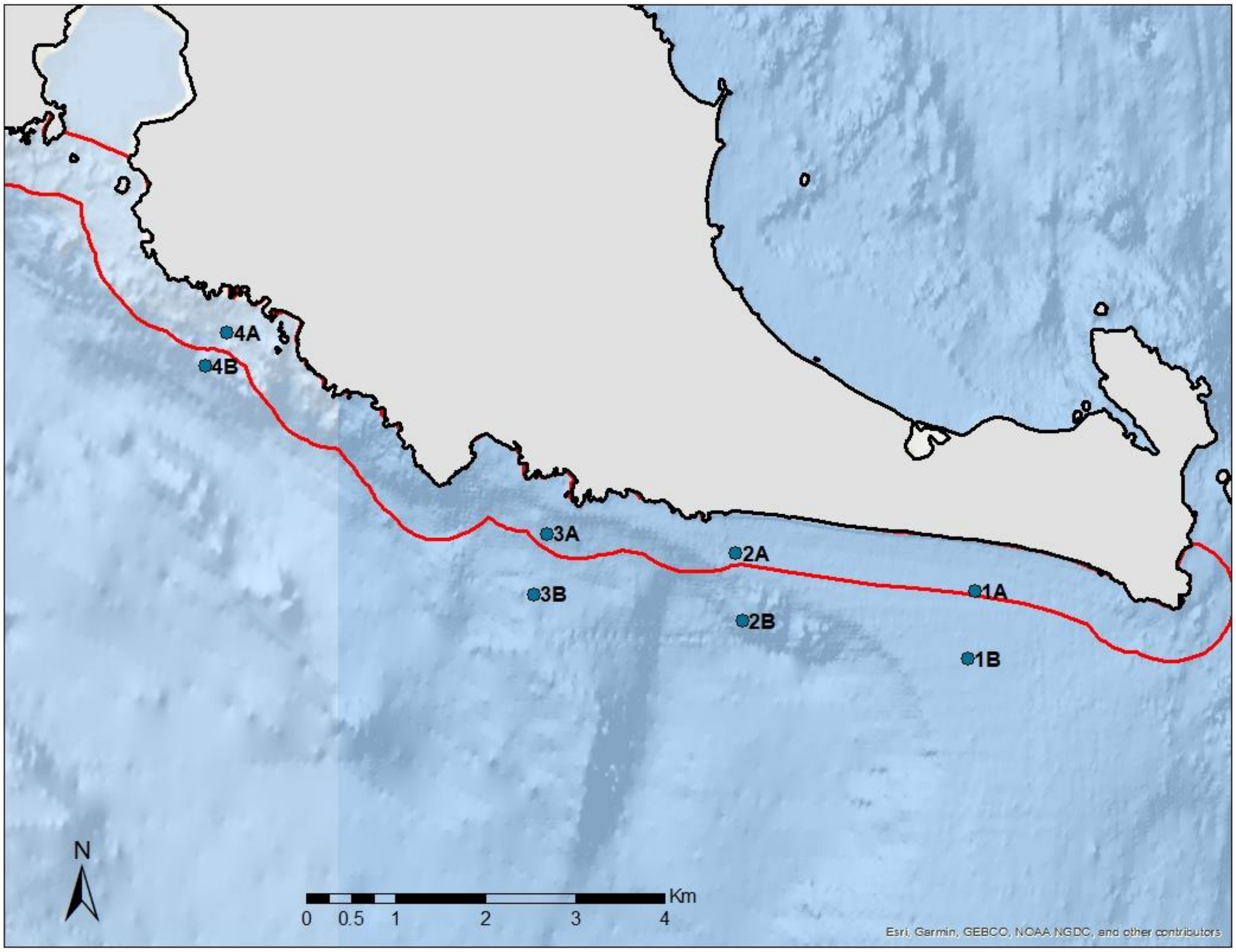

Figure 1. Map of acoustic sampling locations. Data were collected simultaneously at each paired site, with 'a' inside the No-Go zone and 'b' outside the No-Go zone (depicted in red outline).

Table 1. Locations and depth of acoustic deployments.

Location	Lat	Lon	Depth (m)
1A	48.451045	-122.983049	7
1B	48.446545	-122.983762	8
2A	48.453592	-123.006987	9
2B	48.449064	-123.006382	27
3A	48.454896	-123.025929	37
3B	48.450839	-123.027264	61
4A	48.468254	-123.057998	21
4B	48.46603	-123.060205	55

Table 2. Dates of deployments and recoveries.

Deployment Date	Recovery Date	Locations
8/6/2019	8/20/2019	1a, 1b
8/30/2019	9/18/2019	2a, 2b
9/24/2019	10/10/2019	3a*, 3b
5/24/2020	6/10/2020	4a, 4b
6/12/2020	6/25/2020	1a, 1b
6/29/2020	7/13/2020	2a, 2b
7/15/2020	8/3/2020	3a*, 3b
8/7/2020	8/21/2020	4a, 4b
8/25/2020	9/8/2020	1a, 1b

*unit lost.

Acoustic monitoring was conducted with the use of Coastal Acoustic Buoys (CABs). These are autonomous acoustic buoys that can be configured to detect a variety of marine mammal sounds and measure ambient noise levels. The CAB (http://www.smruconsulting.com/products-tools/cab/) consists of a surface float that contains the electronics, batteries, and cellular communication module (Figure 2). The units are held in place with a 75 lbs pyramid anchor and a mooring line. A single Reson TC4014 hydrophone was tethered to the mooring line at a depth of 10 m for each deployment. The acoustic processor was configured to run the PAMGuard (http://www.pamguard.org/) whistle and moan detector for killer whale calls. A long-term spectrogram average (LTSA) was also implemented to allow for data quality checks. Raw acoustic data were stored onboard at a sample rate of 250 kHz and 16-bit depth for post processing. The system was regularly calibrated using a GRAAS 42AC pistonphone at 250 Hz.

Figure 2. Deployment of a Coastal Acoustic Buoy off San Juan Island. Photo credits Frances Robertson.

After recovery of the units, data were downloaded for post processing. PAMGuard whistle and moan detections were checked by visual and aural inspection of the audio files. The start and end time of each SRKW transit were then recorded. We define a transit as a period with SRKW calls that have no more than 30 minutes between successive calls. To measure ambient noise levels audio files were post-processed with custom Matlab scripts modified from Merchant et al. (2015) with a 1 second Hanning window, 50% overlap and Welch's averaging across each 1-minute file. Sound pressure levels (SPL) were calculated in broadband (10 Hz-100 kHz) and four decade bands (10-100 Hz, 100-1,000 Hz, 1-10 kHz, 10-100 kHz). LTSA and power spectral densities (PSD) were also computed for data quality checks and analyses. These noise metrics are consistent with those used by the Vancouver Fraser Port Authority's ECHO Program (e.g., JASCO & SMRU 2020; SMRU 2020) and the European Union under the Marine Strategy Framework Directive. In reporting SPL, we provide exceedance values. That is to say the L_{95} exceedance value indicates the level at which 95% of data are larger than this value. Likewise, the L_{50} indicates the value at which 50% of results exceed this value and the L_5 is the level at which only 5% of the data exceed this value. The mean values reported are mean SPL calculated in units of pressure and then converted back to the dB scale.

Two approaches were used to detect the presence of small vessels (boats) nearby: a boat engine noise detector and a depth sounder/fish finder detector. The boat engine noise detector implemented an energy band detector using four thresholds (Table 3) based on the hourly median sound pressure levels (SPL) rather than fixed values. The boat engine detector was triggered when either:

- Thresholds 1, 2, and 3 were exceeded or
- Threshold 2 was exceeded, and Threshold 4 was not.

These two triggers allowed for detections of boats passing near the hydrophone at a fast speed (i.e., they produced high amplitudes in the 100–1,000 Hz, 1–10 kHz, and 10–100 kHz frequency bands), or when a boat passed at a slower speed. For this latter case, Threshold 4 was used to avoid detecting large commercial ships (i.e., slow boats tend not to produce much sound in the 100–1,000 Hz band, but ships do).

There are a number of caveats that need to be considered when interpreting results of the boat engine detector. The detector is tuned for detecting small boats (e.g., small outboard boats, cruising yachts, sailboats under power) and avoiding detections of large commercial vessels (e.g., container ships, bulk carriers, etc.) but commercial fishing vessels may not be as well detected due to their larger size and operational use (e.g., a tender for a purse seiner closing the sein). In addition, the different depth, bathymetry and current velocity at the four locations may result in different efficacy levels of the boat engine detector. However, results of the boat engine detector should be broadly illustrative of trends in boats that are travelling at high speeds or cruising past the CAB units within several km. Boats that are actively trolling (with low engine rpm) will not be detected by the boat engine detector unless they are close (e.g., < 100 m) to the CAB. Under these conditions, these trolling boats are also likely to be detected by the 50 kHz detector, if they are using their depth sounder or fish finder.

Table 3. The thresholds used in the boat detector.

Threshold Number	Decade Band	Threshold (dB above the median hourly SPL in this decade band)
1	100–1,000 Hz	6
2	1–10 kHz	5
3	10–100 kHz	23
4	100–1,000 Hz	9

The depth sounder/fish finder detector searched for peaks in ambient noise focused at 50 kHz, which is the most common frequency used by consumer depth sounders/fish finders in local waters. Many depth sounders/fish finders also use a 200 kHz signal, but this is above the frequency recorded on the CABs for this project. The depth sounder/fish finder detector was triggered when the 50 kHz power spectral density exceeded 52 dB re 1µPa^2/Hz. For convenience we will refer to this detector as the '50 kHz detector'. Due to the high frequency and directionality of these depth sounder/fish finder transducers, the 50 kHz detector will only be triggered when a vessel is passing close (e.g., < 100 m) to the CAB and at slower speeds (e.g., < 3 knots). This short-range detection should be considered when interpreting the results of the 50 kHz detector.

Because of the large difference in spatial scale between the boat and 50 kHz detectors (several km vs ~100 m, respectively), this also needs to be considered when interpreting results (see Figure 3).

Ambient noise results are provided for all the data combined and seven factors that may explain changes in the local soundscape. These include: 1) Effect of the No-Go Zone, 2) location of monitoring, 3) day vs night, 4) weekend vs midweek, 5) holiday weekend, 6) year, and 7) commercial fish openings.

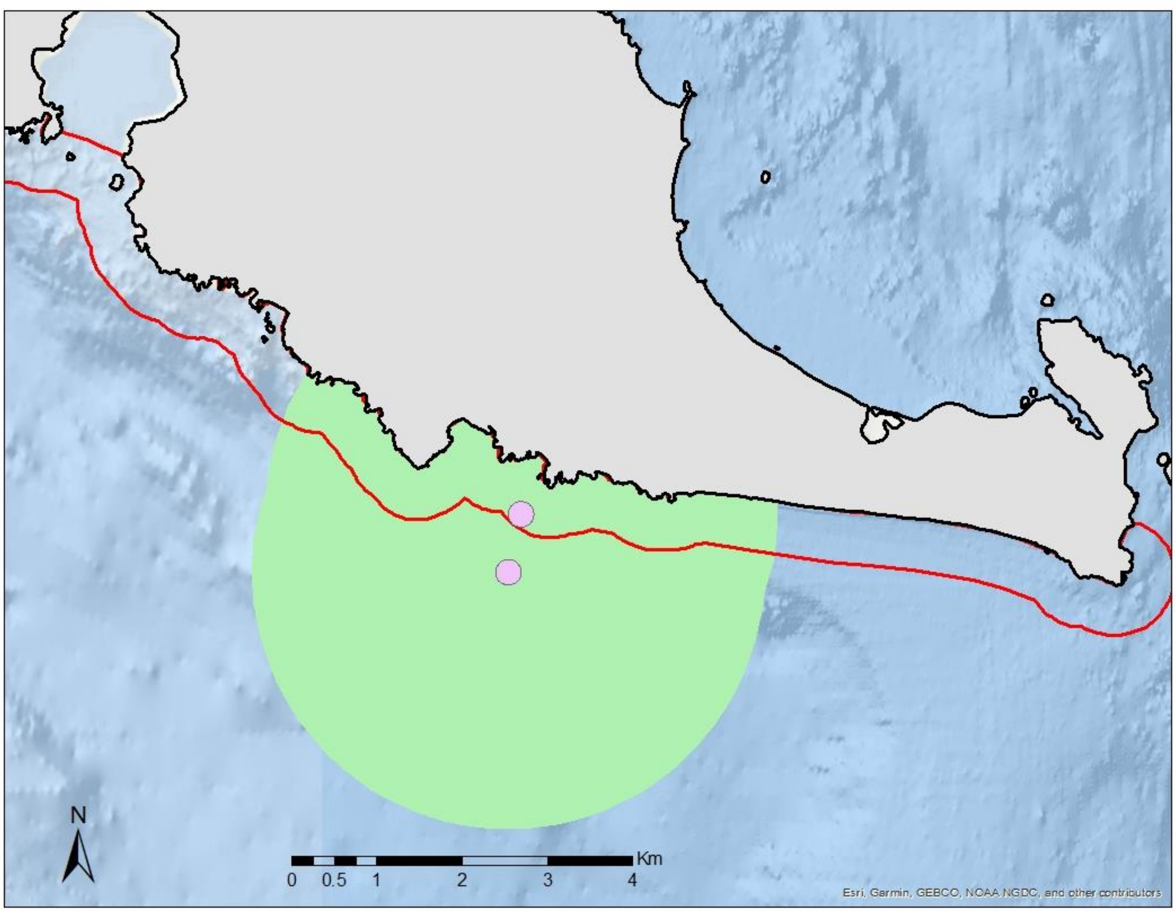

Figure 3. Approximate detection range of the boat detector (green) and 50 kHz detector (pink) at locations 3a and 3b.

3 Results

3.1 SRKW Detections

SRKW were acoustically detected in the study area mainly in August of 2019 while detections were concentrated in July in 2020, with detections occurring during the day and night (Figure 4 and Figure 5). Whales were detected over total of 24.73 hours and 13 unique days in 2019 out of a total of 65 days of monitoring (i.e., detections on 20% of days monitored). While in 2020, they were detected over a total of 42.60 hours and 20 unique days out of a total of 107 days monitored (i.e., detections on 19% of days monitored). This resulted in an average detection time of 1.90 hours and 2.13 hours per detection day in 2019 and 2020, respectively. For comparison, SRKW were acoustically detected at Lime Kiln during the same period of CAB deployments for a total of 27.82 hours and 14 unique days in 2019 and for 56.82 hours and 23 unique days in 2020 (JASCO & SMRU 2020; JASCO & SMRU 2021). This resulted in an average detection time of 1.98 hours and 2.47 hours per detection day in 2019 and 2020, respectively, at Lime Kiln. Habitat use by SRKW changes from year to year. However, the number of days and total hours of detection within a year, and between Lime Kiln and the study area are comparable. This suggests that the area between Cattle Point and Pile Point is used as much by SRKW as the area around Lime Kiln is.

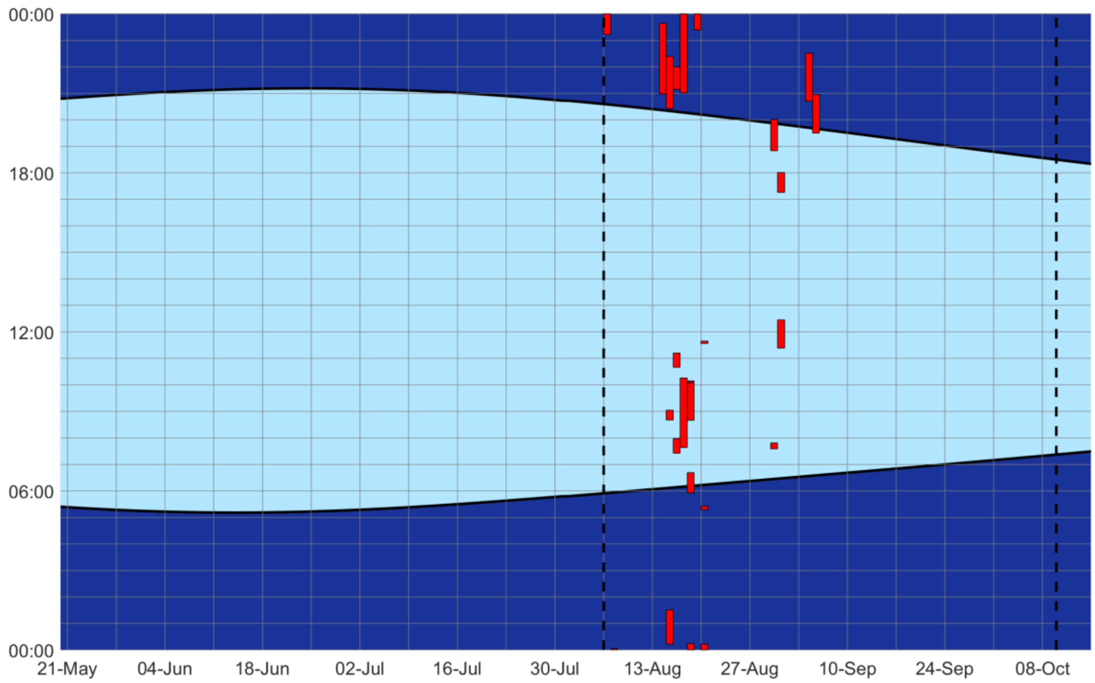

Figure 4. SRKW detections in 2019. Red rectangles indicate the date and time of SRKW detections. Dark blue background indicates nighttime and light blue daytime. Dashed vertical lines indicate the start and end of monitoring in 2019.

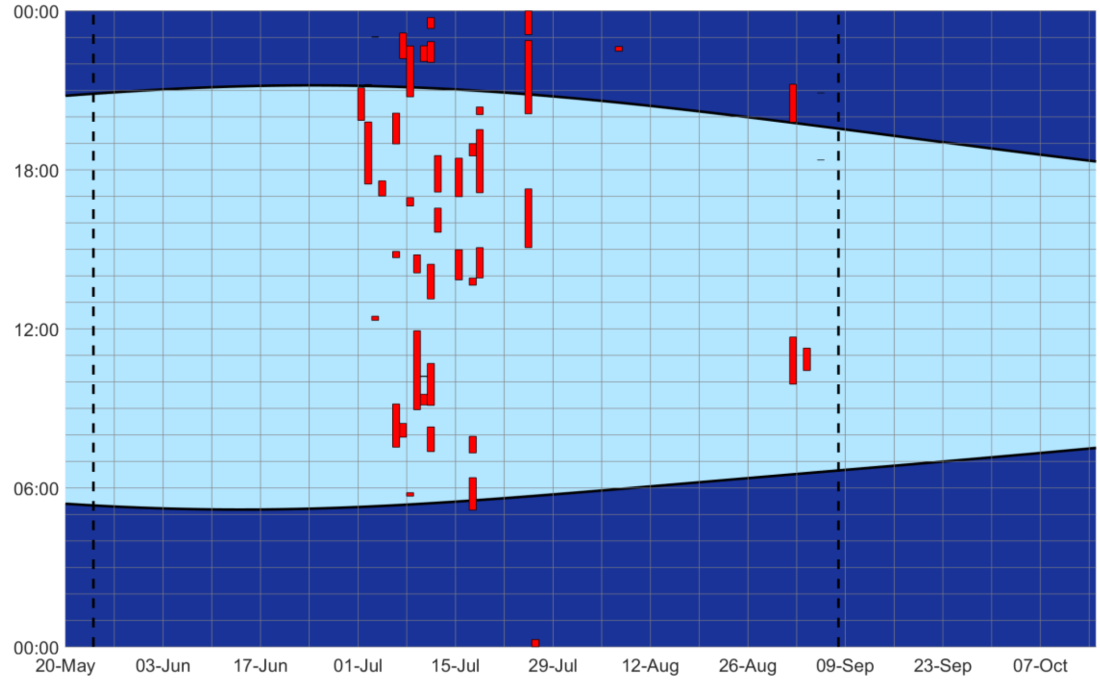

Figure 5. SRKW detections in 2020. Red rectangles indicate the date and time of SRKW detections. Dark blue background indicates nighttime and light blue daytime. Dashed vertical lines indicate the start and end of monitoring in 2020.

3.2 All Acoustic Data

A total of 288,732 minutes (200.5 days) of acoustic data were collected in 2019 and 2020. While data quality was generally good, the biggest issues arose from tidally induced currents. Both deployments in 2019 and 2020 at Location 3a (Figure 1) were lost when those CABs dragged anchor and drifted off. At other locations, current velocities were high enough to pull the CABs underwater (Figure 6). Once currents eased these units came back to the surface and continued working. Currents create flow noise on hydrophones in much the same way that wind causes noise on a microphone. These sounds do not propagate in the environment and are therefore not part of these soundscapes. Most flow noise on hydrophones is concentrated below 100 Hz (see annotation in Figure 7).

In general, the underwater soundscape between Cattle Point and Pile Point is driven by diurnal patterns, with higher amplitudes during daylight hours and lower amplitudes during nighttime hours (see annotation in Figure 7). Some of this sound may be biological in nature, but it is likely that much of this is being driven by localized anthropogenic activities (see later sections for further details). There is also evidence of echosounder use in this soundscape (see annotation in Figure 7). Overall, the boat detector was triggered 7.8% of the time and the 50kHz detector was triggered 8.4% of the time. Due to the large effect of flow noise in these highly tidal sites, we focus on reporting results and trends in the second decade band (e.g., 100-1,000 Hz; bolded in tables), although we do report the broadband (10 Hz – 100 kHz) and other decade bands. The second decade band will also contain much of the noise produced by boats (see annotation in Figure 7). The L_{50} in the 100-1,000 Hz band was 103.0 dB re 1µPa, in the 1-10 kHz band it was 100.4 dB re 1µPa, and in the 10-100 kHz band it was 99.8 dB re 1µPa (Table 4). Exceedance cumulative distribution function plots (we refer to these as CDF plots) are provided in the Appendix (Figure 9 through Figure 13).

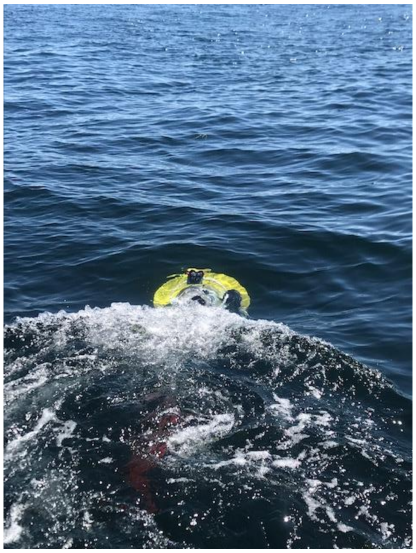

Figure 6. CAB being pulled underwater by strong currents.

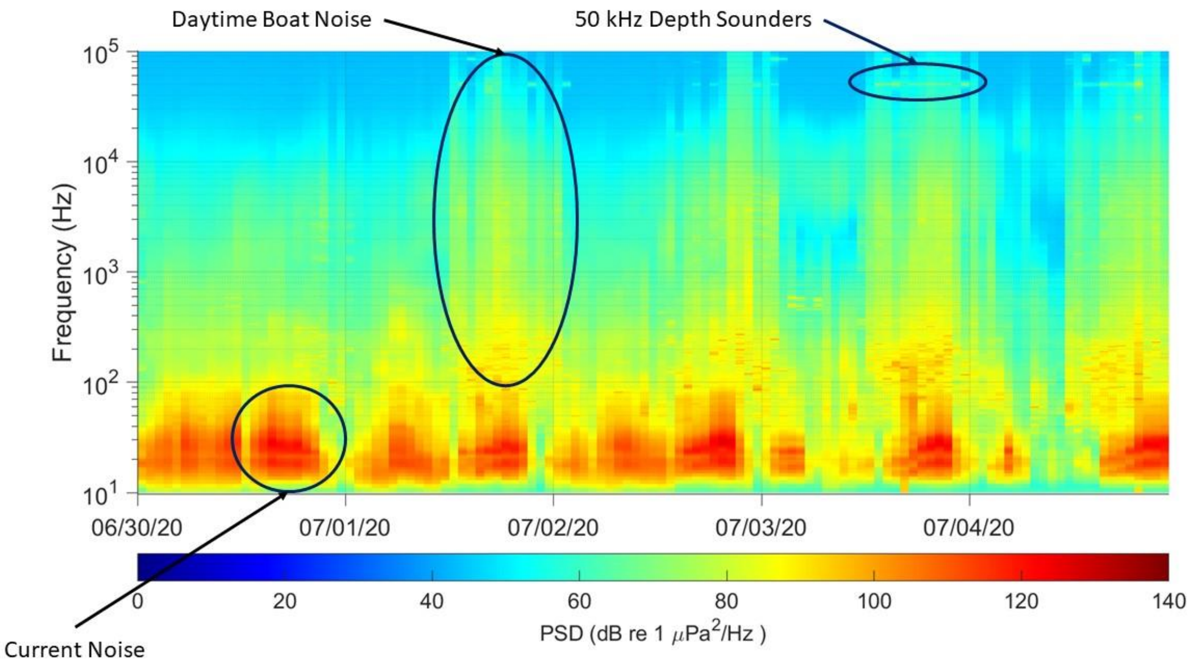

Figure 7. Annotated long term spectrogram average of data collected at Location 2a in 2020. Note date marks are in UTC and hence 7 hours ahead of PDT.

Table 4. Exceedance SPL (dB re 1µPa) descriptive statistics for all the acoustic data collected.

	All Data			
	L_{95}	L_{50}	L_5	Mean
Broadband	103.7	114.9	138.1	117.8
10-100Hz	94.1	112.2	138.0	114.1
100-1,000Hz	**90.8**	**103.0**	**117.8**	**103.9**
1-10kHz	89.5	100.4	115.9	101.6
10-100kHz	95.3	99.8	109.0	101.1

3.3 Effect of No-Go Zone

A total of 103,602 minutes of data were recorded inside the No-Go zone, and 185,130 minutes outside the zone. More boats and 50kHz depth sounders were detected outside the No-Go Zone than inside (Table 5). This would explain why the L_{50} SPL increased by 0.7 dB in the 100-1,000 Hz band and the L_5 SPL increased by 3.5 dB in that same band outside the No-Go Zone (Table 6). Whether boats are avoiding the ¼ mile No-Go Zone on purpose or because they prefer to transit (when they will make more noise) further offshore is not known. CDF plots are provided in the appendix (Figure 14 through Figure 18).

Table 5. Percent time the boat and 50 kHz detector were triggered and sample size inside and outside the No-Go Zone.

	Inside No-Go Zone	Outside No-Go Zone
Boat Detector	5.7%	9.0%
50 kHz Detector	5.6%	9.9%
N (minutes)	103,602	185,130

Table 6. Exceedance SPL (dB re 1µPa) descriptive statistics for acoustic data collected inside and outside the No-Go Zone.

	Inside No-Go Zone				Outside No-Go Zone			
	L_{95}	L_{50}	L_5	Mean	L_{95}	L_{50}	L_5	Mean
Broadband	103.7	112.5	132.1	115.1	103.7	117.0	140.5	119.3
10-100Hz	92.9	107.2	132.0	109.9	95.1	115.2	140.4	116.4
100-1,000Hz	**91.3**	**102.6**	**115.4**	**103.2**	**90.5**	**103.3**	**118.9**	**104.3**
1-10kHz	89.6	102.0	112.6	102.3	89.5	99.6	119.0	101.3
10-100kHz	96.4	101.5	108.8	102.3	95.2	99.1	109.6	100.4

3.4 Location

Location 1 had the highest sample size and Location 3 the lowest (due to CAB losses at Location 3a; Table 7). There are interesting patterns that emerged from the acoustic detectors. Location 4 had the highest percentage of boat detections, by far. Based on the detector characteristics, this may indicate a location with the highest proportion of cruising or fast travelling boats. In contrast, Locations 2 and 3 had the highest percentage of 50 kHz detections. This is indicative of boats moving at slow speeds near to the CABs (perhaps trolling). Location 1 had the lowest percentage of boat and 50 kHz detections, suggesting that this location is less heavily used by transiting and trolling boats. This does not mean Location 1 is not used by boaters. Based on detector results at Location 1, there were boats transiting within several km 4.7% of the time and boats moving slowly within 100 m 3.2% of the time. Because of the smaller detection range of the 50 kHz detector, that would suggest a higher number of slow-moving boats if extrapolated to the several km of the boat detector range, assuming the CAB locations are representative of the areas nearby. In addition, based on the day vs night results (see next section) and a ratio of 1.8 between day and night data, the percentages of detection time reported may be up to 1.8 times higher, if only considering daytime hours.

The L_{50} SPL ranged from 101.5 dB re µPa at Location 3 to 103.7 dB re µPa at Location 2 in the 100-1,000 Hz band (Table 8). This does not match well with the patterns seen in the boat and 50 kHz detectors. This indicates that boat use in these four locations is not the primary driver of **average** ambient noise conditions in the 100-1,000 Hz band between locations (although it will contribute to the soundscape). However, there is a clear effect of cruising vessels at high SPL. The L_5 SPL at Location 4 was 123.4 dB re µPa in the 100-1,000 Hz band, which is much higher than the L_5 SPL at the other three locations (Table 8). This matches the boat detector pattern and suggests that the higher amplitude episodes at Location 4 are being driven by boat transits at moderate to high speeds. CDF plots are provided in the Appendix (Figure 19 through Figure 23).

Table 7. Percent time the boat and 50 kHz detector were triggered and sample size at each location.

	Location 1	Location 2	Location 3	Location 4
Boat Detector	4.7%	6.5%	6.4%	16.2%
50 kHz Detector	3.2%	16.6%	12.3%	4.1%
N (minutes)	106,541	74,512	47,542	60,137

Table 8. Exceedance SPL (dB re 1µPa) descriptive statistics for acoustic data collected at each location.

	Location 1				Location 2			
	L_{95}	L_{50}	L_5	Mean	L_{95}	L_{50}	L_5	Mean
Broadband	103.2	111.8	128.0	114.0	104.6	113.3	128.9	115.1
10-100Hz	92.1	105.6	127.2	108.2	94.8	109.0	128.6	110.7
100-1,000Hz	**92.4**	**103.1**	**116.3**	**103.9**	**91.7**	**103.7**	**115.7**	**104.3**
1-10kHz	92.5	102.1	113.8	103.0	93.9	102.0	113.2	103.2
10-100kHz	95.8	101.0	108.9	102.1	96.3	101.2	109.3	102.3

	Location 3				Location 4			
	L_{95}	L_{50}	L_5	Mean	L_{95}	L_{50}	L_5	Mean
Broadband	105.1	118.9	137.1	120.4	102.9	125.3	148.2	125.7
10-100Hz	100.7	118.2	137.1	119.1	98.6	125.1	148.2	124.8
100-1,000Hz	**87.8**	**101.5**	**114.2**	**101.9**	**90.1**	**102.9**	**123.4**	**105.2**
1-10kHz	89.1	96.0	109.0	97.5	88.1	96.3	126.6	100.5
10-100kHz	95.2	99.3	104.7	99.8	95.1	97.0	112.7	98.9

3.5 Day vs Night

The rough mid-point in data collection (July 15) was used to define day and night based on sunrise at 5:30 am and sunset at 9:00 pm across the dataset. Based on this definition, more of our acoustic recording occurred during the day (Table 9), which makes sense given the day length is longer than the night length at this time of year. As would be expected, both the boat detector and 50 kHz detector recorded much higher percentages during the day (Table 9). This has implications for interpretations of other factors (e.g., Location, weekend vs midweek, etc.) in other sections of this report. The nighttime boat detector results are higher than one would expect given the assumption that small boats are not using local waters in the dark. These detections could be false positives from larger commercial vessels which would be more easily detected during the lower amplitude periods typical of the nighttime soundscape in the locations sampled. Some of these detections will be true positives though.

There is a 2.9 dB reduction in L_{50} SPL in the 100-1,000 Hz band at nighttime and an 8.9 dB drop in the L_5 SPL (Table 10). This diurnal trend is clearly marked in the annotation in Figure 7. This suggests that anthropogenic noise sources are large contributors to the soundscape at the locations sampled. In addition, because large commercial ships do not have a diurnal trend, the most likely anthropogenic source in this area is boats. There are no high amplitude biological sources in local waters that have a diurnal trend either. CDF plots are provided in the Appendix (Figure 24 through Figure 28).

Table 9. Percent time the boat and 50 kHz detector were triggered and sample size by day and night.

	Day	Night
Boat Detector	9.6%	4.6%
50 kHz Detector	12.9%	0.2%
N (minutes)	185,919	102,813

Table 10. Exceedance SPL (dB re 1µPa) descriptive statistics for acoustic data collected by day and night.

	Day				Night			
	L_{95}	**L_{50}**	**L_5**	**Mean**	**L_{95}**	**L_{50}**	**L_5**	**Mean**
Broadband	104.0	116.6	140.7	119.2	103.2	112.6	132.4	115.2
10-100Hz	94.1	113.7	140.6	115.4	94.0	109.8	132.3	111.7
100-1,000Hz	**92.5**	**104.2**	**120.0**	**105.5**	**88.7**	**101.3**	**111.1**	**101.2**
1-10kHz	90.8	101.2	119.1	103.0	88.5	98.7	110.3	99.2
10-100kHz	95.4	100.1	111.0	101.6	95.3	99.2	106.8	100.3

3.6 Weekend vs Midweek

The weekend was defined as Saturday and Sunday for these analyses, while midweek was defined as Tuesday and Wednesday. Sample sizes were similar across these two day periods (Table 11). The boat detector was slightly higher during the weekend than midweek, but the 50 kHz detector had almost double the percent time of detections (Table 11). Given these data were all collected during summer months, this pattern could be explained by vacationers cruising through this area on a summer vacation (i.e., they have taken more than a weekend off work and are thus almost as likely to be in the area midweek as at the weekend). Whereas, fishing activity may be more concentrated during the weekend when more locals have time off, which results in higher 50 kHz detections during the weekend. These patterns are clearly visible in Figure 7 which covers the period of 30 June 2020 (a Tuesday) through 4 July 2020 (a Saturday).

Because faster moving boats contribute more to the local soundscape than slow moving (trolling) boats, and there is only a small drop in boat detections midweek, the L_{50} SPL in the 100-1,000 Hz band only drops 0.4 dB whereas during higher amplitude periods, the L_5 drops by 1.7 dB midweek (Table 12). CDF plots are provided in the Appendix (Figure 29 through Figure 33).

Table 11. Percent time the boat and 50 kHz detector were triggered and sample size for weekends and midweek.

	Weekend	Midweek
Boat Detector	8.0%	7.4%
50 kHz Detector	11.0%	6.0%
N (minutes)	86,496	81,836

Table 12. Exceedance SPL (dB re 1µPa) descriptive statistics for acoustic data collected for weekends and midweek.

	Weekend				Midweek			
	L_{95}	L_{50}	L_5	Mean	L_{95}	L_{50}	L_5	Mean
Broadband	103.9	115.4	137.3	117.8	103.7	114.5	138.9	117.7
10-100Hz	94.8	112.4	137.2	114.2	93.9	112.0	138.8	114.1
100-1,000Hz	**90.7**	**103.2**	**118.6**	**104.3**	**90.7**	**102.8**	**116.9**	**103.6**
1-10kHz	89.6	100.8	116.3	102.0	89.7	100.3	115.5	101.6
10-100kHz	95.4	100.0	109.6	101.3	95.3	99.6	108.3	100.9

3.7 Holiday Weekend

The holiday weekend is defined here as the Saturday, Sunday and Monday of Memorial Day and Labor Day of 2020 (no data were collected during this time in 2019). The 'post-holiday weekend' is defined as the three days after these holiday (e.g., the Tuesday, Wednesday, and Thursday after these long weekends). By dint of being so selective in time, the sample sizes are much smaller than for other comparisons. This should be considered when interpreting these results. The holiday weekends had 1.4 times the boat detection time than the post-holiday period and 2.1 times the 50 kHz detection times (Table 13). This resulted in an L_{50} SPL increase of 2.3 dB in the 100-1,000 Hz band and a 7.1 dB increase in the L_5 SPL. CDF plots are provided in the Appendix (Figure 34 through Figure 38).

Table 13. Percent time the boat and 50 kHz detector were triggered and sample size for holiday weekends and the three days following.

	Holiday Weekend	Post-Holiday Weekend
Boat Detector	7.8%	5.4%
50 kHz Detector	6.3%	3.0%
N (minutes)	9,848	4,631

Table 14. Exceedance SPL (dB re 1µPa) descriptive statistics for acoustic data collected on holiday weekends and the three days following.

	Holiday Weekend				Post-Holiday Weekend			
	L_{95}	L_{50}	L_5	Mean	L_{95}	L_{50}	L_5	Mean
Broadband	103.7	113.0	140.8	115.9	100.2	114.8	148.9	120.4
10-100Hz	91.2	104.9	140.7	108.5	90.3	112.6	148.9	116.2
100-1,000Hz	**92.5**	**103.6**	**120.9**	**105.6**	**88.6**	**101.3**	**113.8**	**101.7**
1-10kHz	91.1	101.9	117.7	102.8	88.3	95.4	109.4	97.1
10-100kHz	95.6	101.8	110.1	102.8	95.1	95.8	106.4	98.4

3.8 2019 vs 2020

Due to a longer field season, the sample size for 2020 was over two times the sample size in 2019 (Table 15). As a reminder, the summer of 2019 was a ‘typical’ summer in the San Juans. The summer of 2020 occurred during lockdowns to try and control the spread of Covid-19. The border with Canada was shut to boaters and anecdotally, a cruising holiday on a self-contained boat may have been perceived as ‘Covid safe’. These two factors likely drove a large increase in boat detection time from 4.9% to 9.2% of time from 2019 to 2020. Why the 50 kHz detector was triggered a higher proportion of time in 2019 is less clear. It may be related to a larger sample size at Locations 2 and 3 compared to Location 3 and 4 in 2019 (see Section 3.4).

The higher proportion of cruising boats in 2020 led to a small increase in the L_{50} SPL of 0.4 dB in the 100-1,000 Hz band (Table 16). There was a much larger increase during high amplitude periods (L_5) of 5.8 dB in that same frequency band. CDF plots are provided in the Appendix (Figure 39 through Figure 43).

Table 15. Percent time the boat and 50 kHz detector were triggered and sample size 2019 and 2020.

	2019	2020
Boat Detector	4.9%	9.2%
50 kHz Detector	10.4%	7.4%
N (minutes)	91,127	197,605

Table 16. Exceedance SPL (dB re 1µPa) descriptive statistics for acoustic data collected in 2019 and 2020.

	2019				**2020**			
	L_{95}	L_{50}	L_5	**Mean**	L_{95}	L_{50}	L_5	**Mean**
Broadband	104.6	115.1	132.1	116.9	103.3	114.9	140.5	118.2
10-100Hz	93.9	112.5	131.9	113.2	94.2	112.1	140.4	114.5
100-1,000Hz	**90.3**	**102.7**	**113.6**	**102.9**	**91.0**	**103.1**	**119.4**	**104.4**
1-10kHz	90.9	100.9	111.7	101.6	89.1	100.1	118.4	101.7
10-100kHz	96.3	101.6	107.8	102.5	95.3	98.1	109.8	100.5

3.9 Commercial Fish Openings

'Commercial' fish opening dates were provided by WDFW and also acquired from the Fraser Panel in season opening announcements. Regardless of whether openings were for purse seiners, gill netters, reef netters, Tribal or commercial groups, openings were all included together. Likewise, different openings started or ended at different times of day. Since this was not known for every opening, and most openings were for large portions of the day, we used all the recordings during any day with an opening in our 'commercial' fish opening subset. All other days were used for the 'no commercial' fish opening subset. Since there are not a lot of commercial fish openings, the sample size for this subset of data was much smaller than the days of data without an opening (Table 17). Interestingly, there were 2.3 times fewer boat detection periods and 1.4 times fewer 50 kHz detection periods during commercial fish openings (Table 17). Whether this means that commercial fishing activities displace some private boat use in the area is difficult to assess from these data.

The L_{50} SPL decreased by 1.9 dB in the 100-1,000 Hz band and by 4.1 dB in the L_5 SPL in the same frequency band (Table 18). It is not known how much commercial fisheries use this area, but this may indicate that commercial fisheries contribute less to the soundscape in these areas than private boaters do. CDF plots are provided in the Appendix (Figure 44 through Figure 48).

Table 17. Percent time the boat and 50 kHz detector were triggered and sample size during commercial fish openings and times when there were no commercial fish openings.

	Commercial Fish Opening	No Commercial Fish Opening
Boat Detector	3.5%	8.1%
50 kHz Detector	6.2%	8.5%
N (minutes)	13,979	274,753

Table 18. Exceedance SPL (dB re 1µPa) descriptive statistics for acoustic data collected during commercial fish openings and times when there were no commercial fish openings.

	Commercial Fish Opening				No Commercial Fish Opening			
	L_{95}	L_{50}	L_5	Mean	L_{95}	L_{50}	L_5	Mean
Broadband	105.7	117.6	133.5	118.8	103.6	114.8	138.3	117.7
10-100Hz	96.5	116.3	133.3	116.4	94.0	111.9	138.3	114.0
100-1,000Hz	**88.3**	**101.2**	**113.9**	**101.8**	**90.9**	**103.1**	**118.0**	**104.0**
1-10kHz	91.5	99.0	110.7	100.4	89.5	100.5	116.2	101.7
10-100kHz	98.9	100.5	106.6	101.8	95.3	99.6	109.2	101.1

4 Discussion

Average (L_{50}) SPL in the 100-1,000 Hz band at the four locations sampled in the summer of 2019 and 2020 was 103.0 dB re 1µPa while the L_5 SPL in the same frequency band was 117.8 dB re 1µPa. For comparison, the L_{50} in the 100-1,000 Hz band at Lime Kiln (roughly 9-15 km to the NW) during the period of June 17 – July 16, 2019 was 99.9 dB re 1µPa and the L_5 was 118.4 dB re 1µPa (SMRU 2019). Both of these locations (Lime Kiln & the area covered in this project) have soundscapes dominated by vessel noise. At Lime Kiln, which is closer to the commercial shipping lanes that go to and from the Port of Vancouver, are often exposed to commercial shipping noise, with quieter periods in between ship transits. Lime Kiln is also used by transiting boats and anglers. Those transiting boats are likely driving the L_5 values in the 100-1,000 Hz band, just as they do in this project's study area. Hence why the L_5 SPL are similar across these sites. This project's study area is less exposed to commercial shipping traffic and more exposed to boat noise.

To help focus on the main drivers of ambient noise in the study area, across the seven factors considered, we provide Table 19. This shows that being inside the No-Go Zone decreased boat and 50 kHz detections as well as L_{50} and L_5 levels in the 100-1,000 Hz band. Comparing Location 4 and 2 shows that boat detections are higher at Location 4 and L_5 SPL much higher. Day, Weekend, and Holiday weekend increase detections and SPL in the 100-1,000 Hz bands to varying degrees. The trend that can be inferred here is that the more boats present, the higher the ambient noise levels in the 100-1,000 Hz band. The year 2020 shows this same general pattern (except for 50 kHz detections) compared to 2019 but is (hopefully) not indicative of an increasing trend in boats and noise levels. Intriguingly, commercial fish openings lead to reductions in detections and SPL in the 100-1,000 Hz band. It is not known why this occurs.

If there were any doubt as to small boat traffic dominating the soundscape in the study area, we provide Figure 8 and Table 20. For these, we selected data when the boat or 50 kHz detectors were triggered as well as the remaining periods with neither of these detections. When vessel related detections occur, the L_{50} in the 100-1,000 Hz band increases by 10 to 11 dB above periods when there are no vessel related detections. At the L_5 SPL in the same frequency band, there is an increase of 10-14 dB. Given the logarithmic dB scale, these are large increases.

Table 19. Comparison of the difference in key metrics by factor.

	No-Go Zone	Location*	Day	Weekend	Holiday Weekend	2020	Commercial Fish Opening
Boat Detections	-3.3%	9.7%	5.0%	0.6%	2.4%	4.3%	-4.6%
50 kHz Detections	-4.3%	-12.5%	12.7%	5.0%	3.3%	-3.0%	-2.3%
L_{50} (100-1,000 Hz; dB)	-0.7	-0.8	2.8	0.4	2.2	0.4	-1.8
L_5 (100-1,000 Hz; dB)	-3.4	7.6	8.9	1.6	7.1	5.8	-4.1

*Comparison of Location 4 with Location 2.

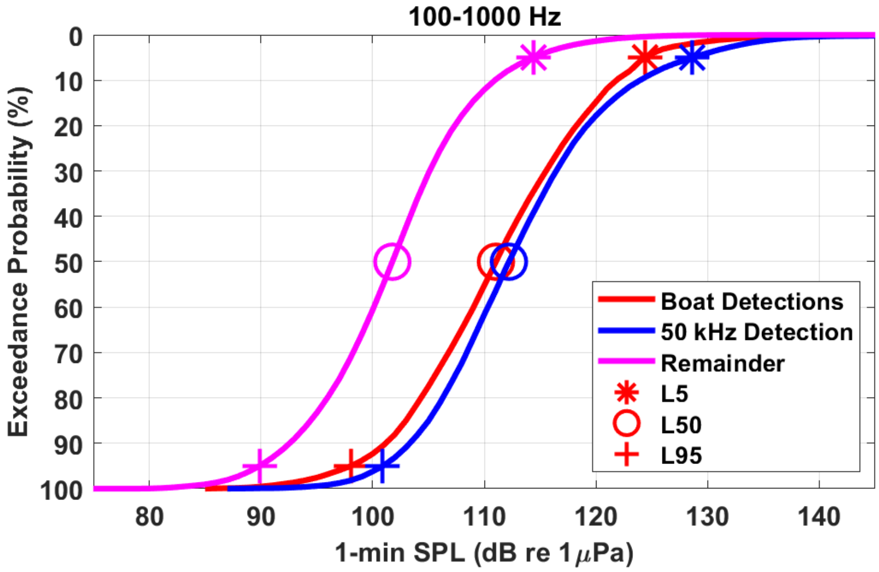

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Figure 8. Exceedance CDF plots of ambient noise in the 100-1,000 Hz band during boat and 50 kHz detections and remaining periods without those detections.

Table 20. Exceedance SPL (dB re 1µPa) descriptive statistics for acoustic data in the 100-1,000 Hz band during boat and 50 kHz detections and remaining periods of data without those detections.

	L_{95}	L_{50}	L_5	Mean
Boat Detections	98.1	111.0	124.4	111.8
50 kHz Detections	100.9	112.2	128.6	113.6
Remainder	89.9	101.8	114.4	102.3

5 Conclusions

- SRKW utilized the study area approximately 20% of the days monitored. This is comparable to their presence at Lime Kiln. This highlights the importance of both areas to this population.
- Due to the high currents in the study area, we focus on reporting sound pressure levels in the 100-1,000 Hz frequency band. In that band, the L_{50} was 103.0 dB re 1µPa, and the L_5 was 117.8 dB re 1µPa. The boat detector was triggered 7.8% of the time and the 50 kHz detector 8.4% of the time suggested a high usage of this area by boats.
- Sound pressure levels in the 100-1,000 Hz band were slightly lower within the No-Go Zone (Inside: L_{50} = 102.6, L_5 = 115.4; Outside: L_{50} = 103.3, L_5 = 118.9 dB re 1µPa). The boat and 50 kHz detectors were triggered approximately 5.6% of the time inside the No-Go Zone and between 9 and 10% of the time outside the No-Go Zone, suggesting higher use by boat outside the No-Go Zone.
- Average sound pressure levels in the 100-1,000 Hz band were lowest at Location 3 (L_{50} = 101.5 dB re 1µPa) and highest at Location 2 (L_{50} = 103.7 dB re 1µPa) but Location 4 had the highest L_5 value (123.4 dB re 1µPa). These differences are likely driven by different uses of these areas by boats. Location 4 had the highest boat detection rates (16.2%) suggesting it is influenced by transiting boats. Locations 2 and 3 had the highest 50 kHz detection rates (16.6 and 12.3%, respectively) suggesting the area is used by slow moving (probably trolling) boats.
- Sound pressure levels in the 100-1,000 Hz band are consistently lower during the night than during the day. This is being driven by boat presence. The boat detector was triggered 9.6% of the daytime and the 50 kHz detector was triggered 12.9% of the daytime.
- Weekend vs midweek and similar comparisons around holiday weekends shows that boats and 50 kHz signals are detected more on weekends and holidays and that this drives sound pressure levels in the 100-1,000 Hz band upwards especially at L_5 levels. Summer weekends see a small increase in boat detections (7.4 to 8.0%) and a large increase in 50 kHz detections (6.0 to 11.0%) indicating a larger increase in trolling activity during the weekend.
- Although sampling effort was lower in 2019, data suggest an increase in the sound pressure levels in the 100-1,000 Hz band during 2020. This was likely driven by higher boat traffic from border closures and a perceived ‘Covid safe’ activity.
- Commercial fish opening resulted in reduced sound pressure levels in the 100-1,000 Hz band as well as reduced boat and 50 kHz detections.
- The L_{50} sound pressure levels in the 100-1,000 Hz band during periods with boat or 50 kHz detections compared with periods without these detections finds an approximately 10 dB difference, suggesting that boats heavily influence the soundscape in the study site.

6 Acknowledgements

We gratefully acknowledge the help of our summer interns, Diana Haass, Zachary Nachod, and Echo Wood. We were fortunate to be assisted by Brendan Flynn, Byron Rot, Ken Hunter, and several others who helped us recover or search for lost CAB units. We are grateful to the Lummi Nation for engaging in the permitting process and working with us to find solutions for equipment deployment. Fisheries openings were kindly provided by Washington State Department of Fish and Wildlife as well as San Juan County. This effort has been funded through the National Fish and Wildlife Foundation by NOAA Fisheries and SeaWorld Parks and Entertainment.

7 References

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8 Appendix

CDF plots (for broadband and all four bands) are provided here in the appendix for each factor assessed.

8.1 All Acoustic Data

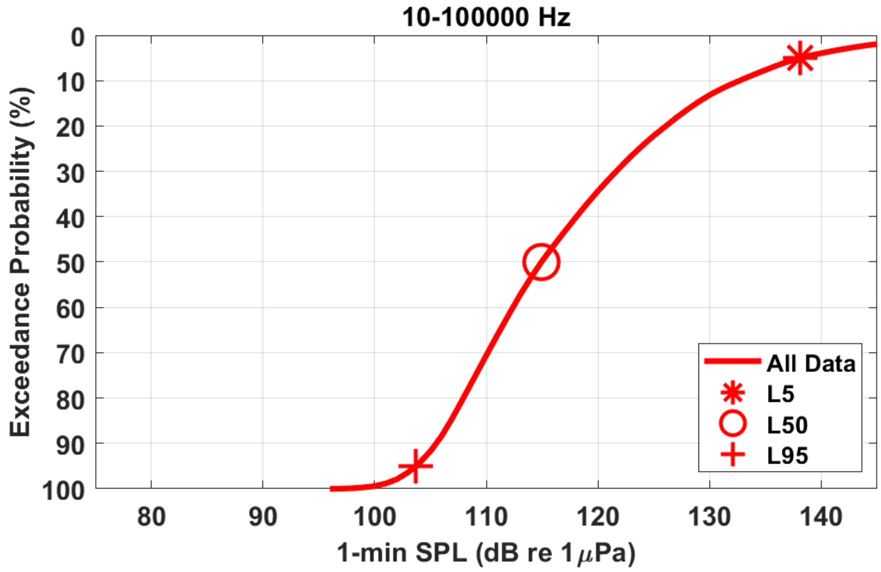

Figure 9. Broadband (10 Hz-100 kHz) exceedance Cumulative Distribution Functions (CDFs) for all data collected.

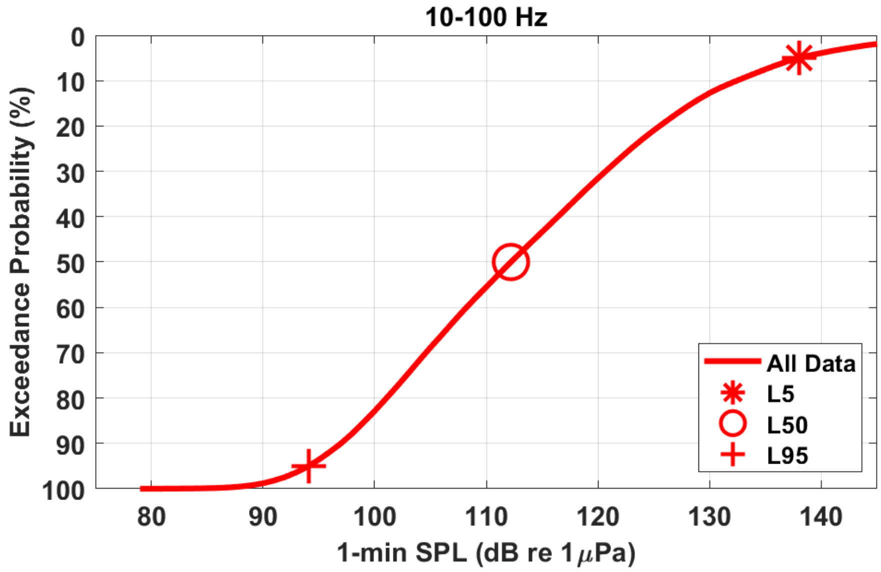

Figure 10. Decade 1 (10-100 Hz) band exceedance Cumulative Distribution Functions (CDFs) for all data collected.

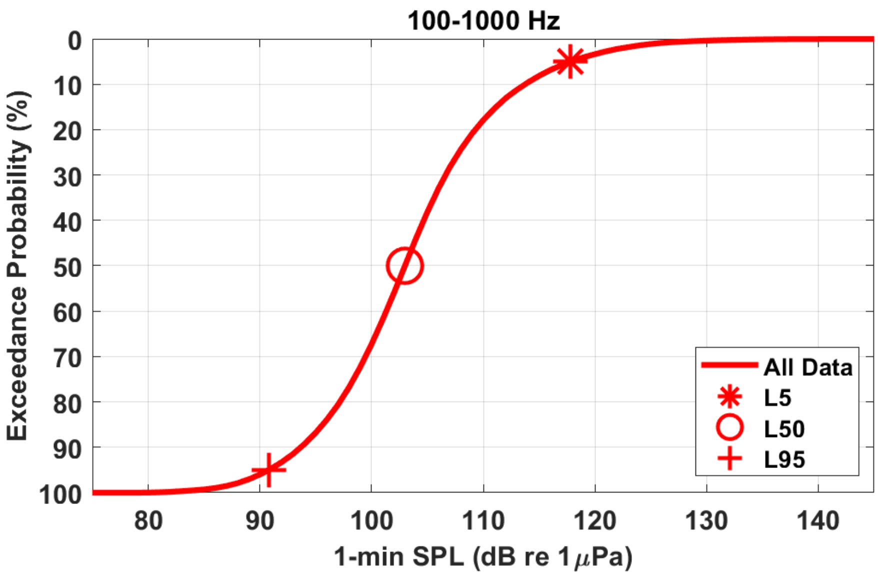

Figure 11. Decade 2 (100-1,000 Hz) band exceedance Cumulative Distribution Functions (CDFs) for all data collected.

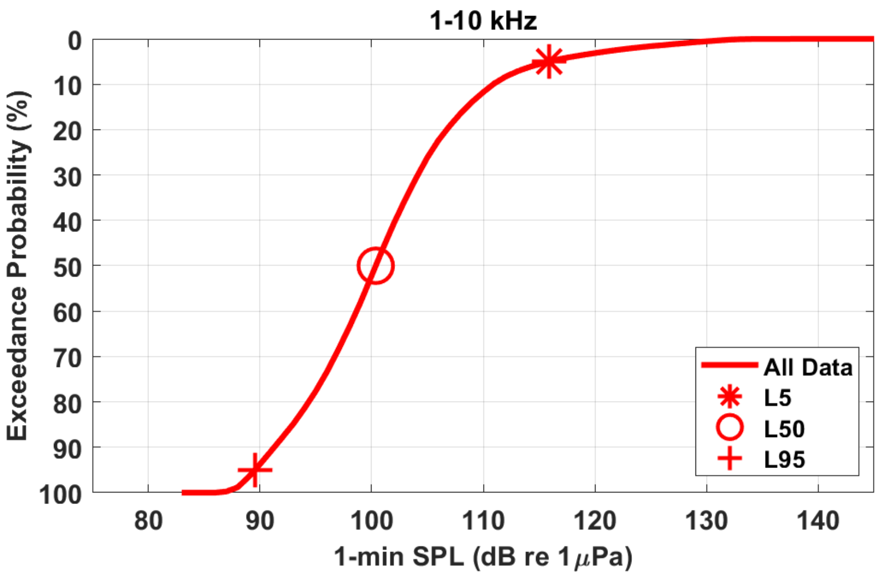

Figure 12. Decade 3 (1-10 kHz) band exceedance Cumulative Distribution Functions (CDFs) for all data collected.

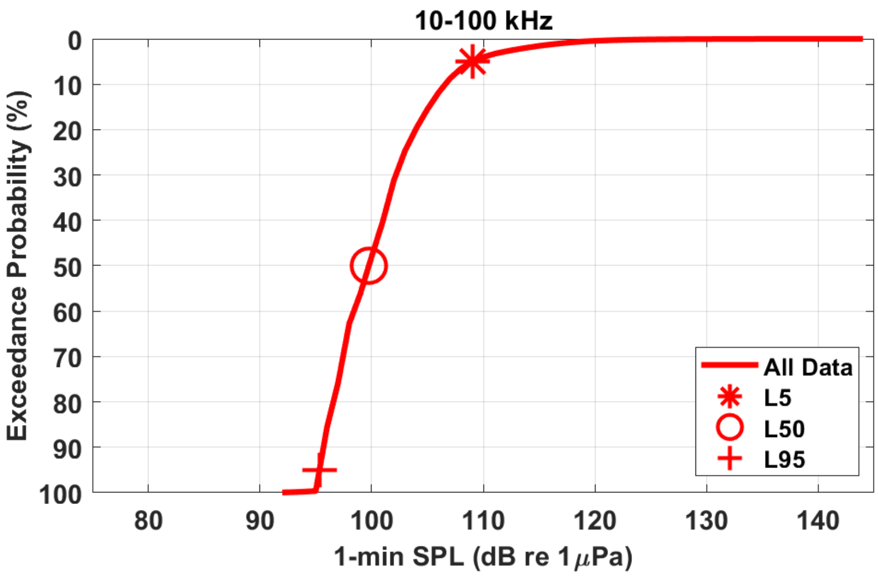

Figure 13. Decade 4 (10-100 kHz) band exceedance Cumulative Distribution Functions (CDFs) for all data collected.

8.2 Effect of No-Go Zone

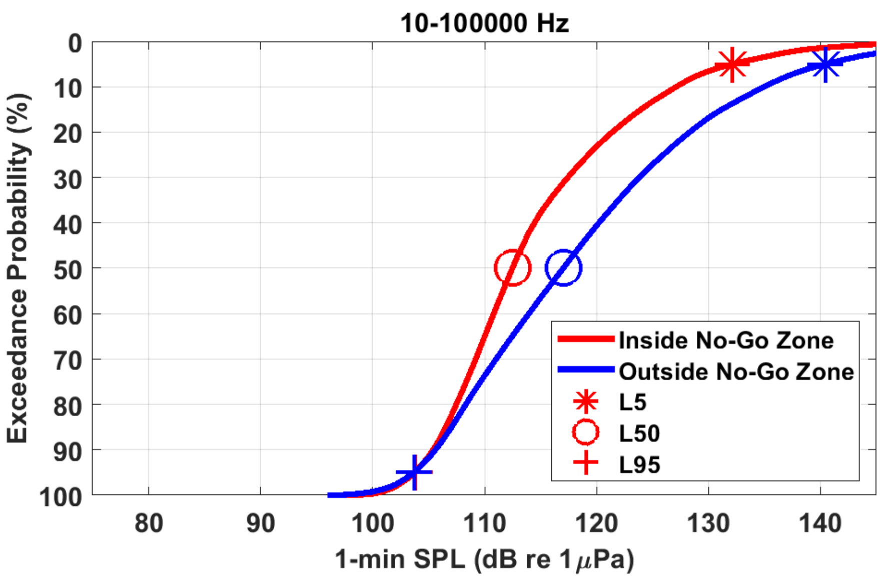

Figure 14. Broadband (10 Hz-100 kHz) exceedance Cumulative Distribution Functions (CDFs) for inside and outside the No-Go Zone.

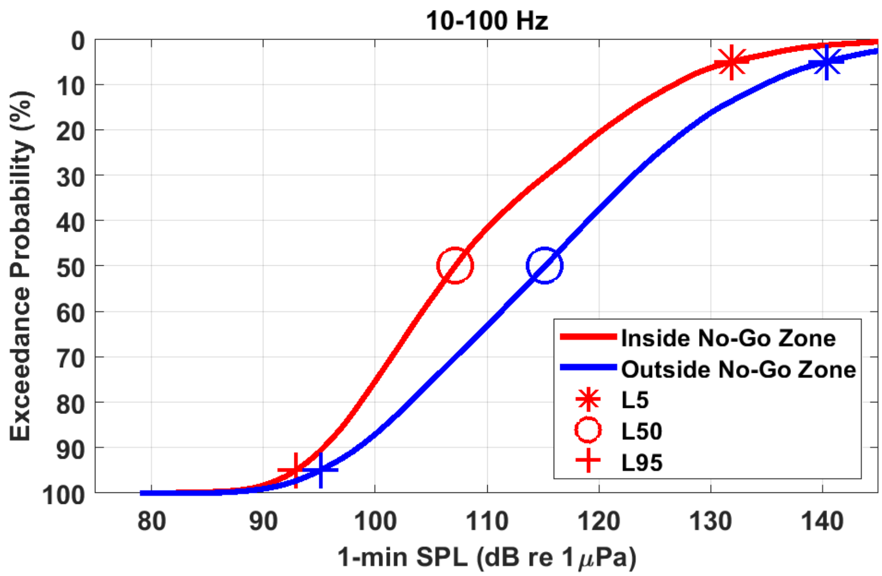

Figure 15. Decade 1 (10-100 Hz) band exceedance Cumulative Distribution Functions (CDFs) for inside and outside the No-Go Zone.

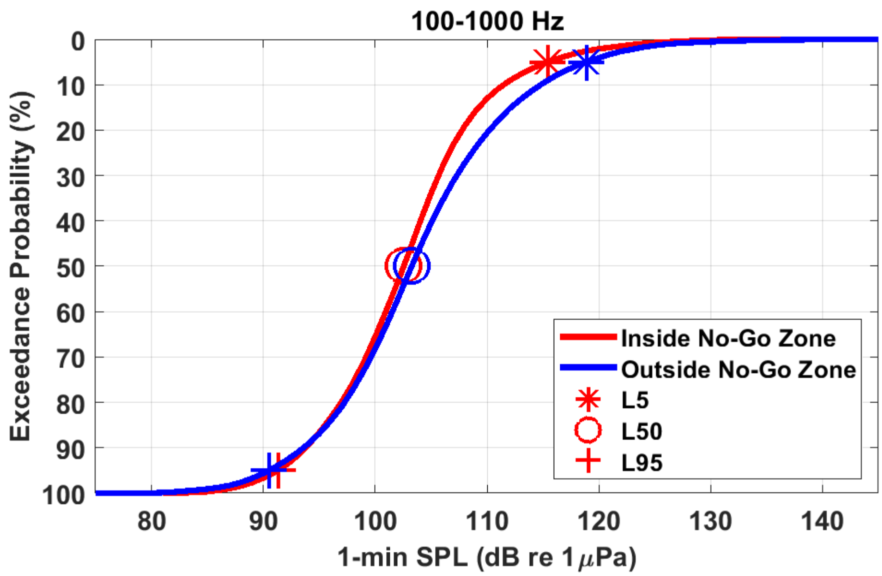

Figure 16. Decade 2 (100-1,000 Hz) band exceedance Cumulative Distribution Functions (CDFs) for inside and outside the No-Go Zone.

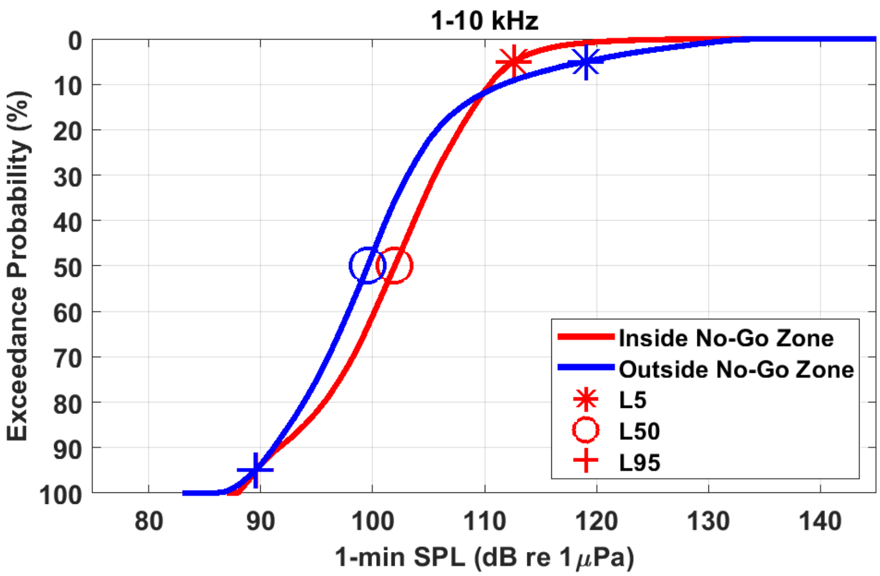

Figure 17. Decade 3 (1-10 kHz) band exceedance Cumulative Distribution Functions (CDFs) for inside and outside the No-Go Zone.

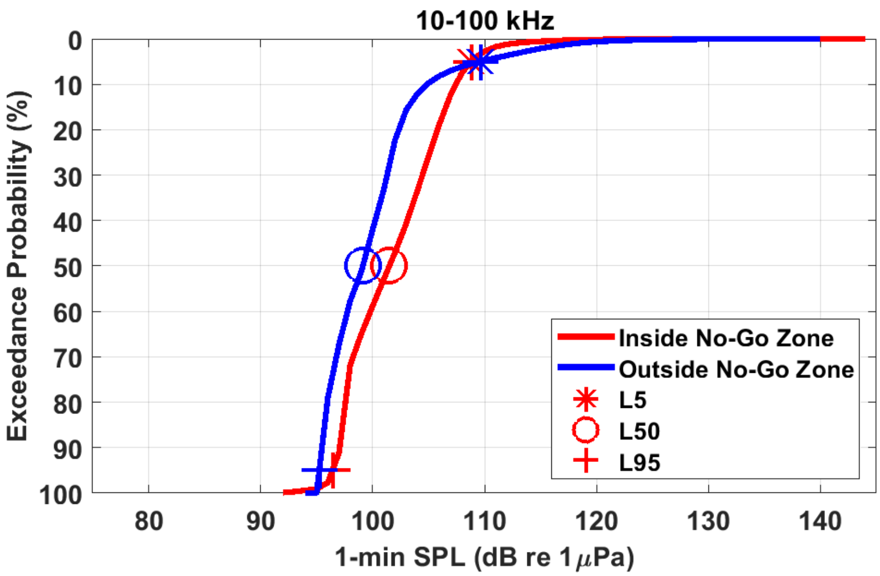

Figure 18. Decade 4 (10-100 kHz) band exceedance Cumulative Distribution Functions (CDFs) for inside and outside the No-Go Zone.

8.3 Location

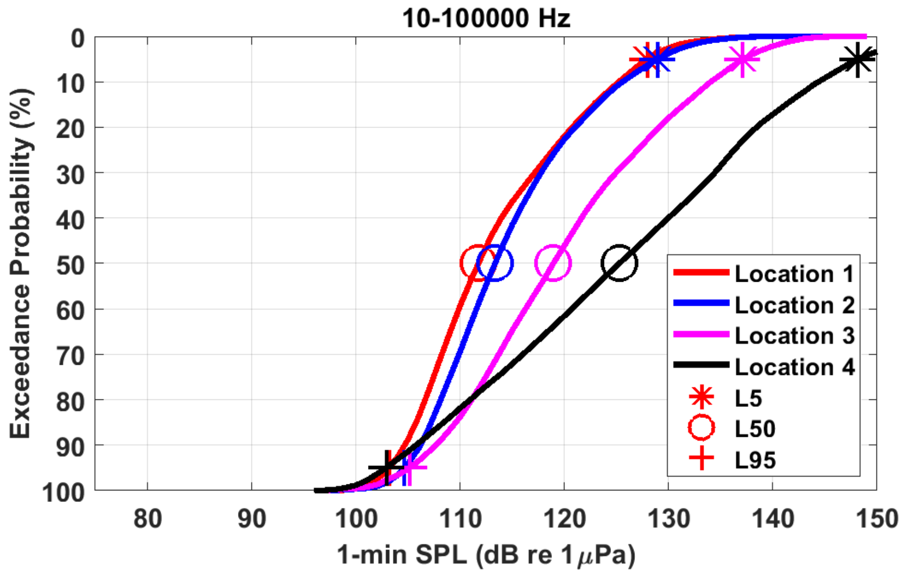

Figure 19. Broadband (10 Hz-100 kHz) exceedance Cumulative Distribution Functions (CDFs) by location.

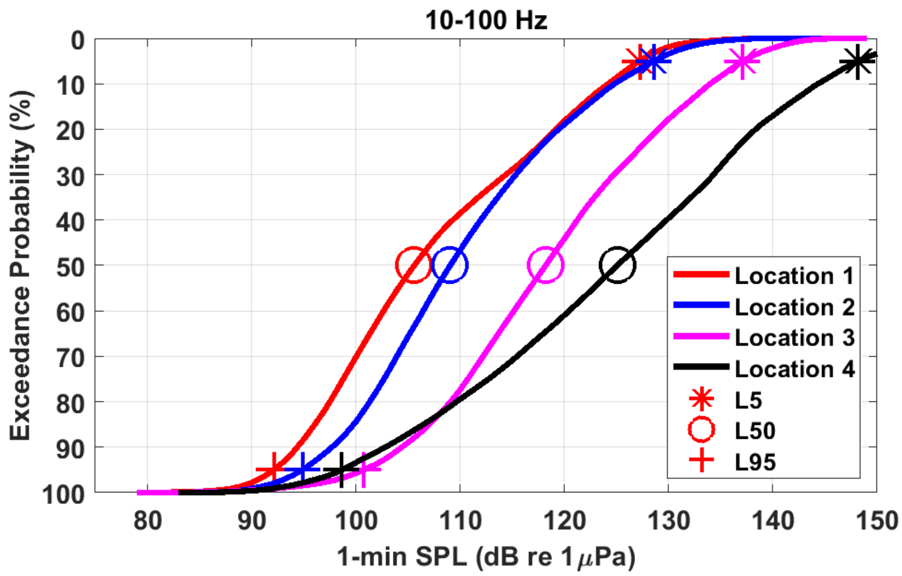

Figure 20. Decade 1 (10-100 Hz) band exceedance Cumulative Distribution Functions (CDFs) by location.

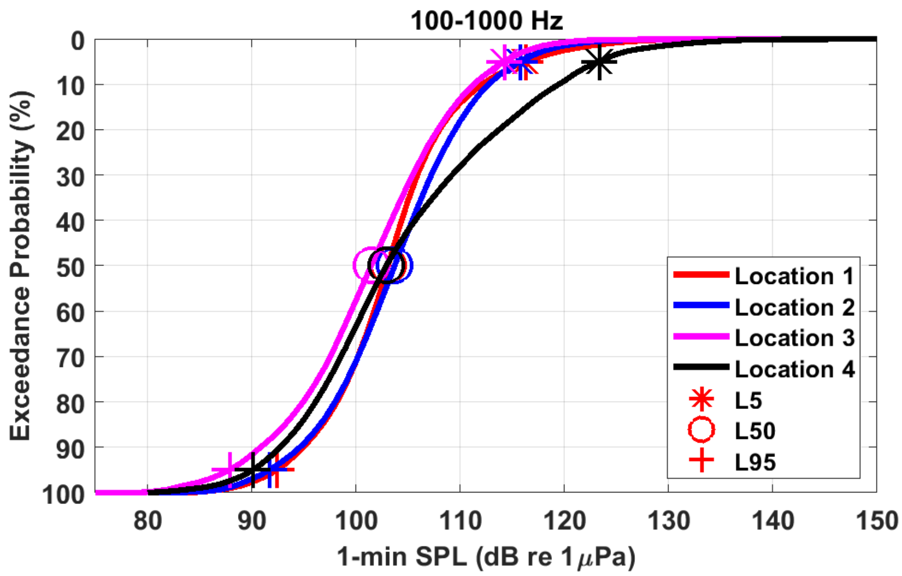

Figure 21. Decade 2 (100-1,000 Hz) band exceedance Cumulative Distribution Functions (CDFs) by location.

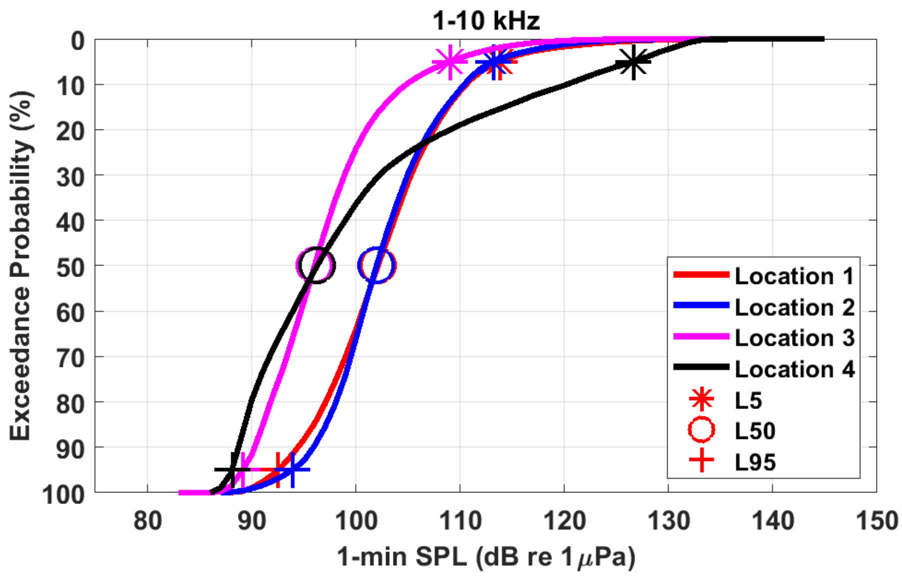

Figure 22. Decade 3 (1-10 kHz) band exceedance Cumulative Distribution Functions (CDFs) for by location.

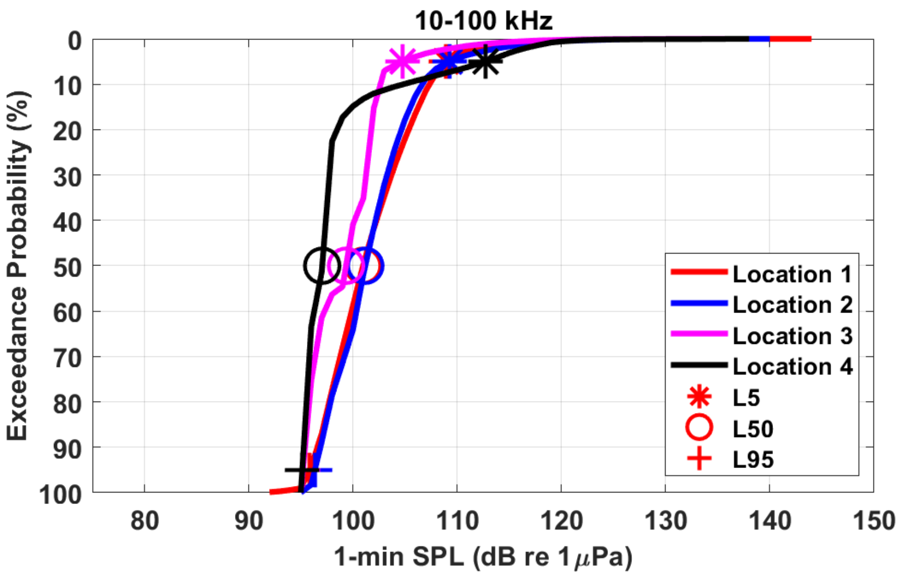

Figure 23. Decade 4 (10-100 kHz) band exceedance Cumulative Distribution Functions (CDFs) for by location.

8.4 Day vs Night

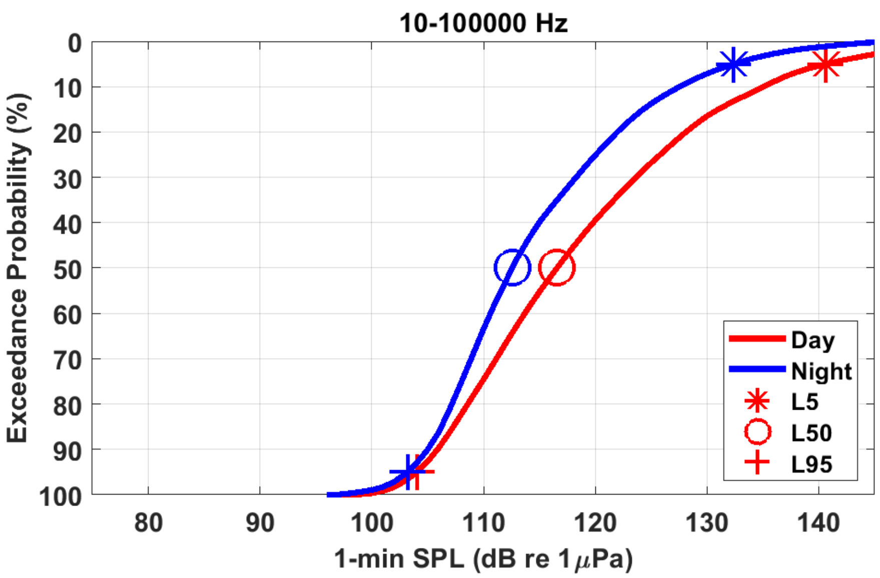

Figure 24. Broadband (10 Hz-100 kHz) exceedance Cumulative Distribution Functions (CDFs) for day vs night.

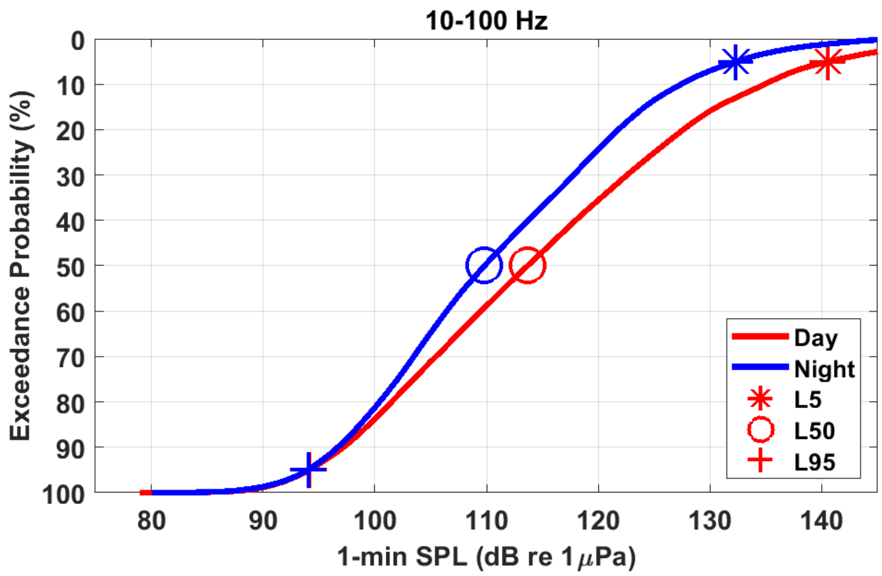

Figure 25. Decade 1 (10-100 Hz) band exceedance Cumulative Distribution Functions (CDFs) for day vs night.

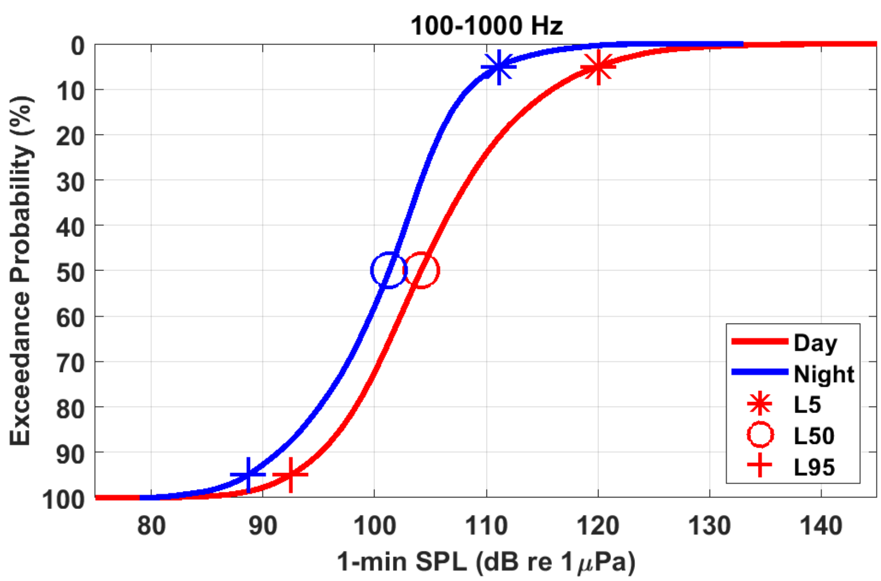

Figure 26. Decade 2 (100-1,000 Hz) band exceedance Cumulative Distribution Functions (CDFs) for day vs night.

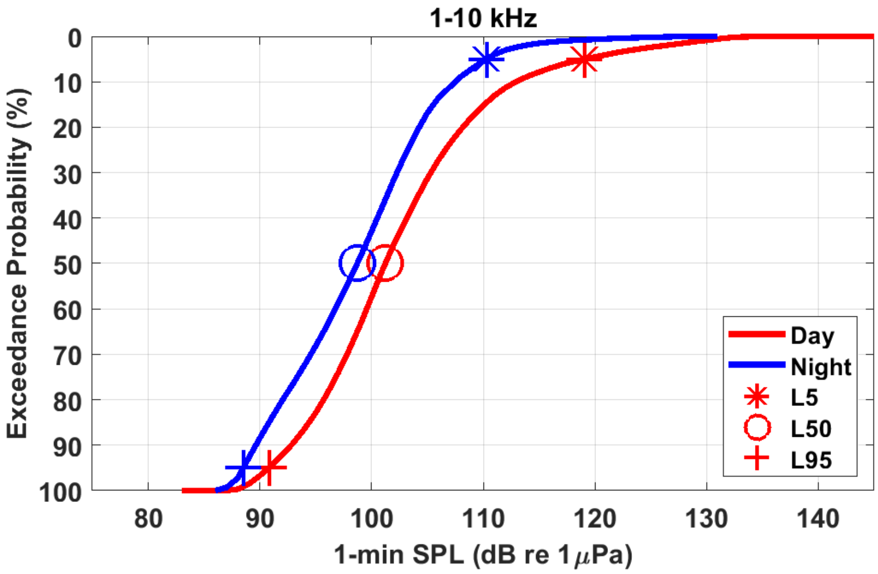

Figure 27. Decade 3 (1-10 kHz) band exceedance Cumulative Distribution Functions (CDFs) for day vs night.

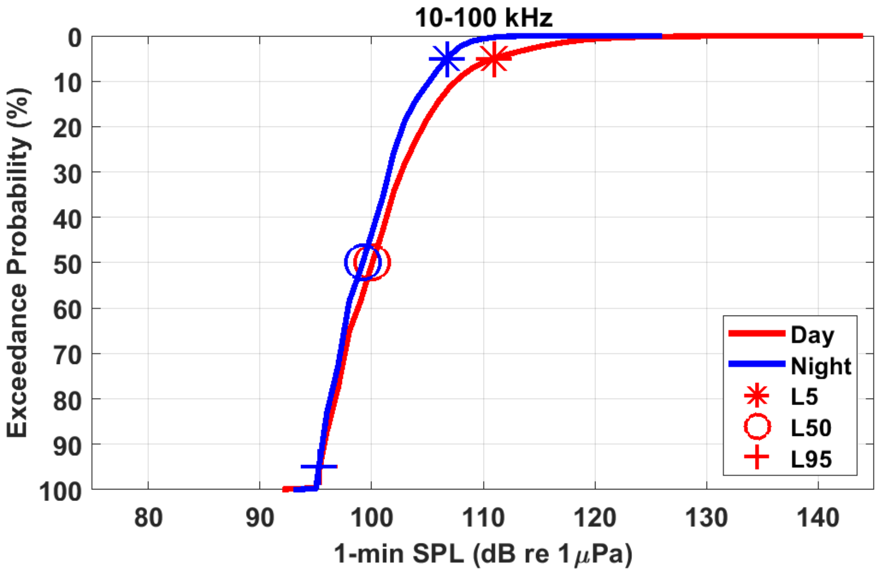

Figure 28. Decade 4 (10-100 kHz) band exceedance Cumulative Distribution Functions (CDFs) for day vs night.

8.5 Weekend vs Midweek

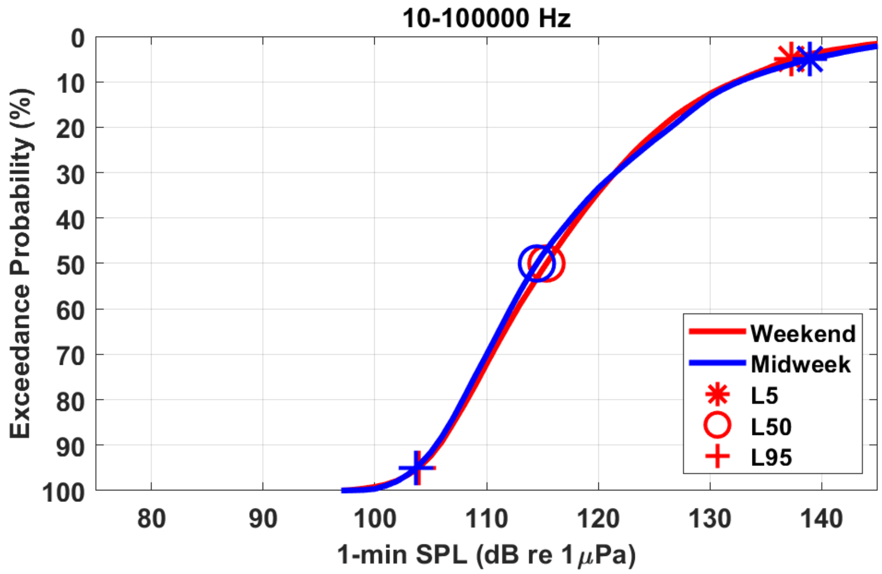

Figure 29. Broadband (10 Hz-100 kHz) exceedance Cumulative Distribution Functions (CDFs) for weekend vs midweek.

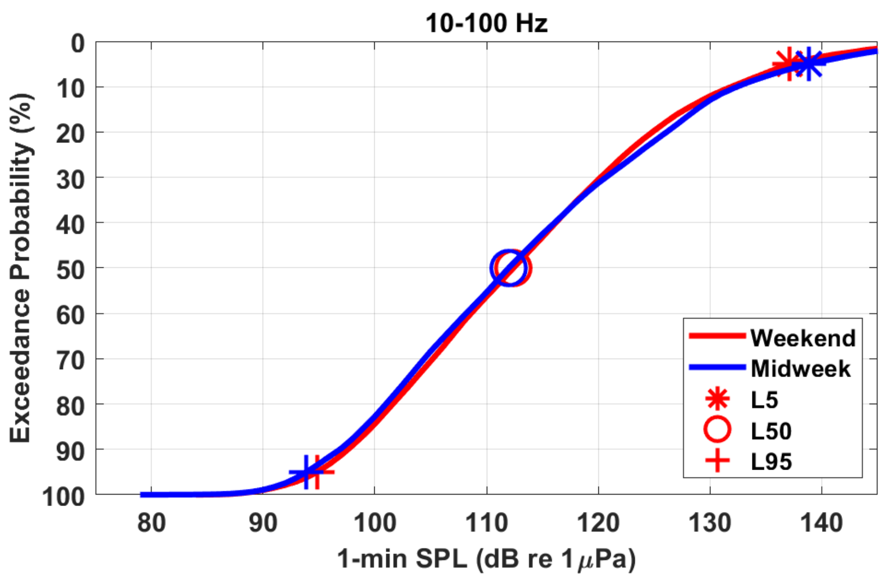

Figure 30. Decade 1 (10-100 Hz) band exceedance Cumulative Distribution Functions (CDFs) for weekend vs midweek.

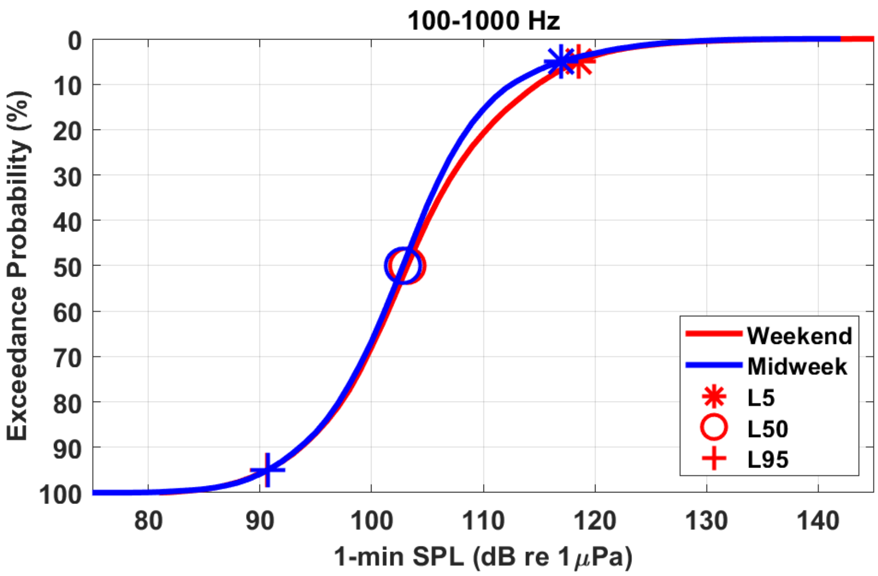

Figure 31. Decade 2 (100-1,000 Hz) band exceedance Cumulative Distribution Functions (CDFs) for weekend vs midweek.

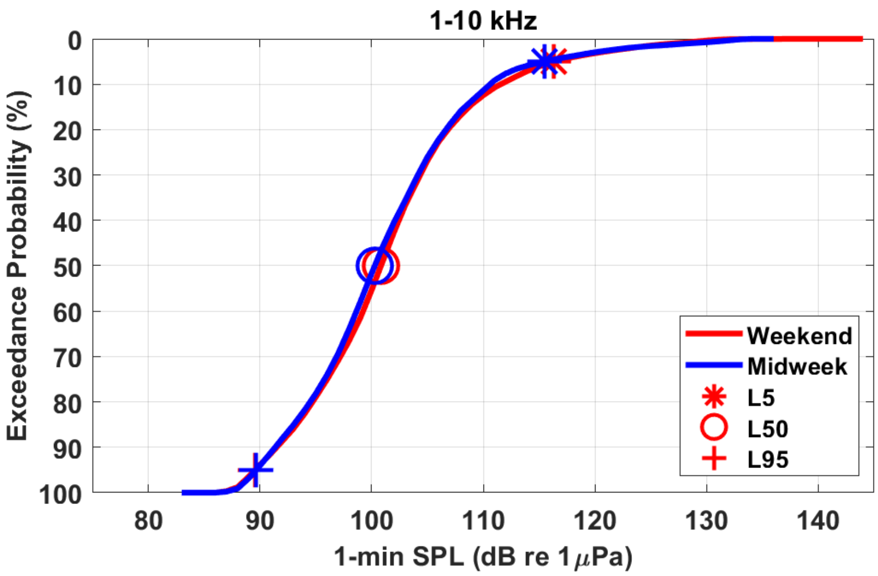

Figure 32. Decade 3 (1-10 kHz) band exceedance Cumulative Distribution Functions (CDFs) for weekend vs midweek.

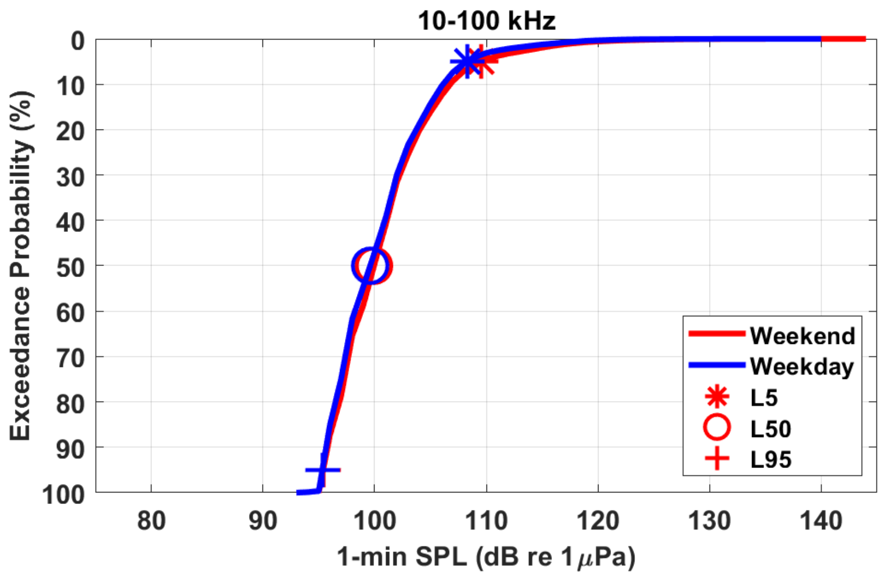

Figure 33. Decade 4 (10-100 kHz) band exceedance Cumulative Distribution Functions (CDFs) for weekend vs midweek.

8.6 Holiday Weekend

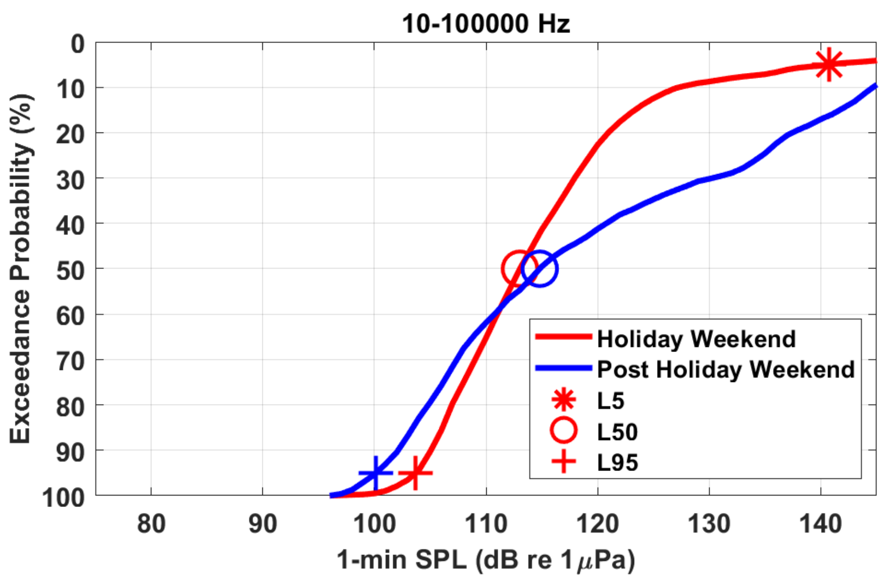

Figure 34. Broadband (10 Hz-100 kHz) exceedance Cumulative Distribution Functions (CDFs) for holiday weekends vs the three days following.

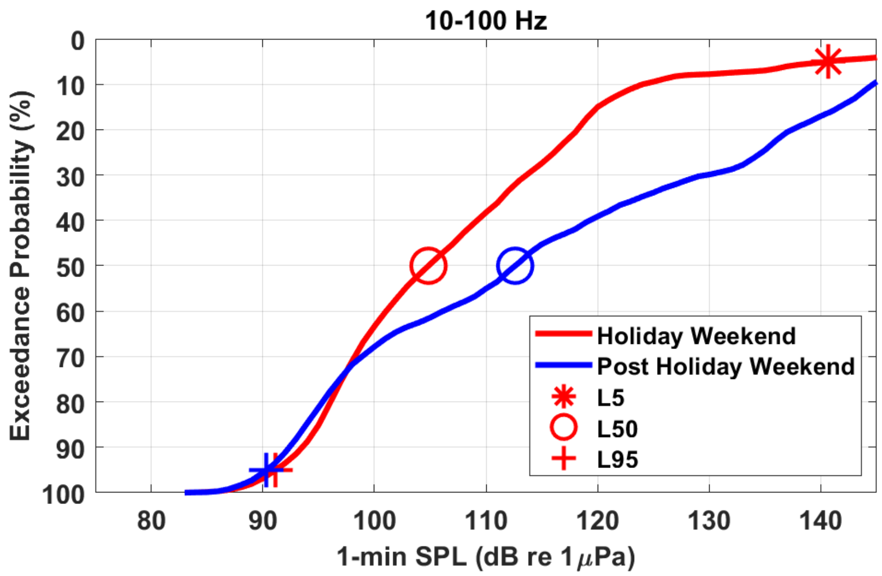

Figure 35. Decade 1 (10-100 Hz) band exceedance Cumulative Distribution Functions (CDFs) for holiday weekends vs the three days following.

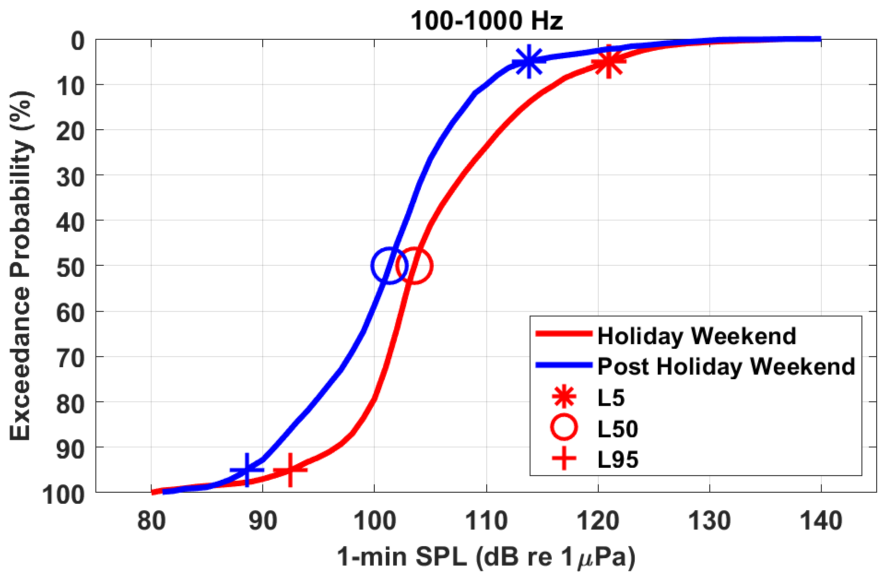

Figure 36. Decade 2 (100-1,000 Hz) band exceedance Cumulative Distribution Functions (CDFs) for holiday weekends vs the three days following.

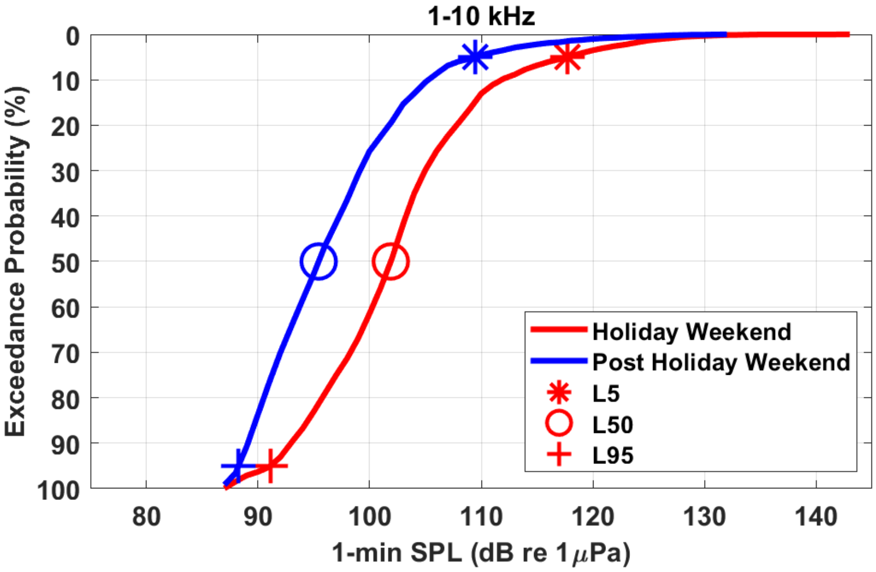

Figure 37. Decade 3 (1-10 kHz) band exceedance Cumulative Distribution Functions (CDFs) for holiday weekends vs the three days following.

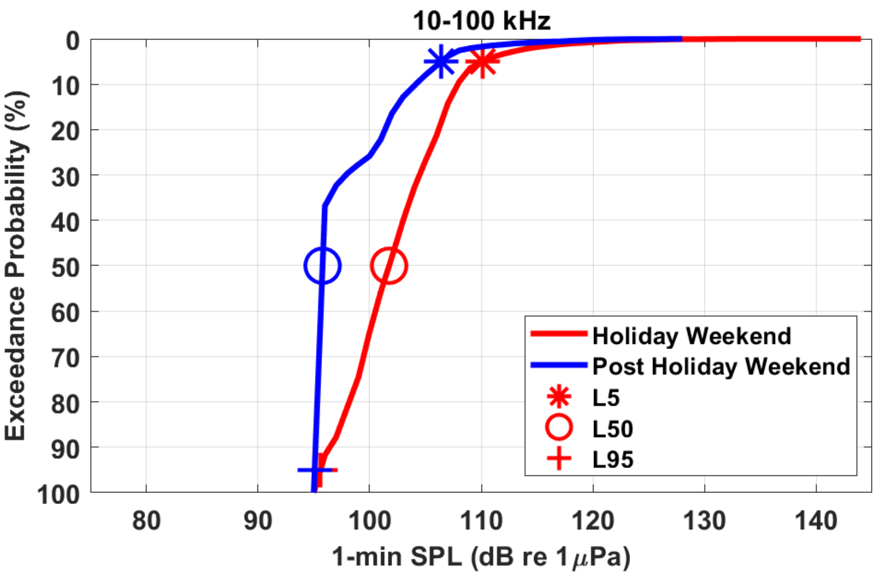

Figure 38. Decade 4 (10-100 kHz) band exceedance Cumulative Distribution Functions (CDFs) for holiday weekends vs the three days following.

8.7 2019 vs 2020

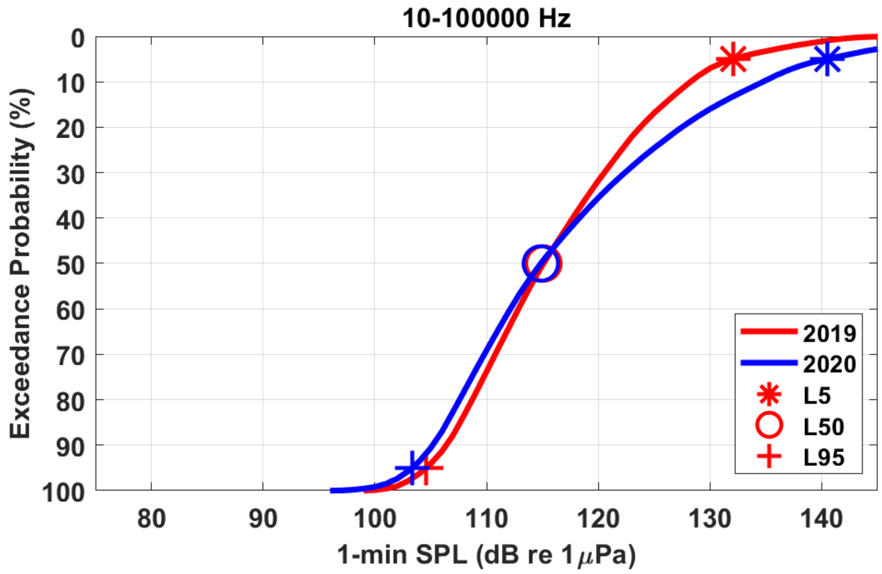

Figure 39. Broadband (10 Hz-100 kHz) exceedance Cumulative Distribution Functions (CDFs) for 2019 vs 2020.

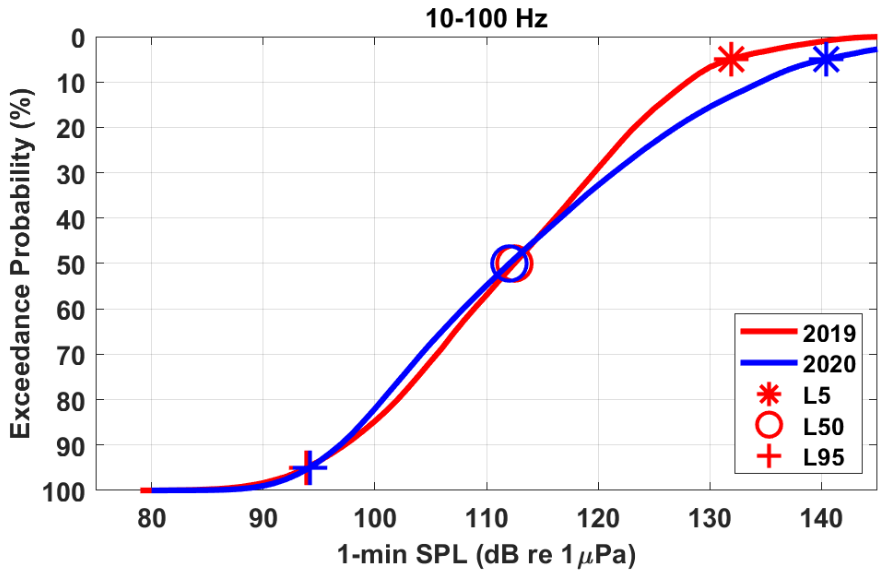

Figure 40. Decade 1 (10-100 Hz) band exceedance Cumulative Distribution Functions (CDFs) for 2019 vs 2020.

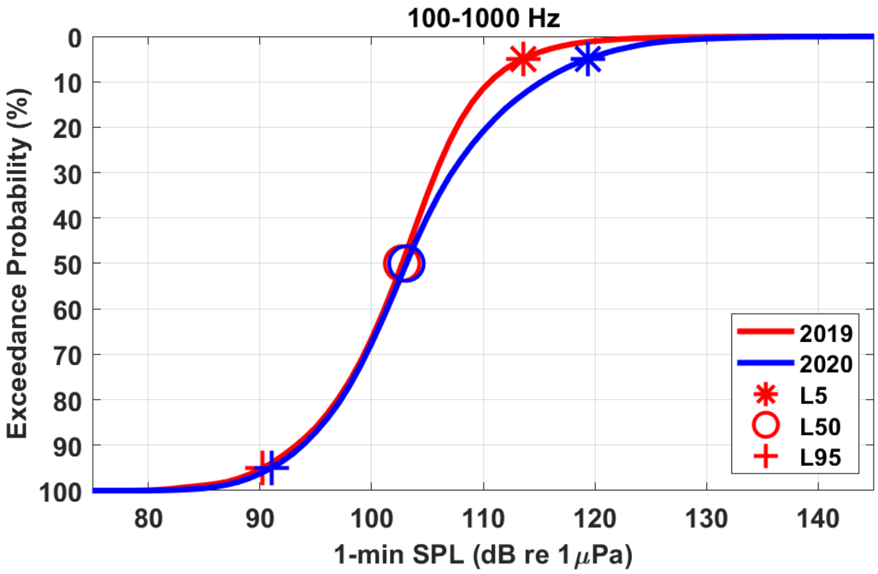

Figure 41. Decade 2 (100-1,000 Hz) band exceedance Cumulative Distribution Functions (CDFs) for 2019 vs 2020.

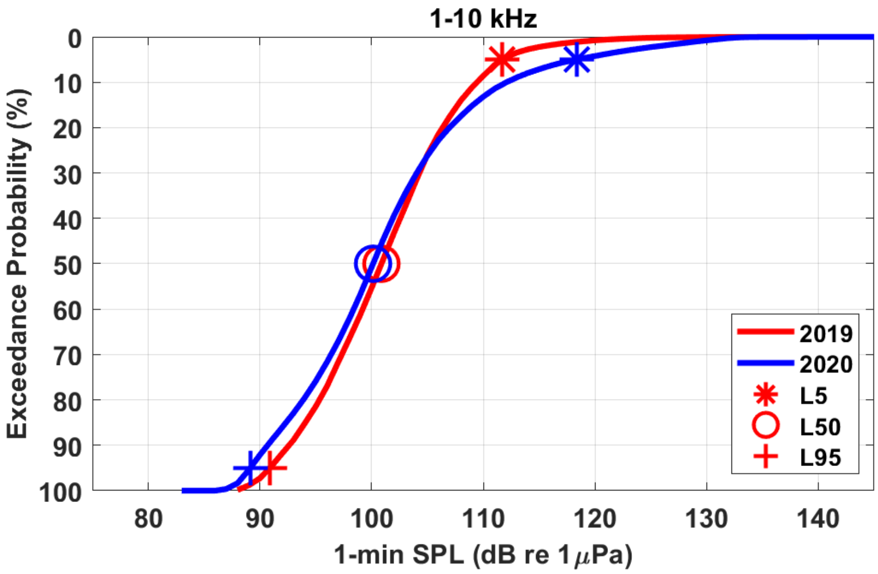

Figure 42. Decade 3 (1-10 kHz) band exceedance Cumulative Distribution Functions (CDFs) for 2019 vs 2020.

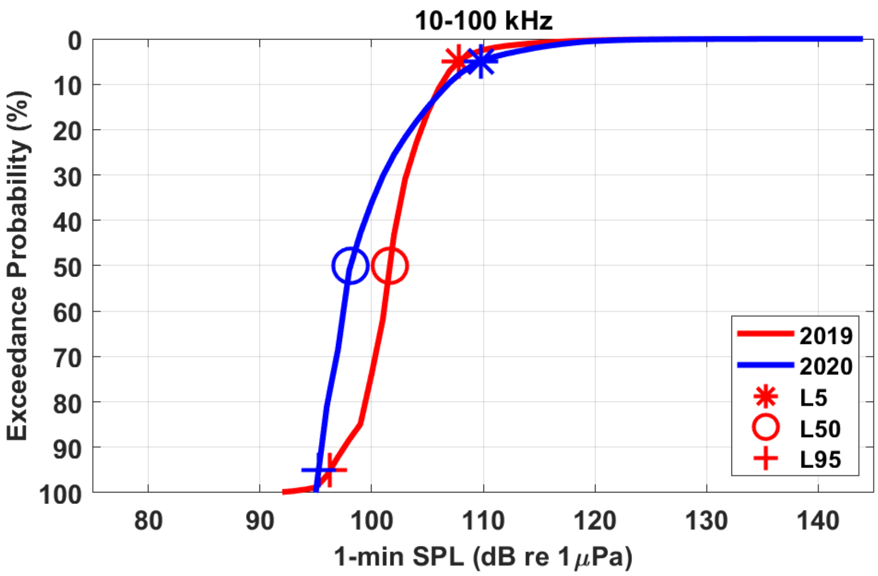

Figure 43. Decade 4 (10-100 kHz) band exceedance Cumulative Distribution Functions (CDFs) for 2019 vs 2020.

8.8 Commercial Fish Openings

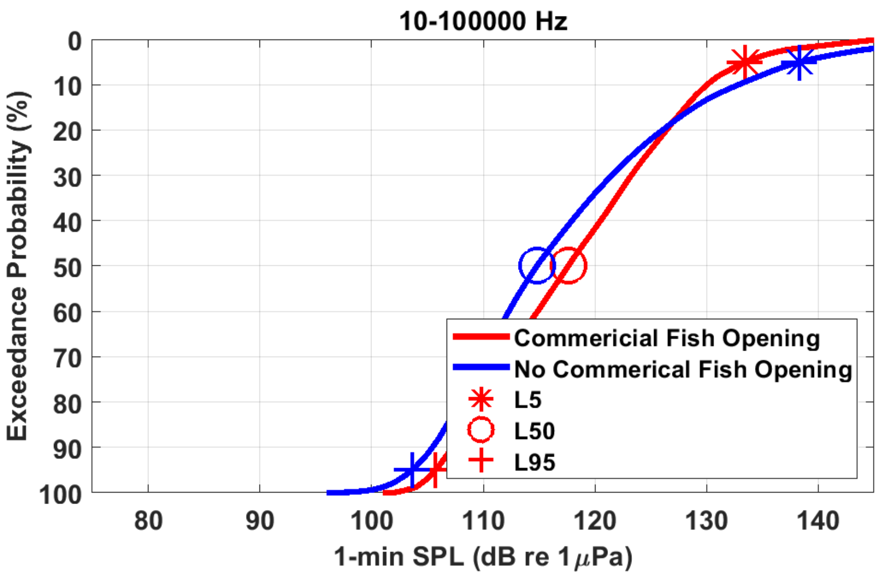

Figure 44. Broadband (10 Hz-100 kHz) exceedance Cumulative Distribution Functions (CDFs) for days with commercial fish openings vs other days.

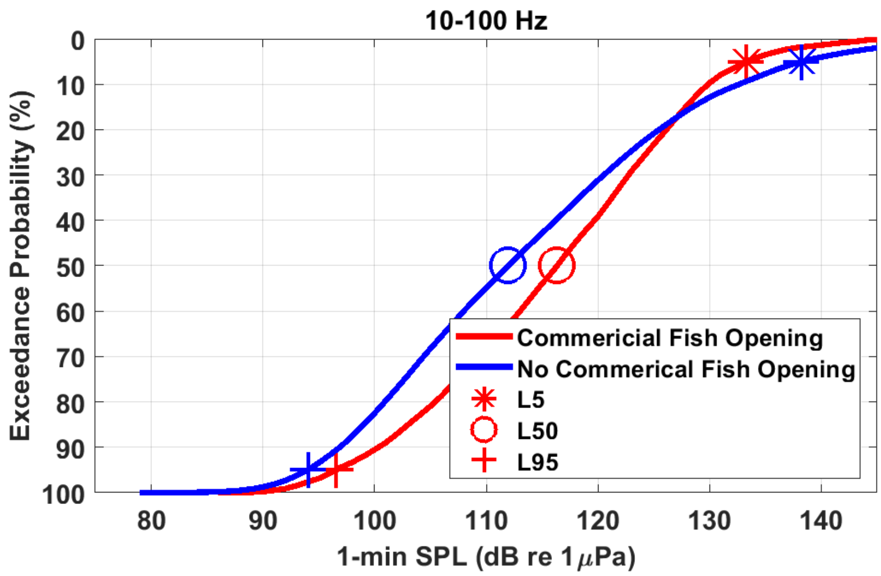

Figure 45. Decade 1 (10-100 Hz) band exceedance Cumulative Distribution Functions (CDFs) for days with commercial fish openings vs other days.

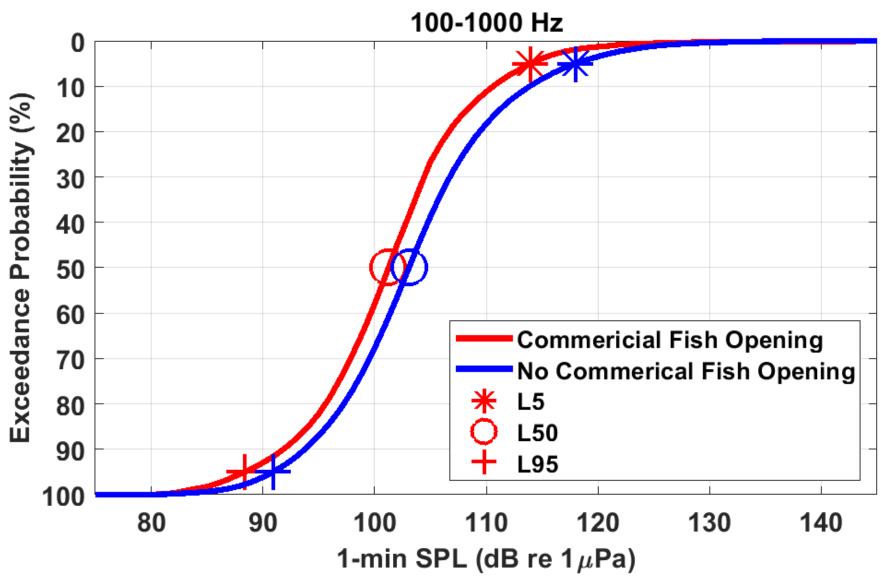

Figure 46. Decade 2 (100-1,000 Hz) band exceedance Cumulative Distribution Functions (CDFs) for days with commercial fish openings vs other days.

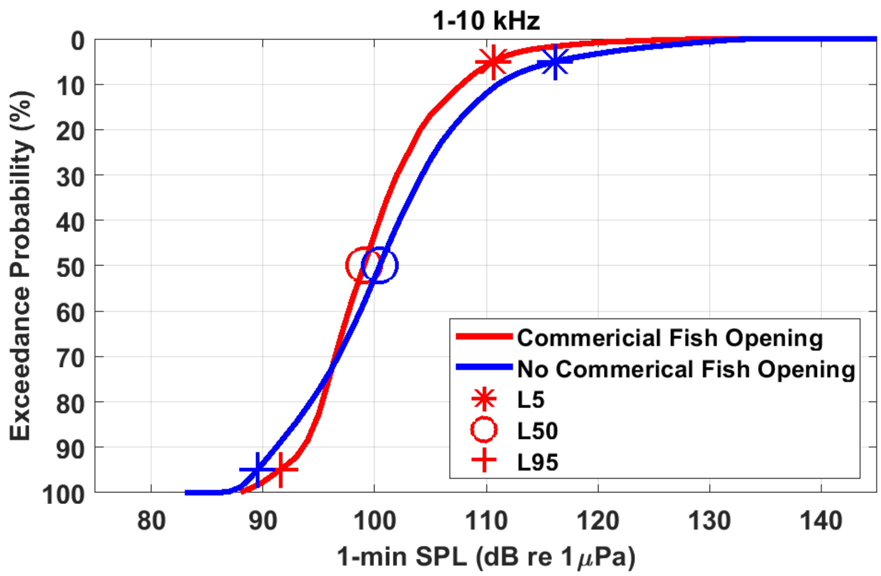

Figure 47. Decade 3 (1-10 kHz) band exceedance Cumulative Distribution Functions (CDFs) for days with commercial fish openings vs other days.

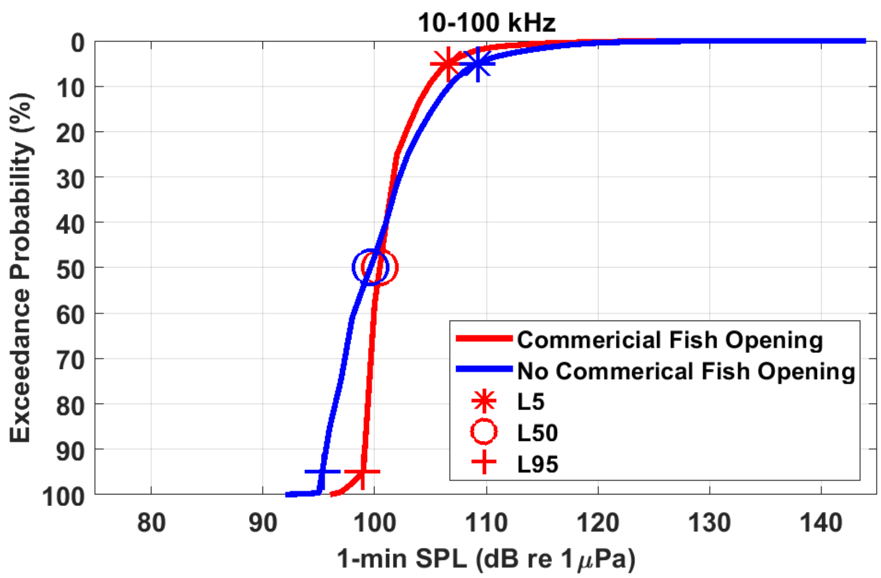

Figure 48. Decade 4 (10-100 kHz) band exceedance Cumulative Distribution Functions (CDFs) for days with commercial fish openings vs other days.