WSF UNDERWATER BACKGROUND MONITORING PROJECT

COMPENDIUM OF BACKGROUND SOUND LEVELS FOR FERRY TERMINALS IN PUGET SOUND

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EXECUTIVE SUMMARY

This technical report is an update of the 2015 report (Laughlin, 2015). Updating the marine mammal functional hearing groups to correspond to the NOAA (2018) guidance published after the 2015 analysis. The updated analysis includes using the updated marine mammal functional hearing groups published in 2018 (NOAA, 2018) after the 2015 report was published. This analysis applies more accurate marine mammal weighting functions, the data is analyzed using more accurate and more suitable MatLab 2020a scripts allowing application of the weighting functions and streamlining the analysis process

This report describes the data collected near various Washington State Ferry Terminals to determine typical underwater background sound levels. An Autonomous Multichannel Acoustic Recording device (AMAR) was deployed for up to 10 days at various locations at a distance of approximately ½ mile from the ferry terminal and away from the path of the ferry route. Three consecutive 24-hour periods of continuous recording was analyzed to determine the background sound level (Table 1). In addition a separate analysis was conducted using only the daytime background sound levels over those three days (Table 2).

Table 1: Underwater Background Monitoring Results, 3, 24-hour Periods by ferry terminal and functional hearing groups.

Ferry Terminal	1Hz to 20 kHz Broadband	7 Hz to 20 kHz Low Frequency	50 Hz to 20 kHz Phocids	60 Hz to 20 kHz Otariids	150 Hz to 20 kHz Mid Frequency	275 Hz to 20 kHz High Frequency
Port Townsend[1]	108	108	106	106	101	100
Anacortes[2]	121	116	112	112	106	104
Edmonds[3]	116	114	110	110	104	102
Seattle[4]	119	117	113	113	107	106
Mukilteo (2011) [5]	117	115	111	111	105	103
Mukilteo (2015) [10]	117	112	110	110	104	102
Kingston[6]	118	116	109	109	101	98
Vashon[7]	119	116	111	111	105	103
Southworth[8]	117	114	110	110	105	103
Coupeville[9]	118	113	109	109	104	102
Lake Keechelus[11]	107	-	-	-	-	-

[1] Dahl et al. 2010. Measured in April 2010.
[2] Laughlin 2011b. Measured in March 2011.
[3] Laughlin 2011c. Measured in April 2011.
[4] Laughlin 2011d. Measured in April 2011.
[5] Laughlin 2011a. Measured in May 2011.
[6] Measured in October 2013.
[7] Measured in February 2014.
[8] Measured in February 2014.
[9] Measured in April 2015.
[10] Measured in April 2015.
[11] Soderberg and Laughlin, 2016.

Table 2: Underwater Background Monitoring Results, Daytime Only.

Ferry Terminal	1Hz to 20 kHz Broadband	7 Hz to 20 kHz Low Frequency	50 Hz to 20 kHz Phocids	60 Hz to 20 kHz Otariids	150 Hz to 20 kHz Mid Frequency	275 Hz to 20 kHz High Frequency
Port Townsend[1]	108	109	105	105	101	99
Anacortes[2]	122	118	113	113	107	105
Edmonds[3]	117	115	112	111	106	104
Seattle[4]	120	117	113	113	108	106
Mukilteo (2011)[5]	118	116	112	112	106	105
Mukilteo (2015)[10]	118	116	111	111	105	103
Kingston[6]	118	116	109	110	101	98
Vashon[7]	120	117	113	113	107	106
Southworth[8]	117	115	111	111	106	104
Coupeville[9]	118	114	110	110	104	102
Lake Keechelus[11]	107	-	-	-	-	-

[1] Dahl et al. 2010. Measured in April 2010.
[2] Laughlin 2011b. Measured in March 2011.
[3] Laughlin 2011c. Measured in April 2011.
[4] Laughlin 2011d. Measured in April 2011.
[5] Laughlin 2011a. Measured in May 2011.
[6] Measured in October 2013.
[7] Measured in February 2014.
[8] Measured in February 2014.
[9] Measured in April 2015.
[10] Measured in April 2015.
[11] Soderberg and Laughlin, 2016.

INTRODUCTION

This technical report presents results of an updated analysis based on the original underwater background level report (Laughlin, 2015). This report updates the analysis by;

- Updating the marine mammal functional hearing groups to correspond to the NOAA (2018) guidance published after the 2015 analysis,
- Applies a marine mammal weighting to the data for each group rather than a simple high-pass filter at the low frequency limit of each functional hearing group,
- Uses MatLab 2020a scripts to conduct the analysis which allowed us to apply the more accurate marine mammal weighting which the Bruel and Kjaer Pulse software, used in the previous analysis, was not capable of doing. The Pulse software was also designed for airborne measurements in the auto and aircraft industries and not completely adaptable for this type of analysis.
- Using Matlab scripts allowed us to streamline our analysis process cutting the analysis time by more than half.

Underwater background sound levels measured near various ferry terminals in Puget Sound in an effort to determine site specific underwater background sound levels to assist biologists in the determination of the boundary of the zone of influence for marine mammals. Five to seven days of data were collected at each location at different times of the year over 2 years. Three consecutive full 24-hour cycles (e.g., 6AM to 6AM) were analyzed as part of this report at each location. A nylon shroud was place over the hydrophone to minimize flow noise for all sites except for Port Townsend.

For the Port Townsend data a 20 Hz high-pass filter was applied to the data before analysis to remove the potential influence of flow noise on this dataset. 30-second RMS values both with and without a marine mammal weighting for the low frequency cetaceans, the Phocid pinnipeds, the Otariid pinnipeds, the mid frequency cetaceans (including Killer Whales) and the high frequency cetaceans described in Southall et al., (2007) and NOAA (2013, 2018). For all other terminals a 20 Hz hi-pass filter was not applied since these deployments used a nylon shroud over the hydrophone to minimize flow noise. The data were plotted using a Cumulative Density Function (CDF) to determine the percent of time each sound level occurred during a continuous 72-hour recording. The 50th percentile from the CDF plot reflects a kind of average background sound level near the ferry terminal.

Typical marine mammal hearing range extends well past the 20 kHz upper limit of the equipment used to collect data, although their sensitivity to noise at the higher frequencies diminishes with increasing frequencies. According to Dr. Peter Dahl of the University of Washington Applied Physics Lab, the additional higher frequencies, and frequencies below 1Hz, do not substantially add to overall sound levels (Dahl, pers. comm., 2010).

Washington State Ferries (WSF) plans to collect underwater background data for all of the ferry terminal areas. Seasonal variation due to small motor boats can potentially raise the background +3 dB_{RMS} during summer days (Veirs 2006). If a project is taking place in the summer, and background levels were measured in another season, it may be appropriate to add +3 dB_{RMS} to the reported background.

UNDERWATER SOUND LEVELS

Characteristics of Underwater Sound

Several descriptors are used to describe underwater noise impacts. Two common descriptors are the Root Mean Square (RMS) pressure level and the Sound Exposure Level (SEL). The RMS level is the square root of the energy divided by the impulse duration. This level, presented in dB re: 1 μPa, has been used by the National Marine Fisheries Service (NMFS) in criteria for judging impacts to marine mammals from underwater vibratory or continuous-type sounds. It can be presented in Pascals (Pa) or decibels (dB) referenced to a pressure of 1 micropascal (μPa). Since water and air are two distinctly different media, a different sound level reference pressure is used for each. In water, the most commonly used reference pressure is 1 μPa whereas the reference pressure for air is 20 μPa. Except where otherwise noted, sound levels reported in this report are expressed in dB re: 1 μPa.

One-third octave band analysis offers a more convenient way to look at the composition of the sound. One-third octave bands are frequency bands whose upper limit in hertz is $2^{1/3}$ (1.26) times the lower limit. The width of a given band is 23% of its center frequency. For example, the 1/3-octave band centered at 100 Hz extends from 89 to 112 Hz, whereas the band centered at 1000 Hz extends from 890 to 1120 Hz. The 1/3-octave band level is calculated by integrating the spectral densities between the band frequency limits. Conversion to decibels is

dB = 10*LOG (sum of squared pressures in the band)

Sound levels are often presented for 1/3-octave bands because the effective filter bandwidth of mammalian hearing systems is roughly proportional to frequency and often about 1/3-octave. In other words, a mammal’s perception of a sound at a given frequency will be strongly affected by other sounds within a 1/3-octave band around that frequency. The overall level (summing all frequencies) of a broadband sound exceeds the level in any single 1/3-octave band.

METHODOLOGY

No frequency weighting (*e.g.*, A-weighting or C-weighting) was applied to the underwater acoustic measurements presented in this report. Underwater sound levels quoted in this report are given in decibels relative to the standard underwater acoustic reference pressure of 1 micro Pascal.

One hydrophone was deployed with the Autonomous Multichannel Acoustic Recorder (AMAR) approximately 10 feet from the bottom and approximately ½ mile from the various ferry terminals. The frequency response range of the hydrophone is 1 Hz to 150 kHz. The water depth varied where the AMAR was deployed. With the exception of the first deployment at Port Townsend, the AMAR had a nylon sleeve or 'sock' over the cage which protects the hydrophone from any potential flow noise that could become an issue at current speeds above 1 meter per second. The Port Townsend data had a 20 Hz high-pass filter applied to the data prior to analysis to eliminate any potential interference from flow noise, otherwise, the frequency range analyzed for the AMAR data is 1 Hz to 20 kHz.

Broadband, 1 Hz to 20 kHz, and marine mammal weighting was applied for the following frequency ranges corresponding to the different functional hearing groups (NOAA, 2018), 7 Hz to 20 kHz, 50 Hz to 20 kHz, 60 Hz to 20 kHz , 150 Hz to 20 kHz, and 275 Hz to 20 kHz and 30-second Root Mean Square (RMS) noise levels were calculated for each 30-seconds recorded during the three 24-hour continuous recordings with a 50% overlap that were analyzed for each terminal as part of this report.

Following the 2009 NMFS guidance on collecting and reporting underwater background noise levels and the functional hearing groups from Southall et al. (2007) and NOAA (2013, 2018), 30-second RMS values were calculated and the NOAA weighting functions applied to the broadband signal. A Probability Density Plot was used for each days data to determine if each day of data was approximately normally distributed. Then the results of all three days were plotted using a Cumulative Density Function (CDF) plot to determine the percent of time each sound level occurred during the 72-hour recording. The 50th percentile was determined from the CDF plot and reflects the average background sound level near the ferry terminal.

Typical marine mammal hearing range extends well past our 20 kHz upper limit of the equipment although their sensitivity to noise at the higher frequencies diminishes with increasing frequencies. According to Dr. Peter Dahl of the University of Washington Applied Physics Lab the additional higher frequencies do not add to the overall sound levels by a substantial amount (Dahl, pers. Comm., 2010).

Background sound levels during the daytime are dominated by the presence of ferry traffic cargo shipping traffic and occasional outboard motorboats. Root Mean Square (RMS) background noise levels are reported in terms of the 30-second average continuous sound level with a 50% overlap window and have been computed from the Fourier transform of pressure waveforms in 30-second time intervals. The distribution of the data is approximately log-normal however there is some variability in the daily distributions of the data.

The data were plotted in 1/3-octave bands for the entire 72-hour recording analyzed to evaluate the frequency distribution of the background noise levels. One-third octave band analysis offers a more convenient way to look at the composition of the sound and is an improvement over the spectral density plots. One-third octave bands are frequency bands whose upper limit in hertz is $2^{1/3}$ (1.26) times the lower limit. The width of a given band is 23% of its center frequency. For example, the 1/3-octave band centered at 100 Hz extends from 89 to 112 Hz, whereas the band centered at 1000 Hz extends from 890 to 1120 Hz. The 1/3-octave band level is calculated by integrating the spectral densities between the band frequency limits. Conversion to decibels is

= 10*LOG (sum of squared pressures in the band)

Sound levels are often presented in 1/3-octave bands because the effective filter bandwidth of mammalian hearing systems is roughly proportional to frequency and often about 1/3-octave. In other words a mammal's perception of a sound at a given frequency will be strongly affected by other sounds within a 1/3-octave band around that frequency. The overall level (summing all frequencies) of a broadband sound exceeds the level in any single 1/3-octave band.

The 30-second RMS data were averaged on an hourly basis for each frequency range analyzed. These averages are plotted over time indicating that there is a daily peak at each location monitored. The sound levels measured during the daytime appear to be slightly less variable than the nighttime sound levels which is probably due to the regular ferry traffic in the area during the daytime hours.

RESULTS

Port Townsend Ferry Terminal

Seven days of data were collected between April 19, 2010 and April 28, 2010 near the Port Townsend ferry terminal (Figure 1). Three full 24-hour cycles (e.g., 6AM to 6AM) were analyzed as part of this report from 6:10 AM on Tuesday March 22nd through 6:10 AM Friday March 25th. One hydrophone was deployed with the Autonomous Multichannel Acoustic Recorder (AMAR) approximately 10 feet from the bottom and approximately 3,000 feet from the Port Townsend ferry terminal. The water depth was 48 feet where the AMAR was deployed. There are 10 daily arrival/departures at the Port Townsend ferry terminal about every 90 minutes.

The distribution of the data is approximately log-normal however there is some variability in the daily distributions of the data (Figure 2).

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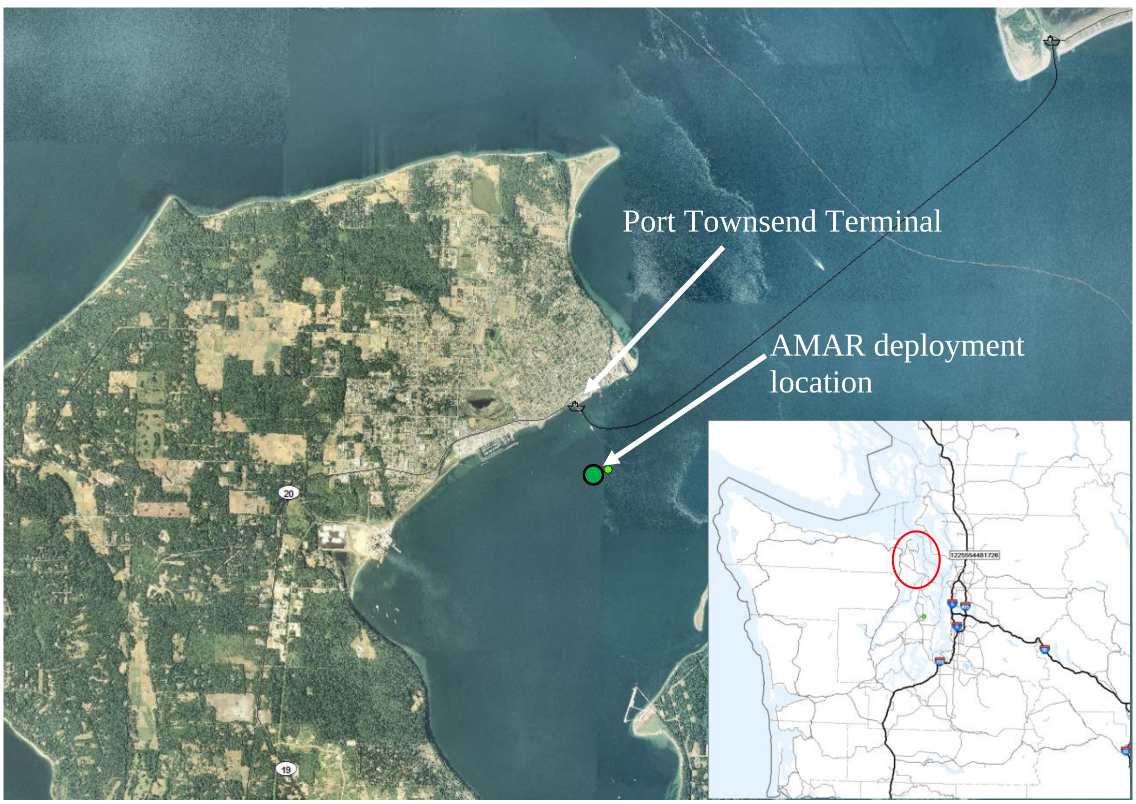

Figure 1: Location of the Autonomous Multichannel Acoustic Recorder (AMAR) deployment at Port Townsend.

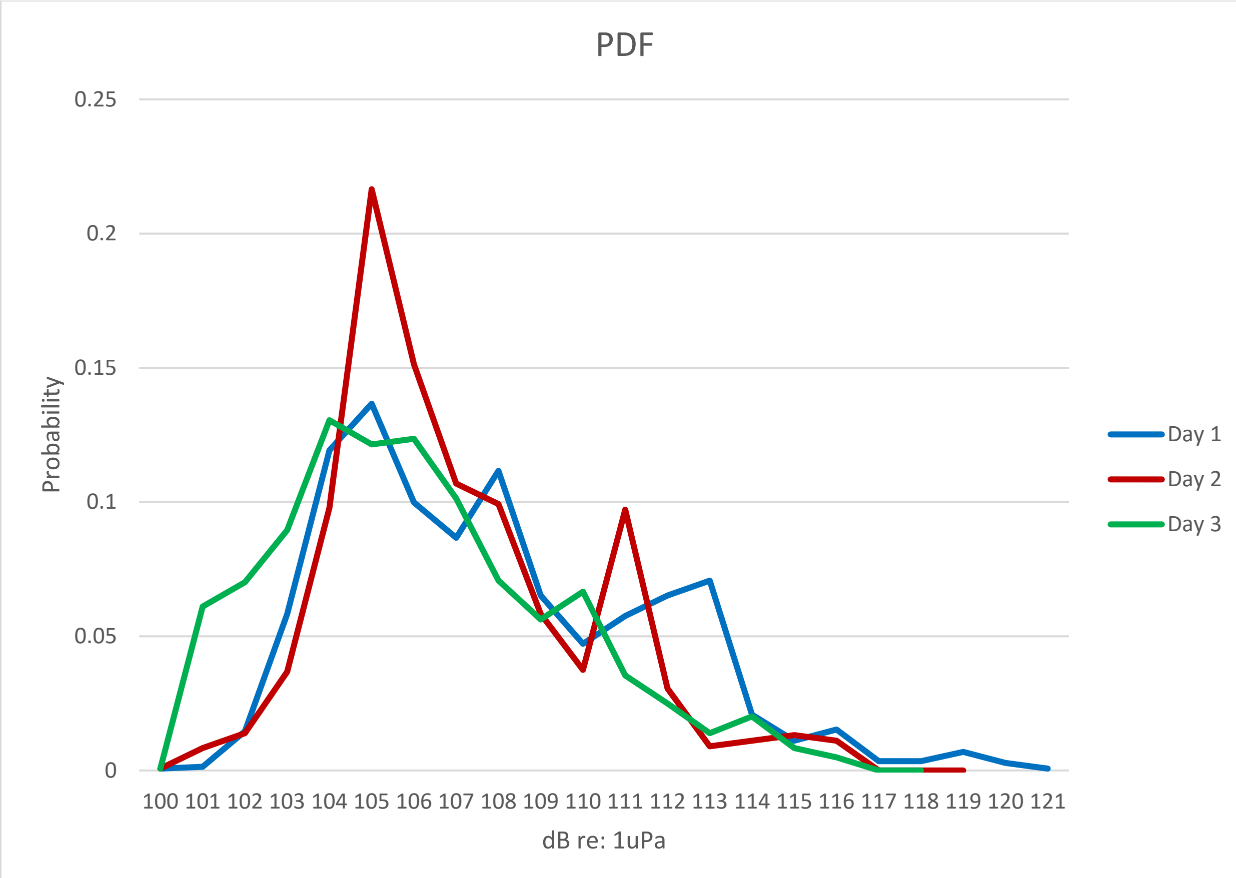

Figure 2: Probability Density Function (PDF) for the 20 Hz to 20 KHz analysis on a daily (24-hr) basis for Port Townsend (Dahl et al., 2010).

A CDF plot for the full frequency range (Figure 3) shows the typical sigmoid or 'S' shape. The overall average background sound level is approximated with the 50th percentile. The background sound levels for all frequencies measured between 20 Hz and 20 kHz ranged between 101 dB and 124 dB with the 50th percentile occurring at 108 dB (Figure 3). Background sound level analysis for functional hearing groups from Southall et al. (2007) and NOAA (2013, 2018) is shown in Table 3.

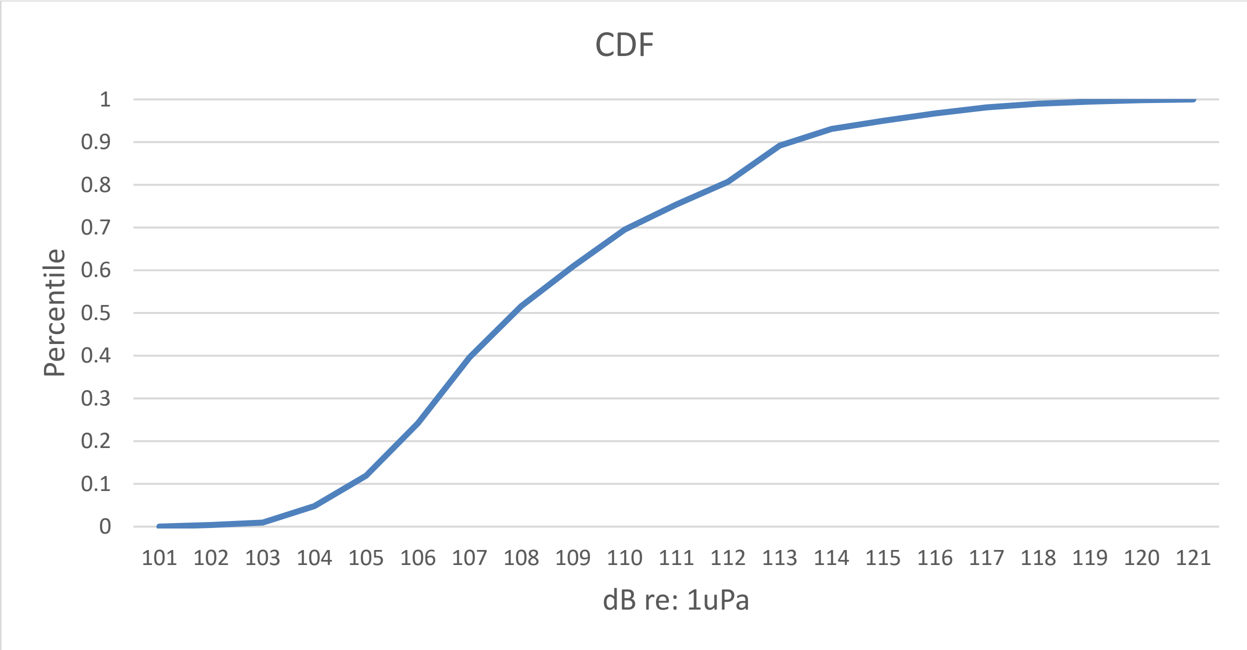

Figure 3: Cumulative Distribution Function (CDF) for the 20 Hz to 20 kHz analysis for all three days at Port Townsend.

In addition to the continuous sound level recording analysis for the 72-hour period NMFS allows background levels to be reported for only the daytime (6 AM to 6PM). Table 3 includes the same data analyzed for background sound levels representing daytime periods.

Table 3: Background Sound Level Results, Port Townsend Ferry Terminal.

Frequency Range	Functional Hearing Group	72-h 50% Cumulative Density Function (dB)	Daytime 50% Cumulative Density Function (dB)
7 Hz to 20 kHz	Low Frequency Cetaceans	108	109
50 Hz to 20 kHz	Phocid Pinnipeds	106	105
60 Hz to 20 kHz	Otariid Pinnipeds	106	105
150 Hz to 20 kHz	Mid Frequency Cetaceans	101	101
275 to 20 kHz	High Frequency Cetaceans	100	99
20 Hz to 20 kHz	N/A	108	108

Figure 4 shows the overall 1/3-octave bands for the entire 72-hour recording analyzed for Port Townsend. The dominant frequency is at 100 Hz with the energy of the frequencies on either side dropping off. These low frequency sources at 100 Hz are most likely from the ferry vessel traffic in the area and are typical of larger vessels. There is also a secondary unexplained peak at about 3 kHz.

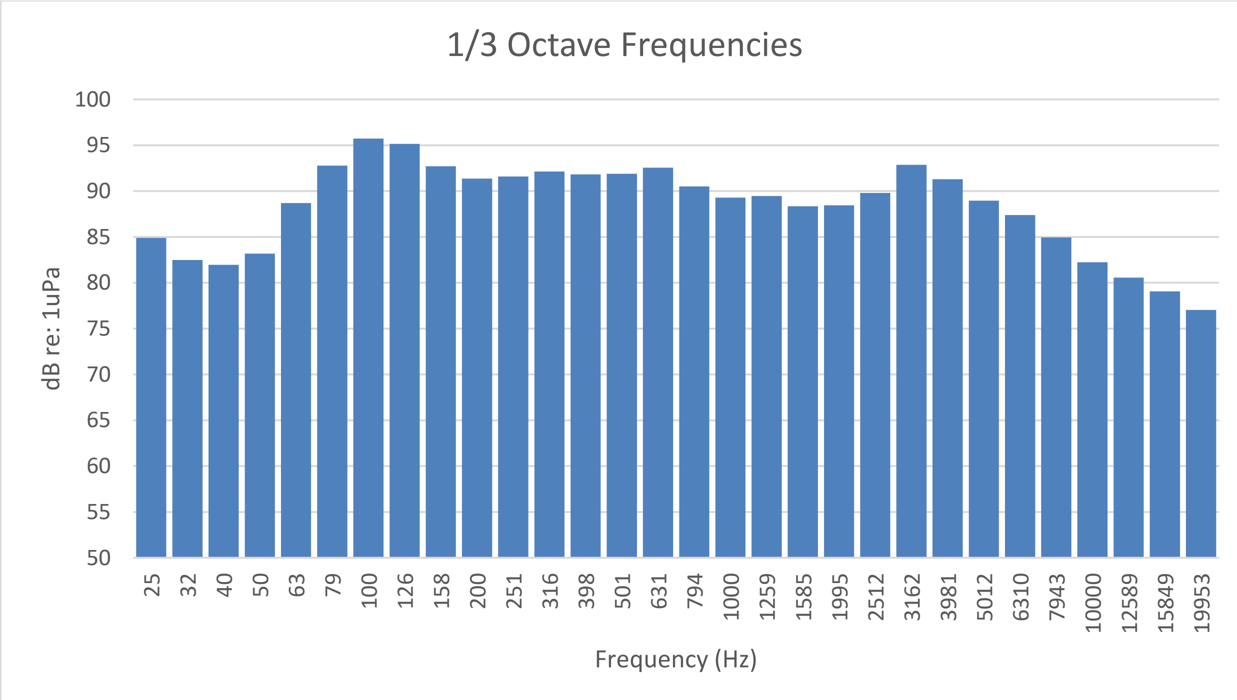

Figure 4: 1/3rd octave analysis of the broadband 20 Hz to 20 kHz frequencies for the 72-hour period near the Port Townsend ferry terminal.

Figure 5 shows results of the hourly averages of RMS values calculated between 20 Hz and 20 kHz. The lowest values at night are approximately 16 dB lower than the highest levels measured during the daytime.

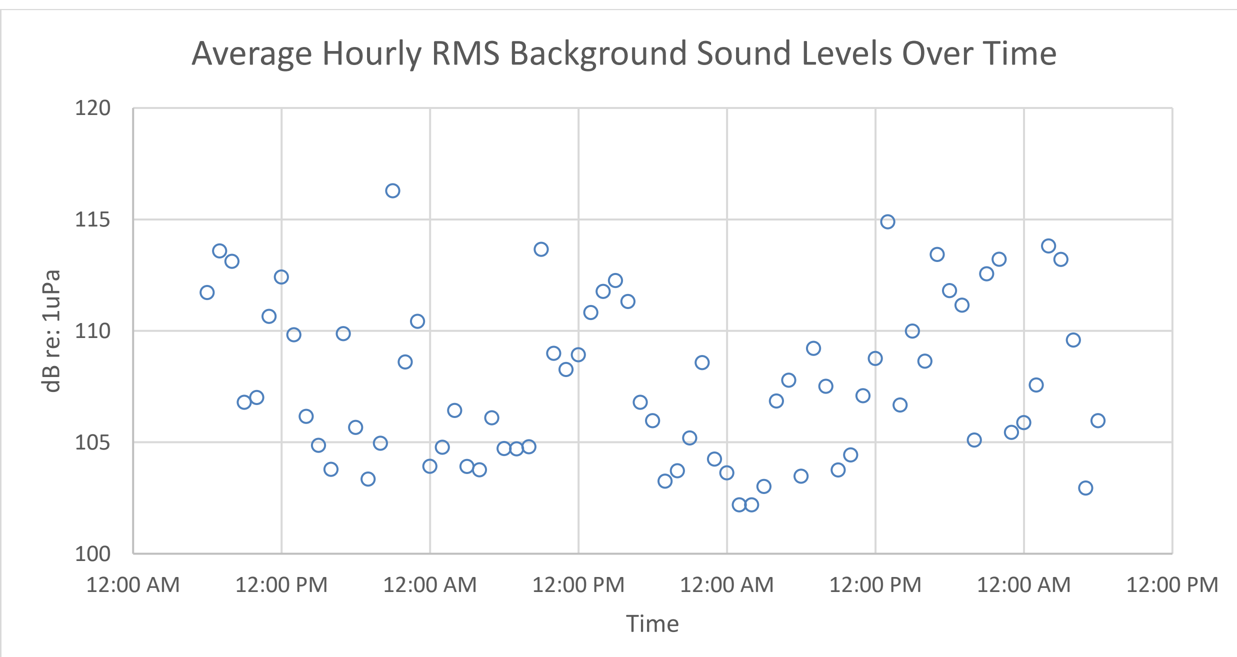

Figure 5: Average hourly background sound levels measured for a 72-hour period near the Port Townsend Ferry terminal including frequencies between 20 Hz and 20 kHz.

There is a fair amount of variability in the hourly average sound levels at Port Townsend. This is likely due to the relatively low frequency of ferry departures and arrivals and the 90 minute ferry intervals not corresponding well with the hourly averages.

Anacortes Ferry Terminal

Seven days of data were collected between March 21, 2011 and March 28, 2011 near the Anacortes ferry terminal (Figure 6). Three full 24-hour cycles (e.g., 6AM to 6AM) were analyzed as part of this report from 6:10 AM on Tuesday March 22nd through 6:10 AM Friday March 25th. One hydrophone was deployed with the Autonomous Multichannel Acoustic Recorder (AMAR) approximately 10 feet from the bottom and 2,772 feet from the Anacortes ferry terminal. The water depth was 78 feet where the AMAR was deployed.

There is only one ferry departure in the morning to Friday Harbor and Sidney, B.C and one arrival at Anacortes in the afternoon from these destinations. Additionally, three separate vessels depart Anacortes approximately every hour and arrive from the San Juan Islands approximately every hour or two in-between. A total of ten ferry vessels per day arrive / depart the Anacortes ferry terminal daily during spring weekdays when this data was collected. The slope of the sea bottom in the study area near the Anacortes ferry terminal only 0.6 degrees.

The distribution of the data is approximately log-normal however there is some variability in the daily distributions of the data (Figure 7).

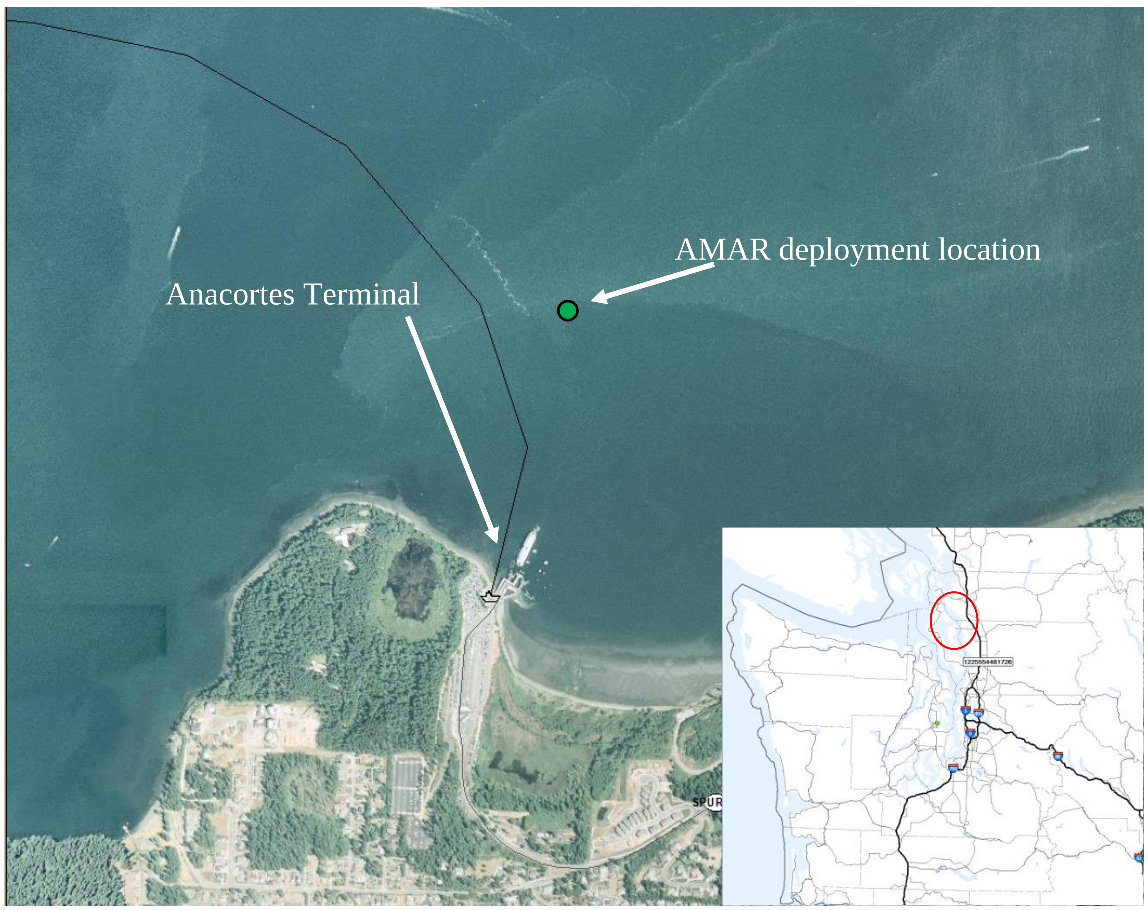

Figure 6: Location of the Autonomous Multichannel Acoustic Recorder (AMAR) deployment at Anacortes.

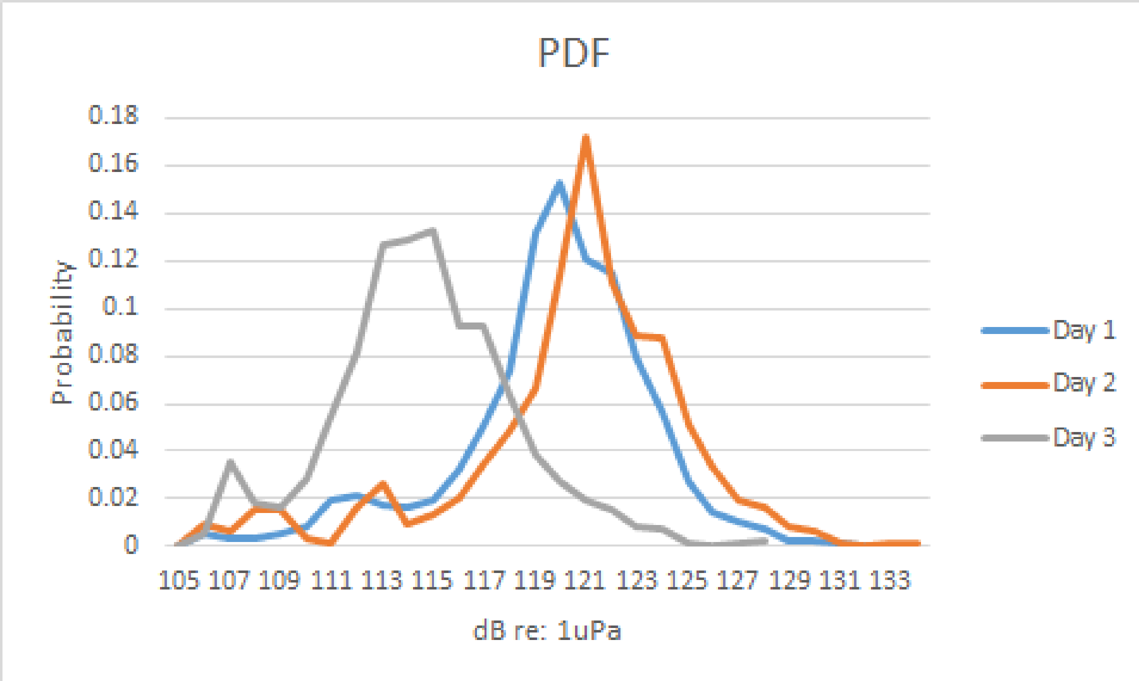

Figure 7: Probability Density Function (PDF) for the 1 Hz to 20 kHz analysis on a daily (24-hr) basis.

The background sound levels for all frequencies measured between 1 Hz and 20 kHz ranged between 105 dB and 134 dB with the 50th percentile occurring at 121 dB (Figure 3). Analyses of the other functional hearing group frequencies are summarized in Table 4.

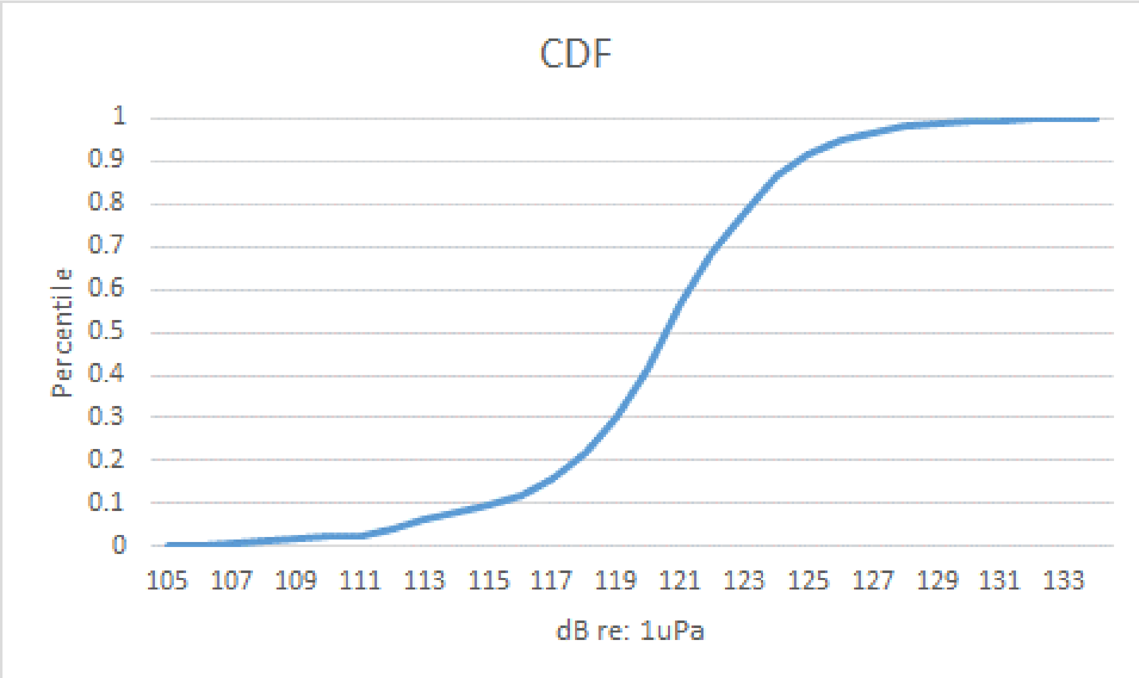

Figure 8: Cumulative Distribution Function (CDF) for the 1 Hz to 20 kHz analysis for all three days at Anacortes.

Table 4: Background Sound Level Results, Anacortes Ferry Terminal.

Frequency Range	Functional Hearing Group	72-h 50% Cumulative Density Function (dB)	Daytime 50% Cumulative Density Function (dB)
7 Hz to 20 kHz	Low Frequency Cetaceans	116	118
50 Hz to 20 kHz	Phocid Pinnipeds	112	113
60 Hz to 20 kHz	Otariid Pinnipeds	112	113
150 Hz to 20 kHz	Mid Frequency Cetaceans	106	107
275 to 20 kHz	High Frequency Cetaceans	104	105
1 Hz to 20 kHz	N/A	121	122

Figure 9 shows the overall 1/3-octave bands for the entire 72-hour recording analyzed for Anacortes. The dominant frequency is at 50 Hz with the energy of the remaining frequencies above and below dropping off gradually. These low frequency sources at 50 Hz are typical of larger vessels and so are most likely from the ferry vessel traffic in the area.

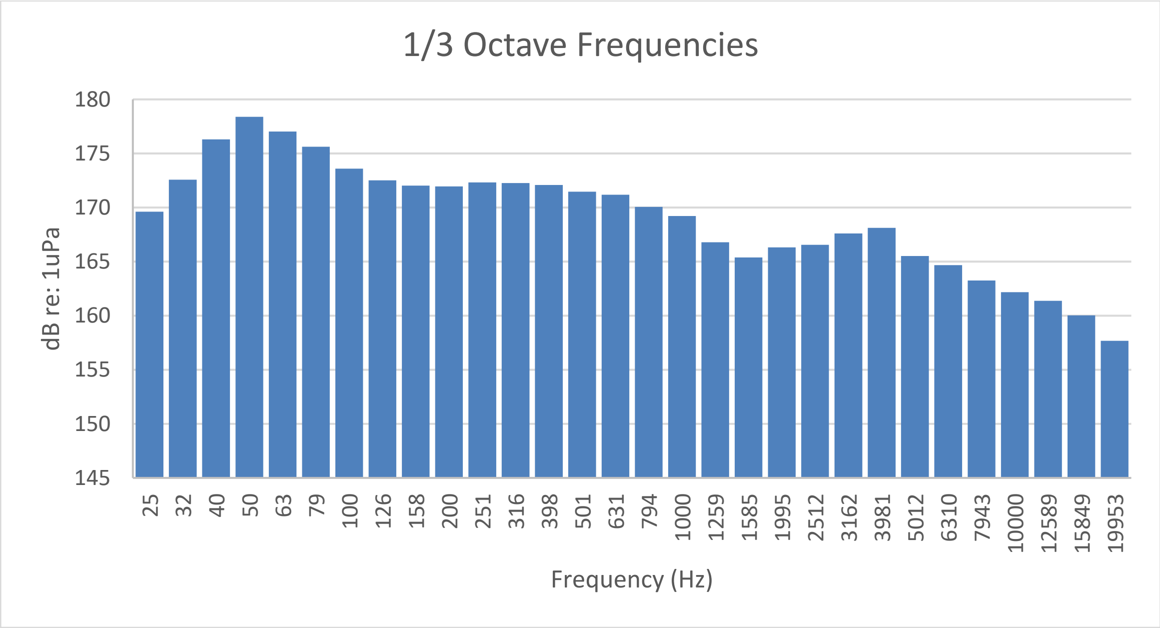

Figure 9: 1/3rd octave analysis of the broadband 1 Hz to 20 kHz frequencies for the 72-hour period near the Anacortes ferry terminal.

Figure 10 shows results of the hourly averages of RMS values calculated between 1 Hz and 20 kHz. The lowest values at night are approximately 24 dB lower than the highest levels measured during the daytime.

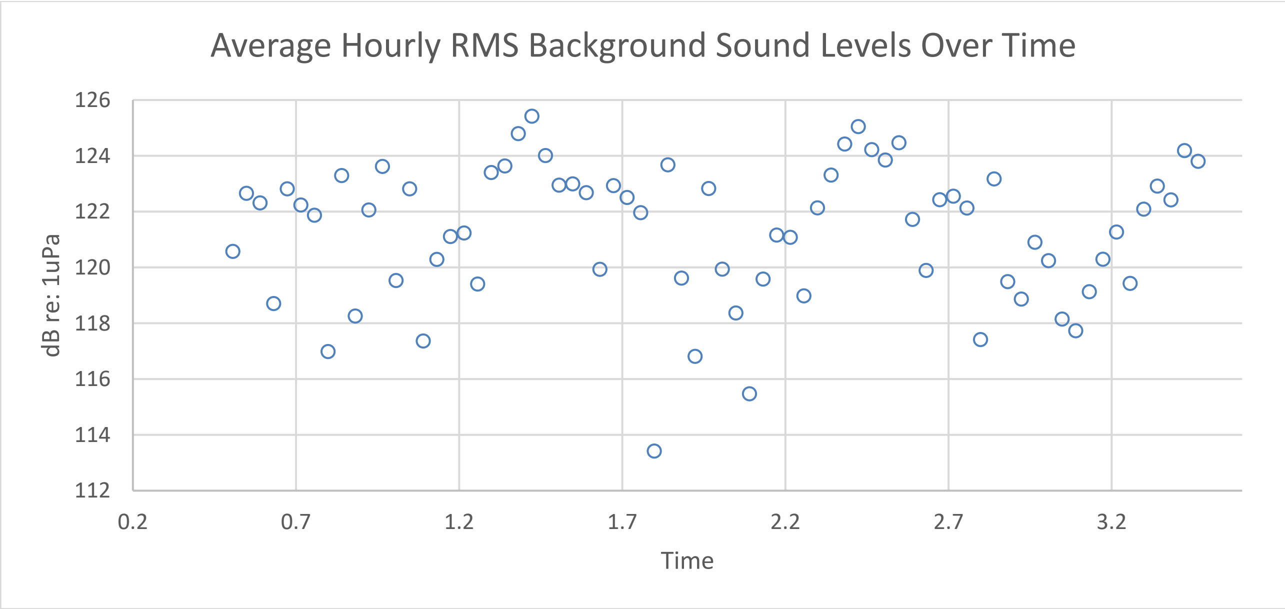

Figure 10: Average hourly background sound levels measured for a 72-hour period near the Anacortes Ferry terminal including frequencies between 1 Hz and 20 kHz.

Edmonds Ferry Terminal

Seven days of data were collected between April 7, 2011 and April 14, 2011 near the Edmonds ferry terminal (Figure 11). Three full 24-hour cycles (e.g., 6AM to 6AM) were analyzed as part of this report from 6:17 AM on Monday April 11th through 6:17 AM Thursday April 14th.

One hydrophone was deployed with the Autonomous Multichannel Acoustic Recorder (AMAR) approximately 10 feet from the bottom and 2,737 feet from the Edmonds ferry terminal. The water depth was 360 feet where the AMAR was deployed. The slope in the study area near the Edmonds ferry terminal is only 2.2 degrees slope.

Background sound levels during the daytime are dominated by the presence of ferry traffic and occasional outboard motorboats. Twenty-six ferry vessels per day arrive / depart the Edmonds ferry terminal daily during spring weekdays.

The distribution of the data is approximately log-normal however there is some variability in the daily distributions of the data (Figure 12).

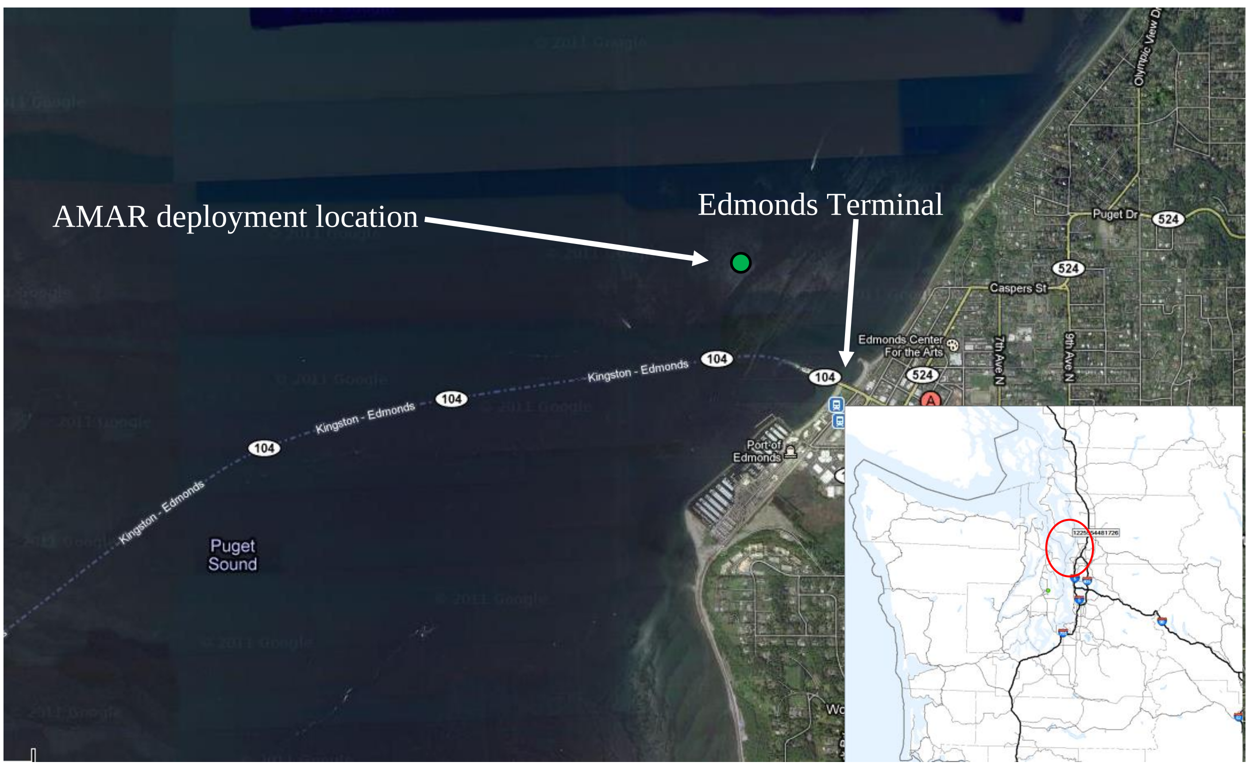

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Figure 11: Location of the Autonomous Multichannel Acoustic Recorder (AMAR) deployment at Edmonds.

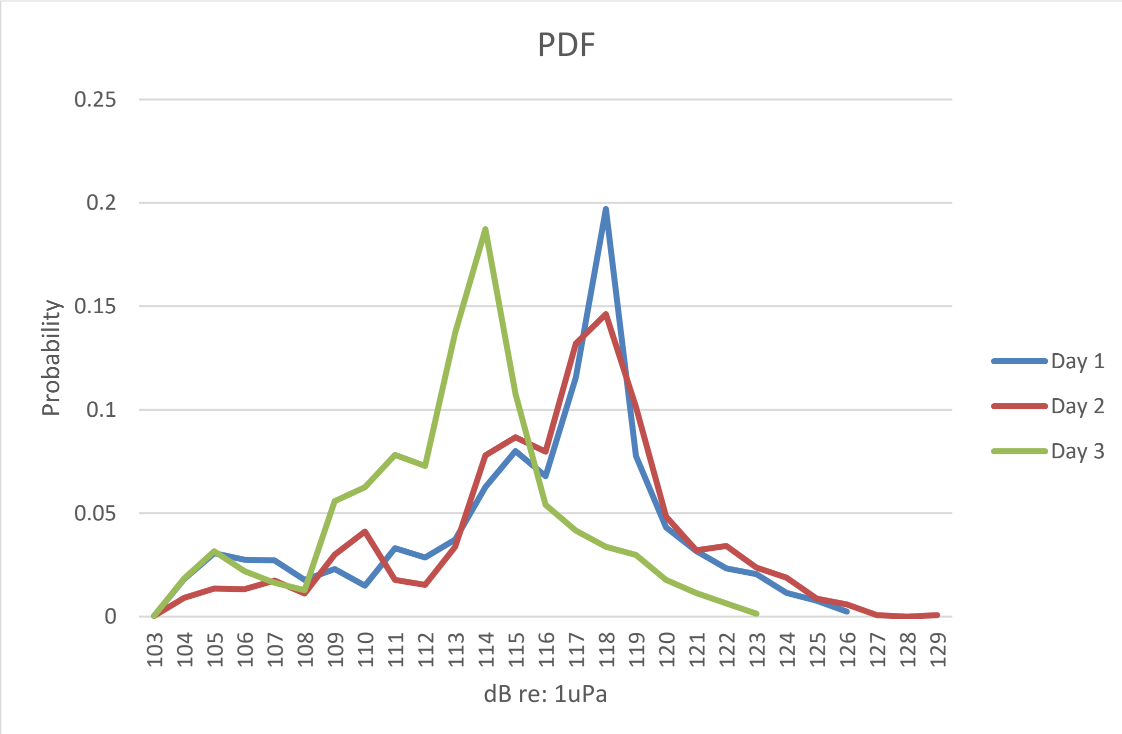

Figure 12: Probability Density Function (PDF) for the 1 Hz to 20 kHz analysis on a daily (24-hr) basis near Edmonds.

The background sound levels for all frequencies measured between 1 Hz and 20 kHz ranged between 103 dB and 129 dB with the 50th percentile occurring at 116 dB (Figure 13). Analyses of the other functional hearing group frequencies are summarized in Table 5.

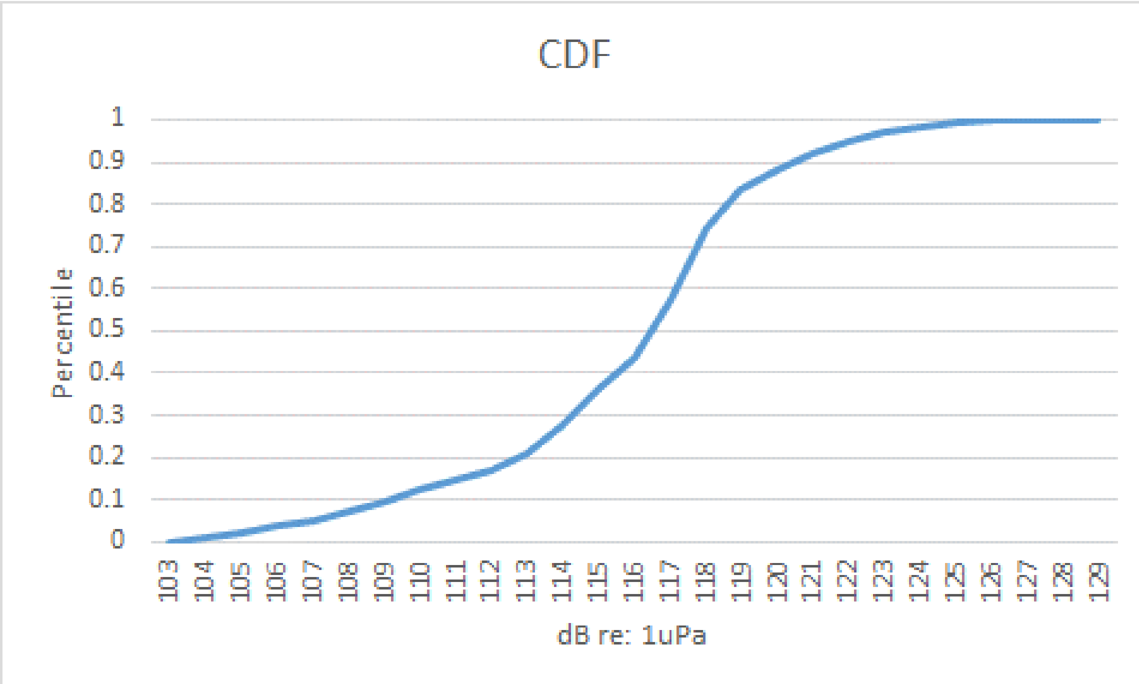

Figure 13: Cumulative Density Function (CDF) for the 1 Hz to 20 kHz analysis for all three days near Edmonds.

Table 5: Background Sound Level Results, Edmonds Ferry Terminal.

Frequency Range	Functional Hearing Group[1]	72-h 50% Cumulative Density Function (dB)	Daytime 50% Cumulative Density Function (dB)
7 Hz to 20 kHz	Low Frequency Cetaceans	114	115
50 Hz to 20 kHz	Phocid Pinnipeds	110	112
60 Hz to 20 kHz	Otariid Pinnipeds	110	111
150 Hz to 20 kHz	Mid Frequency Cetaceans	104	106
275 Hz to 20 kHz	High Frequency Cetaceans	102	104
1 Hz to 20 kHz	N/A - Broadband	116	117

[1] – Southall et al., 2007 describes the functional hearing groups for marine mammals and the frequency ranges of each group.

Figure 14 shows the overall 1/3-octave bands for the entire 72-hour recording analyzed for this report. The dominant frequency is approximately 63 Hz with the energy of the remaining frequencies below dropping off gradually. These low frequency sources around 63 Hz are most likely from the ferry vessel traffic in the area.

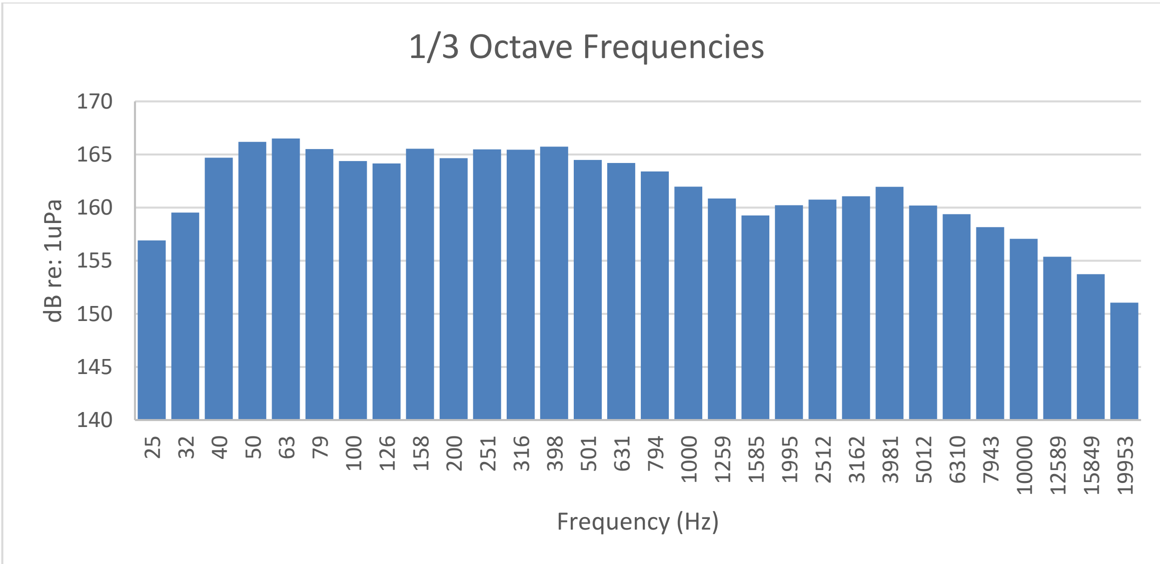

Figure 14: 1/3rd octave analysis of the broadband 20 Hz to 20 kHz frequencies for the 72-hour period near Edmonds.

The 30-second RMS data were averaged on an hourly basis and plotted over time (Figure 15). Figure 15 shows that there is a daily peak between 2 PM and 3 PM each day with the lowest sound levels recorded over this period between about 2 AM and 3 AM each day. Tuesday and Wednesday daytime hourly sound levels were approximately 10 dB higher than the daytime hourly sound levels on Monday. The sound levels measured during the daytime appear to be slightly less variable than the nighttime sound levels which is probably due to the regular ferry traffic in the area during the daytime hours. The lowest values at night are approximately 45 dB lower than the highest levels measured during the daytime.

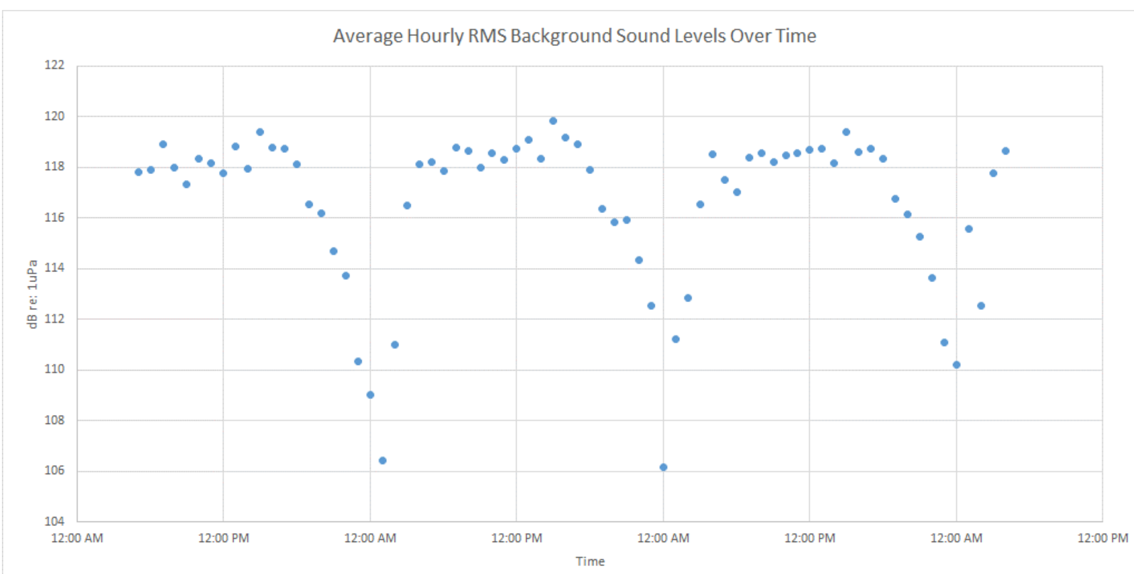

Figure 15: Average hourly background sound levels measured for a 72-hour period near the Edmonds Ferry terminal including frequencies between 1 Hz and 20 kHz.

Seattle Ferry Terminal

Seven days of data were collected between April 18, 2011 and April 22, 2011 near the Seattle ferry terminal (Figure 16). Three full 24-hour cycles (e.g., 6AM to 6AM) were analyzed as part of this report from 6:26 AM on Tuesday April 19th through 6:26 AM Friday April 22nd. The water depth was approximately 190 feet where the AMAR was deployed.

Background sound levels at the Seattle ferry terminal are dominated by the presence of ferry traffic and occasional outboard motorboats. Thirty-five ferry vessels per day arrive / depart the Seattle ferry terminal daily during spring weekdays. Background levels were measured at 2,864 feet northwest of the ferry terminal using the AMAR system.

The distribution of the data is approximately log-normal however there is some variability in the daily distributions of the data (Figure 17).

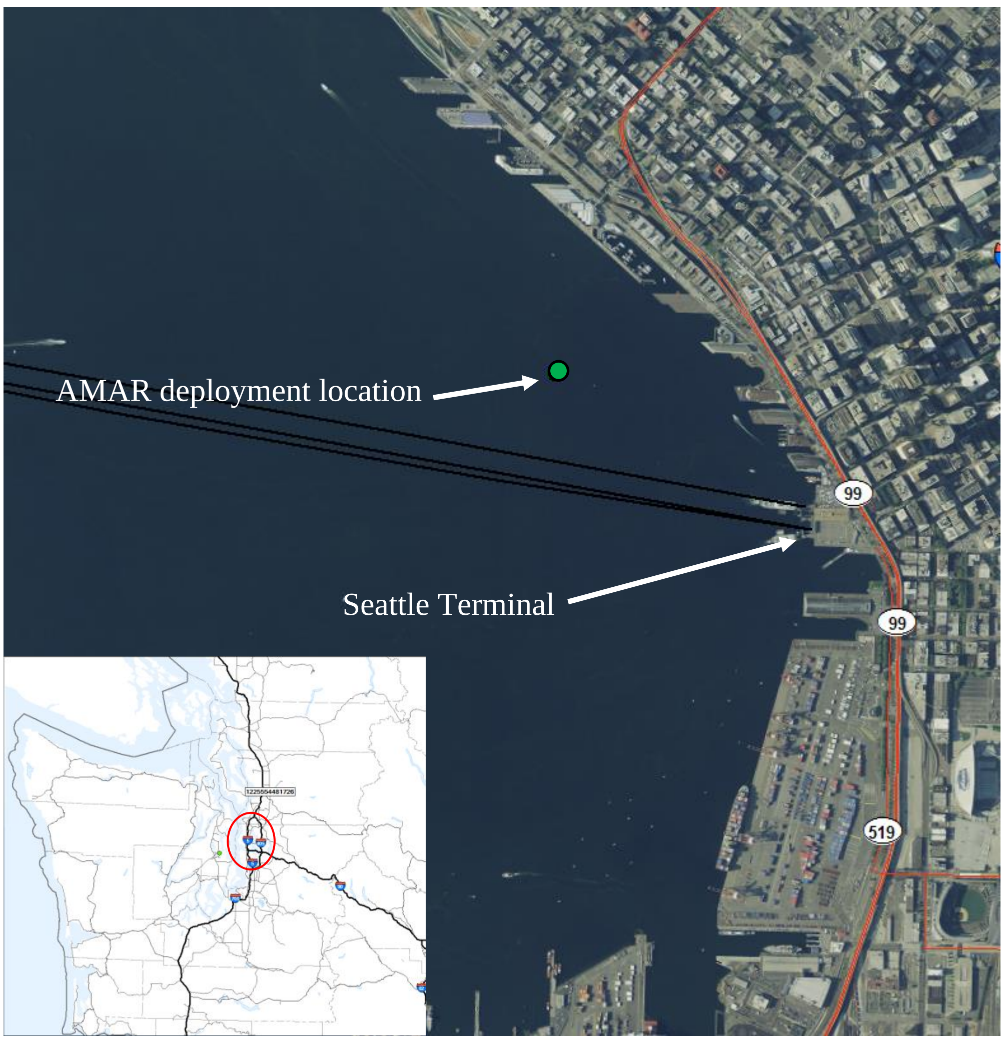

Figure 16: Location of the Autonomous Multichannel Acoustic Recorder (AMAR) deployment at Colman Dock in Seattle.

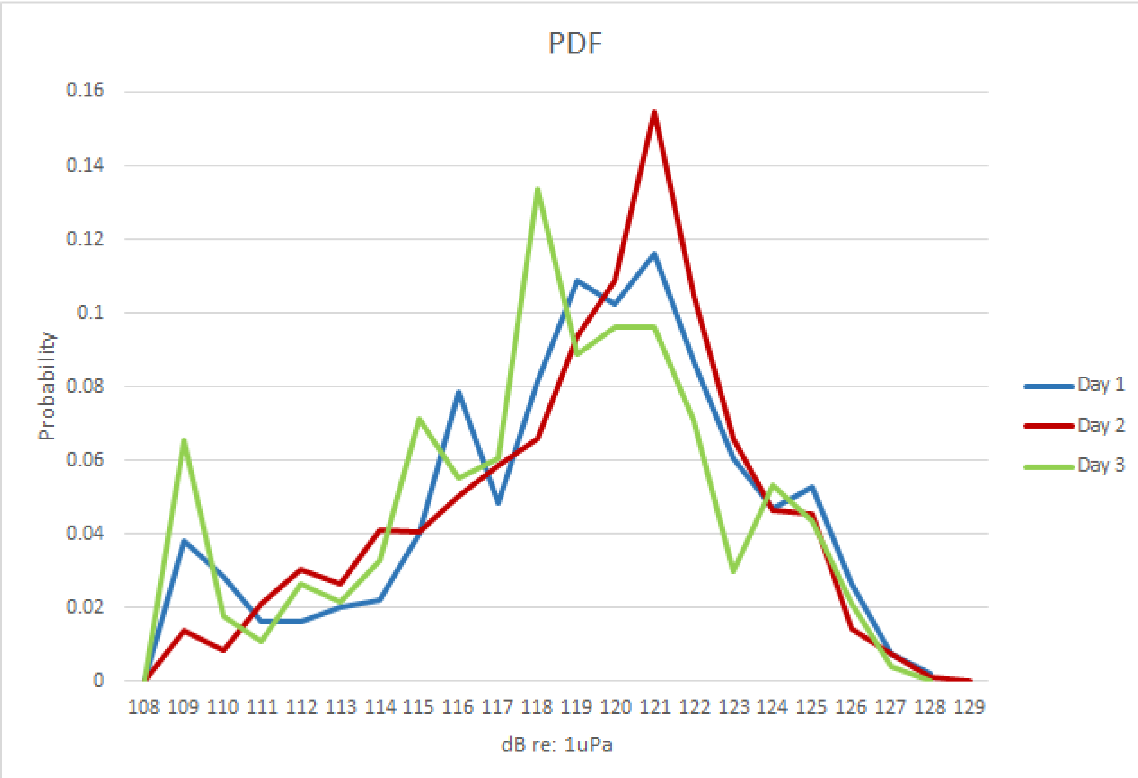

Figure 17: Probability Density Function (PDF) for the 1 Hz to 20 kHz analysis on a daily (24-hr) basis for the Seattle Ferry Terminal.

Once it was determined that the data was approximately log-normally distributed the data for all three days were then plotted as a Cumulative Distribution Function following the NOAA (2012, 2018) guidance on analyzing background sound levels. Figure 18 is the CDF plot for the full frequency range. The overall average background sound level is approximated with the 50th percentile.

The background sound levels for all frequencies measured between 1 Hz and 20 kHz (Broadband) ranged between 108 dB and 128 dB with the 50th percentile occurring at 119 dB (Figure 18). Analyses of the other functional hearing group frequency ranges are summarized in Table 6.

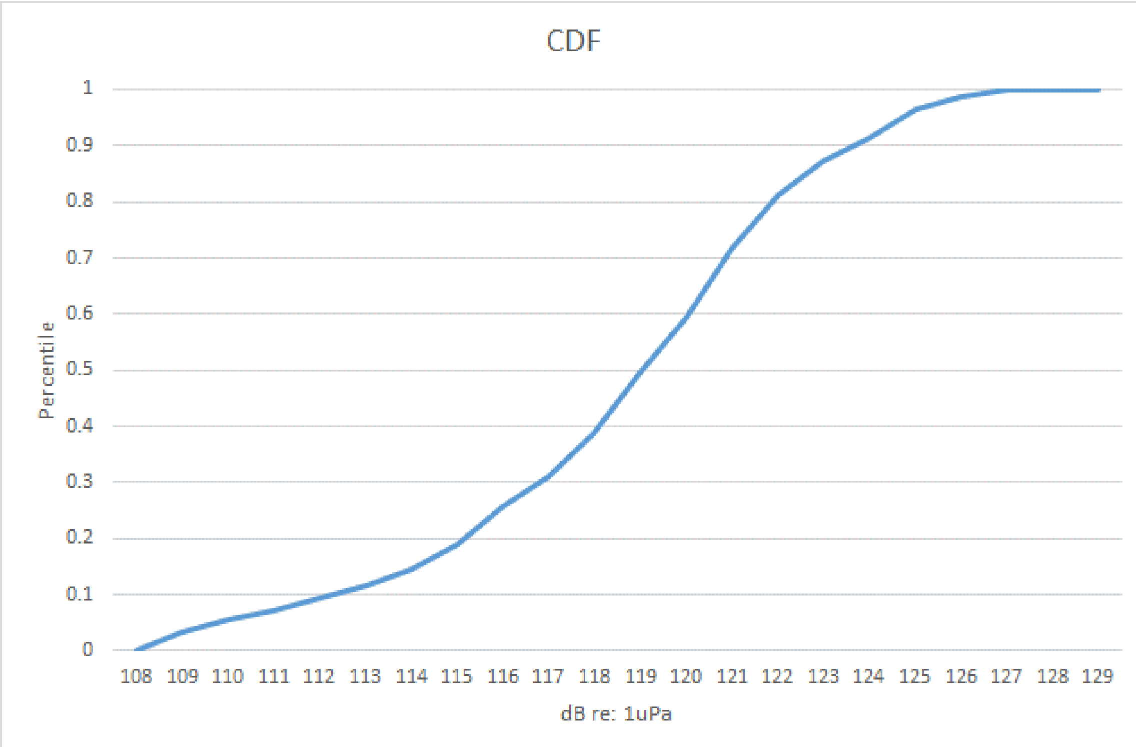

Figure 18: Cumulative Density Function (CDF) for the 1 Hz to 20 KHz analysis for all three days near Seattle.

Table 6: Background Sound Level Results, Seattle Ferry Terminal.

Frequency Range	Functional Hearing Group[1]	72-h 50% Cumulative Density Function (dB)	Daytime 50% Cumulative Density Function (dB)
7 Hz to 20 kHz	Low Frequency Cetaceans	117	117
50 Hz to 20 kHz	Phocid Pinnipeds	113	113
60 Hz to 20 kHz	Otariid Pinnipeds	113	113
150 Hz to 20 kHz	Mid Frequency Cetaceans	107	108
275 Hz to 20 kHz	High Frequency Cetaceans	106	106
20 Hz to 20 kHz	N/A - Broadband	119	120

[1] – Southall et al., 2007 describes the functional hearing groups for marine mammals and the frequency ranges of each group.

Figure 19 shows the overall 1/3-octave bands for the entire 72-hour recording analyzed for this report. The dominant frequency is approximately at 63 Hz with the energy of the remaining frequencies below dropping off gradually. These low frequency sources around 63 Hz are most likely from the ferry vessel traffic in the area.

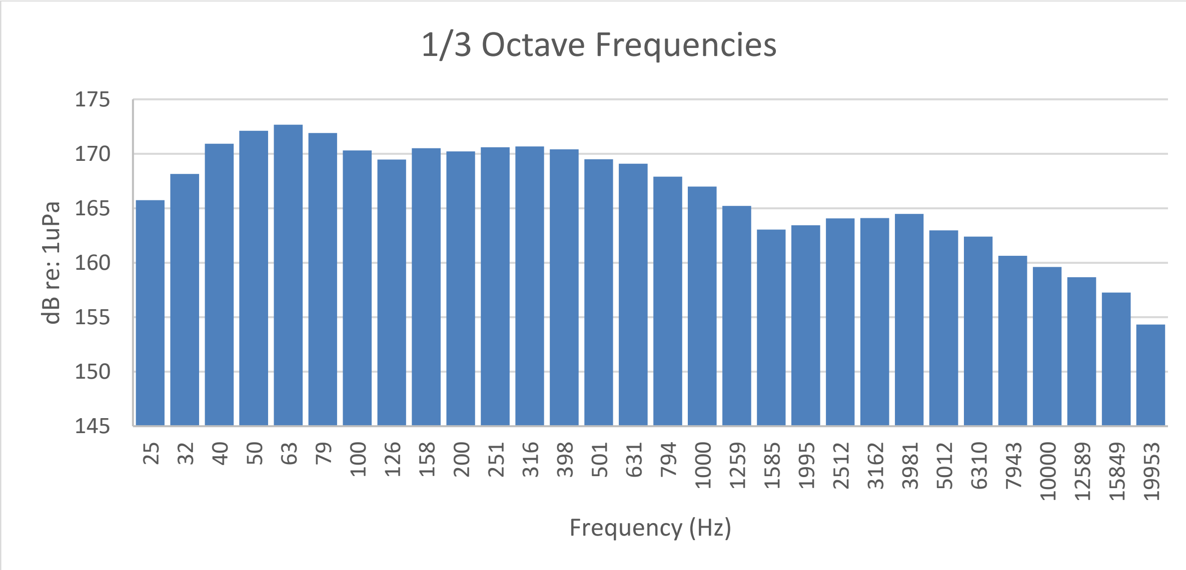

Figure 19: 1/3rd octave analysis of the broadband 20 Hz to 20 kHz frequencies for the 72-hour period near Seattle.

The 30-second RMS data were averaged on an hourly basis for each frequency range analyzed. These averages are plotted over time (Figure 20). Each Figure shows that there are two daily peaks at approximately 8 AM and 8 PM each day with the lowest sound levels recorded over this period between about 2 AM and 4 AM each day. The sound levels measured during the daytime appear to be slightly less variable than the nighttime sound levels which is probably due to the regular ferry traffic in the area during the daytime hours.

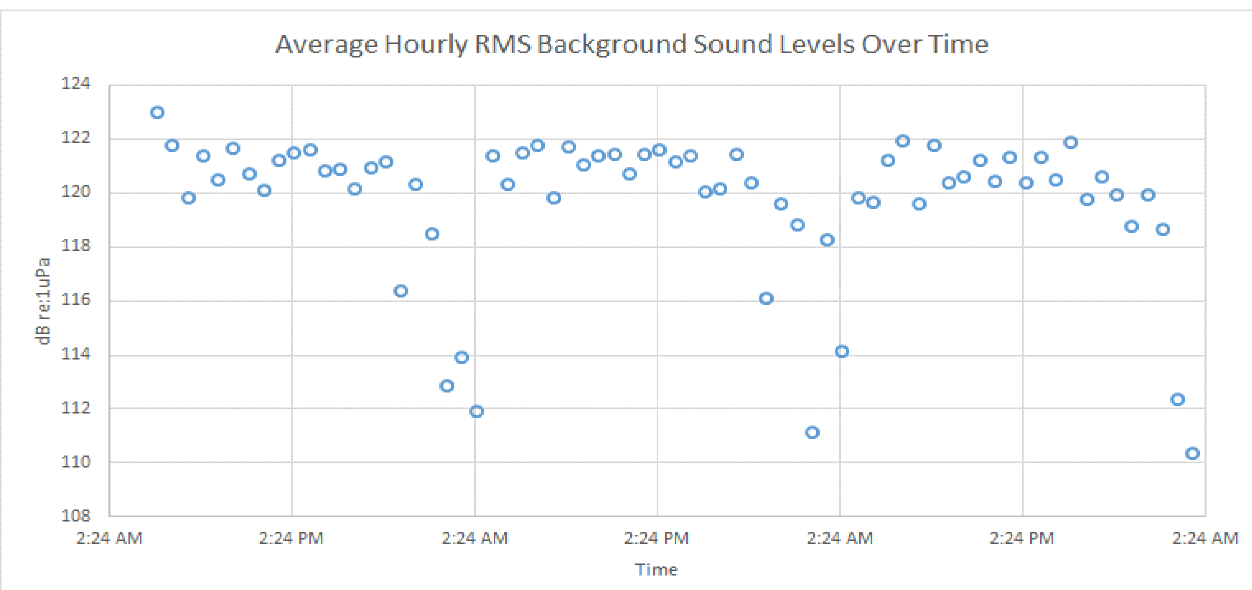

Figure 20: Average hourly background sound levels measured for a 72-hour period near the Seattle Ferry terminal including frequencies between 1 Hz and 20 kHz.

Mukilteo Ferry Terminal

2011 Measurements

Background sound levels were measured near the Mukilteo ferry terminal in May of 2011 to determine site specific underwater background sound levels. Nine days of data were collected between May 24, 2011 and June 2, 2011 near the Mukilteo ferry terminal (Figure 21). Three full 24-hour cycles (e.g., 6AM to 6AM) were analyzed as part of this report from 6:05 AM on Wednesday May 25th through 6:05 AM Saturday May 28th.

The AMAR was deployed approximately 10 feet from the bottom and 2,690 feet from the Mukilteo ferry terminal and 2,432 feet (741 meters) from the nearest point of the ferry traffic lane. The water depth was 462 feet where the AMAR was deployed. The slope in the study area near the Mukilteo ferry terminal is approximately 14 degrees slope.

Background noise levels during the daytime are dominated by the presence of ferry traffic and occasional outboard motorboats and fishing vessels. Thirty-nine ferry vessels per day arrive / depart the Mukilteo ferry terminal daily during spring weekdays.

The distribution of the data is approximately log-normal however there is some variability in the daily distributions of the data (Figure 22).

Figure 21: Location of the Autonomous Multichannel Acoustic Recorder (AMAR) deployment at Mukilteo (2011).

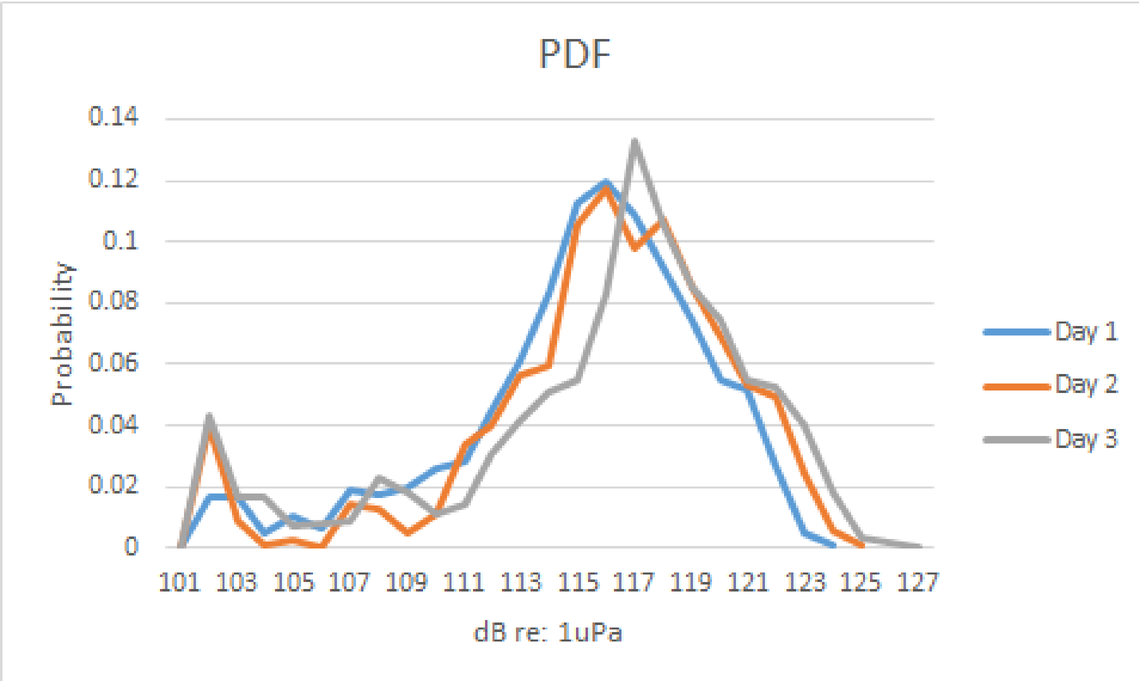

Figure 22: Probability Density Function (PDF) for the 1 Hz to 20 kHz analysis on a daily (24-hr) basis near Mukilteo (2011).

The background sound levels for all frequencies measured between 1 Hz and 20 kHz ranged between 101 dB and 126 dB with the 50th percentile occurring at 117 dB (Figure 23). Analyses of the other functional hearing group frequency ranges are summarized in Table 7.

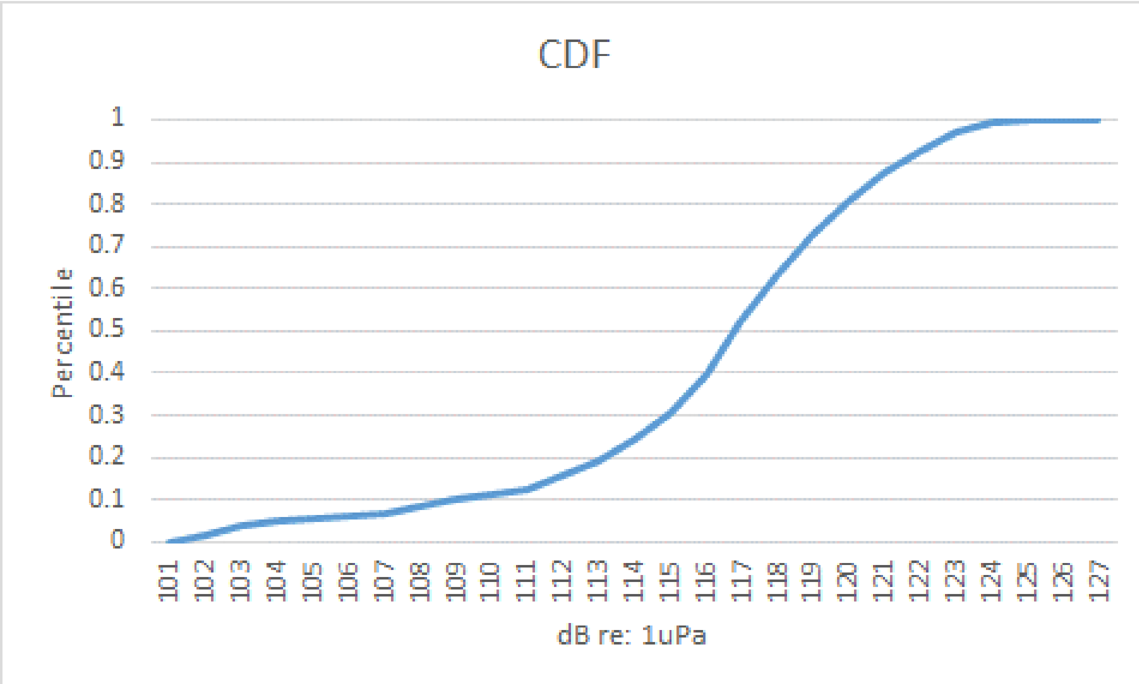

Figure 23: Cumulative Density Function (CDF) for the 1 Hz to 20 kHz analysis for all three days near Mukilteo (2011).

Table 7: Background Sound Level Results (2011), Mukilteo Ferry Terminal.

Frequency Range	Functional Hearing Group[1]	72-h 50% Cumulative Density Function (dB)	Daytime 50% Cumulative Density Function (dB)
7 Hz to 20 kHz	Low Frequency Cetaceans	115	116
50 Hz to 20 kHz	Phocid Pinnipeds	111	112
60 Hz to 20 kHz	Otariid Pinnipeds	111	112
150 Hz to 20 kHz	Mid Frequency Cetaceans	105	106
275 Hz to 20 kHz	High Frequency Cetaceans	103	105
1 Hz to 20 kHz	N/A - Broadband	117	118

Figure 24 shows the overall 1/3-octave bands for the entire 72-hour recording analyzed for this report. The dominant frequency is between 50 Hz and 63 Hz with the energy of the remaining frequencies below dropping off gradually. These low frequency sources between 50 Hz and 63 Hz are most likely from the ferry vessel traffic in the area and are within the typical frequencies for larger vessels.

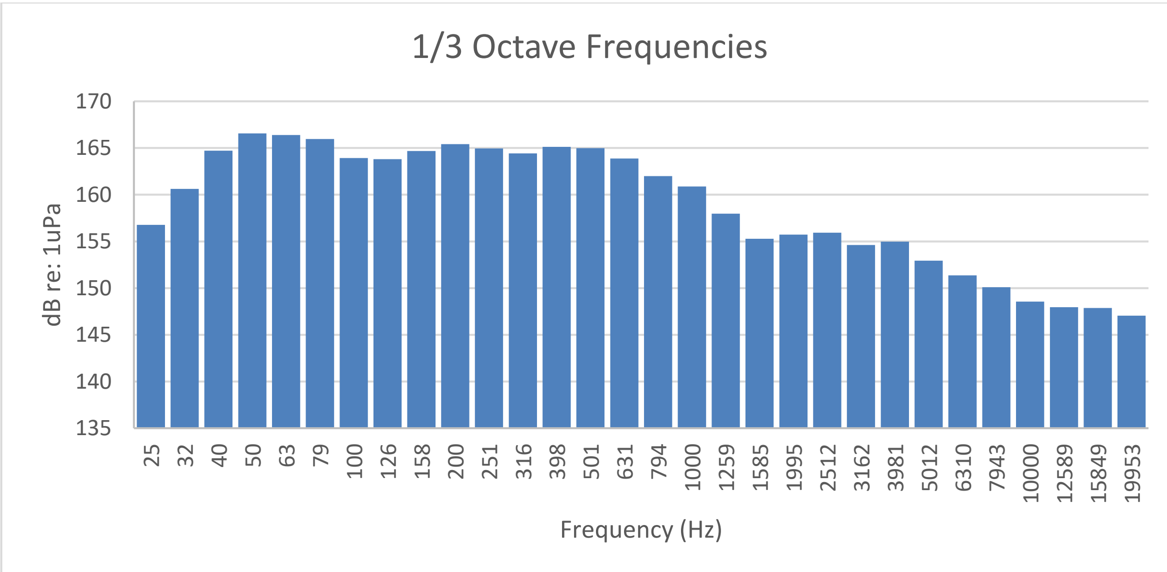

Figure 24: 1/3rd octave analysis of the broadband 20 Hz to 20 kHz frequencies for the 72-hour period near Mukilteo (2011).

The 30-second RMS data were averaged on an hourly basis for 1 Hz to 20 kHz. These averages are plotted over time (Figure 25). Figure 25 shows that during the daytime the hourly average sound levels are relatively constant due to regular ferry traffic. The lowest sound levels recorded over this period were between about 2 AM and 3 AM each day.

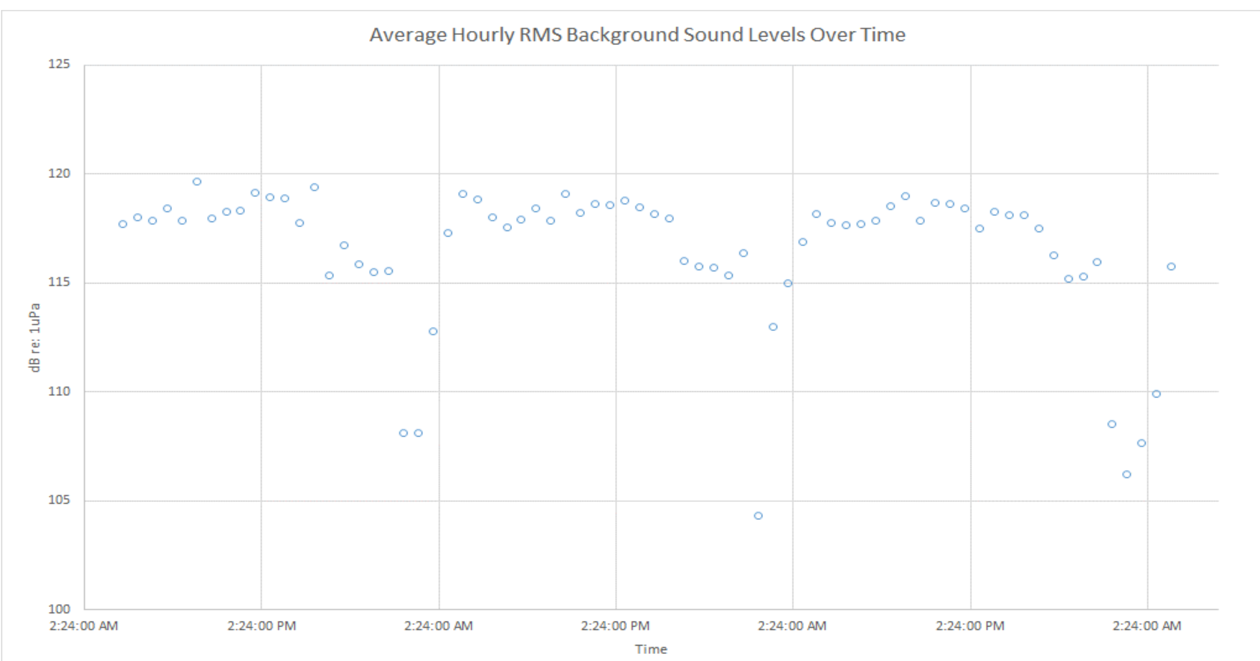

Figure 25: Average hourly background sound levels measured for a 72-hour period near the Mukilteo Ferry (2011) terminal including frequencies between 1 Hz and 20 kHz.

2015 Mukilteo Measurements

Background sound levels were measured near the Mukilteo ferry terminal a second time in April of 2015 to determine if the site specific underwater background sound levels had changed as a result of adding the new Tokitae vessel to the route. Three days of data were collected between April 27, 2015 and April 30, 2015 at the same location as the previous measurements (Figure 21). Three full 24-hour cycles (e.g., 6AM to 6AM) were analyzed as part of this report from 6:00 AM on Monday April 27th through 6:00 AM Thursday April 30th.

The Tokitae vessel is the first of three new Olympic Class 144-car ferry vessels that will replace the 1950's era Evergreen Class vessels. Background noise levels during the daytime are dominated by the presence of ferry traffic and occasional outboard motorboats and fishing vessels.

The distribution of the data is approximately log-normal however there is some slight variability in the daily distributions of the data (Figure 26).

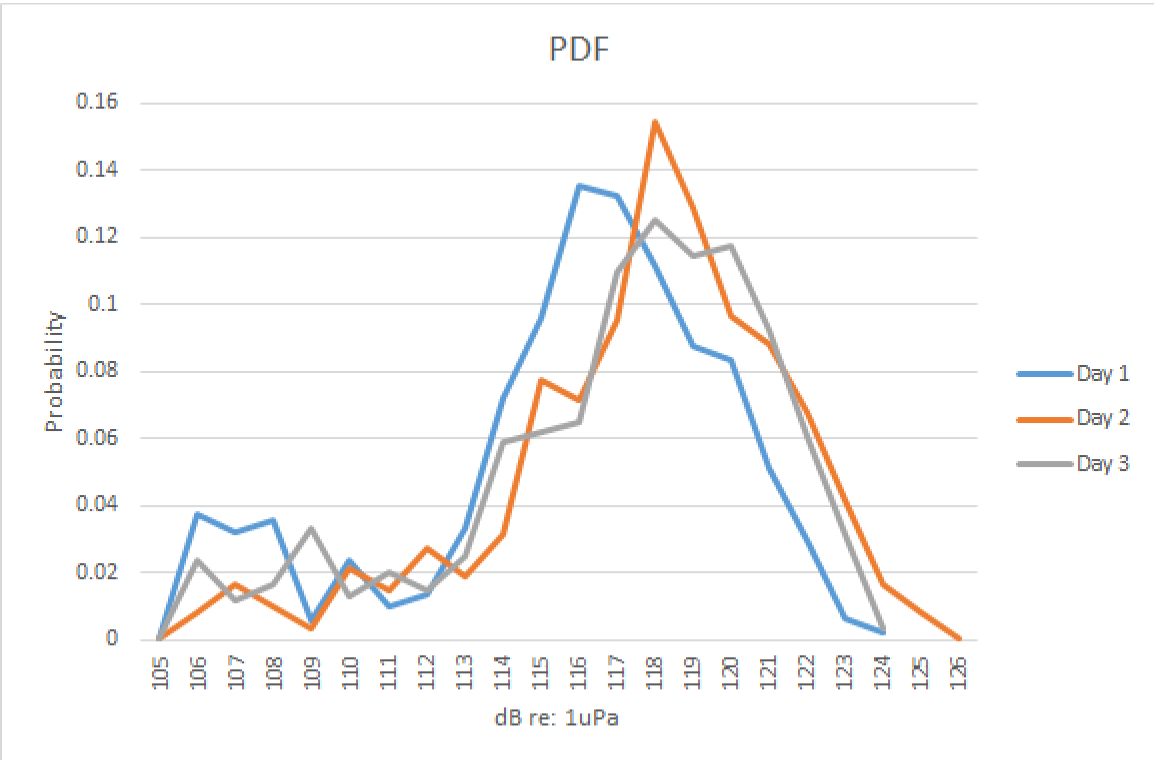

Figure 26: Probability Density Function (PDF) for the 1 Hz to 20 kHz analysis on a daily (24-hr) basis near Mukilteo (2015).

The background sound levels for all frequencies measured (Broadband) between 1 Hz and 20 kHz ranged between 105 dB and 125 dB with the 50th percentile occurring at 117 dB (Figure 27). Analyses of the other functional hearing group frequency ranges are summarized in Table 8.

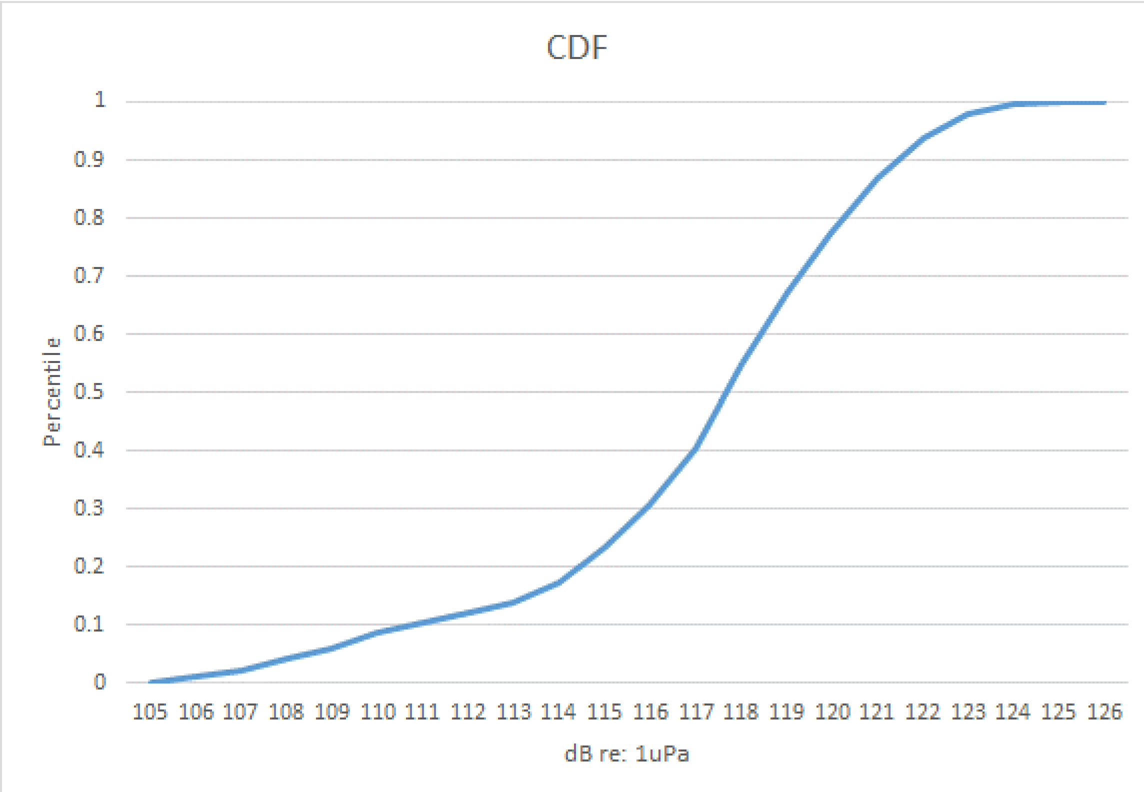

Figure 27: Cumulative Density Function (CDF) for the 1 Hz to 20 kHz analysis for all three days near Mukilteo (2015).

Table 8: Background Sound Level Results, Mukilteo Ferry Terminal (2015).

Frequency Range	Functional Hearing Group[1]	72-h 50% Cumulative Density Function (dB)	Daytime 50% Cumulative Density Function (dB)
7 Hz to 20 kHz	Low Frequency Cetaceans	112	116
50 Hz to 20 kHz	Phocid Pinnipeds	110	111
60 Hz to 20 kHz	Otariid Pinnipeds	110	111
150 Hz to 20 kHz	Mid Frequency Cetaceans	104	105
275 Hz to 20 kHz	High Frequency Cetaceans	102	103
1 Hz to 20 kHz	N/A - Broadband	117	118

Figure 28 shows the overall 1/3-octave bands for the entire 72-hour recording analyzed for 2015. The dominant frequency is between 50 and 63 Hz, with the energy of the remaining frequencies below dropping off gradually. These low frequency sources between 50 and 63 Hz are most likely from the ferry vessel traffic in the area and are within the typical frequencies for larger vessels.

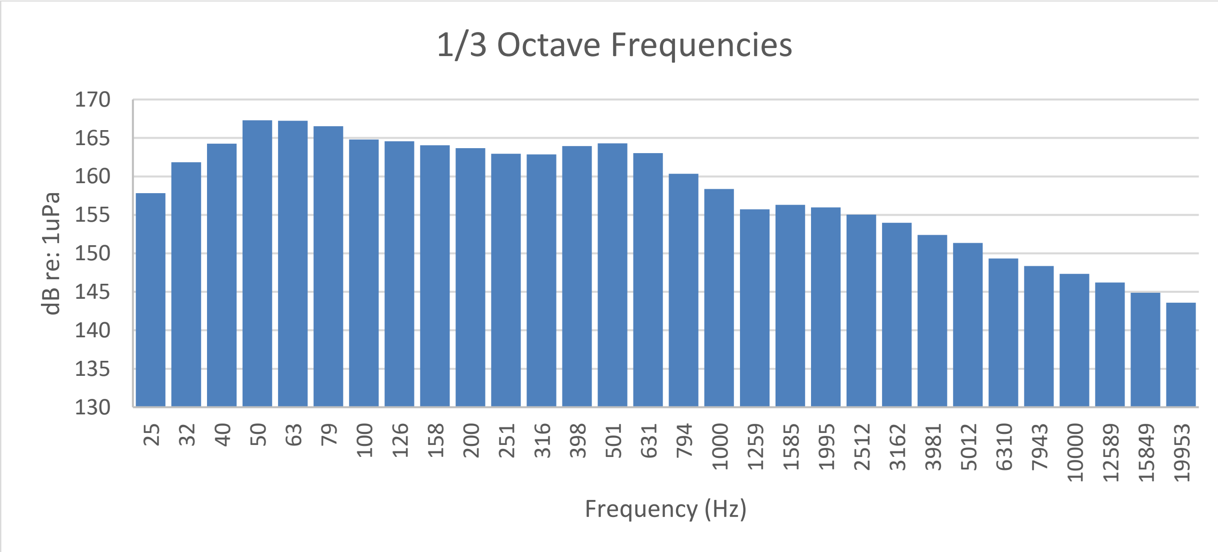

Figure 28: 1/3rd octave analysis of the broadband 20 Hz to 20 kHz frequencies for the 72-hour period near Mukilteo (2015).

The 2015 measurements including the new Tokitae vessel showed a slightly lower overall sound level at the broadband and functional hearing group frequency ranges. Whether this was specifically due to the new Tokitae vessel or simply a coincidental snapshot in time is unclear.

Kingston Ferry Terminal

Background sound levels were measured near the Kingston ferry terminal in an effort to determine site specific underwater background sound levels. Seven days of data were collected between November 19, 2012 and November 26, 2012 near the Kingston ferry terminal (Figure 29). Three full 24-hour cycles (e.g., 6AM to 6AM) were analyzed as part of this report from 6:10 AM on Tuesday November 20th through 5:40 PM Thursday November 22nd.

The AMAR was deployed in approximately 160 feet of water and 2,712 feet from the Kingston ferry terminal, 3,204 feet from the nearest point of the ferry traffic lane. The slope in the study area near the Kingston ferry terminal is approximately 0.06 degrees slope.

Background sound levels during the daytime are dominated by the presence of ferry traffic, cargo ships and occasional outboard motorboats and fishing vessels. Forty six ferry vessels per day arrive / depart the Kingston ferry terminal daily during fall weekdays.

The distribution of the data is approximately log-normal however there is some variability in the daily distributions of the data, especially day 2 (Figure 30).

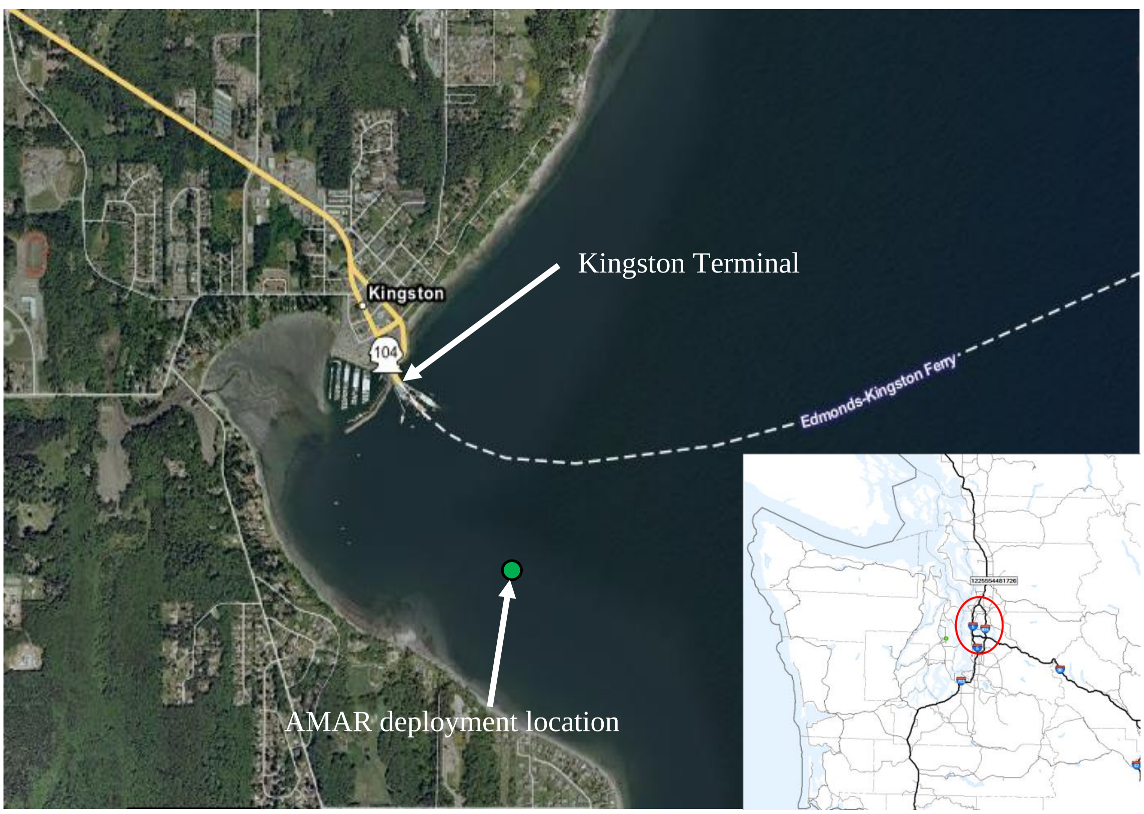

Figure 29: Location of the Autonomous Multichannel Acoustic Recorder (AMAR) deployment at Kingston.

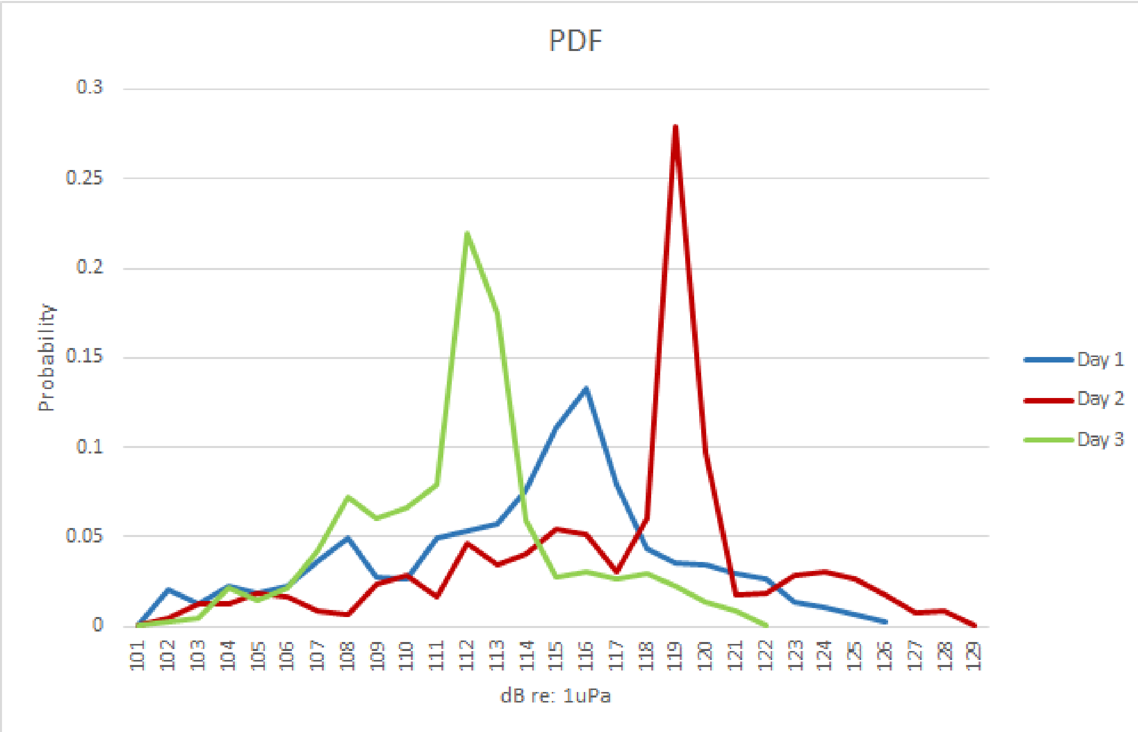

Figure 30: Probability Density Function (PDF) for the 1 Hz to 20 kHz analysis on a daily (24-hr) basis near Kingston.

The background sound levels for all frequencies measured between 1 Hz and 20 kHz (Broadband) ranged between 101 dB and 128 dB with the 50th percentile occurring at 118 dB (Figure 31). Analyses of the other functional hearing group frequency ranges are summarized in Table 9.

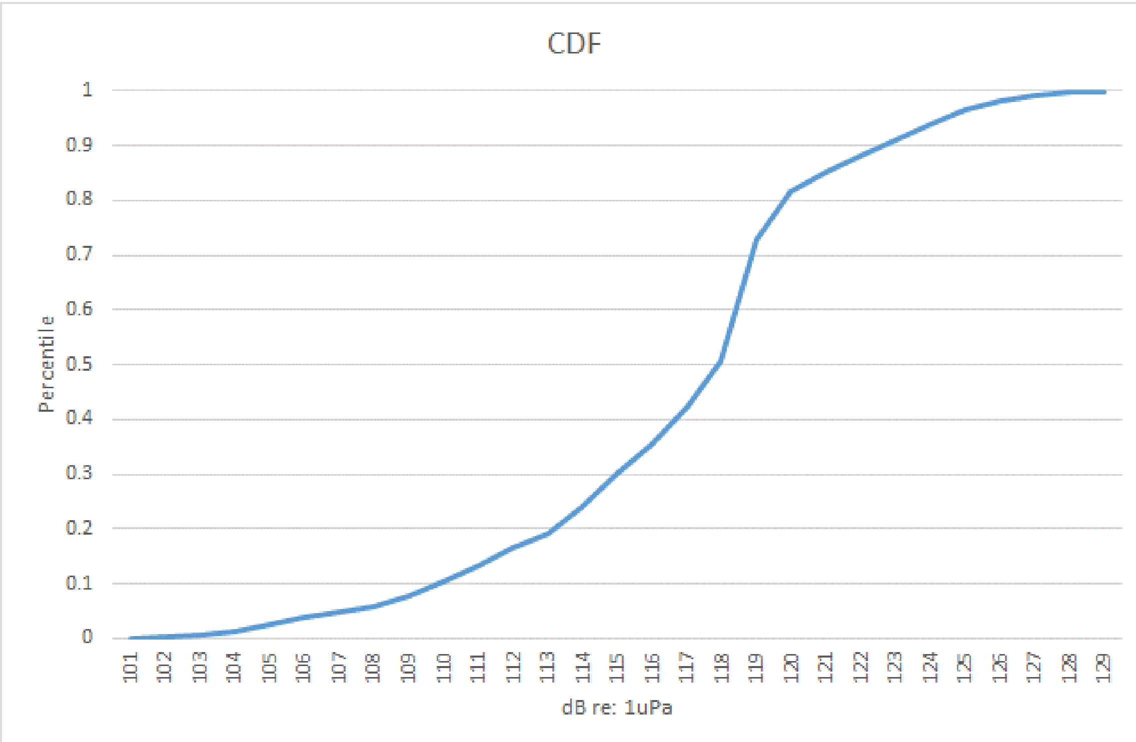

Figure 31: Cumulative Density Function (CDF) for the 1 Hz to 20 kHz analysis for all three days near Kingston.

Table 9: Background Sound Level Results, Kingston Ferry Terminal.

Frequency Range	Functional Hearing Group[1]	72-h 50% Cumulative Density Function (dB)	Daytime 50% Cumulative Density Function (dB)
7 Hz to 20 kHz	Low Frequency Cetaceans	116	116
50 Hz to 20 kHz	Phocid Pinnipeds	109	109
60 Hz to 20 kHz	Otariid Pinnipeds	109	110
150 Hz to 20 kHz	Mid Frequency Cetaceans	101	101
275 Hz to 20 kHz	High Frequency Cetaceans	98	98
1 Hz to 20 kHz	N/A - Broadband	118	118

Figure 32 shows the overall 1/3-octave bands for the entire 72-hour recording analyzed for this report. AMAR was not capable of collecting all frequencies in one channel. For that reason, the 1/3rd Octave frequencies are plotted only up to 8 kHz but still capture the dominant frequencies. The dominant frequency is between 63 Hz and 79 Hz with the energy of the remaining frequencies below dropping off gradually. These low frequency sources between 63 Hz and 79 Hz are most likely from the ferry vessel traffic in the area and are within the typical frequencies for larger vessels.

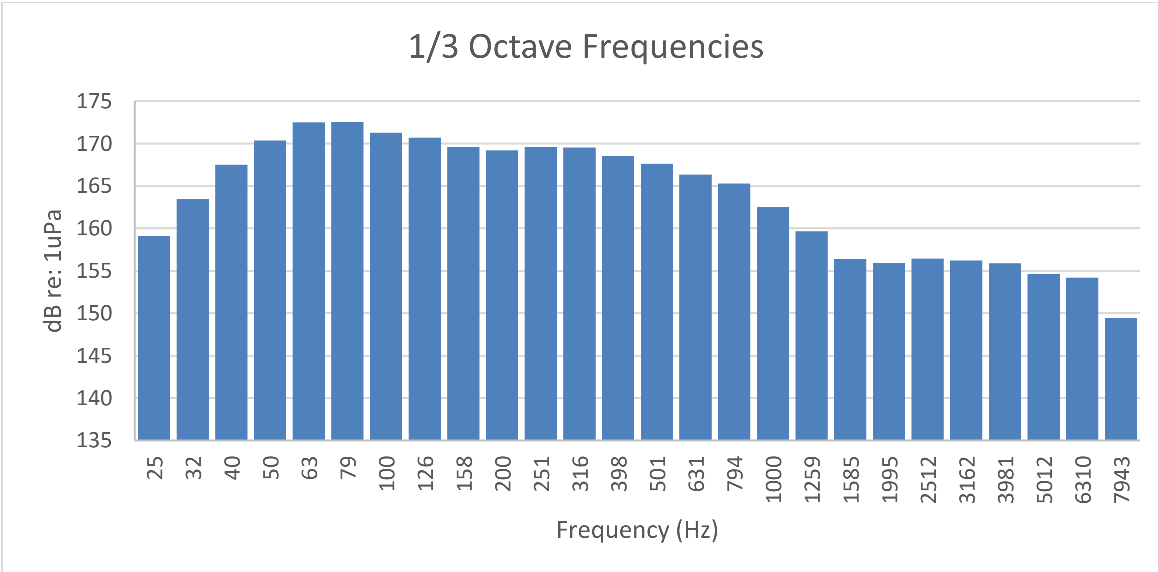

Figure 32: 1/3rd octave analysis of the broadband 20 Hz to 8 kHz frequencies for the 72-hour period near Kingston.

The 30-second RMS data were averaged on an hourly basis for 1 Hz to 20 kHz. These averages are plotted over time (Figure 33). Figure 33 shows that during the daytime the hourly average sound levels are relatively constant due to regular ferry traffic. The lowest sound levels recorded over this period at about 2 AM each day.

The Kingston terminal sound levels compared with the Edmonds terminal sound levels which are on the same vessel route showed that the Kingston levels were 1 to 2 dB lower than for Edmonds during the 72-hour period and Kingston was 1 to 2 dB higher than Edmonds for Broadband and LF Cetacean frequencies but lower for the other hearing groups during the daytime hours.

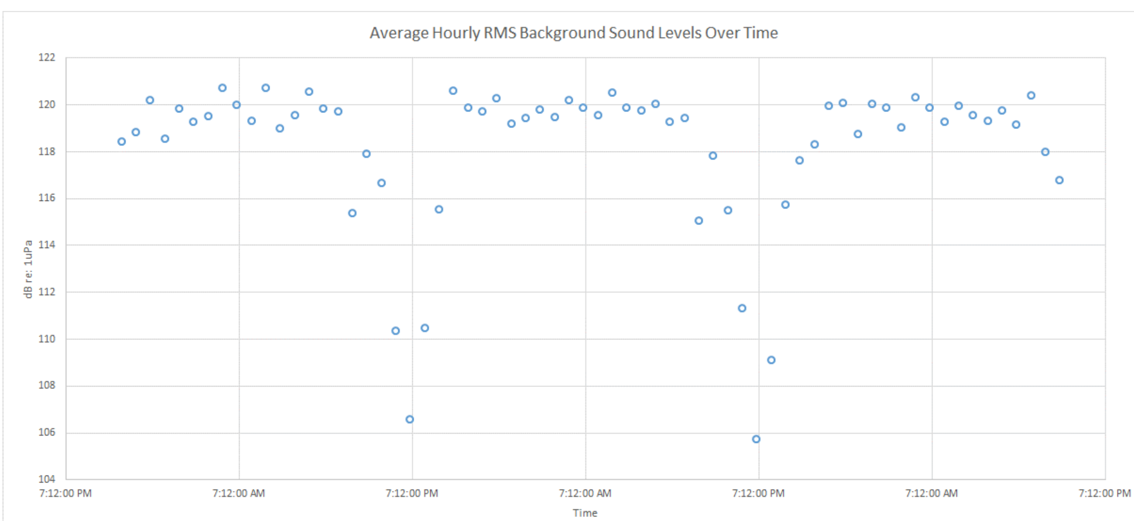

Figure 33: Average hourly background sound levels measured for a 72-hour period near the Kingston Ferry terminal including frequencies between 1 Hz and 20 kHz.

Vashon Ferry Terminal

Background sound levels were measured near the Vashon ferry terminal in an effort to determine site specific underwater background sound levels. Six days of data were collected between October 8 and 14, 2013 near the Vashon ferry terminal (4). Three full 24-hour cycles (e.g., 6AM to 6AM) were analyzed as part of this report from 5:57 AM on Wednesday October 9th through 5:57 AM Saturday October 12th.

The AMAR was deployed in approximately 125 feet of water, 3,700 feet from the Vashon ferry terminal and 800 feet from the nearest point of the ferry traffic lane. The slope in the study area near the Vashon ferry terminal is approximately 17 degrees slope.

Background sound levels during the daytime are dominated by the presence of ferry traffic and occasional outboard motorboats and fishing vessels. Fifty-four ferry vessels per day arrive / depart the Vashon ferry terminal daily during fall weekdays plus an additional six King County water taxis per day.

The distribution of the data is approximately log-normal with little variability in the daily distributions of the data over the three days (Figure 35).

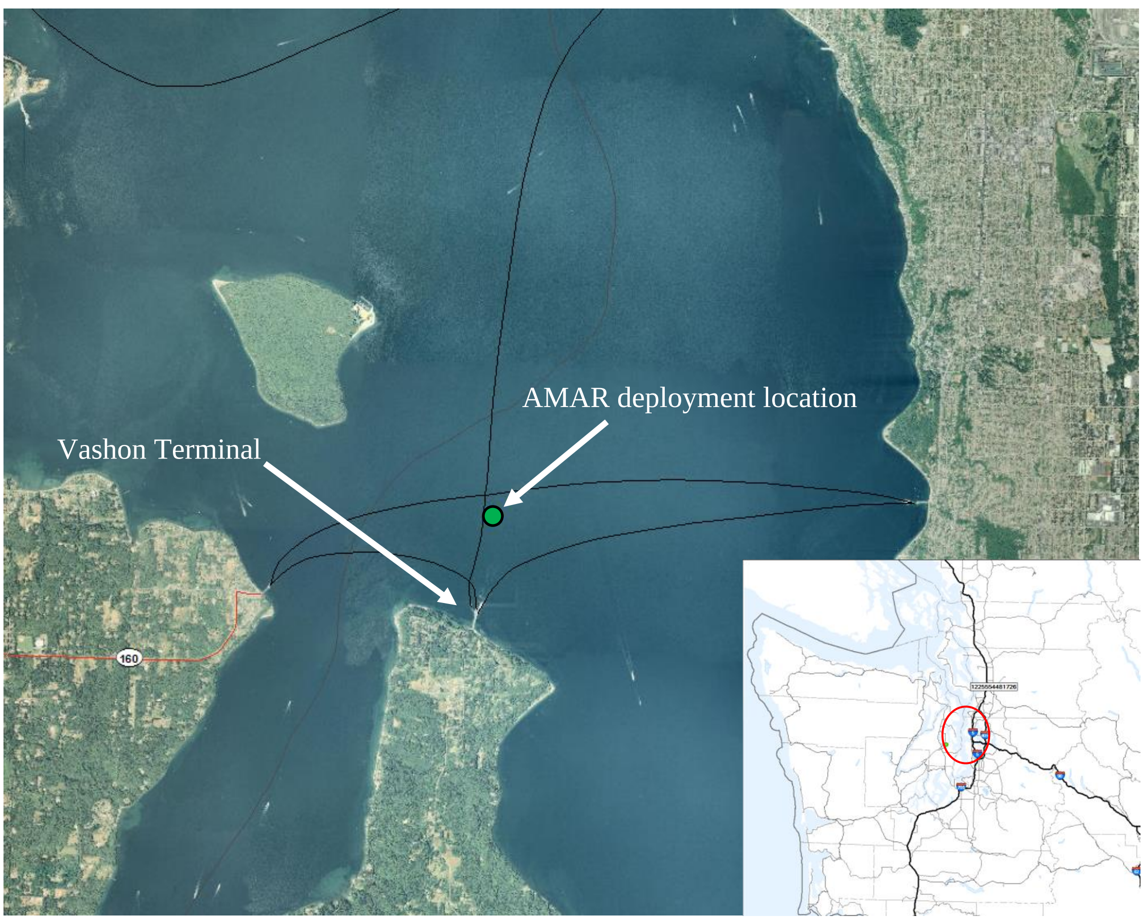

Figure 34: Location of the Autonomous Multichannel Acoustic Recorder (AMAR) deployment at Vashon Island.

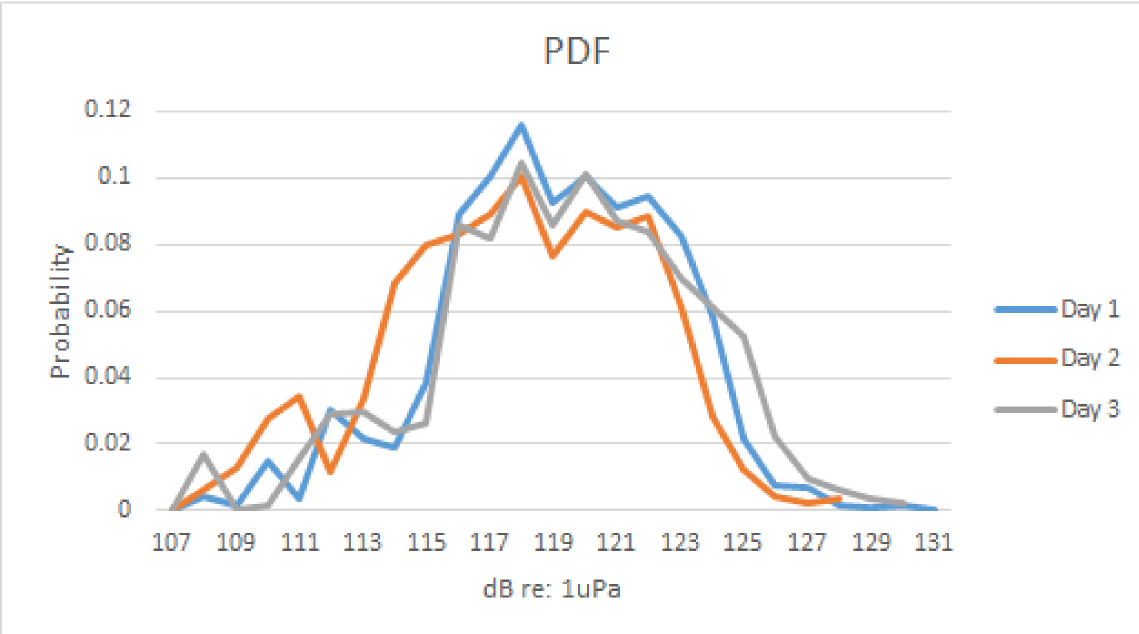

Figure 35: Probability Density Function (PDF) for the 1 Hz to 20 kHz analysis on a daily (24-hr) basis near Vashon.

The background sound levels for all frequencies measured between 1 Hz and 20 kHz ranged between 107 dB and 131 dB with the 50th percentile occurring at 119 dB (Figure 36). Analyses of the other functional hearing group frequency ranges are summarized in Table 10.

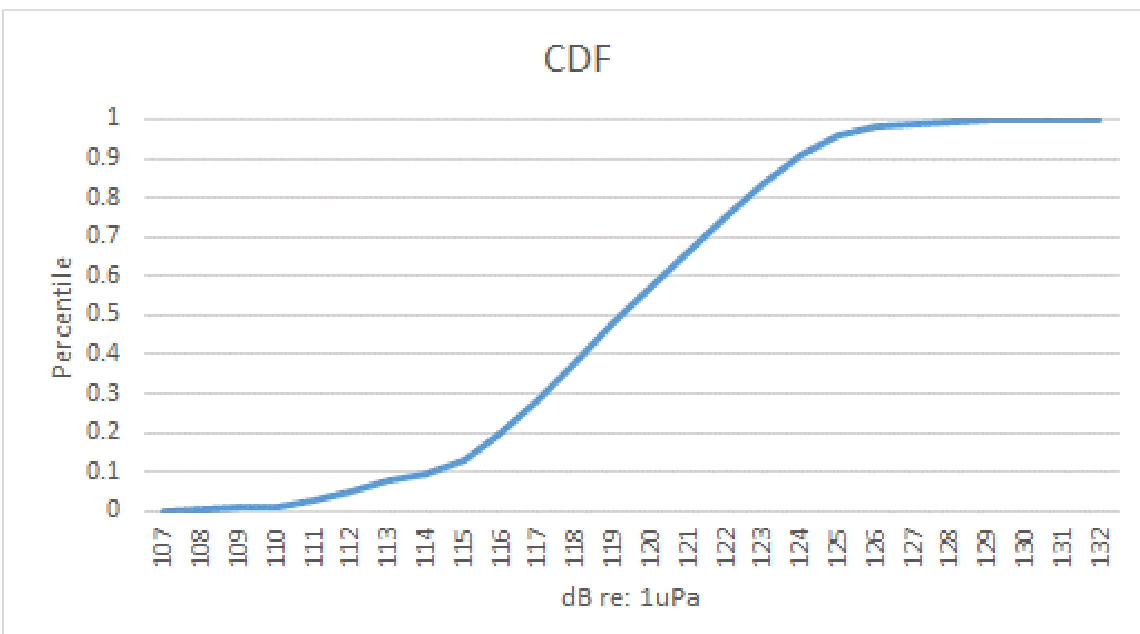

Figure 36: Cumulative Density Function (CDF) for the 1 Hz to 20 kHz analysis for all three days near Vashon Island.

Table 10: Background Sound Level Results, Vashon Ferry Terminal.

Frequency Range	Functional Hearing Group[1]	72-h 50% Cumulative Density Function (dB)	Daytime 50% Cumulative Density Function (dB)
7 Hz to 20 kHz	Low Frequency Cetaceans	116	117
50 Hz to 20 kHz	Phocid Pinnipeds	111	113
60 Hz to 20 kHz	Otariid Pinnipeds	111	113
150 Hz to 20 kHz	Mid Frequency Cetaceans	105	107
275 Hz to 20 kHz	High Frequency Cetaceans	103	106
1 Hz to 20 kHz	N/A - Broadband	119	120

Figure 37 shows the overall 1/3-octave bands for the entire 72-hour recording analyzed for this report. The dominant frequency is 50 Hz with the energy of the remaining frequencies below dropping off gradually. This low frequency source at 50 Hz are most likely from the ferry vessel traffic in the area and are within the typical frequencies for larger vessels.

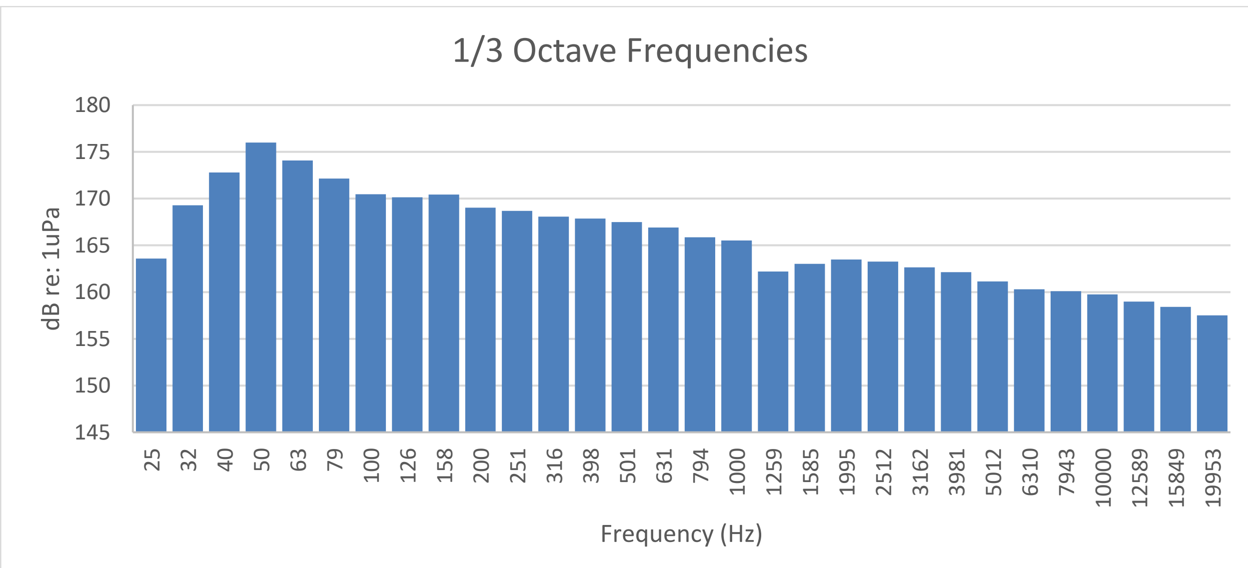

Figure 37: 1/3rd octave analysis of the broadband 1 Hz to 20 kHz frequencies for the 72-hour period near Vashon.

The 30-second RMS data were averaged on an hourly basis for 1 Hz to 20 kHz. These averages are plotted over time (Figure 38). Figure 38 shows that during the daytime the hourly average sound levels are relatively constant due to regular ferry traffic. The lowest sound levels recorded over this period at about 2 AM to 3 AM each day.

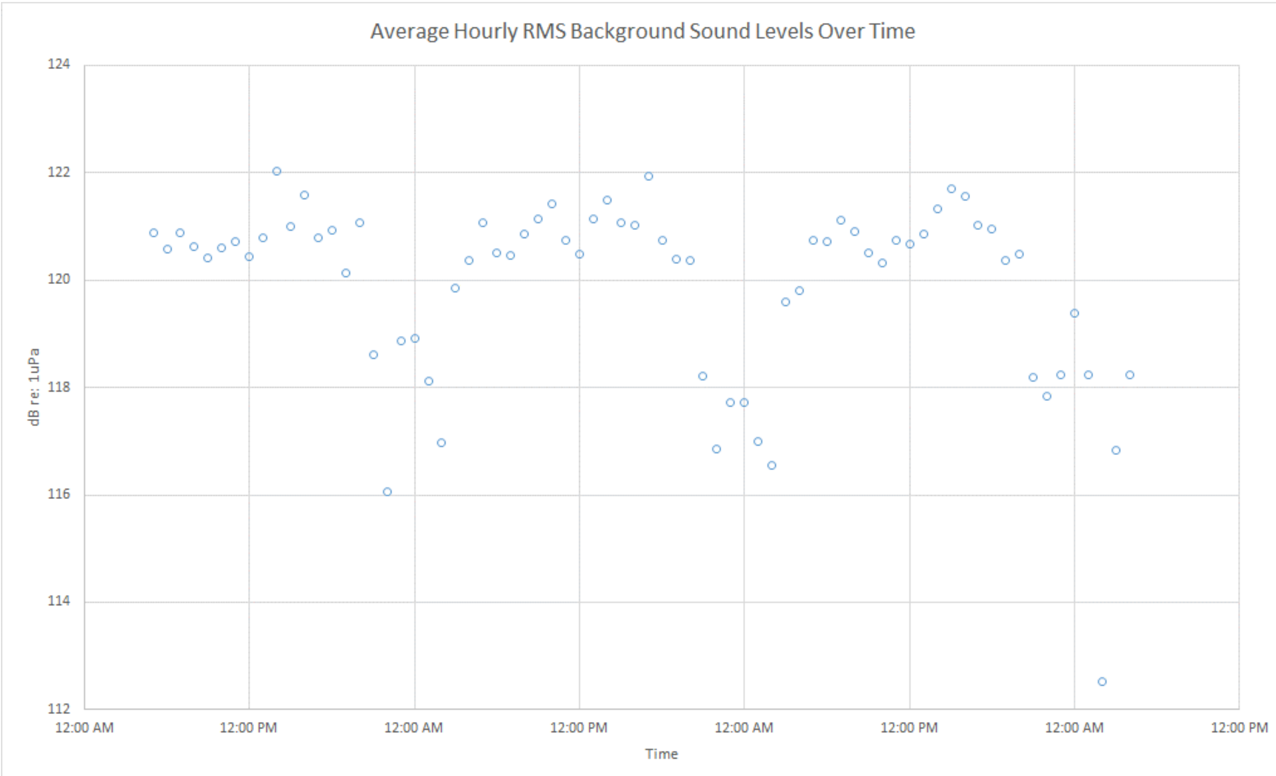

Figure 38: Average hourly background sound levels measured for a 72-hour period near the Vashon Ferry terminal including frequencies between 1 Hz and 20 kHz.

Southworth Ferry Terminal

Background sound levels were measured near the Southworth ferry terminal in an effort to determine site specific underwater background sound levels. Three days of data were collected between February 10 and 13, 2014 near the Southworth ferry terminal (Figure 39). Three full 24-hour cycles (e.g., 8AM to 8AM) were analyzed as part of this report from 8:00 AM on Monday February 10th through 8:00 AM Thursday February 13th.

The AMAR was deployed in approximately 1,000 feet of water and 3,300 feet from the Southworth ferry terminal, 90 feet from the nearest point of the Fauntleroy ferry traffic lane. The slope in the study area near the Vashon ferry terminal is approximately 7 degrees slope.

Background noise levels during the daytime are dominated by the presence of ferry traffic and occasional outboard motorboats and fishing vessels. Forty-nine ferry vessels per day arrive / depart the Southworth ferry terminal daily during winter weekdays.

The distribution of the data is approximately log-normal with little variability in the daily distributions of the data over the three days (Figure 40).

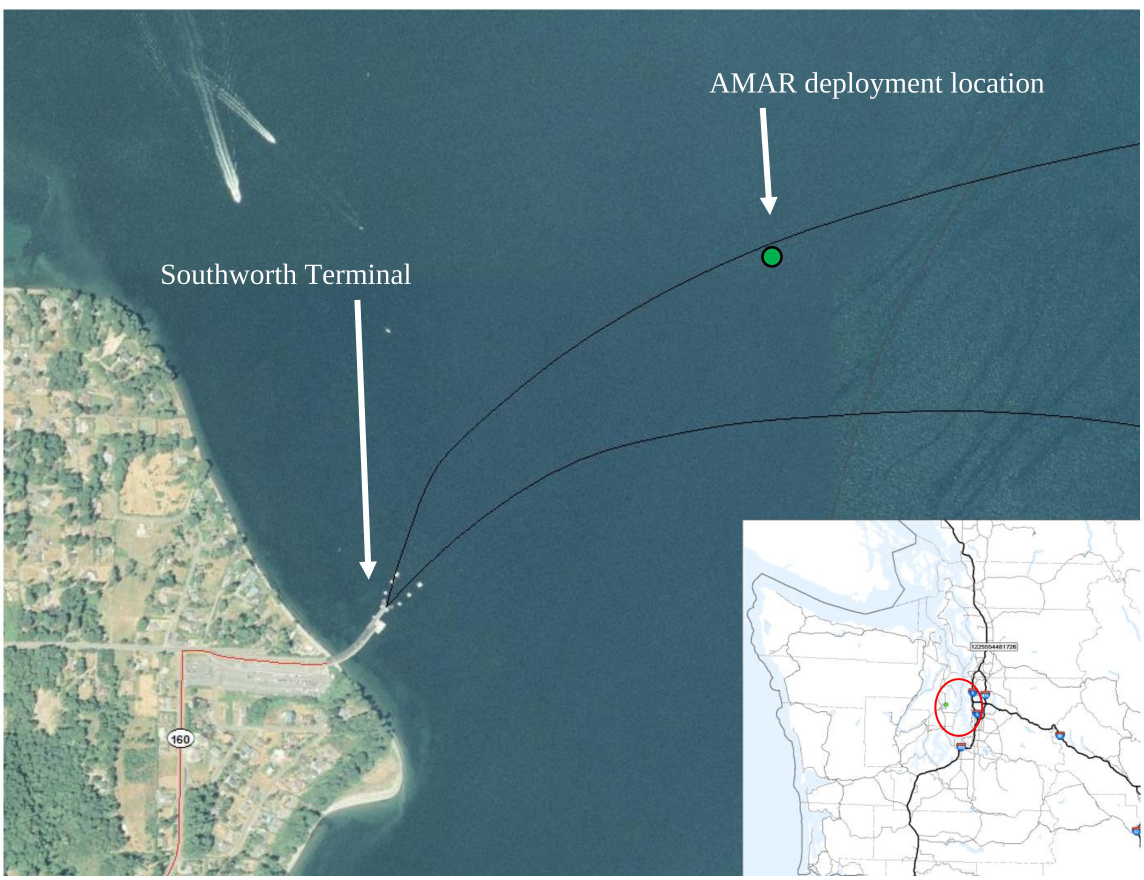

Figure 39: Location of the Autonomous Multichannel Acoustic Recorder (AMAR) deployment at Southworth.

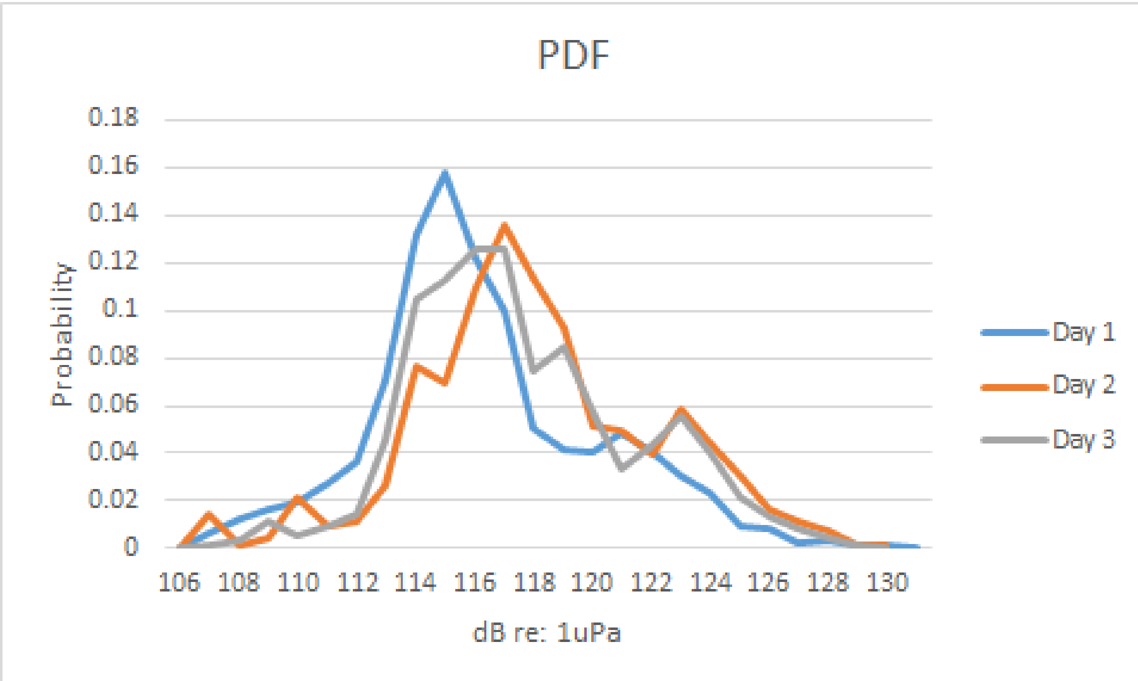

Figure 40: Probability Density Function (PDF) for the 1 Hz to 20 kHz analysis on a daily (24-hr) basis near Southworth.

The background sound levels for all frequencies measured between 1 Hz and 20 kHz ranged between 106 dB and 132 dB with the 50th percentile occurring at 117 dB (Figure 41). Analyses of the other functional hearing group frequency ranges are summarized in Table 11.

The Southworth ferry terminal is just west of the Vashon ferry terminal and the Vashon terminal background levels were 1 to 2 dB higher overall and 1 to 3 dB higher in the daytime than at Southworth. There were 5 additional ferry vessels arriving/departing at Vashon than at Southworth and the Vashon terminal was closer to the normal shipping lanes which could have contributed to the higher background sound levels.

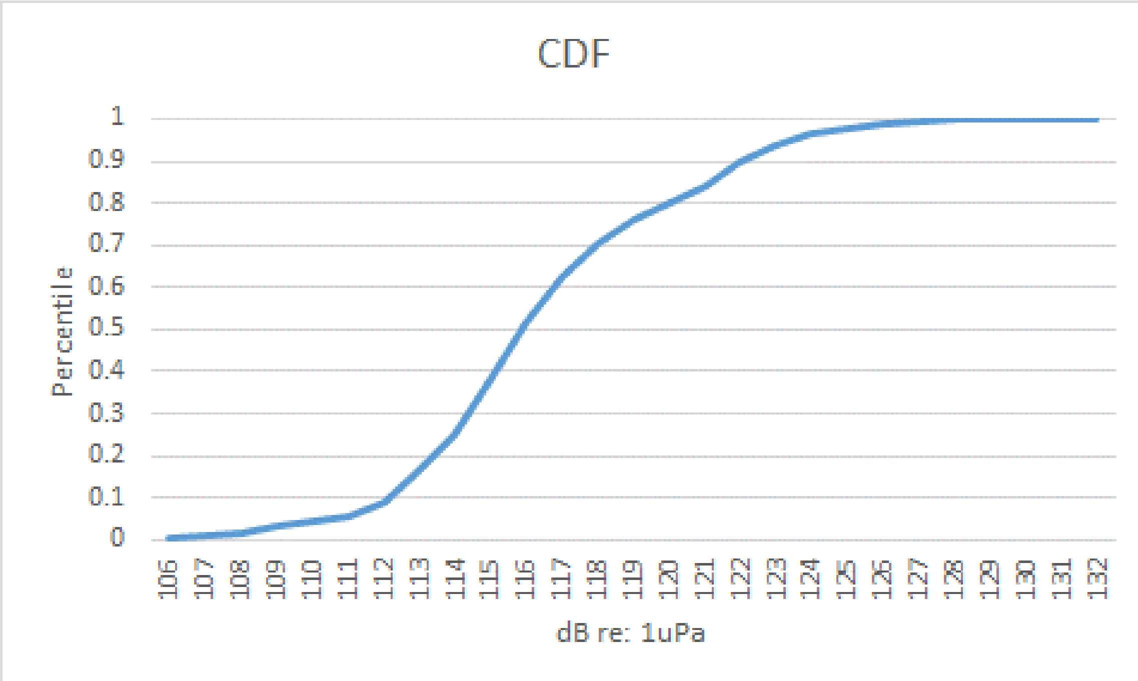

Figure 41: Cumulative Density Function (CDF) for the 1 Hz to 20 kHz analysis for all three days near Southworth.

Table 11: Background Sound Level Results, Southworth Ferry Terminal.

Frequency Range	Functional Hearing Group[1]	72-h 50% Cumulative Density Function (dB)	Daytime 50% Cumulative Density Function (dB)
7 Hz to 20 kHz	Low Frequency Cetaceans	114	115
50 Hz to 20 kHz	Phocid Pinnipeds	110	111
60 Hz to 20 kHz	Otariid Pinnipeds	110	111
150 Hz to 20 kHz	Mid Frequency Cetaceans	105	106
275 Hz to 20 kHz	High Frequency Cetaceans	103	104
1 Hz to 20 kHz	N/A - Broadband	117	117

Figure 42 shows the overall 1/3-octave bands for the entire 72-hour recording analyzed for this report. The dominant frequency is 50 Hz with the energy of the remaining frequencies below dropping off gradually. These low frequency sources at 50 Hz are most likely from the ferry vessel traffic in the area and are within the typical frequencies for larger vessels.

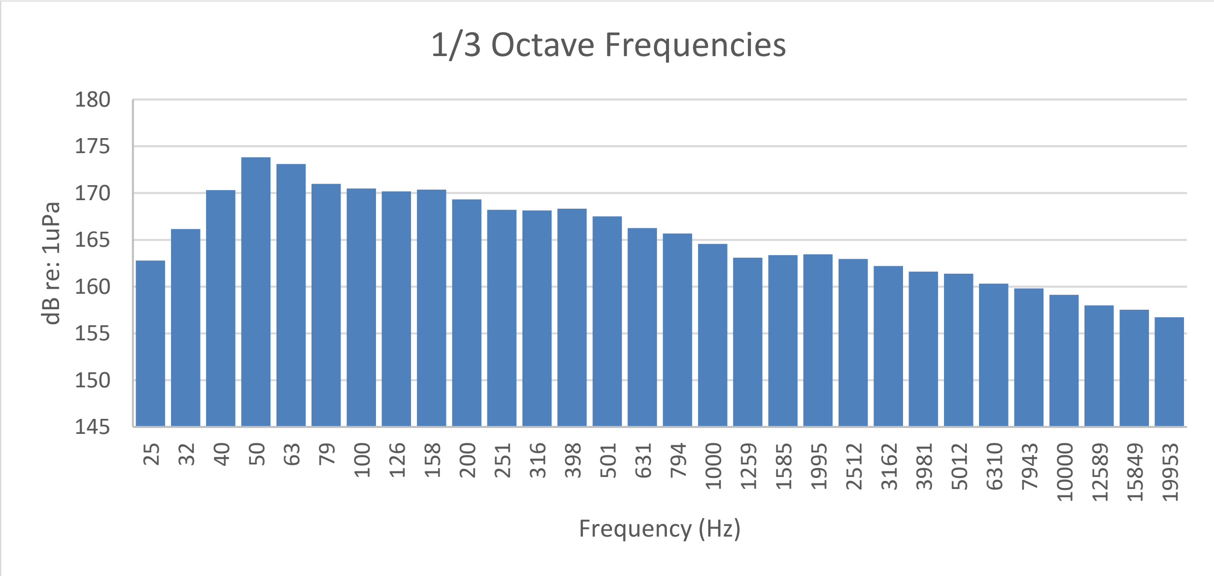

Figure 42: 1/3rd octave analysis of the broadband 20 Hz to 20 kHz frequencies for the 72-hour period near Southworth.

The 30-second RMS data were averaged on an hourly basis for 1 Hz to 20 kHz. These averages are plotted over time (Figure 43). Figure 43 shows that during the daytime the hourly average sound levels are relatively constant due to regular ferry traffic. The lowest sound levels recorded over this period between midnight and 2 AM each day.

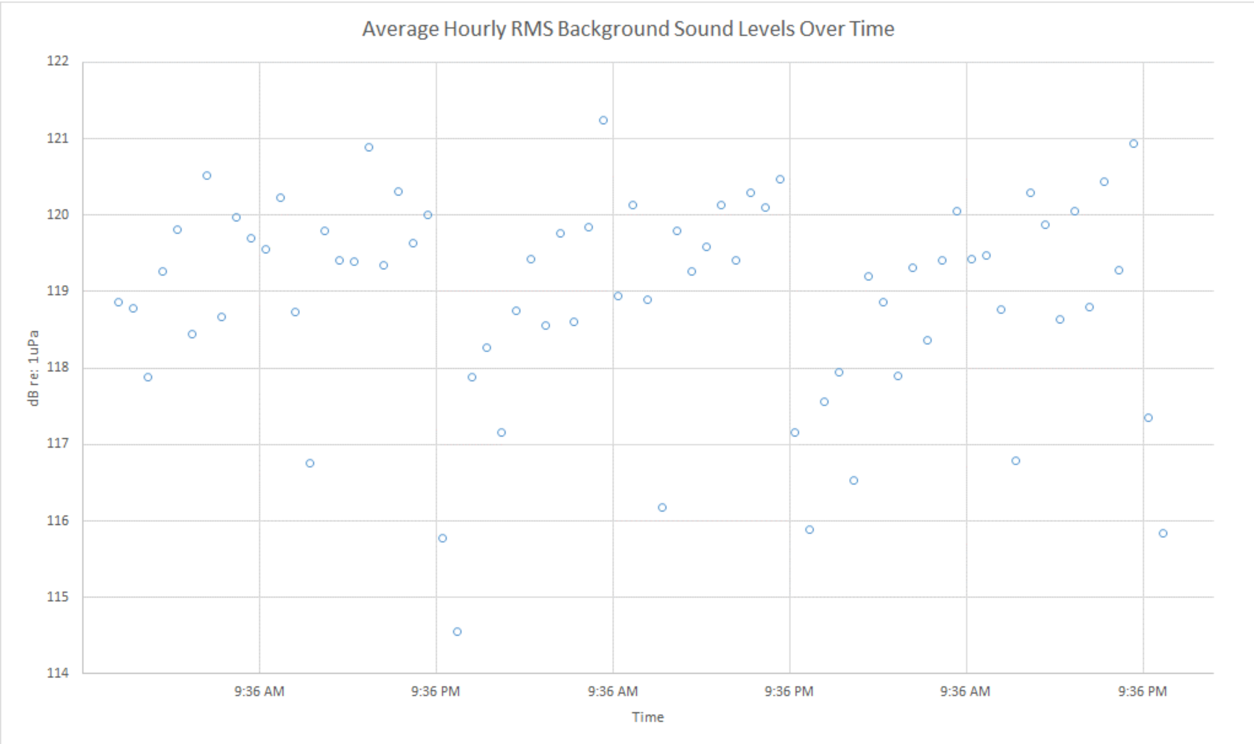

Figure 43: Average hourly background sound levels measured for a 72-hour period near the Southworth Ferry terminal including frequencies between 1 Hz and 20 kHz.

Coupeville (Keystone) Ferry Terminal

Background sound levels were measured near the Coupeville (Keystone) ferry terminal in an effort to determine site specific underwater background sound levels. Seven days of data were collected between February 24 and March 3, 2014 near the Coupeville ferry terminal (Figure 44). Three full 24-hour cycles (e.g., 6AM to 6AM) were analyzed as part of this report from 6:25 AM on Tuesday February 25th through 6:25 AM Friday February 28th.

The AMAR was deployed in approximately 180 feet of water and 3,200 feet from the Coupeville ferry terminal, 245 feet from the nearest point of the ferry traffic lane. The slope in the study area near the Coupeville ferry terminal is approximately 33 degrees slope.

Background noise levels during the daytime are dominated by the presence of ferry traffic and cargo ships. Ten ferry vessels per day arrive / depart the Coupeville ferry terminal daily during winter weekdays.

The distribution of the data is approximately log-normal with little variability in the daily distributions of the data over the three days (Figure 45).

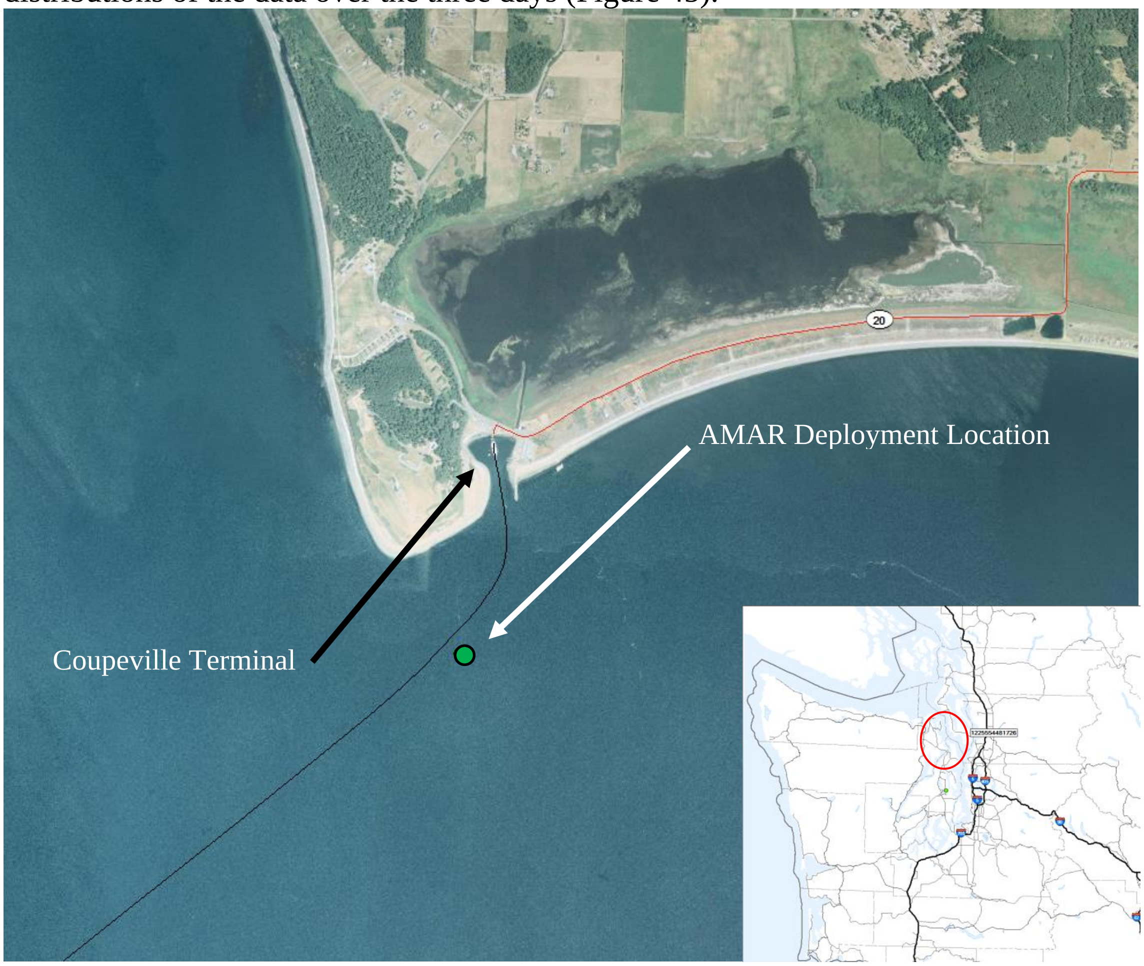

Figure 44: Location of the Autonomous Multichannel Acoustic Recorder (AMAR) deployment at Coupeville.

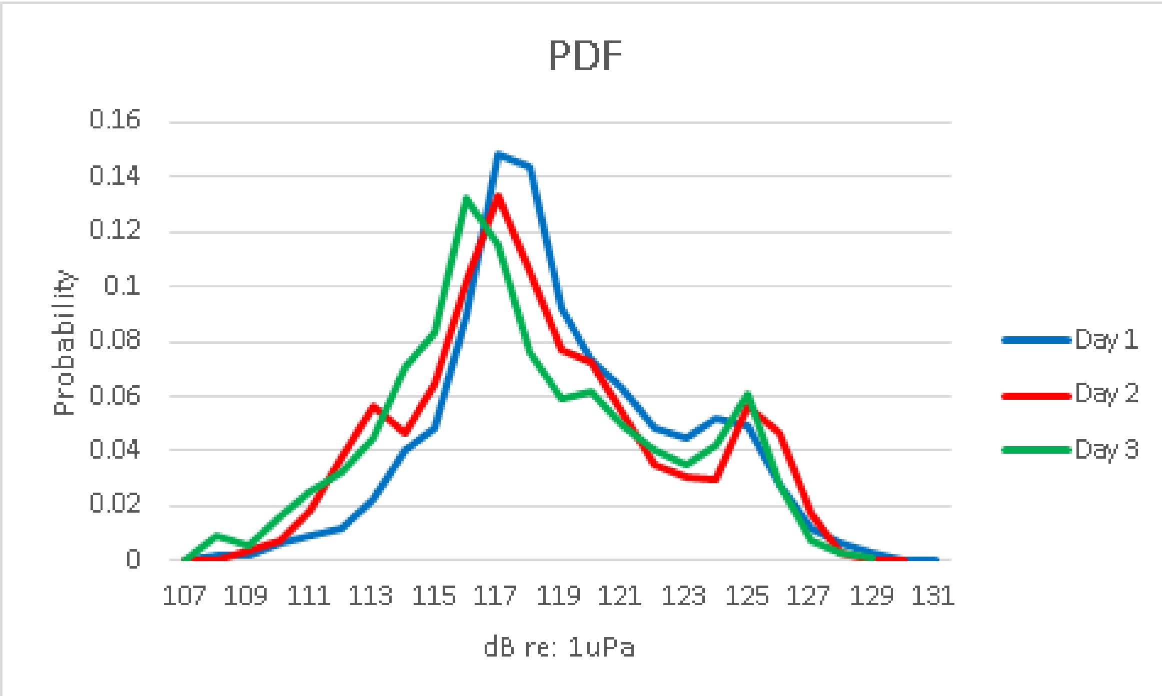

Figure 45: Probability Density Function (PDF) for the 1 Hz to 20 kHz analysis on a daily (24-hr) basis near Coupeville.

The background sound levels for all frequencies measured between 1 Hz and 20 kHz ranged between 107 dB and 130 dB with the 50th percentile occurring at 118 dB (Figure 46). Analyses of the other functional hearing group frequency ranges are summarized in Table 12.

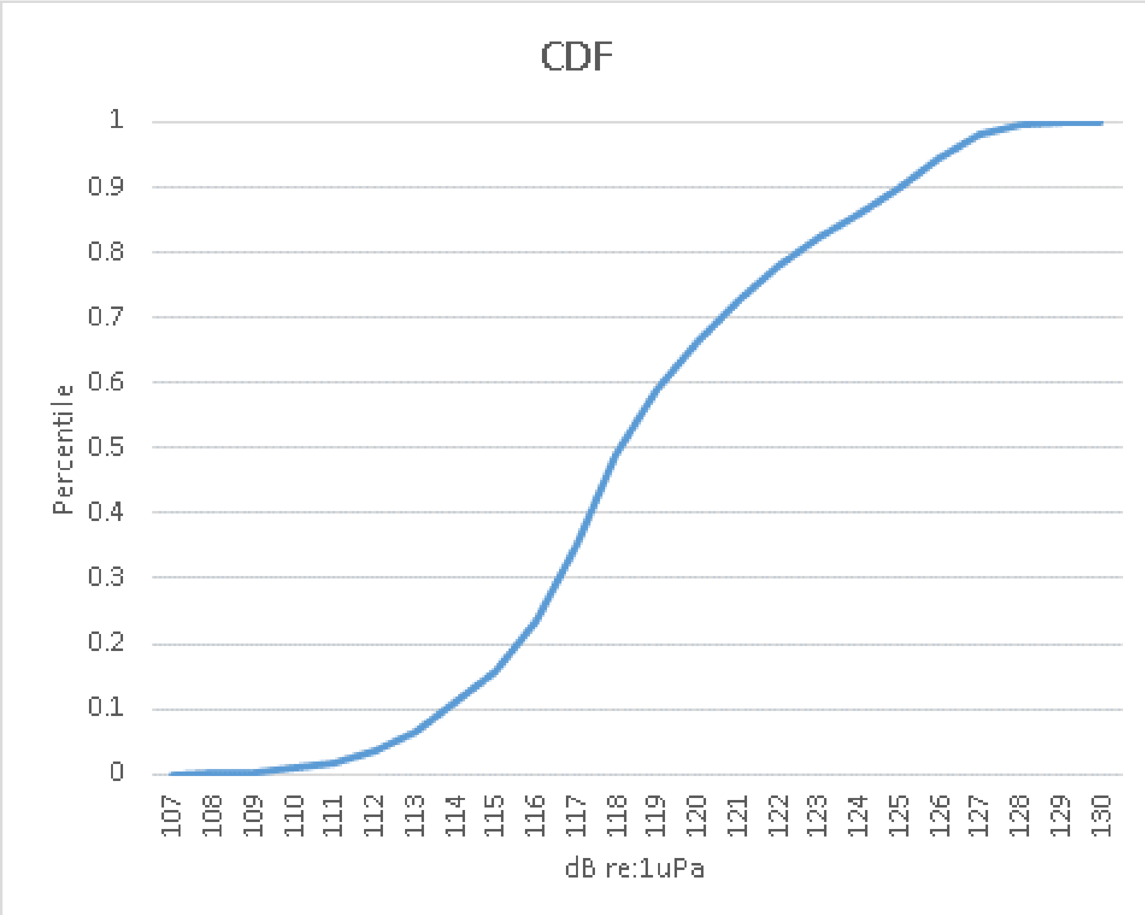

Figure 46: Cumulative Density Function (CDF) for the 1 Hz to 20 kHz analysis for all three days near Coupeville.

Table 12: Background Sound Level Results, Coupeville Ferry Terminal.

Frequency Range	Functional Hearing Group[1]	72-h 50% Cumulative Density Function (dB)	Daytime 50% Cumulative Density Function (dB)
7 Hz to 20 kHz	Low Frequency Cetaceans	113	114
50 Hz to 20 kHz	Phocid Pinnipeds	109	110
60 Hz to 20 kHz	Otariid Pinnipeds	109	110
150 Hz to 20 kHz	Mid Frequency Cetaceans	104	104
275 Hz to 20 kHz	High Frequency Cetaceans	102	102
1 Hz to 20 kHz	N/A - Broadband	118	118

Figure 47 shows the overall 1/3-octave bands for the entire 72-hour recording analyzed for this report. The dominant frequency is at 63 Hz with the energy of the remaining frequencies below dropping off gradually. These low frequency sources of 63 Hz are most likely from the ferry vessel traffic in the area and are within the typical frequencies for larger vessels.

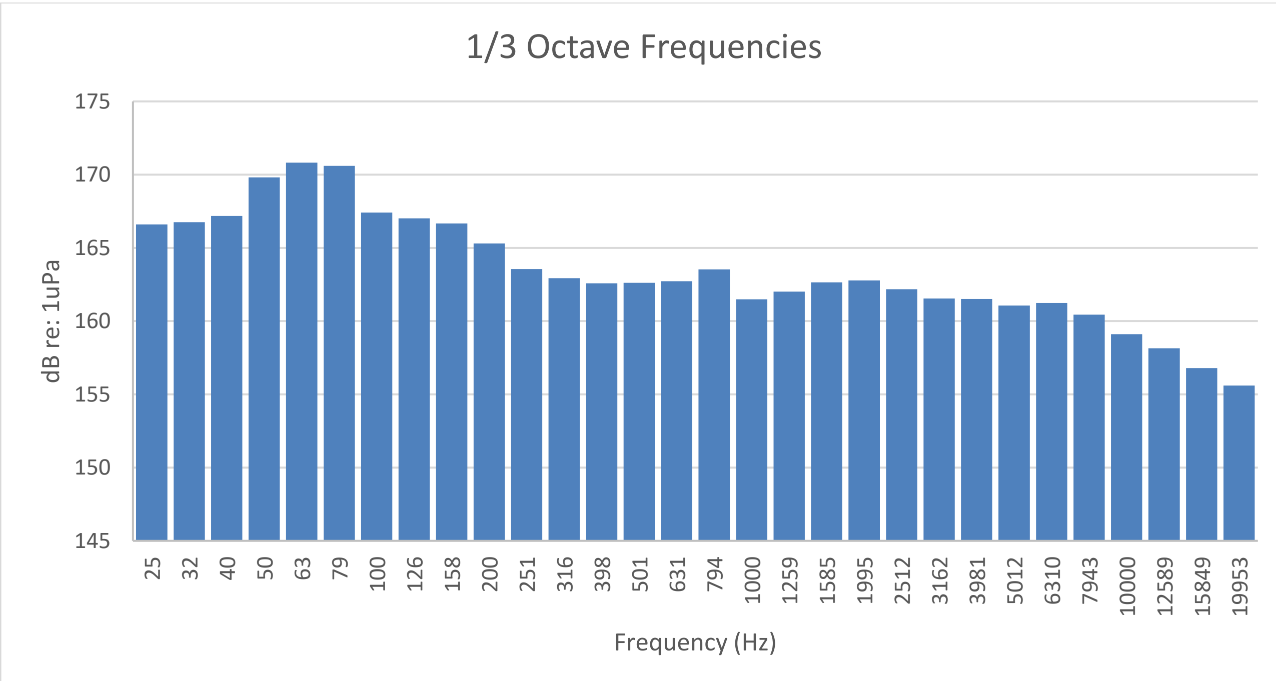

Figure 47: 1/3rd octave analysis of the broadband 20 Hz to 20 kHz frequencies for the 72-hour period near Coupeville.

The 30-second RMS data were averaged on an hourly basis for 1 Hz to 20 kHz. These averages are plotted over time (Figure 48). Figure 48 shows that during the daytime the hourly average sound levels are relatively constant due to regular ferry traffic. The lowest sound levels recorded over this period at about 2 AM each day.

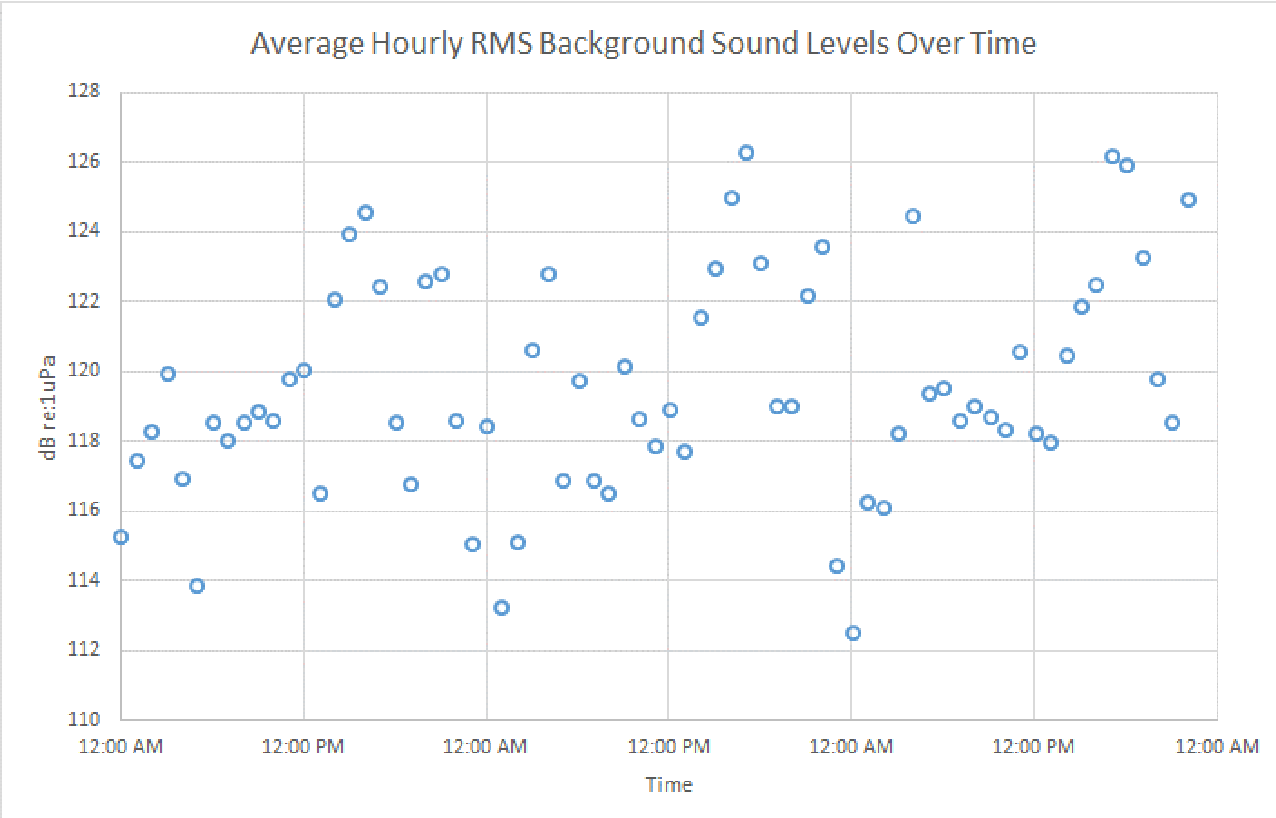

Figure 48: Average hourly background sound levels measured for a 72-hour period near the Coupeville Ferry terminal including frequencies between 1 Hz and 20 kHz.

Background Sound Levels vs. Number of Ferry Vessels

The background sound levels are dominated by ferry vessels traveling to and from the terminal as well as some cargo ships. We looked to see if there was any correlation between the number of ferry vessels traveling to and from a particular terminal and the background sound level, both overall and daytime only. Figure 49 shows the correlation between broadband sound level and number of ferry vessels arriving/departing each day during the measurement period for each terminal for the full three day period.

Figure 51 indicates that with the exception of those locations where the number of ferry vessels drops to around 10 per day the difference in sound levels vary by only about 3 to 4 dB regardless of the number of ferry vessels. Those terminals which have a relatively low number of vessels arriving/departing are more variable and could be more influenced by the other sources in the area such as cargo ships, fishing vessels and pleasure boats. Results at all terminals could also be influenced by their relative proximity to the major shipping lanes.

The daytime only results showed similar trends. Without excluding the other sources in the area from the results it is not possible to predict what the sound levels will be based only on the number of ferry vessels arriving and departing.

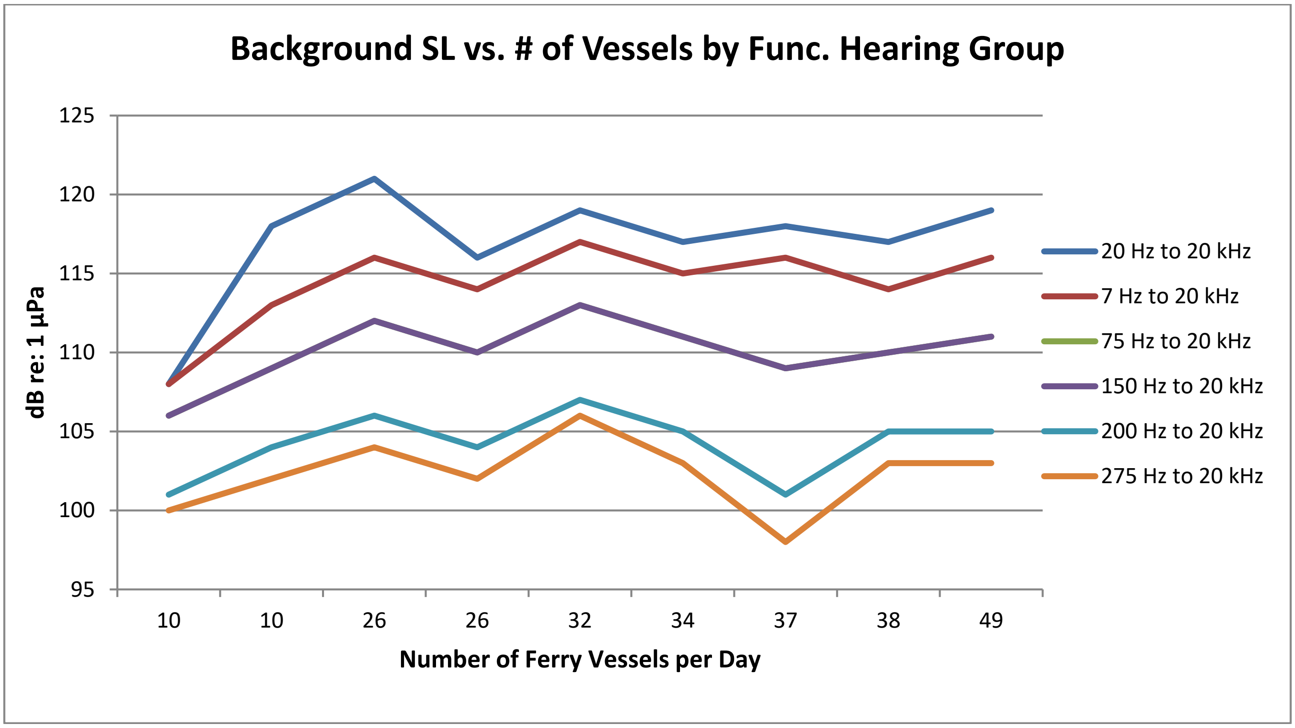

Figure 49: Background sound levels by functional hearing group and number of ferry vessels per day for a 72-hour period for all terminals.

Lake Keechelus

Background sound levels were measured near I-90 at Keechelus Lake in an effort to determine site specific underwater background sound levels in an alpine lake system. Three days of data were collected between July 18, 2016 and July 21, 2016 in Keechelus Lake (Figure 50). Three full 24-hour cycles (e.g., 6AM to 6AM) were analyzed as part of this report from 9:54 AM on Monday July 18th through 10:54 AM Thursday July 21st.

The AMAR was deployed in approximately 226 feet of water and 1,600 feet from the eastern shore of the lake.   The bottom topography in the area is relatively flat with steep slopes near shore.

Background noise levels during the daytime are dominated by the presence of wind, rain and the occasional boat traffic and faint traffic on I-90.

The distribution of the data is approximately log-normal with little variability in the daily distributions of the data over the three days (Figure 51).

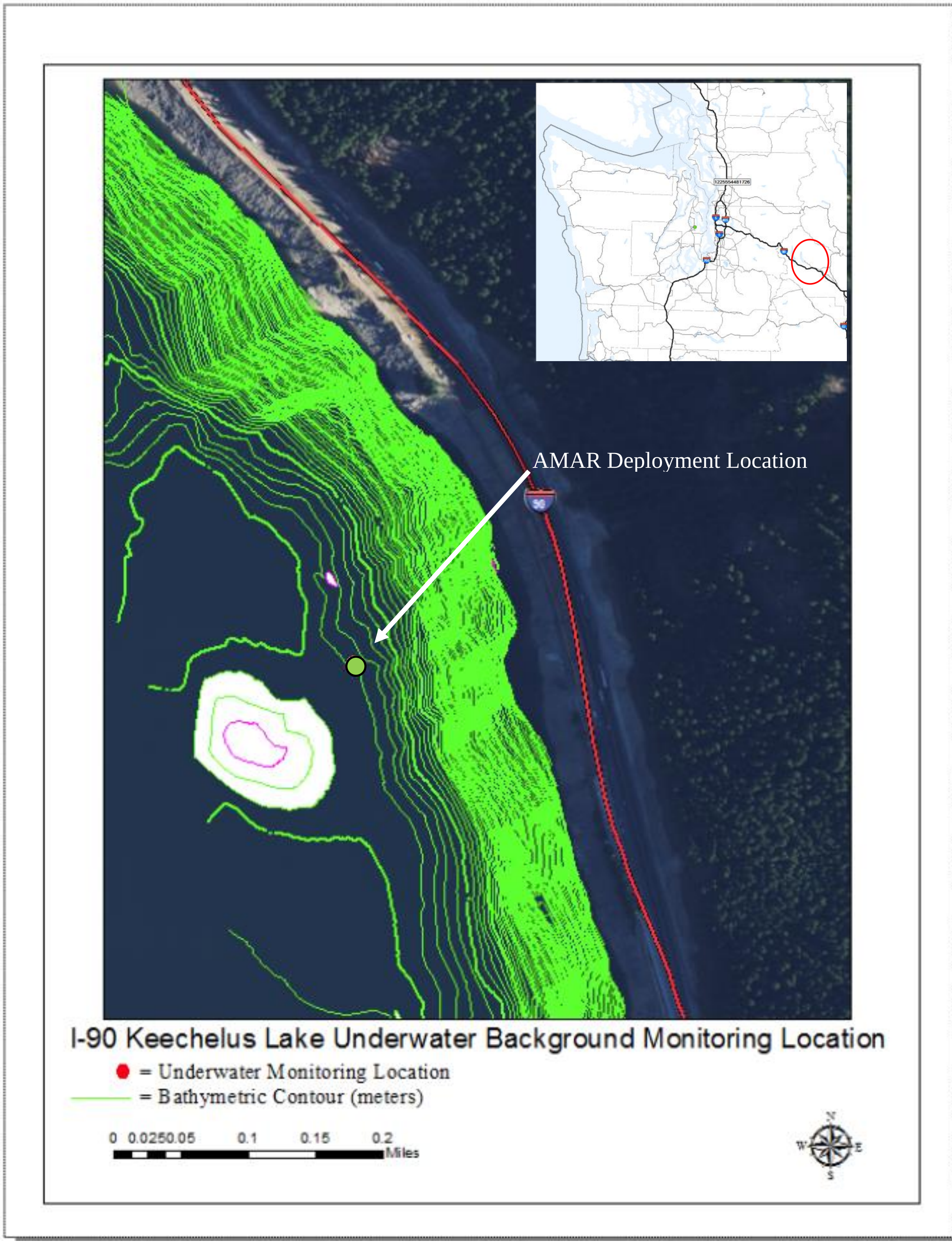

Figure 50: Location of the Autonomous Multichannel Acoustic Recorder (AMAR) deployment at Keechelus Lake.

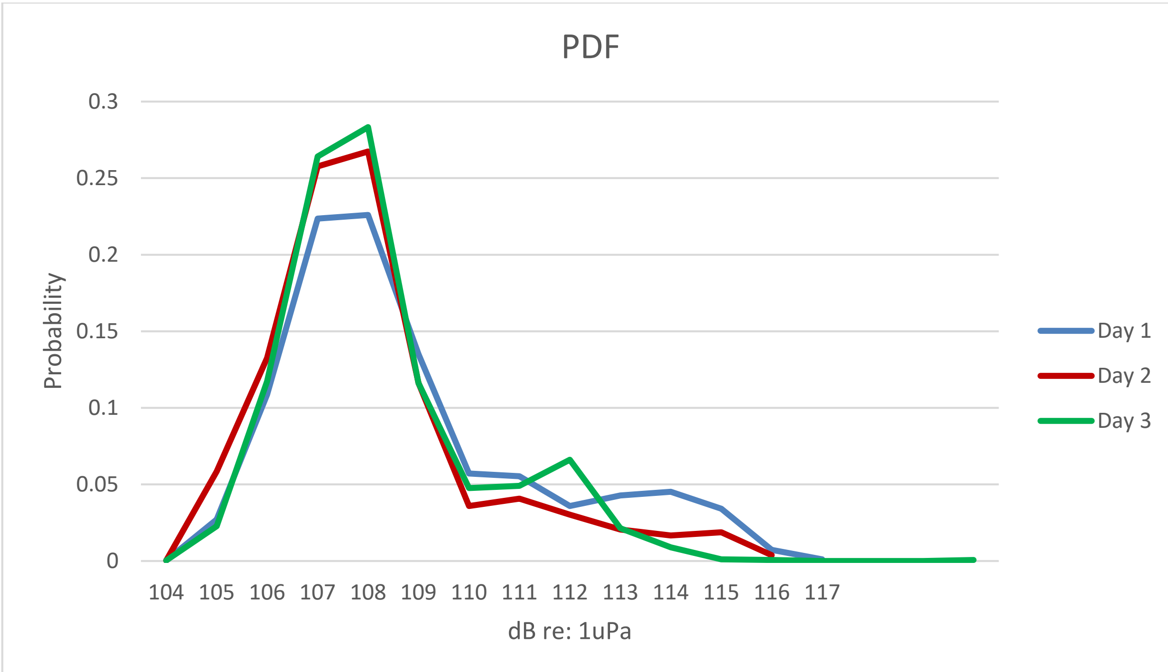

Figure 51: Probability Density Function (PDF) for the 1 Hz to 20 kHz analysis on a daily (24-hr) basis near Keechelus Lake.

The background sound levels for all frequencies measured between 1 Hz and 20 kHz ranged between 104 dB and 117 dB with the 50th percentile occurring at 107 dB (Figure 52).

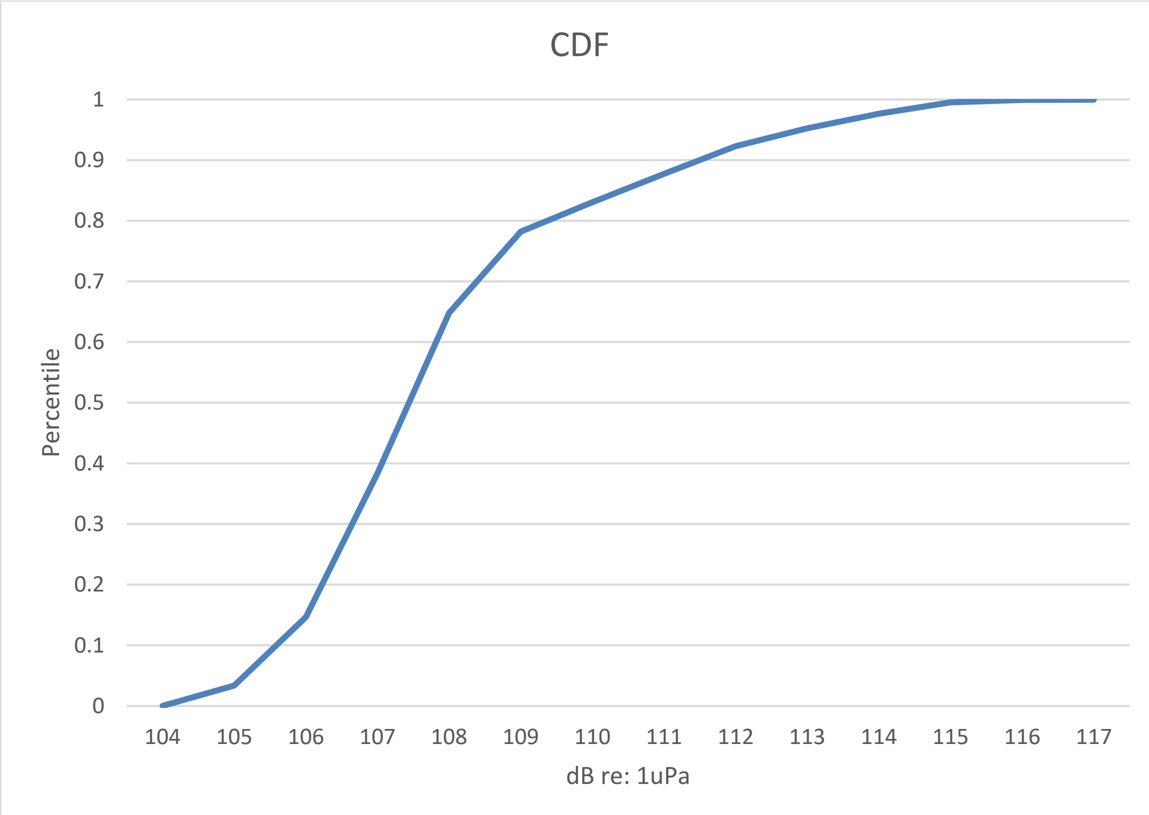

Figure 52: Cumulative Density Function (CDF) for the 1 Hz to 20 kHz analysis for all three days near Keechelus Lake.

Figure 53 shows the overall 1/3-octave bands for the entire 72-hour recording analyzed for this report. The dominant frequency is at 63 Hz with the energy of the remaining frequencies below dropping off gradually. These low frequency sources of 63 Hz could be due to intermittent construction equipment operating on shore or vehicular traffic on I-90.

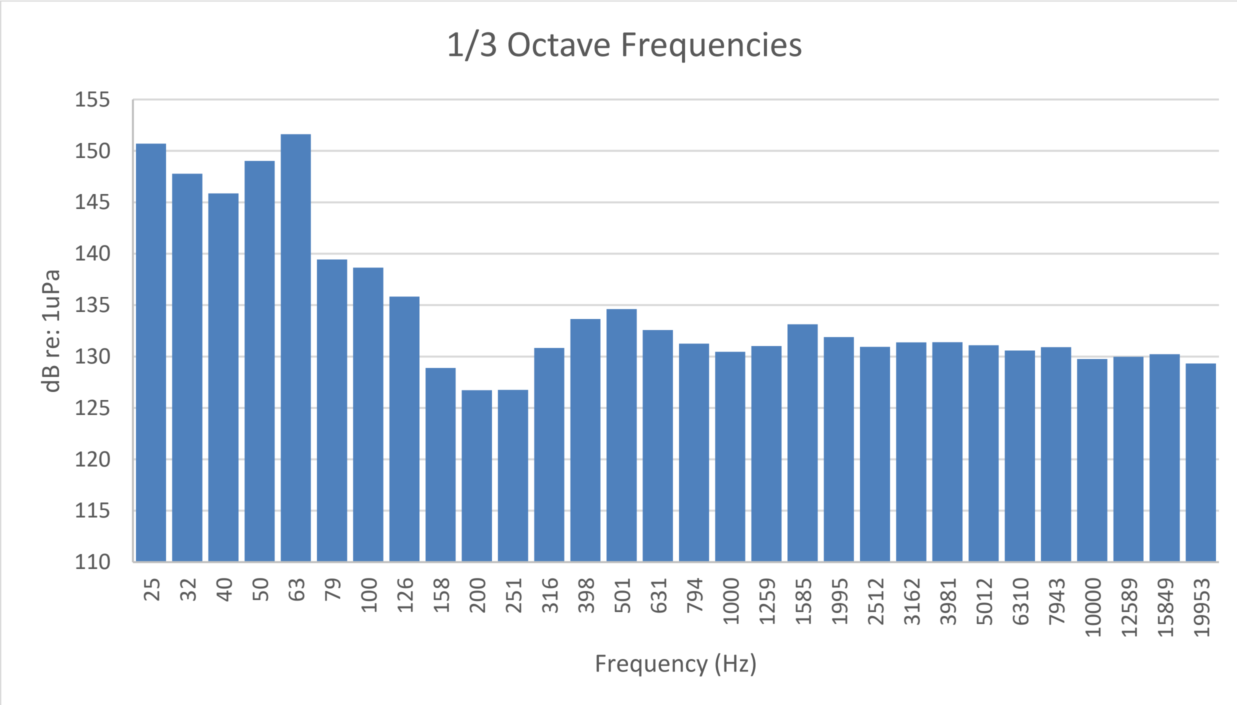

Figure 53: 1/3rd octave analysis of the broadband 20 Hz to 20 kHz frequencies for the 72-hour period near Keechelus Lake.

The 30-second RMS data were averaged on an hourly basis for 1 Hz to 20 kHz. These averages are plotted over time (Figure 54). Figure 54 shows that there are daily peaks at 2 PM on the first day, 3 PM on the second day and 3 AM on the third day with the lowest sound levels recorded over this period at 3 AM on the first day, 1 AM on the second day and 11 PM on the third day. The peak sound levels at 3 AM on the third day were the result of a distant boat motoring around the lake at that time.

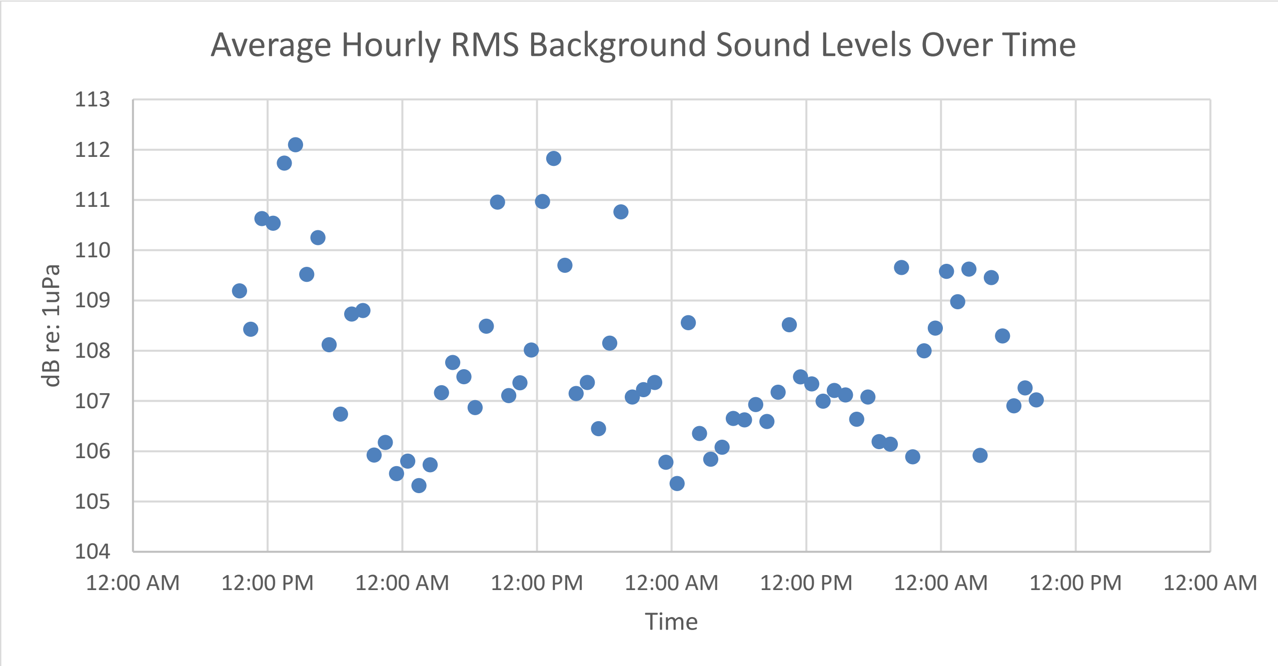

Figure 54: Average hourly background sound levels measured for a 72-hour period near the Keechelus Lake Ferry terminal including frequencies between 1 Hz and 20 kHz.

Table 13: Underwater Background Monitoring Results, 3, 24-hour Periods by Terminal and Marine Mammal Functional Hearing Group.

Ferry Terminal	1Hz to 20 kHz Broadband	7 Hz to 20 kHz Low Frequency	50 Hz to 20 kHz Phocids	60 Hz to 20 kHz Otariids	150 Hz to 20 kHz Mid Frequency	275 Hz to 20 kHz High Frequency
Port Townsend[1]	108	108	106	106	101	100
Anacortes[2]	121	116	112	112	106	104
Edmonds[3]	116	114	110	110	104	102
Seattle[4]	119	117	113	113	107	106
Mukilteo (2011)[5]	117	115	111	111	105	103
Mukilteo (2015)[10]	117	112	110	110	104	102
Kingston[6]	118	116	109	109	101	98
Vashon[7]	119	116	111	111	105	103
Southworth[8]	117	114	110	110	105	103
Coupeville[9]	118	113	109	109	104	102
Lake Keechelus[11]	107	-	-	-	-	-

[1] Dahl et al. 2010. Measured in April 2010.
[2] Laughlin 2011b. Measured in March 2011.
[3] Laughlin 2011c. Measured in April 2011.
[4] Laughlin 2011d. Measured in April 2011.
[5] Laughlin 2011a. Measured in May 2011.
[6] Measured in October 2013.
[7] Measured in February 2014.
[8] Measured in February 2014.
[9] Measured in April 2015.
[10] Measured in April 2015.
[11] Soderberg and Laughlin, 2016.

Table 14: Underwater Background Monitoring Results, Daytime Only by Terminal and Marine Mammal Functional Hearing Group.

Ferry Terminal	1Hz to 20 kHz Broadband	7 Hz to 20 kHz Low Frequency	50 Hz to 20 kHz Phocids	60 Hz to 20 kHz Otariids	150 Hz to 20 kHz Mid Frequency	275 Hz to 20 kHz High Frequency
Port Townsend[1]	108	109	105	105	101	99
Anacortes[2]	122	118	113	113	107	105
Edmonds[3]	117	115	112	111	106	104
Seattle[4]	120	117	113	113	108	106
Mukilteo (2011)[5]	118	116	112	112	106	105
Mukilteo (2015)[10]	118	116	111	111	105	103
Kingston[6]	118	116	109	110	101	98
Vashon[7]	120	117	113	113	107	106
Southworth[8]	117	115	111	111	106	104
Coupeville[9]	118	114	110	110	104	102
Lake Keechelus[11]	107	-	-	-	-	-

[1] Dahl et al. 2010. Measured in April 2010.
[2] Laughlin 2011b. Measured in March 2011.
[3] Laughlin 2011c. Measured in April 2011.
[4] Laughlin 2011d. Measured in April 2011.
[5] Laughlin 2011a. Measured in May 2011.
[6] Measured in October 2013.
[7] Measured in February 2014.
[8] Measured in February 2014.
[9] Measured in April 2015.
[10] Measured in April 2015.
[11] Soderberg and Laughlin, 2016.

CONCLUSIONS

The overall average background sound level for the frequency range of 20 Hz to 20 kHz is estimated to range between 108 dB and 121 dB in Puget Sound for three consecutive 24-hour periods (Table 13).

The underwater background sound levels during the daytime near the ferry terminals are dominated by ferry vessel traffic. The dominant 1/3rd octave band frequency contained in the background sound levels ranges between 50 Hz and 63 Hz. Frequencies within this range are typical for ferry vessel traffic. The magnitude of the underwater background sound levels is in part dependent upon the number of ferry vessels arriving and departing from the terminal as well as the size of the vessels.

A comparison of the Evergreen Class (Klikitat) vessels and the new Olympic Class vessels (Tokitae) indicate that the Olympic Class vessels are possibly quieter although the overall sound levels may be influenced by other sources in the area and show little or no difference when compared to previous measurements at the same location.

According to current NMFS (2012) guidance on the collection and analysis of underwater background sound levels three consecutive daytime only datasets can be analyzed to determine background sound levels if the pile driving will occur only during the daytime hours. In this report we also analyzed the data using only the daytime sound levels (Table 14).

Background sound levels during daytime hours are slightly higher than the combined daytime and nighttime background sound levels. This slight change is probably due to the fact that ferry vessels often run until 10 pm or later at some terminals.

The background sound levels at Keechelus Lake are typical for an alpine lake with sound levels during the daytime dominated by wind, rain and the occasional boat traffic and faint traffic on I-90. The background sound levels for all frequencies measured between 1 Hz and 20 kHz ranged between 104 dB and 117 dB with the 50th percentile occurring at 107 dB.

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