Summary of Ambient and Anthropogenic Sound in the Gulf of Alaska and Northwest Coast

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Executive Summary

Underwater ambient and anthropogenic sounds were recorded over multiple years in areas where the U.S. Navy conducts periodic at-sea training, one in the Gulf of Alaska and the other offshore of the northwest Pacific coast of the continental U.S. The Gulf of Alaska Temporary Maritime Activities Area (GATMAA) was acoustically monitored for marine mammal, ambient, and anthropogenic sounds from July 2011 to September 2015 (Baumann-Pickering *et al.*, 2012; Debich *et al.*, 2013; Debich *et al.*, 2014b; Rice *et al.*, 2015). The Northwest Training Range Complex (NWTRC), now part of the Northwest Training and Testing area, was also monitored for sounds from marine mammals, ambient soundscape, and anthropogenic sources from September 2004 to May 2014 (Širović *et al.*, 2011a; Širović *et al.*, 2011b; Kerosky *et al.*, 2013; Debich *et al.*, 2014a; Trickey *et al.*, 2015).

For both areas, the ambient soundscape sound pressure levels were re-processed using new and improved techniques, including calculating long (multi-year) spectrograms, sound pressure spectrum level percentiles, and average sound pressure spectrum levels over the recording periods. Over 3,700 days of passive acoustic data were obtained from the GATMAA, and over 3,100 days of passive acoustic data were obtained from the NWTRC. Detections of the anthropogenic sources from broadband ship, mid-frequency active (MFA) sonar, low-frequency active (LFA) sonar, and explosions are summarized and reported.

The ambient soundscape was similar at both areas, with GATMAA showing higher levels from blue and fin whales calls at low frequencies (<30 Hz) and NWTRC showing higher levels from commercial shipping and fishing vessels (~30 – 100 Hz), confirmed by higher number of detections of broadband ship sounds.

MFA sonar (~3.5 kHz) was detected in GATMAA only during one period of 10 consecutive days in June 2015 during a known U.S. Navy exercise, and was detected in NWTRC at relatively low numbers on several occasions (~20 h [0.8 d] cumulatively over 1,635 days analyzed over the period from 2008 – 2014). Low-Frequency Active (LFA) sonar at a frequency of ~200 – 220 Hz was detected at GATMAA at one site, but only at low levels a few times (~13 h [0.5 d] cumulatively over 2,356 days analyzed from 2013 – 2015). The source of this signal is unidentified at this time, but the U.S. Navy confirmed none of its LFA sonars was used in or adjacent to GATMAA, or in the same month elsewhere in the Pacific as the GATMAA detections (C. Johnson, U.S. Navy Pacific Fleet, personal communication, 2/28/2017). LFA sonar was also detected at NWTRC at low levels and low numbers at frequencies between 900 – 1000 Hz (~21 h [0.9 d] cumulatively over 306 days analyzed over 2013 – 2014).

Explosions were detected at both areas, only sporadically and at relatively low numbers. There was no explosive use by the U.S. Navy in GATMAA during the study period, and only limited far offshore use in NWTRC (C. Johnson, U.S. Navy Pacific Fleet, personal communication, 2/28/2017). The majority of explosive detections are most likely related to fishing operations such as the use of “seal bombs” as pinniped deterrents.

Background

The northeast Pacific contains two U.S. Navy training areas, one in the far north near Alaska: Gulf of Alaska Temporary Maritime Activities Area (GATMAA); and the other in the east, offshore of Washington, Oregon and northern California: Northwest Training Range Complex (NWTRC) (Figure 1). The GATMAA is a temporary training area typically only used over a one to three week period every other year. NWTRC is an established offshore training area with infrequent, but periodic annual small scale training and testing events.

GATMAA is an area approximately 300 nautical miles (nm) long by 150 nm wide, situated south of Prince William Sound and east of Kodiak Island. It extends from the shallow continental shelf region, over the shelf break and into deep offshore waters. The region has a subarctic climate and is a highly productive marine ecosystem as a result of upwelling linked to the counterclockwise gyre of the Alaska Current. A diverse array of marine mammals is found here, including baleen whales, beaked whales, other toothed whales, and pinnipeds. Endangered marine mammals that are known to inhabit this area include blue (*Balaenoptera musculus*), fin (*B. physalus*), humpback (*Megaptera novaeangliae*), North Pacific right (*Eubalaena japonica*), and sperm (*Physeter macrocephalus*) whales.

NWTRC contains an offshore area that extends west 250 nautical miles offshore of the northwest coast of the continental U.S. This region is a productive ecosystem inhabited by many species of marine mammals. The area includes deep water habitats, utilized by a variety of beaked and sperm whales, as well as continental shelf waters that are frequented by coastal marine mammals including mysticetes, odontocetes, and pinnipeds. Endangered species known to occur in this area include blue whales, fin whales, North Pacific right whales, humpback whales, sperm whales, and killer whales (*Orcinus orca*).

To characterize the sounds of these marine mammals along with the ocean ambient soundscape and anthropogenic sound sources, passive acoustic monitoring (PAM) was employed in both ranges using long-term acoustic recorders deployed at five locations in GATMAA and three locations in NWTRC from which reports on these monitoring efforts were previously submitted to the U. S. Navy. This report summarizes the underwater ambient and anthropogenic sounds from those recordings.

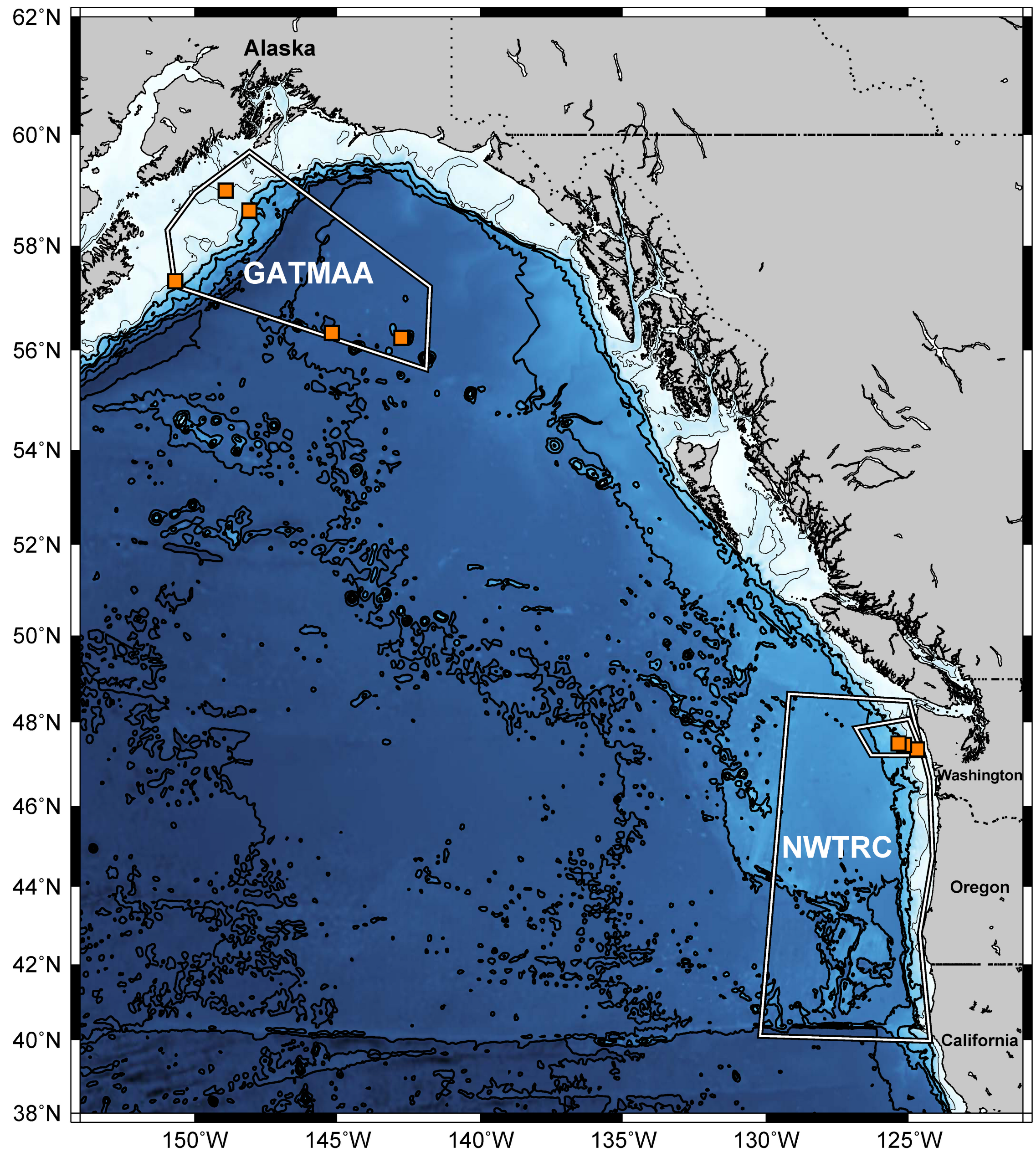

Figure 1. Northeast Pacific showing U.S. Navy training areas outlined in white: Gulf of Alaska Temporary Maritime Activities Area (GATMAA) and Northwest Training Range Complex (NWTRC). Orange squares are passive acoustic monitoring (PAM) recorders deployment locations and bathymetric contours are 200 m, and 1000 – 5000 m at 1000 m intervals. Detailed maps of each area are shown in Figures 2 and 3.

Methods

Passive Acoustic Monitoring Recorders

High-frequency Acoustic Recording Packages (HARPs - Wiggins and Hildebrand, 2007) were used to record marine mammal, ambient, and anthropogenic sounds in both GATMAA and NWTRC. HARPs are autonomous, battery-operated instruments capable of recording underwater sounds from 10 Hz to 100 kHz continuously over long periods (up to ~1 year) to provide a comprehensive time series of the marine soundscape. HARPs are configurable into standard large oceanographic-style moorings, medium or small moorings, and seafloor mounted instrument frames, all of which use a releasable ballast-weight anchor to secure the instrument to the sea floor until planned recovery. A combination of these configurations were used at GATMAA and NWTRC, and were chosen depending on deployment and site requirements.

To capture underwater sounds, HARPs use hydrophones tethered and buoyed above the seafloor approximately 10 – 30 m. The hydrophones typically used were constructed with two channels, one for low-frequency sounds (<2 kHz) and the other for mid- and high-frequency signals (>2 kHz) with different lead-zirconium-titanate (PZT) ceramic elements and different preamplifier, filter, and signal conditioning electronics for each channel. Each hydrophone's electronic circuit board was calibrated in the laboratory at Scripps Institution of Oceanography and representative data loggers with complete hydrophones were full-system calibrated at the U.S. Navy's Transducer Evaluation Center in San Diego, CA to provide the full-band frequency response of the system so that accurate sound pressure levels can be measured from the recordings.

Acoustic data were recorded to an array of standard laptop computer style 2.5" hard disk drives in a compressed format. Upon instrument recovery, used batteries and disk drives were removed and replaced with new batteries and empty disk drives along with a new ballast-weight anchor to ready the HARP for the next deployment.

Data Acquisition

The GATMAA recordings span four years starting in the summer of 2011 and ending in the fall of 2015 at five locations: two on the shelf (KO and CA), one on the slope (CB) and two on seamounts (QN and PT) (Figure 2; Table 1).

Deployments were analyzed for the ocean ambient soundscape, anthropogenic sources, and marine mammal presence, including seasonal and daily patterns, and detailed reports of these analyses and results were previously provided to the Navy via the Marine Physical Laboratory (MPL) Technical Memorandums (TMs) 538, 546, 551, and 600 (Baumann-Pickering *et al.*, 2012; Debich *et al.*, 2013; Debich *et al.*, 2014b; Rice *et al.*, 2015). Anthropogenic sound sources summarized in this report include broadband ship sounds, mid-frequency active (MFA) sonar, low-frequency active (LFA) sonar, and explosions.

The NWTRC recordings span ten years starting in the summer of 2004 and ending in spring 2014 and used three sites: one on the shelf (CE) and two on the slope covering different periods (QCA and QCB) (Figure 3; Table 2). Deployments were previously analyzed for the ocean ambient soundscape, anthropogenic sources, and marine mammal presence, including seasonal and daily patterns. The first NWTRC recordings (2004 – 2008) were used only for soundscape analysis in this report, but details on marine mammal presence from these recordings was previously reported (Oleson *et al.*, 2007; Oleson *et al.*, 2009; Oleson and Hildebrand, 2012). Detailed reports of the analyses and results from the later NWTC recordings (2008 – 2014) were also previously provided to the Navy via MPL TMs 534, 535, 542, 550, and 557 (Širović *et al.*, 2011a; Širović *et al.*, 2011b; Kerosky *et al.*, 2013; Debich *et al.*, 2014a; Trickey *et al.*, 2015). Anthropogenic sound sources summarized in this report include broadband ship sounds, mid-frequency active (MFA) sonar, low-frequency active (LFA) sonar and explosions.

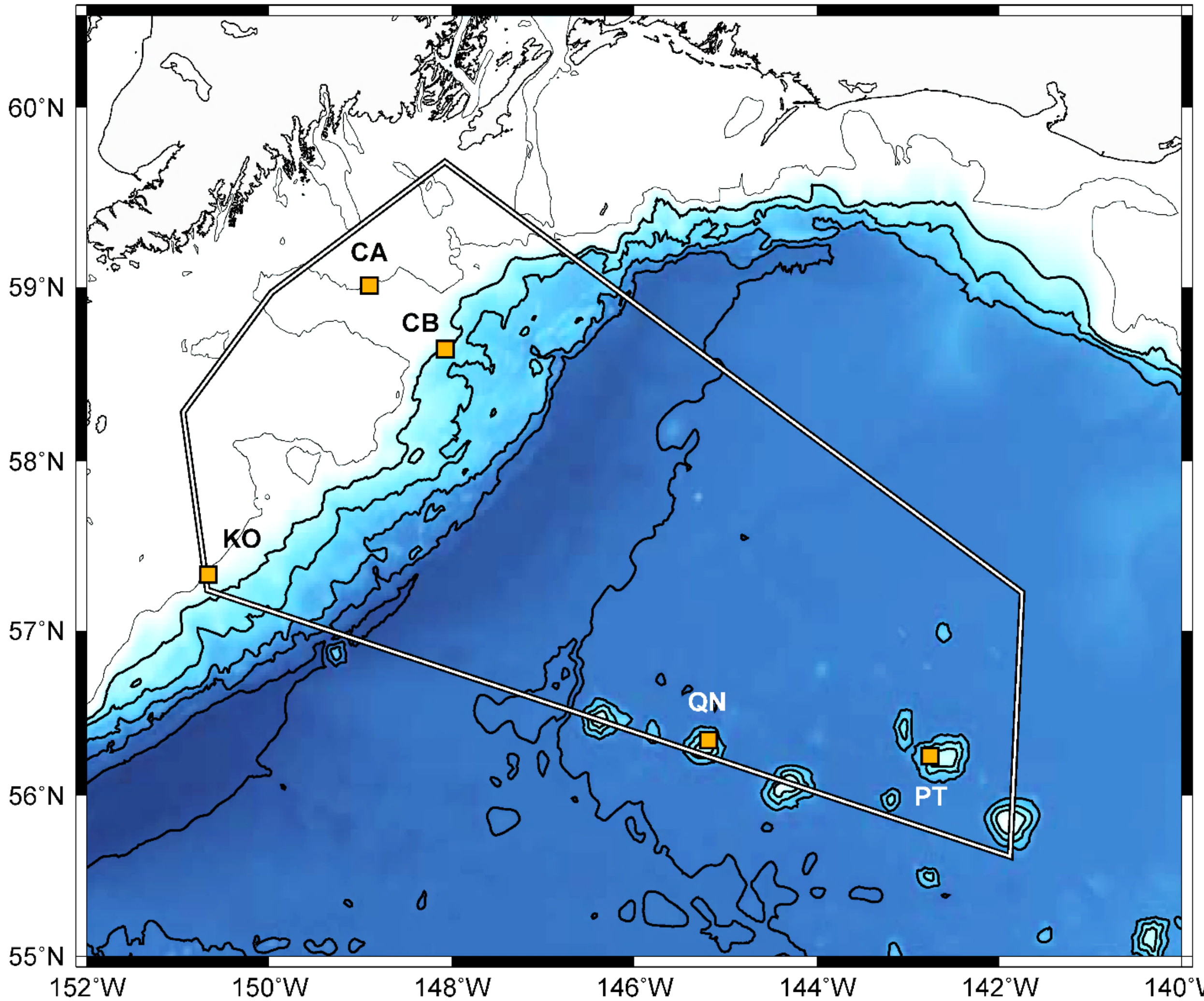

Figure 2. Map of the Gulf of Alaska, showing U.S. Navy's Gulf of Alaska Temporary Maritime Activities Area (GATMAA) outlined in white. Orange squares show sites of High-frequency Acoustic Recording Packages (HARPs) with KO and CA on the continental shelf, CB on the continental slope, and QN and PT each on a seamount. Thin bathymetric contour line on the shelf is at 200 m depth; whereas, the thicker contours are at 1000 m depth intervals. See Table 1 for site geographical coordinates, depths, and analysis periods.

Table 1. GATMAA HARP locations. Site name, deployment name, latitude, longitude, depth, original TM report number, analysis effort: ambient ocean soundscape (Amb), broadband ship sounds (Shp), MFA sonar, LFA sonar, explosions (Exp) are marked with "x" for manual and "a" for automatic detector analysis. Start and end dates of the whole analysis period and number of days analyzed.

Site Name	Deploy Name	Lat N	Lon W	Depth [m]	TM #	Amb	Shp	MFA	LFA	Exp	Analysis Period	Effort Days
KO												
	KO01	57° 20.2′	150° 41.8′	234	551	x	x	x	x	x	06/10/13 – 06/26/13	17
	KO02	57° 20.1′	150° 42.0′	230	551	x	x	x	x	a	09/09/13 – 04/30/14	231
	KO03	57° 20.0′	150° 40.1′	232	600	x	x	x	x	a	05/02/14 – 09/10/14	129
												377
CA												
	CA01	59° 00.5′	148° 54.5′	202	538	x	x	x		x	07/13/11 – 12/17/11	119
	CA02	59° 00.4′	148° 54.5′	203	546	x	x	x		x	05/04/12 – 11/26/12	300
	CA03	59° 00.7′	148° 54.3′	200	551	x	x	x	x	x	06/06/13 – 06/16/13	10
	CA04	59° 00.6′	148° 54.0′	203	551	x	x	x	x	a	09/06/13 – 04/27/14	206
	CA05	59° 00.5′	148° 54.1′	201	600	x	x	x	x	a	04/29/14 – 09/08/14	130
												765
CB												
	CB01	58° 38.7′	148° 04.1′	1000?	538	x	x	x		x	07/13/11 – 02/18/12	221
	CB02	58° 40.3′	148° 01.3′	900	546	x	x	x		x	05/03/12– 02/12/13	227
	CB03	58° 40.4′	148° 00.6′	877	551	x	x	x	x	x	06/07/13 – 09/04/13	90
	CB04	58° 40.3′	148° 01.3′	858	551	x	x	x	x	a	09/06/13 – 04/27/14	234
	CB05	58° 40.3′	148° 01.4′	914	600	x	x	x	x	a	04/29/14 – 09/08/14	133
	CB06	58° 40.3′	148° 01.5′	900	600	x	x	x	x	a	09/10/14 – 04/30/15	233
	CB07	58° 39.3′	148° 05.5′	835	-	x		a			05/02/15 – 09/05/15	104
												1242
QN												
	QN01	56° 20.3′	145° 11.2′	930	551	x	x	x	x	x	06/11/13 – 09/10/13	92
	QN02	56° 20.4′	145° 11.2′	930	551	x	x	x	x	a	09/12/13 – 04/16/14	217
	QN04	56° 20.5′	145° 11.0′	900	600	x	x	x	x	a	09/11/14 – 05/01/15	233
	QN05	56° 20.4′	145° 11.1′	910	-	x		a			05/03/15 – 08/17/15	107
												649
PT												
	PT01	56° 14.6′	142° 45.4′	989	546	x	x	x		x	09/09/12 – 06/09/13	274
	PT02	56° 14.6′	142° 45.4′	987	551	x	x	x	x	x	06/11/13 – 08/19/13	70
	PT03	56° 14.6′	142° 45.4′	988	551	x	x	x	x	a	09/04/13 – 03/20/14	198
	PT04	56° 14.6′	142° 45.4′	988	600	x	x	x	x	a	04/30/14 – 09/09/14	133
												675
Total												***3708***

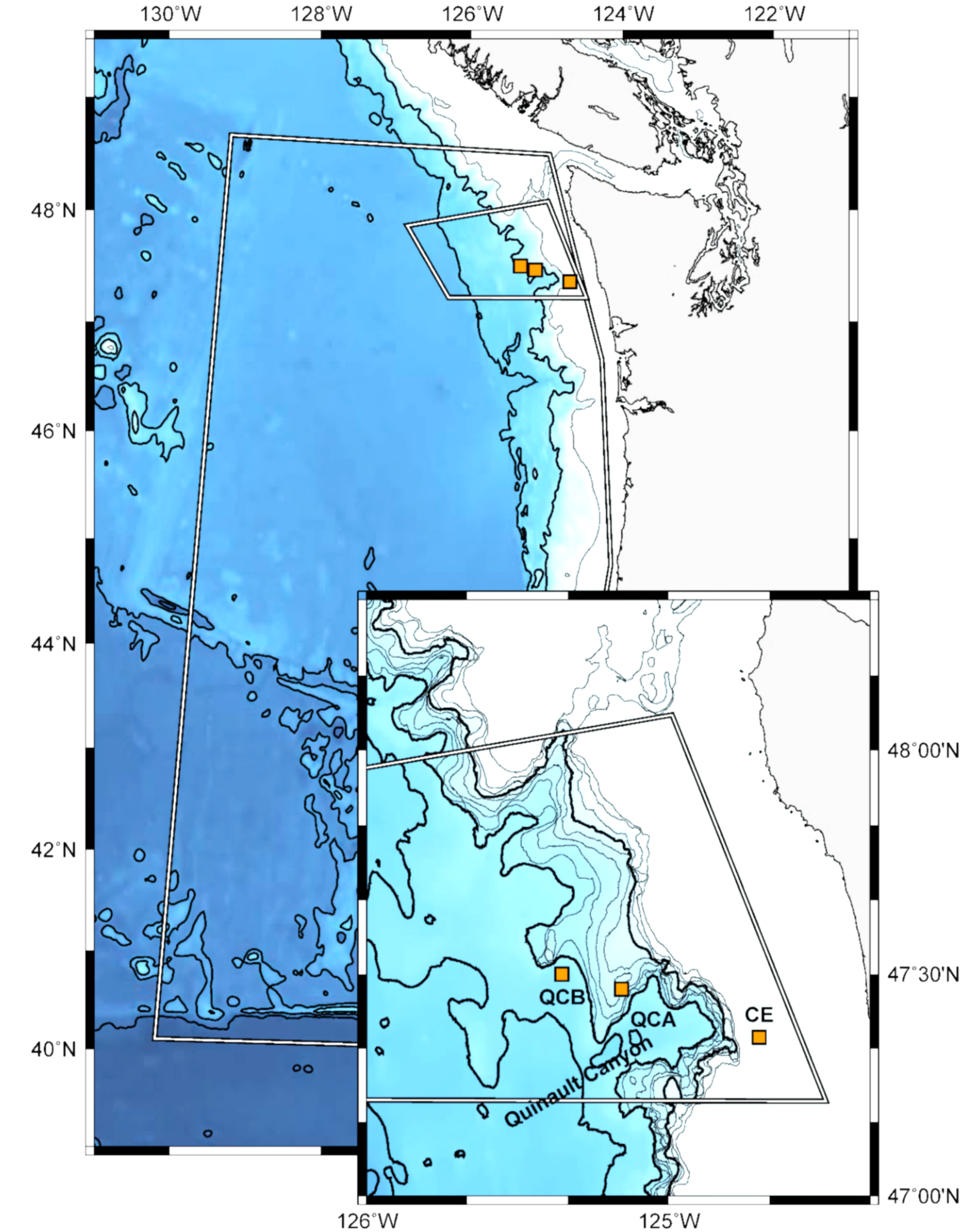

Figure 3. Map of the U.S. Navy's Northwest Training Range Complex (NWTRC). Orange squares indicate sites of High-frequency Acoustic Recording Packages (HARPs) with CE on the continental shelf, QCA and QCB on the continental slope near Quinault Canyon. The small area outlined in white is the 'focus area' (Fleet, 2010) with bathymetric contours at 200 m (thin), and at 1000 m intervals (thick). Inset map: thin bathymetric contour lines are at 200, 300, 400, 600, 700, 800, and 900 m depth; whereas, the thick contours are at 500m depth intervals. See Table 2 for site geographical coordinates, depths, and analysis periods.

Table 2. NWTRC HARP locations. Site name, deployment name, latitude, longitude, depth, original TM report number, analysis effort: ambient ocean soundscape (Amb), broadband ship sounds (Shp), MFA sonar, LFA sonar, explosions (Exp) are marked with "x" for manual and "a" for automatic detector analysis. Start and end dates of the whole analysis period and number of days analyzed. *QC16 had a poorly performing hydrophone, allowing only MFA and LFA sonar detection effort.

Site Name	Deploy Name	Lat N	Lon W	Depth [m]	TM #	Amb	Shp	MFA	LFA	Exp	Analysis Period	Effort Days
CE												
	CE01	47° 21.8′	124° 45.4′	150	-	x					07/12/04 – 10/05/04	86
	CE04	47° 21.7′	124° 42.1′	109	-	x					08/18/06 – 03/11/07	205
	CE05	47° 21.6′	124° 42.1′	100	-	x					04/21/07 – 07/03/07	73
	CE07	47° 21.5′	124° 41.0′	100	-	x					10/14/07 – 06/16/08	247
	CE08	47° 21.5′	124° 41.0′	100	534	x		x		x	06/17/08 – 06/09/09	358
	CE13	47° 21.1′	124° 43.3′	118	535	x	x	x		x	05/21/11 – 11/06/11	169
	CE14	47° 21.1′	124° 43.3′	120	542	x	x	x		x	12/07/11 – 01/17/12	42
	CE16	47° 21.2′	124° 42.5′	120	557	x	x	x	x	a	07/17/13 – 08/04/13	17
												1197
QCA												
	QC02	47° 27.6′	125° 07.9′	915	-	x					10/19/04 – 01/25/05	99
	QC03	47° 28.1′	125° 09.2′	823	-	x					07/28/05– 02/20/06	208
	QC04	47° 28.1′	125° 09.8′	615	-	x					08/18/06 – 02/08/07	175
	QC05	47° 28.0′	125° 09.2′	620	-	x					04/21/07 – 07/03/07	74
	QC06	47° 28.0′	125° 09.2′	653	-	x					07/05/07 – 06/15/08	347
												903
QCB												
	QC12	47° 30.0′	125° 21.2′	1394	535	x	x	x		x	01/27/11 – 10/07/11	253
	QC14	47° 30.0′	125° 21.2′	1394	542	x	x	x		x	12/07/11 – 07/11/12	218
	QC15	47° 30.0′	125° 21.2′	1394	550	x	x	x		x	09/14/12 – 06/30/13	289
	*QC16	47° 30.0′	125° 21.3′	1384	557			x	x		07/17/13 – 05/02/14	289
												1049
Total												***3149***

Data Processing

The standard sampling rate for HARPs is 200 kHz with 16-bit samples typically compressed by a factor of two. This results in about one terabyte (TB) of HARP disk usage for every two months of recording. Upon uncompressing the HARP recordings, over 12 TBs per instrument-year are generated for analysis, which typically are processed in about 2 – 4 weeks.

During the data processing procedure, three sets of lossless wav files are created: full-band up to 100 kHz, decimated mid-frequency up to 5 kHz and decimated low-frequency up to 1 kHz. Decimation is accomplished via application of a low-pass filter to the data both forward and backwards to prevent time shifts and resampled at a lower rate. Decimation allows for more efficient data analysis of signals at low frequencies compared to the full-band recordings. For each of the three data sets, long-term spectral averages (LTSAs) are constructed from 5 s window spectral averages and arranged sequentially as long-duration spectrograms. These long spectrograms allow for easily identifying sound events of interest and for general data quality evaluation over hours to days. The LTSAs also provide a means of quickly opening and evaluating the fine-detail wav files through a graphical index scheme where an analyst can click a mouse cursor on an event of interest in the LTSA display to open the related wav file (Wiggins and Hildebrand, 2007). Automatic detection and additional spectral analyses can be performed directly on the relatively small LTSA files without needing the large number of large size source wav files.

Data Analysis

After the HARP data were processed into wav and LTSA files, the recordings were analyzed by various methods depending on the signals of interest, available techniques, and quality of data. For example, the ocean ambient soundscape is a continuous, long-term process so analysis often involves averaging techniques over different time scales to observe changes and provide comparisons; whereas, discrete event such as explosions or sonar pings utilize detectors that use either analyst-based manual/visual or computer algorithm-based automatic methods.

Ocean ambient soundscape

Ocean ambient sound pressure levels generally decrease as frequency increases over the HARP's bandwidth from 10 Hz to 100 kHz (Wenz, 1962). At frequencies below ~100 Hz, baleen whales, large ships, and seismic exploration airguns dominate the soundscape in many places (e.g., Širović *et al.*, 2004; McDonald *et al.*, 2006; Wiggins *et al.*, 2016). From ~200 Hz to 20 kHz, local wind agitates the sea surface such that increased wind speed causes an increase in sound pressure levels (Knudsen *et al.*, 1948). During low wind and sea states, ambient sound levels can drop below levels that are measurable by the current state-of-the-art single hydrophones at frequencies above 10 kHz. For ambient sound levels at GATMAA and NWTRC, HARP recordings were decimated by a factor of 100 to provide an effective bandwidth of 10 Hz to 1 kHz from which LTSAs were constructed with 1 Hz frequency and 5 s temporal resolution using the Welch method (Welch, 1967). Therefore, ocean ambient sound pressure levels reported include sources primarily from baleen whales, large ships, seismic exploration and wind.

During recording sessions, HARPs write sequential 75 s acoustic records such that 15, 5 s sound pressure spectrum levels were calculated for each 75 s acoustic record. However, system self-noise can be present when the HARP is writing to disk (typically 12 s out of each 75 s record), so the first three 5 s spectra were not used for averaging. Average spectra were computed per day, with partial days and days with deployment/recovery ships sounds or with known instrument self-noise problems discarded. Also, hydrophone cable strumming from ocean tidal currents was present in some of the recordings, especially at shallow water sites up on the shelf. Strumming can mask ambient soundscape sound levels, especially at low frequencies, so a filter was developed and used to omit periods of intense strumming. The sequential 5 s spectra were further analyzed with custom MATLAB-based (MathWorks, Natick, MA) software to provide average and percentile sound pressure spectrum levels for the eight sites over the study periods in addition to long-term spectrograms.

Broadband ship sounds

Ships radiate low-frequency (<100 Hz) sound in the ocean from bubble cavitation at the tips of their propellers and to a lesser extent at higher frequencies from on-board machinery. The low-frequency propulsion sounds travel long distances in the ocean and can often dominate the ambient soundscape. When ships pass nearby a hydrophone (< 5 km), received broadband ship sounds can extend beyond 5 kHz and can last for 10's of minutes up to a few hours depending on ship speed and radiated source levels and signature. Detections of these signals were used to quantify local ship presence over the recording periods. Broadband ship sounds often produce a characteristic constructive and destructive interference pattern in the LTSA from the interaction of ship radiated direct and reflected sound waves (e.g., McKenna *et al.*, 2012).

Decimated LTSAs with an effective bandwidth of 10 – 5,000 Hz and window duration of 3 h were scanned visually by an analyst for broadband ship passages as a means of detecting nearby ship presence. Start and end detection times of the broadband ship sounds were defined as when the sound levels above 1 kHz were sufficiently above background levels to deem nearby. While this detection scheme provides some uncertainty in the precise timing of close ship passages, the general trends are preserved. Detection times were logged to a spreadsheet and were used to estimate the percentage of cumulative number of hours per week that broadband ship sounds were present.

Mid-frequency active sonar

Mid-Frequency Active (MFA) sonar is used by the U.S. Navy for anti-submarine warfare (ASW) training. There are different types of MFA sonar signals ranging in frequency between 1-10 kHz. These signals are composed of pulses of both continuous wave (CW) single-frequency tones and frequency modulated (FM) sweeps grouped in packets typically with durations from >1 s to <5 s. Packets can be composed of singular or multiple pulses and are transmitted repetitively as wave trains with inter-packet-intervals typically >20 s. One of the most common types of U.S. Navy surface ship MFA sonar, known as the AN/SQS-53C, is an approximately 3.5 kHz directional signal produced with a reported root-mean-square (rms) source level of 235 dB_{rms} re 1 μPa @ 1m (Evans and England, 2001).

One of two methods were used to detect MFA sonar, depending on the analysis period. In the first approach, an analyst visually detected MFA sonar events (wave trains) in an LTSA, with an effective bandwidth of 10 Hz – 5 kHz and window duration of 0.75 h. Start and end times of each MFA sonar event were logged. The second approach used a computer-algorithm automatic detector to detect MFA events over the complete data sets and was based on a modified version of the *silbido* detection system designed for detecting and characterizing toothed whale whistles (Roch *et al.*, 2011). The algorithm identifies peaks in time-frequency distributions (e.g. spectrogram) and determines which peaks should be linked into a graphical structure based on heuristic rules that include examining the trajectory of existing peaks, tracking intersections between time-frequency trajectories, and allowing for brief signal drop-outs or interfering signals. In both cases, a second computer-algorithm was executed over these event periods to count individual packets and provide statistical metrics of the MFA sonar events such as received sound pressure levels, number of packets per wave train, and cumulative sound exposure levels (CSEL) (Wiggins, 2015).

Low-frequency active sonar

The Surveillance Towed Array Sensor System (SURTASS) Low-Frequency Active (LFA) sonar, used by the U.S. Navy for ASW, is typically in the 100 – 500 Hz band with array source levels around 235 dB_{rms} re 1 μPa @ 1m and packet durations of ~ 5 to 100 s composed of CW and FM signals less than 10 s. At these low frequencies, sounds attenuate less than higher frequencies, allowing LFA signals to travel longer distances than higher frequency MFA sonar.

To detect LFA sonar, analyst visually scanned decimated LTSAs with an effective bandwidth of 10 – 1000 Hz and a window duration of 1 h, and start and end times were logged to estimate weekly cumulative hourly presence.

Explosions

Explosive sound sources in the ocean include military ordnances, seismic exploration airguns, naturally occurring earthquakes, and "seal bombs" used by the fishing industry for pinniped deterrent. Because the onset of an explosion is relatively rapid, it appears as a vertical spike in the LTSA that, when expanded to finer detailed spectrogram, shows the sharp onset decaying over time into a reverberant signal.

Explosions were detected either by manual analyst-based visual detections using LTSAs for data sets analyzed during early years of reporting or by a computer-algorithm automatic process for data sets analyzed during later years of reporting. In the manual method, an analyst visually scanned decimated LTSAs with an effective bandwidth of 10 Hz – 5 kHz and window duration of 0.75 h. Explosions have energy as low as 10 Hz and often extend up to 2,000 Hz or higher, lasting for a few seconds including the reverberation. Start and end times of explosion events, defined as groups of one or more explosions without a gap in explosions of more than 0.5 h, were logged to provide estimates of weekly cumulative hourly presence.

Explosions that were detected automatically used a matched filter detector on recordings decimated to 10 kHz sampling rate. The acoustic time series was filtered with a 10^{th} order Butterworth bandpass filter between 200 Hz and 2 kHz. Cross correlation was computed between 75 seconds of the envelope of the filtered time series and the envelope of a filtered example explosion (0.7 s, Hann windowed) as the matched filter signal. The cross correlation was squared to 'sharpen' peaks of explosion detections. A floating threshold was calculated by taking the median cross correlation value over the current 75 seconds of data to account for detecting explosions within noise, such as shipping. A cross correlation threshold of $3x10^{-6}$ above the median was set. When the correlation coefficient reached above threshold were considered a detection and the time series of detections was inspected more closely per below.

Consecutive explosions were required to have a minimum time distance of 0.5 seconds to be detected. A 300-points (0.03 s) floating average energy across the detection was computed. The start and end of the detection above threshold was determined when the energy rose by more than 2 dB above the median energy across the detection. Peak-to-peak (pp) and rms received levels (RL) were computed over the potential detection period and over the length of the template window before and after the detection. The potential detection was classified as false and deleted if: 1) the dB difference for the pp and rms levels between the signal detection period and the period after the detection was less than 4 dB or 1.5 dB, respectively; 2) the dB difference for pp and rms levels between signal detection period and period before signal was less than 3 dB or 1 dB, respectively; and 3) the detection was shorter than 0.03 or longer than 0.55 seconds of duration. The thresholds were evaluated based on the distribution of histograms of manually verified true and false detections. A trained analyst subsequently verified the remaining detections for accuracy.

Results

Ocean ambient soundscape

The long-term spectrograms computed from 3708 and 2860 daily averaged sound pressure spectrum levels from the recordings of 4 years at GATMAA and 9 years at NWTRC, respectively, show similarities and differences between the two training areas and between each site (Figures 4 & 5). Less than the overall total effort days of 3149 for NWTRC were used for the long-term spectrograms because the low-frequency channel of the hydrophone used for the last deployment at QCB performed poorly (Table 2).

Both areas show a yearly seasonal pattern around 20 Hz from fin and blue whale calls, but the sound levels at GATMAA were much higher than NWTRC, with near-shore sites KO, CA, and CB showing the highest levels

Fin whale calls ~20 – 30 Hz are present in both NWTRC and GATMAA long-term spectrograms at all sites, but weakest at the shallowest of all sites, CE. At GATMAA, northeast-Pacific blue whale calls show up clearly in the long-term spectrogram in the 40 – 50 Hz band as the third-harmonic of their B-type call is above the background soundscape, except at site CA.

Also, from ~30 – 600 Hz in late May of all three years, increased ship noise can be seen at QCB, potentially related to reoccurring fishing operations.

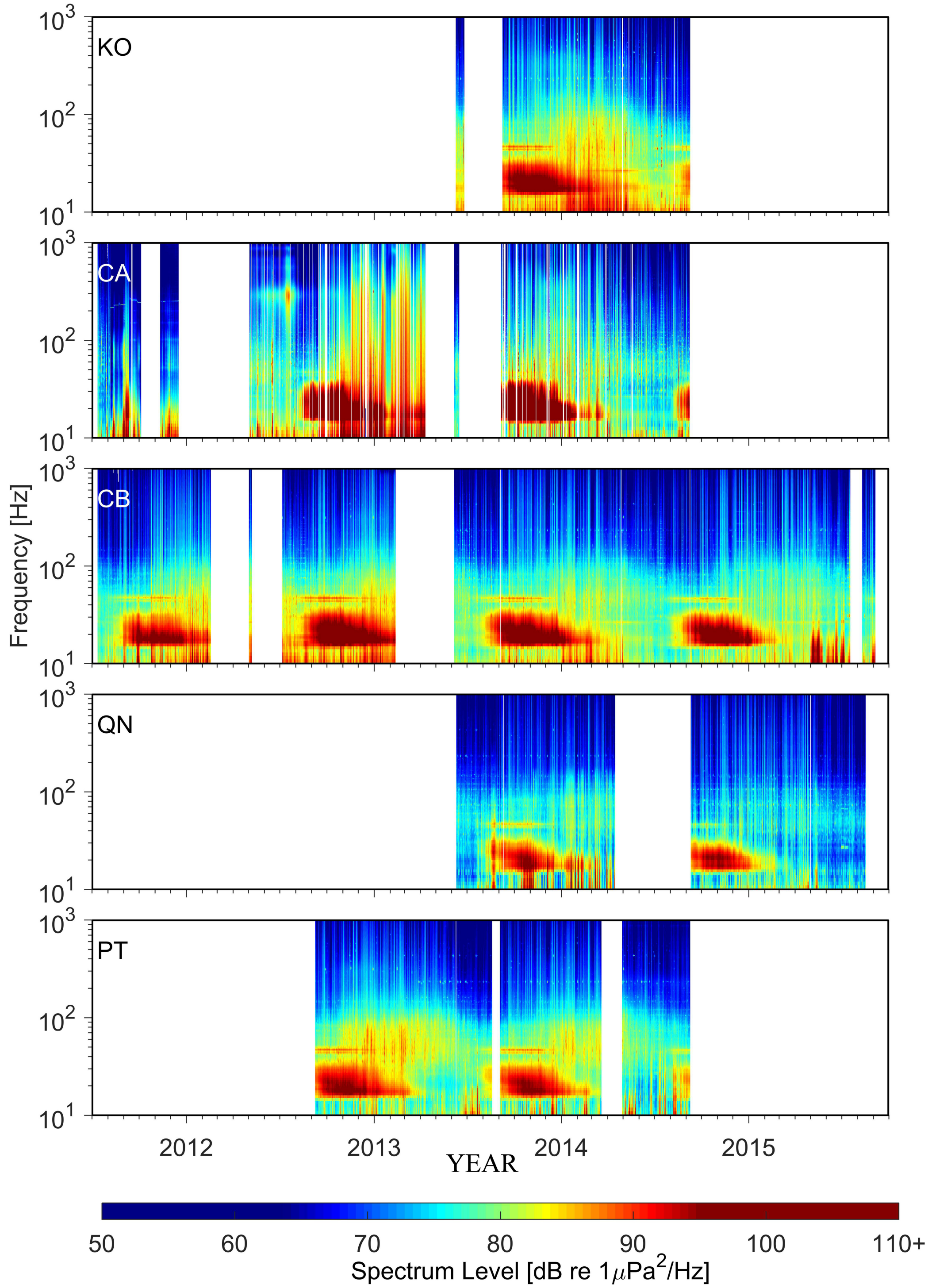

Figure 4. GATMAA long-term spectrograms using daily averaged sound pressure spectrum levels for each site over the deployment period. White regions are gaps between the end of one recording and the start of the next, or due to instrumentation problems or excessive hydrophone cable strumming.

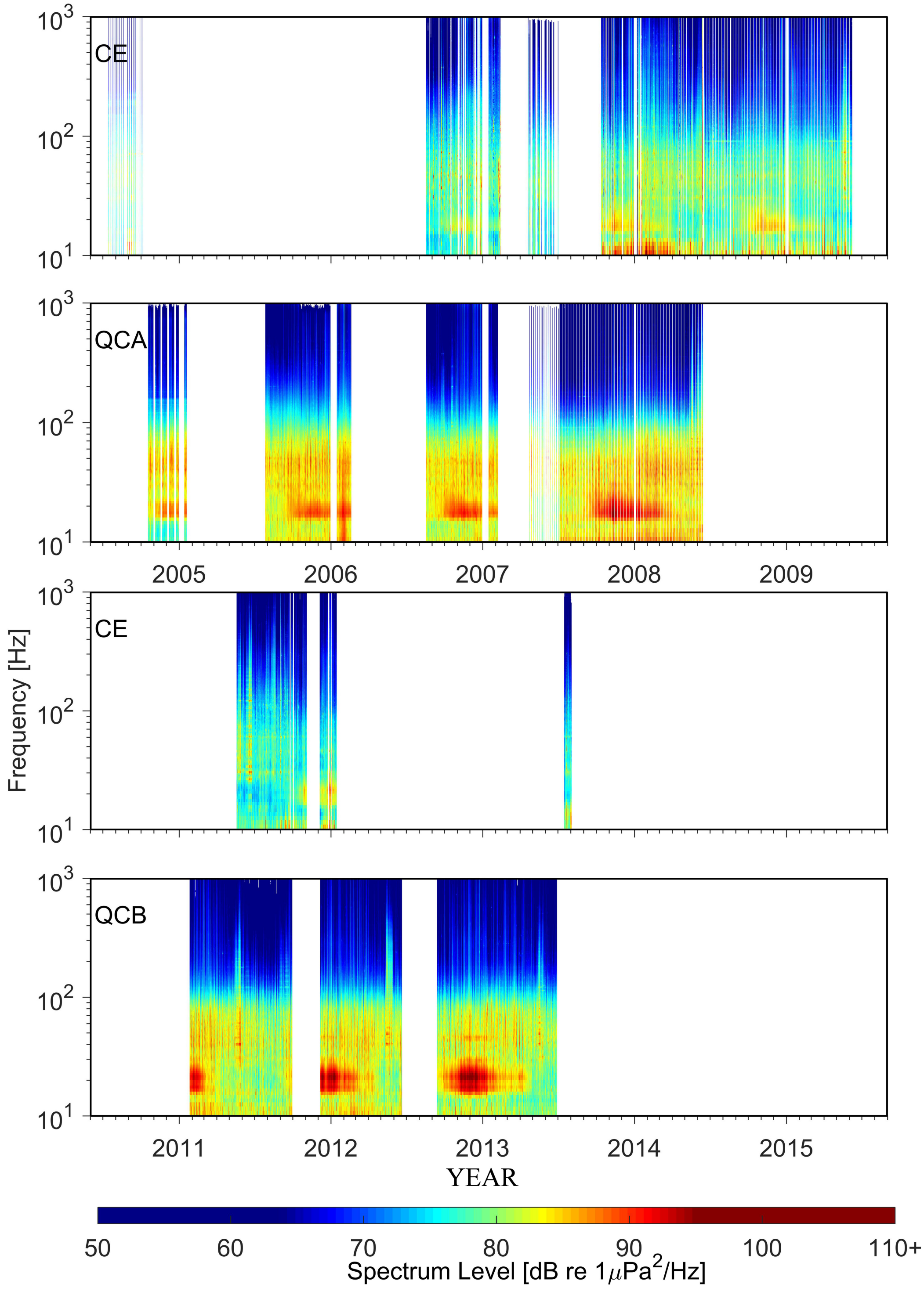

Figure 5. NWTRC long-term spectrograms using daily averaged sound pressure spectrum levels for each site over the deployment period. White regions are gaps between the end of one recording and the start of the next, or due to instrumentation problems or excessive hydrophone cable strumming.

Sound pressure spectrum levels averaged at each site over their deployment periods show similar sound level peaks at 20 – 30 Hz and 40 – 50 Hz from fin and blue whale calls with peaks up to ~8 dB above averaged background levels (Figures 6 & 7), while seasonal peaks can be up to 30 dB above non-calling periods, as shown in the long-term spectrograms (Figures 4 & 5).

In addition to the differences in blue and fin whale call sound levels at the two training areas, NWTRC deep-water sites QCA and QCB had the highest levels in the 30 – 100 Hz band with a spectral shape characteristic of ship sounds.

In the 200 Hz – 1 kHz band, GATMAA had higher levels than NWTRC likely because of higher wind and sea state conditions at higher latitudes in the Gulf of Alaska, with QN showing the lowest levels for GATMAA over the whole band below 1 kHz, and at NWTRC CE showing the lowest levels below 100 Hz and QC showing the lowest levels above 100 Hz.

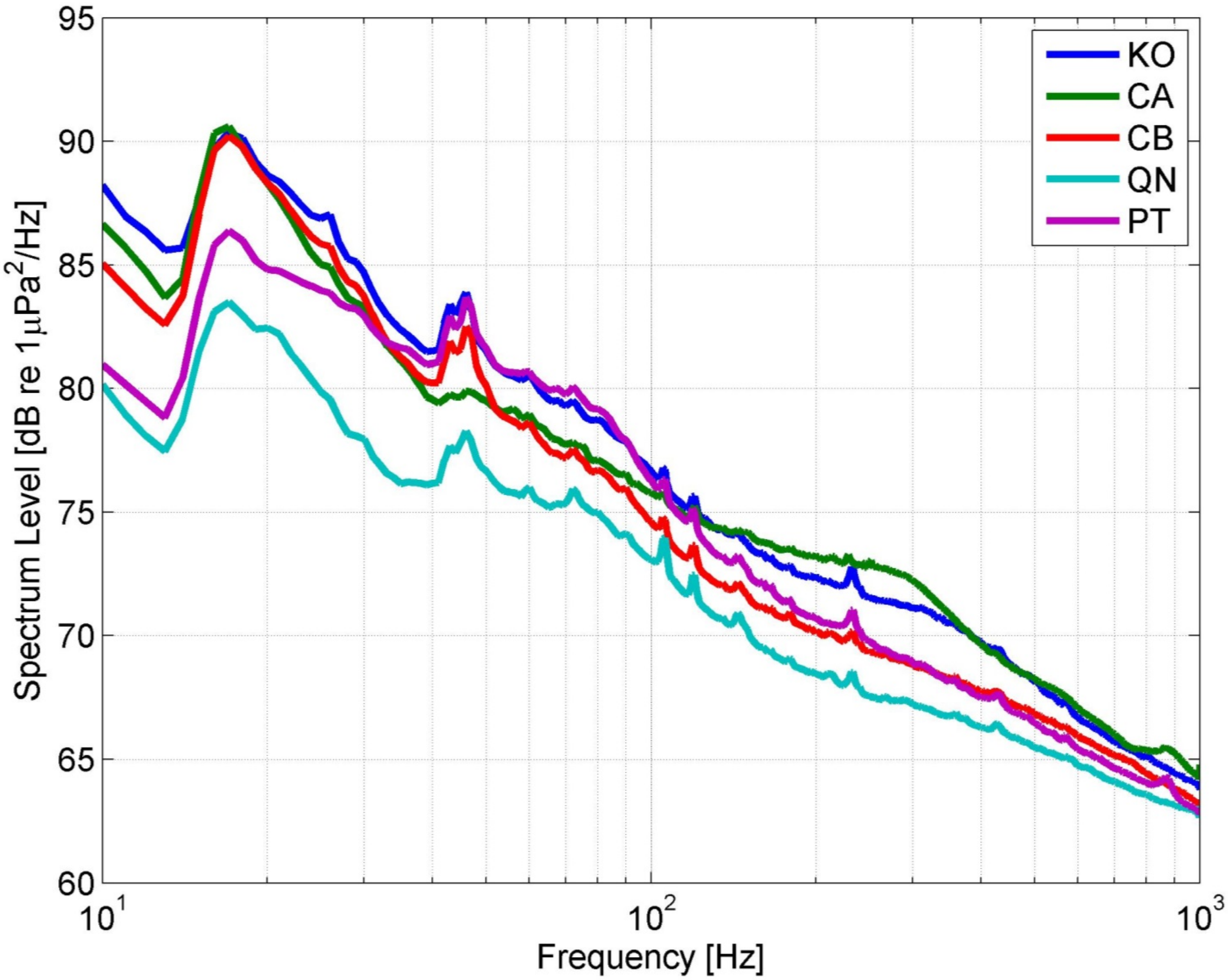

Figure 6. GATMAA average sound pressure spectrum levels by site over entire deployment period. See Table 1 for total number of days used for each average.

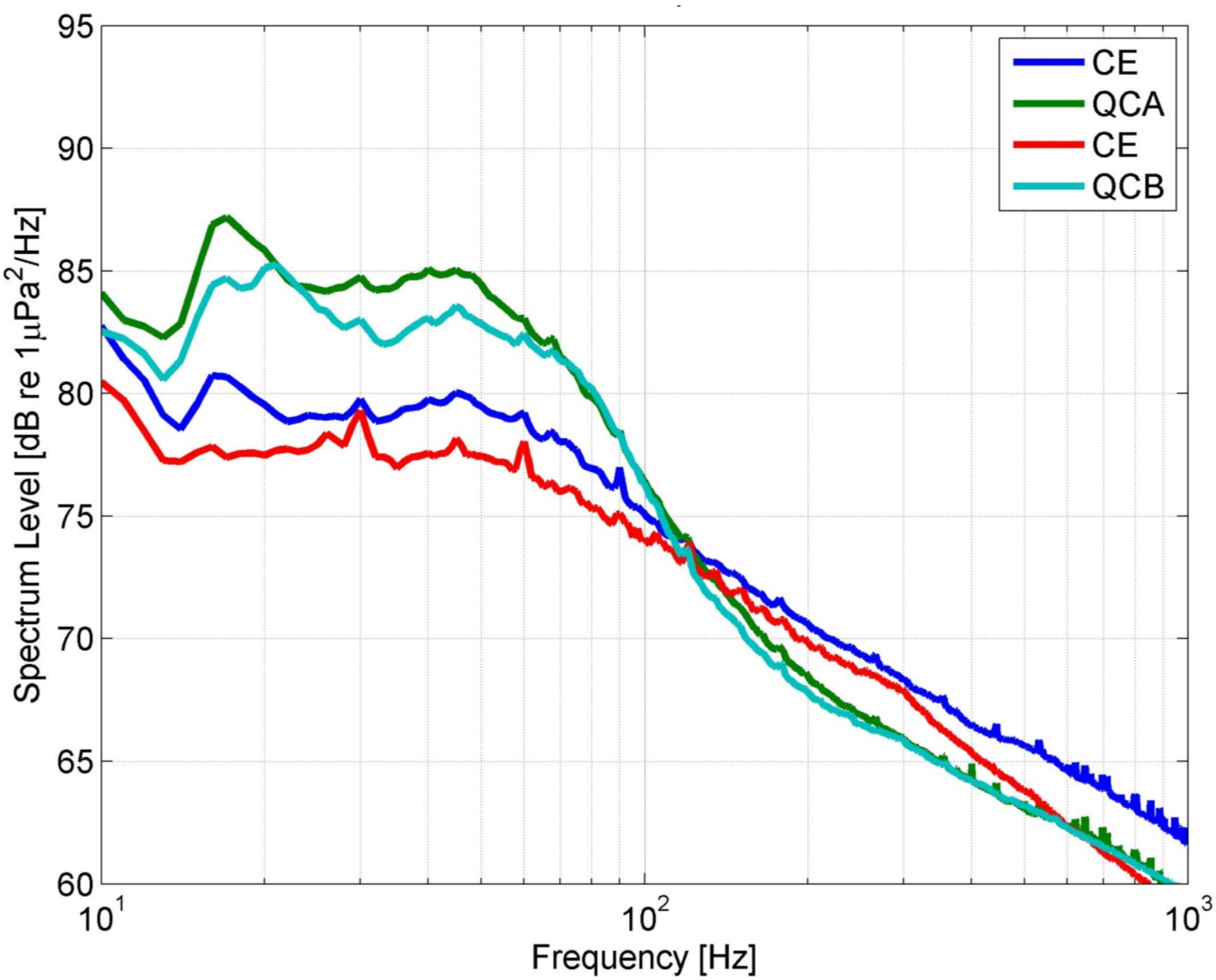

Figure 7. NWTRC average sound pressure spectrum levels by site over entire deployment period. The blue spectrum curve is from the early CE recordings (2004 – 2009); whereas, the red spectrum is from the later CE recordings (2011 – 2013). See Table 2 for total number of days used for each average.

Percentile plots for each site over the deployment period show sound pressure spectrum levels that are approximately normally distributed except in the blue and fin whale calling bands (Figures 8 & 9). The highest levels and greatest variability occurred at the northern most, shallow water site, CA.

Monthly average sound pressure spectrum levels, as provided in the original MPL TMs, are provided in Appendices A (GATMAA) and B (NWTRC) and show the fin and blue whale yearly seasonal patterns also present in the long-term spectrograms.

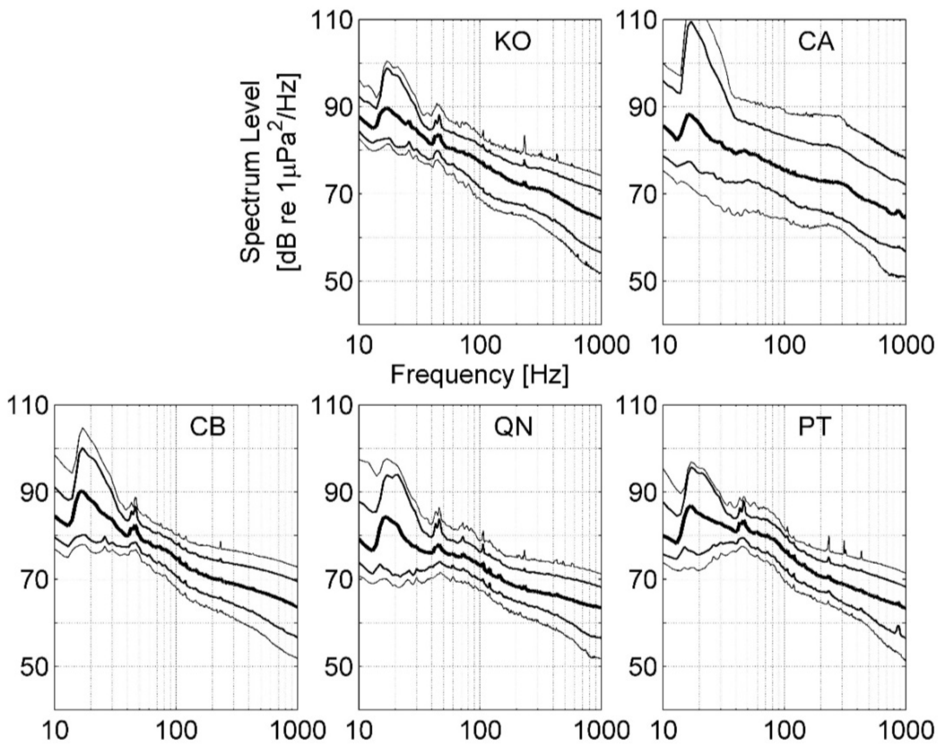

Figure 8. GATMAA distribution of daily average sound pressure spectrum levels as percentiles. 1(lowest), 10, 50 (thick middle line), 90, and 99% (highest).

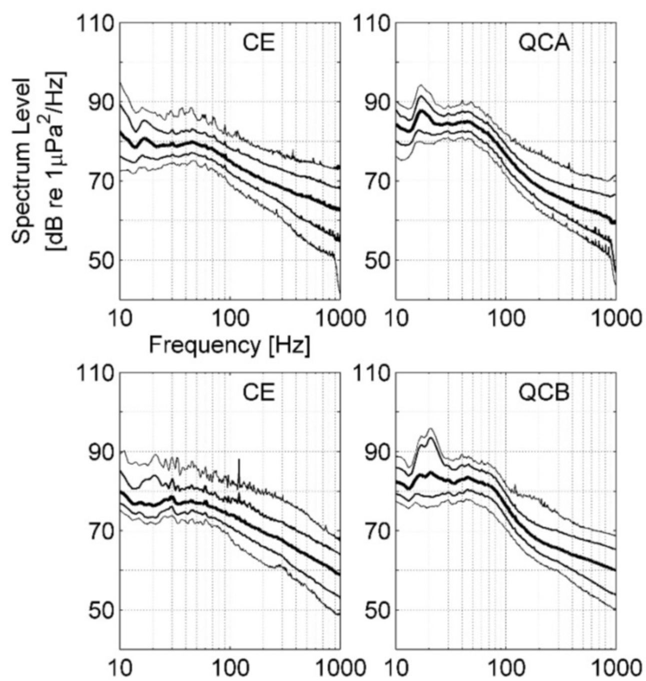

Figure 9. NWTRC distribution of daily average sound pressure spectrum levels as percentiles. 1(lowest), 10, 50 (thick middle line), 90, and 99% (highest).

Broadband ship sounds

Analyst detected broadband ship sounds, calculated as percent hours present per week over the deployment periods. Lower levels of ship activity were detected in GATMAA than NWTRC with study area average percent hours per week <4 % and >20 %, respectively (Figures 10 & 11). Site CE on the shelf in NWTRC had the highest weekly occurrence of nearby ship passages, while the longer time series at the deep site QCB showed ~30% decrease in ship sounds between 2011 and 2013.

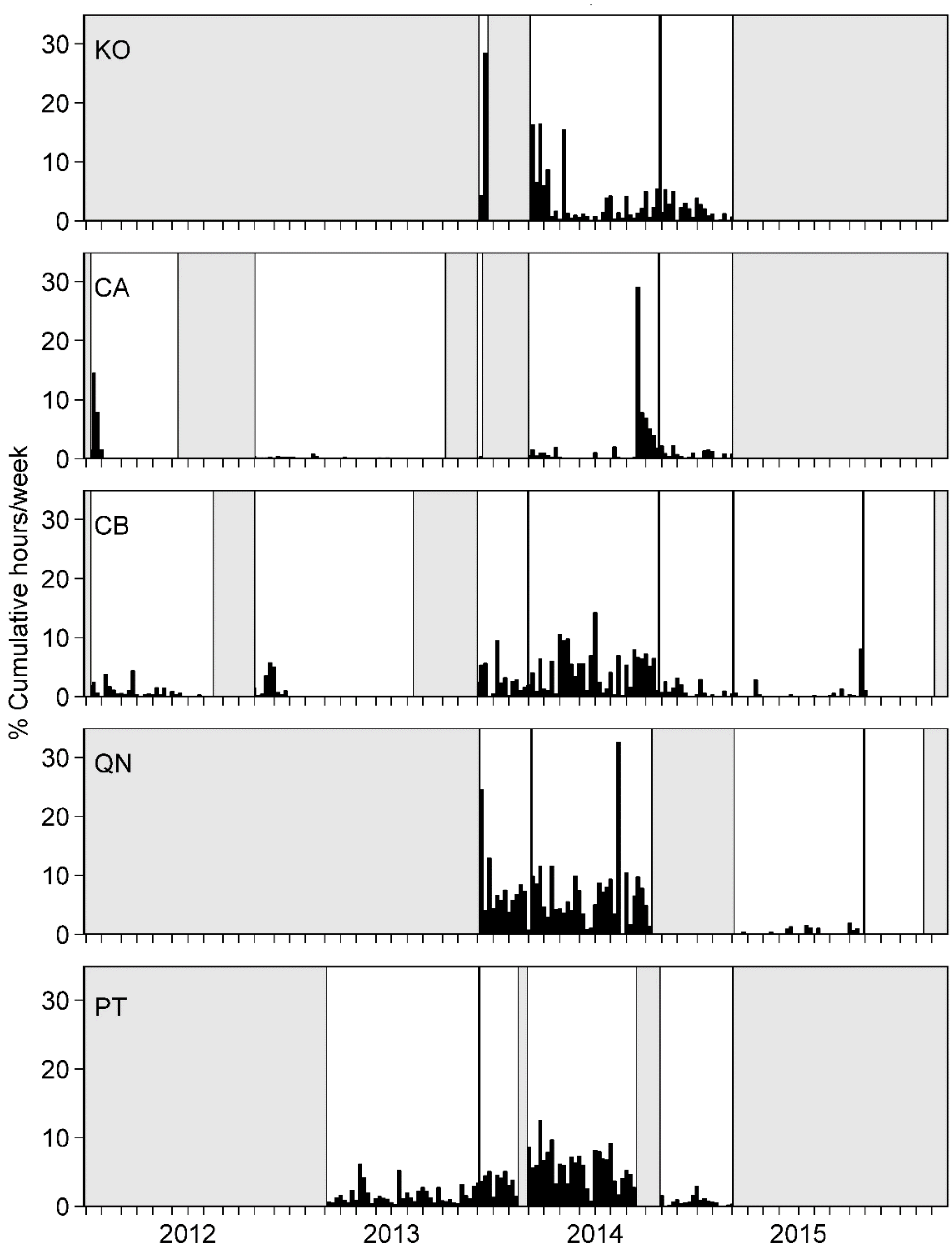

Figure 10. GATMAA percent cumulative hours per week of broadband (nearby) ship sound detections over the deployment periods.

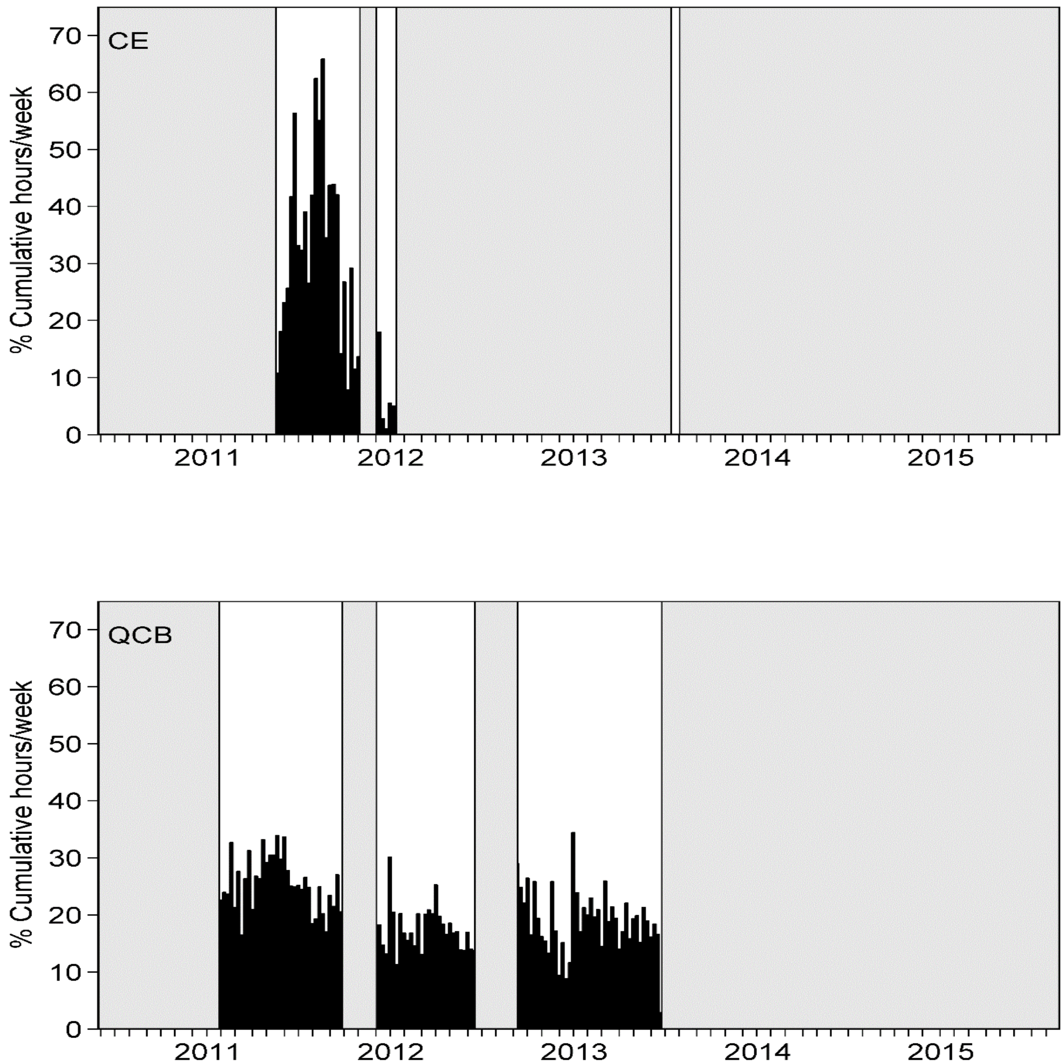

Figure 11. NWTRC percent cumulative hours per week of broadband (nearby) ship sound detections over the deployment periods. Early CE and QCA were not analyzed for broadband ship sounds (Table 2).

Mid-frequency active sonar

In GATMAA from the spring of 2011 to fall of 2015, MFA sonar was detected only at sites CB and QN from 16 to 26 June 2015 during a known U.S. Navy exercise utilizing three destroyer (DDG) surface ships (C. Johnson, U.S. Navy Pacific Fleet, personal communication,12/27/16).

MFA sonar was detected more frequently and at higher received sound pressure levels at site CB than site QN (Table 3) even though a higher detection threshold was used for CB (116 dB_{pp} re 1 μPa) than QN (110 dB_{pp} re 1 μPa) to account for the higher background sound levels at site CB. These thresholds are about 20 dB less than the 130 dB_{pp} re 1 μPa used for MFA detections at the U.S. Navy's more heavily used Southern California (SOCAL) Range Complex, resulting in a detection range greater than 20 km in GATMAA (Wiggins, 2015). Furthermore, a shorter pulse lockout period (9 s) than SOCAL was used to account for some MFA events with shorter (<10 s) intervals between packets.

Table 3. GATMAA MFA sonar detections and maximum received sound pressure levels.

Site Name	Deployment Names	Analysis Effort [days]	Number of Wave Trains	Wave Trains Total Duration [hours]	Number of Packets	Maximum Received Level [dB_{pp} re 1 μPa]
KO						
	KO01 – 03	377	0	0	0	-
CA						
	CA01 – 05	765	0	0	0	-
CB						
	CB01 – 06	1138	0	0	0	-
	CB07	104	13	35	2019	144
QN						
	QN01, 02, 04	542	0	0	0	-
	QN05	107	5	7	402	132
PT						
	PT01 – 04	675	0	0	0	-
Total		3708	18	42	2421	144

There were 18 sonar events detected at CB and QN for a combined total of 42 hours out of 3708 days analyzed over the four-year period. However, of the five MFA sonar events detected at QN (Table 3), the first four occur during periods of events detected at CB, but at different levels likely because of different distances from receivers to the source and perhaps directionality of the source (Figures 12 & 13). If these four events detected at QN are the same ones detected at CB, then the cumulative number of distinct MFA sonar events in GATMAA would be 14 over a total of ~38 hours. CB had the highest number of packets detected in a wave train (520) and the greatest cumulative sound exposure level (CSEL) at 145 dB re 1 μPa^2·s. However, this was much less than typically detected in the U.S. Navy's SOCAL Range Complex probably due to differences in proximity between MFA sources and HARP receivers (Wiggins, 2015).

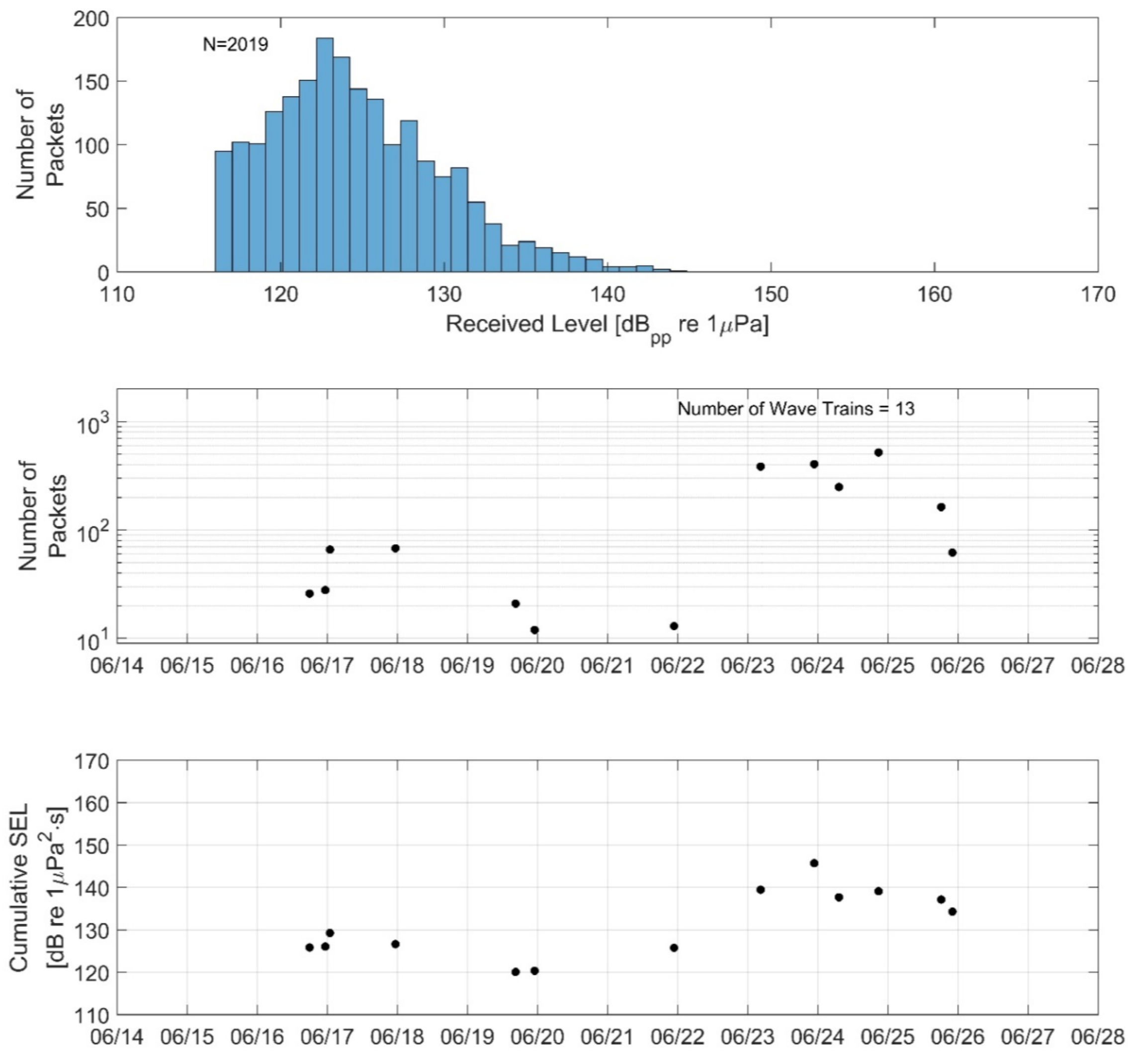

Figure 12. GATMAA site CB MFA metrics.
Top: **Distribution of received peak-to-peak sound pressure levels of detected MFA packets.**
Center: **Number of MFA packets detected in each wave train exceeding 116 dB$_{pp}$ re 1 μPa.**
Bottom: **Cumulative sound exposure levels (CSEL) of each wave train event.**

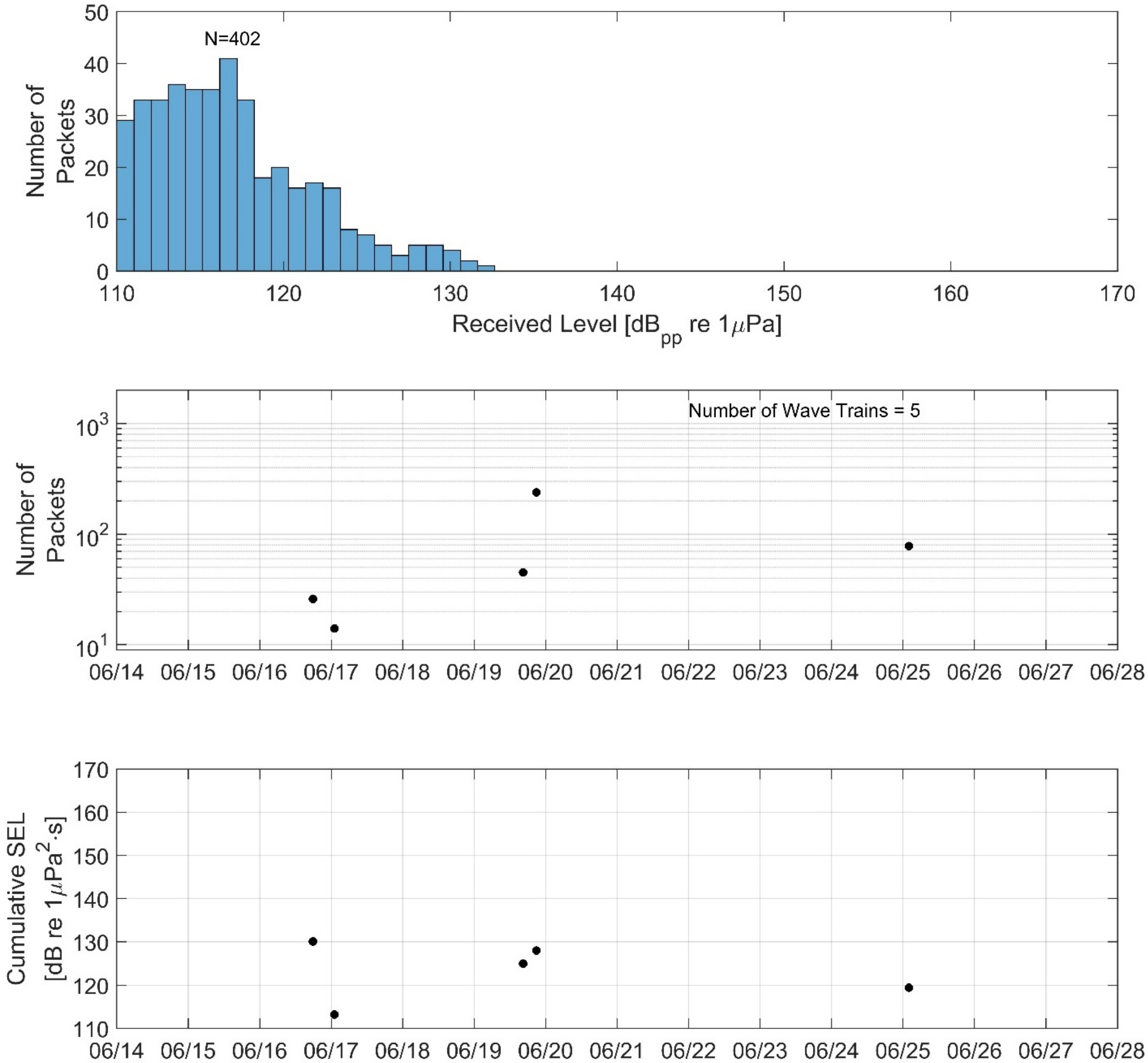

Figure 13. GATMAA site QN MFA metrics.
Top: **Distribution of received peak-to-peak sound pressure levels of detected MFA packets.**
Center: **Number of MFA packets detected in each wave train exceeding 110 dB_{pp} re 1 µPa.**
Bottom: **Cumulative sound exposure levels (CSEL) of each wave train event.**

In NWTRC, there were no large scale, multiple platform training exercises. Instead, generally small-scale individual unit training and testing occurred during our study periods. Most MFA sonar training in this area occurred far offshore past the shelf break and beyond over the abyssal plain with small-scale testing events possible either offshore or some limited on-shelf events (Navy, 2015).

At site CE, two MFA sonar events (wave trains) were detected, totaling about 4 h of activity and about 200 packets with a peak received sound pressure level of 148 dB_{pp} re 1 μPa.

Site QCB, exposed to deep water, had 13 MFA sonar events totaling about 16 h of activity (Table 4). Peak received level of 160 dB_{pp} re 1 μPa at QCB occurred during an approximately 2.5 h event with 129 packets received above 130 dB_{pp} re 1 μPa on 1 August 2011 (Figure 14); whereas, all of the other 12 MFA sonar events at QCB had peak received levels ≤127 dB_{pp} re 1 μPa. CSEL for the August 2011 event was 158 dB re 1 $\mu Pa^2 \cdot s$. While this one event was noteworthy, activity at NWTRC was much less than observed in the U.S. Navy's SOCAL Complex (Wiggins, 2015).

For NWTRC, at the on-shelf site CE, only a cumulative total of 4 h (0.2 days) of U.S. Navy MFA sonar were detected out of 586 days analyzed over the five-year monitoring period between 2008 and 2013. At the deep water off-shelf site QCB, a cumulative total of 16 h (0.7 days) of MFA sonar were detected out of 1,049 days analyzed over the three-year monitoring period between 2011 and 2014.

Table 4. NWTRC MFA sonar detections and maximum received sound pressure levels.

Site Name	Deploy Name	Analysis Effort [days]	Number of Wave Trains	Wave Trains Total Duration [hours]	Number of Packets	Maximum Received Level [dB_{pp} re 1 μPa]
CE						
	CE08	358	1	1.25	30	128
	CE13	169	1	2.75	171	148
	CE14	42	0	0	0	-
	CE16	17	0	0	0	-
QCB						
	QC12	253	5	8.50	129	160
	QC14	218	4	2.50	59	127
	QC15	289	3	4.75	101	127
	QC16	289	1	<0.25	25	105
Total		1635	15	20	515	160

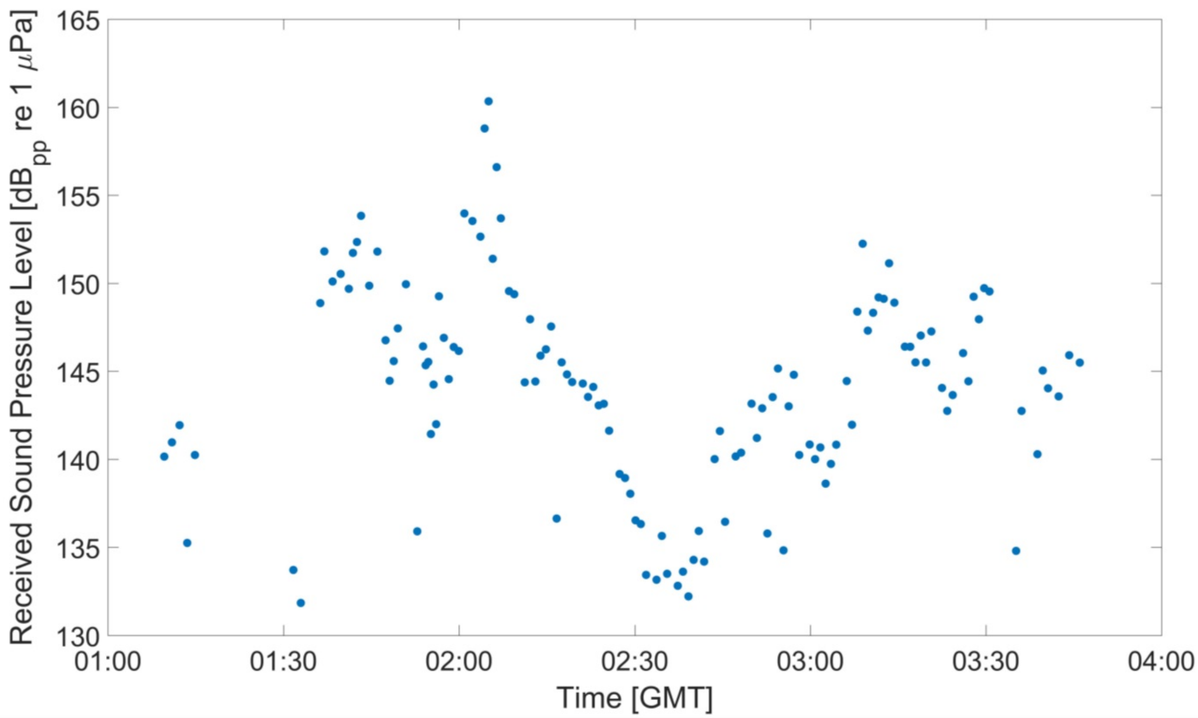

Figure 14. Received sound pressure level of 129 MFA sonar packets from one event on 1 August 2011 at site QCB.

Low-frequency active sonar

LFA sonar was detected mostly during daylight hours over a seven-week period from 13 June to 20 July 2013 at site QN in GATMAA, but at low sound pressure levels and low occurrence of 13 one-hour periods with LFA sonar. Signals were ~200 – 220 Hz tones with a peak received level ~112 dB_{pp} re 1 μPa detected on 23 June 2013 lasting over 2 minutes, but other pulses were much shorter duration and lower received levels. . The source of this signal is unidentified at this time, but the U.S. Navy confirmed none of its LFA sonars was used in or adjacent to GATMAA, or in the same month elsewhere in the Pacific as the GATMAA detections (C. Johnson, U.S. Navy Pacific Fleet, personal communication, 2/28/2017).

In the NWTRC at site QCB, LFA sonar was detected on three daylight occasions: mid-August 2013, late-September 2013, and early-February 2014. In all three cases, LFA sonar was 900 – 1000 Hz with frequency modulated upsweeps and tonal pulses from around 3 s to >5 s duration, occurring sporadically over a few hours each day of occurrence and over two to three days each of the three periods. While LFA sonar was detected in 21 one-hour bins, the hydrophone from this deployment appeared to perform poorly such that received level measurements may not be reliable; however, the most intense signals were about 17 dB above the background sound pressure levels.

Explosions

Explosions were detected in both training areas, but in low numbers compared to the U.S. Navy's SOCAL Range Complex (e.g., Debich *et al.*, 2015) and mostly in summer and fall (Figures 15 & 16).

The NWTRC deep water site QCB had the largest percent of cumulative hours per week of explosions at 68% in the mid-late June 2012 while GATMAA sites QN and KO had the lowest activity of explosions in 2014.

Most detected explosions occurred during daylight hours and based on their spectral and temporal character, are likely related to fishing operations such as the use of "seal bombs" as pinniped deterrents.

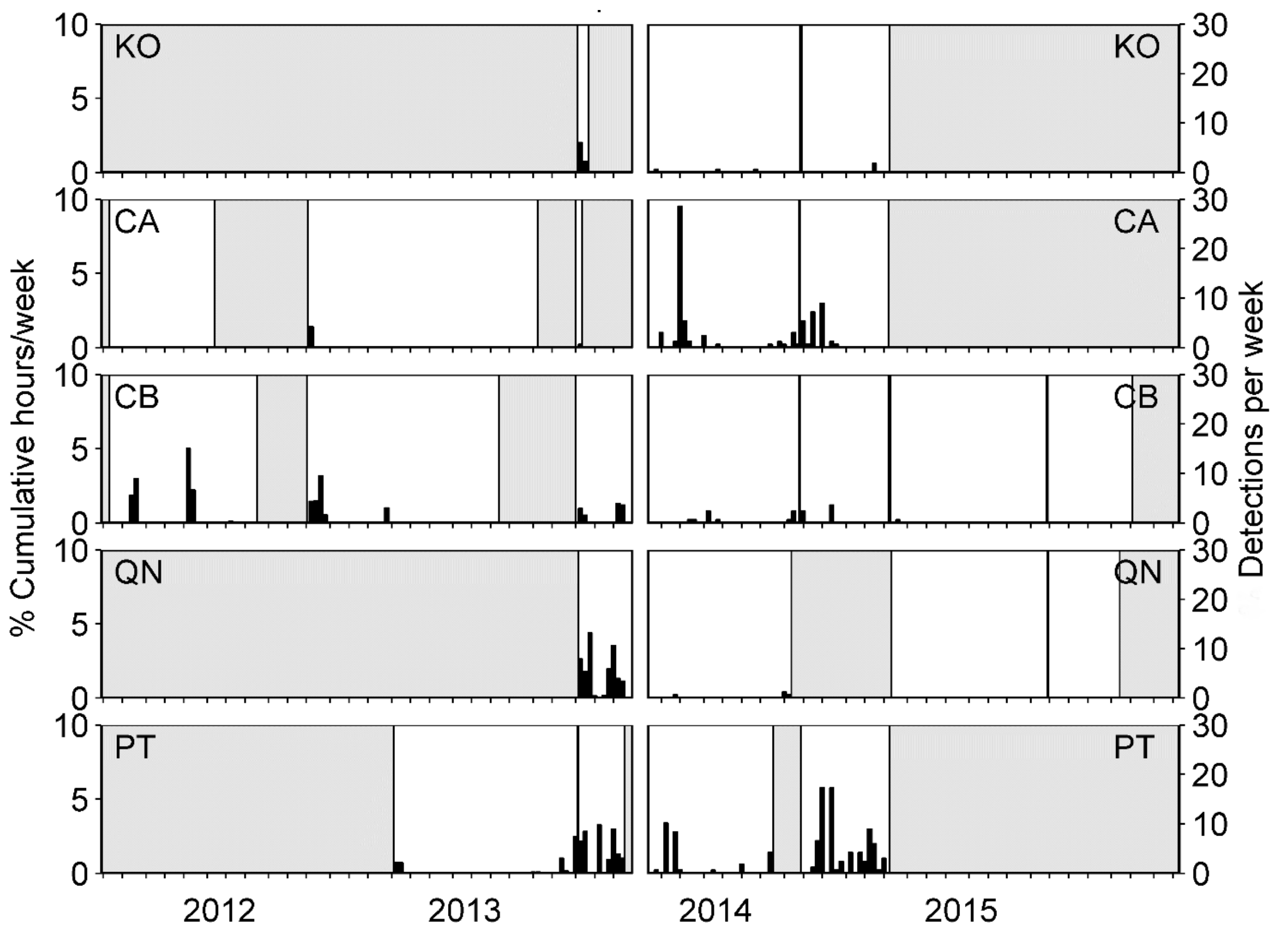

Figure 15. GATMAA explosion detections. Analyst manual visual detections on left, automatic computer algorithm detects on right.

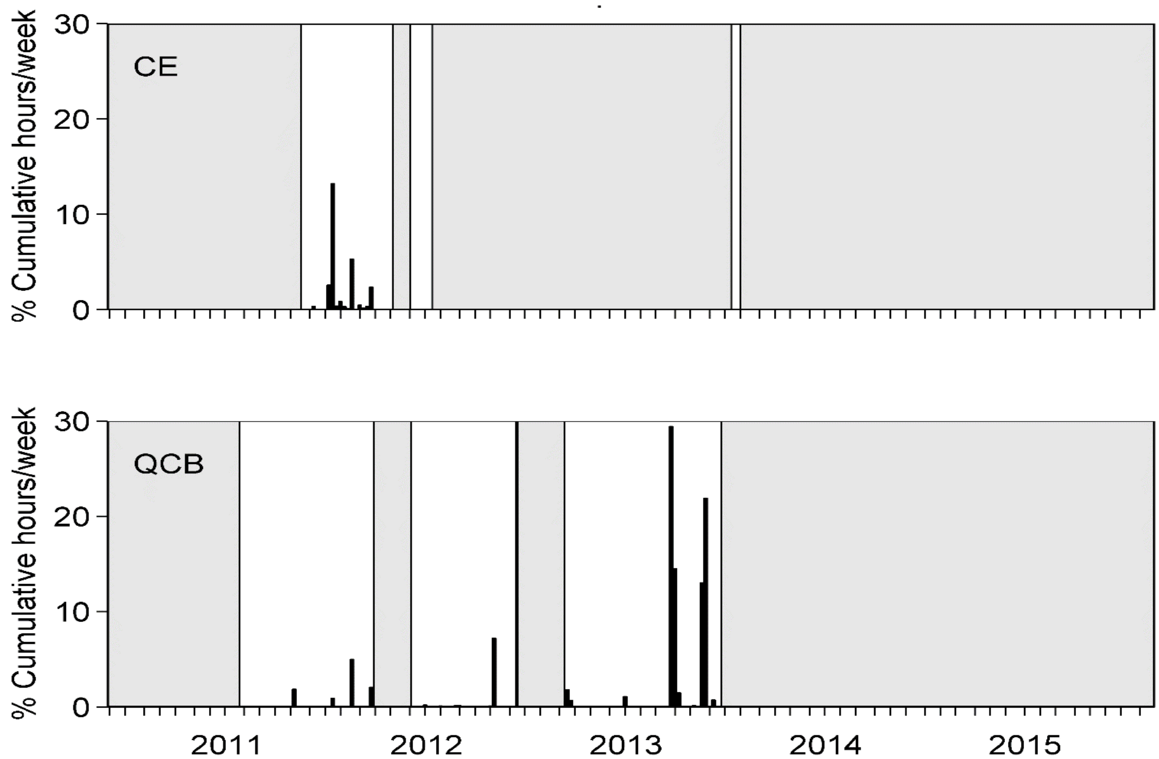

Figure 16. NWTRC explosion detection via analyst visual method.
Not shown are the results from the automatic computer algorithm method used for CE during 2013 which detected 200 – 500 detections per week as the metrics were different and were over a very short duration. Early CE and QCA were not analyzed for explosions (Table 2).

Conclusions

Underwater ambient and anthropogenic sounds were recorded in both shallow (100 – 235 m) and deep (~600 – 1400 m) water over four years in GATMAA at five locations and over 9 years in NWTRC at three locations. Although analysis of these recordings was reported previously, this report presents a summary including time series and levels of ambient ocean soundscape, broadband ship sounds, MFA sonar, LFA sonar, and explosions.

Ambient soundscape was similar for both areas, including the seasonal presence of blue and fin whale calls, but with higher received levels for these animals at GATMAA. MFA sonar was detected at both area, but at relatively low numbers and low levels compare to the U.S. Navy's more heavily used SOCAL Range Complex. LFA sonar was also detected in both areas at even lower levels than MFA sonar, and was not confirmed as originating from U.S. Navy sources. Explosions detected in both areas were sporadic and at relatively low number, and were most likely related to seal bombs used as pinniped deterrents in fishing operations.

Future work includes passive acoustic monitoring with HARPs in GATMAA starting in the spring of 2017 at three locations: on the slope at CB, on a seamount at QN, and at a new deep water site between CB and QN. No acoustic monitoring work is currently planned for NWTRC. Data sets from both areas continue to be analyzed for ambient soundscape, marine mammal, and anthropogenic sounds potentially resulting in peer-reviewed journal articles.

Acknowledgements

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References

Baumann-Pickering, S., Širović, A., Hildebrand, J., Debich, A., Gottlieb, R., Johnson, S., Kerosky, S., Roche, L., Berga, A. S., Wakefield, L., and Wiggins., S. (**2012**). "Passive Acoustic Monitoring for Marine Mammals in the Gulf of Alaska Temporary Maritime Activities Area 2011-2012," in *Marine Physical Laboratory Technical Memorandum 538* (Scripps Institution of Oceanography University of California San Diego, La Jolla, CA).

Debich, A. J., Baumann-Pickering, S., Širović, A., Hildebrand, J. A., Alldredge, A. L., Gottlieb, R. S., Herbert, S., Johnson, S. C., Roche, L. K., Thayre, B., Trickey, J. S., and Wiggins, S. M. (**2014a**). "Passive Acoustic Monitoring for Marine Mammals in the Northwest Training Range Complex 2012-2013," in *Marine Physical Laboratory Technical Memorandum 550* (Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA), p. 70.

Debich, A. J., Baumann-Pickering, S., Širović, A., Hildebrand, J. A., Alldredge, A. L., Gottlieb, R. S., Herbert, S. T., Johnson, S. C., Rice, A. C., Roche, L. K., Thayre, B. J., Trickey, J. S., Varga, L. M., and Wiggins, S. M. (**2015**). "Passive Acoustic Monitoring for Marine Mammals in the SOCAL Naval Training Area Dec 2012 – Jan 2014," in *Marine Physical Laboratory Technical Memorandum 552* (Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA), p. 96.

Debich, A. J., Baumann-Pickering, S., Širović, A., Hildebrand, J. A., Alldredge, A. L., Rachel S. Gottlieb, Herbert, S. T., Johnson, S. C., Rice, A. C., Roche, L. K., Thayre, B. J., Trickey, J. S., Varga, L. M., and Wiggins, S. M. (**2014b**). "Passive Acoustic Monitoring for Marine Mammals in the Gulf of Alaska Temporary Maritime Activities Area 2013-2014 " in *Marine Physical Laboratory Technical Memorandum 551* (Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, La Jolla, CA), p. 101.

Debich, A. J., Baumann-Pickering, S., Širović, A., Hildebrand, J. A., Buccowich, J. S., Gottlieb, R. S., Jackson, A. N., Johnson, S. C., Roche, L. K., Trickey, J. T., Wakefield, L., and Wiggins, S. M. (**2013**). "Passive Acoustic Monitoring for Marine Mammals in the Gulf of Alaska Temporary Maritime Activities Area 2012-2013 " in *Marine Physical Laboratory Technical Memorandum 546* (Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA).

Evans, D. L., and England, G. R. (**2001**). "Joint interim report Bahamas marine mammal stranding event of 15-16 March 2000," (U.S. Department of Commerce, U.S. Secretary of the Navy), p. 59.

Fleet, C. U. S. P. (**2010**). "Northwest Training Range Complex Monitoring Plan," in *Monitoring Plan submitted to National Marine Fishiers Service (NMFS) June 2010* (U.S. Navy, Pacific Fleet Environmental Office, Silverdale, WA), p. 119.

Kerosky, S. M., Baumann-Pickering, S., Širović, A., Buccowich, J. S., Debich, A. J., Gentes, Z., Gottlieb, R. S., Johnson, S. C., Roche, L. K., Thayre, B., Wiggins, S. M., and Hildebrand, J. A. (**2013**). " Passive Acoustic Monitoring for Marine Mammals in the Northwest Training Range Complex 2011-2012.," in *Marine Physical Laboratory Technical Memorandum 542* (Scripps Institution of Oceanography University of California San Diego,, LA Jolla, CA).

Knudsen, V. O., Alford, R. S., and Emling, J. W. (**1948**). "Underwater ambient noise," Journal of Marine Research **7**, 410-429.

McDonald, M. A., Hildebrand, J. A., and Wiggins, S. M. (**2006**). "Increases in deep ocean ambient noise in the northeast Pacific west of San Nicolas Island, California," Journal of the Acoustical Society of America **120**, 711-718.

McKenna, M. F., Ross, D., Wiggins, S. M., and Hildebrand, J. A. (**2012**). "Underwater radiated noise from modern commercial ships," The Journal of the Acoustical Society of America **131**, 92-103.

Navy, U. S. D. (**2015**). "Northwest Training and Testing Activities Final Environmental Impact Statement/ Overseas Environmental Impact Statement," (Naval Facilities Engineering Command, Northwest, Silverday, WA), p. 3470.

Oleson, E., and Hildebrand, J. (**2012**). "Marine mammal demographics off the outer Washington coast and near Hawaii," in *Technical Report NPS-OC-12-001CR* (Naval Postgraduate School, Monterey, California).

Oleson, E. M., Calambokidis, J., Falcone, E., Schorr, G., and Hildebrand, J. A. (**2009**). "Acoustic and visual monitoring of cetaceans along the outer Washington Coast.," in *Technical Report NPS-OC-09-001* (Naval Postgraduate School, Monterey, California).

Oleson, E. M., Hildebrand, J. A., Calambokidis, J., Schorr, G., and Falcone, E. (**2007**). "2006 Progress Report on Acoustic and Visual Monitoring for Cetaceans along the Outer Washington Coast," in *Technical Report NPS-OC-07-003* (Naval Postgraduate School, Monterey, California).

Rice, A. C., Baumann-Pickering, S., Širović, A., Hildebrand, J. A., Brewer, A. M., Debich, A. J., Herbert, S. T., Thayre, B. J., Trickey, J. S., and Wiggins., S. M. (**2015**). "Passive Acoustic Monitoring for Marine Mammals in the Gulf of Alaska Temporary Maritime Activities Area 2014-2015," in *Marine Physical Laboratory Technical Memorandum 600* (Scripps Institution of Oceanography University of California San Diego, La Jolla, CA).

Roch, M. A., Brandes, T. S., Patel, B., Barkley, Y., Baumann-Pickering, S., and Soldevilla, M. S. (**2011**). "Automated extraction of odontocete whistle contours," The Journal of the Acoustical Society of America **130**, 2212-2223.

Širović, A., Hildebrand, J. A., Baumann-Pickering, S., Buccowich, J., Cummins, A., Kerosky, S., Roche, L., Berga, A. S., and Wiggins, S. M. (**2011a**). "Passive Acoustic Monitoring for Marine Mammals in the Northwest Training Range Complex 2011," in *Marine Physical Laboratory Technical Memorandum 535* (Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA).

Širović, A., Hildebrand, J. A., Wiggins, S. M., McDonald, M. A., Moore, S. E., and Thiele, D. (**2004**). "Seasonality of blue and fin whale calls and the influence of sea ice in the Western Antarctic Peninsula," Deep-Sea Research Part Ii-Topical Studies in Oceanography **51**, 2327-2344.

Širović, A., Oleson, E. M., Calambokidis, J., Baumann-Pickering, S., Cummins, A., Kerosky, S., Roche, L., Simonis, A., Wiggins, S. M., and Hildebrand, J. A. (**2011b**). "Marine Mammal Demographics of the Outer Washington Coast during 2008-2009," in *Marine Physical Laboratory Technical Memorandum 534* (Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, La Jolla, CA).

Trickey, J. S., Baumann-Pickering, S., Širović, A., Hildebrand, J. A., Brewer, A. M., Debich, A. J., Herbert, S., Rice, A. C., Thayre, B., and Wiggins, S. M. (**2015**). "Passive Acoustic Monitoring for Marine Mammals in the Northwest Training Range Complex July 2013 - April 2014," in *Marine Physical Laboratory Technical Memorandum 557* (Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA), p. 47.

Welch, P. D. (**1967**). "The use of fast Fourier transform for the estimation of power spectra: A method based on time averaging over short, modified periodograms," IEEE Transactions Audio and Electroacoustics **15**, 70-73.

Wenz, G. M. (**1962**). "Acoustic Ambient Noise in the Ocean: Spectra and Sources," Journal of the Acoustical Society of America **34**, 1936-1956.

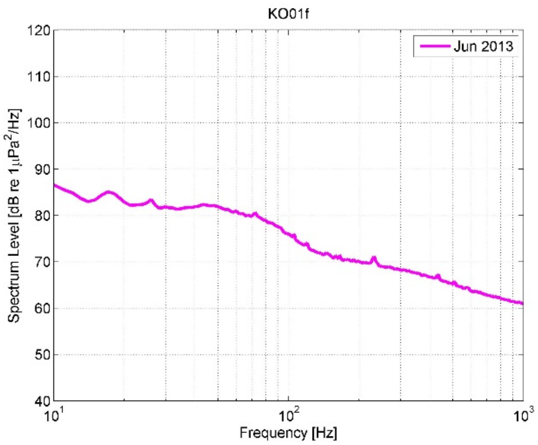
Wiggins, S. M. (**2015**). "Methods for quantifying mid-frequency active sonar in the SOCAL Range Complex," in *Marine Physical Laboratory Memorandum 553* (Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA), p. 14.

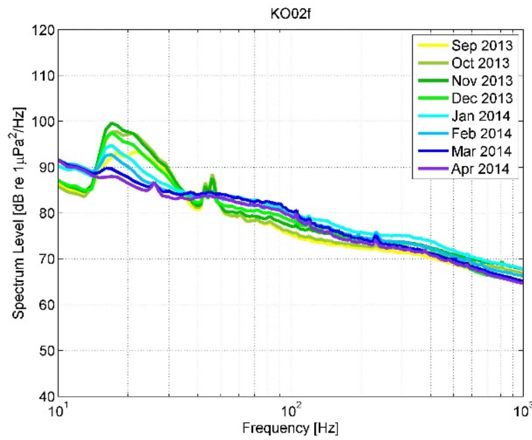
Wiggins, S. M., Hall, J. M., Thayre, B. J., and Hildebrand, J. A. (**2016**). "Gulf of Mexico low-frequency ocean soundscape impacted by airguns," Journal of the Acoustical Society of America **140**, 176-183.

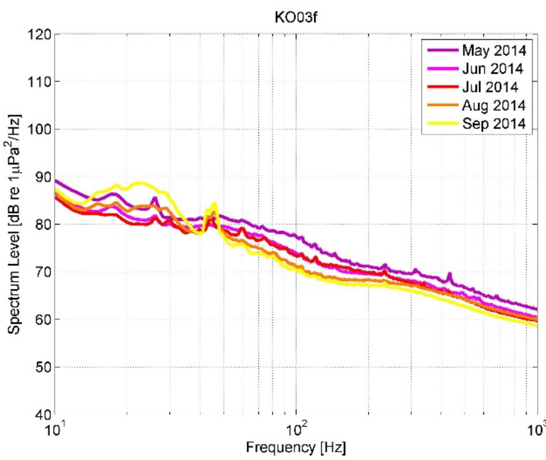
Wiggins, S. M., and Hildebrand, J. A. (**2007**). "High-frequency Acoustic Recording Package (HARP) for broad-band, long-term marine mammal monitoring," in *International Symposium on Underwater Technology 2007 and International Workshop on Scientific Use of Submarine Cables & Related Technologies 2007* (IEEE, Tokyo, Japan), pp. 551-557.

Appendix

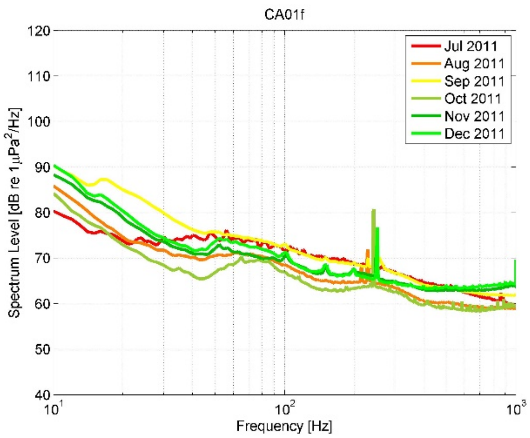
A1. GATMAA site KO Monthly Sound Pressure Spectrum Levels

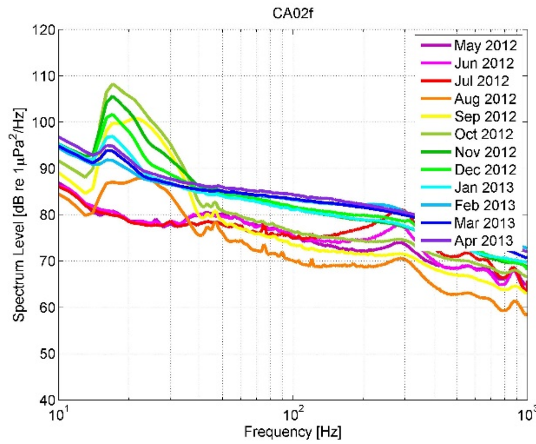


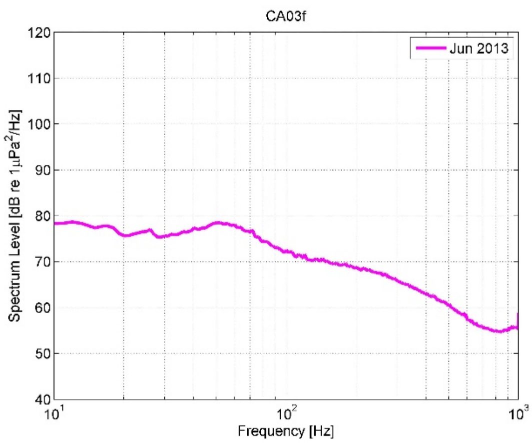


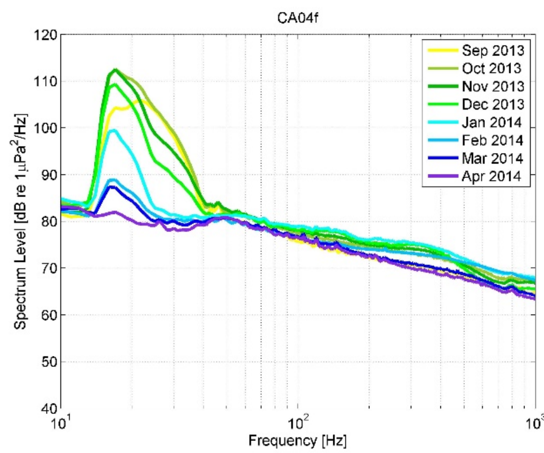


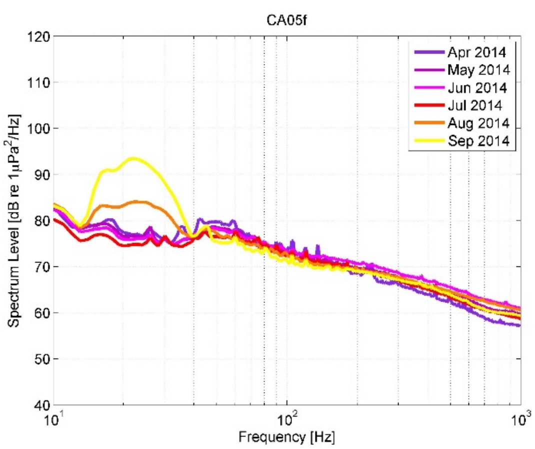
A2. GATMAA Site CA Monthly Sound Pressure Spectrum Levels



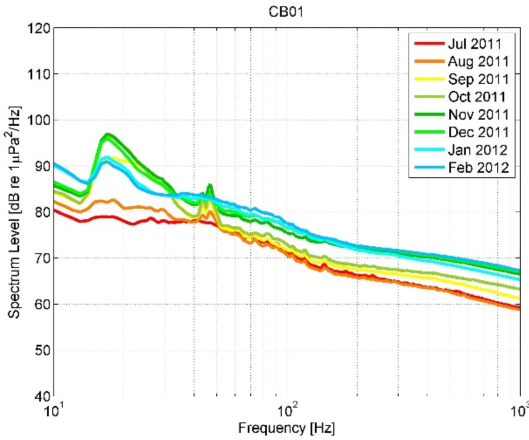


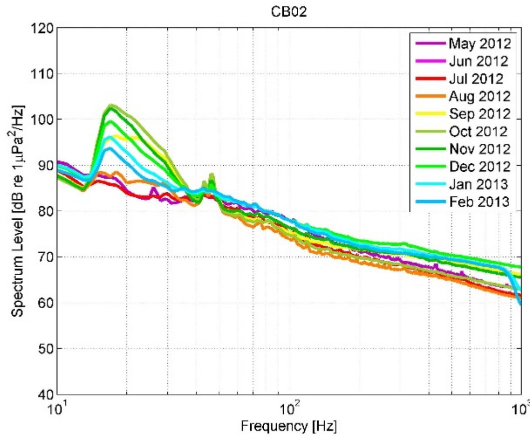


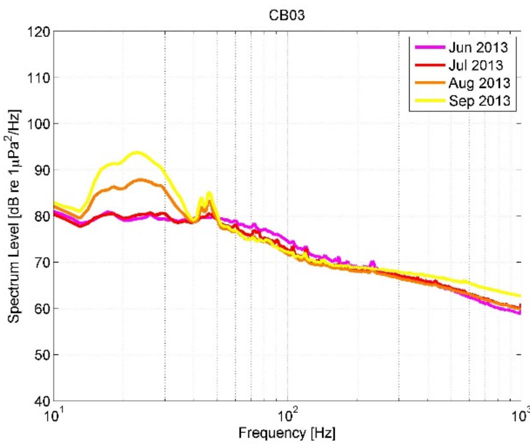


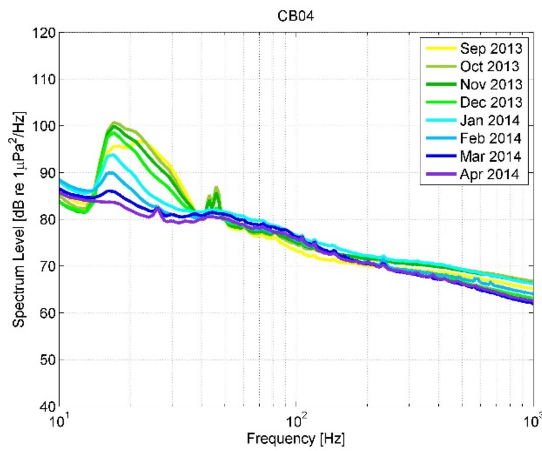


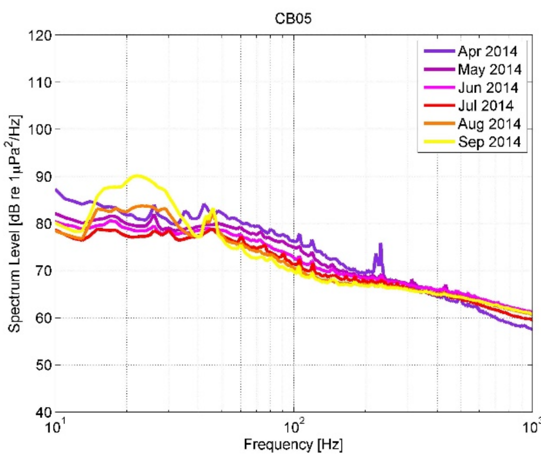
A3. GATMAA Site CB Monthly Sound Pressure Spectrum Levels

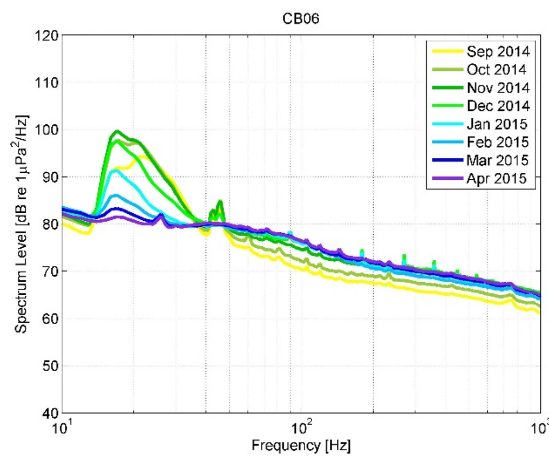


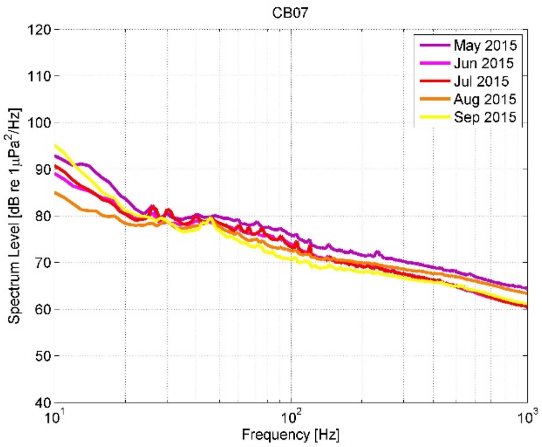




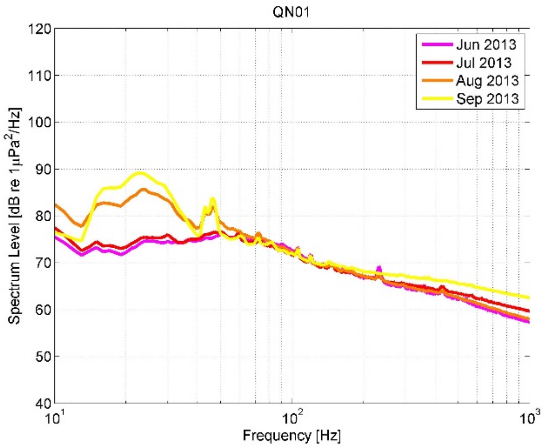


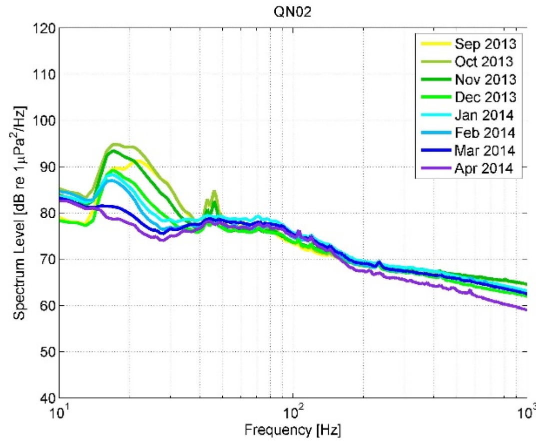


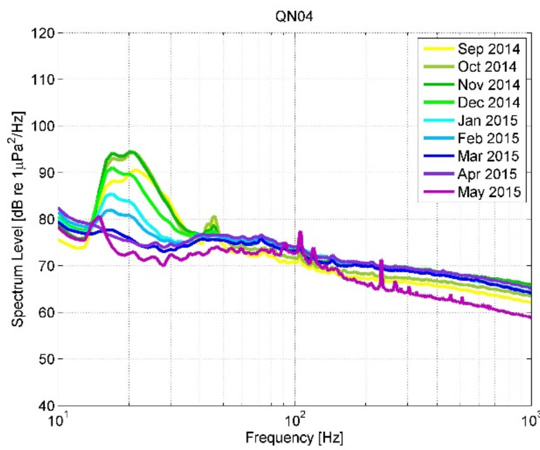


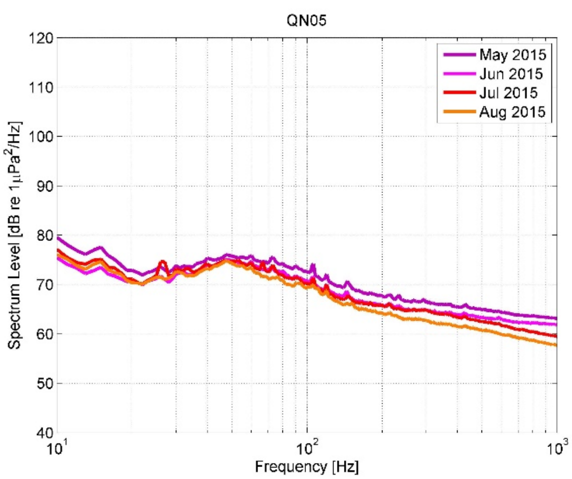

CB07
May 2015
Jun 2015
Jul 2015
Aug 2015
Sep 2015
Spectrum Level [dB re 1μPa²/Hz]
Frequency [Hz]
120
110
100
90
80
70
60
50
40
10¹
10²
10³

A4. GATMAA Site QN Monthly Sound Pressure Spectrum Levels

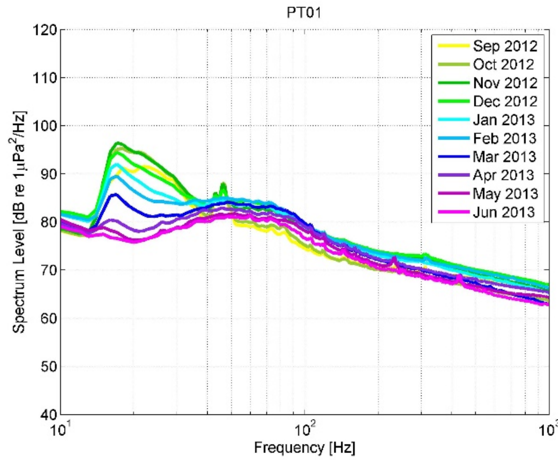


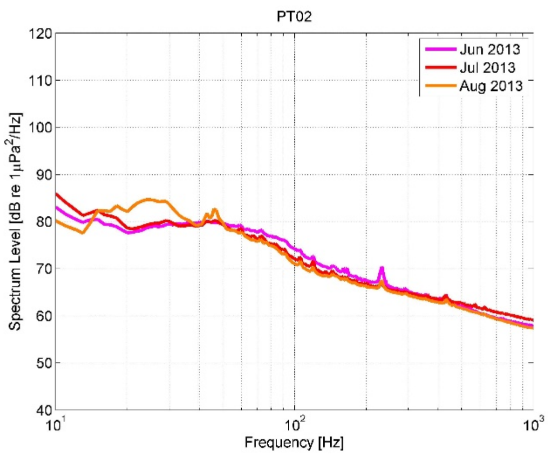


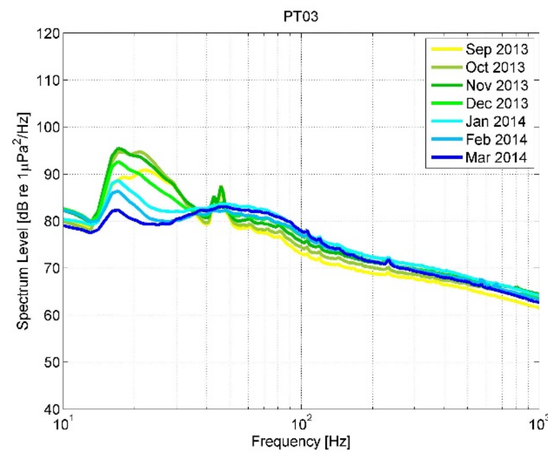


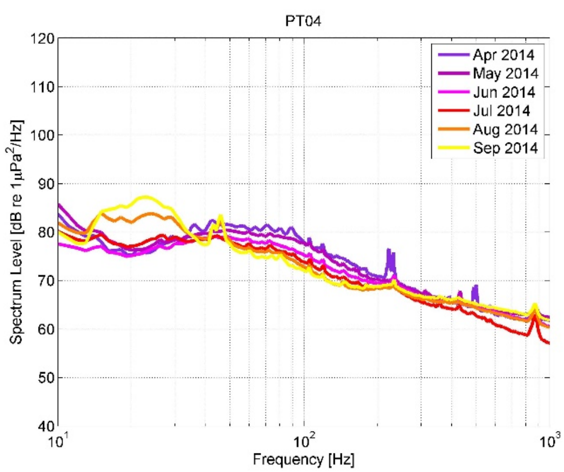


A5. GATMAA Site PT Monthly Sound Pressure Spectrum Levels

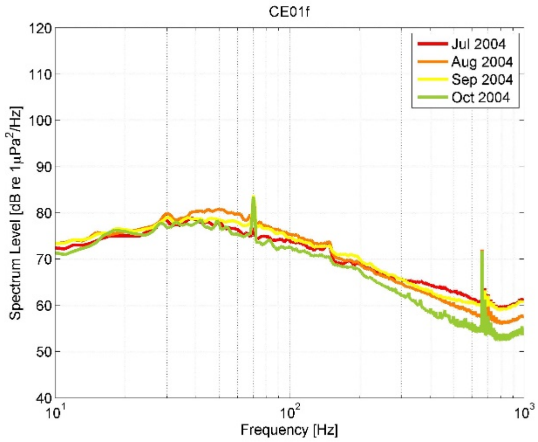


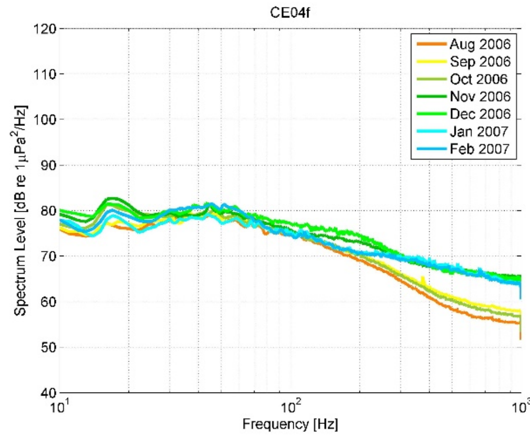


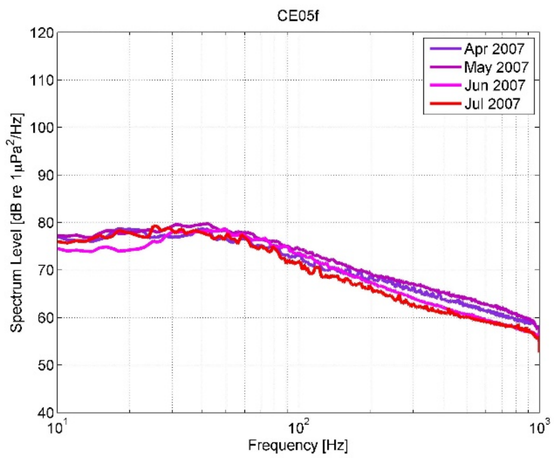


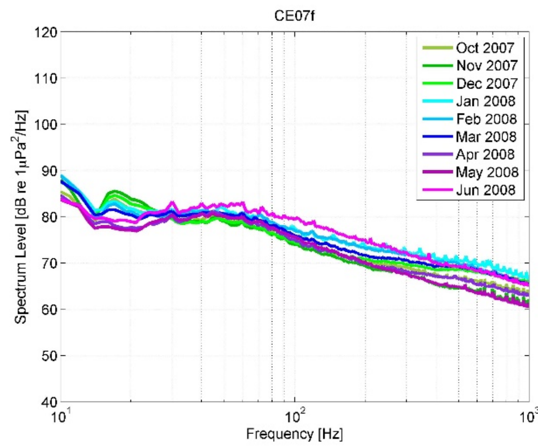


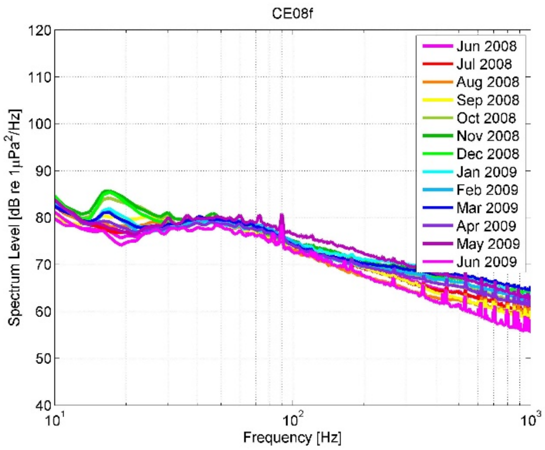
B1. NWTRC site CE Monthly Sound Pressure Spectrum Levels

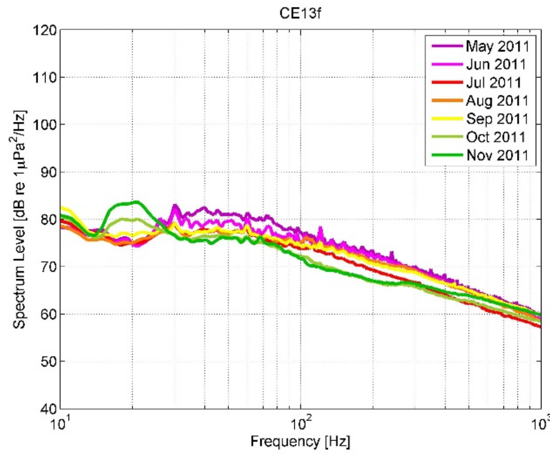


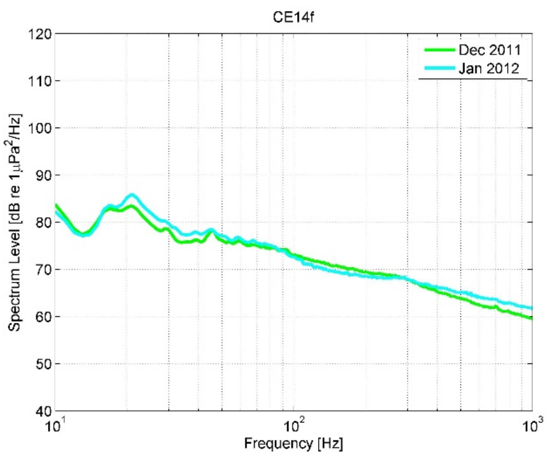


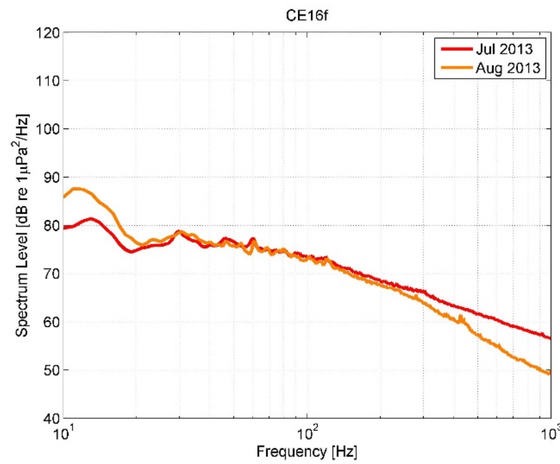




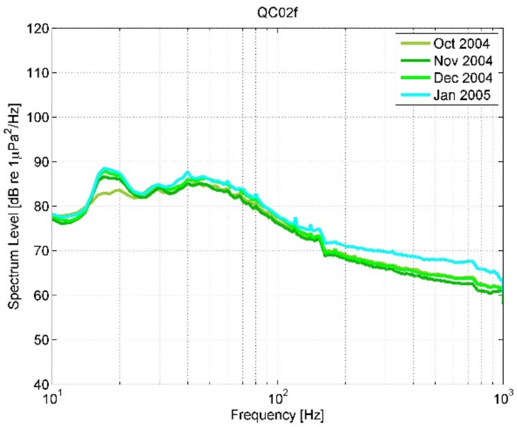

CE08f
Spectrum Level [dB re 1μPa²/Hz]
Frequency [Hz]
Jun 2008
Jul 2008
Aug 2008
Sep 2008
Oct 2008
Nov 2008
Dec 2008
Jan 2009
Feb 2009
Mar 2009
Apr 2009
May 2009
Jun 2009

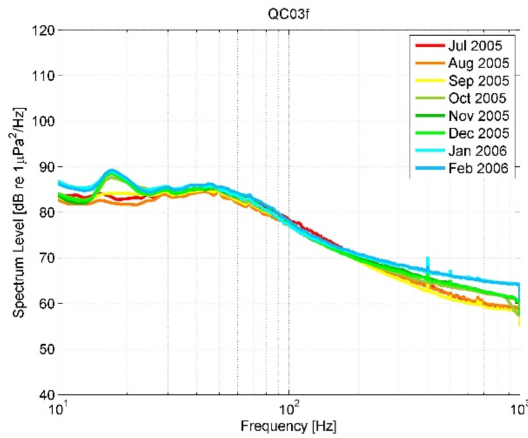

CE13f
Spectrum Level [dB re 1μPa²/Hz]
Frequency [Hz]
May 2011
Jun 2011
Jul 2011
Aug 2011
Sep 2011
Oct 2011
Nov 2011

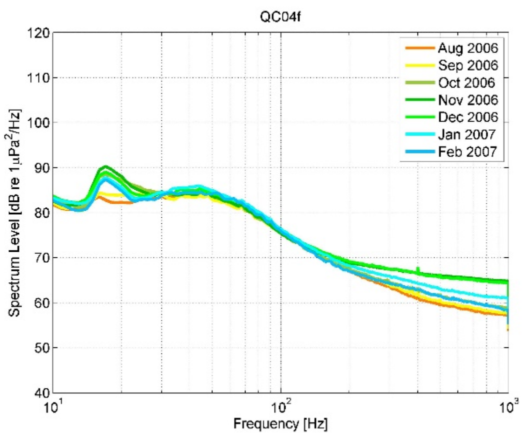

CE14f
Spectrum Level [dB re 1μPa²/Hz]
Frequency [Hz]
Dec 2011
Jan 2012

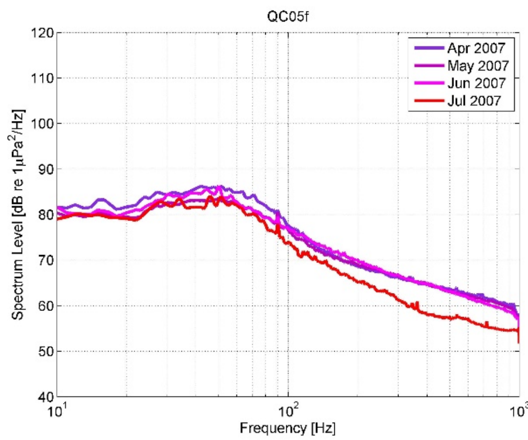

CE16f
Spectrum Level [dB re 1μPa²/Hz]
Frequency [Hz]
Jul 2013
Aug 2013

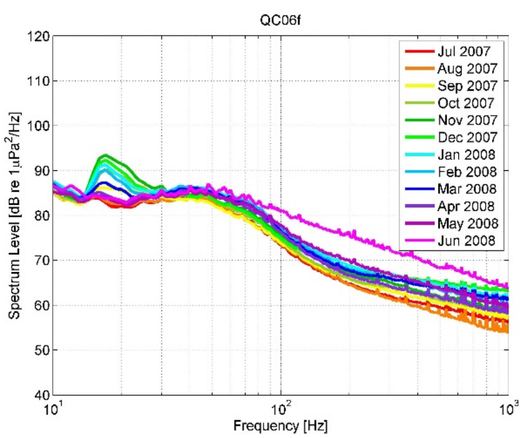
B2. NWTRC site QCA Monthly Sound Pressure Spectrum Levels











B3. NWTRC site QCB Monthly Sound Pressure Spectrum Levels