Summary of Five Years of Ambient and Anthropogenic Sound in the SOCAL Range Complex 2012 - 2017

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Executive Summary

Underwater ambient and anthropogenic sounds were recorded over five years in the U.S. Navy's Southern California Range Complex, the site of periodic at-sea training. The area was acoustically monitored and reported on for three sites ranging from ~500 m to 1300 m deep from June 2012 to June 2017 (Kerosky *et al.*, 2013; Debich *et al.*, 2015a; Debich *et al.*, 2015b; Širović *et al.*, 2016; Rice *et al.*, 2017; Rice *et al.*, 2018). While there were a variety of marine mammal sounds analyzed from the recordings, this report summarizes low-frequency ambient soundscape and anthropogenic sounds from mid-frequency active sonar and explosions over the five year period. Over 3400 days of passive acoustic monitoring data from the three sites were used for the analysis.

Ambient soundscape sound pressure levels were re-processed, analyzed and displayed using new and improved techniques, including calculating long (multi-year) spectrograms, sound pressure spectrum level percentiles, and average sound pressure levels over the five year recording period. In addition to reporting sound pressure spectrum levels in one-Hz bins, one-third octave levels are presented.

Long-term average ambient sound pressure levels were highest at the shallow near-shore site (P) and lowest at the site (H) in the western San Nicolas Basin, likely related to nearby vessel activity. Low-frequency (<50Hz) peaks in sound pressure spectrum levels at all sites during the fall were caused by blue whale calls, whereas winter peaks were from fin whale calls. Blue and fin call presence decreased during the study period, likely related to the 2014 -2016 El Niño event.

Mid-frequency active sonar (~3.5 kHz) was detected throughout the five year period, with the highest cumulative sound exposure levels and number of packet detections at the site south of San Clemente Island (N) and the fewest at the shallow near-shore site (P). Mid-frequency sonar activity was episodic with high numbers and levels of detections typically observed during known major Navy exercises.

Explosions were detected at all three sites throughout the five year period with a general decrease in activity over time and with the highest number at the site (H) in the western San Nicolas Basin.

Background

The U.S. Navy's Southern California (SOCAL) Range Complex is located in the Southern California Bight and the adjacent deep waters to the west. In January 2009, an acoustic monitoring effort was initiated within the SOCAL Range Complex with support from the U.S. Pacific Fleet. The goal of this effort was to characterize the vocalizations of marine mammal species and anthropogenic sound sources present in the area, determine marine mammal daily and seasonal presence, and to evaluate the potential for impact on marine mammals from naval training.

This report summarizes five years, from June 2012 to June 2017, of ambient soundscape, Mid-Frequency Active sonar and explosion activity in the SOCAL Range Complex at three sites around San Clemente Island: west at site H ~1000 m deep, south at site N ~1300 m deep, and east at site P ~500 m deep (Figure 1; Tables 1-3).

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 the SOCAL Range Complex. 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 in the SOCAL Range Complex, 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.

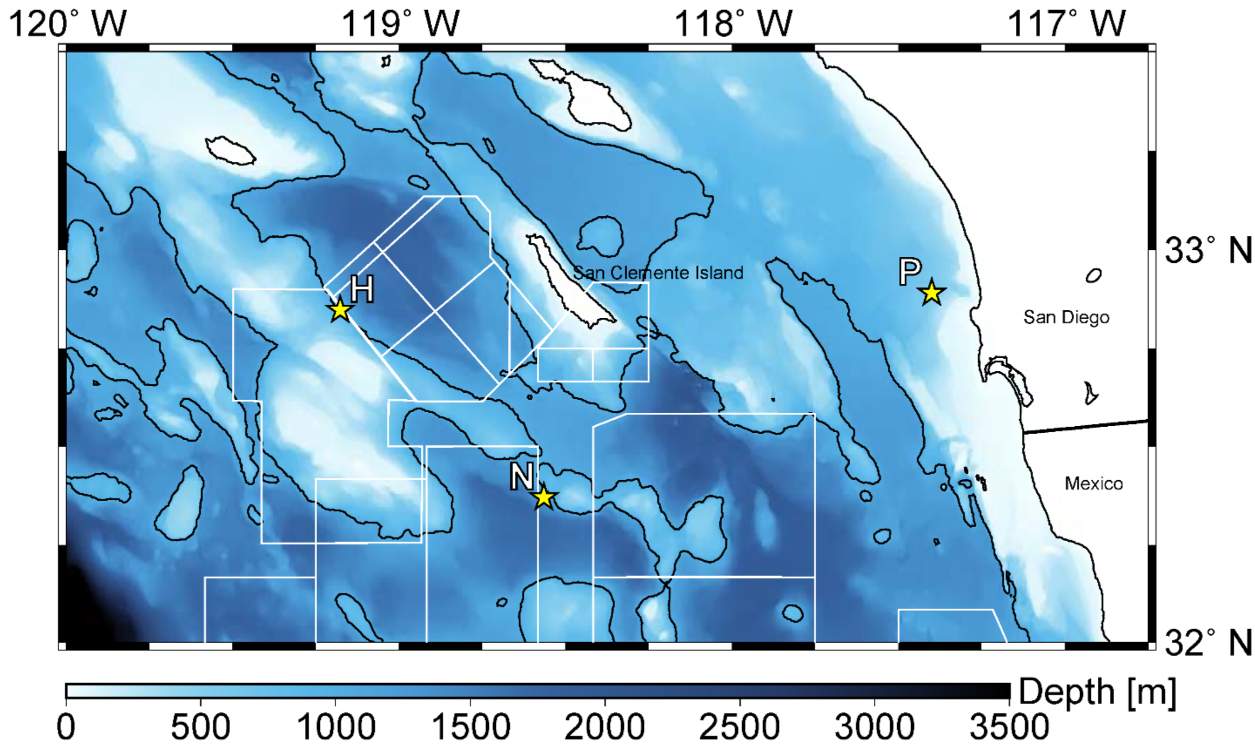

Figure 1. SOCAL Range Complex acoustic recorder site locations and bathymetric map. Acoustic recorder locations are shown as yellow stars at sites H, N and P. White polygons are Navy operational areas. Black contours are coastlines and 1000 m depths, darker colors are deeper.

Table 1. SOCAL Range Complex site H acoustic recorder deployments.
Deployment name, locations, original Technical Memorandum (TM) report, analysis periods, and number of days analyzed.

Deploy Name	Lat N	Lon W	Depth [m]	TM #	Analysis Period	Effort Days
SOCAL_H_47	32° 50.8’	119° 10.6’	1006	544	08/10/12 – 12/20/12	133
SOCAL_H_48	32° 50.5’	119° 10.3’	1000	552	12/21/12 – 04/30/13	131
SOCAL_H_50	32° 50.3’	119° 10.0’	1000	552	09/10/13 – 01/07/14	118
SOCAL_H_51	32° 50.3’	119° 10.0’	960	554	01/07/14 – 04/03/14	87
SOCAL_H_52	32° 50.8’	119° 10.6’	986	554	04/04/14 – 07/30/14	117
SOCAL_H_53	32° 50.7’	119° 10.6’	1000	607	07/30/14 – 11/05/14	98
SOCAL_H_54	32° 50.8’	119° 10.5’	1000	607	11/05/14 – 02/04/15	92
SOCAL_H_55	32° 50.8’	119° 10.6’	1000	607	02/05/15 – 06/01/15	117
SOCAL_H_56	32° 50.8’	119° 10.6’	1000	610	06/02/15 – 10/03/15	123
SOCAL_H_58	32° 50.8’	119° 10.6’	1000	610	11/21/15 – 04/25/16	156
SOCAL_H_59	32° 50.7’	119° 10.6’	1000	618	07/06/16 – 11/09/16	126
SOCAL_H_61	32° 50.8’	119° 10.5’	1000	618	02/22/17 – 06/06/17	105
						Total 1403

Table 2. SOCAL Range Complex site N acoustic recorder deployments.
Deployment name, locations, original Technical Memorandum (TM) report, analysis periods, and number of days analyzed.

Deploy Name	Lat N	Lon W	Depth [m]	TM #	Analysis Period	Effort Days
SOCAL_N_46	32° 22.2’	118° 33.9’	1292	544	06/08/12* - 08/05/12	58*
SOCAL_N_47	32° 22.2’	118° 33.9’	1285	544	08/10/12 – 12/06/12	119
SOCAL_N_48	32° 22.2’	118° 33.9’	1300	552	12/21/12 – 05/01/13	133
SOCAL_N_49	32° 22.2’	118° 33.9’	1292	552	05/02/13 – 09/11/13	131
SOCAL_N_51	32° 22.2’	118° 33.9’	1280	554	01/07/14 – 02/16/14	40
SOCAL_N_52	32° 22.2’	118° 33.9’	1280	554	04/04/14 – 07/30/14	117
SOCAL_N_53	32° 22.2’	118° 33.8’	1280	607	07/30/14 – 11/05/14	98
SOCAL_N_54	32° 22.2’	118° 34.0’	1280	607	11/05/14 – 02/05/15	92
SOCAL_N_56	32° 22.2’	118° 33.8’	1280	610	06/02/15 – 10/03/15	124
SOCAL_N_57	32° 22.2’	118° 33.9’	1260	610	10/03/15 – 11/21/15	49
SOCAL_N_59	32° 22.3’	118° 33.9’	1260	618	07/07/16 – 11/08/16	125
SOCAL_N_60	32° 22.2’	118° 33.9’	1260	618	11/09/16 – 02/21/17	104
SOCAL_N_61	32° 22.3’	118° 33.9’	1300	618	02/21/17 – 06/07/17	105
						Total 1295

** indicates only the latter half of the recording was used for analysis.*

Table 3. SOCAL Range Complex site P acoustic recorder deployments.
Deployment name, locations, original Technical Memorandum (TM) report, analysis periods, and number of days analyzed.

Deploy Name	Lat N	Lon W	Depth [m]	TM #	Analysis Period	Effort Days
LJ_P_23	32° 53.5’	117° 24.0’	422	554	01/25/14 – 03/05/14	39
LJ_P_26	32° 53.4’	117° 24.1’	450	554	03/06/14 – 06/27/14	113
LJ_P_31	32° 53.4’	117° 24.0’	450	610	06/02/15 – 09/18/15	108
LJ_P_32	32° 53.4’	117° 24.0’	450	610	09/25/15 – 10/19/15	24
LJ_P_33	32° 53.4’	117° 24.0’	450	610	10/20/15 – 11/20/15	31
LJ_P_34_01	32° 52.0’	117° 23.5’	468	610	11/20/15 – 03/01/16	102
LJ_P_35	32° 52.1’	117° 23.5’	470	618	04/09/16 – 08/11/16	124
LJ_P_36	32° 52.1’	117° 22.5’	380	618	08/12/16 – 10/26/16	75
LJ_P_39_01	32° 53.1’	117° 23.6’	504	618	02/14/17 – 05/24/17	99
						Total 715

Data Acquisition

The SOCAL recordings reported here span five years starting in the summer of 2012 and ending in the summer of 2017 at three locations: one near-shore at site P with 9 deployments and 715 days of recording and two offshore in deeper water at site H with 12 deployments and 1403 days of recording and site N with 13 deployments and 1295 days of recording (Figure 1; Tables 1-3).

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) 544, 552, 554, 607, 610, and 618 (Kerosky *et al.*, 2013; Debich *et al.*, 2015a; Debich *et al.*, 2015b; Širović *et al.*, 2016; Rice *et al.*, 2017; Rice *et al.*, 2018). Anthropogenic sound sources summarized in this report include mid-frequency active (MFA) sonar and explosions, in addition to reporting on low-frequency ambient soundscape.

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 events 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 in the SOCAL Range Complex, 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, vessels, explosions 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 ship sounds or with known instrument self-noise problems discarded. 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 in 1 Hz and 1/3-octave (with band center-frequencies including 62.5 and 125 Hz) for the three sites over the study period in addition to long-term spectrograms.

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 recording period. In the first approach, for recordings before 30 July 2014, 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, for recordings after 30 July 2014, used an automatic computer-algorithm 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 methods, MFA detections were then reviewed by a trained analyst and valid periods of MFA events were quantified by a second computer-algorithm to detect and count individual packets above 130 dB_{pp} re 1 µPa in the 2.4 to 4.5 kHz pass band. Instrument maximum received level was ~162 dB_{pp} re 1 µPa, above which waveform clipping occurred. Packets were grouped into wave trains separated by more than 1 hour and provide statistical metrics of the MFA sonar events such as event time, peak-to-peak (pp) and root-mean-square (rms) received sound pressure levels (RL), number of packets per wave train, and cumulative sound exposure levels (CSEL) (Wiggins, 2015).

Explosions

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

Explosions were detected automatically over the five years and three sites using 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 above the median was set. When the correlation coefficient met or exceeded the threshold, the event was considered a potential detection and the time series was inspected more closely as described 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 (RLs) 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 the 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

Daily averaged sound pressure spectrum levels in 1-Hz bins were concatenated to produce long-term spectrograms for the three sites over the five year study period (Figure 2). Fin whale 20-Hz calls are clearly visible during winter periods at site H, but with decreasing intensity over the study period, potentially related to the strong 2014-2016 El Niño event. Site N also shows this fin whale call pattern, but with less call intensity and more broad-band energy below ~100 Hz potentially from distant shipping vessels masking the calls. Site P shows relatively little fin whale 20-Hz calls, although there is little recording effort at times when fin whales were most present at the other two sites. Site P had higher overall sound levels up to ~ 200 Hz compared to the other sites, likely from local small vessel traffic. Blue whale B calls are readily apparent in the long-spectrogram from site H around 15, 30, and 45 Hz during the fall, but with lesser intensity and poorer signal-to-noise ratio at site N. Blue B calls also are at lower levels during 2014-2016 compared to 2012, but the decrease does not appear as much as for fin whale calls.

Average monthly sound pressure spectrum levels for 1/3-octave bands centered at 62.5 and 125 Hz levels were typically higher for the 62.5 Hz band than the 125 Hz band (Figure 3). The band levels varied over the study period on a seasonal or yearly interval, but there does not appear to be a long-term trend. Site P had the highest level and site H, on average, had the lowest levels, although some months site H had higher levels than site N.

Broad-band sound pressure levels below ~100 Hz varied between the sites mainly based on their exposure to vessel traffic. Site P, the shallowest and closest to near shore boats site, had the highest levels, and site H had the lowest levels because its location in the San Nicolas Basin was shadowed from distant shipping (McDonald *et al.*, 2008). Five year and monthly averaged sound pressure spectrum levels also show the spectral peaks associated with fin whale and blue whale calls (Figures 4 and 5; Appendix A – F).

Above ~200 Hz, wind is often a dominant source in the soundscape (Wenz, 1962). Sound pressure spectrum level percentiles above 200 Hz show greater variability at the deep water sites with ~20 dB for H and N than the shallow site P with ~10 dB (Figures 6 and 7).

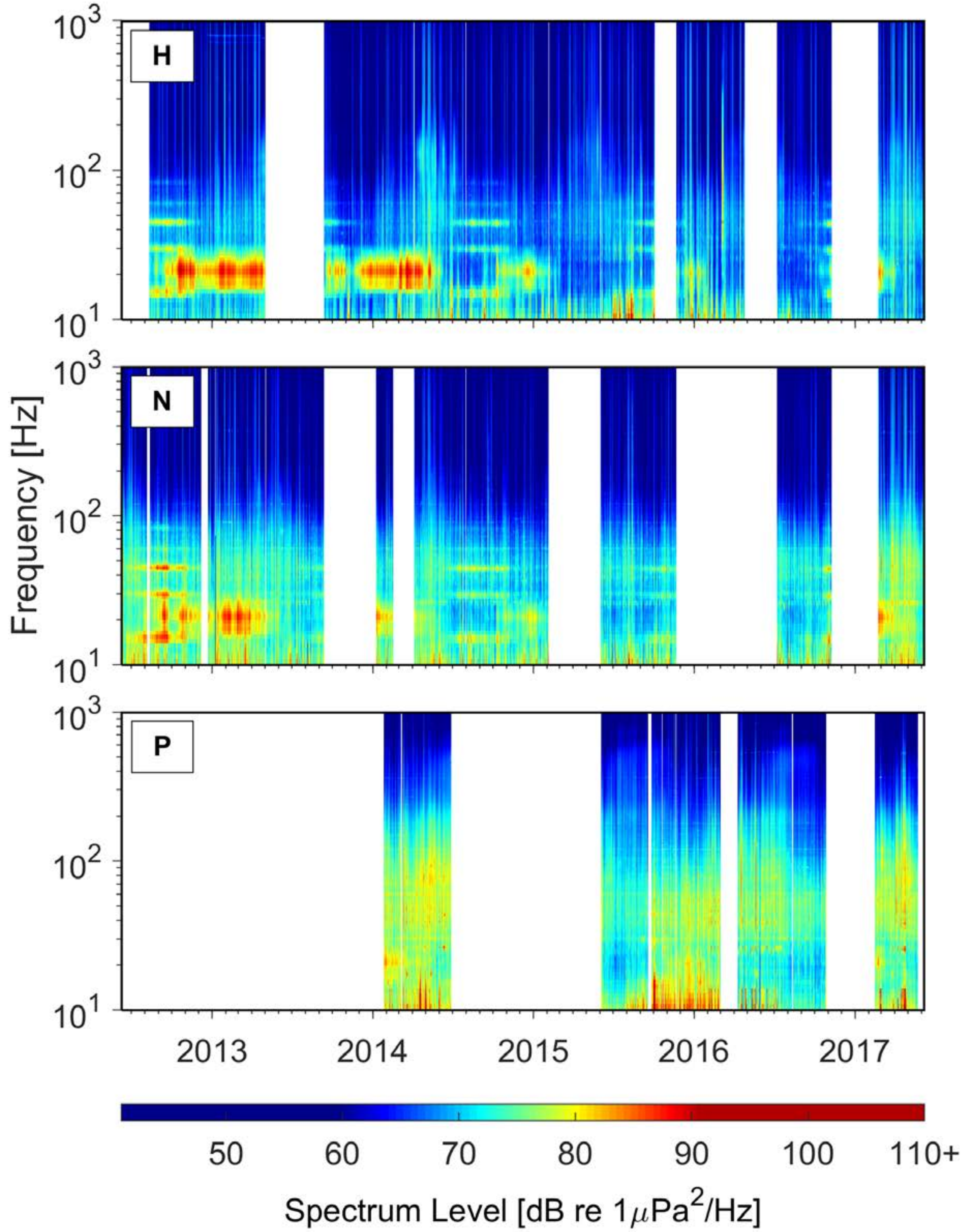

Figure 2. Long-term spectrograms from site H, N, and P in the SOCAL Range Complex.

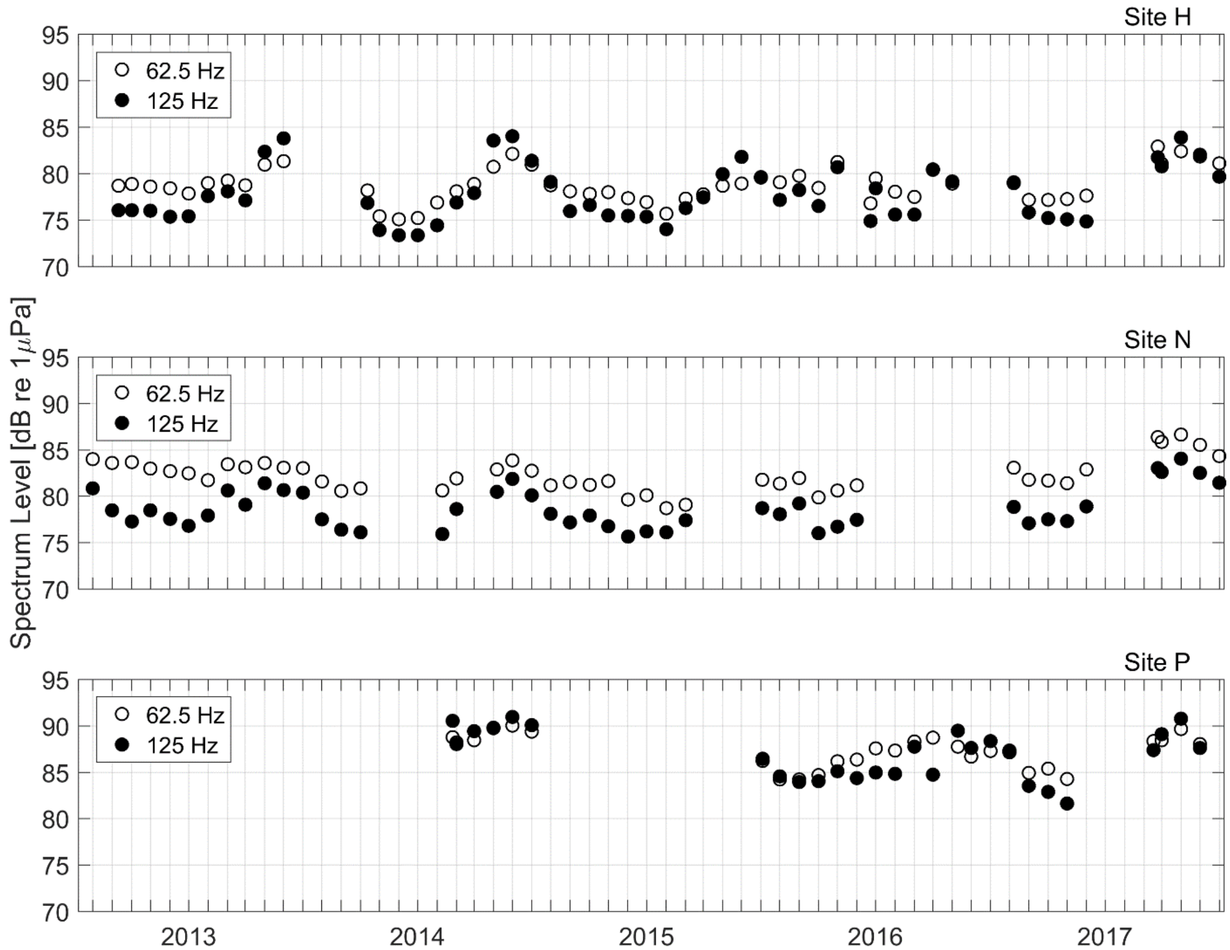

Figure 3. Average monthly spectrum levels of 1/3-octave bands 62.5 and 125 Hz.
For SOCAL Range Complex three sites, H, N, and P, the 62.5 Hz 1/3-octave band monthly average sound pressure spectrum level are open circles and 125 Hz band are closed circles. Ticks along the horizontal axis are months.

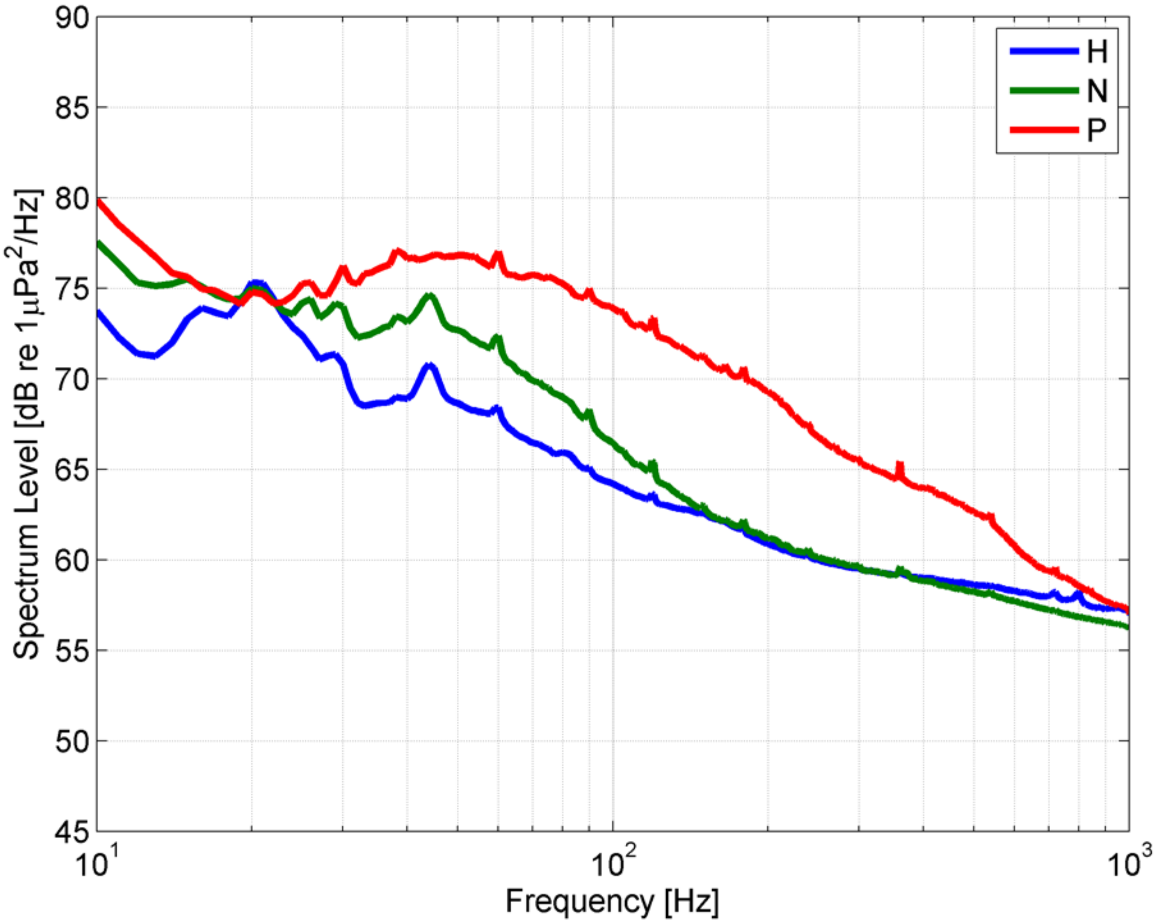

Figure 4. SOCAL Range Complex 1-Hz bin average sound pressure spectrum levels over five years by site.

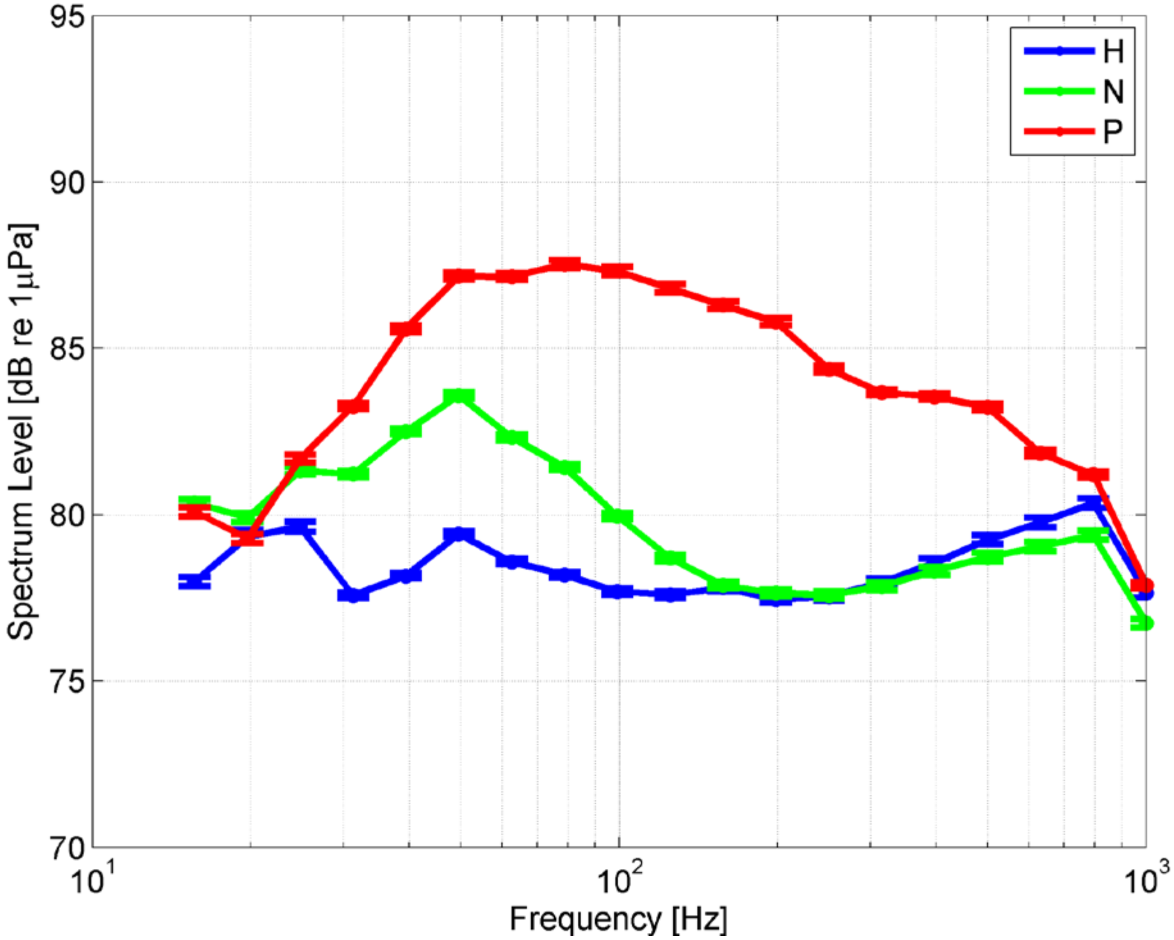

Figure 5. SOCAL Range Complex 1/3-octave bin average sound pressure spectrum levels over five years by site.
Error bars are standard error.

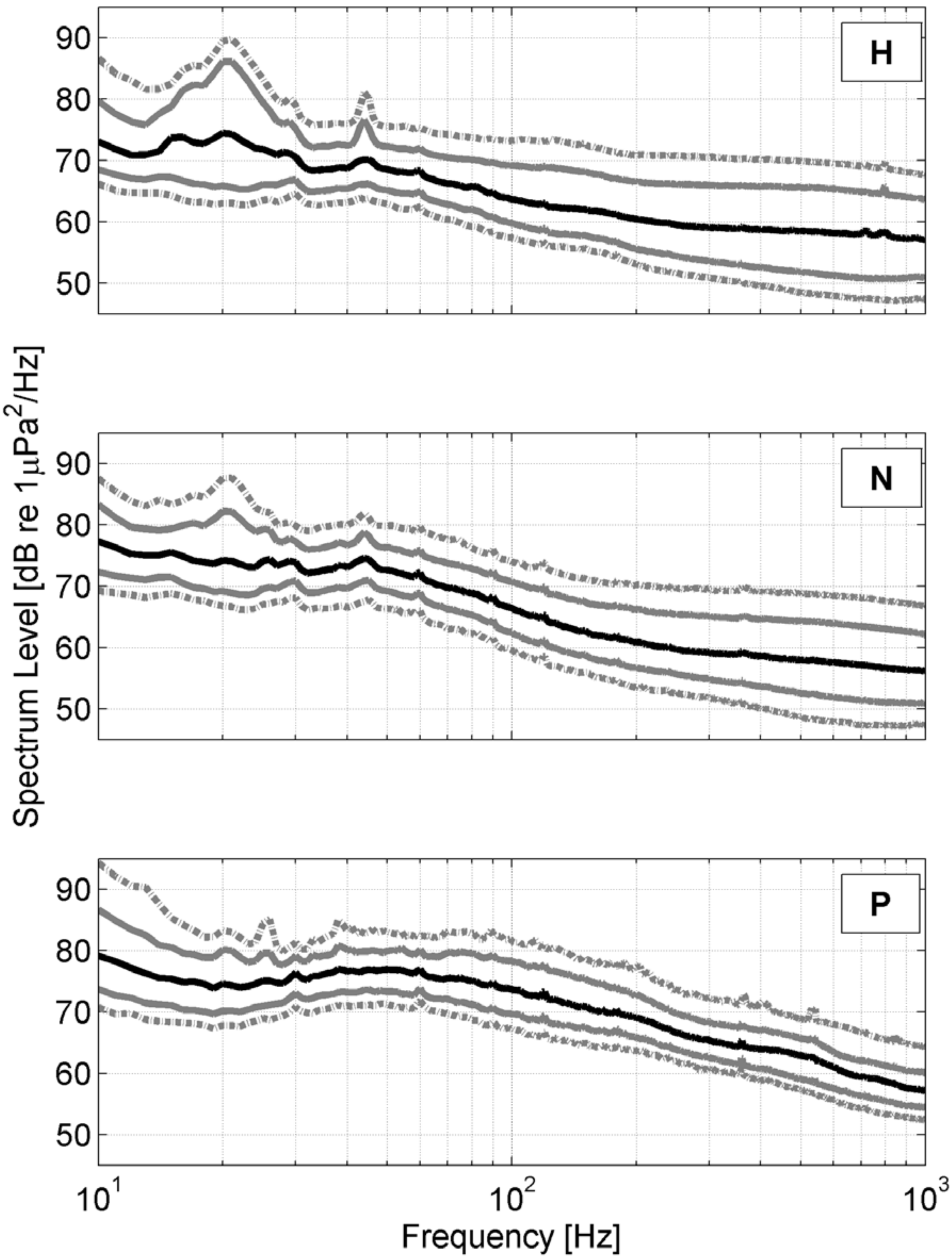

Figure 6. SOCAL Range Complex 1-Hz bin spectrum percentile for over five years by site. Percentiles: 1 (lowest), 10, 50 (black middle), 90, and 99% (highest lines).

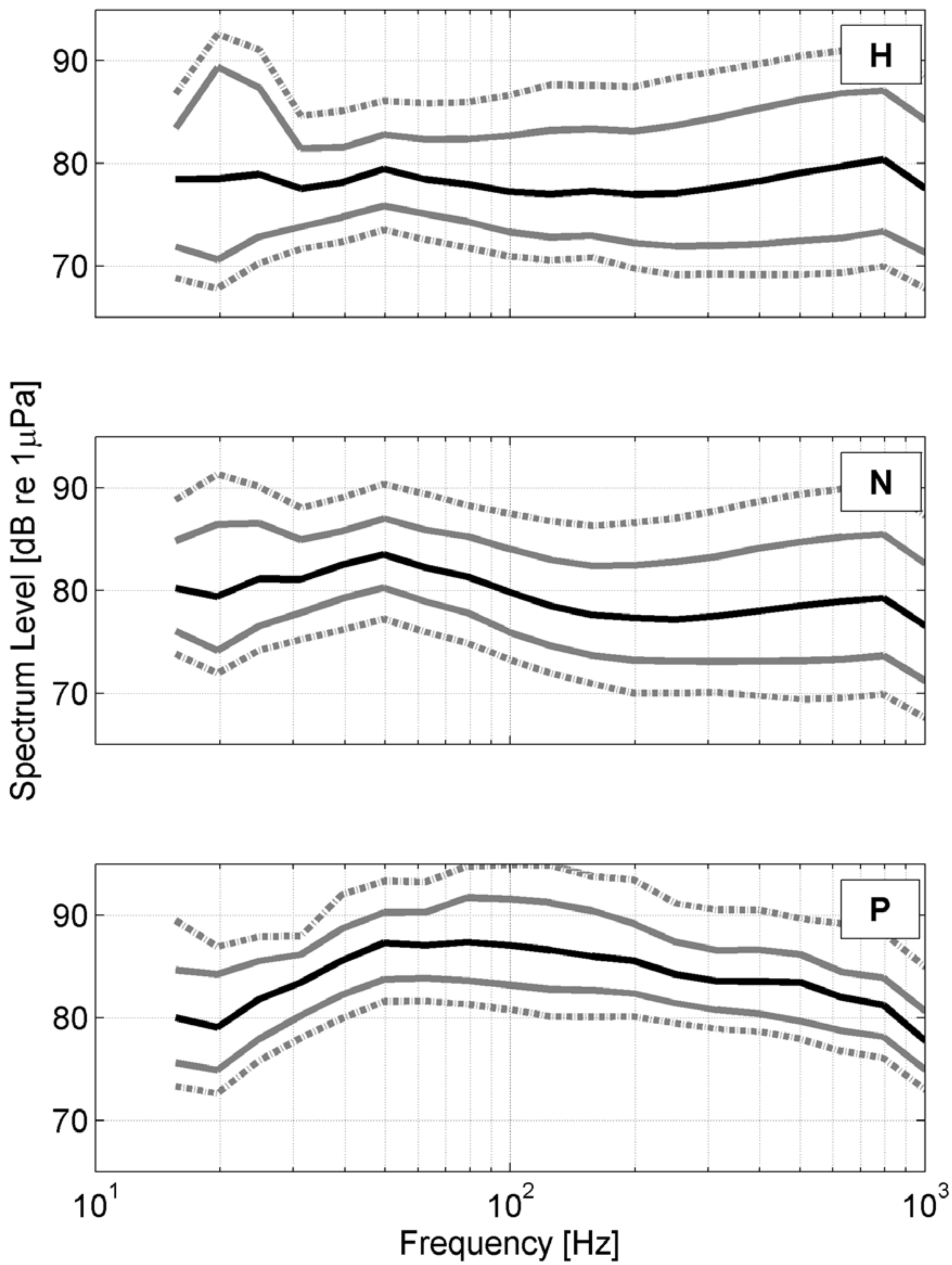

Figure 7. SOCAL Range Complex 1/3-octave bin spectrum percentile for over five years by site.
Percentiles: 1 (lowest), 10, 50 (black middle), 90, and 99% (highest lines).

Mid-frequency active sonar

MFA sonar was a commonly detected anthropogenic sound in the SOCAL Range Complex with about twice as many packets detected per year at site N than site H, or more than five times as many at site N than site P (Figure 8; Table 4). Site N averaged over 130 wave trains per year, over 16,000 packets per year, and almost 24% of the days monitored had wave trains. In addition, site N had 15 wave trains with at least 500 packets, compared to site H with only three and none at site P. Dates of major naval training exercises in the SOCAL Range Complex between July 2012 and May 2017 are listed in Table 5 (C. Johnson, U.S. Navy Pacific Fleet, personal communication). MFA sonar used outside the designated major exercises is likely attributable to unit-level training.

Table 4. MFA sonar wave train and packet detections

Total effort at each site in days (years), number of and extrapolated yearly estimates of wave trains and packets at each site (> 130 dB_{pp} re 1 µPa).

Site	Period Analyzed Days (Years)	Number of Wave Trains	Wave Trains per year	Percent days with Wave Trains	Number of Packets	Packets per year
H	1403 (3.84)	352	92	17.3	31,945	8,319
N	1295 (3.55)	472	133	23.6	58,876	16,585
P	715 (1.96)	94	48	11.2	5,882	3,001

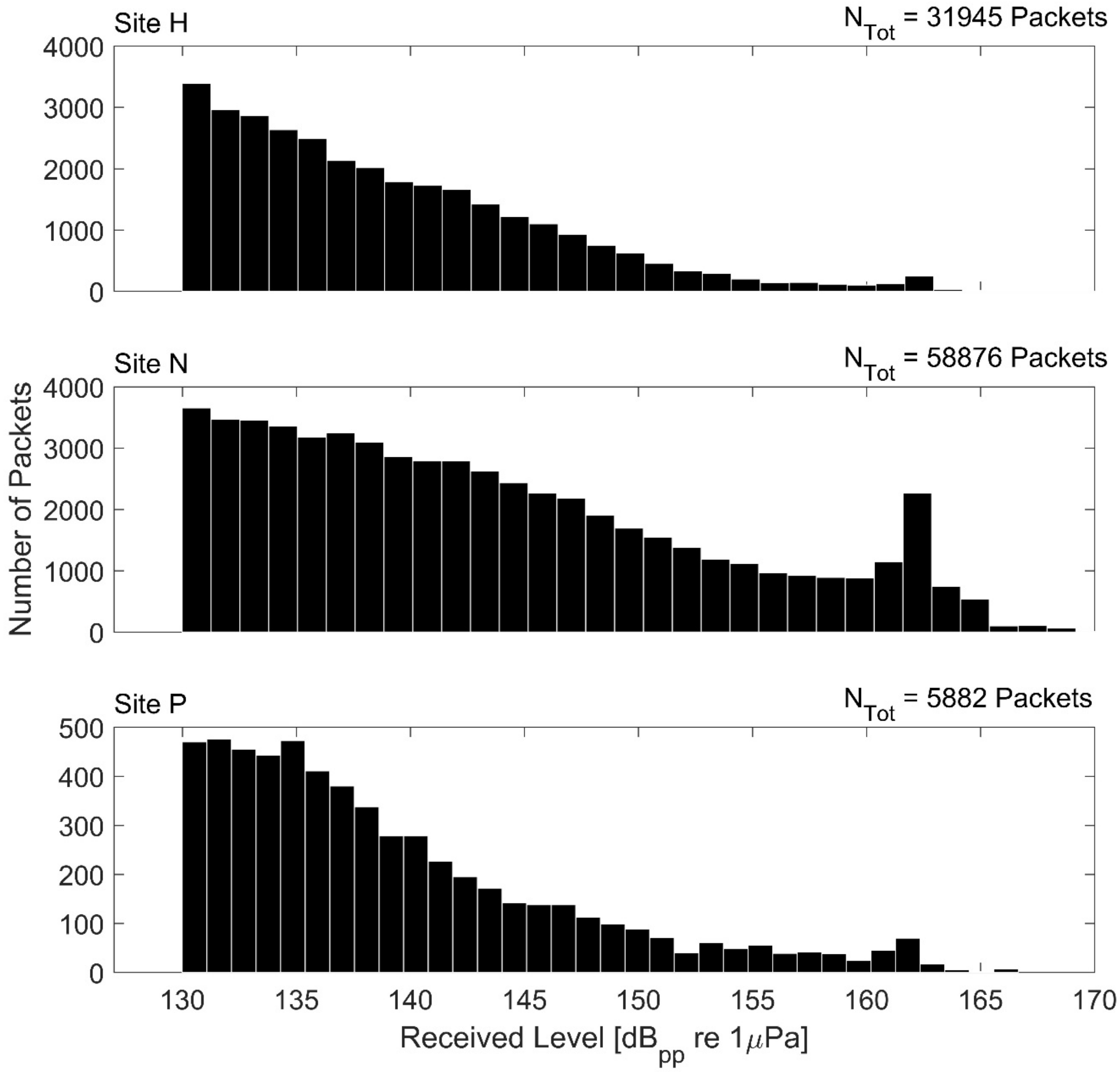

Figure 8. MFA sonar packet receive level distributions.
The total number of MFA sonar packets detected above 130 dB_{pp} re 1 µPa is shown in upper right corner of each panel for SOCAL Range Complex sites H, N, and P. Instrument clipping levels are around 161-165 dB_{pp} re 1 µPa depending on hydrophone configuration. Note the vertical axis for the bottom panel is different than the top and middle panels.

Table 5. Major naval training exercises in SOCAL Range Complex between June 2012 and June 2017

CERTEX = Certification Exercise; C2X / COMPTUEX = Composite Training Unit Exercise; IAC = Integrated Anti-Submarine Warfare Course; JTFEX = Joint Task Force Exercise; SUSTEX = Sustainment Exercise.

Type	Period	Duration (Days)
SUSTEX	07/05/12 – 07/18/12	14
IAC II	07/12/12 – 07/14/12	3
COMPTUEX	10/17/12 – 11/05/12	20
IAC II	10/29/12 – 11/04/12	7
JTFEX	11/06/12 – 11/12/12	7
SUSTEX	04/02/13 – 04/18/13	17
COMPTUEX	07/08/13 – 07/19/13	12
IAC II	11/06/13 – 11/15/13	8
COMPTUEX	05/06/14 – 06/02/14	28
IAC II	05/17/14 – 05/22/14	6
JTFEX	06/03/14 – 06/09/14	7
IAC	10/20/14 – 10/31/14	12
C2X *	03/16/15 – 04/01/15	16
IAC	04/25/15 – 04/28/15	4
C2X	07/27/15 – 08/20/15	24
IAC	08/14/15 – 08/18/15	5
JTFEX	08/21/15 – 08/27/15	7
C2X **	10/19/15 – 11/05/15	18
SUSTEX	11/05/15 – 11/16/15	12
SUSTEX **	01/19/16 – 01/22/16	4
CERTEX	02/26/16 – 03/06/16	10
C2X	08/12/16 – 08/25/16	14
C2X	10/24/16 – 11/09/16	17
JTFEX	11/10/16 – 11/21/16	12
C2X	03/28/17 – 04/24/17	28
C2X	05/01/17 – 05/07/17	7

** may or may not have involved sonar-equipped ships*

***Exercises by non-sonar equipped ships with no sonar usage associated with this event planned. Any sonar detections during this period would be from individual ships not affiliated with the exercise and conducting small scale unit level training.*

MFA sonar was present throughout the five year study with episodic periods of high CSEL and high numbers of packet and wave train detections typically occurred during major naval training exercises. While site N showed the highest level of MFA sonar activity, site H also had substantial MFA sonar present. Over the five years of monitoring, there were four training periods that correlated with high numbers of wave trains and packets along with high CSEL, primarily at site N: fall 2012, spring 2014, summer 2015, and fall 2016, each including Composite Training Unit Exercise (COMPTUEX/C2X), Joint Task Force Exercise (JTFEX), and Integrated Anti-Submarine Warfare Course (IAC) exercises, except the fall 2016 which did not include IAC exercise (Figures 9 and 10; Table 5).

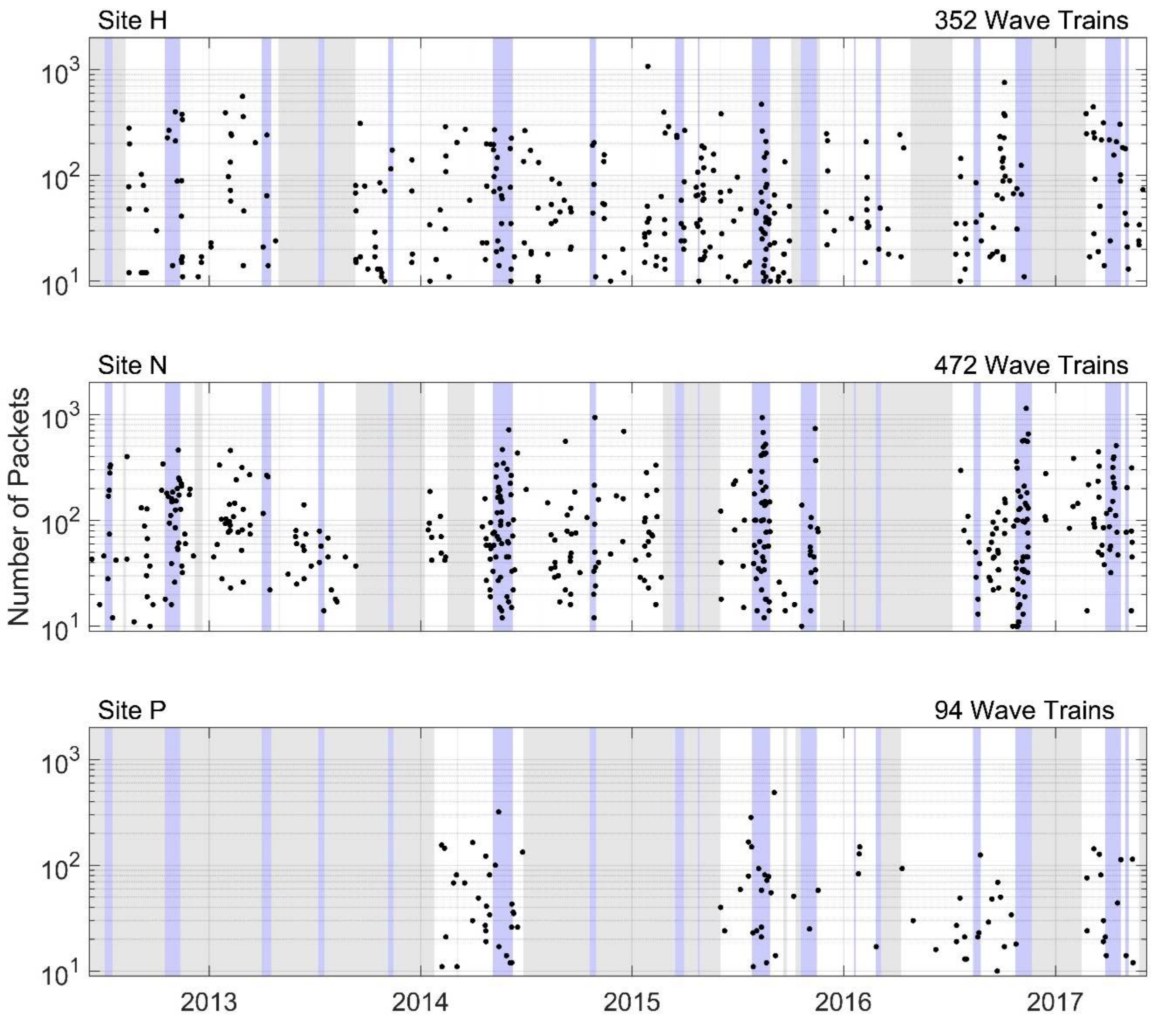

Figure 9. Number of MFA sonar packets per each wave train at sites H, N, and P. Violet/blue shaded regions are during periods of major naval training exercises listed in Table 5. Gray shaded regions are periods of no effort. Vertical axis is logarithmic base-10.

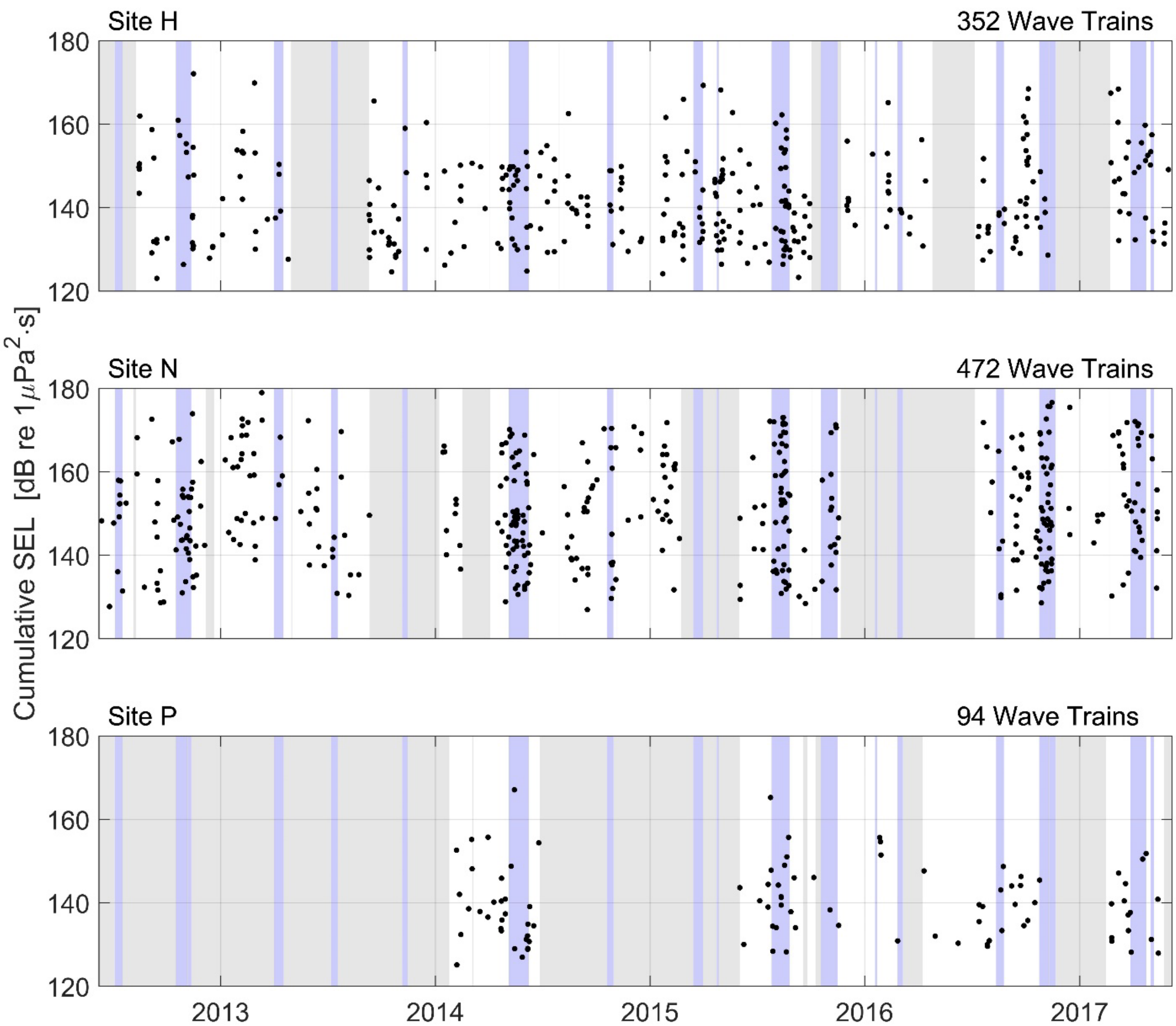

Figure 10. Cumulative sound exposure level for each wave train at sites H, N, and P
Violet/blue shaded regions are during periods of major naval training exercises listed in Table 5. Gray shaded regions are periods of no effort.

Along with the greatest number of wave trains and packets, site N also had the highest CSEL with one wave train at 179 dB re 1 µPa-s, in addition to 32 wave trains ≥170 dB re 1 µPa-s, compared to site H with only one and none at site P. Some CSEL values are low estimates since some of the MFA detection waveforms were clipped (i.e., received levels ≥ 162 dB_{pp}) with site N having the greatest number of wave trains (124) and packets (3,202) with clipped MFA waveforms.

Explosions

Explosions were detected at all three sites over the five year period with the greatest number at site H and the fewest at site P (Table 6). The number of detections decreased at all sites over the study period with numbers near 1000 detections per week from 2012 to 2015 to less than 50 per week in 2016 and 2017 (Figure 11). The number of detected explosions per year was similar for sites N and P, with site P having fewer days without detections.

Finer scale temporal analysis shows that most of the explosions over the five year study period occurred at night with relatively short duration reverberations and moderate received levels suggesting the majority of the explosions are from 'seal bombs' and related to fishing activity as a pinniped deterrent (Meyer-Löbbecke *et al.*, 2016; Meyer-Löbbecke *et al.*, 2017), not naval exercises (Kerosky *et al.*, 2013; Debich *et al.*, 2015a; Debich *et al.*, 2015b; Širović *et al.*, 2016; Rice *et al.*, 2017; Rice *et al.*, 2018). The decrease in the number of explosions in recent deployments is likely due to a geographical shift in fishing effort of the squid fishery fleet northward during the 2014-2016 El Niño period and a remaining fishery focus on other species than squid.

Table 6. Detected explosions at sites H, N, and P.
Site name, period analyzed, number of detected explosions and number of detected explosions per year in the SOCAL Range Complex from June 2012 to June 2017.

Site	Period Analyzed Days (Years)	Number of Explosion Detections	Number of Explosion Detections per year
H	1403 (3.84)	36,533	9,514
N	1295 (3.55)	11,784	3,319
P	715 (1.96)	6,361	3,245

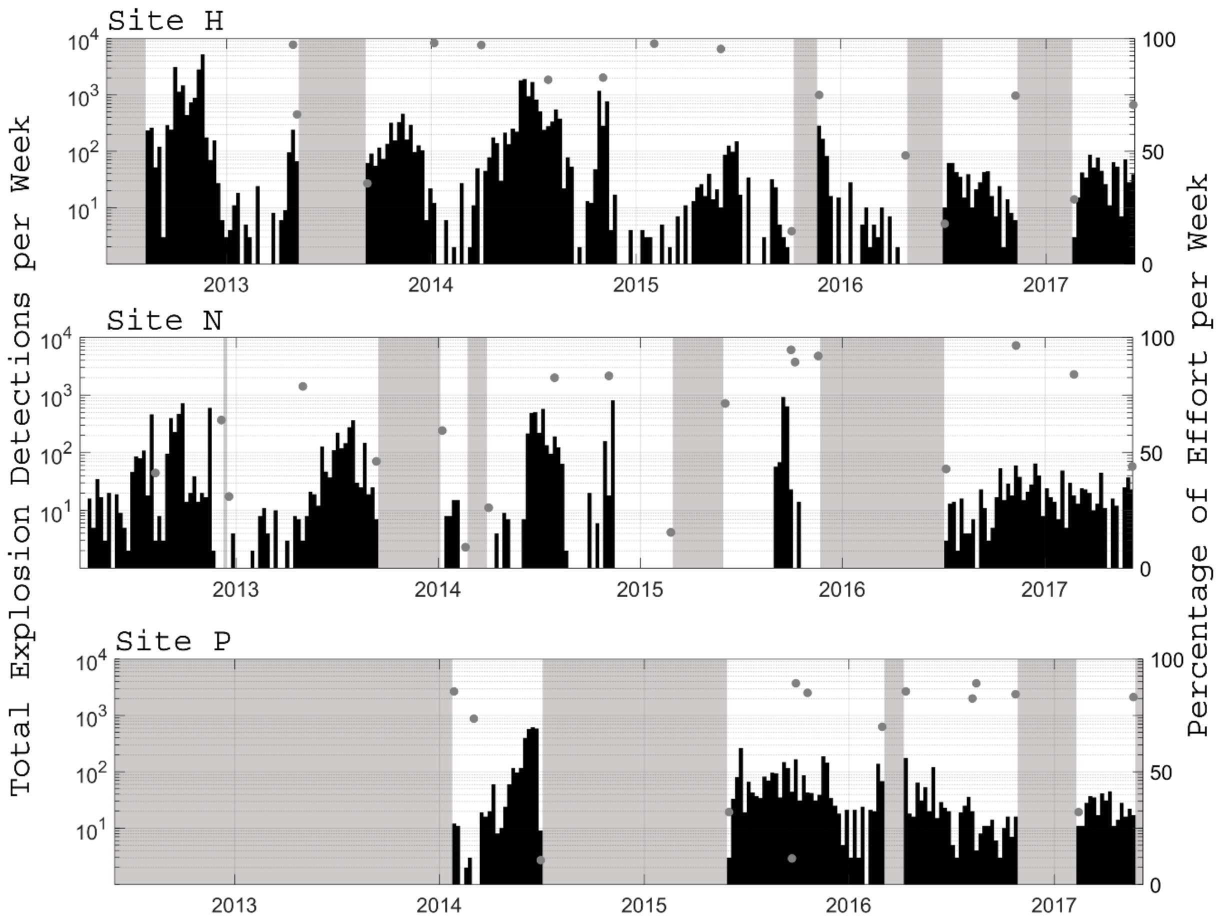

Figure 11. Explosion detections per week at sites H, N and P.
Gray dots represent percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week. Note vertical axis is logarithmic base-10 due to the wide range of weekly detections over the five year study period.

Conclusions

Underwater ambient and anthropogenic sounds were recorded at three sites in the SOCAL Range Complex over five years east, west and south of San Clemente Island at depths of around 500, 1000 and 1300 m, respectively. Although analysis of these recordings was reported previously, this report presents a summary including time series and levels of ambient ocean soundscape, MFA sonar and explosions.

Ambient soundscape varied by site based on exposure to different sound sources such as small vessels, large ships, wind and whales. Seasonal presence of both fin and blue whales, including lower presence during the 2014 – 2016 El Niño event, were observed at site H owing to its good signal-to-noise ratio. MFA sonar was detected at all three sites throughout the study period, with the highest CSELs, number of wave trains and packets, and percent days with MFA sonar at site N, and typically occurring during major naval exercises. Explosions were also detected at each site, with numbers highest at site H, but decreased for all sites over the five years of monitoring. Temporal characteristics of the majority of explosions suggest they were likely from ‘seal bombs’ used as pinniped deterrents in fishing operations.

Future work in the SOCAL Range Complex includes additional passive acoustic monitoring with HARPs to investigate long-term trends of ambient soundscape and anthropogenic sounds and how these sounds may affect marine mammals. Results from these studies will continue to be published in peer-reviewed journals.

Acknowledgements

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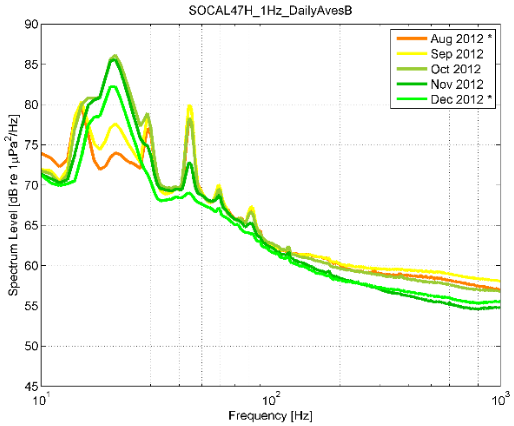
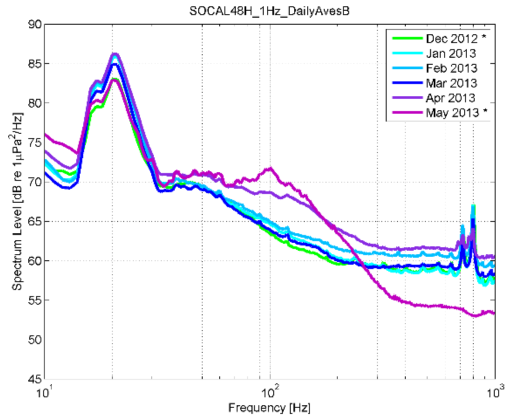
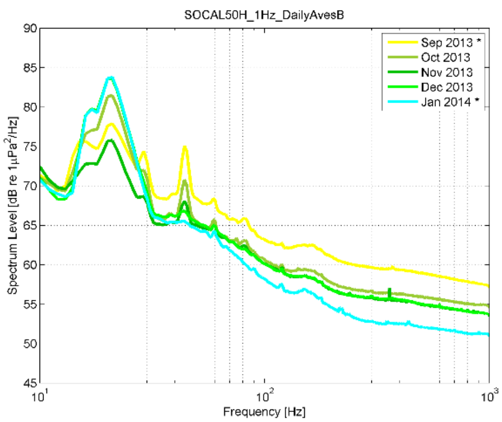
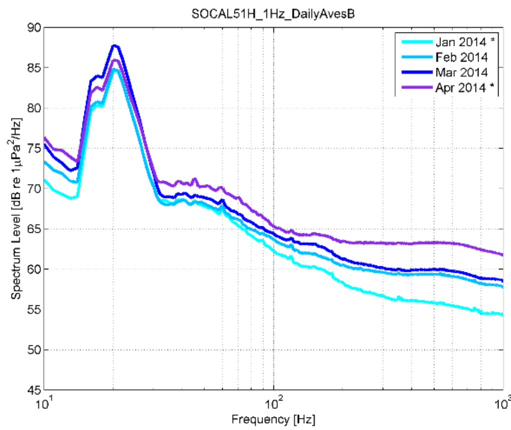
Appendix

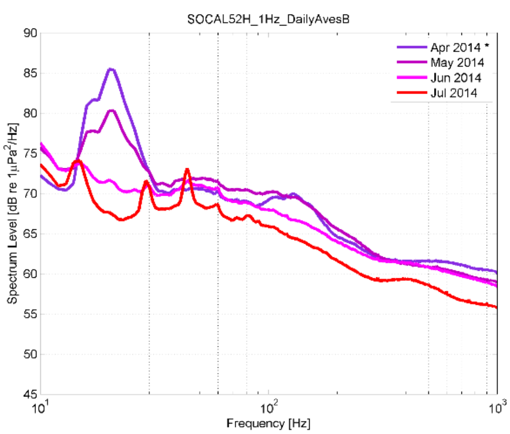
A. SOCAL Site H Monthly Sound Pressure Spectrum Levels – 1 Hz bins
Legend shows month color-code. Partial month effort denoted with *.

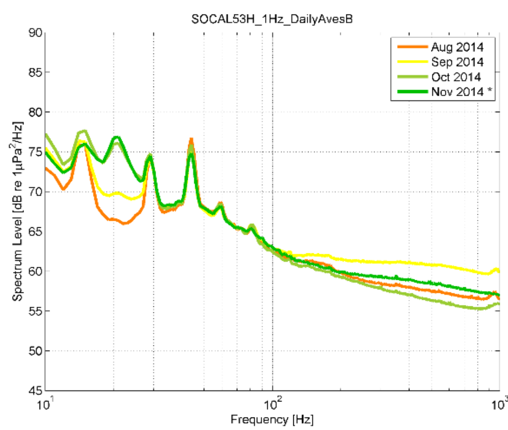


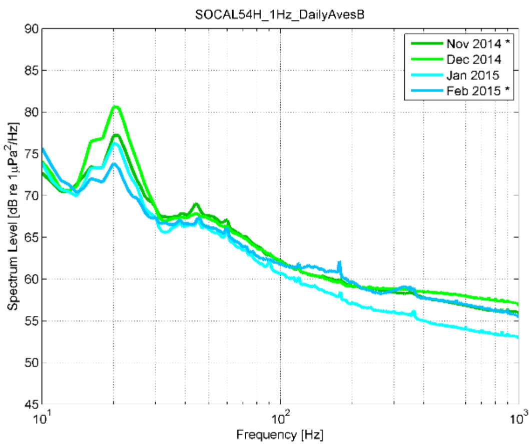








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Jan 2015
Feb 2015 *
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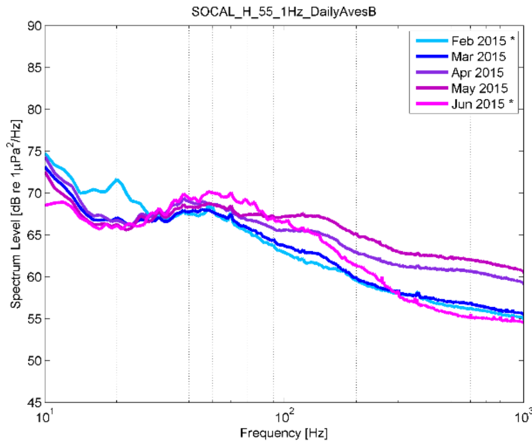
Frequency [Hz]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Jun 2015 *
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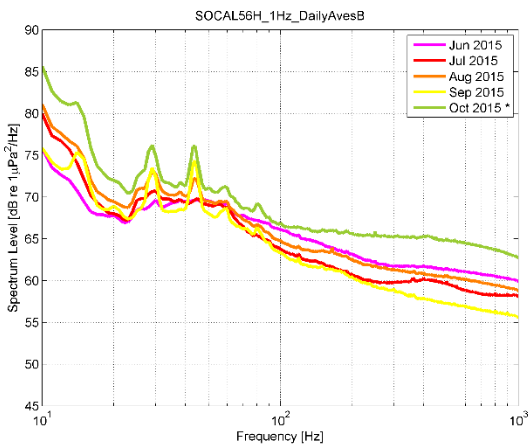
Frequency [Hz]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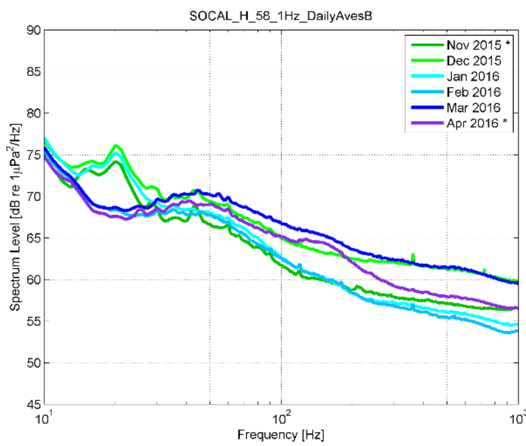
Jul 2015
Aug 2015
Sep 2015
Oct 2015 *
Spectrum Level [dB re 1μPa²/Hz]
Frequency [Hz]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Mar 2016
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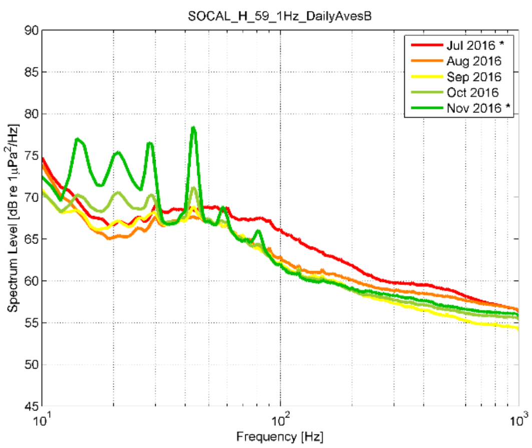
Frequency [Hz]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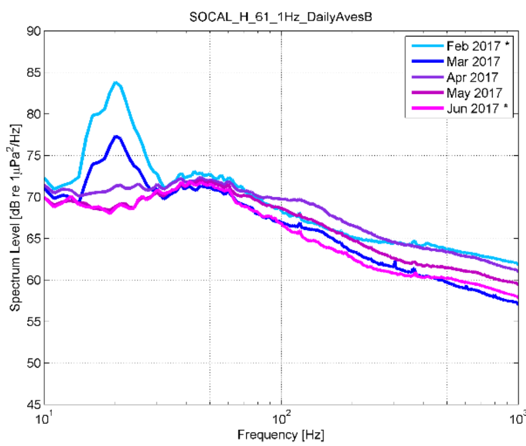
Frequency [Hz]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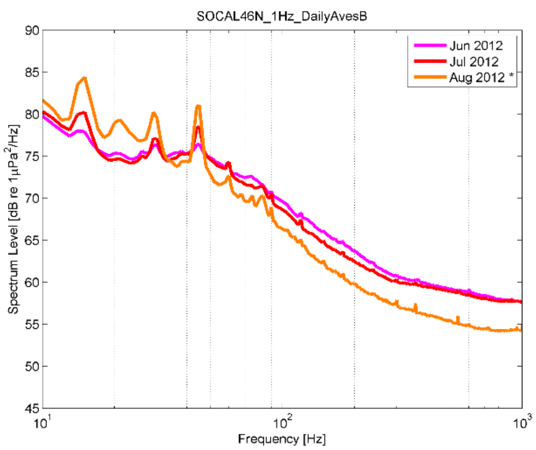
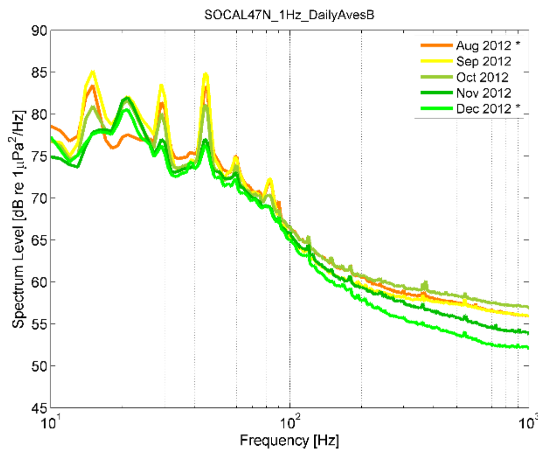
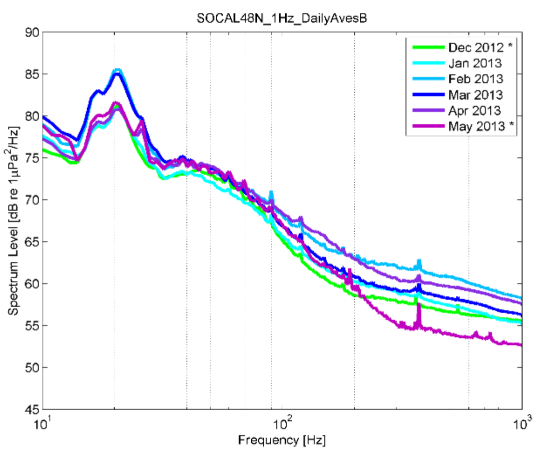
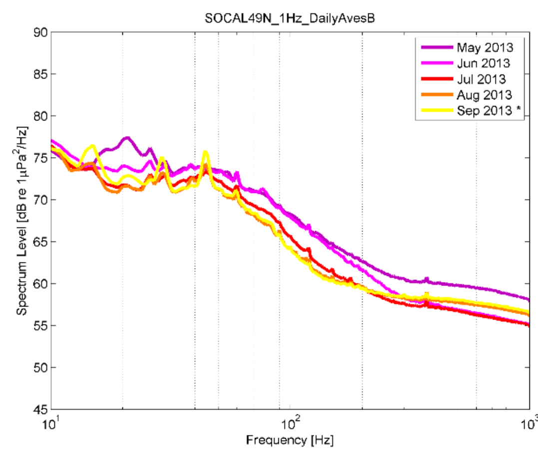
Mar 2017
Apr 2017
May 2017
Jun 2017 *
Spectrum Level [dB re 1μPa²/Hz]
Frequency [Hz]

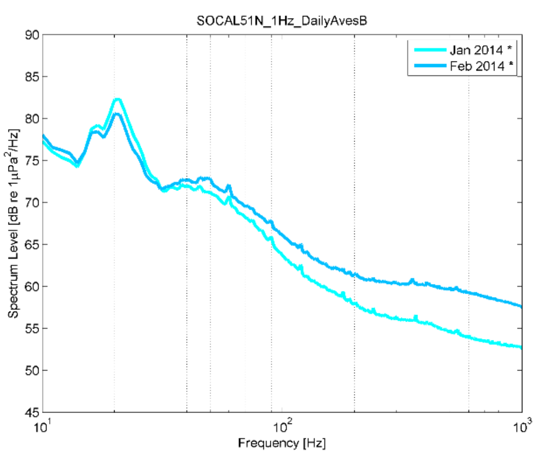
B. SOCAL Site N Monthly Sound Pressure Spectrum Levels – 1 Hz bins
Legend shows month color-code. Partial month effort denoted with *.

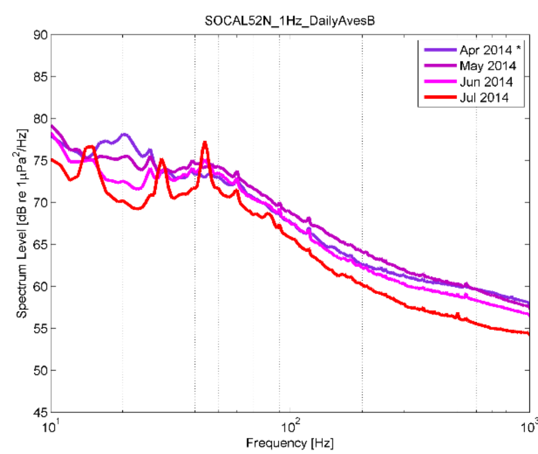


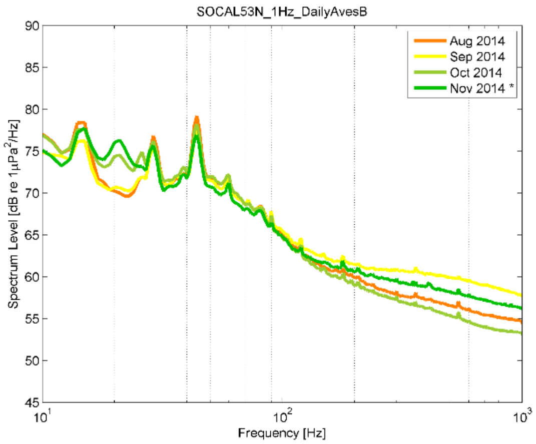








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Oct 2014
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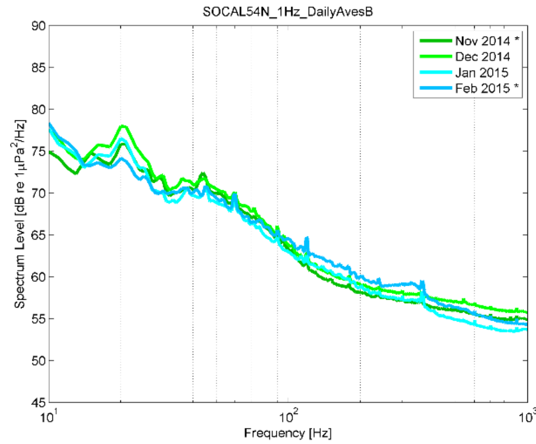
Frequency [Hz]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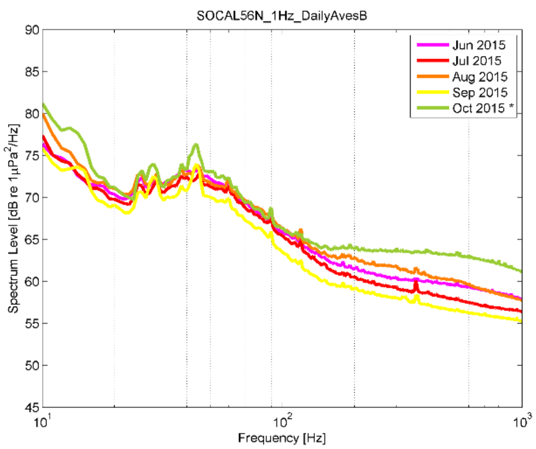
Frequency [Hz]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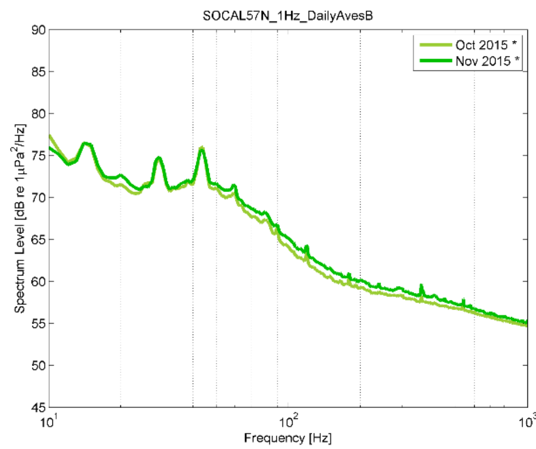
Frequency [Hz]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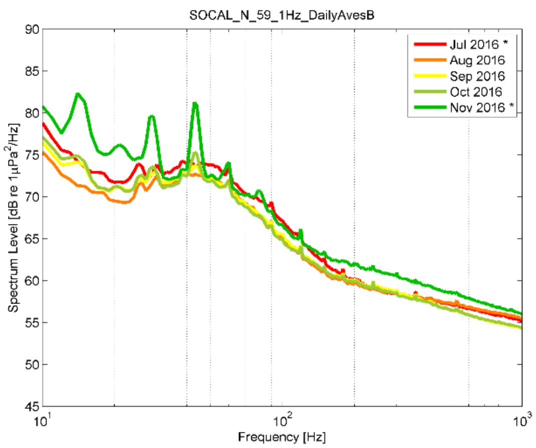
Frequency [Hz]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Nov 2016 *
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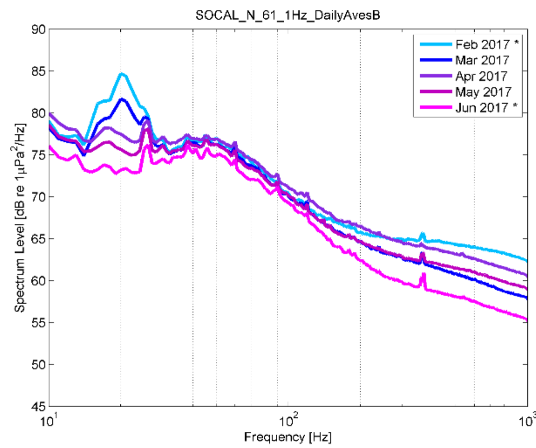
Frequency [Hz]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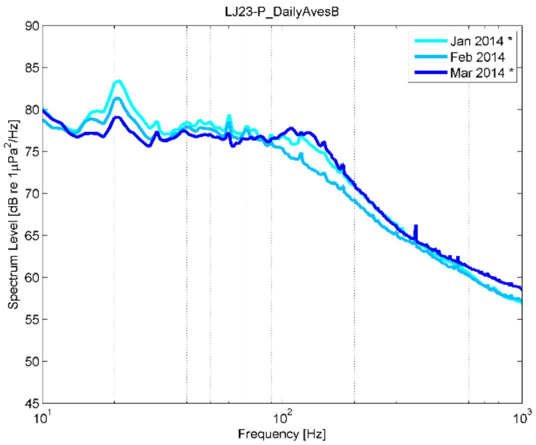
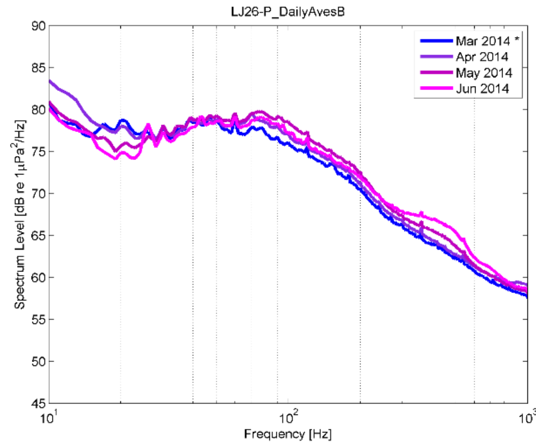
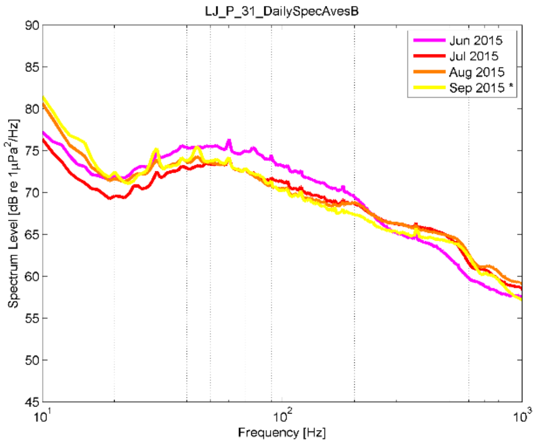
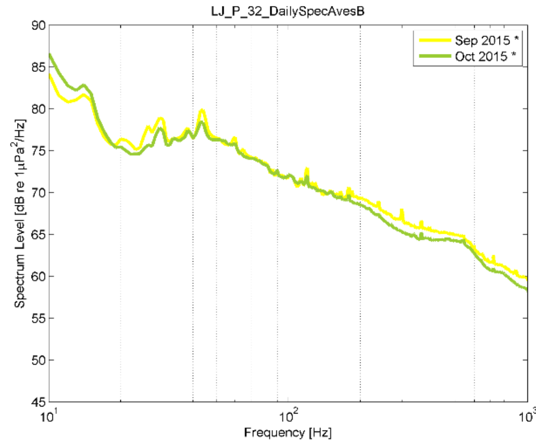
Feb 2017 *
Mar 2017
Apr 2017
May 2017
Jun 2017 *
Spectrum Level [dB re $1\mu Pa^2/Hz$]
Frequency [Hz]

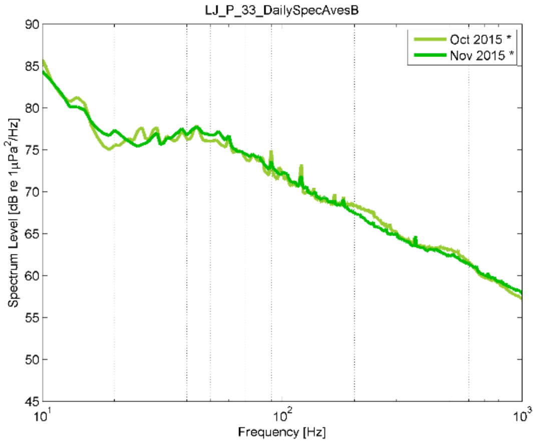
C. SOCAL Site P Monthly Sound Pressure Spectrum Levels – 1 Hz bins
Legend shows month color-code. Partial month effort denoted with *.

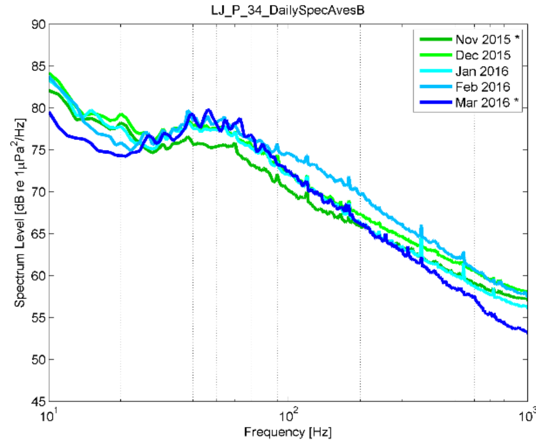


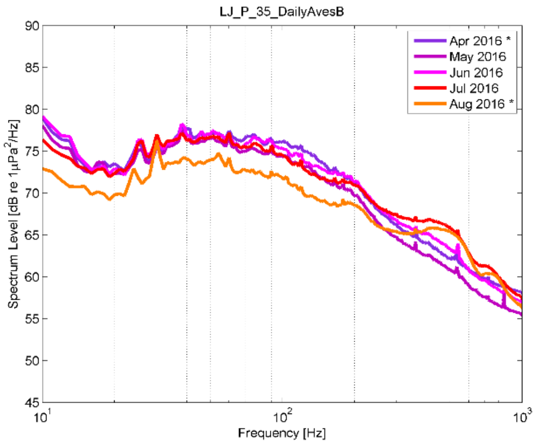








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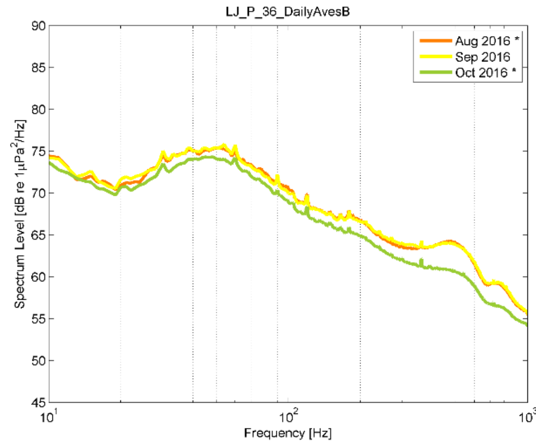
Spectrum Level [dB re 1μPa²/Hz]
Frequency [Hz]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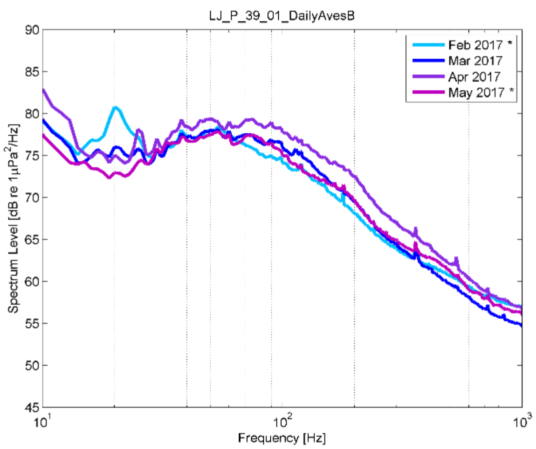
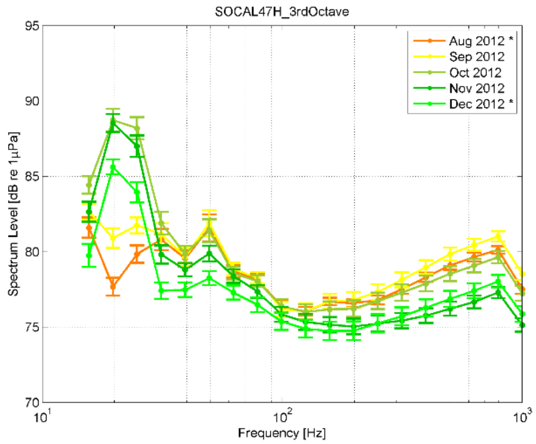
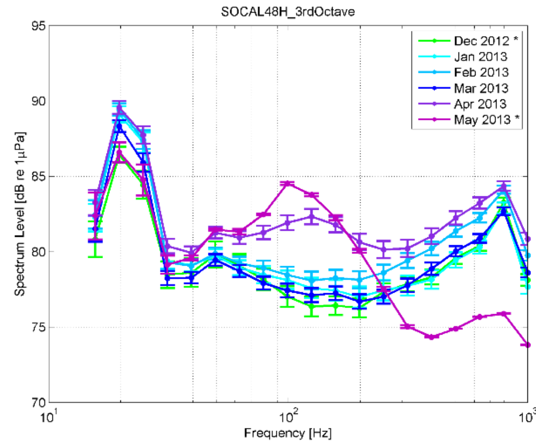
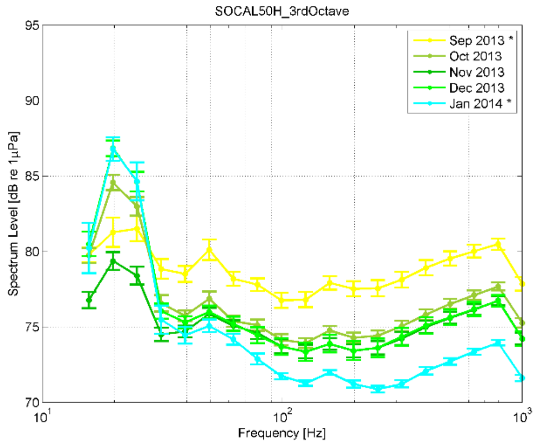
Frequency [Hz]

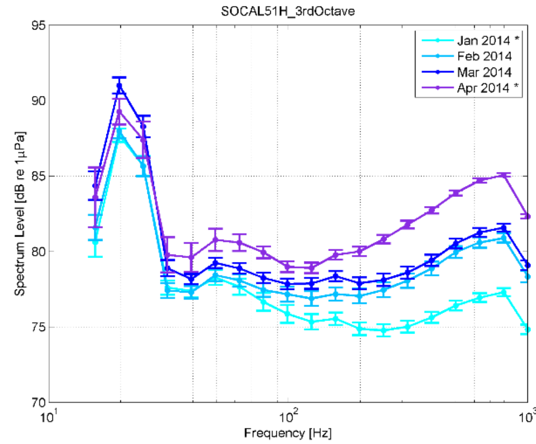

LJ_P_39_01_DailyAvesB
Feb 2017 *
Mar 2017
Apr 2017
May 2017 *
Spectrum Level [dB re 1μPa²/Hz]
Frequency [Hz]

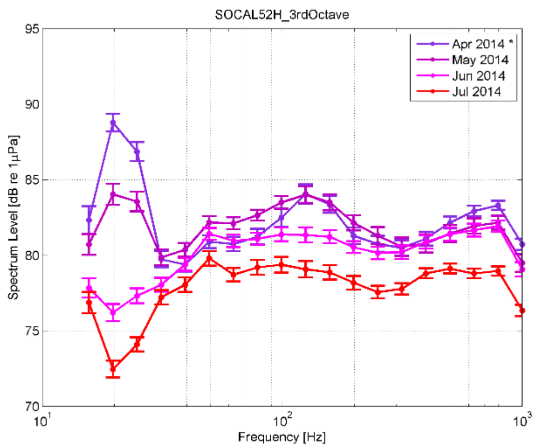
D. SOCAL Site H Monthly Sound Pressure Spectrum Levels – 1/3-octave bins
Legend shows month color-code. Partial month effort denoted with *. Error bars are standard error.

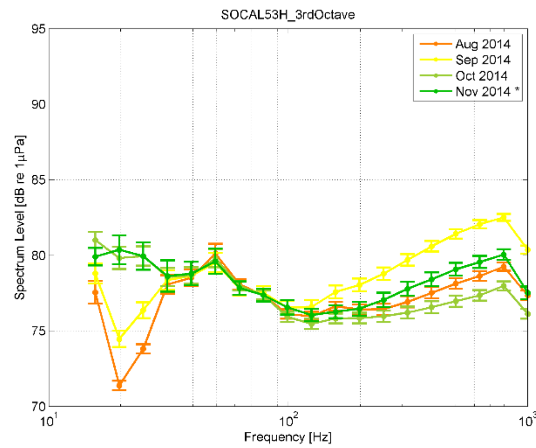


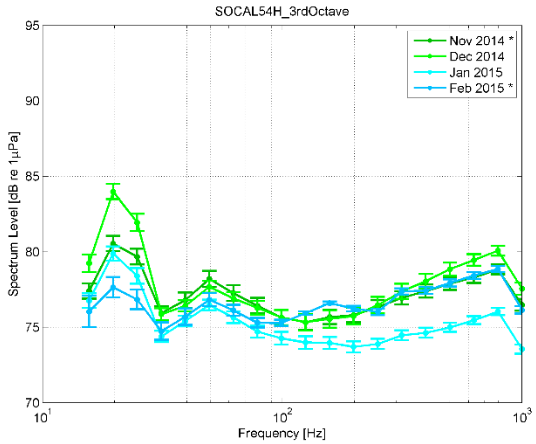


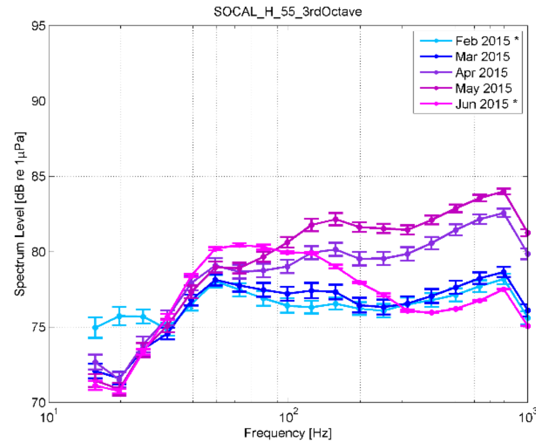


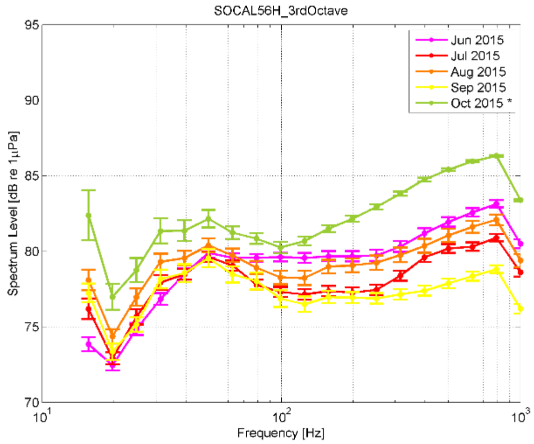


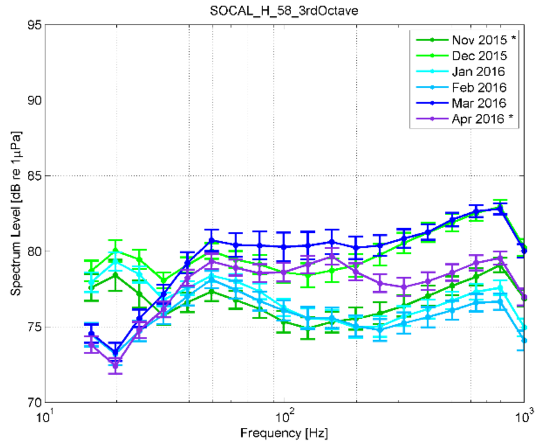


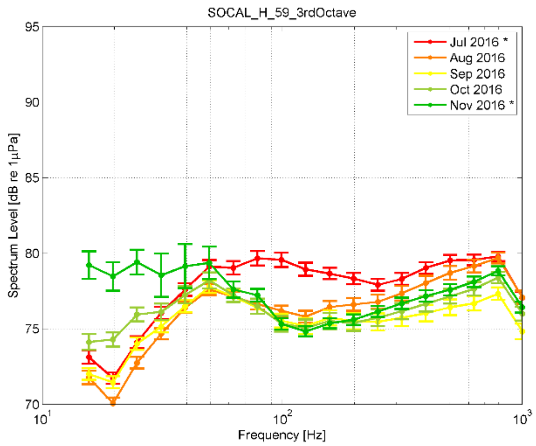


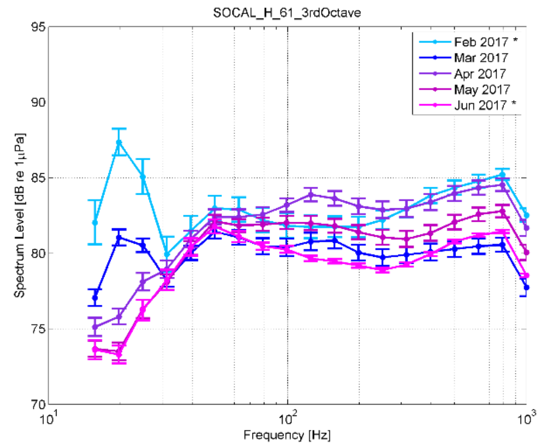

SOCAL54H_3rdOctave
Nov 2014 *
Dec 2014
Jan 2015
Feb 2015 *
Spectrum Level [dB re 1μPa]
Frequency [Hz]


SOCAL_H_55_3rdOctave
Feb 2015 *
Mar 2015
Apr 2015
May 2015
Jun 2015 *
Spectrum Level [dB re 1μPa]
Frequency [Hz]

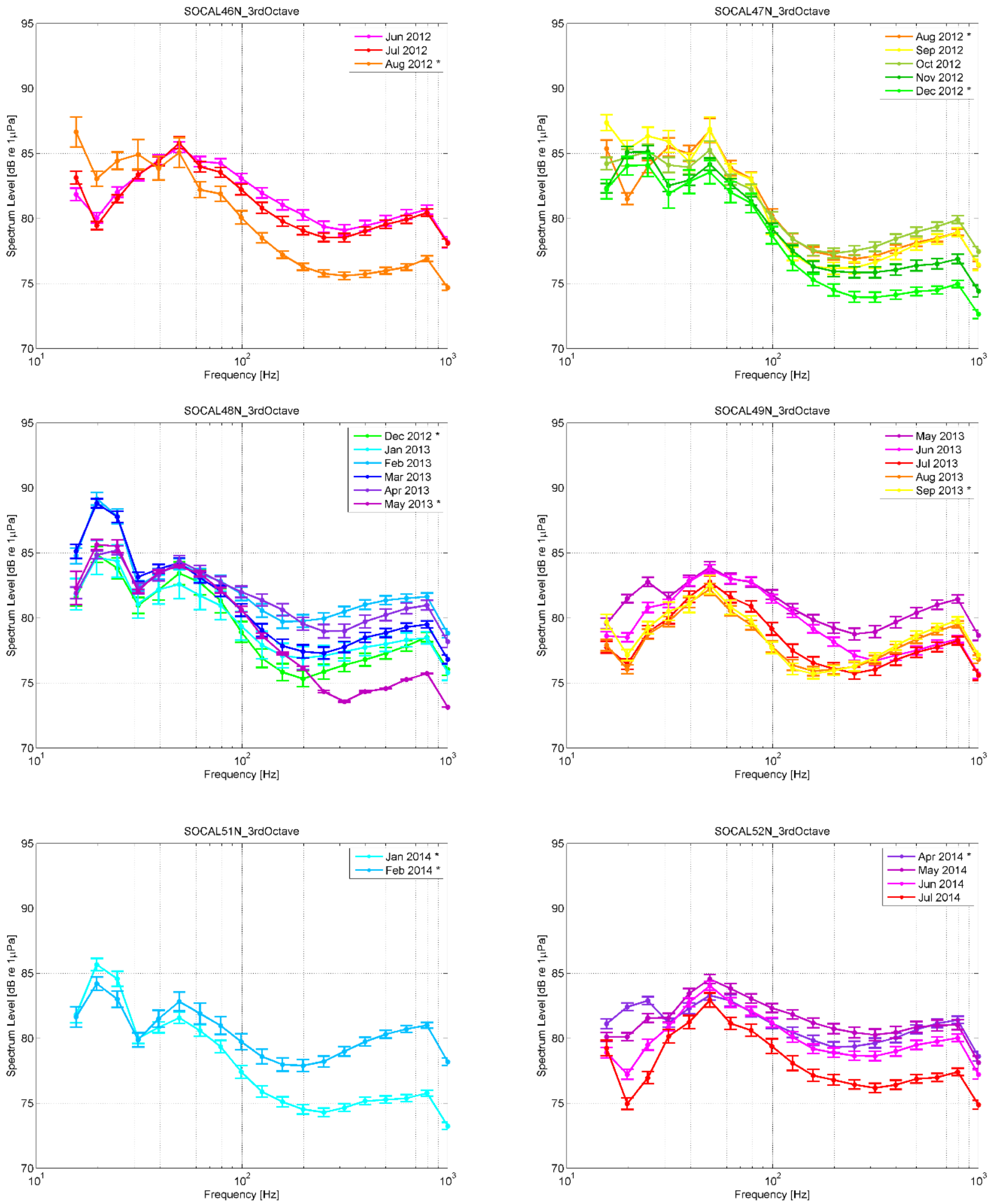

SOCAL56H_3rdOctave
Jun 2015
Jul 2015
Aug 2015
Sep 2015
Oct 2015 *
Spectrum Level [dB re 1μPa]
Frequency [Hz]

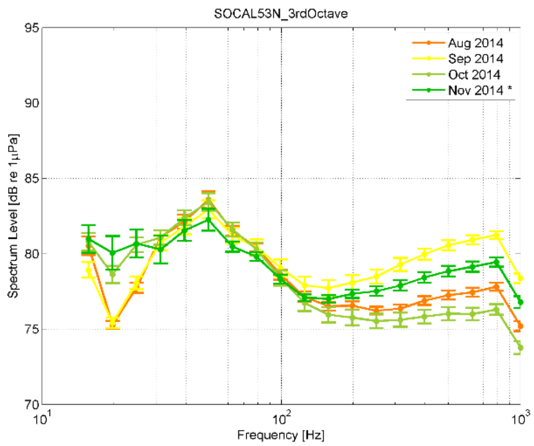

SOCAL_H_58_3rdOctave
Nov 2015 *
Dec 2015
Jan 2016
Feb 2016
Mar 2016
Apr 2016 *
Spectrum Level [dB re 1μPa]
Frequency [Hz]

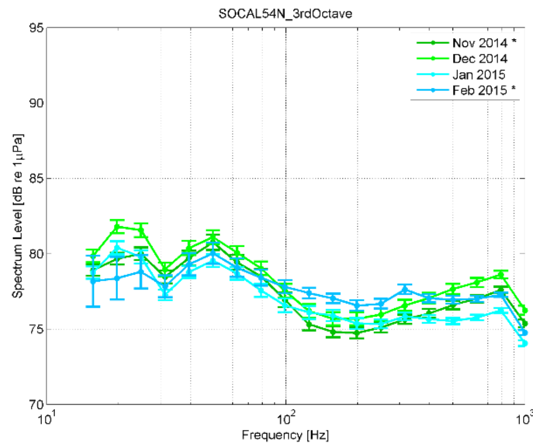

SOCAL_H_59_3rdOctave
Jul 2016 *
Aug 2016
Sep 2016
Oct 2016
Nov 2016 *
Spectrum Level [dB re 1μPa]
Frequency [Hz]

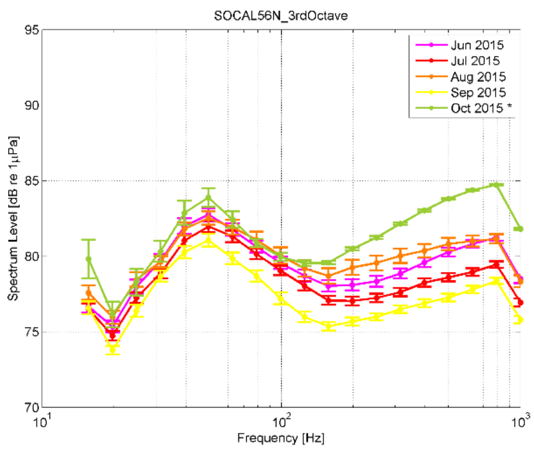

SOCAL_H_61_3rdOctave
Feb 2017 *
Mar 2017
Apr 2017
May 2017
Jun 2017 *
Spectrum Level [dB re 1μPa]
Frequency [Hz]

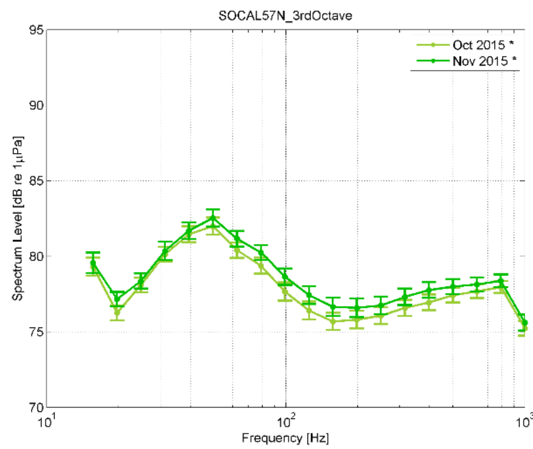
E. SOCAL Site N Monthly Sound Pressure Spectrum Levels – 1/3-octave bins.
Legend shows month color-code. Partial month effort denoted with *. Error bars are standard error.

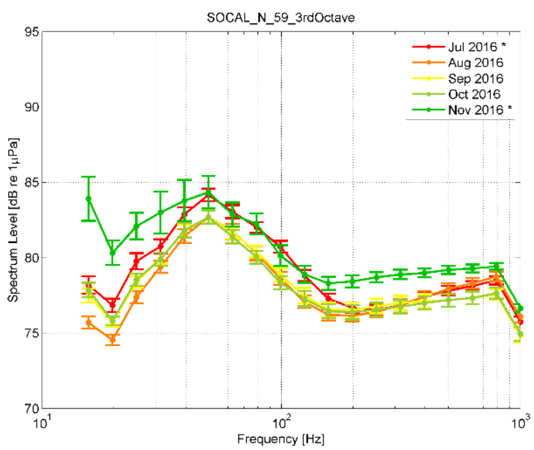


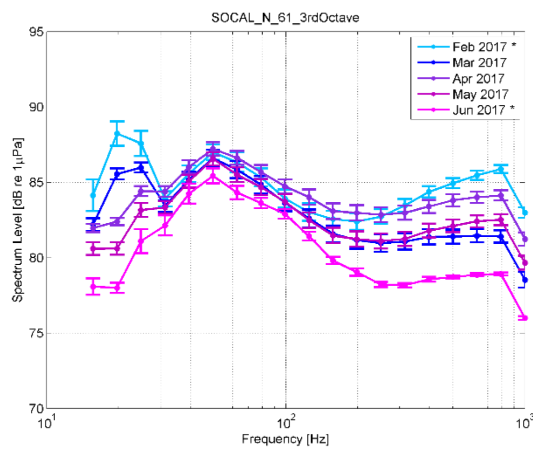

SOCAL53N_3rdOctave
Aug 2014
Sep 2014
Oct 2014
Nov 2014 *
Spectrum Level [dB re 1μPa]
Frequency [Hz]


SOCAL54N_3rdOctave
Nov 2014 *
Dec 2014
Jan 2015
Feb 2015 *
Spectrum Level [dB re 1μPa]
Frequency [Hz]

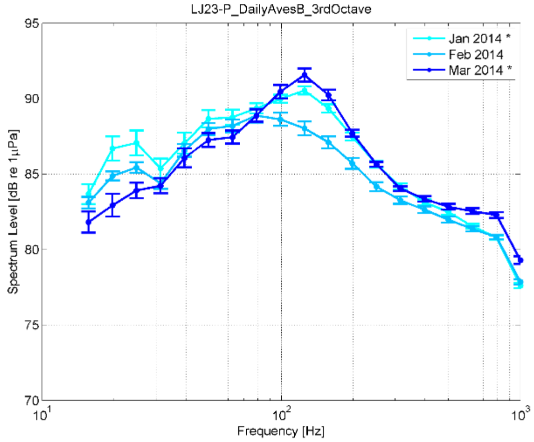

SOCAL56N_3rdOctave
Jun 2015
Jul 2015
Aug 2015
Sep 2015
Oct 2015 *
Spectrum Level [dB re 1μPa]
Frequency [Hz]

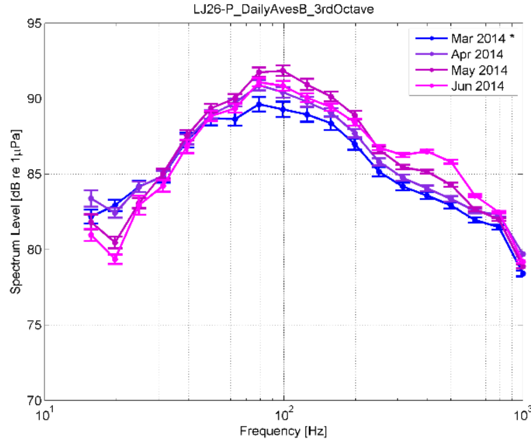

SOCAL57N_3rdOctave
Oct 2015 *
Nov 2015 *
Spectrum Level [dB re 1μPa]
Frequency [Hz]

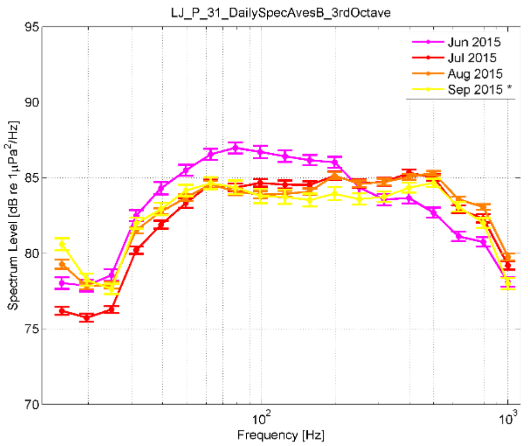

SOCAL_N_59_3rdOctave
Jul 2016 *
Aug 2016
Sep 2016
Oct 2016
Nov 2016 *
Spectrum Level [dB re 1μPa]
Frequency [Hz]

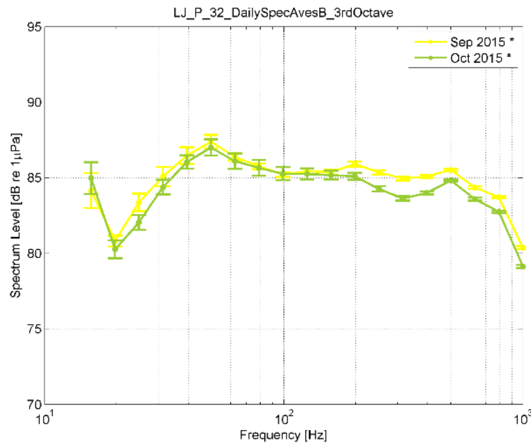

SOCAL_N_61_3rdOctave
Feb 2017 *
Mar 2017
Apr 2017
May 2017
Jun 2017 *
Spectrum Level [dB re 1μPa]
Frequency [Hz]

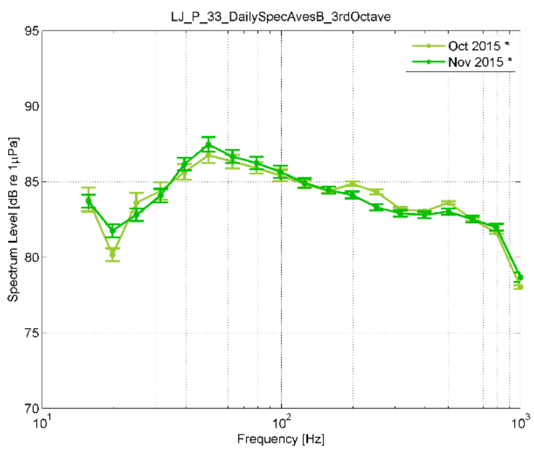
F. SOCAL Site P Monthly Sound Pressure Spectrum Levels – 1/3-octave bins.
Legend shows month color-code. Partial month effort denoted with *. Error bars are standard error.

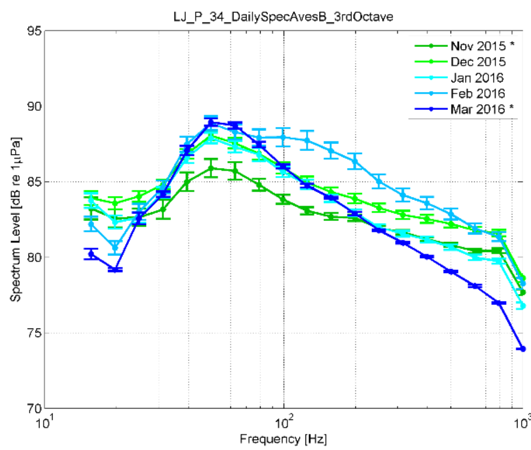


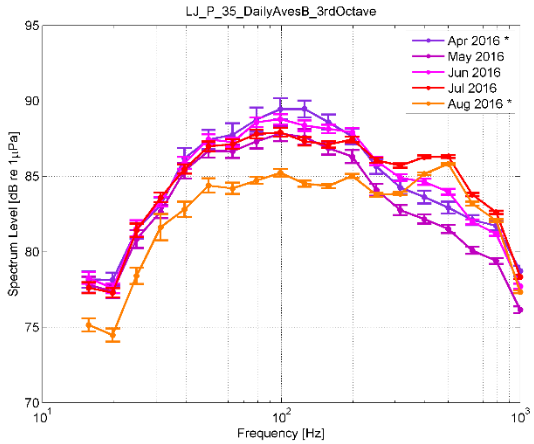


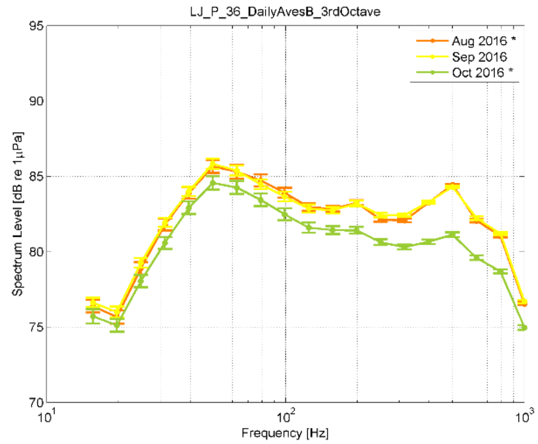


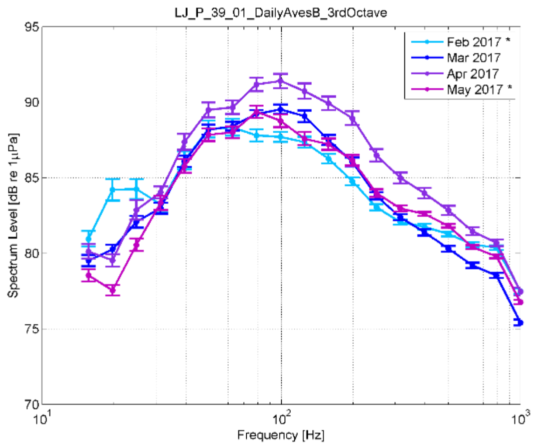







LJ_P_35_DailyAvesB_3rdOctave
Apr 2016 *
May 2016
Jun 2016
Jul 2016
Aug 2016 *
Spectrum Level [dB re 1μPa]
Frequency [Hz]


LJ_P_36_DailyAvesB_3rdOctave
Aug 2016 *
Sep 2016
Oct 2016 *
Spectrum Level [dB re 1μPa]
Frequency [Hz]


LJ_P_39_01_DailyAvesB_3rdOctave
Feb 2017 *
Mar 2017
Apr 2017
May 2017 *
Spectrum Level [dB re 1μPa]
Frequency [Hz]