Marine Physical Laboratory of the Scripps Institution of Oceanography University of California, San Diego

WHALE ACOUSTICS LABORATORY

Passive Acoustic Monitoring of Marine Mammals Offshore of Diablo Canyon November 2012 – March 2013

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Baird's Beaked Whale (*Berardius bairdii*)
Photo Credit: Katherine Whitaker

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Table of Contents

Executive Summary

Two High-Frequency Acoustic Recording Packages (HARPs) were deployed from November 2012 to March 2013 to record marine mammal sounds and study the environmental impacts of offshore geophysical surveys planned near the Diablo Canyon Power Plant. One HARP was deployed on the seafloor at approximately at 100 m in shallow water to collect full-bandwidth recordings of harbor porpoises and coastal bottlenose dolphins. A second HARP was deployed at approximately 1,000 m depth to monitor the full range of marine mammal species present within the vicinity of the Diablo Canyon seismic survey. The analysis conducted in this report focuses on the second HARP deployed for a variety of marine mammal species. The HARP recorded sound in the frequency band 10 Hz–100 kHz. Data analysis consisted of analyst-scans of long-term spectral averages (LTSAs) and spectrograms. Three frequency bands were analyzed for marine mammal vocalizations: (1) Low-frequency, between 10–500 Hz, (2) Mid-frequency, between 500–5,000 Hz, and (3) High-frequency, between 5–100 kHz. The low-frequency ambient soundscape and the presence of Mid-Frequency Active (MFA) sonar were also analyzed.

Ambient sound levels had spectral peaks along with lower frequency harmonics at 45-47 Hz from November to December, related to blue whale B calls. Prominent peaks in sound spectrum levels observed in the frequency band 15-30 Hz during winter are related to seasonally increased presence of fin whale calls.

Three baleen whale species were recorded: blue, fin, and humpback whales. Fin whales were detected throughout the monitoring period with higher activity from November to December 2012. Blue whale B and D calls were found in high numbers from November 2012 to January 2013. Humpback whale call types were detected throughout the recording period, but began to decrease starting in February 2013.

Several known odontocete signals were detected. Cuvier’s beaked whales were detected in low numbers throughout the monitoring period. Baird’s beaked whales were detected in low numbers in November and December 2012. Two acoustically identifiable delphinid species were Risso’s dolphins and Pacific White-Sided dolphins, whose echolocation clicks occurred between early February and March 2013. Sperm whales were detected intermittently throughout the recording period but were highest in December 2012. Unidentified odontocete clicks greater than 20 kHz were detected throughout the monitoring period and peaked in December 2012.

Project Background

The Diablo Canyon site is located in the offshore waters of the Pacific Ocean, adjacent to the San Luis Obispo County shoreline. Seismic surveys were planned for the offshore region of the Diablo Canyon Power Plant (DCPP) to help delineate nearby fault zones. A diverse group of marine mammals are known to be present in the proposed project area including species listed under the Endangered Species Act (ESA). Stocks of marine mammals are known to use the study area for migration and as their preferred habitat. This report documents the analysis of data recorded by a High-Frequency Acoustic Recording Packages (HARP) that was deployed at Diablo Canyon and collected data from November 2012 to March 2013 (Figure 1).

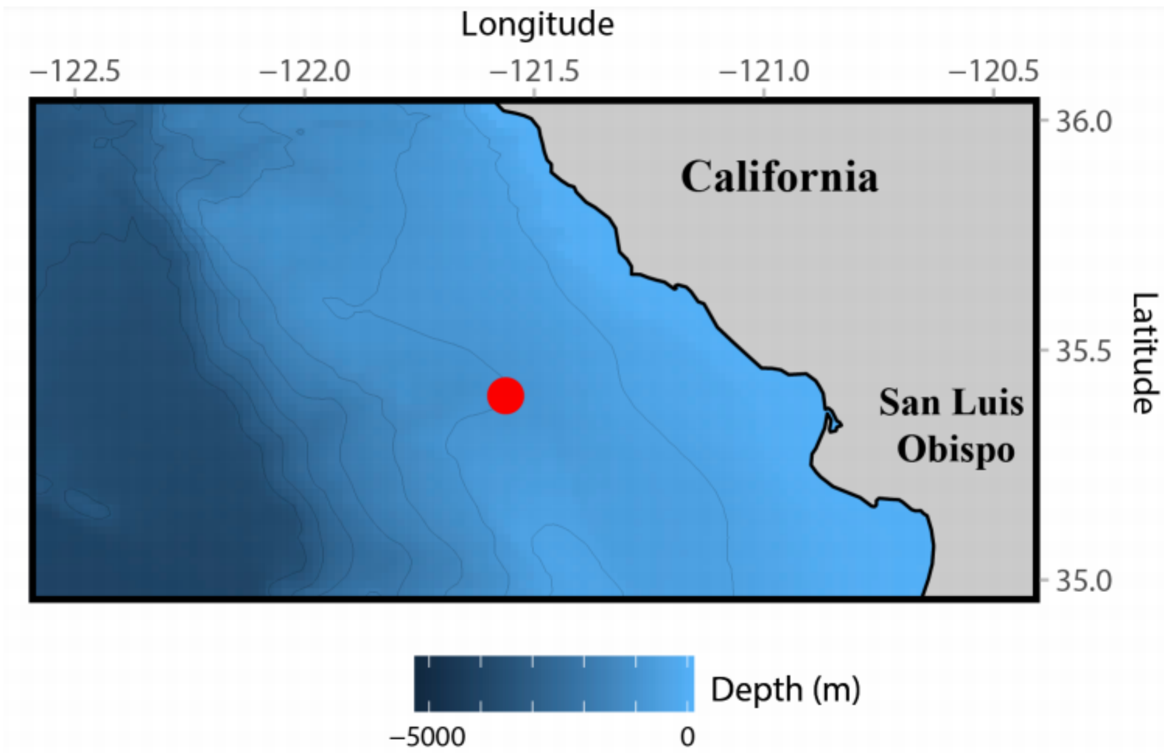

Figure 1. Location of the High-Frequency Acoustic Recording Packages (HARP) at site DCPP01C located at 35° 24.000 N, 121° 33.750 W, depth 1,000 m deployed in the Diablo Canyon study area from November 2012 to March 2013.

Methods

High-Frequency Acoustic Recording Package (HARP)

HARPs are autonomous underwater acoustic recording packages that can record sounds over a bandwidth from 10 Hz up to 160 kHz and are capable of approximately a year of continuous data storage. The HARPs were deployed in a small mooring configuration with the hydrophone suspended approximately 22 m above the seafloor. Each HARP is calibrated in the laboratory to provide a quantitative analysis of the received sound field. Representative data loggers and hydrophones were also calibrated at the Navy's TRANSDEC facility to verify the laboratory calibrations (Wiggins and Hildebrand, 2007).

Data Collected

One HARP recorded from November 2012 to March 2013 at DCPP at Site C and sampled continuously at 200 kHz to provide 100 kHz of effective bandwidth. The instrument (35° 24.000 N, 121° 33.750 W, depth 1,000 m) recorded for 132 days from November 7, 2012 to March 19, 2013.

Data Analysis

Recording over a broad frequency range of 10 Hz to 100 kHz allows detection of the low-frequency ambient soundscape, baleen whales (mysticetes), and toothed whales (odontocetes). Analysis was focused on the following species: blue whales (*Balaenoptera musculus*), fin whales (*B. physalus*), humpback whales (*Megaptera novaeangliae*), killer whales (*Orcinus orca*), Cuvier's beaked whales (*Ziphius cavirostris*), Baird's beaked whales (*Berardius bairdii*), Risso's dolphins (*Grampus griseus*), Pacific White-Sided dolphins (*Lagenorhynchus obliquidens*), and sperm whales (*Physeter macrocephalus*). Individual blue whale B calls, D calls, and Cuvier's beaked whale echolocation clicks were detected automatically using computer algorithms. Presence of fin whale 20 Hz calls was detected using an energy detection method and is reported as a daily average, termed the 'fin whale acoustic index' (Širović *et al.*, 2015). Detections of Risso's dolphins, Pacific White-Sided dolphins, odontocete echolocation clicks, sperm whales, and Baird's beaked whales were detected manually. Details of all detection methods are described below.

We summarize acoustic data collected at DCPP Site C from November 2012 to March 2013. We discuss seasonal occurrence and relative abundance of calls for different species that were consistently identified in the recordings.

Low-Frequency Ambient Soundscape

To determine ambient sound levels, HARP recordings were decimated by a factor of 100 to provide an effective bandwidth of 10 Hz to 1 kHz from which Long-Term Spectral Averages (LTSAs) were constructed with 1 Hz frequency and 5 s temporal resolution. Daily spectra were computed by averaging 5 each, 5 s sound pressure spectrum levels calculated from each 75 s acoustic record. System self-noise due to disk drive activation was excluded from these averages.

Low-Frequency Marine Mammals

The Diablo Canyon site is inhabited by a wide array of low-frequency baleen whale species, particularly including blue whales (*Balaenoptera musculus*) and fin whales (*B. physalus*). In addition, North Pacific right whales (*Eubalaena japonica*) may infrequently appear in this region (Josephson *et al.*, 2008, Širović *et al.*, 2014). For the low-frequency data analysis (10–500 Hz), the 200 kHz sampled raw data were decimated by a factor of 100 for an effective bandwidth of 1 kHz. LTSAs were created using a time average of 5 s and frequency bins of 1 Hz.

By examining low frequency sound, the detection range for marine mammal calls, such as those of blue whales and fin whales, may extend to ranges of ~100 km or more (Širović *et al.*, 2015). The limitation for their detection range is often based on the interaction of the sound with a shallow bathymetric feature. In the case of DCPP Site C, a greater detection range will be experienced for animals located further offshore, where the water depths are generally deep and increasing in depth, versus inshore locations where the water depth is becoming shallow.

Blue whale B and D calls were automatically detected using the spectrogram correlation and general power law methods, respectively, described below. Fin whale 20 Hz calls were detected automatically using an energy detection method and are reported as a daily average termed the ‘fin whale acoustic index’. A manual search for North Pacific right whale up calls was undertaken by scrutiny of LTSAs and spectrograms in the custom software program Triton.

Blue Whales

Blue whales produce a variety of calls worldwide (McDonald *et al.*, 2006). Calls recorded in the eastern North Pacific include the Northeast Pacific blue whale B call (Figure 2) and the D call (Figure 3). Northeast Pacific blue whale B calls are geographically distinct and potentially associated with mating functions (McDonald *et al.*, 2006; Oleson *et al.*, 2007). They are low-frequency (fundamental frequency <20 Hz), long duration (> 10 s) calls that are often produced in regularly repeated sequences. D calls are downswept in frequency (approximately 100-40 Hz) with a duration of several seconds. These calls are similar worldwide and are associated with feeding animals; they may be produced as call-counter call between multiple animals (Oleson *et al.*, 2007).

Northeast Pacific Blue Whale B Calls

Blue whale B calls (Figure 2) were detected automatically using spectrogram correlation (Mellinger and Clark, 1997). The detection kernel was based on frequency and temporal characteristics measured from 30 calls recorded in the data set, each call separated by at least 24 hours. The kernel was comprised of four segments, three 1.5 s and one 5.5 s long, for a total duration of 10 s.

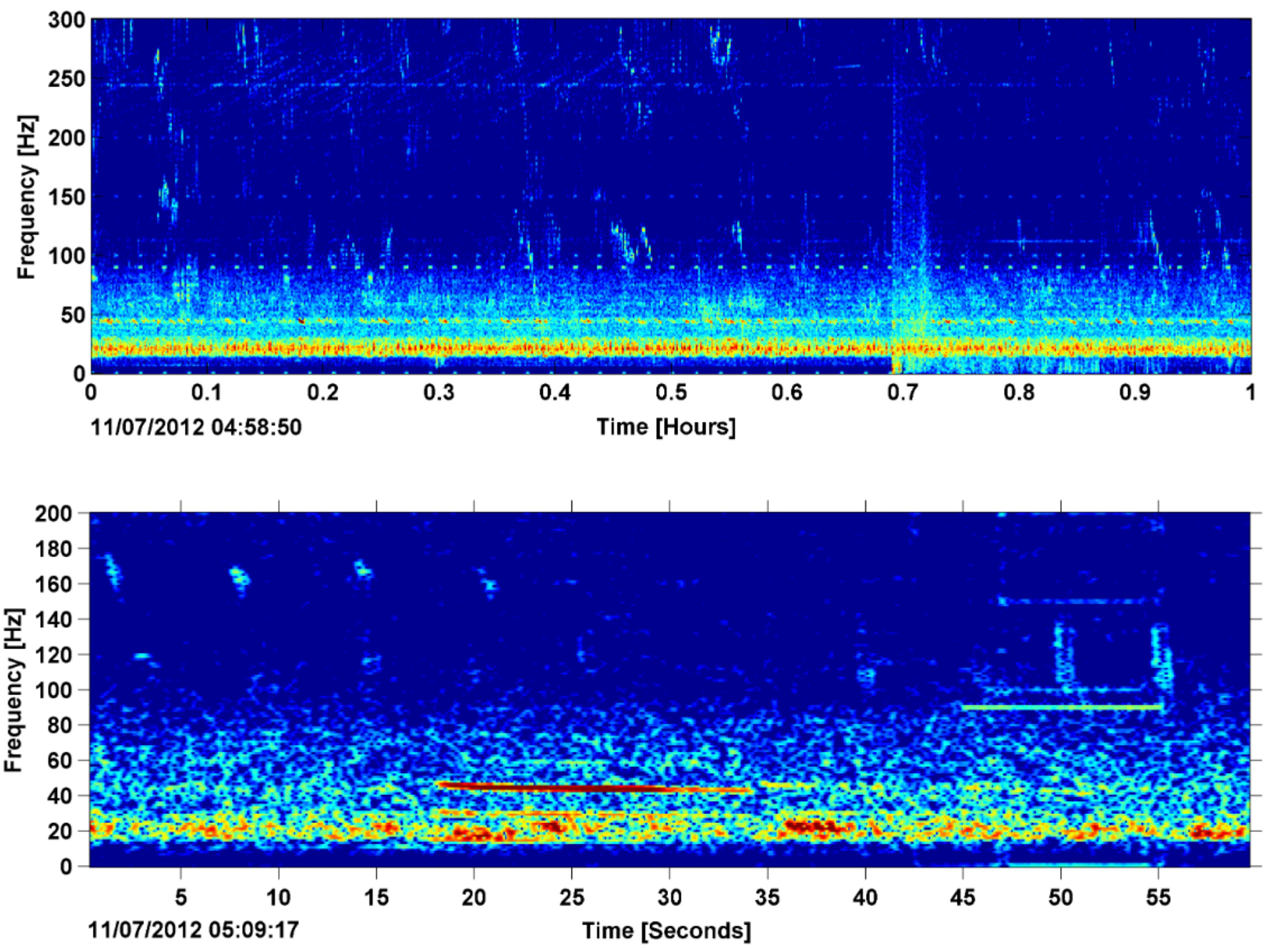

Figure 2. Northern Pacific blue whale B calls (just below 50 Hz) in Long-Term Spectral Average (LTSA; top) and spectrogram (bottom) at the DCPP Site C, November 2012.

Blue Whale D Calls

Blue whale D calls were detected using an automatic algorithm based on the generalized power law (Helble *et al.*, 2012). This algorithm was adapted for the detection of D calls by modifying detection parameters that included the frequency space over which the detector operates. A trained analyst subsequently verified the detections (Figure 3).

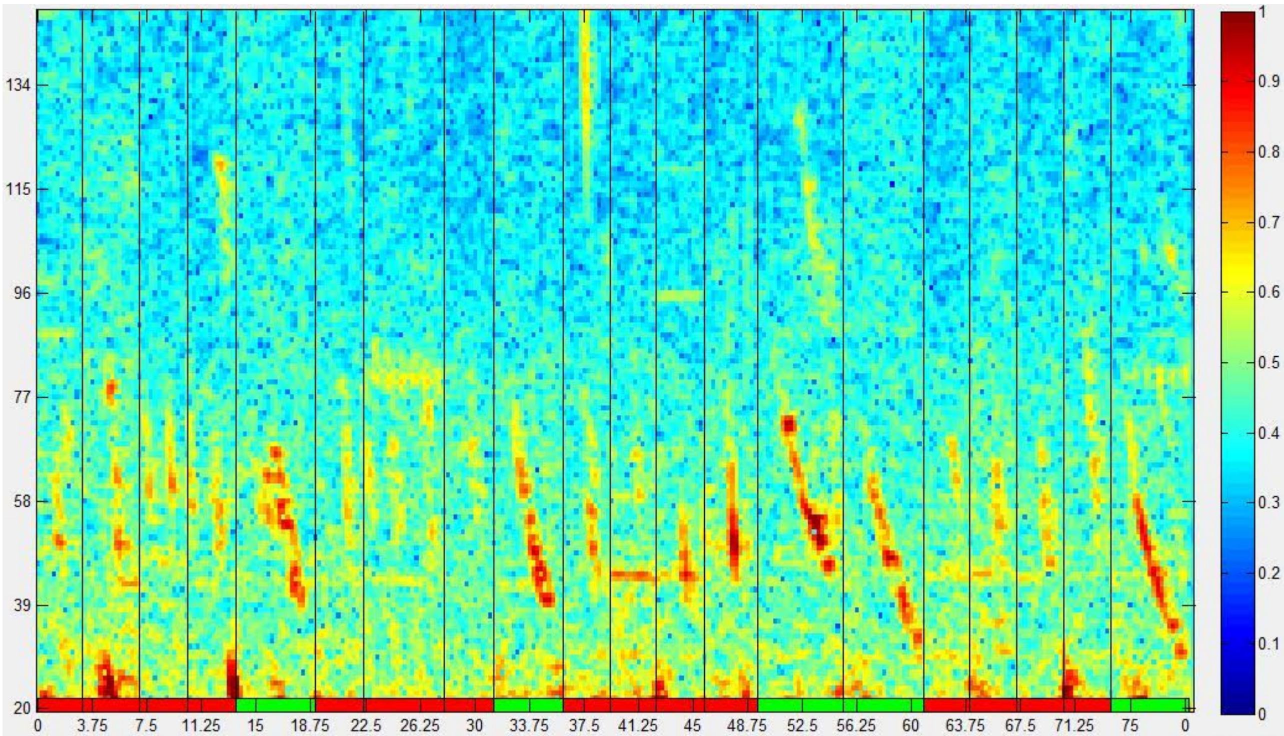

Figure 3. Blue whale D calls from DCPP Site C in the analyst verification stage of the detector. Green along the bottom evaluation line indicates true detections and red indicates false detections.

Fin Whales

Fin whales produce two types of short (approximately 1 s duration), low-frequency calls. The most common is a frequency downsweep from 30 to 15 Hz, called 20 Hz calls (Watkins, 1981; Figure 4) The 20 Hz calls can occur at regular intervals as song (Thompson *et al.*, 1992; Oleson *et al*. 2014), or irregularly as call counter-calls among multiple, traveling animals (McDonald *et al.*, 1995). The second call is frequency downswept from 75 to 40 Hz, designated as 40 Hz calls (Širović et al., 2012). The 40 Hz calls most often occur in irregular patterns (Wiggins and Hildebrand, 2020).

Fin Whale 20 Hz Calls

In the Diablo Canyon study area, fin whale 20 Hz calls are so abundant that it is often impossible to distinguish, and therefore detect, individual calls (Watkins *et al.*, 2000; Širović *et al.*, 2015). Therefore, fin whale 20 Hz calls (Figure 4) were detected automatically using an energy detection method (Širović *et al.*, 2015). The method uses a difference in acoustic energy between signal and noise, calculated from a long-term spectral average (LTSA) over 5 s with 1 Hz frequency resolution. The frequency at 22 Hz was used as the signal frequency (Nieukirk *et al.*, 2012; Širović *et al.*, 2015), while noise was calculated as the average energy between 10 and 34 Hz. The resulting ratio is termed 'fin whale acoustic index' and is reported as a daily average. All calculations were performed on a logarithmic scale.

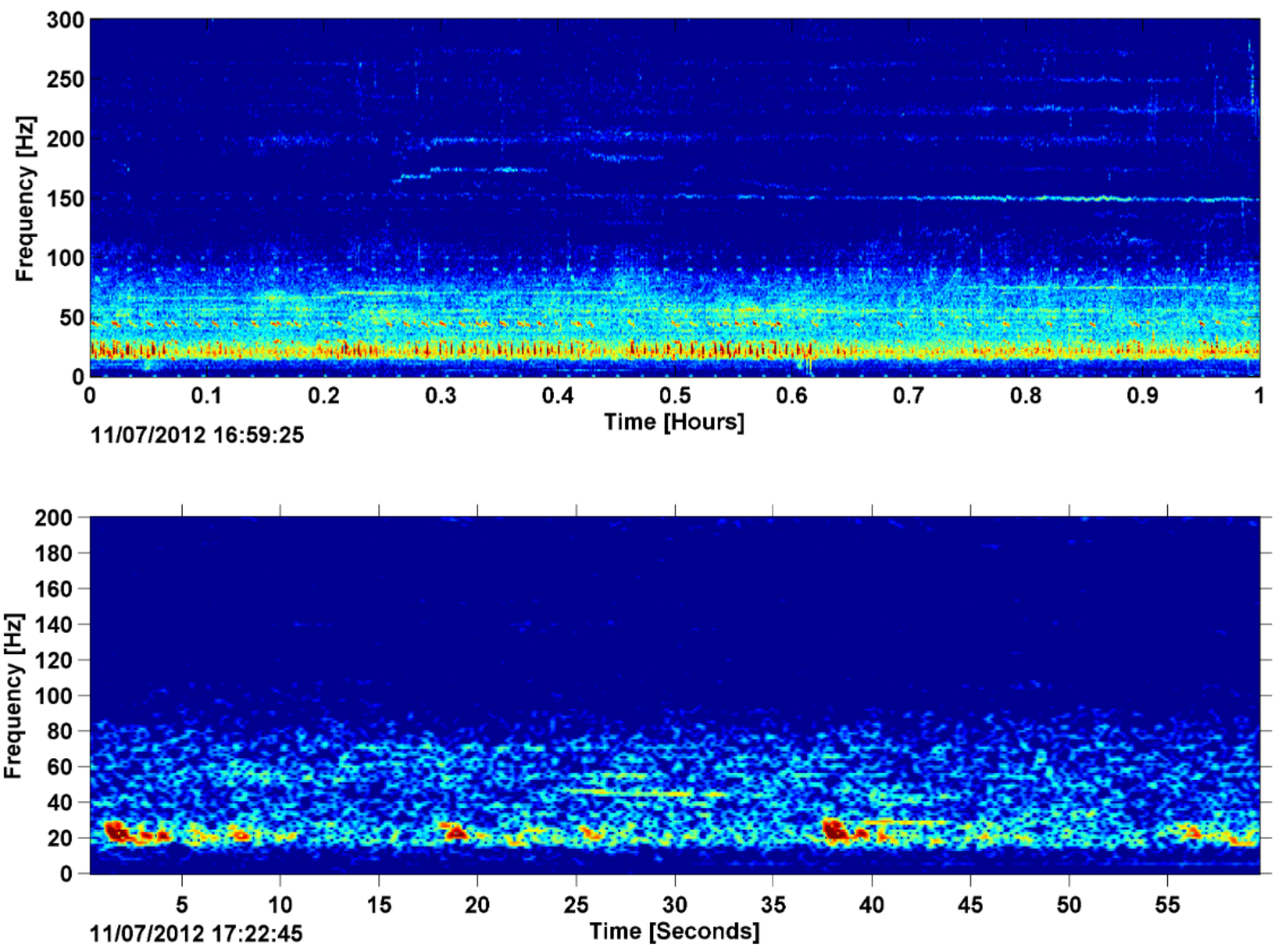

Figure 4. Fin whale 20 Hz call in LTSA (top) and spectrogram (bottom) at DCPP Site C, November 2012.

North Pacific Right Whales

Historical whaling activities are responsible for the near extirpation of the eastern population of the North Atlantic right whale, making it difficult to detect in eastern Pacific waters (NMFS 2006). These whales make a variety of sounds, the most common of which is the up call (Figure 5). The up call typically sweeps from about 90 to 150 Hz or as high as 200 Hz, and has a duration of approximately 1 s (McDonald and Moore, 2002).

North Pacific Right Whale Up Calls

For the manual detection of North Pacific right whale up calls, the LTSA frequency was set to display between 1-300 Hz with a 1-hour plot length. To observe individual calls, the spectrogram window was typically set to display 1-200 Hz with a 60 s plot length. The FFT was generally set between 1500 and 2000 data points, yielding about a 1 Hz frequency resolution, with a 90% overlap. When a potential call of interest was identified in the LTSA or spectrogram, it's presence during that hour was logged. No North Pacific right whale up calls were detected during this recording period.

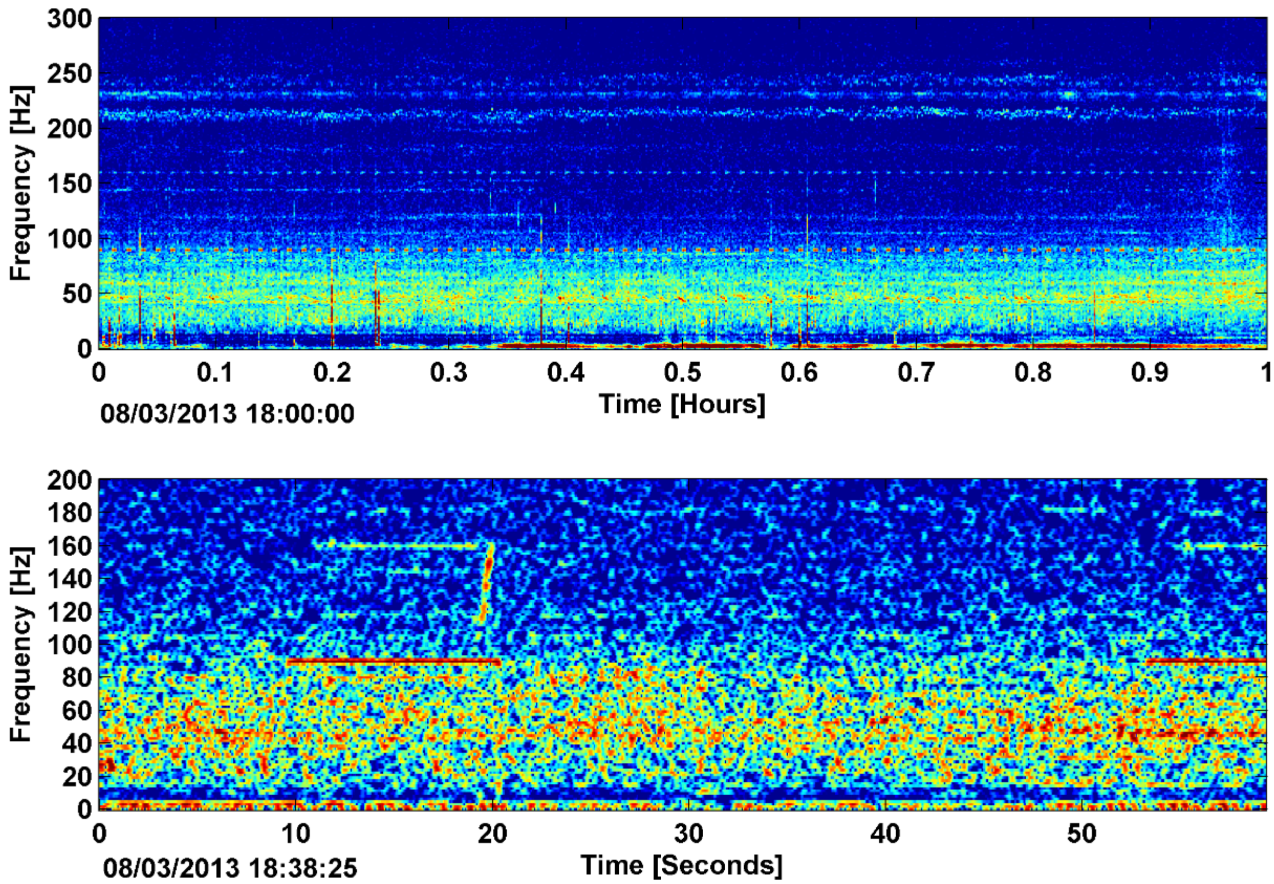

Figure 5. North Pacific right whale up call in the LTSA (top) and spectrogram (bottom) recorded in the Gulf of Alaska, August 2013.

Mid-Frequency Marine Mammals

Humpback whales *(Megaptera novaeangliae)* and killer whales (*Orcinus orca*) were the only marine mammal species at Diablo Canyon Site C with calls in the mid-frequency range (500–5,000 Hz) monitored for this report. We detected humpback whale calls using an automatic detection algorithm based on the generalized power law (Helble *et al.*, 2012). The detections were subsequently verified for accuracy by a trained analyst. When humpback calls were identified, they were logged according to the start time and end time of the encounter. An encounter was considered to end when there were no calls for 30 min or more. The encounter durations were added to estimate cumulative hourly presence.

Humpback Whales

Humpback whales produce both song (Figure 6) and non-song calls. The song is categorized by the repetition of units, phrases, and themes for a variety of calls as defined by Payne & McVay (1971). Non-song vocalizations such as social and feeding sounds consist of individual units that can last from 0.15 to 2.5 seconds (Dunlop *et al.*, 2007; Stimpert *et al.*, 2011). Most humpback whale vocalizations are produced between 100 - 3,000 Hz. There was no effort to separate song and non-song calls in our analysis.

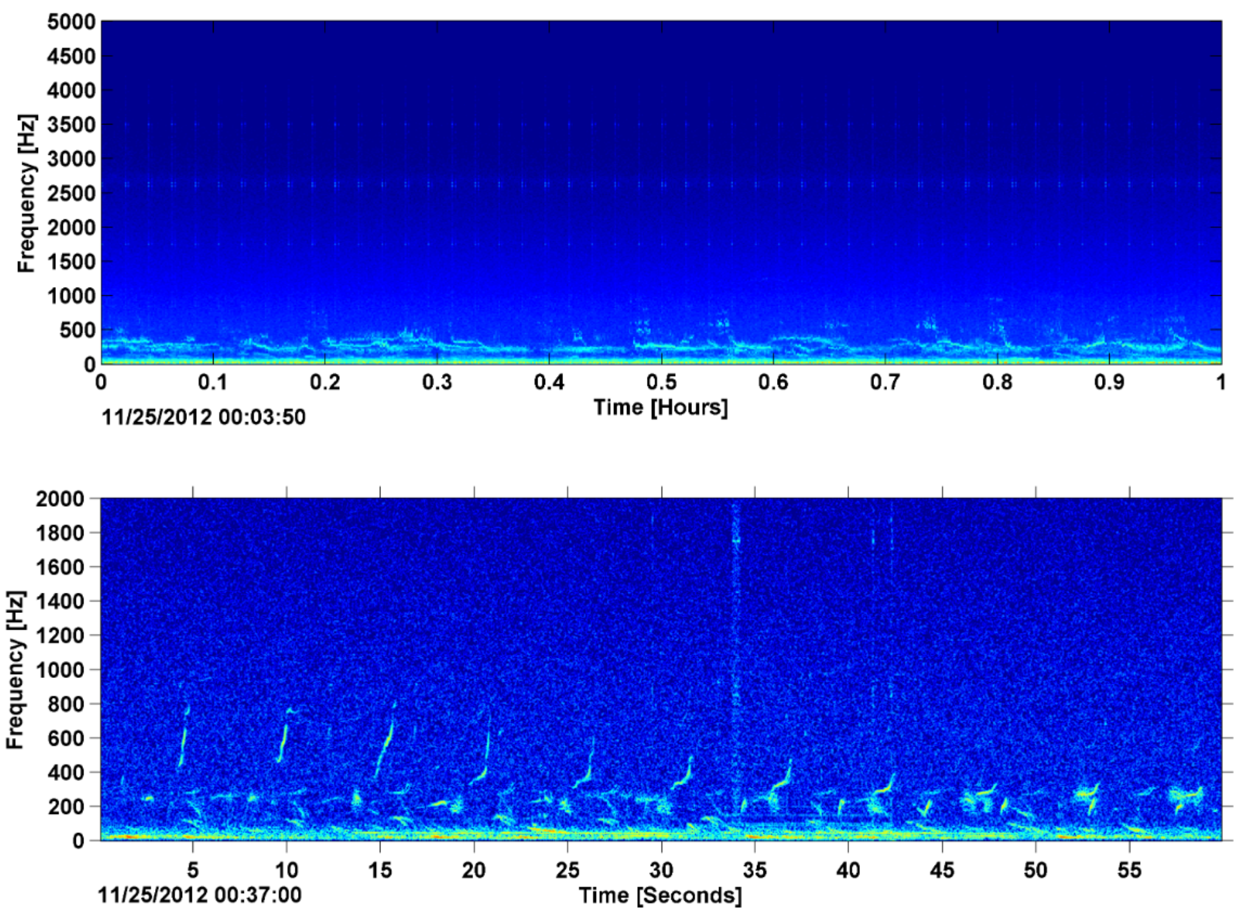

Figure 6. Humpback whale song calls in the LTSA (top) and spectrogram (bottom) recorded at DCPP Site C, November 2012.

Killer Whales

Killer whales are known to produce four call types: pulsed calls, low-frequency whistles, echolocation clicks, and high-frequency modulated (HFM) signals (Ford 1989, Samarra *et al.* 2010, Simonis *et al.* 2012). Killer whale pulsed calls are well documented and are the best described of all killer whale call types (Figure 7). The primary energy of pulsed calls is between 1 and 6 kHz, with high frequency components occasionally >30 kHz and duration primarily between 0.5 and 1.5 seconds (Ford & Fisher 1983; Ford 1989). HFM signals have only recently been attributed to killer whales in both the Northeast Atlantic (Samarra *et al.* 2010) and the North Pacific (Filatova *et al.* 2012, Simonis *et al.* 2012), and have fundamental frequencies between 17 and 75 kHz, the highest of any known delphinid tonal calls. Killer whale whistles and pulsed calls were detected via manual scanning of the recordings.

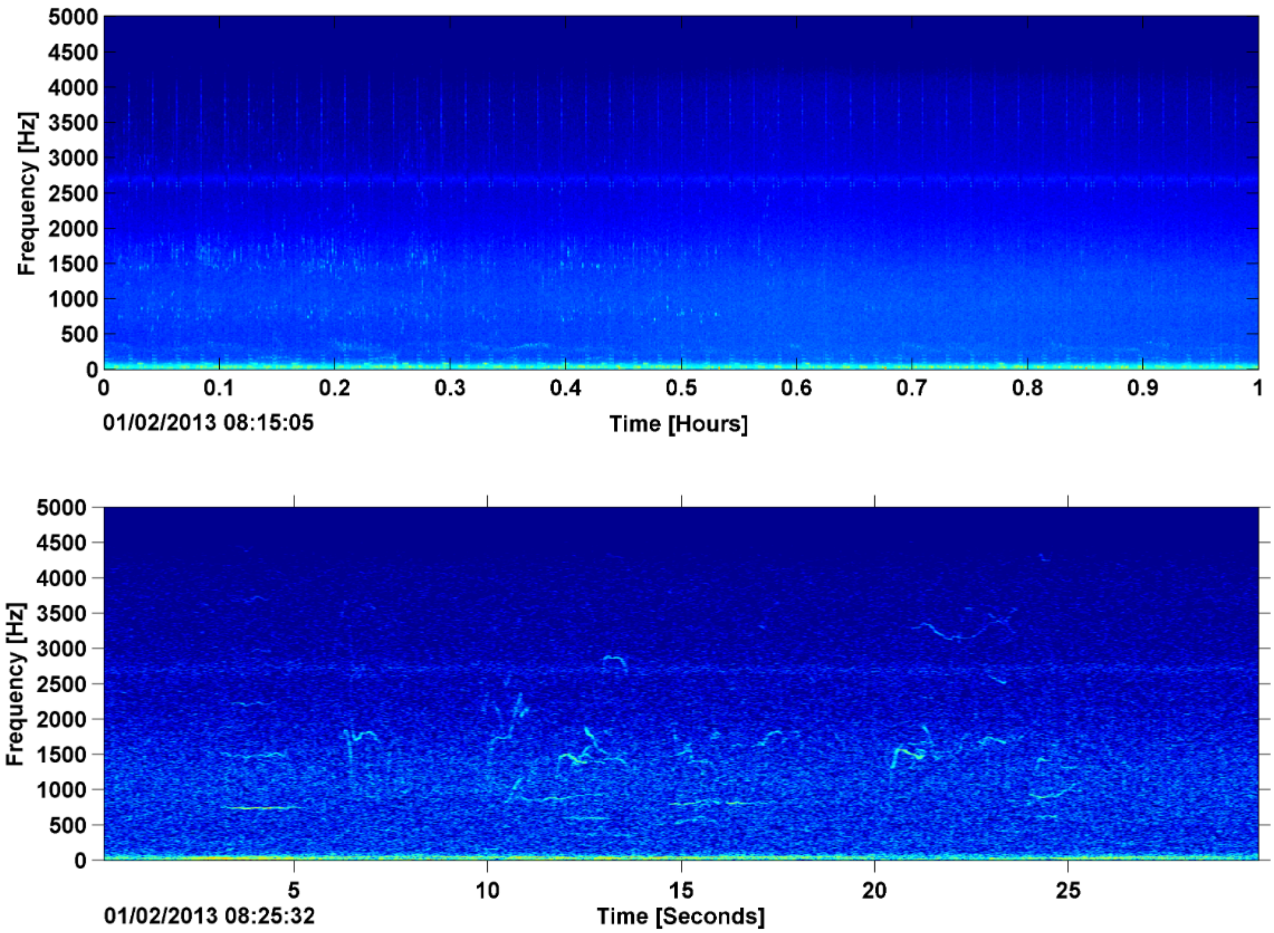

Figure 7. Killer whale calls in the LTSA (top) and spectrogram (bottom) recorded at DCPP Site C, January 2013.

High-Frequency Marine Mammals

Marine mammal species with sounds in the high-frequency range (5–100 kHz) and possibly found in the Diablo Canyon include harbor porpoises (*Phocoena phocoena*), Dall's porpoise (*Phocoenoides dalli*), Pacific white-sided dolphins (*Lagenorhynchus obliquidens*), Risso's dolphins (*Grampus griseus*), Northern right whale dolphin (*Lissodelphis borealis*), bottlenose dolphins (*Tursiops truncatus*), short-beaked common dolphins (*Delphinus delphis*), long-beaked common dolphin (*Delphinus capensis*), Striped dolphin (*Stenella coeruleoalba*), short-finned pilot whale (*Globicephala macrorhynchu*), pygmy killer whales (*Feresa attenuata*), melon-headed whales (*Peponocephala electra*), sperm whales (*Physeter macrocephalus*), dwarf sperm whales (*Kogia sima*), Cuvier's beaked whales (*Ziphius cavirostris*), Baird's beaked whales (*Berardius bairdii),* Blainville's (*Mesoplodon densirostris*), Stejneger's (*Mesoplodon stejnegeri*), Hubbs' (*Mesoplodon carlhubbsi*), Perrin's (*Mesoplodon perrini*), and pygmy (*Mesoplodon peruvianus*) beaked whales.

Beaked Whales

Beaked whale species potentially found in the California Current include Baird's, Cuvier's, Blainville's, Stejneger's, Hubbs', Perrin's, and pygmy beaked whales (Baumann-Pickering *et al*., 2014; Jefferson *et al.*, 2015).

Beaked whales can be identified acoustically by their echolocation signals (Baumann-Pickering *et al.*, 2013a). These signals are frequency-modulated (FM) upsweep pulses, which appear to be species specific and distinguishable by their spectral and temporal features. Identifiable signals are known for Baird's, Blainville's, Cuvier's, and Stejneger's beaked whales (Baumann-Pickering *et al.*, 2013b).

Other beaked whale signals detected in the California Current include FM pulses known as BW35, BW43, and BW70, which may belong to Hubbs', Perrin's, and pygmy beaked whales, respectively (Baumann-Pickering *et al.*, 2013a; Baumann-Pickering *et al.*, 2014; Griffiths *et al.*, 2018). Only Cuvier's and Baird's beaked whales were detected during this recording period, and their signals are described below in more detail.

Beaked whale FM pulses were detected with an automated method. This automated effort was applied for all identifiable beaked whale signals found in the California Current except for those produced by Baird's beaked whales because they produce a signal with a lower frequency content than that typical of other beaked whales, and therefore are not reliably identified by the detector. After all echolocation signals were identified with a Teager Kaiser energy detector (Soldevilla *et al.*, 2008; Roch *et al.*, 2011), an expert system discriminated between delphinid clicks and beaked whale FM pulses.

A decision about presence or absence of beaked whale signals was based on detections within a 75 second segment. Only segments with more than seven detections were used in further analysis. All echolocation signals with a peak and center frequency below 32 and 25 kHz, respectively, a duration less than 355 µs, and a sweep rate of less than 23 kHz/ms were deleted. If more than 13% of all initially detected echolocation signals remained after applying these criteria, the segment was classified to have beaked whale FM pulses. This threshold was chosen to obtain the best balance between missed and false detections. A third classification step, based on computer-assisted manual decisions by a trained analyst, was used to label the automatically detected segments to pulse type level and reject false detections (Baumann-Pickering *et al.*, 2013). The rate of missed segments is generally approximately 5%, varying slightly across deployments. The start and end of each segment containing beaked whale signals was logged and their durations were added to estimate cumulative weekly presence.

Cuvier's Beaked Whales

Cuvier's echolocation signals are polycyclic, with a characteristic FM pulse upsweep, peak frequency around 40 kHz (Figure 8) and uniform inter-pulse interval of about 0.4 – 0.5 s (Johnson *et al.*, 2004; Zimmer *et al.*, 2005). An additional feature that helps with the identification of Cuvier's FM pulses is that they have two characteristic spectral peaks around 17 and 23 kHz.

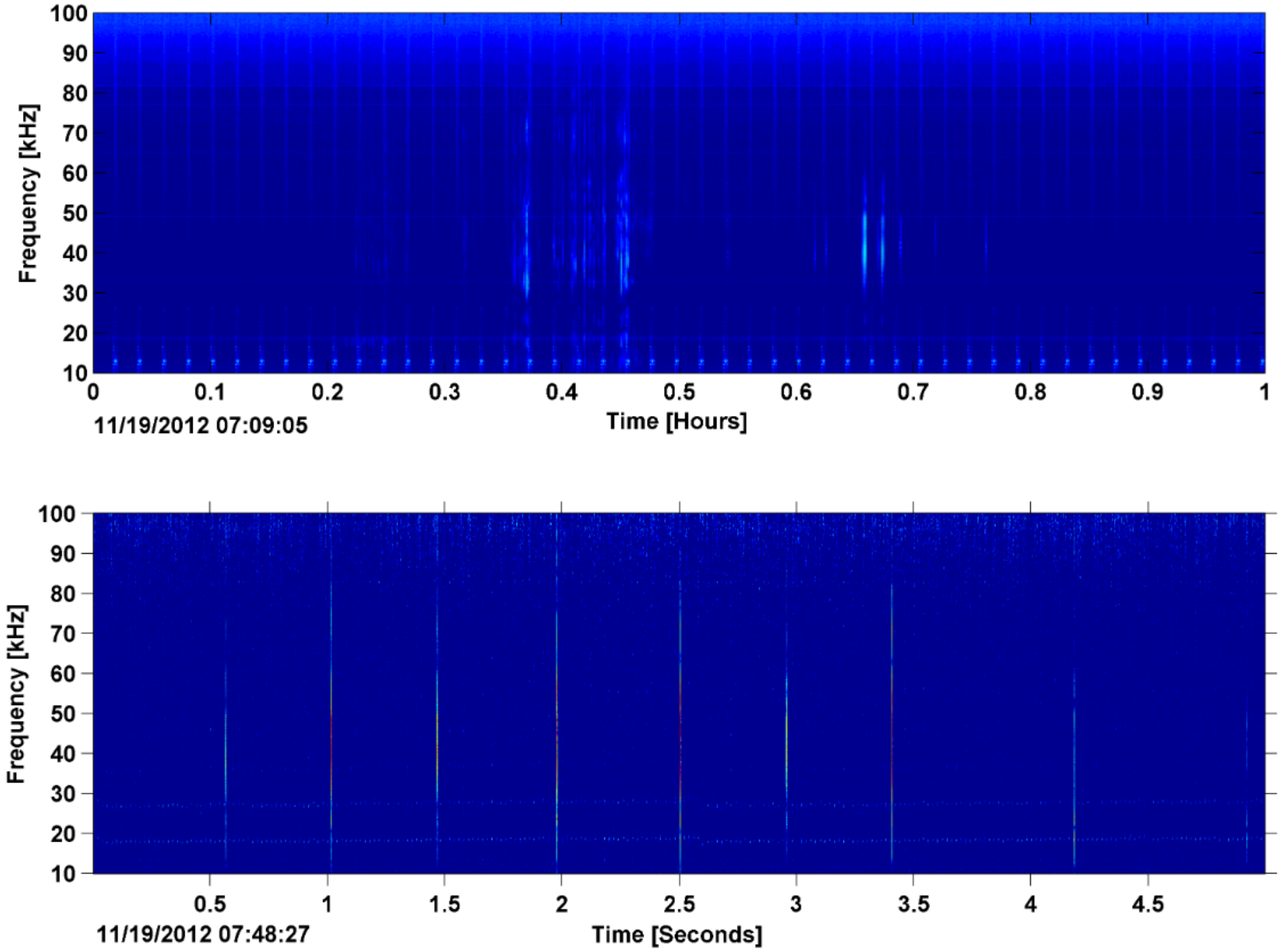

Figure 8. Cuvier's beaked whale signals in LTSA (top) and spectrogram (bottom) from HARP recording at DCPP Site C, November 2012.

Baird's Beaked Whales

Baird's beaked whale echolocation signals have a multiple peak structure with the largest spectral peak between 22 and 25 kHz, and the second largest spectral peak between 35 and 45 kHz (Figure 9). Baird's beaked whales use two distinctly different echolocation signals: an FM pulse and a broadband click. Both signal types showed a consistent multi-peak structure in their spectra with peaks at approximately 9, 16, 25, and 40 kHz (Baumann-Pickering *et al.*, 2013).

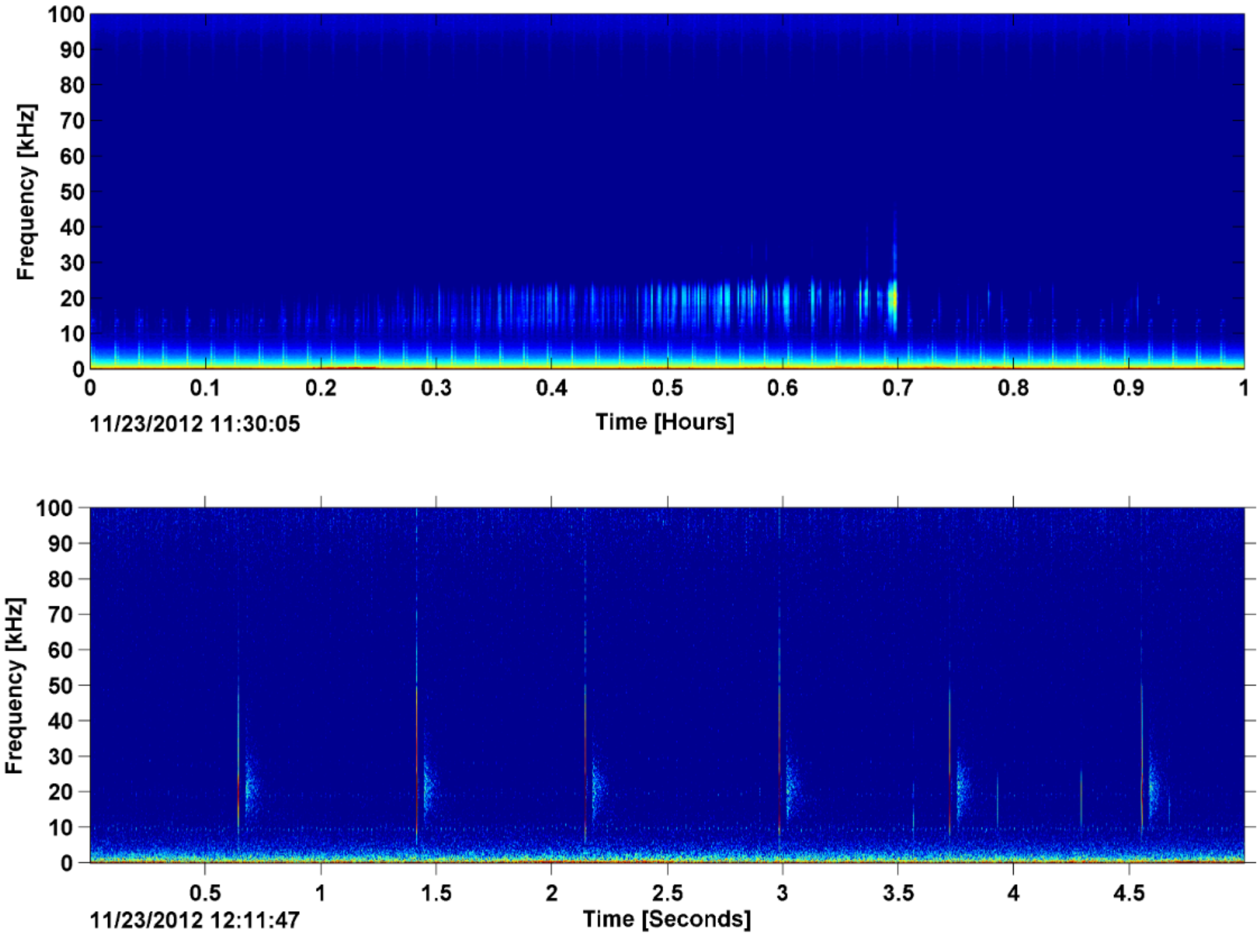

Figure 9. Baird's beaked whale echolocation clicks in LTSA (top) and spectrogram (bottom) from HARP recording at DCPP Site C, November 2012.

Dolphins

Echolocation Clicks

Delphinid echolocation click analysis effort consisted of manual scans and review of the LTSA with a 1 hour display duration and a frequency range of 10-10,000 Hz.

Risso's Dolphins

Risso's dolphin echolocation clicks can be identified to species by their distinctive banding patterns observable in the LTSA (Figure 10). Studies show that spectral properties of Risso's dolphin echolocation clicks vary based on geographic region (Soldevilla *et al.,* 2017). Risso's dolphin clicks detected in this recording period had peaks at 23, 26, and 33 kHz. Modal inter-click interval (ICI) was 165 ms.

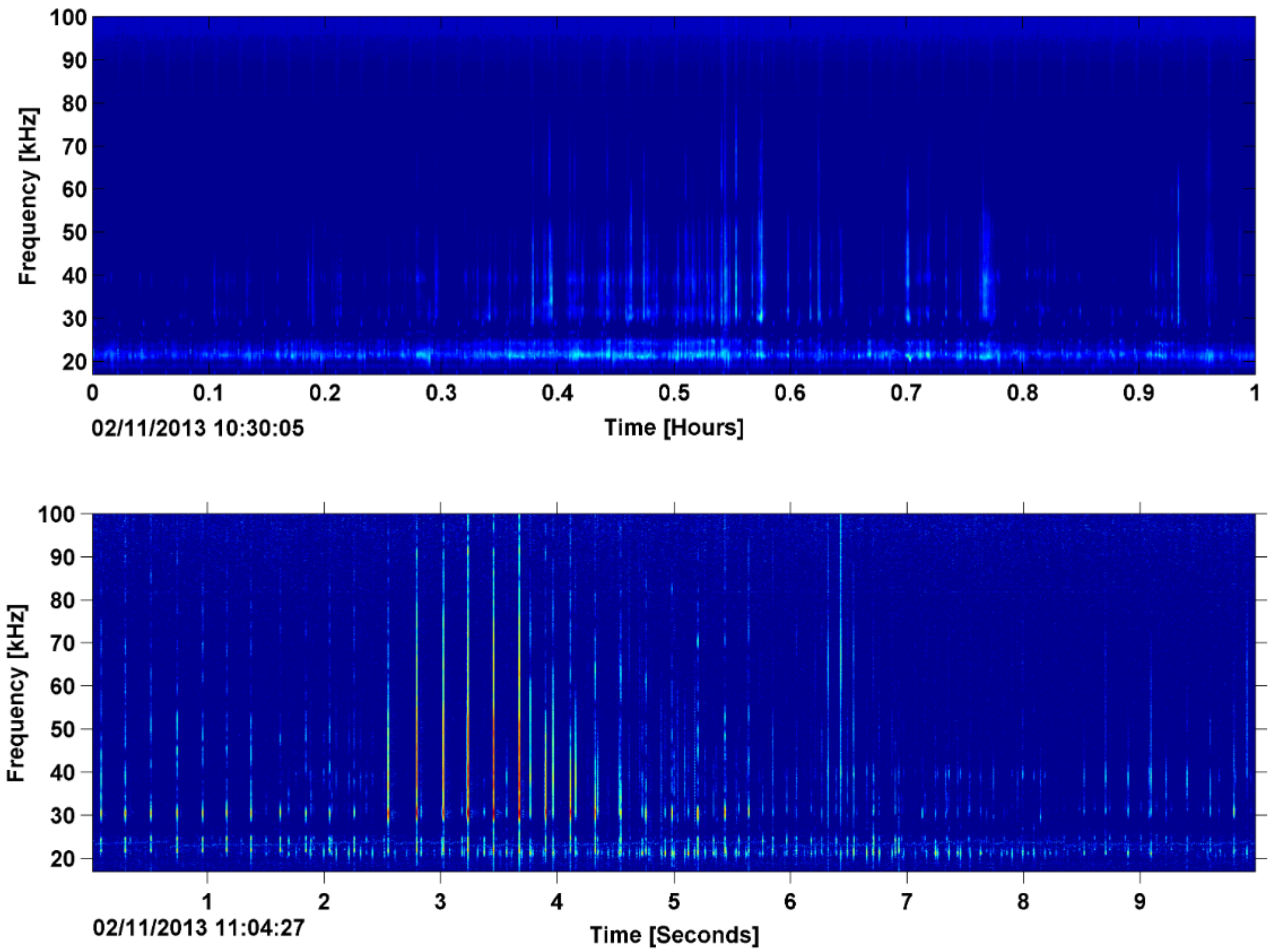

Figure 10. Risso's dolphin acoustic encounter in LTSA (top) and spectrogram (bottom) from HARP recording at DCPP Site C, February 2013.

Pacific White-Sided Dolphins

Pacific white-sided dolphin clicks can be separated into two click types, designated type A and B. The significance of these two click types remains unknown and for this recording period both click types were logged. In combination with the other peaks and notches, a frequency peak near either 27.4 or 26.1 kHz can distinguish these clicks as type A or B, respectively (Soldevilla *et al.*, 2008).

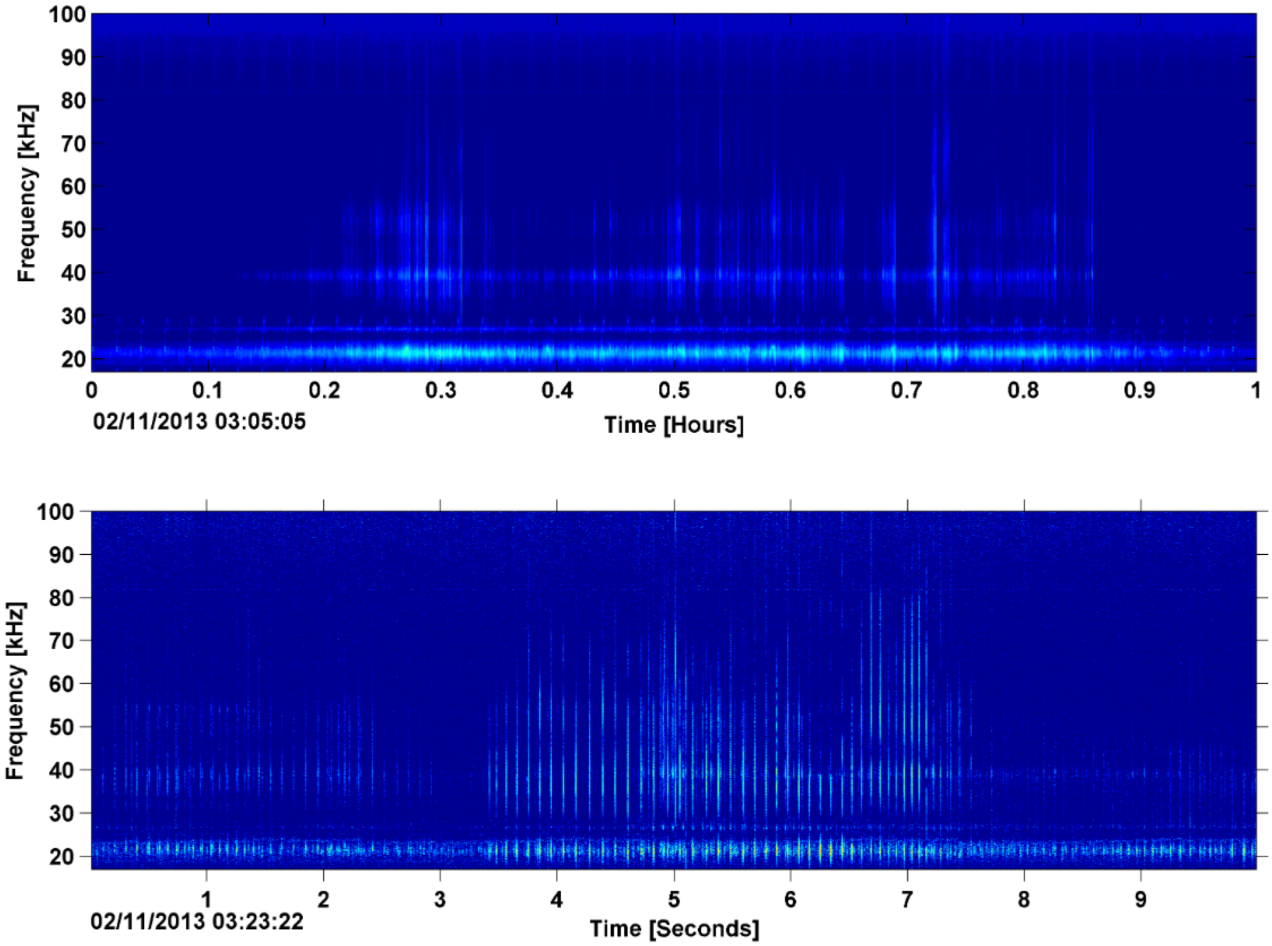

Figure 11. Pacific white-sided dolphin type B echolocation clicks in LTSA (top) and spectrogram (bottom) recorded at DCPP Site C, February 2013.

Sperm Whales

Sperm whale clicks contain energy from 2 to 20 kHz, with most energy between 10 and 15 kHz (Møhl *et al.*, 2003) (Figure 12). Regular clicks, observed during foraging dives, demonstrate an ICI from 0.25 to 1 s (Goold and Jones, 1995; Madsen *et al.*, 2002a). Short bursts of closely-spaced clicks called creaks are observed during foraging dives and are believed to indicate a predation attempt (Wysocki *et al.*, 2006). Slow clicks (> 1 s ICI) are used only by males and are more intense than regular clicks (Madsen *et al.*, 2002b). Codas are stereotyped sequences of clicks which are less intense and contain lower peak frequencies than regular clicks (Watkins and Schevill, 1977). Effort was not expended to denote whether sperm whale detections were codas, regular or slow clicks.

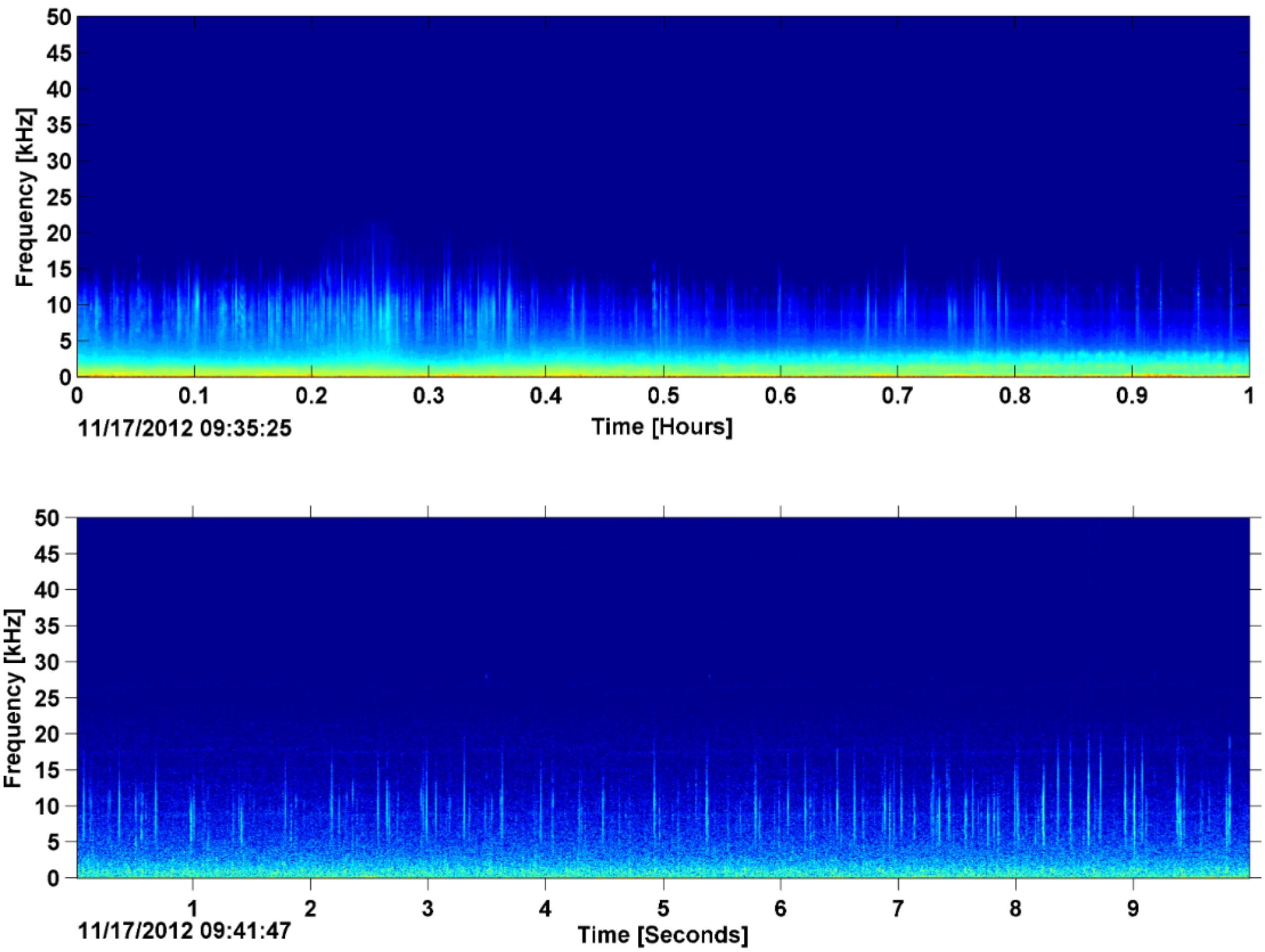

Figure 12. Sperm whale echolocation clicks in LTSA (top) and spectrogram (bottom) recorded at DCPP Site C, November 2012.

Unidentified Odontocete Clicks Greater Than 20 kHz

Unidentified odontocete clicks greater than 20 kHz are not currently identified to species, but was used as a general category for manual analysis. An example encounter is shown in Figure 13.

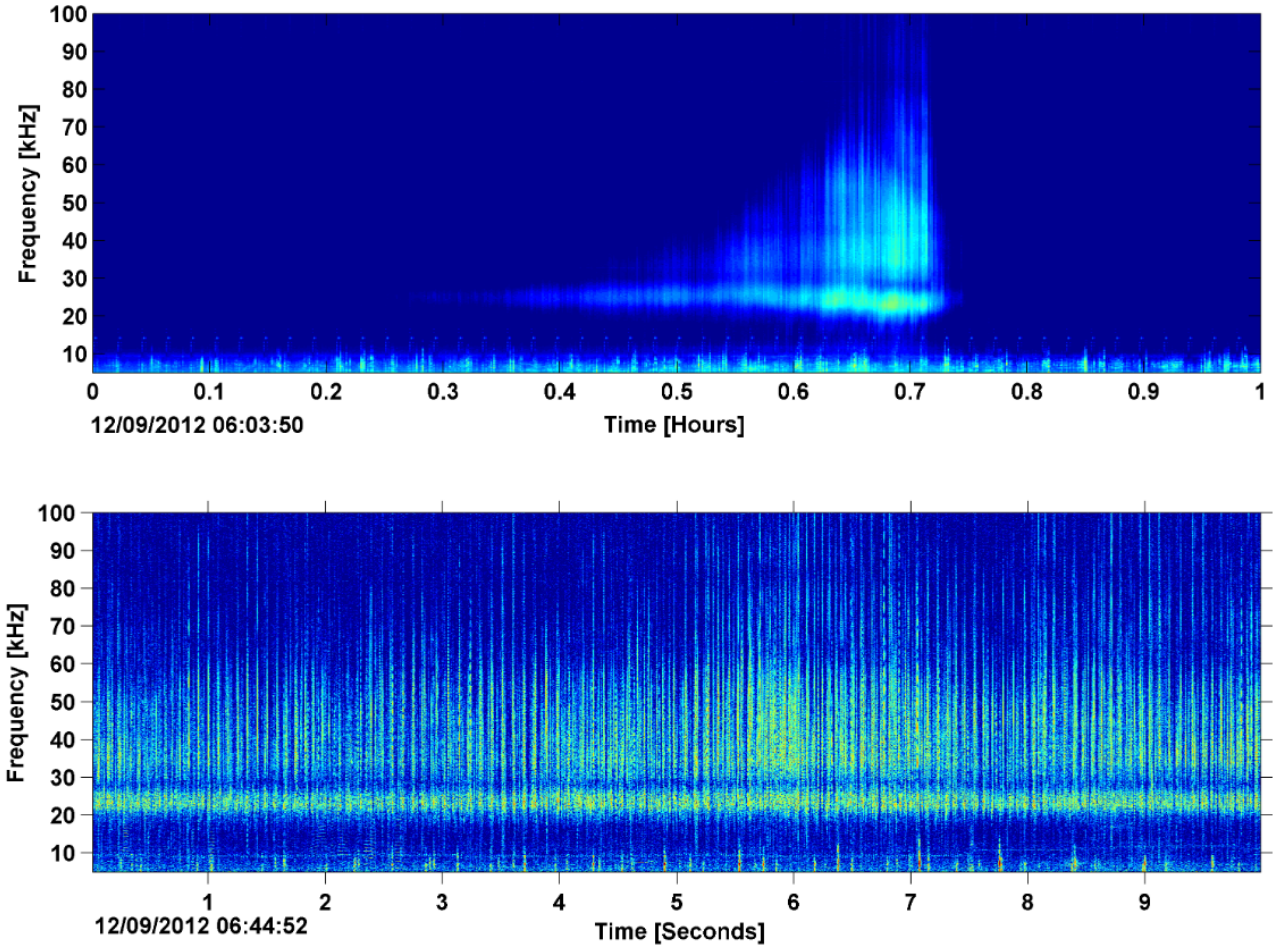

Figure 13. UO CT > 20 kHz acoustic encounter in LTSA (top) and spectrogram (bottom) recorded at DCPP Site C, December 2012.

Anthropogenic Sounds

One anthropogenic sound was monitored for this report: Mid-Frequency Active (MFA) sonar. These sounds were detected by a computer algorithm. The start and end of each sonar session was logged and their durations were added to estimate cumulative weekly presence.

Mid-Frequency Active Sonar

Sounds from MFA sonar vary in frequency (1 – 10 kHz) and are composed of pulses of both frequency modulated (FM) sweeps and continuous wave (CW) tones grouped in packets with durations ranging from less than 1 s to greater than 5 s. Packets can be composed of single or multiple pulses and are transmitted repetitively as wave trains with inter-packet-intervals typically greater than 20 s (Figure 14). In the SOCAL Range Complex, off San Clemente Island, the most common MFA sonar signals are between 2 and 5 kHz and are more generically known as '3.5 kHz' sonar.

MFA sonar was detected using a modified version of the *Silbido* detection system (Roch *et al.*, 2011a) originally designed for characterizing toothed whale whistles. The algorithm identifies peaks in time- frequency distributions (e.g. spectrogram) and determines which peaks should be linked into a graph structure based on heuristic rules that include examining the trajectory of existing peaks, tracking intersections between time-frequency trajectories, and allowing for brief signal dropouts or interfering signals. Detection graphs are then examined to identify individual tonal contours looking at trajectories from both sides of time-frequency intersection points. For MFA detection, parameters were adjusted to detect tonal contours at or above 2 kHz in data decimated to a 10 kHz sample rate with signal to noise ratios of 5 dB or above, and contour durations of at least 200 ms with a frequency resolution of 100 Hz. The detector frequently triggered on noise produced by instrumental disk writes that occurred at 75 s intervals, but these times were identified and removed from the analysis.

Over periods of several months, disk write detections dominated the number of detections and could be eliminated using an outlier detection test. Histograms of the detection start times modulo the disk write period were constructed and outliers were discarded. This removed some valid detections that occurred during disk writes, but as the disk writes and sonar signals are uncorrelated this is expected to only have a minor impact on analysis. As the detector did not distinguish between sonar and non-anthropogenic tonal signals within the operating band (e.g. humpback whales), human analysts examined detection output and accepted or rejected contiguous sets of detections.

No MFA detections were found during the recording period.

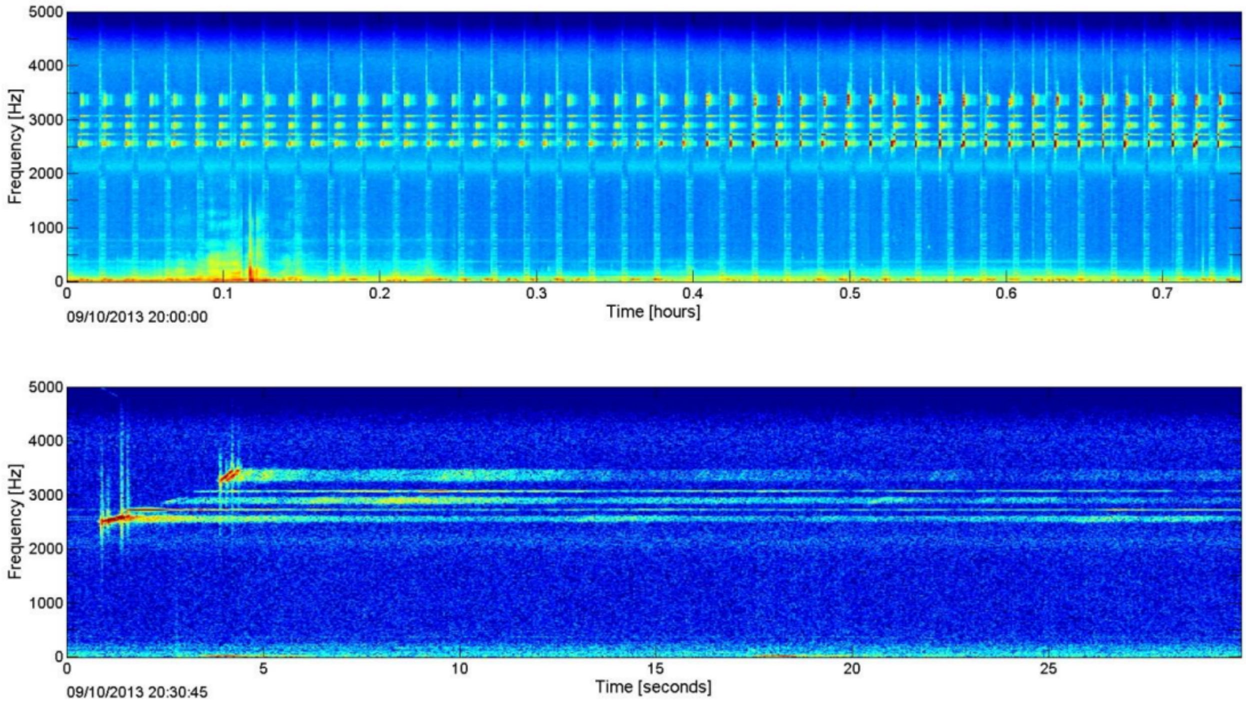

Figure 14. MFA sonar recorded in Southern California at Site H and shown as a wave train event in a 45 minute LTSA (top) and as a single packet with multiple pulses in a 30 second spectrogram (bottom).

Results

The results of acoustic data analysis at DCPP Site C from November 2012 to March 2013 are summarized, and the seasonal occurrence and relative abundance of marine mammal acoustic signals and anthropogenic sounds are documented.

Low-Frequency Ambient Soundscape

The monthly average low-frequency sound spectrum levels at DCPP Site C are shown in Figure 15. These spectra are generally more energetic at low frequencies (< 100 Hz). Various peaks appear in the spectra that correspond to the presence of blue and fin whales as follows.

- November – December spectral peaks at 45-47 Hz, along with lower frequency harmonics are related to blue whale B calls (Figure 15).
- Prominent peaks in sound spectrum levels observed in the frequency band 15-30 Hz during winter are related to seasonally increased presence of fin whale calls (Figure 15).

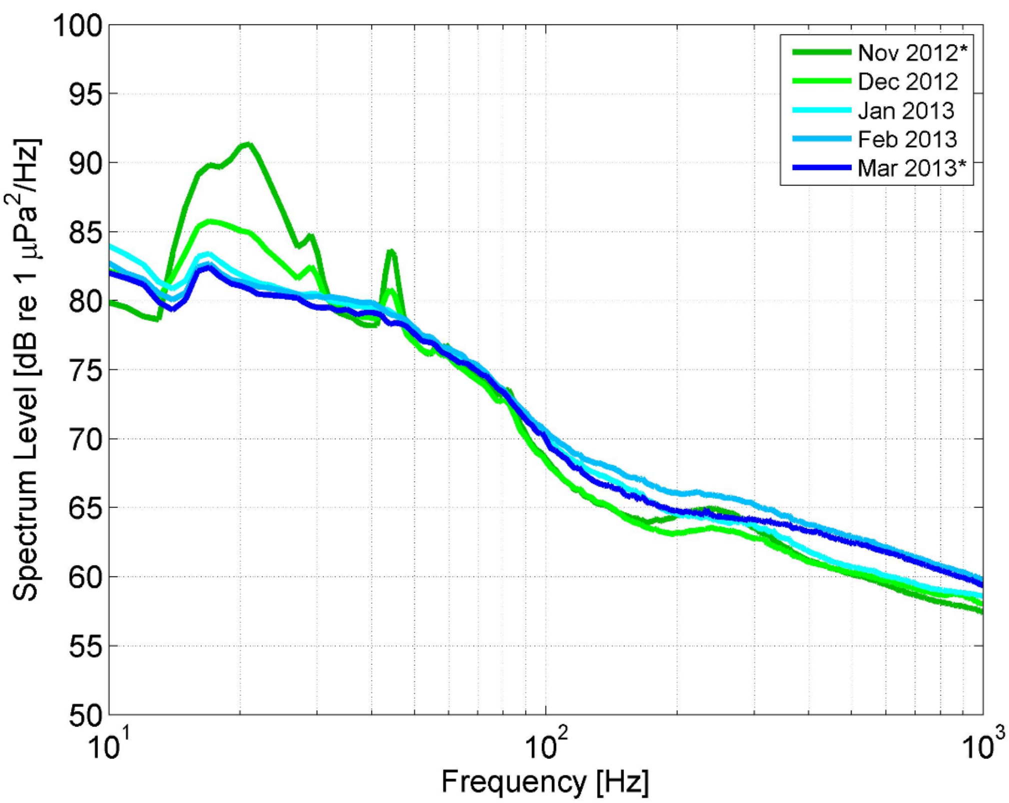

Figure 15. Monthly averages of sound spectrum levels at DCPP Site C from November 2012 to March 2013. Legend gives color-coding by month. * denotes months with partial effort.

Mysticetes

Three known baleen whale species were recorded between November 2012 and March 2013: blue whales, fin whales, and humpback whales. More details of each species' presence are given below.

Blue Whales

Blue whale B and D calls were detected from the beginning of the recording in November, but greatly diminished in January.

Northern Pacific Blue Whale B Calls

- Northern Pacific blue whale B calls were detected in very high numbers from November 2012 to January 2013, drastically dropping off after January 2013 (Figure 16).
- There was no discernible diel pattern for Northern Pacific blue whale B calls (Figure 17).

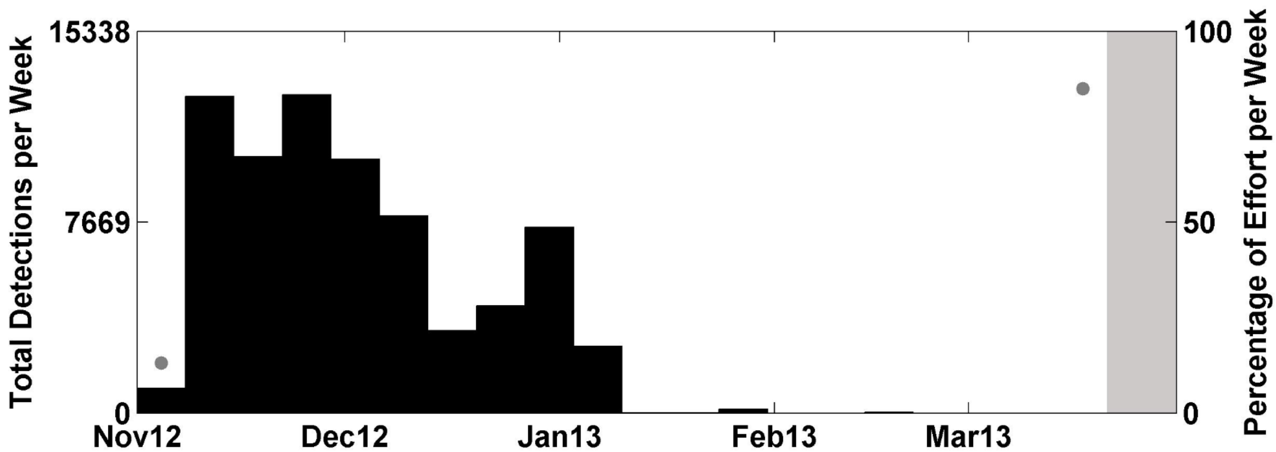

Figure 16. Weekly presence of Northern Pacific blue whale tonal calls detected from November 2012 to March 2013 at DCPP Site C. Gray dots represent percent of effort per week in weeks with less than 100% recording effort. Where gray dots are absent, full recording effort occurred for the entire week. X-axis labels refer to month and year of recording.

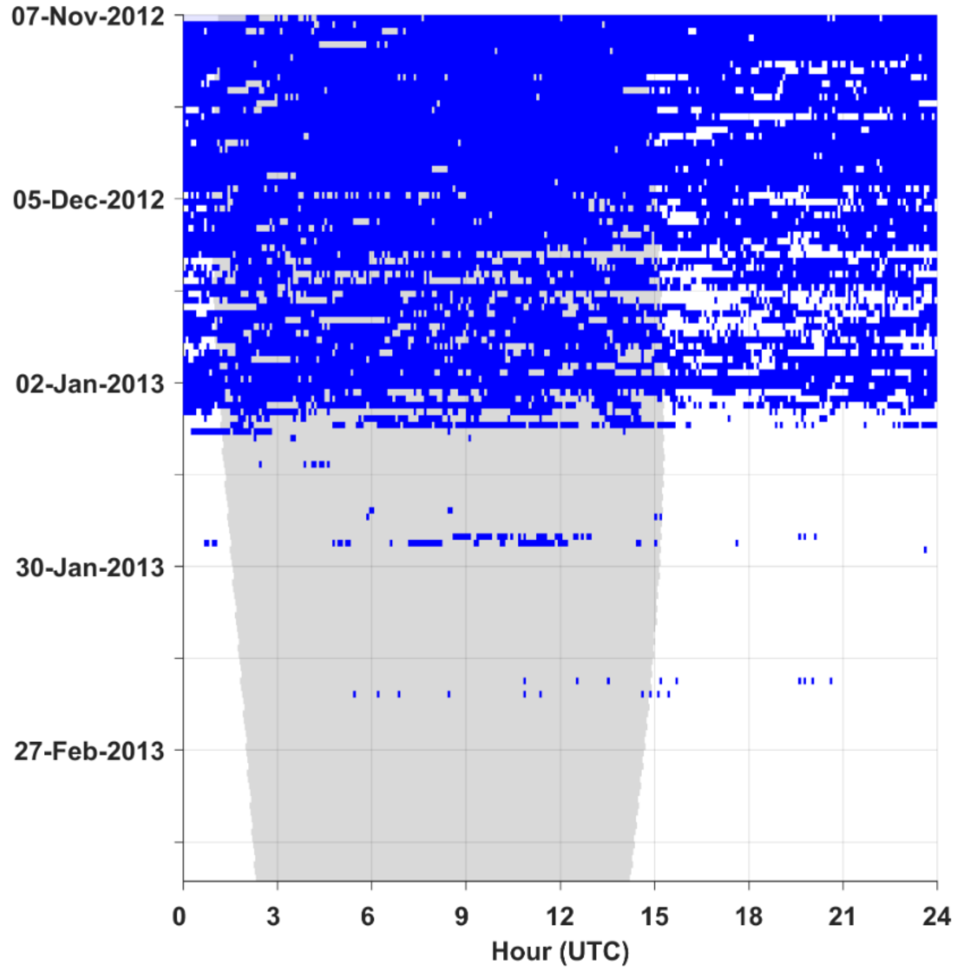

Figure 17. Northern Pacific blue whale tonal calls in hourly bins at DCPP Site C from November 2012 to March 2013. Gray vertical shading denotes nighttime.

Northern Pacific Blue Whale D Calls

- Northern Pacific blue whale D calls were detected in high numbers from November 2012 to January 2013, drastically dropping off after January 2013 (Figure 18).
- There was no discernible diel pattern for Northern Pacific blue whale D calls (Figure 19).

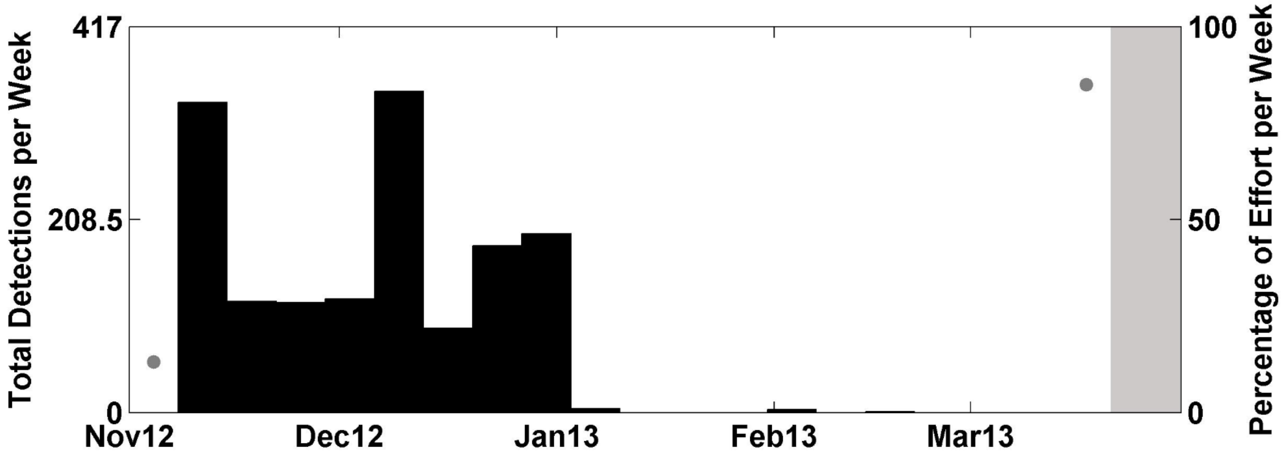

Figure 18. Weekly presence of Northern Pacific blue whale D calls detected from November 2012 to March 2013 at DCPP Site C. Effort markings are described in Figure 6.

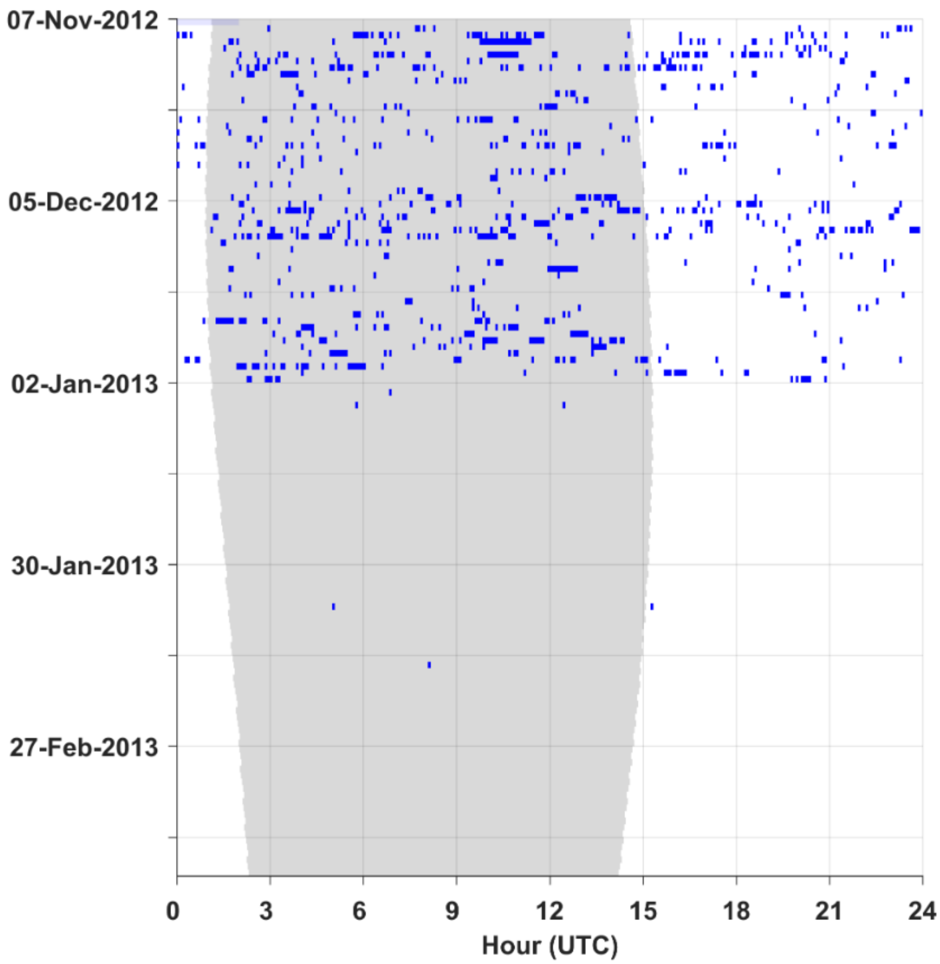

Figure 19. Northern Pacific blue whale D calls in hourly bins at DCPP Site C from November 2012 to March 2013. Gray vertical shading denotes nighttime.

Fin Whales

The fin whale acoustic index, a proxy for 20 Hz calls, was high from November 2012 and the beginning of December 2012 but decreased from mid-December 2012 to January 2013 (Figure 20).

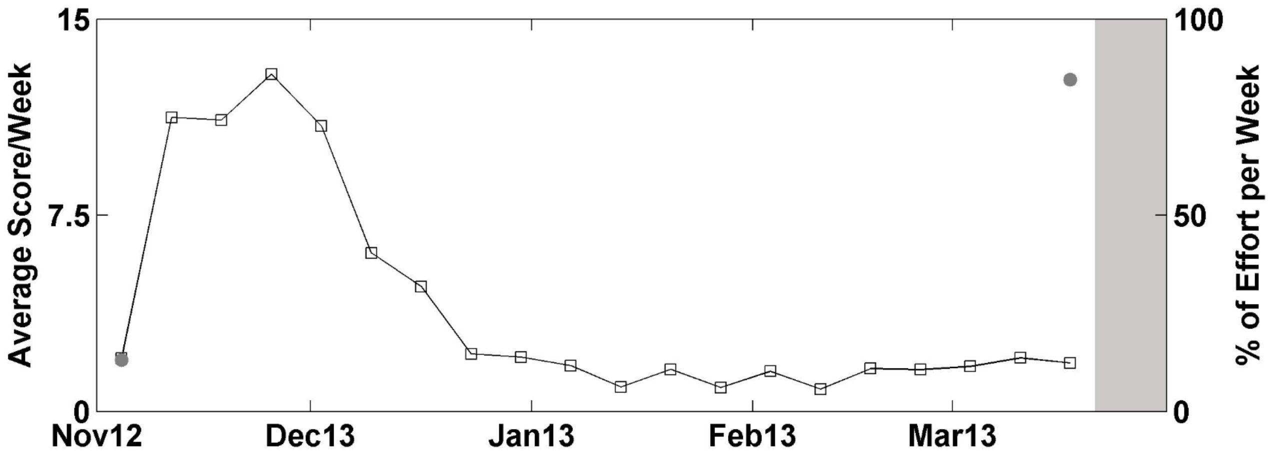

Figure 20. Weekly value of fin whale acoustic index (proxy for 20 Hz calls) detected from May 2017 to 2018 at HAT Site B. Effort markings are described in Figure 16.

Humpback Whales

Humpback whale calls were detected at high numbers from the beginning of the recording in November, and decreased throughout the recording period.

- Humpback whale call types were observed in high numbers in November and December 2012 then gradually decreased (Figure 21).
- There was no discernible diel pattern for humpback whale call types (Figure 22).

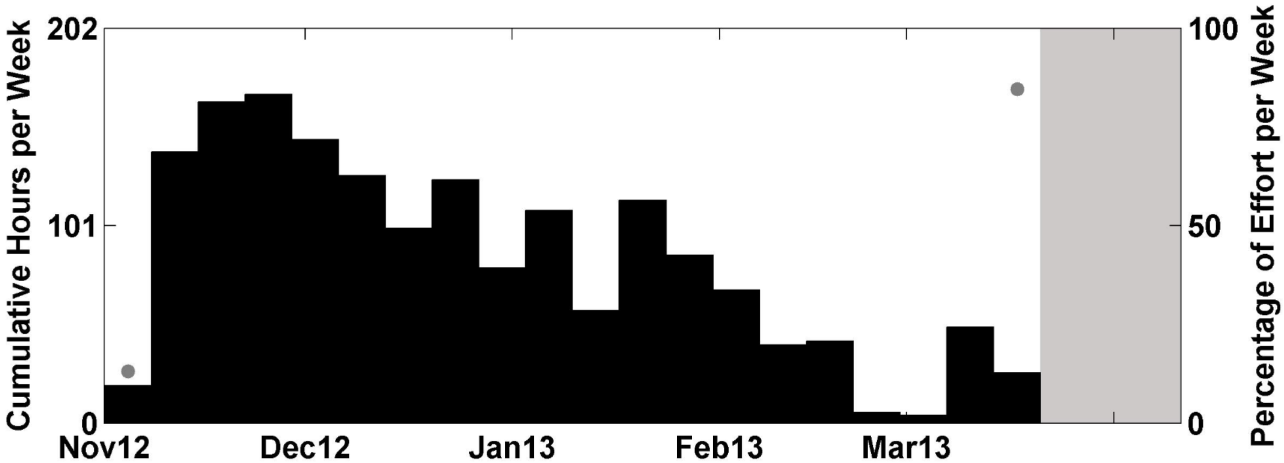

Figure 21. Weekly presence of humpback whale calls from November 2012 to March 2013 at DCPP Site C. Effort markings are described in Figure 16.

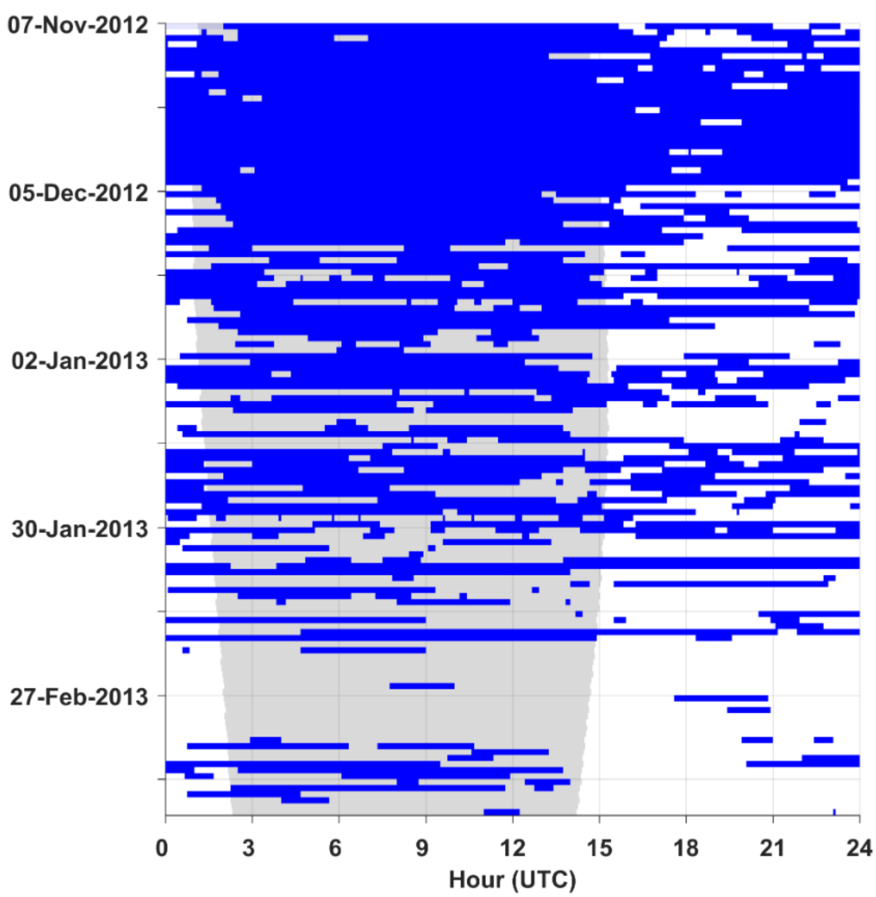

Figure 22. Humpback whale calls in hourly bins at DCPP Site C from November 2012 to March 2013. Gray vertical shading denotes nighttime.

Odontocetes

Killer whale call types, Cuvier's beaked whale, Baird's beaked whale, Risso's dolphins, Pacific White-Sided dolphins, sperm whales, and clicks of unidentified odontocetes were discriminated in the DCPP Site C data. Details of each species' presence are given below.

Killer Whales

- Killer whale call types were detected in low numbers throughout the recording period. Detections occurred in November 2012 and from February to March 2012 (Figure 23).
- There was no discernible diel pattern for killer whale call types (Figure 24).

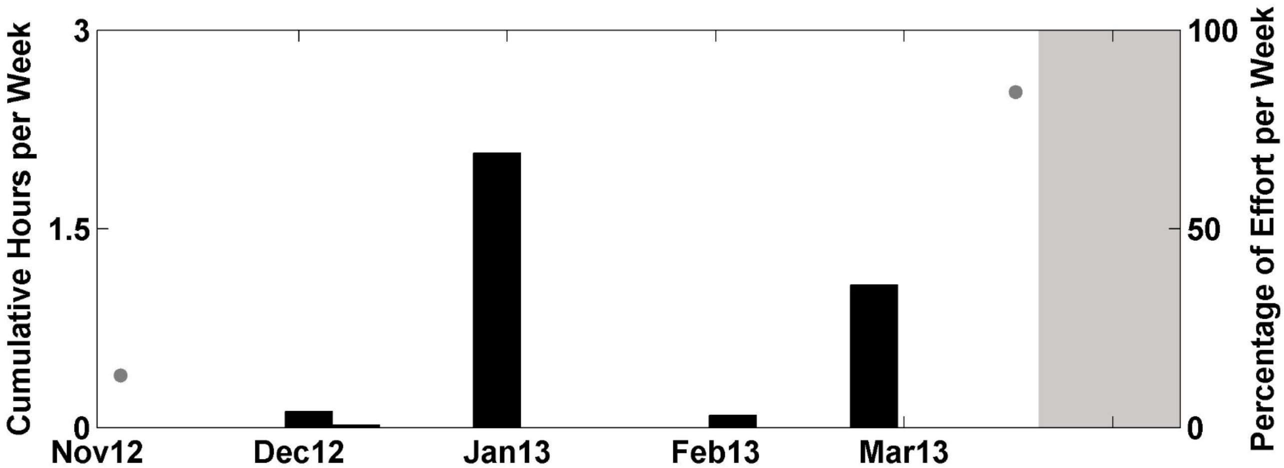

Figure 23. Weekly presence of killer whale call types detected from November 2012 to March 2013 at DCPP Site C. Effort markings are described in Figure 16.

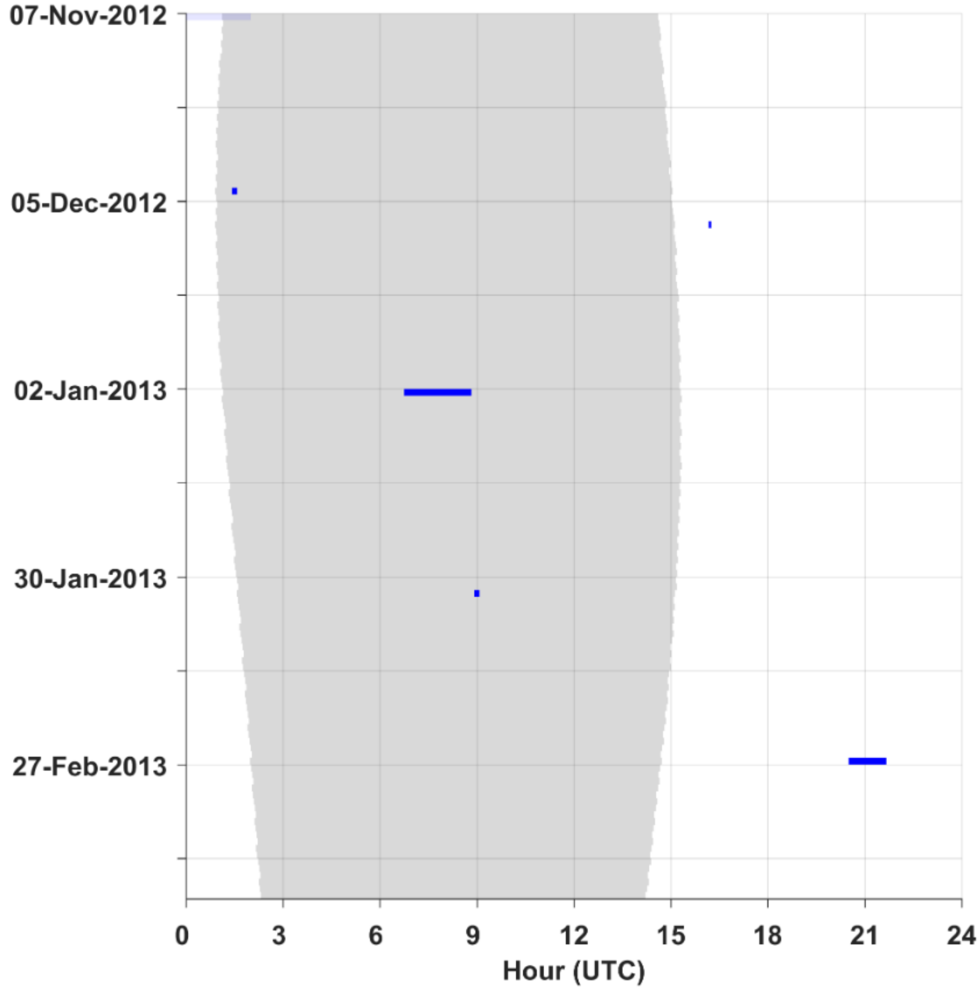

Figure 24. Killer whale call types in one-minute bins at DCPP Site C from November 2012 to March 2013. Gray vertical shading denotes nighttime

Cuvier's Beaked Whale

- Cuvier's beaked whale echolocation clicks were detected in low numbers throughout the recording period. Detections occurred in November 2012 and from February to March 2013 (Figure 25).
- There were not enough encounters to discern a diel pattern (Figure 26).

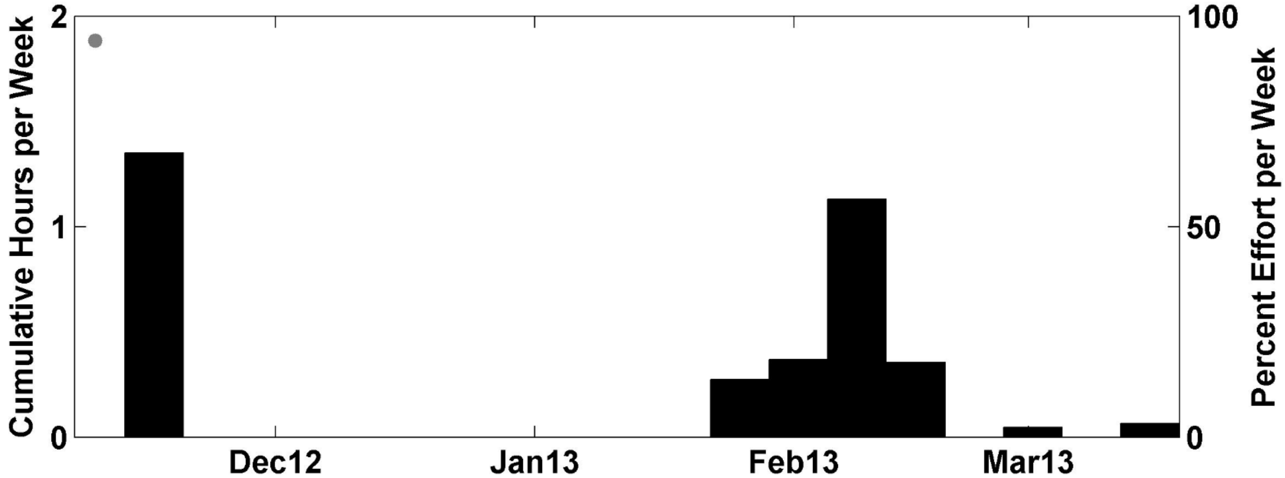

Figure 25. Weekly presence of Cuvier's beaked whale echolocation clicks detected from November 2012 to March 2013 at DCPP Site C. Effort markings are described in Figure 16.

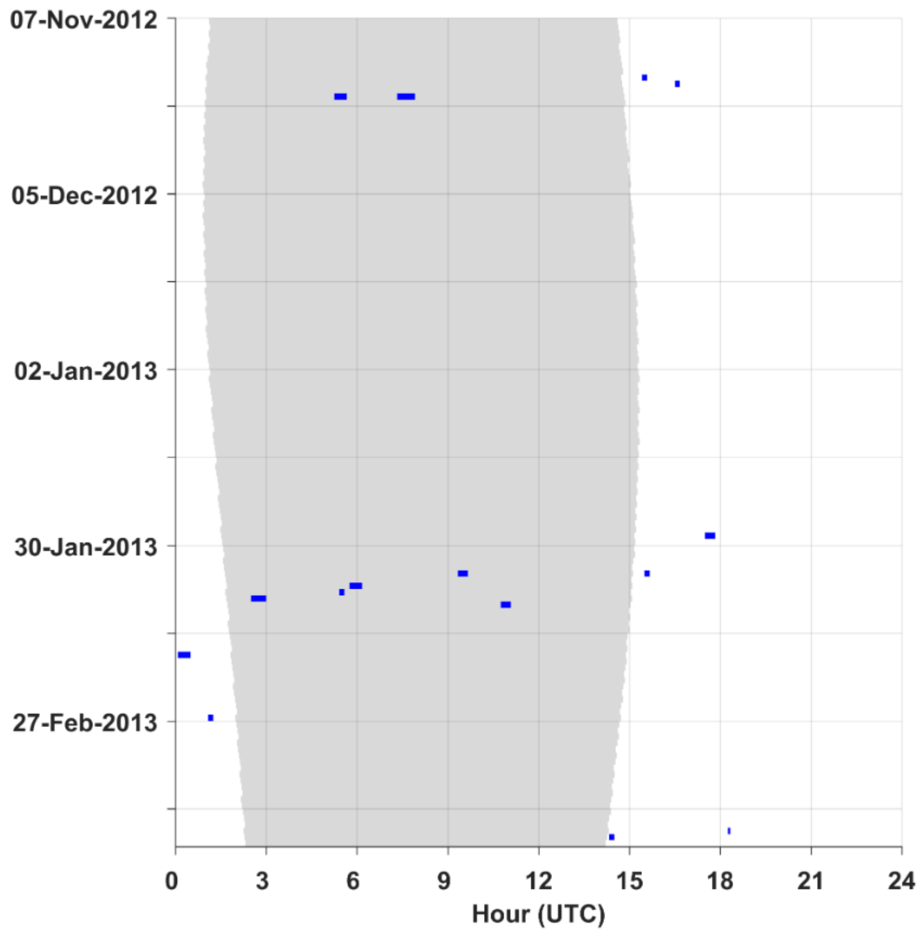

Figure 26. Cuvier's beaked whale echolocation clicks in one-minute bins at DCPP Site C from November 2012 to March 2013. Gray vertical shading denotes nighttime

Bairds' Beaked Whale

- Baird's beaked whale echolocation clicks were detected in low numbers in November and December 2012 (Figure 27).
- There were not enough encounters to discern a diel pattern (Figure 28).

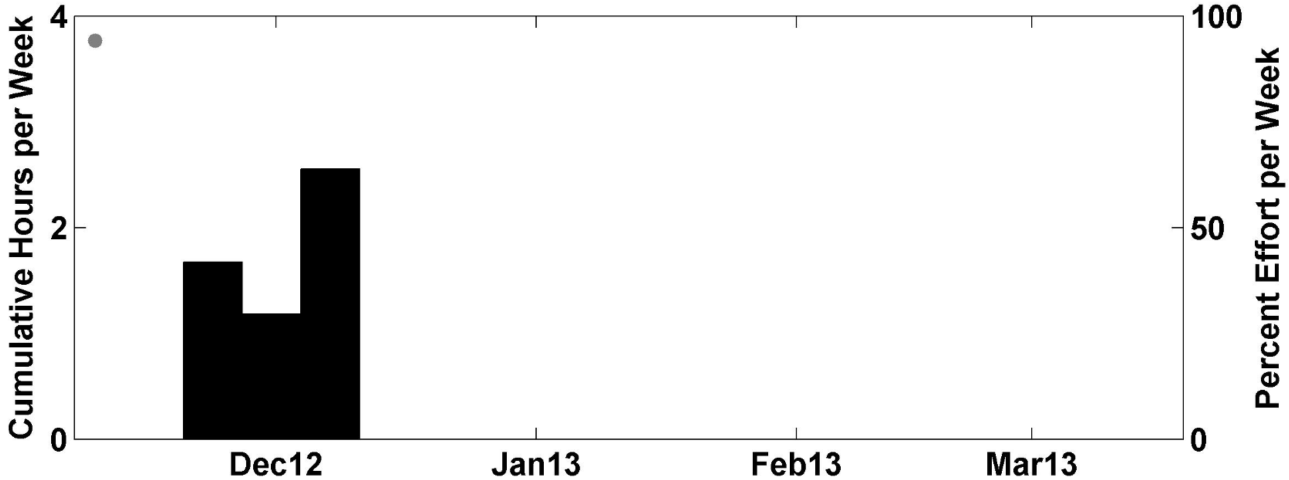

Figure 27. Weekly presence of Baird's beaked whale echolocation clicks from November 2012 to March 2013 at DCPP Site C. Effort markings are described in Figure 16.

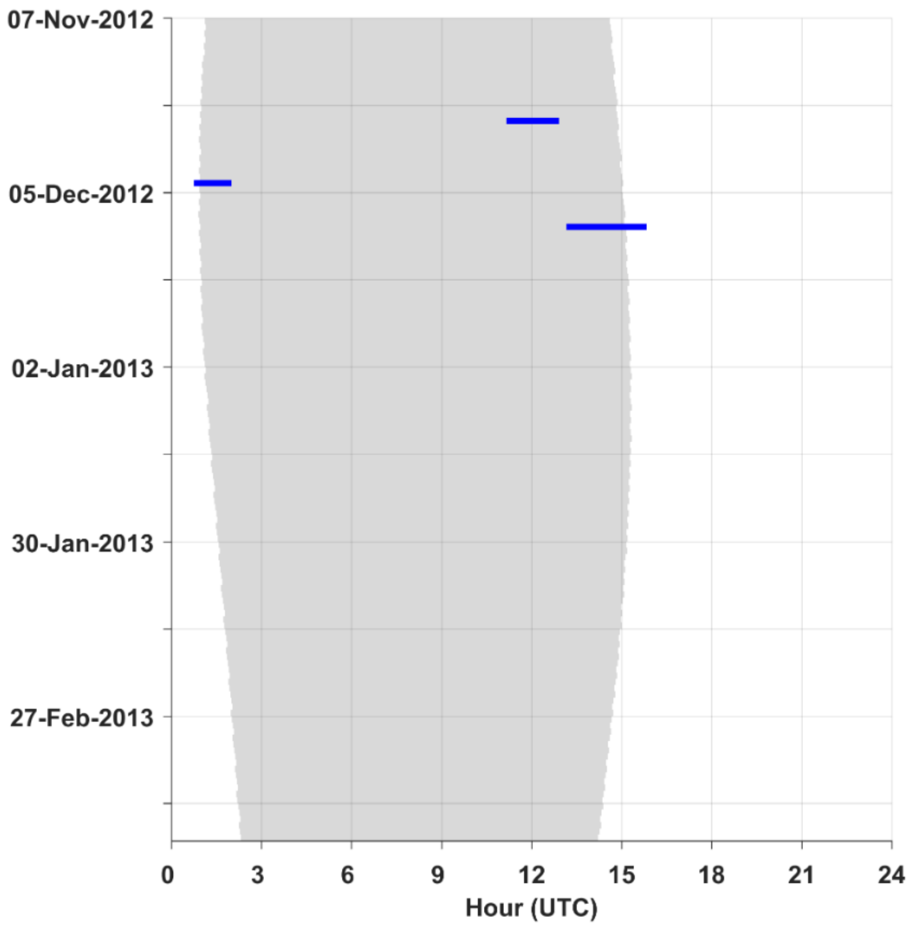

Figure 28. Baird's beaked whale echolocation clicks in one-minute bins at DCPP Site C from November 2012 to March 2013. Gray vertical shading denotes nighttime.

Risso's Dolphins

- Risso's dolphin echolocation clicks began in January 2013 and increased from February to March 2013 (Figure 29).
- Risso's dolphin echolocation clicks were primarily detected during nighttime (Figure 30).

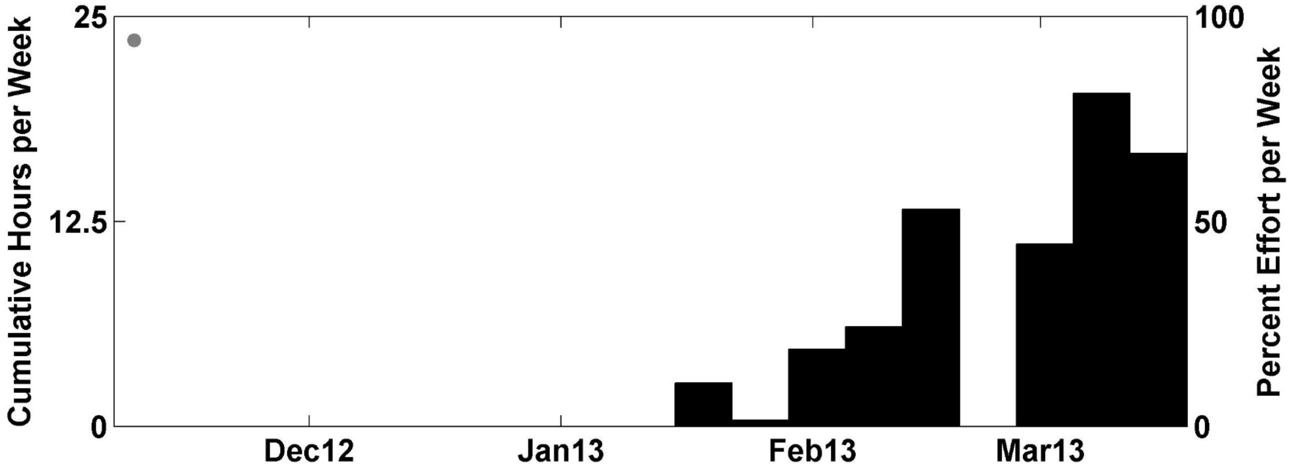

Figure 29. Weekly presence of Risso's dolphin echolocation clicks detected from November 2012 to March 2013 at DCPP Site C. Effort markings are described in Figure 16.

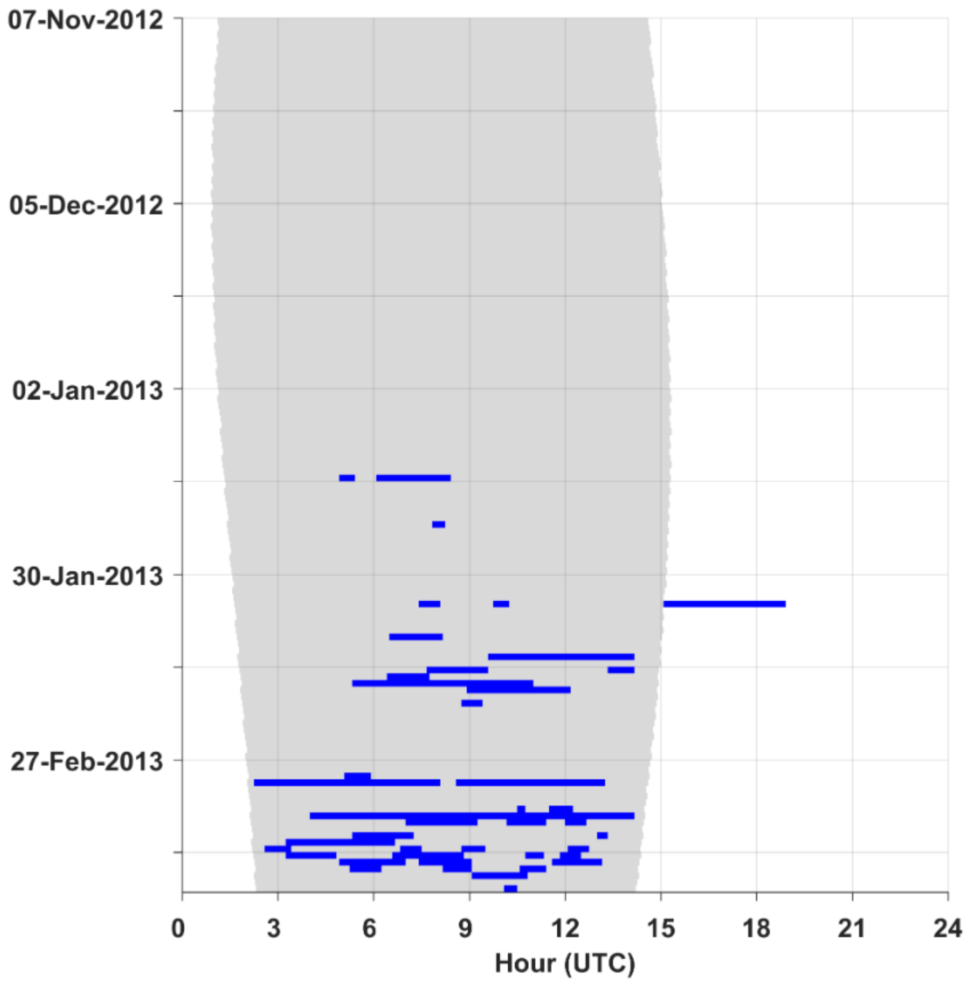

Figure 30. Risso's dolphin echolocation clicks in five-minute bins at DCPP Site C from November 2012 to March 2013. Gray vertical shading denotes nighttime.

Pacific White-Sided Dolphins

- Pacific white-sided dolphin type B echolocation clicks were first detected in low numbers in November 2012 and increased during February and March 2013 (Figure 31). No type A echolocation clicks were logged.
- Type B echolocation clicks were primarily detected during nighttime (Figure 32).

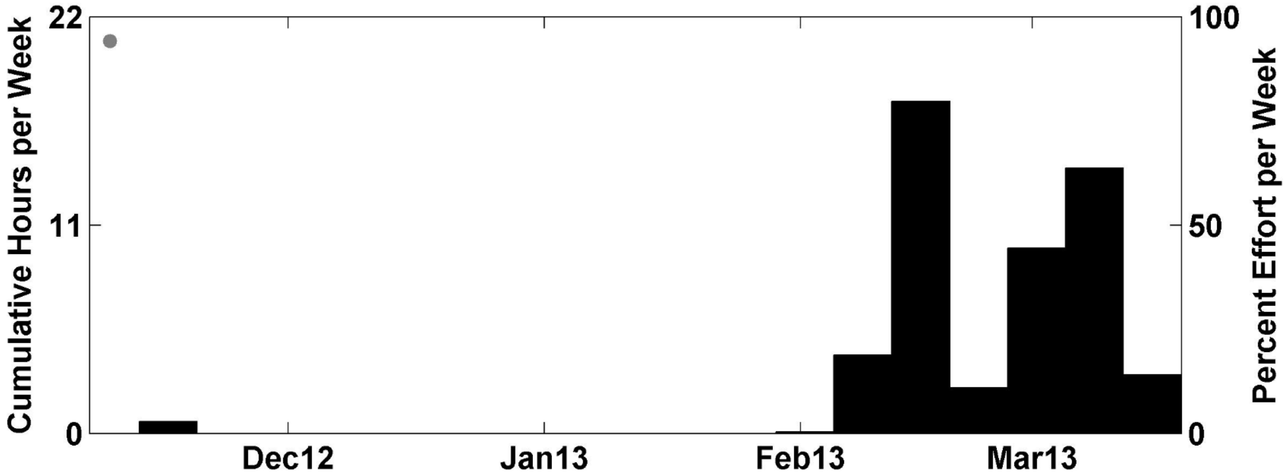

Figure 31. Weekly presence of Pacific White-Sided dolphin echolocation clicks detected from November 2012 to March 2013 at DCPP Site C. Effort markings are described in Figure 16.

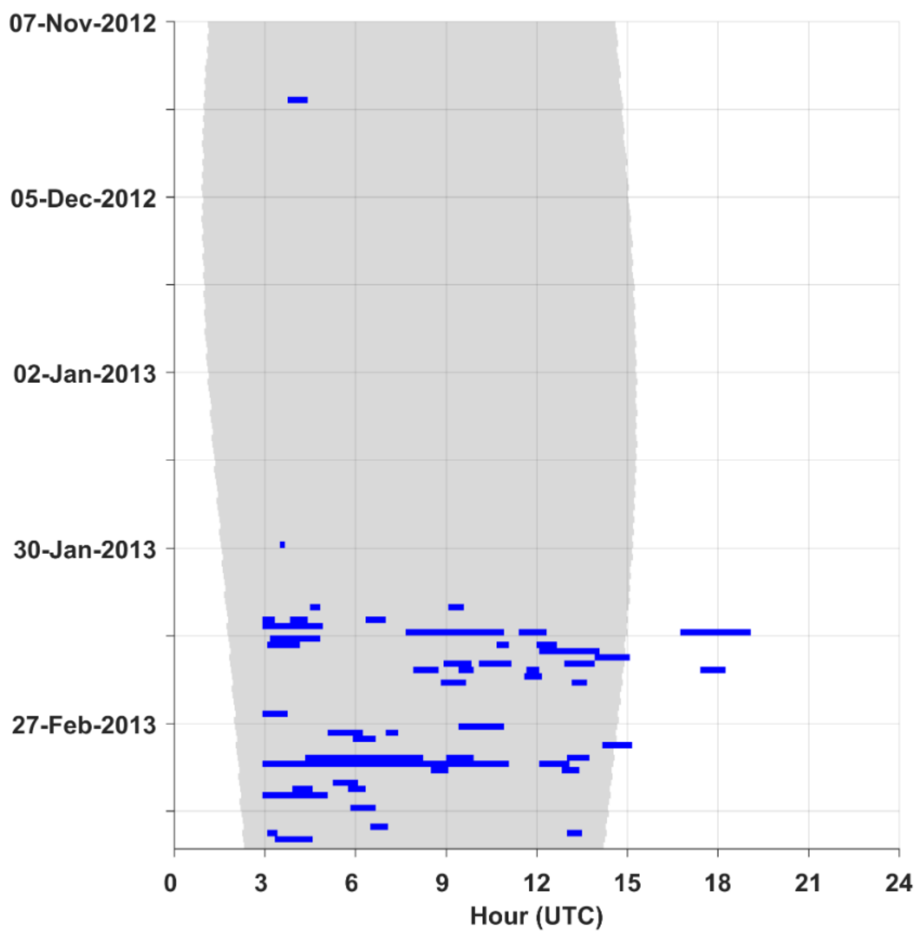

Figure 32. Pacific White-Sided dolphin echolocation clicks in five-minute bins at DCPP Site C from November 2012 to March 2013. Gray vertical shading denotes nighttime.

Sperm Whales

- Sperm whale clicks were detected throughout the recording, although with some fluctuation in their numbers (Figure 33).
- There was no discernible diel pattern for sperm whale clicks (Figure 34).

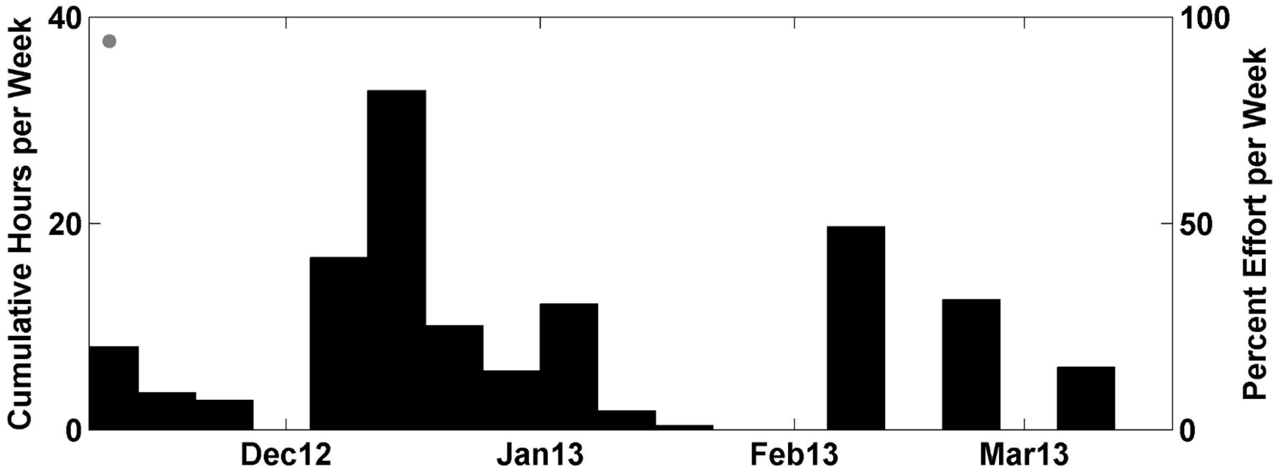

Figure 33. Weekly presence of sperm whale clicks detected from November 2012 to March 2013 at DC PP Site C. Effort markings are described in Figure 16.

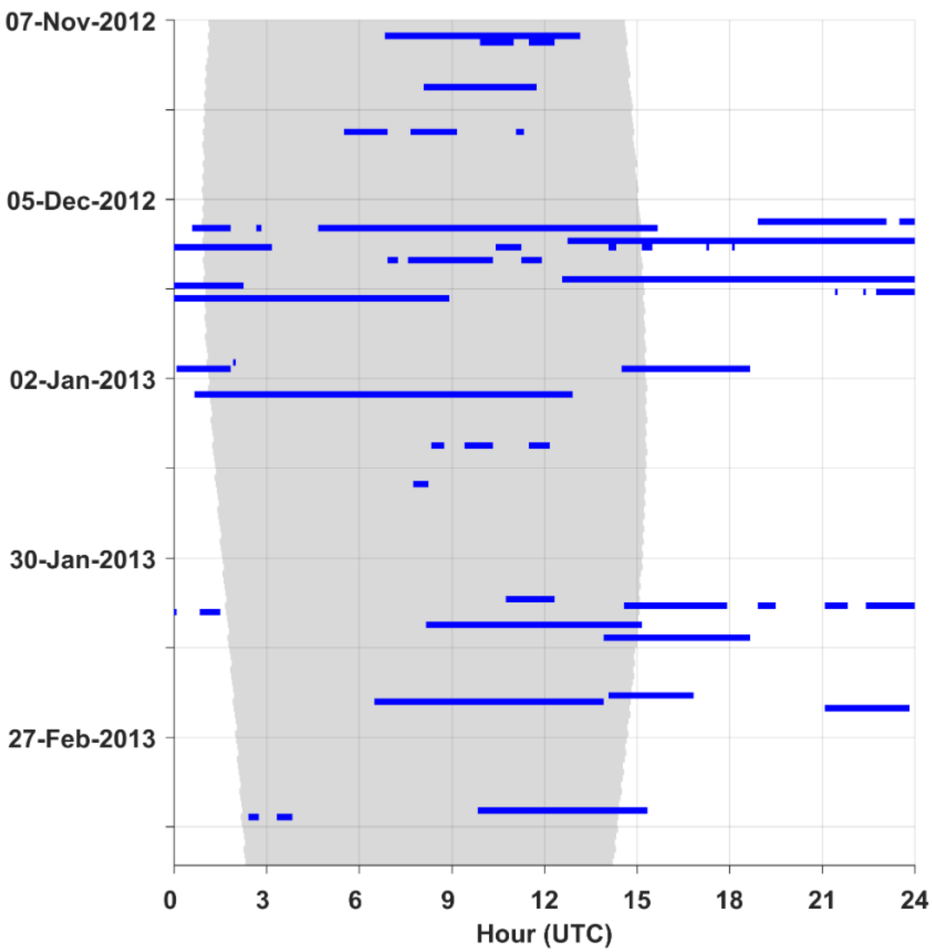

Figure 34. Sperm whale clicks in one-minute bins at DCPP Site C from November 2012 to March 2013. Gray vertical shading denotes nighttime.

Unidentified Odontocete Clicks Greater Than 20 kHz

- UO CT > 20 kHz was detected throughout the deployment with a peak during December (Figure 35).
- UO CT > 20 kHz was more often detected during nighttime (Figure 36).

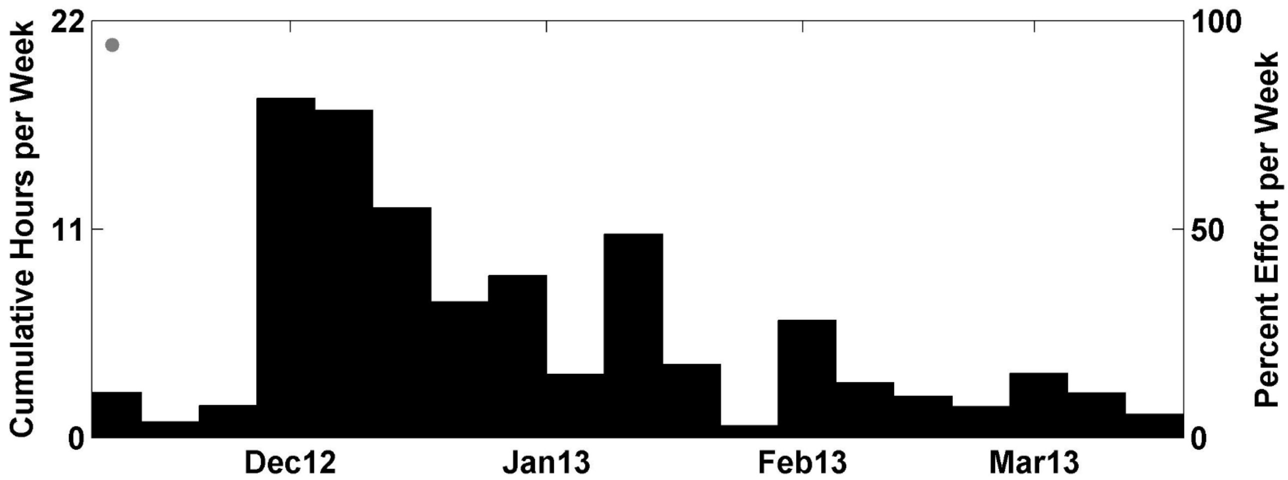

Figure 35. Weekly presence of UO CT > 20 kHz detected from November 2012 to March 2013 at DCPP Site C. Effort markings are described in Figure 16.

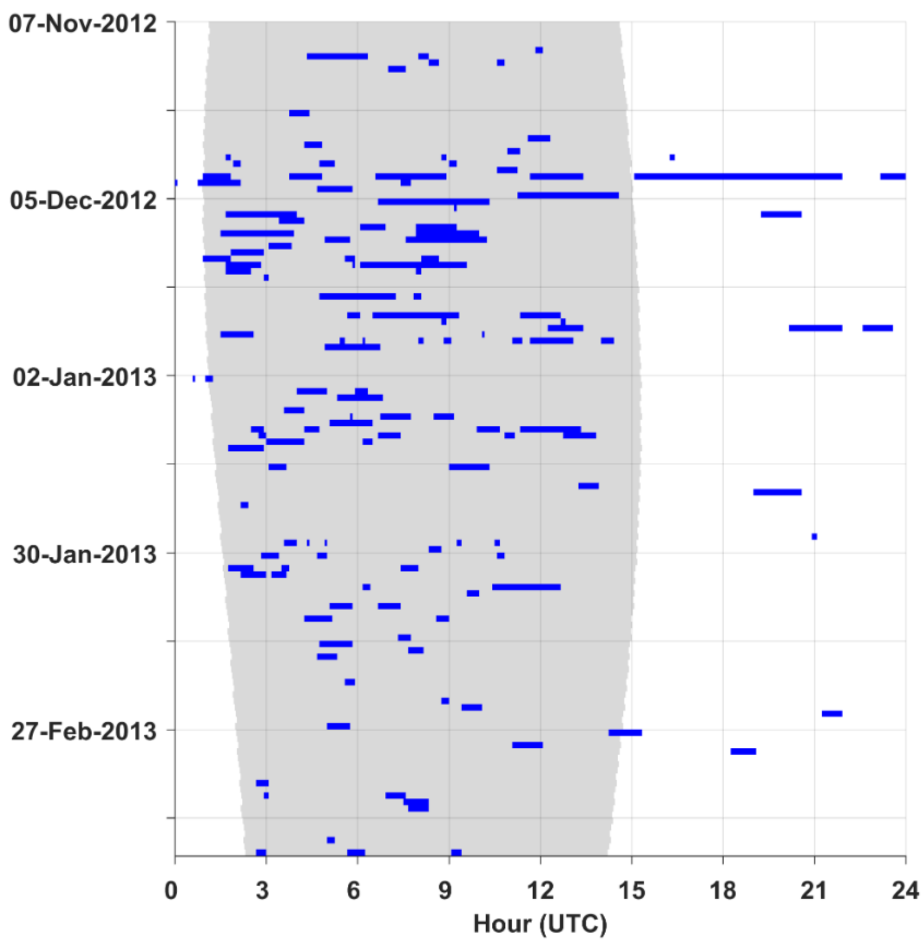

Figure 36. UO CT > 20 kHz in five-minute bins at DCPP Site C from November 2012 to March 2013. Gray vertical shading denotes nighttime.

Conclusions

Passive acoustic monitoring was conducted at the Diablo Canyon Site C from November 2012 to March 2013 to test for the presence of marine mammal signals and anthropogenic sonar. The initial goal of monitoring was to provide insight into the impact of seismic airguns on endangered baleen whales (blue, fin and humpback), and other marine mammals in the region, although the planned seismic survey was cancelled, and no airgun sounds are present in the dataset.

Three baleen whale species were recorded: blue, fin, and humpback whales. Blue whales B and D calls were recorded in high numbers from November 2012 to January 2013, dropping off after January 2013. Fin whales were seen in high numbers in November 2012 but decrease starting in mid-December 2012. Humpback whales were observed in high numbers throughout the monitoring period but began to drop off in late February 2012. No North Pacific Right Whale sounds were detected in this recording.

Seven odontocete species were recorded: killer whales, Cuvier's beaked whales, Baird's beaked whales, Risso's dolphins, Pacific White-Sided dolphins, sperm whales, and unidentified odontocete clicks. Killer whale pulsed calls were detected in low numbers throughout the monitoring period. Cuvier's and Baird's beaked whale echolocation clicks were the lowest detected species within the monitoring period but are consistent with other recordings in the area (Keating *et al.*, 2018). Risso's and Pacific-White Sided dolphin echolocation occurred in high numbers in January through March 2013. Sperm whales were detected throughout the monitoring period, with highest numbers occurring in December 2012. Unidentified odontocete clicks greater than 20 kHz were found throughout the monitoring period. No mid-frequency active sonar (MFA) was found during the monitoring period.

The Diablo Canyon site is specifically of interest for monitoring because species under the Endangered Species Act (ESA) inhabit the area during different periods of the year. Anthropogenic noise at low frequencies, primarily due to commercial shipping, overlaps with blue whale and fin whale calls at low frequencies (< 100 Hz). All three of the detected baleen whales (blue, fin and humpback) had song type calls in these data which suggests some use of the area for breeding.

Future work in the Diablo Canyon area using passive acoustic monitoring over a full annual cycle would enable documentation of the seasonal presence of marine mammal species, as well as the presence of anthropogenic signals and possible study of their potential impacts.

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