Passive Acoustic Monitoring for Marine Mammals Near Norfolk Canyon
June 2018 – May 2019

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Long-Beaked Common Dolphins (*Delphinus capensis*) Photo Credit: Katherine Whitaker

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Additional information on previous HARP deployments and availability of all associated reports is available on the project profile page of the U.S. Navy's Marine Species Monitoring Program web portal.

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Author Contributions:

M.A.R. compiled, wrote, and edited the report, conducted explosion and HFA sonar analysis. J.S.T. conducted beaked whale and MFA sonar analysis. A.C.R. conducted ambient soundscape and LFA sonar analysis, and produced ambient soundscape and MFA metric plots. M.M. conducted *Kogia* spp. analysis. B.J.T. coordinated field work logistics and deployed and recovered instruments. E.O. processed all recovered data. S.M.W. and K.E.F. contributed to algorithm development. K.E.F. managed project. S.B. and J.A.H. developed the project and determined data analysis approaches. L.E.W.H. and A.J.R. funded data collection and determined instrument locations.

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Executive Summary

A High-Frequency Acoustic Recording Package (HARP) was deployed from June 2018 to May 2019 to detect marine mammal and anthropogenic sounds in the Navy's Virginia Capes Range Complex near Norfolk Canyon (NFC). The HARP was deployed 75 nm offshore in approximately 1050 m of water. 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, and automated computer algorithm detection when possible. Three frequency bands were analyzed for marine mammal vocalizations and anthropogenic sounds: (1) Low-frequency, between 10–500 Hz, (2) Mid-frequency, between 1,000–5,000 Hz, and (3) High-frequency, between 5–100 kHz.

Elevated ambient sound levels below 100 Hz are predominantly due to basin-wide commercial shipping. Peaks in spectrum levels at 20 Hz from mid-September 2018 to March 2019 are related to the seasonally increased presence of fin whales. Sound levels at 200–1000 Hz were higher during winter, related to wind and wave noise from higher sea states.

Several known odontocete species were detected. Cuvier's beaked whale detections were found throughout the recording period but were most abundant in June 2018. Gervais'/ True's beaked whales were detected highest from December 2018 to March 2019. Sowerby's beaked whales were detected intermittently but were most abundant from December 2018 to March 2019. There were no detections of Blainville's beaked whales. *Kogia* spp. echolocation clicks were found in low numbers throughout the recording period but were highest in November 2018.

Four types of anthropogenic sounds were identified. Low-Frequency Active sonar (LFA) events were detected infrequently with four events occurring in July and December 2018 and in February and March 2019. Mid-Frequency Active sonar (MFA) was detected intermittently throughout the recording period but was highest in January 2019. High-Frequency Active sonar (HFA) was detected infrequently with two events occurring in November 2018 and January 2019. Explosions were detected intermittently with a total of 152 explosions during the recording period and detections highest in late July to August 2018.

Project Background

The US Navy's Virginia Capes Range Complex is located in the coastal and offshore waters of the western North Atlantic Ocean adjacent to Delaware, Maryland, Virginia, and North Carolina. The seafloor features a broad continental shelf, with an inner zone of less than 200 m water depth, and an outer zone extending to water depths of 2000 m. A diverse array of marine mammals is found in this region, including baleen and toothed whales.

In March 2012, an acoustic monitoring effort was initiated within the boundaries of the Virginia Capes Range Complex with support from U.S. Fleet Forces under contract to HDR and Duke University. The goal of this effort was to characterize the vocalizations of marine mammal species present in the area, to determine their seasonal presence patterns, and to evaluate the potential for impact from naval operations. This report documents the analysis of data recorded by a High Frequency Acoustic Recording Package (HARP) that was deployed within the Virginia Capes Range Complex near Norfolk Canyon and collected data from June 2018 to May 2019 (Figure 1).

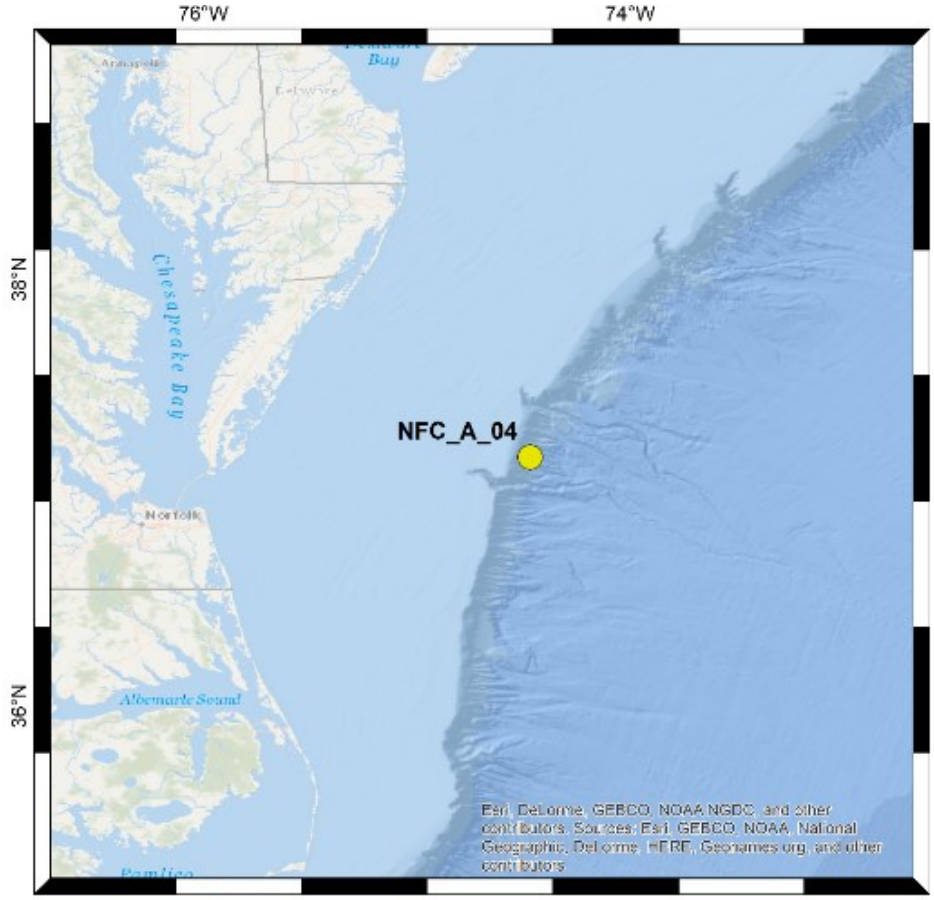

Figure 1. Location of High-Frequency Acoustic Recording Package (HARPs) at NFC Site A (37° 09.87 N, 74° 27.95 W, depth 1050 m) deployed near Norfolk Canyon study area from June 2018 to May 2019.

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 that are capable of approximately 300 days of continuous data storage. The HARP was 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 June 2018 to May 2019 at NFC Site A (37° 09.871', 74° 27.951' W, depth 1050 m) and sampled continuously at 200 kHz to provide 100 kHz of effective bandwidth. The instrument recorded 350.2 days from June 2, 2018 to May 18, 2019, for a total of 8,405 hours of data analyzed. Earlier data collection at the NFC site is documented in previous detailed reports (Rafter *et al.*, 2019; Rafter *et al*., 2018; Debich *et al*., 2016).

Data Analysis

To visualize the acoustic data, frequency spectra were calculated for all data using a time average of 5 seconds and 100 Hz frequency bins for high-frequency, 10 Hz for mid-frequency, and 1 Hz for low-frequency. These data, called Long-Term Spectral Averages (LTSAs), were then examined as a means to detect marine mammal and anthropogenic sounds. Data were analyzed by visually scanning LTSAs in source-specific frequency bands and, when appropriate, using automatic detection algorithms (described below). During visual analysis, when a sound of interest was identified in the LTSA but its origin was unclear, the waveform or spectrogram was examined to further classify the sounds to species or source. Signal classification was carried out by comparison to known species-specific spectral and temporal characteristics.

Recording over a broad frequency range of 10 Hz–100 kHz allows detection of baleen whales (mysticetes), toothed whales (odontocete), and anthropogenic sounds. The presence of acoustic signals from multiple marine mammal species and anthropogenic noise was evaluated in these data. To document the data analysis process, we describe the major classes of marine mammal calls and anthropogenic sound in this band in the Norfolk Canyon region, and the procedures used to detect them. For effective analysis, the data were divided into three frequency bands: (1) Low-frequency, 10–1,000 Hz, (2) Mid-frequency, 1,000–5,000 Hz, and (3) High-frequency, 5–100 kHz.

Each band was analyzed for the sounds of an appropriate subset of species or sources. Low frequency active sonar less than 500 Hz was classified as low-frequency. Explosions and active sonar sounds greater than 500 Hz were classified as mid-frequency. The remaining odontocete and sonar sounds were considered high-frequency. Analysis of low-frequency recordings required

decimation by a factor of 100. For the analysis of the mid-frequency recordings, the data were decimated by a factor of 20.

We summarize acoustic data collected at the NFC Site A from June 2018 to May 2019. We discuss seasonal occurrence and relative abundance of calls for different species and anthropogenic sounds that were consistently identified in the acoustic data.

Low-Frequency Ambient Soundscape

Ocean ambient sound pressure levels tend to decrease as frequency increases (Wenz, 1962). While baleen whales and anthropogenic sources, such as large ships and airguns, often dominate the ambient soundscape below 100 Hz (Širović *et al.*, 2004; McDonald *et al.*, 2006a; Wiggins *et al.*, 2016), wind causes increased sound pressure levels from 200 Hz to 20 kHz (Knudsen *et al.*, 1948). In the absence of wind, ambient sound pressure levels are low and difficult to measure at frequencies above ~10 kHz. Therefore, to analyze the ambient soundscape, the recordings were decimated by a factor of 100 to provide an effective bandwidth of 10 Hz to 1 kHz. LTSAs were then constructed with 1 Hz frequency and 5 s temporal resolution. To determine low-frequency ambient sound levels, daily spectra were computed by averaging five, 5 s sound pressure spectrum levels calculated from each 75 s acoustic record. System self-noise was excluded from these averages. Additionally, daily averaged sound pressure spectrum levels in 1-Hz bins were concatenated to produce long-term spectrograms for each site.

High-Frequency Marine Mammals

Marine mammal species with sounds in the high-frequency range and possibly found in the Virginia Capes Range Complex include bottlenose dolphins (*Tursiops truncatus*), short-finned pilot whales (*Globicephala macrorhynchus*), long-finned pilot whales (*Globicephala melas*), short-beaked common dolphins (*Delphinus delphis*), Atlantic spotted dolphins (*Stenella frontalis*), pantropical spotted dolphins (*Stenella frontalis*), spinner dolphins (*Stenella longirostris*), striped dolphins (*Stenella coeruleoalba*), Clymene dolphins (*Stenella clymene*), rough-toothed dolphins (*Steno bredanensis*), Risso's dolphins (*Grampus griseus*), Fraser's dolphins (*Lagenodelphis hosei*), pygmy killer whales (*Feresa attenuata*), melon-headed whales (*Peponocephala electra*), sperm whales (*Physeter macrocephalus*), dwarf sperm whales (*Kogia sima*), pygmy sperm whales (*Kogia breviceps*), Cuvier's beaked whales (*Ziphius cavirostris*), Gervais' beaked whales (*Mesoplodon europaeus*), Blainville's beaked whales (*Mesoplodon densirostris*), True's beaked whales (*Mesoplodon mirus*) and Sowerby's beaked whales (*Mesoplodon bidens*).

High-Frequency Call Types

Odontocete sounds can be categorized as echolocation clicks, burst pulses, or whistles. Echolocation clicks are broadband impulses with peak energy between 5 and 150 kHz, dependent upon the species. Buzz or burst pulses are rapidly repeated clicks that have a creak or buzz-like sound quality; they are generally lower in frequency than echolocation clicks. Dolphin whistles are tonal calls predominantly between 1 and 20 kHz that vary in frequency content, their degree of frequency modulation, as well as duration. These signals are easily detectable in an LTSA as well as the spectrogram (Figure 2).

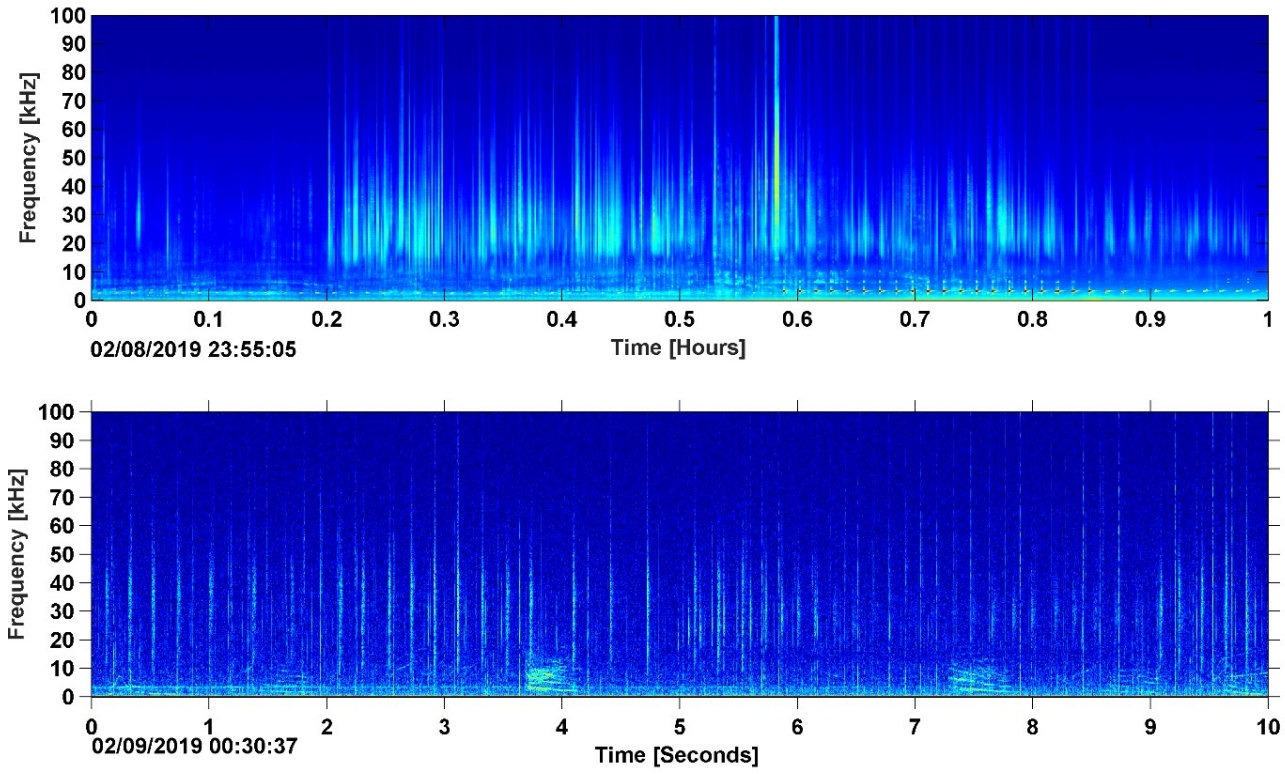

Figure 2. LTSA (top) and spectrogram (bottom) demonstrating odontocete signal types.

Beaked Whales

Beaked whales can be identified acoustically by their echolocation signals (Baumann-Pickering *et al*., 2014). 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 described for all beaked whales known to potentially occur in this region, namely Gervais', Blainville's, Cuvier's, True's, and Sowerby's beaked whales.

Beaked whale FM pulses were detected with an automated method. This automated effort was for all identifiable beaked whale signals found in the Virginia Capes Range Complex. 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 7 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. 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 approximately 5%, varying slightly across deployments.

Blainville's Beaked Whale

Blainville's beaked whale echolocation signals are, like most beaked whales' signals, polycyclic, with a characteristic frequency-modulated upsweep, peak frequency around 34 kHz and uniform inter-pulse interval (IPI) of about 280 ms (Johnson *et al*., 2004; Baumann-Pickering *et al*., 2013). Blainville's FM pulses are also distinguishable in the spectral domain by their sharp energy onset around 25 kHz with only a small energy peak at around 22 kHz (Figure 3). Blainville's beaked whales were not identified at NFC Site A during the recording period.

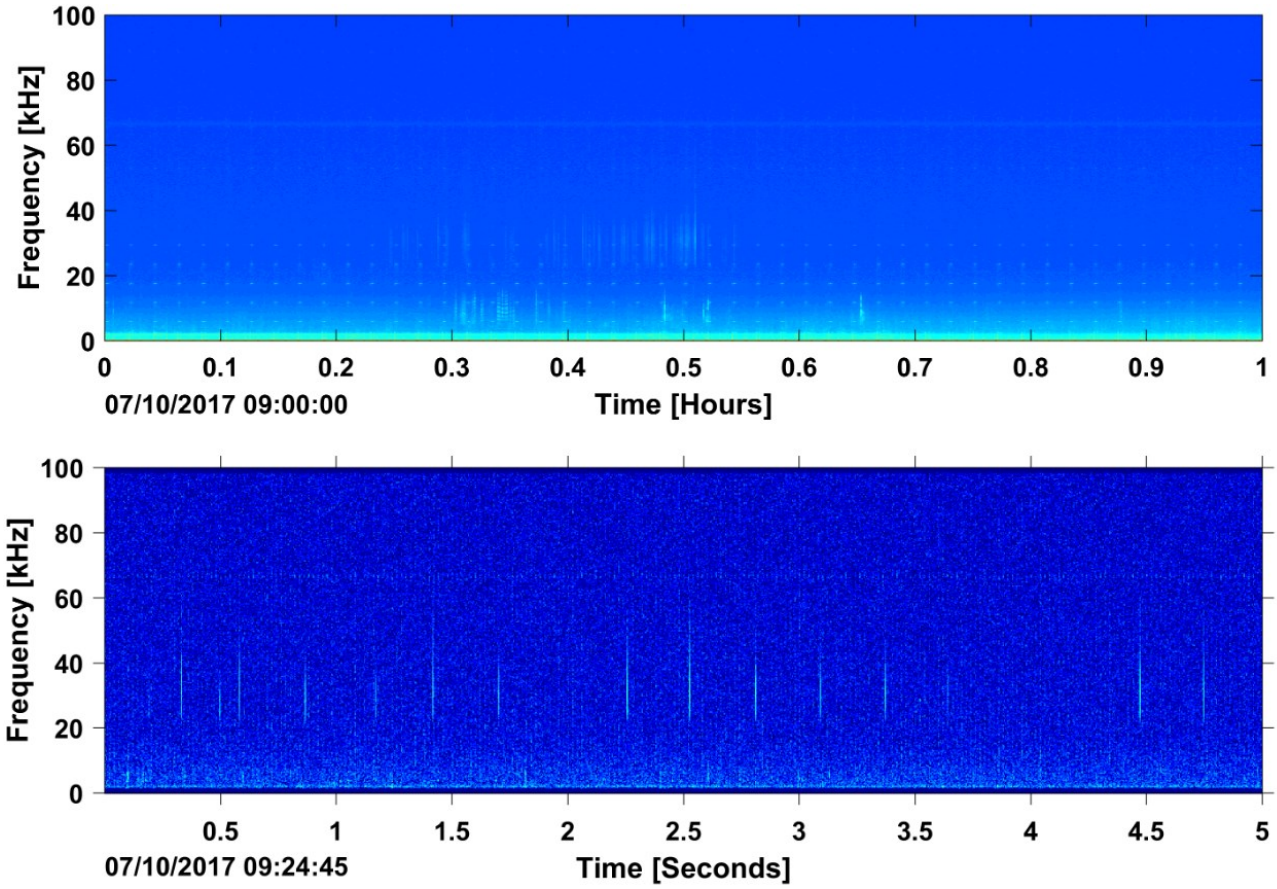

Figure 3. Blainville's beaked whale echolocation clicks in the LTSA (top) and spectrogram (bottom) recorded at NFC Site A, July 2017.

Cuvier's Beaked Whales

Cuvier's echolocation signals are polycyclic, with a characteristic FM pulse upsweep, peak frequency around 40 kHz (Figure 4), and uniform inter-pulse interval of about 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.

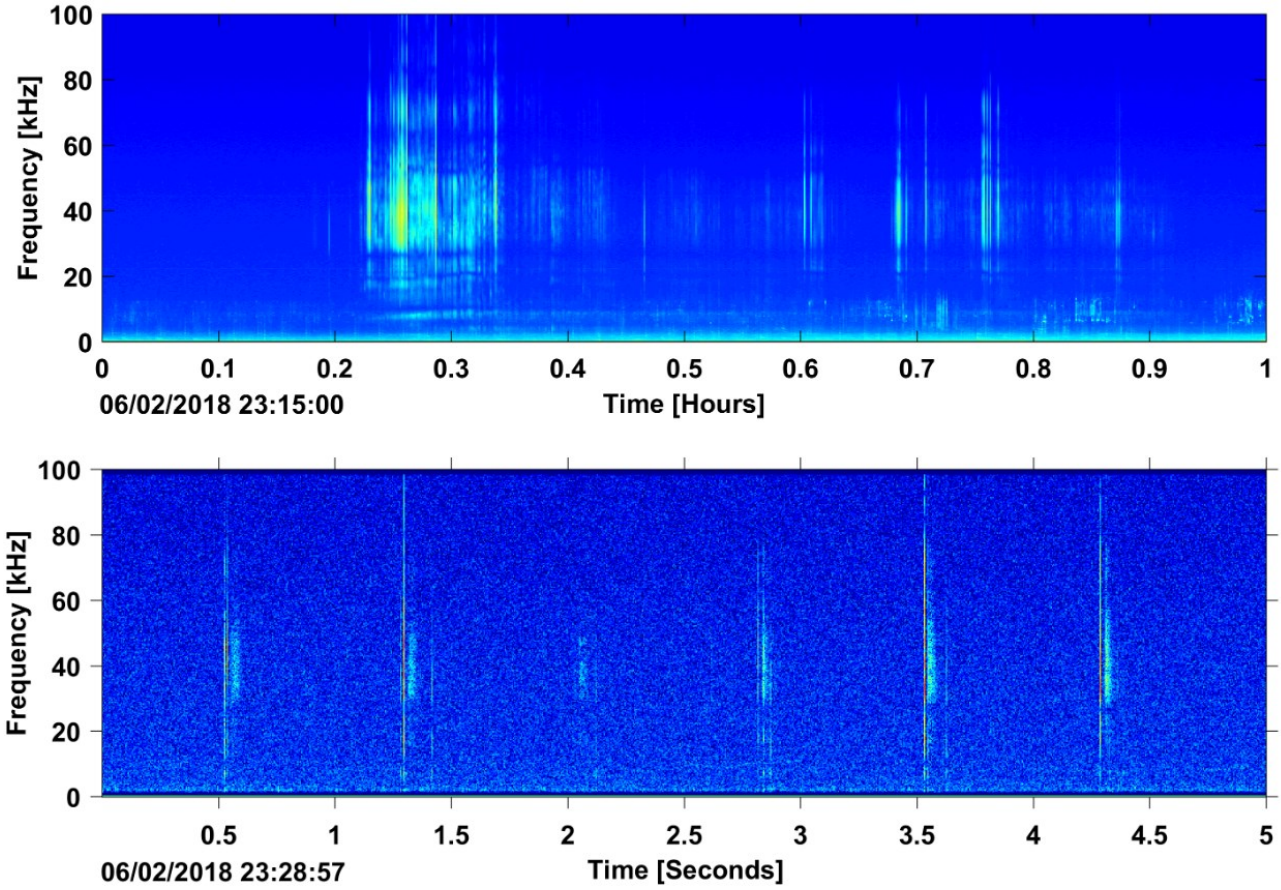

Figure 4. Cuvier's beaked whale signals in LTSA (top) and spectrogram (bottom) recorded at NFC Site A, June 2018.

Gervais' Beaked Whales

Gervais' beaked whale signals have energy concentrated in the 30-50 kHz band (Gillespie *et al*., 2009), with a peak at 44 kHz (Baumann-Pickering *et al*., 2013). While Gervais' beaked whale signals are similar to those of Cuvier's and Blainville's beaked whales, the Gervais' beaked whale FM pulses are at a slightly higher frequency than those of the other two species. Similarly, Gervais' beaked whale FM pulses sweep up in frequency (Figure 5). The IPI for Gervais' beaked whale signals is typically around 275 ms (Baumann-Pickering *et al*., 2013).

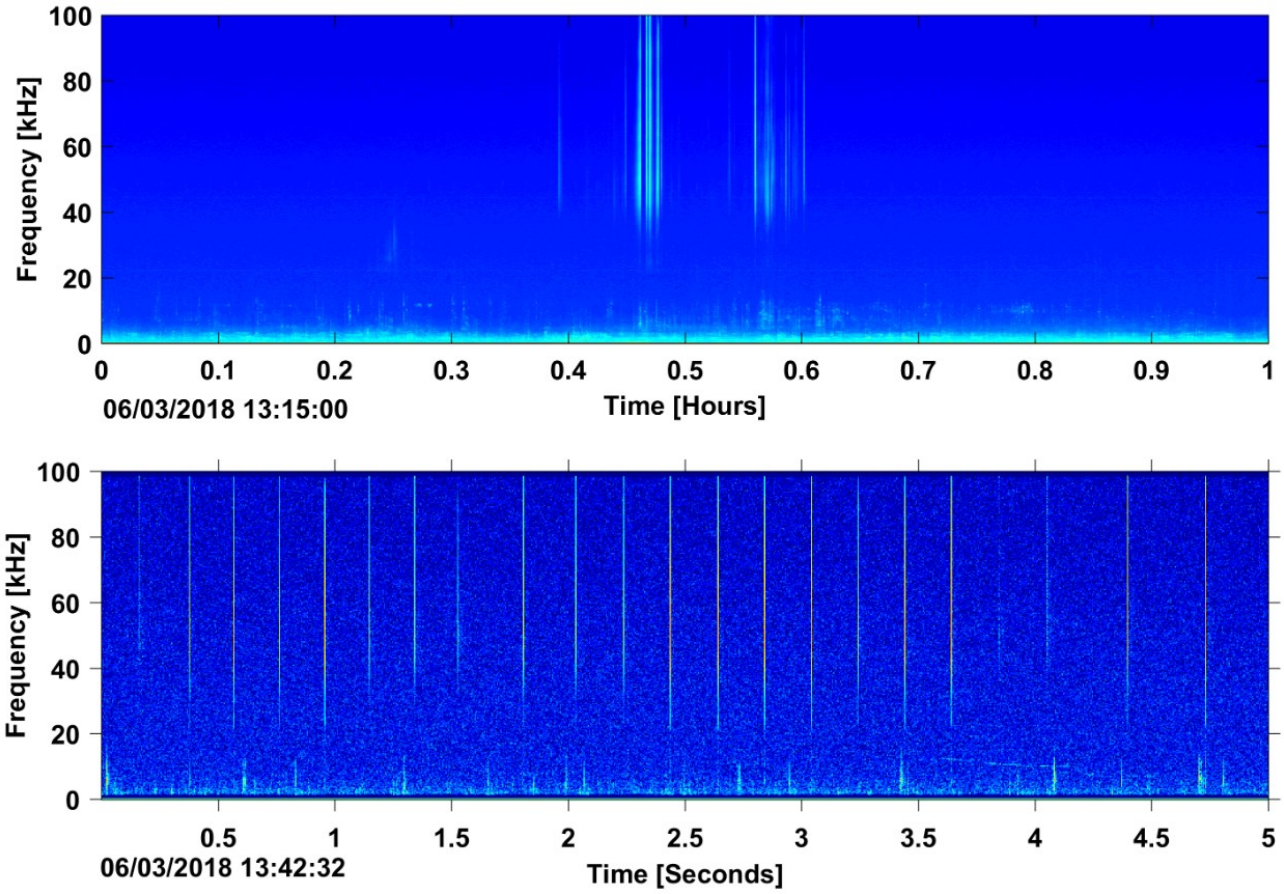

Figure 5. Gervais' beaked whale signals in LTSA (top) and spectrogram (bottom) recorded at NFC Site A, June 2018.

True's Beaked Whale

True's beaked whale echolocation signals are FM upsweep pulses, with peak frequency around 46 kHz and an inter-pulse interval of about 180 ms (Figure 6). The spectral features of True's beaked whale FM pulses closely resemble those produced by Gervais' beaked whales, and acoustic discrimination between these two species remains challenging (DeAngelis *et al*., 2018).

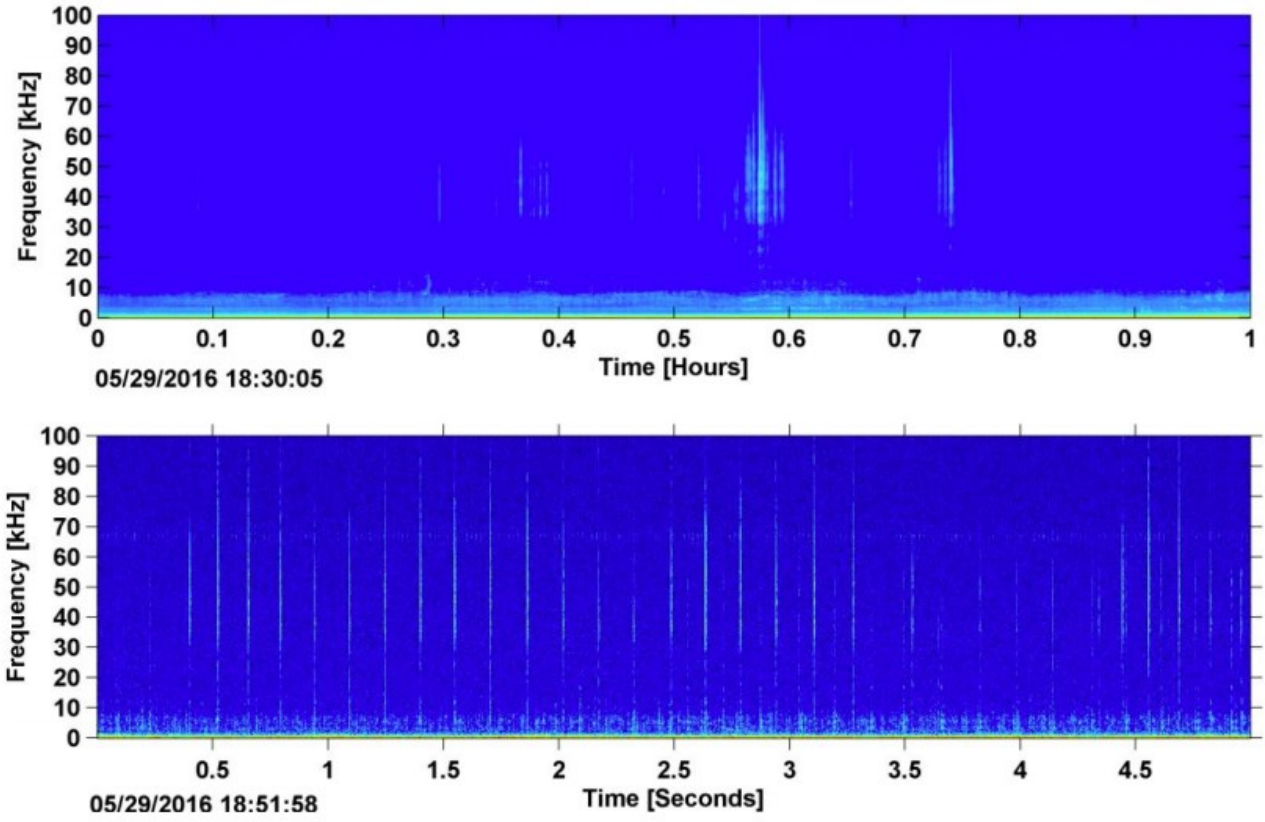

Figure 6. True's beaked whale echolocation clicks in LTSA (top) and spectrogram (bottom) recorded in the Western Atlantic at Nantucket Canyon, May 2016.

Sowerby's Beaked Whales

Sowerby's beaked whale echolocation signals have energy concentrated in the 50-95 kHz band, with a peak at 67 kHz (Figure 7). Sowerby's beaked whale signals have a characteristic FM upsweep, and are distinguishable from other co-occurring beaked whale signal types by their higher frequency content and a relatively short inter-pulse interval of around 150 ms (Cholewiak *et al*., 2013; Clarke *et al.* 2019).

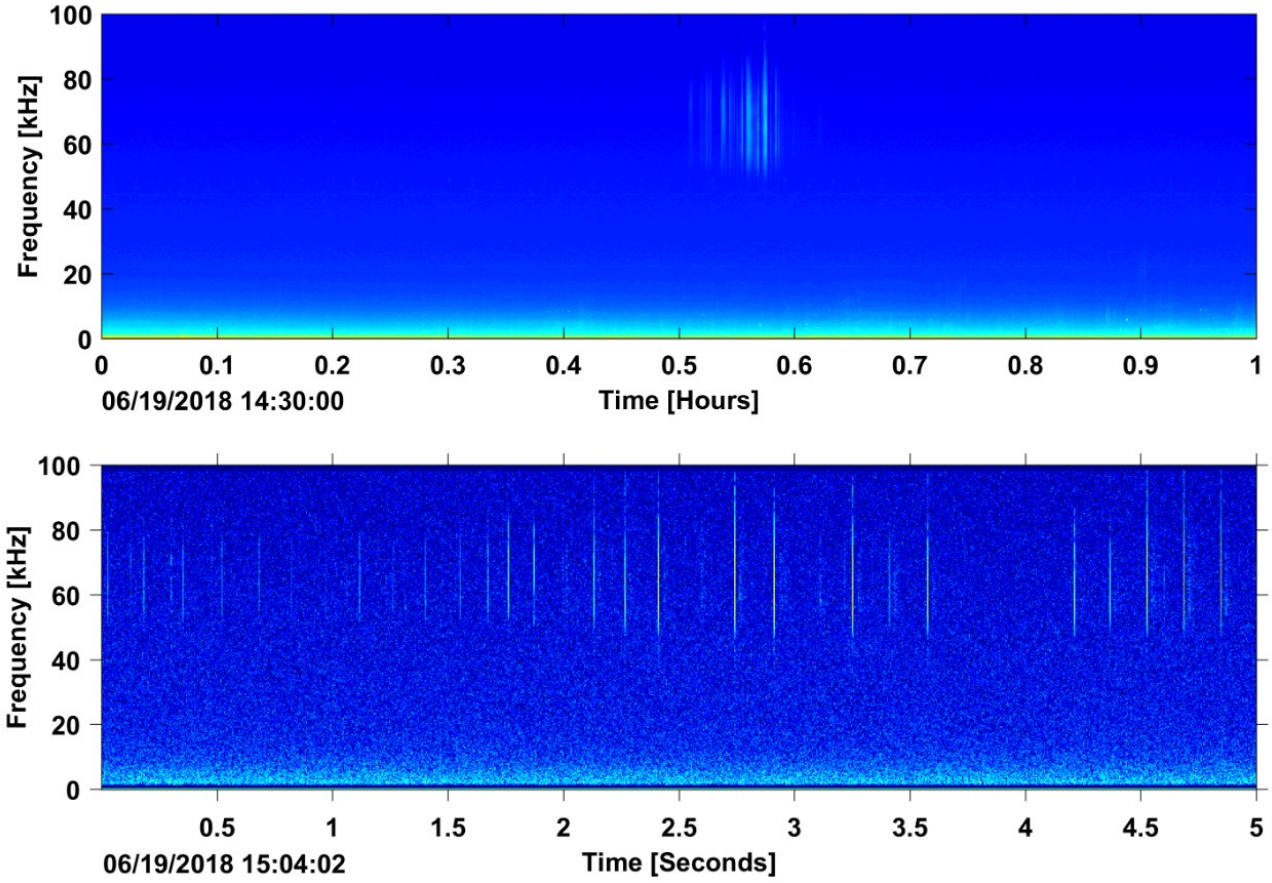

Figure 7. Sowerby's beaked whale echolocation clicks in LTSA (top) and spectrogram (bottom) recorded at NFC Site A, June 2018.

***Kogia* spp.**

Dwarf and pygmy sperm whales emit echolocation signals that have peak energy at frequencies near 130 kHz (Au, 1993). While this is above the frequency band recorded by the HARP, the lower portion of the *Kogia* energy spectrum is within the 100 kHz HARP bandwidth (Figure 8). The observed signal may result both from the low-frequency tail of the *Kogia* echolocation click spectra, and from aliasing of energy from above the Nyquist frequency of 100 kHz. *Kogia* echolocation clicks were analyzed using a multi-step detector. The first step was to identify clicks with energy in the 70-100 kHz band that simultaneously lacked energy in lower frequency bands. An expert system then classified these clicks based on spectral characteristics, and finally an analyst verified all echolocation click bouts manually.

Kogia spp. echolocation clicks were detected automatically using an energy detector with a minimum peak-to-peak received level threshold of 120 dB re: 1 µPa (Frasier *et al.*, 2015). Dominant click types at this site were identified automatically by dividing detections into successive five-minute windows and determining the dominant click type(s) in each window. An automated clustering algorithm was then used to identify recurrent click types as well as false positives across all windows (Frasier *et al.*, 2017). Detections were automatically labeled by a classifier based on the automatically identified categories. All classifications were then verified by an analyst who reviewed LTSAs and mean spectra for each detected bout. A bout was defined as a period of clicking separated before and after by at least 15 minutes without clicking.

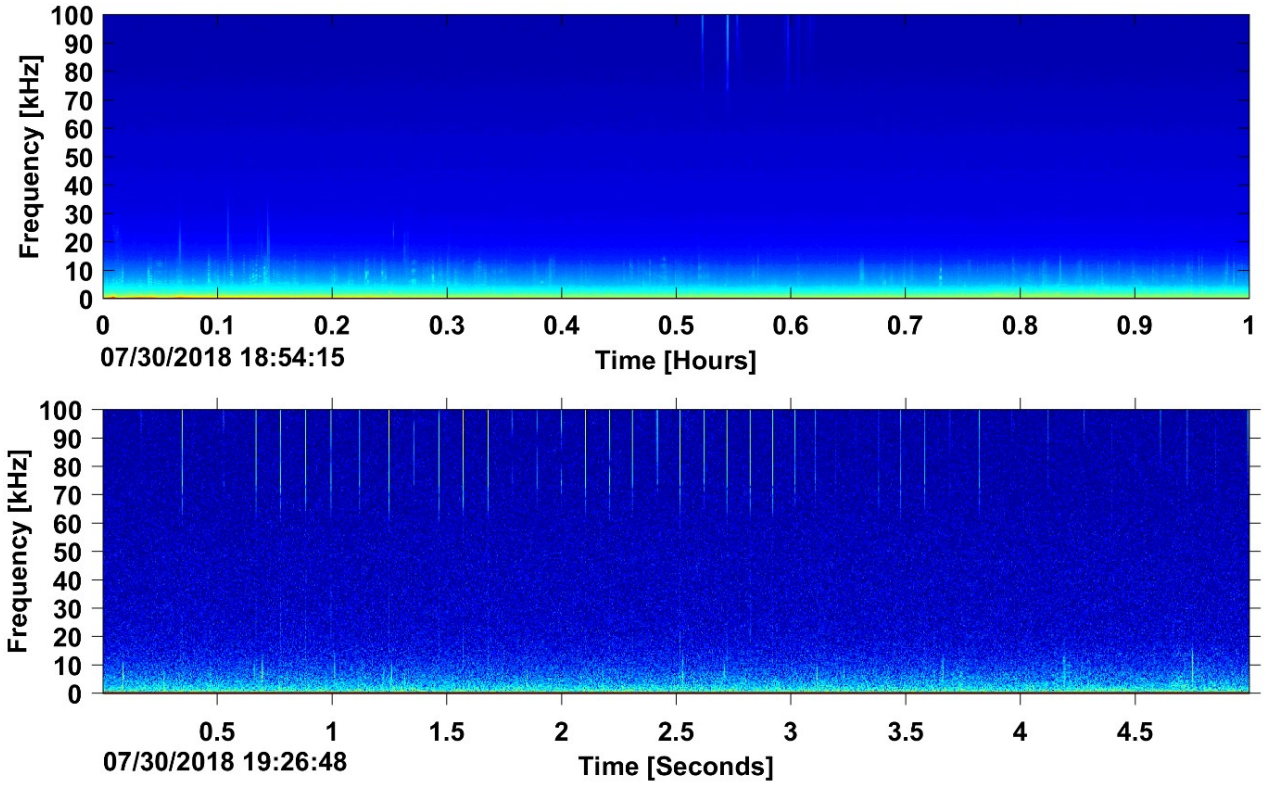

Figure 8. *Kogia* spp. echolocation clicks in LTSA (top) and spectrogram (bottom) from HARP recorded at NFC Site A, July 2018.

Anthropogenic Sounds

Several anthropogenic sounds including Low-Frequency Active (LFA) sonar, Mid-Frequency Active (MFA) sonar, High-Frequency Active (HFA) sonar, and explosions were monitored for this report. The LTSA search parameters used to manually detect LFA and HFA sonars are given in Table 1. The start and end of each sound or session was logged and their durations were added to estimate cumulative hourly presence. Airguns, MFA sonar, and explosions were analyzed by using automated detectors, described below.

Table 1. Anthropogenic sound data manual effort analysis parameters.

Sound Type	LTSA Search Parameters	
	Plot Length (Hour)	Display Frequency Range (Hz)
LFA Sonar	1	10–1,000
HFA Sonar	1	10,000–100,000

Low-Frequency Active Sonar

Low-frequency active sonar includes military sonar between 100 and 500 Hz and other sonar systems up to 1 kHz. Effort was expended for LFA sonar less than 500 Hz and between 500 Hz and 1 kHz (Figure 9).

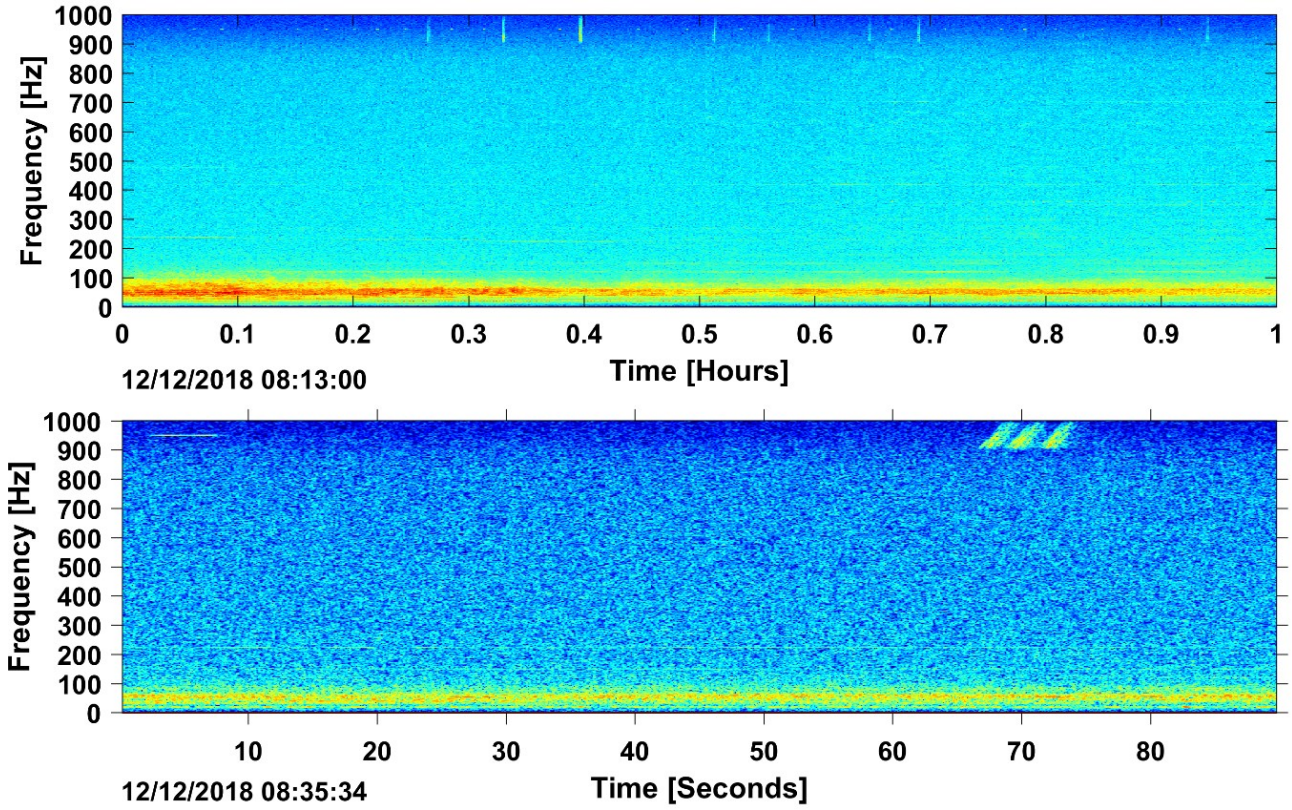

Figure 9. Low-Frequency Active (LFA) sonar in Hz in the LTSA (top) and spectrogram (bottom) recorded at NFC Site A, December 2018.

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 10). In Norfolk Canyon, the most common MFA sonar packet signals are between 2 and 5 kHz and are known more generally 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 21 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 time-frequency peaks 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 instrument disk writes that occurred at 75 s intervals.

Over periods of several months, these 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. Start and end time of these cleaned sonar events were then created to be used in further processing.

These start and end times were used to read segments of waveforms upon which a 2.4 to 4.5 kHz bandpass filter and a simple time series energy detector was applied to detect and measure various packet parameters after correcting for the instrument calibrated transfer function (Wiggins, 2015). For each packet, maximum peak-to-peak (pp) received level (RL), sound exposure level (SEL), root-mean-square (RMS) RL, date/time of packet occurrence, and packet RMS duration (for RLpp – 10 dB) were measured and saved.

Various filters were applied to the detections to limit the MFA sonar detection range to ~20 km for off-axis signals from an AN/SQS 53C source, which resulted in a received level detection threshold of 130 dB pp re 1 µPa (Wiggins, 2015). Instrument maximum received level was ~164 dB pp re 1 µPa, above which waveform clipping occurred. Packets were grouped into wave trains separated by more than 1 hour. Packet received levels were plotted along with the number of packets and cumulative SEL (CSEL) in each wave train over the study period. Wave train duration and total

packet duration were also calculated. Wave train duration is the difference between the first and last packet detections in an event. The total packet duration of for a wave train is the sum of the individual packet (i.e., group of pings) durations, which is measured as the period of the waveform that is 0 to 10 dB less than the maximum peak-to-peak received level of the ping group.

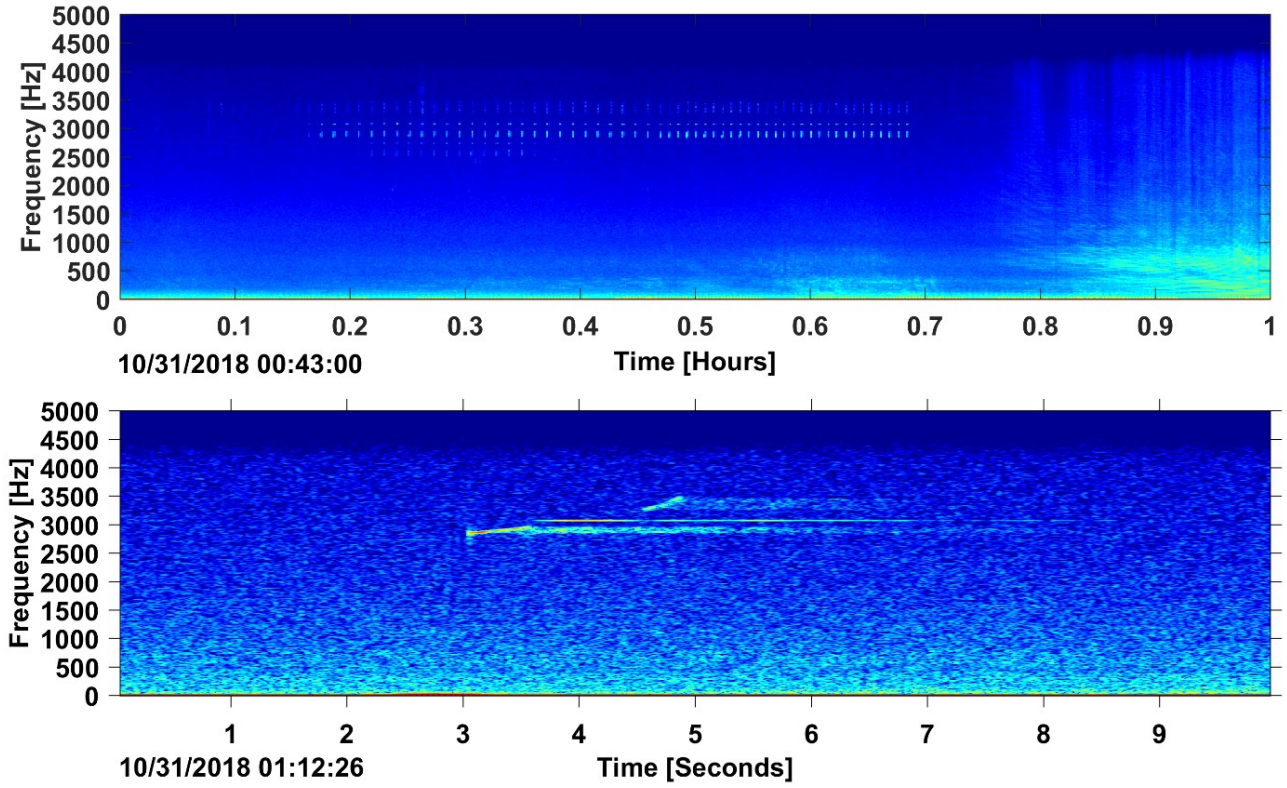

Figure 11. Mid-Frequency Active (MFA) sonar in LTSA (top) and spectrogram (bottom) recorded at NFC Site A, October 2018.

High-Frequency Active Sonar

HFA sonar is used for specialty military and commercial applications including high-resolution seafloor mapping, short-range communications, such as with Autonomous Underwater Vehicles (AUVs), multi-beam fathometers, and submarine navigation (Cox, 2004). HFA sonar upsweeps between 10 and 100 kHz were manually detected by analysts in LTSA plots (Figure 11) for this deployment.

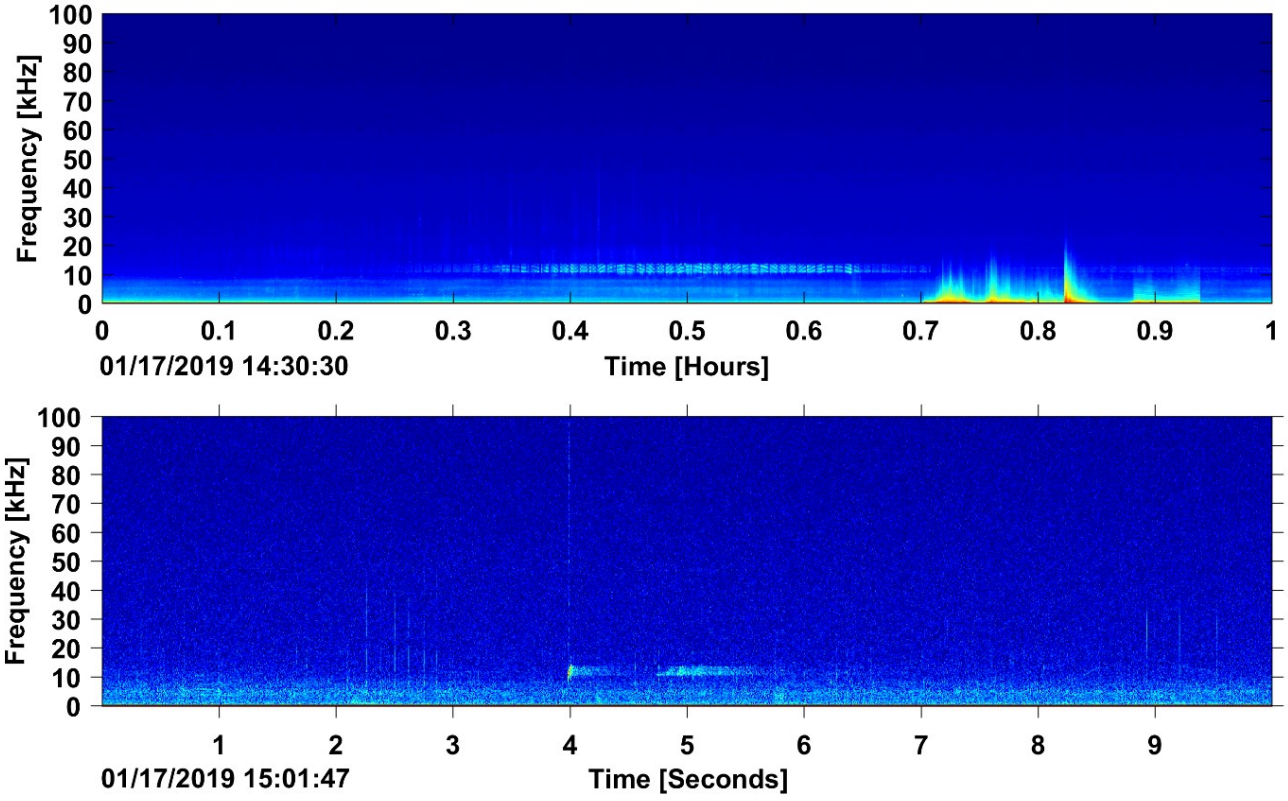

Figure 11. High-Frequency Active (HFA) sonar in LTSA (top) and spectrogram (bottom) recorded at NFC Site A, January 2019.

Explosions

Effort was directed toward finding explosive sounds in the data including military explosions, shows from sub-seafloor exploration, and seal bombs used by the fishing industry. An explosion appears as a vertical spike in the LTSA that, when expanded in the spectrogram, has sharp onset reverberant decay (Figure 12). Explosions were detected automatically using a matched filter detector on data decimated to a 10 kHz sampling rate. The time series was filtered with a 10th order Butterworth bandpass filter between 200 and 2,000 Hz. 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 reached above threshold, the time series was inspected more closely. Consecutive explosions were required to have a minimum time distance of 2 seconds to be detected. A 300-point (0.03 s) floating average energy across the detection was computed. The start and end above threshold was determined when the energy rose by more than 2 dB above the median energy across the detection. Peak-to-peak (pp) and rms received levels (RL) were computed over the potential explosion period and a time series of the length of the explosion template before and after the explosion. The potential explosion was classified as false detection and deleted if 1) the dB difference pp and rms between signal and time after the detection was less than 4 dB or 1.5 dB, respectively; 2) the dB difference pp and rms between signal and time before signal was less than 3 dB or 1 dB, respectively; and 3) the detection was shorter than 0.03 and 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 potential explosions for accuracy. 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 automatically detected and then manually verified to remove false positives associated with airgun activity and fish sounds.

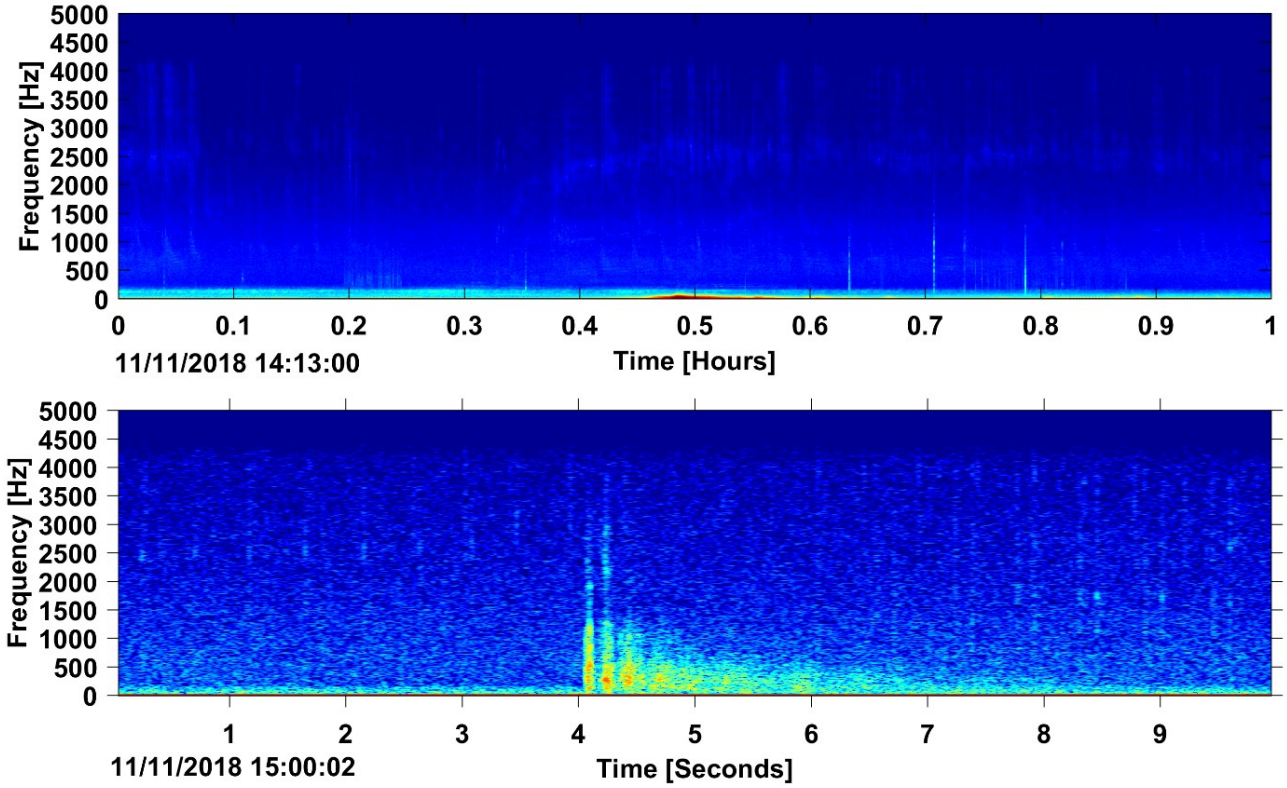

Figure 12. Explosions in LTSA (top) and spectrogram (bottom) recorded at NFC Site A, November 2018.

Results

The results of acoustic data analysis at NFC Site A from June 2018 to May 2019 are summarized, and the seasonal occurrence and relative abundance of marine mammal acoustic signals and anthropogenic sounds are documented.

Ambient Soundscape

To provide a means for evaluating seasonal spectral variability, daily-averaged spectra were processed into monthly averages (Figure 13) and plotted so that months could be compared. Incomplete days have been removed from the analysis, incomplete months were not. Partial months include an asterisk (*) in the color legend (Figure 13). Long-term spectrograms were generated using daily-averaged spectra (Figure 14).

- The increased spectrum levels centered around 45 Hz are a result of commercial shipping activity (Figure 13).
- From mid-September 2017 to mid-March 2018, the peak in spectrum levels at 20 Hz is related to the seasonal increase in fin whale 20 Hz calls (Figure 14).
- Sound levels at 200–1000 Hz are higher during winter, related to wind and wave noise associated with higher sea states (Figure 14).

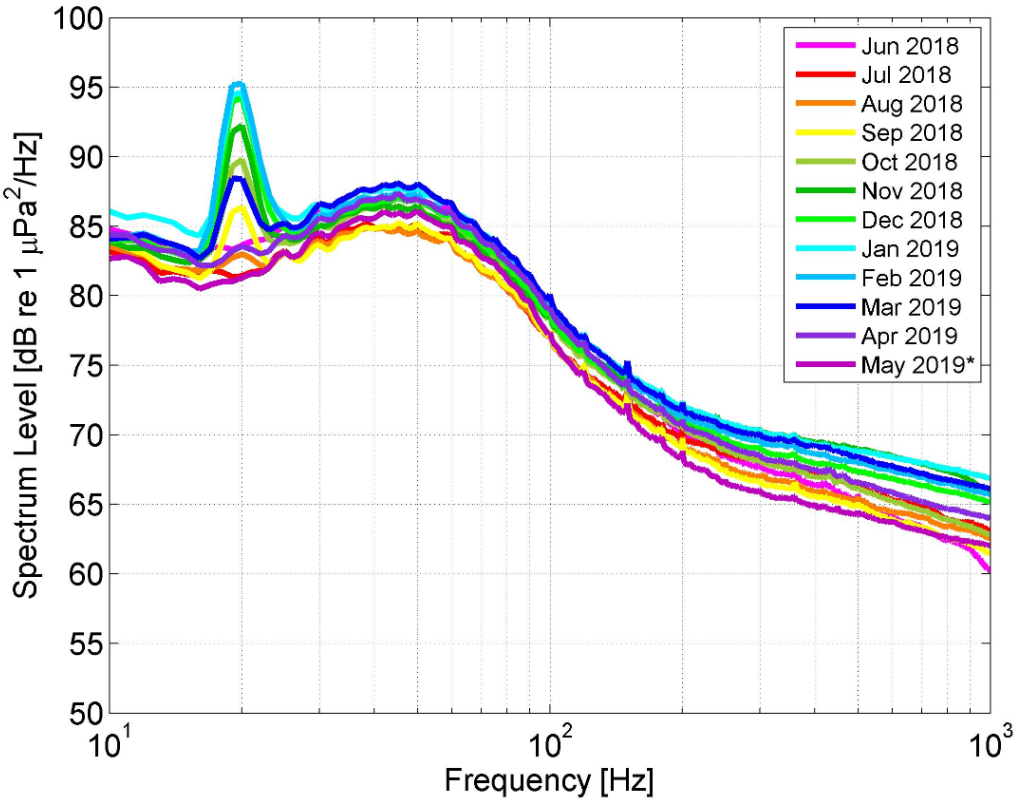

Figure 13. Monthly averages of ambient soundscape at NFC Site A from June 2018 to May 2019. Legend gives color coding by month. Months with an asterisk are partial recording periods.

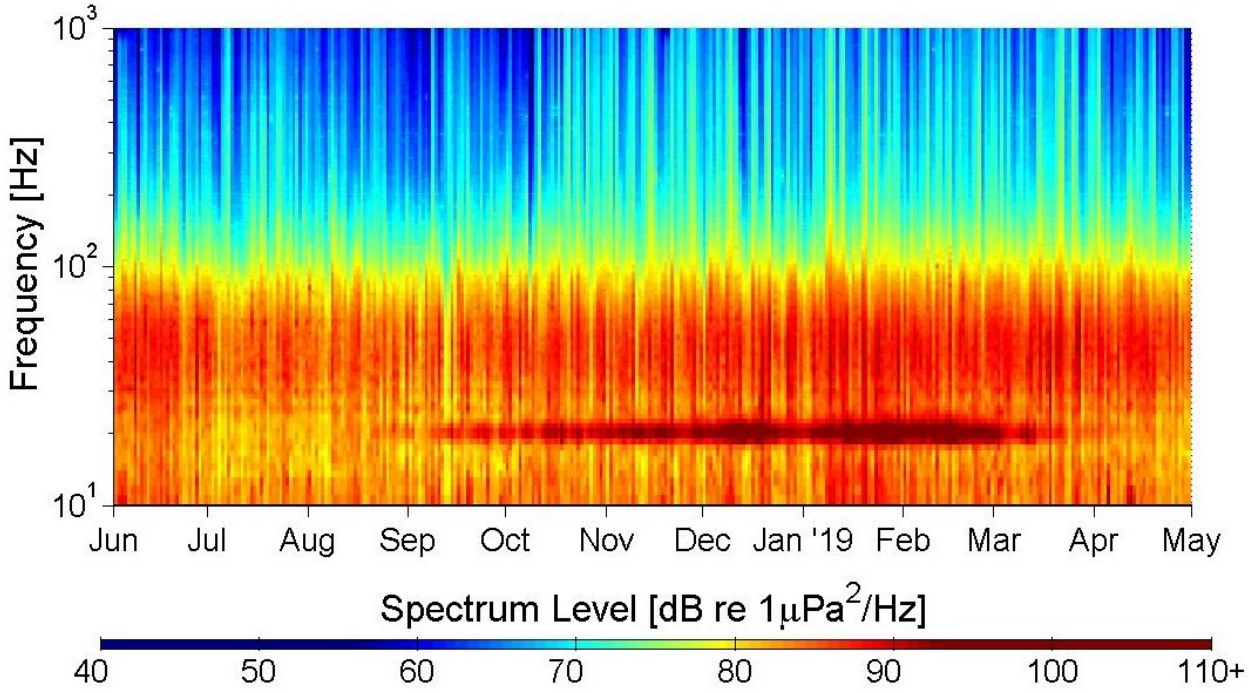

Figure 14. Long-term spectrograms using daily-averaged spectra for NFC Site A from June 2018 to May 2019.

Odontocetes

Clicks from Cuvier's beaked whale, Gervais'/ True's beaked whale, Sowerby's beaked whale, and *Kogia* spp. were detected. No Blainville's beaked whales were detected. Further details of each species' presence from June 2018 to May 2019 are given below.

Cuvier's Beaked Whale

- Cuvier's beaked whale echolocation clicks were detected intermittently but were highest in June 2018 (Figure 15).
- There was no diel pattern in detections of Cuvier's beaked whale echolocation clicks (Figure 16).

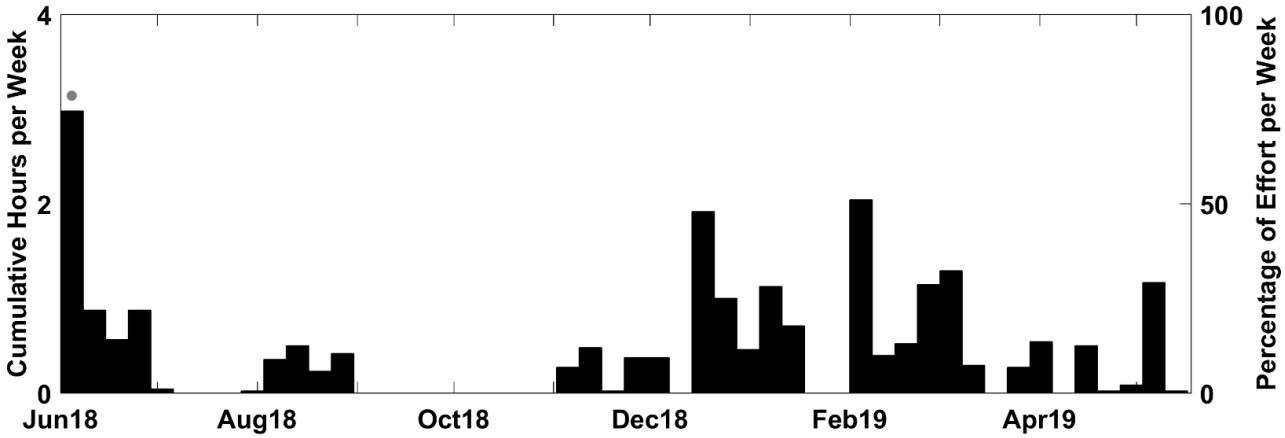

Figure 15. Weekly presence of Cuvier's beaked whale echolocation clicks from June 2018 to May 2019 at NFC Site A. Gray dots represent percent of effort per week in weeks with less than 100% recording effort. Where gray dots are absent, full recording effort occurred for the entire week. X-axis labels refer to month and year of recording.

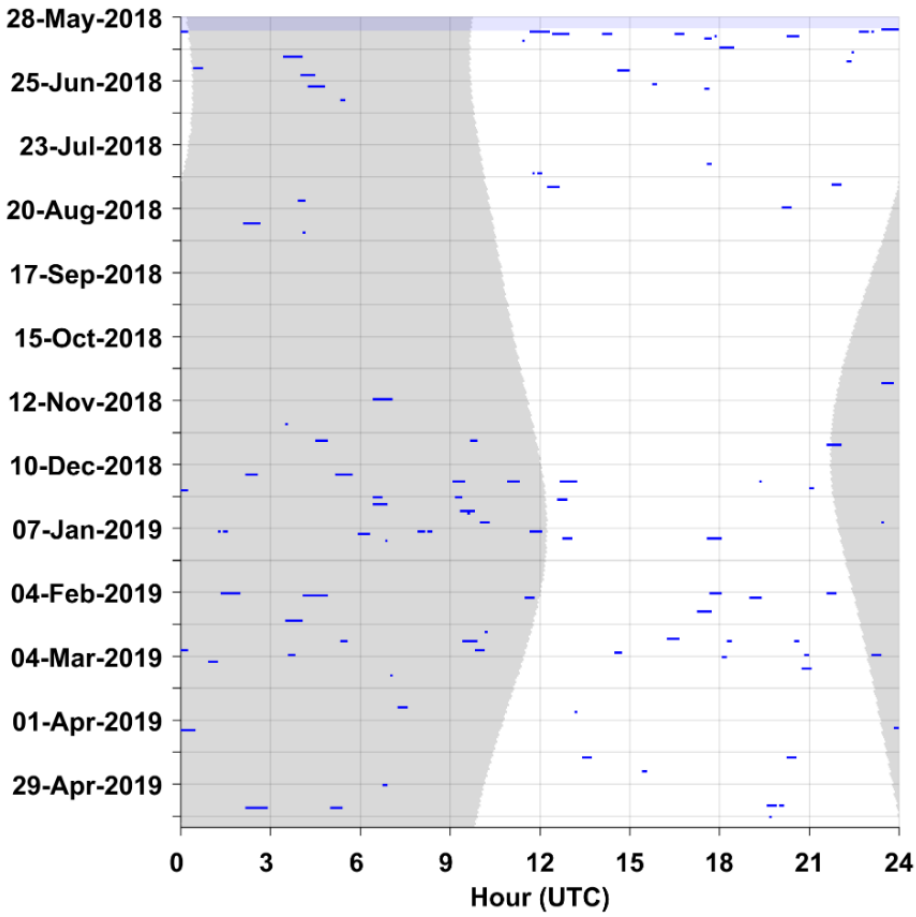

Figure 16. Cuvier's beaked whale echolocation clicks in five minute bins from June 2018 to May 2019 at NFC Site A. Gray vertical shading denotes nighttime.

Gervais' Beaked Whale / True's Beaked Whale

- Gervais'/ True's beaked whale echolocation clicks were detected throughout the recording period but were highest from December 2018 to March 2019 (Figure 17).
- There was no discernible diel pattern for Gervais'/ True's beaked whale clicks (Figure 18).
- Because the FM pulse types produced by Gervais' and True's beaked whales are highly similar and acoustic discrimination between them remains challenging (DeAngelis *et al*. 2018), it was not possible to classify detections of this signal type to the species level.

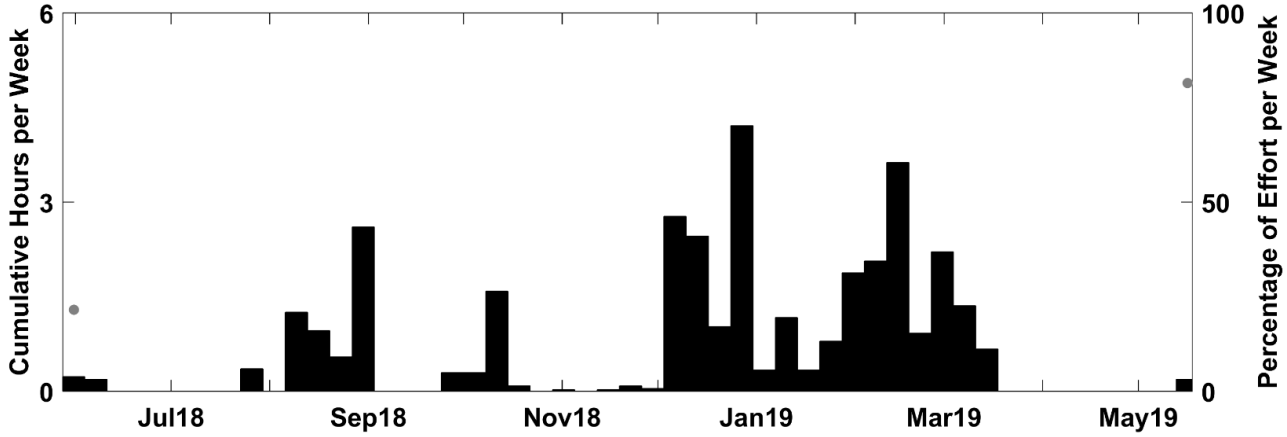

Figure 17. Weekly presence of Gervais' / True's beaked whale echolocation clicks from June 2018 to May 2019 at NFC Site A. Effort markings are described in Figure 15.

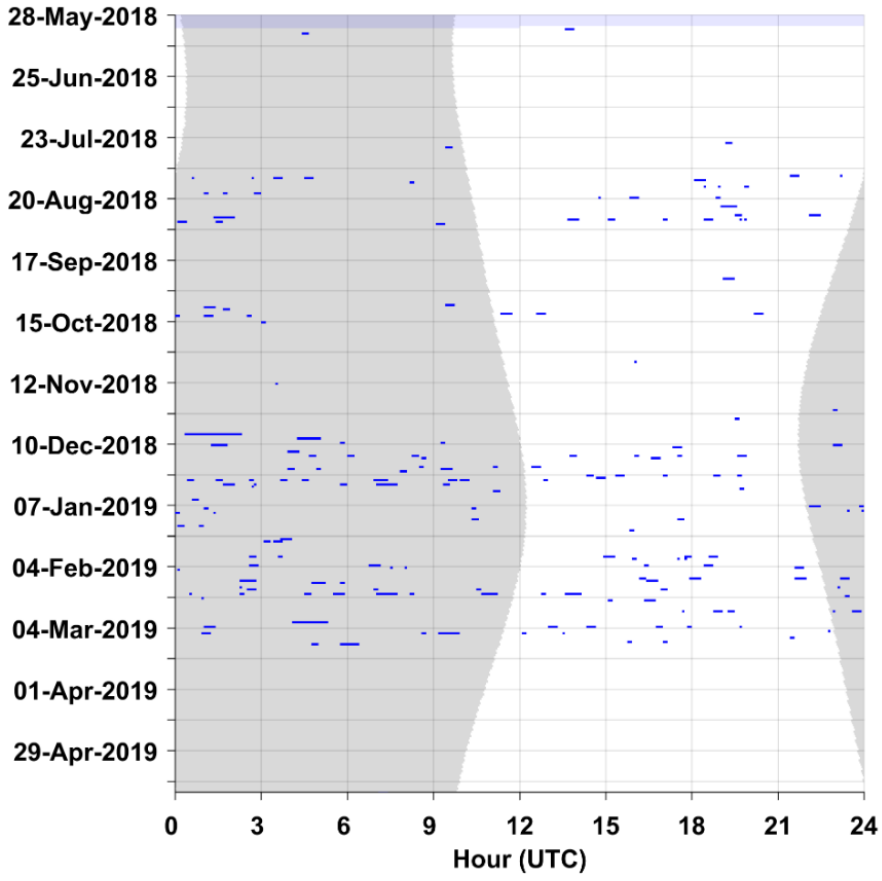

Figure 18. Gervais' / True's beaked whale echolocation clicks in five minute bins from June 2018 to May 2019 at NFC Site A. Effort markings are described in Figure 16.

Sowerby's Beaked Whale

- Sowerby's beaked whale echolocation clicks were detected throughout the recording period but were highest from December 2018 to March 2019 (Figure 19).
- There was no discernible diel pattern for Sowerby's beaked whale clicks (Figure 20).

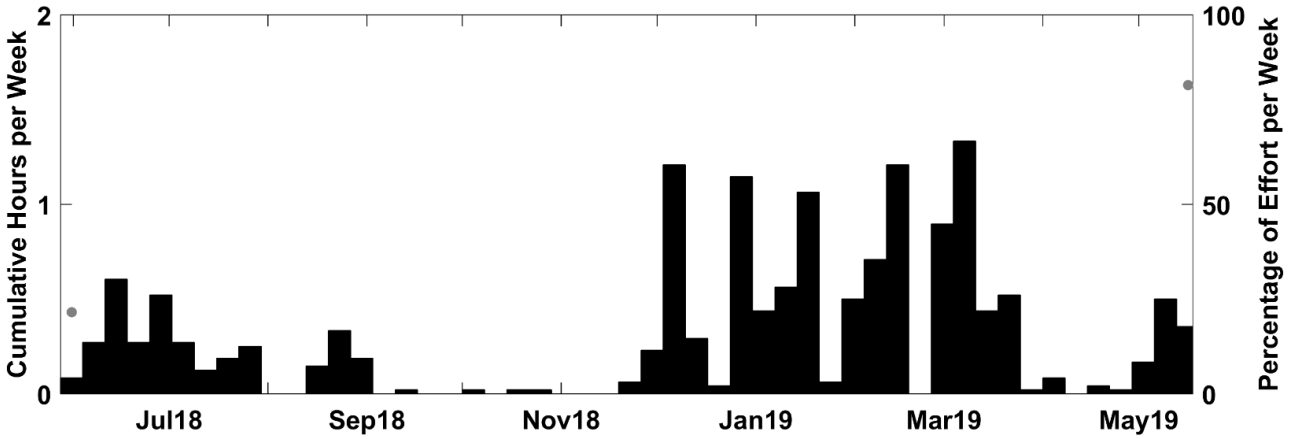

Figure 19. Weekly presence of Sowerby's beaked whale echolocation clicks from June 2018 to May 2019 at NFC Site A. Effort markings are described in Figure 15.

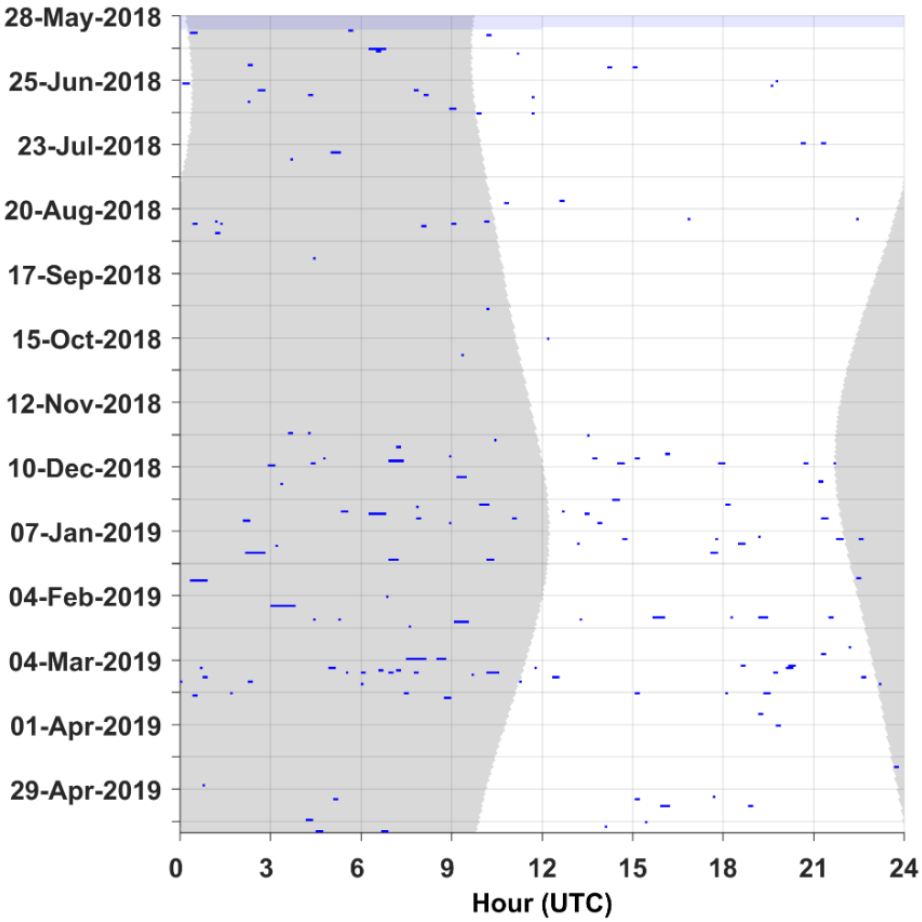

Figure 20. Sowerby's beaked whale echolocation clicks in five minute bins from June 2018 to May 2019 at NFC Site A. Effort markings are described in Figure 16.

***Kogia* spp.**

- *Kogia* spp. echolocation clicks were detected intermittently throughout the detection period with highest number of detections occurring in November 2018 (Figure 21).
- There was no discernible diel pattern for *Kogia* echolocation clicks (Figure 22).

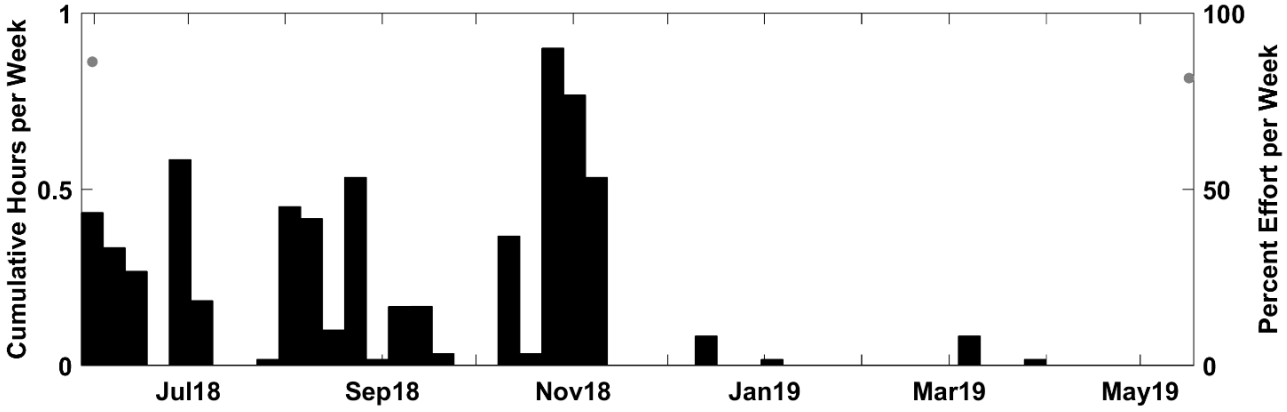

Figure 21. Weekly presence of *Kogia* spp. clicks from June 2018 to May 2019 at NFC Site A. Effort markings are described in Figure 15.

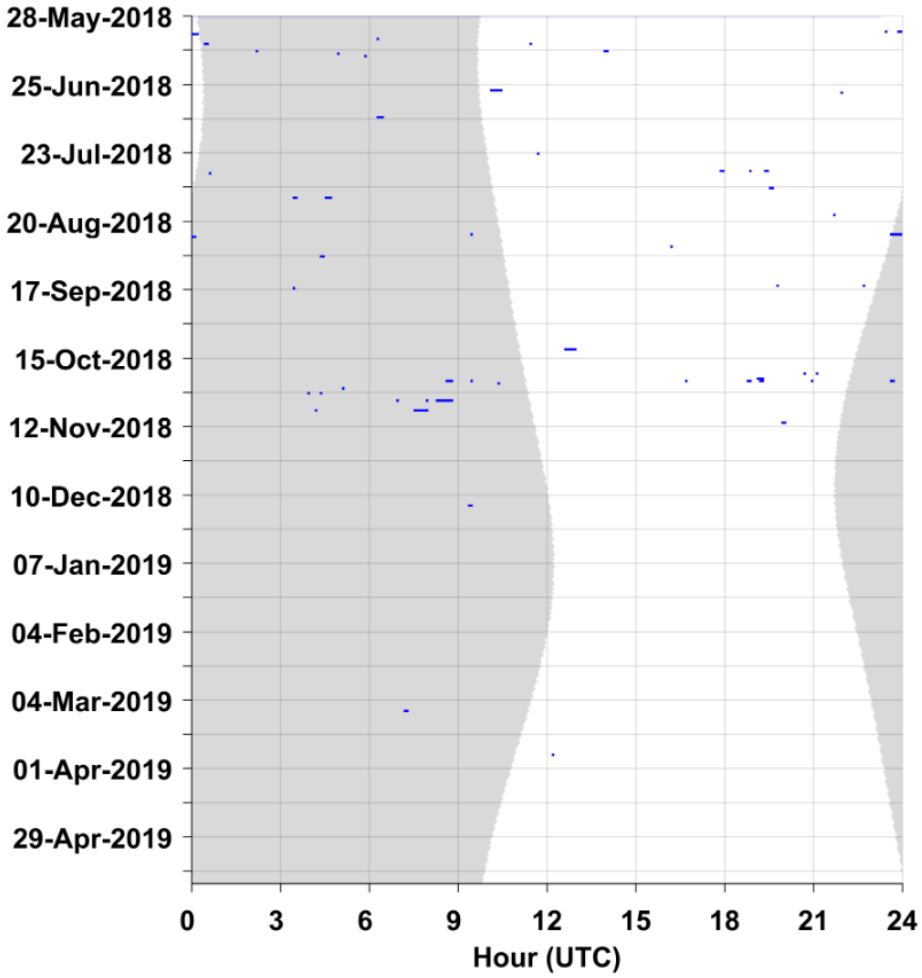

Figure 22. *Kogia* spp. clicks in five-minute bins from June 2018 to May 2019 at NFC Site A. Effort markings are described in Figure 16.

Anthropogenic Sounds

Four types of anthropogenic sounds were detected from June 2018 to May 2019.

LFA Sonar

- LFA sonar greater than 500 Hz was detected three times in July and December 2018 and in February and March 2019 (Figure 23).
- There were not enough encounters of LFA to determine a diel pattern during the recording period (Figure 24).

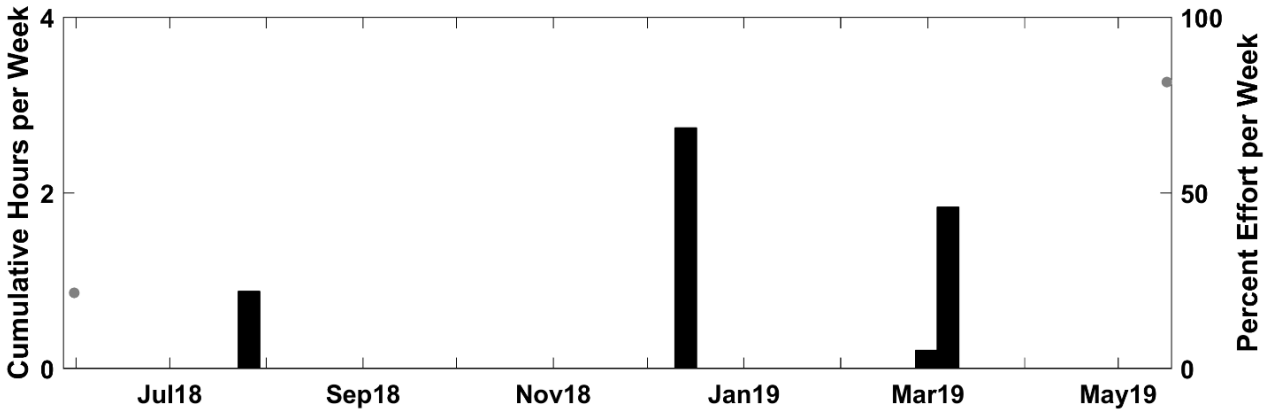

Figure 23. Weekly presence of LFA sonar from June 2018 to May 2019 at NFC Site A. Effort markings are described in Figure 15.

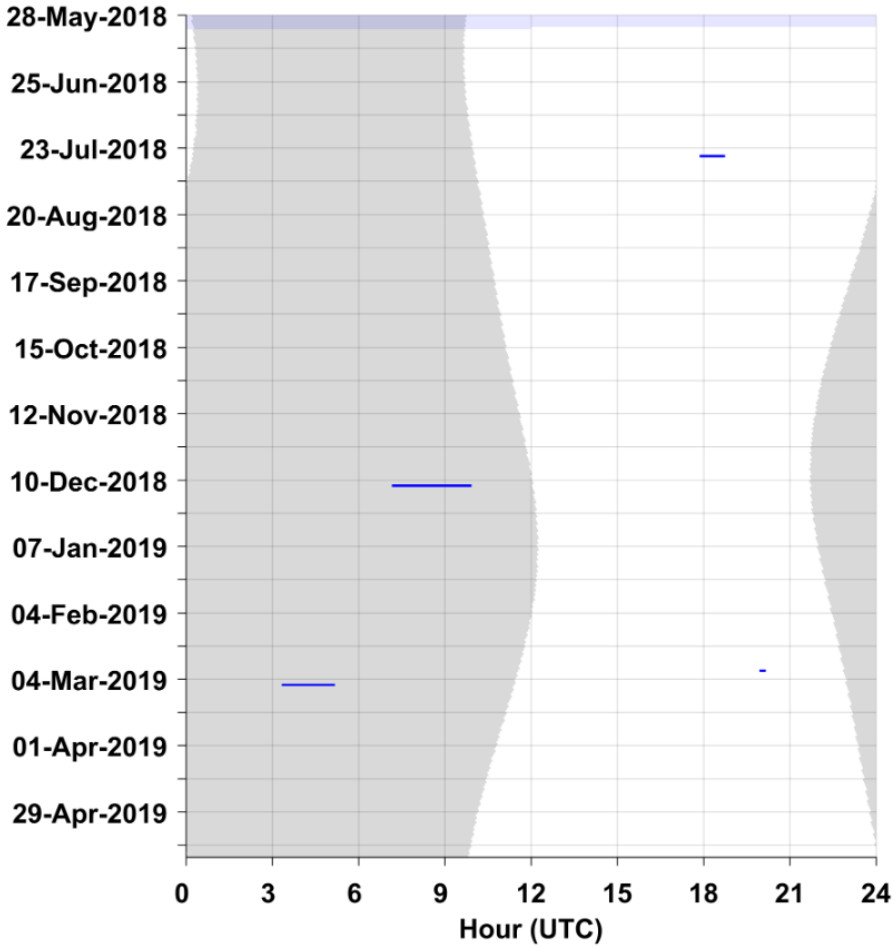

Figure 24. LFA sonar in one-hour bins from June 2018 to May 2019 at NFC Site A. Effort markings are described in Figure 16.

MFA Sonar

- MFA sonar less than 5 kHz were detected intermittently throughout the recording period but were highest in January 2019 (Figure 25).
- There was no discernible diel pattern for MFA sonar less than 5 kHz during the recording period (Figure 26).
- The highest number of packets (>150) as well as cumulative sound exposure levels (CSEL) (~ 160 dB re 1 μPa^2 s) were detected during MFA events in July 2018 (Figure 27).

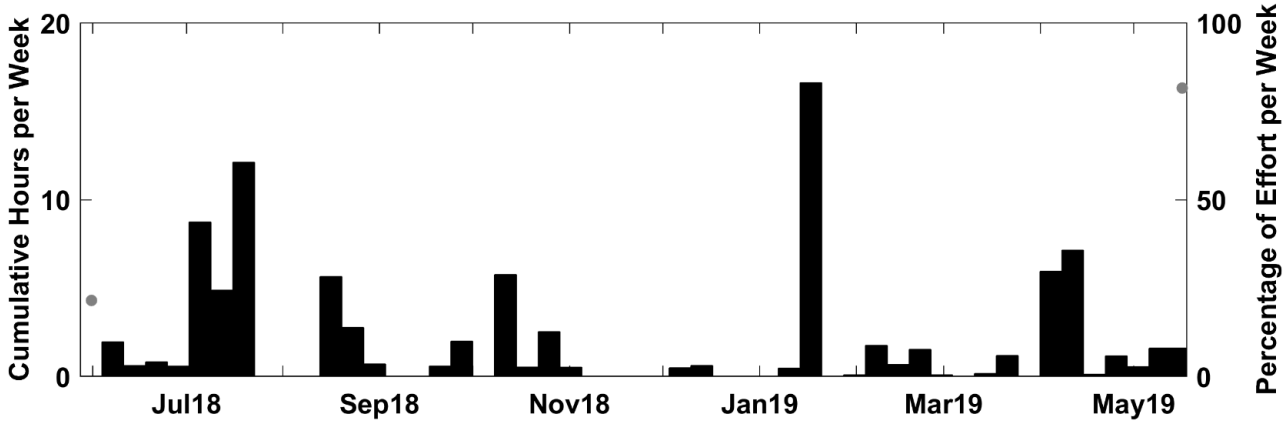

Figure 25. Weekly presence of MFA sonar less than 5 kHz from June 2018 to May 2019 at NFC Site A. Effort markings are described in Figure 15.

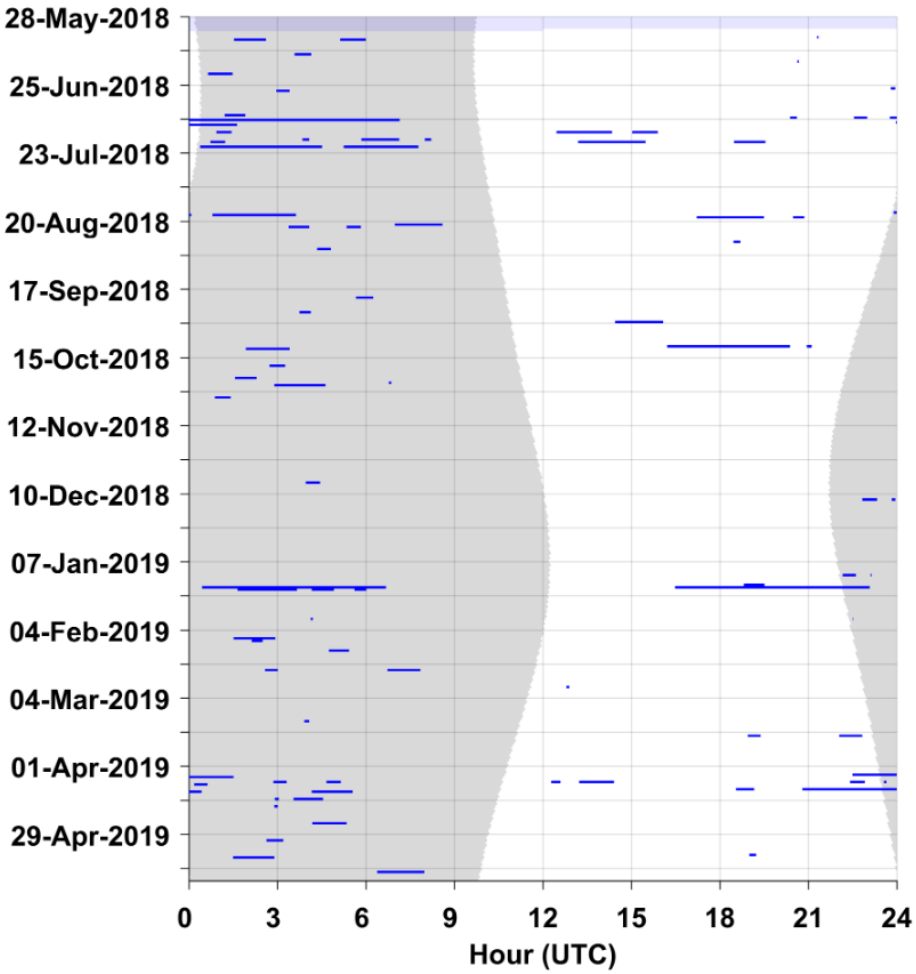

Figure 26. MFA sonar less than 5 kHz in five minute bins from June 2018 to May 2019 at NFC Site A. Effort markings are described in Figure 16.

Table 2. MFA sonar automatic detector results, with wave trains and packets detected by energy detector for this recording period.

Site:	Period Analyzed Day (Years)	Number of Wave Trains	Wave Trains per Year	Number of Packets	Packets per Year	Total Wave Train Duration (h)	Total Packet Duration (s)	Max CSEL (dB re 1 μPa² s)
NFC_A_04	350 (0.96)	11	11.5	538	560.4	10.8	1441	160

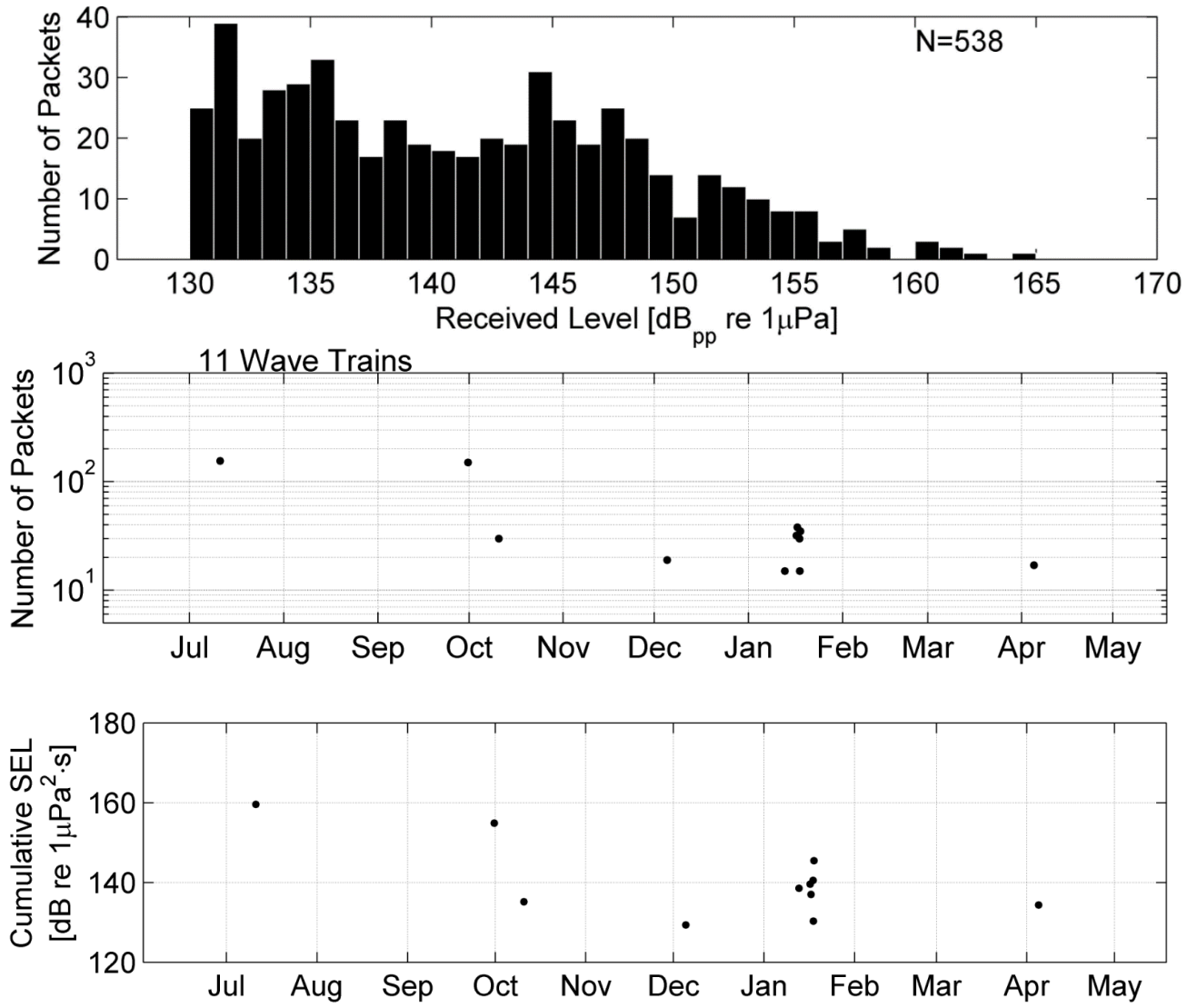

Figure 27. Top: Distribution of received levels (RL) of detected MFA packets. Center: Number of MFA packets detected in each wave train exceeding the minimum RL threshold (130 dBpp re 1μ Pa). Bottom: Cumulative sound exposure levels (CSEL) associated with each wave train.

HFA Sonar

- HFA sonar was detected infrequently with two events occurring in November 2018 and January 2019 (Figure 28).
- HFA greater than 5 kHz was only detected during the daytime (Figure 29).

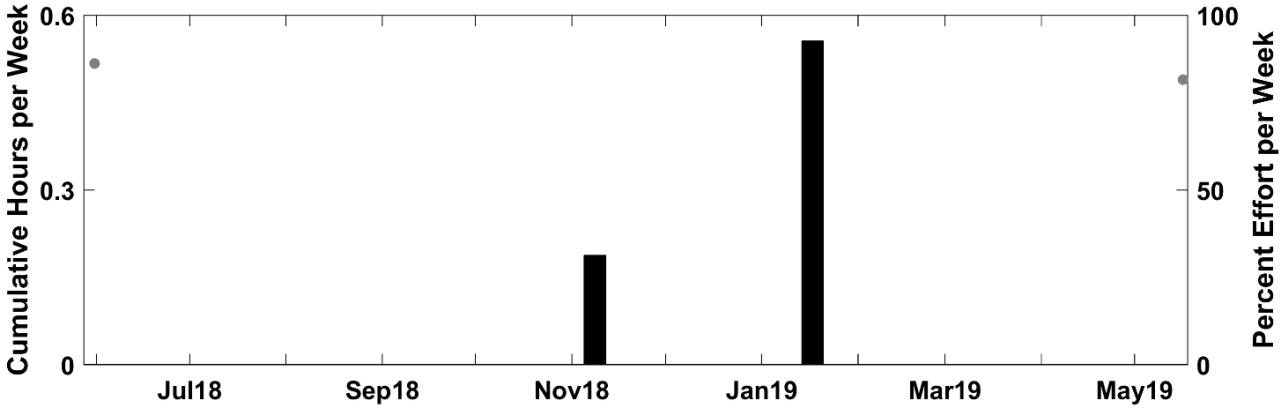

Figure 28. Weekly presence of HFA sonar greater than 5 kHz from June 2018 to May 2019 at NFC Site A. Effort markings are described in Figure 15.

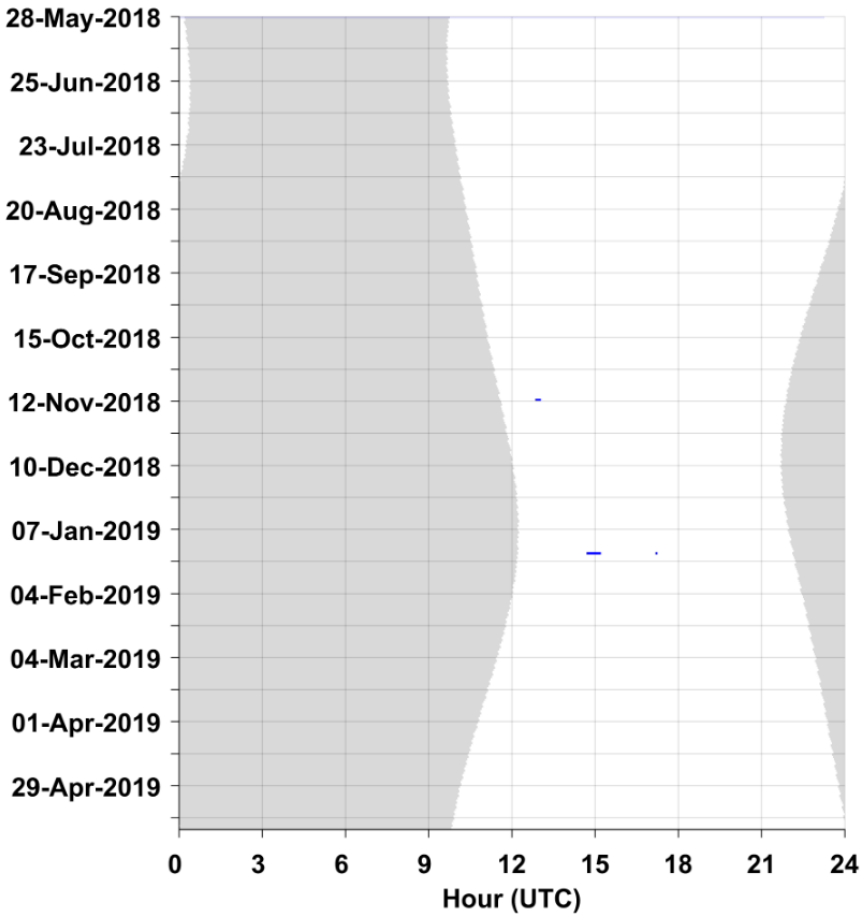

Figure 29. HFA sonar greater than 5 kHz in one-hour bins from June 2018 to May 2019 at NFC Site A. Effort markings are described in Figure 16.

Explosions

- 152 explosions were detected during this recording period, detections highest in late July to August 2018 (Figure 30). Manual analysis was conducted to ensure that explosions were not missed by the automated detector.
- A majority of the explosions were detected during the daytime (Figure 31).

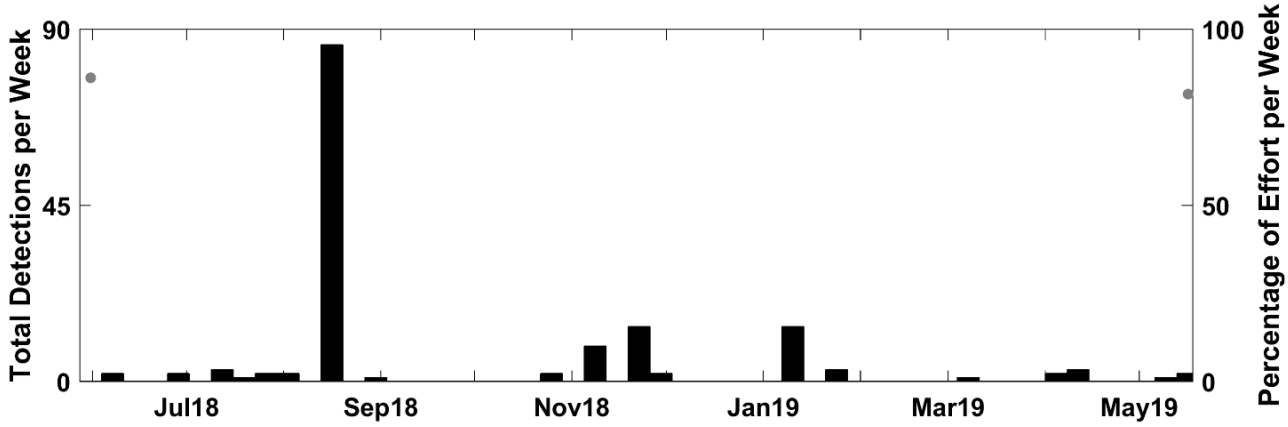

Figure 30. Weekly presence of explosions detected from June 2018 to May 2019 at NFC Site A. Effort markings are described in Figure 15.

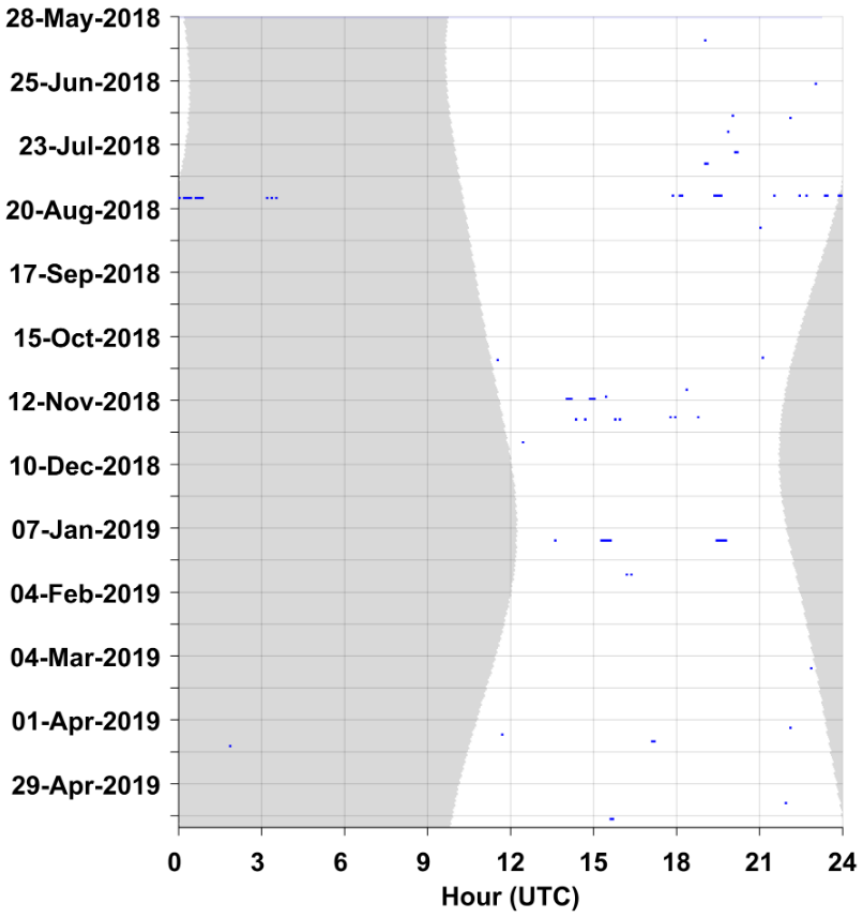

Figure 31. Explosions in five-minute bins from June 2018 to May 2019 at NFC Site A. Effort markings are described in Figure 16.

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