



Buck Island Underwater Acoustic Analysis

Summary of acoustic monitoring in 2016-2020

Overview

Beginning in 2014, the National Oceanic and Atmospheric Administration and the National Park Service (NPS) collaborated to establish a network of ocean noise reference stations in U.S. waters to monitor long-term changes and trends in the underwater ambient sound field (Haver et al., 2018). NPS has used passive acoustic monitoring (PAM) to inform management of noise in terrestrial parks for many years, and more recently has extended monitoring efforts to underwater environments. Soundscapes within U.S. National Parks are considered to be resources based on intrinsic value as well as value to wildlife and human visitors.

The current partnership between the National Park Service (NPS) Water Resources Division (WRD), the Natural Sounds and Night Skies Division (NSNSD), Oregon State University (OSU), and the National Oceanic and Atmospheric Administration (NOAA) includes stations in two park units: the National Park of American Samoa and Buck Island Reef National Monument (BUI), US Virgin Islands. The identical autonomous acoustic recording systems deployed at each reference station were developed and constructed at OSU to ensure proper calibration and consistency of the collected data sets.

This collaboration was initiated to monitor sources and levels of underwater ambient sound, which informs management efforts to help protect marine organisms, the integrity of the ecosystem, and visitor enjoyment of a healthy marine habitat. Additionally, long-term monitoring can facilitate identification of noise sources inappropriate to a park setting and determine how noise may interfere with the life history of various marine wildlife.

Finally, as part of a larger calibrated network established to understand trends in ocean noise conditions within U.S. waters, data collected in National Parks is valuable to identify and monitor underwater acoustic conditions throughout U.S. waters, especially the extent of anthropogenic noise in marine protected areas.

Biological activity and vessels (a main contributor to chronic background noise in many marine environments) are the most significant contributors to the low-frequency (10 Hz–2 kHz) soundscape in BUI.

This report summarizes acoustic monitoring efforts at BUI during years 2016 to 2020, including analysis of sound levels and source identification.



Figure 1. Humpback whales (*Megaptera novaeangliae*) are a common source of sound recorded in the soundscape of BUI (Photo: NPS).

Research Objectives

The goal of this report is to summarize the baseline acoustic condition in BUI, and report on the primary project objectives:

1. Quantify the existing sound levels and multi-year trends.
2. Quantify the existing vessel noise and bioacoustic (humpback whale) activity.

Methods

Acoustic data were collected at a single site near Buck Island, U.S.V.I. (17.78576, -64.65094) in 40 meters of water from November 17th, 2016, to December 3rd, 2020 (Figures 2 and 3).

The BUI monitoring site is located in the tropical Southwest Atlantic in close proximity to many other Caribbean port cities and popular tourist destinations. Specifically, the hydrophone was deployed at 40 m depth along a steep shelf edge, acoustically exposing the site to regional shipping traffic and migrating whales as well as local vessel traffic and soniferous fish.

The hydrophone is model ITC-1032 (International Transducer Corp., Santa Barbara, CA) with a nominal sensitivity of -192 dB re 1 V/μ Pa and a flat frequency response (-/+ 1 dB) between 10 Hz and 2000 Hz. Signals

incoming to the AUH are conditioned by a pre-amplifier and pre-whitening filter to maximize the dynamic range of the 16-bit acoustic data logging system. The single autonomous hydrophone was programmed to continuously record underwater sound at a sample rate of 5kHz.



Figure 2: BUIS study area near St. Croix, U.S.V.I. (red star). Inset map in upper right corner shows location within the great Caribbean.

To quantify acoustic conditions over time and identify patterns in sound sources (e.g., humpback whale vocalizations), long-term spectral averages (LTSA, 10–2,000 Hz range) were calculated using custom Matlab™ routines with 1 Hz and 1 second resolution (Figure 4). The 1 Hz binned spectrum levels were averaged over 5-minute windows and calibrated according to overall system sensitivity (hydrophone sensitivity and pre-amplifier gain curve) to determine sound levels (dB re 1 $\mu\text{Pa}^2/\text{Hz}$) from raw .DAT files.

In compliment to sound level measurements, acoustic data were also analyzed for the presence of humpback whale vocalizations and noise from local and distant vessel traffic. To detect the times and patterns of specific sound sources in the acoustic recordings, original data files (.DAT format) were converted to WAVE audio file format (.wav) using custom Matlab™ routines and then manually reviewed as spectrogram images in Raven Pro interactive sound analysis software (FFT: 4096, Hann window, 50% overlap) (Figure 4). Generating spectrogram images from the audio files is one method to identify specific sound sources in the recordings, and includes analyzing the frequency, duration, and intensity characteristics of each sound.



Figure 3: Bioacoustic monitoring site near BUIS. The hydrophone recording package (NOAA PMEL) was attached to a protective metal lander and secured to the seafloor with sand screws. The hydrophone package is swapped annually for data download and re-programming by NPS dive staff. Photo: National Park Service

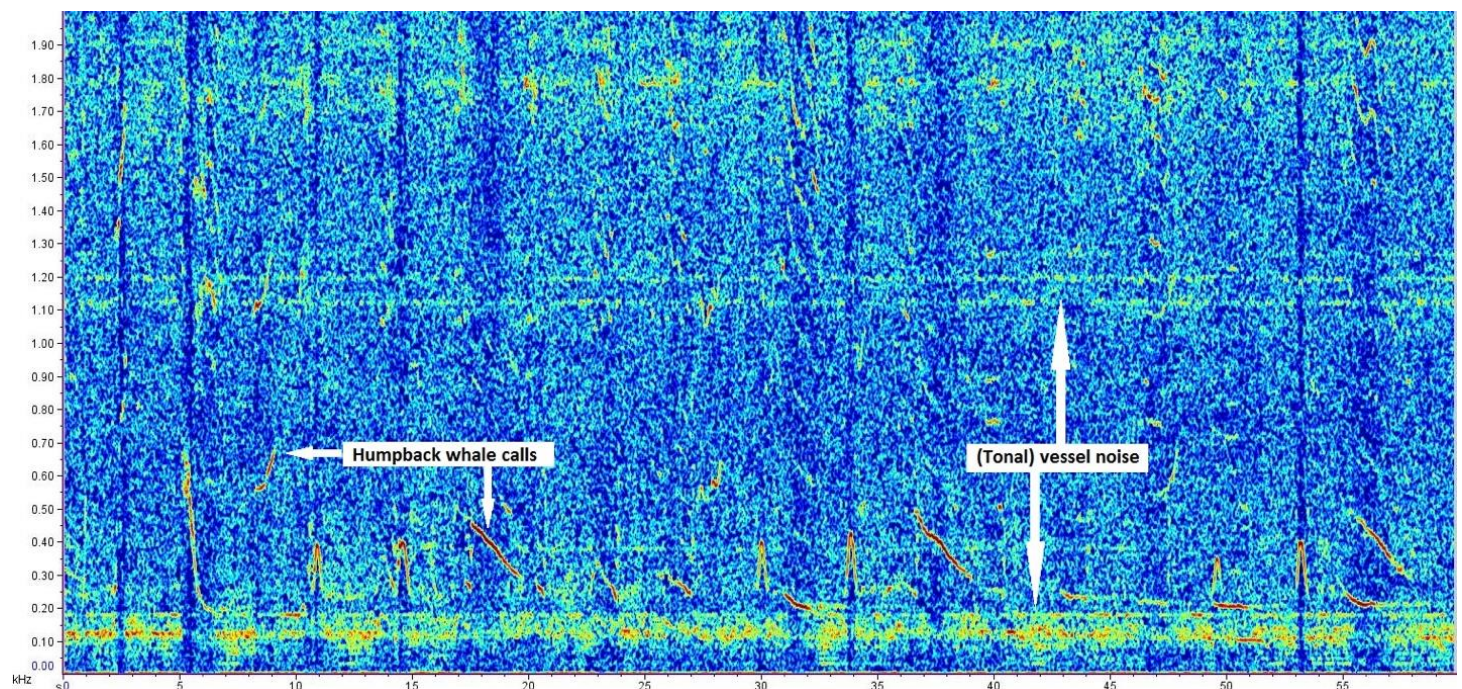


Figure 4: Example spectrogram with annotated vessel noise and humpback whale calls. All data was reviewed in Raven Pro version 1.5 (Cornell Lab of Ornithology). Corresponding .WAV included in supplemental information.

Interpreting Results

The sound levels in this report were measured on a logarithmic scale and reported as decibels (dB) with a pressure reference of 1 microPascal (μPa). The decibel scale is used to measure the amplitude of sound, which is what we perceive as “loudness” or intensity. The amplitude (or pressure) of the sound is also described in reference to the density of medium (i.e., solid, liquid, gas) that it travels through; the pressure reference for sound in water is 1 μPa , whereas in air it is 20 μPa . Because sound levels in water are not equivalent to sound levels in air, it is difficult to precisely compare underwater sound sources to terrestrial sound sources (e.g., vehicle traffic, human speech). For understanding, we can make approximate comparisons between various biological, anthropogenic, and environmental sound sources. Compare the results in this report to the example underwater sound sources (Table 1) to understand how the soundscape of BUIS may be impacted by different sounds.

Table 1. Sound level examples.

Underwater Sound Sources ¹	Sound Level (dB re 1 μPa)	Approximate Equivalent Common Sound Source*
Daily median broadband ambient sound level in BUIS (2016-2020)	55-73	Whisper - Rustling leaves
Reef fish vocalizations	~103	Busy restaurant
Humpback whale song	144 – 174	Lawnmower – Police siren
Tug and Barge (18 km/hour)	171	Jackhammer
Large Tanker	186	Thunder clap
Navy SURTASS-LFA (100-500 Hz)	215	Fireworks
Seismic airguns	260	Seafloor volcano eruption

*In air sound source dB levels adjusted from 20 μPa to 1 μPa reference units for parallel comparison to underwater sources, but exact comparison is not possible.
Air + 62 = ~dB in water

It also important to note that decibel measurement is on a logarithmic scale, meaning that every 10 decibel increase is an order of magnitude. For example, a seismic airgun blast at 260 dB is over 70 times more intense than the sound of a 186dB large tanker vessel.

Existing Sound Levels

Calibrated spectrum levels in 5-minute windows for all years of data collection were analyzed in Matlab™ to

evaluate minimum, maximum, mean, and median and other percentiles over 5-minute, hourly, daily, monthly, and annual time periods.

Percentile Metrics

The existing sound levels were reported as three percentile metrics. Annual percentile levels were calculated from $L_{Aeq, 1s}$ measurements. The average acoustic condition at BUIS was consistent over all the years of data collection (Table 2).

Table 2. Percentile sound levels for existing conditions in BUIS.

Deployment Year	Percentile Sound Levels (dB)*		
	L_{A90}	L_{A50}	L_{A10}
2016+	61.894	64.446	72.078
2017	60.077	63.267	71.882
2018	60.164	64.019	71.578
2019	60.605	64.213	71.784
2020	60.769	64.313	71.808

* $L_{Aeq, 1s}$ in dB re 1 μPa (10 Hz—2 kHz)

+ 2016 is Nov-Dec

The first percentile metric, L_{A90} , reports the sound level exceeded 90% of the time for the specified time period. This is a preferred statistical metric to quantify the *quietest conditions*. In all years, the average sound level at BUIS exceeded 60 dB 90% of the time.

The second metric called the median L_{A50} is the sound level exceeded 50% of the time for the specified time period. This level is referred to as the **existing ambient sound level** and is the preferred metric for *chronic conditions*, as it is insensitive to infrequent loud events. The existing ambient sound level at BUIS was ~64 dB in all years which is more than double the power or approximately 40% louder than the average L_{A90} sound levels (quietest conditions) we recorded.

The third metric, L_{A10} , is the sound level exceeded 10% of the time for the specified time period. This is a preferred metric to quantify the *loudest conditions* or infrequent loud events. The average sound level at BUIS exceeded 71 dB 10% of the time in all years, which is over 10 dB higher than the L_{A90} levels and equivalent to a subjective doubling of the volume/loudness of the of the ambient soundscape.

The little variation between the percentile metrics across years suggest that acoustic conditions at BUIS are relatively stable.

Hourly and Monthly Variation

The median L_{A50} percentile level data reported in Table 2 were broken down by the hour of day and month of the year to determine which hours contribute more noise than others and if those trends were consistent throughout the year. In BUIS, sound levels in the winter months (December-February) were higher than other

¹ Sound levels from DOSITS.org and New York Times
(<https://www.nytimes.com/2019/01/22/science/oceans-whales-noise-offshore-drilling.html>)

months of the year. The lowest sound levels were recorded in September and October. During the Spring and Summer (May-August) a slight (~ 1 dB) diel sound trend is apparent, with lower sound levels in the evening and higher sound levels in the morning hours (Figure 5).

Median sound levels likely reflect the contributions of different drivers to the soundscape. For example, humpback whale song is observed during the winter months and likely increases sound levels for only part of the year. Local vessel activity that is very close or right over the hydrophone may only increase sound levels during daytime hours. Fish, wind, and other man-made sound sources likely also contribute to sound levels at BUIS during specific times of day or months during the year.

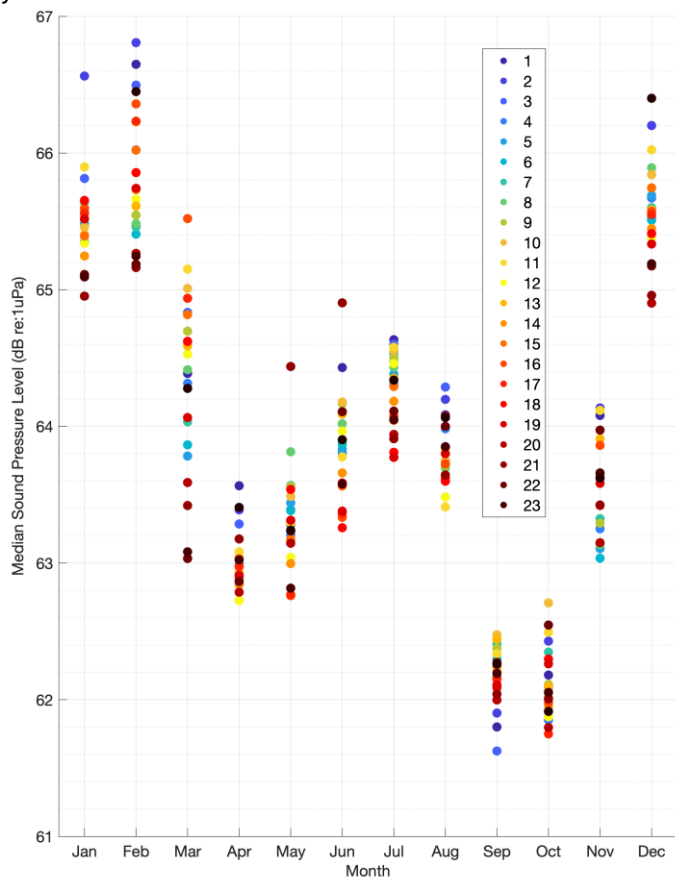


Figure 5: Hourly median L_{A50} percentile sound levels in each month of the year, averaged over all years of data collection. Each hour of the day is indicated by a different color marker, ranging from dark blue for the early morning (starting at 1 am), teal and green in midday (10 am to 5 pm), and yellow shades in the evening and late night (6 pm to midnight).

Frequency Content

The 5-minute percentile sound levels (L_{A90} , L_{A50} , L_{A10}) were quantified in narrow-band (1 Hz) bins to identify patterns and trends across the 10 Hz – 2 kHz broadband recordings (Figure 6A). High frequency sounds (such as small vessels with outboard engines) and low frequency sounds (such as large commercial shipping vessels and humpback whale vocalizations) often occur simultaneously, so the frequency spectrum is split into individual frequency bins in Figures 6 A and B order to determine what types of sounds are contributing to the overall sound pressure

level. See the existing sound source section below for details on what sounds are contributing to certain frequency bands.

In each year of data collection, very low frequency sound (10-130 Hz) was more variable compared to sound between 130 Hz – 2kHz (Figures 6A and 6B). This difference across frequencies is likely related to seasonal and annual patterns of different sound sources in BUIS. Long-term spectral average plots (LTSA) also display differences across both time and frequency domains. Median sound levels were quantified in 1 second, narrow-band (1 Hz) bins and averaged over 1-hour windows in LTSA plots for each deployment year (Figure 7). Mirroring Figure 6, the LTSA plots show very low frequency sound (10-130 Hz) were the most variable across the frequencies recorded.

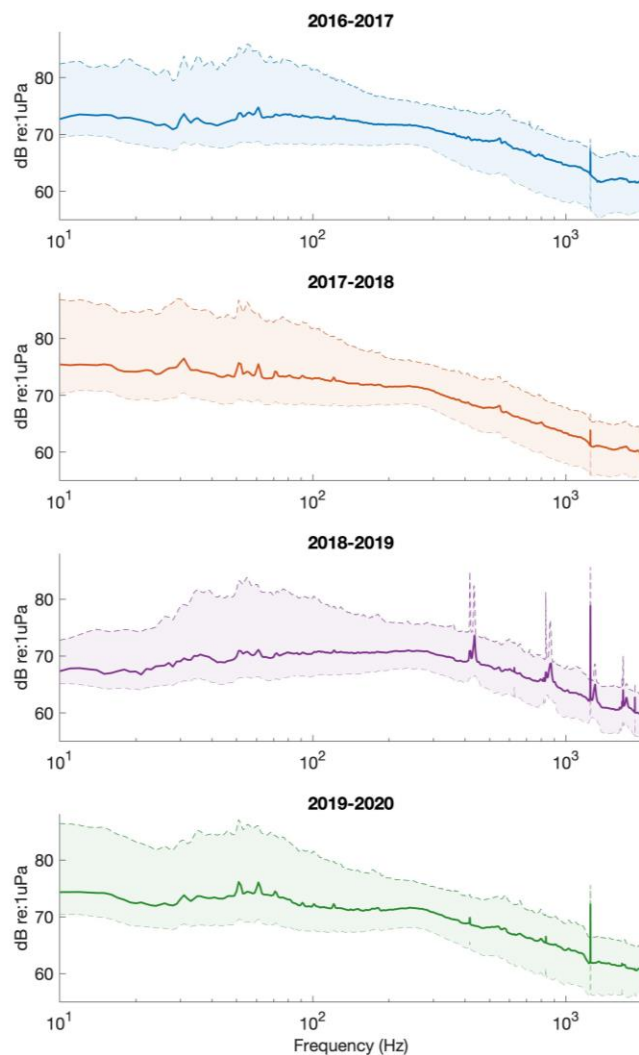


Figure 6A: Narrow-band (1 Hz) percentile sound levels (L_{A90} , L_{A50} , L_{A10}) averaged over four deployment years and plotted by year as different colors. Median L_{A50} levels are plotted in a solid-colored line, while L_{A90} and L_{A10} percentile levels are plotted as filled semi-transparent areas to show the patterns and range of sound levels across each deployment year from 10 Hz to 2KHz. Note some spikes at specific frequencies above 400 Hz are related to instrument self-noise.

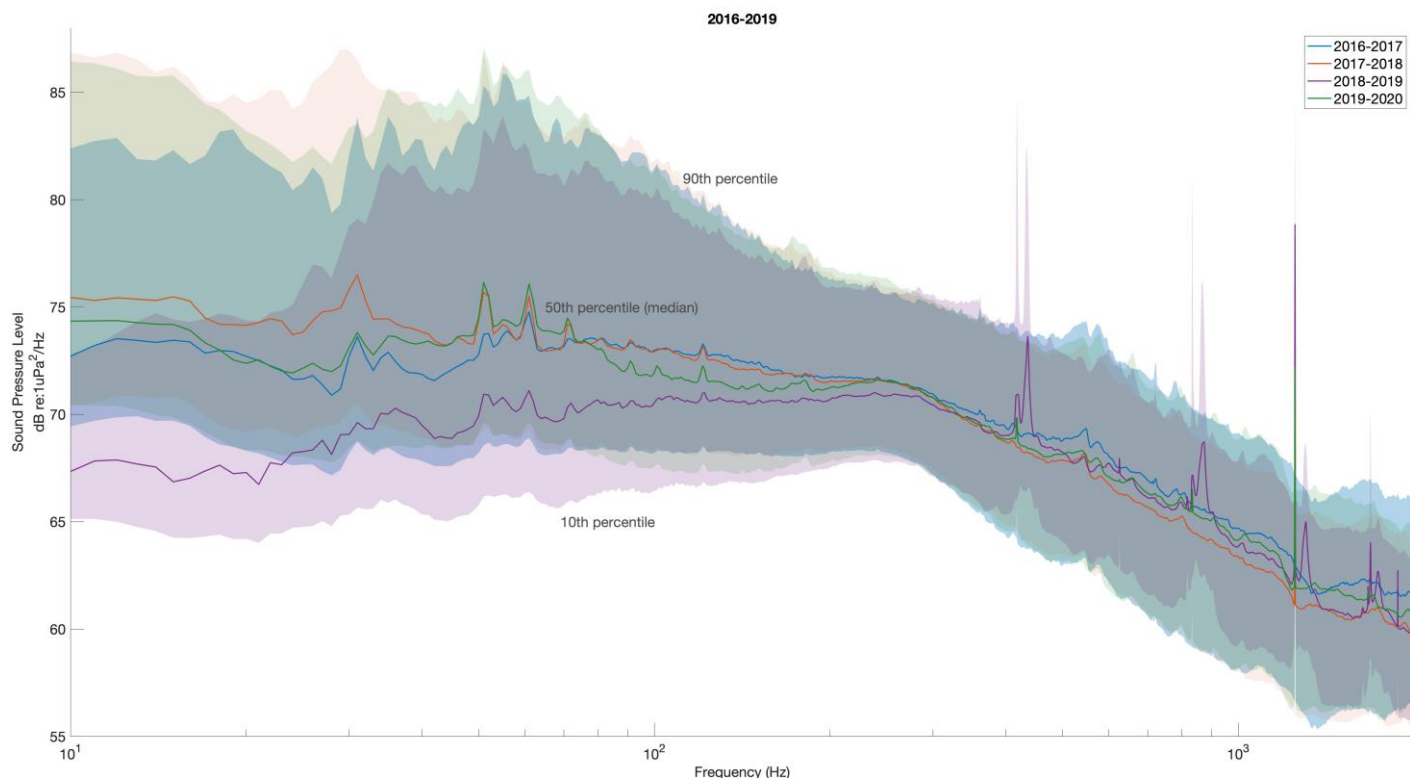


Figure 6B: Narrow-band (1 Hz) percentile sound levels (LA_{90} , LA_{50} , LA_{10}) averaged over four deployment years and plotted as different color transparent layers. Median LA_{50} levels are plotted in a solid-colored line, while LA_{90} and LA_{10} percentile levels are plotted as filled semi-transparent areas to show the patterns and range of sound levels across each deployment year.

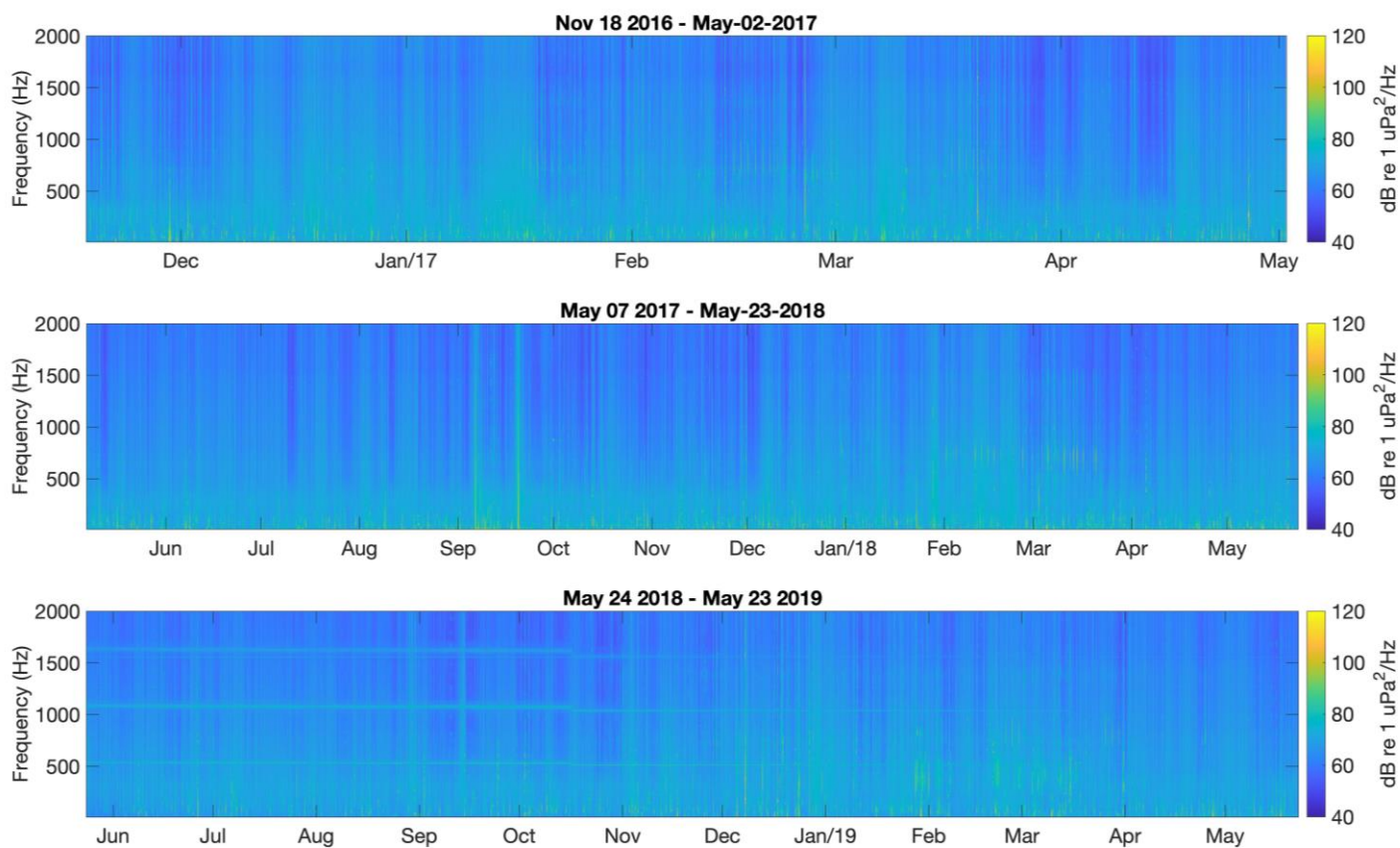


Figure 7: Long-term spectral average (LTSA) plots for each deployment year averaged from 1 second/1 Hz bins and plotted in 5 minute/1 Hz windows. Color shading (blue to yellow) indicated sound intensity at each frequency and time.

Existing Sound Sources

In addition to measuring sound levels, data were also analyzed for the presence of specific sound sources. Given that BUIS is exposed to unmanaged local and regional vessel traffic and is in a biologically rich environment, this site experiences relatively higher sound levels with contributions from both anthropogenic and biological sources. This region is also exposed to seasonal hurricanes which have the potential to significantly elevate sound levels during transient storm events. Thus, biological (e.g., fish, whales), natural physical (e.g., wind, rain), and anthropogenic (e.g., shipping vessels, cruise ships) all contribute to the low-frequency soundscape. The greatest amount of variation in sound levels over time was observed in frequencies between 10 Hz and 130 Hz (Figure 6). Focusing on these lowest frequencies, manual analysis of BUIS recordings were targeted to identify patterns in common sound sources that generate sound within those frequencies, vessels and humpback whales.

Manual analysis of data in real-time playback is time intensive, and thus the six-month time period was selected for daily analysis of humpback whale presence or absence based on detection patterns at neighboring Caribbean recordings sites (Heenehan and Stanistreet, 2017).

Vessel Noise

Aural and visual inspection of the data revealed that vessel noise (tonal and propeller cavitation) was present in nearly every hour of every reviewed day (Figure 8). This is likely related to the high amount of continuous anthropogenic activity in the North Atlantic, exposing BUIS to year-round adjacent and regional vessel noise. Although BUIS (and the greater U.S.V.I. region) does not contain major local shipping lanes, this area has vessel traffic in many directions transiting in the Caribbean Sea and to and from the Panama Canal.

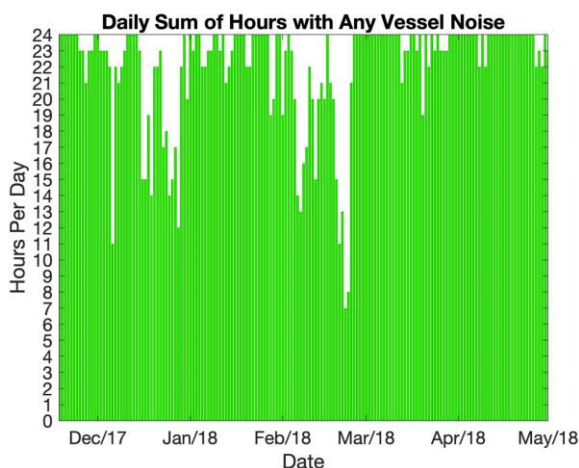


Figure 8: Daily sum hours of aurally and visually detected vessel noise (all types) in BUIS recordings November 18th, 2017 – May 1st, 2018.

To separate adjacent and regional vessel noise, recordings were also analyzed for the presence of a specific acoustic signature that is indicative of a vessel transiting directly over, or in very close proximity to, the hydrophone (Figure 9). One indication of a vessel

traveling very close to the hydrophone is an interference fringe pattern in the spectrogram (also known as Lloyd's mirror effect), where the soundwaves interact in a rippled band pattern similar to how a water drop interrupts surface tension. These patterns were also identified with reduced frequency compared to propeller cavitation and tonal vessel noise that is more indicative of regional vessel activity. Approximate adjacent vessel noise was detected during fewer hours per day than regional vessel noise (Figure 9).

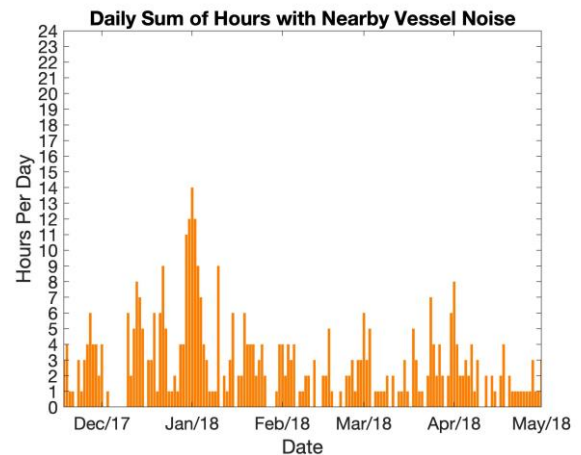


Figure 9: Daily sum hours of aurally and visually detected patterns of nearby vessel noise in BUIS recordings November 18th, 2017 – May 1st, 2018.

Humpback Whale Vocalizations

Humpback whale calls and song were observed at BUIS from January until mid-April via manual detection of vocalizations in 2017-2019 (Figure 10). A trained observer reviewed the acoustic recordings as spectrograms in Raven Pro software (Cornell University) to identify either the presence or absence of vocalizations in each day. December-May were selected for analysis based on results of similar studies in nearby areas (Figure 11; adapted from Heenehan and Stanistreet, 2017).



Figure 10: Multi-year comparison of daily presence (dark gray shading) or absence (light gray shading) of humpback whale vocalizations throughout the primary season for humpback whales in the Caribbean (January – May) in 2017, 2018 and 2019.

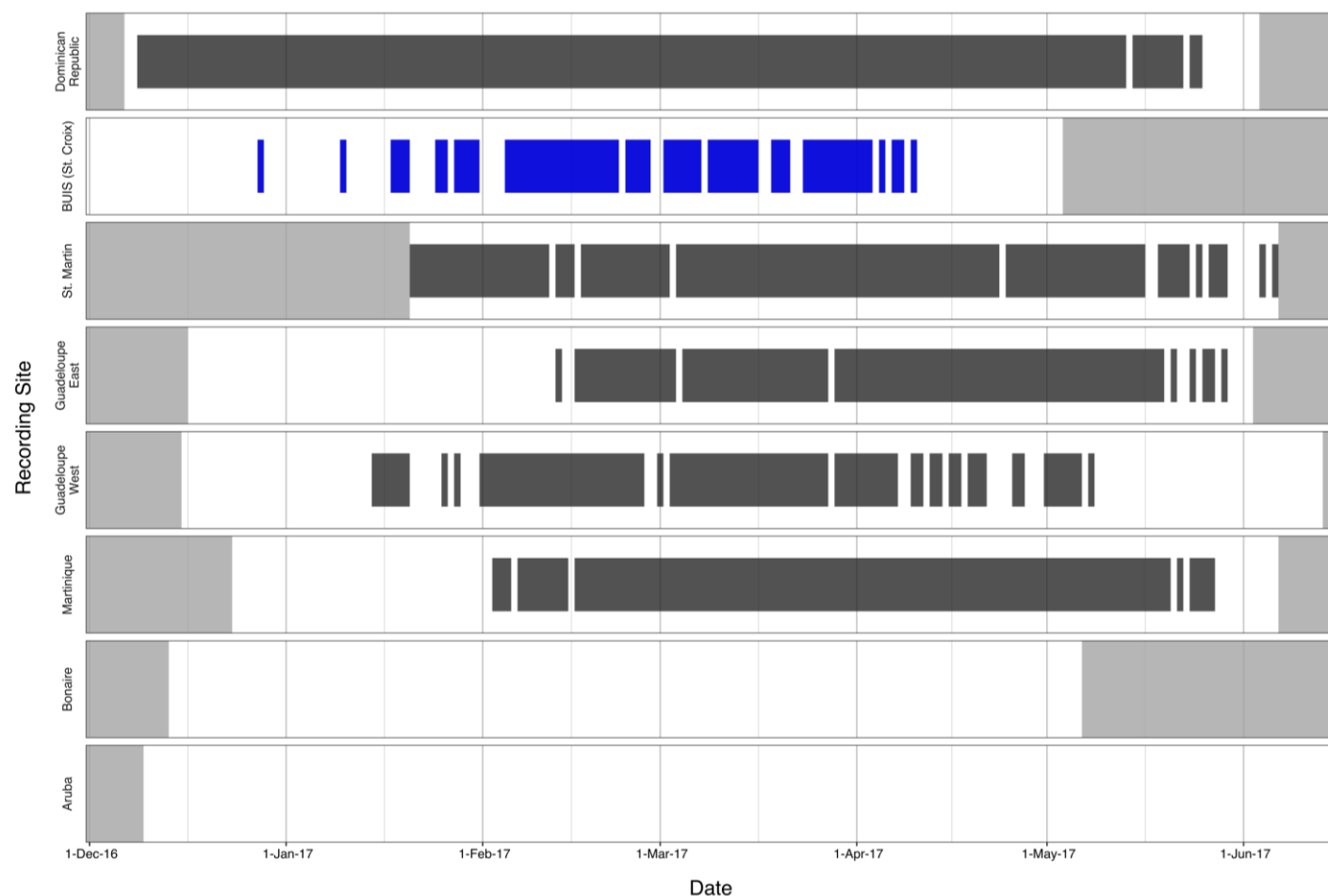


Figure 11: Caribbean region comparison of detections of humpback whale vocalizations. Results from BUIS (here by location at St. Croix) and other sites from data collected between December 2016 – June 2017.

Consistent with vessel noise analysis, data collected in 2018 were analyzed for hourly detections. Days with humpback whale vocalizations present from the initial daily analysis were reviewed on an hourly scale to

quantify diel patterns. In 2018, the peak total hours per day of humpback whale vocalizations were observed in March (Figure 12).

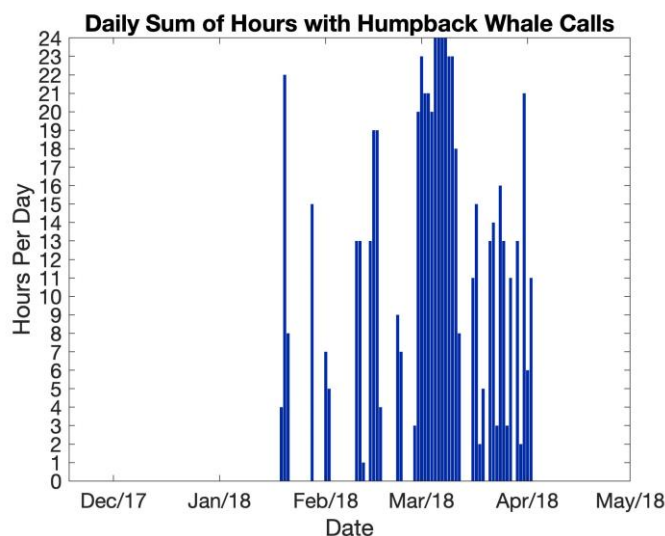


Figure 12: Daily sum hours of aurally and visually detected humpback whale calls (primarily, but not exclusively, song) in BUIS recordings November 18th, 2017 – May 1st, 2018.

Diel Trends

No diel patterns in either vessel noise or humpback whale calling were detected (Figure 13). This consistency is likely related to the high amount of continuous vessel traffic in the Caribbean Sea and to and from the Panama Canal, and the location of BUIS in a low-latitude Caribbean climate zone with warm temperatures year-round. Weather had minimal effect on sound levels in BUIS, except for rare local hurricane events which are detected via increased wind-speed and reflected in short-term increases in band sound levels (see Haver et al., 2019 for further analysis of diel sound level patterns).

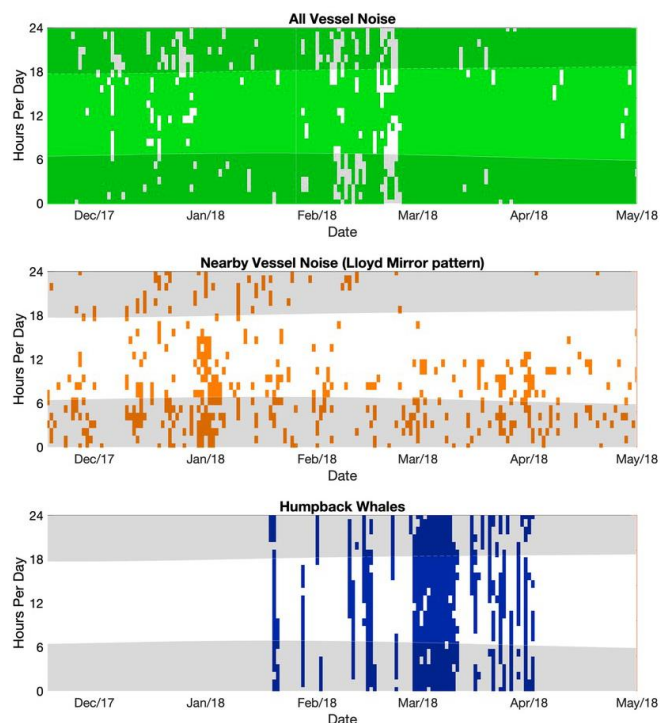


Figure 13: Presence/absence of aurally and visually detected vessel noise (all and nearby vessel noise indicated by Lloyd's mirror spectrogram

patterns) as well as humpback whale vocalizations in BUIS recordings during each hour of each day, November 18th, 2017 – May 1st, 2018. Shading indicates daylight versus nighttime hours.

Next Steps

- All acoustic data collected in BUIS will be archived for open access through NOAA NCEI.²
- Through ongoing data collection and future studies, soundscape analysis of Ocean Noise Reference Station Network sites (including National Marine Sanctuaries, National Parks, and the greater U.S. Exclusive Economic Zone) will reveal how natural and anthropogenic contributors to ocean ambient sound deviate from baseline conditions and vary by location and time across the entire network.

Discussion

Assessing acoustic habitat quality within the Buck Island Reef National Monument not only meets park objectives to monitor underwater soundscape conditions, but also provides quantitative measures to compare with other NPS and NOAA protected underwater parks.

This report details the existing sound levels and multi-year trends of the soundscape of BUIS to document baseline conditions. Analysis of specific sound sources in BUIS data also quantify the presence of both vessel noise and humpback whale vocalizations and primary drivers of underwater sound levels.

In BUIS, soundscape conditions are consistent across years, but on the shorter timescale of months sound levels vary depending on humpback whale vocalizations, as well as vessel activity and weather conditions (e.g., hurricane winds). The highest sound levels were observed in winter months (Dec-Feb) and the lowest sound levels were observed in the fall from Sept-Oct.

While vessel activity is a consistent sound source at BUIS, the noise is likely related to regional vessel traffic transiting in the Caribbean Sea and to and from the Panama Canal as there are not any major shipping lanes or port cities in the Virgin Islands (NOAA Office for Coastal Management, 2017)³. The frequency overlap between the acoustic signature of vessels and vocalizations that support critical life functions in marine mammals (particularly baleen whales), sonic fishes, and marine invertebrates can result in "masking," when the perception of one sound by an animal is affected by the presence of another sound (Clark et al., 2009; Richardson et al., 1995). Loss or reduction in efficiency of information transfer due to masking can have consequences for marine animals that rely on sound to carry out basic life functions (e.g., foraging, navigation, and communication with conspecifics (Erbe et al., 2016). Masking is not the only potential effect of increased noise; individual- and population-level effects such as stress (Rolland et al., 2012) and displacement (Small et al., 2017). However, current conditions at BUIS indicate that humpback whales

² Passive Acoustic Data viewer: <https://www.ngdc.noaa.gov/mgg/pad/>

are vocalizing despite anthropogenic noise; from January through April, humpback whale song vocalizations increase ambient sound levels at BUIS. Nonetheless, chronic vessel noise may limit the capacity of a soniferous marine animal to exercise resilience against ambient noise (e.g., modulating the pitch, duration, or intensity of vocalizations).

In BUIS, ongoing underwater soundscape monitoring efforts will continue to lead to more informed and efficient management of marine protected areas by documenting changes over time to compare the baseline conditions described in this report. For example, continued soundscape monitoring of times when soniferous species (e.g., humpback whales) overlap with anthropogenic sources and other abiotic sounds can provide important information regarding when, where, and how acoustic conditions in marine habitats necessitate management actions (Hatch et al., 2016; Hatch and Frstrup, 2009; Merchant et al., 2018). Documenting the status and trends of animal and human use, as well as environmental conditions, can inform the need for and balance of management plans to protect acoustic habitats within soundscapes, as well as provide a basis for evaluating changes to support management planning and policy development.

More Information

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