



Analysis of Underwater Soundscape Conditions at Buck Island Reef National Monument During the COVID-19 Pandemic

Focused Condition Assessment Report

Natural Resource Report NPS/BUIS/NRR—2022/2478





ON THIS PAGE

Top view of the hydrophone and platform in Buck Island Reef National Monument before recovery
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ON THE COVER

Divers installing the hydrophone platform in Buck Island Reef National Monument
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Analysis of Underwater Soundscape Conditions at Buck Island Reef National Monument During the COVID-19 Pandemic

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Executive Summary

In partnership with the National Oceanic and Atmospheric Administration and Oregon State University, the National Park Service has been collecting continuous acoustic recordings at a stationary autonomous recorder in Buck Island Reef National Monument since 2016. The audio data were previously analyzed to establish baseline soundscape conditions as well as monitor the acoustic presence of vessels and humpback whales. This report specifically investigates potential changes to the soundscape environment during the onset of the COVID-19 pandemic and the consequent “anthro-pause” when human activities such as tourism and commercial shipping were interrupted by public health guidance. Although major declines of anthropogenic activities were observed in other regions of the world, soundscape conditions in Buck Island Reef National Monument were only minimally impacted during early 2020. Furthermore, in latter months of 2020 and into 2021, vessel movement and related noise levels slightly increased from historic levels. Humpback whale vocalizations were also analyzed for seasonal presence in Buck Island Reef National Monument, revealing a consistent pattern with previously analyzed seasons. Ongoing passive acoustic soundscape monitoring will provide data that can be used to evaluate continued impacts of anthropogenic activity in and near Buck Island Reef National Monument.

Acknowledgments

The data analyzed in this report were collected via a cooperative agreement between NPS and Oregon State University. Thanks to the Natural Resource Condition Assessment Program, especially Tammy Cook and Katie Nuessly, for supporting this on-going project and providing the funding the analyses described in this report. Many other current and former NPS headquarters staff also contributed to the acoustic data collection efforts at Buck Island Reef National Monument and the National Park of American Samoa, thanks to Megan McKenna, Eva DiDonato, Kurt Fristrup, Karen Trevino, Christopher Kavanaugh, and Brent Lignell. Thanks to Noise Reference Station principal investigators Jason Gedamke, Leila Hatch, Bob Dziak, and Sofie Van Parijs, as well as Joe Haxel, Lauren Roche, and Haru Matsumoto at the Cooperative Institute for Marine Resources and Ecosystems Studies at Oregon State University. Last, but not least, many thanks to staff at Buck Island Reef National Monument and National Park of American Samoa staff that assisted with data collection, especially Clayton Pollock, Nathan Hanna Holloway, Kristen Ewen, Evan Gwilliam, Ian Moffitt, Bert Fuiava, and Eric Brown.

Focused Condition Assessments – Introduction

The National Park Service’s (NPS) Natural Resource Condition Assessment (NRCA) Program evaluates natural resource conditions in park units and delivers the results to park staff, scientists, strategic planners, and the general public through reports and associated products. All NRCA efforts strive to report resource condition information in a way that informs multiple levels of park stewardship activities. Stewardship activities may include partnerships, resource stewardship plans, and park management plans, and may inform on-the-ground actions that park management can readily implement.

As part of the NRCA program, Focused Condition Assessments (FCAs) are short-term projects where a pressing issue or critical data or knowledge gap exists, prompting the need to assess the current conditions of one, or a few park natural resources. FCAs are intended to address specific natural resource conditions that lend important information for management and decision-making. As short-term projects, FCAs primarily rely on utilization and synthesis of existing science and data. FCAs are intended to strengthen our understanding of current resource conditions and their relation to environmental processes across the landscape and improve the delivery of best available science for park management.

Standard products from FCA projects include a detailed project report and associated products. Associated products may be data summaries, resource briefs, geospatial maps and information, story maps, and others. All reports and associated products are available via the NPS Datastore (<https://irma.nps.gov/DataStore/>).

Chapter 1. Management Issue and Study Approach

1.1. Management Issue and Information Need

Monitoring acoustic environments is a critical aspect of the federal government's mandate for ocean and coastal stewardship. This includes detecting and characterizing: (1) sounds produced and used by living marine resources (e.g., endangered marine mammals); (2) natural sources of noise from physical oceanographic processes; and (3) anthropogenic noise sources that contribute to the overall ocean noise environment.

Noise generated by anthropogenic activities (especially commercial shipping and seismic oil and gas exploration) is recognized as a threat to marine mammals which are protected in the U.S. by the Marine Mammal Protection Act and the Endangered Species Act (Erbe et al. 2019). Increased ambient noise levels may impact animals in a variety of ways, including hindering communication and altering behavior, or causing injury or hearing loss (Richardson et al. 1995; National Research Council of the U.S. 2005). Degraded quality of acoustic habitats may also impact fish and invertebrate species, which are protected resources and have also been observed to be sensitive to ambient noise (Popper and Hastings 2009; Carroll et al. 2016).

For these reasons, science-based regulatory agencies including the National Park Service (NPS) established long-term monitoring projects to collect data to facilitate assessment of baseline trends and changes in the ambient sound field. The Ocean Noise Reference Station (NRS) network is a joint effort between NPS and the National Oceanic and Atmospheric Administration (NOAA) comprised of 12 low-frequency long-term passive acoustic monitoring recorders (Haver et al. 2018). The NRS hydrophones are calibrated to sample consistently and thus results are comparable over time and across sites.

Two of the NRS are deployed in national parks. Passive acoustic data have been collected at Buck Island Reef National Monument (BUIR) in the U.S. Virgin Islands since 2016, and the National Park of American Samoa (NPSA) since 2015. Data collected between 2016–2020 within BUIR and 2015–2018 within NPSA have been previously analyzed for baseline sound levels and comparative conditions, as well as for the presence of specific sound sources, including humpback whales, vessels, and damselfish (Haver et al. 2019; Munger et al. 2022). Acoustic sampling at both the BUIR and NPSA acoustic monitoring sites is on-going as of 2022.

The analysis described in this report documents the acoustic conditions in BUIR leading up to the COVID-19 pandemic through the summer of 2021 to update existing knowledge about the overlap of anthropogenic activities (vessel movement) and humpback whale vocalizations in listening range of the hydrophone.

1.2. Study Approach

The focus of this report is data collected at the onset of the COVID-19 pandemic in March 2020 to evaluate potential changes in the low-frequency (10 Hz–2kHz) acoustic environment due to reduced tourism and regional shipping activity. Following methods in previous studies (see: Haver et al. 2019), soundscape conditions were quantified for time periods between March 2020 and August

2021 to compare with sound levels and trends in previous years, and identify how the acoustic environment may have changed at the onset of COVID-19 in early 2020.

Additionally, the timing of the COVID-19 related reduction of anthropogenic activities in March 2020 corresponds with the expected season for humpback whale presence in and near BUIS (typically January–April; Haver et al. 2019). To determine if humpback whale vocalization presence was different in 2020 compared to previous years, presence/absence was evaluated via manual data review and compared to presence in previous years.

1.2.1. Selection of Key Resources

Underwater noise generated by motorized vessels is a recognized threat for marine mammals, including humpback whales. Thus, the natural experiment of reduced regional vessel activity in spring 2020 (March et al. 2021) was used as an opportunity to evaluate if vessel noise was reduced in BUIS and/or if seasonal patterns humpback whale vocalization presence/absence was altered in 2020 in comparison to previous years. To evaluate fine-scale changes at the onset of the pandemic in March 2020, hourly presence absence of humpback whale song vocalizations and vessel movement nearby the hydrophone (approximately within 1000 m) were summarized for November 18th, 2019–April 30th, 2020 and compared to the same dates in 2017 through 2018.

Since 2010, BUIS has seen reduced visitation when compared to the 1970s–early 2000s, but the park still hosts 30,000–40,000 annual visitors (Ogurcak et al. 2022). Tourism activities such as boat trips for island access and SCUBA diving generate underwater sound and are likely to impact the underwater soundscape. Assessment of vessel noise near the hydrophone can provide information about the impact of tourism activities and other vessel movement nearby (Haver and Nuessly 2022). These analyses are useful for understanding how the pandemic may have elicited changes in human and animal use of park waters, provide information to compliment other resource assessment efforts in the park, and for comparison to acoustic conditions in other marine protected areas.

1.2.2. Data Sources

Acoustic data were collected from November 17th, 2016, to August 28th, 2021 at a single site near St. Croix, USVI within BUIS (17.78576, –64.65094). The monitoring site is in the tropical Southwest Atlantic near other small port cities and popular tourist destinations in the Caribbean region. The hydrophone was deployed at a shelf edge on the seafloor (40 meters depth) to maximize the listening range and to capture regional shipping traffic and migrating whales, as well as local vessel traffic and soniferous fish (Haver et al. 2019). 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 5 kHz (Haver et al. 2018).

1.2.3. Analysis Methodology

To quantify acoustic conditions over time and identify broad patterns in sound levels (e.g., shipping and other large vessel noise), long-term spectral averages of sound pressure levels (LTSA, 10–2,000

Hz range) were calculated using custom Matlab routines with 1 Hz and 1 second resolution. The 1 Hz binned spectral 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 ($\text{dB re } 1 \mu\text{Pa}^2/\text{Hz}$) from raw .DAT files. The 5-minute LTSA sound levels for each deployment were averaged over month and deployment-long time periods for comparison over multiple years.

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 humpback whales and local vessel traffic 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). 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.

To compare monthly humpback whale vocalization trends between 2016 and 2021, monthly median sound levels in the 50 Hz–1,500 Hz band were quantified as root-mean-square sound pressure ($\text{dB}_{\text{RMS re } 1 \mu\text{Pa}}$). Band sound levels between 50 Hz–1,500 Hz are a measurement used to estimate ambient sound trends within the frequency range of humpback whale song vocalizations, and the root-mean-square metric provides a measurement of intensity over time (Haver et al. 2019). Using spectrogram images in Raven Pro, local vessel traffic was detected via manual visual detections of a u-shaped interference pattern known as the “Lloyd Mirror” effect. Each visual detection confirmed with audio playback. To evaluate noise from distant vessel traffic, two one-third octave bands (63 Hz and 125 Hz) were calculated as monthly median sound levels from 1 Hz narrow-band LTSA sound levels. The 63 Hz and 125 Hz one-third octave bands are proxies for large vessel and commercial shipping traffic within a minimum 20 km radius of the hydrophone (Haver et al. 2021).

Chapter 2. Study Results

2.1. Sound Levels

Low-frequency (10–2,000 Hz) sound levels at BUIS were relatively consistent over the entire duration of data collection between November 2016 and August 2021. In all years, narrow-band sound pressure levels (dB *re* 1 $\mu\text{Pa}^2/\text{Hz}$) were more variable between 10 Hz–110 Hz compared to 110 Hz–2,000 Hz. Sound pressure levels were reported as three percentile metrics, 10th, 50th, and 90th. The 90th percentile metric (LA10), quantifies the loudest conditions or infrequent loud events by measuring the sound level exceeded 10% of the time (for the specified period). The 50th percentile (LA50) is the median sound level and is used to measure chronic conditions. Lastly, the 10th percentile (LA90) is used to quantify the quietest conditions as it reports the sound level exceeded 90% of the time (for the specified period). Between 10 Hz–110 Hz, 90th percentile sound levels were as much as 18 dB higher than 10th percentile sound levels (Figure 2.1). This increase is approximately equivalent to a perceptive 350% increase (factor 3.5) of the “loudness” of the sound level. In frequencies between 100 Hz–2,000 Hz, the highest sound levels were recorded between December 2020 and August 2021.

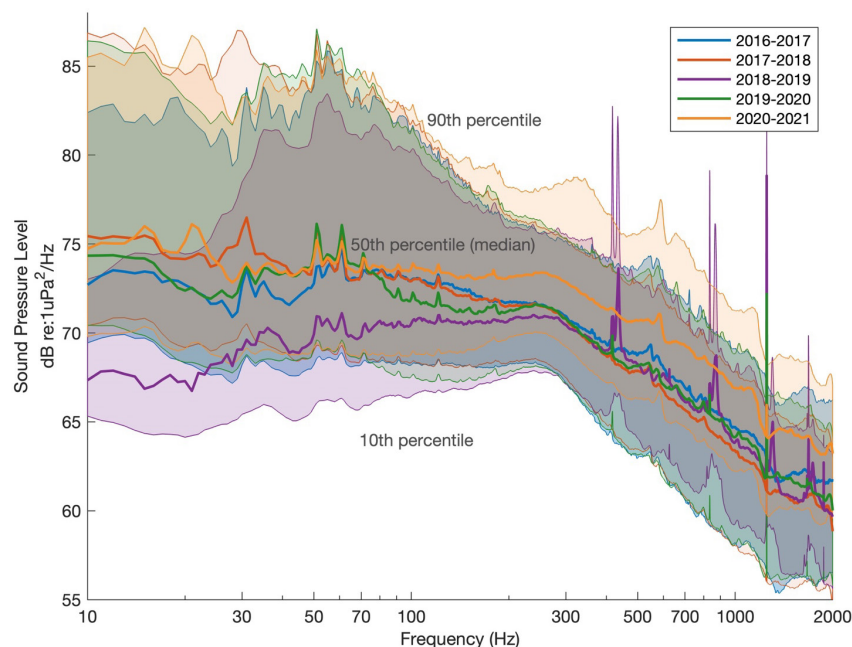


Figure 2.1. Narrow-band (1 Hz) percentile sound levels (LA₉₀, LA₅₀, LA₁₀) averaged over five deployment years and plotted as different color transparent layers. Median LA₅₀ levels are plotted in a solid-colored line, while LA₉₀ and LA₁₀ percentile levels are plotted as filled semi-transparent areas to show the patterns and range of sound levels across each deployment year. The 10th percentile (LA₉₀) quantifies the sound level exceeded 90% of the time, and the 90th percentile (LA₁₀) quantifies the sound level exceeded 10% of the time and is a measurement of the highest intensity sound levels. Figure adapted from Haver and Nuessly, 2022.

2.2. Humpback Whale Vocalization Activity

Analysis of all years of data sampled in BUIS (2016–2021) revealed that monthly median root-mean-square (RMS) sound levels in the 50 Hz–1,500 Hz (dB_{RMS}) band increased between December and May, likely because of humpback whales vocalizing nearby the hydrophone (Figure 2.2). The 50 Hz–1,500 Hz band is the primary frequency range of humpback whale song vocalizations in BUIS (Haver et al. 2019). Between November 2016 and August 2021, monthly median 50 Hz–1,500 Hz dB_{RMS} sound levels were highest in the months of December, January, and February. The highest monthly median 50 Hz–1,500 Hz dB_{RMS} sound levels were recorded in February 2021 and were 3 dB higher than the highest dB_{RMS} sound levels recorded in previous year. Additionally, monthly median 50 Hz–1,500 Hz dB_{RMS} sound levels in March 2021 were higher than sound levels recorded in March of previous years, indicating that comparably higher monthly median sound levels in 2021 were sustained over multiple months.

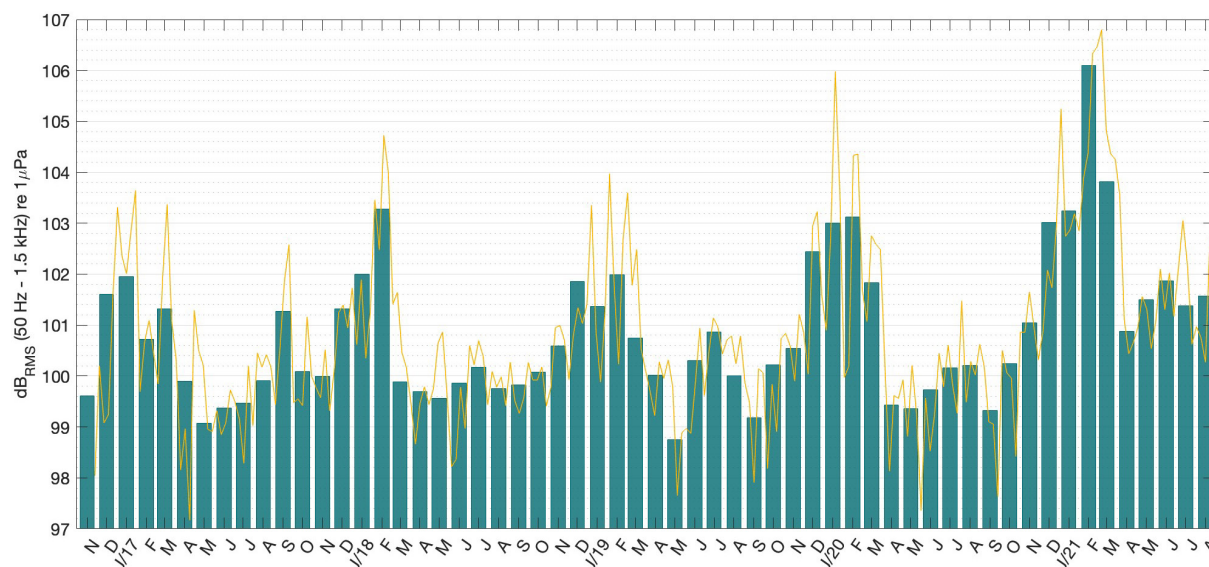


Figure 2.2. Monthly median root-mean-square sound levels in the 50 Hz–1,500 kHz band (dB_{RMS} re 1 μPa) (green bars) and overlaid seven day moving average (yellow line) for acoustic data recorded in BUIS between November 2016 and August 2021.

Manual analysis of humpback whale vocalizations between November 18th and April 30th in 2017/2018 and 2019/2020 revealed increased acoustic presence of humpback whales in 2019/2020. In 2019/2020, humpback whale vocalizations were recorded on more days and for more hours per day compared to 2017/2018 (Table 2.1., Figure 2.3). There was no diel pattern of humpback whale vocalizations detected in either data set; vocalizations were detected equally over day and nighttime hours (Figure 2.4).

Table 2.1. Acoustic presence of humpback whale vocalizations between November 18th and April 30th.

Year	Mean Hours Per Day (all analyzed days)	Number of Days Present	Median Hours Per Day (excluding days with 0 detections)	Mean Hours Per Day (excluding days with 0 detections)
2017–2018	3.60	45	13	13.2
2019–2020	6.24	66	19	15.6

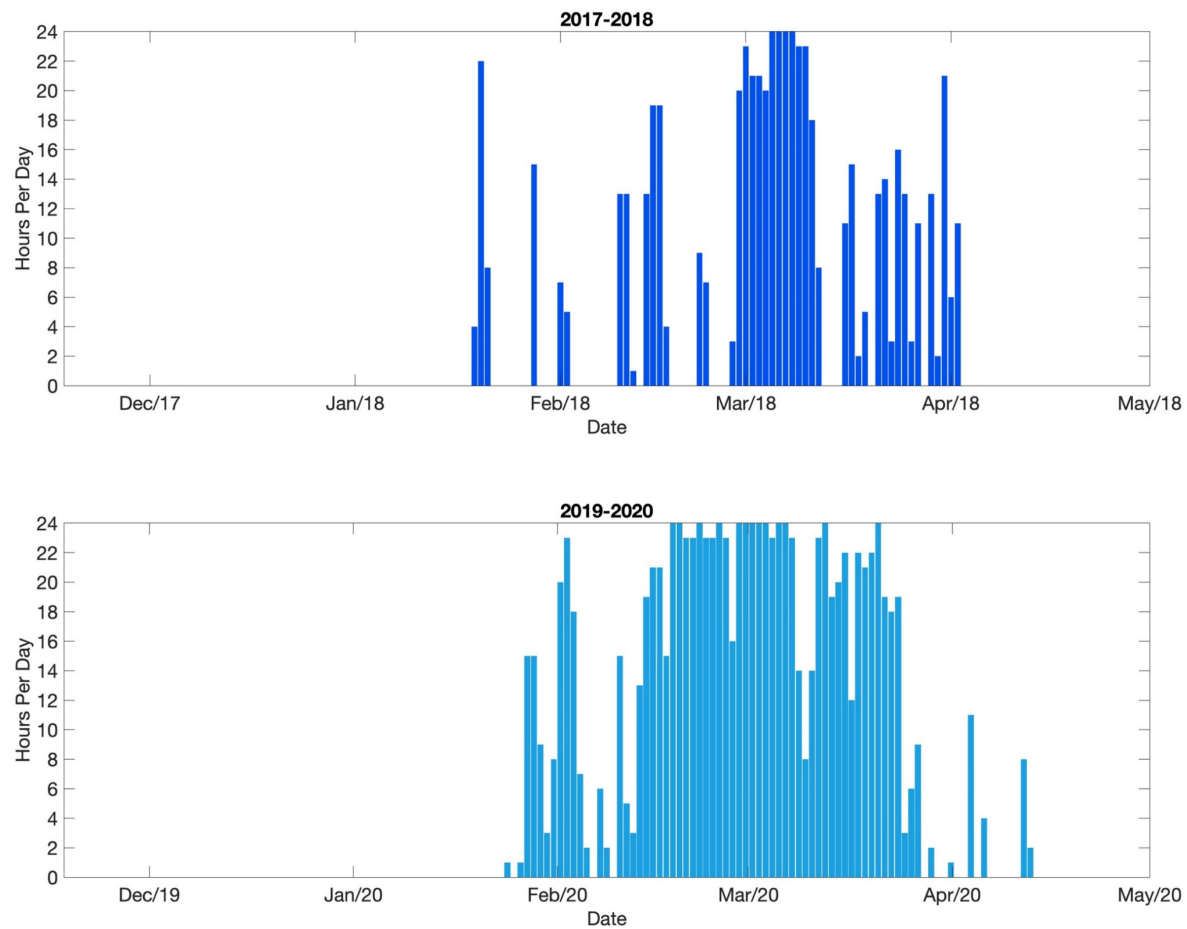


Figure 2.3. Total number of hours per day containing aurally and visually detected humpback whale vocalizations (song) in BUIS recordings during each hour of each day, November 18th, 2017–May 1st, 2018 (top), and November 18th, 2019–May 1st, 2020 (bottom).

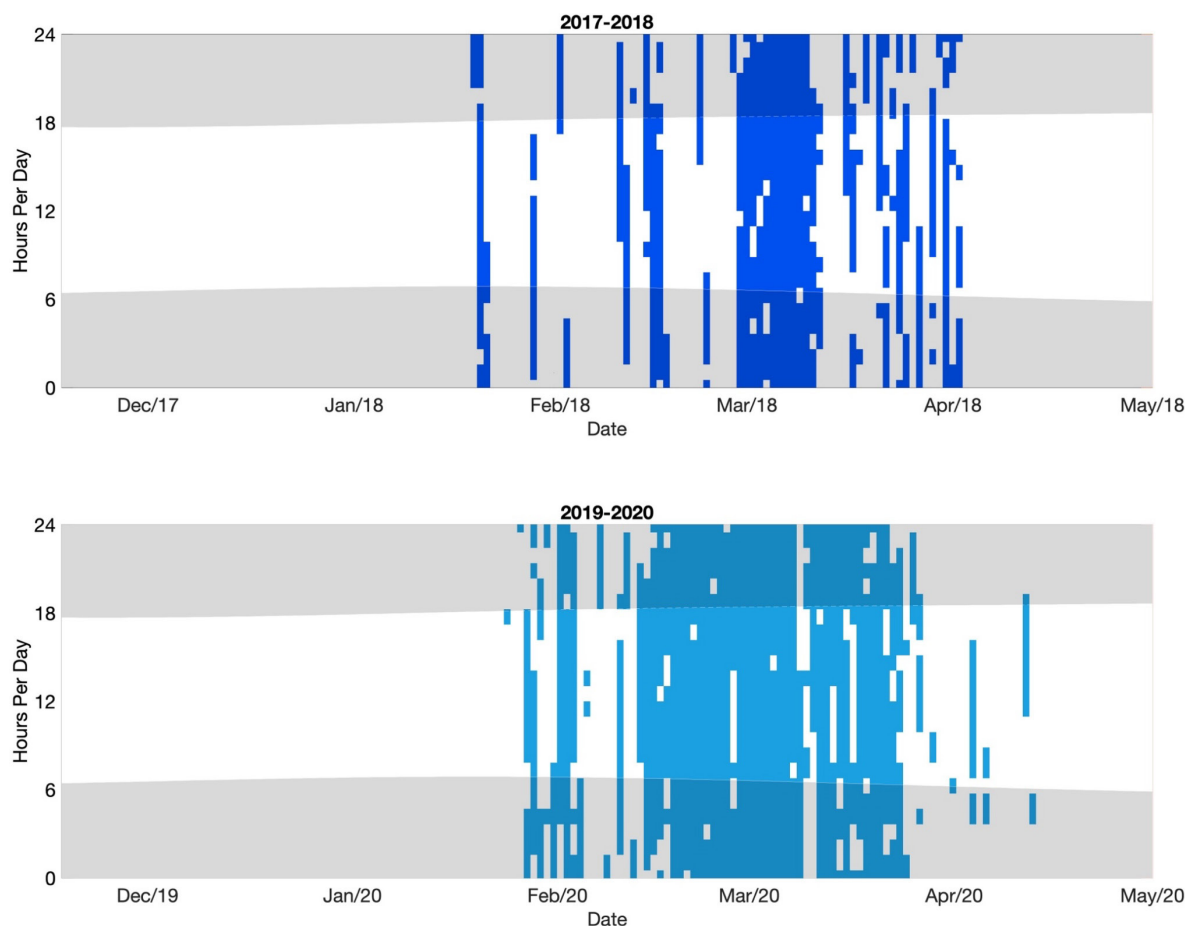


Figure 2.4. Presence/absence of aurally and visually detected humpback whale vocalizations (song) in BUIS recordings during each hour of each day, November 18th, 2017–May 1st, 2018 (top), and November 18th, 2019–May 1st, 2020 (bottom). Shading indicates daylight versus nighttime hours.

2.3. Vessel Noise

2.3.1. Nearby Vessel Movement

Vessel movement occurring nearby the hydrophone (within ~1 km) was detected via manual spectrogram review. Due to the relatively shallow location of the hydrophone (40 m), it is likely that vessels detected nearby were of small to medium size, such as fishing or diving vessels and speed boats, however vessel size was not confirmed in this analysis. Between November 18th and April 30th in 2017/2018 and 2019/2020, vessel noise was detected in a similar number of hours per day (Table 2.2., Figure 2.5). In 2017/2018 the mean number of hours per day that contained vessel noise was 2.60 and the median was 2 hours per day. In 2019/2020 the mean number of hours per day that contained vessel noise was 2.65 and the median was 3 hours per day. In 2017/2018 the highest number of hours with vessel noise detected in one day was 14, while in 2019/2020 the highest number of hours with vessel noise detected in one day was 9. In both data sets, there were some days with no vessel noise detected in any hours of the day.

Table 2.2. Acoustic presence of nearby vessel noise between November 18th and April 30th.

Year	Mean Hours Per Day	Median Hours Per Day	Maximum Hours Per Day
2017–2018	2.60	2	14
2019–2020	2.65	3	9

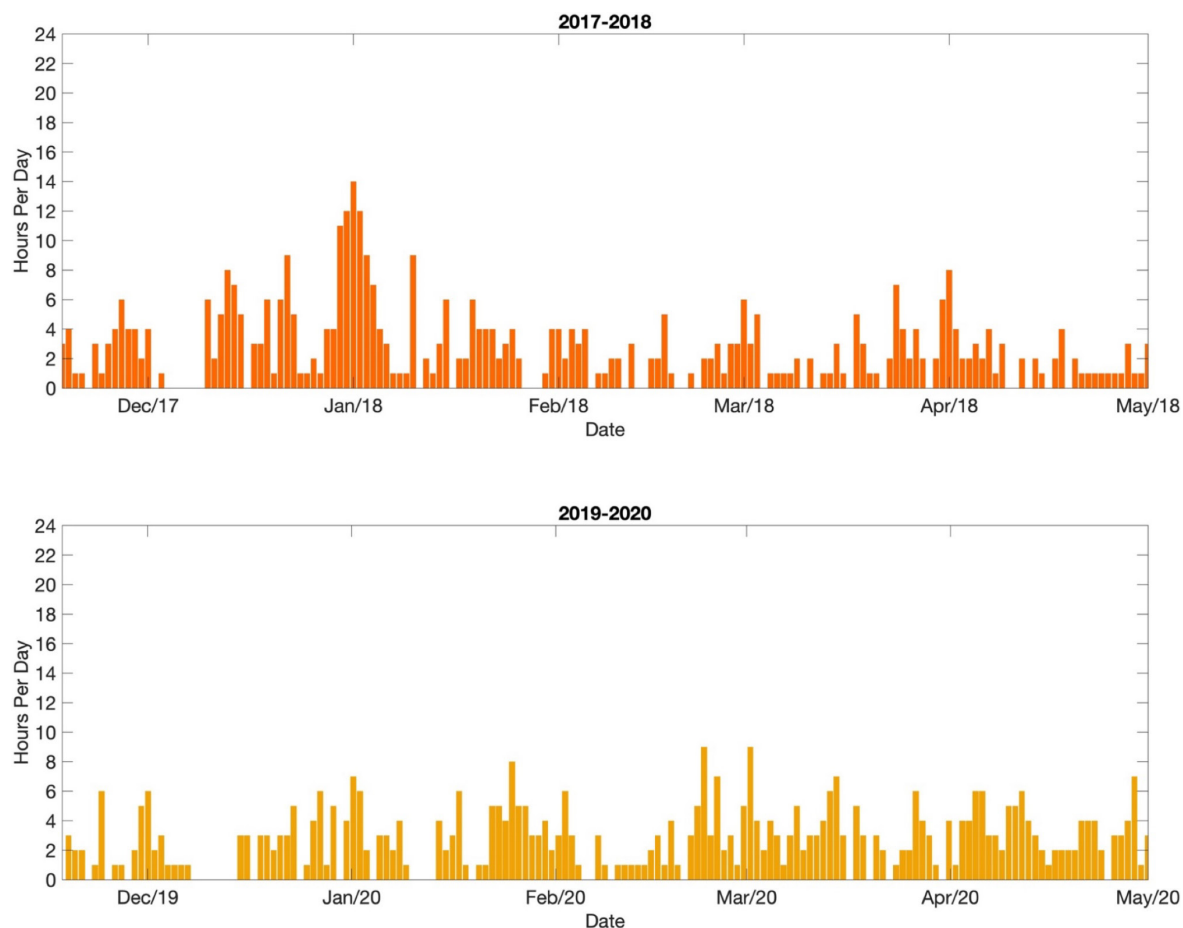


Figure 2.5. Total number of hours per day containing aurally and visually detected nearby (approximately within 1 km distance to hydrophone) vessel noise in BUIS recordings during each hour of each day, November 18th, 2017–May 1st, 2018 (top), and November 18th, 2019–May 1st, 2020 (bottom).

Diel patterns of nearby vessel noise were not consistent between the two deployments in 2017/2018 and 2019/2020 (Figure 2.6). In 2017/2018 more nearby vessel noise was recorded during nighttime hours compared to 2019/2020. In the 2019/2020 recordings, almost all detected vessel noise was recorded during daylight hours.

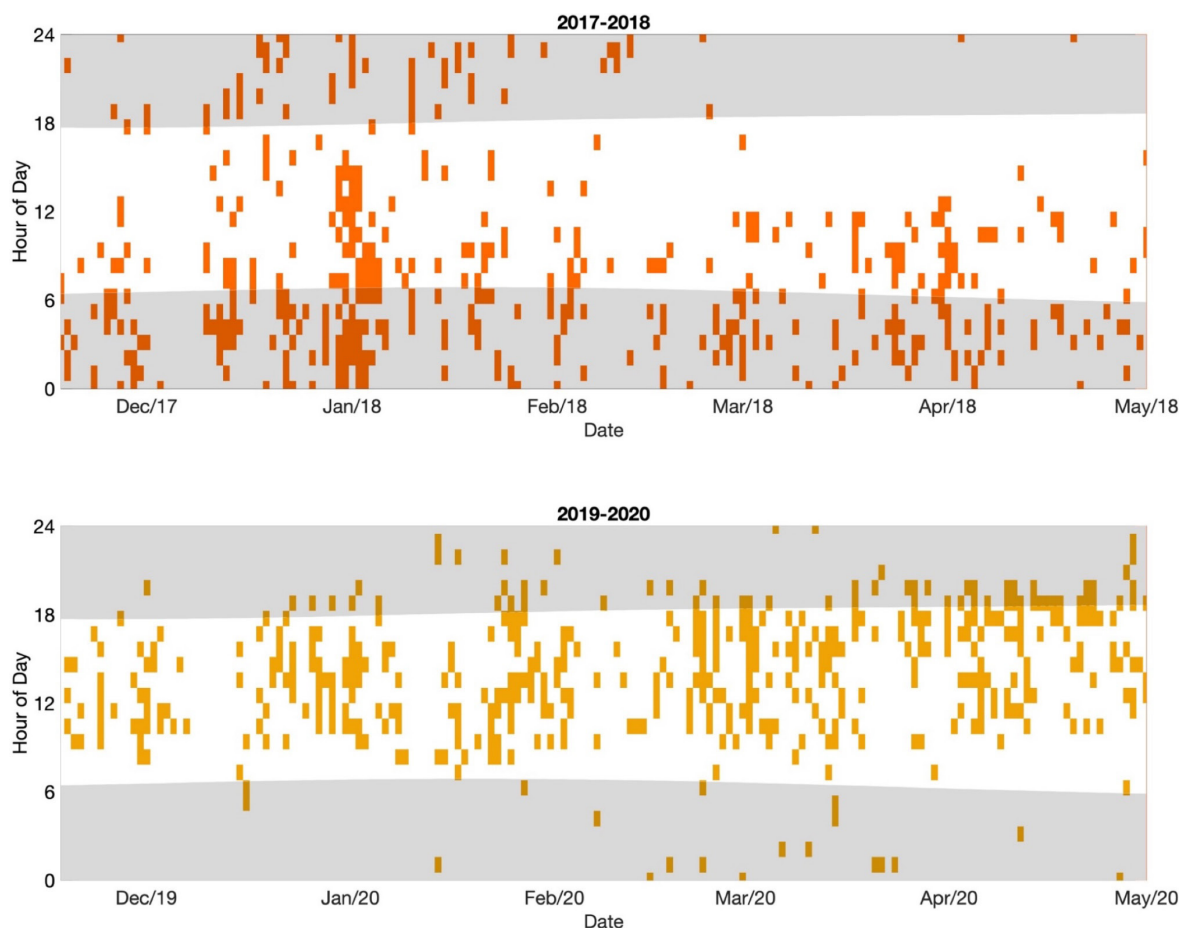


Figure 2.6. Presence/absence of aurally and visually detected nearby (approximately within 1 km distance to hydrophone) vessel noise indicated by Lloyd's mirror spectrogram patterns in BUIS recordings during each hour of each day, November 18th, 2017–May 1st, 2018 (top), and November 18th, 2019–May 1st, 2020 (bottom). Shading indicates daylight versus nighttime hours.

2.3.2. Distant Large Commercial Shipping Vessel Movement

To measure the presence of large cargo and tanker shipping vessels that were further than 20 km from the hydrophone, 63 Hz and 125 Hz one-third octave band sound levels were examined. Sound levels at 63 Hz and 125 Hz serve as proxy acoustic measurements for the presence of large cargo and tanker shipping vessels within a greater distance from the hydrophone (~20 km or more). Monthly 63 Hz and 125 Hz one-third octave band sound levels varied by as much as 5 dB across all months of data collections between November 2016–August 2021 (Figure 2.7). The largest change in monthly sound levels was a ~4 dB decrease (change in perceptive loudness of factor 1.3) observed between May and June 2018 in the 63 Hz one-third octave band. A ~4 dB decrease was also observed between March and April 2020 in the 125 Hz one-third octave band. The ~4 dB drop in sound levels in 2020 is mostly likely related to changes in shipping activity in response to the onset the COVID-19 pandemic. However, the sound level decrease in the early spring (March–May) in previous years as well as 2021, thus the change in 2020 may have occurred regardless of the pandemic. Sound levels were also observed to increase to the highest observed levels in 2021, which may be related to

resumption of large vessel activity and sustained increased levels to meet higher consumer demands for goods and recreation.

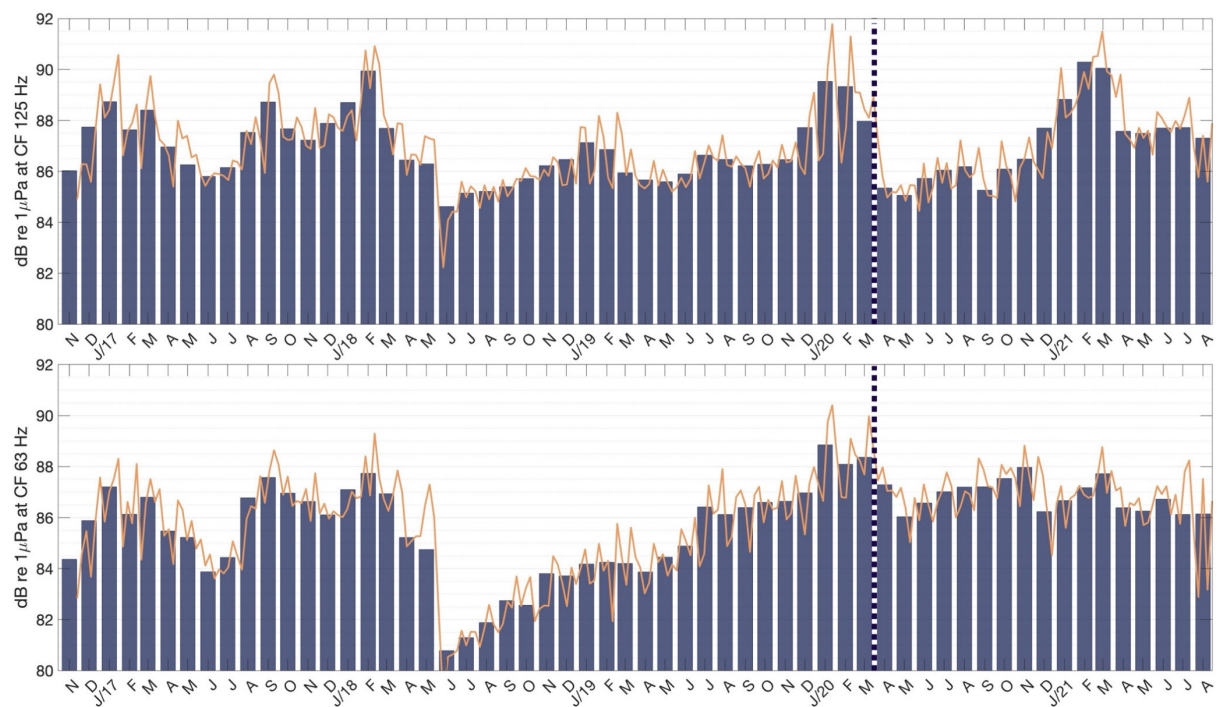


Figure 2.7. Monthly median one-third octave band sound pressure level measurements (dB re 1 μ Pa) for 125 Hz (top) and 63 Hz (bottom) center frequencies (blue bars) and overlaid seven day moving average (orange line) for acoustic data recorded in BUIS between November 2016 and August 2021. Dark line between March and April 2020 indicates beginning of COVID-19 pandemic.

Chapter 3. Discussion

Low-frequency soundscape conditions in BUIS were relatively stable over the five years of data collection between 2016 and 2021. Overall, ambient soundscape conditions in the park should be considered good (Table 3.1). Vessel noise is a variable trend, as noise from vessels passing over or near to the hydrophone (within approximately 1 km) appear to be increasing over time.

Vessel activity near the hydrophone shifted from all-day in 2017/2018 to be more concentrated in daylight hours in 2019/2020. Increased vessel noise near the hydrophone in 2019/2020 may be related to the change in human behaviors at the onset of the COVID-19 pandemic in March 2020. However, similarly minimal amounts of vessel activity in nighttime hours were observed between December 2019 and February 2020, prior to the pandemic declaration, so it is unknown what may have changed since 2017/2018 to result in the observed shift to daylight hours.

Low-frequency noise related to commercial shipping traffic (Haver et al. 2021) is present over the entire duration of passive acoustic data collection (2016–2021) and levels appear to be consistent over time (Haver et al. 2019).

Although vessel noise is pervasive throughout the acoustic data, it does not appear to mask seasonal presence of humpback whale vocalizations. However, passive acoustic data can only provide information when animals are vocalizing and detected; it is impossible to determine if quiet periods are because animals are not vocalizing, not present at all, or if another sound source is masking their vocalizations. Seasonal presence of humpback whale vocalizations is similar to previous years, indicating population stability and health (Haver et al. 2019).

Continued acoustic monitoring in BUIS will provide important data to track conditions in the soundscape, especially related to the potential impact of increasing anthropogenic and climate stressors to the marine ambient sound environment (for a detailed summary see Hildebrand 2009).

Table 3.1. Assessment of soundscape conditions.

Resource	Condition Indicators Assessed	Condition Status/Trend	Rationale & Key Points
Ambient soundscape	Low-frequency sound pressure levels	Good Condition/ Stable Trend	Monthly median sound levels are steady between 2016 and 2021, with consistent patterns of seasonal increases that can be linked to humpback whale vocalizations.
	Vessel passages detected in acoustic data	Variable Condition/ Stable Trend	Vessel noise detected nearby the hydrophone (approximately 1 km) increased slightly between 2017 and 2020.
Humpback whales (<i>Megaptera novaeangliae</i>)	Acoustic detections	Good Condition/ Increasing Trend	Acoustic detections of humpback whale song are seasonally present in all years of data collection. Between 2017 and 2020, the number of hours per day containing detections of humpback whale song increased.

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The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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