



American Samoa Underwater Acoustic Analysis

Summary of acoustic monitoring in 2015-2018

Introduction

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, the Natural Sounds and Night Skies Division, Oregon State University, and the National Oceanic and Atmospheric Administration (NOAA) includes stations in two park units: the National Park of American Samoa (NPSA) and Buck Island Reef National Monument, 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 collected data.

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.

While vessels are main contributor to chronic background noise in many marine environments, the NPSA monitoring site is in the remote, equatorial South Pacific region, with very little commercial vessel traffic. Therefore, anthropogenic sound sources are anticipated to have a minimal impact on the low-frequency (10 Hz–2 kHz) soundscape of NPSA.

Monitoring underwater soundscape conditions in NPSA is a unique opportunity to observe bioacoustic activity in a tropical reef environment that is minimally impacted by man-made noise.



Figure 1. Humpback whales (*Megaptera novaeangliae*) are a seasonal visitor to NPSA and can be monitored via vocalization activity that is commonly recognized as “song” (Photo: NPS).

This report summarizes acoustic monitoring efforts at NPSA since 2015, including analysis of sound levels and sources.

Research Objectives

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

1. Quantify the existing sound levels and multi-year trends.
2. Identify prominent marine animal sound sources and quantify patterns of bioacoustic activity over time.

Methods

Acoustic data were collected at a single site near Tutuila Island, National Park of American Samoa (-14.27, -170.72) at 33 meters depth from June 15th, 2015 to April 4th, 2016, July 27th, 2017 to September 2nd, 2018, and March 12th 2019 to April 1st 2020. Most recently the hydrophone was redeployed on March 8th, 2022. The NPSA monitoring site is in the remote, equatorial South Pacific region, with little commercial vessel traffic present. Specifically, the

hydrophone was deployed in a sandy bottom habitat near offshore reefs (Figures 2 and 3).

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 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 (Haver et al. 2018).

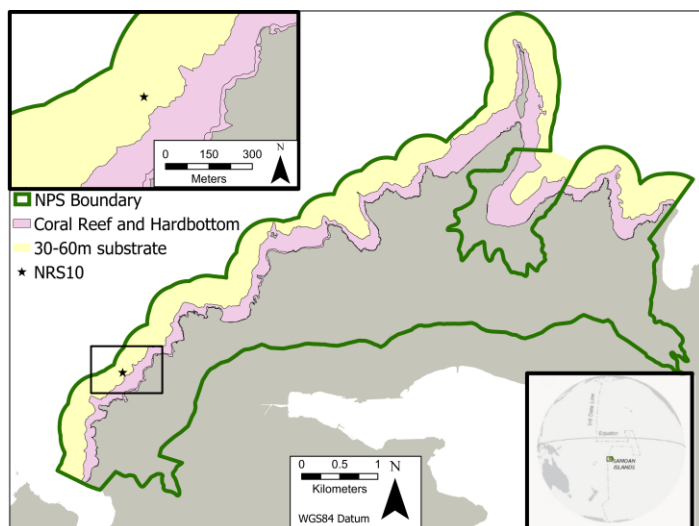


Figure 2: NPSA study area in NPSA (black star). Inset map in lower right corner shows location within the South Pacific. Figure from Munger et al. (2022)¹.

To quantify acoustic conditions over time and identify patterns in highly-vocal bioacoustic sound sources (e.g., humpback whale vocalizations, soniferous fish), long-term spectral averages (LTSA, 10–2,000 Hz range) were calculated using custom Matlab™ routines with 1 Hz and 1 second resolution. 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 μ Pa²/Hz) from raw .DAT files.

In compliment to sound level measurements, acoustic data were also analyzed for the presence of humpback whale vocalizations and pomacentrids (damsel-fishes)². 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. The spectrogram is colored according to sound intensity. For example, Figure 4 shows intensity of a color scale of cool (dark blue) for the quietest sounds to warm (red) for the loudest (highest intensity) sounds. Both detectors used to identify humpback whales and damsselfishes in the NPSA recording utilize spectrogram images during data processing.

The daily presence of humpback whale vocalizations was quantified via an automated software detector, which identified the humpback whale vocalizations via a multivariate discrimination analysis (comparing pitch tracks drawn through high energy tonal sounds). Detector results were manually verified as spectrogram images at a daily resolution to remove any false positives.

Damsel-fish calls were detected with a deep neural network that performed at 94% accuracy using transfer learning to fine-tune an image classifier. The recordings were binned into 2 second segments and the model was used to determine the presence or absence of damsselfish in each segment. This method allows for an efficient way to classify sounds in the marine environment, removing the need for extensive amounts of training data.

The variation in sound production was examined across all four study years using a Kruskal-Wallis non-parametric statistical test. The relationship between wind speed, water temperature, tidal amplitude, and sound pressure levels and the number of subsamples where damsselfish sounds were present was quantified using zero-inflated negative binomial regression analysis.

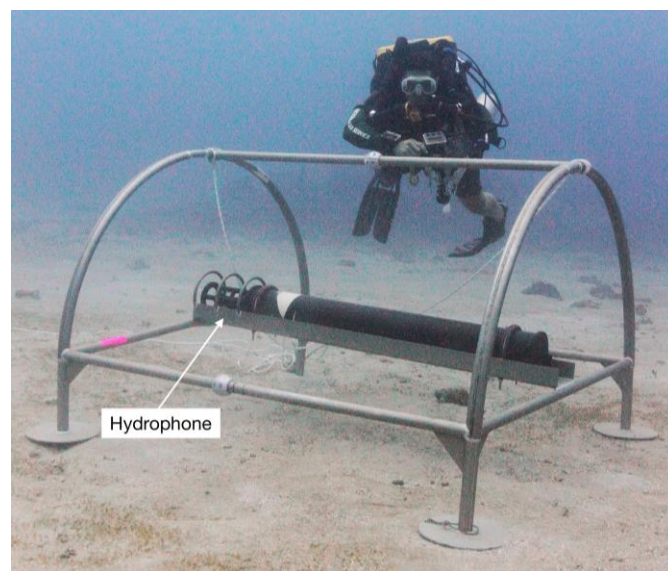


Figure 3: Bioacoustic monitoring site in NPSA. The hydrophone recording package (NOAA PMEL) was attached to a protective metal lander and secured to the seafloor with sand screws. The hydrophone package is swapped annually for data download and re-programming by NPS dive staff. NPS Photo.

¹ Munger et al. (2022) Marine Ecology Progress Series

² Haver et al. (2019) Frontiers in Marine Science

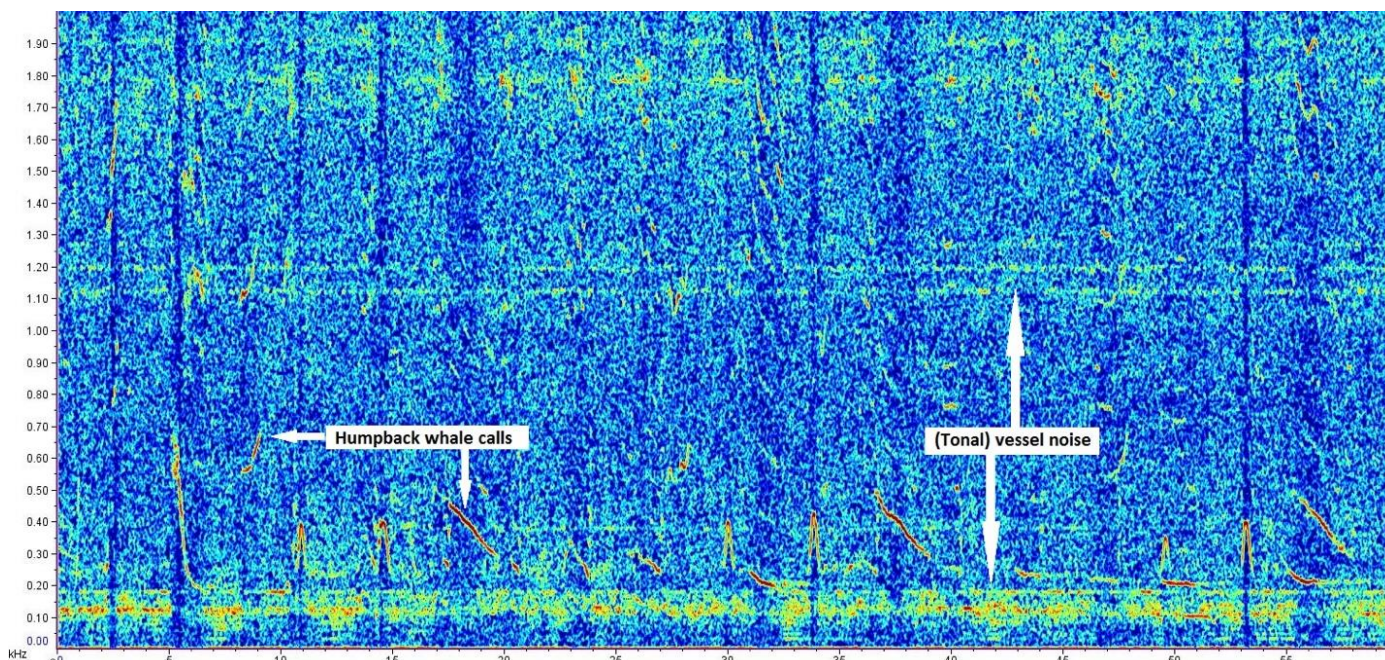


Figure 4: Example spectrogram with annotated vessel noise and humpback whale calls. All data was reviewed in Raven Pro version 1.5 (Cornell Lab of Ornithology). Corresponding .WAV included in supplemental information.

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 NPSA may be impacted by different sounds.

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 186 dB large tanker vessel.

Table 1. Sound level examples³

Underwater Sound Sources	Sound Level (dB re 1 μPa)	Approximate Equivalent Common Sound Source*
Daily median broadband ambient sound level in NPSA	~67-68	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	Thunderclap
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*

³ Sound levels from DOSITS.org and New York Times (<https://www.nytimes.com/2019/01/22/science/oceans-whales-noise-offshore-drilling.html>)

Existing Sound Levels

Calibrated spectrum levels were measured in 5-minute windows 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 NPSA was consistent during data collection (Table 2).

Table 2. Baseline sound levels for existing conditions in NPSA.

Deployment Year	Percentile Sound Levels (dB)*		
	L_{A90}	L_{A50}	L_{A10}
2016-2017	64.13	68.07	79.16
2017-2018	63.29	67.28	74.84

* $L_{Aeq, 1s}$ in dB re 1 μ Pa (10 Hz–2 kHz)

The first percentile metric, L_{A90} , reports the sound level exceeded 90% of the time for the specified time period. This is a preferred metric to quantify the *quietest conditions* (ANSI/ASA S12.18). Our baseline measurement in NPSA is an average sound level in excess of 63-64 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 NPSA was 67-68 dB which is an approximate 150% increase in loudness compared to the average L_{A90} sound levels 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 NPSA exceeded ~75-79 dB 10% of the time in all years, which is over 10 dB higher than the median L_{A90} levels and equivalent to a 200% increase of the loudness of the of the ambient soundscape compared to the median L_{A90} levels.

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 5). Sounds across the frequency spectrum such as the very low-frequency sounds from reef animals and slightly higher frequency humpback whale vocalizations often occur simultaneously, so the frequency spectrum is split into individual frequency bins in Figure 5 to assess 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.

Averaging over data collected from 2015-2018, the loudest sounds were recorded in low frequencies below 40 Hz. Sound levels between 50 Hz – 500 Hz were less

intense, and the lowest sound levels were recorded in frequencies above 1 kHz. This difference across frequencies is related to the dominance of biological sounds in the underwater environment of NPSA.

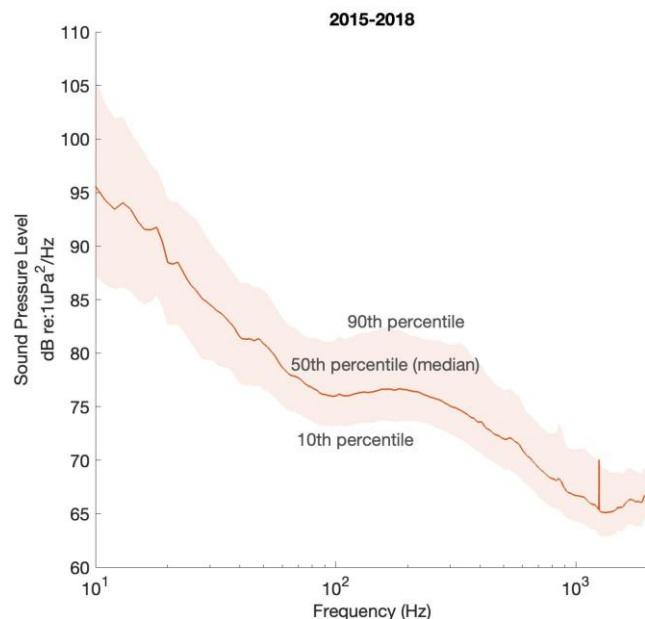


Figure 5: Narrow-band (1 Hz) percentile sound levels (L_{A90} , L_{A50} , L_{A10}) averaged over two deployment years. Median L_{A50} levels are plotted as the darker solid-colored line, while L_{A90} and L_{A10} percentile levels are plotted as the outer limits of the filled semi-transparent area to show the variation of sound levels from 10 Hz to 2 kHz.

Hourly and Monthly Variation

Ambient sound levels in NPSA were also quantified in the 50 Hz -1.5 kHz band, which is representative of the in the overlapping frequency range of humpback whale and fish vocalizations, vessel noise, and environmental sounds. Sound levels in 2015-2016 were averaged over 5-minute windows and plotted by hour of day and day of the year to reveal seasonal and diel patterns within the soundscape (Figure 6; (Haver et al. 2019).

In NPSA, sound levels are relatively stable throughout the year, with ephemeral time-periods of higher intensity sound. Specifically, the seasonal band sound level variations observed in NPSA between August and November are aligned with the expected seasonal period for Southern Hemisphere humpback whales. In February 2016, an isolated weather event increased ambient sound levels when a category five tropical cyclone, Winston, traveled through the South Pacific.

A distinct diel pattern of band sound levels was also observed in NPSA throughout the recording period; band sound levels were lower during daylight hours (compared to nighttime), with the highest daily levels recorded during crepuscular time periods. This diel pattern is likely related to the activities of reef animals, such as the crepuscular feeding behavior of sea urchins, a ubiquitous species in tropical reef environments. Sea urchins feed by scraping algae via a ventral beak-like mouth, and the skeleton of each sea urchin acts as a Helmholtz resonator, magnifying the scraping sounds from each individual (800 Hz– 2 kHz, depending on body size) into a “reef chorus”

that may also include sounds from other animals such as fish or shrimp.

Seasonally, a 29-day lunar cycle in sound levels is also evident in NPSA, with quieter periods throughout the day near full moons.

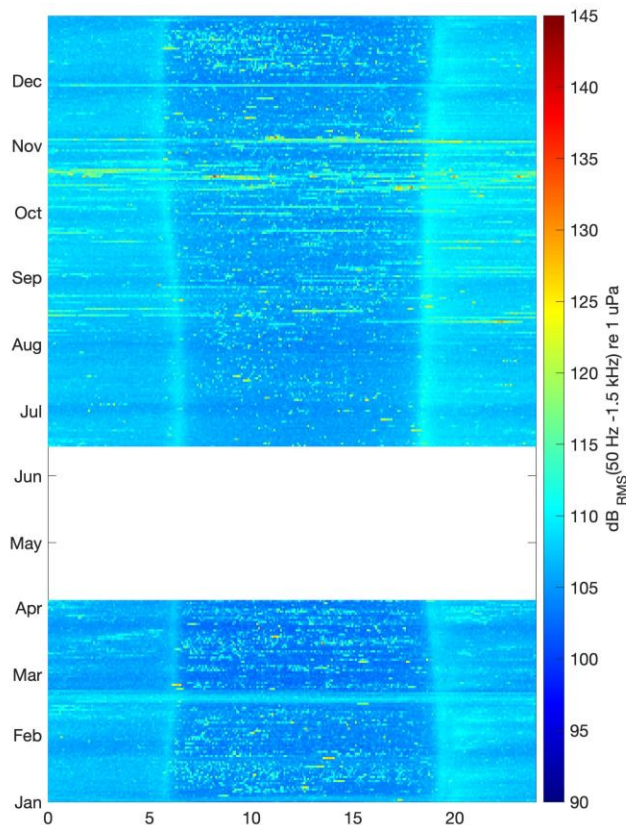


Figure 6: Sound levels in the 50 Hz–1.5 kHz band (dBRMS re 1 µPa) calculated in 5-min bins for June 2015 – April 2016 in NPSA. Color (blue–yellow–red) indicates sound level intensity in each bin, with the lowest levels (90 dB) dark blue and the highest (145 dB) bright red. Acoustic data is plotted by month (January–December) and hour of day (0–24).

Bioacoustic Sound Sources

American Samoa is in a low-latitude remote location in the South Pacific Ocean (Figure 1) where the weather is relatively consistent year-round. Although fully exposed to the open ocean, NPSA is thousands of miles away from any major shipping port (i.e., in Eastern Australia, Northern New Zealand, or Hawai'i), limiting the influence of large vessel noise on sound levels. Instead, an abundance of biological sound sources near the receiver were the primary driver of ambient sound conditions.

Damselfish Calls

Damselfish are an abundant, acoustically prolific, and ecologically important species in coral reef systems making them an excellent candidate for passive acoustic monitoring. Healthy populations of damselfish are associated with healthy reefs with high amounts of coral cover, habitat complexity, and functional diversity (Noonan et al. 2012, Darling et al. 2017).

Damselfish were found to be more sonically active during daylight hours, between 06:00 and 18:00 h local time when many feeding and spawning behaviors occur (Munger et al. 2021). There was also variation year-over-year, with a decline in call rates over the first 3 years of the study and a slight increase in the median number of segments where sound production was detected from 2017 to 2018.

Increases in tidal amplitude, wind speed, and sound pressure level were found to be correlated with more damselfish sound presence. Increased sea surface temperature was associated with less damselfish sound presence. Pairing visual behavioral observations of individual species with these acoustic data would allow for more direct ecological inference.

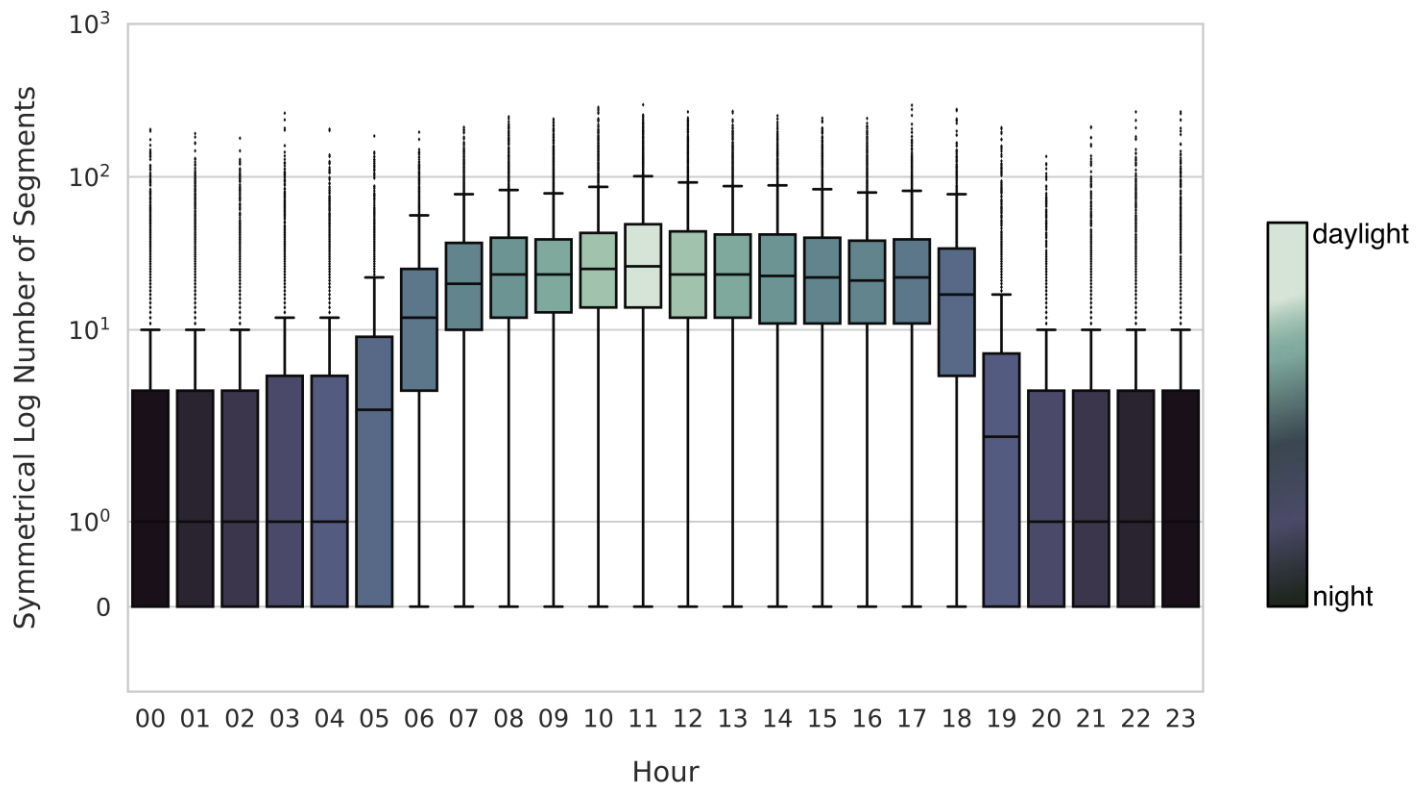


Figure 7: Symmetrical log number of 2 second segments where sound production was detected for each 15 min interval in damselfish over a representative 1-week period (7-13 May 2018). Figure from Munger et al. (2022).

Humpback Whale Vocalizations

Humpback whale calls and song were observed seasonally in NPSA during the austral spring months (August–November) (Fig. 8). Humpback whales are acoustically active throughout their migratory range between high latitude foraging grounds and low-latitude breeding grounds, such as NPSA. On breeding grounds, male Humpback whales produce song, a structured sequence of vocalizations that can last for hours and sometimes over an entire day. The presence of multiple Humpback whale singers is a driver of ambient sound levels in NPSA, and we observed peaks in band sound levels between August until November that were likely driven by humpback whale song vocalizations. Specifically, on days when humpback whale vocalizations were present, daily median 500 Hz sound levels was higher (~ 1 dB) compared to days that humpback whale vocalizations were not detected.

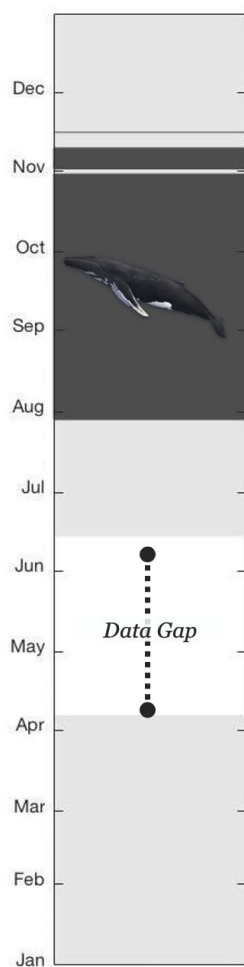


Figure 8: Monthly presence (dark gray shading) or absence (light gray shading) of humpback whale vocalizations. Figure adapted from Haver et al. (2019).

Next Steps

- All acoustic data collected in NPSA will be archived for open access through NOAA NCEI⁴
- 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.

Summary and Conclusion

Assessing acoustic habitat quality within the National Park of American Samoa 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 NPSA to document baseline conditions. Analysis of specific sound sources in NPSA data also quantify the presence of humpback whale and reef fish sound production as primary drivers of underwater sound levels.

In NPSA, soundscape conditions are relatively consistent across years, with predictable seasonal variation due to humpback whale vocalizations and diel variation of reef animal activity. Rare tropical storms can also impact soundscape conditions, primary from high-speed winds. The highest sound levels were observed in the austral spring from August through November, the same months that humpback whale song was detected. The lowest sound levels were observed in March through May, though the variation was minimal.

In NPSA, human uses are relatively quiet and marine animals dominate the soundscape. Compared to other similar shallow (<100 m) marine protected areas, NPSA is currently relatively untouched by anthropogenic sources (Haver et al. 2019). However, 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. 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.

⁴ Passive Acoustic Data viewer: <https://www.ngdc.noaa.gov/mgg/pad/>

The use of machine learning techniques to detect damselfish calls reveals a valuable tool in the extraction of relevant ecological information from PAM. Using these tools to understand the temporal distribution and patterns of fish sound production in a protected area provides a baseline for comparison as conditions change over time in response to climate change and shifting practices in resource management. Observance of patterns over longer periods of time may provide insight into courtship activities and reproduction of pomacentrid species, especially when used to supplement the current monitoring efforts in NPSA.

Through ongoing data collection and future studies, soundscape analysis of Ocean Noise Reference Station Network soundscapes—over time within sites, among shallow and deep-water habitats, and among National Marine Sanctuaries, National Parks, and the greater U.S. Exclusive Economic Zone—will reveal how natural and anthropogenic contributors to ocean ambient sound vary by location and time and identify long-term trends across the entire network. These data support management planning and policy development for protected areas.

References

- Darling, E.S., Graham, N.A.J., Januchowski-Hartley, F.A. et al. Relationships between structural complexity, coral traits, and reef fish assemblages. *Coral Reefs* 36, 561–575 (2017). <https://doi.org/10.1007/s00338-017-1539-z>.
- Haver, S. M., M. E. H. Fournet, R. P. Dziak, C. Gabriele, J. Gedamke, L. T. Hatch, J. Haxel, S. A. Heppell, M. F. McKenna, D. K. Mellinger, and S. M. Van Parijs. 2019. Comparing the Underwater Soundscapes of Four U.S. National Parks and Marine Sanctuaries. *Frontiers in Marine Science* 6(500):1–14.
- Haver, S. M., J. Gedamke, L. T. Hatch, R. P. Dziak, S. Van Parijs, M. F. McKenna, J. Barlow, C. Berchok, E. DiDonato, B. Hanson, J. Haxel, M. Holt, D. Lipski, H. Matsumoto, C. Meinig, D. K. Mellinger, S. E. Moore, E. M. Oleson, M. S. Soldevilla, and H. Klinck. 2018. Monitoring long-term soundscape trends in U.S. Waters: The NOAA/NPS Ocean Noise Reference Station Network. *Marine Policy* 90(February):6–13.
- Munger, J., D. Herrera, S. Haver, L. Waterhouse, M. McKenna, R. Dziak, J. Gedamke, S. Heppell, and J. Haxel. 2021. Machine learning analysis reveals relationship between pomacentrid calls and environmental cues. *Marine Ecology Progress Series* 681:197–210.

More Information

Samara Haver, Ph.D.
Cooperative Institute for Marine Ecosystem and Resources
Studies, Oregon State University
Email: samara.haver@noaa.gov

Katie Nuessly, M.S.
NRSS Natural Sounds and Night Skies Division
Email: kathryn_nuessly@nps.gov
Phone: 970-267-2114

Appendix A: National Park of American Samoa 2015-2020

Due to pandemic related fieldwork interruptions, passive acoustic data collected in NPSA between March 2019 – April 2020 were recovered after completion of analyses for this report. As of October 2022, three years of data are now available: June 2015 – April 2016, July 2017 – March 2018, and March 2019 – April 2020. Across the three separate deployments, conditions in NPSA are relatively stable across years and months (Figures A.1., and A.2). The data have been processed in 1 Hz, 5-minute LTSAs for further analysis and comparison to other soundscapes in future studies.

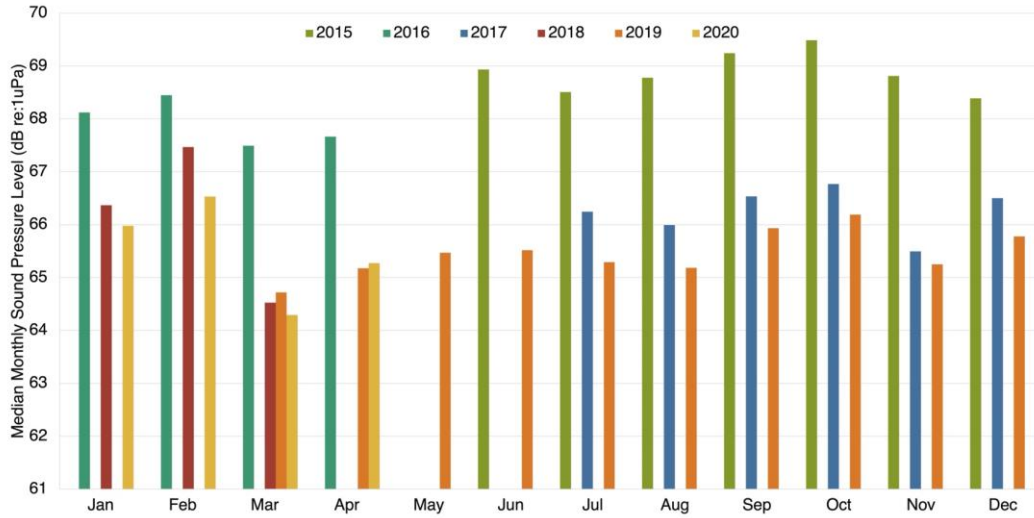


Figure A.1. Monthly median broadband (10 Hz – 2000 Hz) sound pressure level measurements (dB re 1 μ Pa) of all 34 months of data collection between June 2015 and April 2020 and plotted by month and year.

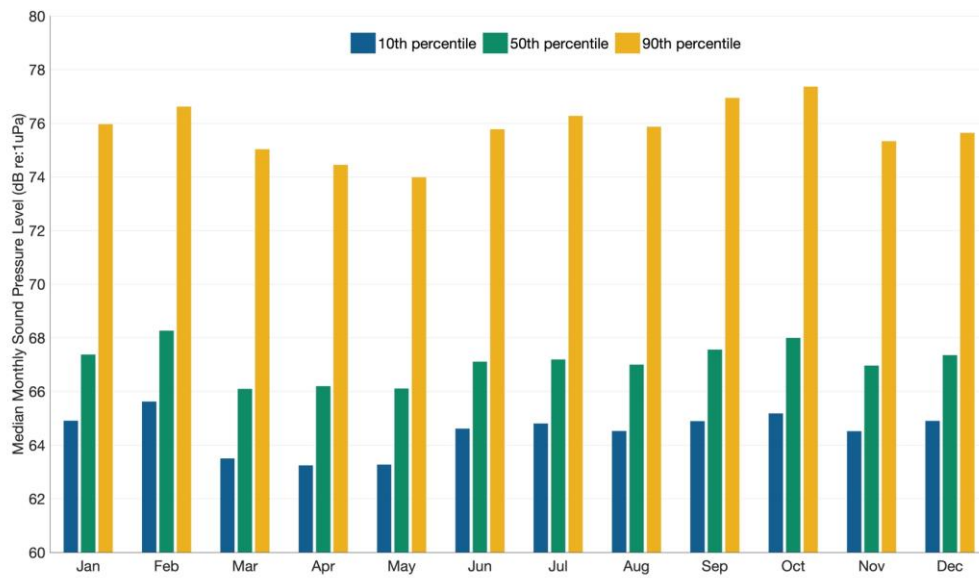


Figure A.2. Monthly median broadband (10 Hz – 2000 Hz) 10th, 50th, and 90th percentile sound pressure level measurements (dB re 1 μ Pa). All 34 months of data collection between June 2015 and April 2020 are included and averaged as single month values.