



Hawai‘i Volcanoes National Park

Acoustic Monitoring Report 2019



Acoustic monitoring in Hawai‘i Volcanoes National Park
NPS / NATURAL SOUNDS PROGRAM

Hawai'i Volcanoes National Park: Acoustic monitoring report 2019

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Contents

	Page
Figures.....	iv
Tables.....	vi
Appendices.....	vii
Abstract.....	viii
Acknowledgments.....	ix
List of Terms or Acronyms.....	x
Executive Summary.....	xiii
Introduction.....	1
National Park Service Natural Sounds and Night Skies Division.....	1
Soundscape Planning Authorities.....	1
Focal Park Unit.....	2
Study Area.....	3
Methods.....	6
Automatic Monitoring.....	6
Monitoring Period.....	6
Calculation of Metrics.....	7
Off-Site Listening and Spectrogram Analysis.....	8
Listening Center Software Analysis.....	8
Results.....	9
Frequency Content.....	9
Sound level: Time Above.....	14
Sound Level: Percentile Levels.....	16
Event Duration.....	22
Listening Center Software.....	22
Conclusions.....	25
Literature Cited.....	28

Figures

	Page
Figure 1. Study sites in Hawai‘i Volcanoes National Park, HI, USA.....	5
Figure 2. A Colorado State University student identifies sound sources using Acoustic Monitoring Toolbox (NPS) software.	8
Figure 3. Day and night percentile sound pressure levels for 33 one-third octave bands at HAVO002 in Spring, 2019.	10
Figure 4. Day and night percentile sound pressure levels for 33 one-third octave bands at HAVO002B in Spring, 2019.....	11
Figure 5. Day and night percentile sound pressure levels for 33 one-third octave bands at HAVO009A in Summer, 2019.	12
Figure 6. Day and night percentile sound pressure levels for 33 one-third octave bands at HAVO009A in Fall, 2019.....	13
Figure 7. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at HAVO002 in spring, 2019.....	18
Figure 8. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at HAVO002B in spring, 2019.....	19
Figure 9. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at HAVO009A in summer, 2019.....	20
Figure 10. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at HAVO009A in fall, 2019.	21
Figure 11. Hourly time audible for the top noise sources and all noise sources at HAVO002 in spring, 2019.....	22
Figure 12. Hourly time audible for the top noise sources and all noise sources at HAVO002B in spring, 2019.	23
Figure 13. Hourly time audible for the top noise sources and all noise sources at HAVO009A in summer, 2019.	23
Figure 14. Hourly time audible for the top noise sources and all noise sources at HAVO009A in fall, 2019.....	24
Figure 15. HAVO002, Mauna Loa.	31
Figure 16. HAVO002B, Halema‘uma‘u.	32
Figure 17. HAVO009A, Pu‘u Huluhulu/ New Lava Flows.....	33
Figure 18. Comprehensive sound source description results from off-site listening at HAVO002 in spring, 2019.....	35

Figures (continued)

	Page
Figure 19. Comprehensive sound source description results from off-site listening at HAVO002B in spring, 2019.	36
Figure 20. Comprehensive sound source description results from off-site listening at HAVO009A in summer, 2019.	37
Figure 21. Comprehensive sound source description results from off-site listening at HAVO009A in fall, 2019.....	38

Tables

	Page
Table 1. Sound level examples.....	xiii
Table 2. Percent time above metrics for acoustic records collected in Hawai‘i Volcanoes National Park (HAVO) in Spring, 2019.....	xv
Table 3. Percent time above metrics for acoustic records collected in Hawai‘i Volcanoes National Park (HAVO) in Summer, 2019.....	xv
Table 4. Percent time above metrics for acoustic records collected in Hawai‘i Volcanoes National Park (HAVO) in Fall, 2019.....	xv
Table 5. Summary of noise sources and sound levels at Hawai‘i Volcanoes National Park (HAVO) in Spring, 2019.....	xvi
Table 6. Summary of noise and sound levels at Hawai‘i Volcanoes National Park (HAVO) in Summer, 2019.....	xvi
Table 7. Summary of noise and sound levels at Hawai‘i Volcanoes National Park (HAVO) in Fall, 2019.....	xvii
Table 8. Metadata for acoustical monitoring sites at Hawai‘i Volcanoes National Park, 2019.....	4
Table 9. Percent time above metrics for acoustic records collected in Hawai‘i Volcanoes National Park (HAVO) in Spring, 2019.....	15
Table 10. Percent time above metrics for acoustic records collected in Hawai‘i Volcanoes National Park (HAVO) in Summer, 2019.....	15
Table 11. Percent time above metrics for acoustic records collected in Hawai‘i Volcanoes National Park (HAVO) in Fall, 2019.....	15
Table 12. Sound levels at Hawai‘i Volcanoes National Park (HAVO) in spring, 2019.....	16
Table 13. Sound levels at Hawai‘i Volcanoes National Park (HAVO) in summer, 2019.....	16
Table 14. Sound levels at Hawai‘i Volcanoes National Park (HAVO) in fall, 2019.....	17
Table 15. Percent time above metrics for acoustic records collected in Hawai‘i Volcanoes National Park (HAVO) in the spring of 2008 and 2019.....	40
Table 16. Sound levels at Hawai‘i Volcanoes National Park (HAVO) in the spring of 2008 and 2019.....	40

Appendices

	Page
Appendix A: Site Photos.....	31
Appendix B: Detailed Sound Source Descriptions	34
Appendix C: Comparison to Unreported Data.....	39

Abstract

In 2018, the Natural Sounds and Night Skies Division (NSNSD) received a technical assistance request (4938) to collect baseline acoustic data at Hawai‘i Volcanoes National Park (HAVO) to pair with a concurring study tracking aircraft over the park. From March to October 2019, acoustical monitoring systems were deployed at three study sites in the park, HAVO002 (Mauna Loa) and HAVO002B (Halema‘uma‘u) during the Spring, and HAVO009A (Pu‘u Huluhulu/New Lava Flows) during the Summer and Fall. Combined, these three seasons of acoustic measurements provide park managers with baseline information about the acoustic environment, including existing ambient sound levels, time-above noise level metrics, and audibility of a variety of sound sources in the park. Aircraft and vehicles were the most frequently heard noise sources at all sites during spring, summer, and fall measurement periods. However, these two sources contributed less than 15% of noise audibility across the entire monitoring period. Overall, across all sites and seasons, existing median ambient sound levels (L_{A50}) ranged from 20.2 dB–32.4 dB during the daytime and 16.8–39.8 dB during the nighttime. Natural ambient sound levels (L_{Anat}) ranged between 19.0–32.0 dB during the day and 16.7–39.8 dB at night. Increased natural ambient sound levels during day and night varied by location and were likely caused by diurnal winds and site-specific ecology that drives insect and bird activity. Over the two measurement periods, during the daytime, hourly L_{Aeq} sound levels exceeded the 52 dBA level, a level at which interpretive programs are likely to be interrupted, less than 3.0% of the time.

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List of Terms or Acronyms

A-weighting: A-weighting is applied to sound levels to account for the sensitivity of the human ear (Harris, 1998). To approximate human hearing sensitivity, A-weighting discounts sounds below 1 kHz and above 6 kHz.

Acoustic Environment: A combination of all the physical sound resources within a given area. This includes natural sounds and cultural sounds, and non-natural human-caused sounds. The acoustic environment of a park can be divided into two main categories: intrinsic and extrinsic.

Acoustic Resources: Includes both natural sounds like wind, water, and wildlife, and cultural and historic sounds like tribal ceremonies, quiet reverence, and battle reenactments.

Amplitude: The relative strength of a sound wave, described in decibels (dB). Amplitude is related to what we commonly call loudness or volume.

ANS Weighting: The Natural Sounds modification to A-weighting eliminates high-frequency sound (leaf rustle, equipment noise, and biologic sounds) allowing for more accurate comparisons of low-frequency ambient sound levels across different land use types (e.g., urban, protected areas; ANSI S3/SC1.100, 2014 [R2020]). This frequency weighting scheme improves ambient sound level measurements in quiet environments.

Audibility: The ability of animals with normal hearing, including humans, to hear a given sound. It can vary depending upon the frequency content and amplitude of sound and by hearing ability of individual animals.

Day-Night average sound levels (L_{dn}): Average equivalent sound level over a 24-hour period, with a 10-dB penalty added for sound levels between 10 p.m. and 7 a.m.

Decibel (dB): A unit of sound energy. Sound levels are measured on a logarithmic scale relative to the reference sound pressure for atmospheric sources, 20 μ Pa. The logarithmic scale is a useful way to express the wide range of sound pressures perceived by the human ear. Every 10 dB increase represents a tenfold increase in energy. Therefore, a 20 dB increase represents a hundredfold increase in energy.

Energy Equivalent Sound Level (L_{Aeq}): The sound energy level averaged over the measurement period. Generally, refers to A-weighted 1-second time averaged sound levels measured between 12.5 Hz and 20 kHz. This is a standard measurement collected using NSNSD acoustic monitoring protocol for sound level meters. Sound levels measured over 1 second intervals are used to calculate summary statistics, specifically percent of the time a sound level of interest is exceeded.

Existing ambient sound level (L_{A50}): Sound level ($L_{Aeq,1s}$) exceeded 50% of the time (50th percentile) for a specified duration. This level is referred to as the existing ambient sound level and the preferred metric for chronic conditions, as it is insensitive to infrequent loud events.

Frequency: Related to the pitch of a sound, and defined as the number of times per second that the wave of sound repeats itself and is expressed in terms of hertz (Hz). Sound levels are often adjusted (“weighted”) to match the hearing abilities of a given animal. In other words, different species of animals and humans are capable of hearing (or not hearing) at different frequencies. Humans with normal hearing can hear sounds between 20 Hz and 20,000 Hz, and as low as 0 dB at 1,000 Hz. Bats, on the other hand, can hear sounds between 20 Hz and 200,000 Hz.

Natural Ambient Sound Level (L_{Anat}): The natural sound conditions in parks, which would exist in the absence of any human-caused noise sources. L_{Anat} is the preferred metric to represent baseline or reference conditions.

Noise Free Interval (NFI): The length of the continuous period during which no human-caused sounds are audible.

Percentile sound levels (L_{A10} , L_{A50} , L_{A90}): Metrics used to describe A-weighted sound pressure levels (L), in decibels, exceeded 10, 50, and 90 percent of the time, respectively. Put another way, half the time the measured levels of sound are greater than the L_{A50} value, while 90 percent of the time the measured levels are higher than the L_{A90} value and 10 percent of the time measured levels are higher than the L_{A10} value.

Sound Exposure Level (SEL): The total sound energy of the actual sound during a specific time period. SEL is usually expressed using a time period of one second.

Sound Pressure: Minute change in atmospheric pressure due to passage of sound that can be detected by microphones.

Sound vs. Noise: Sound and noise are often used interchangeably to describe an acoustic source. A common definition of noise is unwanted sound or sounds that interfere with a signal of interest (Harris 1998; Templeton 1997). However, noise is not a purely subjective designation. Any sound that serves no function is noise. Most sounds produced by human transportation and other machinery are unintended and serve no function, therefore are noise regardless of the attitudes of the listener. While there are unintended sounds in nature, like the footfalls of an animal, these sounds provide vital cues for some receivers and are therefore considered sounds to the receiver, yet noise from the perception of the producer.

Soundscape: The human perception of physical sound resources.

Time Above: Within a defined period, the percent of the time sound levels are above a specified sound level ($L_{Aeq,1s}$). Commonly used levels are 35, 45, 52 dB ($L_{Aeq,1s}$).

Time Audible: The amount of time that various sound sources are audible to humans with normal hearing, commonly expressed in percent of day, or percent of daytime hours and nighttime hours. A sound may be above natural ambient sound pressure levels, but still not audible. Similarly, some sounds that are below the natural ambient can be audible. Time Audible is useful because of its

simplicity. It is a measure that correlates well with visitor complaints of excessive noise and annoyance. Most noise sources are audible to humans at lower levels than virtually all wildlife species. Therefore, time audible is a protective proxy for wildlife. These data can be collected either by a trained observer (on-site listening) or by making high-quality digital recordings for later playback (off-site listening).

Executive Summary

This report presents acoustical data gathered by the Natural Sounds and Night Skies Division (NSNSD) at Hawai‘i Volcanoes National Park (HAVO) across 3 seasons in 2019. There was not an active volcanic eruption during this data collection period, and there was no active lava present anywhere on the island. Data were collected at 3 sites (Figure 1) to provide park managers with information about the acoustical environment, sources of noise, and the existing ambient sound levels within the park. In these deployments, sound pressure level (SPL) was measured continuously every second by a calibrated sound level meter. Other equipment included an anemometer to collect wind speed and a digital audio recorder collecting continuous recordings to document sound sources. In this document, “sound pressure level” refers to broadband (12.5 Hz–20,000 Hz), A-weighted, 1-second time averaged sound level ($L_{Aeq,1s}[12.5-20,000\text{~Hz}]$), and hereafter is referred to as “sound level.” Sound levels are measured on a logarithmic scale relative to the reference sound pressure for atmospheric sources, 20 μPa . The logarithmic scale is a useful way to express the wide range of sound pressures perceived by the human ear. Sound levels are reported in decibels (dB). A-weighting is applied to sound levels to account for the response of the human ear (Harris, 1998). To approximate human hearing sensitivity, A-weighting discounts sounds below 1 kHz and above 6 kHz. For reference, Table 1 provides examples of sound levels measured in parks compared to sound levels of common sources.

Table 1. Sound level examples.

Park Sound Sources	Common Sound Sources	Sound Level dB ^A
Volcano crater (HALE)	Human breathing at 3 m	10
Leaves rustling (CANY)	Whispering	20
Crickets at 5 m (ZION)	Residential area at night	40
Conversation at 5 m (WHMI)	Car at 15 m, 30 mph	60
Cruiser motorcycle at 15 m (BLRI)	Curbside of busy street	80
Thunder (ARCH)	Jackhammer at 2 m	100
Military jet at 100 m AGL (YUCH)	Train horn at 1 m	120

^A dB re 20 μPa A-weighted broadband (12.5 Hz–20 kHz), sound level measured over varied measurement durations and at the distances indicated.

Overall, existing ambient sound levels (L_{A50}) at sites within HAVO ranged from 20.2 dB–32.4 dB during the daytime and 16.8–39.8 dB during the nighttime during the sampling period. Table 2 reports the percent of time that measured levels at the monitoring locations were above four key sound level values. The first value, 35 dB ($L_{Aeq,1s}$), is used by the NPS as an indicator of overall quality of the acoustic environment. Beyond this level, noise begins to negatively affect the visitor experience in an otherwise natural acoustic environment (Pilcher et al., 2009; Watts et al., 2020; Betchkal et al., 2023). Moreover, sound events as low as 35 dB can adversely affect sleeping humans (Haralabidis *et al.* 2008). This level, 35 dB, is also the desired background sound level in classrooms

(ANSI S12.60-2002 [R2012]). The second value addresses the World Health Organization's recommendations that noise levels inside bedrooms remain below 45 dB ($L_{Aeq,1s}$) (Berglund et al. 1999). The third value, 52 dB ($L_{Aeq,1s}$), is based on the EPA's speech interference level for speaking in a raised voice to an audience at 10 meters (EPA 1974). This value addresses the effects of sound on interpretive presentations in parks. The final value, 60 dB ($L_{Aeq,1s}$), provides a basis for estimating speech interference on normal voice communications at 1 meter. Visitors viewing scenic areas in the park would likely be conducting such conversations.

Sound levels are often measured over narrow frequency bands (typically in one-third octave bands between 12.5 Hz–20 kHz) because these smaller bands closely represent how humans distinguish between frequencies of sound. In this study, we examine how often sound levels exceeded key values in two frequency ranges. The top value in each split-cell of Table 2 uses the full frequency range (12.5 Hz–20 kHz) collected, whereas the bottom value focuses on frequencies affected by low frequency noise sources (20–1,250 Hz). This Natural Sounds modification to A-weighting (referred to as A-weighted Natural Sounds (ANS) weighting, ASA/ANSI S3/SC1.100-2014 [2020]) eliminates high-frequency sound (leaf rustle, equipment noise, and biologic sounds) allowing for more accurate comparisons of low-frequency ambient sound levels across different land use types (e.g., urban, protected areas; ASA/ANSI S3/SC1.100-2014 [2020]). This frequency weighting scheme improves ambient sound level measurements in quiet environments. For instance, in the full frequency range, the 35 dB ($L_{Aeq,1s}$) level was exceeded at HAVO009B in the fall 29.95% of the time during the day and 73.78% of the time at night, but in the 20–1,250 Hz range, the 35 dB functional sound level value was exceeded 23.3% of the daytime but rarely exceeded at nighttime. This indicates that daytime exceedances were likely from lower frequency noise and nighttime exceedances were from higher frequency natural sounds. Speech interruption (between two people 1 meter apart) occurs at 60 dB ($L_{Aeq,1s}$) and this level was rarely exceeded at any of the sites.

After data collection was complete, trained technicians calculated how often noise sources were audible. See Methods section for protocol details, equipment specifications, and metrics calculations. Sound source analysis revealed that noise was audible about 7.4–31.6% of the time during the sampling periods at study sites when averaged across all hours of the day (Tables 3–7). The most common noise sources observed during this study were aircraft and vehicles. Natural sources were much more common at HAVO and included wind, rain, songbirds, and insects.. Natural ambient sound levels (L_{Anat}) ranged between 19.0–32.0 dB during the day and 16.7–39.8 dB at night. Increased natural ambient sound levels during day and night varied by location and were likely caused by diurnal winds and site-specific ecology that drives insect and bird activity.

Table 2. Percent time above metrics for acoustic records collected in Hawai'i Volcanoes National Park (HAVO) in Spring, 2019. Sound level functional values are displayed in decibels (dB $L_{Aeq, 1s}$ re 20 μ Pa). The percent of time ANS-weighted sound levels (20–1,250 Hz) are above functional values.

Site	Frequency Range	Time Above Sound Level (% of Daytime Hours, 07:00 To 19:00)				Time Above Sound Level (% of Nighttime Hours, 19:00 To 07:00)			
		35 dB	45 dB	52 dB	60 dB	35 dB	45 dB	52 dB	60 dB
HAVO002	Full (12.5–20,000)	2.64	0.51	0.13	0.01	0.41	0.04	0.00	0.00
HAVO002	ANS (20–1,250)	1.42	0.30	0.08	0.01	0.11	0.00	0.00	0.00
HAVO002B	Full (12.5–20,000)	8.54	4.74	2.85	0.82	0.08	0.00	0.00	0.00
HAVO002B	ANS (20–1,250)	8.18	4.63	2.72	0.73	0.02	0.00	0.00	0.00

Table 3. Percent time above metrics for acoustic records collected in Hawai'i Volcanoes National Park (HAVO) in Summer, 2019. Sound level functional values are displayed in decibels (dB $L_{Aeq, 1s}$ re 20 μ Pa). The percent of time ANS-weighted sound levels (20–1,250 Hz) are above functional values.

Site	Frequency Range	Time Above Sound Level (% of Daytime Hours, 07:00 To 19:00)				Time Above Sound Level (% of Nighttime Hours, 19:00 To 07:00)			
		35 dB	45 dB	52 dB	60 dB	35 dB	45 dB	52 dB	60 dB
HAVO009A	Full (12.5–20,000)	31.05	5.24	2.13	0.56	70.40	0.43	0.01	0.00
HAVO009A	ANS (20–1,250)	19.65	4.42	1.77	0.51	0.65	0.00	0.00	0.00

Table 4. Percent time above metrics for acoustic records collected in Hawai'i Volcanoes National Park (HAVO) in Fall, 2019. Sound level functional values are displayed in decibels (dB $L_{Aeq, 1s}$ re 20 μ Pa). The percent of time ANS-weighted sound levels (20–1,250 Hz) are above functional values.

Site	Frequency Range	Time Above Sound Level (% of Daytime Hours, 07:00 To 19:00)				Time Above Sound Level (% of Nighttime Hours, 19:00 To 07:00)			
		35 dB	45 dB	52 dB	60 dB	35 dB	45 dB	52 dB	60 dB
HAVO009A	Full (12.5–20,000)	29.95	4.89	1.68	0.53	73.78	0.18	0.00	0.00
HAVO009A	ANS (20–1,250)	23.30	4.21	1.53	0.47	1.75	0.01	0.00	0.00

Table 5. Summary of noise sources and sound levels at Hawai'i Volcanoes National Park (HAVO) in Spring, 2019. Included for each site are a) mean percent time audible for all human-caused noise, including the top two known noise sources, and b) existing (L_{A50}) and natural (L_{Anat}) ambient sound levels (dB re 20 μ Pa, A-weighted broadband, 12.5 Hz–20,000 Hz) during the day (0700–1900) and night (1900–0700). The difference between the natural and existing ambient sound levels indicates the deviation from the natural condition.

Site	a) Mean Time Audible for Noise (% of 24-Hour Time Period)				b) Median Existing Ambient (L_{A50}) in dB		b) Median Natural Ambient (L_{Anat}) in dB	
	Noise	Aircraft	Non Natural Other	Non Natural Unknown	Day	Night	Day	Night
HAVO002	8.8	7.6	0.0	1.0	20.2	16.9	19.5	16.9
HAVO002B	13.0	8.2	1.1	3.4	20.4	16.8	19.0	16.7

Table 6. Summary of noise and sound levels at Hawai'i Volcanoes National Park (HAVO) in Summer, 2019. Included for each site are a) mean percent time audible for all human-caused noise, including the top two known noise sources, and b) existing (L_{A50}) and natural (L_{Anat}) ambient sound levels (dB re 20 μ Pa, A-weighted broadband, 12.5 Hz–20,000 Hz) during the day (0700–1900) and night (1900–0700). The difference between the natural and existing ambient sound levels indicates the deviation from the natural condition.

Site	a) Mean Time Audible for Noise (% of 24-Hour Time Period)				b) Median Existing Ambient (L_{A50}) in dB		b) Median Natural Ambient (L_{Anat}) in dB	
	Noise	Aircraft	Non Natural Unknown	Vehicles	Day	Night	Day	Night
HAVO009A	31.6	15.1	6.3	8.2	32.1	38.6	30	38.3

Table 7. Summary of noise and sound levels at Hawai'i Volcanoes National Park (HAVO) in Fall, 2019. Included for each site are a) mean percent time audible for all human-caused noise, including the top two known noise sources, and b) existing (L_{A50}) and natural (L_{Anat}) ambient sound levels (dB re 20 μ Pa, A-weighted broadband, 12.5 Hz–20,000 Hz) during the day (0700–1900) and night (1900–0700). The difference between the natural and existing ambient sound levels indicates the deviation from the natural condition.

Site	a) Mean Time Audible for Noise (% of 24-Hour Time Period)				b) Median Existing Ambient (L_{A50}) in dB		b) Median Natural Ambient (L_{Anat}) in dB	
	Noise	Aircraft	Non Natural Unknown	People	Day	Night	Day	Night
HAVO009A	7.4	6.9	0.2	0.3	32.4	39.8	32	39.8

Introduction

A 1998 survey of the American public revealed that 72 percent of respondents thought that providing opportunities to experience natural quiet and the sounds of nature was a very important reason for having national parks, while another 23 percent thought that it was somewhat important (Haas & Wakefield 1998). In another survey specific to park visitors, 91 percent of respondents considered enjoyment of natural quiet and the sounds of nature as compelling reasons for visiting national parks (McDonald et al. 1995). A 2018 comprehensive survey of the American public revealed that 88 percent of respondents indicated hearing the sound of nature/quiet was an important or very important reason for their last visit to a NPS unit (Resource Systems Group and Wyoming Survey and Analysis Center 2019). Acoustic monitoring provides a scientific basis for assessing the status of acoustic resources, identifying trends in resource conditions, quantifying impacts from other actions, assessing consistency with park management objectives and standards, and informing management decisions regarding desired future conditions.

National Park Service Natural Sounds and Night Skies Division

The Natural Sounds and Night Skies Division (NSNSD) helps parks manage sounds in a way that protects park resources and the visitor experience. The NSNSD addresses acoustic issues raised by Congress, NPS Management Policies, and NPS Director's Orders. The NSNSD works to protect, maintain, or restore acoustic environments throughout the National Park System. Its goal is to provide coordination, guidance, and a consistent approach to soundscape protection with respect to park resources and visitor use. The program also provides technical assistance to parks in the form of acoustic monitoring, data processing, park planning support, and comparative analyses of acoustic environments.

Soundscape Planning Authorities

The National Park Service Organic Act of 1916 states that the purpose of national parks is "... to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." In addition to the NPS Organic Act, the Redwoods Act of 1978 affirmed that, "the protection, management, and administration of these areas shall be conducted in light of the high value and integrity of the National Park System and shall not be exercised in derogation of the values and purposes for which these various areas have been established, except as may have been or shall be directly and specifically provided by Congress." NPS Management Policies 2006 Chapter 4.9 provides direction for management of natural soundscapes:

"The National Park Service will preserve, to the greatest extent possible, the natural soundscapes of parks..."

"The Service will restore to the natural condition wherever possible those park soundscapes that have become degraded by unnatural sounds (noise) and will protect natural soundscapes from unacceptable impacts."

“Using appropriate management planning, superintendents will identify what levels and types of unnatural sound constitute acceptable impacts on park natural soundscapes. The frequencies, magnitudes, and durations of acceptable levels of unnatural sound will vary throughout a park, being generally greater in developed areas. In and adjacent to parks, the Service will monitor human activities that generate noise that adversely affects park soundscapes [acoustic resources], including noise caused by mechanical or electronic devices. The Service will take action to prevent or minimize all noise that through frequency, magnitude, or duration adversely affects the natural soundscape [acoustic resource] or other park resources or values, or that exceeds levels that have been identified through monitoring as being acceptable to or appropriate for visitor uses at the sites being monitored” (NPS 2006a).”

It should be noted that under Management Policies 2006 Chapter 8.2.3, “[t]he natural ambient sound level—that is, the environment of sound that exists in the absence of human-caused noise—is the baseline condition, and the standard against which current conditions in a soundscape [acoustic resource] will be measured and evaluated” (NPS 2006c). However, the desired acoustic condition may also depend upon the resources and the values of the park. For instance, “culturally appropriate sounds are important elements of the national park experience in many parks” (NPS 2006b). In this case, “the Service will preserve soundscape resources and values of the parks to the greatest extent possible to protect opportunities for appropriate transmission of cultural and historic sounds that are fundamental components of the purposes and values for which the parks were established” (NPS 2006b).

Further guidance is provided in Management Policies 2006 §4.1.4 Partnerships, §4.1.5 Restoration of Natural Systems, §8.2 Visitor Use, §8.2.2 Recreational Activities, §8.2.3 Use of Motorized Equipment, and §8.4 Overflights and Aviation Uses (NPS 2006).

Director’s Order 47, Soundscape Preservation and Noise Management (2000) builds on the principles set out in Management Policies, directing park management how and when to consider acoustic resources. Through this order, parks are guided to manage noise by: identifying noise sources, minimizing noise from park operations, considering the acoustic environment in park planning documents, and promoting park sounds and noise management through communication, education, and outreach.

Focal Park Unit

Hawai‘i Volcanoes National Park (HAVO) is on the southern end of the Island of Hawai‘i, the southernmost island of the Hawaiian Archipelago. The park was established by Congress on August 1, 1916, as Hawai‘i National Park (subsequent legislation separated Hawai‘i Volcanoes National Park and Haleakalā National Park).

Today, Hawai‘i Volcanoes National Park protects approximately 354,461 acres of public land, which includes some of the most unique geologic, biologic, and cultural landscapes in the world. Extending from sea level to the summit of Mauna Loa at 13,677 feet, the park encompasses the summits and rift

zones of two of the world’s most active shield volcanoes— Kīlauea, representing the newest land in the Hawaiian Islands chain, and Mauna Loa, the largest volcano in the world (NPS 2017).

The park is committed to protecting its acoustic environment. “Natural Sounds” are identified as a fundamental resource and value in the parks’ foundation document (NPS 2017). Soundscape monitoring was identified as a priority data need, with the “park committed to improving soundscapes and the acoustic environment by reducing artificial noise within wilderness, in and near critical habitat for threatened and endangered species, in traditional cultural areas, and in high visitor use areas.”

In 2018, the Natural Sounds and Night Skies Division (NSNSD) received a technical assistance request ([4938](#)) to collect baseline acoustical data to compliment overflight data to determine impacts of air tour noise. In 2024, NSNSD published a report exploring spatial patterns of overflights at HAVO (Peterson et al. 2024). This report will describe acoustic conditions at locations with common air tour travel patterns overhead.

Study Area

This report presents results from an acoustic inventory conducted over three seasons in 2019 at Hawai‘i Volcanoes National Park (HAVO) (Table 8). Three sites were selected to represent a diverse range of visitation, noise sources, and habitat types. Two sites were deployed during the spring season (HAVO002, HAVO002B), while an additional site was deployed in the following summer and fall seasons (HAVO009B). All sites were located on the eastern boundary of the park. The group of acoustic inventory sites spanned 25 km and was situated north, near, and south of Kīlauea volcano (Figure 1).

Table 8. Metadata for acoustical monitoring sites at Hawai'i Volcanoes National Park, 2019.

Site	Site Name	Dates	Vegetation	Elevation (m)	Latitude	Longitude
HAVO002	Mauna Loa	03/09/2019– 05/31/2019	Mediterranean Forest	2,208	19.50418	-155.3931
HAVO002B	Halema'uma'u	03/07/2019– 05/13/2019	Desert	1,110	19.39404	-155.2834
HAVO009A	Pu'u Huluhulu/ New Lava Flows	06/10/2019– 10/17/2019	Tropical/Subtropical Moist Broadleaf	1,010	19.37433	-155.2082

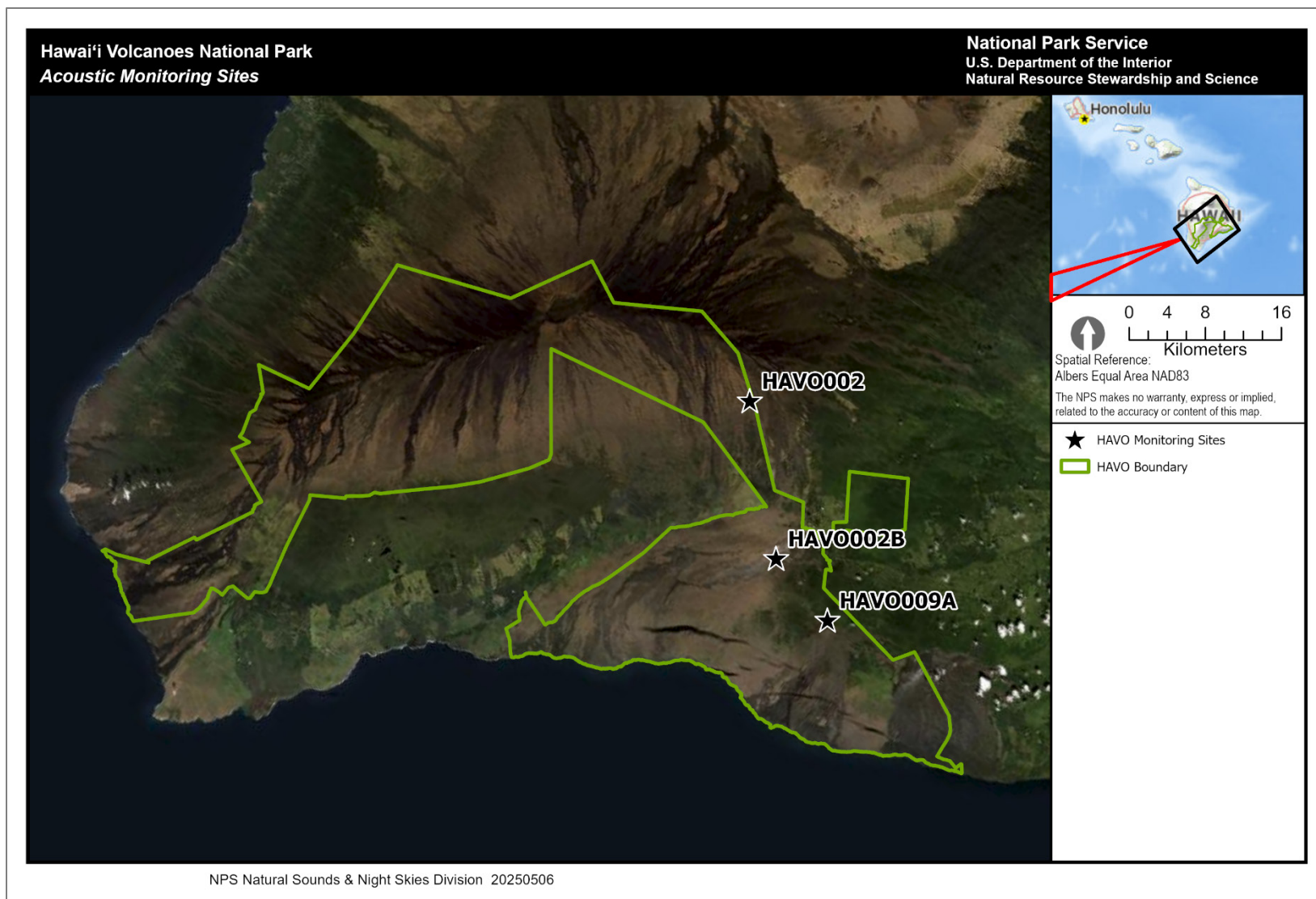


Figure 1. Study sites in Hawai'i Volcanoes National Park, HI, USA.
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Methods

Automatic Monitoring

A Larson Davis sound level meter (SLM) type 831-A was deployed at 3 monitoring sites. The SLM is a hardware-based, real-time analyzer which constantly records one-third octave band sound pressure level (SPL) data. This Larson Davis-based site met American National Standards Institute (ANSI) Type 1 standards (ANSI 1968 [R2020], 1983 [R2006], 1992 [2018]) for accurate survey-grade instrumentation. The sound level meter provided the information needed to calculate metrics described below in Calculation of Metrics.

Acoustic monitoring equipment is used by many practitioners to determine noise levels in different environments, both indoors and outdoors. The NPS uses equipment like that used by other practitioners but has developed a unique configuration that stands up to the potentially harsh environment encountered in national parks (National Park Service 2013). The microphone with environmental shroud was set up on a tripod at 1.5 m above the ground, which approximates the average height of the human ear. The digital audio recorder recorded continuous audio through the entire monitoring period (see details below on the acoustic record). An anemometer was attached to a tripod and placed approximately 10 feet from the microphone to capture local wind conditions.

The sampling station consisted of:

- Type 1 sound level meter
- Microphone with environmental shroud
- Preamplifier
- 12 V battery pack
- Ultrasonic anemometer (wind speed)
- Digital audio recorder

The sampling station was designed to collect:

- Flat-weighted, time-average sound level ($L_{Zeq,1s}$) for each one-third octave frequency band, 12.5–20,000 Hz in dB re 20 μ Pa [collected by Type 1 sound level meter].
- A-weighted, time-average sound level ($L_{Aeq,1s[12.5-20000\text{ Hz}]}$) in dB re 20 μ Pa [collected by Type 1 sound level meter].
- Continuous meteorological data for wind speed [collected by anemometer].
- Continuous digital audio recordings.

Monitoring Period

It is typical to monitor a minimum of 25 days to capture daily differences within a sampling period that occur at each site within a reasonable margin of error (NPS 2005). For this study, the monitoring period ranged from 68 to 130 days.

Calculation of Metrics

The status of the acoustical environment can be characterized by sound level (L_{A50} , $L_{A\text{nat}}$, L_{A90} , L_{A10} , $L_{A\text{eq}}$) and frequency content, and event durations (through off-site listening). NPS uses descriptive figures and metrics to interpret these characteristics.

Two fundamental descriptors are existing ambient (L_{A50}) and natural ambient ($L_{A\text{nat}}$) sound levels. These are both examples of percentile levels, where each L_x value refers to the sound level that is exceeded x % of the time. The L_{A50} represents the median sound level and is drawn from a full dataset (removing data with wind speed > 5 m/s to eliminate error from microphone distortion). The L_{A50} is the preferred metric to represent prevailing acoustic conditions. The natural ambient ($L_{A\text{nat}}$) is an estimate of what the sound levels for a site would be if all human-caused noise sources were removed. $L_{A\text{nat}}$ is the preferred metric to represent baseline or reference conditions.

For a given hour (or other specified time period), $L_{A\text{nat}}$ is calculated to be the sound level exceeded x percent of the time, where x is defined by equation (1):

$$x = \frac{100 - P_H}{2} + P_H$$

where P_H = percentage of samples containing noise for the hour.

For example, if human caused sounds are present 30% of the hour, $x = 65$, and the $L_{A\text{nat}}$ is equal to the L_{65} , or the level exceeded 65% of the time. To summarize and display these data, the median of the hourly $L_{A\text{nat}}$ values for the daytime hours (0700–1900) and the median of the hourly $L_{A\text{nat}}$ values for the nighttime (1900–0700) are displayed in graphical format in the following sections.

Off-Site Listening and Spectrogram Analysis

Listening Center Software Analysis

Off-site analysis is completed by listening to the audio record while simultaneously viewing its spectrogram representation (for more information on Listening Center software, see Appendix A). Auditory analysis was used to calculate the audibility of sound sources at each location. Trained technicians at Colorado State University (Figure 2) listened back to 2–10 days of the audio record, depending on site and season. Technicians considered only a subsample of each day representing the first 10 seconds of every two-minute period. Within each subsample every audible sound source was categorized. This allowed the temporal extent of audibility for each source type to be estimated. The total percent time noise was audible was then used to calculate the natural ambient sound level (L_{Anat}) for each hour (see Equation 1 above for more information). For any off-site audio playback listening techniques, Bose Quiet Comfort Noise Canceling headphones were used to minimize limitations imposed by the office acoustical environment.



Figure 2. A Colorado State University student identifies sound sources using Acoustic Monitoring Toolbox (NPS) software.

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Results

Frequency Content

To determine the effect that noise has on the acoustic environment, it is useful to examine percentile metrics across a frequency range. High frequency sounds (such as a cricket chirping) and low frequency sounds (such as flowing water) often occur simultaneously, so the frequency spectrum is split into 33 narrower bands, each encompassing one-third of an octave. These narrow bands closely represent how humans distinguish between frequencies of sound. The percentile sound levels for 33 one-third octave band frequencies over the day and night periods are shown in Figures 3–6.

Examining the sound energy in each one-third octave band (combined with digital audio recordings) allows acoustic technicians to determine what types of sounds are contributing to the overall sound levels at a site. The grayed areas of Figures 3–6 represent sound levels outside of the typical range of human hearing. The percentile levels (L_x) are also shown for each one-third octave band. They represent the sound levels exceeded x percent of the measurement period. For example, L_{90} is the sound level that has been exceeded 90% of the time, and only the quietest 10% of the samples can be found below this point. On the other hand, the L_{10} is the sound level that has been exceeded 10% of the time, and 90% of the measurements are quieter than the L_{10} . The bold portion of the column represents the difference between L_{50} and L_{nat} . The height of this bold portion is a measure of the contribution of anthropogenic noise to the existing sound levels at this site. The size of this portion of the column is directly related to the percent of time that human caused sounds are audible. When bold portions of the column do not appear the natural and existing sound levels were either very close to each other or were equal. The typical frequency levels for transportation, conversation, and songbirds are presented on the figure as examples for interpretation of the data. These ranges are estimates and are not vehicle-, species-, or habitat-specific.

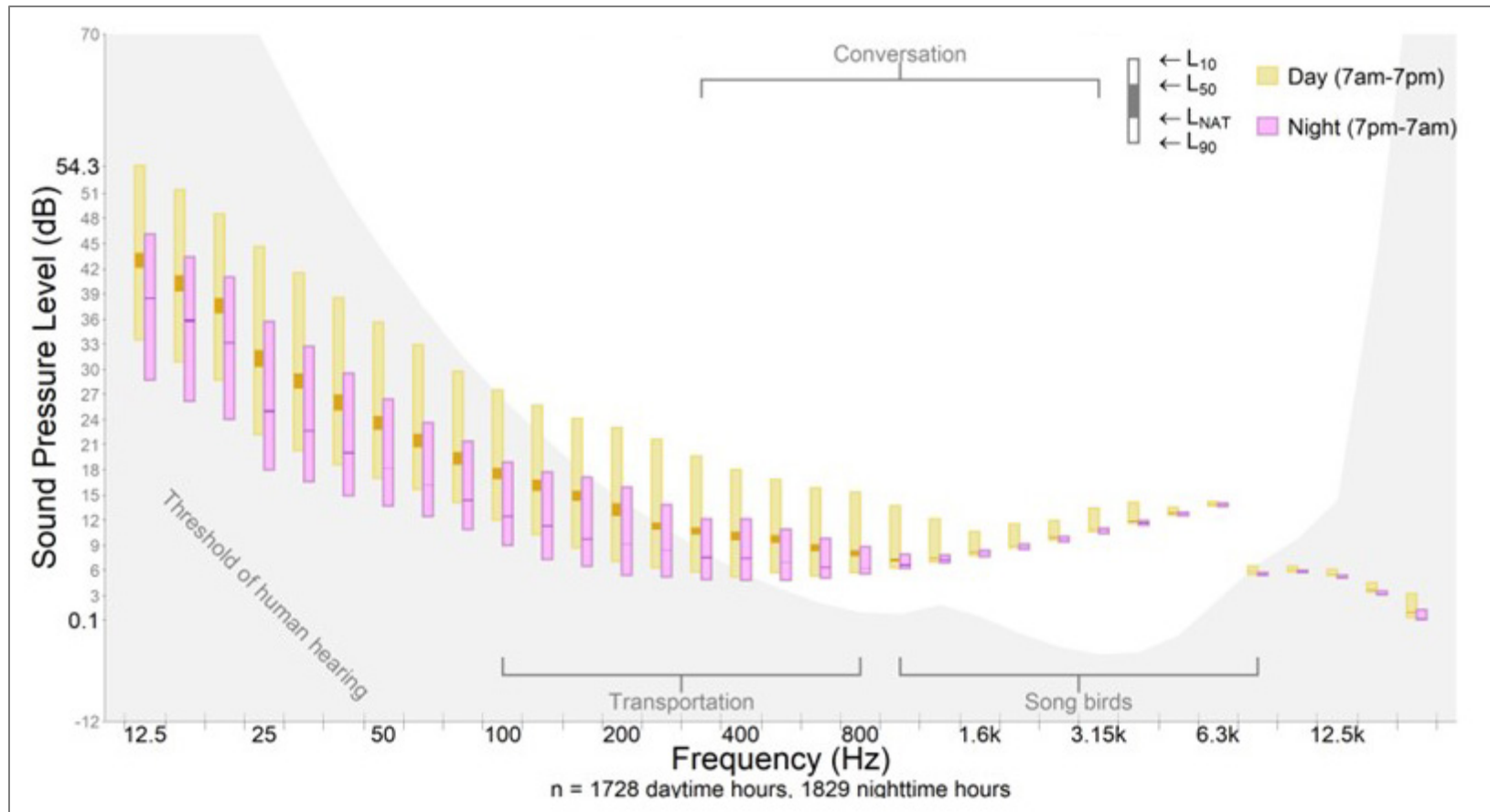


Figure 3. Day and night percentile sound pressure levels for 33 one-third octave bands at HAVO002 in Spring, 2019. For each bar, the bold color indicates the range of existing (L₅₀; upper) and natural (L_{nat}; lower) sound pressure levels.

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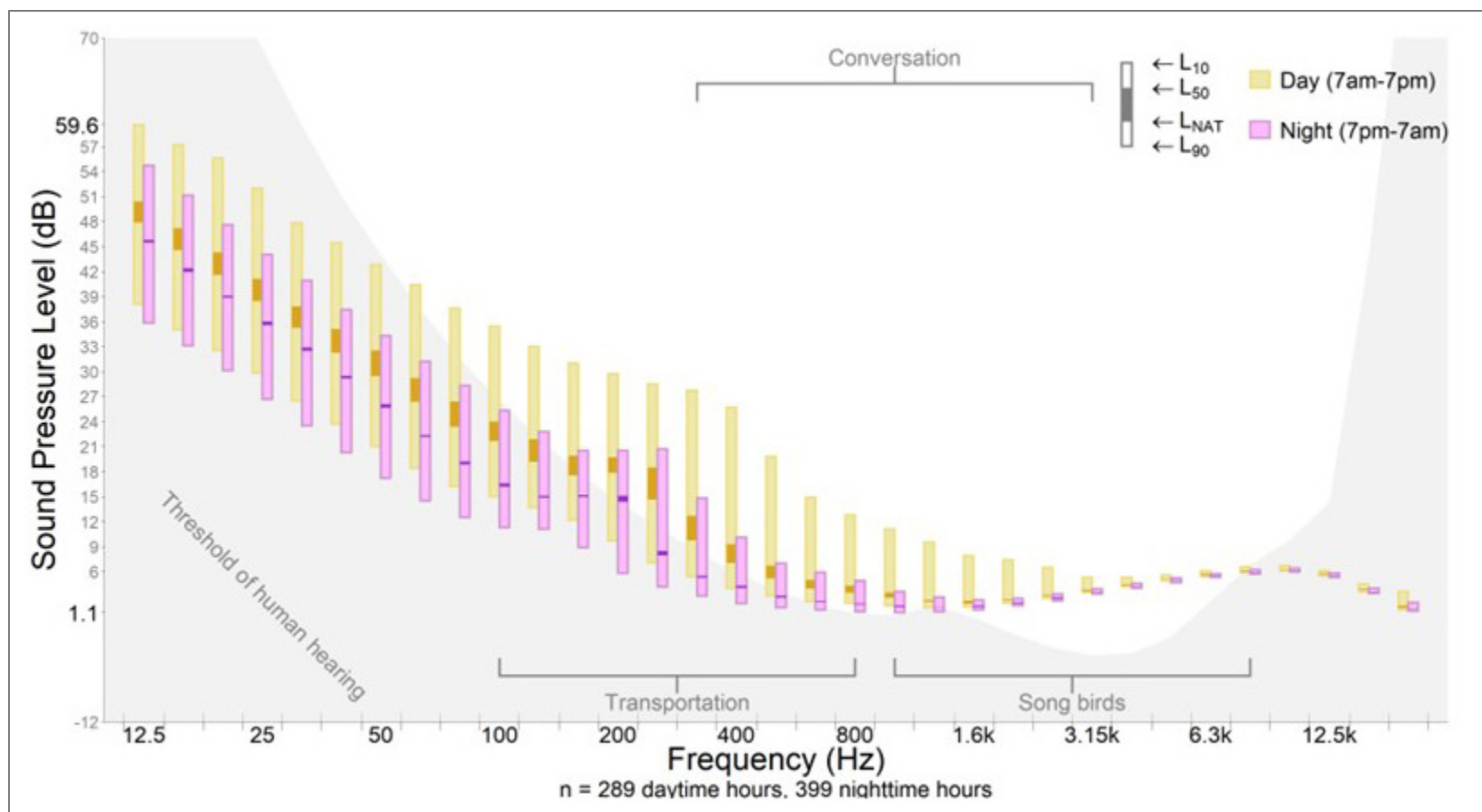


Figure 4. Day and night percentile sound pressure levels for 33 one-third octave bands at HAVO002B in Spring, 2019. For each bar, the bold color indicates the range of existing (L_{50} ; upper) and natural (L_{nat} ; lower) sound pressure levels.

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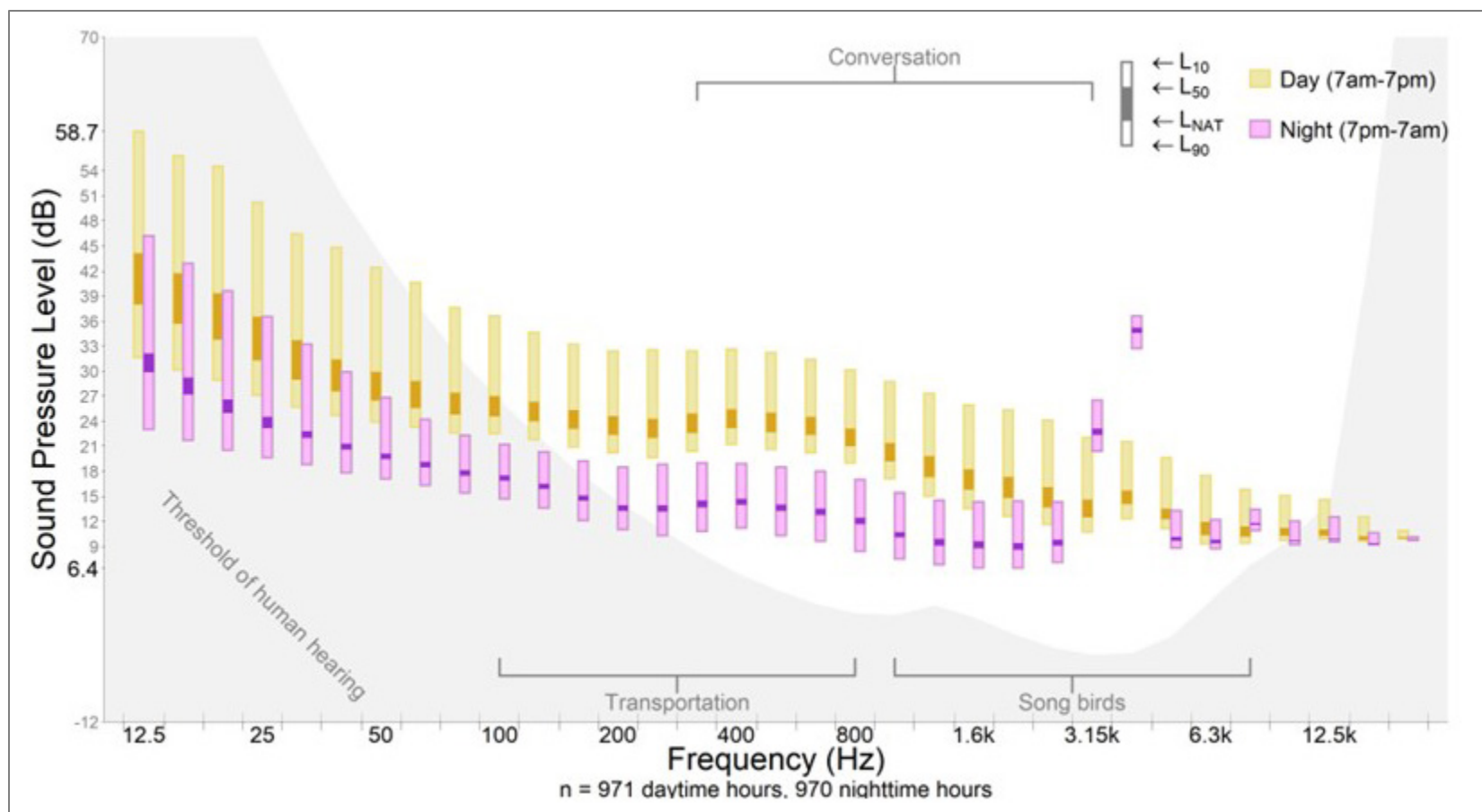


Figure 5. Day and night percentile sound pressure levels for 33 one-third octave bands at HAVO009A in Summer, 2019. For each bar, the bold color indicates the range of existing (L_{50} ; upper) and natural (L_{nat} ; lower) sound pressure levels.

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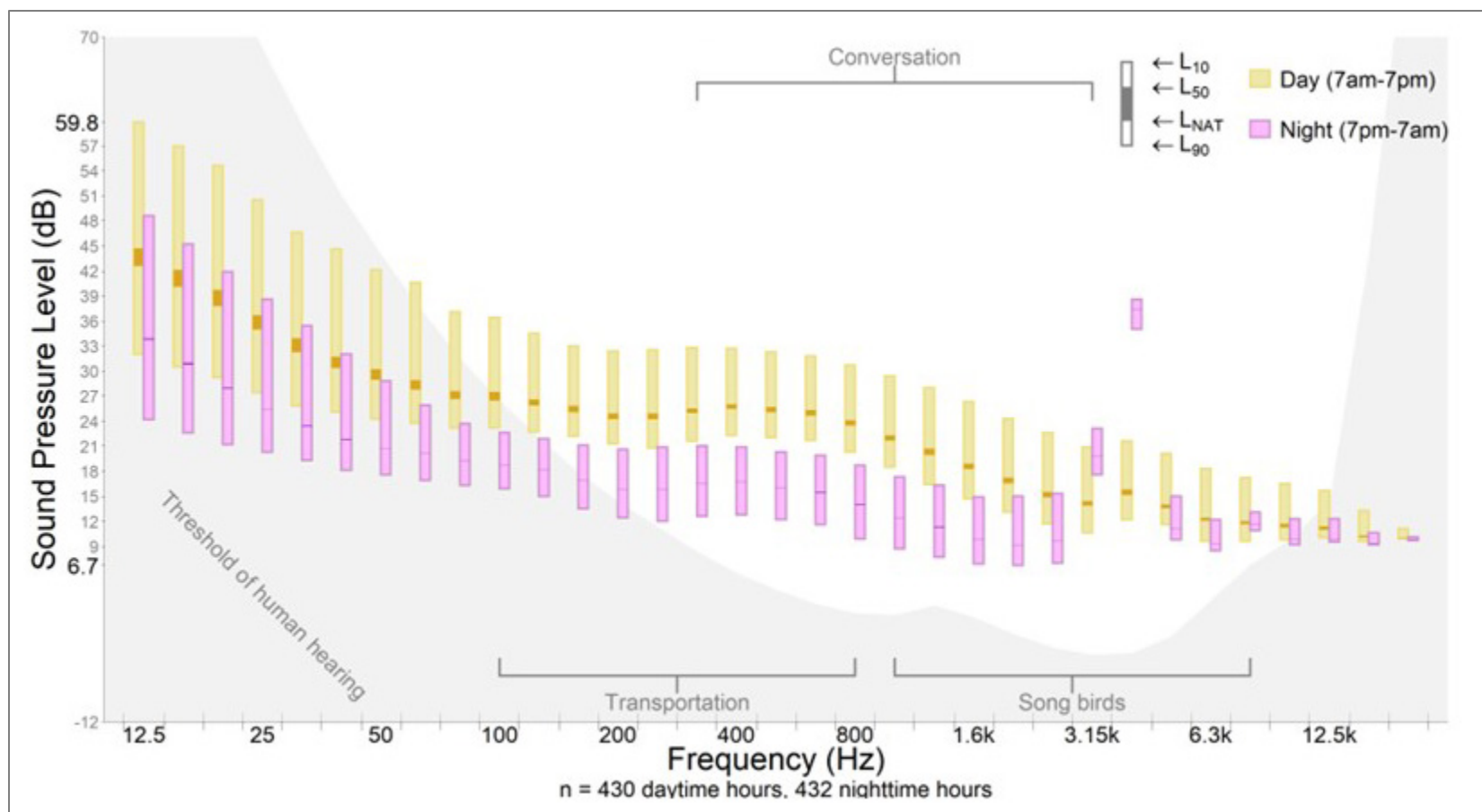


Figure 6. Day and night percentile sound pressure levels for 33 one-third octave bands at HAVO009A in Fall, 2019. For each bar, the bold color indicates the range of existing (L₅₀; upper) and natural (L_{nat}; lower) sound pressure levels.

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Sound level: Time Above

To understand how acoustic conditions in the park might affect visitors, measured sound levels are compared to sound levels of interest. Specifically, Table 5 reports the percent of time that measured sound levels ($L_{Aeq,1s}$) were above four key functional effect levels during the monitoring periods (daytime and nighttime). The top value in each split-cell uses the full frequency range, whereas the bottom values report the percentage of the sample that ANS-weighted sound levels (20–1,250 Hz) were above functional effect thresholds. Most motorized human-caused noise is confined to the truncated, lower-frequency range, while many natural sounds, including insects and birds, are higher in pitch. ANS weighting eliminates high-frequency sound (leaf rustle, and biologic sounds) allowing for more accurate comparisons of low-frequency ambient sound levels across different land use types (e.g. urban, protected areas; ANSI S3/SC1.100, 2014 [R2020]). This frequency weighting scheme improves ambient sound level measurements in quiet environments.

The first functional effect in Tables 9–11 occurs around 35 dB ($L_{Aeq,1s}$), which is designed to address the health effects of sleep interruption. The first value, 35 dB ($L_{Aeq,1s}$), is used by the NPS as an indicator of overall quality of the acoustic environment. Beyond this level, noise begins to negatively affect the visitor experience in an otherwise natural acoustic environment (Pilcher et al., 2009; Watts et al., 2020; Betchkal et al., 2023). Moreover, sound events as low as 35 dB can adversely affect sleeping humans (Haralabidis *et al.* 2008). This is also the desired background sound level in classrooms (ANSI S12.60-2002 [R2012]). For application to the present study, the 35 dB level was exceeded at HAVO009A in the fall 29.95% of the time during the day and 73.78% of the time at night, but in the 20–1,250 Hz range, the 35 dB functional sound level value was exceeded 23.3% of the daytime but rarely exceeded at nighttime. This indicates that daytime exceedances were likely from lower frequency noise and nighttime exceedances were from higher frequency natural sounds. The second functional effect is expected to occur around 45 dB ($L_{Aeq,1s}$). It addresses the World Health Organization's recommendations that noise levels inside bedrooms remain below 45 dB ($L_{Aeq,1s}$) (Berglund et al. 1999). The third functional effect is expected to occur around 52 dB ($L_{Aeq,1s}$), based on the EPA's speech interference threshold for speaking in a raised voice to an audience at 10 meters (EPA 1974). This threshold addresses the effects of sound on interpretive presentations in parks. The final functional effect at 60 dB ($L_{Aeq,1s}$), provides a basis for estimating impacts on normal voice communications at 1 meter. Visitors viewing scenic areas in the park regularly conduct such conversations.

Table 9. Percent time above metrics for acoustic records collected in Hawai'i Volcanoes National Park (HAVO) in Spring, 2019. Sound level functional values are displayed in decibels (dB LAeq, 1s re 20 µPa). The percent of time ANS-weighted sound levels (20–1,250 Hz) are above functional values.

Site	Frequency Range	Time Above Sound Level (% of Daytime Hours, 07:00 to 19:00)				Time Above Sound Level (% of Nighttime Hours, 19:00 to 07:00)			
		35 dB	45 dB	52 dB	60 dB	35 dB	45 dB	52 dB	60 dB
HAVO002	Full (12.5–20,000)	2.64	0.51	0.13	0.01	0.41	0.04	0.00	0.00
HAVO002	ANS (20–1,250)	1.42	0.30	0.08	0.01	0.11	0.00	0.00	0.00
HAVO002B	Full (12.5–20,000)	8.54	4.74	2.85	0.82	0.08	0.00	0.00	0.00
HAVO002B	ANS (20–1,250)	8.18	4.63	2.72	0.73	0.02	0.00	0.00	0.00

Table 10. Percent time above metrics for acoustic records collected in Hawai'i Volcanoes National Park (HAVO) in Summer, 2019. Sound level functional values are displayed in decibels (dB LAeq, 1s re 20 µPa). The percent of time ANS-weighted sound levels (20–1,250 Hz) are above functional values.

Site	Frequency Range	Time Above Sound Level (% of Daytime Hours, 07:00 To 19:00)				Time Above Sound Level (% of Nighttime Hours, 19:00 To 07:00)			
		35 dB	45 dB	52 dB	60 dB	35 dB	45 dB	52 dB	60 dB
HAVO009A	Full (12.5–20,000)	31.05	5.24	2.13	0.56	70.40	0.43	0.01	0.00
HAVO009A	ANS (20–1,250)	19.65	4.42	1.77	0.51	0.65	0.00	0.00	0.00

Table 11. Percent time above metrics for acoustic records collected in Hawai'i Volcanoes National Park (HAVO) in Fall, 2019. Sound level functional values are displayed in decibels (dB LAeq, 1s re 20 µPa). The percent of time ANS-weighted sound levels (20–1,250 Hz) are above functional values.

Site	Frequency Range	Time Above Sound Level (% of Daytime Hours, 07:00 To 19:00)				Time Above Sound Level (% of Nighttime Hours, 19:00 To 07:00)			
		35 dB	45 dB	52 dB	60 dB	35 dB	45 dB	52 dB	60 dB
HAVO009A	Full (12.5–20,000)	29.95	4.89	1.68	0.53	73.78	0.18	0.00	0.00
HAVO009A	ANS (20–1,250)	23.30	4.21	1.53	0.47	1.75	0.01	0.00	0.00

Sound Level: Percentile Levels

Percentile sound levels help quantify the range of acoustic conditions at the park. Tables 12–14 list day and night A-weighted percentile sound levels for the sampling period at HAVO. Figures 7–10 show hourly summaries for the A-weighted percentile sound levels (L_{A90} , L_{Anat} , L_{A50} , and L_{A10}), calculated from the broadband (12.5 Hz–20 kHz) A-weighted, 1-second time averaged sound levels ($L_{Aeq, 1s}$) within each hour of the day. In Figure 7, the A-weighted percentile sound levels (L_{A90} , L_{Anat} , L_{A50} , and L_{A10}) for HAVO002 are shown. The hourly percentile sound levels are calculated from the broadband (12.5 Hz–20 kHz) A-weighted, 1-second time averaged sound levels ($L_{Aeq, 1s}$) within each hour of the day. For instance, in Figure 7, the L_{A50} (median) sound level for HAVO002 during the 9:00 hour is 19.5 dB. On the other hand, the sound level exceeded 10% of the time (L_{A10}) for the same hour at this site is 29.6 dB, meaning 90% of the measurement period is quieter. Hours where the L_{A50} and the L_{Anat} differ the most are usually hours with the most human-caused noise, as shown with site HAVO002B (Figure 8). The larger the span of the black bars, the greater the difference of the existing sound level from natural conditions. At HAVO002B, existing sound levels are closest to natural conditions in the early morning, afternoon, and evening hours but depart from natural conditions from 7:00–12:00 (Figure 8). In general, higher natural ambient sound levels occurred in the afternoon at HAVO002 and HAVO002B and in the late evening at HAVO009A. This is larger due to wind at the former sites and insect and bird activity at the latter site (Figures 7–10).

Table 12. Sound levels at Hawai'i Volcanoes National Park (HAVO) in spring, 2019. The 90th percentile (L_{A10}), existing (L_{A50}), natural (L_{Anat}) and 10th percentile (L_{A90}) ambient sound levels (dB re 20 μ Pa, A-weighted broadband, 12.5 Hz–20 kHz) during the day (0700–1900) and night (1900–0700).

Time	Site	L_{A10}	L_{A50}	L_{Anat}	L_{A90}
Day	HAVO002	28.1	20.2	19.5	16.3
Night	HAVO002	23.3	16.9	16.9	15.0
Day	HAVO002B	30.6	20.4	19.0	16.6
Night	HAVO002B	20.7	16.8	16.7	15.7

Table 13. Sound levels at Hawai'i Volcanoes National Park (HAVO) in summer, 2019. The 90th percentile (L_{A10}), existing (L_{A50}), natural (L_{Anat}) and 10th percentile (L_{A90}) ambient sound levels (dB re 20 μ Pa, A-weighted broadband, 12.5 Hz–20 kHz) during the day (0700–1900) and night (1900–0700).

Time	Site	L_{A10}	L_{A50}	L_{Anat}	L_{A90}
Day	HAVO009A	39.8	32.1	30.0	27.9
Night	HAVO009A	39.9	38.6	38.3	37.4

Table 14. Sound levels at Hawai'i Volcanoes National Park (HAVO) in fall, 2019. The 90th percentile (L_{A10}), existing (L_{A50}), natural (L_{Anat}) and 10th percentile (L_{A90}) ambient sound levels (dB re 20 μ Pa, A-weighted broadband, 12.5 Hz—20 kHz) during the day (0700–1900) and night (1900–0700).

Time	Site	L_{A10}	L_{A50}	L_{Anat}	L_{A90}
Day	HAVO009A	39.3	32.4	32.0	28.9
Night	HAVO009A	40.9	39.8	39.8	38.4

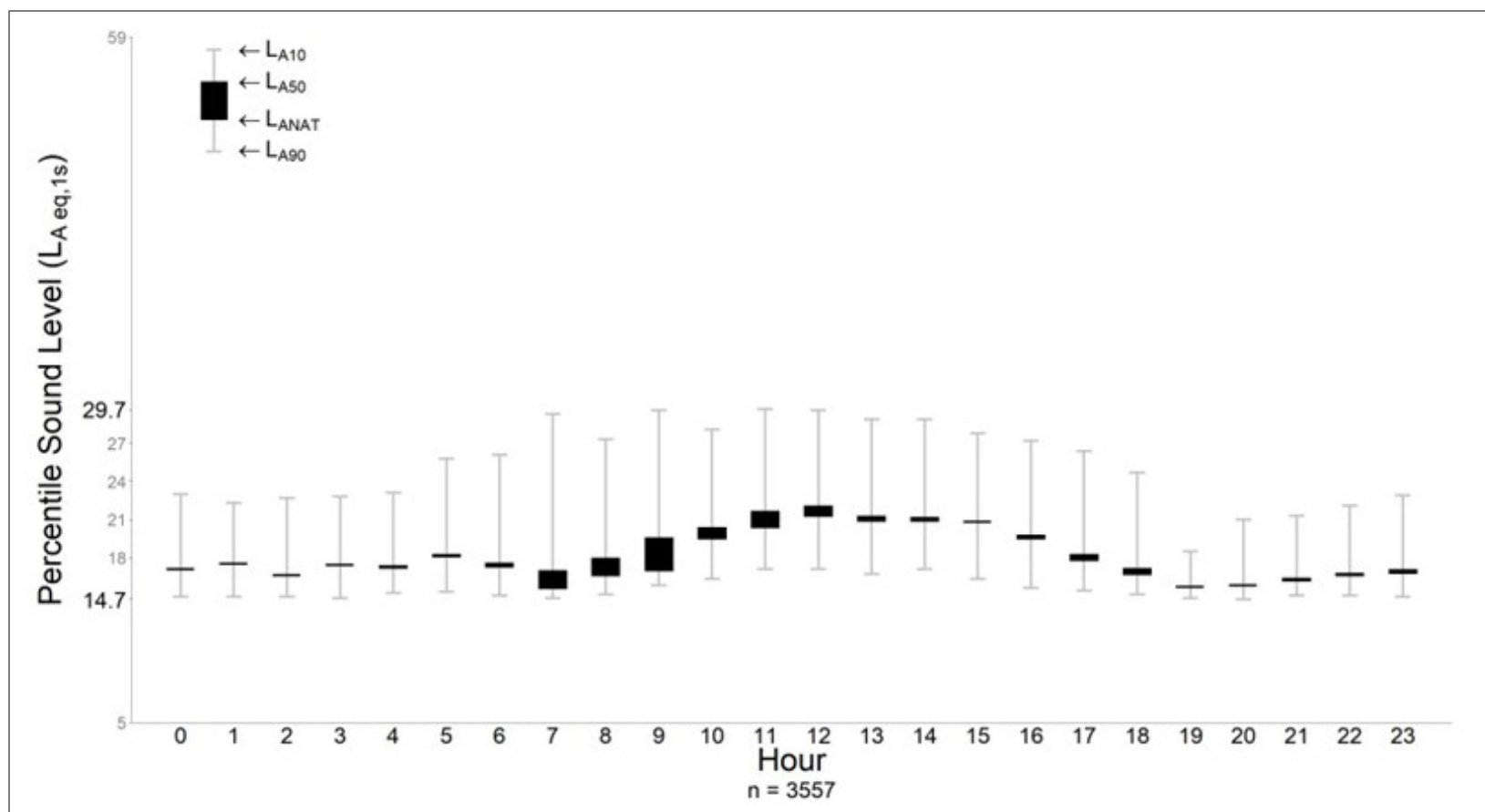


Figure 7. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at HAVO002 in spring, 2019.

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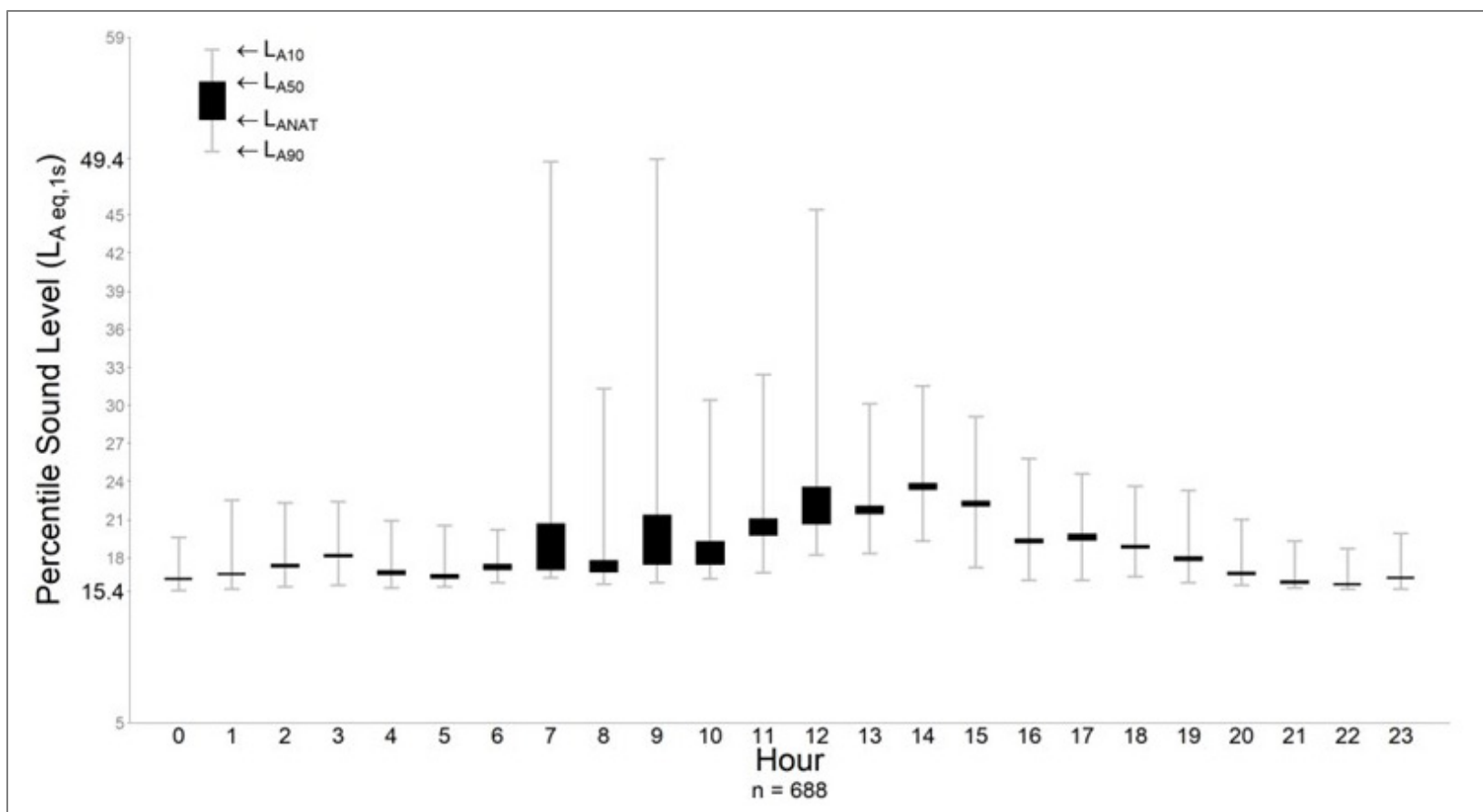


Figure 8. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at HAVO002B in spring, 2019.

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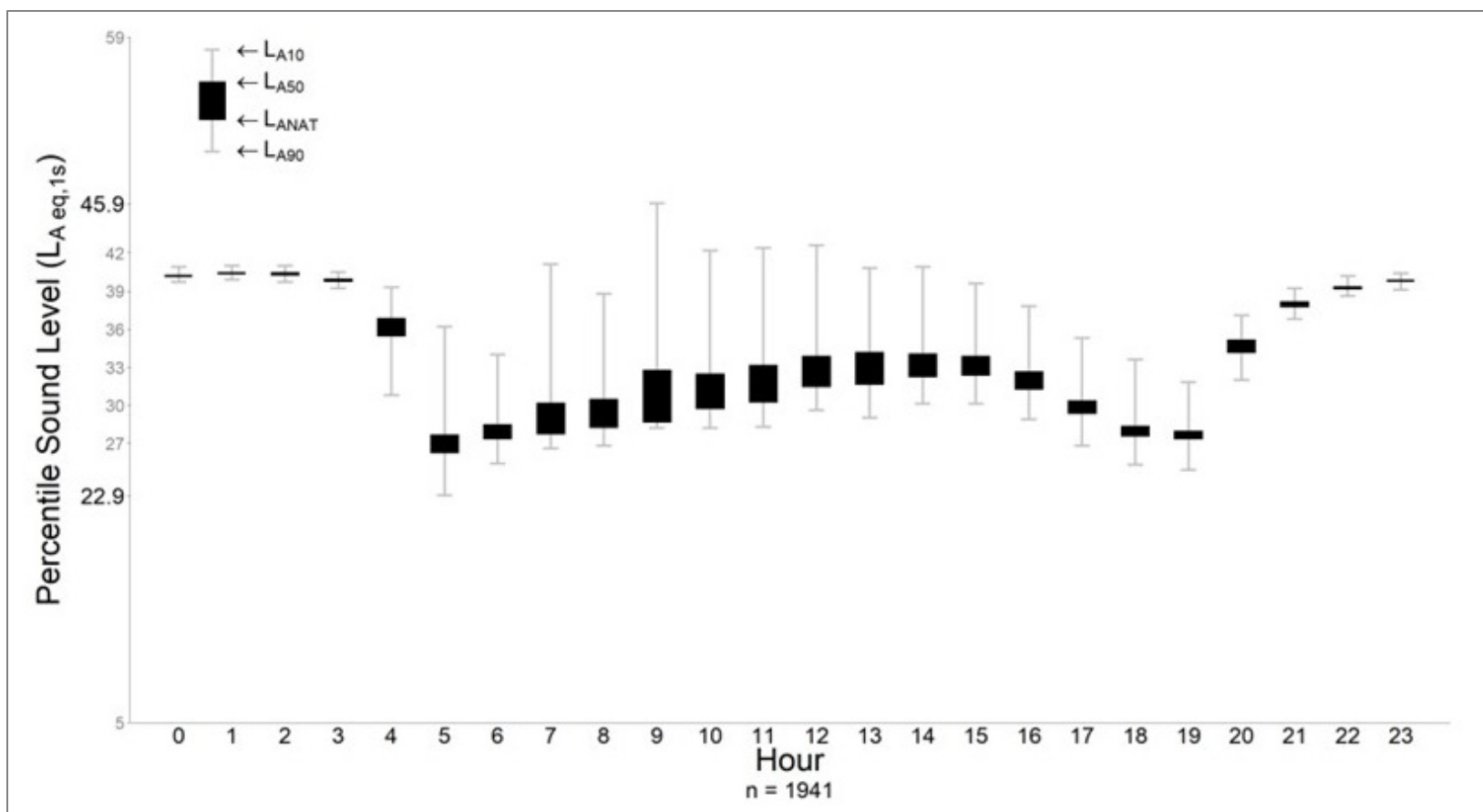


Figure 9. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at HAVO009A in summer, 2019.

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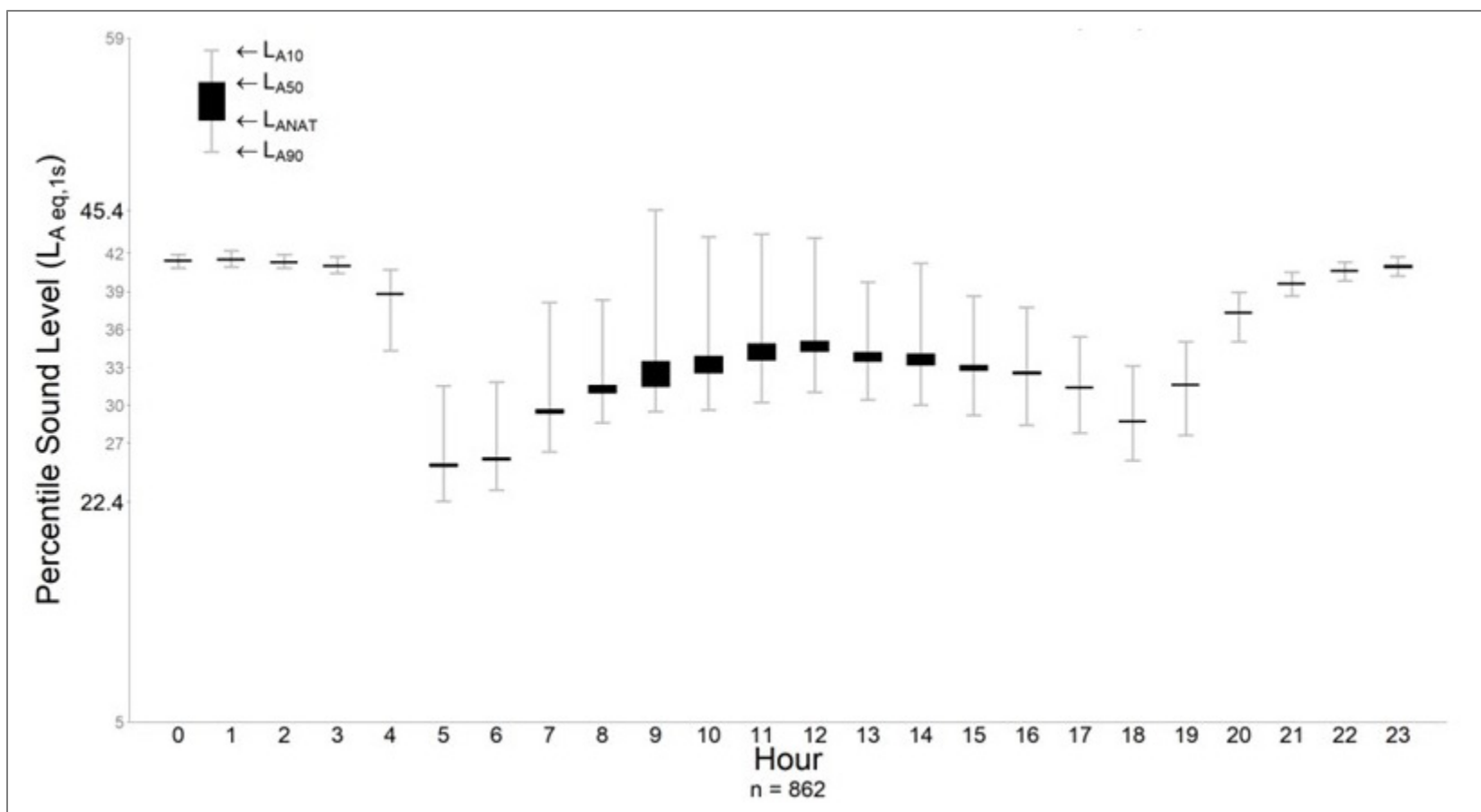


Figure 10. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at HAVO009A in fall, 2019.
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Event Duration

Listening Center Software

Through off-site listening analysis, event duration for all audible sounds is calculated and averaged over the listening period. For both sites, mean hourly audibility was obtained for each hour of the day over a 2 to 10-day listening period (CSU 2020). Hourly audibility is also displayed for all non-natural sources, while also highlighting the top two sources at each site (Figures 11–14). For example, at HAVO009A during the summer, noise levels peaked at 9:00 AM and were audible 70% of the time. During this period, aircraft were the primary source of noise (Figure 13). A similar trend was observed at the site in the fall, where noise also peaked at 9:00 AM, but the audible duration decreased to 45% of the hour. Although the overall noise audibility decreased in the fall, aircraft remained the primary contributor (Figure 14).

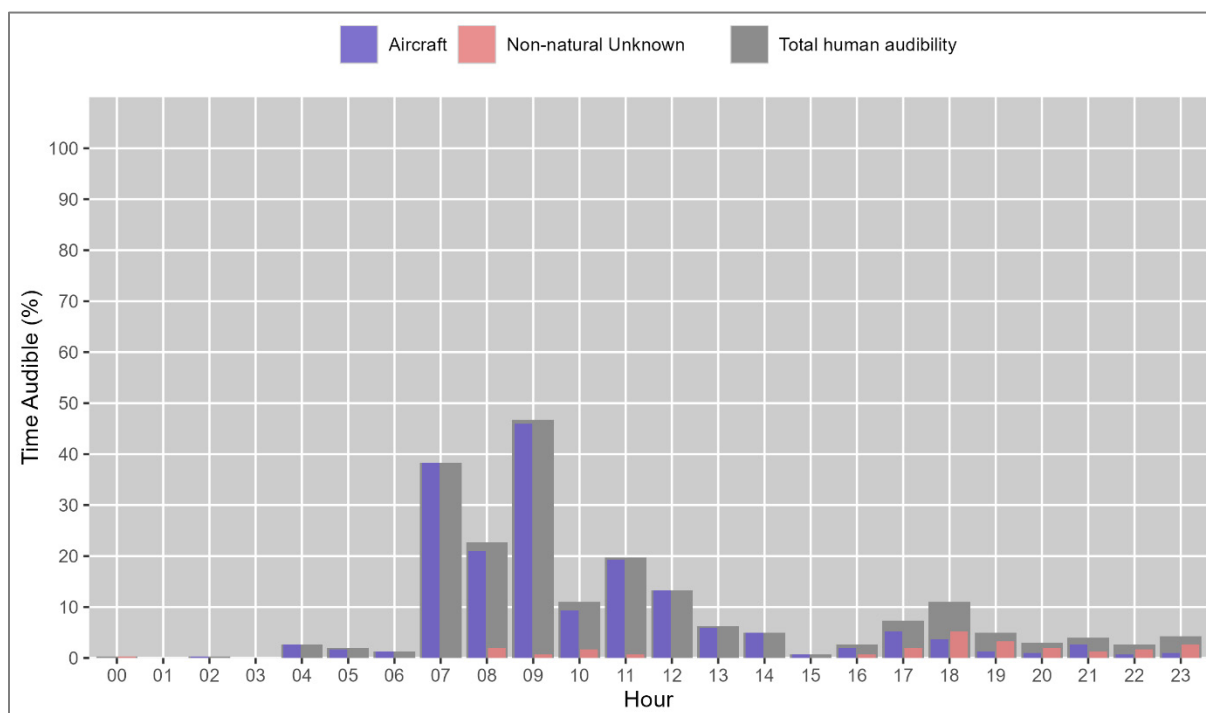


Figure 11. Hourly time audible for the top noise sources and all noise sources at HAVO002 in spring, 2019.

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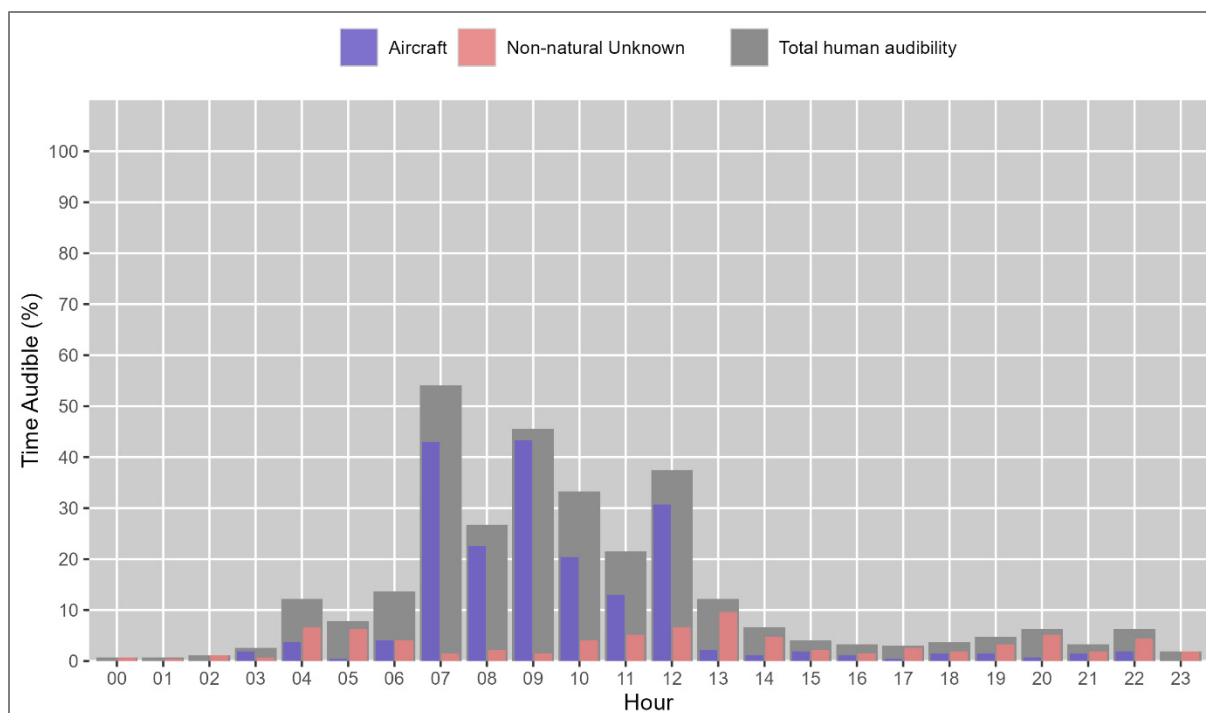


Figure 12. Hourly time audible for the top noise sources and all noise sources at HAVO002B in spring, 2019.

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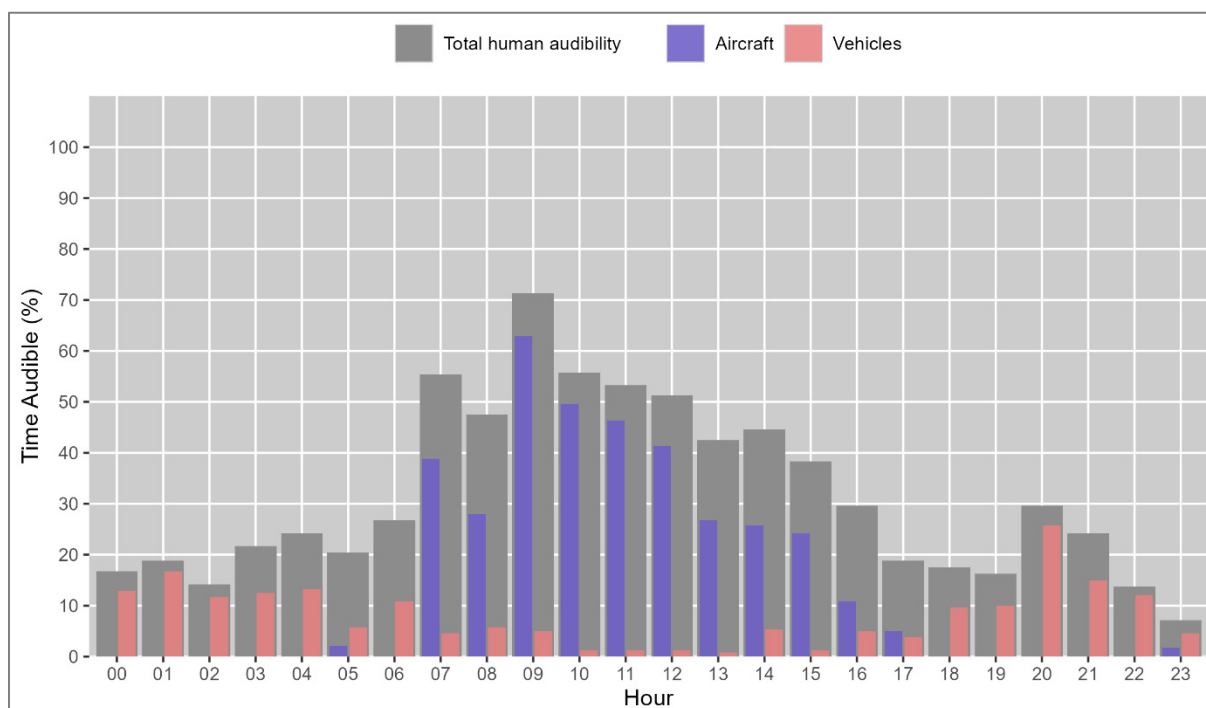


Figure 13. Hourly time audible for the top noise sources and all noise sources at HAVO009A in summer, 2019.

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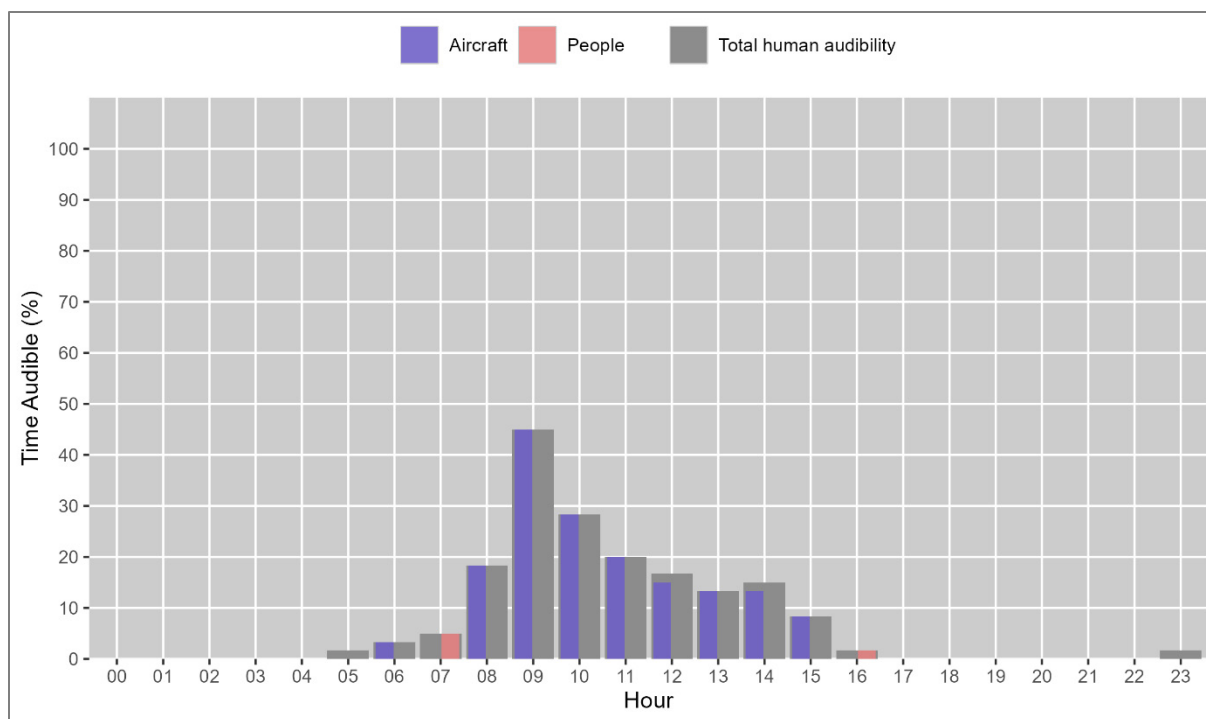


Figure 14. Hourly time audible for the top noise sources and all noise sources at HAVO009A in fall, 2019. Note that this graph represents 2 days of listening rather than the standard 8–10 days.

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Conclusions

Noise has the potential to affect a visitor's experience in parks by causing annoyance (Rapoza et al. 2015), reducing the perceived scenic beauty (Weinzimmer et al. 2014) and tranquility (Watts et al. 2020), and by limiting opportunities for solitude or a wilderness experience. Increased sound levels may also have wide ranging effects on wildlife such as reduced predatory success (Mason 2015), changes in vocal communication, and increased vigilance by keystone species (Shannon et al. 2014). In a review of literature addressing the effects of noise on wildlife published between 1990 and 2013, wildlife responses to noise were observed beginning at about 40 dB (L_{Aeq} , as a composite of multiple metrics with varying time-averaging). Of the papers reviewed, 20% showed impacts to terrestrial wildlife at or below noise levels of 50 dB ($L_{Aeq,1s}$) (Shannon et al. 2016).

This study arose from a technical assistance request from HAVO, which identified the need to improve understanding of the park's acoustic environment. Soundscape data were requested to update baseline conditions and to help evaluate noise impacts from aircraft, including air tours. The park did not have an active eruption occurring during this data collection. Acoustic measurements allow parks to gain environmental insights about extrinsic noise and biological activity. The results can help estimate the effects of noise on park visitors and wildlife, as well as the condition of the acoustic environment.

To carry out this study, 3 monitoring sites were placed in distinct areas of the park that captured common overflight patterns that exist along popular air tour transportation networks in HAVO (Peterson et al. 2024). Results included measures of existing ambient sound levels, calculations of sound source audibility through off-site listening, and estimates of natural ambient sound levels. The results provide insight into the acoustic conditions of the park before the park's Air Tour Management plan was implemented in the Summer of 2024 and before the reduction in tourism and subsequent air tours created by the Covid-19 pandemic.

At HAVO002 in the spring of 2019, functional effect thresholds were exceeded at the most sensitive sound threshold of 35 dB ($L_{Aeq,1s}$) for 1.4% of the day and 0.1% of the night in the ANS-weighted frequency ranges (Table 9). These results are like those in the full frequency range, indicating that sound levels remain low throughout the day. The sound energy contributing to this threshold is divided between lower frequency noise sources and higher frequency natural sources. Existing median sound levels (L_{A50}) were 0.7 dB higher than natural sound levels (L_{Anat}) during the day and the same at night (Table 12), suggesting that noise impacts are very low to non-existent, depending on time of the day. Off-site listening in a subset of the 2019 data revealed that noise was audible 8.8% of the time, with aircraft being the most common noise source, present 7.6% of the time (Table 5). Helicopters were the dominant aircraft source, audible an average of 6.9% of the day but peaking at 46% audible at 9:00 AM (CSU 2020; Appendix B). Propeller aircraft were audible 0.1% of the day, and jets were audible 0.6% of the day.

At HAVO002B in the spring of 2019, functional effect thresholds were exceeded at the most sensitive sound threshold of 35 dB ($L_{Aeq,1s}$) for 8.2% of the day and 0.02% of the night in the ANS-

weighted frequency ranges (Table 9). These results are like those in the full frequency range, indicating that the sound energy contributing to this threshold is likely from higher frequency natural sources. Existing median sound levels (L_{A50}) were 1.4 dB higher than natural sound levels (L_{Anat}) during the day and 0.1 dB at night (Table 12), suggesting that noise impacts are very low to non-existent, depending on time of the day. Off-site listening in a subset of the data revealed that noise was audible 13.0% of the time, with aircraft being the most common noise source, present 8.2% of the time (Table 5). Helicopters were the dominant aircraft source, audible an average of 7.5% of the day but peaking at 42% audible at 7:00 and 9:00 AM (CSU 2020; Appendix B). Propeller aircraft were audible 0.6% of the day, and jets were audible 0.1% of the day.

At HAVO009A in the summer of 2019, functional effect thresholds were exceeded at the most sensitive sound threshold of 35 dB ($L_{Aeq,1s}$) for 19.7% of the day and 0.7% of the night in the ANS-weighted frequency ranges (Table 9). These results differ from those in the full frequency range, indicating that much of the sound energy contributing to this threshold is likely from higher frequency natural sources. Existing median sound levels (L_{A50}) were 2.1 dB higher than natural sound levels (L_{Anat}) during the day and 0.3 dB at night (Table 12), suggesting that noise impacts are found during the day but non-existent at night. At this site, existing sound levels were approximately 12 dB higher during the day and 22 dB higher during the night and natural sound levels were 18 dB higher during the day and 21 dB higher during the night than HAVO002 and HAVO002B. This is likely from differences in season, ecology, and wind at HAVO009A. Off-site listening in a subset of the data revealed that noise was audible 31.6% of the time, with aircraft being the most common noise source, present 15.1% of the time (Table 6). Helicopters were the dominant aircraft source, audible an average of 14.3% of the day but peaking at 62.1% audible at 9:00 AM (CSU 2020; Appendix B). Propeller aircraft were audible 0.4% of the day, and jets were audible 0.4% of the day. Vehicles were audible 8.2% of the day, and likely from the Chain of Craters Road 1.7 miles to the west.

At HAVO009A in the fall of 2019, functional effect thresholds were exceeded at the most sensitive sound threshold of 35 dB ($L_{Aeq,1s}$) for 23.3% of the day and 1.8% of the night in the ANS-weighted frequency ranges (Table 9). These results are like those in the full frequency range in the day, but vastly different from the night, indicating that much of the sound energy contributing to this threshold during the night is from higher frequency natural sources. Existing median sound levels (L_{A50}) were 0.4 dB higher than natural sound levels (L_{Anat}) during the day and the same at night (Table 13), suggesting very little noise impact. At this site, existing and natural sound levels were like the summer season at this site and similarly higher during the day and night than HAVO002 and HAVO002B. This is likely from differences in season, ecology, and wind at HAVO009A. Off-site listening in a subset of the data revealed that noise was audible 7.4% of the time, with aircraft being the most common noise source, present 6.9% of the time (Table 6). Helicopters were the dominant aircraft source, audible an average of 3.2% of the day but peaking at 45.0% audible at 9:00 AM (CSU 2020; Appendix B).

Noise impacts were the greatest at HAVO009A in the summer, and across all sites, helicopter noise was the most pronounced at 9:00 AM. Visitors to HAVO likely experience noticeable noise in the

mornings but enjoy prolonged periods of the day with little audible noise near the measurement sites. The presence of helicopter noise identified in this study is further supported by a recent aircraft tracking report (Peterson et al. 2024). During a two-year flight tracking period using ground-based Automatic Dependent Surveillance-Broadcast (ADS-B) data, nearly 65% of overflights occurred between 8:00 AM and 12:00 PM. Of those overflights, helicopters accounted for 95.8%.

In addition to noise, natural sounds from wildlife were audible in the park. Dawn and dusk bird and insect choruses were weak at HAVO002 and HAVO002B, but not at HAVO009A. The prevalence of animal-derived natural sounds at the latter site is likely due to its location in tropical forest habitat, unlike the other sites, which were sparsely vegetated. Further acoustic analysis, such as machine learning techniques like BirdNET, could generate species lists and daily call patterns from this dataset.

Finally, this is the third comprehensive acoustic assessment at HAVO. In 2002 and 2003, 22 sites and over 900 days of acoustical data were collected to establish baseline conditions in key areas within the park (Lee et al. 2016). In 2013, NSNSD collected additional baseline acoustical data at 4 new sites in the Kahuku Unit of the park, which was acquired by the NPS after the initial monitoring effort (Beeco and Pipkin 2013). Across all sites, metrics, and assessments, only HAVO002 has been revisited more than one time in identical seasons. The first monitoring effort at HAVO002 was in the spring of 2008, but the results were never published in a report. We compare those efforts to the results from HAVO002 in the spring of 2019 that were reported in the present study (Appendix C).

The information presented in this report will be used to inform park managers and planners, and it will also serve as a permanent record of what the park sounded like in the winter of 2019–2020. Sound level data as well as continuous digital audio recordings will be archived with the Natural Sounds and Night Skies Division office in Fort Collins, Colorado.

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Appendix A: Site Photos

Photos of the sampling sites are displayed in Figures 15–17.



Figure 15. HAVO002, Mauna Loa.
NPS / NATURAL SOUNDS PROGRAM



Figure 16. HAVO002B, Halema'uma'u.
NPS / NATURAL SOUNDS PROGRAM



Figure 17. HAVO009A, Pu'u Huluhulu/ New Lava Flows.
NPS / NATURAL SOUNDS PROGRAM

Appendix B: Detailed Sound Source Descriptions

Sound resource description results are displayed in Figures 18–21

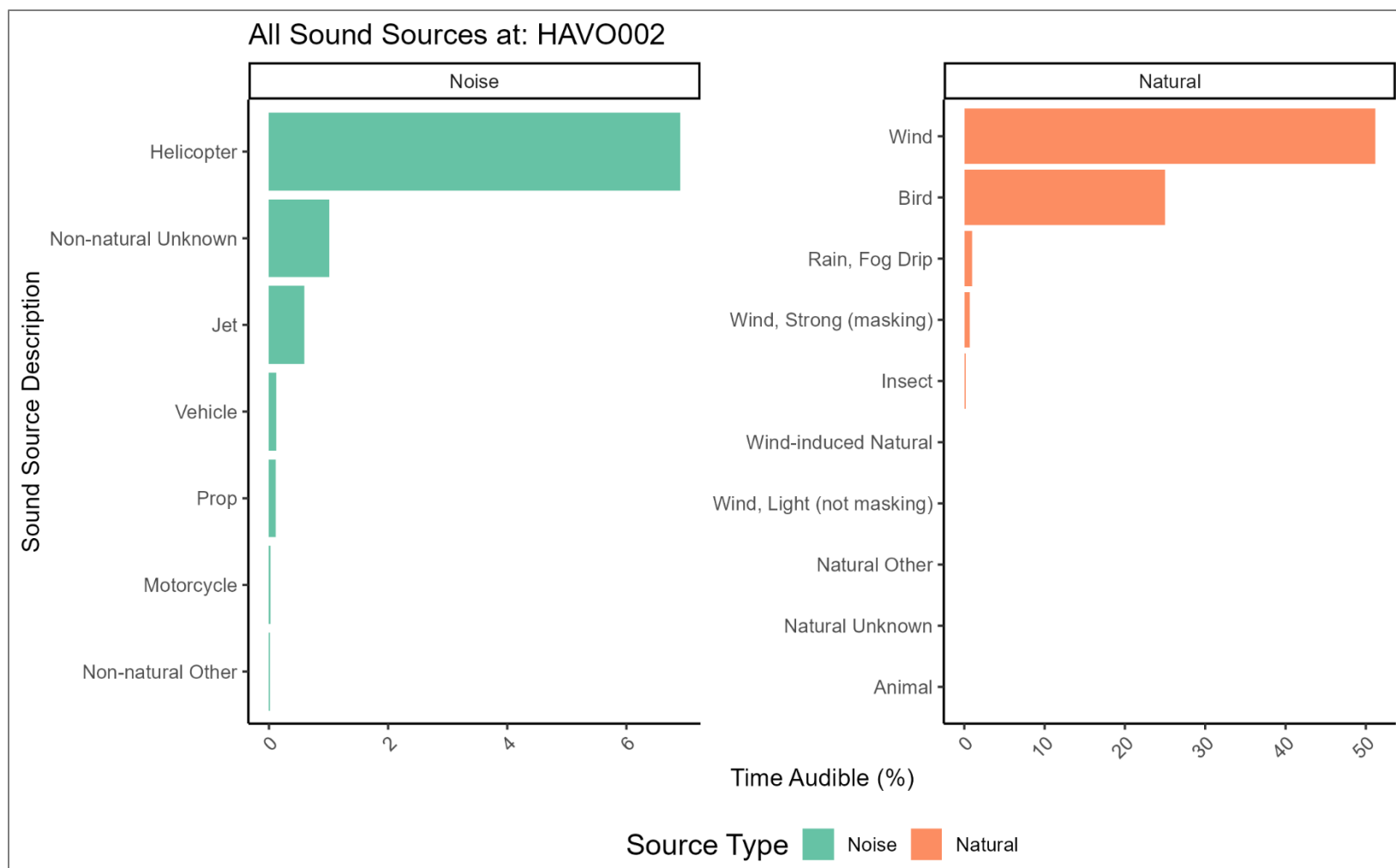


Figure 18. Comprehensive sound source description results from off-site listening at HAVO002 in spring, 2019.
NPS / NATURAL SOUNDS PROGRAM

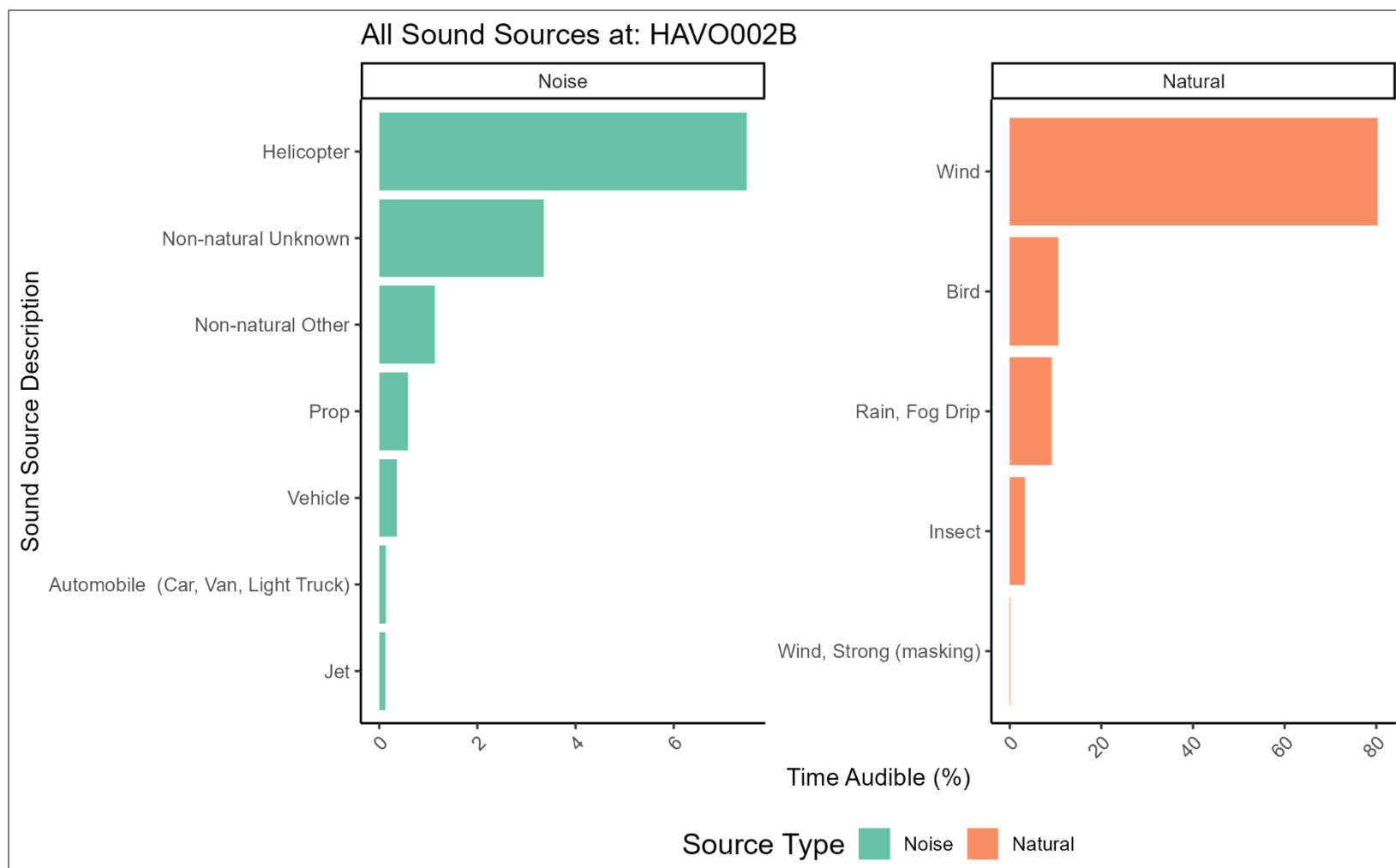


Figure 19. Comprehensive sound source description results from off-site listening at HAVO002B in spring, 2019.

NPS / NATURAL SOUNDS PROGRAM

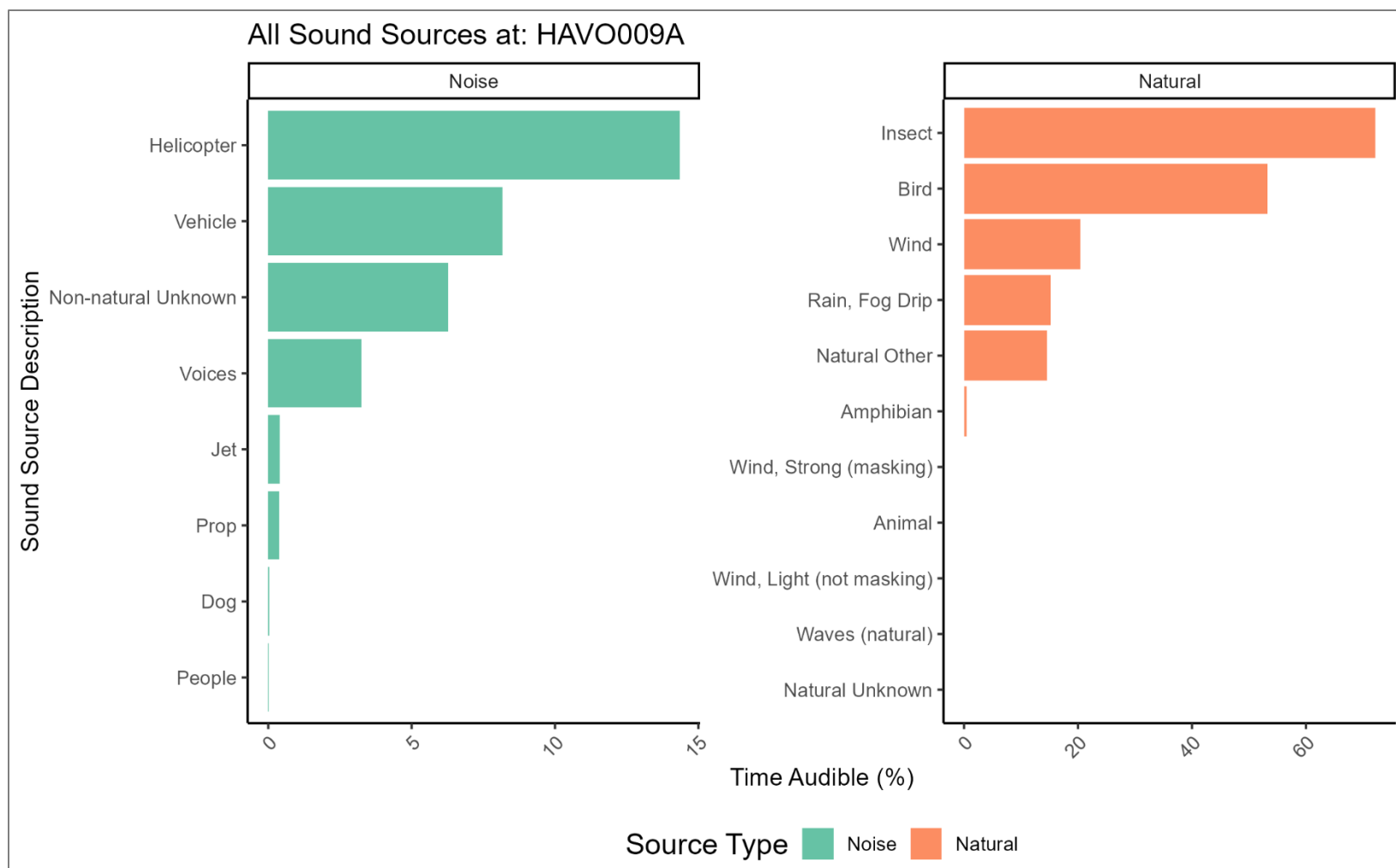


Figure 20. Comprehensive sound source description results from off-site listening at HAVO009A in summer, 2019.
NPS / NATURAL SOUNDS PROGRAM

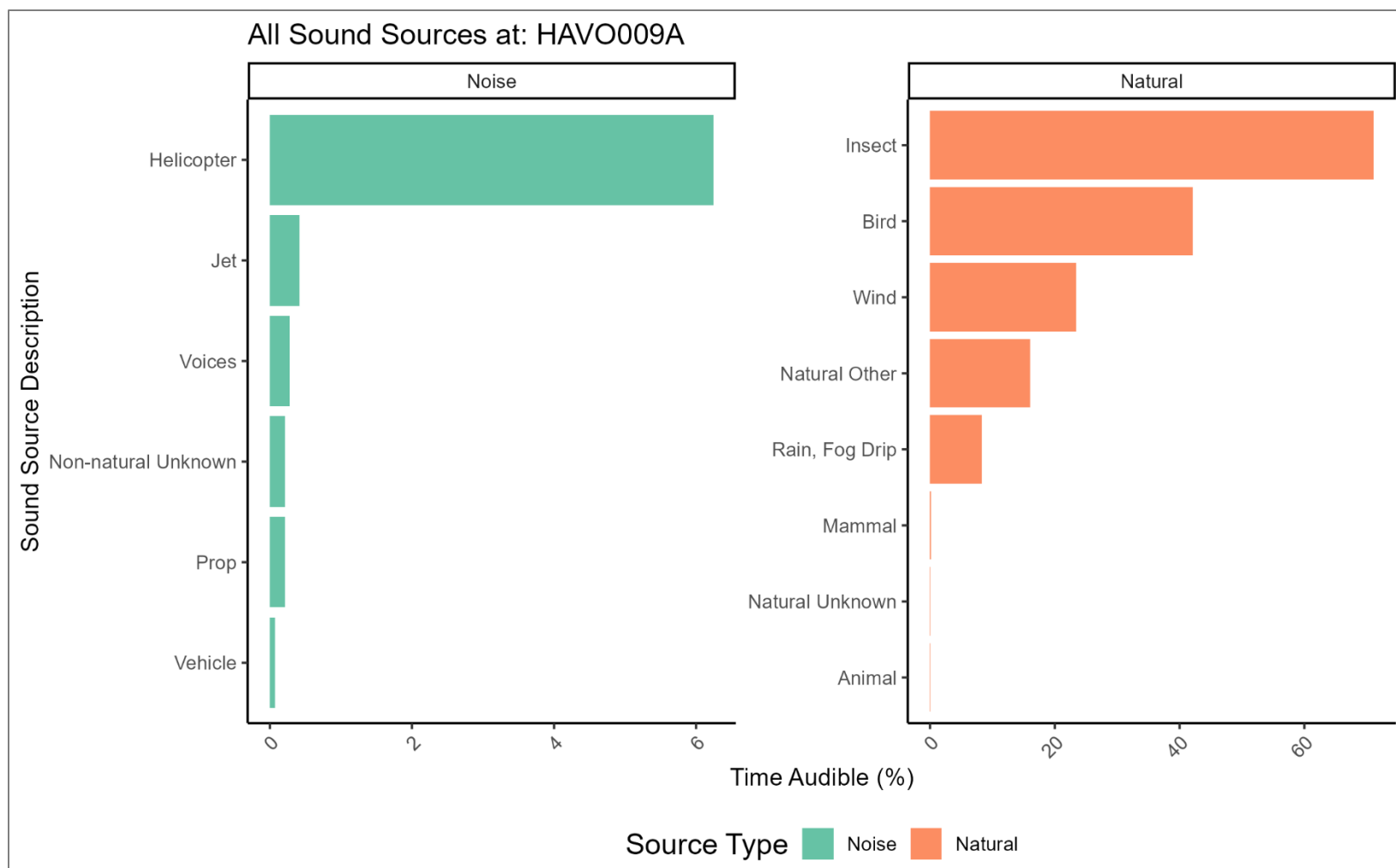


Figure 21. Comprehensive sound source description results from off-site listening at HAVO009A in fall, 2019.
NPS / NATURAL SOUNDS PROGRAM

Appendix C: Comparison to Unreported Data

Monitoring at HAVO002 was conducted in both spring 2008 and 2019; however, results from the 2008 assessment have not yet been reported. During the 2008 monitoring, functional effect thresholds were exceeded, with the 35 dB ($L_{Aeq,1s}$) threshold being surpassed for 2.1% of the day and 0.2% of the night within the ANS-weighted frequency ranges (Table 15). Additionally, median sound levels (L_{A50}) recorded in 2008 were 0.7 dB higher than natural sound levels (L_{Anat}) during the day and 0.1 dB higher at night (Table 16).

The primary source of noise was aircraft, which were present an average of 11.6% of the day. Helicopters constituted the most frequent type of aircraft, being audible 6.2% of the day, with peak audibility reaching 47% at 7:00 AM (NPS 2008). Propeller-driven aircraft were audible 1.5% of the day, while jets accounted for 2.1% of the daytime noise.

From 2008 to 2019, the acoustic environment at HAVO002 demonstrated a slight improvement in noise audibility, but there was an increase in sound levels across all percentiles and times of day (see Conclusions, Tables 15–16). The differences in metrics may be attributed to shifts in aircraft usage patterns, particularly when more people travel to HAVO to observe active volcanic eruptions from the air. For instance, in 2008, there was an active eruption at Pu‘u‘ō‘ō, which likely resulted in increased aircraft activity compared to periods without active volcanoes. Additionally, variations in the metrics could arise from differences in equipment, processing methodologies, and analysis tools used—specifically, the use of Listening Center Software in 2019 compared to SPLAT in 2008.

Table 15. Percent time above metrics for acoustic records collected in Hawai'i Volcanoes National Park (HAVO) in the spring of 2008 and 2019. Sound level functional values are displayed in decibels (dB $L_{Aeq, 1s}$ re 20 μ Pa). The percent of time ANS-weighted sound levels (20–1,250 Hz) are above functional values.

Year	Site	Frequency Range	Time Above Sound Level (% of Daytime Hours, 07:00 To 19:00)				Time Above Sound Level (% of Nighttime Hours, 19:00 To 07:00)			
			35 dB	45 dB	52 dB	60 dB	35 dB	45 dB	52 dB	60 dB
2008	HAVO002	Full (12.5–20,000)	3.10	0.98	0.31	0.06	0.54	0.10	0.02	0.00
2008	HAVO002	ANS (20–1,250)	2.09	0.54	0.21	0.04	0.24	0.00	0.00	0.00
2019	HAVO002	Full (12.5–20,000)	2.64	0.51	0.13	0.01	0.41	0.04	0.00	0.00
2019	HAVO002	ANS (20–1,250)	1.42	0.30	0.08	0.01	0.11	0.00	0.00	0.00

Table 16. Sound levels at Hawai'i Volcanoes National Park (HAVO) in the spring of 2008 and 2019. The 90th percentile (L_{A10}), existing (L_{A50}), natural (L_{Anat}) and 10th percentile (L_{A90}) ambient sound levels (dB re 20 μ Pa, A-weighted broadband, 12.5 Hz—20 kHz) during the day (0700–1900) and night (1900–0700) are shown in the table below.

Year	Time	Site	L_{A10}	L_{A50}	L_{Anat}	L_{A90}
2008	Day	HAVO002	27.7	17.5	16.8	14.6
2008	Night	HAVO002	19.4	15.0	14.9	13.9
2019	Day	HAVO002	28.1	20.2	19.5	16.3
2019	Night	HAVO002	23.3	16.9	16.9	15.0

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