



Hawai‘i Volcanoes National Park

Acoustical Monitoring Report 2013

Natural Resource Report NPS/NRSS/NSNS/NRR—2018/1578



ON THE COVER

Photograph of acoustic equipment located in HAVO at the Kahuku Rainforest site.
Photograph courtesy of the National Park Service and Chris Garsha

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Contents

	Page
Figures.....	Error! Bookmark not defined.
Tables.....	v
Executive Summary	vi
Acknowledgments.....	x
List of Acoustic Terms.....	xi
Introduction.....	1
The NPS Visitor	1
National Park Service Natural Sounds and Night Skies Division	1
Soundscape Planning Authorities.....	1
Study Area	3
Methods.....	6
Automated Monitoring	6
On-Site Listening.....	6
Calculation of Metrics	6
Off-Site Listening/ Audibility Analysis	7
Results.....	9
On-site Listening	9
Off-Site Data Analysis	10
Metrics.....	11
Audibility.....	15
Discussion	21
Aircraft	23
Literature Cited	25

Figures

	Page
Figure 1. Location of acoustic monitoring sites at Hawai‘i Volcanoes National Park.	3
Figure 2. Location of acoustic monitoring sites within Kahuku Unit.....	4
Figure 3. An example of a spectrogram at HAVO005 with natural sounds of birds (A) and insects (B). An aircraft event is also identified (C).	7
Figure 4. Day and night dB levels for 33 one-third octave bands at HAVO004 summer 2013.....	12
Figure 5. Day and night dB levels for 33 one-third octave bands at HAVO005 summer 2013.....	12
Figure 6. Day and night dB levels for 33 one-third octave bands at HAVO006 summer 2013.....	13
Figure 7. Day and night dB levels for 33 one-third octave bands at HAVO007 summer 2013.....	13
Figure 8. Comparison of hourly aircraft audibility and overall noise audibility at (HAVO004).	18
Figure 9. Comparison of hourly aircraft audibility and overall noise audibility at (HAVO005).	19
Figure 10. Comparison of hourly aircraft audibility and overall noise audibility at (HAVO006).	19
Figure 11. Comparison of hourly aircraft audibility and overall noise audibility at (HAVO007).	20
Figure 12. HAVO004 monitoring station in a temperate grassland at 1,109 meters elevation.....	27
Figure 13. HAVO005 monitoring station in a tropical moist broadleaf forest at 1,891 meters elevation.	28
Figure 14. HAVO006 monitoring station in a montane subalpine environment at 2,035 meters elevation.	29
Figure 15. HAVO007 monitoring station in an alpine environment at 2,469 meters elevation.....	30
Figure 16. Map of predicted acoustic impact levels in the park for an average summer day. The mean acoustic impact level at the park is 0.3 dBA and the median is 0.1 dBA.....	32
Figure 17. An example of a known aircraft route at HAVO.....	33

Tables

	Page
Table 1. Location and characteristics of the monitoring sites.	vii
Table 2. Functional effects at discrete acoustic values.	viii
Table 3. Percent time above sound levels for daytime and nighttime during the monitoring period.....	viii
Table 4. Location and characteristics of the monitoring sites.	5
Table 5. HAVO sites and their distances from a major road.	5
Table 6. The number of hours used for sound pressure levels metric analysis	7
Table 7. Summary of on-site audible sound sources for HAVO004 (n=4).....	9
Table 8. Summary of on-site audible sound sources for HAVO005 (n=4).....	10
Table 9. Summary of on-site audible sound sources for HAVO006 (n=2).....	10
Table 10. Summary of on-site audible sound sources for HAVO007 (n=2).....	10
Table 11. Sound source examples with associated SPLs.	11
Table 12. Effects at discrete acoustic values.	13
Table 13. Percent time above sound levels for daytime and nighttime during the monitoring period.....	14
Table 14. Exceedance levels for existing conditions in HAVO.....	15
Table 15. The eight days at each site that were used for off-site listening.....	15
Table 16. Mean hourly percent time audible for each noise source at HAVO004.	16
Table 17. Mean hourly percent time audible for each noise source at HAVO005.	16
Table 18. Mean hourly percent time audible for each noise source at HAVO006.	16
Table 19. Mean hourly percent time audible for each noise source at HAVO007.	17
Table 20. Provides DNL and LAeq metrics across the four sites.	34
Table 21. Provides the median SPL of aircraft noise heard at each site.	34

Appendices

	Page
Appendix A: Site Photos.....	27
Appendix B: Modeled Impact Levels	31
Appendix C: Example Air Tour Route	33
Appendix D: Additional Acoustic Metrics	34

Executive Summary

In 2013, the Natural Sounds and Night Skies Division received a request to collect baseline acoustical data in the Kahuku Unit of Hawai‘i Volcanoes National Park (HAVO). The request was a continuation of support from the Natural Sounds and Night Skies Division (NSNSD) to assist HAVO with air tour management planning. The Kahuku Unit was acquired by the National Park Service (NPS) in July 2003 after a previous monitoring effort in HAVO that collected data at 22 sites within the previous boundary of the park (USDOT 2016). The goal of this study was to determine ambient sound levels as a baseline condition in the Kahuku Unit that currently has limited public access. Through the months of September to November 2013, four acoustical monitoring systems were deployed. Table 1 describes the location and characteristics of the monitoring sites.

Table 1. Location and characteristics of the monitoring sites.

Site	Site Name	Dates	Vegetation	Elevation	Latitude	Longitude
HAVO004	Kahuku Paddocks	9/20/2013-11/22/2013	Woody Grasslands	1109m	19.114869	-155.687637
HAVO005	Kahuku Rainforest	9/21/2013-11/04/2013	Tropical Moist Broadleaf	1891m	19.249783	-155.597601
HAVO006	Nēnē Cabin	9/21/2013-11/15/2013	Montane Subalpine	2035m	19.262354	-155.610702
HAVO007	Alpine	9/22/2013-10/14/2013	Alpine	2469m	19.336650	-155.568149

Three different methods were used to analyze the acoustic environment, including on-site listening, calculation of sound pressure level (SPL) metrics, and visual/auditory analysis of spectrograms. The method of on-site listening is designed to help researchers know *what* or *who* is making the sound by placing an observer near the acoustic monitoring station to listen for a designated period of time. The listener identifies all sound sources and their durations. Thus, 12 periods of on-site listening were conducted at the four sites, to discern the type, timing, and duration of typical sounds. At each site, continuous SPL measurements were taken, along with audio recordings and meteorological data. SPL measurements provide quantitative metrics that describe the general acoustic environment of an area.

The visual/auditory analysis of spectrograms were evaluated at all four sites. Spectrograms are visual representations of the acoustic conditions. Examining spectrograms allows for the analysis of the frequency, duration, and intensity of sound events at a site. This method also allows the calculations of audibility metrics - the amount of time a sound source is audible to humans with normal hearing. Within this document “noise” is referred to as anthropogenic sounds.

In determining the current conditions of an acoustic environment, it is informative to examine how often SPLs exceed certain values. Table 2 summarizes SPL values that relate to human health and speech as documented in the scientific literature. These values are relevant to various aspects of the

visitor experience including camping in front-country and backcountry sites, communication between park staff and visitors, and informal communication. Human responses can serve as a proxy for potential impacts to other vertebrates because humans have hearing that is more sensitive at low frequencies than many species (Dooling and Popper, 2007; Fay, 1988).

Table 2. Functional effects at discrete acoustic values.

SPL (dBA)	Relevance
35	Blood pressure and heart rate increase in sleeping humans (Haralabidis et al., 2008) Desired background sound level in classrooms (ANSI S12.60-2002)
45	World Health Organization's recommendation for maximum noise levels inside bedrooms (Berglund, Lindvall, and Schwela, 1999)
52	Speech interference for interpretive programs (U.S. Environmental Protection Agency, 1974)
60	Speech interruption for normal conversation (U.S. Environmental Protection Agency, 1974)

For a given frequency range, the *percent time above* metric indicates the amount of time that the SPL exceeds a specified decibel value. By comparing the amount of time that SPLs are above certain values, variations in levels can be observed over time (or between sites). Table 3 reports the percent of time that measured SPLs were above the values in Table 2. These values are useful for making comparisons, but should not be construed as thresholds of impact. The top value in each split-cell of Table 3 reports the *percent time above* for the 20 – 1,250 Hz range. It is useful to look at this low-frequency range because it includes frequencies common to transportation noise while excluding higher-frequency bird and insect sounds. The bottom *percent time above* value in each split-cell is calculated from the full 12.5 – 20,000 Hz range measured at the sites.

Table 3. Percent time above sound levels, represented in a truncated (T) frequency range and the full measured frequency range, for daytime and nighttime during the monitoring period.

Site	Frequency (Hz)	% Time above sound level: 0700 to 1900 (DAY)				% Time above sound level: 1900 to 0700 (NIGHT)			
		35dBA	45dBA	52dBA	60dBA	35dBA	45dBA	52dBA	60dBA
HAVO004	20-1250 (T)	1.6	0.0	0.0	0.0	1.8	0.0	0.0	0.0
	12.5-20,000	8.8	0.5	0.0	0.0	4.1	0.0	0.0	0.0
HAVO005	20-1250 (T)	2.6	0.0	0.0	0.0	0.1	0.0	0.0	0.0
	12.5-20,000	71.7	18.7	1.5	0.0	11.1	3.0	0.1	0.0
HAVO006	20-1250 (T)	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	12.5-20,000	1.6	0.1	0.0	0.0	0.3	0.0	0.0	0.0
HAVO007	20-1250 (T)	1.7	0.0	0.0	0.0	0.1	0.0	0.0	0.0
	12.5-20,000	3.2	0.1	0.0	0.0	0.2	0.0	0.0	0.0

The results from this analysis suggest that the Kahuku Unit is dominated by natural sounds and had very little anthropogenic noise. Generally, median existing ambient was higher at sites located at lower elevations. This is mostly a result of higher density vegetation and increased habitat diversity of vocalizing species at lower elevation sites. The lower naturally occurring SPL values at high elevation sites in the park make this incredibly quiet area more sensitive to anthropogenic noise (Lynch 2011).

Each monitoring site exhibited a unique existing ambient condition. These differences are likely attributed to both natural and anthropogenic factors. Natural factors include the elevation, habitat, and species present. Anthropogenic factors include all other non-natural noise sources, mostly transportation. Appendix B includes a predictive model for estimating noise impacts. This predictive model is supported by the ground based data showing that the Kahuku Unit is impacted very little by anthropogenic noise.

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List of Acoustic Terms

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, & 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.

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 an individual animal's hearing ability.

Decibel (dB)- A unit of sound energy. Every 10 dB increase represents a tenfold increase in energy. Therefore, a 20 dB increase represents a hundredfold increase in energy. When sound levels are adjusted for human hearing they are expressed as dBA.

DNL (or Ldn)- Day-Night Average Sound Level. 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.

Extrinsic Sound- Any sounds not forming an essential part of the park unit, or a sound originating from outside the park boundary. This could include voices, radio music, or jets flying thousands of feet above the park.

Frequency- Related to the pitch of a sound, it is 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, humans and different species of animals 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.

Intrinsic Sound- Belongs to a park by the park's very nature, based on its purposes, values, and establishing legislation. Intrinsic sounds can include natural, cultural, and historic sounds that contribute to the acoustic environment of the park.

L50, L90- Metrics used to describe sound pressure levels (L), in decibels, exceeded 50 and 90 percent of the time, respectively. Put another way, half the time the measured levels of sound are greater than the L50 value, while 90 percent of the time the measured levels are higher than the L90 value.

LAeq- The A-weighted energy equivalent sound level. The sound energy level averaged over the measurement period. For example LAeq₁₂ measures energy equivalent sound level over 12 hours.

Ln_{nat} (Natural Ambient Sound Level)- The natural sound conditions in parks which exist in the absence of any human-produced noise.

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

Percent Time Above Natural Ambient- The amount of time that various sound sources are above the natural ambient sound pressure levels in a given area. It is most commonly used to measure the amount of time that human-caused sounds are above natural ambient levels. This measure is not specific to the hearing ability of a given animal, but a measure of when and how long human-caused sounds exceed natural ambient levels.

Percent Time Audible (TA%)- The amount of time that various sound sources are audible to humans with normal hearing. 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. Percent 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 percent time audible is a protective proxy for wildlife. These data can be collected by either a trained observer (on-site listening) or by making high-quality digital recordings for later playback (off-site listening).

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

Sound vs. Noise- The NSNSD differentiates between the use of sound and noise, since these definitions have been used inconsistently in the literature. Although sound is sometimes incorrectly used as a synonym for noise, it is in fact noise that is undesired or extraneous to an environment. Humans perceive sound as an auditory sensation created by pressure variations that move through a medium such as water or air and are measured in terms of amplitude and frequency (Harris, 1998; Templeton, 1997).

Soundscape- The human perception of the physical sound resource.

Introduction

The NPS Visitor

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). Acoustical monitoring provides a scientific basis for assessing the current status of acoustic resources, identifying trends in resource conditions, quantifying impacts from actions within and outside of the park, 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 acoustical issues raised by Congress (such as air tour management), NPS Management Policies, and NPS Director's Orders. The NSNSD works to protect, maintain, or restore acoustical 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 acoustical monitoring, data processing, noise modeling, park planning support, and comparative analyses and interpretation of acoustical 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."

Direction for management of natural soundscapes is represented in 2006 Management Policy 4.9:

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 "the 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 2006b). However, the desired acoustical condition may also depend upon the resources and the values of the park. For instance, Management Policies 5.3.1.7 Cultural Soundscapes, states that "culturally appropriate sounds are important elements of the national park experience in many parks." 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 2006c).

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

Directors Order 47, Preservation of the Acoustic Environment and Noise Management (NPS, 2000) builds on the principles set out in Management Policies, but goes on to direct how and when to consider acoustic resources in park management. 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.

National Parks Air Tour Management Act (NPATMA) was passed on April 5, 2000 to manage commercial air tour operations for each unit of the National Park System, or abutting tribal land, where such operations occur or are proposed. The Act required the Federal Aviation Administration (FAA), in cooperation with the NPS, to develop an Air Tour Management Plan (ATMP) for each unit of the National Park System to provide acceptable and effective measures to mitigate or prevent the significant adverse impacts, if any, of commercial air tour operations upon natural and cultural resources and visitor experiences. In 2012, NPATMA was amended to allow the FAA and NPS to enter into voluntary agreements with a commercial air tour operator as an alternative to an ATMP.

Study Area

Hawai‘i Volcanoes National Park (HAVO) is located on the Island of Hawai‘i in the Pacific Ocean (Figure 1). HAVO became a National Park on August 1, 1916, signed into law by President Woodrow Wilson. HAVO was named an International Biosphere Reserve in 1980 because of its outstanding scenic and scientific values. In 1987, HAVO was named a World Heritage Site by the United Nations Educational, Scientific, and Cultural Organization, recognizing and protecting the outstanding natural, historical, and cultural values. Today, HAVO protects 333,086 acres of volcanic terrain and native plants and animals – many of them endemic to the island (<https://www.nps.gov/havo/learn/kidsyouth/park-history.htm>).

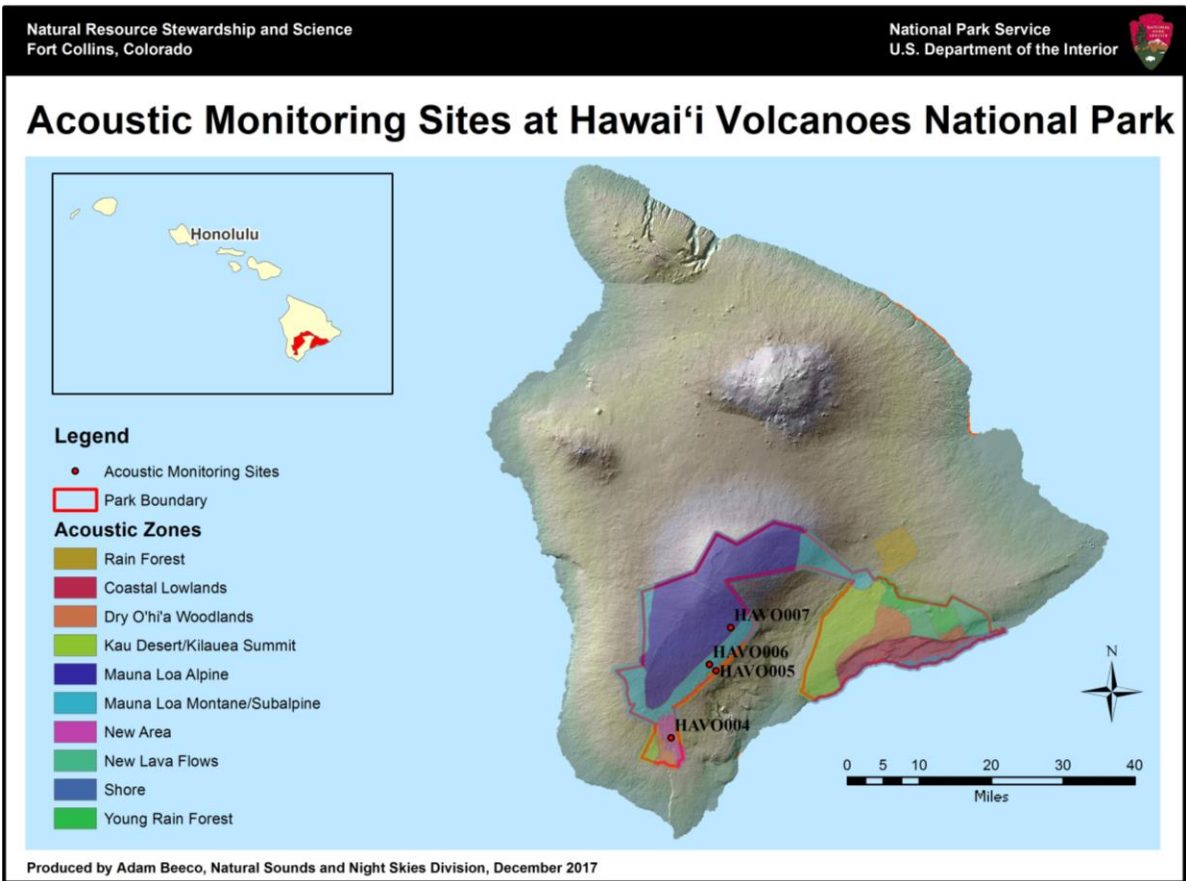


Figure 1. Location of acoustic monitoring sites at Hawai‘i Volcanoes National Park.

The specific area of the park surveyed for this study was the Kahuku Unit. HAVO acquired the 115,653 acre Kahuku Unit in 2003 (Figure 2). The Kahuku Unit has exceptional natural resources including endemic Hawaiian plants and birds, many of which are federally listed threatened and endangered species (Hess, et.al, 2006; Benitez, et.al., 2008). The Kahuku Unit is located in the western portion of the park and abuts the Mauna Loa Wilderness. The upper section of the Kahuku Unit has been determined eligible for wilderness designation. The elevation of the Kahuku Unit ranges from approximately 2,000 ft to 12,600 ft. This elevation profile in combination with tradewinds and moisture create microclimates in the park that result in a diverse range of habitats in a relatively small geographical space ([Natural Features and Ecosystems](#) 2017). The unique habitat characterized in Table 4 along this elevational gradient created soundscapes uncommonly different for being so relatively close in proximity.

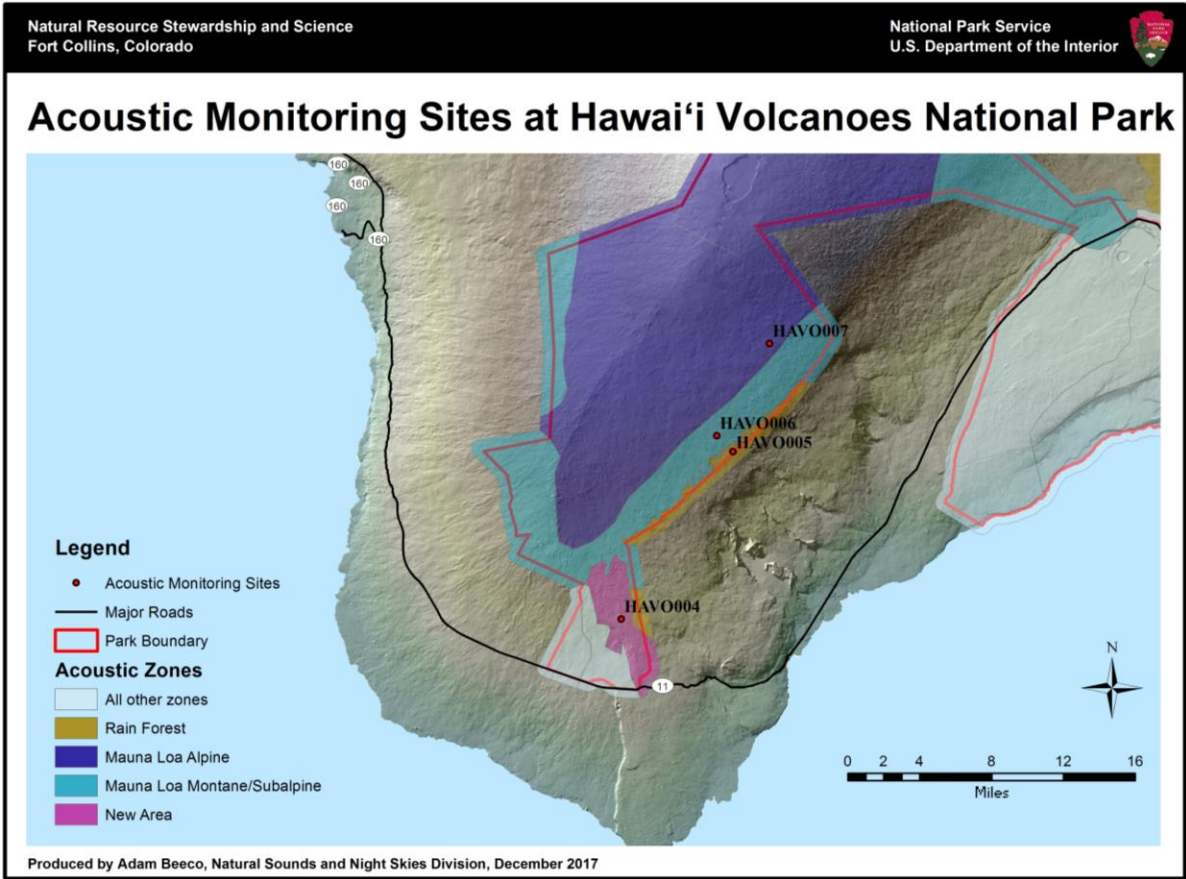


Figure 2. Location of acoustic monitoring sites within Kahuku Unit

The goal of the study was to determine existing ambient sound levels as a baseline condition in the Kahuku Unit which currently has limited public access. Four acoustic monitoring stations were set up to monitor existing ambient at a variety of elevations and habitats (Table 4 and Figure 2). Figure 2 also displays the current Acoustic Zones that overlap with the Kahuku Unit. Appendix A displays a photo of each monitoring site.

Table 4. Location and characteristics of the monitoring sites.

Site	Site Name	Dates	Vegetation	Elevation	Latitude	Longitude
HAVO004	Kahuku Paddocks	9/20/2013-11/22/2013	Temperate Grasslands	1109m	19.114869	-155.687637
HAVO005	Kahuku –Rain Forest	9/21/2013-11/04/2013	Tropical Moist Broadleaf	1891m	19.249783	-155.597601
HAVO006	Nēnē Cabin	9/21/2013-11/15/2013	Montane Subalpine	2035m	19.262354	-155.610702
HAVO007	Alpine	9/22/2013-10/14/2013	Alpine	2469m	19.336650	-155.568149

Table 5 displays the relationship between elevation and distance from Hwy 11. Road noise is a common source of noise in many national parks. Highway 11 is the only major road near the monitoring sites. Although there are closer roads, the closer the site is to Hwy 11 the more accessible it is.

Table 5. HAVO sites and their distances from a major road.

Acoustic Monitoring Site	Elevation	Distance from Major Road
HAVO004	1109m	6182 m (6.182 km)
HAVO005	1891m	13801 m (13.801 km)
HAVO006	2035m	15755 (15.755 km)
HAVO007	2469m	15841 (15.841 km)

Methods

Automated Monitoring

Larson Davis 831 sound level meters (SLM) were employed at each of the HAVO sites. The Larson Davis SLM is a hardware-based, real-time analyzer which constantly records one second SPL and 1/3 octave band data. These Larson Davis-based sites met American National Standards Institute (ANSI) Type 1 standards. The sound level meters provided the information needed to calculate metrics described below in Off-Site Listening/Calculation of Metrics.

The sampling stations consisted of:

- Microphone with environmental shroud
- Preamplifier
- 6 V alkaline lantern batteries
- Anemometer (wind speed and direction)
- Temperature and humidity probe
- MP3 recorder

The sampling stations collected:

- SPL data in the form of A-weighted decibel readings (dBA) every second
- Continuous digital audio recordings
- One third octave band data every second ranging from 12.5 Hz – 20,000 Hz
- Meteorological data including wind speed, direction, temperature, and relative humidity

On-Site Listening

While the sound level meter provides information about how loud or quiet the acoustic environment is at a given time, we need .mp3 recordings or on-site listening sessions to identify the sound source. On-site listening is the practice of placing an observer near the acoustic monitoring station with a handheld personal digital assistant (Apple iTouch®). The observer listens for a designated period of time (in this case, one hour) and identifies all sound sources and their durations. On-site listening takes full advantage of human binaural hearing capabilities, and closely matches the experience of most park visitors. Logistic constraints prevent comprehensive sampling by this technique, but selective samples of on-site listening provide a basis for relating the results of off-site listening, from audio recorders, to the probable auditory perception of events by park visitors and wildlife. On-site listening sessions are also an excellent screening tool for parks initiating acoustic research. They produce an extensive inventory of sound sources, require little equipment or training, and can help educate park staff and volunteers. Four sessions were conducted at HAVO004 and HAVO005, and two sessions at both HAVO006 and HAVO007 were completed. As recommended by NSNSD protocol (NPS 2005), these sessions lasted for one hour each. These listening sessions were split between two different listeners. Staff recorded the beginning and ending times of all audible sound sources using custom-designed software (SoundLog). These on-site listening sessions provided the basis for the calculation of metrics including the period of time between noise events (average noise free interval), percent time each sound source was audible, and maximum, minimum, and mean length (in seconds) of sound source events. The results of these on-site listening sessions are summarized in Tables 7-10 in the Results section.

Calculation of Metrics

The status of the acoustical environment can be characterized by spectral measurements, durations, and overall sound levels (intensities). The NSNSD uses descriptive figures and metrics to interpret these characteristics. A fundamental descriptor is existing ambient (L_{50}) sound levels. Existing ambient or L_{50} is an example of an exceedance level, where an L_x value refers to the SPLs that are exceeded x% of the time. The L_{50} represents the median sound pressure level, and is comprised of spectra (in dB) drawn from a full dataset (removing data with wind speed > 5m/s to eliminate error from microphone distortion). Another example, the L_{90} , represents the sound pressure level that is exceeded 90% of the time, therefore, only 10% of the sound levels that occur are below the L_{90} . The natural ambient (L_{nat}) is an estimate of what the ambient sound level for a site would be if all

extrinsic or anthropogenic sources were removed. Unlike the existing ambient, the natural ambient is comprised of spectra drawn from a subset of the original data.

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

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

and P_H is the percentage of samples containing extrinsic or anthropogenic sounds for the hour. For example, if human caused sounds are present 30% of the hour, $x = 65$, and the L_{nat} is equal to the L_{65} , or the level exceeded 65% of the time. Additional metrics can be found in Appendix D that are not discussed in this section but the park may find useful.

Acoustic metrics are calculated from the entire monitoring period. Table 6 displays the number of hours (daytime and nighttime) of data that was collected for each site. Figures 4-7 in the Results section show the amount of time used in the analysis at the bottom of the graph. The results of these on-site listening sessions are summarized in Tables 7-10 in the Results section.

Table 6. The number of hours used for sound pressure levels metric analysis

Monitoring Site	Day	Night	Total (hrs)
HAVO004	764	761	1525 hrs (63 days)
HAVO005	537	532	1069 hrs (44 days)
HAVO006	652	654	1306 hrs (54 days)
HAVO007	268	269	537 hrs (22 days)

Off-Site Listening/ Audibility Analysis

Audibility is the amount of time a sound source is audible to humans with normal hearing – measured as percent time audible. In this method, 1/3 octave band SPL data are displayed graphically (see spectrogram in Figure 3). Because different sounds have different frequencies, intensities, and durations, each sound has a different spectral (acoustic) signature that may be identified on a spectrogram. Acoustic signatures can be visually identified by scanning spectrograms more readily than listening to audio. Additionally, the spectrograms can be time-synchronized with on-site continuous audio recordings to verify the sound source or identify unknown visual signatures.

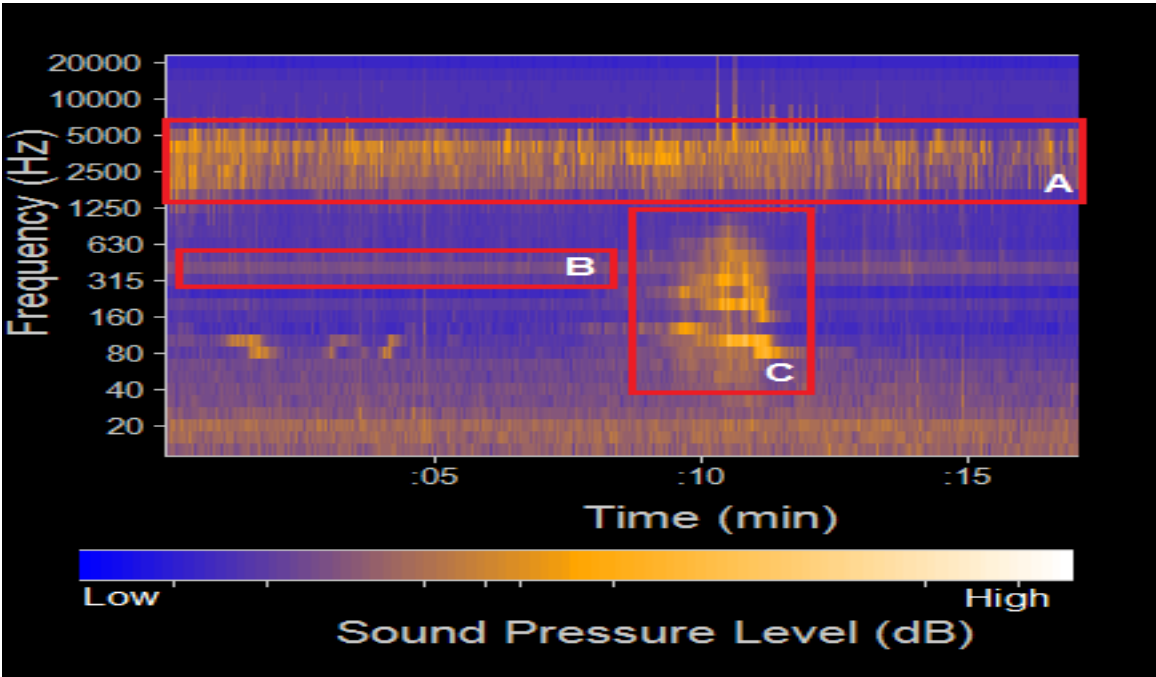


Figure 3. An example of a spectrogram at HAVO005 with natural sounds of birds (A) and insects (B). An aircraft event is also identified (C).

Auditory/visual analysis was used to calculate the audibility of sound sources at HAVO. A representative sub-sample of eight days at each of the four sites was analyzed. Trained technicians at

Colorado State University visually analyzed data using the custom built software Sound Pressure Level Annotation Tool (SPLAT). Noise sources with unique visual signatures on a spectrogram were annotated within SPLAT (Figure 3) to gather information about the timing, duration, frequency, and amplitude of these sources. The technicians focused on annotating all anthropogenic sounds (e.g., mechanized noise such as vehicles or aircraft). This dataset also included continuous audio that can be played for events with questionable sound signatures. Bose Quiet Comfort noise canceling headphones were used for off-site audio playback to minimize limitations imposed by the office acoustic environment. For the complete results of this thorough audibility analysis, see Tables 15-18, and Figures 8-11 in the Audibility sub-section of the Results below.

Results

On-site Listening

Tables 7, 8, 9, and 10 display the results of the on-site listening sessions at HAVO. The observers listened for a designated period of one hour, and identified all sound sources and their durations. Four sessions each were conducted at HAVO004 and HAVO005, and two sessions each at HAVO006 and HAVO007.

Each audible sound source is listed in the first column. Percent time audible (TA%) is shown in the second column. The third column, Max Event, reports the maximum event length among the sessions for each sound source. Likewise, Mean Event and Min Event columns report the mean and minimum length of events, respectively. SD reports the standard deviation among event lengths, and the Events column reports the audible discrete occurrences of each sound source. Anthropogenic noises are displayed with a white background and natural sounds are highlighted in gray. The last row in the table, noise free interval, is a metric describing the length of time between extrinsic or human-caused events (when only natural sounds were audible). These on-site listening tables are essentially a sound inventory of each site. They reveal the sounds a visitor is likely to hear at or near this location.

Table 7. Summary of on-site audible sound sources for HAVO004 (n=4)

Sound Source Description	TA (%)	Max Event (mm:ss)	Mean Event (mm:ss)	Min Event (mm:ss)	SD (mm:ss)	Event Count
Propeller*	0.6	1:30	1:30	1:30	0:00	1
Vehicle*	0.1	0:08	0:08	0:08	0:00	1
Wind**	99.8	59:59	59:53	59:40	0:09	4
Bird**	94.2	59:58	4:43	0:09	9:19	48
Insect**	0.1	0:07	0:06	0:04	0:02	3
Natural, Other**	4.3	1:17	0:18	0:06	0:14	35
Natural, Unknown**	0.1	0:09	0:09	0:08	0:01	2
Noise-Free Interval		60:00	39:44	15:19	18:45	6

*Anthropogenic sounds
**Natural sounds

Table 8. Summary of on-site audible sound sources for HAVO005 (n=4)

Sound Source Description	TA (%)	Max Event (mm:ss)	Mean Event (mm:ss)	Min Event (mm:ss)	SD (mm:ss)	Event Count
Wind*	90.7	59:58	6:36	0:13	11:37	33
Rain, Fog Drip*	2.2	2:28	0:44	0:10	0:47	7
Bird*	99.7	59:58	26:35	0:40	28:23	9
Insect*	0.6	0:13	0:09	0:06	0:02	10
Natural, Other*	6.4	1:08	0:17	0:04	0:15	55
Noise-Free Interval*		60:00	60:00	60:00	0:00	4

*Natural sounds (No anthropogenic sounds for HAVO005).

Table 9. Summary of on-site audible sound sources for HAVO006 (n=2)

Sound Source Description	TA (%)	Max Event (mm:ss)	Mean Event (mm:ss)	Min Event (mm:ss)	SD (mm:ss)	Event Count
Wind*	99.8	59:55	29:57	0:39	24:38	4
Bird*	94.9	23:00	5:42	0:14	6:21	20
Natural, Other*	7.5	1:15	0:27	0:01	0:18	20
Noise-Free Interval		60:00	60:00	60:00	0:00	2

*Natural sounds (No anthropogenic sounds for HAVO005).

Table 10. Summary of on-site audible sound sources for HAVO007 (n=2)

Sound Source Description	TA (%)	Max Event (mm:ss)	Mean Event (mm:ss)	Min Event (mm:ss)	SD (mm:ss)	Event Count
Wind*	91.1	20:24	5:45	0:20	6:04	19
Rain, Fog Drip*	3.4	1:21	0:49	0:08	0:29	5
Bird*	5.2	0:45	0:09	0:02	0:08	41
Insect*	0.5	0:08	0:07	0:06	0:01	6
Noise-Free Interval		60:00	60:00	60:00	0:00	2

*Natural sounds (No anthropogenic sounds for HAVO005).

Using this method, anthropogenic noises were only identified at the HAVO004 site and were heard less than 1% of the time. The noise-free interval for HAVO005, HAVO006, and HAVO007 lasted the entirety of the attended listening sessions. Bird sounds were prevalent at HAVO004, HAVO005, and HAVO006, while wind was prevalent at all four sites.

Off-Site Data Analysis

The logarithmic dB scale can be difficult to interpret, and the functional effect of a seemingly small change in SPL can be greater than anticipated. When noise disrupts our ability to hear natural sounds, the noise *masks* the natural sounds, and this affects the extent of the listening area. For example, if the natural ambient SPL is 30 dBA, and transportation noise raises the ambient to 33 dBA (a 3 dB increase), the listening area for humans (and many birds and mammals) is reduced by 50%. Increasing the ambient SPL an additional 3 dB (to 36 dB) would reduce the listening area by half again, to 25% of the initial area. Note, however, that changes in SPL do not proportionately translate to changes in perceived loudness. The rate of change of loudness is complex and dependent on the stimulus itself and other environmental factors (e.g., SPL, frequency, bandwidth, duration, background). Table 11 presents park sound sources and other common sound sources with their corresponding A-weighted decibel values (dBA).

Table 11. Sound source examples with associated SPLs.

Park Sound Sources	Common Sound Sources	dBA
Volcano crater (Haleakala National Park)	Human breathing at 3m	10
Leaves rustling (Canyonlands National Park)	Whispering	20
Crickets at 5m (Zion National Park)	Residential area at night	40
Conversation at 5m (Whitman Mission National Historic Site)	Busy restaurant	60
Motorcycle at 30m (Blue Ridge Parkway)	Curbside of busy street	80
Thunder (Arches National Park)	Jackhammer at 2m	100
Military jet at 100m Above Ground Level (Yukon-Charley Rivers National Preserve)	Train horn at 1m	120

Metrics

In order to determine the effect that extrinsic noise audibility has on the acoustic environment, it is useful to examine the median hourly exceedance metrics. The dB levels for 33 one-third octave band frequencies over the day and night periods are shown in Figures 4 through 7. 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 smaller ranges, each encompassing one-third of an octave. For each one-third octave band, dB level was recorded once per second for the duration of the monitoring period. Recording the sound intensity of 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 pressure level of a site. The gray shading of the graphs represent sound levels outside of the typical range of human hearing. The exceedance levels (L_x) are also shown for each one-third octave band. They represent the dB level exceeded x percent of the time. For example, L_{90} is the dB level that has been exceeded 90% of the time, and only the quietest 10% of SPLs can be found below this point. On the other hand, the L_{10} is the dB 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} (existing ambient) and L_{nat} (natural ambient). The height of this bold portion measures the contribution of anthropogenic noise to the existing ambient sound levels at this site. The size of this portion of the column is directly related to the percent time that human caused sounds are audible. When bold portions of the column do not appear the natural and existing ambient levels were either very close to each other, or were equal.

L_{nat} and L_{50} are bordered above by L_{10} and below by L_{90} , which essentially mark the median (L_{50}), maximum (L_{90}), and minimum (L_{10}) sounds pressure levels over the monitoring period. 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. It can be useful to review each one-third octave band on these figures to predict the audibility of one sound or the masking of another. Notice that songbirds and transportation noise are audible at different frequency spectrums. Sometimes transportation sounds are occurring at the same time as birds singing. In this case, bird sounds would not be masked because their song is audible at a different frequency. If both sound sources are within similar or overlapping frequency ranges, this occasionally occurs between wind and vehicles, when one sound source is louder the listener can expect the quieter sound to be masked.

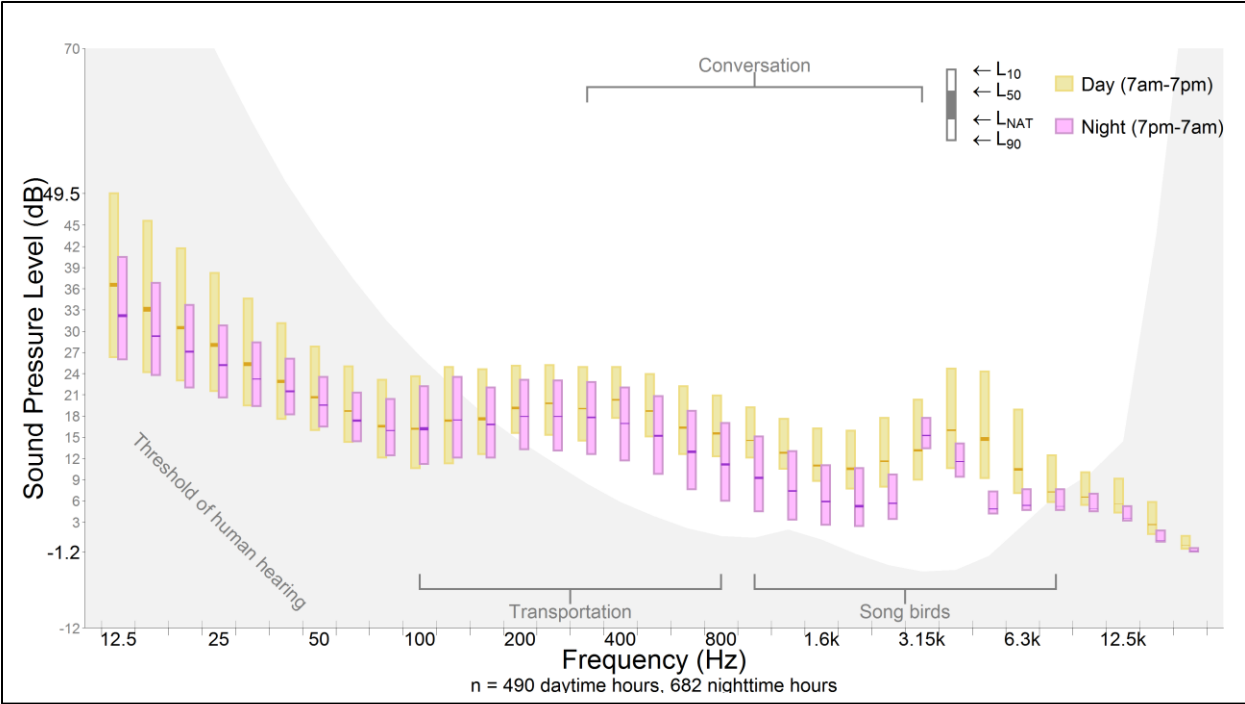


Figure 4. Day and night dB levels for 33 one-third octave bands at HAVO004 summer 2013.

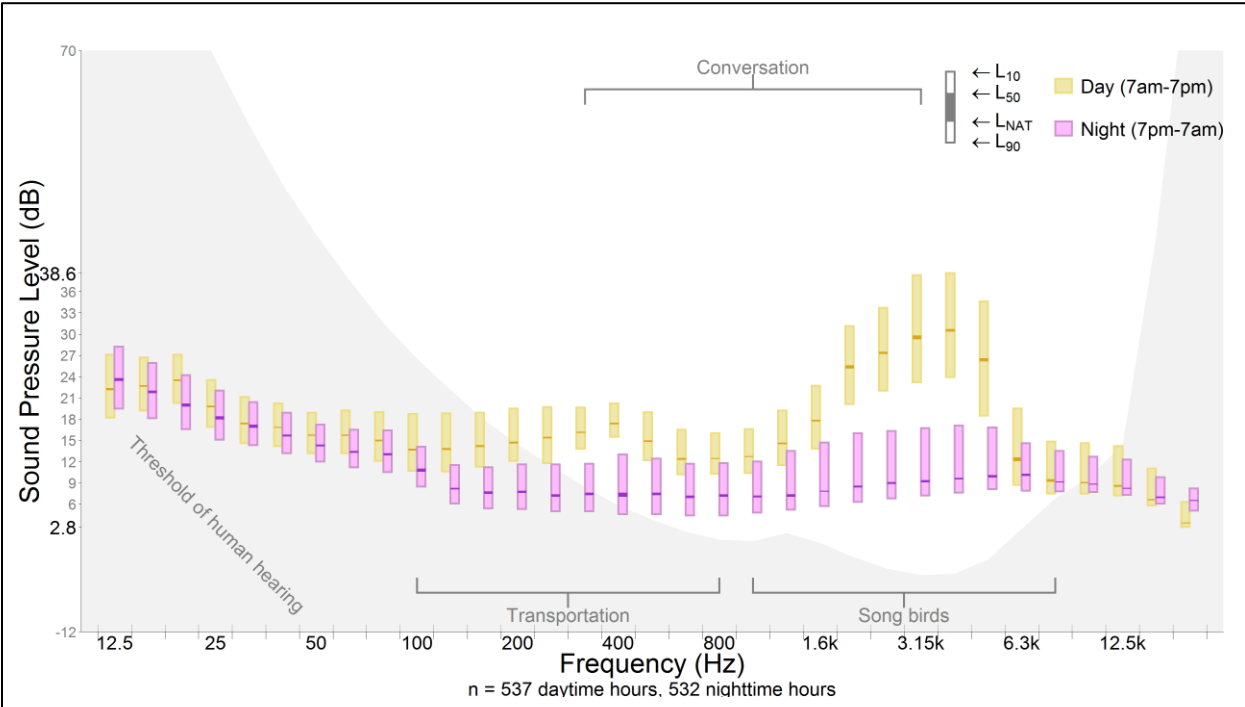


Figure 5. Day and night dB levels for 33 one-third octave bands at HAVO005 summer 2013.

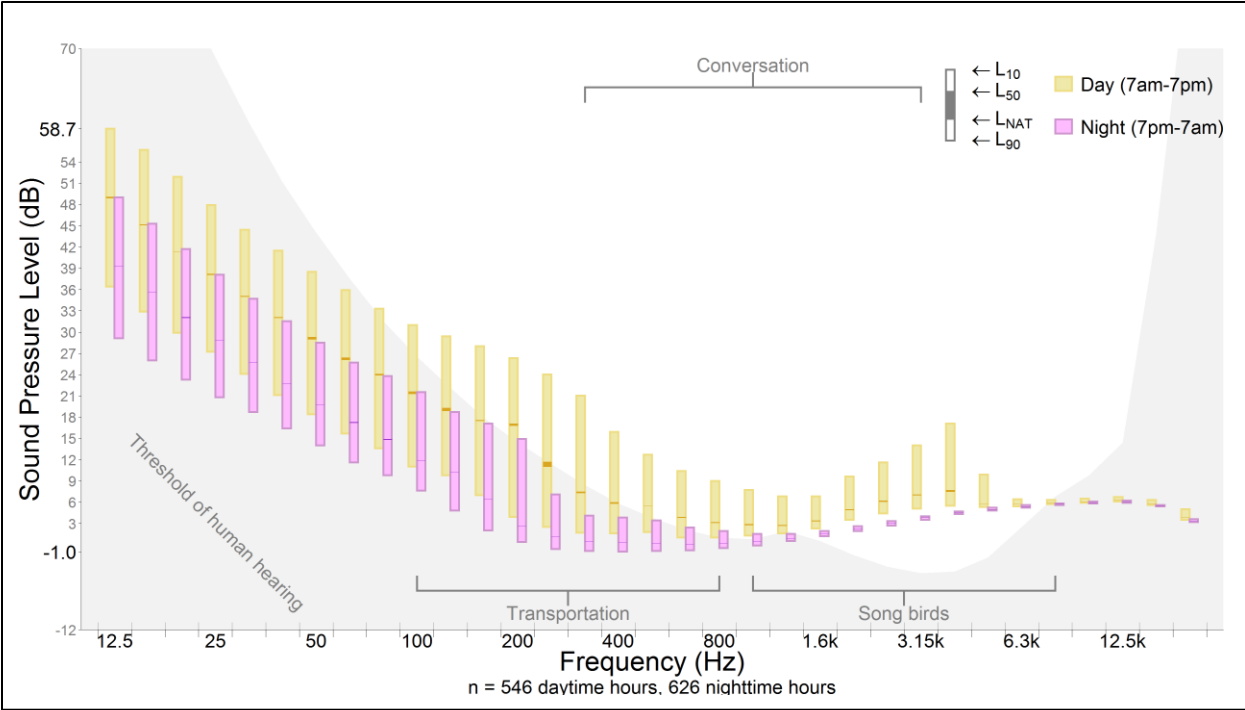


Figure 6. Day and night dB levels for 33 one-third octave bands at HAVO006 summer 2013.

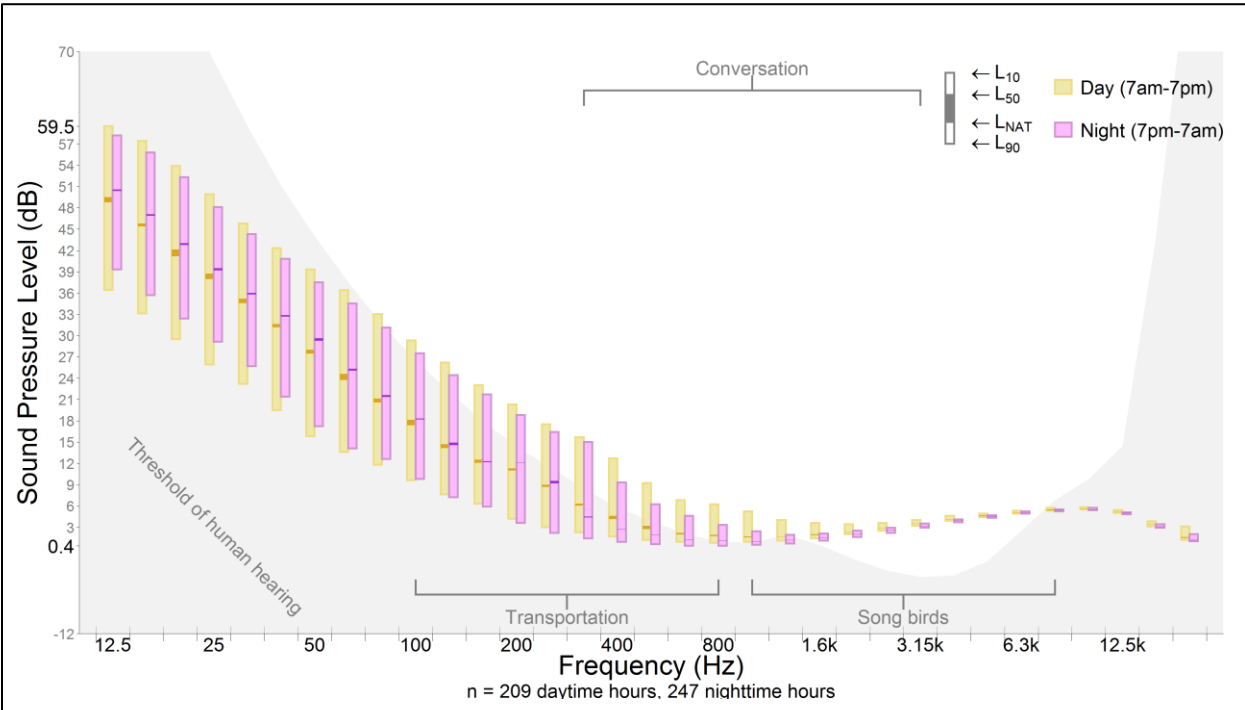


Figure 7. Day and night dB levels for 33 one-third octave bands at HAVO007 summer 2013.

Figures 4, 5, 6, and 7 reveal very different existing ambient conditions. For example, HAVO005 is characterized by more high frequency daytime sounds than the other sites. This biologically active area has the most frequent vocalizations of wildlife, while the other sites had less biological activity due to changes in habitat type.

Table 12 summarizes SPLs that relate to human health and speech as documented in the scientific literature. Human responses can serve as a proxy for potential impacts to other vertebrates because humans have hearing that is more sensitive at low frequencies than many species (Dooling and Popper, 2007, Fay, 1988). To help interpret the acoustic data collected within HAVO, and to better understand the implications of the data, it is helpful to consider SPL in relation to the functional effects listed in Table 12.

Table 12. Effects at discrete acoustic values.

SPL (dBA)	Relevance
35	Blood pressure and heart rate increase in sleeping humans (Haralabidis et al., 2008)

SPL (dBA)	Relevance
	Desired background sound level in classrooms (ANSI S12.60-2002)
45	World Health Organization's recommendation for maximum noise levels inside bedrooms (Berglund, Lindvall, and Schwela, 1999)
52	Speech interference for interpretive programs (U.S. Environmental Protection Agency, 1974)
60	Speech interruption for normal conversation (U.S. Environmental Protection Agency, 1974)

For a given frequency range, the *percent time above* metric indicates the amount of time that the SPL exceeds a specified decibel value. By comparing the amount of time that SPLs are above certain values, variations can be observed over time (or between sites). Table 13 reports the percent of time that measured SPLs were above the values in Table 12. These values are useful for making comparisons, but should not be construed as thresholds of impact. The top value in each split-cell of Table 13 reports the *percent time above* for the 20 – 1,250 Hz range. It is useful to look at this truncated low-frequency range because it includes transportation noise while excluding higher-frequency bird and insect sounds (ANSI 2014). Transportation is often a major contributor of low frequency sound, but the 20 – 1,250 frequency range does not correspond to a specific aircraft or type of transportation. Note that many anthropogenic sounds also occur in frequencies higher than this range, and many natural sounds (e.g., flowing water) also occur in the lower frequency range. The bottom *percent time above* value in each split-cell is calculated from the full 12.5 – 20,000 Hz range.

Table 13. Percent time above sound levels, represented in a truncated (T) frequency range and the full measured frequency range, for daytime and nighttime during the monitoring period.

Site	Frequency (Hz)	% Time above sound level: 0700 to 1900				% Time above sound level: 1900 to 0700			
		35dBA	45dBA	52dBA	60dBA	35dBA	45dBA	52dBA	60dBA
HAVO004	20-1250 (T)	1.6	0.0	0.0	0.0	1.8	0.0	0.0	0.0
	12.5-20,000	8.8	0.5	0.0	0.0	4.1	0.0	0.0	0.0
HAVO005	20-1250 (T)	2.6	0.0	0.0	0.0	0.1	0.0	0.0	0.0
	12.5-20,000	71.7	18.7	1.5	0.0	11.1	3.0	0.1	0.0
HAVO006	20-1250 (T)	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	12.5-20,000	1.6	0.1	0.0	0.0	0.3	0.0	0.0	0.0
HAVO007	20-1250 (T)	1.7	0.0	0.0	0.0	0.1	0.0	0.0	0.0
	12.5-20,000	3.2	0.1	0.0	0.0	0.2	0.0	0.0	0.0

Exceedance levels (L_x) represent the SPL exceeded x percent of time during the given measurement period. For example, L_{90} is the dB 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 dB level that has been exceeded 10% of the time, and 90% of the measurements are quieter than the L_{10} . Table 14 reports the L_{90} , L_{50} , and L_{10} values for all sites. For each split-cell in Table 14, the top value reports the L_x for the 20 – 1,250 Hz subset of the frequency range, and the bottom L_x value is calculated from the full 12.5 – 20,000 Hz spectrum.

Table 14. Exceedance levels for existing conditions in HAVO, for daytime and nighttime in a truncated (T) frequency range and the full measured frequency range, for daytime and nighttime during the monitoring period.

Site	Frequency (Hz)	Exceedance levels (dBA): 0700 to 1900				Exceedance levels (dBA): 1900 to 0700			
		L ₉₀	L ₅₀	L _{nat}	L ₁₀	L ₉₀	L ₅₀	L _{nat}	L ₁₀
HAVO004	20-1250 (T)	20.4	23.4	23.8	28.8	15.3	20.0	20.2	25.5
	12.5-20,000	23.9	27.4	27.7	33.6	21.2	24.0	24.2	29.1
HAVO005	20-1250 (T)	19.3	21.7	21.5	25.1	12.9	15.6	15.3	20.1
	12.5-20,000	33.2	38.5	38.9	44.8	19.1	21.3	21.1	28.2
HAVO006	20-1250 (T)	10.0	15.7	15.8	24.5	7.4	8.8	8.8	14.1
	12.5-20,000	17.4	20.9	21.1	28.3	15.2	15.5	15.5	17.8
HAVO007	20-1250 (T)	9.2	12.7	13.2	21.4	8.5	12.6	12.6	19.3
	12.5-20,000	15.3	16.8	16.8	22.4	15.1	16.3	16.3	20.5

Audibility

Audibility is measured as percent time audible - the amount of time a sound source is audible to humans with normal hearing. The exact days data were collected are listed in Table 15. Audibility results are presented in tables 16 through 19 and show the mean percentage of time that all noise sources were audible at each monitoring location. These tables do not provide information on how loud a source of noise is, only if it was visually recognized on a spectrogram during the 8 day subsample period. Sounds with high audibility from anthropogenic sounds do not necessarily align with the loudest sites in the park. These results are based on eight days of off-site auditory analysis. In the following tables natural sounds are shaded in gray, while the human created sound sources are white.

Table 15. The eight days at each site that were used for off-site listening.

Site	Dates of Off-site Listening
HAVO004	10/12, 10/13, 10/18, 10/21, 11/6, 11/9, 11/12, 11/21
HAVO005	9/27, 9/28, 9/30, 10/10, 10/12, 10/19, 10/22, 10/25
HAVO006	10/7, 10/10, 10/12, 10/13, 10/17, 10/21, 10/23, 11/10
HAVO007	9/30, 10/1, 10/2, 10/7, 10/10, 10/12, 10/13, 10/14

Table 16. Mean hourly percent time audible for each noise source at HAVO004. N = 8 days off-site sound source analysis.

Sound Source	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Aircraft*	0	0	0	0	0	0	0	0	0	1.6	0.6	0.6	0.7	0	1.2	0	0	0.8	0	0	0	0	0	0
Vehicle*	7.7	1.4	0.9	1.8	3.3	9.1	10	10	10	0.8	2.5	9.2	0	2.5	4.5	1.7	3.2	1.7	3	3.5	5.3	1.3	2.2	3.1
Wind**	0	0	0	0	0	0	11	12.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Insect**	0	0	0	0	0	0	69	87.5	92	88	80	100	88	100	100	100	100	85	8.7	0	0	0	0	0

*Anthropogenic sounds

**Natural sounds

Table 17. Mean hourly percent time audible for each noise source at HAVO005. N = 8 days off-site sound source analysis.

Sound Source	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Propeller Plane*	0	0	0	0	0	0	0	0	0.8	2.5	0	1.4	1.4	0	0	0	0	0.8	0	0	1.1	0	0	0
Vehicle*	10.6	10.1	9.1	3.5	7.6	8.8	12.7	8.4	12.6	5.5	2.1	8.8	3.8	4.9	2.2	3	0.6	2.4	6.3	9.5	10.9	4.9	8.8	6
Non-Natural Unknown*	0	0	0	0.1	0	4.4	0.1	1.4	0	0.3	0	0.3	0.2	0.1	0.5	0	0.2	0	0	0.3	0	0	0	0.2
Insect**	0	0	0	0	0	8.3	67.6	75	67.6	62.5	62.5	62.5	75	75	75	75	81.6	87.5	21.7	0	0	0	0	0

*Anthropogenic sounds

**Natural sounds

Table 18. Mean hourly percent time audible for each noise source at HAVO006. N = 8 days off-site sound source analysis.

Sound Source	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Jet*	0	0	0	0	0	0	0	0	1.8	1.5	0	1.7	0	0	0	0	0	0	0	0	0	0	0	0
Propeller Plane*	0	0	0	0	0	0	6.1	10.2	5.3	5.6	1.2	0	0	0	0	0	0	0	0	0	0	0	0	0

*Anthropogenic sounds

Table 19. Mean hourly percent time audible for each noise source at HAVO007. N = 8 days off-site sound source analysis.

Sound Source	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Aircraft*	0	0	0	0	0	0	0	0	0	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-Natural Unknown*	0	0	0	0	0	0	0	12.5	5.5	5.4	2	2	0	0	1.5	0	0	0	0	0	0	0	0	0
Motor*	2.6	0.5	0	1.4	0.8	1.1	1	2.5	3.6	3.7	0.3	1.6	0	2.1	0.7	0	0.8	2.3	2.8	1.1	1.7	1.2	1.7	0.1

*Anthropogenic sounds

Figures 8 through 11 show hourly audibility results from anthropogenic sound sources from the 8 days of off-site listening and then evaluate how aircraft, a source of interest for this report, contribute to this metric. Audibility at all four sites was relatively low, with aircraft being the only anthropogenic sound source annotated at HAVO006.

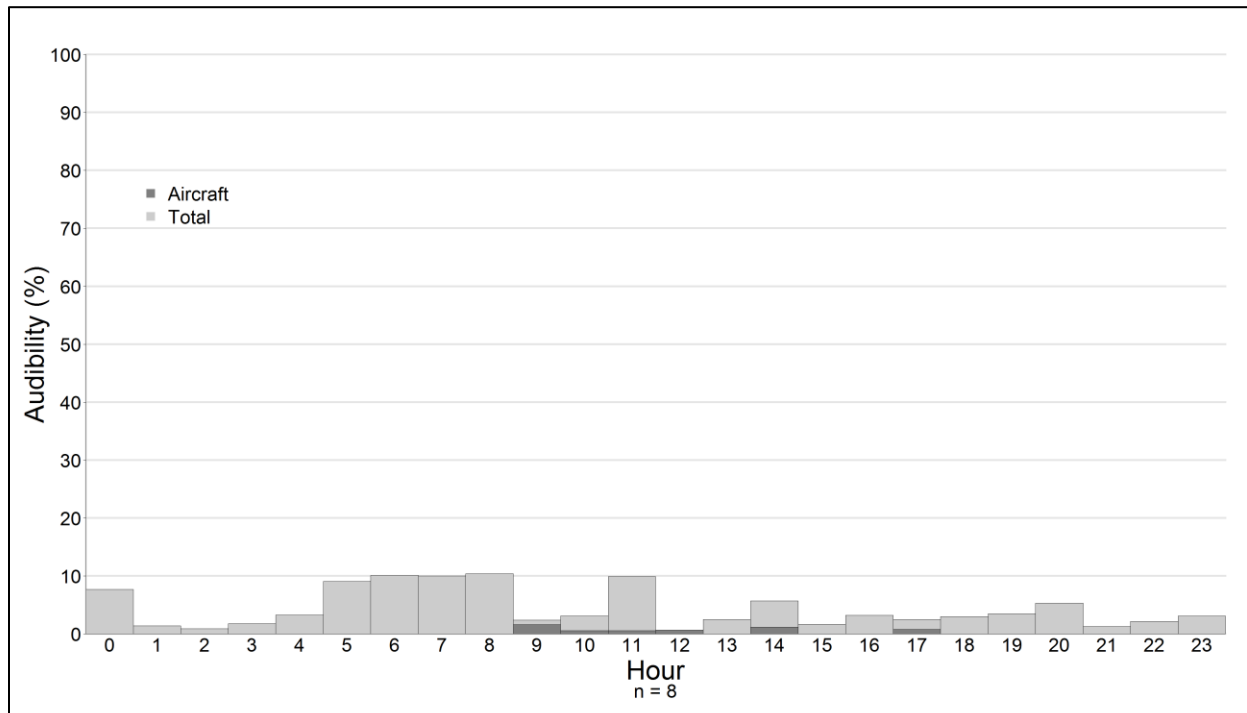


Figure 8. Comparison of hourly aircraft audibility and overall noise audibility at (HAVO004).

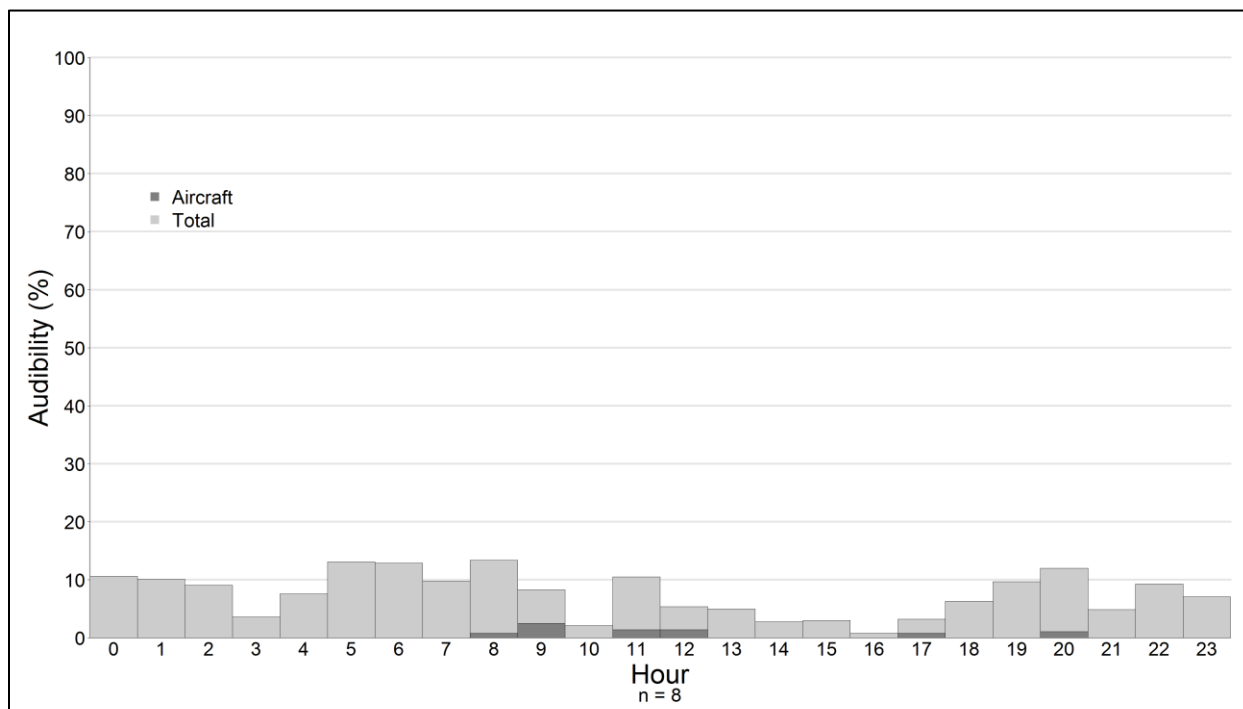


Figure 9. Comparison of hourly aircraft audibility and overall noise audibility at (HAVO005).

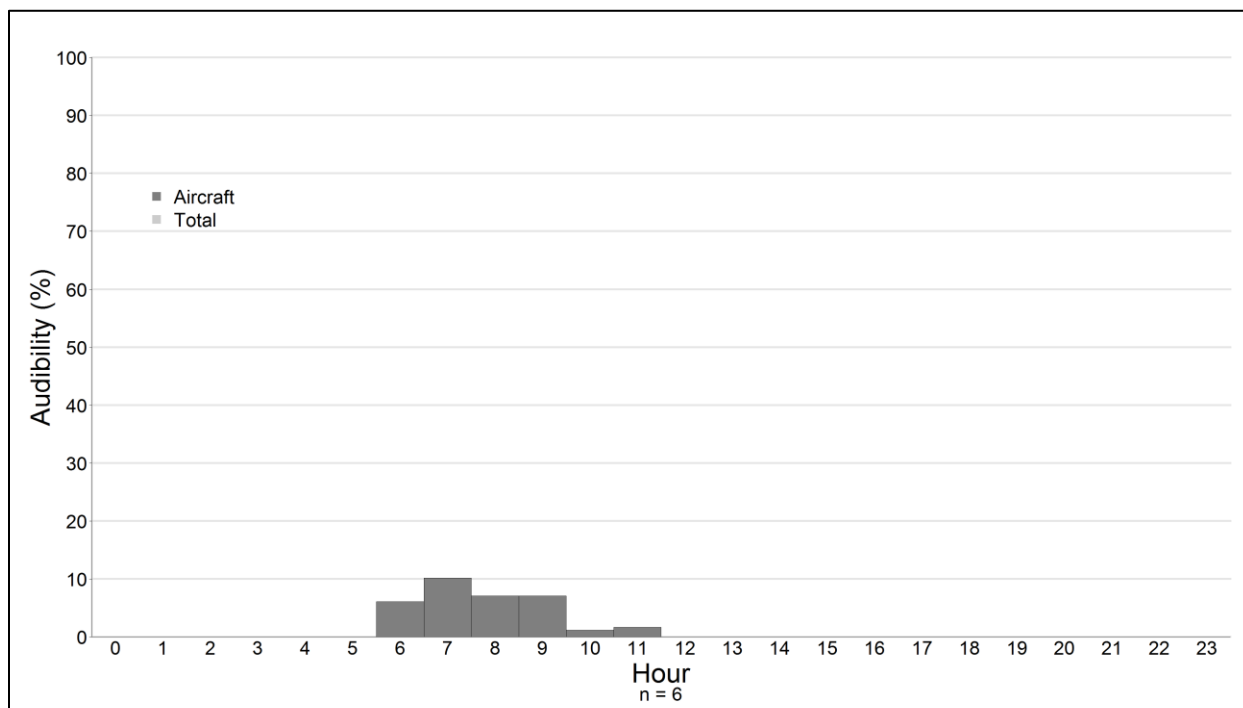


Figure 10. Comparison of hourly aircraft audibility and overall noise audibility at (HAVO006).

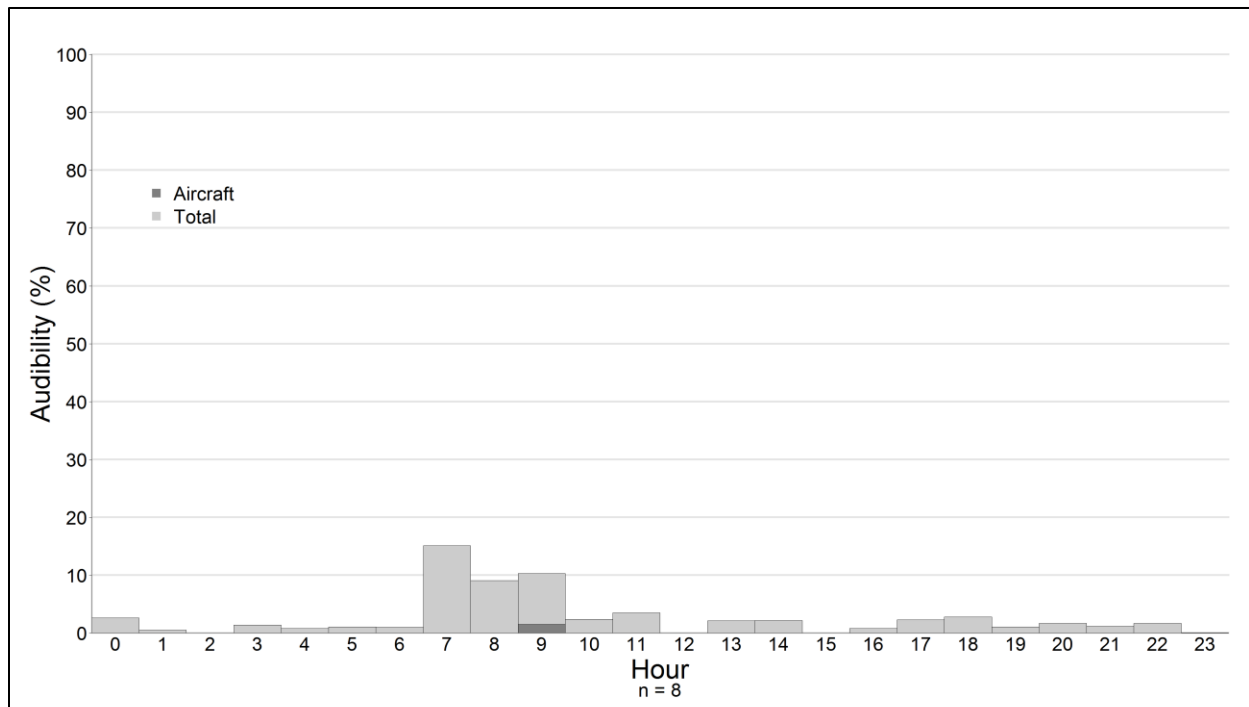


Figure 11. Comparison of hourly aircraft audibility and overall noise audibility at (HAVO007).

Discussion

The purpose of this study was to assess current conditions of the acoustical environment at HAVO, specifically the Kahuku Unit of the park. Monitoring results characterizing the existing sound levels are intended to provide the park with baseline information as well as to inform management decisions. SPL data, meteorological conditions, continuous audio, and on-site listening were collected from four different sites. Data was analyzed using visual/auditory analysis of spectrograms and summarized using a suite of metrics. Acoustic technicians listened while visiting the sites to provide a small sample of on-site listening that could be used to describe the full suite of anthropogenic and natural sounds while at the site. The acoustical monitoring site locations were chosen to best assess noise impacts to sites at varying elevations and habitats within the Kahuku Unit of the park. The goal of the study was to determine existing ambient sound levels as a baseline condition in the Kahuku Unit, which currently has limited public access.

Overall, results indicate that the Kahuku Unit contains remarkable natural soundscapes with infrequent anthropogenic sounds. Each monitoring site exhibited a unique existing ambient. These differences are likely attributed to both natural and human-caused factors. Natural factors include the elevation, habitat, and species present. Human-caused factors include the sounds of aircraft and vehicles. Appendix B includes a predictive model for estimating noise impacts. This predictive model supports the conclusions that the Kahuku Unit is only minimally exposed to anthropogenic noise.

HAVO004 is characterized by abundant natural sounds during the daytime and nights. The daytime L_{50} for the site was 23.4 dBA for the truncated frequencies and 27.4 dBA for all frequencies measured (Table 14). The L_{nat} was 0.3 dBA higher during the day and 0.2 dBA higher at night than the respective L_{50} . Vehicles were the most common anthropogenic sound source and were audible during each hour of the day. This site is also the closest to Highway 11, being approximately 6,182 meters (3.84 miles) away (Table 19 and Figure 7). Other nearby roads, like Lorenzo Road also make this site more accessible than the other four sites. The differences between daytime and nighttime SPL's are likely a result of biological and human activity as shown in Figure 4. There is a spike in the amount of daytime high frequency sounds that can be attributed to birds. Additionally, a harmonic insect chorus that occurred primarily during the day was notable in the spectrograms. Nighttime insect activity was also audible in the recordings. The level, frequency, and duration of natural sounds at this site may have masked anthropogenic noise at the site.

HAVO005 recorded the highest ambient SPL of all sites monitored. The HAVO005 site was characterized by a predominantly natural soundscape that was especially biologically active during the day. The daytime L_{50} for HAVO005 was 21.7 dBA at truncated frequencies and 38.5 dBA for all measured frequencies (Table 14). This is the largest difference in ambient and truncated ambient between all sites. This difference is due to the dominance of high frequency birds and insect activity during the daytime period and small amount of low frequency sounds. Like HAVO004 there was also a lot of harmonic daytime insect sound during the day. HAVO005 has very little exposure to anthropogenic noise, with vehicles being the predominant noise. The L_{nat} was 0.4 dBA higher during

the day and 0.2 dBA higher at night. Low frequency natural sound sources, like water and wind were present according to onsite listening (Table 8) but this site had the smallest range of low frequency sound (Figure 5). This site recorded a large amount of bird vocalization, enough to substantially raise the overall ambient of the site. The tropical broadleaf habitat would be expected to have a louder avian chorus than the other three areas. Finally, no noise events were noted during on-site listening sessions (Table 8).

HAVO006 had a lower daytime ambient than the previous two sites and the lowest nighttime ambient SPL, 8.8 dBA, of all the sites. The daytime full spectrum L_{50} was 20.9 dBA and the truncated frequency L_{50} was 15.7 dBA. The daytime had an elevated L_{50} only 0.3 dBA above L_{nat} and the nighttime ambient was not elevated by anthropogenic noise. There was a fairly consistent difference between ambient SPL during the day and night for this site most notable in the lower frequencies (Figure 6 and Table 14). A dawn chorus was still strong enough to change the acoustic frequencies heard at the site (Figure 6). This site was in a subalpine location of HAVO006 so we might expect to hear less biological activity at this location than the Temperate Grassland or Tropical Broadleaf forest. The only anthropogenic noise recorded at the site was from aircraft.

The differences between HAVO005 and HAVO006 are notable. A distance of only 1,957 meters (1.2 miles) and an elevation of 144 meters (472 feet) separate these two sites. Habitats vary quickly over this landscape and these two sites vary widely. The existing ambient conditions differed considerably between these two sites. HAVO005 recorded higher levels of noise audibility because of its proximity to the road (Figure 9), higher levels of higher frequency noise, because of the bird and insect activity heard frequently here (Figure 5 and 6), and a higher full spectrum daytime ambient (L_{50} ; Table 14). The L_{50} for HAVO005 was 38.9 dBA and HAVO006 was 21.9 dBA, a difference of 17 dBA, this means that the amount and consistency for interspecies and intraspecies communication between wildlife is very different between each site. HAVO005 was placed in tropical moist broadleaf forest, which provides more opportunities to record natural sounds, such as birds or vegetation rustling, while HAVO006 was located in a montane subalpine habitat.

HAVO007 was the quietest daytime site out of the four with the least amount of difference between day and night ambient SPL. This is likely due to limited vocal biological activity typical of high elevation alpine zone sites with sparse vegetation, and harsh conditions. Daytime full frequency ambient was 16.8 dBA and truncated ambient was 13.2 dBA. There was no difference in existing ambient and natural ambient SPL. This location had very low levels of noise from a non-natural unknown anthropogenic sound source (the sound source was so quiet it could not be identified by our technicians; Table 18). The natural soundscape at this site still included biological activity with the presence of wind and water playing a larger role. This site differs the most from the other three sites acoustically.

All four sites had nearly untouched natural soundscapes with no more than 0.3 dBA added to the ambient SPL from anthropogenic sound sources. HAVO004 and HAVO005 stood out as locations with an abundance of high frequency bird song. Aircraft was audible at all four sites but very few flights were heard. HAVO006 had the highest peak TA% (10.2% during the 7:00am hour) and only had 20 events over the 8 day period; this value is much lower than in other zones previously

monitored. For example HAVO002, monitored in 2008, had a peak of 50.2 TA% and 233 events over an 8 day period. Vehicle noise was audible only at HAVO004 and HAVO005. These two sites are nearest to Highway 11 and other nearby access roads and are at the lowest elevation. However, noise at all sites was of low intensity and did not contribute to large increases above natural ambient.

Aircraft

In the audibility portion of this study, listeners identified aircraft at all four sites (Tables 16-19; Figures 8-11). It should be noted that ‘aircraft’ is a term which includes jets, propeller aircraft, and helicopters. Aircraft is used as the coding term when the listener cannot distinguish which type of aircraft they are hearing.

Understanding how HAVO’s frequent air tours impact the acoustic environment and the resources the NPS protects was of interest in this study. In September, October, and November of 2013, 3,500 air tours were reported to take place over the park. Reporting commercial air tours is required as part of U.S Code– *Overflights of national parks* (49 U.S.C. § 40128(d)) – and operators submit quarterly reports. The reported data were extracted from calendar year 2013, third and fourth quarter reports submitted to FAA and NPS by eight air tour operators.¹ Of the reported air tours during this period, 3,483 were reports as helicopter flights and 17 from fixed wing/propeller aircraft.

Both the on-site listening and auditory/visual analysis of spectrograms identified propeller aircraft as a noise source. The on-site listening method identified a single event that included a propeller aircraft at HAVO004. No other sites identified aircraft using the on-site listening method. The auditory/visual analysis of spectrograms identified propeller aircraft noise at two sites (Tables 16 and 17). However, the percent time audible for propeller aircraft was limited at all sites. HAVO006 (Table 17) recorded the highest amount of percent time audible for aircraft.

The discrepancy between the large number of air tours and the lack and type of aircraft noise in the Kahuku Unit may be explained by reporting data from September, October, and November of 2013 and further detailed in Appendix C. Reporting data and other outreach efforts with operators suggest that most helicopter air tours fly over the eastern/northeastern portion of the park where Kīlauea Caldera is located and lava flows are common. For example, Appendix C presents two known, actual travel patterns along a single route that were flown on May 9, 2017 by a Bell 407 helicopter. The route travels over HAVO near the northeast boundary of the park and continues to the southeastern section of the park, while the acoustic monitoring sites are located in the western section of the park. Take note of the substantial terrain shielding by Mauna Loa Volcano between the air tour route and the acoustic monitoring sites. Of the four monitoring sites, the closest portion of the air tour route is near HAVO007, which is over 20 kilometers (13 miles) away. The aircraft noise picked up by our audio equipment in this study was mostly likely from a different route. Some of the known routes conducted by helicopters are similar to this pattern of flight, which mostly avoid the study area. However, past information on air tour routes indicate that a fixed-wing, propeller driven aircraft flies a different route closer to the study area (17 reported flights during the monitoring period). This

¹ Note: Eight air tour operators submitted reports, but only five conducted air tours.

information gives a possible explanation why no helicopters were detected in this study, but some propeller aircraft were identified.

Overall, these results suggest that at the time of the study, the monitoring sites had only low audibility of anthropogenic noise, including aircraft. These data will help establish baseline information about soundscapes in the Kahuku Unit that can be used to inform park planning efforts such as an air tour management plan or agreement. Additionally, HAVO park staff have identified the coqui frog (*Eleutherodactylus coqui*) as an invasive species that has the potential to heavily influence the acoustic environment. Specifically, the frog has a high decibel call (80 – 90 dBA at 0.5 meter; Beard and Pitt, 2005), can have a high density population (90,000 frogs per hectare; Pitt et al., 2012), and makes frequent vocalizations (21 calls per minute; Benevides Jr., et al, 2017). In addition to its' predatory impacts on native insects, park staff are concerned that the frog's range in the park could significantly alter the natural acoustic environment. These acoustic data serve as a baseline to evaluate future changes to the acoustic environment caused by coqui frogs and other invasive species.

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Appendix A: Site Photos



Figure 12. HAVO004 monitoring station in a temperate grassland at 1,109 meters elevation.



Figure 13. HAVO005 monitoring station in a tropical moist broadleaf forest at 1,891 meters elevation.

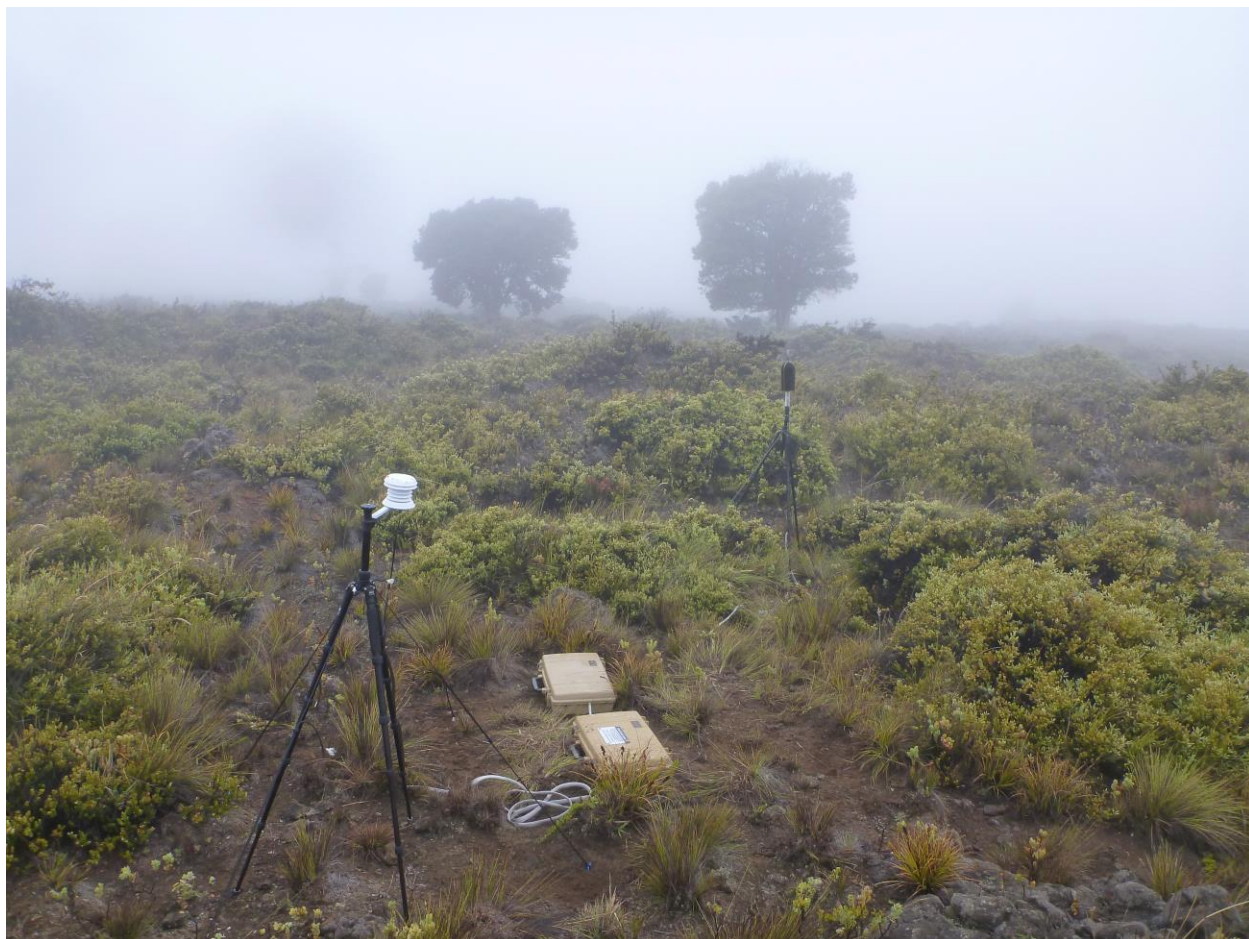


Figure 14. HAVO006 monitoring station in a montane subalpine environment at 2,035 meters elevation.



Figure 15. HAVO007 monitoring station in an alpine environment at 2,469 meters elevation.

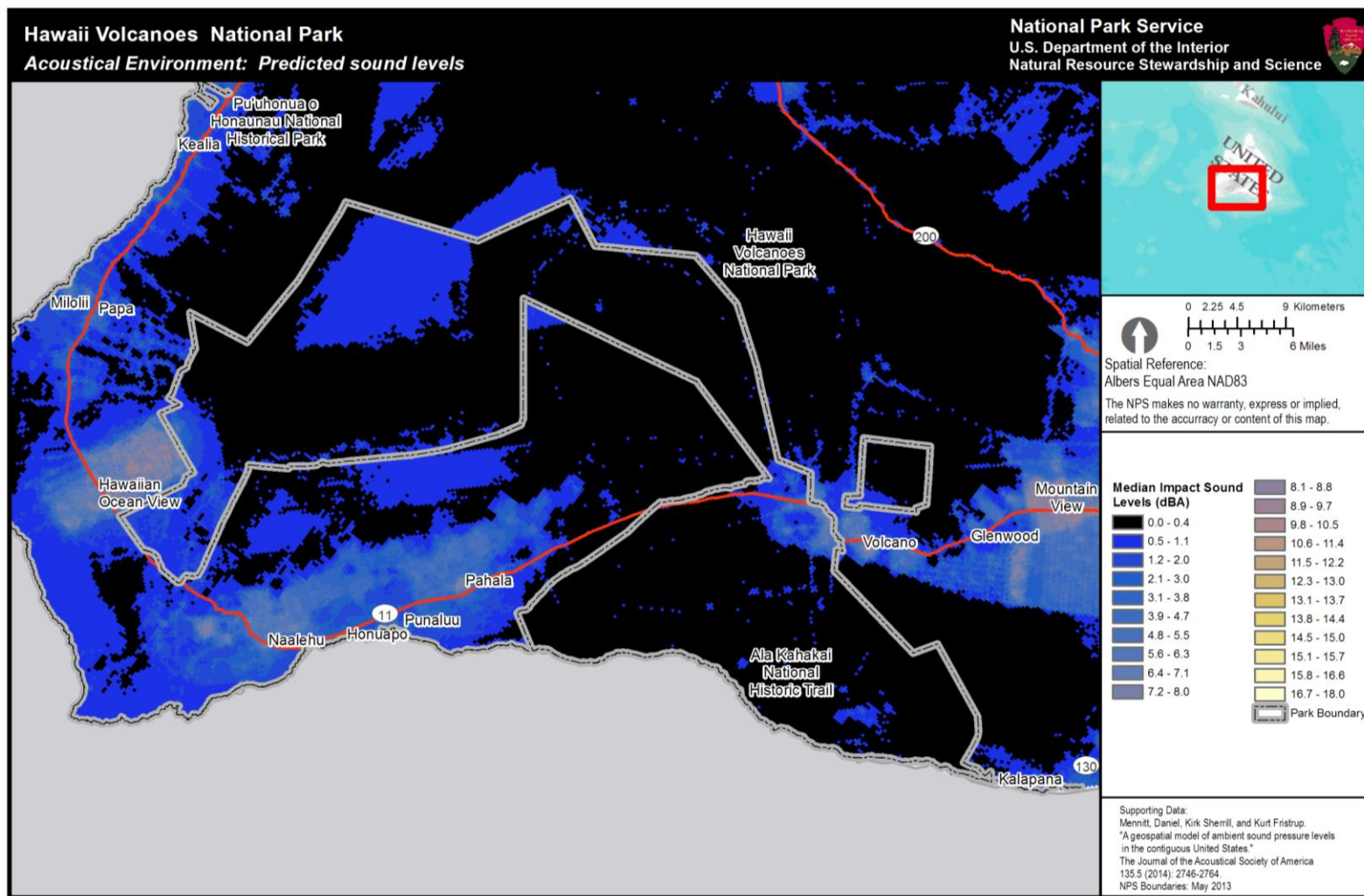
Appendix B: Modeled Impact Levels

NSNSD developed a model (Mennitt et al. 2014) that predicts the median sound level using measurements made in hundreds of national park sites as well as 109 explanatory variables such as location, climate, land cover, hydrology, wind speed, and proximity to noise sources such as roads, railroads, and airports. It is important to note that the model does not account for air traffic, including air tours. Unlike roads, air traffic has more variability in routes and noise, which is why it was not included in the model.

The resulting model (Mennitt et al. 2014) predicts sound levels anywhere in the contiguous U. S., and also estimates how much lower these sound levels would be in the absence of human activities. The same methods were used to create a model for Hawaii, although certain base-layer data were from different sources than the original model (for example the vegetation maps layers were designed differently). The difference between the modeled existing and modeled natural sound level (L_{50} impact) at HAVO is shown in Figure 16, and provides a measure of how much anthropogenic noise is increasing the existing sound level above the natural sound level, on an average summer day. At HAVO, the mean modeled sound level impact is 0.3 dBA (ranging from 0 decibels (dBA) in the least impacted areas to 7.4 decibels (dBA) in the most impacted areas). The average existing sound level is predicted to be 0.3 dBA above natural conditions. Figure 16 shows a map of predicted acoustic impact levels in the park for an average summer day. The color scale indicates how much man-made noise increases the sound level (in A-weighted decibels, or dBA), with 270 meter resolution. Black or dark blue colors indicate low impacts while yellow or white colors indicate greater impacts. Note that this graphic may not reflect recent localized changes such as new access roads or development and does not include air traffic. The mean acoustic impact level at the park is 0.3 dBA and the median is 0.1 dBA. Each pixel in the graphic shown in Figure 16 represents 270 m.

For reference in translating sound level impacts into functional effects (for human visitors and resident wildlife), an increase in background sound level of 3 dB produces an approximate decrease in listening area of 50%. In other words, by raising the sound level at HAVO by just 3 dB, the ability of listeners to hear the sounds around them is effectively cut in half. Furthermore, an increase of 7 dB leads to an approximate decrease in listening area of 80%. An increase of 0.3 dBA would reduce the listening area for wildlife and visitors by 6.7%. For example, if a predator can hear a potential prey animal in an area of 100 square feet in a setting with natural ambient sounds, that animal's ability to hear would be reduced to 93 square feet if the sound levels were increased by 0.3 dBA.

Modeled metrics and on the ground park-based metrics were similar. This modeled data continues to demonstrate that sounds intrinsic to the park are a resource important to protect in the park environment. Compared to parks throughout the national park system, this is a low number and shows a prominence of natural sounds and natural quiet that should be preserved and protected.



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Figure 16. Map of predicted acoustic impact levels in the park for an average summer day. The mean acoustic impact level at the park is 0.3 dBA and the median is 0.1 dBA.

Appendix C: Example Air Tour Route

Figure 17 displays an example of two known aircraft flights over HAVO. These two flights are along the same route and display minimum variation. The portion of this route that travels over HAVO occurs over the northeast boundary of the park, while the acoustic monitoring sites are based in the western section of the park. These flight routes were obtained using ADS-B technology at the website Flightaware.com on May 23, 2017. The flights occurred on May 9, 2017 on a Bell 407 helicopter. The flight was identified by entering known air tour operator's aircraft tail number into Flight Aware; consider this and the similarity of the two separate flight tracks likely means the tracks are actual air tours.

Take note of the substantial terrain shielding by Mauna Loa Volcano between the aircraft route and the acoustic monitoring sites. Of the four monitoring sites, the closest portion of the aircraft route is near HAVO007, which is over 20 kilometers (13 miles) away. Therefore, the aircraft noise picked up by our audio equipment in this study were very likely from a different route, particularly since the aircraft recorded was a fixed wing.

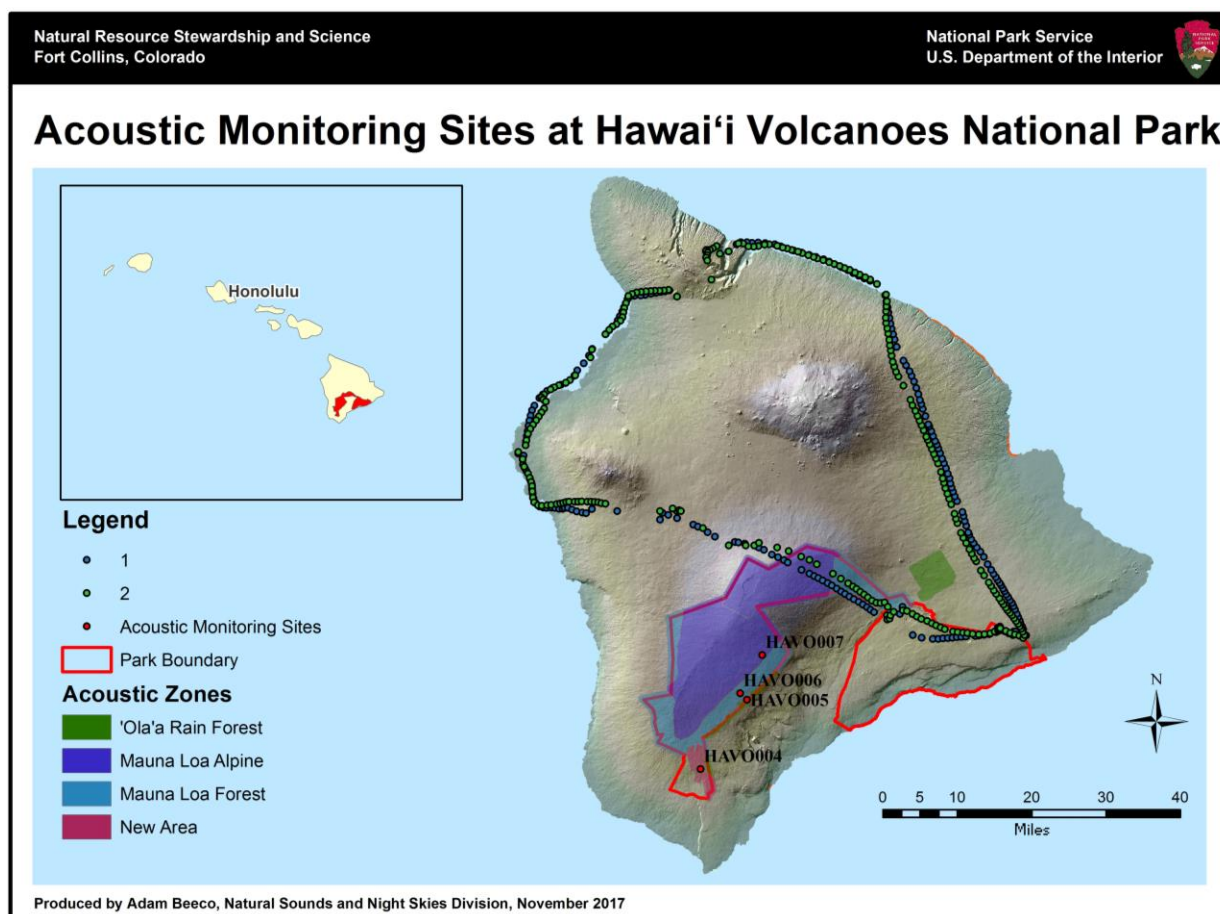


Figure 17. An example of a known aircraft route at HAVO.

Appendix D: Additional Acoustic Metrics

Additional metrics like Day-Night Level (DNL) and the average sound pressure level (LAeq) are frequently used in acoustic literature but are not typically reported in standard acoustic monitoring reports from the National Park Service. DNL is not typically reported by NPS because it is human-centric, development-centric metric that penalizing sounds which occur at night because they are more likely to disturb human sleep in an urban or suburban environment. While sleep disturbance is something we certainly want to avoid in parks, DNL does not distinguish between natural sounds and noise which occur at night (it penalizes both equally).

Both of these metrics represent the values over a 24-hour day and are A-weighted. The metrics in this appendix are discussed in the report but are provided here to give the park additional information about the acoustic environment. They are in this section as a reference and comparison to additional research that measures acoustic indices.

Table 20. Provides DNL and LAeq metrics across the four sites.

Site	Frequencies	DNL	LAeq
HAVO004	12.5-20,000	52.1	33.5
HAVO005	12.5-20,000	58.8	42
HAVO006	12.5-20,000	44.3	27.4
HAVO007	12.5-20,000	41.4	20.9

Table 21. Provides the median SPL of aircraft noise heard at each site. The interquartile range describes the SPL that 50% of the aircraft fall under. For example at HAVO004 50% of the aircraft recorded had an SPL between 40.1-60.3 dBA.

Site	Frequencies	Median MaxSPL Aircraft (dBA)	Interquartile Range ± (dBA)
HAVO004	12.5-20,000	50.2	10.1
HAVO005	12.5-20,000	51.4	16.2
HAVO006	12.5-20,000	41.2	7.6
HAVO007	12.5-20,000	31.4	2

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