National Park Service
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Natural Resource Stewardship and Science

# Haleakalā National Park

## *Acoustic Monitoring Report*

Natural Resource Report NPS/NRSS/NSNS/NRR—2018/1678

**ON THE COVER**
Nu'u unit of Haleakalā National Park
Photograph by: Jessica Briggs, NPS

# Haleakalā National Park

## *Acoustic Monitoring Report*

Natural Resource Report NPS/NRSS/NSNS/NRR—2018/1678

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# Executive Summary

In 2013, the Natural Sounds and Night Skies Division (NSNSD) received a request to collect baseline acoustical data at Haleakalā National Park (HALE). Between September and November 2013, one acoustical monitoring system was deployed for approximately 58 days within the park boundary. The goal of the study was to establish a baseline soundscape inventory of the newly acquired Nu'u unit, as well as inform possible air tour management at HALE. This inventory will be used to establish indicators and thresholds of soundscape quality that will support the park and NSNSD in developing a comprehensive approach to protecting the acoustic environment through soundscape management planning. Results of this study will help the park evaluate the exposure of this area to overflight noise, as well as provide a baseline understanding of the acoustical environment for use in potential future comparative studies. Previous studies at HALE related to noise from overflights, including two ambient measurement studies, social science research, and an ethnographic study, are summarized in Lynch 2012.

For the purposes of this document, we will refer to "noise" as any human-caused sound that masks or degrades natural sounds (Lynch et al. 2011). Ambient sound pressure level (SPL) was measured continuously every second over the 58 day monitoring period by a calibrated, Type 1, Larson Davis 831 sound level meter. Trained technicians calculated percent time audible metrics after monitoring was complete. See Methods section for protocol details, equipment specifications, and metric calculations. Median existing ($L_{50}$) and natural ambient ($L_{nat}$) metrics are also reported for daytime (0700–1900 hours) and nighttime (1900-0700 hours). Prominent noise sources in the Nu'u unit included aircraft and a non-natural unknown low frequency rumble that the listening lab technician thought was most likely nearby farm equipment. Table 1 displays percent time audible values for each of these noise sources during the monitoring period, as well as ambient sound levels.

**Table 1.** Mean percent time audible for extrinsic, aircraft, and non-natural unknown noise sources, existing and natural ambient sound levels at HALE004.

| | | Mean percent time audible noise (in 24 hour time period)a | | | Median Existing Ambient (L50) in dBAb | | Median Natural Ambient (Lnat) in dBA | |
|---|---|---|---|---|---|---|---|---|
| **Site ID** | **Site Description** | **All Extrinsic** | **Aircraft** | **Non-natural unknown** | **Dayc** | **Nightc** | **Day** | **Night** |
| HALE004 | Nu'u | 36.0 | 25.0 | 11.7 | 23.5 | 22.3 | 21.1 | 21.7 |

[a] Over a 24-hour period, based on eight days of analysis.

[b] For comparison, nighttime sound level in a typical residential area is about 40 dBA.

[c] Day hours are 0700-1900; night hours are 1900-0700.

In determining the current conditions of an acoustical environment, it is informative to examine how often SPLs exceed certain values. Table 2 reports the percent of time that measured levels at HALE004 were above four key values. The first value, 35 dBA, is designed to address the health effects of sleep interruption. Recent studies suggest that sound events as low as 35 dB can have

adverse effects on blood pressure while sleeping (Haralabidis et al. 2008). This is also the desired background sound level in classrooms (ANSI S12.60-2002). The second value addresses the World Health Organization's recommendations that noise levels inside bedrooms remain below 45 dBA (Berglund et al. 1999). The third value, 52 dBA, 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 dBA, 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. The top value in each split-cell focuses on frequencies affected by low frequency noise sources (20-1250 Hz), whereas the bottom values use the full frequency range (12.5-20,000 Hz) collected. 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. Therefore, the truncated range (20-1250 Hz) is more appropriate for identifying impacts from anthropogenic noise in parks (Acoustical Society of America 2014).

**Table 2.** Percent time above metrics for HALE004.

| Site ID | Frequency (Hz) | % Time above sound level: 07:00 to 19:00 (Day) | | | | % Time above sound level: 19:00 to 07:00 (Night) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 35 dBA | 45 dBA | 52 dBA | 60 dBA | 35 dBA | 45 dBA | 52 dBA | 60 dBA |
| HALE004 | 20-1250 | 3.06 | 0.82 | 0.17 | 0.02 | 0.26 | 0 | 0 | 0 |
| | 12.5-20,000 | 6.05 | 1.05 | 0.21 | 0.02 | 1.08 | 0.07 | 0 | 0 |

# Acknowledgments

The authors of this report wish to express their gratitude to Jessica Briggs and Christopher Garsha for their work in deploying the acoustic monitoring station and off-site analysis of the acoustical data. HALE staff members who assisted with site deployment included Liz Gordon and Timmy Bailey. The authors would also like to thank Emma Brown and Vicki Ward for their review of a draft of this report.

# Glossary of Acoustical Terms

Acoustical Terms

| Term | Definition |
| --- | --- |
| 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 | Include 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 dB (A). |
| 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, different species of animals and humans are capable or 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 acoustical environment of the park. |
| $L_{50}$, $L_{90}$ | 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 $L_{50}$ value, while 90 percent of the time the measured levels are higher than the $L_{90}$ value. |
| $L_{dn}$ | 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. |
| $L_{eq}$ | Energy Equivalent Sound Level. The sound energy level averaged over the measurement period. |
| $L_{nat}$ (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. |

Acoustical Terms, continued

| **Term** | **Definition** |
|---|---|
| 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 | 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 either by a trained observer (on-site listening) or by making high-quality digital recordings for later playback (off-site listening). |
| 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 | The NSNSD differentiates between the use of *sound* and *noise*, since these definitions have been used inconsistently in the literature. Although *noise* is sometimes incorrectly used as a synonym for sound, it is in fact sound 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 physical sound resources. |

# 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). Acoustical 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 acoustical issues raised by Congress, 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, park planning support, and comparative analyses 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[1] 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

[1] The 2006 Management Policy 4.9 and related documents refer to "soundscapes" instead of "acoustic resources." When quoting from this authority, it is advisable to note that the term often refers to resources rather than visitor perceptions.

> 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, "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).

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

Haleakalā National Park (HALE) was formally established in 1961, after being split from Hawai'i Volcanoes National Park in what was formally known as Hawai'i National Park. HALE is located on the island of Maui. Within the Park, approximately 24,000 acres are designated as a Wilderness Area. The Nu'u parcel, is one of Maui's largest undeveloped tracts of land, to ensure that critical cultural and natural resources would be preserved and protected for future generations the park service acquired this parcel in 2008 (NPS 2016). There is little access to the unit, Pillani highway sits at the furthest southern edge of the unit and visitation by the public is restricted.

The NPS Nu'u parcel, is significant because it:

• Contains rare, threatened and endangered plant and animal species. - Habitat protection offers refugia for these species, especially the 'ua'u.

• Once contained tropical dryland forest, which are among the most diverse yet threatened ecosystems in the world. These forests supported an abundance of native Hawaiian flora and fauna, some of which is found nowhere else in the world.

• Is a near-ideal candidate for restoration of tropical dryland forest.

• Includes many significant Hawaiian cultural sites. Protecting the Nu'u parcel helps preserve places, resources, and stories held sacred by Native Hawaiians (NPS 2016).

During the fall of 2013, one acoustic monitoring station was deployed in the Nu'u unit, in the southwestern arm of the park. Table 3 shows site information regarding the monitoring station. Figure 1 shows the location of the acoustic monitoring station in the Nu'u unit along with acoustic data previously collected in the park. Photos of the acoustic monitoring station site (HALE004) are in Appendix A

**Table 3.** HALE acoustical monitoring site.

| Site ID | Site Name | Dates Deployed | Vegetation | Elevation (m) | Latitude | Longitude |
|---|---|---|---|---|---|---|
| HALE004 | Nu'u | 9/17/2013 – 11/14/2013 | Tropical grassland | 364 | 20.645632 | -156.186704 |

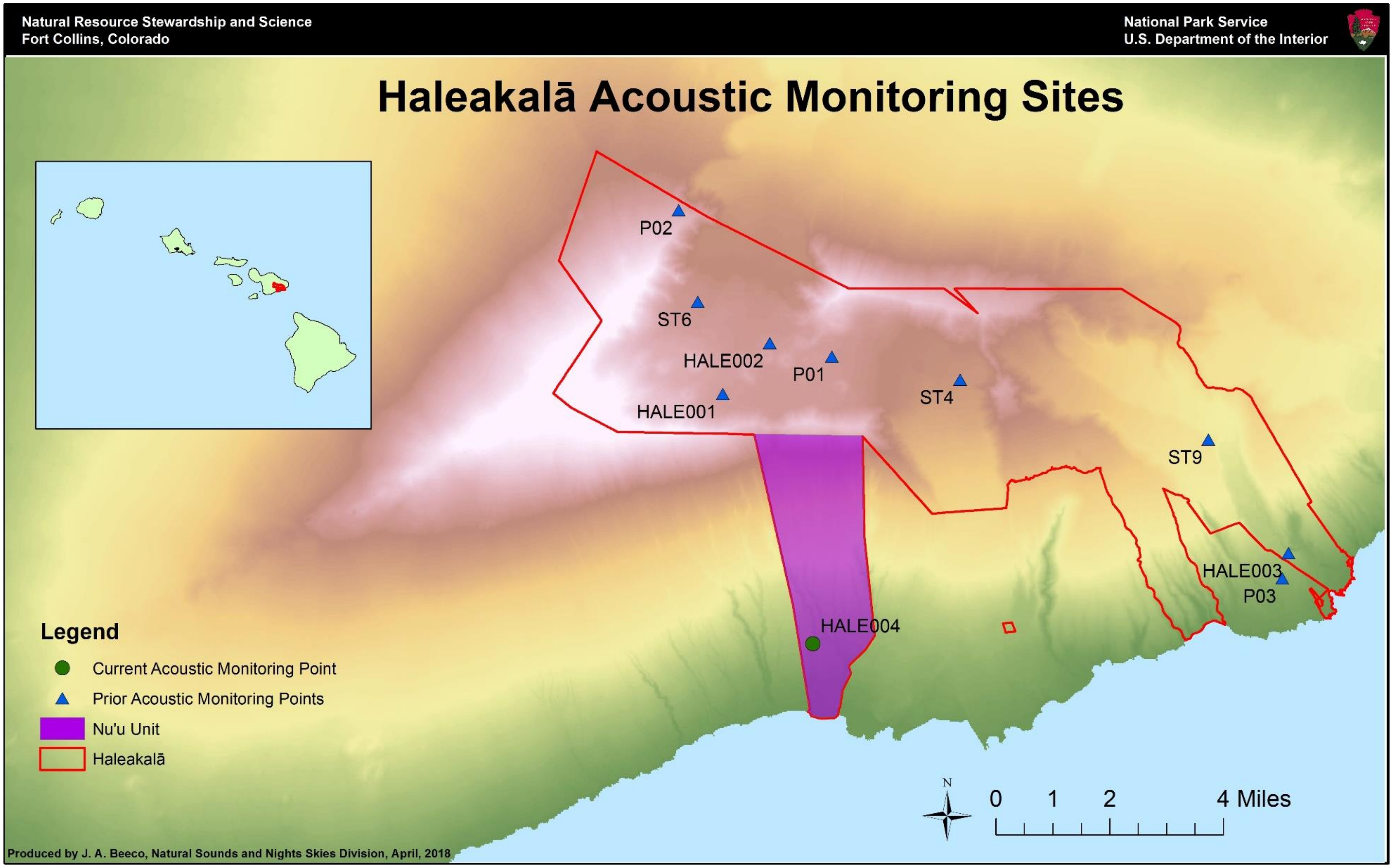


**Figure 1.** Location of acoustic monitoring site at Haleakalā National Park.

# Methods

## Automatic Monitoring

A Larson Davis 831 sound level meter (SLM) was deployed over the 58-day monitoring period at the HALE site. The Larson Davis SLM is a hardware-based, real-time analyzer which continuously records one second SPL and 1/3 octave band data. This Larson Davis-based site met American National Standards Institute (ANSI) Type 1 standards. The sound level meter provided the information needed to calculate metrics described below in Calculation of Metrics.

The sampling stations consisted of:

- Microphone with environmental shroud
- Preamplifier
- 12 V alkaline battery packs
- Anemometer (wind speed and direction)
- Relative humidity and temperature sensor
- MP3 recorder

The sampling stations collected:

- SPL data in the form of A-weighted decibel readings (dBA) every second
- Continuous digital audio recordings (stopped recording after 8 days)
- One-third octave band data every second ranging from 12.5 Hz – 20,000 Hz
- Continuous meteorological data for wind speed, relative humidity, and temperature

## Calculation of Metrics

The status of the acoustical environment can be characterized by spectral measurement. Spectral measurements, durations, and overall sound levels (intensities) can characterize the status of the acoustical environment. The NSNSD uses descriptive figures and metrics to interpret these characteristics. Two fundamental descriptors are existing ambient ($L_{50}$) and natural ambient ($L_{nat}$) sound levels. These are both examples of exceedance levels, where each $L_x$ value refers to the SPL that is exceeded x% of the time. The $L_{50}$ represents the median SPL, and is comprised of spectra (in dBA) drawn from a full dataset (removing data with wind speed > 5m/s to eliminate error from microphone distortion). The natural ambient ($L_{nat}$) is an estimate of what the ambient level for a site would be if all extrinsic (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):

$$x = \frac{100 - P_H}{2} + P_H \quad , \qquad (1)$$

$P_H$ 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. To summarize and display these data, the median of the hourly $L_{nat}$ values for the daytime hours (0700-1900) and the median of the hourly $L_{nat}$ values for the nighttime (1900-0700) are displayed in Figure 3 in the results section. Additionally, this figure separates the data into 33 one-third octave bands.

## On-site Listening

While the sound level meter provides information about how loud or quiet the acoustical environment is at a given time, we need .mp3 recordings or on-site listening sessions to know *what* or *who* is making the sound. On-site listening places an observer near the acoustical monitoring station. The observer listens for a designated period of time and identifies all sound sources and their durations using a phone application. 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 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 acoustical environment studies. They produce an extensive inventory of sound sources, require little equipment or training, and can help educate park staff and volunteers.

Thus, two sessions of on-site listening were conducted at the acoustic monitoring site, in order to discern the type, timing, and duration during sound-level data collection As recommended by NSNSD protocol (NPS 2005), each of the two listening sessions lasted for at least one hour Staff recorded the beginning and ending times of all audible sound sources using custom-designed software. The on-site listening session provided the basis a few of the metrics provided in the report 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 the on-site listening session are summarized in Table 4.

## Off-Site Listening/ SPLAT Analysis

Off-site listening is normally done by listening to the audio recorder and simultaneously visually analyzing a spectrogram (described below). However, the audio recorder at the acoustic monitoring site stopped recording 8 days into the monitoring period, preventing an auditory analysis from being conducted. The site is fairly remote and visitation is restricted in the Nu'u unit, limiting the number of potential noise sources at the site. As such, an analysis of SPL data was conducted using the custom built software SPL Annotation Tool (SPLAT). SPLAT converts SPL measurements for each of the 33 octave bands into a visual representation of the acoustical environment, called a spectrogram (Figure 2). A trained technician identified noise sources with unique visual signatures on the spectrogram. They then annotated these sources within SPLAT to describe their timing, duration, frequency, and amplitude. Noise sources with unique visual signatures on a spectrogram were annotated within SPLAT by a trained technician, gathering information about the timing, duration, frequency, and amplitude of these sources. The technician focused on annotating all aircraft events, as well as a continuous low frequency noise that was classified as a non-natural unknown noise source.

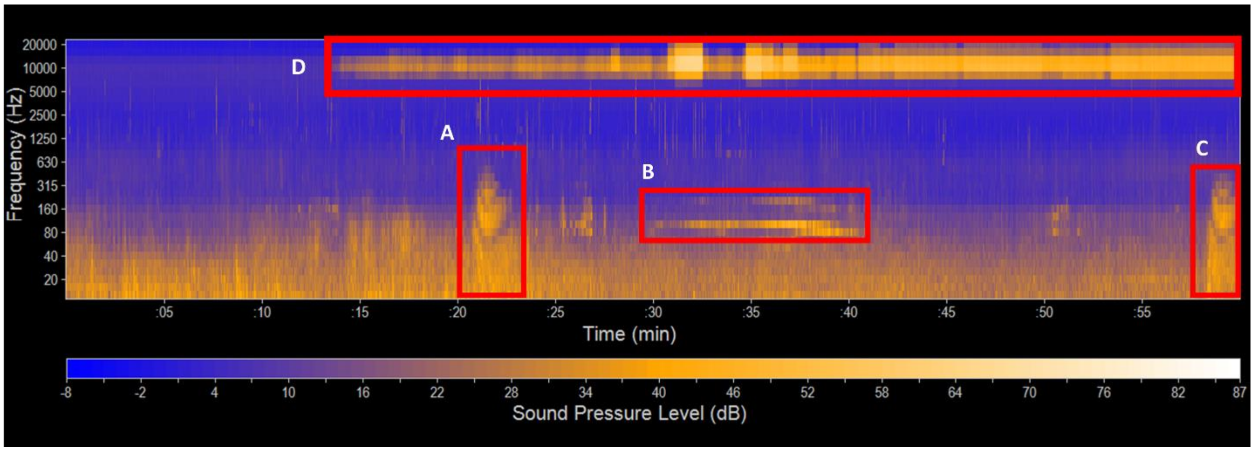


**Figure 2.** Example spectrogram in SPLAT used to annotate the presence of aircraft overflights (jet aircraft; labels ‘A’ and ‘C’), as well as a non-natural unknown noise source (label ‘B’) and natural sounds of singing birds and insects (‘D’).

# Results

## On-site Listening

Table 4 displays the results of the on-site listening sessions at HALE. Each audible sound source is listed in the first column. Percent time audible, or TA, is shown in the second column. The third column, Max Event, reports the maximum event length during the session 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. The last row in the table, noise free interval, is a metric that describes the length of time between extrinsic or human-caused events (when only natural sounds were audible). This on-site listening table is essentially a sound inventory of the monitoring site that reveals the sounds one is likely to hear at or near the monitoring site. In Table 4, the natural sounds at the site are highlighted in dark gray and the noise-free interval is highlighted in light grey. The percent time audible for all noise sources combined is 40.5 percent of the time.

**Table 4.** Summary of on-site audible sound sources for HALE004. N=2 sessions totaling 180 minutes.

| Sound Source | TA (%) | Max Event (mm:ss) | Mean Event (mm:ss) | Min Event (mm:ss) | SD (mm:ss) | Events |
|---|---|---|---|---|---|---|
| Jet | 1.1 | 01:22 | 01:22 | 01:22 | n/a | 1 |
| Propeller | 9.1 | 04:07 | 02:10 | 00:37 | 01:20 | 5 |
| Helicopter | 28.6 | 10:05 | 03:49 | 00:25 | 03:44 | 9 |
| Vehicle | 1.7 | 02:03 | 02:03 | 02:03 | n/a | 1 |
| Wind | 99.9 | 119:56 | 119:56 | 119:56 | n/a | 1 |
| Bird | 40.8 | 04:57 | 01:11 | 00:04 | 01:04 | 41 |
| Noise-free interval | – | 17:33 | 04:28 | 00:02 | 05:31 | 16 |

## Off-Site Data Analysis

### *Metrics*

In order to determine the effect that extrinsic noise audibility has on the acoustical environment, it is useful to examine the median hourly exceedance metrics. The dBA levels for 33 one-third octave band frequencies over the day and night periods are shown in Figure 3. 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, SPL 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 SPL of a site. The gray area of the graph represents 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 SPL exceeded x percent of the time. For example, $L_{90}$ is the SPL 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 SPL 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 existing ambient and natural ambient. The height of this bold portion is a measure of 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 marks the median ($L_{50}$), near maximum ($L_{10}$), and near minimum ($L_{90}$) sounds pressure levels over the 58 day monitoring period. This bar shows 80% of the SPL's recorded excluding extremes. 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.

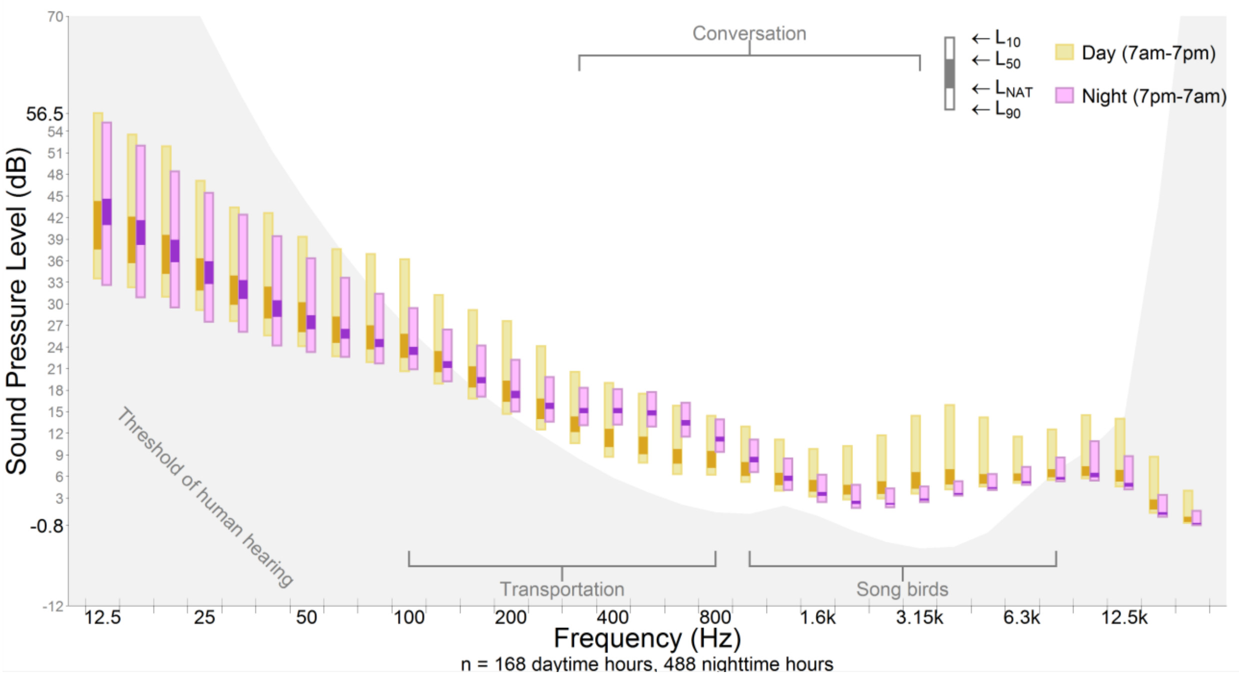


**Figure 3.** Day and night Sound Pressure Level for 33 one-third octave bands at HALE004.

Table 5 reports the $L_{90}$, $L_{nat}$, $L_{50}$, and $L_{10}$ values for the Nu'u site. The top value in each cell focuses on frequencies affected by transportation noise, whereas the lower values use the conventional full frequency range. Most human-caused noise is confined to the truncated, lower-frequency range, while many loud natural sounds, including insects and birds, are higher in pitch. Therefore, the truncated range is more appropriate for identifying noise levels in parks (Acoustical Society of America 2014). As described above, exceedance levels ($L_x$) represent the SPL exceeded **x** percent of time during the given measurement period. In Table 5, the $L_{90}$ is 19.7 dBA a 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 27.3 dBA level that has been exceeded 10% of the time, and 90% of the measurements are quieter than the $L_{10}$.

**Table 5.** Exceedance levels for existing conditions in HALE.

| Site | Frequency (Hz) | Exceedance levels (dBA): 0700 to 1900 hurs (Day) | | | | Exceedance levels (dBA): 1900 to 0700 hours (Night) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **L90** | **Lnat** | **L50** | **L10** | **L90** | **Lnat** | **L50** | **L10** |
| HALE004 | 20-1,250 | 17.2 | 18.3 | 20.7 | 27.3 | 18.4 | 19.9 | 20.6 | 23.6 |
| | 12.5-20,000 | 19.7 | 21.1 | 23.5 | 31.6 | 20.2 | 21.7 | 22.3 | 25.9 |

In determining the current conditions of an acoustical environment, it is important to examine how often SPLs exceed certain values. Table 6 reports the percent of time that measured levels were above four key values during the monitoring period (daytime and nighttime). The top value in each split-cell focuses on frequencies affected by transportation noise whereas the lower values use the conventional full frequency range. The first, 35 dBA, is designed to address the health effects of sleep interruption. Recent studies suggest that sound events as low as 35 dB can have adverse effects on blood pressure while sleeping (Haralabidis et al. 2008). This is also the desired background sound level in classrooms (ANSI S12.60-2002). The second value addresses the World Health Organization's recommendations that noise levels inside bedrooms remain below 45 dBA (Berglund et al. 1999). The third value, 52 dBA, is 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 value, 60 dBA, provides a basis for estimating impacts on normal voice communications at 1 meter. Visitors viewing scenic areas in the park would likely be conducting such conversations. The top value in each split-cell focuses on frequencies affected by lower-frequency noise (20 – 1250 Hz) whereas the bottom values use the full frequency range (12.5 – 20,000 Hz) collected. 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. Therefore, the truncated range (20 – 1250 Hz) is more appropriate for identifying impacts from anthropogenic noise in parks (Acoustical Society of America 2014).

The results of Table 6 display the difference between day and night SPLs. Additionally, these results show that both the truncated and full-spectrum values for %TA are very low for both day and night.

**Table 6.** Percent time above metrics for existing conditions in HALE.

| Site ID | Frequency (Hz) | % Time above sound level: 0700 to 1900 (Day) | | | | % Time above sound level: 1900 to 0700 (Night) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **35 dBA** | **45 dBA** | **52 dBA** | **60 dBA** | **35 dBA** | **45 dBA** | **52 dBA** | **60 dBA** |
| HALE004 | 20-1250 | 3.06 | 0.82 | 0.17 | 0.02 | 0.26 | 0 | 0 | 0 |
| | 12.5-20,000 | 6.05 | 1.05 | 0.21 | 0.02 | 1.08 | 0.07 | 0 | 0 |

## Existing Data

Acoustic data has been collected at HALE in two other periods in areas away from the Nu'u unit. In Table 7 all sites equal to or longer than 15 days are included from the VOLPE report that provided baseline ambient sound levels to the park in 2003. All data from the 2008 data collection were added to the report. The data collected in this report as well as existing data provides a good spatial and temporal representation of the acoustic environment at HALE.

**Table 7.** 2003 and 2008 soundscape data collected at HALE.

| Site Name | Year | Vegetation Type | $L_{nat}$[a] | $L_{50}$ | $L_{90}$ |
|---|---|---|---|---|---|
| Namana o ke Akua | 2003 | Shrubland | 22.5 | 24.5 | 18.6 |
| Waimoku Falls | 2003 | Forested Upland | 45.3 | 43.5 | 38.2 |
| West Rim Crater | 2003 | Shrubland | 27.7 | 27.2 | 21.5 |
| Haleakalā Crater/Silversword Loop | 2003 | Bare Rock/Sand/Clay | 21.4 | 23.5 | 19.2 |
| Haleakalā Crater/Paliku Kaupo Gap | 2003 | Shrubland | 22.6 | 22.5 | 18.8 |
| Upper Kipahulu Valley | 2003 | Evergreen Forest | 30.7 | 34.9 | 30.0 |
| Sliding Sands | 2008 | Alpine | 17.3 | 18.2 | 15.1 |
| Rain Gauge | 2008 | Alpine | 19.5 | 21.9 | 15.8 |
| Kīpahulu | 2008 | Coastal | 38.0 | 38.9 | 35.1 |
| Nu'u Unit | 2013 | Tropical Grassland | 21.9 | 23.4 | 20.1 |

[a] It should be noted that Volpe (2003) and NPS (2008 & 2013) used different techniques to calculate natural ambient. See the "Calculation of Metric" section in this report for NPS protocol. See Lee, et. al. 2006 for Volpe protocol

### *Audibility of noise sources*

Identifying the percent of time a noise source is audible is an important step in understanding the acoustic environment. As stated above, only 8 days of audio recordings were captured due to an equipment failure. 8 shows the mean percentage of time that aircraft and non-natural unknown noise sources were audible by hour, based on eight days of off-site SPLAT analysis.

The results in Table 8 suggest that aircraft (which does not distinguish between jets, propeller planes, and helicopters) can be heard nearly the entire day. There is a concentration of helicopters from

0800-1600 hours. Additionally, the noise source labeled ‘non-natural unknown’ is heard throughout the entire night, but not during the morning and afternoon hours.

Figures 4 and 5 show hourly audibility results and compare overall noise audibility to that of aircraft and non-natural unknown noise sources. The results of Figure 4 and 5 suggest that aircraft is a major contributor of daytime noise, while the non-natural unknown noise source is a major contributor of nighttime noise.

The highest hourly SPL over a 24-hour period for aircraft, helicopter and jet events are graphically represented in Figure 6. Jets are shown in blue, helicopters in red, and aircraft that could not be classified are shown in green. Helicopters and propeller planes can be hard to distinguish from one another and are often marked under the general term ‘aircraft’ if there is uncertainty. The existing ambient SPL of each hour is shown with a dark gray square. The existing ambient is influenced by all the natural and non-natural sound sources from a particular period (an hour in this case) including aircraft events. A technique called alpha blending was used to plot the Maximum Sound Pressure Level (Max SPL) of events over the course of the monitoring period by hour. Alpha blending is the process of graphing multiple translucent events that combine with each other to form increasingly opaque blocks representing increasing event intensity. The increased opacity of the square means there was a higher occurrence of events for that hour (x-axis) that registered at that decibel level (y-axis).

**Table 8.** Mean hourly percent time audible for each noise source at HALE004. 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 | 2.2 | 4.1 | 4.6 | 3.6 | 11.4 | 0.6 | 6.9 | 33.1 | 28.3 | 27.1 | 17.7 | 13.2 | 15.6 | 17.1 | 18.5 | 26 | 29.3 | 27.8 | 33.1 | 20.4 | 12.6 | 16.2 | 2.5 | 0.8 |
| Jet | 0.7 | 0 | 0 | 4.8 | 0 | 7.9 | 5.2 | 3.5 | 1.9 | 0 | 1.1 | 0.6 | 2.5 | 0 | 0.4 | 1.1 | 5 | 4.6 | 6.9 | 6.4 | 2.5 | 0 | 3.7 | 0 |
| Propeller Plane | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Helicopter | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 39 | 39.9 | 30.9 | 13.6 | 4.3 | 1.3 | 4.7 | 8 | 5.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Non-Natural Unknown[a] | 13 | 14 | 17.3 | 23.5 | 17.4 | 19 | 24 | 8.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.2 | 1.9 | 12.6 | 31.6 | 24.3 | 14.7 | 22.5 | 25.1 |
| Thunder | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.9 | 5.4 | 3 | 1.9 |

[a] Non-natural unknown sound sources are associated with human activity, but their exact identity is unclear.

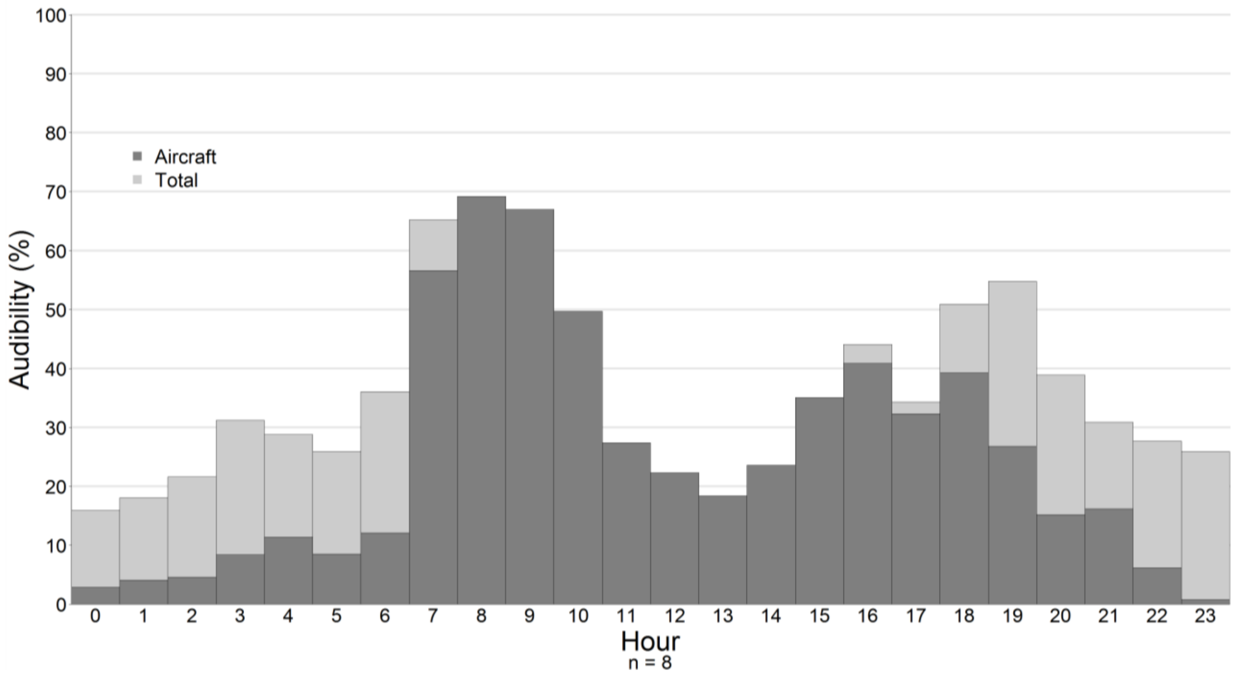


**Figure 4.** Comparison of hourly aircraft and overall noise audibility at HALE004. N=8 days off-site sound source analysis.

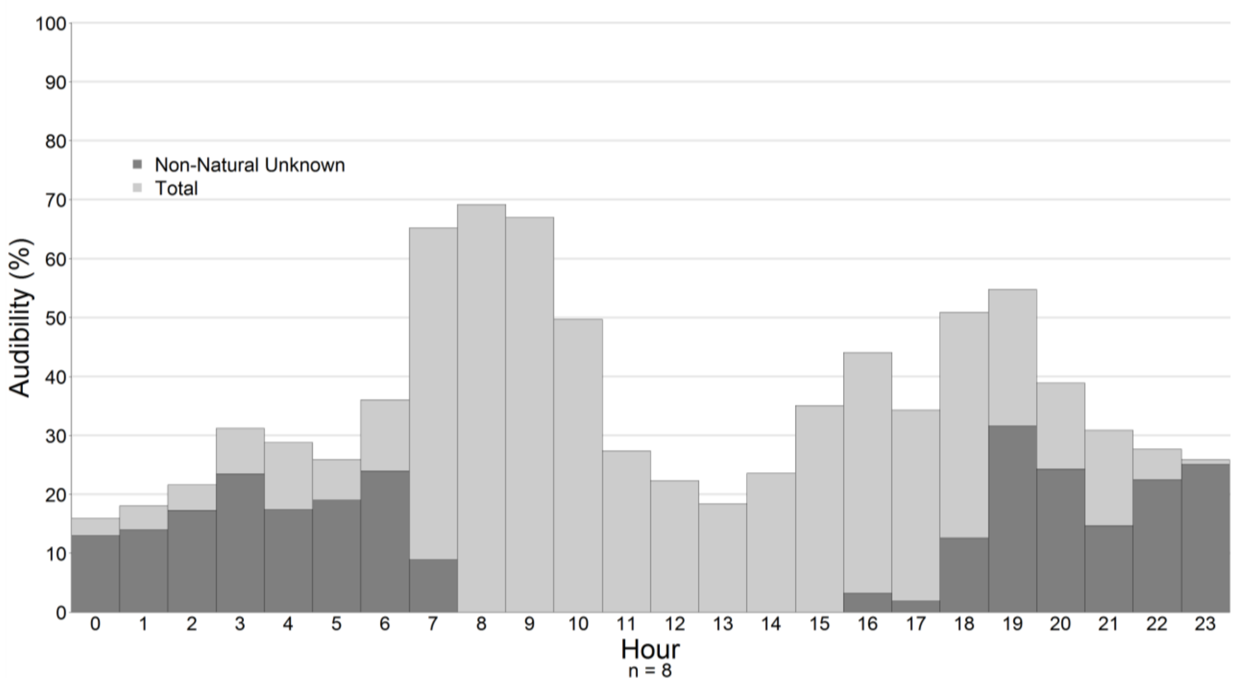


**Figure 5.** Comparison of hourly non-natural unknown noise sources and overall noise audibility at HALE004. N=8 days off-site sound source analysis.

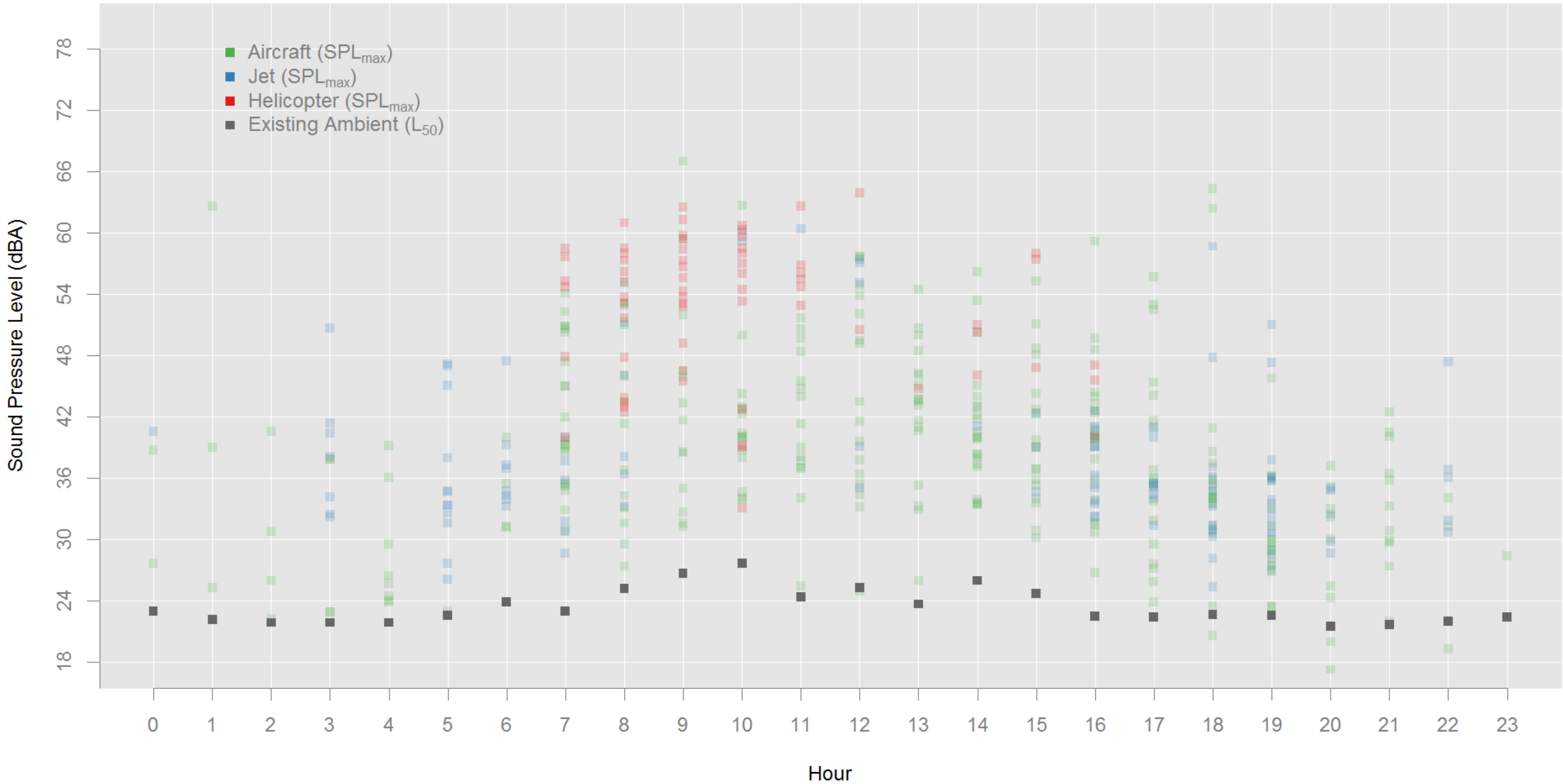


**Figure 6**. Combined hourly Max SPL for all aircraft recorded during the monitoring period at HAVO004, Nu'u Unit, over the course of the 24-hour day.

# Discussion

The purpose of this study was to assess current conditions of the acoustical environment at the Nu'u unit incorporated into HALE. Monitoring results characterize existing sound levels and estimate natural ambient sound levels within the park, which are intended to provide baseline information and inform management decisions, specifically with respect to aircraft. SPL data and meteorological data were collected from one site for approximately 58 days, while continuous audio were only recorded for 8 days due to equipment failure. The acoustical monitoring station was chosen to assess the effects of noise from an isolated section of the park with abundant natural and cultural resources but currently without the presence of visitors.

Results indicate that the estimated natural ambient sound levels ($L_{nat}$) during the monitoring period at HALE004 were 21.1 dBA during the daytime and 21.7 dBA at night (Table 5). Existing ambient sound levels ($L_{50}$) were slightly higher with daytime ambient over the 12-hour period being 23.5 dBA and 22.3 dBA at night. These results show that there was more anthropogenic noise during daytime than during the night. We do not have any other data from the Nu'u unit but we do have data from other parts of the park for comparison. Compared to ten other sites in the park, it is the fourth quietest. HALE004 is nearly average in its ambient and natural ambient level with a higher level of disturbance than HAVO001 and HAVO003 but lower than HAVO002. According to these results 1.5 dBA were added to the acoustic environment which would cause a 29% decrease in listening area of wildlife on average. Increased sound levels may have wide ranging effects on wildlife such as reduced predatory success (Mason 2015) to increased vigilance by keystone species (Shannon et al. 2014).

Natural ambient SPLs were very similar across the daytime and nighttime. Figure 3 shows the differences in octave bands across the day and night. Birds added to the natural soundscape during the day. Mid frequency sounds between 400 Hz and 800 Hz were higher at night. The increase in daytime ambient SPL over nighttime can be attributed to anthropogenic noise sources, like aircraft. Figure 3 clearly shows the difference between daytime and nighttime SPL's across all frequency bands. There is a clear dawn chorus when looking at frequencies common to songbirds in Figure 3, this is confirmed in the spectrograms. The dawn chorus at HALE004 shows that the natural soundscape here is dominant and demonstrates why the natural soundscape is considered as an important resource defined in the Haleakala Foundation Document Overview (NPS 2015). Table 5 shows that the truncated frequencies and full frequencies have the same pattern of increase from natural ambient to existing ambient for both day and night, showing that anthropogenic noise was present in low frequency bands. Table 6 shows that exceedance for each of the categories rarely occurred. The loudest occurrence 0.2% over 60 dBA are associated with aircraft as shown in the decibel values of aircraft in Figure 6.

Despite the low overall SPLs, noise still exists at HALE. The mean 24 hour percent time audibility of noise was 36.0% and an annotated analysis of spectrograms created using SPLs indicated that noise from aircraft was present for 25.0% of day and nighttime hours (Table 1; see the Aircraft section below). A non-natural unknown source was present 11.4% of the time. The spectrogram image of this noise source (Figure 2) is consistent with motorized noise and the acoustic technician thought that the source might be farm equipment from a neighboring farm but could not be sure from spectrograms, and therefore was conservative in the designation of this source. Tables 4 and 5 illustrate that aircraft noise was most prominent during daytime hours (0700-1900) and that the non-natural unknown noise source mostly occupied nighttime hours (1900-0700).

The noise-free periods at the park measured during on-site listening (table 4) provide another important metric. Results found a mean noise-free period of 4:28 over the 180 minute sampling period. This result suggests a relatively fragmented soundscape with brief interruptions.

Figure 6 shows all the aircraft events (excluding one propeller plane) that occurred over the 8-day analysis of the audio data. Overall, there were 453 aircraft events, 66 of those were easily notated as helicopters. Helicopters have a clear pattern of use between the daytime hours between 700-1100. These events tend to be, on average louder at the Nu'u site than the other two types of aircraft. Many of the aircraft events have a Maximum SPL that exceeds the $L_{10}$ of 30.6 or 25.9 (daytime and nighttime) meaning that aircraft events are in the top 10% of the highest SPL events at Nu'u. The majority of the time conditions at the park are quiet but occasional loud events were recorded. Listeners, both wildlife and humans, would could expect the loudest 10% of sound pressure levels (1 second) to be around 30.6 dBA during the daytime at Nu'u while the average of the 10 loudest aircraft signals at the site were 63.3 dBA (9.6-fold increase).

A recent study found that anthropogenic noise doubled background sound levels in 63% of U.S. protected area units and caused a 10-fold or greater increase in 21%, surpassing levels known to interfere with human visitor experience and disrupt wildlife behavior, fitness, and community composition (Buxton 2017). The Nu'u unit has a daytime ambient that is 2.4 dBA above natural ambient, but there are hours throughout the day that had an average increase in noise higher than 3 dBA. This increase occurred from 800-1000 which Figure 6 shows as the highest and loudest concentration of aircraft traffic at the site. During these hours anthropogenic noise doubled background sound levels.

## Aircraft

To understand how aircraft influence a soundscape the intensity of the aircraft noise, the amount of time aircraft are audible, and the type of aircraft must be considered.

The intensity of noise can be understood by comparing the $L_{nat}$ and $L_{50}$ in Table 5. During the daytime hours $L_{nat}$ was 21.1 dBA, while $L_{50}$ was 23.5 dBA. For the nighttime hours the $L_{nat}$ was 21.7 dBA and $L_{50}$ was 22.3 dBA. While this increase in dBA can be attributed to noise, it cannot solely be attributed to aircraft. However, Figure 4 does suggest that aircraft do contribute the majority of the noise during daytime hours, because their flights are so frequent. Because the addition in anthropogenic noise at this site comes from the low frequency truncated range as shown by the consistent levels of increase (2.4) across dBA and dBT this increases support not only for the number of aircraft but for the increased noise in the acoustic environment. As a reminder dBA includes the full frequency range, while the dBT includes only low frequencies commonly associated with transportation.

The off-site data analysis for the audibility portion of the study focused on the 8-day sub-sample. This portion of study found that “aircraft” were audible nearly all hours of the day (Table 7) and were audible 25.0% of the time overall (Table 1). However, “aircraft” is a catch all term for jets, propeller aircraft, and helicopters. This is also true for Figure 4, which identifies “aircraft” as a consistent contributor of noise.

Identifying the specific types of aircraft can sometimes be more challenging. The on-site portion of the study (Table 4) identified one jet, 5 propeller aircraft, and 9 helicopters over 180 minutes. This suggests that helicopters may be the primary source of aircraft noise. Further, because thousands of air tours are reported over HALE every year, understanding how HALE's frequent air tours influence the acoustic environment and the resources the NPS protects was of interest in this study. 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. There were 1,104 air tour operations over HALE during September through November 2013. For the specific dates of this study (September 17 – November 14) 708 air tours were reported. One-hundred percent of these reported tours were helicopters. Four different operators reported these flights. Again however, we cannot definitively say that the “aircraft” noise found in this study is directly attributable to air tours because without specific tracking data of specific aircraft it is impossible to assume all the helicopter noise is actually an air tour.

Appendix D includes an example of a known aircraft route using FlightAware.com. The route was obtained by entering a known air tour operator’s tail number into Flight Aware and downloading the tracking route – making it very likely this was an actual air tour. This route does fly within 1.5 miles of the acoustic monitoring station, so it is plausible a route similar to this would be audible at the monitoring site. While not definitive, overall, this data and the on-site listening suggest helicopters may be the primary source of aircraft noise in this area of the park.

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# Appendix A: Site Photographs

**Figure 7**. HALE004, ‘Nu’u’ acoustical monitoring site looking north.

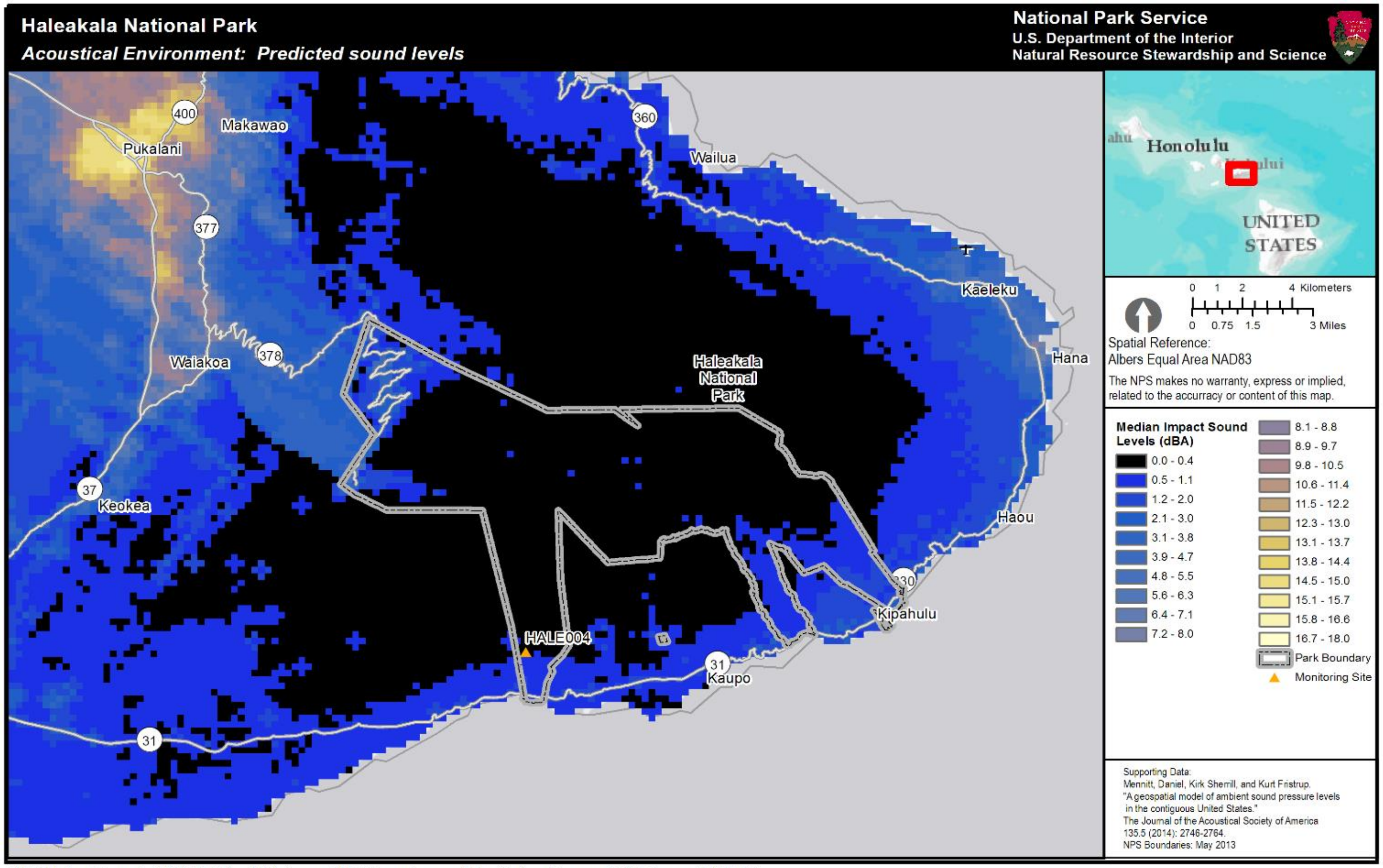
**Figure 8.** HALE004, ‘Nu’u’ acoustical monitoring site facing southeast

# Appendix B: Geospatial Modeling

NSNSD developed a geospatial sound level model (Mennitt et al. 2014) that predicts the median sound level ($L_{50}$) 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.

The model can predict sound levels anywhere in the U.S., and it can also estimate the amount that anthropogenic noise increases sound levels above natural levels. When on the ground data cannot be collected we use modeled data to predict conditions. This model was used to predict the difference between the existing ambient and natural ambient sound level at HALE (Figure 9), on an average summer day. Within the park, the median level of noise added to the environment is 0.3 dBA and ranges from 0.3 dBA-5.5 dBA. At the Nu's site the model shows an increase of 0-0.4 dBA. These modeled results underestimate the amount of anthropogenic noise added to the environment at Nu'u which was 2.4 dBA based on the acoustic data collected. Data from this report will go into the geospatial model to improve prediction capabilities.

Each pixel in the graphic shown in Figure 9 represents 270 meters For reference in translating added anthropogenic noise 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 by 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%, and an increase of 10 dB decreases listening area by approximately 90%. The modeled results of 0.3 dBA over the entire park would decrease listening area by 6.7%. The acoustic data collected in this study found an increase of 2.4 dBA which would reduce listening area by 42.5%.




NPS Natural Sounds & Night Skies Division and NPS Inventory and Monitoring Program MAS Group 20160803

**Figure 9.** Modeled median increases in sound level in the area immediately surrounding HALE and the nearby region (inset). Map of predicted increased decibel levels in the park for an average summer day. The color scale indicates how much anthropogenic noise increases the ambient sound level (in A-weighted decibels, or dBA), with 270 meter resolution. Black or dark blue colors indicate low increases while yellow or white colors indicate greater increases. Note that this graphic may not reflect recent localized changes such as new access roads or development. The mean anthropogenic increase in acoustic energy is 0.3 dBA.

## Appendix C: Example Air Tour Route

Figure 10 displays an example of a known aircraft flight over HALE. This route travels over HAVO at numerous different points along the southern border of the park. The flight makes an s-turn just south of the crater, but does not enter the crater. The acoustic monitoring site HALE004 is just to the south of the route approximately 1.5 miles. This flight track was downloaded from FlightAware.com on May 23, 2017. The flight occurred on May 22, 2017 in an EC130 helicopter for a duration of approximately 1h 9m. The flight was identified by entering a known air tour operator's aircraft registration number into Flight Aware, which likely means the track is an air tour.

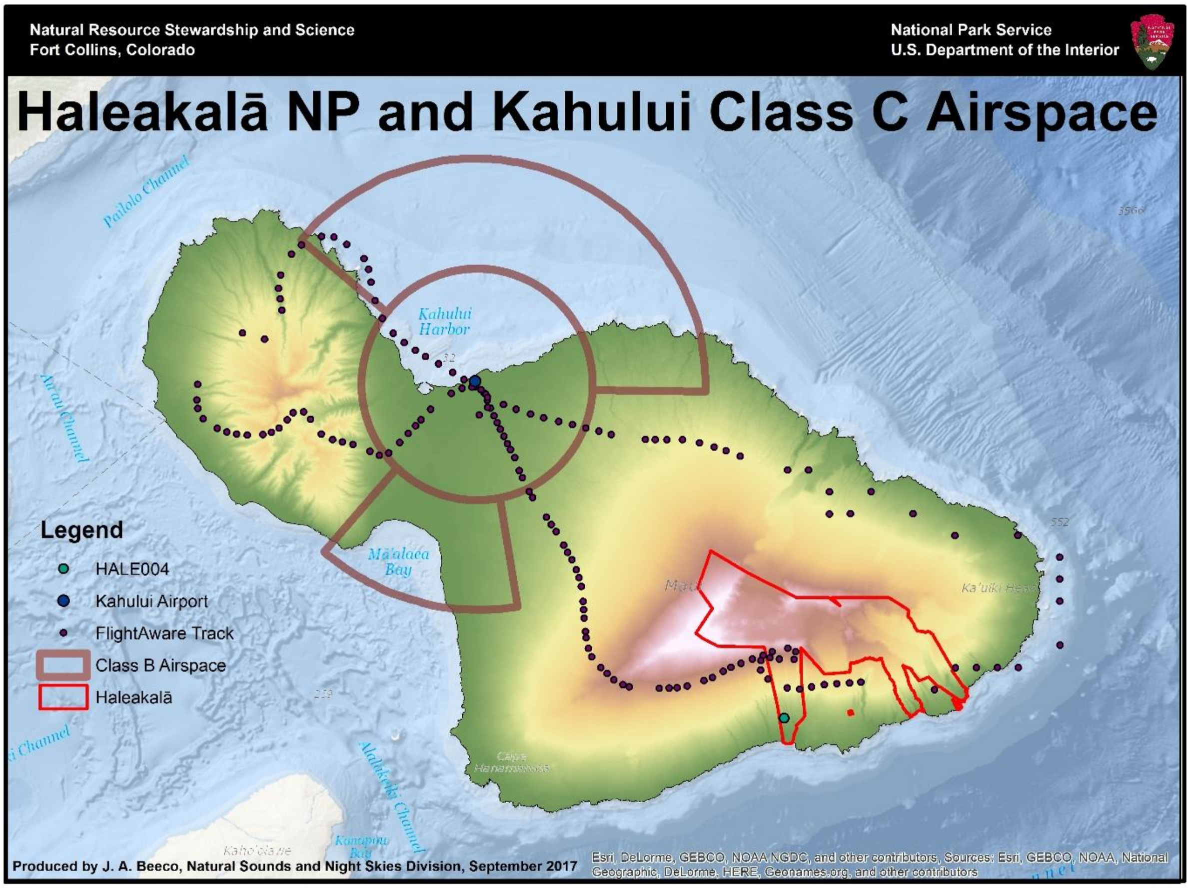



**Figure 10.** Aircraft route over HALE.

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