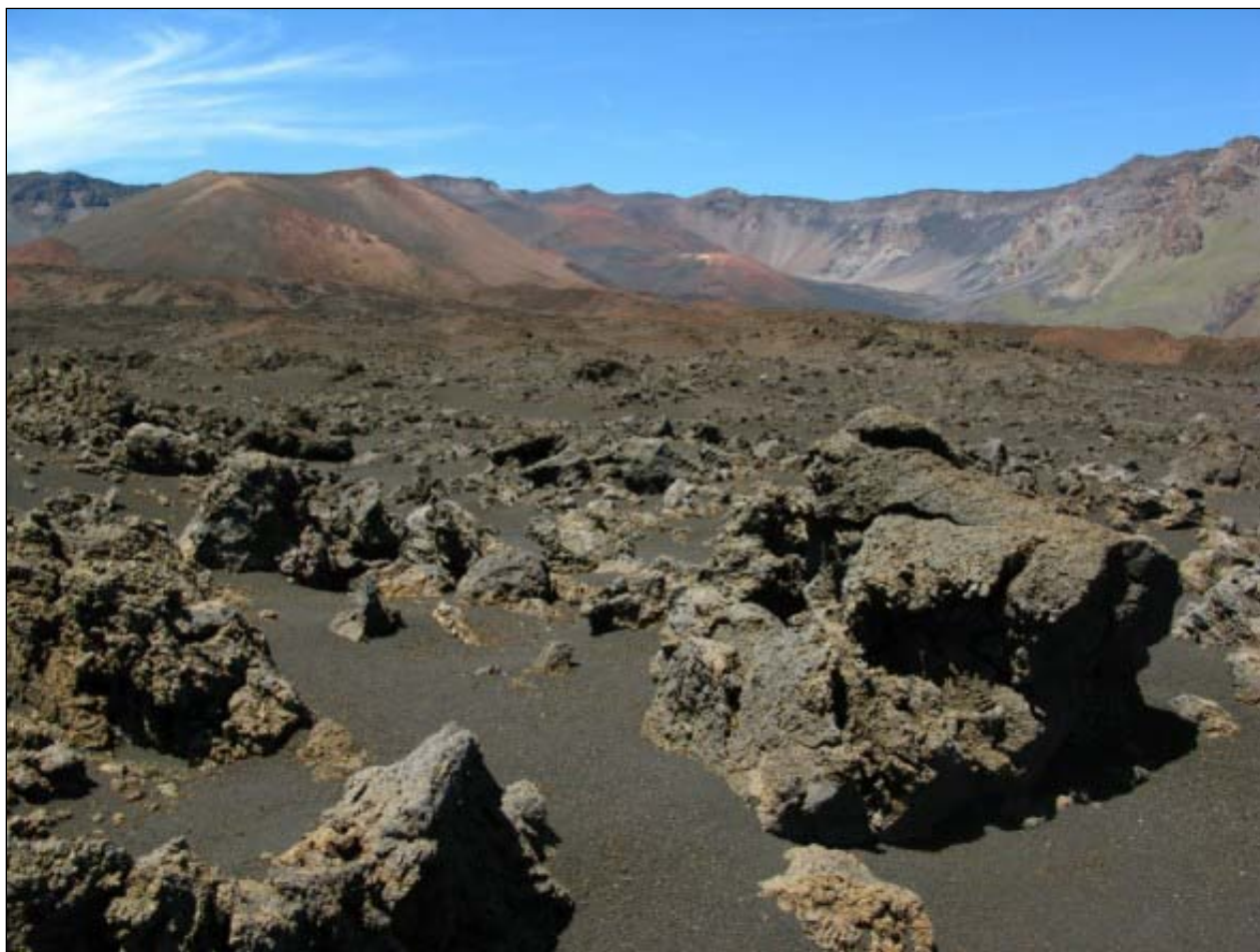




Haleakalā National Park

Acoustical Monitoring Report

Natural Resource Technical Report NPS/NRSS/NRTR—2012/549



ON THE COVER

Halemau'u Trail

NPS Photo

Haleakalā National Park

Acoustical Monitoring Report

Natural Resource Technical Report NPS/NRSS/NRTR—2012/549

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The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado publishes a range of reports that address natural resource topics of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Technical Report Series is used to disseminate results of scientific studies in the physical, biological, and social sciences for both the advancement of science and the achievement of the National Park Service mission. The series provides contributors with a forum for displaying comprehensive data that are often deleted from journals because of page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

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Executive Summary

Development of an air tour management plan (ATMP) for Haleakalā National Park (HALE) has been underway since 2003 when collection of acoustic data to establish baseline ambient conditions was conducted. Due to the length of time it has taken to develop the ATMP and substantial changes in economic conditions in Hawaii since the National Parks Air Tour Management Act was passed in 2000, the National Park Service lacks information about the current level of commercial air tour activity for HALE. Since the first measurement study in 2003, advancements in acoustic monitoring and data analysis now allow for acoustic signatures of aircraft to be easily identified in the spectral data. Therefore, with the assistance of park staff, Natural Sounds Program technicians deployed three acoustic monitoring systems in HALE (see Table 1) in spring 2008. The purpose of this measurement study was to gather data about the current level of commercial air tour operations for use in defining current conditions for the ATMP and associated environmental impact statement. Existing ambient sound levels were collected. The data will be used to estimate natural ambient and determine percent time audible statistics for sound sources and serve as a permanent record of existing acoustical conditions in the spring of 2008. Systems were deployed for thirty days to log one-second sound pressure levels and gather continuous audio recordings.

Table 1. Sites monitored in 2008

Site Location	Elevation (meters)	Latitude	Longitude
HALE001: Sliding Sands Trail	2257	20.70989	-156.21082
HALE002: Rain Gauge/ Halemau'u Trail	2248	20.72296	-156.19809
HALE003: Kīpahulu	310	20.66848	-156.05808

Table 2 shows existing and natural ambient statistics in dBA for two time periods: day and night. Because the majority of air tour activity occurs during daytime, these two periods were extracted to show the conditions during times of day with and without the influence of aircraft. Median existing ambient (L_{50}) describes the acoustical environment as is, including both natural and extrinsic sounds. Natural ambient (L_{nat}) estimates what the acoustical environment might sound like without the contribution of extrinsic sounds. This table also shows exceedence metrics L_{10} and L_{90} , which essentially mark the average maximum and minimum exceedence levels over the 30 day monitoring periods. When interpreting sound pressure level data, it should be noted that the decibel scale is logarithmic. As such, a 3 dB increase in sound pressure level is actually a doubling of sound energy. Overall, this study found the natural ambient of the two Haleakalā Crater sites to be very similar, and remarkably quiet. The natural ambient levels at Kīpahulu were slightly higher because the sound of Waimoku Falls was audible from this site.

Table 2. Median natural and existing ambient for all sites during day and night

Site Name	Daytime Ambient (7:00 – 18:59)				Nighttime Ambient (19:00 - 6:59)			
	L _{nat}	L ₁₀	L ₅₀	L ₉₀	L _{nat}	L ₁₀	L ₅₀	L ₉₀
Sliding Sands	17.3	27.3	18.2	15.9	16.0	18.8	16.2	15.0
Rain Gauge	19.5	32.4	21.9	15.8	15.3	18.9	15.5	14.6
Kīpahulu	38.0	45.4	38.9	35.1	36.5	41.6	36.6	33.9

Table 3 shows the estimated number of helicopter overflights based on the 2008 acoustic monitoring. The current conditions for number of helicopter overflights at HALE were calculated based on the following rationale:

(# events based on mean of 8 days analysis) x 365 (days in one year) = annual operations

Park administrative helicopter flights were conducted during the monitoring period, but did not occur on the 8 days of analysis. Therefore, helicopter overflights are assumed to be commercial air tours. Some air tours are currently conducted outside the HALE ATMP planning area (over the park and ½ mile from the boundary) because the operator does not have interim operating authority. The operator stated at a meeting in February 2008, they are flying approximately 4,000 flights/year, north of Haleakalā Crater, just outside the ATMP planning boundary. These new entrant flights would be audible at monitoring site HALE002 and, therefore, were subtracted from the annual operations within the HALE ATMP planning area. The results of these calculations are shown below in Table 3.

Table 3. Estimated annual helicopter operations at HALE based on 2008 acoustic monitoring

	Mean # Events	Yearly Ops	New Entrant Ops	Estimated Ops within ATMP boundary
Sliding Sands	17.1	6241.5	N/A	6241.5
Rain Gauge	20.8	7592.0	4140.0	3452.0
Kīpahulu	25.6	9344.0	N/A	9344.0

Introduction

Preparation of an air tour management plan (ATMP) for Haleakalā National Park (HALE) is required by the National Parks Air Tour Management Act (NPATMA) of 2000. The NPATMA also required commercial air tour operators to apply for authority to conduct air tours over national park units or within ½-mile outside the boundary of any national park unit. When an operator who conducted air tours over a park unit before NPATMA was passed (i.e. an existing operator) applies for operating authority, the Federal Aviation Administration (FAA) must grant the existing operator interim operating authority, which lasts until 180 days after the ATMP is completed. In accordance with NPATMA, the number of air tours under interim operating authority is based on either an air tour operator's total number of air tours during the 12-month period before NPATMA was passed or the average number of annual air tours conducted in the 36 months before NPATMA was passed, whichever is greater. The NPATMA also contains provisions for granting interim operating authority (IOA) to operators who had not conducted air tours over a particular national park unit before NPATMA (new entrants) and for granting increases in IOA for existing operators over and above their pre-NPATMA level of activity.

Ten existing air tour operators applied for 26,325 flights annually with one new entrant requesting 4,140 flights over HALE. IOA was granted to the existing operators by FAA. The new entrant request was still pending at the time of the study in 2008. Commercial air tour operators were not required to provide documentation supporting the level of IOA being applied for under NPATMA and there is no mechanism to verify the number of air tours conducted before or since NPATMA was passed or to verify that the IOA granted to operators by FAA was based on factual data. The Government Accounting Office found that some operators deliberately inflated their operations in their applications (GAO-06-263)¹. FAA and the National Park Service (NPS) acknowledge that current flight activity in the ATMP planning area for HALE is substantially below IOA but the exact level is unknown. Operators are legally allowed to fly up to their maximum IOA level until the level of flights for operating authority is determined by the ATMP.

Scoping for an environmental assessment for the HALE ATMP began in 2004. The National Environmental Policy Act (NEPA) document was changed to an environmental impact statement (EIS) in 2006 due to NPS concerns regarding impacts from the level of yearly flights granted under IOA. The current conditions must be described in the NEPA document, however air tour operators are not required to report the number of air tours they conduct. Consequently, FAA and NPS made several attempts to collect information regarding current flight activity. A survey of air tour operators in 2003 by Volpe elicited only a few responses from air tour companies regarding their level of flight activity. At a meeting with air tour operators in February 2008, most operators declined to provide information to FAA and NPS regarding their current level of operations.

Air tour operators are required to pay a \$25.00 fee to HALE for each air tour conducted over the park.² While the fee data provides some information regarding the level of air tours conducted

¹ United States Government Accountability Office, National Parks Air Tour Fees, GAO-06-468.

² The Omnibus Budget Reconciliation Act of 1993 required the NPS to begin collecting fees from operators that conduct air tours over national park units that meet certain criteria. HALE meets the criteria to collect air tour fees.

over the park, it does not include all air tours within the ATMP planning area (over the park and ½ mile outside the boundary) because some operators have not been paying the fee on a regular basis or have not been paying the fee at all. Some air tours do not fly over the park and are not subject to the fee, but occur within ½ mile outside of the park boundary. Fee data from HALE shows a downward trend in air tour activity from 2002 to 2008 even when unpaid fees are accounted for. The new entrant operator conducted air tours just outside the ATMP planning area in 2008³. Noise from these air tours could still be heard within the park.

Previous Studies at Haleakalā National Park Related to Overflights

Studies Associated with the Overflights Act of 1987

The National Parks Overflights Act of 1987 (P.L. 100-91) mandated a number of studies related to the effects of overflights on parks. HALE was included in these studies due to long-standing concerns regarding the impact of air tours on visitor experience and wildlife. Prior to passage of the Overflights Act, which established an altitude restriction over Haleakalā Crater, park management reported that commercial tour helicopters flew down to levels 300 feet above the crater floor. The altitude restriction somewhat reduced the noise levels in the crater, however, acoustic measurements made at four sites in HALE in 1992 showed that aircraft were audible 38-76% of the time and at the rates of about eight to ten per hour. Aircraft heard were predominantly helicopters. Median ambient sound levels (L_{50}) in the absence of aircraft were between 12- 25 dBA with Leq between 15 and 30 dBA. Maximum sounds levels from aircraft (L_{max}) were typically 35 to 60 dBA (Anderson, et. al., 1993, Horonjeff, et. al., 1993).

Two other studies were conducted in response to the requirements of the Overflights Act to identify the effects of overflights on visitors and measure visitor reactions to overflight sounds. The System-wide survey showed that enjoying the natural quiet as a reason for visiting national parks was about as important as viewing natural scenery, with over 90% of the visitors reporting moderate to extreme importance for both. A dose-response study at HALE showed that more than 70% of the visitors heard aircraft and 30% of them were annoyed (Anderson, et. al., 1993).

Conclusions from the 1995 Report to Congress on Effects of Aircraft Overflights on the National Park System (U.S. Department of Interior, 1995), prepared pursuant to the Overflights Act, stated that numbers of overflights have an important impact on length of time visitors have an opportunity to experience natural quiet. In the report, HALE was identified as a top priority for resolution of airspace issues and for protection of natural quiet. In March 1994, the U.S. Department of Transportation and the U.S. Department of Interior issued a joint Advance Notice of Proposed Rulemaking in the Federal Register soliciting public ideas on how to reduce adverse effects from commercial air tours on national parks such as the Grand Canyon, Hawaii Volcanoes, and Haleakalā. Several legislative proposals were introduced in House and Senate committees to control airspace over national parks during the 103rd Congress but these did not make it out of the committees. Eventually, NPATMA was signed in 2000.

³ As of 2010, the new entrant operator is no longer conducting air tours outside the HALE ATMP planning area.

Ambient Measurement Study

Baseline ambient data was collected in 2003 (Lee, et. al., 2006) to provide data for the baseline ambient environment in HALE to establish a foundation from which potential noise impacts could be assessed using the Integrated Noise Model for the ATMP. The FAA, with assistance of the Volpe Center's Environmental Measurement and Modeling Division, and the NPS, conducted baseline ambient sound level measurements during the period of February 27 through May 27, 2003. One hundred sixty-five days of acoustical and meteorological data were measured at 10 sites throughout the park: three "permanent" sites (i.e. longer than 2 weeks up to approximately two months) and 7 "mobile" sites (i.e. one to two weeks). Results from the study are summarized later in this report.

Social Science Research

A social science study (Lawson, et. al., 2007) was conducted to examine the effects of natural and human-caused sounds, including air tours, on visitors' experiences of HALE's soundscape. The study consisted of two components. The first component used a procedure referred to as attended listening, coupled with a visitor survey, to provide an empirical basis for understanding the sounds people hear while visiting the park, and their cognitive and affective responses to those sounds. The second component of the study used a visitor survey, coupled with audio recordings of simulated park soundscapes, to assess visitor based standards for: 1) prominence of air tour sounds in HALE; and 2) how often visitors hear helicopter sounds while hiking in the park. The attended listening exercises and associated surveys were administered from May through July 2007 to visitors at two sites at the park on 13 randomly selected days at each site. The audio recordings based visitor surveys were administered during June and July 2007 to people at one site in the park on 14 randomly selected days.

The sounds that visitors most commonly reported hearing in HALE include nature sounds, the sounds of other visitors walking and talking, and animal sounds. More than half (55.3%-62.7%) of all visitors also reported hearing aircraft. Of the aircraft sounds visitors reported hearing, 39.6%-52.3% of visitors heard helicopter sounds. On average, visitors reported hearing nature sounds, sounds of other visitors walking and talking, and animal sounds as generally acceptable and pleasing to hear. On average, visitors considered aircraft sounds unacceptable and annoying to hear. Furthermore, 55.1%-78.8% of visitors reported that hearing helicopters every 15-30 minutes is unacceptable.

Ethnographic Study

An ethnographic study (Prasad and Tomonari-Tuggle, 2008) was conducted to document the views and concerns about the effects of commercial air tours on cultural practices and cultural resources through interviews with Native Hawaiians and other individuals who are traditionally associated with HALE. The study also documented recommendations for alternative courses of action, if any, for commercial air tour operations in the park. Based on the documentary research and ethnographic data gathered during this study, as well as information gathered from previous ATMP public scoping and Section 106 of the National Historic Preservation Act consultation meetings, cultural impacts from commercial air tours over Haleakalā fall into several categories; the most important being the negative impacts on traditional Hawaiian places and sites and ceremonial practices. Helicopters were noted as being visually intrusive and noisy. Commercial

air tours were considered to have little to no impacts on traditional non-ceremonial practices of ranching and “going holoholo” (hiking).

Study Objectives

The intent of this spring 2008 acoustical monitoring study at HALE is to gather current overflight and ambient data from sites that would capture helicopter noise from the commonly flown commercial air tour routes that would be used to inform current conditions for the air tour management planning process. It is intended to supplement a previous study conducted in 2003 (Lee, et. al., 2006) which did not collect such data.

National Park Service Natural Sounds Program

The NPS Natural Sounds Program (NSP) Office was established in 2000 to help parks manage sounds in a way that balances access to the park with the expectations of park visitors and the protection of park resources. The NSP addresses acoustical issues raised by Congress, NPS Management Policies, and NPS Directors Orders. An important element of this mission is working with the FAA to implement NPATMA. Congress mandated that FAA and NPS jointly develop ATMPs for more than 106 parks where commercial air tours operate. The program also provides technical assistance to parks in the form of acoustic monitoring, data processing, park planning support, and comparative analyses of acoustic environments throughout the national park system.

Soundscape Planning Authorities

The NPS 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 soundscapes⁴ 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

⁴ 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.

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 acoustic condition may also depend upon the resources and the values of the park. For instance, “culturally appropriate sounds are important elements of the national park experience in many parks” (NPS 2006b). In this case, “the Service will preserve soundscape resources and values of the parks to the greatest extent possible to protect opportunities for appropriate transmission of cultural and historic sounds that are fundamental components of the purposes and values for which the parks were established” (NPS 2006b).

Study Area

Haleakalā National Park is located on the island of Maui in the Hawaiian Islands. The park was established in 1916 and encompasses a vast array of habitats within its 33,223 acres. In 1976, the 19,270 acres of HALE was designated as wilderness in accordance with the Wilderness Act of 1964. The Haleakalā Wilderness area was recently expanded in 2002 to 24,719 acres. It is primarily a day use park.

Three acoustic monitoring stations were deployed in HALE in April of 2008. The Sliding Sands and Rain Gauge/ Halemau'u Trail sites were located within a sparsely-vegetated alpine/Aeolian landscape in Haleakalā Crater, while the Kīpahulu site was located in a coastal zone that is a mosaic of forest and grasslands. All were long-term, 30 day monitoring deployments. These sites were intended to replicate as closely as possible sites which were previously monitored by the Department of Transportation (Lee et. al. 2006). The Sliding Sands trail was selected to record south slope air tour operations and audible sounds while the Rain Gauge/ Halemau'u Trail site was chosen to record north slope air tour operations and audible sounds. The final site, Kīpahulu, was selected to record air tour operations and audible sounds at Kīpahulu.

Table 4. Site locations

Site Location	Habitat	Acoustic Zone	Elevation (meters)	Latitude	Longitude
Sliding Sands	Bare lava rock and ash	Natural	2257	20.70989	-156.21082
Rain Gauge/ Halemau'u Trail	Bare lava rock and ash/ silversword	Natural	2248	20.72296	-156.19809
Kīpahulu	Grassland/ scattered guava	Coastal Developed	310	20.66848	-156.05808

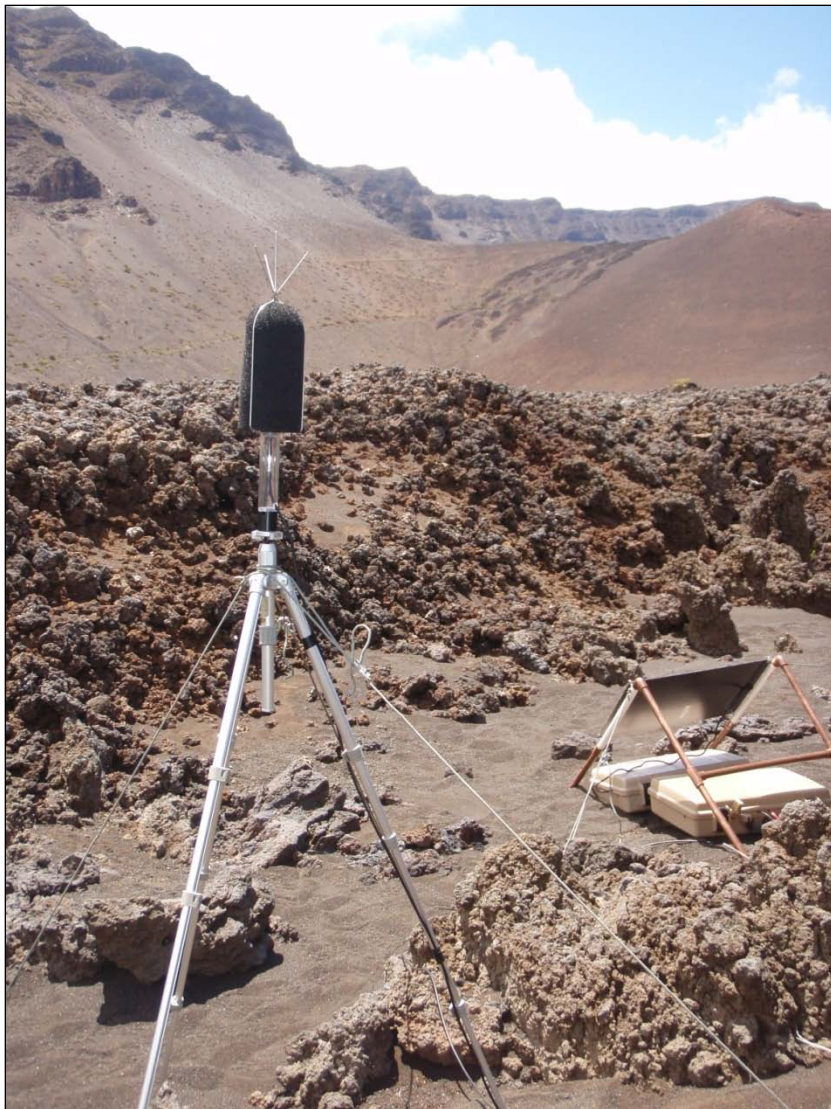


Figure 1. HALE001, Sliding Sands Trail



Figure 2. HALE002, Rain Gauge/ Halemau'u Trail



Figure 3. HALE003, Kīpahulu

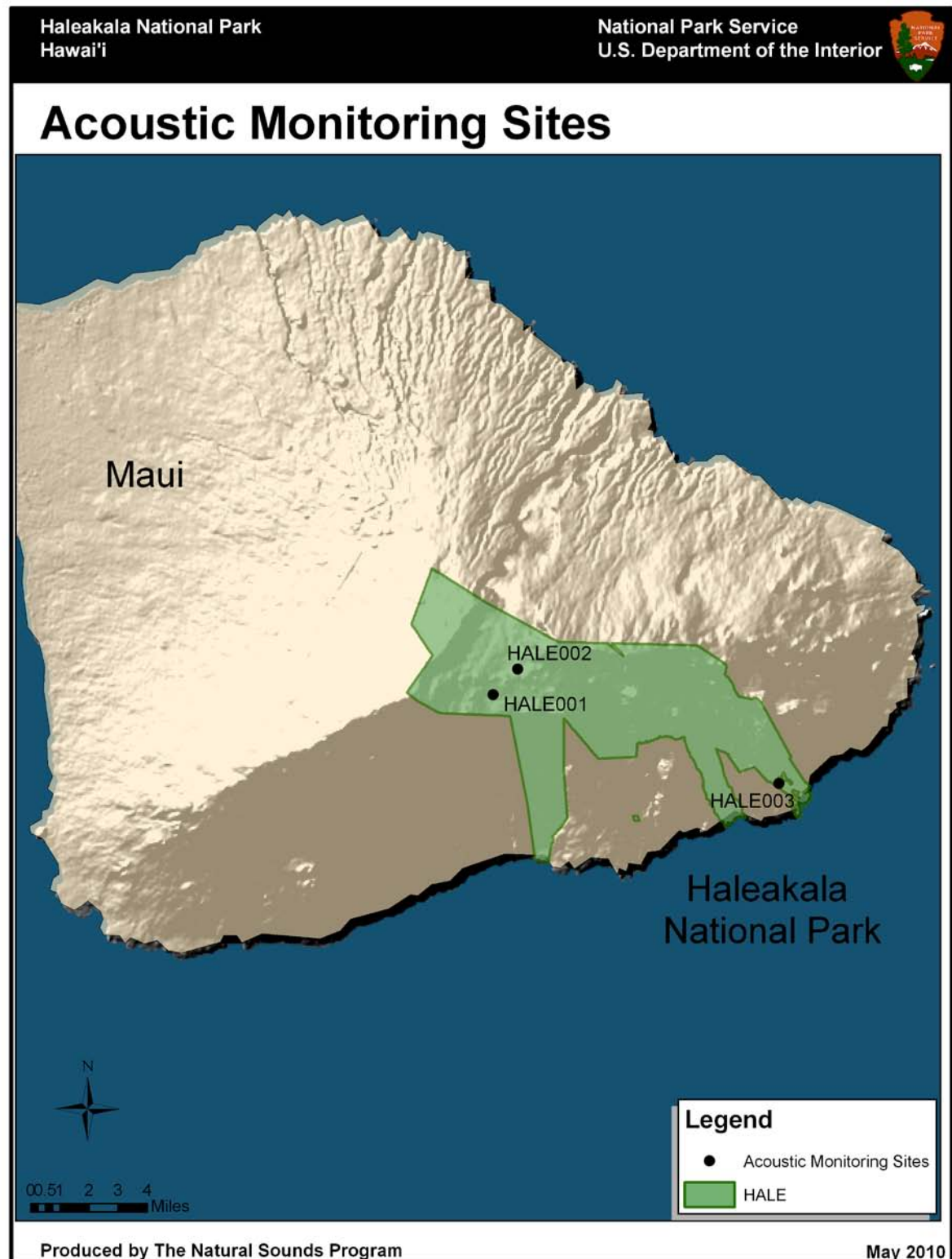


Figure 4. Acoustic monitoring sites in Haleakalā National Park.

Methods

Automatic Monitoring

Larson Davis 831 sound level meters (SLM) were employed over the thirty day monitoring periods at HALE. The Larson Davis SLM is a hardware-based, real-time analyzer which constantly records one second sound pressure level (SPL) and 1/3 octave band data, and exports these data to a portable storage device (thumb drive). These Larson Davis-based sites meet American National Standards Institute (ANSI) Type 1 standards.

Each Larson Davis sampling station consisted of:

- Microphone with environmental shroud
- Preamplifier
- Solar panel and batteries
- MP3 recorder

Each acoustic sampling station 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

Off-Site Listening/ Visual Analysis

Visual analysis was used to analyze HALE 001, 002 and 003 since there were few enough sound sources to easily distinguish them visually. From the 30 days of monitoring, Natural Sounds Program (NSP) staff visually analyzed a randomly selected subset of SPL samples (eight days) in order to identify durations of audible sound sources. Audio samples were employed to confirm identification. See Appendix A for further information on off-site listening/visual analysis methods. Hourly time audible statistics are then inserted into a formula which produces natural ambient sound level estimates (see Calculation of Metrics below). The total percent time extrinsic sounds were audible was then used to calculate the natural ambient sound level. Bose Quiet Comfort Noise Canceling headphones were used for off-site audio playback to minimize limitations imposed by the office acoustic environment.

On-Site Listening

On-site listening is the practice of placing an observer near the acoustical monitoring station with a handheld personal digital assistant (PDA). 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 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 acoustic environment studies. They produce an extensive inventory of sound sources, require little equipment or training, and can help educate park staff and volunteers.

Thus, periods of on-site listening were conducted in order to discern the type, timing, and duration during sound-level data collection at HALE. As recommended by NSP protocol (NPS 2005) these sessions generally began at the top of an hour and lasted for one hour. Staff recorded the beginning and ending times of all audible sound sources using custom-designed PDA software. 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 [NFI]), percent time each sound source was audible, and maximum, minimum, and mean length (in seconds) of sound source events.

Calculation of Metrics

Since sound levels fluctuate, several metrics are calculated in order to provide some detail about the characteristics of the acoustical environment. The current status of the acoustical environment can be characterized by a number of measurements including sound levels across the 1/3 octave band spectrum (from 12.5 Hz to 20,000 Hz), overall sound pressure levels, time above specified dBA values, and percent time audible durations for various sound sources. Two fundamental descriptors of the acoustical environment are existing and natural ambient sound levels which are presented as exceedence levels (L_x). They represent the dBA exceeded x percent of the time during the given measurement period. For example, measured in dBA, the existing ambient (L_{50}) is the sound level exceeded 50% of the time, or median sound level. It is the uncensored composite of all sounds at a site, both human caused and natural. NSP also calculates L_{10} and L_{90} , which describe the sound levels exceeded 10% and 90% of the time, respectively.

The natural ambient estimates what the acoustic environment would be without the contribution of anthropogenic sounds. The differences between L_{50} and L_{nat} values allow NPS to answer the following questions:

1. What are the listening opportunities in the absence of human development and activities?
2. How are these listening opportunities compromised by increased sound levels due to noise?

To calculate L_{nat} , NSP does the following:

- NPS staff calculate the percentage of all samples containing extrinsic sounds for each hour of the day (P_H) by either listening to samples, or analyzing daily spectrograms, for eight days.
- P_H is used to complete this formula for every hour: $x = \frac{1 - P_H}{2} + P_H$
- Hourly x_H values are entered into a database of all octave band information.
- Example: if extrinsic sounds are audible 50% of the time ($P_H = 0.5$), then x_H is 0.75.
- L_{nat} is computed as the sound level that is exceeded $100 * x_H$ percent of the time.
- (In practice, L_{nat} is calculated by sorting the relevant sound level measurements and using x_H to extract the appropriate order statistic).

This procedure approximates the sound levels that would have been measured in the absence of extrinsic noise. The procedure is guaranteed to produce an estimate that is equal to or below the existing ambient sound levels, and the results of this calculation have produced consistent results at most backcountry sites.

Results

Hourly Exceedence Levels

In order to determine the effect extrinsic noise audibility has on the acoustic environment, it is useful to examine the median hourly exceedence metrics. Figures 5, 6 and 7 show existing ambient levels and natural ambient levels. The existing ambient (or median) level for each hour is marked by the upper limit of the gray boxes while natural ambient levels (L_{nat}) are marked by the lower limit of the gray boxes. The height of the box is a measure of the contribution of anthropogenic noise to the existing ambient sound levels at this site. The size of these boxes is directly related to the percent time that human caused sounds are audible. When boxes do not appear, the natural and existing ambient levels were either very close to each other, or equal for that hour.

These figures also show exceedence metrics L_{10} and L_{90} , which essentially mark the average maximum and minimum levels over the 30 day monitoring periods. As is evident in the figures, human caused sounds raised the natural ambient levels more during the daytime hours than at night. During the early morning hours in the crater sites (HALE001 and HALE002), the existing and natural ambient levels were very near the noise floor of the recording equipment (the lower limit of recording equipment), indicating that these sites were at times remarkably quiet. The Kīpahulu site seems to have inherently higher existing and natural ambient levels due to its proximity to Waimoku Falls. When the hourly L_{10} and L_{90} lines differ greatly from each other, this implies that there is large variation in the ambient levels for that hour. This happens often in the midday hours on the graphs for the sites located in Haleakalā Crater. Such variation is likely due to wind, as these two sites were deployed in exposed areas. The peak hours of human-caused sound can be inferred from this graph by comparing the size of the gray boxes. The larger the box, the larger the contribution of human-caused sound during that hour. The size of the boxes is directly related to the percent time audible.

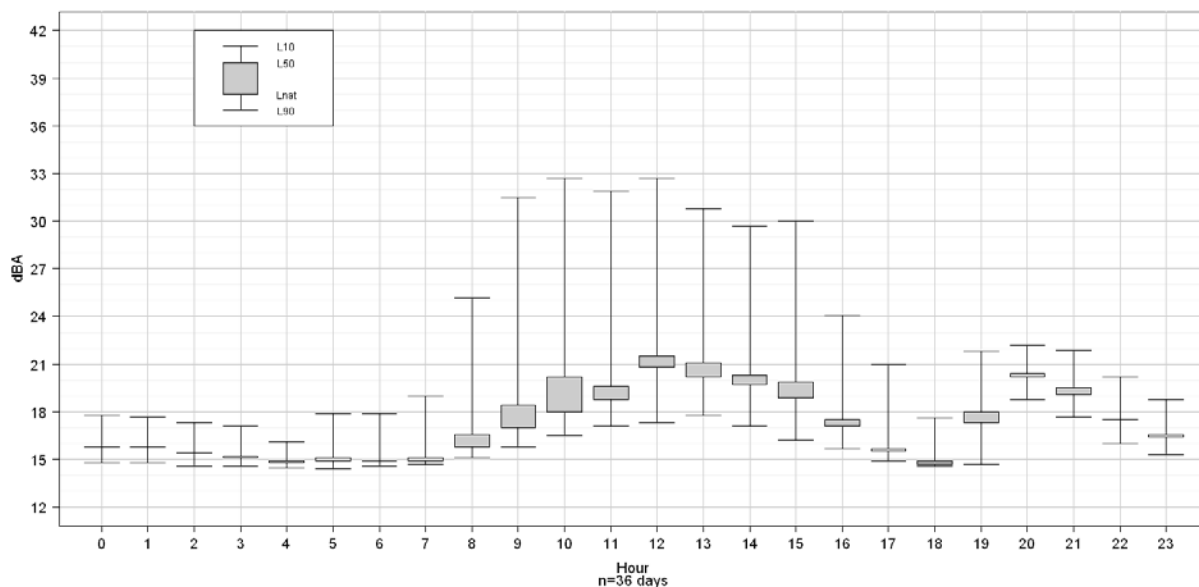


Figure 5. Hourly exceedence levels at HALE001 (Sliding Sands)

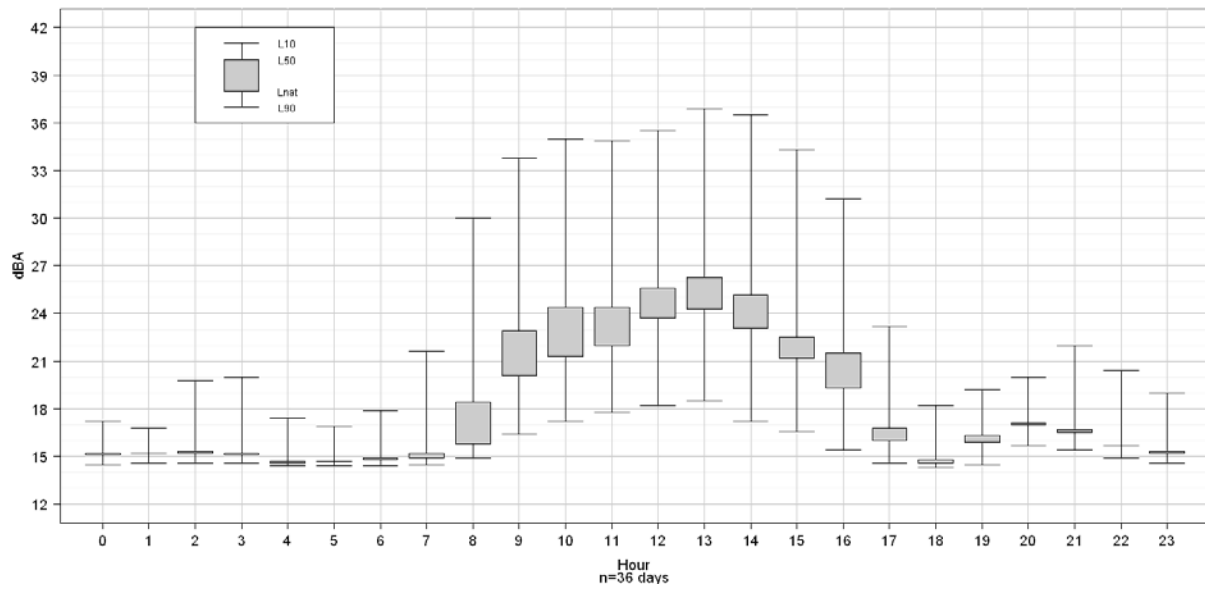


Figure 6. Hourly exceedence levels at HALE002 (Rain Gauge/ Halemau'u Trail)

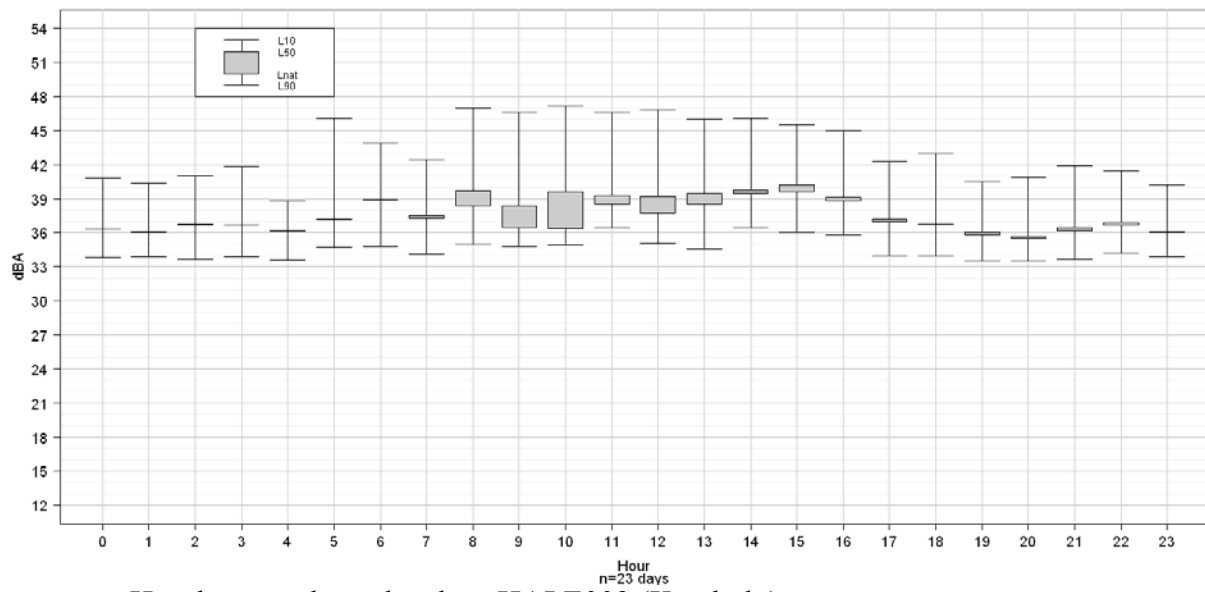


Figure 7. Hourly exceedence levels at HALE003 (Kīpahulu)

Table 6 displays how often key sound sources were audible based on visual analysis/off-site listening for each site. This table reports mean statistics for daytime and nighttime. Only extrinsic noise sources were noted during visual analysis. The dominant extrinsic noise at all sites during the day was helicopters. At night, high-altitude jets are the dominant extrinsic sound source.

Table 5. Mean percent time audible statistics from visual analysis for day and night

Sound Source	Day (7:00 - 18:59)			Night (19:00 - 6:59)		
	HALE 001	HALE 002	HALE 003	HALE 001	HALE 002	HALE 003
Jet	6.9	8.1	1.7	7.8	8.2	3.9
Propeller	0.7	1.1	1.2	0.6	1.4	0
Helicopter	14.6	19.7	16.6	0.0	0.2	0

Yearly Operations Count

Individual events identified as aircraft overflights (i.e. helicopter, propeller, and jet) were counted for the subset of SPL samples (eight days) selected for visual analysis/off-site listening (see Appendix B for further information). The current conditions for number of helicopter overflights at HALE were estimated based on the following rationale:

(#events based on mean of 8 days analysis) x 365 (days in one year) – annual operations

Park administrative helicopter flights were conducted during the monitoring period, but did not occur on the days selected for off-site listening. Therefore, helicopter overflights are assumed to be commercial air tours.

Some air tours are currently conducted outside the HALE ATMP planning area because the operator does not have IOA. The operator stated at a meeting in February 2008, they are flying the number of flights/year reported in their new entrant application, just north of Haleakalā Crater. In the case that there were new entrant operations audible near a site, as at Rain Gauge/ Halemau'u Trail, these were subtracted from annual operations because the new entrant is currently flying outside the ATMP planning area. The results of these calculations are shown below in Table 7.

Table 6. Annual helicopter operations at HALE based on 2008 acoustic monitoring

	Mean # Events	Yearly Ops	# New Entrant Ops	Estimated HALE Annual Ops
Sliding Sands	17.1	6241.5	N/A	6241.5
Rain Gauge	20.8	7592.0	4140.0	3452.0
Kīpahulu	25.6	9344.0	N/A	9344.0

Time Above

When assessing current conditions at a site, it is important to provide some detail about the characteristics of the acoustical environment since sound levels fluctuate. In order to understand the implications of the acoustic data fully, it is also important to describe the distribution of sound levels in relation to potential functional effects since this information may be useful in resource management decisions. The decibel (dBA) is a logarithmic measure of sound energy that approximates human hearing sensitivity (Harris, 1998). As decibel measures may not be easily comprehended by the lay person, Table X presents park sound sources and common sound sources with their corresponding A-weighted decibel levels (dBA) to provide a frame of reference.

Table X. Interpreting sound levels

Park Sound Sources	Common Sound Sources	dBA
Crater (HALE)	Human breathing at 3m	10
Leaves rustling (CANY)	Whispering	20
Crickets at 5m (ZION)	Residential area at night	40
Conversation at 5m (WHMI)	Busy restaurant	60
Snowcoach at 30m (YELL)	Curbside of busy street	80
Thunder (ARCH)	Jackhammer at 2m	100
Military jet at 100m AGL(YUCH)	Train horn at 1m	120

Note: An increase of 10dBA represents a tenfold multiplication of energy

Table 8 summarizes sound level values 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 more sensitive hearing at low frequencies than most species (Dooling and Popper, 2007). Time above metrics provide information about how much time sound levels are above specified values. By comparing the amount of time that sound levels are above certain values, variations in sound levels can be illustrated. Table 8 reports the percent of time that measured levels were above the values in Table 7. These values should not be construed as thresholds of impact but rather sound levels which have been identified in scientific literature as having relevance to the human or wildlife experience in parks.

Table 9 reports the percent of time that measured levels were above these values at each of the monitoring sites. The sound pressure levels at Kīpahulu were considerably louder than the other sites because of the proximity of Waimoku Falls. The low percent time above for all sound levels at both Sliding Sands and Rain Gauge suggest that very loud sounds occur infrequently in Haleakalā Crater, even though aircraft are audible often during the day (as shown in Table 6). Thus, percent time above metrics offer additional useful information about the quality of sound and current conditions at each site

Table 7. Explanation of sound level values.

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

Table 8. Percent time above metrics for day and night

Site Name	% Time above sound level (7am - 6:59 pm)				% Percent time above sound level (7pm - 6:59am)			
	35 dBA	45 dBA	52 dBA	60 dBA	35 dBA	45 dBA	52 dBA	60 dBA
Sliding Sands	4.44	0.89	0.07	0.00		0.04	0.00	0.00
Rain Gauge	8.79	0.43	0.01	0.00	0.45	0.05	0.00	0.00
Kīpahulu	88.65	12.23	2.67	0.40	76.17	5.71	0.41	0.04

The graphs below show the percent time audible statistics for helicopters for each site by hour. These statistics were extracted from the eight days of SPL samples selected for visual analysis. The most affected site in terms of hourly audibility seems to be the Rain Gauge/ Halemau'u site where helicopters were audible an average of 41 percent of the time during the 10:00 am hour. In all cases, these figures show that the peak hours of operation for helicopter air tours are during the morning hours.

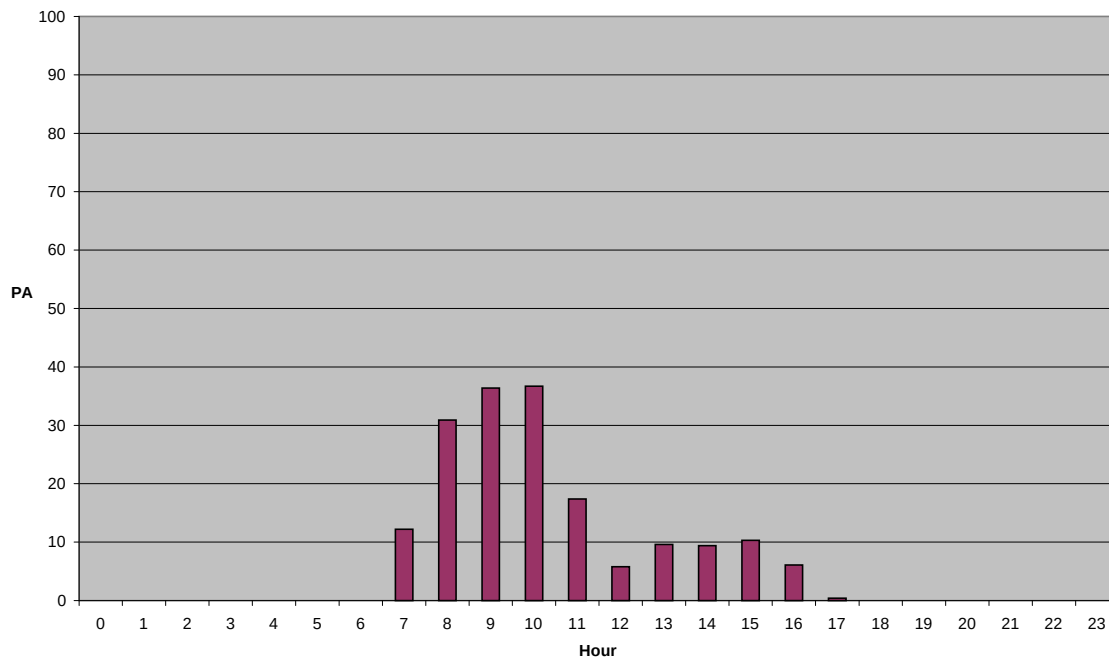


Figure 8. Mean percent time helicopters audible at HALE001 (Sliding Sands)

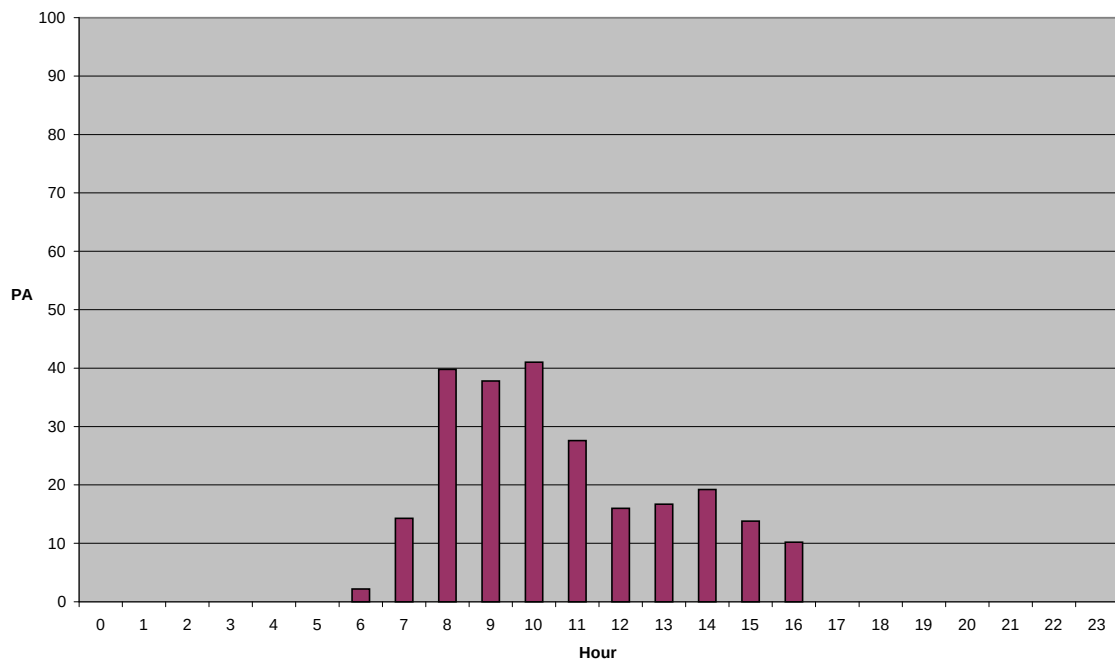


Figure 9. Mean percent time helicopters audible at HALE002 (Rain Gauge/ Halemau'u Trail)

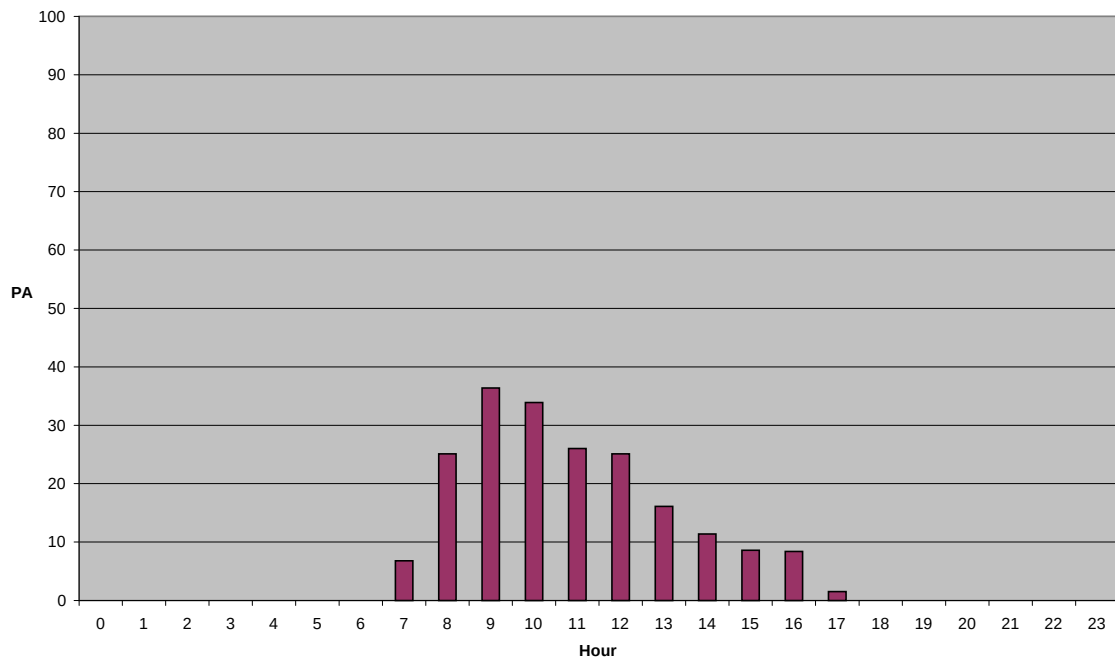


Figure 10. Mean percent time helicopters audible at HALE003 (Kīpahulu)

On-site Listening

Table 10, Table 11, and Table 12 below display the results of on-site listening sessions. On site listening was conducted for 3 hours at HALE001, 1 hour at HALE002 and 4 hours at HALE003. Each audible sound source is listed in the first column. Percent time audible, or PA, is the second column. The third column, Max, reports the maximum event length among the sessions for each sound source in minutes and seconds. Likewise, mean event and min event columns report the mean and minimum length of events in minutes and seconds. SD reports the standard deviation among event lengths in minutes and seconds, and count reports the number of times that each sound source was audible. The last row in the table, noise free interval (NFI), is a metric which describes the length of time between extrinsic or human-caused events. These on-site listening tables are essentially a sound inventory of each site. They reveal the sounds one is likely to hear at or near these locations.

Table 9. Summary of on-site audible sound sources for HALE001 (Sliding Sands Trail)

Sound Source	% Time Audible	Max Event (min:sec)	Mean Event (min:sec)	Min Event (min:sec)	SD Event (min:sec)	Count
Aircraft	12	6:16	1:32	0:10	1:37	14
Jet, Commercial	2	2:13	1:56	1:39	0:24	2
Helicopter	0	0:12	0:12	0:12	0:01	
Helicopter, Air Tour	17	8:05	4:22	1:18	2:38	7
People	2	0:45	0:11	0:01	0:14	18
People, Voices	2	2:29	0:31	0:03	0:53	7
Horse	0	0:02	0:02	0:02	0:01	
Wind	95	59:58	10:02	0:05	19:05	17
Bird	42	27:04	1:54	0:01	5:44	40
Insect	18	4:12	0:28	0:00	0:49	71
All Aircraft	31.1					
All Non-natural Sources	34.6					
All Natural Sources	98.7					
Noise Free Interval	65.4	14:41	2:34	0:03	2:59	46

Table 10. Summary of on-site audible sound sources for HALE002 (Rain Gauge/ Halemau'u Trail)

Sound Source	% Time Audible	Max Event (min:sec)	Mean Event (min:sec)	Min Event (min:sec)	SD Event (min:sec)	Count
Jet	8	2:37	1:41	0:57	0:51	3
Helicopter	22	4:36	3:14	1:27	1:19	4
Helicopter, Air Tour	41	12:46	8:18	3:51	4:28	3
People	0	0:05	0:05	0:05	0:01	
Wind	100	30:36	14:56	0:18	14:44	4
Bird	36	7:03	0:50	0:01	1:44	26
Insect	11	1:43	0:12	0:00	0:21	35
All Aircraft	68					
All Non-natural Sources	68					
All Natural Sources	99.7					
Noise Free Interval	32	4:37	2:08	0:02	1:27	9

Table 11. Summary of on-site audible sound sources for HALE003 (Kīpahulu)

Sound Source Description	% Time Audible	Max Event (min:sec)	Mean Event (min:sec)	Min Event (min:sec)	SD Event (min:sec)	Count
Aircraft	3	2:04	1:05	0:19	0:47	6
Jet, Commercial	1	2:09	1:41	1:13	0:40	2
Aircraft, Propeller	1	2:57	2:57	2:57	0:01	
Propeller, Air Tour	2	3:12	1:47	0:03	1:36	3
Propeller, General Aviation	1	1:34	1:34	1:34	0:01	
Helicopter	1	1:14	1:06	0:59	0:11	2
Helicopter, Air Tour	20	5:54	2:56	0:31	1:42	16
Alarm, Horn	0	0:02	0:02	0:02	0:01	
Grounds Care	1	1:23	0:21	0:03	0:29	7
People, Voices	0	0:01	0:01	0:01	0:01	
Domestic Animal	0	0:03	0:03	0:03	0:01	
Dog	0	0:10	0:08	0:06	0:03	2
Cow	1	0:20	0:04	0:01	0:04	28
Wind	37	51:30	4:05	0:01	10:43	22
Flowing Water	71	59:43	24:24	3:27	19:12	7
Waterfall	23	39:57	27:54	15:51	17:02	2
Waves (natural)	53	30:21	6:03	0:01	9:54	21
Mammal	0	0:17	0:17	0:17	0:01	
Bird	100	60:05	59:56	59:44	0:09	4
Insect	5	1:56	0:12	0:01	0:24	60
Animal (Natural)	1	1:14	0:40	0:06	0:48	2
Natural Other	22	51:30	8:59	0:03	20:50	6
Natural Unknown	0	0:05	0:03	0:02	0:02	3
All Aircraft	27.7					
All Road Vehicles	0					
All Non-natural Sources	29.5					
All Natural Sources	99.8					
Noise Free Interval	70.5	35:34	2:44	0:01	5:14	62

Previous Acoustical Studies

As previously stated, ambient data were gathered in 2003 (Lee, et. al., 2006). The results of this previous study and the 2008 study are presented below for comparison. It should be noted that daytime was defined as 6am – 6pm in the 2003 study while daytime was defined as 7am – 7pm in the 2008. When the 2003 study was conducted, the cooperators involved in this project (NPS, FAA, and Volpe) were still developing standards for acoustic monitoring in national parks. Thus, differences in daytime definitions can be attributed to minor changes in monitoring protocol over time. Because the majority of air tour overflights at HALE occur well within these two time periods (see Figures 8-10) it is unlikely that changing the changing the periods of interest from 7 am -7 pm, to 6 am to 6 pm (or vice versa) would change the outcomes in Table 13.

Sliding Sands, Rain Gauge/Halemau'u Trail, and Namana o ke Akua sites are located in Haleakalā Crater. Kīpahulu and Waimoku Falls sites are both located on the eastern Kīpahulu side of the park. All the sites were long term sites of over 25 days. All measured and calculated levels in 2003 are slightly higher than same metrics in 2008. There are a number of possible explanations for these differences. Both sets of data were collected with type-1 calibrated systems which should be similarly sensitive and responsive, so equipment differences is an unlikely explanation. The data were collected in the same season, but it is possible that variation in weather conditions (particularly wind patterns) caused ambient levels in 2003 to be higher than the later study. Furthermore, variation in the location of monitoring sites could result in slightly different ambient level measurements. What these two studies offer is a likely *range* of ambient levels for the sampling areas in the park.

Table 12. Daytime metrics and site information for 2003 and 2008 acoustic monitoring in HALE

Site ID		Year	Vegetation Type	L_{nat}^*	L_{50}	L_{90}
HALE001	Sliding Sands	2008	Alpine	17.3	18.2	15.1
HALE002	Rain Gauge	2008	Alpine	19.5	21.9	15.8
P01	Namana o ke Akua	2003	Shrubland	22.5	24.5	18.6
HALE003	Kīpahulu	2008	Coastal	38.0	38.9	35.1
P03	Waimoku Falls	2003	Forested Upland	45.3	43.5	38.2

*It should be noted that Volpe and NPS used different techniques to calculate natural ambient. See Calculation of Metrics above for NPS protocol. See Lee, et. al. 2006 for Volpe protocol.

Discussion

This study was intended to provide current overflight data at HALE. It was intended to supplement a previous study conducted in 2003 which did not collect such data. Both studies provide information that will inform and facilitate the formulation of an ATMP for the park (a Congressional mandate). Overall, NSP staff found the selected sites to be affected by extrinsic noise most during daytime hours. The dominant extrinsic noise from 7:00 am to 7:00 pm at all sites was helicopters, while the dominant noise source from 7:00 pm to 7:00 am was high altitude jets. During peak morning hours, helicopters were audible between 35 and 41 percent of the time. Propellers were also audible during both time periods, but less frequently. Yearly air tour overflight operations within the HALE ATMP planning area were estimated to be 6,241 for south slope (Sliding Sands), 3,452 for north slope (Rain Gauge/ Halemau'u Trail), and 9,344 for the Kīpahulu area.

The acoustic monitoring systems also collected detailed records of ambient sound pressure levels. These data can be used to report existing ambient levels, and in conjunction with percent time audible statistics, can help estimate the natural ambient levels. The existing ambient (L_{50}) level is the median sound level. It is the composite of all sounds at a site, both human caused and natural. The natural ambient (L_{nat}) estimates what the acoustic environment would be without the contribution of anthropogenic sounds. At both crater sites (Sliding Sands and Rain Gauge/ Halemau'u Trail), natural and existing ambient levels were extremely quiet. In fact, at night, sound pressure levels at these sites were very close to the noise floor (which is the lower recording limit) of NSP monitoring equipment. Sound levels as low as these are extremely rare and highly sensitive to the influence of extrinsic sound events. Variations in the existing and natural ambient sound levels at the Kīpahulu site were somewhat tempered by the presence of Waimoku Falls. This constant background sound produced data that were higher and more consistent in value than the Haleakalā Crater sites.

When ambient data were compared to the data collected in 2003, similar trends were observed. Crater sites were quieter during the day than Kīpahulu sites. Overall, ambient levels in the 2003 study were consistently louder than the 2008 study. Although the data were collected in the same season, it is possible that variation in weather conditions (particularly wind patterns) caused ambient levels in the 2003 study to be higher than the later study. Furthermore, variation in the location of monitoring sites could result in different ambient level measurements. Regardless of slight variations in ambient values, these two studies present a likely *range* of ambient levels for the sampling areas in the park.

Acoustic monitoring in parks not only offers us insight into the prevalence of extrinsic noise, but also allows us to determine the presence of biologic (or geologic) activity. Both on-site and off-site listening sessions produced a number of interesting biologic, meteorologic, and geologic sound recordings such as 'ua'u (*Pterodroma sandwichensis*), nēnē (*Branta sandvicensis*), thunder storms, and rock fall.

As it stands today, HALE has one of the most extensive acoustical monitoring datasets in the National Park Service system, both in terms of visitor experience and ambient monitoring. The data included in this report will inform the ATMP, but it could also be used to inform a General Management Plan, Resource Stewardship Strategy, Natural Resource Conditions Assessment,

other park plans, or NEPA documents that include soundscapes. The NSP suggests that the park also consider preparing a Soundscape Management Plan. Some additional monitoring could be required depending on the need to monitor ambient conditions once an ATMP is established, if additional information regarding other sound sources is needed, or ambient conditions need to be established in other areas of the park, such as new land acquisitions.

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Glossary of Acoustical Terms

Acoustical Environment

The actual physical sound resources, regardless of audibility, at a particular location.

Amplitude

The instantaneous magnitude of an oscillating quantity such as sound pressure. The peak amplitude is the maximum value.

Audibility

The ability of animals with normal hearing, including humans, to hear a given sound. Audibility is affected by the hearing ability of the animal, the masking effects of other sound sources, and by the frequency content and amplitude of the sound.

dBA

A-weighted decibel. A-Weighted sum of sound energy across the range of human hearing. Humans do not hear well at very low or very high frequencies. Weighting adjusts for this.

Decibel

A logarithmic measure of acoustic or electrical signals. The formula for computing decibels is: $10(\log_{10}(\text{sound level}/\text{reference sound level}))$. 0 dB represents the lowest sound level that can be perceived by a human with healthy hearing. Conversational speech is about 65 dB.

Diel

A 24-hour period usually consisting of a day and the adjoining night.

Extrinsic Sound

Any sound not forming an essential part of the park unit, or a sound originating from outside the park boundary.

Frequency

The number of times per second that the sine wave of sound repeats itself. It can be expressed in cycles per second, or Hertz (Hz). Frequency equals Speed of Sound/ Wavelength.

Hearing Range (frequency)

By convention, an average, healthy, young person is said to hear frequencies from approximately 20Hz to 20000 Hz.

Hertz

A measure of frequency, or the number of pressure variations per second. A person with normal hearing can hear between 20 Hz and 20,000 Hz.

Human-Caused Sound

Noise. Any sound that is attributable to a human source.

Intrinsic sound

A sound which belongs to a park by its very nature, based on the park unit purposes, values, and establishing legislation. The term “intrinsic sounds” has replaced “natural sounds” in order to incorporate both cultural and historic sounds as part of the acoustic environment of a park.

Listening Horizon

The range or limit of one’s hearing capabilities. Just as smog limits the visual horizon, so noise limits the acoustic horizon.

 L_{eq}

Energy Equivalent Sound Level. The level of a constant sound over a specific time period that has the same sound energy as the actual (unsteady) sound over the same period.

 L_x

A metric used to describe acoustic data. It represents the level of sound exceeded x percent of the time during the given measurement period.

Masking

The process by which the threshold of audibility for a sound is raised by the presence of another sound.

Noise-Free Interval

The period of time between noise events (not silence).

Noise

Sound which is unwanted, either because of its effects on humans, its effect on fatigue or malfunction of physical equipment, or its interference with the perception or detection of other sounds (Source: McGraw Hill Dictionary of Scientific and Technical Terms).

Off-site Listening

The systematic identification of sound sources using digital recordings previously collected in the field.

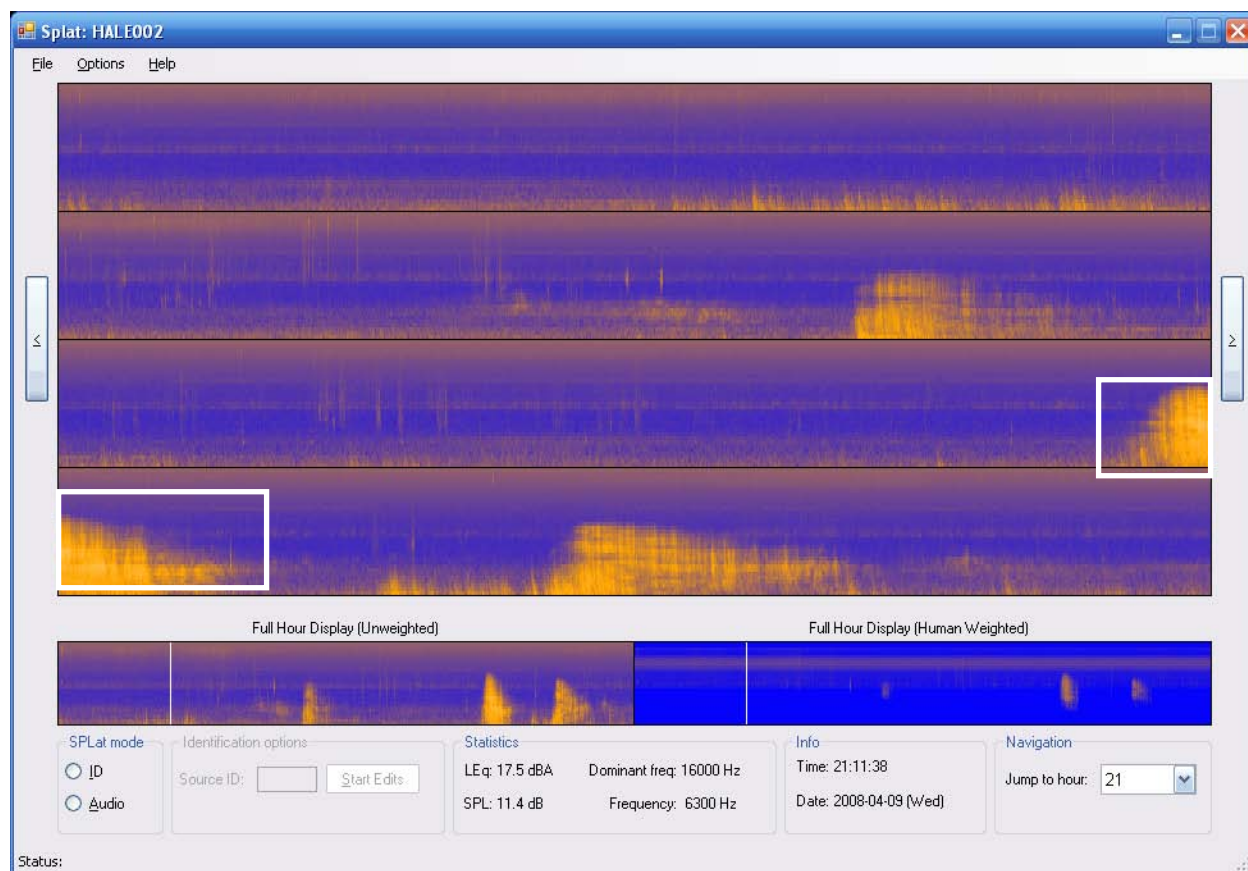
Sound Level Floor (Noise Floor)

The lowest amplitude measurable by sound monitoring equipment.

Appendix A. Analyzing audibility with visual tools

When the ATMP acoustic monitoring protocol was developed from 2003-2005, the amount of power it took to run the audio recorder and the limit on the storage devices used in the monitoring systems were such that 10 second audio recordings were made every 2 minutes. Per the 2005 protocol, investigators should conduct several hours of observer logging or recording playback (at least 2.5 percent of the measurement duration for that site location). This equates to 16 hours of on-site observer logging for a 25 day monitoring study. The sample size is based on the availability of staff in the field during the equipment set up to perform the on-site listening. If using audio recordings to analyze audibility off-site, 16 hours works out to be eight days worth of 10 second/2 minute samples. Since the 2003 study, commercially audio recorders have become much smaller, use less power and digital storage devices have much larger capacities, therefore, continuous recordings are now collected which was done during the 2008 study. In addition visual analysis of SPL samples is now used which allows a large subset of the data to be analyzed more quickly. Due to the efficiency of visual analysis, eight full days of SPL data was analyzed rather than just 8 hours. Audio samples were employed to confirm identification.

Sound pressure levels (SPL) from one hour at an acoustic monitoring site at HALE are shown below. One hour of SPL data is displayed over four lines. Each line shows SPL values from low frequency 12.5 Hz (bottom of line) to high frequency 20 kHz (top of line). Values are represented with a color scale, where dark blue is quiet and yellow/white is loud. Thus, individual events stand out against the quiet blue background, appearing as yellow areas.



The two white boxes above mark the first and second half of a high altitude jet overflight. Without any correction, these two boxes would be logged as two events. To correct for this overcounting of flights, we filtered the data for corresponding sound source events that ended and began one second apart (as shown in above diagram). We then subtracted this number of split events from the total number of marked events. For instance, if our filter located two pairs of split overflights, we would subtract two events from the total number of events. We believe that this presents us with a very accurate count of aircraft overflights.

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

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