



Lava Beds National Monument

Acoustical Monitoring Report

Natural Resource Report NPS/LABE/NRR—2017/1409



ON THE COVER

Photograph of the landscape at Lava Beds from the Hovey Point Acoustical Monitoring Station.
Photograph courtesy of the National Park Service, Misty Nelson

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Ashley R. Pipkin

National Park Service
Natural Sounds and Night Skies Division
1201 Oakridge Drive, Suite 100
Fort Collins, Colorado 80525

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Executive Summary

In 2014, the Natural Sounds and Night Skies Division (NSNSD) received a request to collect baseline acoustic data at Lava Beds National Monument (LBE). From August 2014 to September 2014 three acoustic monitoring systems were deployed across the park. These stations were configured to collect sound pressure level data and continuous audio recordings for approximately thirty days. The baseline data collected during this period will help managers and planners assess the current condition of the acoustic environment at LBE. Results of this study will help assess future impacts of a new designated military airspace over the park. The measured existing and natural ambient conditions may also be used as a baseline for noise modeling efforts.

LBE offers a variety of unique pristine natural sounds not found in most urban or suburban environments. This quiet setting provides a very special dimension to the park experience. The quiet affords visitors an opportunity to hear faint or very distant natural sounds such as grass blowing in the wind, and the call of a coyote. Sources of noise at LBE include trains, vehicles, and aircraft. 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). Table 1 displays percent time audible values for each of the most common noise sources during the monitoring period as well as ambient sound levels. Ambient sound pressure levels were measured continuously, every second, over the 30-day monitoring period by calibrated, Type 1, Larson Davis 831 sound level meters. After monitoring was complete percent time audible metrics were calculated. See the Methods section for protocol details, equipment specifications and calculation of metrics. Median existing (L_{50}) and natural ambient (L_{nat}) metrics are also reported for daytime (7 am – 7 pm) and nighttime (7 pm – 7am).

Table 1. Mean percent time audible for all extrinsic sounds, aircraft and vehicles

Site Description	Mean percent time audible (in 24 hour period)				Median Existing Ambient (L_{50}) in dBA		Median Natural Ambient (L_{nat}) in dBA	
	All Extrinsic	Aircraft	Vehicles	Trains	Day	Night	Day	Night
LBE001	95.2	10.3	32.7	16.5	25.4	20.1	20.3	16.8
LBE002	58.0	20.1	11.8	3.5	19.5	30.8	17.5	26.0
LBE003	67.7	25.2	2.4	30.3	18.2	17.5	16.3	15.8

In determining the current conditions of an acoustic environment, it is informative to examine how often sound pressure levels exceed certain values. Table 2 reports the percent of time that measured levels were above four thresholds during the monitoring period (daytime and nighttime). The top value in each split-cell focuses on frequencies affected by transportation noise (20-1250 Hz) and measures a truncated (T) set of frequencies, whereas the lower values represent the conventional full frequency range (12.5-20,000 Hz). Recent studies suggest that sound events as low as 35 dBA, the lowest value in table 2, can have adverse effects on blood pressure while sleeping (Haralabidis, 2008). 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 impacts on average voice communications at 1 meter. Hikers or other visitors viewing scenic areas in the park would likely be conducting such conversations.

Table 2. Percent time above sound thresholds represented in a truncated frequency range and the full measured frequency range.

Site	Frequency (Hz)	%Time above sound level: 0700 to 1900				%Time above sound level: 1900 to 0700			
		35dBA	45dBA	52dBA	60dBA	35dBA	45dBA	52dBA	60dBA
LABE001: Hovey Point	20-1250 (T)	2.93	0.31	0.08	0.00	0.73	0.07	0.00	0.00
	12.5-20,000	3.84	0.88	0.11	0.00	1.49	0.14	0.01	0.00
LABE002: Cave Loop Road	20-1250 (T)	1.42	0.13	0.01	0.00	0.21	0.01	0	0.00
	12.5-20,000	1.99	0.19	0.02	0.00	39.37	13.45	0.02	0.00
LABE003: Backcountry	20-1250 (T)	1.14	0.20	0.01	0.00	0.16	0.00	0.00	0.00
	12.5-20,000	1.36	0.20	0.01	0.00	0.39	0.01	0.00	0.00

This report shows that overall anthropogenic noise is very commonly audible at the three sites, however overall acoustic impacts and exceedance levels are low, meaning that while noise is audible, it does not introduce substantial sound energy to the acoustic environment. In many cases only listeners with very sensitive hearing would find a majority of the anthropogenic sound sources identified at LABE audible. If unchecked, impacts could increase over time, but if sound levels are kept low or are reduced through mitigation, this could result in one of the most natural soundscapes in the area. Efforts to maintain the low levels of impacts could include (but are not limited to) interpretive signs about the acoustic environment, educating small craft pilots especially when flying over wilderness areas, about natural soundscapes or installing quieter pavement types on main roads. These are a few examples that could improve the acoustic environment and reduce audibility from sound sources.

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List of Acoustic Terms

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

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

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

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

Decibel (dB) - A unit of sound energy. Every 10 dB increase represents a tenfold increase in energy. Therefore, a 20 dB increase represents a hundredfold increase in energy. When sound levels are adjusted for human hearing, they are expressed as 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, humans and different species of animals are capable of hearing (or not hearing) at different frequencies. Humans with normal hearing can hear sounds between 20 Hz and 20,000 Hz, and as low as 0 dB at 1,000 Hz. Some bats, on the other hand, can hear sounds between 20 Hz and 200,000 Hz.

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

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

Leq- Energy Equivalent Sound Level. The sound energy level averaged over the measurement period.

Lnat (Natural Ambient Sound Level) - The natural sound conditions in parks, which exist in the absence of any human-produced noise.

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

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

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

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

Soundscape- The human perception of the physical sound resource.

Introduction

The NPS Visitor

A 1998 survey of the American public revealed that 72 percent of respondents thought that providing opportunities to experience natural quiet and the sounds of nature was a very important reason for having national parks, while another 23 percent thought that it was somewhat important (Haas & Wakefield 1998). In another survey specific to park visitors, 91 percent of respondents considered enjoyment of natural quiet and the sounds of nature as compelling reasons for visiting national parks (McDonald et al. 1995). Acoustical monitoring provides a scientific basis for assessing the current status of acoustic resources, identifying trends in resource conditions, quantifying impacts from actions within and outside of the park, assessing consistency with park management objectives and standards, and informing management decisions regarding desired future conditions.

National Park Service Natural Sounds and Night Skies Division

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

Soundscape Planning Authorities

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

Direction for management of natural soundscapes [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 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 2006).

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 2006). However, the desired acoustical condition may also depend upon the resources and the values of the park. For instance, Management Policies 5.3.1.7 Cultural Soundscapes, states, “culturally appropriate sounds are important elements of the national park experience in many parks.” In this case, “the Service will preserve soundscape resources and values of the parks to the greatest extent possible to protect opportunities for appropriate transmission of cultural and historic sounds that are fundamental components of the purposes and values for which the parks were established” (NPS 2006).

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

Directors Order 47, Preservation of the Acoustic Environment and Noise Management (2015) builds on the principles set out in Management Policies, but goes on to direct how and when to consider acoustic resources in park management. Through this order, parks are guided to manage noise by: identifying noise sources, minimizing noise from park operations, considering the acoustic environment in park planning documents, and promoting park sounds and noise management through communication, education, and outreach.

National Parks Air Tour Management Act (NPATMA) was passed on April 5, 2000 to regulate 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

Lava Beds National Monument is located in northern California and encompasses 46,560 acres at the junction of the Sierra-Klamath, Cascade, and Great Basin geologic provinces (Figure 1). President Calvin Coolidge established Lava Beds National Monument by presidential proclamation on November 21, 1925. The monument protects and interprets volcanic and other natural features of scientific importance, and evidence of prehistoric and historic human settlement, use, and conflict (National Park Service, 2010).

The monument contains a range of Great Basin vegetation communities, including ponderosa pine forest, mountain mahogany/juniper woodland, Great Basin sagebrush/bunchgrass steppe, and the Tule Lake wetland margin. These areas provide habitat for a wide range of animal species including mammals, birds, amphibians, insects, reptiles, arthropods, and both aboveground and cave invertebrates. The lava tube caves and volcanic landscape in the monument provide habitat for at least 15 bat species (National Park Service, 2010).

The boundary of the monument is bordered by the Modoc National Forest, the Klamath National Forest, the Lower Klamath Basin National Wildlife Refuges, Bureau of Reclamation property, and Bureau of Land Management property, as well as private lands. Primary access to Lava Beds National Monument is from the north, over paved Siskiyou and Modoc County roads that connect with California State Highways 161 and 139. Volcanic Legacy Scenic Byway also labeled Hill road, Rd 10 and Lava Beds National Monument Road meets Lyons Road and are the two main thoroughfares in the park. There are railroad tracks outside of the boundaries of the park on the west and east that meet in the north, the closest tracks are on the eastern side of the park and there is an active railroad yard to the northeast of the park. LABE001 is near Lyons Road and is the site closest to a major road. LABE002 is near Cave Loop Road, a one-way loop road that provides access to many volcanic features in the park. LABE003 is located near a system of caves in one of the two federally designated wilderness areas in the park which is accessible only to hikers (Table 3).

Table 3. LABE long-term acoustical monitoring sites.

Site	Site Name	Dates Deployed	Vegetation	Elevation	Latitude	Longitude
LABE001	Hovey Point	8/18/2014-9/23/2014	Desert	1285m	41.81	-121.52
LABE002	Cave Loop Road	8/18/2014-9/23/2014	Desert	1540m	41.70	-121.51
LABE003	Backcountry	8/19/2014-9/22/2014	Desert	1298m	41.76	-121.49

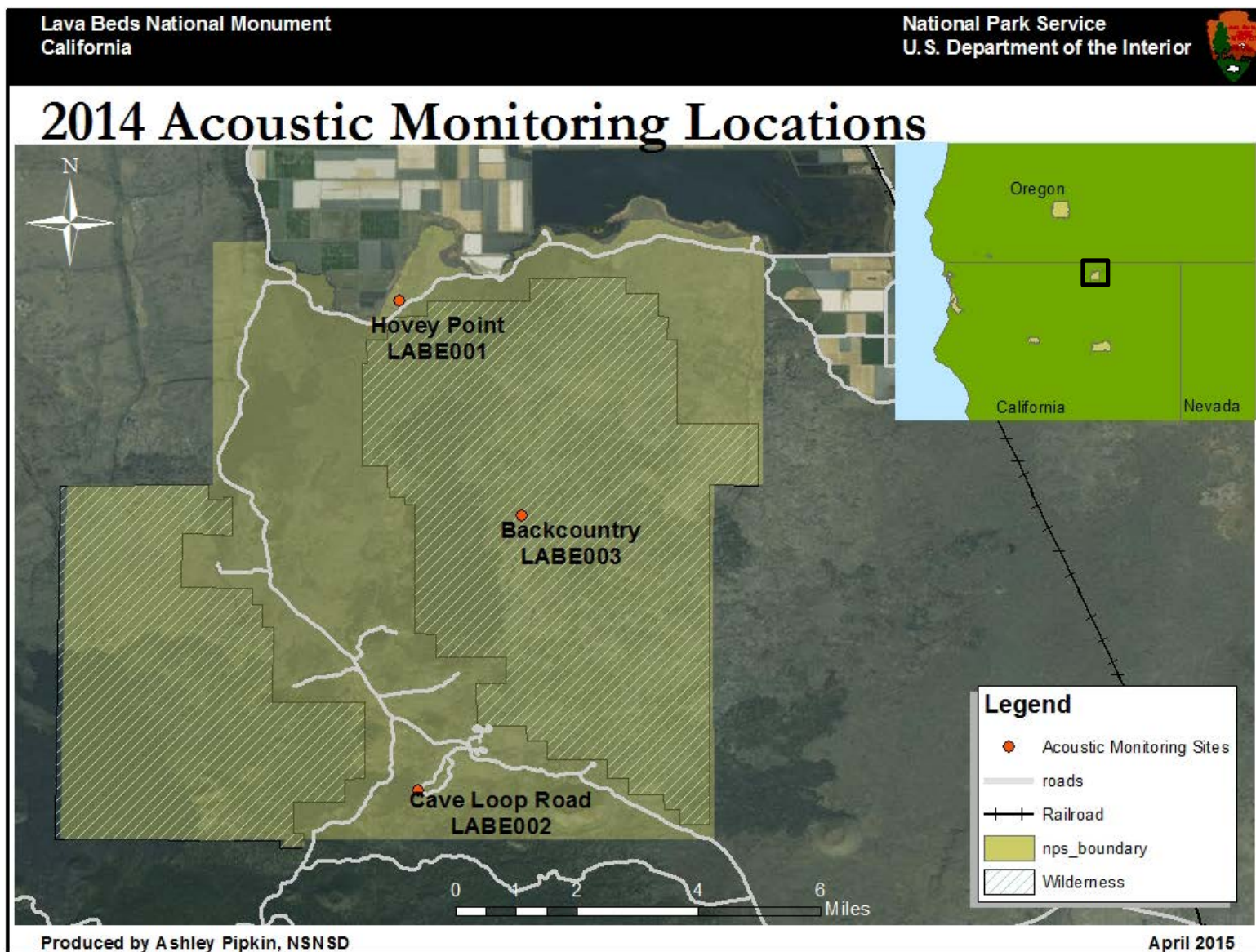


Figure 1. Location of acoustic monitoring sites at Lava Beds National Monument.

Methods

Automatic Monitoring

Larson Davis 831 sound level meters (SLM) were employed over the thirty-day monitoring period at each of the LABE sites (Table 3). 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. These Larson Davis-based sites met American National Standards Institute (ANSI) Type 1 standards. The sound level meters provided the information needed to calculate metrics described below in Calculation of Metrics.

The sampling stations consisted of:

- Microphone with environmental shroud
- Preamplifier
- Eight 3.2 V LiFe rechargeable battery packs
- Anemometer (wind speed and direction)
- Temperature and humidity probe
- MP3 recorder

The sampling stations collected:

- SPL data in the form of A-weighted decibel readings (dBA) every second
- Continuous digital audio recordings¹
- One third octave band data every second ranging from 12.5 Hz – 20,000 Hz
- Continuous meteorological data including wind speed, direction, temperature, and relative humidity

Calculation of Metrics

The current status of the acoustic environment can be characterized by spectral measurements, durations, and overall sound levels (intensities). 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 sound pressure levels that is exceeded x% of the time. The L_{50} represents the median sound pressure level, and is comprised of spectra (in dB) drawn from a full dataset (removing data with wind speed > 5m/s to eliminate error from microphone distortion.). The natural ambient (L_{nat}) is an estimate of what the ambient sound level for a site would be if all extrinsic or anthropogenic sources were removed. Unlike the existing ambient, the natural ambient is comprised of spectra drawn from a subset of the original data.

¹ An equipment malfunction at LABE002 and LABE003 caused there to be gaps in the continuous audio 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):

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

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 Figures 2 through 4 in the results section. Additionally, these figures separate the data into 33 one-third octave bands.

On-Site Listening

While the sound level meter provides information about how loud or quiet the acoustic environment is at a given time, we need .mp3 recordings or on-site listening sessions to know *what* or *who* is making the sound. On-site listening is the practice of placing an observer near the acoustic monitoring station with a handheld digital device (Apple iPod Touch®). The observer listens for a designated period of time (in this case, one hour), and identifies all sound sources and their durations. On-site listening takes full advantage of human binaural hearing capabilities, and closely matches the experience of most park visitors. Logistic constraints prevent comprehensive sampling by this technique, but selective samples of on-site listening provide a basis for relating the results of off-site listening 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, four periods of on-site listening were conducted at each of the three sites, in order to discern the type, timing, and duration during sound-level data collection. As recommended by NSNSD protocol (NPS 2005), these sessions lasted for one hour each. Staff recorded the beginning and ending times of all audible sound sources using custom-designed software (SoundLog). These on-site listening sessions provided the basis for the calculation of metrics including the period of time between noise events (average noise free interval [NFI]), percent time each sound source was audible, and maximum, minimum, and mean length (in seconds) of sound source events. The results of these on-site listening sessions are summarized in Tables 5-7.

Off-Site Listening/ Auditory Analysis

Auditory analysis was used to calculate the audibility of sound sources at LABE. Trained technicians at Colorado State University analyzed a subset of .mp3 samples (10 seconds every two minutes for eight days of audio) in order to identify durations of audible sound sources. The total percent time extrinsic sounds were audible was used to calculate the natural ambient sound level for each hour (see Equation 1 for more information). Due to an equipment malfunction at LABE002, 5.7% of the audio data used to compute this metric was corrupt and was coded as unknown. To increase usable audio and calculate the best estimate of natural ambient sound pressure levels at LABE, technicians

used days with the most complete audio. To supplement missing hours of audio, at LABE002 alternate days were used to compensate for missing hours. On August 27, 98 minutes are used to supplement that exact time frame that data was missing on August 22. LABE003 also had some technical difficulties but 8 full days were able to be extracted from the dataset. Bose Quiet Comfort Noise Canceling headphones were used for off-site audio playback to minimize limitations imposed by the office acoustic environment.

Results

On-site Listening

Tables 4, 5, 6, and 7 display the results of the on-site listening sessions at LABE. Each audible sound source is listed in the first column. Percent time audible, or PA, is shown in the second column. The third column, Max Event, reports the maximum event length among the sessions for each sound source. Likewise, Mean Event and Min Event columns report the mean and minimum length of events, respectively. Std Dev 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 (NFI), is a metric that describes the length of time between extrinsic or human-caused events (when only natural sounds were audible). The NFI row and the Max Event, Mean Event, Min Event, and Std Dev columns are reported in minutes:seconds. 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 this location.

Table 4. Summary of on-site audible sound sources for Hovey Point (LABE001) n=4 hour-long sessions. Events are measured in minutes:seconds. Sessions started at 9:00, 10:15, 10:30 and 11:15.

Category	Sound Source	PA (%)	Max Event	Mean Event	Min Event	Std Dev	Events
Extrinsic (human-caused)	Aircraft	3.6	07:08	02:51	00:22	03:44	3
	Jet	16.4	04:20	01:38	00:03	01:12	24
	Propeller	7.1	05:27	02:50	00:45	01:47	6
	Vehicle	23.2	13:22	01:28	00:13	02:37	38
	Farm Equipment	48.5	57:53	10:52	00:05	18:58	11
	Vehicle Alarm	1.0	00:33	00:12	00:04	00:08	12
	Door	0.0	00:03	00:02	00:01	00:01	2
	Motors	11.5	21:52	06:55	01:23	09:58	4
	People	0.0	00:03	00:03	00:03	00:00	1
	Talking	0.1	00:08	00:08	00:07	00:01	2
	Construction	2.1	04:57	04:57	04:57	00:00	1
Natural Sounds	Wind	24.7	03:20	00:45	00:02	00:38	80
	Bird	40.2	31:42	01:21	00:02	03:50	71
	Insect	37.4	11:49	01:15	00:01	01:58	72
Noise-Free Interval		–	05:52	00:53	00:01	01:22	34

Table 5. Summary of on-site audible sound sources for Cave Loop Road (LABE002) n=4 hour-long sessions. Events are measured in minutes:seconds. Sessions started at 8:45, 10:45, 15:00 and 16:00.

Category	Sound Source	PA (%)	Max Event	Mean Event	Min Event	Std Dev	Events
Extrinsic (human-caused)	Aircraft	2.0	04:51	04:51	04:51	–	1
	Jet	16.7	03:58	01:49	00:09	01:12	22
	Propeller	9.5	06:05	02:33	00:22	01:50	9
	Vehicle	31.5	06:41	01:02	00:13	01:00	73
	Vehicle Alarm	0.0	00:01	00:01	00:01	–	1
	Vehicle Door	1.5	00:15	00:04	00:01	00:04	60
	Motor	1.2	02:57	02:57	02:57	–	1
	People	0.0	00:04	00:04	00:04	–	1
	Talking	6.8	02:10	00:29	00:01	00:33	34
	Walking	1.3	01:26	00:46	00:05	00:39	4
	Dog	0.1	00:18	00:18	00:18	–	1
Natural Sounds	Wind	61.5	20:07	02:10	00:05	03:06	68
	Bird	59.2	26:16	01:55	00:01	04:10	74
	Insect	37.2	08:53	00:48	00:01	01:16	112
Noise-Free Interval		–	08:24	00:51	00:01	01:16	121

Table 6. Summary of on-site audible sound sources for Backcountry (LABE003) n=4 hour-long sessions. Events are measured in minutes: seconds Sessions started at 12:00, 13:00, 14:00 and 15:00.

Category	Sound Source	PA (%)	Max Event	Mean Event	Min Event	Std Dev	Events
Extrinsic (human-caused)	Aircraft	1.7	04:07	04:07	04:07	–	1
	Jet	21.0	03:50	01:48	00:10	01:08	28
	Propeller	10.1	05:51	02:42	00:28	02:00	9
	Motor	3.7	03:06	01:29	00:31	01:00	6
	Non-natural Unknown	2.4	02:46	01:26	00:38	00:58	4
Natural Sounds	Wind	70.8	25:25	03:05	00:11	05:13	55
	Bird	63.3	19:41	02:14	00:01	03:45	68
	Insect	74.6	39:08	03:54	00:02	07:23	46
Noise-Free Interval		–	43:46	04:11	00:02	08:15	38

Off-Site Data Analysis

Metrics

In order to determine the effect that extrinsic noise audibility has on the acoustic environment, it is useful to examine the median hourly exceedance metrics. The dB levels for 33 one-third octave band frequencies over the day and night periods are shown in Figures 2 through 5. High frequency sounds (such as a cricket chirping) and low frequency sounds (such as flowing water) often occur simultaneously, so the frequency spectrum is split into 33 smaller ranges, each encompassing one-third of an octave. For each one-third octave band, dB level was recorded once per second for the duration of the monitoring period. Recording the sound intensity of each one-third octave band (combined with digital audio recordings) allows acoustic technicians to determine what types of sounds are contributing to the overall sound pressure level of a site. The gray shading of the 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 dB level exceeded x percent of the time. For example, L_{90} is the dB level that has been exceeded 90% of the time, and only the quietest 10% of the samples can be found below this point. On the other hand, the L_{10} is the dB level that has been exceeded 10% of the time, and 90% of the measurements are quieter than the L_{10} . The bold portion of the column represents the difference between L_{50} (existing ambient) and L_{nat} (natural ambient). The height of this bold portion 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 mark the median (L_{50}), maximum (L_{90}), and minimum (L_{10}) sounds pressure levels over the 34 day monitoring period. The typical frequency levels for transportation, conversation and songbirds are presented on the figure as examples for interpretation of the data. These ranges are estimates and are not vehicle, species, or habitat-specific. It can be useful to review each one-third octave band on these figures to predict the audibility of one sound or the masking of another. Notice that songbirds and transportation noise are audible at different frequency spectrums. Sometimes transportation sounds are occurring at the same time as birds singing. In this case, bird sounds would not be masked because their song is audible at a different frequency. If both sound sources are within similar or overlapping frequency ranges, and one sound source is louder the listener can expect the quieter sound to be masked.

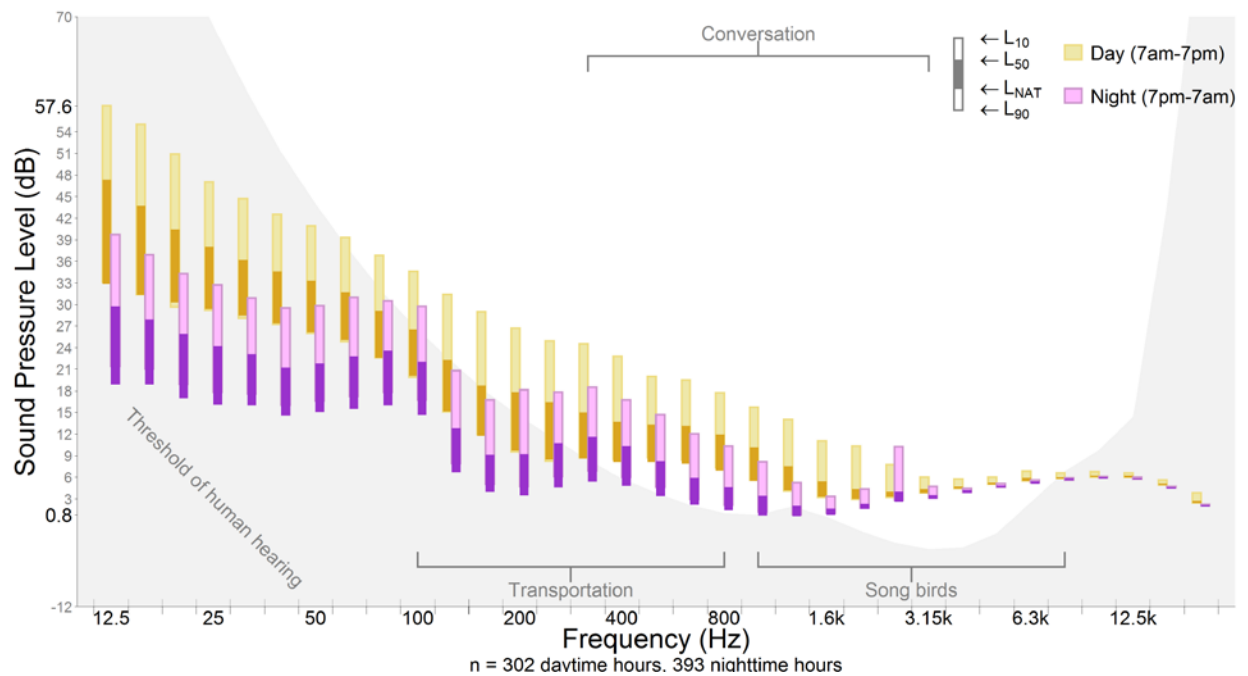


Figure 2. Day and night dB levels for 33 one-third octave bands at Hovey Point (LABE001) summer 2014.

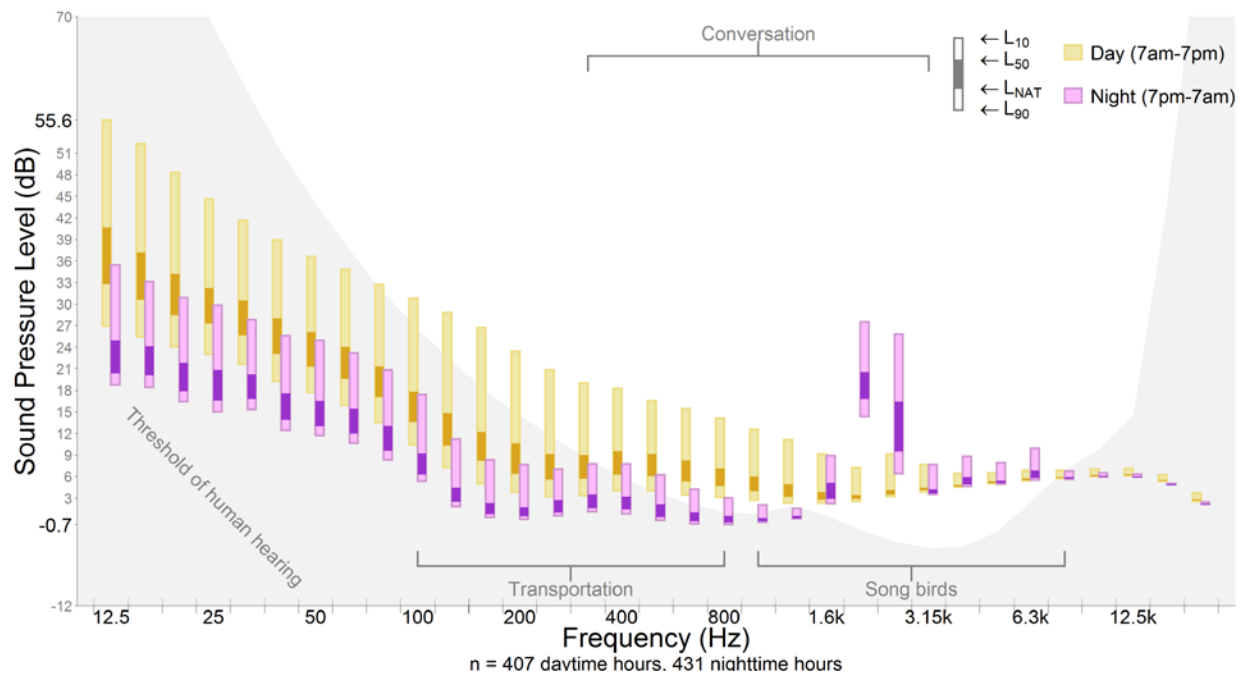


Figure 3. Day and night dB levels for 33 one-third octave bands at Cave Loop Road (LABE002) summer 2014.

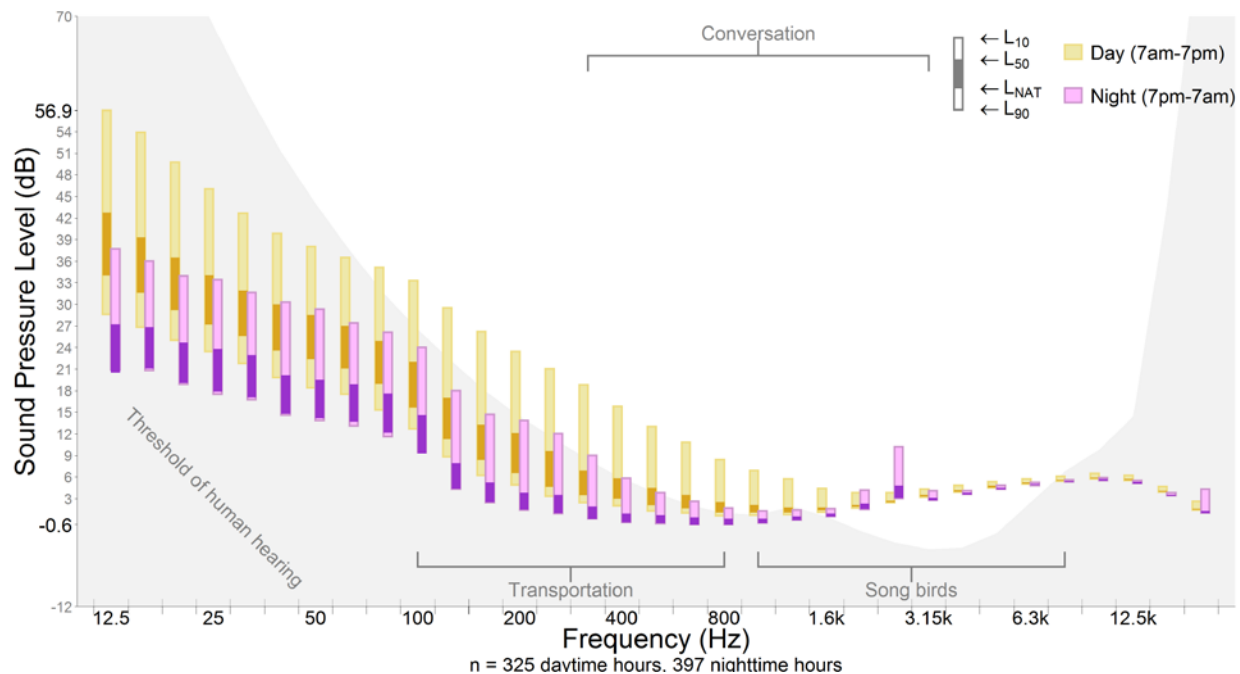


Figure 4. Day and night dB levels for 33 one-third octave bands at Backcountry (LBE003) summer 2014.

Table 7 reports the L_{90} , L_{nat} , L_{50} , and L_{10} values for the sites measured at LBE. 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 distinctive 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.

Table 7. Exceedance levels for existing conditions in LBE.

Site	Frequency (Hz)	Exceedance levels (dBA): 0700 to 1900				Exceedance levels (dBA): 1900 to 0700			
		L90	Lnat	L50	L10	L90	Lnat	L50	L10
LBE001: Hovey Point	20-1250 (T)	17.5	17.0	22.3	29.2	12.4	11.1	16.2	22.3
	12.5-20,000	19.6	19.2	23.6	30.3	17.4	16.7	19.8	25.2
LBE002: Cave Loop Road	20-1250 (T)	11.2	13.4	16.5	25.9	7.4	7.7	9.1	13.2
	12.5-20,000	16.4	17.4	19.3	27.5	23.6	26	30.8	36.1
LBE003: Backcountry	20-1250 (T)	9.8	11.1	14.7	24.9	7.6	7.6	9.1	15.7
	12.5-20,000	15.6	16.0	17.7	26.2	15.7	15.7	17.4	22.5

In determining the current conditions of an acoustic environment, it is important to examine how often sound pressure levels exceed certain values. Table 8 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 (20-1250 Hz) whereas

the lower values use the conventional full frequency range (12.5-20,000 Hz). The first, 35 dBA, is designed to address the health effects of sleep interruption. Recent studies suggest that sound events as low as 35 dBA can have adverse effects on blood pressure while sleeping (Haralabidis, 2008). 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. Hikers and visitors viewing scenic vistas in the park would likely be conducting such conversations.

Table 8. Percent time above metrics for LABE

Site	Frequency (Hz)	%Time above sound level: 0700 to 1900				%Time above sound level: 1900 to 0700			
		35dBA	45dBA	52dBA	60dBA	35dBA	45dBA	52dBA	60dBA
LABE001: Hovey Point	20-1250 (T)	2.93	0.31	0.08	0.00	0.73	0.07	0.00	0.00
	12.5-20,000	3.84	0.88	0.11	0.00	1.49	0.14	0.01	0.00
LABE002: Cave Loop Road	20-1250 (T)	1.42	0.13	0.01	0.00	0.21	0.01	0.00	0.00
	12.5-20,000	1.99	0.19	0.02	0.00	39.37	13.45	0.02	0.00
LABE003: Backcountry	20-1250 (T)	1.14	0.20	0.01	0.00	0.16	0.00	0.00	0.00
	12.5-20,000	1.36	0.20	0.01	0.00	0.39	0.01	0.00	0.00

Audibility

Audibility results are presented in tables 9 through 11 and show the mean percentage of time that all noise sources were audible at each monitoring location. These tables do not provide information on how loud a source of noise is, only if it can be heard in the recording collected at the site. Sounds with high audibility from anthropogenic sounds do not necessarily align with the loudest sites in the park. These results are based on eight days of off-site auditory analysis. Natural Sounds are white, while the sound sources highlighted in gray are human caused. Figures 6 through 11 show hourly audibility results from anthropogenic sound sources and then evaluate how three sources of interest; aircraft, vehicles and trains, contribute to this metric. In tables 9 through 11 sources of sound are specifically identified unless the source was not discernable. “Vehicles”, for example, were not able to be specifically characterized so have a general label, while automobiles, farm equipment, horn alarms, car doors and trucks were able to be specifically identified. Figures 6 and 9 show vehicle noise, lumping together specific and general vehicle noise to provide a complete metric about the category.

Table 9. Mean hourly percent time audible for each noise source at Hovey Point (LABE001) n=8 days off-site sound source analysis.

Category	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
Extrinsic (human-caused)	Jet	0.4	0.0	0.0	1.7	0.8	2.5	2.5	5.4	8.3	4.2	15.4	5.0	5.4	5.8	9.6	3.8	4.2	5.8	10.0	22.9	10.4	15.0	9.6	3.0
	Prop	0.4	0.0	0.0	0.0	0.0	0.0	2.5	16.7	1.7	8.7	6.7	12.1	5.8	2.1	1.7	7.9	7.1	5.8	9.2	0.8	5.0	1.7	0.0	0.4
	Helicopter	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Vehicle	3.8	4.2	0.4	1.7	3.3	3.3	5.0	12.5	17.9	17.5	12.9	17.1	16.7	14.6	11.3	12.1	12.9	12.9	12.5	13.8	7.5	8.7	5.0	2.5
	Automobile	0.4	0.4	0.0	0.0	1.2	0.4	0.4	1.2	1.2	2.5	3.8	2.5	2.9	1.2	2.5	3.3	0.8	0.4	0.4	1.7	0.4	1.7	0.0	0.4
	Farm Equipment	0.8	0.8	0.0	2.1	3.8	1.7	1.2	12.1	25.8	30.8	36.7	32.1	29.2	27.1	24.2	21.2	8.7	9.6	14.2	2.5	0.0	0.0	0.0	0.0
	Alarm, Horn	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Door	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Truck	0.0	0.0	0.0	0.0	0.0	0.4	2.5	7.5	4.2	5.0	7.9	2.1	0.0	0.4	4.6	1.2	2.1	3.3	2.5	2.1	0.8	0.8	0.0	0.8
	Heavy Equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.6	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Train	15.8	14.2	20.8	19.2	29.2	20.4	21.7	5.4	0.4	0.4	4.2	0.0	0.0	0.0	0.4	0.4	0.0	0.0	3.8	1.2	10.4	17.1	31.2	32.1
	Train Rumble	22.9	15.8	16.7	9.2	7.9	14.2	11.3	6.7	5.4	1.2	0.0	0.0	0.0	0.0	2.1	2.5	0.0	0.0	1.2	2.9	4.6	0.0	0.4	4.6
	Train Whistle	2.1	1.7	2.5	1.2	3.3	1.7	0.8	0.0	1.2	2.5	0.0	0.0	0.0	0.4	0.8	0.8	0.8	0.0	1.2	1.2	1.7	0.8	0.4	1.7
	Voices	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0
	Walking	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.7	0.4	1.7	0.8	0.8	0.0	0.0	0.0	1.7	0.4	0.0	0.0	0.0	0.0
	Gunshot	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Dog	0.4	0.0	2.5	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.4	0.0	0.0	0.0	0.0	0.8	0.4	0.0	0.0	0.0
	Construction	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Non-Natl Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.8	0.8	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0
	Non-Nat Unk	54.6	63.8	54.6	65.8	58.8	60.4	57.9	39.6	40.0	29.2	11.3	14.2	14.2	24.2	22.9	21.7	14.6	9.6	18.8	47.9	50.8	49.2	52.5	47.5
Natural Sounds	Wind	14.6	24.2	19.2	20.0	8.3	0.0	2.5	2.1	6.2	23.7	36.7	69.2	79.6	92.9	87.9	90.8	96.2	95.8	69.2	35.4	25.4	16.7	13.3	16.7
	Rain, Fog Drip	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 9 (continued). Mean hourly percent time audible for each noise source at Hovey Point (LABE001) n=8 days off-site sound source analysis.

Category	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
Natural Sounds (continued)	Mammal	0.0	0.4	0.4	0.4	2.1	1.7	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	3.8	0.0	0.8	0.4	0.0	0.0	0.0
	Squirrel	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0
	Coyote	0.0	0.8	0.0	0.4	0.0	0.8	0.4	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.8	2.1	1.7
	Bird	20.0	23.3	13.3	20.4	18.3	41.3	90.0	93.3	86.2	75.0	53.8	30.8	26.7	18.3	25.0	23.7	26.2	49.2	55.0	52.1	16.7	11.3	10.0	20.4
	Insect	64.2	39.6	20.8	2.5	2.5	0.8	0.4	0.4	3.3	17.9	31.2	48.8	54.2	45.0	33.7	32.9	29.2	30.4	22.5	24.6	95.0	99.6	98.3	92.1
	Animal	0.4	0.4	0.4	0.0	1.2	0.4	0.0	0.0	0.0	0.4	0.4	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.0	0.0	3.8	0.4	1.2	1.2
	Natural Other	0.8	0.0	0.8	0.0	0.4	0.0	0.0	0.0	0.0	0.4	1.7	0.4	0.4	0.8	0.4	0.0	0.0	0.8	0.0	0.4	0.4	0.0	0.4	0.4
	Wind-Induced Nat	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0
	Natural Unknown	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0
Unknown		0.4	0.0	0.4	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.4	0.4	0.0

Table 10. Mean hourly percent time audible for each noise source at Cave Loop Road (LABE002) n=8 days off-site sound source analysis.

Category	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
Extrinsic (human-caused)	Jet	0.8	1.2	1.2	2.9	2.1	1.2	4.6	16.3	30.4	6.7	33.3	20.4	22.9	9.6	22.5	10.8	21.7	12.5	3.8	20.0	33.3	30.4	19.6	8.7
	Military Jet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Prop	2.1	0.0	0.0	0.0	0.8	2.1	10.4	13.3	9.6	10.4	10.8	21.2	10.0	13.8	11.7	7.5	8.3	6.7	2.1	3.8	5.0	2.1	0.0	0.0
	Helicopter	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Vehicle	3.8	1.7	4.2	0.4	2.5	10.0	17.9	15.4	1.7	4.6	5.0	8.3	6.7	10.4	12.1	7.1	11.7	5.0	2.5	5.8	9.6	7.9	3.3	4.2
	Automobile	0.0	0.4	0.4	0.0	0.0	2.1	16.7	10.4	2.5	10.0	10.0	9.6	7.5	3.3	7.9	12.1	4.6	0.8	0.0	0.0	0.0	0.0	0.8	1.7
	Alarm, Horn	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.0	2.9	2.1	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0
	Door	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.8	0.4	0.8	1.2	0.0	0.4	0.0	0.0	0.0	0.0	0.4	0.8	0.0
	Motorcycle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 10 (continued). Mean hourly percent time audible for each noise source at Cave Loop Road (LABE002) n=8 days off-site sound source analysis.

Category	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
Extrinsic (human-caused) (continued)	Heavy Equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.0	0.0	0.0	0.0	0.8	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Train Rumble	2.9	0.8	12.1	9.2	13.8	0.0	2.5	4.6	2.1	2.1	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	5.0	22.9
	Train Whistle	0.0	0.0	0.0	1.2	1.2	0.0	0.0	1.2	0.4	0.8	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7
	Grounds Care	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	2.1	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Voices	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	1.2	1.7	0.4	1.7	2.9	3.3	2.5	7.1	1.2	0.0	0.0	0.0	2.1	6.2	3.3
	Audio Device	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Gunshot	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0
	Construction	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Non-Natural Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Non-Nat Unknown	56.7	66.7	48.3	48.3	58.8	58.3	41.3	31.7	16.3	4.2	7.1	2.1	3.8	2.5	0.8	1.2	1.7	1.2	0.4	1.7	1.2	1.7	11.3	31.2
Natural Sounds	Wind	44.2	40.8	41.7	37.9	25.8	27.5	27.9	37.1	34.2	43.8	60.4	67.5	76.2	76.2	73.3	84.2	83.3	71.3	43.8	63.3	56.7	46.3	50.4	47.5
	Rain, Fog Drip	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Mammal	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.0	0.0	0.0	0.0	1.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Bird	0.8	1.2	2.1	5.8	7.1	28.7	87.5	93.3	66.7	50.0	58.3	39.6	36.7	30.4	25.4	28.3	34.6	37.5	10.8	27.9	12.1	2.1	0.4	0.0
	Amphibian	1.7	2.9	3.3	2.1	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	1.2	0.0
	Insect	99.6	100.0	95.4	94.6	72.1	23.7	2.9	4.6	7.9	20.8	53.8	69.2	67.1	69.2	60.4	58.3	40.0	23.3	5.0	16.7	98.3	99.6	100.0	98.7
	Animal	0.0	0.4	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.4	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Natural Other	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.4
	Natural Unknown	0.4	1.7	1.7	1.7	1.2	0.4	0.4	0.4	0.4	0.8	1.7	1.2	2.5	0.8	0.4	0.4	1.2	0.4	0.0	0.8	1.2	1.2	0.4	1.2
	Wind Distortion	1.2	0.4	0.0	0.8	0.0	0.0	0.0	0.0	0.0	1.7	3.8	7.5	25.0	22.1	26.7	22.1	39.6	32.9	25.8	28.3	5.4	0.8	0.8	1.2

Table 10 (continued). Mean hourly percent time audible for each noise source at Cave Loop Road (LABE002) n=8 days off-site sound source analysis.

Category	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
Natural Sounds (continued)	Field Personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unknown		0.4	1.2	0.4	0.4	0.0	0.4	0.0	0.0	26.7	32.1	0.0	0.0	0.0	0.0	0.0	0.8	1.7	9.6	53.3	18.8	0.4	0.4	0.8	0.8

Table 11. Mean hourly percent time audible for each noise source at Backcountry (LABE003) n=8 days off-site sound source analysis.

Category	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
Extrinsic (human-caused)	Aircraft	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.4	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0
	Jet	0.0	0.0	1.2	4.6	2.9	1.7	7.1	19.2	13.3	11.3	32.1	19.2	20.8	7.1	20.8	10.0	13.3	15.8	19.6	42.5	27.5	30.8	11.3	2.9
	Prop	0.8	1.2	0.4	0.0	0.0	2.1	10.8	28.3	20.4	32.1	24.2	26.2	10.8	20.0	6.7	8.7	12.1	12.1	15.0	5.4	6.2	1.2	1.7	0.0
	Vehicle	1.7	2.1	0.8	1.2	2.1	0.8	0.8	5.8	5.8	7.5	10.0	8.7	2.5	0.4	1.2	0.0	0.0	0.0	0.0	0.4	0.0	1.7	0.4	0.8
	Farm Equipment	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Truck	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0
	Train	0.4	0.4	6.7	11.3	12.5	4.6	10.4	1.7	0.0	1.2	0.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0
	Train Rumble	57.9	58.3	62.5	42.5	58.3	57.1	49.2	37.5	35.0	22.5	7.5	5.4	0.0	2.1	3.3	2.1	4.6	1.2	2.5	12.1	22.9	18.3	43.8	52.1
	Train Whistle	2.1	0.8	1.7	0.8	0.8	6.7	4.2	8.7	11.7	9.6	2.1	1.7	0.0	1.2	1.7	2.9	1.7	3.3	1.2	0.8	4.2	0.4	2.1	3.3
	Motor	11.3	7.9	4.2	12.9	15.4	19.2	10.4	1.2	1.2	2.1	2.5	4.2	2.1	2.1	1.2	2.9	0.8	0.0	0.8	2.5	0.4	0.0	2.9	2.1
	Portable-Audio	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.2	0.0	0.0
	Non-Natural Unk	2.5	3.8	11.3	18.8	2.1	0.4	1.7	4.2	16.7	8.7	8.7	8.7	6.2	2.5	2.9	7.9	0.4	1.7	4.2	2.5	0.8	5.4	6.2	0.0
Natural Sounds	Wind	30.8	26.7	10.0	5.8	4.2	2.9	1.7	9.6	21.7	38.3	40.0	56.7	81.2	82.9	80.8	83.7	85.4	85.4	73.3	44.2	24.2	9.6	15.8	10.4
	Mammal	14.6	16.7	25.4	20.8	28.3	27.5	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.4	8.7	3.8	6.2	10.4
	Coyote	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Bird	7.9	4.2	5.0	12.5	10.0	26.2	77.1	82.5	58.3	50.0	34.2	20.4	15.8	19.2	18.8	11.3	14.6	14.2	17.5	26.7	10.0	8.3	4.6	2.9
	Insect	98.7	92.9	57.1	30.4	10.8	1.7	1.7	2.9	9.6	14.6	32.1	43.3	54.2	55.8	50.4	40.8	40.8	44.2	47.5	40.0	85.4	87.5	86.7	80.8

Table 11 (continued). Mean hourly percent time audible for each noise source at Backcountry (LABE003) n=8 days off-site sound source analysis.

Category	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
Natural Sounds (continued)	Animal	15.4	15.8	12.9	17.9	17.9	13.8	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	5.8	3.3	2.9	8.3
	Natural Other	4.2	5.4	10.8	10.8	11.7	24.6	12.9	0.0	0.4	0.4	0.0	1.2	0.4	0.4	0.4	0.8	0.0	0.0	0.0	10.0	14.6	2.5	2.1	2.9
	Wind-Induced Nat	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.8	0.8	0.8	1.7	1.7	0.8	1.2	0.0	1.2	0.8	0.0	0.4	0.0
	Natural Unknown	0.4	0.0	0.4	0.0	0.8	0.8	1.2	0.0	0.8	0.0	0.4	1.2	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.4	0.4	0.4	0.0	0.4
	Artifact from Equip	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.4	0.0	3.8	5.0	0.4	0.0	0.0	0.0	0.4	0.0
	Wind distortion	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	5.8	10.4	5.4	5.4	0.4	0.4	0.0	0.0	0.0	0.0
Unknown		0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.8	6.2

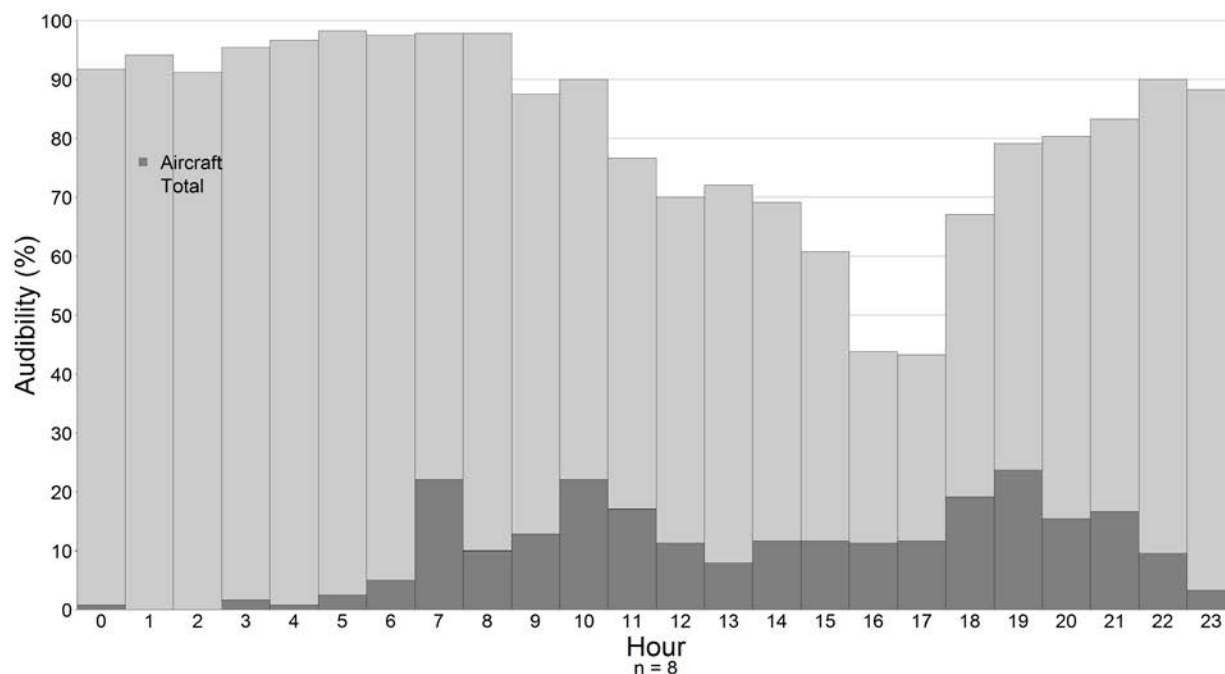


Figure 5. Comparison of hourly aircraft audibility and overall noise audibility at (LABE001). This graph includes jets, helicopters and propeller planes.

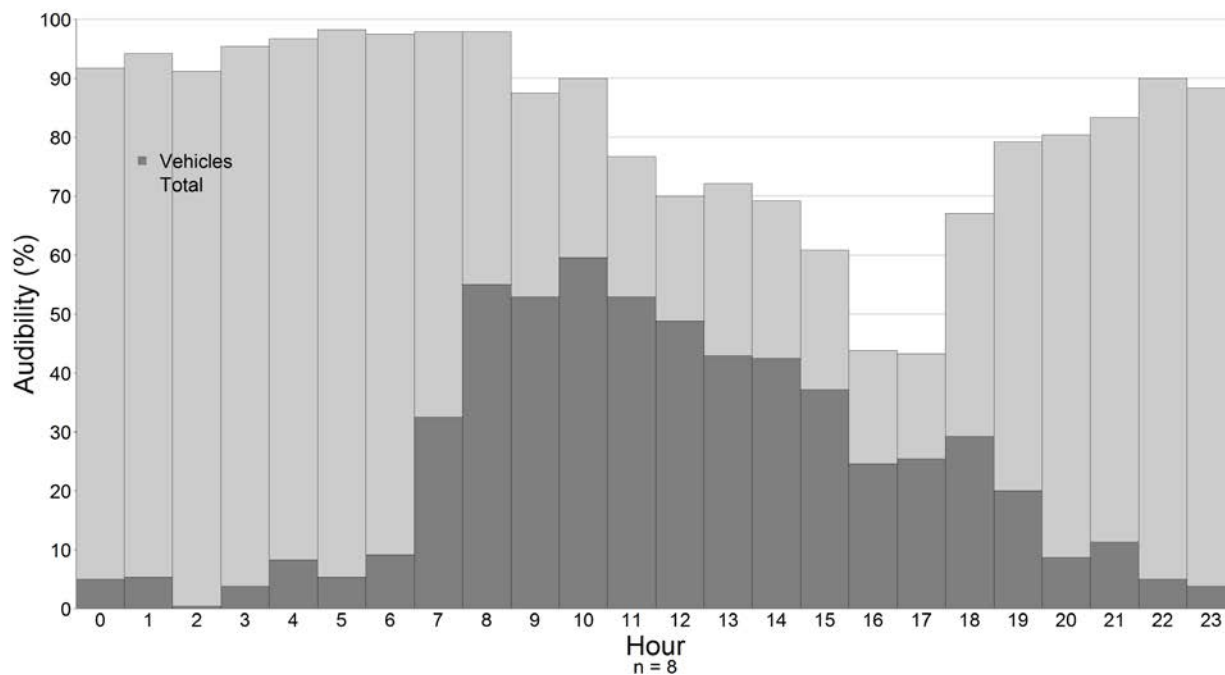


Figure 6. Comparison of hourly vehicle audibility and overall noise audibility at (LABE001). The vehicle category includes all sound sources generically marked as a vehicle and those that were able to be more specifically identified like automobiles, car alarms, car doors, motorcycles and heavy equipment.

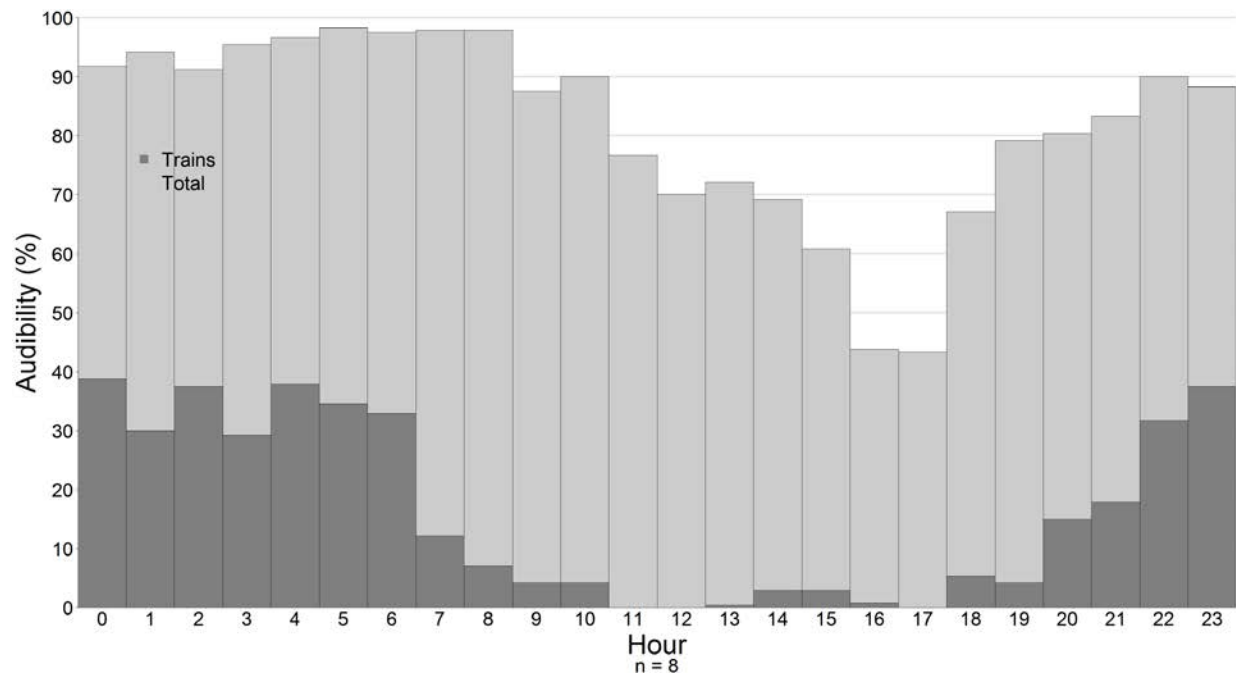


Figure 7. Comparison of hourly train audibility and overall noise audibility at (LABE001)

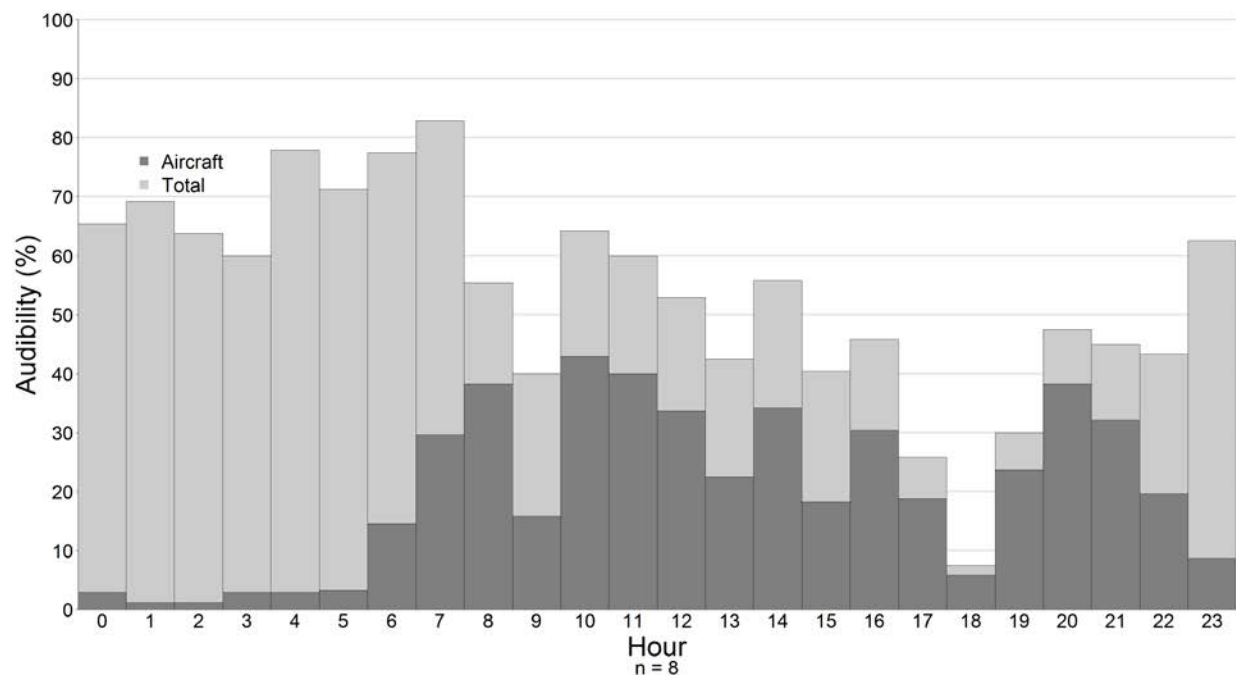


Figure 8. Comparison of hourly aircraft audibility and overall noise audibility at (LABE002). This graph includes jets and propeller planes.

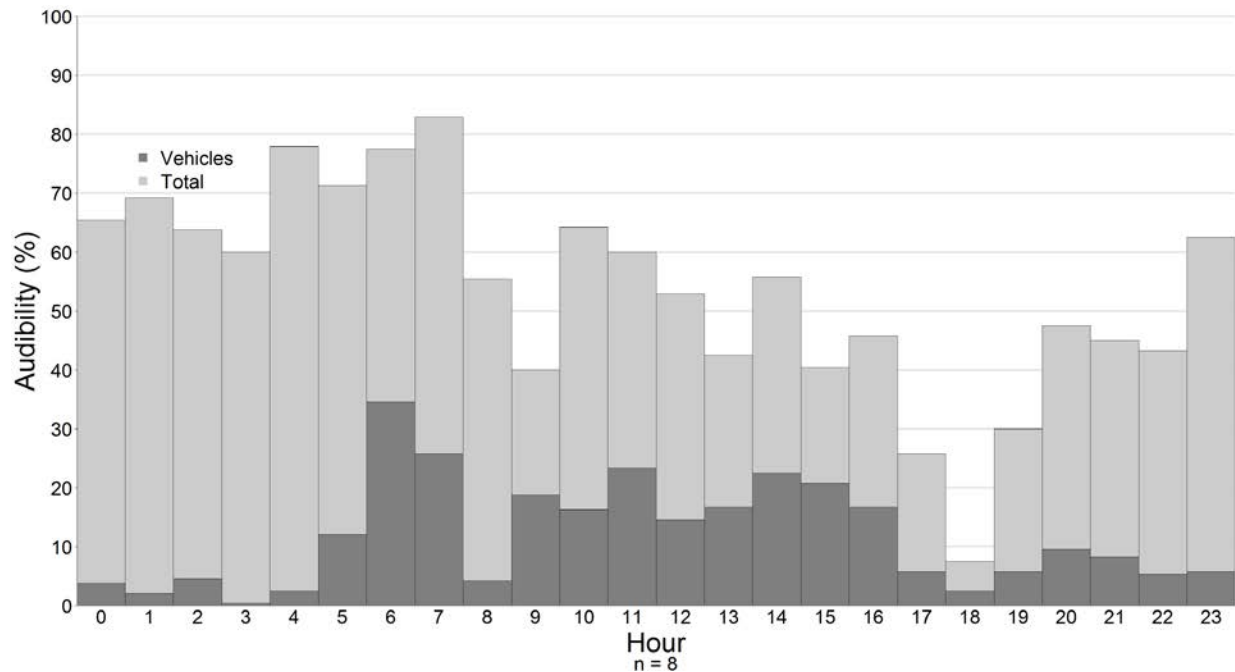


Figure 9. Comparison of hourly vehicle audibility and overall noise audibility at (LABE002). The vehicle category includes all sound sources generically marked as a vehicle and those that were able to be more specifically identified like automobiles, car alarms, car doors, motorcycles and heavy equipment

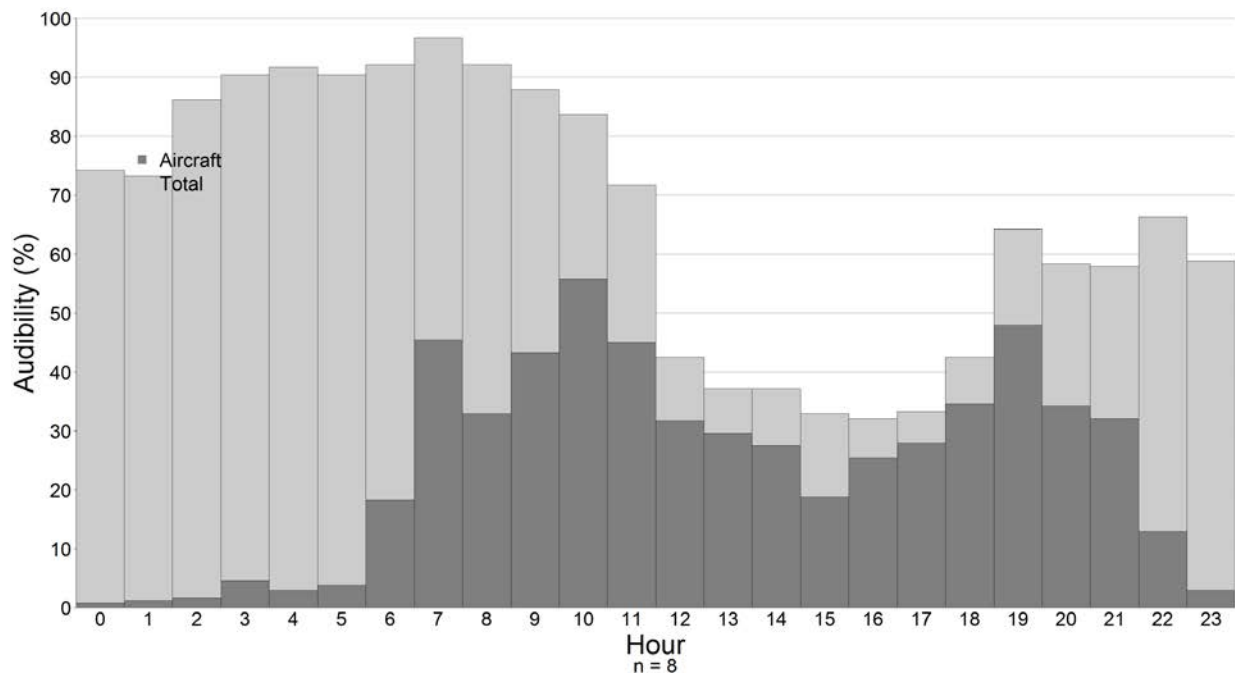


Figure 10. Comparison of hourly aircraft audibility and overall noise audibility at (LABE003). This graph includes jets, military jets, helicopters and propeller planes.

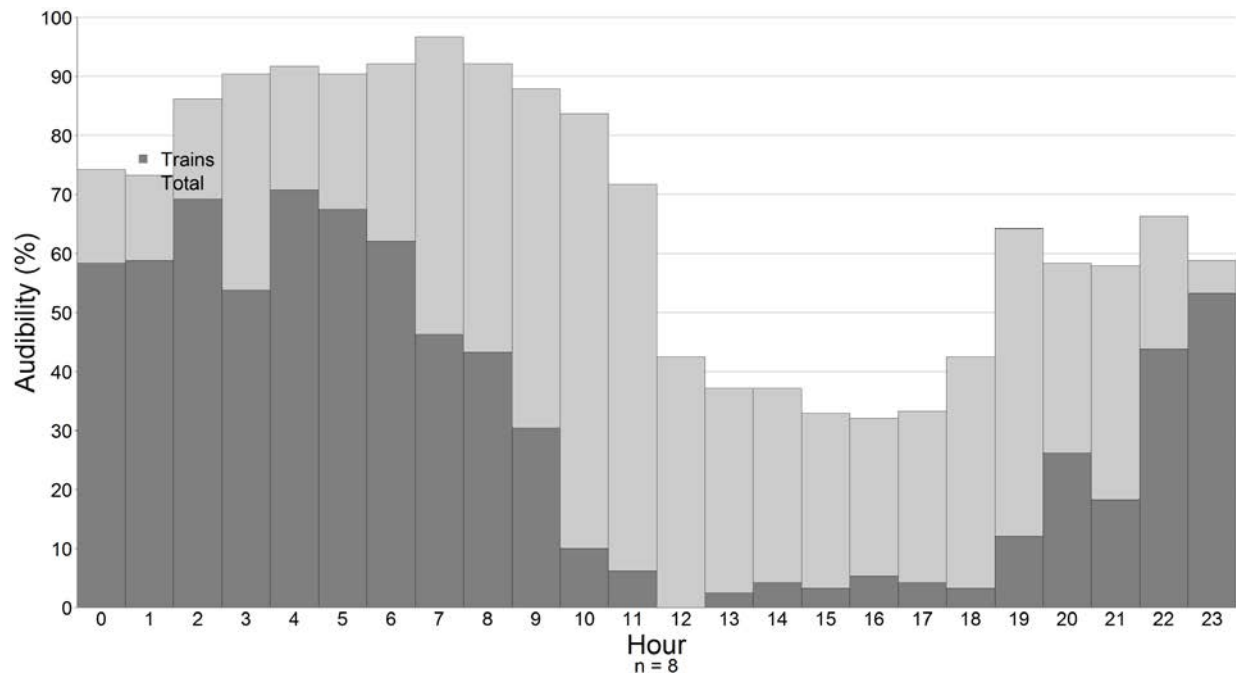


Figure 11. Comparison of hourly train audibility and overall noise audibility at (LBE003).

Discussion

The purpose of this study was to assess the current condition of the acoustic environment at Lava Beds National Monument. Monitoring results characterize existing sound levels and estimate natural ambient sound levels within LABE. This data is intended to provide the park with baseline acoustic conditions and to inform management decisions. Sound pressure level data, meteorological data, and audio were collected for more than 34 days from three sites across the park. One site was placed near Hovey Point another close to Cave Loop Road and the third was within Schonchin Wilderness Area. The locations of acoustic monitoring stations were chosen to further understand and compare the acoustic environment at more developed and backcountry areas in the park. Hovey Point represents a developed area near the main thoroughfare leading into the park. The Cave Loop Road site is near a parking area and interpretive roadway that has fairly frequent low-speed automobile traffic. The Backcountry site was placed in a wilderness area relatively far away from development. The vegetation, topography and visitor use are diverse between sites, which help shape the acoustic environment at each location.

Results of natural sounds were included in the off-site analysis but anthropogenic sound sources were the priority for annotation, therefore, the natural sounds may not be as thoroughly assessed in the analysis. The off-site analysis detected natural sounds including coyotes, amphibians (mostly Boreal Toads), squirrels and other mammals not picked up by the on-site listening. Because of equipment malfunctions, 5.7% of the audio could not be analyzed for LABE002. Enough audio was collected at all three sites to calculate the natural ambient sound level. Results from the 2014 monitoring indicate that the median natural ambient sound level (L_{nat}) for the monitoring period at Hovey Point was 19.2 dBA (daytime) and 16.7 dBA (nighttime), an additional 4.4 dB were added to the daytime SPL and 3.1 dB during the night that were from anthropogenic sources. This site had higher impacts from human noise than the other sites and higher overall SPLs. The Backcountry site had the lowest impacts from anthropogenic noise and had a daytime natural ambient of 16 dBA and at nighttime it was 15.7 dBA. For reference, a typical residential area is around 40 dBA at nighttime. When translating sound level impacts into functional effects (for human visitors and resident wildlife), an increase in background sound level of 3 dB produces an approximate decrease in listening area of 50%. In other words, by raising the sound level at LABE by just 3 dB, the ability of listeners to hear the sounds around them is effectively cut in half.

Natural ambient was higher during the daytime than the nighttime hours at both Hovey Point and Backcountry but at Cave Loop Road there is a dramatic increase during the nighttime. Figure 3 shows a nighttime increase in sound levels between the 2,500 Hz octave band and the 3,150 Hz octave band, from insects. Insect sounds, a seasonal sound source very common at the end of summer, is also noticeable at the other two sites on Figures 2 and 4, but the sound level is much lower. Both the Backcountry site and Hovey point had incredibly low nighttime sound pressure levels. This made it possible to hear faint background noise that was not audible at Cave Loop road because of the louder natural sounds of insects at this site.

Hovey Point had the most impacts from anthropogenic noise. The most common identifiable anthropogenic noise source category at this site was vehicles; this category includes automobiles, farm equipment, car horns and doors, trucks and heavy equipment (Figure 10). This site was the closest to the main park road, agricultural fields and the state-line highway to the north. Vehicles were audible 26% of the time. Trains were also common, mostly at night and were audible 17% of the time. The non-natural unknown category is higher than usual (40%) after sound source analysis. The most common sound in this category was a low rumble that has been difficult to identify. The most likely source of the rumble would be a very distant train, or possibly a nearby generator. This non-natural unknown sound source occurred at all three sites and mostly at night when other sounds and a higher ambient SPL could have masked it during the day. Natural sounds including wind, birds and insects were very common at this site. Coyotes were also audible at this site. There does not seem to be a very loud dawn chorus, (Figure 2), but the frequent audibility of birds between the hours of 5 and 9 (Table 10) show that they were certainly active during this time. Birds had higher audibility at this site than the other two sites. This site is closest to Tule Lake, a prominent stopover site for migratory birds (D. Riggs, personal communication, February 2017). When comparing the attended listening sessions the noise free interval was lower at this site (Table 4) than the other two. Farm equipment is the most notable sound source during these listening sessions. Nearby Tule Lake National Wildlife Refuge, which is guided by the Kuchel Act, mandates the coexistence of commercial agriculture and wetland wildlife habitat. Agricultural lands at the refuge as well as nearby private farms, likely the source of farm equipment noise, cause an increase in anthropogenic sound at the park (USFWS 2017).

Cave Loop Road had high audibility impacts but relatively low sound pressure level impacts from anthropogenic noise sources. This site is the furthest away from railroad tracks. At Cave Loop Road, trains were heard the least out of the three sites but had the highest audibility of an unknown non-natural sound source. This supports a theory that much of the non-natural unknown sound sources likely emanated from trains. The closer a site was to the tracks, the more train noise was audible and identifiable (and the less non-natural unknown sources were audible). Vehicles, including farm equipment and trucks, were audible 11.8% of the day with a peak between 6:00-16:00. This site was near a parking area and the sounds of automobile horns and doors slamming were more common here than the other two sites. Nighttime natural sounds at Cave Loop road produced a lot of energy in the high frequencies from insect activity (Figure 3 and Table 11). The high energy natural sounds of insects made this site the loudest at night. The 35dBA and 45dBA metric are exceeded most frequently at night at Cave Loop Road. Paired with noise audibility results (indicating that noise was low at night), this result suggests a rich natural soundscape with bountiful activity. Cave Loop Road lost 5.4% of the audio data which was not evaluated due to an equipment malfunction.

The noise free interval was highest at the Backcountry site, according to the attended listening sessions. The Backcountry site was closest to railroad tracks and had the highest audibility (32.7%) from trains out of the three sites. The clear and attributable sounds of trains at this site correlated with a lower level of non-natural unknown audibility (5.6%). Aircraft audibility was also the highest at this site. There were more jets throughout the day and early evening. Propeller planes during the day were also common at this site. Vehicle noise consisted mostly of farm equipment and had low

audibility. The trains could most often be heard at nighttime, this may be due to their peak operation hours occurring at that time or because the lower overall noise levels during the nighttime hours make them more likely to be heard. Although trains were audible at this site for long periods of time they did not cause high-energy sound level impacts because of the relatively low sound pressure levels recorded at the site from this source. The attended listening sessions show the least amount of diversity in the types of non-natural sounds heard at the Backcountry site and so does the attended listening. Interestingly, motors and non-natural unknowns are also recorded during the attended listening sessions. This further supports the theory that trains were audible but not loud enough to be clearly identifiable at the three sites in the park.

The high audibility of non-natural sound sources at these sites despite low sound pressure levels are likely a result of two different issues. First, the higher ambient sound pressure level during the day at all the sites (except Cave Loop Road) caused any low level non-natural sounds to be masked, but at night when ambient was lower, anthropogenic sound sources were audible. Second, the days used for analysis are chosen on the basis of having low levels of wind. Temperature inversions in the Klamath Basin are common and nighttime/radiation inversions, that occur over a 24-hour period are most common during periods of low wind (Barnack, 2012). Review of the weather data also showed a correlation with low winds and large temperature swings over a 24-hour period. Low winds at night that accompanied monitoring period days with as much as a 40 degree temperature swing likely resulted in poor atmospheric mixing at the surface overnight, providing evidence for inversions. Although these inversions are most common during the winter when there can be large temperature swings, they occur at other times of year too. These inversions are likely the cause of low frequency, low SPL non-natural noises that were common at Backcountry and Hovey Point. Under inversion conditions, acoustic energy is refracted downwards and near ground sound levels consequently increase. Animals like the coyote tend to use inversions like the one present at these sites to increase the distance of their vocalizations and were heard frequently calling during the monitoring period that coincided with suspected inversions (Larom, et. al 1996). The presence of distant low frequency bass music (portable audio) at the Backcountry Wilderness sight between 20:00-22:00 provides further evidence that inversions occurred at these sites.

In addition to gathering information about sound sources at the park, this data will also help assess how future impacts from the military airspace near the park may increase potential acoustic impacts. The closest Naval Air Station to the park is Klamath Falls a part of Kingsley Field Air National Guard Base. Flights out of this base, that use the Goose North MOA (Military Operations Area) located near the eastern boundary of LABE (Appendix C), cause the highest acoustic impacts from military operations to the park. The aeronautical chart defines the active hours of Goose North MOA between 0700-1900 and the altitude as 3,000 feet above ground level (AGL) (FAA 2015). The active hours of the MOA had 92.6% higher audibility of jets than the non-active hours at the most eastern site, Backcountry, that is closest to the MOA. Military jets and commercial jets were not differentiated in this report so it is likely that there is a mix of both types designated as “jet”. The acoustic signatures of the two types of jets were not distinctive enough to separate them by type.

The closest airport open the public is the Tulelake Municipal Airport and the largest airport nearby is the Crater Lake-Klamath Regional Airport. Crater Lake-Klamath Falls Regional Airport and Kingsley Field Air National Guard Base are in the same location. According to the FAA aeronautical charts, there is a VR (visual route) that traverses the northeastern portion of the park. The path V.452 uses a route where the suggested altitude is below 1,500 feet AGL, this could explain the number of propeller planes audible in the park. The park is outlined and includes the information in the FAA Advisory Circular 91-36 that suggests flying at least 2,000 feet over the park because it is a noise sensitive area (FAA 2015).

When evaluating Figures 5 through 11, trends starts to emerge. Anthropogenic noise is very commonly audible at the three sites, however overall acoustic impacts and exceedance levels are not very high, meaning that while noise is audible, it does not introduce substantial acoustic energy into the environment. If unchecked, impacts could increase over time, but if sound levels can be kept low or reduced through mitigation, this could result in one of the most natural soundscapes in the area. Efforts to maintain the low impacts could include (but are not limited to) interpretive signs about the acoustic environment, or educating small craft pilots especially when flying over wilderness areas about natural soundscapes. Installing quieter pavement types on the main roads may also improve the acoustic environment and reduce audibility from sound sources.

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Appendix A: Site Photos



Figure 12. LBE001, Hovey Point Acoustic Monitoring Station, picture taken with view of the west.



Figure 13. LABE002, Cave Loop Road Acoustic Monitoring Station, picture taken with view of the north.



Figure 14. LABE003, Backcountry Acoustic Monitoring Station, picture taken with view of the north.

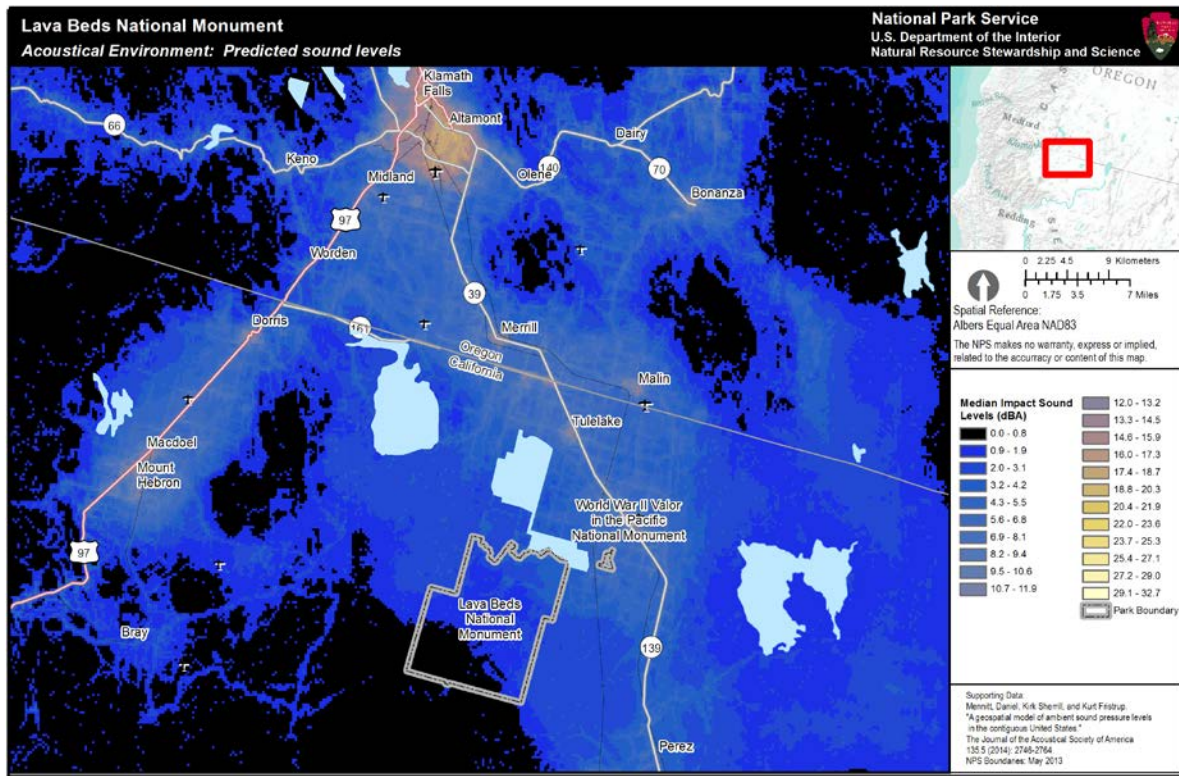
Appendix B: Modeled Impact Levels

NSNSD developed a model (Mennitt et al. 2014) that predicts the median sound level using measurements made in hundreds of national park sites as well as 109 explanatory variables such as location, climate, land cover, hydrology, wind speed, and proximity to noise sources such as roads, railroads, and airports. Each pixel in the graphic shown in Figure 12 and 13 represents 270 m.

The resulting model can predict sound levels anywhere in the contiguous U. S., and also estimate how much lower these sound levels would be in the absence of human activities. The modeled difference between the existing and predicted natural sound level (L_{50} impact) at LABE is shown in Figure 12, and provides a measure of how much anthropogenic noise is increasing the existing sound level above the natural sound level, on an average summer day, in the park. At LABE, the mean modeled sound level impact is 1.7 dBA (ranging from 0 decibels (dBA) in the least impacted areas to 8 decibels (dBA) in the most impacted areas.) The average existing sound level is predicted to be 1.7 dBA above natural conditions. According to measured sound level data, there is a range of median acoustic daytime impacts from 4.4dBA (Hovey Point) to 1.7 dBA (Backcountry) across the three sites at LABE.

For reference in translating sound level impacts into functional effects (for human visitors and resident wildlife), an increase in background sound level of 3 dB produces an approximate decrease in listening area of 50%. In other words, by raising the sound level at LABE by just 3 dB, the ability of listeners to hear the sounds around them is effectively, cut in half. Furthermore, an increase of 7 dB leads to an approximate decrease in listening area of 80%. An increase of 1.7 dBA would reduce the listening area for wildlife and visitors by 32%. For example, if a predator can hear a potential prey animal in an area of 100 square feet in a setting with natural ambient sounds, that animal's ability to hear would be reduced to 68 square feet if the sound levels were increased by 1.7 dBA. This demonstrates that sounds intrinsic to the park are a resource important to protect in the park environment. Compared to parks throughout the national park system, this is a fairly low impact and shows a prominence of natural sounds that should be preserved and protected.

Figure 13 provides modeled results for the larger region. This figure provides L_{50} or median sound pressures levels for the region as opposed to the levels of impact. The modeled data has an L_{50} of 28.83 for Hovey Point, a modeled L_{50} of 29.59 for Cave Loop Road and a modeled L_{50} of 25.27 for Backcountry. The modeled data is higher than actual ambient conditions collected for this report. Either this period had lower sound pressure than usual, or the model predicts the impacts to be higher than true conditions. Cities along I-15 like Redding, Sacramento and Portland show up significantly louder than surrounding National Parks. Note that both Figures 12 and 13 will not reflect recent localized changes such as new access roads or development.



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Figure 15. Map of predicted acoustic impact levels in the park for an average summer day. The color scale indicates how much man-made noise increases the sound level (in A-weighted decibels, or dBA), with 270 meter resolution. Black or dark blue colors indicate low impacts while yellow or white colors indicate greater impacts. The mean acoustic impact level at the park is 1.7 dBA.

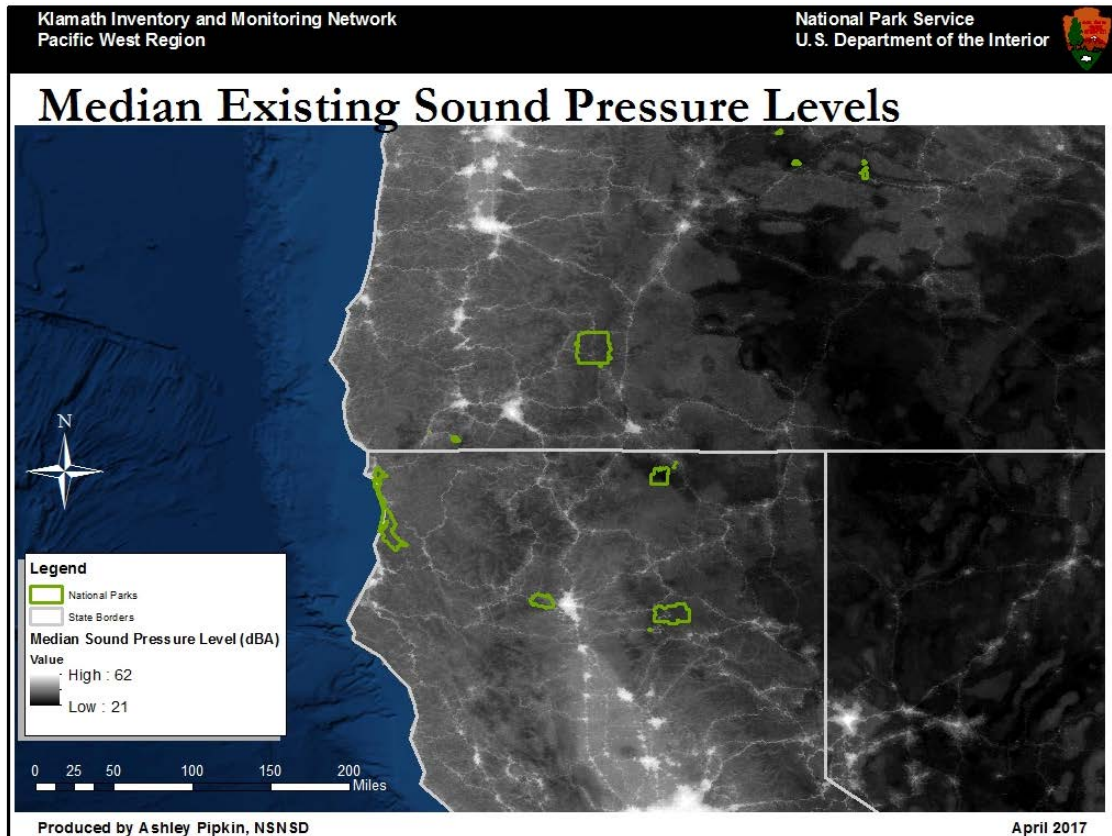


Figure 16. Map of predicted existing acoustic levels in the park for an average summer day. The color scale indicates sound pressure level (in A-weighted decibels, or dBA), with 270 meter resolution. Black indicates low impacts white color indicates greater impacts.

Appendix C: FAA Aeronautical Chart of Klamath Falls

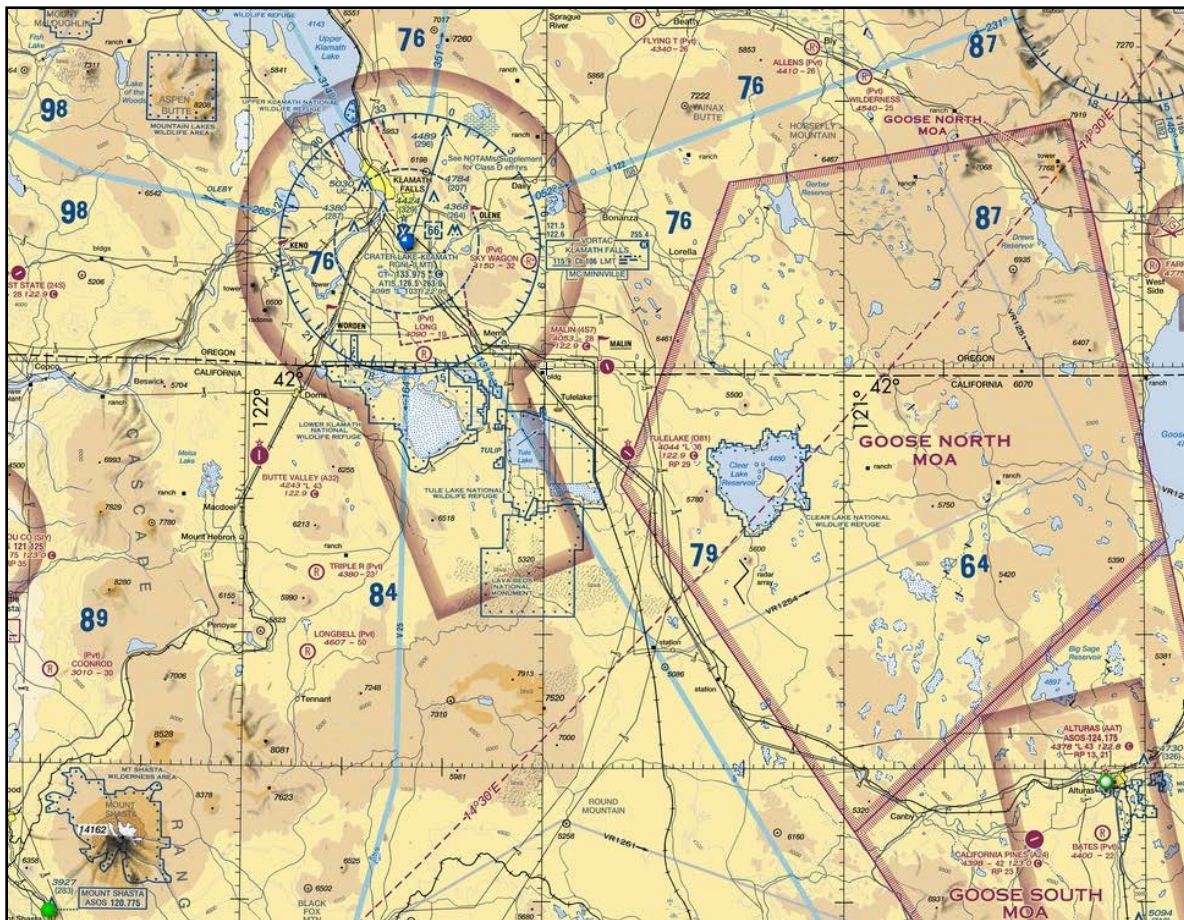


Figure 17. The FAA Aeronautical Chart, Klamath Falls, showing LABE near the center. The Goose North MOA is to the east of the park. The Tulelake Municipal Airport is northeast of the park and the larger Crater Lake-Klamath Regional Airport is north. There is a Class D airspace intersecting the park. The V452 is a visual route shown by a blue line that goes through the northeast part of LABE. The park is marked on the chart as a noise sensitive area that requests pilots to fly 2,000 feet AGL. The western portion of LABE is located on a sectional that has a maximum elevation of 8,400 feet and on the east the maximum elevation is 7,900 feet (FAA, 2015).

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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U.S. Department of the Interior



Natural Resource Stewardship and Science

1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov