



Lassen Volcanic National Park

Acoustic Monitoring Report

Natural Resource Report NPS/NRSS/NSNSD/NRR—2016/1306



ON THE COVER

Photograph of recording equipment at the Manzanita Creek Site.

Photograph courtesy of the National Park Service taken by Misty Nelson.

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October 2016

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Pipkin, A. R. 2016. Lassen Volcanic National Park: Acoustic monitoring report. Natural Resource Report NPS/NRSS/NSNSD/NRR—2016/1306. National Park Service, Fort Collins, Colorado.

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Executive Summary

In 2013, the Natural Sounds and Night Skies Division (NSNSD) received a request to collect baseline acoustic data during the summer of 2014 at Lassen Volcanic National Park (LAVO). From August to October 2014 three acoustic monitoring systems were deployed in three spatially dispersed areas of the park. These stations were configured to collect sound pressure level data and continuous audio recordings for approximately thirty days but remained deployed for an additional month due to logistics of retrieval. The baseline data collected during this period will help managers and planners assess the current condition of the acoustic environment in different areas of the park. Results of this study will help the park better manage wilderness areas and will inform the Wilderness Stewardship Plan.

LAVO offers a variety of unique pristine natural sounds not found in most urban or suburban environments. This quiet setting provides a special dimension to the park experience. The quiet affords visitors an opportunity to hear faint or very distant natural sounds such as steaming fumaroles, and the call of a hawk. However, LAVO is not free from unnatural sounds. Sources of noise vary at LAVO with vehicles and aircraft being the most common. 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 these common noise sources during the monitoring period as well as ambient sound levels. Because of an equipment malfunction at LAVO001, these metrics could not be calculated and are not displayed in Table 1. Ambient sound pressure levels were measured continuously every second over the 30 day monitoring period by calibrated sound level meters. After monitoring was complete, percent time audible metrics were calculated by trained technicians from the Colorado State University Listening Lab. Because of equipment issues, approximately 2.7% of the audio from Bumpass Hell and 1.3% of the audio from Big Bear Lake were corrupt, therefore it is not included in the analysis. Median existing (L_{50}) and natural (L_{nat}) ambient metrics are reported for daytime (7 am – 7 pm) and nighttime (7 pm – 7am) during the monitoring period. Refer to the “Methods” section for protocol details, equipment specifications and for detailed information on the calculation of metrics.

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 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 bottom values use the full frequency range (12.5-20,000 Hz) collected. The first value, 35 dBA, is designed to address the health effects of sleep interruption. Recent studies suggest that sound events as low as 35 dB can have adverse effects on blood pressure while sleeping (Haralabidis, 2008). This value also refers to the desired background levels in classrooms (ANSI S12.60-2002). The second value addresses the World Health Organization’s recommendations that noise levels inside bedrooms remain below 45 dBA (Berglund et al., 1999). The third value, 52 dBA, is based on the EPA’s speech interference level for speaking in a raised voice to an audience at 10 meters (EPA 1974). This value addresses the effects of sound on interpretive presentations in parks. The final value, 60 dBA,

provides a basis for estimating impacts on normal voice communications at 1 meter. Hikers or other visitors viewing scenic areas in the park would likely be conducting such conversations.

Table 1. Mean percent time audible for all extrinsic sounds, aircraft and vehicles at Bumpass Hell (LAVO002) and Big Bear Lake (LAVO003). Missing data and artifacts* that occurred in the audio are also shown in this table.

Site Description	Mean percent time audible (in 24 hour period)					Median Existing Ambient (L50) in dBA		Median Natural Ambient (Lnat) in dBA	
	All Extrinsic	Aircraft	Vehicles	Artifacts	Missing	Day	Night	Day	Night
LAVO002	24.6	6.4	11.4	27.7	2.7	28.0	22.5	25.6	22.1
LAVO003	18.4	8.4	0.9	0.1	1.7	26.7	14.8	25.9	14.7

*Audio classified as an artifact is partially distorted. An artifact can be caused by a number of external or internal factors including wind, static from the recording system and/or precipitation. The presence of an artifact does not mean the recording was inaudible; it does mean that the listener may not be able to hear all sound sources due to feedback causing the loss of complete audibility. Sound sources in this category are not logged as non-natural.

Table 2. Percent time above sound thresholds for day and night.

Site	Frequency	% Time above sound level: 0700 to 1900				% Time above sound level: 1900 to 0700			
	(Hz)	35dBA	45dBA	52dBA	60dBA	35dBA	45dBA	52dBA	60dBA
LAVO001 Manzanita Creek	20-1250 (T)	19.56	0.76	0.06	0	2.44	0.01	0	0
	12.5-20,000	24.63	1.51	0.14	0.01	3.41	0.05	0	0
LAVO002 Bumpass Hell	20-1250 (T)	13.59	0.58	0.06	0	12.93	0.22	0	0
	12.5-20,000	17.36	0.97	0.09	0	14.16	0.44	0.01	0
LAVO003 Big Bear Lake	20-1250 (T)	5.07	0.21	0.05	0	0.09	0	0	0
	12.5-20,000	9.16	0.41	0.09	0.01	0.62	0.14	0.02	0

Acknowledgments

This report would not have been possible without help from Michelle Havens, Elizabeth Palmer Dave Worthington, Michael Magnuson, Jason Mateljak, and Deirdre Hanners. Katie Johnson-Hansen, Juanita Bonnifield, Elizabeth Hale, Alyssa Olenberg-Meltzer, and Thomas Kneppers were instrumental in helping to carry equipment to and from the monitoring sites. Special thanks to Misty Nelson and Jessica Briggs for setting up the equipment and to Cecilia White and Jacob Job for coordinating those who listened to the recordings and identified the noise sources including Grete Wilson-Henjum, Sarah Brandenburg, Alex Avrin, Taylor Greene, Meredith Lewis, Colton Raab and Gabrielle Staats.

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. 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.

Ldn- Day-Night Average Sound Level. Average equivalent sound level over a 24-hour period, with a 10-dB penalty added for sound levels between 10 p.m. and 7 a.m.

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 by either a trained observer (on-site listening) or by making high-quality digital recordings for later playback (off-site listening).

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

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

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

Soundscape- The human perception of the physical sound resource.

Introduction

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). Acoustic monitoring provides a scientific basis for assessing the current status of acoustic resources, identifying trends in resource conditions, quantifying impacts from other actions, assessing consistency with park management objectives and standards, and informing management decisions regarding desired future conditions.

National Park Service Natural Sounds and Night Skies Division

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

Soundscape Planning Authorities

The National Park Service Organic Act of 1916 states that the purpose of national parks are "... 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 soundscapes¹ 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

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

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

It should be noted that “the natural ambient sound level—that is, the environment of sound that exists in the absence of human-caused noise—is the baseline condition, and the standard against which current conditions in a soundscape [acoustic resource] will be measured and evaluated” (NPS 2006b). However, the desired 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

Lassen Volcanic National Park is located in Northern California at the southern end of the Cascade Range and only miles from the northern terminus of the Sierra Nevada Mountains. Establishment as a National Park unit in 1916 came after the first in a set of eruptions of Lassen Peak that began in 1914. The park continues to have volcanic activity and provides visitors with a representation of the aftermath of a volcanic eruption and a picture of ecological succession after a major eruption. In addition to Lassen Peak the park contains many other dynamic geological features (Lassen Volcanic National Park 2003).

The park is located in 4 different counties and is 166.3mi². The park is surrounded on all sides by Lassen National Forest. The majority of the eastern border of the park is shared with the Caribou Wilderness Area. Inside the park there is over 79,062 acres of designated wilderness covering more than 70% of the park, there is also an additional 13,151 acres of proposed wilderness in the park. In addition to volcanic peaks and features there are also lakes, meadows, forests, streams and a rich diversity of wildlife. The Lassen Volcanic National Park Highway bisects the park and generally follows a winding path around Lassen Peak from north to south. The highway is a non-wilderness corridor through the park bordered by wilderness on both sides.

Three acoustic monitoring stations were set up in the park (Table 3.) One site was placed near Manzanita Creek another close to Bumpass Hell and the third was near Big Bear Lake. 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. Manzanita Creek (LAVO001) is located on the border of a wilderness area along a trail. This site is close to one of the largest campsites in the park and towards the western edge of the park border. Bumpass Hell (LAVO002) is the most front country site chosen for data collection. Bumpass Hell is the closest to the Visitor's Center and not located in the designated wilderness area. Big Bear Lake (LAVO003) is the most remote site, without nearby roads but close to hiking trails. The vegetation, topography and visitor use are diverse from site to site which help to shape the acoustic environment at each location. Pictures of all of these sites can be found in Appendix A.

Table 3. Locations of recording equipment at LAVO.

Site #	Site Name	Dates	Vegetation	Elevation (m)	Latitude	Longitude
LAVO001	Manzanita Creek	8/23/2014-10/29/2014	Temperate Coniferous Forest	615	40.51491	-121.550507
LAVO002	Bumpass Hell	8/25/2014-10/24/2014	Temperate Coniferous Forest	538	40.461067	-121.509174
LAVO003	Big Bear Lake	8/26/2014-10/08/2014	Temperate Coniferous Forest	2026	40.52458	-121.401436



2014 Acoustic Monitoring Locations

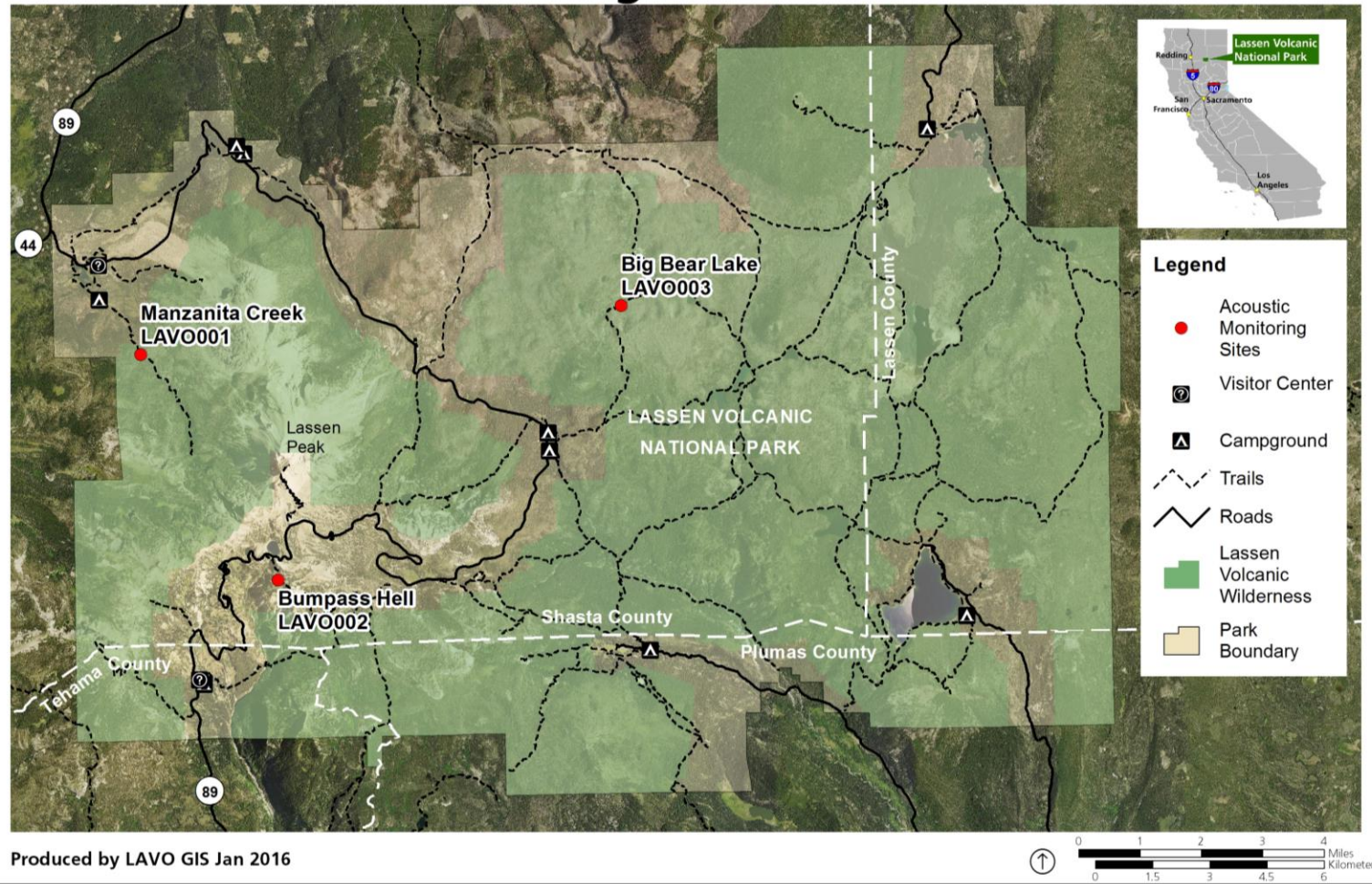


Figure 1. Locations of acoustic monitoring sites.

Methods

Automatic Monitoring

Larson Davis 831 sound level meters (SLM) were employed over the thirty day monitoring period at each of the LAVO sites. 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 recordings²
- 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

² An equipment malfunction at all three sites caused there to be gaps in the continuous audio data. The audio data was most compromised at LAVO001. The other sites only had small percentages of missing data, see Table 4.

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

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

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

and P_H is the percentage of samples containing extrinsic or anthropogenic sounds for the hour. For example, if human caused sounds are present 30% of the hour, $x = 65$, and the L_{nat} is equal to the L_{65} , or the level exceeded 65% of the time. 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 3 and 4 in the results section, Figure 2 from LAVO001 does not include natural ambient. Additionally, these figures separate the data into 33 one-third octave bands.

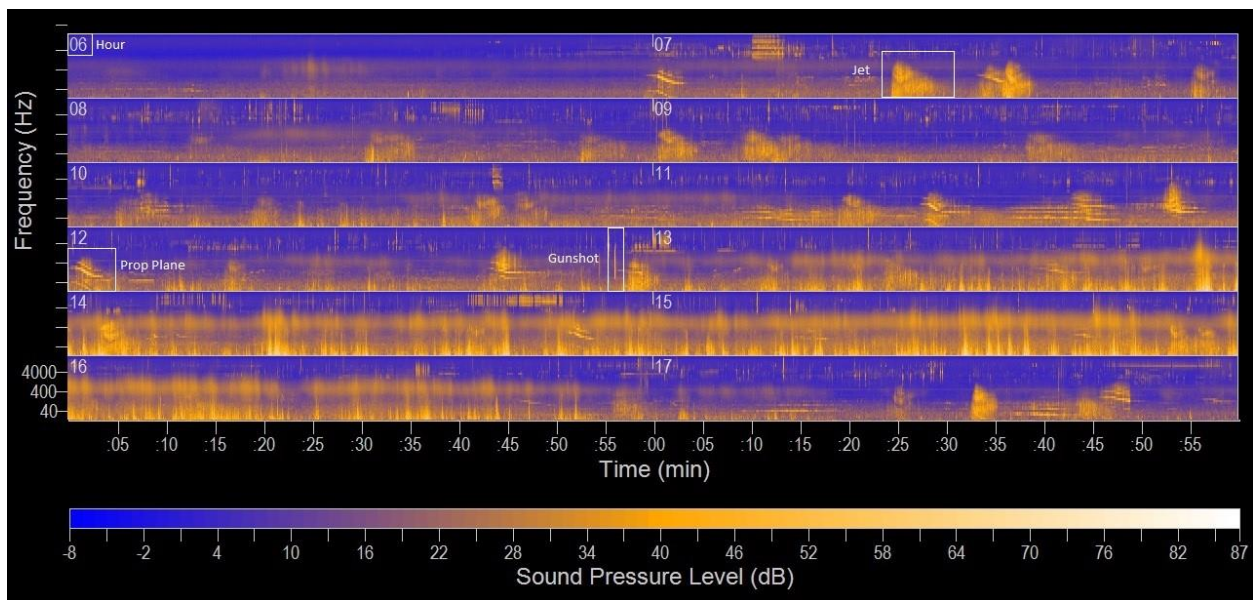


Figure 2. A spectrogram with specific sound sources identified. Visual analysis is used when looking for a specific sound source or when audio data is incomplete.

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 personal digital assistant (Apple iTouch®). The observer listens for a designated period of time (in this case, one hour), and identifies all sound sources and their durations. On-site listening takes full advantage of human binaural hearing capabilities, and closely matches the experience of most park visitors. Logistic constraints prevent comprehensive sampling

by this technique, but selective samples of on-site listening provide a basis for relating the results of off-site listening 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 LAVO. 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. Staff used the total percent time extrinsic sounds were audible to calculate the natural ambient sound level for each hour (see Equation 1 for more information). Due to an equipment malfunction this analysis could not be completed at LAVO001. Portions of the audio data at all three sites had been compromised to varying degrees. Even though SPL data was uncompromised, the reduction in clear audio resulted in analysis gaps needed to calculate the natural ambient SPL at the three sites. To increase usable audio and calculate the best estimate of natural ambient sound pressure levels at Bumpass Hell and Big Bear Lake technicians used days with the most complete audio. To supplement missing hours of audio, during this period, alternate days were used to compensate for missing hours at Bumpass Hell and Big Bear Lake. This resulted in a more complete dataset to obtain the most accurate natural ambient measurements from the data collected. For example if 2 hours of data were missing from 11:00-13:00 at Bumpass Hell on the date sampled then technicians looked for other days at that site and between the hours of 11:00 and 13:00 and included that data in the analysis. More details are displayed in Table 4. Bose Quiet Comfort Noise Canceling headphones were used for off-site audio playback to minimize limitations imposed by the office acoustic environment.

Table 4. Incomplete audio from the sample period was supplemented by additional audio collected during the monitoring period to obtain the most complete dataset for each site. At Bumpass Hell, 8 hours and 46 minutes were used from other days and at Big Bear Lake an additional 3 hours and 42 minutes were used to more completely represent a 24 hour period.

Site	Date with incomplete audio	Supplemental time included in analysis (hh:mm)	Dates Audio came from
Bumpass Hell (LAV0002)	9/14/2014	3:30	9/20/2014; 8/31/2014
	9/15/2014	2:40	9/7/2014
	9/16/2014	2:36	9/25/2014
Big Bear Lake (LAV0003)	9/3/2014	0:16	8/28/2014
	9/5/2014	3:16	9/1/2014; 8/29/2014

Visual Analysis of Spectrograms

NSNSD took an alternate approach when analyzing data from LAVO001 because of an incomplete set of audio files collected here. Staff chose to visually analyze SPL samples to identify the frequency and durations of mechanized sound sources. From the SPL data, spectrograms were created with the accompanying available recorded audio. Spectrograms are plots that display sound level as a function of time and frequency. Since aircraft and other mechanized events have a recognizable sound signature, they are visually identifiable on spectrograms and their impacts on the acoustic environment can be isolated. For every noise event, the user records begin and end times, as well as the frequencies spanned, maximum sound pressure level, and sound exposure level (SEL). This method uses a platform created for sound pressure level annotation referred to as SPLAT found in the NSNSD's *Acoustic Monitoring Toolbox* program.

Results

On-site Listening

Tables 5, 6, and 7 display the results of the on-site listening sessions at LAVO. 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. Standard deviation (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, is a metric which 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. In the following tables anthropogenic noises are white and the natural sounds are highlighted in gray.

Table 5. Summary of on-site audible sound sources for Manzanita Creek (LAVO001) n=4 hour-long sessions. Events are measured in minutes:seconds.

Sound Source	PA (%)	Max Event	Mean Event	Min Event	Std Dev	Events
Jet	5.7	03:19	01:31	00:27	00:51	9
Prop	4.2	03:24	02:01	00:44	01:11	5
Vehicle	8.9	02:48	00:44	00:09	00:38	29
Wind	90	59:59	15:26	00:07	20:56	14
Mammal	31.3	07:13	00:50	00:02	01:20	90
Bird	98.6	59:58	13:55	00:26	20:17	17
Insect	7.3	01:05	00:09	00:02	00:08	113
Natural, Other	0.1	00:06	00:03	00:01	00:02	3
Noise-Free Interval	--	27:55	04:20	00:01	05:54	45

Table 6. Summary of on-site audible sound sources for Bumpass Hell (LAVO002) n=4 hour-long sessions. Events are measured in minutes:seconds.

Sound Source	PA (%)	Max Event	Mean Event	Min Event	Std Dev	Events
Jet	11.7	06:11	02:48	01:08	01:26	10
Propeller	2.2	02:27	01:46	01:00	00:44	3
Vehicle	81.2	33:06	03:37	00:16	06:12	54
Vehicle Alarm	0.2	00:04	00:02	00:01	00:01	20
Vehicle Door	0.6	00:09	00:03	00:01	00:02	34
Motorcycle	1.6	01:33	00:45	00:01	00:42	5

Table 6, (continued). Summary of on-site audible sound sources for Bumpass Hell (LAVO002) n=4 hour-long sessions. Events are measured in minutes:seconds.

Sound Source	PA (%)	Max Event	Mean Event	Min Event	Std Dev	Events
Dumpster / Trashcan	0	00:03	00:03	00:03	00:00	1
People	0.2	00:19	00:08	00:01	00:10	3
Talking	44.6	07:26	00:47	00:01	01:04	138
Walking	17.6	03:37	00:43	00:01	00:42	59
Building Sound	0.1	00:06	00:04	00:02	00:03	2
Door	0.1	00:03	00:02	00:01	00:01	6
Wind	52.2	59:53	17:54	00:14	25:35	7
Mammal	3.2	05:06	01:54	00:12	02:11	4
Bird	76.4	54:55	01:57	00:01	05:51	94
Insect	26.3	14:13	00:49	00:02	02:24	77
Noise-Free Interval	--	02:27	00:25	00:01	00:32	48

Table 7. Summary of on-site audible sound sources for Big Bear Lake (LAVO003) n=4 hour-long sessions. Events are measured in minutes:seconds.

Sound Source	PA (%)	Max Event	Mean Event	Min Event	Std Dev	Events
Jet	14.1	07:22	02:16	00:24	01:46	15
Propeller	8.8	05:17	02:38	00:46	01:30	8
Motors	1.7	02:18	00:50	00:08	00:51	5
People	0	00:07	00:07	00:07	00:00	1
Talking	12.8	16:22	03:51	00:29	05:48	8
Walking	0	00:07	00:07	00:07	00:00	1
Dog	0.1	00:05	00:04	00:03	00:01	2
Human, Unknown	1.5	03:41	03:41	03:41	00:00	1
Wind	87.9	59:56	13:11	00:22	20:57	16
Water	3.6	03:58	01:06	00:02	01:14	8
Mammal	12.5	05:59	00:47	00:03	01:09	38
Bird	99.7	59:59	39:54	03:16	23:55	6
Insect	49.2	59:58	11:48	00:04	22:30	10
Natural, Other	0.1	00:06	00:02	00:01	00:02	6
Noise-Free Interval	--	26:07	05:08	00:03	07:11	31

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 4. 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 height 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 minimum (L_{90}), and maximum (L_{10}) sound pressure levels over the 30 day monitoring period. As is common in environmental monitoring, outliers can skew results. However, when extreme events are measured on a logarithmic scale like the decibel scale, they can have a strong biasing effect on overall results. As a result, it is standard practice in acoustic studies to closely track the central eighty percent of the data to determine what predominant conditions were during the study 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. There may be times when transportation sounds are louder than the songbirds. In this case, bird sounds would not be masked because their song is audible at a different frequency. If both of these sounds are within similar or overlapping frequency ranges, and one sound is louder than the other, then the quieter sound could be masked.

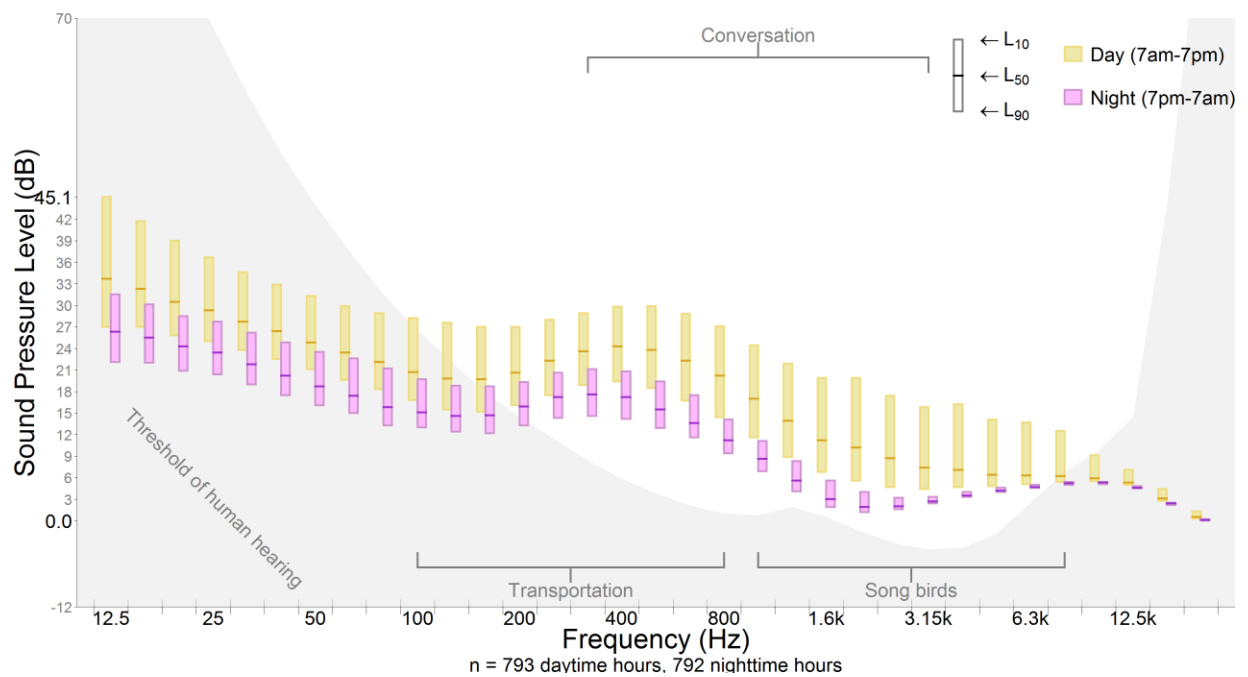


Figure 3. Day and night dB levels for 33 one-third octave bands at Manzanita Creek (LAVO001) summer 2014. This figure does not provide natural ambient sound pressure levels.

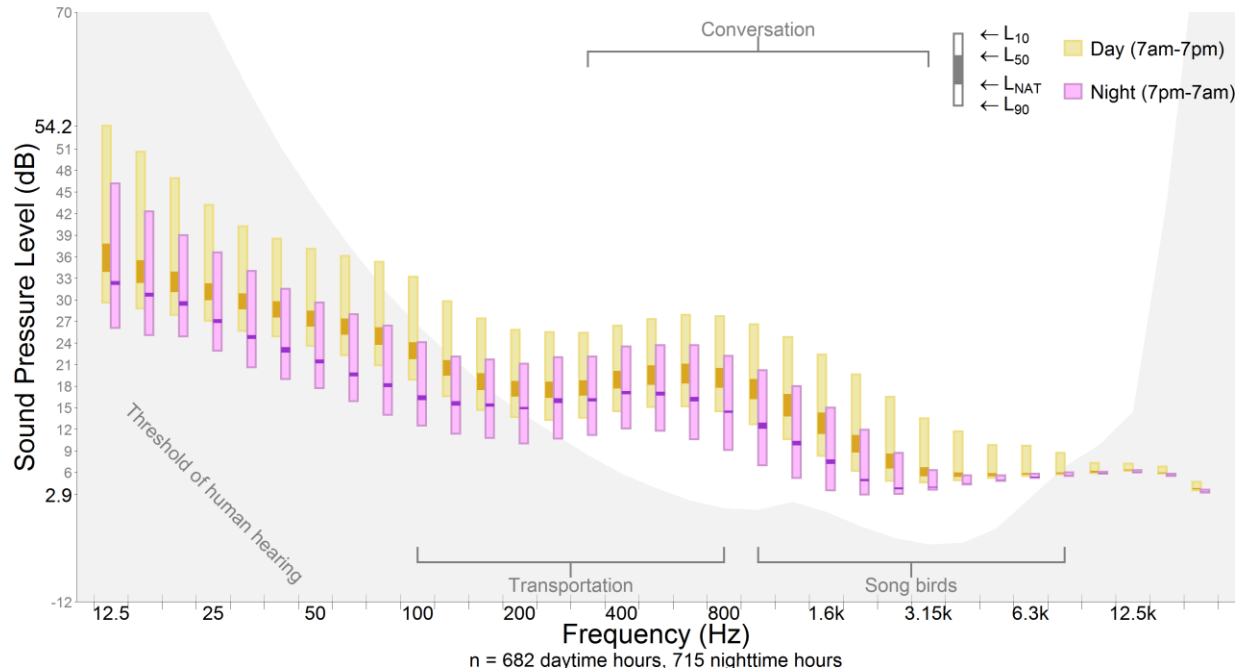


Figure 4. Day and night dB levels for 33 one-third octave bands at Bumpass Hell (LAVO002) summer 2014.

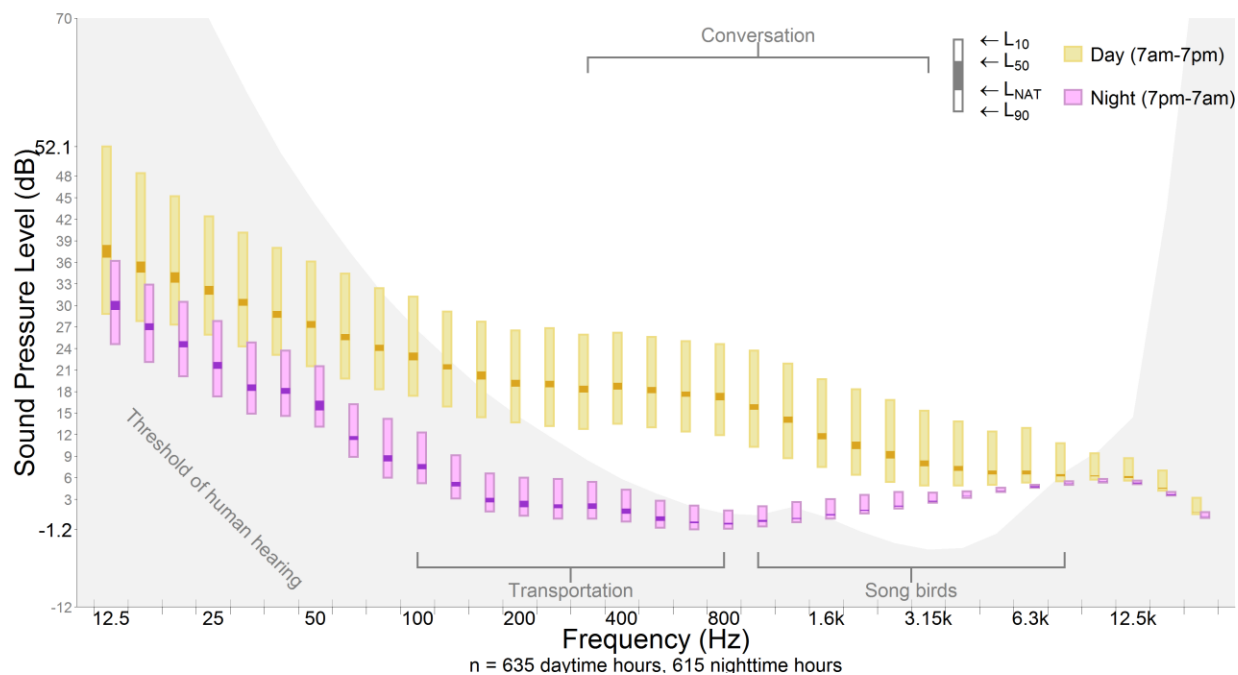


Figure 5. Day and night dB levels for 33 one-third octave bands at Big Bear Lake (LAVO003) summer 2014.

Table 8 reports the L_{90} , L_{nat} , L_{50} , and L_{10} values for the sites measured at LAVO. The top value in each cell focuses on frequencies affected by transportation noise whereas the lower values use the conventional full frequency range. Most motorized human-caused noise is confined to the truncated, lower-frequency range, while many loud natural sounds, including insects and birds, are higher in pitch. Therefore, the truncated range (20-1250 Hz) is more appropriate for identifying impacts from anthropogenic noise in parks (Acoustical Society of America 2014).

Table 8. Exceedance levels (dBA) for existing conditions in LAVO

Site	Frequency (Hz)	Exceedance levels (dBA): 0700 to 1900				Exceedance levels (dBA): 1900 to 0700			
		L_{90}	L_{nat}	L_{50}	L_{10}	L_{90}	L_{nat}	L_{50}	L_{10}
LAVO001 Manzanita Creek	20-1250	22.7	--	27.9	34.3	17.8	--	20.0	23.7
	12.5-20,000	24.2	--	29.0	35.6	19.2	--	21.2	24.5
LAVO002 Bumpass Hell	20-1250	21.2	24.2	26.9	33.4	16.1	20.9	21.5	28.3
	12.5-20,000	22.8	25.6	28.0	34.6	18.5	22.1	22.5	28.9
LAVO003 Big Bear Lake	20-1250	19.4	24.1	25.4	31.8	6.9	7.8	8.0	10.9
	12.5-20,000	21.6	25.9	26.7	33.0	14.4	14.7	14.8	17.3

In determining the current conditions of an acoustic environment, it is important to examine how often sound pressure levels exceed certain values. Table 9 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 dB can have adverse effects on blood pressure while sleeping (Haralabidis, 2008). This value also refers to the desired background levels in classrooms (ANSI S12.60-2002). The second value addresses the World Health Organization's recommendations that noise levels inside bedrooms remain below 45 dBA (Berglund et al., 1999). The third value, 52 dBA, is based on the EPA's speech interference threshold for speaking in a raised voice to an audience at 10 meters (EPA 1974). This threshold addresses the effects of sound on interpretive presentations in parks. The final value, 60 dBA, provides a basis for estimating impacts on normal voice communications at 1 meter. Hikers and visitors viewing scenic vistas in the park would likely be conducting such conversations.

Table 9. Percent time above metrics for LAVO

Site	Frequency	% Time above sound level: 0700 to 1900				% Time above sound level: 1900 to 0700			
	(Hz)	35dBA	45dBA	52dBA	60dBA	35dBA	45dBA	52dBA	60dBA
LAVO001 Manzanita Creek	20-1250 (T)	19.56	0.76	0.06	0	2.44	0.01	0	0
	12.5- 20,000	24.63	1.51	0.14	0.01	3.41	0.05	0	0
LAVO002 Bumpass Hell	20-1250 (T)	13.59	0.58	0.06	0	12.93	0.22	0	0
	12.5- 20,000	17.36	0.97	0.09	0	14.16	0.44	0.01	0
LAVO003 Big Bear Lake	20-1250 (T)	5.07	0.21	0.05	0	0.09	0	0	0
	12.5- 20,000	9.16	0.41	0.09	0.01	0.62	0.14	0.02	0

Audibility

Although there was not enough information from LAVO001 to calculate natural ambient sound levels, some anthropogenic sound events could be extracted from spectrograms and are presented in Table 10. In Table 10 the average maximum sound pressure level (Lmax) provided information about what the loudest sounds from each event were. The total length is the total amount of time that particular sound sources impacted the site according to visual analysis in the 192 hour monitoring period. The audibility results are presented in Tables 11 and 12. These tables show the mean percentage of time that all noise sources were audible at each monitoring location. These results are based on eight days of off-site auditory analysis. Natural sounds are white, sound sources highlighted in light gray are human caused while the sound sources at the bottom highlighted in dark gray are issues caused by equipment malfunctions. Figures 5 through 8 show hourly audibility results from

the anthropogenic sound sources at Bumpass Hell and Big Bear Lake and highlights the sound sources most common to these areas.

Table 10. Results from SPL_{AT} analysis for LAVO001.

Sound Source	Events	Average Lmax	Total Length hh:mm:ss	Average Length mm:ss
Jet	215	36.24	10:41:07	02:59
Prop Plane	184	40.30	11:08:16	03:38
Vehicle	1	30.80	0:00:22	00:22
Motor	37	34.18	1:39:13	02:41
Gunshot	3	49.70	0:00:23	00:08

Table 11. Mean hourly percent time audible for each noise source at (LAVO001) n=8 days off-site sound source analysis. A large percentage of data was missing from the analysis.

Sound Source	00h-08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h-23h
Jet	0	0	0.4	0	3	1.5	2.6	1.9	1.9	0	0
Prop Plane	0	1.1	0	13.3	3.7	6.7	5.9	10	9.3	1.9	0
Vehicle	0	0	0	0.7	1.1	0.4	1.1	0	0	0	0
Motor	0	0	0	0	0	0.4	0	0	0	0	0
Trashcan	0	0.4	0	0	0	0	0	0	0	0	0
Gunshot	0	0	0	0	0.4	0	0	0	0	0	0
Non-Natural Unknown	0	0	0.4	0	0	0	0.4	1.1	0	0	0
Wind	0	3.3	24.8	66.7	91.9	98.1	98.5	99.3	55.6	9.6	0
Mammal	0	0	3	4.4	1.5	0.7	0.7	1.9	1.5	0.4	0
Squirrel	0	0	4.4	7.8	10	8.1	3	5.6	4.4	0	0
Bird	0	3.7	22.6	58.1	73.3	77.4	85.9	84.8	50.7	7.8	0
Insect	0	0	3.7	11.5	25.9	41.5	37.8	21.1	10.4	2.6	0
Animal	0	0.4	0.4	0.4	0.7	0.7	1.1	2.6	1.1	0	0
Natural Other	0	0	0.4	0.4	0	1.9	0.7	0.4	0.4	0	0
Wind-Induced Natural	0	0	0	1.5	0.7	1.1	0.4	1.9	0	0	0
Natural Unknown	0	0.4	0.7	1.1	2.2	2.6	0.7	0.4	0	0	0
Artifact	0	0	0	0.7	0	0	0	0	0	0	0
Missing	100	96.3	75.2	32.6	5.9	0	0	0	44.4	90.4	100

Table 12. Mean hourly percent time audible for each noise source at (LAVO002) n=8 days off-site sound source analysis.

Sound Source	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Jet	0	0.8	0	0	0.4	0.8	0	2.1	5	6.2	4.2	5.4	2.1	4.6	2.5	1.2	1.2	3.3	2.5	5	9.2	1.2	3.8	1.2
Prop Plane	0	0	0	0.8	0	0.8	0.4	8.3	6.7	4.2	2.1	2.9	6.2	10.4	10.4	10.8	11.3	3.3	5.8	2.9	1.2	0	2.9	0
Helicopter	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
Vehicle	0.8	0.8	1.2	0.4	2.9	7.9	8.3	3.8	3.8	9.2	12.9	12.1	20.8	14.6	11.7	16.3	16.7	13.3	11.7	14.2	0.4	5.4	5.8	1.2
Automobile	1.7	0	0	0	0.4	0.8	1.2	3.3	4.2	4.6	9.6	12.9	7.9	3.8	5.4	5	6.7	0.8	3.3	0	0.8	0	0	0.4
Car Horn/Alarm	0	0	0	0	0	0	0	0	0	0	0	0	0.4	0.4	0.4	0	0	1.2	0.4	0	0	0	0	0
Door	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	0	0	0	0	0.8	0	0	0	0
Motorcycle	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
Motors	0	0	0	0	0	0	0	0	0.8	0.8	1.2	0	0	0	0	0	0	0	0	0	0	0	0	0
People	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
Human Voices	0	0	0	0	0	0	0	0	2.1	2.5	6.7	17.1	25	23.7	23.3	16.7	13.3	16.3	5.4	0.8	0	0.4	0	0
People Walking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	2.1	0.8	9.6	5.4	0	0	0	0	0
Wind	70.4	81.7	95.8	100	100	100	100	100	99.2	100	100	100	99.2	99.6	99.6	98.7	96.7	94.6	98.7	92.5	78.7	80	85.4	65
Strong Wind	0	0	1.7	0	0	0	0	0	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rain	0	0	0	8.3	10	7.1	10.4	10.8	11.3	10.8	6.2	1.7	0.4	0	0	0	0	0	0	0	0	0	0	0
Mammal	0	0	0	0	0	0	0	0.4	0	0.8	0	0	0	0.4	0	0	0	0.4	0.4	0.8	0	0	0	0
Squirrel	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
Coyote	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
Bird	0	0.4	2.9	0.4	1.2	3.8	29.6	59.6	62.5	62.5	56.7	37.9	38.8	36.2	32.1	30	26.7	21.2	32.5	16.3	1.7	0.8	0.8	0
Insect	1.2	0.4	4.6	0.8	0.4	3.3	0.4	1.7	2.9	6.2	16.3	22.9	20	24.2	15.8	14.2	5.8	2.1	5.4	4.2	5.8	4.6	5.8	0.8
Animal	0	0	0	1.2	0	0	0	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 12, (continued). Mean hourly percent time audible for each noise source at (LAVO002) n=8 days off-site sound source analysis.

Sound Source	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Wind-induced	0.4	0	0	0	0.8	1.2	0.4	5.4	6.7	2.1	1.7	1.7	0	0	0.4	0.4	0	0.4	1.7	0.4	0	0	0	1.2
Natural Unknown	0	0	1.2	2.5	0.4	0	0	0.4	0.8	0.4	0.8	0	1.2	2.1	0	0.4	0.4	0	0.8	0	0	0	0	0
Artifact	0	0	0.4	0	0	0.4	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0.8	1.2	0	0.8	0.8
Wind Distortion	23.7	29.6	41.3	33.3	25.4	20	20	21.7	23.7	22.5	29.2	32.1	29.2	33.7	35.8	36.2	31.2	30.4	31.2	21.2	22.9	22.5	23.3	20
Missing	15.4	5.8	0	0	0	0	0	0	0	0	0	0	0.4	0.4	0	0.4	2.1	0	0	0	8.7	7.5	2.1	22.5

Table 13. Mean hourly percent time audible for each noise source at Big Bear Lake (LAVO003) n=8 days off-site sound source analysis.

Sound Source	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Jet	2.9	0.8	1.2	1.2	0.4	1.2	0.8	2.5	8.3	9.2	5.4	2.5	2.5	4.2	4.2	3.3	7.5	5	5.4	13.3	12.1	15.4	11.7	3.3
Prop Plane	1.7	0	4.2	2.1	2.5	2.1	0.4	5.8	4.6	6.7	2.5	8.7	2.1	3.8	4.2	5.8	5.8	3.3	7.5	0.8	2.1	1.7	1.7	1.2
Vehicle	0	1.2	2.1	2.1	0	0	2.1	3.3	1.7	0.4	1.2	0	0	0	0	0	0	0.8	0.8	0	3.3	1.2	0.8	0.4
Train	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
Grounds Care	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
People	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
Human Voices	0	0	0	0	0	0	0	0	0.4	0.8	2.1	0.4	1.2	1.2	6.2	5.8	8.3	8.3	5.8	4.6	2.9	5.4	7.9	6.2
People Walking	0.4	0	0	0	0	0	0	0	0	0	1.7	0	0.4	0.8	1.2	0.4	0.4	0	0	0	0	0	0.4	0
Gunshot	0.4	0.4	0	1.2	0.4	0.4	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	1.2	0.8	0
Non-Natural Unknown	6.2	1.2	1.2	6.7	19.2	32.9	38.8	22.5	0	1.2	0	0	0.4	0	0.4	0	0	0	0.8	0.8	0.8	1.2	0.4	0
Wind	92.1	97.5	96.2	98.7	99.6	97.5	91.7	84.6	93.3	99.2	98.7	99.2	99.6	99.2	99.2	98.3	97.9	97.5	96.2	86.2	88.7	88.7	88.3	76.7
Water	1.2	0.8	2.5	2.1	0	1.2	0	0	0.4	5.4	17.1	15.4	14.6	13.8	5.4	10.4	5.8	5.8	1.7	0.8	2.1	0.8	1.2	0
Rain	3.8	3.3	2.5	1.2	1.2	0.8	1.2	0	0	0.8	0.4	0	0	0	0	0	0	0	0	0	1.2	0.8	0	0

Table 13, (continued). Mean hourly percent time audible for each noise source at Big Bear Lake (LAVO003) n=8 days off-site sound source analysis.

Sound Source	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Mammal	0	0.8	0	0.8	0	0.4	0.4	0	0	0	0	0	0	0	0.4	0.4	0.8	0.4	0	0	0	0	0	0
Bird	6.2	4.6	9.2	18.3	7.5	20	90.8	100	100	91.7	86.2	88.3	84.2	79.2	80.4	83.3	77.1	78.7	82.5	85.8	21.2	5.8	2.9	2.1
Amphibian	19.2	17.1	11.7	8.7	6.2	4.2	0.4	0	5.4	27.9	32.5	35.4	39.6	37.1	36.2	42.9	47.1	58.8	73.8	69.6	77.1	57.5	41.3	17.1
Insect	2.5	5.4	4.2	7.1	2.9	1.7	0.8	1.7	5.4	10.4	22.5	13.3	15.8	19.6	17.5	16.3	9.2	5.8	4.6	5	13.8	7.5	7.5	21.7
Animal	3.3	7.1	3.8	5	0.4	0.4	1.2	1.2	1.2	4.2	6.2	4.2	2.5	6.7	4.2	4.6	7.1	2.9	0.8	0	0	0.4	0.4	0
Natural Other	7.5	9.6	11.7	10	12.9	10.4	3.3	0	1.2	0.8	0.8	2.1	2.5	0.8	0.8	0.8	0.8	2.9	1.7	0.8	4.6	5.4	4.2	3.8
Wind-induced	9.2	8.3	8.3	9.6	7.1	5	1.7	0	1.2	2.1	0.4	0.8	1.2	0.4	2.5	1.7	2.5	2.1	2.9	1.2	3.3	4.2	2.5	4.6
Natural	2.1	6.2	3.8	2.1	2.9	2.1	1.2	0	0	0	0	0	0	0	0	0.4	0	0	0	0	0.8	0.8	2.1	1.2
Unknown	0	0	0.4	0	0.4	0	0	0	0	0	0	0.4	0	0.8	0	0.4	0	0	0	0	0	0	0	0
Artifact	0	0	0	0	0	0	0	0	0	3.3	2.5	4.2	3.3	6.2	5	5	3.3	3.3	0.4	0	0	0	0	0
Wind Distortion	0	0	0	0	0	0	0	0	0	0.4	0.8	0	1.2	0	0	0	0	0	0	0	0	0	0	0
Field Personnel	0.4	0	0	0	0	0	0	0	0	0.4	0.8	0.4	0	0	0	0	0	0	0	5.8	2.5	1.2	7.5	22.9
Unknown																								

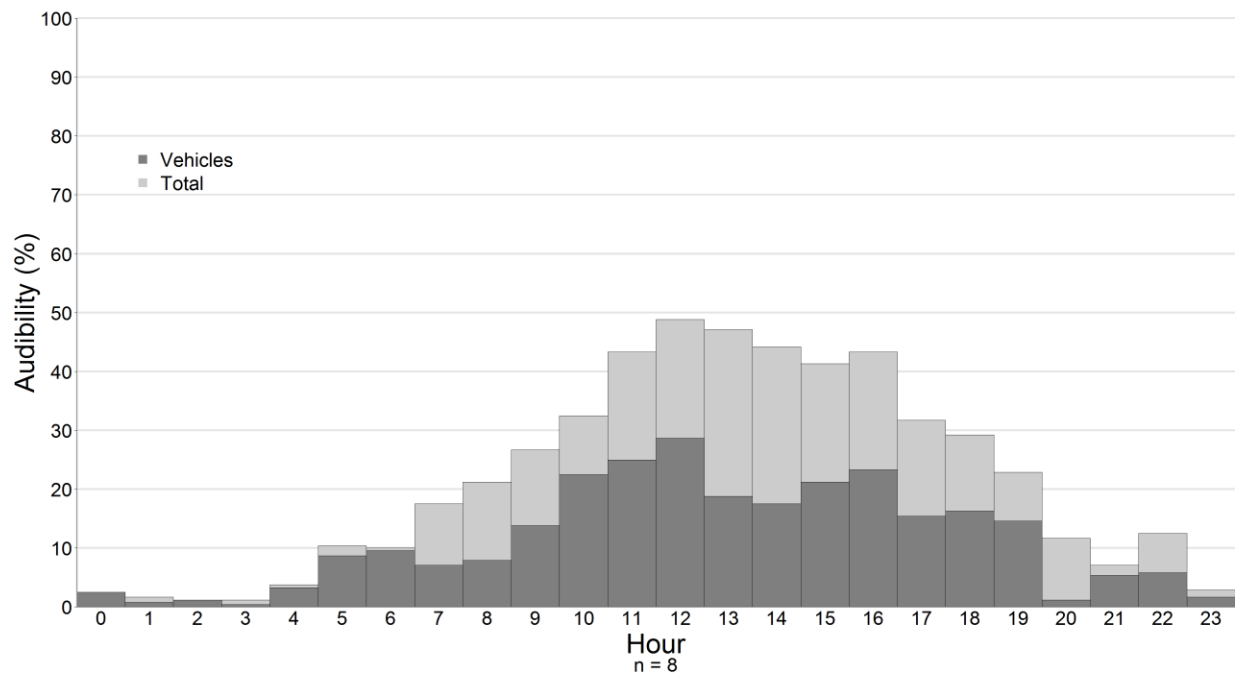


Figure 6. Comparison of hourly vehicle audibility and overall noise audibility at Bumpass Hell (LAVO002)

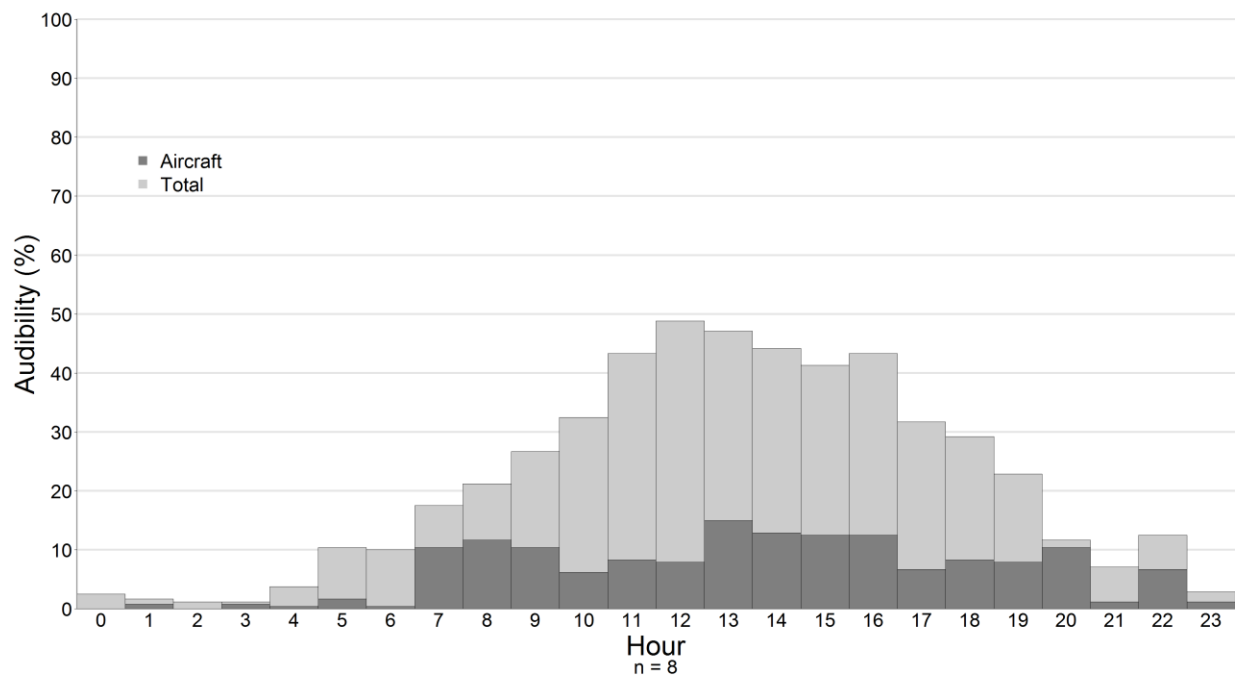


Figure 7. Comparison of hourly aircraft audibility and overall noise audibility at Bumpass Hell (LAVO002)

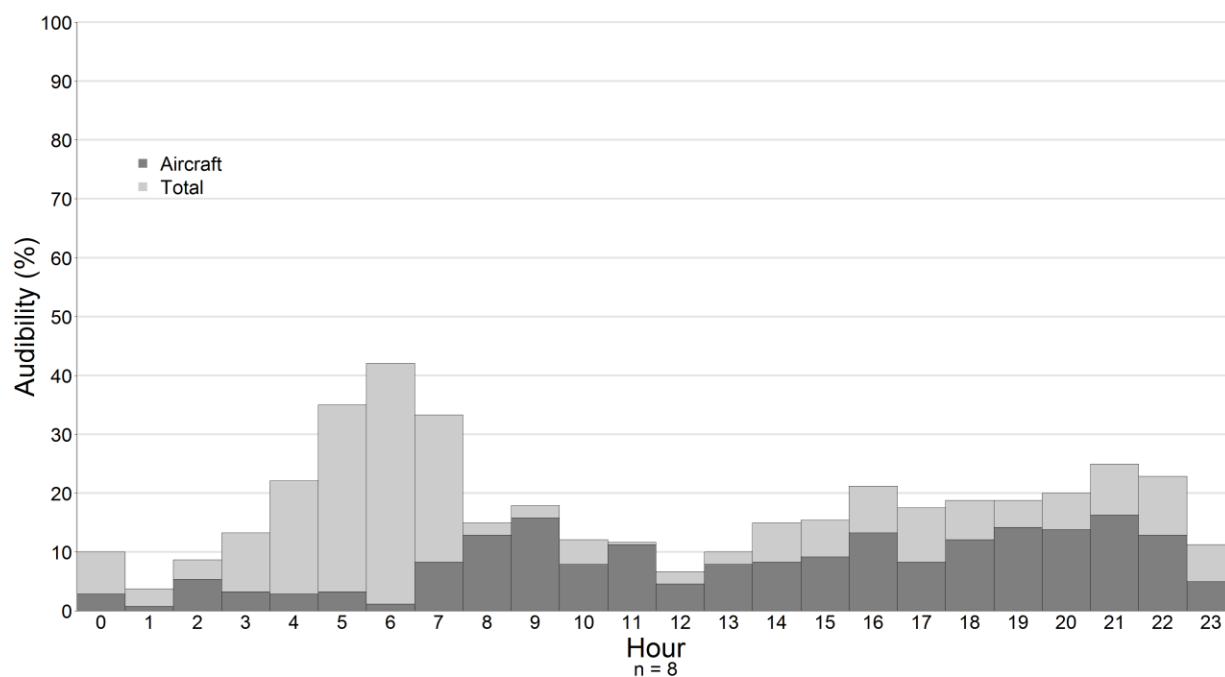


Figure 8. Comparison of hourly aircraft audibility and overall noise audibility at Big Bear Lake (LAVO003).

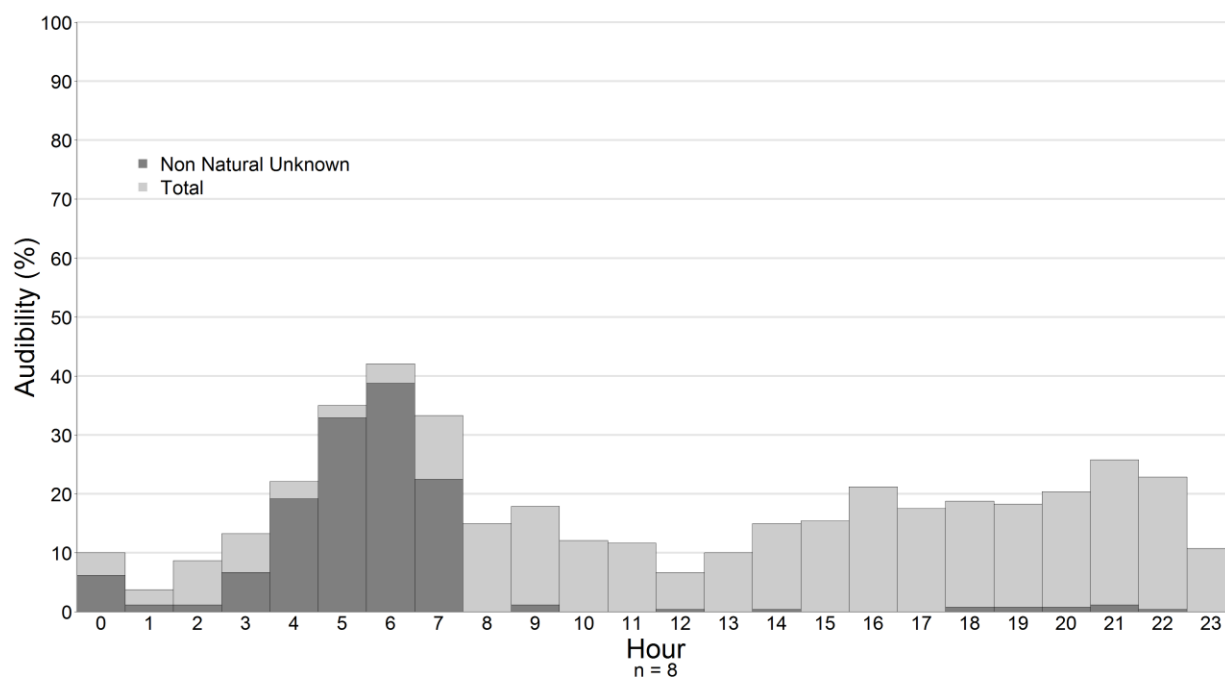


Figure 9. Comparison of hourly non-natural unknown audibility and overall noise audibility at Big Bear Lake (LAVO003).

Discussion

The purpose of this study was to assess the current condition of the acoustic environment at Lassen Volcanic National Park. Monitoring results characterize existing sound levels and estimate natural ambient sound levels within LAVO. This data is intended to provide the park with baseline information and to inform management decisions. Sound pressure level data, meteorological data, and audio were collected for approximately 30 days from three sites across the 106,452 acre park.

Because of equipment malfunctions continuous audio was not collected at all three sites. Enough audio was collected at Bumpass Hell and Big Bear Lake to calculate the natural ambient sound level and ambient sound level was collected at all three sites. At Manzanita Creek spectrogram analysis (SPL_{AT}) was used to extract sound source information but natural ambient was not calculated. Results from the 2014 monitoring indicate that the median natural ambient sound level (L_{nat}) at these two sites ranged between 14.7 dBA and 25.9 dBA. Both existing and natural ambient values were higher during the daytime than the nighttime at all locations, likely due to increased biological (e.g. birds) activity and anthropogenic sources of noise (aircraft and cars) during the day (7:00-19:00).

At Manzanita Creek both propeller planes and high altitude aircraft were fairly common sources of noise. For the eight days analyzed propeller planes were audible 5.8% of the time and high altitude jets were audible 5.6% of the time. The average maximum sound pressure levels from jets, propeller planes and the three gunshots from this analysis are higher than the L_{10} values at this site. This suggests that these anthropogenic noises were some of the loudest heard at this site. A higher diversity of noise sources are shown in Table 11 than in Table 10 because analysis of spectrograms, or visual analysis, tends to provide much better data on anthropogenic noise sources, especially aircraft, than on natural sound sources that you can hear in audibility analysis. Motorized sound sources show similar patterns in a spectrogram while many biological sound sources do not share this consistent pattern. Most of the hours from Manzanita Creek available for analysis occurred during the daytime, so Table 11 provides data on sound sources during the daytime hours.

Both Bumpass Hell and Big Bear Lake had more complete datasets making these locations more comparable. There was a larger discrepancy between the natural ambient sound pressure level and existing ambient sound pressure level at Bumpass Hell than Big Bear Lake (not calculated at Manzanita Creek). Bumpass Hell is closer to a road and more developed so we can expect to see higher impacts from anthropogenic sources causing an increase in sound pressure level. We would also expect the acoustic impacts to be higher during the daytime when humans are more active. We indeed see that on average, anthropogenic noise sources at Bumpass Hell added 2.4 dBA during the daytime and 0.4 dBA at nighttime. Anthropogenic noise sources most commonly heard at this site were vehicles, human voices, propeller planes and high altitude jets in that order. Although Big Bear Lake had fewer anthropogenic noise impacts there were still anthropogenic noises heard at this site including human voices, jets and propeller planes. Despite the relatively low overall sound levels, anthropogenic sounds were audible 1.2-62.4% of the time at Bumpass Hell. The highest audible anthropogenic noise at Bumpass Hell occurred between 11:00 and 16:00, this coincided with the most frequent sounds produced by human voices and vehicles. Big Bear Lake had a percent time

audibility ranging from 3.6-36.6% from anthropogenic sounds with a peak from 5:00 to 7:00 that was mostly caused by a source which was non-natural, and not identifiable through acoustic analysis. Staff at NSNSD have speculated that this noise could be emanating from a distant train and that the only times it is audible is during the quietest early morning hours at this fairly quiet wilderness site. The closest train tracks approximately 14.3 miles away (geodesic measurement) this is a considerable distance for train sound to travel but it seems the most likely source.

On-site analysis revealed a relatively active natural acoustic environment at LAVO. Based on 12 total hours of daytime listening, birds were audible over 75% of the time at all three sites and were especially common at Big Bear Lake. Off-site analysis focused primarily on assessing anthropogenic sources of sound, and as such, the results provide an accurate assessment of these noise sources. 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 wind, rain, thunder, coyotes, squirrels, birds, insects and amphibians in addition to many other natural sounds as shown in Tables 11-13.

Literature Cited

- American National Standards Institute. ANSI S12.60-2002. New York: ANSI; 2009. Acoustical Performance Criteria, Design Requirements and Guidelines for Schools.
- Acoustical Society of America. 2014. Methods to Define and Measure the Residual Sound in Protected Natural and Quiet Residential Areas, Melville, NY. ANSI/ASA S3/SC1.100-2014.
- Berglund, B., Lindvall, T. and Schwela, D.H (Eds.). 1999. HWO. Guidelines for community noise. World Health Organization, Geneva.
- Bell, J. and D. Hinson. 2010. Natural resource condition assessment: John Day Fossil Beds National Monument. Natural Resource Report NPS/UCBN/NRR—2010/174. National Park Service, Fort Collins, Colorado.
- Environmental Protection Agency. Information on Levels of Noise Requisite to Protect the Public Health and Welfare with an Adequate Margin of Safety, March 1974.
- Environmental Protection Agency (1982) National Ambient Noise Survey. Office of Noise Abatement and Control, Washington, DC.
- Federal Aviation Administration. (2010). FAA Aerospace Forecast Fiscal Years 2010-2030. U.S. Department of Transportation Federal Aviation Policy and Plans, Washington D.C.
- Haas, G.E., & Wakefield, T.J. 1998. National parks and the American public: A national public opinion survey on the national park system. Washington D.C. and Fort Collins, CO.: National Parks and Conservation Association and Colorado State University.
- Haralabidis Alexandros S., et. al. 2008. “Acute effects of night-time noise exposure on blood pressure in populations living near airports” European Heart Journal Advance Access. Published online February 12, 2008.
- Lassen Volcanic National Park. 2003. Lassen Volcanic National Park General Management Plan. National Park Service, Department of the Interior. Denver, CO.
- Lynch, E., Joyce, D., and Fristrup, K. 2011. An assessment of noise audibility and sound levels in U.S. National Parks. *Landscape Ecology* 26: 1297-1309.
- McDonald, C. D., Baumgarten, R. M., and Iachan, R. 1995. Aircraft management studies: National Park Service Visitors Survey. HMMH Report No. 290940.12; NPOA Report No. 94-2, National Park Service, U.S. Department of the Interior.
- National Park Service. 2005. Acoustic and Soundscape Studies in National Parks: Draft. Fort Collins, CO: NPS Natural Sounds and Night Skies Division.
- National Park Service. 2006a. Management Policy 4.9: Soundscape Management.

National Park Service. 2006b. Management Policy 8.2.3: Use of Motorized Equipment.

U.S. Federal Highway Administration. (2013). Traffic Volume Trends: May 2013 (p. 10). Retrieved from http://www.fhwa.dot.gov/policyinformation/travel_monitoring/13maytvvt/13maytvvt.pdf

Appendix A: Site Photos



Figure 10. LAVO001, Manzanita Creek Acoustic Monitoring Site



Figure 11. LAVO002, Bumpass Hell Acoustic Monitoring Site.



Figure 12. LAVO003, Big Bear Lake Acoustic Monitoring Site.

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 represents 270 m.

The resulting model can predict sound levels anywhere in the contiguous U. S., and it can 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 LAVO 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 LAVO, the mean modeled sound level impact is 0.7 dBA (ranging from 0 decibels (dBA) in the least impacted areas to 6.0 decibels (dBA) in the most impacted areas.) That is, the average existing sound level (with the influence of human-caused sounds) is predicted to be 0.7 dBA above natural conditions.

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 LAVO 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%, and an increase of 10 dB decreases listening area by approximately 90%. An increase of 0.7 dBA would reduce the listening area for wildlife and visitors by 15 %. 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 85 square feet if the sound levels were increased by 0.7 dBA.

Modeled metrics and park-based metrics were similar. When existing sound levels are compared to natural ambient sound levels, Big Bear Lake Site has the lowest impacts at 0.8 dBA during the day and 0.1 dBA during the night, while the Bumpass Hell site has a higher acoustic impact of 2.4 dBA during the day and 0.4 dBA at night. The relatively undisturbed condition of the acoustic environment at LAVO 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, there is a low impact at LAVO which shows a prominence of natural sounds that should be preserved and protected.

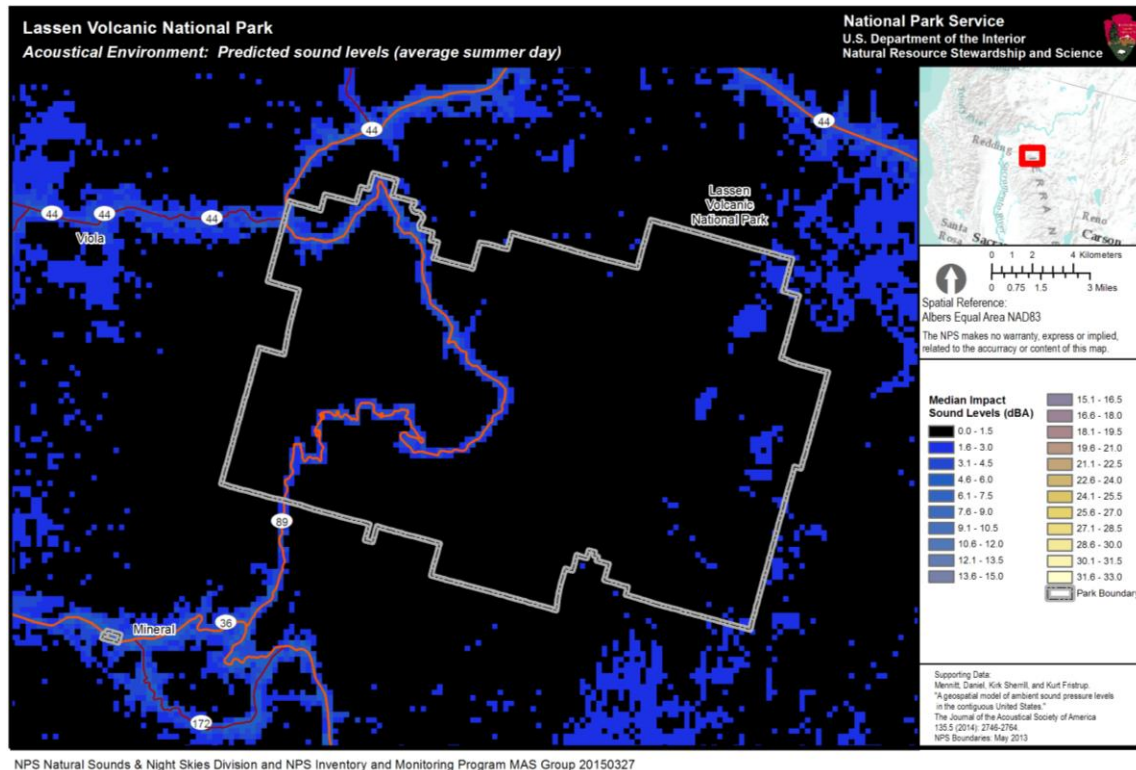


Figure 13. Map of predicted acoustic impact levels in the park for an average summer day. The color scale indicates how much man-made noise increases the sound level (in A-weighted decibels, or dBA), with 270 meter resolution. Black or dark blue colors indicate low impacts while yellow or white colors indicate greater impacts. Note that this graphic may not reflect recent localized changes such as new access roads or development. The mean acoustic impact level at the park is 0.7 dBA.

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.

NPS 111/134598, October 2016

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