



Valles Caldera National Preserve

Acoustic Monitoring Report

Natural Resource Report NPS/NRSS/NSNSD/NRR—2020/2137



ON THE COVER

History Grove at Valles Caldera National Preserve

Photograph by: Emma Brown, NSNSD

Valles Caldera National Preserve

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June 2020

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:

Job, J. R. 2020 Valles Caldera National Preserve: Acoustic monitoring report. Natural Resource Report NPS/NRSS/NSNSD/NRR—2020/2137. National Park Service, Fort Collins, Colorado.

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Executive Summary

In 2016, the Natural Sounds and Night Skies Division (NSNSD) received a request to collect baseline acoustical data at Valles Caldera National Preserve (VALL). Between June and July 2017, two acoustical monitoring stations were deployed within the park. Both sites were disturbed by elk with only three days of usable data gathered at VALL002. The goal of the study was to establish a baseline soundscape inventory of the park. This inventory will be used to establish indicators and thresholds of soundscape quality that will support the park and NSNSD in developing a comprehensive approach to protecting the acoustic environment through soundscape management planning. Additionally, results of this study will help the park identify major sources of noise within the park, as well as provide a baseline understanding of the acoustical environment as a whole for use in potential future comparative studies.

In this deployment, sound pressure level (SPL) was measured continuously every second by a calibrated sound level meter. Other equipment included an anemometer to collect wind speed and a digital audio recorder collecting continuous recordings to document sound sources. In this document, “sound pressure level” refers to broadband (12.5 Hz - 20 kHz), A-weighted, 1-second time averaged sound level ($L_{Aeq, 1s}$), and hereafter referred to as “sound level.” Sound levels are measured on a logarithmic scale relative to the reference sound pressure for atmospheric sources, 20 μ Pa. The logarithmic scale is a useful way to express the wide range of sound pressures perceived by the human ear. Sound levels are reported in decibels (dB). A-weighting is applied to sound levels in order to account for the response of the human ear (Harris, 1998). To approximate human hearing sensitivity, A-weighting discounts sounds below 1 kHz and above 6 kHz. For reference, Table 1 provides examples of sound levels measured in parks compared to sound levels of common sound sources.

Table 1. Sound level examples

Park Sound Sources	Common Sound Sources	Sound Level dB*
Volcano crater (HALE)	Human breathing at 3m	10
Leaves rustling (CANY)	Whispering	20
Crickets at 5m (ZION)	Residential area at night	40
Conversation at 5m (WHMI)	Busy restaurant	60
Cruiser motorcycle at 15m (BLRI)	Curbside of busy street	80
Thunder (ARCH)	Jackhammer at 2 m	100
Military jet at 100m AGL (YUCH)	Train horn at 1 m	120

* dB re 20 μ Pa A-weighted broadband (12.5 Hz—20 kHz), sound level measured over varied measurement durations and at the distances indicated.

Table 2 reports the percent of time that measured levels at the monitoring locations were above four key sound level values. The first value, 35 dB ($L_{Aeq, 1s}$), addresses the health effects of sleep interruption. Recent studies suggest that sound events as low as 35 dB can have adverse effects on blood pressure in sleeping humans (Haralabidis et al. 2008). This level, 35 dB, is also the desired

background sound level in classrooms (ANSI S12.60-2002). The second value addresses the World Health Organization’s recommendations that noise levels inside bedrooms remain below 45 dB ($L_{Aeq, 1s}$) (Berglund et al. 1999). The third value, 52 dB ($L_{Aeq, 1s}$), 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 dB ($L_{Aeq, 1s}$), provides a basis for estimating speech interference on normal voice communications at 1 meter. Visitors viewing scenic areas in the park would likely be conducting such conversations.

Table 2. Time above metrics for VALL001 and VALL002.

Site ID	Frequency (Hz)	Time above sound level (% of daytime hours, 07:00 to 19:00)				Time above sound level (% of nighttime hours, 19:00 to 07:00)			
		35 dB*	45 dB*	52 dB*	60 dB*	35 dB*	45 dB*	52 dB*	60 dB*
VALL001	12.5-20,000	30.0	18.4	5.0	0.4	2.4	0.3	0.0	0.0
	20-1,250	3.9	0.4	0.1	0.0	1.3	0.1	0.0	0.0
VALL002	12.5-20,000	63.6	5.6	0.1	0.0	20.6	5.4	0.4	0.1
	20-1,250	38.4	1.0	0.0	0.0	4.1	0.4	0.1	0.0

* dB $L_{Aeq, 1s}$ re 20 μ Pa

Sound levels are often measured over narrow frequency bands (typically in one-third octave bands between 12.5 Hz - 20 kHz) because these smaller bands closely represent how humans distinguish between frequencies of sound. In this study, we examine how often sound levels exceeded key values in two frequency *ranges*. The top value in each split-cell of Table 3 uses the full frequency range (12.5 Hz - 20 kHz) collected, whereas the bottom value focuses on frequencies affected by low frequency noise sources (20-1,250 Hz). This Natural Sounds (NS) modification to A-weighting (referred to as ANS weighting, ANSI S3/SC1.100, 2014) eliminates high-frequency sound (leaf rustle, equipment noise, and biologic sounds) allowing for more accurate comparisons of low-frequency ambient sound levels across different land use types (e.g. urban, protected areas; ANSI S3/SC1.100, 2014). This frequency weighting scheme improves ambient sound level measurements in quiet environments. For instance, in the full frequency range, the 35 dB ($L_{Aeq, 1s}$) level was exceeded at VALL001 30 % of the time during the day and 2.4 % of the time at night, but in the 20-1,250 Hz range, the 35 dB functional sound level value was very rarely exceeded in daytime or nighttime. Speech interruption occurs (between two people 1 meter apart) at 60 dB ($L_{Aeq, 1s}$) and this level was never (or very rarely) exceeded at either site.

Trained technicians calculated percent time audible metrics after monitoring was complete. See Methods section for protocol details, equipment specifications, and metric calculations. Prominent noise sources included aircraft at both sites and vehicles at VALL002. Table 3 displays percent time audible values for each of these noise sources during the monitoring period, as well as ambient sound levels.

Table 3. Mean time audible for human-caused, aircraft, and vehicle noise sources, existing and natural ambient sound levels (dB re 20 μ Pa, A-weighted broadband, 12.5 Hz—20 kHz) at VALL001 and VALL002 (where day is 7:00 – 19:00 and night is 19:00 – 7:00)

Site ID	Site Description	Season	Mean time audible for noise (% of 24 hour time period) ^a			Median Existing Ambient (L_{A50}) in dB		Median Natural Ambient (L_{Anat}) in dB	
			All Noise	Aircraft	Vehicle	Day	Night	Day	Night
VALL001	Valle Toledo	Summer	26.5	24.5	0.0	26.6	16.5	24.5	16.0
VALL002	History Grove	Summer	29.7	18.5	7.5	36.6	23.3	34.5	22.4

^a Over a 24-hour period, based on eight days of analysis at VALL001 and three days of analysis at VALL002.

Overall, existing ambient sound levels (L_{A50}) at the preserve ranged from 26.6 dB to 36.6 dB during the day and from 16.0 dB to 22.4 dB at night. Sound source analysis results show that aircraft are the primary source of noise within the park; however, vehicles also contribute to the acoustical environment at VALL002. The overall audibility of noise at VALL001 and VALL002 over the 24-hour day was 26.5% and 29.7% respectively, providing visitors the opportunity for solitude. The acoustical environment at these sites consists of natural sounds not found in most urban or suburban environments. These sounds add a unique dimension to the park experience, and the combination of extended noise-free intervals and relatively quiet overall sound levels afford visitors an opportunity to hear faint or very distant natural sounds.

Acknowledgments

The author of this report wishes to express his gratitude to Emma Brown and Scott Compton for their work in deploying the acoustical monitoring stations. The author would also like to thank Hannah Vincelette for her work in the off-site analysis of the acoustical data.

Glossary of Acoustical Terms

Glossary of acoustic terms and definitions

Term	Definition
A-weighting	A-weighting is applied to sound levels in order to account for the sensitivity of the human ear (Harris, 1998). To approximate human hearing sensitivity, A-weighting discounts sounds below 1 kHz and above 6 kHz.
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.
ANS Weighting	The Natural Sounds (NS) modification to A-weighting eliminates high-frequency sound (leaf rustle, equipment noise, and biologic sounds) allowing for more accurate comparisons of low-frequency ambient sound levels across different land use types (e.g. urban, protected areas; ANSI S3/SC1.100, 2014). This frequency weighting scheme improves ambient sound level measurements in quiet environments.
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 hearing ability of individual animals.
Decibel (dB)	A unit of sound energy. Sound levels are measured on a logarithmic scale relative to the reference sound pressure for atmospheric sources, 20 μ Pa. The logarithmic scale is a useful way to express the wide range of sound pressures perceived by the human ear. Sound levels are reported as decibels (dB). Every 10 dB increase represents a tenfold increase in energy. Therefore, a 20 dB increase represents a hundredfold increase in energy.
Existing ambient sound level (L_{A50})	sound level ($L_{Aeq, 1s}$) exceeded 50% of the time (50 th percentile) for a specified duration. This level is referred to as the existing ambient sound level and the preferred metric for chronic conditions, as it is insensitive to infrequent loud events.
Frequency	Related to the pitch of a sound, and defined as the number of times per second that the wave of sound repeats itself and is expressed in terms of hertz (Hz). Sound levels are often adjusted ("weighted") to match the hearing abilities of a given animal. In other words, different species of animals and humans are capable or hearing (or not hearing) at different frequencies. Humans with normal hearing can hear sounds between 20 Hz and 20,000 Hz, and as low as 0 dB at 1,000 Hz. Bats, on the other hand, can hear sounds between 20 Hz and 200,000 Hz.
Percentile sound levels (L_{A10} , L_{A50} , L_{A90})	Metrics used to describe A-weighted sound pressure levels (L), in decibels, exceeded 10, 50, and 90 percent of the time, respectively. Put another way, half the time the measured levels of sound are greater than the L_{A50} value, while 90 percent of the time the measured levels are higher than the L_{A90} value, and 10 percent of the time measured levels are higher than the L_{A10} value.

Glossary of acoustic terms and definitions (continued)

Term	Definition
Day-Night average sound levels (L_{dn})	Day-Night Average Sound Level. Average equivalent sound level over a 24-hour period, with a 10-dB penalty added for sound levels between 10 p.m. and 7 a.m.
Energy Equivalent Sound Level (L_{Aeq})	The sound energy level averaged over the measurement period. Generally, refers to A-weighted 1-second time averaged sound levels measured between 12.5 Hz - 20 kHz. This is a standard measurement collected using NSNSD acoustic monitoring protocol for sound level meters. Sound levels measured over 1 second intervals are used to calculate summary statistics, specifically percent of the time a sound level of interest is exceeded.
Natural Ambient Sound Level (L_{Anat})	The natural sound conditions in parks, which would exist in the absence of any human-caused noise sources. L_{Anat} is the preferred metric to represent baseline or reference conditions.
Noise Free Interval (NFI)	The length of the continuous period of time during which no human-caused sounds are audible.
Time Above	Within a defined time period, the percent of the time sound levels ($L_{Aeq, 1s}$) are above a specified sound level ($L_{Aeq, 1s}$). Commonly used levels are 35, 45, 52 dB ($L_{Aeq, 1s}$).
Time Audible	The amount of time that various sound sources are audible to humans with normal hearing, commonly expressed in percent of day, or percent of daytime hours and nighttime hours. 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. 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, time audible is a protective proxy for wildlife. These data can be collected either by a trained observer (on-site listening) or by making high-quality digital recordings for later playback (off-site listening).
Sound Exposure Level (SEL)	The total sound energy of the actual sound during a specific time period. SEL is usually expressed using a time period of one second.
Sound Pressure	Minute change in atmospheric pressure due to passage of sound that can be detected by microphones.
Sound vs. Noise	Sound and noise are often used interchangeably to describe an acoustic source. A common definition of noise is unwanted sound or sounds that interfere with a signal of interest (Harris 1998; Templeton 1997). However, noise is not a purely subjective designation. Any sound that serves no function is noise. Most sounds produced by human transportation and other machinery are unintended and serve no function, therefore are noise regardless of the attitudes of the listener. While there are unintended sounds in nature, like the footfalls of an animal, these sounds provide vital cues for some receivers and are therefore considered sounds to the receiver, yet noise from the perception of the producer.
Soundscape	The human perception of physical sound resources.

Introduction

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

National Park Service Natural Sounds and Night Skies Division

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

Soundscape Planning Authorities

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

Direction for management of natural 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 natural soundscapes. The frequencies, magnitudes, and durations of acceptable levels of

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

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

It should be noted that “the natural ambient sound level—that is, the environment of sound that exists in the absence of human-caused noise—is the baseline condition, and the standard against which current conditions in a soundscape [acoustic resource] will be measured and evaluated” (NPS 2006b). However, the desired acoustical condition may also depend upon the resources and the values of the park. For instance, “culturally appropriate sounds are important elements of the national park experience in many parks” (NPS 2006b). In this case, “the Service will preserve soundscape resources and values of the parks to the greatest extent possible to protect opportunities for appropriate transmission of cultural and historic sounds that are fundamental components of the purposes and values for which the parks were established” (NPS 2006b).

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

Valles Caldera National Preserve (VALL) was formally established in 2000 by Congress and President Bill Clinton to preserve the unique volcanic landscape and homeland of ancestral native Puebloans. From June to July 2017, two acoustical monitoring stations were deployed in the park. The Valle Toledo (VALL001) site was chosen to document quiet background sound levels, as predicted by a recently completed noise model (Mennitt 2014), and low visitor use, as it was behind a closed gate, and accessed infrequently for administrative purposes. The History Grove (VALL002) site was designated as a higher use, frontcountry monitoring site. Both sites were disturbed by elk with VALL002 recording only three days of analyzable data (June 23-25, 2017). Elk also disturbed VALL001, but to a lesser degree, and this system ran for a total of 22 days. Table 4 shows site information regarding the monitoring stations. Figure 1 shows the location of the acoustical monitoring sites within the park. It should be noted that at the time these measurements were gathered, the number of visitor vehicles permitted past the entrance station at VALL per day was 35. This limit was commonly reached on both weekdays and weekends during the summer months.

Table 4. VALL acoustic monitoring sites.

Site ID	Site Name	Dates Deployed	Vegetation	Elevation (m)	Latitude	Longitude
VALL001	Valle Toledo	June 22, 2017 – July 17, 2017	Temperate Grasslands	2637	35.95393	-106.47450
VALL002	History Grove	June 22, 2017 – July 17, 2017	Temperate Grasslands	2642	35.87658	-106.51070



Produced by E. Brown, Natural Sounds and Night Skies Division, March 2020

Figure 1. Location of acoustical monitoring sites at Valles Caldera National Preserve.

Methods

Automatic Monitoring

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

Acoustical monitoring equipment is used by many industries to determine noise levels in different environments, both indoors and outdoors. NPS uses equipment that is similar to the equipment used by other industries but has developed a unique configuration that stands up to the potentially harsh environment encountered in national parks. The microphone with environmental shroud was set up on a tripod at 1.5 m, which approximates the average height of the human ear. The digital audio recorder recorded continuous audio throughout the entire monitoring period. An anemometer was attached to a tripod and placed near the microphone, to capture local wind conditions without recording possible sound from anemometer wind cup rotation. At both sites, equipment was deployed inside an elk enclosure to discourage wildlife from disrupting the measurement.

Each sampling station consisted of:

- Type 1 sound level meter
- Microphone with environmental shroud
- Preamplifier
- 12 V battery pack
- Anemometer (wind speed and direction)
- Digital audio recorder

Each sampling station collected:

- A-weighted 1 second time averaged sound level ($L_{Aeq, 1s}$) in dB re 20 μ Pa
- Continuous digital audio recordings
- One-third octave band data every second ranging from 12.5 Hz – 20,000 Hz
- Continuous meteorological data for wind speed

Monitoring Period

NSNSD has determined that 25 day monitoring periods during opposing seasons allow the data to capture seasonal difference that occur at each site within a reasonable margin of error (NPS 2005). The monitoring period lasted 22 days at VALL001 and 3 days at VALL002. Both measurement periods were shortened by elk disturbance.

Calculation of Metrics

The status of the acoustical environment can be characterized by sound level (L_{A50} , L_{Anat} , L_{A90} , L_{A10} , L_{Acq}) and frequency content, and event durations (through off-site listening). NPS uses descriptive figures and metrics to interpret these characteristics.

Two fundamental descriptors are existing ambient (L_{A50}) and natural ambient (L_{Anat}) sound levels. These are both examples of percentile levels, where each L_x value refers to the sound level that is exceeded $x\%$ of the time. The L_{A50} represents the median sound level, and is drawn from a full dataset (removing data with wind speed $> 5\text{m/s}$ to eliminate error from microphone distortion). The L_{A50} is the preferred metric to represent prevailing acoustic conditions. The natural ambient (L_{Anat}) is an estimate of what the sound levels for a site would be if all human-caused noise sources were removed. L_{Anat} is the preferred metric to represent baseline or reference conditions.

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

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

P_H is the percentage of samples containing noise for the hour. For example, if human caused sounds are present 30% of the hour, $x = 65$, and the L_{Anat} 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_{Anat} values for the daytime hours (0700-1900) and the median of the hourly L_{Anat} values for the nighttime (1900-0700) are displayed in Figure 4 in the results section.

Off-Site Listening

Off-site listening is normally done by listening to an audio recording and simultaneously visually analyzing a spectrogram. Auditory analysis was used to calculate the audibility of sound sources at the monitoring locations. A trained technician at Colorado State University analyzed a subset of .mp3 samples (10 seconds every two minutes for eight days of audio for VALL001 and three days of audio for VALL002) in order to identify durations of audible sound sources. Staff used the total percent time noise was audible to calculate the natural ambient sound level for each hour (see Equation 1 above for more information). Bose Quiet Comfort Noise Canceling headphones were used for off-site audio playback to minimize limitations imposed by the office acoustical environment. For the complete results of this thorough audibility analysis, see Table 6 and Table 7 in the Event duration section below.

Results

Frequency content

In order to determine the effect that noise has on the acoustical environment, it is useful to examine percentile metrics across a frequency range. 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. These smaller bands closely represent how humans distinguish between frequencies of sound. For each one-third octave band, sound level ($L_{eq, 1s}$) was recorded once per second for the duration of the monitoring periods. The percentile sound levels for 33 one-third octave band frequencies over the day and night periods are shown in Figure 2 and Figure 3.

Examining the sound energy in 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 level at a site. The grayed area of Figure 2 and Figure 3 represents sound levels outside of the typical range of human hearing. The percentile levels (L_x) are also shown for each one-third octave band. They represent the sound levels exceeded x percent of the measurement period. For example, L_{90} is the sound 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 sound 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} and L_{nat} . The height of this bold portion is a measure of the contribution of anthropogenic noise to the existing 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 sound levels were either very close to each other or were equal. The typical frequency levels for transportation, conversation, and songbirds are presented on the figure as examples for interpretation of the data. These ranges are estimates and are not vehicle-, species-, or habitat-specific.

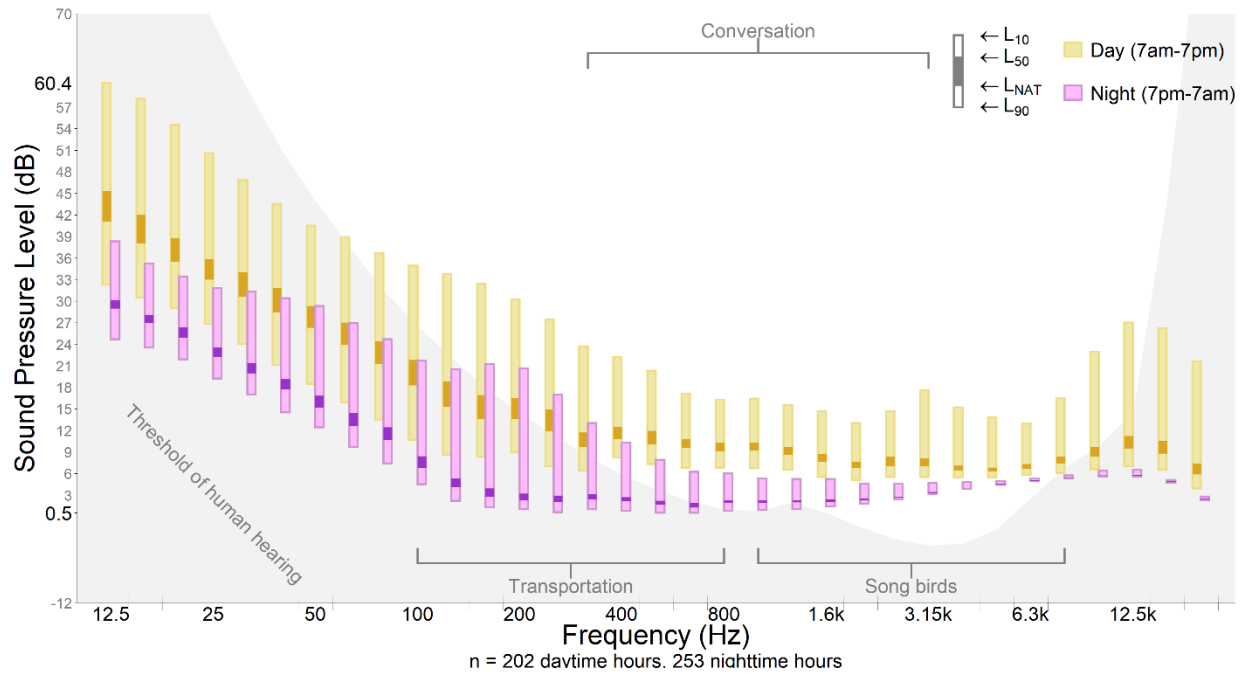


Figure 2. Day and night percentile sound pressure levels for 33 one-third octave bands at VALL001.

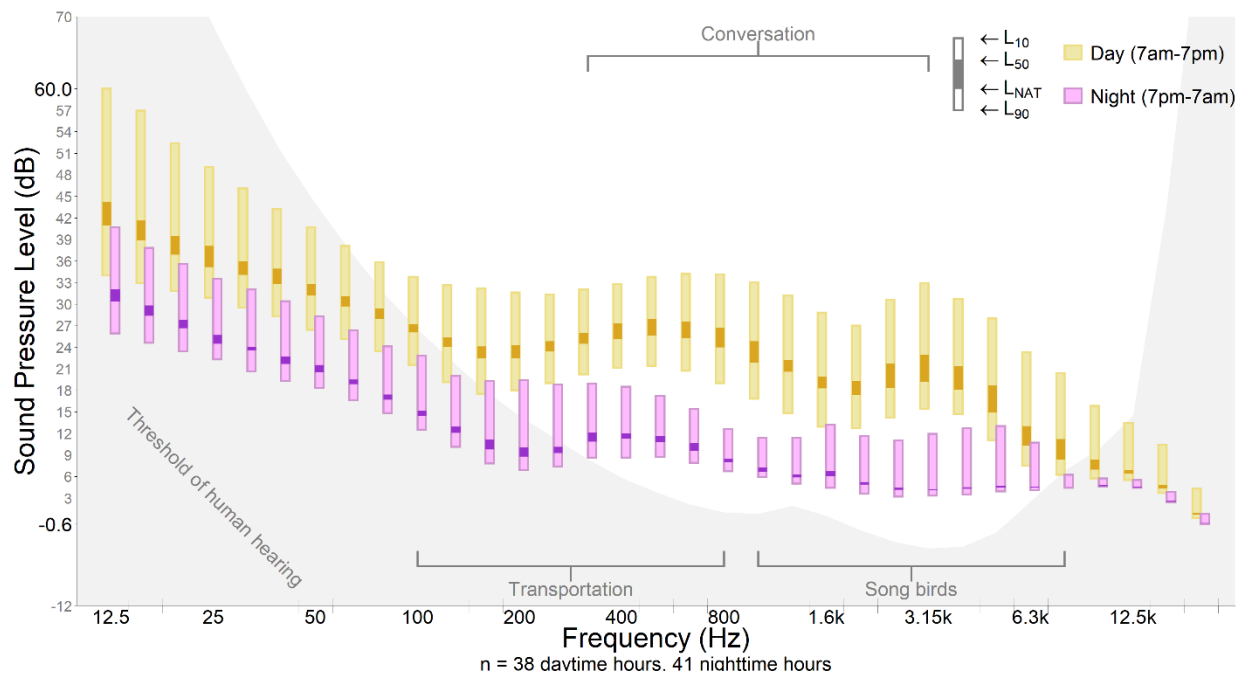


Figure 3. Day and night percentile sound pressure levels for 33 one-third octave bands at VALL002.

Sound level: Time Above

To understand how acoustic conditions in the park might affect visitors, measured sound levels are compared to established sound levels. Specifically, Table 5 reports the percent of time that measured sound levels ($L_{Aeq,1s}$) were above four key functional values during the monitoring periods (daytime

and nighttime). The first functional value in Table 5 is 35 dB ($L_{Aeq,1s}$), which is designed to address the health effects of sleep interruption. Studies suggest that sound events as low as 35 dB can have adverse effects on blood pressure in sleeping humans (Haralabidis et al. 2008). This is also the desired background sound level in classrooms (ANSI S12.60-2002). The second sound level value, 45 dB ($L_{Aeq,1s}$), addresses the World Health Organization’s recommendations that noise levels inside bedrooms remain below 45 dB ($L_{Aeq,1s}$) (Berglund et al. 1999). The third sound level value, 52 dB ($L_{Aeq,1s}$), 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 dB ($L_{Aeq,1s}$), provides a basis for estimating impacts on normal voice communications at 1 meter. Visitors viewing scenic areas in the park would likely be conducting such conversations.

The top value in each split-cell uses the full frequency range, whereas the bottom values report the percent of time ANS-weighted sound levels (20-1,250 Hz) are above functional values. Most motorized human-caused noise is confined to the truncated, lower-frequency range, while many natural sounds, including insects and birds, are higher in pitch. ANS weighting eliminates high-frequency sound (leaf rustle, equipment noise, and biologic sounds) allowing for more accurate comparisons of low-frequency ambient sound levels across different land use types (e.g. urban, protected areas; ANSI S3/SC1.100, 2014). This frequency weighting scheme improves ambient sound level measurements in quiet environments. For instance, in the full frequency range, the 35 dB ($L_{Aeq, 1s}$) level was exceeded at VALL001 30 % of the time during the day and 2.4 % of the time at night, but in the 20-1,250 Hz range, the 35 dB functional sound level value was exceeded only 3.9 % during the daytime and only 1.3 % at night (Table 5).

Table 5. Time above metrics for VALL001 and VALL002.

Site ID	Frequency (Hz)	Time above sound level (% of daytime hours, 07:00 to 19:00)				Time above sound level (% of nighttime hours, 19:00 to 07:00)			
		35 dB*	45 dB*	52 dB*	60 dB*	35 dB*	45 dB*	52 dB*	60 dB*
VALL001	12.5-20,000	30.0	18.4	5.0	0.4	2.4	0.3	0.0	0.0
	20-1,250	3.9	0.4	0.1	0.0	1.3	0.1	0.0	0.0
VALL002	12.5-20,000	63.6	5.6	0.1	0.0	20.6	5.4	0.4	0.1
	20-1,250	38.4	1.0	0.0	0.0	4.1	0.4	0.1	0.0

* dB $L_{Aeq, 1s}$ re 20 μ Pa

Sound Level: Percentile Levels

To understand the range of acoustic conditions at the park, percentile sound levels are reported. In Figure 4 and Figure 5 below, the A-weighted percentile sound levels (L_{A90} , L_{Anat} , L_{A50} , and L_{A10}) for VALL001 and VALL002 are shown. The hourly percentile sound levels are calculated from the broadband (12.5 Hz - 20 kHz) A-weighted, 1-second time averaged sound levels ($L_{Aeq, 1s}$) within each hour of the day. For instance, in Figure 4, the L_{A50} (median) sound level for VALL001 during the 8:00 hour is 28.1 dB. On the other hand, the sound level exceeded 10% of the time (L_{A10}) for the same hour at this site is 46.6 dB, meaning 90% of the measurement period is quieter than this level. High percentile sound levels in the 9:00 and 10:00 hours are largely due to insect activity (Figure 4). Hours where the L_{A50} and the L_{Anat} differ the most are usually hours with the most human-caused noise. In the case of VALL001, the 8:00 hour seems to be heavily impacted by noise. If we cross reference Table 6, we see that aircraft were audible on average 50 % of this hour. At VALL002, the highest sound level occurred during the 5:00 hour, which corresponds with a robust morning bird chorus.

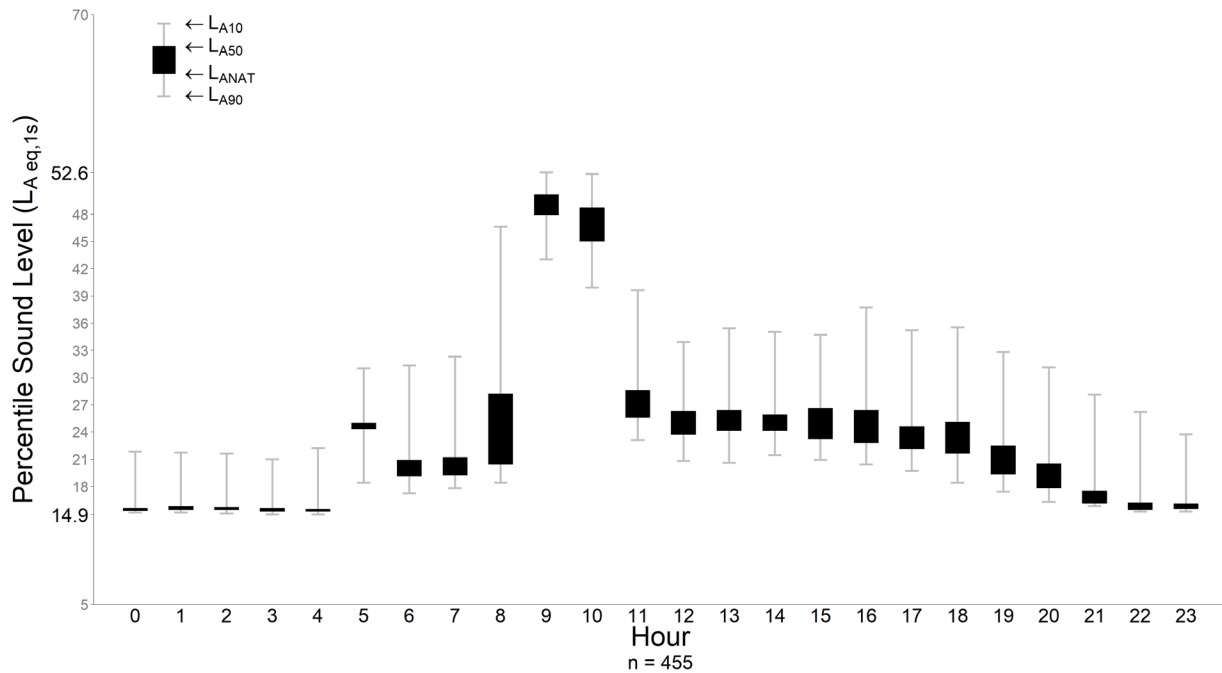


Figure 4. Median percentile sound levels ($L_{Aeq, 1s}$), in dB re 20 μ Pa, at VALL001

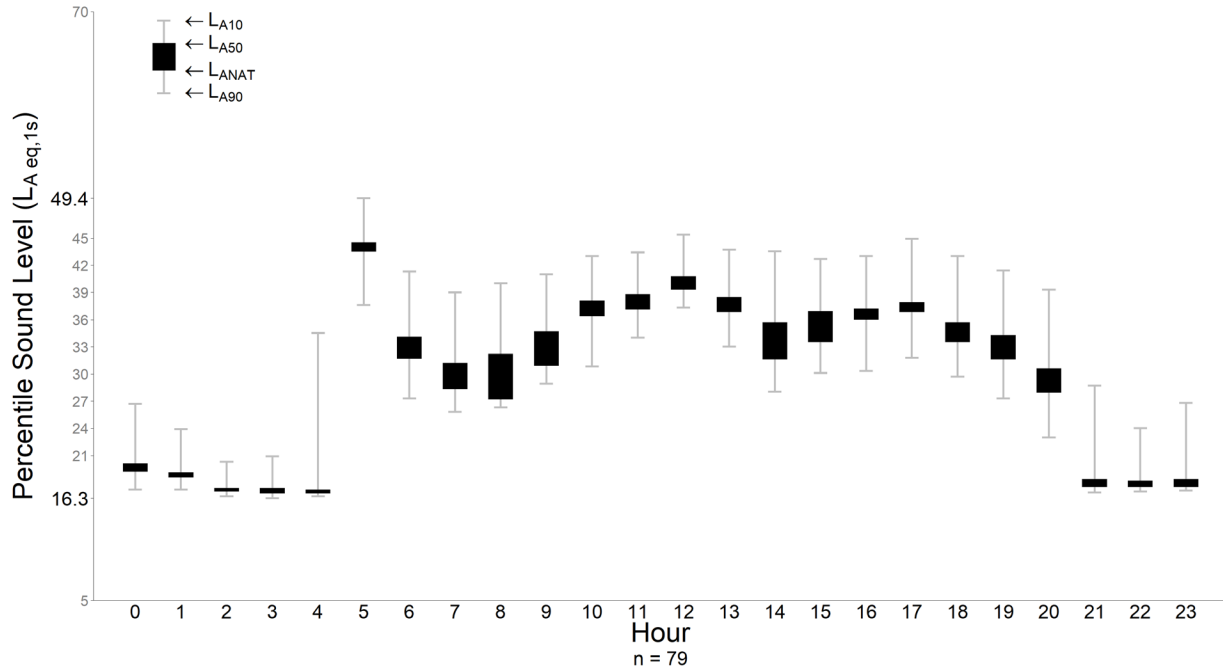


Figure 5. Median percentile sound levels (L_{Aeq, 1s}), in dB re 20 µPa, at VALL002

Event duration

Through off-site listening analysis, event duration for all audible sounds is calculated. Table 6 and Table 7 list audible natural sounds and noise sources at VALL001 and VALL002. Mean hourly audibility was calculated over eight days of analysis for VALL001 and 3 days for VALL002. Figure 6 and Figure 7 display hourly audibility for all non-natural sources, as compared to audibility of two noise sources of interest: aircraft and vehicles.

Table 6. Mean hourly percent time audible for each noise and sound source at VALL001. n = 8 days of analysis.

Sound Source	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h	
Aircraft	17.1	21.2	11.7	13.8	9.6	5.4	25.8	33.7	50.8	47.9	27.5	32.1	23.7	21.7	12.5	11.3	14.2	30.4	28.7	34.2	27.9	33.3	23.7	31.7	
Vehicle	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	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	0.4	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
Non-Natural Unknown ^{a,c}	5.0	2.1	1.2	0.8	0.8	1.2	0.8	3.3	1.7	2.5	0.4	0.4	0.4	1.2	2.1	1.2	3.3	0.0	0.0	0.8	4.2	4.2	6.2	0.8	
Wind ^c	99.2	100	99.6	100	99.6	100	100	100	100	100	99.6	95.0	99.6	100	100	100	99.6	98.7	99.6	100	100	99.6	99.6	100	
Precipitation ^c	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	2.5	2.5	12.1	25.4	24.2	8.3	6.2	7.5	0.0	12.9	16.7	11.3	
Thunder ^c	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	13.3	12.5	31.7	27.1	14.6	12.5	16.3	21.2	7.1	7.1	2.9	
Mammal ^c	11.3	17.9	7.5	15.4	5.8	7.9	26.2	26.7	16.3	1.2	4.6	7.5	6.7	3.3	3.8	2.9	5.4	3.3	12.1	13.8	15.8	8.3	9.6	22.5	
Bird ^c	1.2	1.7	3.3	0.4	30.0	100	99.6	99.6	95.8	82.9	71.7	74.2	77.5	67.5	52.5	54.2	60.4	59.6	74.2	80.0	88.7	2.1	5.8	5.0	
Insect ^c	24.6	17.9	12.1	3.8	1.2	2.9	4.2	32.9	86.2	100	99.6	97.1	92.1	92.9	80.4	75.0	64.6	74.6	83.7	62.1	31.2	30.4	19.2	21.7	
Animal ^c	31.7	38.8	33.7	27.1	10.8	0.8	5.0	3.8	2.9	2.1	3.3	0.4	1.7	1.7	3.8	0.8	2.1	5.4	2.9	10.8	2.5	10.0	12.1	10.4	
Wind-Induced Natural ^c	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	0.0
Natural Unknown ^{b,c}	0.8	0.8	0.4	1.7	0.0	0.4	0.4	0.4	0.8	0.4	0.4	0.0	0.0	0.0	0.0	0.4	0.4	0.8	0.4	0.0	0.4	2.1	1.2	0.0	

^a Non-natural unknown noise sources are associated with human activity, but their exact identity is unclear.

^b Natural unknown sound sources are not associated with human activity, but their exact identity is unclear.

^c Natural sound sources (also shaded).

Table 7. Mean hourly percent time audible for each noise and sound source at VALL002. n = 3 days of analysis.

Sound Source	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Aircraft	14.4	10.0	17.8	11.1	10.0	3.3	10.0	18.9	34.4	27.8	8.9	21.1	17.8	20.0	22.2	21.1	6.7	12.2	23.3	33.3	21.1	26.7	26.7	25.6
Vehicle	1.1	0.0	0.0	10.0	0.0	6.7	11.1	27.8	23.3	21.1	6.7	3.3	4.4	8.9	24.4	13.3	4.4	3.3	2.2	2.2	0.0	0.0	0.0	5.6
Non-Natural Unknown ^a	2.2	0.0	0.0	1.1	1.1	2.2	7.8	2.2	15.6	5.6	5.6	7.8	10.0	1.1	1.1	3.3	1.1	0.0	2.2	1.1	3.3	8.9	8.9	2.2
Wind ^c	100	100	100	98.9	98.9	18.9	88.9	97.8	98.9	91.1	95.6	100	94.4	96.7	96.7	92.2	85.6	97.8	98.9	95.6	95.6	100	100	100
Precipitation ^c	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	8.9	5.6	2.2	0.0	0.0	0.0	0.0	0.0	0.0
Thunder ^c	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	2.2	27.8	7.8	0.0	0.0	0.0	0.0	0.0	0.0
Mammal ^c	7.8	1.1	0.0	1.1	2.2	2.2	24.4	18.9	18.9	14.4	5.6	1.1	2.2	4.4	4.4	1.1	1.1	8.9	15.6	62.2	70.0	15.6	17.8	5.6
Bird ^c	1.1	5.6	4.4	6.7	36.7	100	100	98.9	100	98.9	97.8	100	97.8	98.9	100	95.6	96.7	98.9	100	98.9	96.7	13.3	3.3	2.2
Insect ^c	0.0	1.1	0.0	1.1	0.0	10.0	4.4	8.9	20.0	6.7	5.6	5.6	7.8	2.2	6.7	4.4	4.4	0.0	1.1	2.2	3.3	1.1	3.3	0.0
Animal ^c	12.2	5.6	3.3	6.7	12.2	0.0	3.3	2.2	1.1	5.6	3.3	7.8	3.3	5.6	6.7	5.6	2.2	3.3	1.1	8.9	2.2	16.7	11.1	6.7
Wind-Induced Natural ^c	52.2	51.1	33.3	40.0	34.4	33.3	4.4	1.1	31.1	70.0	100	100	95.6	100	97.8	81.1	81.1	100	98.9	66.7	30.0	38.9	48.9	40.0
Natural Unknown ^{b,c}	2.2	1.1	1.1	1.1	0.0	1.1	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	2.2	1.1	1.1

^a Non-natural unknown noise sources are associated with human activity, but their exact identity is unclear.

^b Natural unknown sound sources are not associated with human activity, but their exact identity is unclear.

^c Natural sound sources (also shaded).

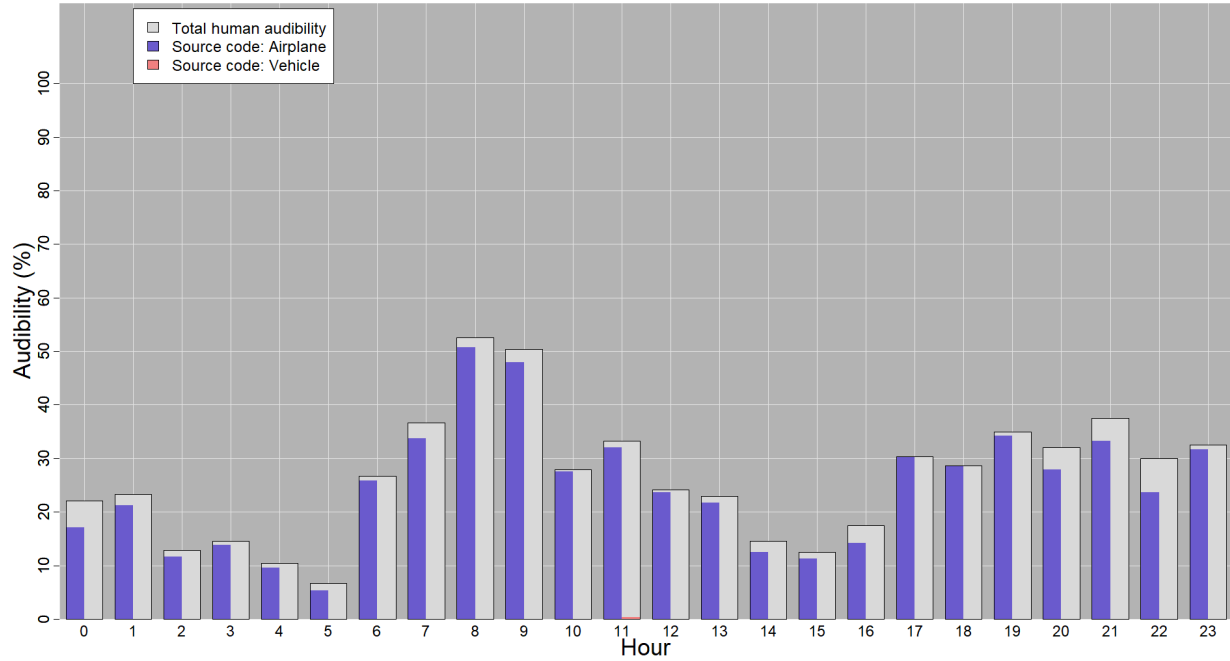


Figure 6. Hourly time audible for aircraft, vehicle, and all noise sources at VALL001.

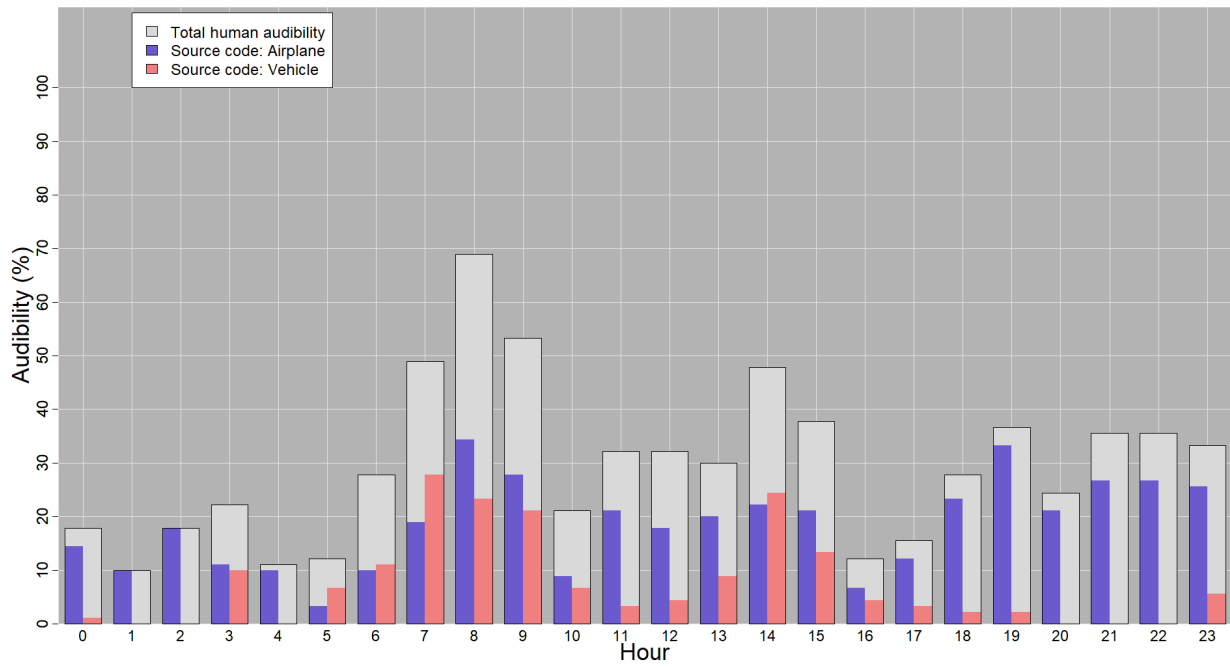


Figure 7. Hourly time audible for aircraft, vehicle, and all noise sources at VALL002.

Discussion

The purpose of this study was to assess current conditions of the acoustical environment at VALL. Monitoring results include existing ambient sound levels, calculations of sound source audibility through off-site listening, and estimates of natural ambient levels, all of which are intended to provide the park with baseline information and to inform management decisions. The site locations were chosen to assess the effects of noise on the acoustical environment from a backcountry and frontcountry location.

Results indicate that natural ambient sound levels (L_{Anat}) at VALL001 ranged from 24.5 dB during the daytime to 18.6 dB at night. Natural ambient sound levels ranged from 34.5 dB during the daytime to 31.1 dB at night at VALL002. Existing ambient sound levels (L_{A50}) were higher, ranging from 26.6 dB during the day to 20.4 dB at night at VALL001 (Figure 4). Existing ambient sound levels ranged from 36.6 dB during the day to 33.6 dB at night at VALL002 (Figure 5). For comparison, a comprehensive 1982 study of noise levels in residential areas found that nearly 87% of US residents were exposed to day-night sound levels (L_{dn}) over 55 dB, and an additional 53% were exposed to L_{dn} over 60 dB (EPA 1982). Noise levels have increased nationally with population growth since the EPA study (Suter 1991; Barber et al. 2010). Therefore, the results imply that natural ambient sound pressure levels during the monitoring period were considerably quieter than most residential areas.

Despite low overall sound levels, noise still exists at VALL, but it occurs infrequently. The mean 24-hour time audible of noise was 26.5% at VALL001 and 29.7% at VALL002, presenting visitors with opportunities for relatively prolonged periods of solitude (Table 3). Noise at VALL001 and VALL002 largely originated from overflights (Tables 6 and 7), with noise from vehicles also contributing to the acoustical environment at VALL002 (Table 7). Outside of these sources, the only other prominent noise source was unknown in origin but might have come from distant vehicles considering patterns of presence were consistent with the morning commute (see ‘Non-Natural Unknown’ in Tables 6 and 7).

Noise has the potential to affect a visitor’s experience in parks by causing annoyance (Rapoza et al. 2015), reducing the perceived scenic beauty (Weinzimmer et al. 2014), or simply by limiting opportunities for solitude. Increased sound levels may also have wide ranging effects on wildlife such as reduced predatory success (Mason 2015), changes in vocal communication, or increased vigilance by keystone species (Shannon et al. 2014). In a review of literature addressing the effects of noise on wildlife published between 1990 and 2013, wildlife responses to noise were observed beginning at about 40 dB ($L_{\text{Aeq, x}}$).² Of the papers reviewed, 20% showed impacts to terrestrial wildlife at or below noise levels of 50 dB ($L_{\text{Aeq, 1s}}$) (Shannon et al. 2015).

² This metric is a composite of multiple metrics with varying time averaging metrics.

Natural sound sources within the park were quite prevalent and varied. The most common sources were birds, insects, and wind blowing through vegetation (Table 6 and Table 7). Additionally, several species of mammals could be heard, including coyotes, elk, and prairie dogs. The combination of these natural sounds and periods of noise-free silence provide visitors with a unique opportunity to connect with nature in the preserve. The information presented in this report will be used to inform park managers and planners when they make management decisions, but it will also serve as a permanent record of what the park sounded like in 2016. Sound level data as well as continuous digital audio recordings will be stored at the Natural Sounds and Night Skies Division office in Fort Collins, Colorado for archiving purposes.

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Appendix A: Site Photographs

Figures 8 and 9 are site photos of VALL001 and VALL002.



Figure 8. Site photograph of VALL001, 'Valle Toledo'.



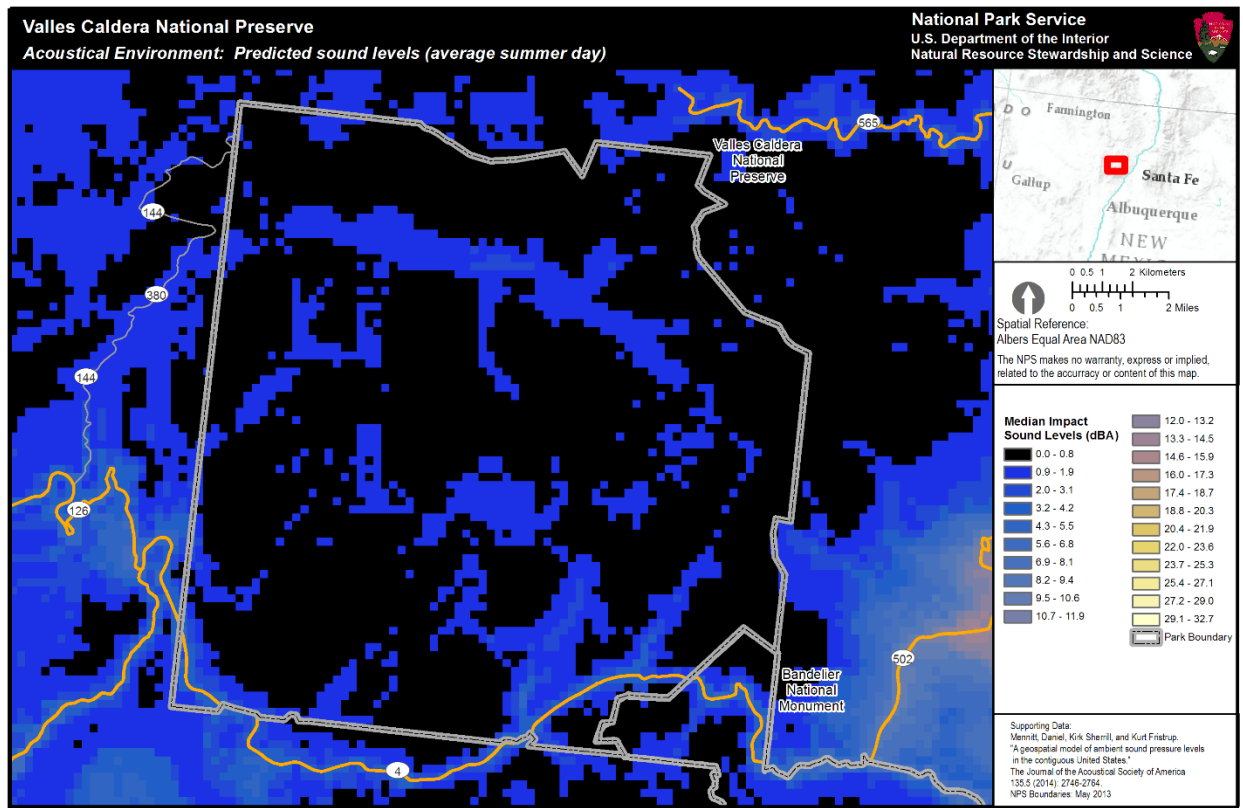
Figure 9. Site photograph of VALL002, 'History Grove'.

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.

The resulting model can predict sound levels anywhere in the contiguous U.S., and it can 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_{A50} impact) at VALL001 and VALL002 is shown in Figure 10. The analysis that informed this map 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 preserve. At VALL, the mean modeled sound level impact is 0.5 dB, and this value represents a close approximation of expected impact levels at a randomly chosen point within the preserve.

Each pixel in the graphic shown in Figure 10 represents 270m. 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 in VALL 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%. The modeled results of 0.5 dB over the entire park would decrease listening area by 11%. Observed mean impact at VALL001 and VALL002 was 2.1 dB (which would decrease listening area by 38.3%).



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Figure 10. Modeled median sound level impacts in the area immediately surrounding VALL and the nearby region (inset). 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 (Noise impact or noise exceedance [$L_{A50, impact}$]), with 270 m 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 modeled acoustic impact level at the park is 0.5 dB.

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 216/170371, June 2020

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