National Park Service
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Natural Resource Stewardship and Science

Pipestone National Monument

Acoustic Monitoring Report

Natural Resource Technical Report NPS/NRSS/NRTR— 2014/879

ON THIS PAGE
Pipestone Creek from the top of Winnewissa Falls along the Circle Trail at Pipestone National Monument.
Photograph by: Misty D. Nelson

ON THE COVER
White-tailed deer (*Odocoileus virginianus*) near the acoustic monitoring site at Pipestone National Monument.
Photograph by: Misty D. Nelson

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June 2014

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

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

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

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Please cite this publication as:

Nelson, M.D. 2014. Pipestone National Monument: Acoustic monitoring report. Natural Resource Technical Report NPS/NRSS/NRTR— 2014/879. National Park Service, Fort Collins, Colorado.

NPS 372/124858, June 2014

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Executive Summary

In 2012, the Natural Sounds and Night Skies Division received a request to collect baseline acoustical data at Pipestone National Monument (PIPE). During the months of May and June 2013, one acoustical monitoring system was deployed for approximately 30 days. The goal of the technical assistance request was to complete a baseline soundscape inventory. This inventory will be used to establish indicators and standards of soundscape quality that will support the park in developing a comprehensive approach to soundscape management planning. Results of this study will help the park evaluate the potential effects of various man-made sound sources, including nearby community buildings and facilities, highways, and railroads, as well as internal park operations. Additionally, results from this project will be included in the Heartland Network's Natural Resource Condition Assessment currently being drafted for the park.

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). The most common sources of noise at PIPE include vehicles, trains, and aircraft. Table 1 displays percent time audible values for each of these common noise sources during the monitoring period, as well as ambient sound levels. Ambient sound pressure levels were measured continuously every second over the 30 day monitoring period by a calibrated, Type 1, Larson Davis 831 sound level meter. Percent time audible metrics were calculated by trained technicians after monitoring was complete. See Methods section for protocol details and equipment specifications. Median existing (L_{50}) and natural (L_{nat}) ambient metrics are also reported for daytime (7 am – 7 pm) and nighttime (7 pm – 7am). See Methods section for detailed information on how these metrics are calculated. L_{50} values at PIPE001 were slightly higher during the day than at night, which could be a result of increased human activity during the day. PIPE001 also had a higher L_{nat} during the day than at night, likely due to increased bird activity during daylight hours.

Table 1. Mean percent time audible for extrinsic, aircraft, train, and vehicle sounds; existing and natural ambient sound levels.

		Mean percent time audible (in 24 hour time period)[a]				Median Existing Ambient (L_{50}) in dBA[b]		Median Natural Ambient (L_{nat}) in dBA	
Site ID	**Site Description**	**All Extrinsic**	**Aircraft**	**Trains**	**Vehicles**	**Day[c]**	**Night**	**Day**	**Night**
PIPE001	Sundance Grounds	66.6	8.8	11.9	44.6	39.3	37.0	36.3	34.6

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

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

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

In determining the current conditions of an acoustical environment, it is informative to examine how often sound pressure levels exceed certain values. Table 2 reports the percent of time that measured levels were above four key values. The first value, 35 dBA, is designed to address the health effects of sleep interruption. Recent studies suggest that sound events as low as 35 dB can have adverse effects on blood pressure while sleeping (Haralabidis et al. 2008). This is also the desired background

sound level in classrooms (ANSI S12.60-2002). The second value addresses the World Health Organization's recommendations that noise levels inside bedrooms remain below 45 dBA (Berglund et al. 1999). The third value, 52 dBA, is based on the EPA's speech interference level for speaking in a raised voice to an audience at 10 meters (EPA 1974). This value addresses the effects of sound on interpretive presentations in parks. The final value, 60 dBA, provides a basis for estimating impacts on normal voice communications at 1 meter. Hikers or visitors viewing scenic areas in the park would likely be conducting such conversations. At PIPE, the site exceeded 35 dBA 88% of the time during the day and nearly 60% of the time at night.

Table 2. Percent time above metrics.

Site	**Frequency (Hz)**	**% Time above sound level: 0700 to 1900 (Day)**				**% Time above sound level: 1900 to 0700 (Night)**			
		35 dBA	**45 dBA**	**52 dBA**	**60 dBA**	**35 dBA**	**45 dBA**	**52 dBA**	**60 dBA**
PIPE001	20-1250	64.69	4.29	0.93	0.19	37.24	2.41	0.64	0.13
	12.5-20,000	88.44	14.68	3.23	0.45	59.96	6.64	1.57	0.24

Acknowledgements

This report would not have been possible without the input of E. Lynch and S. Hendriks. A. Avrin, A. Dickson, and C. White assisted with data analysis.

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

Soundscape Planning Authorities

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

Direction for management of natural soundscapes[1] is represented in 2006 Management Policy 4.9:

> The Service will restore to the natural condition wherever possible those park soundscapes that have become degraded by unnatural sounds (noise), and will protect natural soundscapes from unacceptable impacts. Using appropriate management planning, superintendents will identify what levels and types of unnatural sound constitute acceptable impacts on park natural soundscapes. The frequencies, magnitudes, and durations of acceptable levels of

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

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

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

Study Area

Pipestone National Monument preserves and protects certain cultural and natural resources in southwestern Minnesota associated with catlinite quarries that have been used by American Indians since prehistoric times. These resources include the pipestone quarries themselves, which are still utilized by American Indian tribes, as well as archaeological resources, ceremonial sites, and the natural prairie grassland surrounding the quarries. During the summer of 2013, one long-term acoustical monitoring station was deployed at PIPE. The site (PIPE001) was selected to represent the typical acoustical conditions of the park. Table 3 shows site information for the monitoring station, and Figure 1 shows the location of the acoustic monitoring station. See Figure 6 in Appendix A for site photos.

Table 3. PIPE long-term acoustical monitoring site

Site	Site Name	Dates Deployed	Vegetation	Elevation (m)	Latitude	Longitude
PIPE001	Sundance Grounds	5/7/13-6/12/13	Temperate Grasslands	510	44.01740	-096.32489

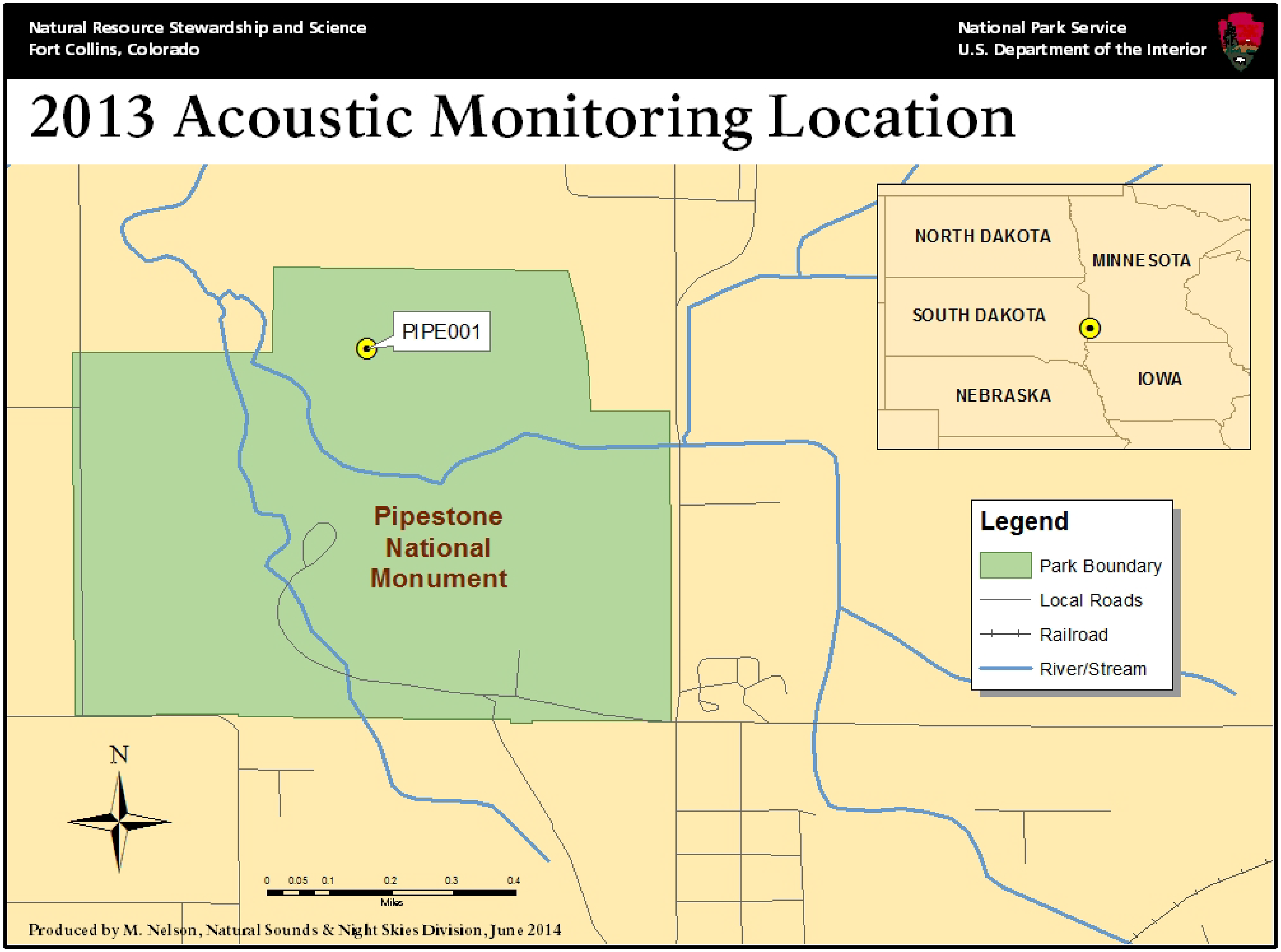

Figure 1. Location of acoustic monitoring site at Pipestone National Monument

Methods

Automatic Monitoring

One Larson Davis 831 sound level meter (SLM) was employed over the thirty day monitoring period at the PIPE site. 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. This Larson Davis-based site met American National Standards Institute (ANSI) Type 1 standards. This sound level meter provided the information needed to calculate metrics described below in Calculation of Metrics.

The sampling stations consisted of:

- Microphone with environmental shroud
- Preamplifier
- 9 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 recordings
- 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 acoustical 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 exceedence levels, where each L_x value refers to the sound pressure level 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 level for a site would be if all extrinsic or anthropogenic sources were removed. Unlike the existing ambient, the natural ambient is comprised of spectra drawn from a subset of the original data.

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

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

,

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 Figure 2 in the results section. Additionally, this figure separates the data into 33 one-third octave bands.

On-Site Listening

While the sound level meter provides information about how loud or quiet the acoustical environment is at a given time, we need .mp3 recordings or on-site listening sessions to know *what* or *who* is making the sound. On-site listening is the practice of placing an observer near the acoustical monitoring station with a handheld personal digital assistant (PDA; or in this case, an Apple iPod Touch device). The observer listens for a designated period of time (in this case, one hour), and identifies all sound sources and their durations. On-site listening takes full advantage of human binaural hearing capabilities, and closely matches the experience of park visitors. Logistic constraints prevent comprehensive sampling by this technique, but selective samples of on-site listening provide a basis for relating the results of off-site listening to the probable auditory perception of events by park visitors and wildlife. On-site listening sessions are also an excellent screening tool for parks initiating acoustical environment studies. They produce an extensive inventory of sound sources, require little equipment or training, and can help educate park staff and volunteers.

Thus, four periods of on-site listening at PIPE001 were conducted 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. 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 Table 4.

Off-Site Listening/ Auditory Analysis

Auditory analysis was used to calculate the audibility of sound sources at PIPE. 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 above for more information). Bose Quiet Comfort Noise Canceling headphones were used for off-site audio playback to minimize limitations imposed by the office acoustic environment. For the complete results of this thorough audibility analysis, see Table 7 in the Off-Site Data Analysis section below.

Results

On-site Listening

Table 4 displays the results of the four on-site listening sessions at PIPE001. Each audible sound source is listed in the first column. Percent time audible, or PA, is 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. SD reports the standard deviation among event lengths, and the Count column reports the number of times that each sound source was audible. Max Event, Mean Event, Min Event, and SD Event are reported in minutes:seconds. The last row in the table, noise free interval (NFI), is a metric which describes the length of time between extrinsic or human-caused events (when only natural sounds were audible). NFI is also reported in minutes:seconds. These on-site listening tables are essentially a sound inventory of each site. They reveal the sounds one is likely to hear at or near this location.

Table 4. Summary of on-site audible sound sources for PIPE001 n=4 hour-long sessions. Events are measured in minutes:seconds.

Sound Source	PA	Max Event	Mean Event	Min Event	SD Event	Count
Jet	5.8	01:58	01:24	00:47	00:25	10
Propeller	5.1	02:41	01:32	00:21	00:52	8
Vehicle	98.4	59:56	14:46	00:28	16:21	16
Alarm, Horn	0.4	00:23	00:04	00:01	00:05	18
Rumble Strip	0	00:01	00:01	00:01		1
Truck (6+ tires)	0.4	00:54	00:54	00:54		1
Trains	4.9	09:50	05:51	01:52	05:38	2
Grounds Care	2.9	06:15	00:28	00:01	01:36	15
People	10.1	02:00	00:30	00:04	00:24	49
Gunshot	0	00:02	00:02	00:02		1
Dog	2.3	02:06	00:26	00:02	00:37	13
Door	0.2	00:04	00:01	00:00	00:01	21
Human, Unknown	74.8	59:50	25:39	00:02	27:45	7
Wind	97	35:55	13:41	00:10	11:23	17
Mammals	1.8	03:25	01:24	00:18	01:45	3
Bird	99.8	59:57	39:56	06:51	24:30	6
Amphibian	97.5	59:55	21:17	00:36	21:22	11
Insect	6.2	02:06	00:10	00:01	00:14	94
Animal	0.7	01:36	01:36	01:36		1
All Aircraft	9.8					
All Vehicles	98.4					
All People	10.1					
Total Non-natural	99.6					
Noise-Free Interval		00:17	00:09	00:03	00:06	7

Off-Site Data Analysis

Metrics

In order to determine the effect that extrinsic noise audibility has on the acoustical environment, it is useful to examine the median hourly exceedence metrics. The dB levels for 33 one-third octave band frequencies over the day and night periods are shown in Figure 2. 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 grayed area of the graph represents sound levels outside of the typical range of human hearing. The exceedence levels (L_x) are also shown for each one-third octave band. They represent the dB level exceeded x percent of the time. For example, L_{90} is the dB level that has been exceeded 90% of the time, and only the quietest 10% of the samples can be found below this point. On the other hand, the L_{10} is the dB level that has been exceeded 10% of the time, and 90% of the measurements are quieter than the L_{10}. The bold portion of the column represents the difference between L_{50} (existing ambient) and L_{nat} (natural ambient). The height of this bold portion is a measure of the contribution of anthropogenic noise to the existing ambient sound levels at this site. The size of this portion of the column is directly related to the percent time that human caused sounds are audible. When bold portions of the column do not appear the natural and existing ambient levels were either very close to each other, or were equal.

L_{nat} and L_{50} are bordered above by L_{10} and below by L_{90}, which essentially mark the median (L_{50}), maximum (L_{90}), and minimum (L_{10}) sounds pressure levels over the 30 day monitoring period. The typical frequency levels for transportation, conversation, and songbirds are presented on the figure as examples for interpretation of the data. These ranges are estimates and are not vehicle-, species-, or habitat-specific. Notice in Figure 2 that contributions of songbirds are prominent in daytime hours, and that nighttime sound levels in the same frequencies are quieter. 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. For example, vehicle noise, wind, and aircraft have overlapping frequency components and may mask one another.

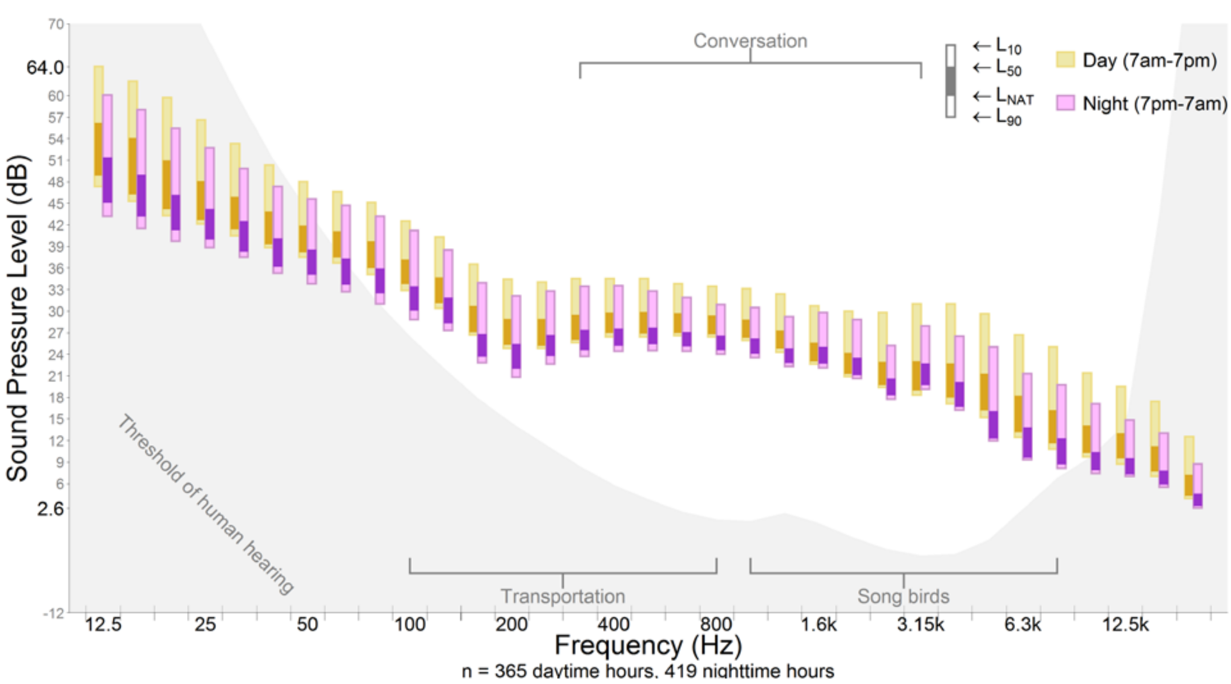

Figure 2. Day and night dB levels for 33 one-third octave bands at PIPE001

Table 5 reports the L_{90}, L_{nat}, L_{50}, and L_{10} values for the sites measured at PIPE. The top value in each cell focuses on frequencies affected by transportation noise whereas the lower values use the conventional full frequency range. Most human-caused noise is confined to the truncated, lower-frequency range, while many loud natural sounds, including insects and birds, are higher in pitch. Therefore, the truncated range is more appropriate for identifying noise levels in parks.

Table 5. Exceedence levels for existing conditions in PIPE

Site	Frequency (Hz)	Exceedence levels (dBA): 0700 to 1900 hours (Day)				Exceedence levels (dBA): 1900 to 0700 hours (Night)			
		L_{90}	L_{nat}	L_{50}	L_{10}	L_{90}	L_{nat}	L_{50}	L_{10}
PIPE001	20-1,250	33.9	34.2	36.9	41.4	31.5	32.1	34.3	39.3
	12.5-20,000	35.9	36.3	39.3	45.2	34.1	34.6	37.0	42.4

In determining the current conditions of an acoustical environment, it is important to examine how often sound pressure levels exceed certain values. Table 6 reports the percent of time that measured levels were above four key values during the monitoring period (daytime and nighttime). The top value in each split-cell focuses on frequencies affected by transportation noise whereas the lower values use the conventional full frequency range. The first, 35 dBA, is designed to address the health effects of sleep interruption. Recent studies suggest that sound events as low as 35 dB can have adverse effects on blood pressure while sleeping (Haralabidis, 2008). This is also the desired background sound level in classrooms (ANSI S12.60-2002). The second value addresses the World Health Organization’s recommendations that noise levels inside bedrooms remain below 45 dBA (Berglund et al., 1999). The third value, 52 dBA, is based on the EPA’s speech interference threshold for speaking in a raised voice to an audience at 10 meters (EPA 1974). This threshold addresses the effects of sound on interpretive presentations in parks. The final value, 60 dBA, provides a basis for estimating impacts on normal voice communications at 1 meter. Visitors viewing scenic areas in the park would likely be conducting such conversations.

Table 6. Percent time above metrics

Site	Frequency (Hz)	% Time above sound level: 0700 to 1900 (Day)				% Time above sound level: 1900 to 0700 (Night)			
		35 dBA	45 dBA	52 dBA	60 dBA	35 dBA	45 dBA	52 dBA	60 dBA
PIPE001	20-1250	64.69	4.29	0.93	0.19	37.24	2.41	0.64	0.13
	12.5-20,000	88.44	14.68	3.23	0.45	59.96	6.64	1.57	0.24

Audibility

Audibility results are presented below. Table 7 shows the mean percentage of time that all noise sources were audible, based on eight days of off-site auditory analysis. Figure 3, Figure 4, and Figure 5 show hourly audibility results and compare overall noise audibility to three sources of interest: aircraft, trains, and vehicles.

Table 7. Mean hourly percent time audible for each noise source at PIPE001. n=8 days off-site sound source analysis

Sound Source	**00h**	**01h**	**02h**	**03h**	**04h**	**05h**	**06h**	**07h**	**08h**	**09h**	**10h**	**11h**	**12h**	**13h**	**14h**	**15h**	**16h**	**17h**	**18h**	**19h**	**20h**	**21h**	**22h**	**23h**
Aircraft	0.4	0	0.4	0	0	0	0	0	0	0	0	0	1.2	0.8	0	0	0	0	0	0	0	0	0	0.4
Jet	2.5	0.8	1.7	1.2	3.8	4.6	1.2	1.7	1.7	4.6	6.7	7.9	8.7	12.1	5.4	5.8	7.1	10.8	7.9	10	5	6.2	9.2	4.2
Propeller	2.1	0	0	0	0	1.2	0	1.2	2.5	3.3	4.6	12.1	4.6	4.2	8.3	7.1	7.5	5.8	3.8	3.3	0.8	0.4	3.3	0.8
Vehicles	20.8	18.8	32.1	17.1	29.6	42.9	46.3	47.9	57.9	52.9	37.1	31.2	41.7	44.2	42.1	42.5	46.7	44.2	42.5	48.8	60.8	48.3	43.8	39.2
Automobile	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
Alarm, Horn	0.4	0	0	0	0	0	0.8	3.3	4.6	0.4	0.8	0.8	1.7	3.8	4.2	3.8	5	2.5	1.2	1.2	0	0	0.4	0
Vehicle Door	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
Rumble Strip	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
Motorcycle	0	0	0.4	0	0	0.4	0.8	0.4	0.8	0.8	0.8	0	0	0	0	0.8	1.2	0	0.8	0.8	1.2	0	0	0
Truck (6+ tires)	0	0.8	0	1.2	0	0	0.4	0	2.5	1.7	0	0.4	0.4	0.8	0	3.8	1.7	1.7	11.7	5.4	1.2	0.4	1.7	4.6
Heavy Equipment	0	0	0	0	0	0.8	0	0	0	0	1.7	0.8	0	0	8.7	2.1	3.3	3.8	1.7	2.5	0.8	3.8	0	0.8
Trains	2.5	1.2	7.1	7.5	0	0	3.3	4.2	0.8	0	0	3.3	0	0	0.8	0	0	0	0	0	4.6	2.1	1.2	2.1
Train Rumble	5.4	12.1	3.3	13.3	11.3	8.3	11.3	12.1	5.8	5.8	6.7	3.8	4.2	1.7	2.5	6.2	3.8	4.2	13.3	3.3	1.7	19.6	12.9	6.2
Train Whistle	7.1	8.7	1.2	6.7	7.9	4.2	4.2	10	7.1	6.2	5.8	10.4	5.8	5	5	4.2	2.1	2.9	6.7	3.3	1.2	10.8	4.6	5.4
Motors	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9.2	9.2	0	0	0	0
Pump	0	4.6	0	0	4.6	9.2	7.5	4.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.5	0
Grounds Care	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.7	11.7	5.4	0	0	0
Voices	0	0	0	0	0	0	0	0	0.4	2.1	2.1	1.7	0.4	1.2	2.1	0.8	1.7	0.8	3.8	4.2	5.4	5.4	10.8	3.8
Portable Audio Devices	0	0	0	0	0	0	0	0	0	0	0	0	0.8	0	0	0.4	0.4	0	0	0	0	0	0	1.7
Domestic Animals	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
Dog	5.4	1.7	3.3	3.8	8.7	5.4	2.5	0.4	0	3.8	2.5	2.1	1.2	0.4	2.1	2.1	1.7	2.5	0.8	2.5	3.8	3.8	5.4	3.3
Cow	0	0.4	0	0	0	0.4	1.7	1.2	0	0	0	0	0.4	0	0	0.8	0	1.7	0	0.4	0.4	0.4	0.8	0
Non-natural Unknown	0	0	3.8	5	0	2.5	0.4	0	2.1	0.8	0	0	2.5	2.1	1.7	1.2	0.4	0	0	0	3.8	0	0.4	0.8
Total Aircraft	**5**	**0.8**	**2.1**	**1.2**	**3.8**	**5.8**	**1.2**	**2.9**	**4.2**	**7.9**	**11.3**	**20**	**14.2**	**17.1**	**13.8**	**12.9**	**14.2**	**16.3**	**11.7**	**13.3**	**5.8**	**6.7**	**12.5**	**5.4**
Total Trains	**13.3**	**16.3**	**10.8**	**22.1**	**15.4**	**9.6**	**16.3**	**20.4**	**10.8**	**8.7**	**9.2**	**15.4**	**9.2**	**5.8**	**7.5**	**8.7**	**4.2**	**6.2**	**14.6**	**5**	**6.7**	**23.7**	**14.6**	**10**
Total Vehicles	**21.2**	**19.6**	**32.5**	**18.3**	**29.6**	**44.2**	**47.9**	**50.4**	**61.7**	**55.4**	**39.2**	**33.3**	**42.5**	**46.3**	**52.5**	**50.4**	**54.6**	**49.2**	**56.7**	**57.9**	**63.8**	**52.5**	**45.4**	**44.6**
Total Non-natural	**40.8**	**40.8**	**50**	**48.3**	**55.4**	**69.6**	**70.8**	**73.8**	**75.4**	**70.8**	**56.7**	**64.2**	**65.8**	**65.8**	**72.5**	**70**	**71.3**	**69.2**	**86.7**	**84.6**	**79.2**	**78.3**	**76.7**	**62.5**

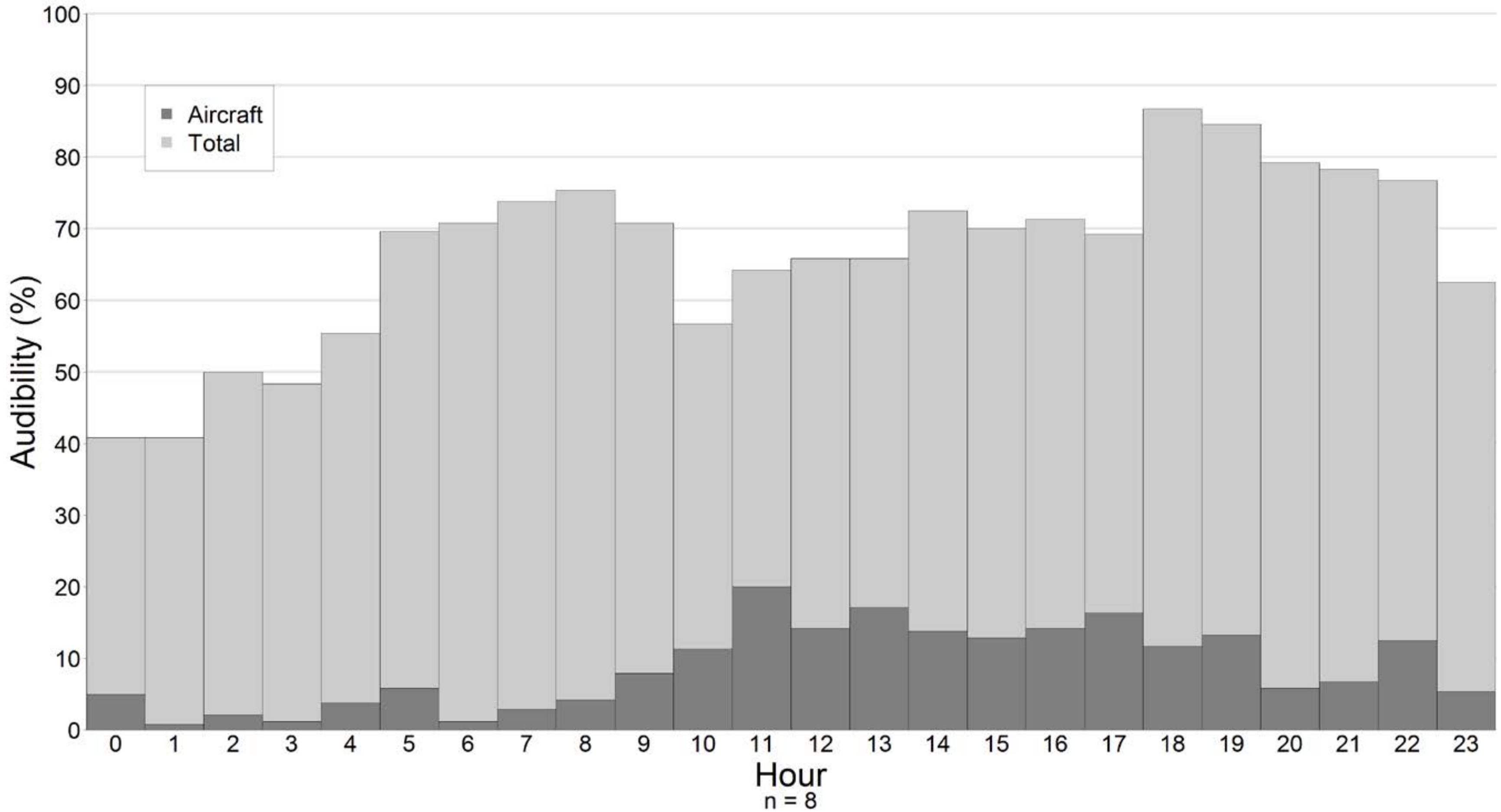

Figure 3. Comparison of hourly aircraft audibility and overall noise audibility at PIPE001

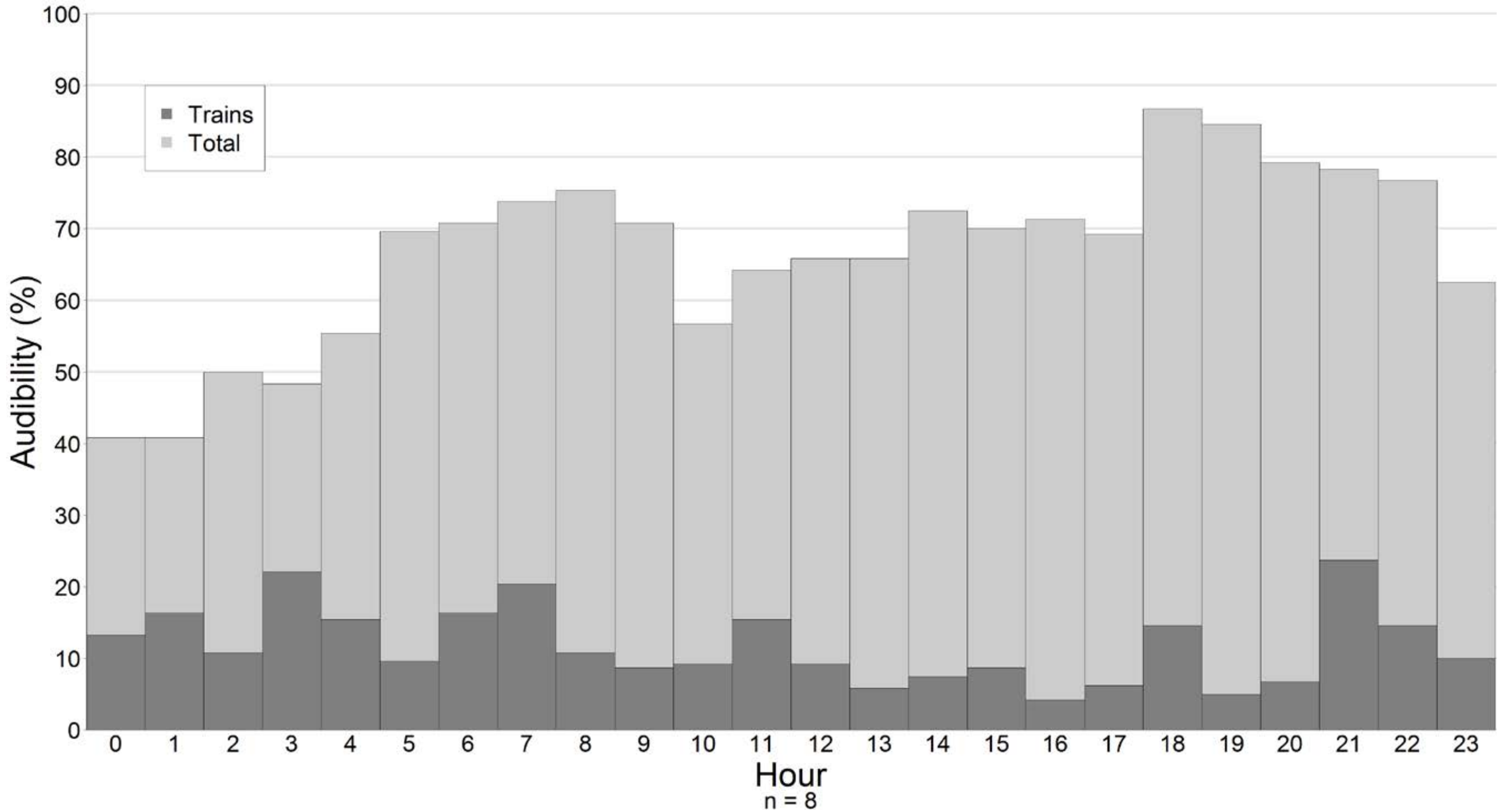

Figure 4. Comparison of hourly train audibility and overall noise audibility at PIPE001

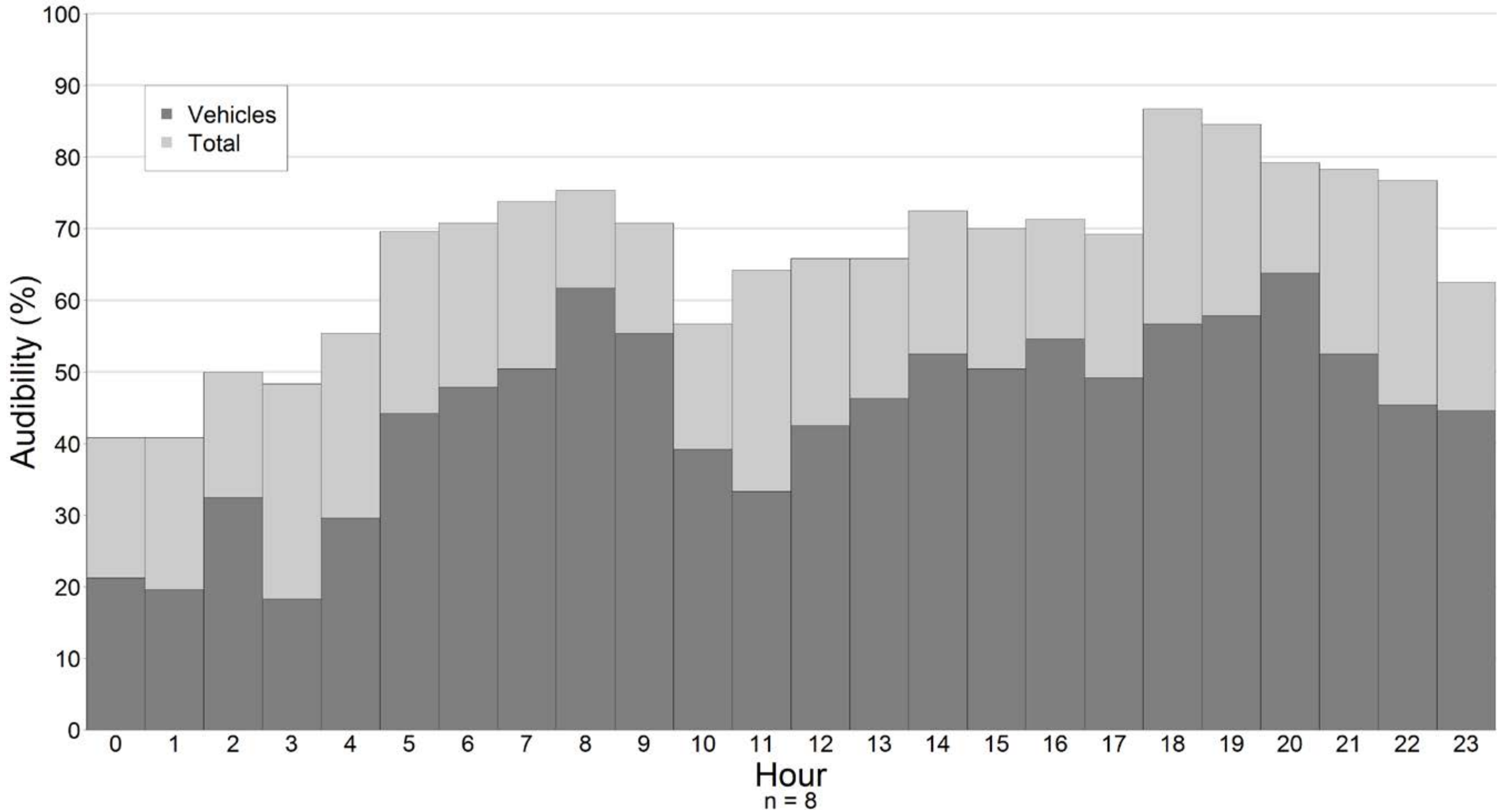

Figure 5. Comparison of hourly vehicle audibility and overall noise audibility at PIPE001

Discussion

The purpose of this study was to assess current conditions of the acoustical environment in the park. Monitoring results characterize existing sound levels and estimate natural ambient sound levels within the park, which are intended to provide the park with baseline information as well as to inform management decisions. Sound pressure level data, meteorological data, and continuous audio were collected from one site near the Sundance Grounds for approximately 30 days. The acoustical monitoring station location was chosen because its vegetation and biologic activity were representative of the rest of the park.

Results indicated that the natural ambient sound level (L_{nat}) at this site ranged between 36.3 dBA during the daytime and 34.6 dBA at night. Existing ambient sound levels (L_{50}) were higher, ranging from 39.3 dBA during the day to 37.0 dBA at night. 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 the natural ambient sound level during the monitoring period was quieter than most residential areas. Despite the relatively quiet overall sound levels, anthropogenic noise was audible nearly 67% of the time in PIPE's acoustic environment. A detailed analysis of audibility at this site found that three major noise sources (aircraft, trains, and vehicles) contributed significant amounts of noise to the acoustical environment. Vehicles were the most common source of anthropogenic noise at PIPE, and were audible 20-60% of the time at all hours of the day and night. Train sounds, which included both train whistles and the rumble of trains on a track, could also be heard up to 20% of the time at all hours of the day and night. Aircraft were heard less frequently during nighttime hours than vehicles or trains, but could still be heard up to 20% of the time during the day. Other sounds heard during the monitoring period included domestic animals (dogs and cows in particular), people talking, and the sound of motors, which could have been water pumps being used at the quarries.

Off-site analysis focused primarily on anthropogenic sources of sound, and as such, the results do not reflect natural sound sources in the acoustic environment. However, on-site analysis revealed a relatively active natural acoustic environment at PIPE001. Based on four hours of daytime listening, birds were audible nearly 100% of the time, insects could be heard 6% of the time, and amphibians and the sound of wind blowing were both audible 97% of the time.

Literature Cited

Barber J.R., C. Crooks, and K. Fristrup. 2010. The costs of chronic noise exposure for terrestrial organisms. Trends in Ecology and Evolution 25:180–189.

Berglund, B., T. Lindvall, and D. H. Schwela (Eds.). 1999. HWO. Guidelines for community noise. World Health Organization, Geneva.

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.

Haas, G.E., and T. J. Wakefield. 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.

Harris, C. M. (1998). Handbook of Acoustical Measurements and Noise Control, 3rd ed. McGraw-Hill, New York.

Lynch, E., D. Joyce, and K. Fristrup. 2011. An assessment of noise audibility and sound levels in U.S. National Parks. Landscape Ecology 26: 1297-1309.

McDonald, C. D., R. M. Baumgarten, and R. Iachan. 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.

Mennitt, D., K. Sherrill, and K. Fristrup. 2014. A geospatial model of ambient sound pressure levels in the contiguous United States. Journal of the Acoustical Society of America 135:2746-2764.

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.

Suter, A. H. Noise and its Effects. Administrative Conference of the United States, 1991. Available at: http://www.nonoise.org/library/suter/suter.htm (accessed 17 January 2014).

Templeton, D (Ed.). 1997. Acoustics in the built environment: advice for the design team. Architectural Press, Oxford

Appendix A: Site Photos

Figure 6. PIPE001, Sundance Grounds long-term acoustical monitoring site

Appendix B: Glossary of Acoustical Terms

Term	Definition
Acoustic Environment	A combination of all the physical sound resources within a given area. This includes natural sounds and cultural sounds, and non-natural human-caused sounds. The acoustic environment of a park can be divided into two main categories: intrinsic and extrinsic.
Acoustic Resources	Include both natural sounds like wind, water, & wildlife and cultural and historic sounds like tribal ceremonies, quiet reverence, and battle reenactments.
Amplitude	The relative strength of a sound wave, described in decibels (dB). Amplitude is related to what we commonly call loudness or volume.
Audibility	The ability of animals with normal hearing, including humans, to hear a given sound. It can vary depending upon the frequency content and amplitude of sound and by an individual animal's hearing ability.
Decibel (dB)	A unit of sound energy. Every 10 dB increase represents a tenfold increase in energy. Therefore, a 20 dB increase represents a hundredfold increase in energy. When sound levels are adjusted for human hearing they are expressed as dB(A).
Extrinsic Sound	Any sounds not forming an essential part of the park unit, or a sound originating from outside the park boundary. This could include voices, radio music, or jets flying thousands of feet above the park.
Frequency	Related to the pitch of a sound, it is defined as the number of times per second that the wave of sound repeats itself and is expressed in terms of hertz (Hz). Sound levels are often adjusted ("weighted") to match the hearing abilities of a given animal. In other words, different species of animals and humans are capable or hearing (or not hearing) at different frequencies. Humans with normal hearing can hear sounds between 20 Hz and 20,000 Hz, and as low as 0 dB at 1,000 Hz. Bats, on the other hand, can hear sounds between 20 Hz and 200,000 Hz.
Intrinsic Sound	Belongs to a park by the park's very nature, based on its purposes, values, and establishing legislation. Intrinsic sounds can include natural, cultural, and historic sounds that contribute to the acoustical environment of the park.
L_{50}, L_{90}	Metrics used to describe sound pressure levels (L), in decibels, exceeded 50 and 90 percent of the time, respectively. Put another way, half the time the measured levels of sound are greater than the L_{50} value, while 90 percent of the time the measured levels are higher than the L_{90} value.
L_{dn}	Day-Night Average Sound Level. Average equivalent sound level over a 24-hour period, with a 10-dB penalty added for sound levels between 10 p.m. and 7 a.m.
L_{eq}	Energy Equivalent Sound Level. The sound energy level averaged over the measurement period.
L_{nat} (Natural Ambient Sound Level)	The natural sound conditions in parks which exist in the absence of any human-produced noise.
Noise Free Interval (NFI)	The length of the continuous period of time during which no human-caused sounds are audible.
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.

Term	Definition
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 *noise* is sometimes incorrectly used as a synonym for sound, it is in fact sound that is undesired or extraneous to an environment. Humans perceive *sound* as an auditory sensation created by pressure variations that move through a medium such as water or air and are measured in terms of amplitude and frequency (Harris, 1998; Templeton, 1997).
Soundscape	The human perception of physical sound resources.

Appendix C: 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 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 PIPE is shown in Figure 7, 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 PIPE, the mean modeled sound level impact is 9.1 dBA, and this value represents a close approximation of expected impact levels at a randomly chosen point within the park. This modeled metric is somewhat higher than the measured difference between daytime natural and existing ambient sound levels at PIPE, which is 3.0 dBA. This difference can likely be explained by the fact that the monitoring site was chosen because it was one of the quieter locations in the park, and the modeled impact value is averaged over the entire park. Each pixel in the graphic shown in Figure 7 represents 270 m. 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 PIPE 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%.

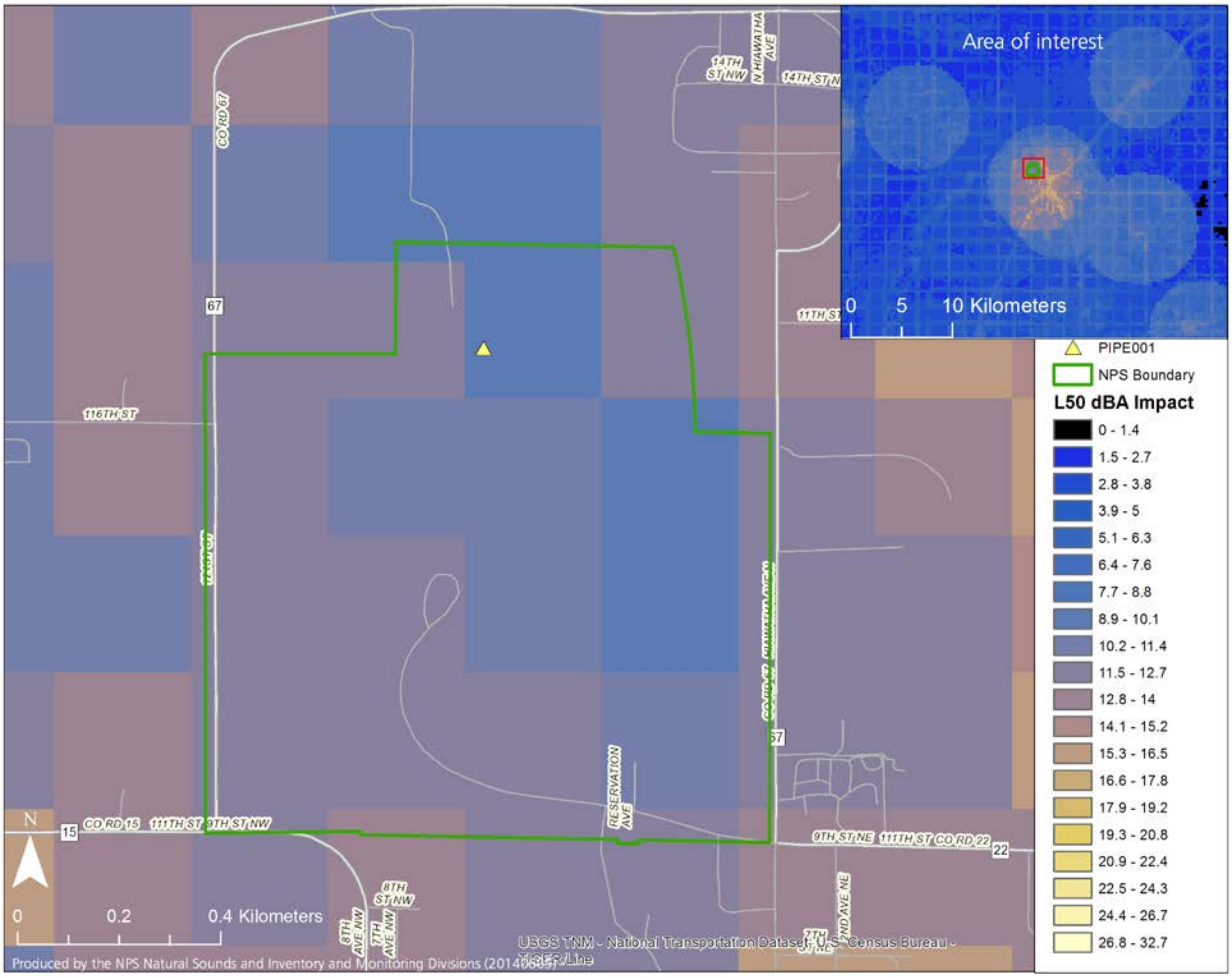

Figure 7. Modeled median sound level impacts in the area immediately surrounding PIPE and in the nearby region (inset).

NPS 372/124858, June 2014

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