



Bandelier National Monument

Acoustic Monitoring Report

Natural Resource Technical Report NPS/NRSS/NRTR—2014/844



ON THE COVER

Acoustic monitoring equipment on mesa top near the Burro trail, Bandelier National Monument
Photograph by: NSNSD staff

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Natural Resource Technical Report NPS/NRSS/NRTR—2014/844

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Contents

	Page
Figures.....	iv
Tables.....	v
Appendices.....	vii
Executive Summary	viii
Acknowledgements.....	xi
Introduction.....	1
Study Area	3
Methods.....	5
Automatic Monitoring.....	5
Calculation of Metrics	5
On-Site Listening.....	6
Off-Site Sound Source Analysis.....	6
Results.....	8
On-site Listening	8
Off-Site Data Analysis	14
Metrics.....	14
Audibility.....	20
Discussion.....	32
Literature Cited	33

Figures

	Page
Figure 1. Location of acoustic monitoring sites at Bandelier National Monument.	4
Figure 2. Day and night dB levels for 33 one-third octave bands at BAND001, summer	15
Figure 3. Day and night dB levels for 33 one-third octave bands at BAND001, winter	15
Figure 4. Day and night dB levels for 33 one-third octave bands at BAND002, summer	16
Figure 5. Day and night dB levels for 33 one-third octave bands at BAND002, winter	16
Figure 6. Day and night dB levels for 33 one-third octave bands at BAND003, summer	17
Figure 7. Day and night dB levels for 33 one-third octave bands at BAND003, winter	17
Figure 8. Day and night dB levels for 33 one-third octave bands at BAND004, summer	18
Figure 9. Day and night dB levels for 33 one-third octave bands at BAND004, winter	18
Figure 10.	28
Figure 11. Comparison of hourly noise audibility for propeller aircraft, all aircraft types, and total human-caused noise at BAND001 winter	28
Figure 13. Comparison of hourly noise audibility for propeller aircraft, all aircraft types, and total human-caused noise at BAND002 winter	29
Figure 14. Comparison of hourly noise audibility for propeller aircraft, all aircraft types, and total human-caused noise at BAND003 summer.	30
Figure 15. Comparison of hourly noise audibility for propeller aircraft, all aircraft types, and total human-caused noise at BAND003 winter	30
Figure 16. Comparison of hourly noise audibility for propeller aircraft, all aircraft types, and total human-caused noise at BAND004 summer.	31
Figure 17. Comparison of hourly noise audibility for propeller aircraft, all aircraft types, and total human-caused noise at BAND004 winter	31
Figure 18. BAND001, Lower Frijoles Canyon long-term acoustical monitoring site (a. winter; b. summer).	35
Figure 19. BAND002, Cerro elk enclosure long-term acoustical monitoring site (a. winter; b. summer).	35
Figure 20. BAND003, Pinon-juniper mesatop long-term acoustical monitoring site (a. winter; b. summer).	36
Figure 21. BAND004, Rio Grande long-term acoustical monitoring site (a. winter; b. summer).	37
Figure 22. L ₅₀ dBA impact map, as generated by ver. 2.31 of geospatial model	40

Tables

	Page
Table 1. Mean percent time audible for extrinsic, aircraft, and vehicle sounds; existing and natural ambient sound levels.	ix
Table 2. Percent time above metrics.	x
Table 3. BAND long-term acoustical monitoring sites.....	3
Table 4. Summary of on-site audible sound sources for BAND001 n=4 hour-long Summer sessions. Events are measured in minutes:seconds.	9
Table 5. Summary of on-site audible sound sources for BAND001 n=4 hour-long Winter sessions. Events are measured in minutes:seconds.....	10
Table 6. Summary of on-site audible sound sources for BAND002 n=4 Summer hour-long sessions. Events are measured in minutes:seconds.....	11
Table 7. Summary of on-site audible sound sources for BAND002 n=4 Winter hour-long sessions. Events are measured in minutes:seconds.....	11
Table 8. Summary of on-site audible sound sources for BAND003 n=4 Summer hour-long sessions. Events are measured in minutes:seconds.....	12
Table 9. Summary of on-site audible sound sources for BAND003 n=4 Winter hour-long sessions. Events are measured in minutes:seconds.....	12
Table 10. Summary of on-site audible sound sources for BAND004 n=4 Summer hour-long sessions. Events are measured in minutes:seconds.....	13
Table 11. Summary of on-site audible sound sources for BAND004 n=3 Winter hour-long sessions. Events are measured in minutes:seconds.....	13
Table 12. Exceedence levels for existing conditions in BAND.....	19
Table 13. Percent time above metrics.....	20
Table 14. Mean hourly percent time audible for each noise source at BAND001 summer. n=8 days off-site sound source analysis.....	21
Table 15. Mean hourly percent time audible for each noise source at BAND001 winter. n=8 days off-site sound source analysis.....	22
Table 16. Mean hourly percent time audible for each noise source at BAND002 summer. n=8 days off-site sound source analysis.....	23
Table 17. Mean hourly percent time audible for each noise source at BAND002 winter. n=8 days off-site sound source analysis.....	24
Table 18. Mean hourly percent time audible for each noise source at BAND003 summer. n=8 days off-site sound source analysis.....	25
Table 19. Mean hourly percent time audible for each noise source at BAND003 winter. n=8 days off-site sound source analysis.....	25

Contents (continued)

	Page
Table 20. Mean hourly percent time audible for each noise source at BAND004 summer. n=8 days off-site sound source analysis.....	26
Table 21. Mean hourly percent time audible for each noise source at BAND004 winter. n=8 days off-site sound source analysis.....	27

Appendices

	Page
Appendix A: Site Photos.....	34
Appendix B: Glossary of Acoustical Terms	38
Appendix C: Modeled impact levels.....	40

Executive Summary

In 2011, the Natural Sounds and Night Skies Division received a request to collect baseline acoustical data at Bandelier National Monument (BAND). During the months of February and June, 2012, four acoustical monitoring systems were deployed for 28 and 35 days, respectively.

The goal of the technical assistance request was to complete a baseline soundscape inventory throughout BAND, especially in the much-visited Frijoles Canyon portion of the park. The results of this inventory will be used in conjunction with a visitor soundscape survey to establish indicators and standards of soundscape quality that will support the park in developing a comprehensive approach to soundscape management planning. This project will develop a Soundscape Desired Condition for the park's pending Foundation for Planning and Management document, provide an impact assessment threshold for development projects within the canyon, and assist the park in assessing potential effects from ongoing and proposed air tourism and helicopter overflights related to park operations.

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). Common sources of noise at BAND include aircraft and road vehicles. Table 1 displays percent time audible values for each of these sources during the monitoring period as well as ambient sound levels. Ambient sound pressure levels were measured continuously every second over the 30 day monitoring period by calibrated, Type 1, Larson Davis 831 sound level meters. 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. Other sources of noise at BAND included a generator that was audible at BAND001 and unidentified faint motor sounds at BAND003 and BAND004. See Table 14-Table 21 for detailed audibility reports, including all noise sources heard at each site.

BAND001 had the highest overall percent time audible of noise, as expected given its proximity to the visitor center, parking area, and popular trails. Aircraft was the most common noise source at BAND003 and BAND004, where it was audible approximately 25% of the time, more frequently than at BAND001 or BAND002. Vehicle noise was most commonly heard at BAND002, where it was audible over 40% of the time during the summer. These noise sources were seldom very loud however, as indicated by the low L_{50} levels across all sites and seasons. This median existing ambient level never exceeded 35 dBA and was generally only few dBA in excess of the median natural ambient. Most sites were louder during the day than at night, as is generally expected due to increased human as well as biological activity. The one exception was at BAND004 summer, likely due to increased insect activity at night.

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

Site ID	Site Description	Season	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	
			All Extrinsic	Aircraft	Vehicles	Day ^c	Night	Day	Night
BAND001	Frijoles Canyon	Summer	67.1	14.4	19.5	33.6	27.6	29.3	26.6
		Winter	72.8	18.5	13.4	31.2	29.5	30.0	29.2
BAND002	Cerro elk enclosure	Summer	61.3	13.9	41.5	34.9	25.6	30.6	21.6
		Winter	33.5	13.0	15.3	34.4	27.2	32.0	25.8
BAND003	Pinon-juniper Mesatop	Summer	48.2	24.6	4.9	23.2	17.0	20.1	15.7
		Winter	36.1	26.2	2.5	22.7	16.5	20.3	15.8
BAND004	Rio Grande corridor	Summer	34.6	24.8	4.3	24.5	26.0	22.1	24.7
		Winter	23.9	23.5	0.3	20.4	14.2	18.5	14.0

^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.

xi.

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). It is also recommended that background sound levels in classrooms not exceed 35 dBA (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. These results indicate that BAND is a very quiet place, seldom exceeding 45 dBA at any of the sites measured. Only one site exceeded 35 dBA more than 50% of the time (BAND002, daytime only). However, wind was a significant contributor to the soundscape at this location, elevating the overall levels.

Table 2. Percent time above metrics.

Site	Season	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
BAND001	Summer	20-800	27.27	1.86	0.09	0.00	2.24	0.11	0.00	0.00
		12.5-20,000	41.01	3.84	0.27	0.01	8.77	0.76	0.09	0.00
	Winter	20-800	18.81	0.90	0.05	0.00	1.54	0.04	0.00	0.00
		12.5-20,000	21.15	1.16	0.10	0.00	1.80	0.05	0.00	0.00
BAND002	Summer	20-800	36.76	1.16	0.07	0.00	13.34	0.68	0.02	0.00
		12.5-20,000	50.91	2.63	0.12	0.01	20.27	1.10	0.04	0.00
	Winter	20-800	51.33	2.13	0.14	0.00	21.28	1.70	0.01	0.00
		12.5-20,000	52.81	2.25	0.18	0.00	22.47	2.19	0.06	0.00
BAND003	Summer	20-800	8.99	0.56	0.08	0.00	2.07	0.08	0.00	0.00
		12.5-20,000	11.61	1.37	0.16	0.01	3.09	0.26	0.03	0.00
	Winter	20-800	9.74	0.58	0.06	0.00	1.21	0.06	0.00	0.00
		12.5-20,000	11.28	0.92	0.10	0.00	1.37	0.09	0.00	0.00
BAND004	Summer	20-800	6.66	0.59	0.15	0.01	1.04	0.07	0.00	0.00
		12.5-20,000	10.28	1.07	0.24	0.02	5.77	0.14	0.01	0.00
	Winter	20-800	6.55	0.81	0.16	0.03	1.12	0.12	0.01	0.00
		12.5-20,000	7.95	1.02	0.27	0.03	1.21	0.16	0.02	0.00

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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 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 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

Bandelier National Monument (BAND) protects over 33,000 acres of rugged but beautiful canyon and mesa country as well as evidence of a human presence going back over 11,000 years. Best known for mesas, sheer-walled canyons, and several thousand ancestral Pueblo dwellings found among them, Bandelier also includes more than 23,000 acres of designated Wilderness.

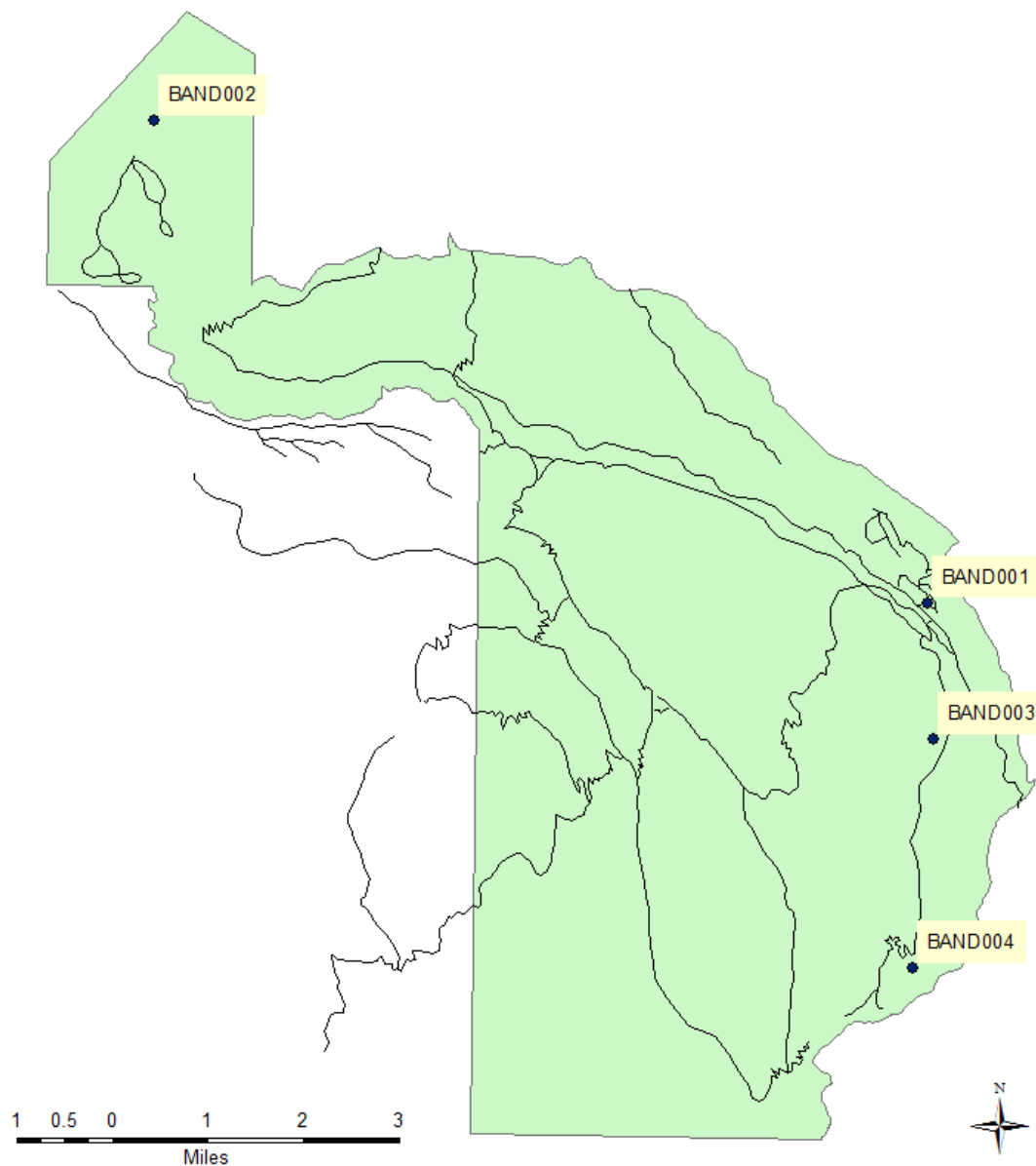
In 2012, four long-term acoustical monitoring stations were deployed at BAND for approximately one month each of winter and summer data collection. The site locations were selected to represent the range of habitats and visitor uses typical of the park. BAND001 was in a riparian area near the Visitor Center and popular archaeological sites. BAND002 was located at high elevation in the northern part of the park, near the less busy Cerro Grande trail. BAND003 and BAND004 were both adjacent to the Burro trail, but represented different elevations and vegetation types. Table 3 provides site information for each acoustical monitoring station, and Figure 1 shows locations of the monitoring stations. See Figure 18-Figure 21 in Appendix A for site photos.

Table 3. BAND long-term acoustical monitoring sites

Site	Site Name	Winter Dates	Summer Dates	Vegetation	Elevation (m)	Latitude	Longitude
BAND001	Lower Frijoles Canyon	2/6/12-3/5/12	6/13/12-7/18/12	temperate conifer/riparian	1864	35.77942	-106.27256
BAND002	Cerro elk enclosure	2/6/12-3/4/12	6/13/12-7/18/12	ponderosa-aspen meadow	2750	35.85084	-106.41782
BAND003	Mesa top	2/8/12-3/6/12	6/14/12-7/25/12	piñon-juniper, desert scrub	1955	35.75877	-106.27115
BAND004	Rio Grande corridor	2/7/12-3/6/12	6/14/12-7/25/12	desert scrub near Rio Grande	1707	35.72405	-106.27440



Acoustical Monitoring Sites



Produced by NPS Natural Sounds and Night Skies Division September 2013

FILE: Untitled.mxd

Figure 1. Location of acoustic monitoring sites at Bandelier National Monument.

Methods

Automatic Monitoring

Larson Davis 831 sound level meters (SLM) were employed over the thirty day monitoring period at each of the BAND 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. 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
- 8 3.2 V LiFe rechargeable battery packs
- Anemometer (wind speed and direction)
- Temperature and humidity sensor
- 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 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 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):

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

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 and Figure 3, and Figure 4 in the results section. Additionally, these figures separate the data into 33 one-third octave bands.

On-Site Listening

While the sound level meter provides information about how loud or quiet the 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 were conducted at each site in order to discern the type, timing, and duration during sound-level data collection (except for BAND004, winter, where only three were conducted due to logistical constraints). 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 minutes and seconds) of sound source events. The results of these on-site listening sessions are summarized in Table 4, Table 5, and Table 6.

Off-Site Sound Source Analysis

Auditory analysis was used to calculate the audibility of sound sources at BAND. Acoustic 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.

At sites where anthropogenic noise occurs infrequently (such as BAND003 and BAND004 in winter), NSNSD staff can further accelerate source identification using daily spectrograms generated from sound pressure level data. Spectrograms are plots which display sound level as a function of time and frequency. Because most anthropogenic sounds possess recognizable sound signatures, staff can quickly examine many samples within the measurement period, noting duration, frequency span, maximum level, and sound exposure level (SEL) of each noise event. However, for events with less distinctive sound signatures, corresponding audio files are played back through noise canceling headphones. When all events have been identified, NSNSD software calculates the total percent time anthropogenic sounds were audible. This information is then used to calculate the estimated natural ambient sound level for each hour, as discussed in the “Calculation of Metrics” section.

For the complete results of this thorough audibility analysis, see Table 14-Table 21 in the Off-Site Data Analysis section below.

Results

On-site Listening

Table 4-Table 11 display the results of four one-hour on-site listening sessions per site, per season at BAND (except for BAND004 winter, when only three sessions were completed due to logistical constraints). 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 (for sources heard more than once), 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 and 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 BAND001 n=4 hour-long Summer sessions. Events are measured in minutes:seconds.

Sound Source	PA	Max Event	Mean Event	Min Event	SD Event	Count
Jet	30.0	05:24	01:53	00:16	01:22	38
Aircraft, Propeller	3.0	02:29	01:13	00:14	01:00	5
Vehicle	69.0	13:53	03:20	00:01	03:27	50
Vehicle Door	0.0	00:02	00:01	00:00	00:01	36
Grounds Care	12.0	09:59	00:34	00:00	01:30	51
People	87.0	28:17	05:39	00:09	06:49	37
People, Voices	43.0	23:31	05:43	00:09	07:49	18
People, Walking	6.0	03:18	00:41	00:01	00:53	22
Wind	50.0	06:50	01:46	00:01	01:41	68
Water	50.0	00:00	59:58	59:56	00:03	2
Mammal	8.0	19:58	19:58	19:58		1
Bird	100.0	59:58	47:47	03:47	24:41	5
Insect	11.0	03:23	00:14	00:00	00:27	115
Natural Other	7.0	02:00	00:54	00:04	00:30	20
All Aircraft	31.6					43
All Road Vehicles	69.4					86
All Non-natural Sources	99.0					257
All Natural Sources	99.9					191
Noise Free Interval	1.0	00:58	00:12	00:02	00:15	12

Table 5. Summary of on-site audible sound sources for BAND001 n=4 hour-long Winter sessions. Events are measured in minutes:seconds.

Sound Source	PA	Max Event	Mean Event	Min Event	SD Event	Count
Aircraft	1.0	02:04	02:04	02:04		1
Jet	32.0	05:33	01:50	00:11	01:22	42
Aircraft, Propeller	3.0	02:28	01:13	00:13	00:59	5
Vehicle	3.0	03:37	01:12	00:07	01:28	7
Automobile	27.0	03:56	01:00	00:04	00:48	65
Alarm, Horn	0.0	00:07	00:02	00:00	00:02	9
Vehicle Door	1.0	00:08	00:02	00:00	00:01	126
Truck (6+ tires)	1.0	00:54	00:32	00:16	00:15	5
Motor	5.0	05:53	03:58	00:23	03:07	3
Grounds Care	3.0	05:16	00:11	00:00	00:54	34
People	0.0	00:24	00:24	00:24		1
People, Voices	24.0	04:38	00:35	00:01	00:44	100
People, Walking	1.0	01:48	00:18	00:02	00:31	11
Gunshot	0.0	00:02	00:02	00:02		1
Dog	0.0	00:03	00:03	00:03		1
Non-natural Unknown	1.0	00:33	00:16	00:06	00:12	5
Wind	44.0	25:57	03:41	00:04	05:37	29
Water	39.0	24:16	05:31	00:28	05:41	17
Flowing Water	50.0	59:54	39:54	21:49	19:07	3
Mammal	8.0	17:04	01:38	00:02	04:52	12
Bird	44.0	09:50	00:53	00:00	01:23	119
Canada Goose	0.0	00:42	00:22	00:04	00:19	3
Insect	0.0	00:02	00:02	00:01	00:01	2
All Aircraft	35.6					48
All Road Vehicles	32.9					212
All Non-natural Sources	74.2					416
All Natural Sources	99.7					185
Noise Free Interval	25.9	03:52	00:27	00:01	00:39	140

Table 6. Summary of on-site audible sound sources for BAND002 n=4 Summer hour-long sessions. Events are measured in minutes:seconds.

Sound Source	PA	Max Event	Mean Event	Min Event	SD Event	Count
Jet	18.0	03:05	01:23	00:17	00:48	31
Aircraft, Propeller	1.0	01:29	01:29	01:29	00:00	2
Vehicle	47.0	07:30	00:53	00:03	01:05	128
Motorcycle	1.0	00:39	00:26	00:11	00:11	6
Heavy Equipment	0.0	00:29	00:29	00:29		1
People	1.0	02:01	02:01	02:01		1
People, Voices	1.0	01:52	01:52	01:52		1
People, Walking	0.0	00:52	00:52	00:52		1
Wind	86.0	59:59	09:24	00:21	18:01	22
Bird	100.0	59:57	47:57	03:54	24:41	5
Amphibian	0.0	00:00	00:00	00:00		1
Insect	53.0	37:19	01:02	00:00	04:17	124
Natural Other	32.0	42:12	04:17	00:19	09:35	18
All Aircraft	19.0					33
All Road Vehicles	47.8					134
All Non-natural Sources	59.9					171
All Natural Sources	99.9					170
Noise Free Interval	40.1	04:02	00:46	00:01	00:51	125

Table 7. Summary of on-site audible sound sources for BAND002 n=4 Winter hour-long sessions. Events are measured in minutes:seconds.

Sound Source	PA	Max Event	Mean Event	Min Event	SD Event	Count
Jet	25.0	03:46	01:48	00:09	01:05	34
Aircraft, Propeller	6.0	03:13	01:26	00:09	01:11	10
Vehicle	16.0	04:51	00:53	00:10	00:59	43
Automobile	10.0	05:04	00:42	00:01	00:55	34
People, Voices	0.0	00:03	00:03	00:03		1
People, Walking	1.0	01:06	00:30	00:02	00:31	5
Non-natural Other	0.0	00:02	00:02	00:02		1
Wind	99.0	39:37	16:56	01:28	09:58	14
Squirrel	0.0	00:04	00:04	00:04		1
Bird	10.0	02:41	00:21	00:00	00:32	70
Natural Other	0.0	00:15	00:05	00:01	00:04	13
Tree creaking	1.0	00:18	00:07	00:02	00:05	13
All Aircraft	31.2					44
All Road Vehicles	25.7					77
All Non-natural Sources	50.5					128
All Natural Sources	98.9					111
Noise Free Interval	49.5	05:12	01:13	00:01	01:16	98

Table 8. Summary of on-site audible sound sources for BAND003 n=4 Summer hour-long sessions. Events are measured in minutes:seconds.

Sound Source	PA	Max Event	Mean Event	Min Event	SD Event	Count
Aircraft	1.0	01:05	00:38	00:11	00:38	2
Jet	18.0	06:52	01:38	00:01	01:46	27
Aircraft, Propeller	15.0	05:26	02:11	00:22	01:23	17
Vehicle	2.0	03:59	03:59	03:59		1
Wind	73.0	55:01	03:39	00:09	09:37	48
Bird	15.0	03:49	00:26	00:00	00:39	83
Insect	48.0	05:14	00:40	00:00	00:48	172
Natural Other	26.0	23:34	04:27	00:03	07:27	14
All Aircraft	34.2					46
All Road Vehicles	1.7					1
All Non-natural Sources	35.9					47
All Natural Sources	93.9					317
Noise Free Interval	64.1	12:49	03:16	00:02	03:18	47

Table 9. Summary of on-site audible sound sources for BAND003 n=4 Winter hour-long sessions. Events are measured in minutes:seconds.

Sound Source	PA	Max Event	Mean Event	Min Event	SD Event	Count
Aircraft	21.0	19:11	04:10	00:00	05:40	12
Jet	51.0	07:26	02:29	00:08	01:49	49
Aircraft, Propeller	19.0	08:26	01:13	00:08	01:43	38
Helicopter	4.0	07:04	04:27	01:50	03:42	2
Vehicle	1.0	00:28	00:18	00:11	00:06	9
Automobile	0.0	00:24	00:18	00:09	00:08	3
Non-natural Unknown	1.0	02:15	00:50	00:02	01:14	3
Wind	38.0	06:09	01:04	00:01	01:16	85
Mammal	0.0	00:00	00:00	00:00		1
Bird	12.0	04:29	00:12	00:00	00:28	155
Insect	0.0	00:09	00:05	00:03	00:03	3
Natural Other	0.0	00:02	00:02	00:02		1
All Aircraft	85.8					101
All Road Vehicles	1.5					12
All Non-natural Sources	86.7					116
All Natural Sources	42.4					245
Noise Free Interval	13.3	02:17	00:26	00:01	00:33	73

Table 10. Summary of on-site audible sound sources for BAND004 n=4 Summer hour-long sessions. Events are measured in minutes:seconds.

Sound Source	PA	Max Event	Mean Event	Min Event	SD Event	Count
Jet	24.0	04:23	01:27	00:14	00:59	39
Aircraft, Propeller	11.0	05:49	02:36	00:23	01:50	10
Wind	94.0	59:59	11:54	00:01	21:30	19
Bird	61.0	30:36	02:10	00:00	05:06	68
Insect	100.0	59:58	26:37	00:19	26:53	9
Natural Other	1.0	01:01	00:32	00:05	00:28	3
All Aircraft	34.0					49
All Non-natural Sources	34.0					49
All Natural Sources	99.9					99
Noise Free Interval	66.0	26:21	03:14	00:01	04:50	49

Table 11. Summary of on-site audible sound sources for BAND004 n=3 Winter hour-long sessions. Events are measured in minutes:seconds.

Sound Source	PA	Max Event	Mean Event	Min Event	SD Event	Count
Jet	40.0	04:47	02:01	00:06	01:29	36
Aircraft, Propeller	16.0	04:00	01:34	00:08	01:19	19
Wind	38.0	25:00	01:34	00:07	04:16	44
Bird	21.0	03:55	00:18	00:00	00:30	124
Insect	9.0	00:41	00:06	00:00	00:06	159
Natural Other	0.0	00:21	00:20	00:20	00:01	2
All Aircraft	54.2					55
All Non-natural Sources	54.2					55
All Natural Sources	55.5					329
Noise Free Interval	45.8	12:35	01:43	00:01	02:25	48

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, Figure 3, and Figure 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 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. The grayed area of each graph represents frequency and levels that are generally outside the range of human hearing. Overall, sound levels tended to be higher during the day than at night across all sites and frequencies. The one notable exception is two high-frequency bands at BAND004 summer (Figure 8), which are likely attributable to increased insect activity at night. Notice that at BAND003 and BAND004, much of the sound energy, especially at night, is outside the range of human hearing (grayed area), making these very quiet locations.

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.

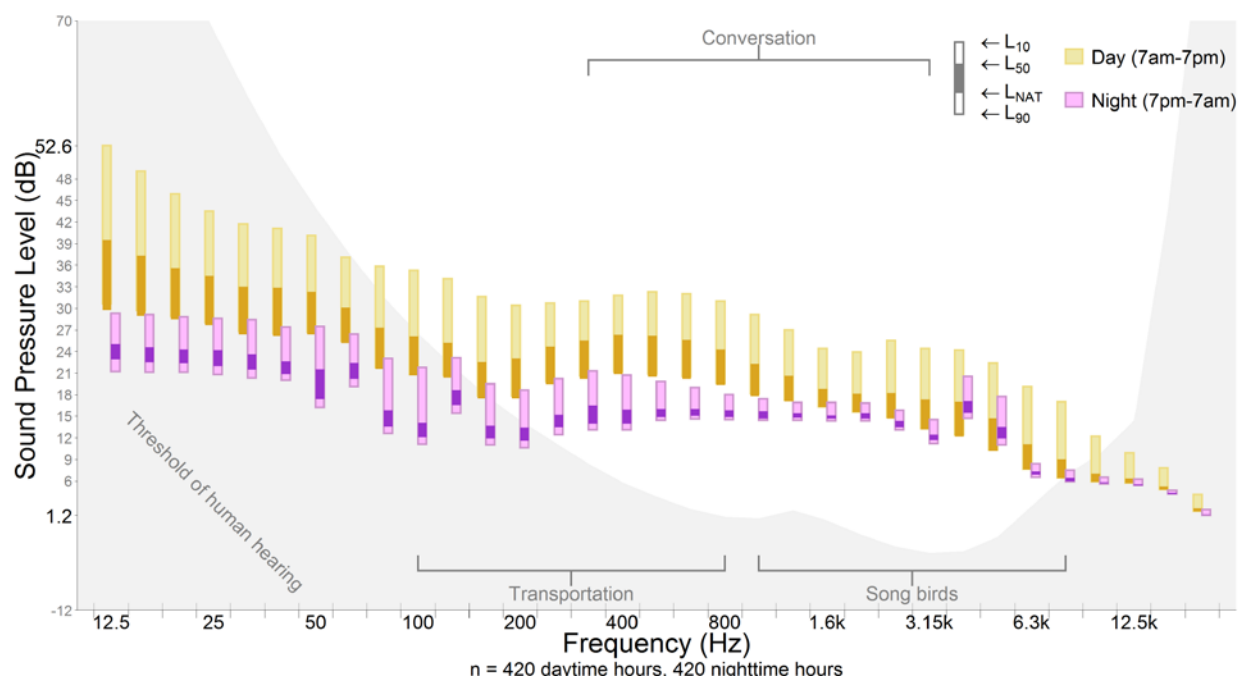


Figure 2. Day and night dB levels for 33 one-third octave bands at BAND001, summer

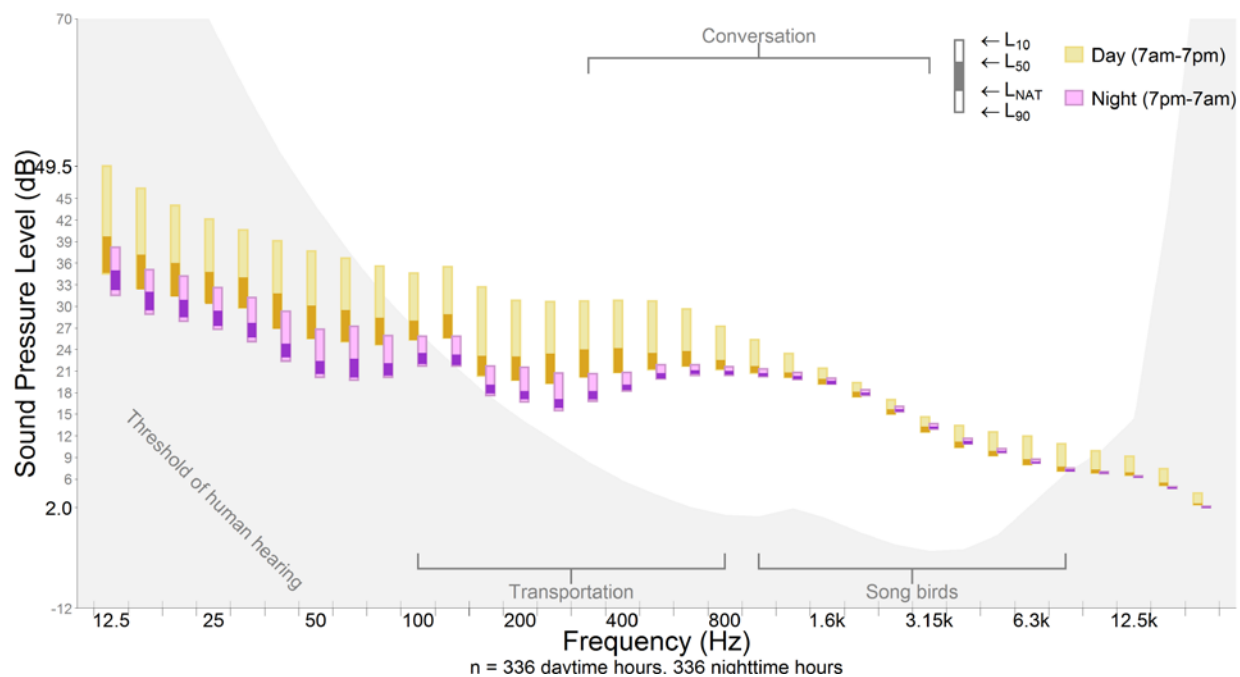


Figure 3. Day and night dB levels for 33 one-third octave bands at BAND001, winter

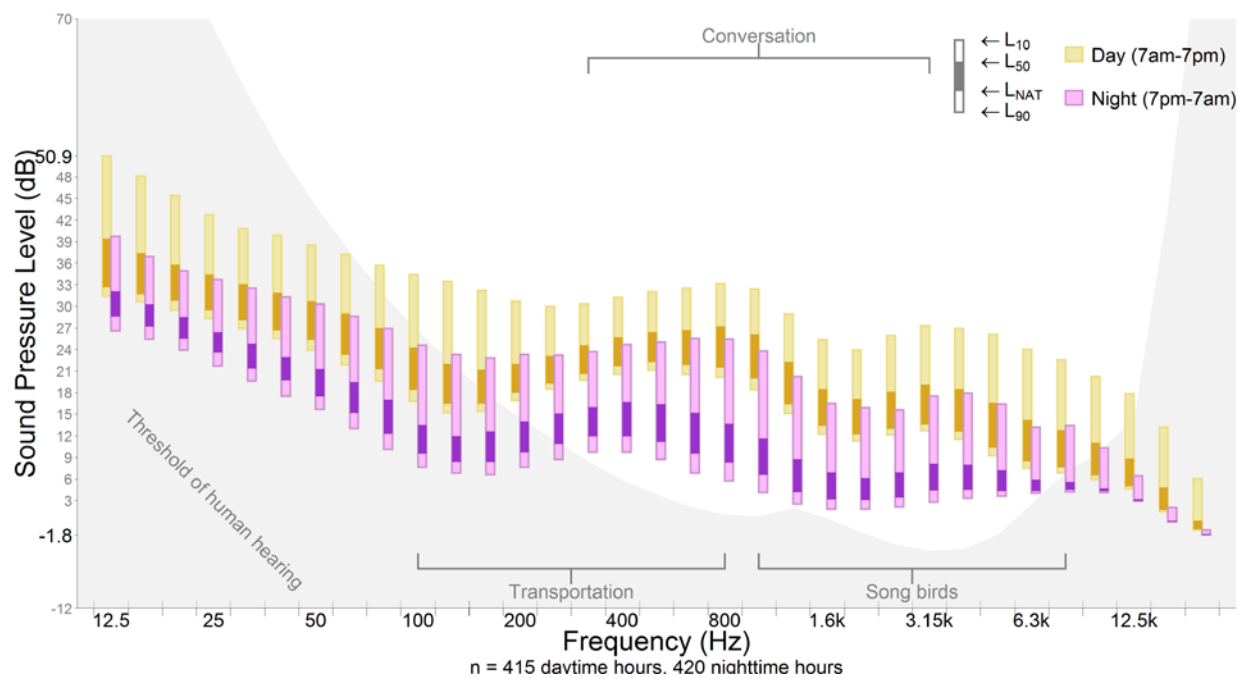


Figure 4. Day and night dB levels for 33 one-third octave bands at BAND002, summer

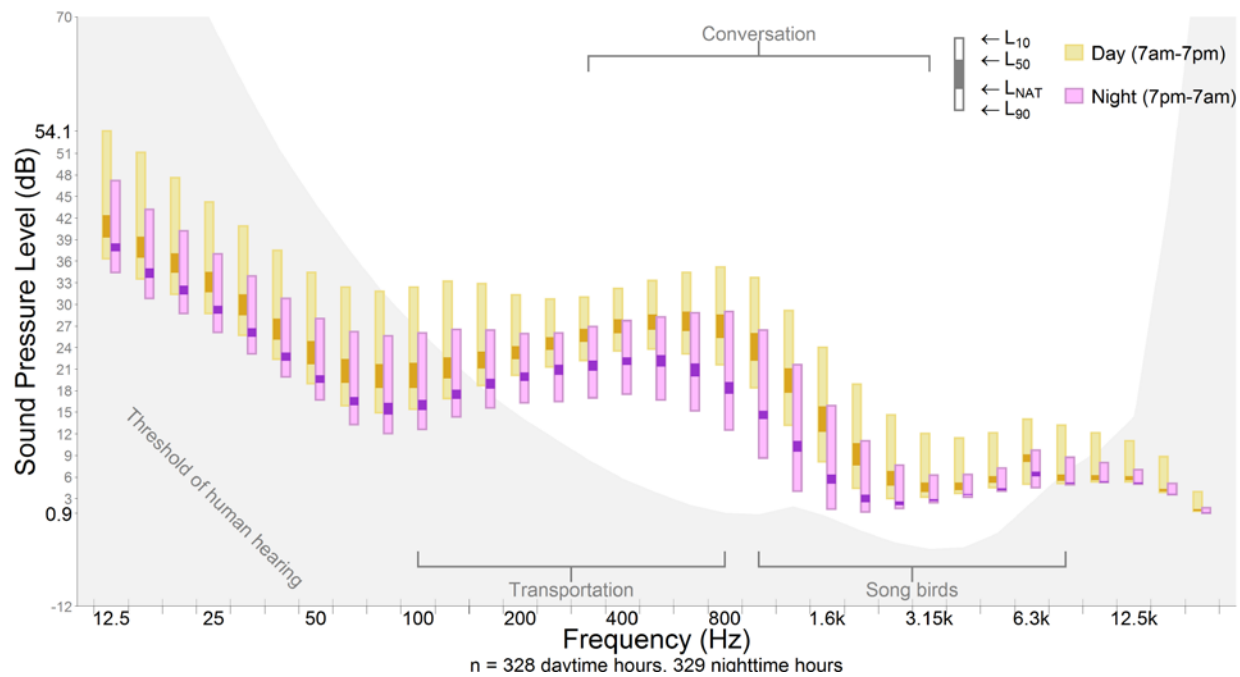


Figure 5. Day and night dB levels for 33 one-third octave bands at BAND002, winter

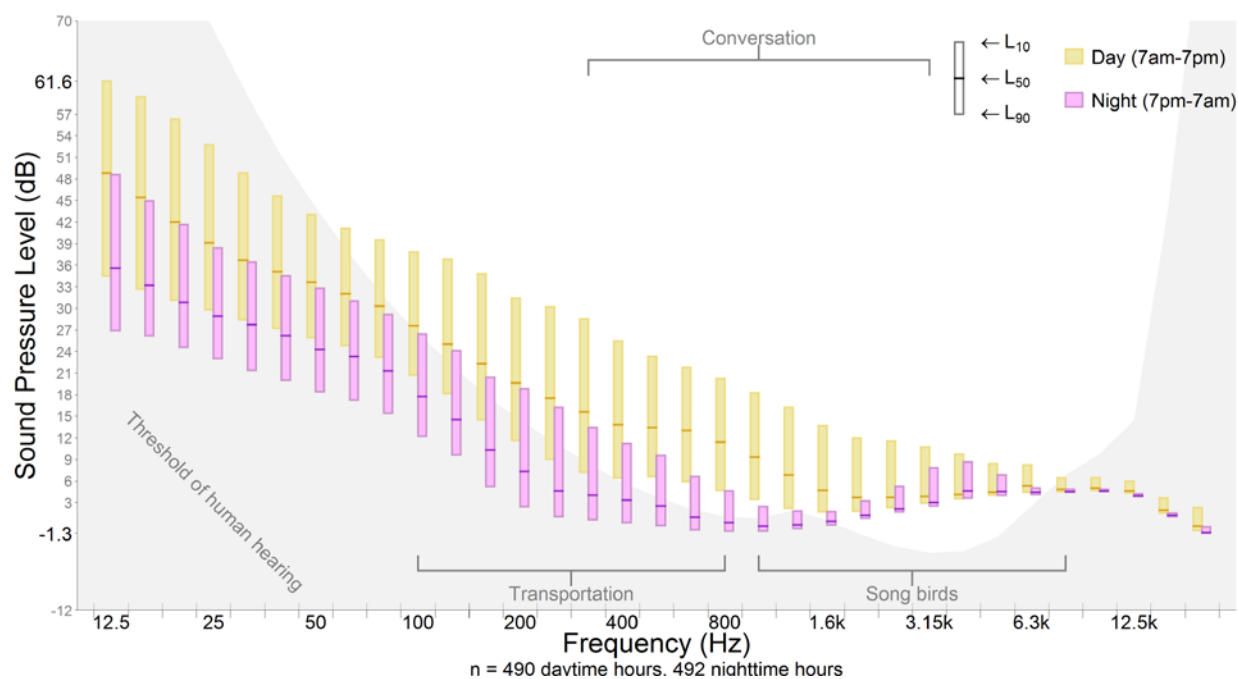


Figure 6. Day and night dB levels for 33 one-third octave bands at BAND003, summer

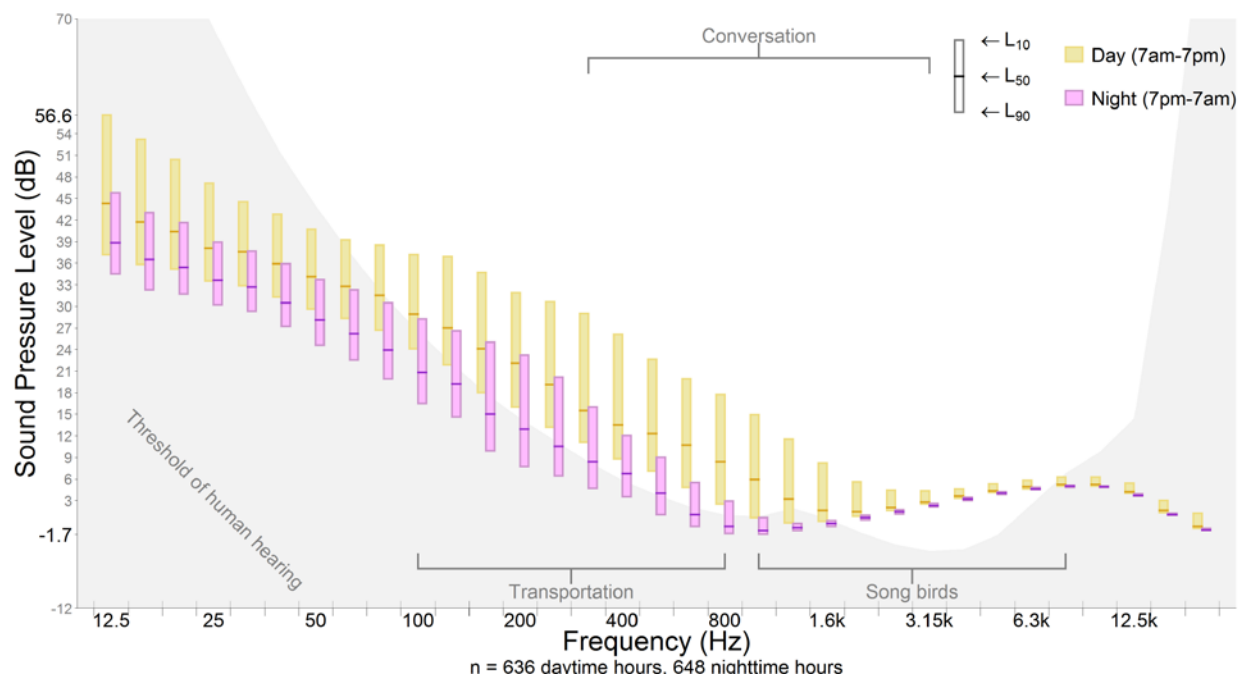


Figure 7. Day and night dB levels for 33 one-third octave bands at BAND003, winter

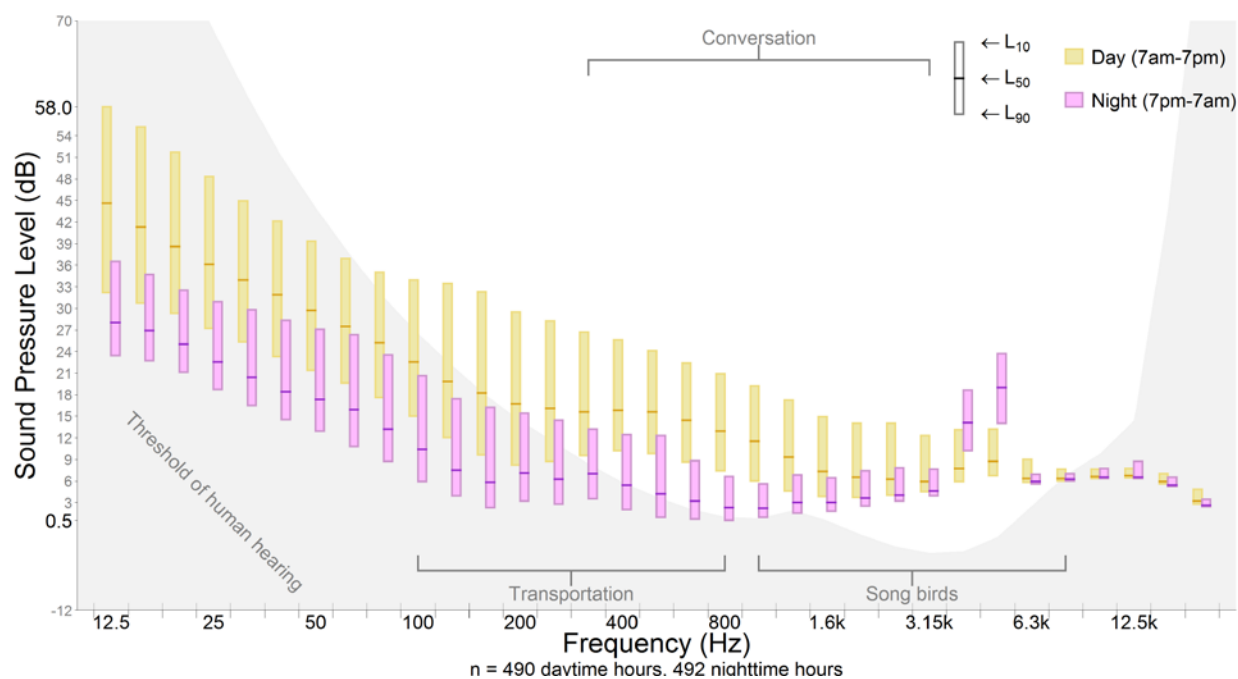


Figure 8. Day and night dB levels for 33 one-third octave bands at BAND004, summer

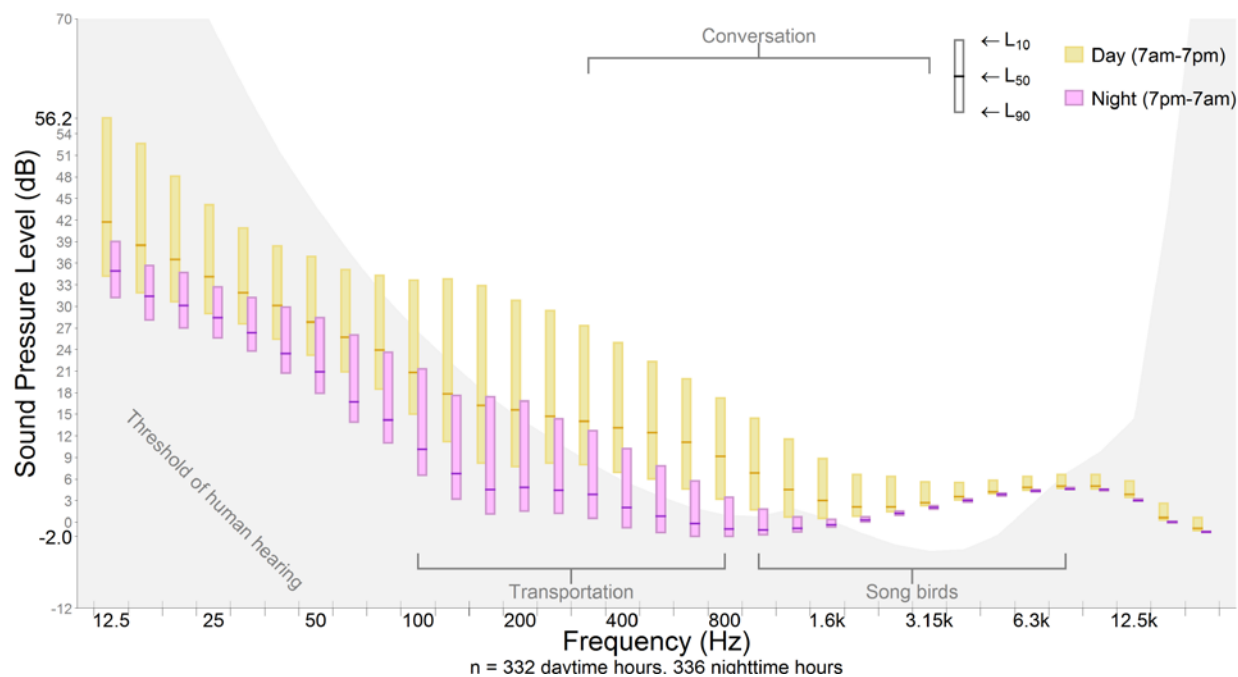


Figure 9. Day and night dB levels for 33 one-third octave bands at BAND004, winter

Table 12 reports the L_{90} , L_{nat} , L_{50} , and L_{10} values for the sites measured at BAND. 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 12. Exceedence levels for existing conditions in BAND

Site	Season	Frequency (Hz)	Exceedence levels (dBA): 0700 to 1900 hours (Day)				Exceedence levels (dBA): 1900 to 0700 hours (Night)			
			L90	Lnat	L50	L10	L90	Lnat	L50	L10
BAND001	Summer	20-1,250	27.1	27.0	31.7	37.6	21.7	22.1	23.1	26.0
		12.5-20,000	29.5	29.3	33.6	39.6	26.2	26.6	27.6	30.8
	Winter	20-1,250	28.2	28.2	30.0	35.7	27.1	27.2	27.5	28.2
		12.5-20,000	29.9	30.0	31.2	36.3	29.2	29.2	29.5	30.0
BAND002	Summer	20-1,250	26.8	28.2	33.2	38.8	14.4	17.0	21.9	32.5
		12.5-20,000	29.3	30.6	34.9	41.0	19.5	21.6	25.6	34.8
	Winter	20-1,250	28.1	31.7	34.1	39.8	21.1	25.5	27.0	34.8
		12.5-20,000	28.6	32.0	34.4	40.2	22.0	25.8	27.2	35.0
BAND003	Summer	20-1,250	15.1	18.5	21.9	32.1	8.2	9.3	11.2	19.4
		12.5-20,000	17.7	20.1	23.2	33.3	15.1	15.7	17.0	24.3
	Winter	20-1,250	17.3	19.4	22.3	32.4	10.6	12.6	13.9	20.8
		12.5-20,000	18.7	20.3	22.7	32.7	15.0	15.8	16.5	21.5
BAND004	Summer	20-1,250	15.7	19.3	21.7	31.3	8.9	10.3	11.4	18.9
		12.5-20,000	19.7	22.1	24.5	33.0	22.0	24.7	26.0	30.2
	Winter	20-1,250	12.8	16.7	19.3	31.0	6.6	7.8	8.5	17.1
		12.5-20,000	16.0	18.5	20.4	31.4	13.7	14.0	14.2	19.2

In determining the current conditions of an acoustical environment, it is important to examine how often sound pressure levels exceed certain values. Table 13 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. Hikers and visitors viewing scenic vistas in the park would likely be conducting such conversations.

Table 13. Percent time above metrics

Site	Season	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
BAND001	Summer	20-800	27.27	1.86	0.09	0.00	2.24	0.11	0.00	0.00
		12.5-20,000	41.01	3.84	0.27	0.01	8.77	0.76	0.09	0.00
	Winter	20-800	18.81	0.90	0.05	0.00	1.54	0.04	0.00	0.00
		12.5-20,000	21.15	1.16	0.10	0.00	1.80	0.05	0.00	0.00
BAND002	Summer	20-800	36.76	1.16	0.07	0.00	13.34	0.68	0.02	0.00
		12.5-20,000	50.91	2.63	0.12	0.01	20.27	1.10	0.04	0.00
	Winter	20-800	51.33	2.13	0.14	0.00	21.28	1.70	0.01	0.00
		12.5-20,000	52.81	2.25	0.18	0.00	22.47	2.19	0.06	0.00
BAND003	Summer	20-800	8.99	0.56	0.08	0.00	2.07	0.08	0.00	0.00
		12.5-20,000	11.61	1.37	0.16	0.01	3.09	0.26	0.03	0.00
	Winter	20-800	9.74	0.58	0.06	0.00	1.21	0.06	0.00	0.00
		12.5-20,000	11.28	0.92	0.10	0.00	1.37	0.09	0.00	0.00
BAND004	Summer	20-800	6.66	0.59	0.15	0.01	1.04	0.07	0.00	0.00
		12.5-20,000	10.28	1.07	0.24	0.02	5.77	0.14	0.01	0.00
	Winter	20-800	6.55	0.81	0.16	0.03	1.12	0.12	0.01	0.00
		12.5-20,000	7.95	1.02	0.27	0.03	1.21	0.16	0.02	0.00

Audibility

Audibility results are presented below. Table 14-Table 21 show the mean percentage of time that all noise sources were audible, based on eight days of off-site auditory analysis². Figure 10-Figure 17 show hourly audibility results and compare overall noise audibility to one source of interest: total aircraft.

² When sounds could not be specifically identified, they were placed in more general categories (e.g., aircraft or vehicle as opposed to propeller or truck).

Table 14. Mean hourly percent time audible for each noise source³ at BAND001 summer. 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	1.2	0.4	2.5	0.0	0.8	0.8	1.7	1.2	1.7	0.8	0.0	2.5	0.0	0.8	3.3	0.8	1.2	1.2	0.8	0.0	0.4	0.0	0.0	0.8
Jet	5.4	4.2	2.9	3.8	2.9	3.8	5.8	6.2	22.9	15.4	17.1	12.5	10.4	14.2	14.2	9.2	17.1	18.8	20.0	21.2	16.3	20.8	12.5	9.6
Propeller	0.0	0.0	0.4	0.0	0.8	1.2	0.0	2.5	2.1	4.6	4.2	2.5	1.7	2.5	2.1	2.5	1.7	2.1	1.7	0.0	1.7	0.8	0.8	2.5
Helicopter	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.8	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
Vehicle	0.4	0.8	1.2	4.6	9.6	5.8	12.9	30.8	24.2	29.6	25.0	31.2	29.6	35.0	25.4	29.6	30.4	28.3	18.8	16.3	11.3	10.4	10.8	2.5
Alarm, Horn	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vehicle door	0.4	0.0	0.0	0.0	0.0	0.0	0.4	2.9	3.3	3.3	2.9	2.9	4.6	9.2	3.3	2.1	3.8	2.9	3.3	2.1	1.7	0.8	0.8	0.4
Motorcycle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0
Truck	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Motor	0.0	0.0	0.0	0.0	0.0	1.7	7.1	0.4	2.1	1.7	0.4	0.0	0.0	0.0	0.0	0.0	0.0	1.2	2.5	7.5	4.2	7.1	10.8	10.8
Generator	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	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
Lawnmower	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dumpster/ trashcan	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	0.4	0.0	0.0	0.0	0.0	0.0
Voices	0.8	0.0	0.0	0.0	0.0	0.0	1.7	6.7	25.4	42.5	66.7	70.8	70.8	63.3	57.5	51.3	50.8	47.5	25.4	20.4	7.1	2.9	1.2	0.0
Walking	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.2	0.0	0.8	1.7	4.6	5.8	5.0	2.9	1.7	0.4	0.8	0.0	1.7	0.0	0.0
Construction	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	1.2	0.0	0.8	1.7	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Non-natural unknown	37.5	41.3	42.5	42.1	35.4	39.2	38.8	28.7	14.6	17.9	13.8	17.5	12.9	12.5	14.2	11.3	8.7	17.5	10.4	10.0	15.8	31.2	45.8	32.9
Total Vehicles	0.8	0.8	1.2	4.6	9.6	5.8	13.8	33.7	27.1	32.5	27.5	34.2	33.3	40.4	27.9	31.7	33.3	31.2	21.7	18.3	12.9	11.3	11.7	2.9
Total Aircraft	5.4	4.2	4.6	3.8	4.6	5.8	6.2	9.2	25.8	21.2	22.1	17.5	12.1	17.9	19.6	12.5	20.0	22.1	22.5	21.2	18.3	21.7	13.3	12.9
Total non-natural	42.9	45.8	46.7	47.9	47.9	48.8	58.8	65.8	76.2	81.7	93.7	89.6	87.5	86.2	79.2	76.2	82.5	80.8	63.8	59.6	52.9	65.8	73.3	55.4

³ Unspecified “Motor” and most of the “Non-natural unknown” sounds at this site were attributable to the generator.

Table 15. Mean hourly percent time audible for each noise source⁴ at BAND001 winter. 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	1.2	0.4	0.0	0.0	0.8	0.0	0.4	0.4	0.0	0.4	0.0	0.8	0.4	0.8	1.7	1.2	0.4	1.2	2.1	0.8	2.5	4.2	2.5	0.8
Jet	5.4	3.8	2.5	2.5	4.6	5.8	7.9	7.1	22.1	22.9	18.8	11.7	17.1	15.0	12.5	13.8	20.8	22.9	20.4	11.7	8.7	10.0	7.5	7.5
Propeller	0.0	0.0	0.4	0.0	0.4	0.4	2.9	1.2	2.5	2.9	2.9	3.8	0.8	2.1	2.9	0.4	0.0	2.9	6.2	30.4	29.6	5.8	14.6	23.7
Helicopter	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0
Vehicle	0.8	0.4	2.1	0.4	1.7	5.4	6.7	12.5	25.4	20.0	20.8	19.2	20.4	22.5	15.8	20.8	21.2	21.2	9.6	2.5	3.3	5.8	2.5	0.4
Alarm, Horn	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.4	0.8	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vehicle door	0.0	0.0	0.0	0.4	0.8	0.0	0.0	2.1	2.5	3.8	3.3	8.7	7.9	7.5	10.4	8.7	5.4	2.9	0.8	0.0	0.0	0.0	0.4	0.0
Motorcycle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Motor	5.8	9.6	10.4	12.1	12.5	10.4	11.7	6.7	0.8	2.9	4.2	0.8	0.0	0.4	0.0	0.8	0.4	0.0	0.0	4.2	7.9	8.3	7.5	8.7
Generator	25.0	24.6	25.0	25.0	25.0	25.0	24.2	24.2	14.2	8.3	14.6	19.2	13.8	10.8	12.5	17.5	18.8	11.3	19.6	11.7	16.7	23.3	15.0	12.9
Dumpster/trashcan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.8	0.8	0.0	0.4	0.8	0.4	1.2	0.4	1.7	0.8	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	0.0	0.0	0.4	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Voices	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.8	4.2	7.9	13.3	27.9	32.5	31.7	31.2	37.5	28.3	11.3	0.4	0.4	0.0	1.2	0.0	0.0
Walking	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	3.3	3.8	7.5	2.1	2.1	0.4	2.1	0.8	0.0	0.0	0.0	0.0	0.0	0.0
Dog	0.0	0.4	0.0	0.0	0.8	0.0	0.4	0.0	0.4	0.0	0.0	0.0	0.8	0.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Non-natural other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Non-natural unknown	25.4	24.6	25.0	25.0	23.3	24.2	28.3	29.6	18.8	2.5	6.7	18.3	25.4	31.7	23.3	27.5	18.8	13.3	13.8	17.5	21.7	20.8	24.6	20.4
Total Vehicles	0.8	0.4	2.1	0.8	2.5	5.4	7.1	14.6	27.1	22.9	24.2	26.7	27.9	30.4	25.4	28.3	27.1	23.7	10.4	2.5	3.3	5.8	2.9	0.4
Total Aircraft	6.7	4.2	2.9	2.5	5.8	6.2	11.3	8.7	24.6	26.7	21.7	16.3	19.2	17.9	17.1	15.4	21.2	27.1	28.7	42.9	40.8	20.0	23.7	32.1
Total non-natural	60.8	62.9	62.9	62.9	65.8	67.1	75.4	74.6	77.9	59.6	67.9	79.6	87.9	87.1	79.6	86.2	84.2	72.1	65.0	75.8	83.7	70.8	65.4	71.7

⁴ Unspecified “Motor” and most of the “Non-natural unknown” sounds at this site were attributable to the generator.

Table 16. Mean hourly percent time audible for each noise source⁵ at BAND002 summer. 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	2.1	4.2	1.7	2.1	4.2	2.5	2.9	1.2	10.8	10.0	6.2	5.0	5.4	4.2	4.6	5.0	2.9	7.1	5.0	4.2	5.0	3.8	3.3	1.7
Jet	2.9	3.8	0.8	2.1	1.2	1.7	7.1	8.3	12.9	11.7	11.7	10.8	10.8	8.3	6.7	4.2	10.0	12.9	16.7	8.3	12.5	14.2	6.2	4.6
Propeller	0.0	0.0	2.5	0.0	0.0	0.8	0.4	1.7	1.2	2.5	1.7	1.2	3.3	1.7	0.8	0.8	1.2	1.7	3.3	2.1	0.0	1.2	2.1	1.7
Helicopter	0.0	0.0	0.0	0.4	0.0	0.0	0.4	0.8	0.8	1.2	0.4	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0
Vehicle	17.1	10.4	4.2	3.8	13.8	33.7	57.1	66.7	56.7	50.4	50.4	45.8	48.3	41.3	46.3	49.2	56.7	57.1	64.6	51.7	43.3	38.8	24.6	32.9
Automobile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.8	0.0	0.0	2.1	2.9	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alarm, Horn	0.4	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.0
Vehicle door	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0
Motorcycle	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.8	0.8	1.2	0.4	0.4	0.4	0.4	0.4	0.4	0.0	0.4	0.4	0.0	0.0
Truck	0.4	0.0	0.0	0.4	0.4	2.1	2.1	2.1	1.2	1.7	0.4	1.7	0.4	0.4	1.2	0.4	0.8	0.4	0.8	1.6	1.2	0.8	0.0	0.0
Voices	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	1.2	0.8	0.0	1.2	1.7	0.4	1.2	0.8	0.8	0.0	0.8	0.0	0.0	0.0	0.0
Non-natural unknown	25.8	31.2	37.1	37.1	37.1	27.1	27.9	26.7	30.8	20.0	14.2	12.1	10.4	9.6	11.3	16.3	11.7	10.0	10.8	11.3	10.4	17.1	21.2	26.2
Total Vehicles	17.9	10.4	4.2	4.2	13.8	36.2	59.6	69.2	58.3	52.1	51.3	49.6	52.5	42.9	47.9	50.0	57.9	57.9	65.8	53.3	44.6	39.6	25.0	32.9
Total Aircraft	5.0	7.9	5.0	4.6	5.4	5.0	10.8	12.1	25.8	25.4	20.0	17.1	19.6	14.6	12.1	10.0	14.2	21.7	25.4	14.6	17.5	19.2	11.7	7.9
Total non-natural	37.1	42.5	42.9	45.0	49.6	58.3	80.8	84.2	77.9	75.0	68.8	65.4	67.1	55.8	59.2	59.2	66.7	71.3	77.1	66.7	57.9	62.9	45.0	53.8

⁵ Most of the “Non-natural unknown” sounds at this site were likely attributable to distant traffic noise.

Table 17. Mean hourly percent time audible for each noise source⁶ at BAND002 winter. 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	3.8	2.5	1.2	0.4	1.7	2.1	7.1	6.2	5.0	8.3	11.3	5.0	7.9	8.7	7.5	12.1	10.8	8.7	7.1	7.9	7.1	11.7	7.9	3.3
Jet	2.9	2.1	2.1	0.8	1.7	2.9	6.7	5.0	8.7	12.5	8.3	5.4	5.0	7.9	5.8	7.1	8.7	6.2	7.9	4.6	2.9	6.2	3.8	1.7
Propeller	0.0	0.0	0.0	0.0	0.0	4.2	0.8	2.9	2.1	0.4	0.4	3.3	1.7	0.8	2.9	2.1	1.7	2.9	0.4	0.8	0.0	0.4	1.2	0.4
Helicopter	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vehicle	0.4	0.4	2.5	0.8	3.8	14.6	23.3	32.5	20.0	19.2	16.3	15.4	15.8	15.8	18.3	16.7	26.7	31.7	24.2	20.8	22.5	13.7	10.4	0.8
Automobile	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Motor	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dumpster/trashcan	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
Voices	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.7	0.4	0.8	2.1	0.8	1.7	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0
Non-natural other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	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	11.7	7.9	12.5	10.8	14.2	19.6	8.7	7.5	11.7	9.2	5.4	6.7	6.7	8.7	8.3	10.8	13.3	9.6	6.7	8.3	10.8	7.9	6.7	2.5
Total Vehicles	0.4	0.4	2.9	0.8	3.8	14.6	23.3	32.5	20.0	19.2	16.3	15.4	15.8	15.8	18.3	16.7	26.7	31.7	24.2	20.8	22.5	13.7	10.4	0.8
Total Aircraft	6.7	4.6	3.3	1.2	3.3	9.2	14.6	14.2	15.8	21.2	21.2	13.8	14.6	17.5	16.3	21.2	21.2	17.9	15.4	13.3	10.0	18.3	12.9	5.4
Total non-natural	19.2	12.5	17.9	12.9	19.2	36.2	38.8	45.0	39.6	40.8	42.1	33.7	34.6	40.4	37.9	43.8	49.6	51.7	39.6	37.5	38.8	36.2	28.3	8.3

⁶ Most of the “Non-natural unknown” sounds at this site were likely attributable to distant traffic noise.

Table 18. Mean hourly percent time audible for each noise source⁷ at BAND003 summer. 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	0.0	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	0.4	0.0	0.4	0.0	0.4	0.0	0.0	0.0	0.0	0.0
Jet	11.7	17.9	5.8	6.2	5.8	4.2	9.2	15.0	33.3	30.8	31.7	27.5	20.0	17.5	16.3	16.7	25.0	24.2	26.2	24.2	29.2	25.8	17.9	12.9
Propeller	0.0	0.4	2.5	0.0	1.2	3.8	6.7	10.0	10.4	11.3	16.3	10.8	5.8	10.8	5.4	5.8	5.4	4.6	2.9	3.8	3.8	1.7	0.0	7.1
Helicopter	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.8	0.0	0.0	0.0	0.0	0.8	0.0
Vehicle	9.6	9.6	3.3	1.2	5.4	9.6	7.9	17.5	8.7	5.4	2.1	2.9	3.3	1.2	0.4	1.2	4.6	5.0	3.8	2.5	2.5	4.2	2.5	1.2
Motor	21.7	19.2	25.4	37.1	30.0	54.2	45.8	37.1	31.2	24.6	10.0	6.2	9.6	3.8	2.9	5.8	7.9	5.0	12.5	9.6	14.2	20.8	19.2	29.2
Voices	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
Non-natural unknown	0.0	0.4	0.0	0.8	0.0	0.0	0.0	1.2	0.4	0.4	2.9	0.8	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Vehicles	9.6	9.6	3.3	1.2	5.4	9.6	7.9	17.5	8.7	5.4	2.1	2.9	3.3	1.2	0.4	1.2	4.6	5.0	3.8	2.5	2.5	4.2	2.5	1.2
Total Aircraft	11.7	18.3	8.3	6.2	7.1	7.9	15.8	25.0	45.0	42.1	47.9	38.8	25.8	28.3	22.1	22.5	31.7	29.6	29.6	27.9	32.9	27.5	18.8	20.0
Total non-natural	42.5	47.9	36.7	44.2	40.4	67.5	66.7	74.2	80.0	71.3	60.0	48.3	38.8	33.3	25.4	29.6	40.0	36.2	45.4	38.8	49.2	51.3	39.6	50.4

Table 19. Mean hourly percent time audible for each noise source at BAND003 winter. 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	9.0	6.0	3.6	1.3	2.1	4.0	4.9	8.8	16.9	22.9	16.2	18.1	25.7	18.4	15.1	20.2	30.5	30.8	27.5	14.8	18.7	28.3	18.4	7.0
Propeller	0.0	0.0	0.0	0.0	0.0	3.6	9.5	10.1	15.5	11.0	20.6	33.1	21.6	16.1	14.6	13.3	13.4	11.1	11.9	16.1	14.6	5.9	10.4	13.4
Helicopter	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	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
Vehicle	0.0	0.0	0.1	0.1	0.0	1.3	1.2	5.5	1.7	5.9	3.0	1.3	3.0	3.5	0.3	3.7	3.8	7.6	7.2	2.5	4.8	2.1	2.5	0.0
Motor	22.5	19.8	39.9	34.2	7.4	1.3	12.2	3.5	1.2	2.4	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	1.9	0.0	7.1	5.0	6.8	15.5
Dog	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Building alarm	0.0	0.0	0.1	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	0.0	0.0	0.0	0.0	0.0	0.0
Total Vehicles	0.0	0.0	0.1	0.1	0.0	1.3	1.2	5.5	1.7	5.9	3.0	1.3	3.0	3.5	0.3	3.7	3.8	7.6	7.2	2.5	4.8	2.1	2.5	0.0
Total Aircraft	9.0	6.0	3.6	1.3	2.1	7.6	14.4	18.9	32.2	33.0	38.9	48.1	46.3	34.3	28.9	33.0	43.8	41.3	39.4	30.5	33.3	34.0	27.6	20.4
Total non-natural	31.2	25.7	43.4	35.6	9.5	10.2	27.8	27.9	35.2	40.3	41.5	49.4	49.9	37.7	29.2	36.7	47.4	48.4	47.8	33.1	44.5	41.0	36.8	35.9

⁷ Unspecified “Motor” sounds at this site could were faint and distant, and could have been industrial/generator or distant traffic noise.

Table 20. Mean hourly percent time audible for each noise source at BAND004 summer. 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	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jet	9.6	15.4	7.5	5.0	7.9	5.8	6.7	8.7	33.3	31.7	24.2	32.9	23.3	21.7	17.1	18.3	27.5	26.7	29.6	28.3	28.3	25.0	16.7	13.3
Propeller	0.0	0.0	2.5	0.0	2.9	3.3	6.2	9.6	16.7	16.7	7.1	14.6	9.2	10.4	6.7	4.6	5.8	3.8	1.2	2.5	0.8	3.3	0.4	3.3
Helicopter	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vehicle	4.6	1.2	3.3	4.2	3.8	5.8	14.6	12.9	4.6	3.3	1.2	1.2	2.1	0.0	0.0	2.1	0.8	0.4	3.3	1.7	3.3	8.3	2.5	7.1
Automobile	0.0	0.4	0.0	0.0	0.0	2.1	1.7	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.4	0.8	0.0	0.0	1.2
Truck	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Motor	11.7	15.8	9.6	19.6	15.0	6.2	11.3	16.7	7.9	2.9	0.4	1.2	0.8	0.0	0.0	0.0	0.0	0.0	2.5	0.4	1.2	2.9	5.4	10.0
Voices	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	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Portable audio devices	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0
Dog	0.0	0.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0
Non-natural unknown	0.8	0.4	0.0	0.4	0.0	0.0	0.0	0.4	0.4	0.4	0.0	0.4	0.0	0.0	0.4	0.4	1.2	0.0	0.4	0.0	0.0	0.0	0.0	0.4
Total Vehicles	4.6	1.7	3.3	4.2	3.8	10.4	16.3	13.8	4.6	3.3	1.2	1.2	2.1	0.0	0.0	2.1	0.8	0.8	3.3	2.1	4.2	8.3	2.5	8.3
Total Aircraft	10.0	15.4	10.0	5.0	10.8	9.2	12.9	18.3	50.0	47.9	31.7	47.5	32.5	31.2	23.3	22.9	33.7	30.4	30.8	30.8	29.2	28.3	17.1	16.7
Total non-natural	25.8	31.2	22.1	28.7	27.5	26.2	40.4	49.2	60.8	54.6	33.3	50.0	35.4	31.2	24.2	25.4	35.8	30.8	36.7	32.9	34.6	38.8	25.0	30.8

Table 21. Mean hourly percent time audible for each noise source at BAND004 winter. 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	8.9	7.8	2.1	1.6	4.6	2.2	3.5	9.5	23.9	26.1	19.6	17.2	24.4	20.7	21.8	27.0	26.4	24.0	25.6	21.6	19.1	20.2	15.7	7.8
Propeller	3.9	0.0	0.0	1.1	0.0	2.9	2.2	2.6	7.2	8.4	9.9	17.5	14.0	11.7	8.6	8.2	9.6	7.4	5.7	11.5	7.0	2.9	8.6	12.6
Helicopter	0.0	0.0	0.0	0.0	0.0	0.3	16.6	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	5.4	0.1	0.0	0.0	0.0	0.0
Vehicle	0.0	0.0	0.1	0.0	0.0	0.0	0.2	0.0	2.0	0.0	1.7	0.0	0.0	0.0	0.0	0.2	1.3	0.0	0.3	1.8	0.5	0.0	0.0	0.0
Voices	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	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
Gunshot	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dog	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Total Vehicles	0.0	0.0	0.1	0.0	0.0	0.0	0.2	0.0	2.0	0.0	1.7	0.0	0.0	0.0	0.0	0.2	1.3	0.0	0.3	1.8	0.5	0.0	0.0	0.0
Total Aircraft	12.8	7.8	2.1	2.7	4.6	5.5	22.1	12.8	30.9	34.3	29.4	34.6	38.1	32.4	30.4	35.2	35.6	33.5	34.5	32.8	26.0	23.0	24.3	19.4
Total non-natural	12.8	7.8	2.2	2.7	4.6	5.7	22.3	12.8	32.9	34.3	31.6	34.6	38.1	32.4	30.4	35.4	36.8	33.6	34.9	34.6	26.5	23.0	24.3	19.4

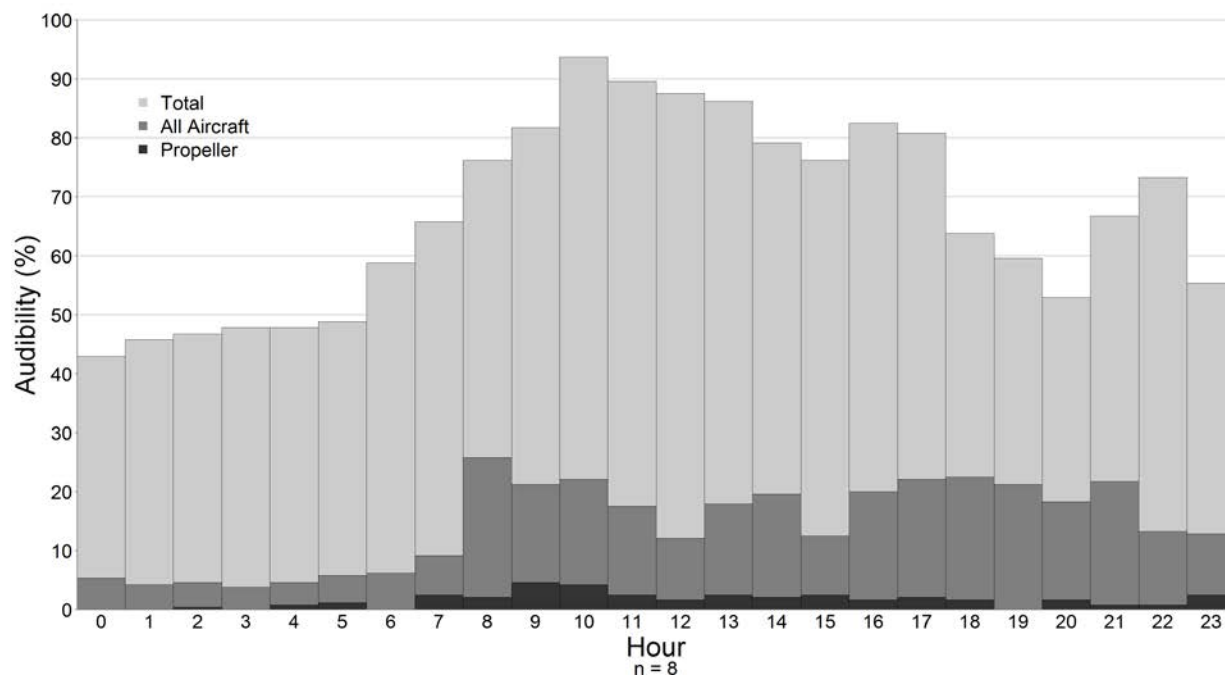


Figure 10. Comparison of hourly noise audibility for propeller aircraft, all aircraft types, and total human-caused noise at BAND001 summer.

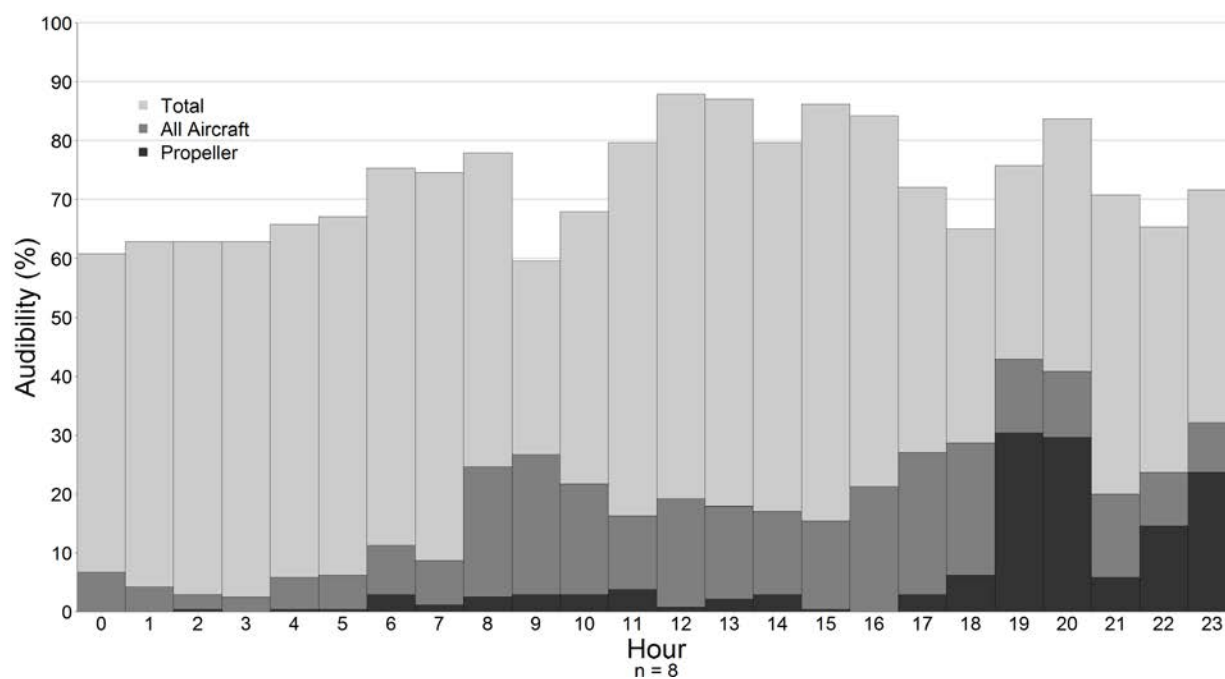


Figure 11. Comparison of hourly noise audibility for propeller aircraft, all aircraft types, and total human-caused noise at BAND001 winter.

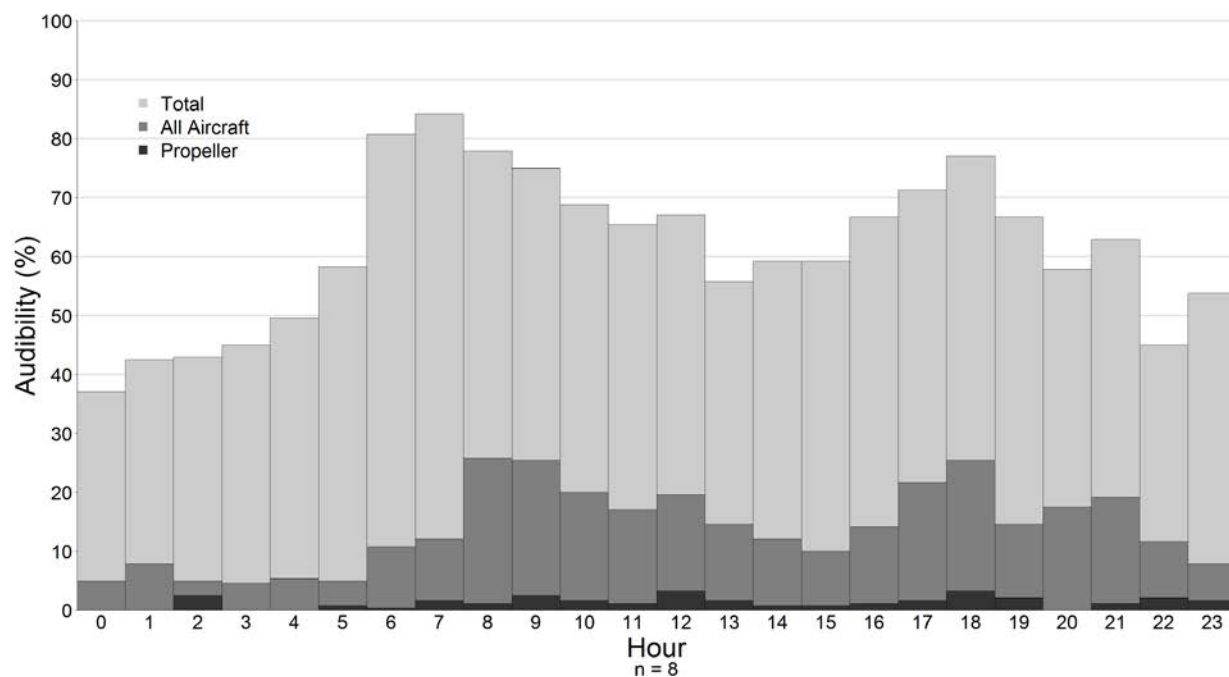


Figure 12. Comparison of hourly noise audibility for propeller aircraft, all aircraft types, and total human-caused noise at BAND002 summer.

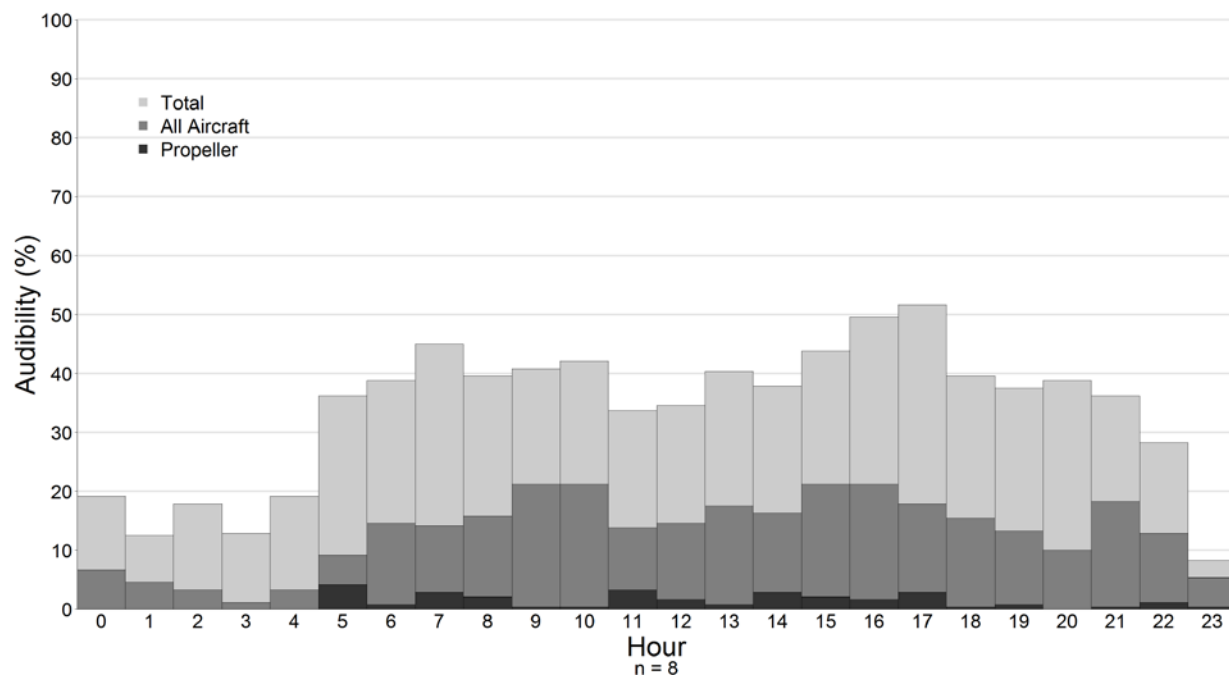


Figure 13. Comparison of hourly noise audibility for propeller aircraft, all aircraft types, and total human-caused noise at BAND002 winter.

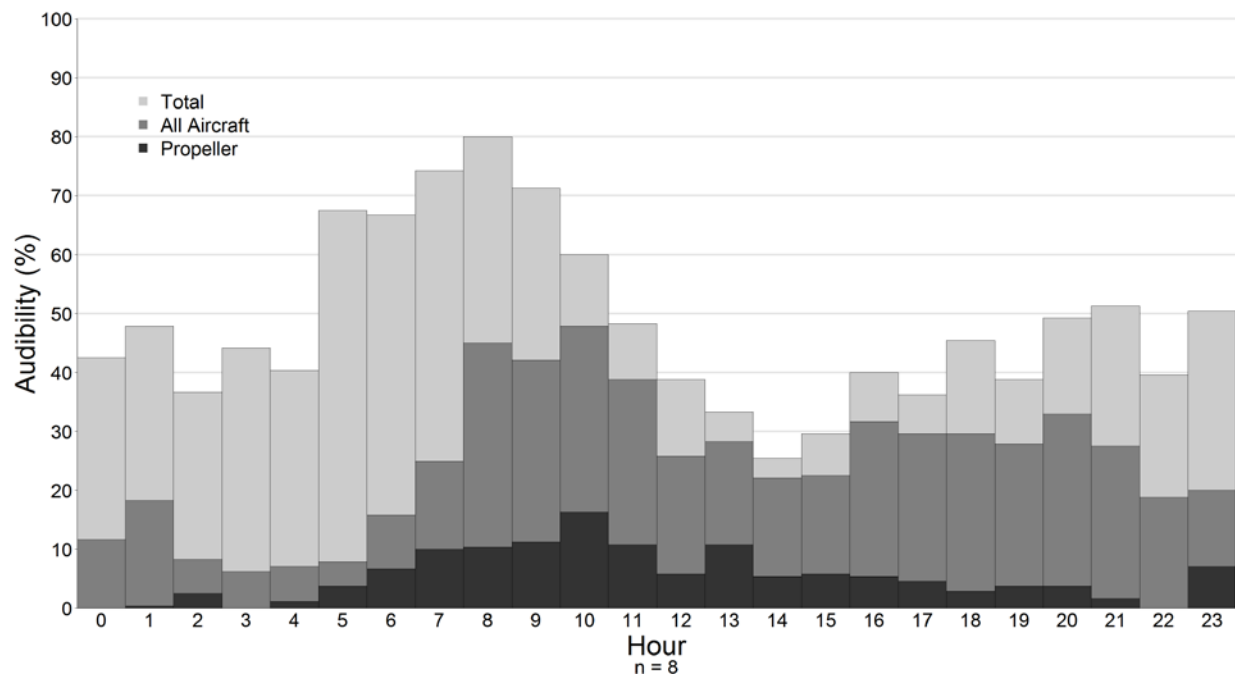


Figure 14. Comparison of hourly noise audibility for propeller aircraft, all aircraft types, and total human-caused noise at BAND003 summer.

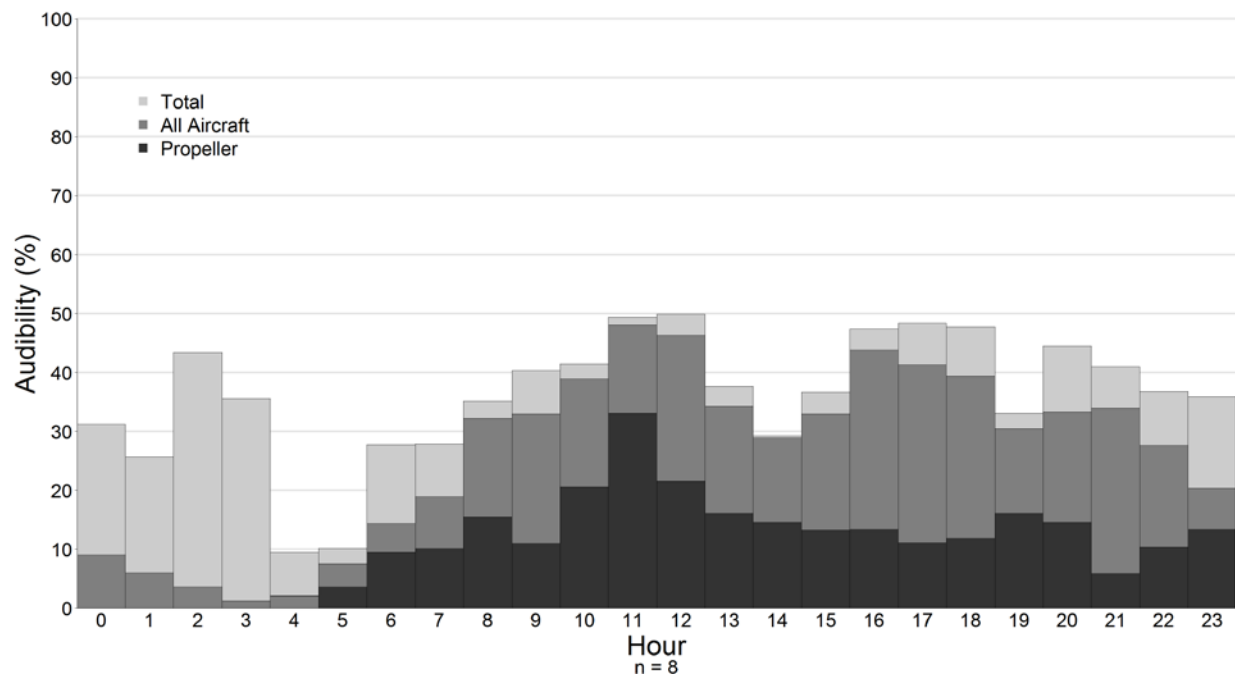


Figure 15. Comparison of hourly noise audibility for propeller aircraft, all aircraft types, and total human-caused noise at BAND003 winter.

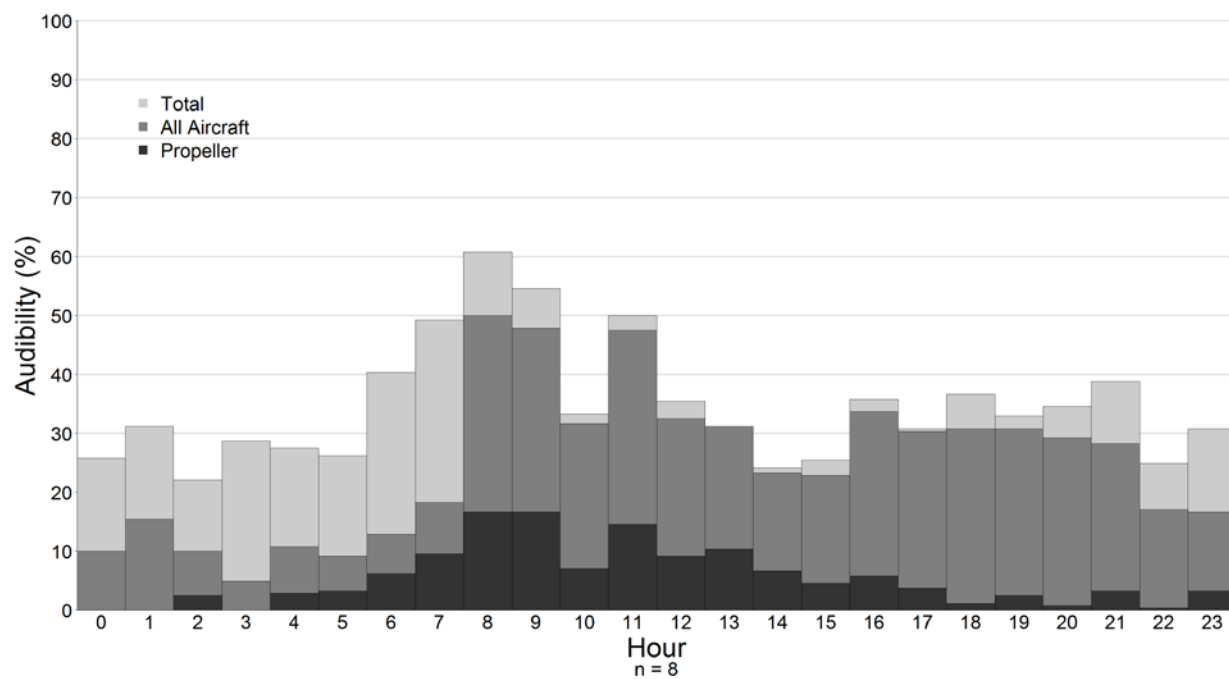


Figure 16. Comparison of hourly noise audibility for propeller aircraft, all aircraft types, and total human-caused noise at BAND004 summer.

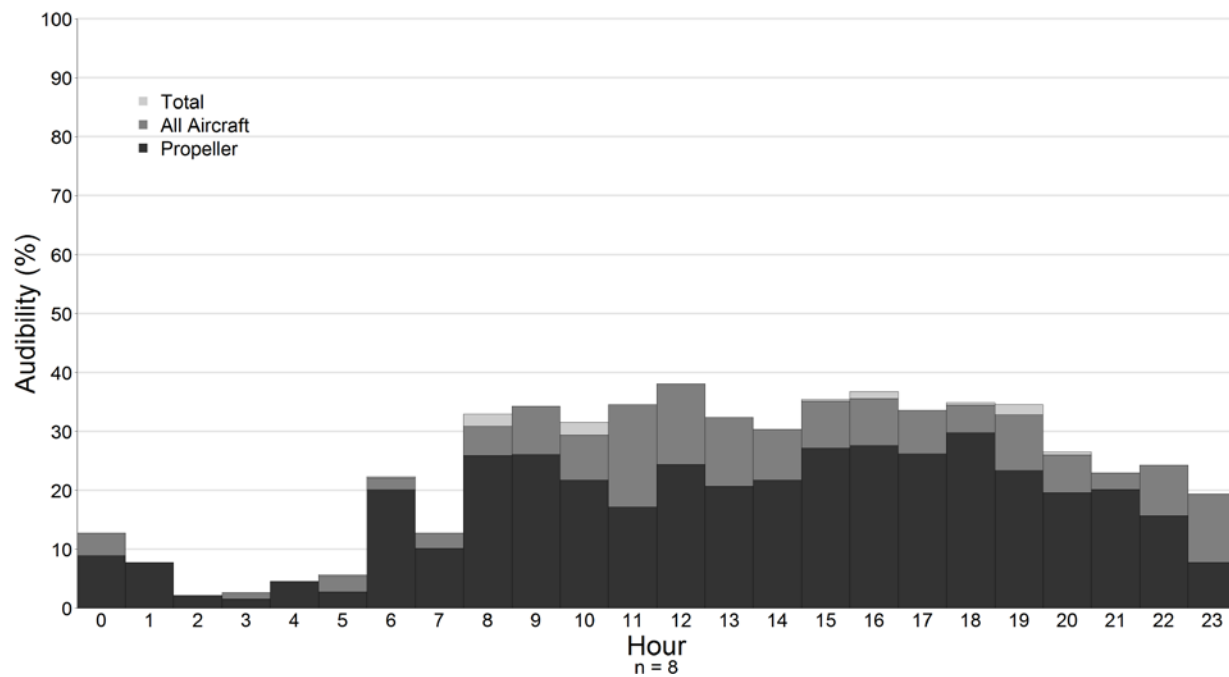


Figure 17. Comparison of hourly noise audibility for propeller aircraft, all aircraft types, and total human-caused noise at BAND004 winter.

Discussion

The existing ambient conditions at Bandelier National Monument are quiet to very quiet, even at the busiest site. At BAND001, located near the Visitor Center, parking lot, popular hiking trails, and archaeological sites, non-natural sounds could be heard 67.1% (summer) – 72.8% (winter) of the time. However, the median existing ambient levels were quite low, the highest being 33.6 dBA (summer, daytime). 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 over 55 dB (and an additional 53% was exposed to day-night sound levels over 60 dB) (EPA 1982). Noise levels have increased nationally with population growth since the EPA study (Suter 1991; Barber et al. 2010). Therefore, these results imply that although noise was common at BAND001 during the monitoring period, it was considerably quieter than most residential areas. The most common sources of noise at this site were people talking, vehicles, and a building generator.

BAND002 was a much less-visited area of the park, along the trail to Cerro Grande peak. Although the site was about one mile from the road, vehicles were clearly audible. Vehicles could be heard 41.5% of the time during the summer deployment, making up the majority of the 61.3% time audible of all non-natural noise. All noise sources, including vehicles, were less commonly heard in the winter (33.5% and 15.3% time audible, respectively). The only other significant sources of noise at this site were aircraft, mainly high-altitude jets.

Noise was least frequently heard at the two sites along the Burro Trail, BAND003 (mesatop) and BAND004 (Rio Grande corridor). Mean percent time audible at these sites ranged from 23.9% (BAND004, winter) to 48.2% (BAND003, summer). The most common noise source at both sites was aircraft, including both high-altitude jets and lower-flying propeller aircraft. Three regional airports proximate to BAND include Los Alamos, Ohkay Owingeh (Espanola), and Santa Fe Municipal. A faint, unidentified motor noise could also be heard at both sites at times, and may have been related to industrial activity in Los Alamos or nearby.

In general, BAND had low existing sound levels, with median existing ambient levels measured within just a few dBA of natural ambient levels (range: 0.2 – 4.3 dBA difference; see Table 1). Natural ambient is the sound level that would exist in the absence of human-caused noise. Sound levels at BAND fell below several key dBA values for much of the time; no site exceeded 35 dBA for more than 53% of the daytime hours or 23% of nighttime hours (see Table 2). The 45 dBA and higher levels were very rarely exceeded at BAND. Despite overall low noise levels, human-caused sounds were frequently heard at the most visited site, BAND001. Social science surveys have shown that some visitors at BAND are annoyed by vehicle, aircraft, and mechanical noise (Newman et al. 2013).

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Appendix A: Site Photos



a.



b.

Figure 18. BAND001, Lower Frijoles Canyon long-term acoustical monitoring site (a. winter; b. summer).



a.



b.

Figure 19. BAND002, Cerro elk enclosure long-term acoustical monitoring site (a. winter; b. summer).



a.



b.

Figure 20. BAND003, Pinon-juniper mesatop long-term acoustical monitoring site (a. winter; b. summer).



a.



b.

Figure 21. BAND004, Rio Grande long-term acoustical monitoring site (a. winter; b. summer).

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 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 acoustical 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 L ₅₀ value, while 90 percent of the time the measured levels are higher than the L ₉₀ value.
Leq	Energy Equivalent Sound Level. The sound energy level averaged over the measurement period.
Lnat (Natural Ambient Sound Level)	The natural sound conditions in parks which exist in the absence of any human-produced noise.
Noise Free Interval (NFI)	The length of the continuous period of time during which no human-caused sounds are audible.
Percent Time Above Natural Ambient	The amount of time that various sound sources are above the natural ambient sound pressure levels in a given area. It is most commonly used to measure the amount of time that human-caused sounds are above natural ambient levels. This measure is not specific to the hearing ability of a given animal, but a measure of when and how long human-caused sounds exceed natural ambient levels.
Percent Time Audible	The amount of time that various sound sources are audible to humans with normal hearing. A sound may be above natural ambient sound pressure levels, but still not audible. Similarly, some sounds that are below the natural ambient can be audible. Percent Time Audible is useful because of its simplicity. It is a measure that correlates well with visitor complaints of excessive noise and annoyance. Most noise sources are audible to humans at lower levels than virtually all wildlife species. Therefore percent time audible is a protective proxy

Term	Definition
	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 <i>sound</i> and <i>noise</i> , since these definitions have been used inconsistently in the literature. Although <i>noise</i> is sometimes incorrectly used as a synonym for sound, it is in fact sound that is undesired or extraneous to an environment. Humans perceive <i>sound</i> 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 and Sacre, 1997).
Soundscape	The human perception of physical sound resources.

Appendix C: Modeled impact levels

NSNSD developed a model 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, landcover, 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 difference between the existing and predicted natural sound level (L_{50} impact), shown below, can be used to evaluate acoustic environmental condition. Each pixel in the graphic below represents 270 m. Low impact levels are represented by black pixels, while higher levels of impact are blue to yellow.

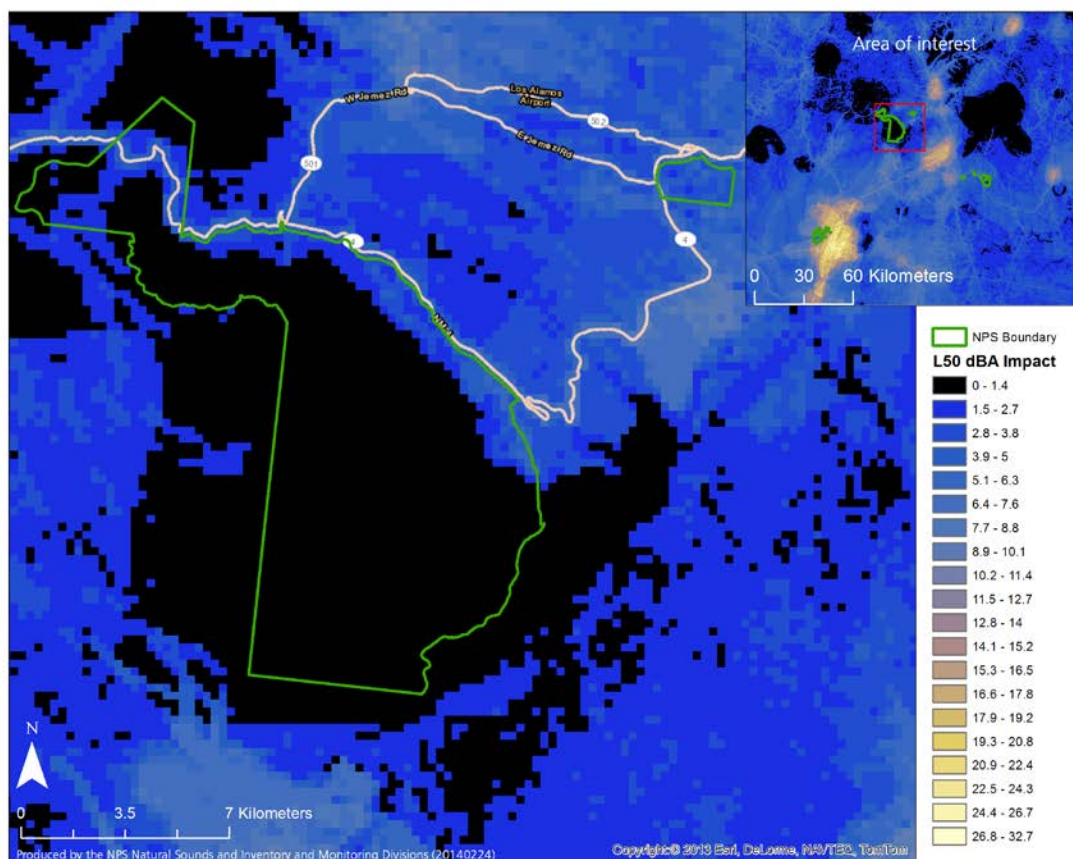


Figure 22. L_{50} dBA impact map, as generated by ver. 2.31 of geospatial model

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

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