



Walnut Canyon National Monument

Acoustic Monitoring Report

Natural Resource Report NPS/NRSS/NSNSD/NRR—2020/2135



ON THE COVER

Scenic view of Walnut Canyon (NPS)

Walnut Canyon National Monument

Acoustic Monitoring Report

Natural Resource Report NPS/NRSS/NSNSD/NRR—2020/2135

Dr. Jacob R. Job

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

June 2020

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

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

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 analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available in digital format from the [Natural Sounds and Night Skies Division website](#) and the [Natural Resource Publications Management website](#). If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

Please cite this publication as:

Job, J. R. 2020. Walnut Canyon National Monument: Acoustic monitoring report. Natural Resource Report NPS/NRSS/NSNSD/NRR—2020/2135. National Park Service, Fort Collins, Colorado.

Contents

	Page
Figures.....	iv
Tables.....	vi
Executive Summary	viii
Introduction.....	1
National Park Service Natural Sounds and Night Skies Division	1
Soundscape Planning Authorities.....	1
Study Area	3
Methods.....	5
Automatic Monitoring.....	5
Monitoring Period	5
Calculation of Metrics	5
Off-Site Listening.....	6
Results.....	7
Frequency Content.....	7
Sound Level: Percentile Levels	12
Sound Level: Time Above.....	14
Audibility of noise sources	14
Discussion.....	29
Literature Cited	31
Appendix A. Site Photographs.....	33
Appendix B. Comparison with 2010 monitoring data	34

Figures

	Page
Figure 1. Location of acoustic monitoring sites at Walnut Canyon National Monument.	4
Figure 2. Day and night percentile sound pressure levels for 33 one-third octave bands at WACA003 during the summer of 2011.....	8
Figure 3. Day and night percentile sound pressure levels for 33 one-third octave bands at WACA003 during the fall of 2012.	8
Figure 4. Day and night percentile sound pressure levels for 33 one-third octave bands at WACA003 during the winter of 2013.....	9
Figure 5. Day and night percentile sound pressure levels for 33 one-third octave bands at WACA003 during the spring of 2013.....	9
Figure 6. Day and night percentile sound pressure levels for 33 one-third octave bands at CHERRY001 during the fall of 2014.	10
Figure 7. Day and night percentile sound pressure levels for 33 one-third octave bands at CHERRY001 during the winter of 2015.....	10
Figure 8. Day and night percentile sound pressure levels for 33 one-third octave bands at CHERRY001 during the spring of 2015.....	11
Figure 9. Day and night percentile sound pressure levels for 33 one-third octave bands at CHERRY001 during the summer of 2015.....	11
Figure 10. Day and night percentile sound pressure levels for 33 one-third octave bands at CHERRY001 during the fall of 2015.....	12
Figure 11. Comparison of hourly train, gunshot, and overall noise audibility at WACA003 during the summer of 2011.....	24
Figure 12. Comparison of hourly train, gunshot, and overall noise audibility at WACA003 during the fall of 2012.	24
Figure 13. Comparison of hourly train, gunshot, and overall noise audibility at WACA003 during the winter of 2013.....	25
Figure 14. Comparison of hourly train, gunshot, and overall noise audibility at WACA003 during the spring of 2013.....	25
Figure 15. Comparison of hourly train, gunshot, and overall noise audibility at CHERRY001 during the fall of 2014.	26
Figure 16. Comparison of hourly train, gunshot, and overall noise audibility at CHERRY001 during the winter of 2015.....	26

Figures (continued)

	Page
Figure 17. Comparison of hourly train, gunshot, and overall noise audibility at CHERRY001 during the spring 2015.	27
Figure 18. Comparison of hourly train, gunshot, and overall noise audibility at CHERRY001 during the summer of 2015.	27
Figure 19. Comparison of hourly train, gunshot, and overall noise audibility at CHERRY001 during the fall of 2015.	28
Figure 20. Site photograph of CHERRY001 acoustical monitoring site during the summer deployment.	33
Figure 21. Site photograph of WACA002, Northeast Rim, acoustical monitoring site during the 2010 deployment.	35
Figure 22. Day and night percentile levels for 33 one-third octave bands at WACA002.	36

Tables

	Page
Table 1. Sound level examples.....	viii
Table 2. Mean time audible for human-caused noise, aircraft, and vehicle noise sources, existing and natural ambient sound levels at WACA003, and CHERRY001.	ix
Table 3. Time above metrics for WACA003 and CHERRY001.	x
Table 4. Acoustical terms and their definitions.....	xii
Table 5. WACA acoustical monitoring sites.....	3
Table 6. Median percentile sound levels for existing conditions in WACA, ($L_{Aeq, 1s}$), in dB re 20 μ Pa.	13
Table 7. Time above metrics for key sound levels at WACA sites.....	14
Table 8. Mean hourly percent time audible for each noise source at WACA003 during the summer of 2011.	15
Table 9. Mean hourly percent time audible for each noise source at WACA003 during the fall of 2012.	16
Table 10. Mean hourly percent time audible for each noise source at WACA003 during the winter of 2013.	17
Table 11. Mean hourly percent time audible for each noise source at WACA003 during the spring of 2013.	18
Table 12. Mean hourly percent time audible for each noise source at CHERRY001 during the fall of 2014.....	19
Table 13. Mean hourly percent time audible for each noise source at CHERRY001 during the winter of 2015.....	20
Table 14. Mean hourly percent time audible for each noise source at CHERRY001 during the spring of 2015.....	21
Table 15. Mean hourly percent time audible for each noise source at CHERRY001 during the summer of 2015.	22
Table 16. Mean hourly percent time audible for each noise source at CHERRY001 during the fall of 2015.....	23
Table 17. WACA acoustical monitoring site information, 2010.....	34

Tables (continued)

	Page
Table 18. Mean time audible for human-caused noise, aircraft, and vehicle noise sources, existing and natural ambient sound levels at WACA003, and CHERRY001.	36
Table 19. Percent time above metrics for key sound levels at WACA sites.	37

Executive Summary

Between January 2011 and May 2013 an acoustical monitoring station (WACA003) was deployed in Walnut Canyon National Monument (WACA) by park staff. After repeated vandalism events, a new station (CHERRY001) was established nearby between September 2014 and December 2015. The goal of the study was to establish a baseline soundscape inventory of the acoustical soundscape within the park, specifically focusing on patterns of presence of gunshots, trains, and overflights. This inventory will be used to establish indicators and thresholds of soundscape quality that will support the park and NSNSD in developing a comprehensive approach to protecting the acoustical environment through soundscape management planning. Additionally, results of this study will help the park identify major sources of noise within the park, as well as provide a baseline understanding of the acoustical environment as a whole for use in potential future comparative studies.

In each deployment, sound pressure level (SPL) was measured continuously every second by a calibrated, Type 1, Larson Davis 831 sound level meter. In this document, “sound pressure level” refers to broadband (12.5 Hz–20 kHz), A-weighted, 1-second time averaged sound level ($L_{Aeq, 1s}$), hereafter referred to as “sound level.” Sound levels are measured on a logarithmic scale relative to the reference sound pressure for atmospheric sources, 20 μ Pa. The logarithmic scale is a useful way to express the wide range of sound pressures perceived by the human ear. Sound levels are reported in decibels (dB). A-weighting is applied to sound levels in order to account for the response of the human ear (Harris, 1998). To approximate human hearing sensitivity, A-weighting discounts sounds below 1 kHz and above 6 kHz. Table 1 provides examples of sound levels measured in parks and common sound sources for general reference.

Table 1. Sound level examples.

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

* dB re 20 μ Pa A-weighted broadband (12.5 Hz—20 kHz), sound level measured over the duration of the event (L_{Aeq} , event)

After data collection was complete, trained technicians calculated how often noise sources were audible. 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). See Methods section for protocol details, equipment specifications, and metric calculations. Table 2 displays time audible values for each of these noise sources during the monitoring period, as well as measured sound levels. Median existing (L_{A50}) and natural ambient (L_{Anat}) sound levels are also reported for daytime (7:00–19:00) and

nighttime (19:00–7:00). Noise from trains was present the majority of the time at both sites, especially during the nighttime hours. Gun shots were heard infrequently throughout the study period, but mostly frequently during the fall season. Aircraft were heard consistently throughout all seasons and years.

Table 2. Mean time audible for human-caused noise, aircraft, and vehicle noise sources, existing and natural ambient sound levels (dB re 20 μ Pa, A-weighted broadband, 12.5 Hz–20 kHz) at WACA003, and CHERRY001.

Site ID	Year	Season ^e	Mean time audible for noise (% of 24 hour time period) ^a				Median Existing Ambient (LA ₅₀) in dB ^b		Median Natural Ambient (LA _{nat}) in dB	
			All Noise	Gunshot	Train	Aircraft	Day ^c	Night ^c	Day	Night
WACA002	2010	Summer	— ^d	—	—	—	29.7	31.7	22.1	N/A
WACA003	2011	Summer	89.8	0.3	52.9	15.4	34.6	23.3	26.2	18.2
WACA003	2012	Fall	85.2	2.5	70.8	10.7	24.2	21.5	20.4	17.0
WACA003	2013	Winter	97.8	1.0	86.3	13.7	28.0	26.5	22.2	20.0
WACA003	2013	Spring	90.6	1.5	64.9	18.3	30.5	23.4	24.1	18.1
CHERRY001	2014	Fall	95.0	7.6	77.3	16.3	25.9	26.4	21.2	20.0
CHERRY001	2015	Winter	95.3	2.1	84.9	12.4	29.2	26.6	24.0	20.3
CHERRY001	2015	Spring	95.1	3.0	78.5	16.3	27.4	26.0	21.9	19.1
CHERRY001	2015	Summer	97.9	2.7	76.3	19.2	27.9	28.1	21.1	20.4
CHERRY001	2015	Fall	95.1	4.6	75.1	16.8	29.0	28.7	22.6	22.6

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

^b For comparison, nighttime sound level (LA_{eq}) in a typical residential area is about 40 dB.

^c Day hours are 0700–1900; night hours are 1900–0700.

^d Audibility of different sources tracked for this dataset. Time audible of fixed wing aircraft and helicopters = 10.9 %, other aircraft sounds = 16.0 %, all other human sounds = 49.1 %.

^e Winter = December, January, February, Spring = March, April, May, Summer = June, July, and August, and Fall = September, October, November

Table 3 reports the percent of time that measured levels at the three monitoring locations were above four key values. The first value, 35 dB (LA_{eq, 1s}), 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 in sleeping humans (Haralabidis et al. 2008). This level, 35 dB, is also the desired background sound level in classrooms (ANSI S12.60-2002). The second value addresses the World Health Organization’s recommendations that noise levels inside bedrooms remain below 45 dB (LA_{eq, 1s}) (Berglund et al. 1999). The third value, 52 dB (LA_{eq, 1s}), is based on the EPA’s speech interference level for speaking in a raised voice to an audience at 10 meters (EPA 1974). This value addresses the effects of sound on interpretive presentations in parks. The final value, 60 dB (LA_{eq, 1s}), provides a basis for estimating speech interference on normal voice communications at 1 meter. Visitors viewing scenic areas in the park would likely be conducting such conversations.

Sound levels are typically measured over narrow frequency bands (typically in one-third octave bands between 12.5 Hz–20 kHz) because these smaller bands closely represent how humans distinguish between frequencies of sound. In this study, we examine how often sound levels exceeded these key values in two frequency *ranges*. The top value in each split-cell of Table 3 uses the full frequency range (12.5 Hz–20 kHz) collected, whereas the bottom value focuses on frequencies affected by low frequency noise sources (20–1,250 Hz). Most motorized human-caused noise is confined to the truncated, lower-frequency range, while many natural sounds, including insects and birds, are higher in pitch. Therefore, the truncated range (20–1,250 Hz) is more appropriate for identifying impacts from anthropogenic noise in parks (Acoustical Society of America 2014).

Table 3. Time above metrics for WACA003 and CHERRY001.

Site ID	Frequency (Hz)	Time above sound level (% of daytime hours, 07:00 to 19:00)				Time above sound level (% of nighttime hours, 19:00 to 07:00)			
		35 dB*	45 dB*	52 dB*	60 dB*	35 dB*	45 dB*	52 dB*	60 dB*
WACA003 Summer 2011	12.5–20,000	58.0	18.5	4.4	0.1	7.6	0.6	0.1	0.0
	20–1,250	19.1	1.2	0.2	0.0	6.1	0.4	0.1	0.0
WACA003 Fall 2012	12.5–20,000	6.6	0.5	0.1	0.0	2.3	0.1	0.0	0.0
	20–1,250	5.4	0.4	0.1	0.0	2.0	0.1	0.0	0.0
WACA003 Winter 2013	12.5–20,000	16.5	1.1	0.2	0.0	12.1	0.5	0.1	0.0
	20–1,250	15.0	0.8	0.1	0.0	10.5	0.4	0.1	0.0
WACA003 Spring 2013	12.5–20,000	36.7	2.6	0.3	0.0	7.8	0.4	0.1	0.0
	20–1,250	29.9	1.9	0.2	0.0	6.9	0.3	0.1	0.0
CHERRY001 Fall 2014	12.5–20,000	10.6	0.9	0.2	0.0	11.1	0.4	0.1	0.0
	20–1,250	7.1	0.6	0.1	0.0	4.4	0.3	0.0	0.0
CHERRY001 Winter 2015	12.5–20,000	21.3	1.0	0.2	0.0	8.8	0.3	0.1	0.0
	20–1,250	18.4	0.9	0.2	0.0	8.6	0.3	0.0	0.0
CHERRY001 Spring 2015	12.5–20,000	13.3	1.0	0.2	0.0	9.0	0.4	0.1	0.0
	20–1,250	11.6	0.8	0.1	0.0	7.4	0.4	0.1	0.0
CHERRY0001 Summer 2015	12.5–20,000	16.2	1.1	0.2	0.0	16.7	0.8	0.1	0.0
	20–1,250	13.3	0.8	0.2	0.0	6.6	0.3	0.1	0.0
CHERRY001 Fall 2015	12.5–20,000	16.9	2.0	0.2	0.0	22.5	0.6	0.1	0.0
	20–1,250	11.2	0.8	0.2	0.0	5.2	0.3	0.0	0.0

* dB re 20 µPa

Noise is highly prevalent in the WACA soundscape, but introduces only moderate acoustic energy into the environment. Noise audibility was over 85% at both sites for the duration of the study and was often over 95%, leaving few opportunities for a noise-free experience at the monitoring sites.

Acknowledgments

On-site acoustical data were collected by Mark Szydlo, Paul Whitefield, Tamaryn Gladden, Brent Hetzler, Katie Kees, Kerry Gaiz, and Catherine Bollich. The authors of this report wish to express their gratitude to Henry Joyner, Jared Lamb, and Haley Stapleton for their work in the off-site analysis of the acoustical data.

Glossary of Acoustical Terms

Table 4. Acoustical terms and their definitions.

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).
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.
L _{A50} , L _{A90}	Metrics used to describe A-weighted 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 _{A50} value, while 90 percent of the time the measured levels are higher than the L _{A90} 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 _{Aeq}	A-weighted Energy Equivalent Sound Level. The sound energy level averaged over the measurement period.
L _{Anat} (Natural Ambient Sound Level)	The natural sound conditions in parks, which would 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.

Table 4 (continued). Acoustical terms and their definitions.

Term	Definition
Time Audible	The amount of time that various sound sources are audible to humans with normal hearing, commonly expressed in percent of day, or percent of daytime hours and nighttime hours. A sound may be above natural ambient sound pressure levels, but still not audible. Similarly, some sounds that are below the natural ambient can be audible. Time Audible is useful because of its simplicity. It is a measure that correlates well with visitor complaints of excessive noise and annoyance. Most noise sources are audible to humans at lower levels than virtually all wildlife species. Therefore, time audible is a protective proxy for wildlife. These data can be collected either by a trained observer (on-site listening) or by making high-quality digital recordings for later playback (off-site listening).
Sound Exposure Level (SEL)	The total sound energy of the actual sound during a specific time period. SEL is usually expressed using a time period of one second.
Sound Pressure	Minute change in atmospheric pressure due to passage of sound that can be detected by microphones.
Sound vs.Noise	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 1997).
Soundscape	The human perception of physical sound resources.

Introduction

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

National Park Service Natural Sounds and Night Skies Division

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

Soundscape Planning Authorities

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

Direction for management of natural soundscapes¹ is represented in 2006 Management Policy 4.9:

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

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

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

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

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

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

National Parks Air Tour Management Act (NPATMA) was passed on April 5, 2000 to regulate commercial air tour operations for each unit of the National Park System, or abutting tribal land, where such operations occur or are proposed. The Act required the Federal Aviation Administration (FAA), in cooperation with the NPS, to develop an Air Tour Management Plan (ATMP) for each unit of the National Park System to provide acceptable and effective measures to mitigate or prevent the significant adverse impacts, if any, of commercial air tour operations upon natural and cultural resources and visitor experiences. In 2012, NPATMA was amended to allow the FAA and NPS to enter into voluntary agreements with a commercial air tour operator as an alternative to an ATMP.

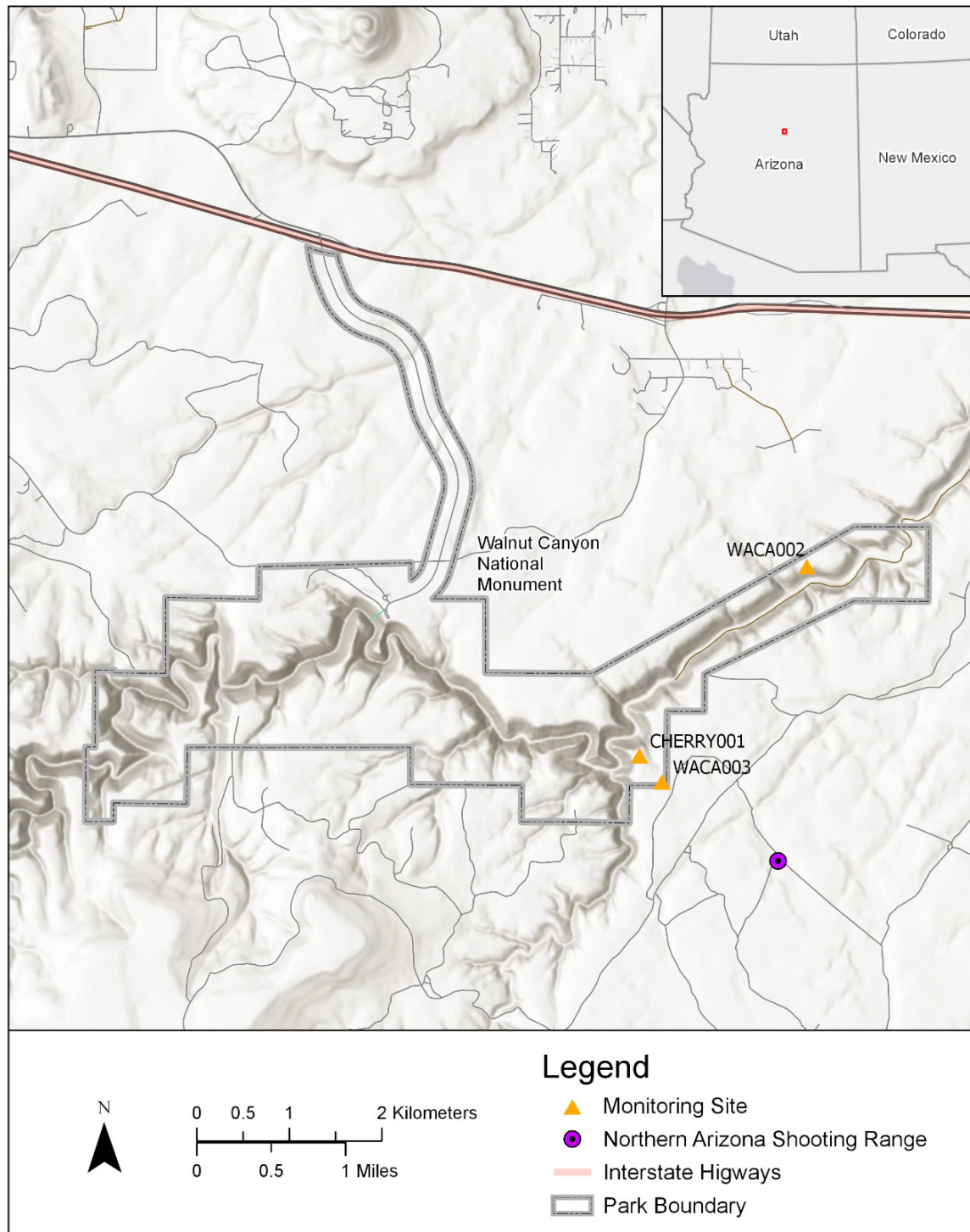
Study Area

Walnut Canyon National Monument (WACA) was formally established in 1915 by President Woodrow Wilson to “preserve ancient cliff dwellings,” referring to the works of the Ancestral Puebloan people. In 2017, more than 165,000 visitors explored the park. The 3,600 acre monument protects about ten miles of Walnut Creek. This creek carved the 400 foot deep, quarter-mile wide Walnut Canyon over millions of years.

Starting in the summer of 2011 and continuing through winter 2013, an acoustical monitoring station (WACA003) was deployed in the park. However, this station experienced multiple instances of vandalism that required the monitoring location to be moved to a new location (CHERRY001). Table 5 shows site information regarding the monitoring stations (details about WACA002, an earlier site, are included for reference: see Appendix B for more information on this site). Figure 1 shows the location of the acoustic monitoring stations in the park. A photo of the CHERRY001 acoustical monitoring station is included in Appendix A.

Table 5. WACA acoustical monitoring sites.

Site ID	Dates Deployed	Vegetation	Elevation (m)	Latitude	Longitude
WACA002	7/6/10–8/5/10	Pinyon-Juniper Shrubland	1982	35.17731	–111.45950
WACA003	7/14/15–8/5/15 & 2/23/16–4/4/15	Pinyon-Juniper Shrubland	2029	35.15623	–111.47660
CHERRY001	7/15/15–8/5/15 & 2/23/16–3/22/16	Pinyon-Juniper Shrubland	2034	35.15878	–111.47920



Produced by E. Brown, Natural Sounds and Night Skies Division, August 2019

Figure 1. Location of acoustic monitoring sites at Walnut Canyon National Monument.

Methods

Automatic Monitoring

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

The sampling stations consisted of:

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

The sampling stations collected:

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

Monitoring Period

The monitoring period lasted approximately 29 days. NSNSD has determined that 25 day monitoring periods during opposing seasons allow the data to capture seasonal difference that occur at each site within a reasonable margin of error (NPS 2005). Seasons were defined as Winter = December/ January/ February, Spring = March/ April/ May, Summer = June/ July/ August, and Fall = September/ October/ November. Though data from all seasons were not available at all sites, dividing results into season helps park staff see changes in conditions over time.

Calculation of Metrics

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

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

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

P_H is the percentage of samples containing noise for the hour. For example, if human caused sounds are present 30% of the hour, $x = 65$, and the L_{Anat} is equal to the L_{65} , or the level exceeded 65% of the time. To summarize and display these data, the median of the hourly L_{Anat} values for the daytime hours (0700–1900) and the median of the hourly L_{Anat} values for the nighttime (1900–0700) are displayed in Figures 2–10 in the results section. Additionally, these figures separate the data into 33 one-third octave bands.

Off-Site Listening

Off-site listening is normally done by listening to an audio recording and simultaneously visually analyzing a spectrogram. Auditory analysis was used to calculate the audibility of sound sources at the monitoring locations. 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 noise was audible to calculate the natural ambient sound level for each hour (see Equation 1 above for more information). Bose Quiet Comfort Noise Canceling headphones were used for off-site audio playback to minimize limitations imposed by the office acoustical environment. For the complete results of this thorough audibility analysis, see Tables 7–15 in the Off-Site Data Analysis section below.

Results

Frequency Content

In order to determine the effect that noise audibility has on the acoustical environment, it is useful to examine the percentile metrics across a frequency range. High frequency sounds (such as a cricket chirping) and low frequency sounds (such as flowing water) often occur simultaneously, so the frequency spectrum is split into 33 smaller ranges, each encompassing one-third of an octave. These smaller bands closely represent how humans distinguish between frequencies of sound. For each one-third octave band, sound level ($L_{eq, 1s}$) was recorded once per second for the duration of the monitoring periods. The percentile sound levels for 33 one-third octave band frequencies over the day and night periods are shown in Figures 2–10.

Examining the sound energy in each one-third octave band (combined with digital audio recordings) allows acoustic technicians to determine what types of sounds are contributing to the overall sound levels at a site. The grayed area of the graph represents sound levels outside of the typical range of human hearing. The percentile levels (L_x) are also shown for each one-third octave band. They represent the sound levels exceeded x percent of the time. For example, L_{90} is the sound level that has been exceeded 90% of the time, and only the quietest 10% of the samples can be found below this point. On the other hand, the L_{10} is the sound level that has been exceeded 10% of the time, and 90% of the measurements are quieter than the L_{10} . The bold portion of the column represents the difference between L_{50} and L_{nat} . The height of this bold portion is a measure of the contribution of anthropogenic noise to the existing sound levels at this site. The size of this portion of the column is directly related to the percent time that human caused sounds are audible. When bold portions of the column do not appear the natural and existing sound levels were either very close to each other, or were equal.

The typical frequency levels for transportation, conversation, and songbirds are presented on the figure as examples for interpretation of the data. These ranges are estimates and are not vehicle-, species-, or habitat-specific.

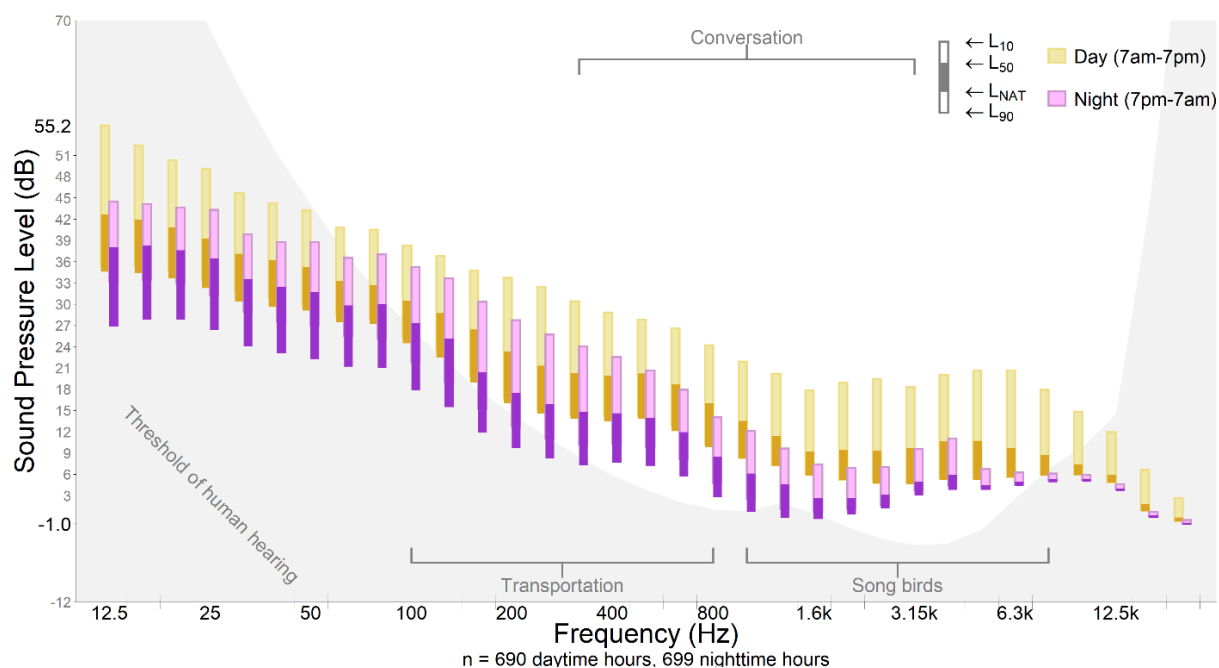


Figure 2. Day and night percentile sound pressure levels for 33 one-third octave bands at WACA003 during the summer of 2011.

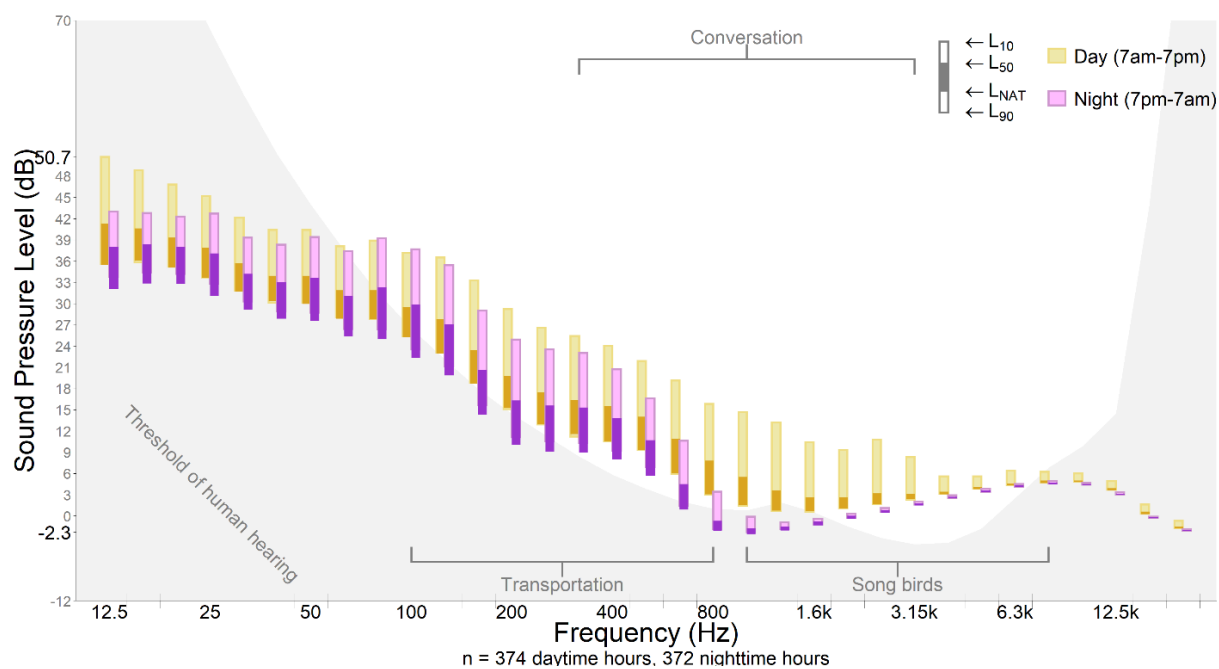


Figure 3. Day and night percentile sound pressure levels for 33 one-third octave bands at WACA003 during the fall of 2012.

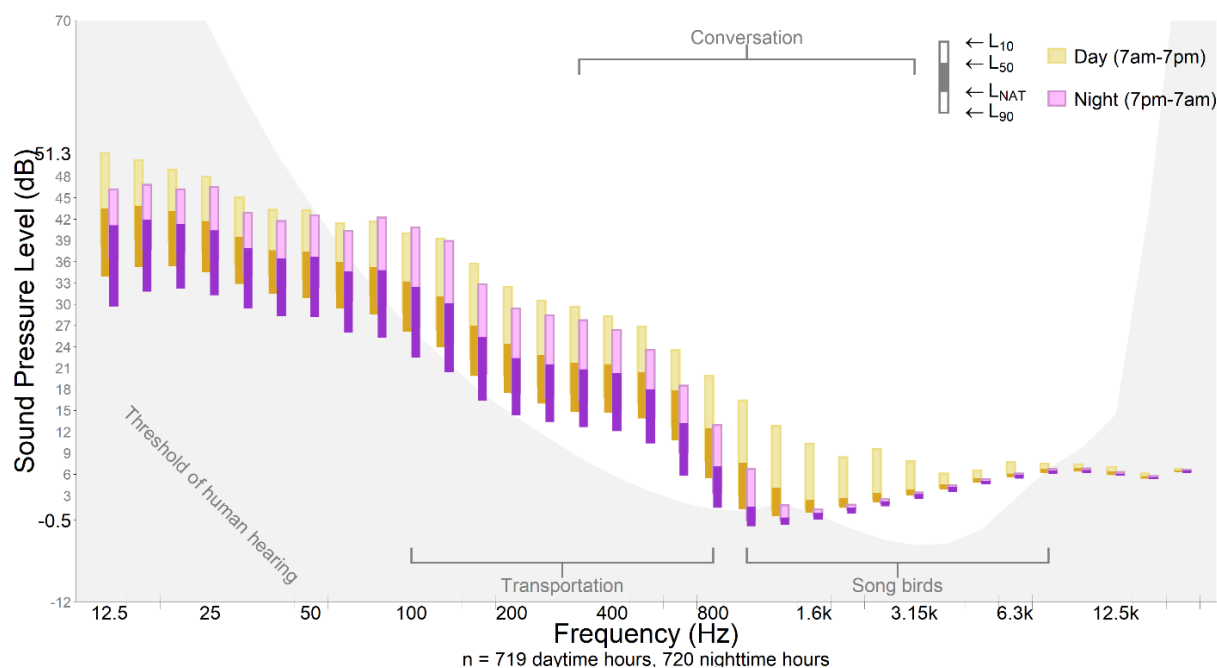


Figure 4. Day and night percentile sound pressure levels for 33 one-third octave bands at WACA003 during the winter of 2013.

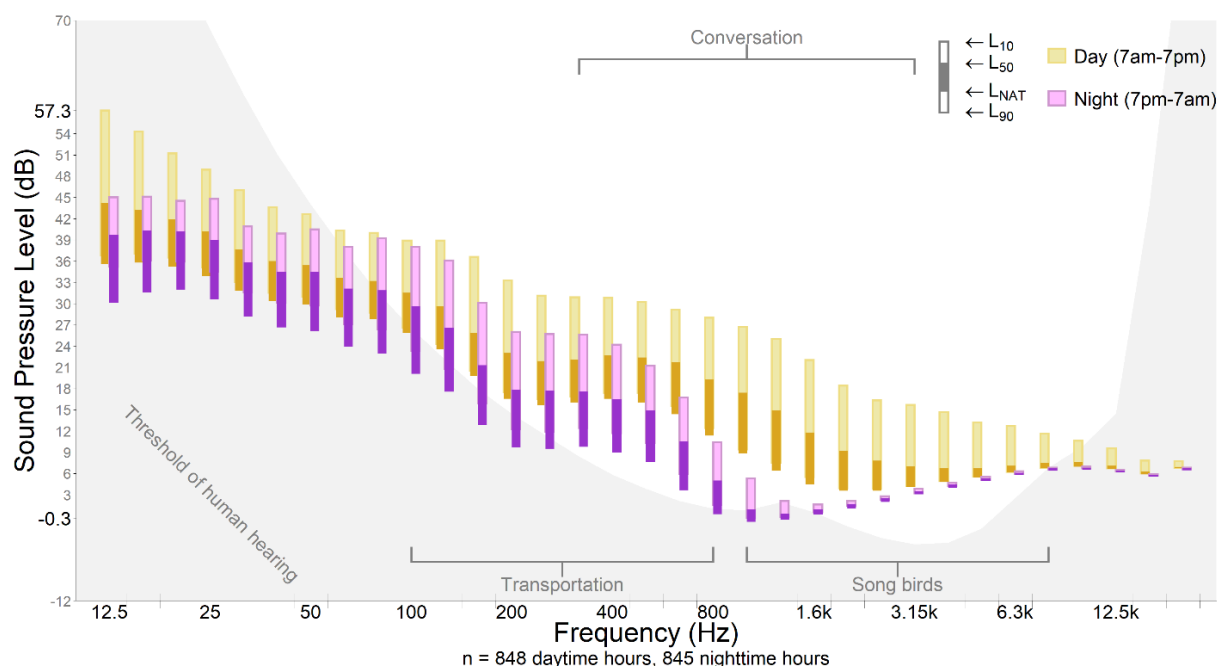


Figure 5. Day and night percentile sound pressure levels for 33 one-third octave bands at WACA003 during the spring of 2013.

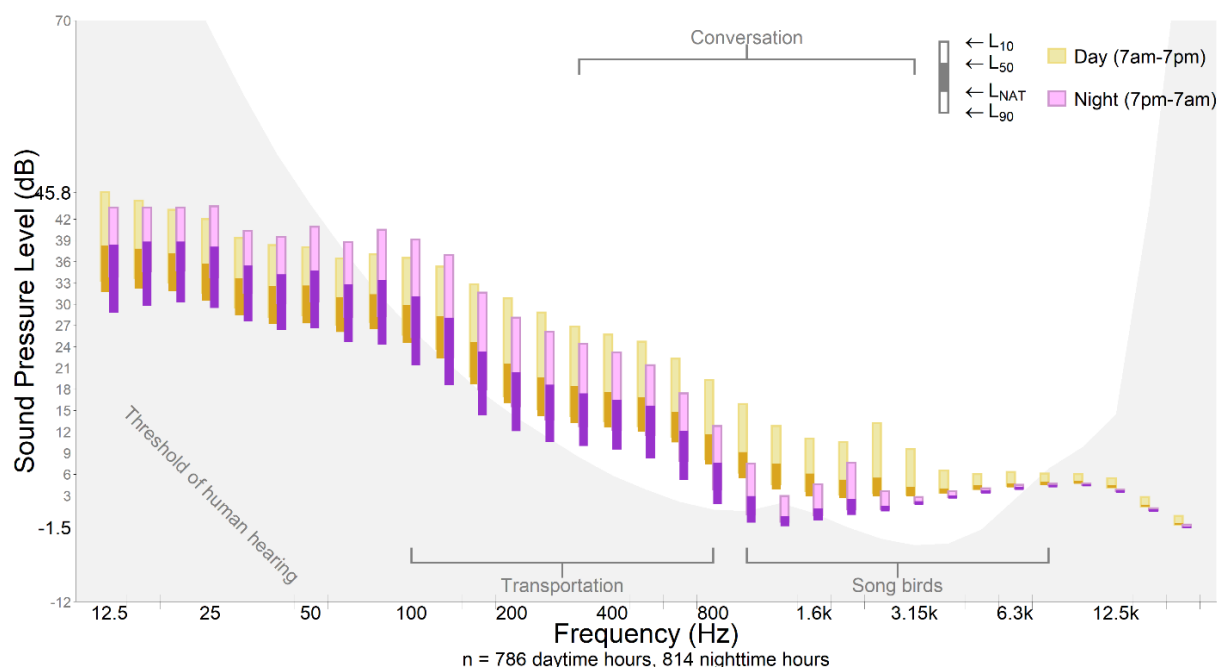


Figure 6. Day and night percentile sound pressure levels for 33 one-third octave bands at CHERRY001 during the fall of 2014.

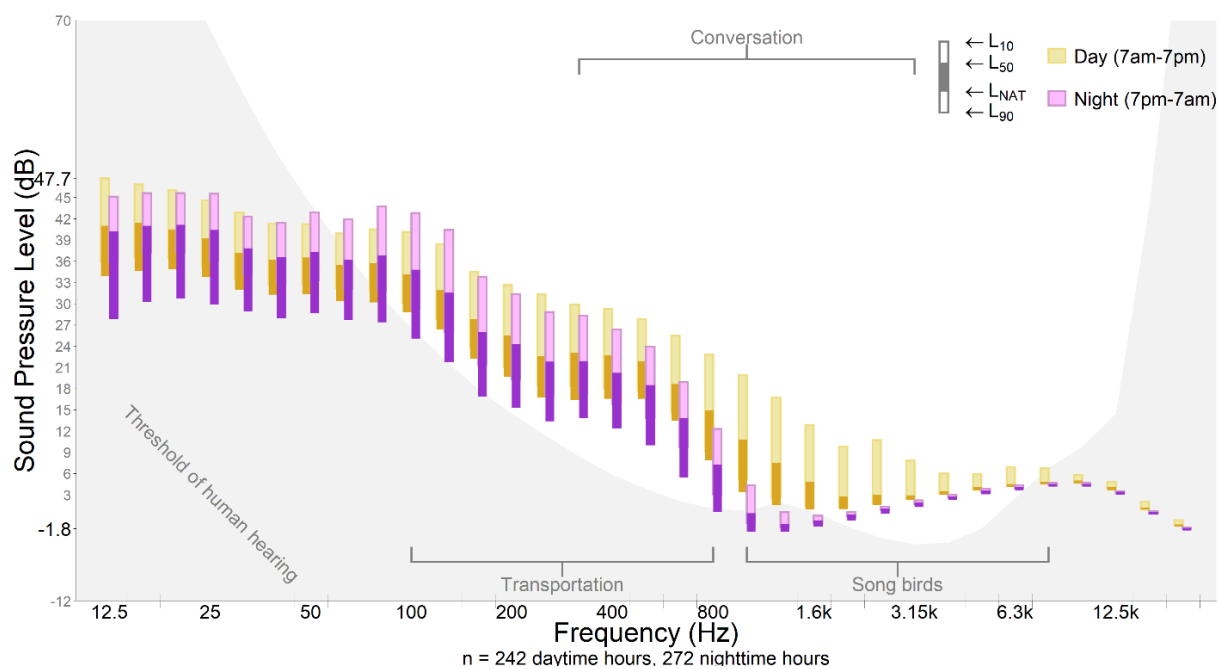


Figure 7. Day and night percentile sound pressure levels for 33 one-third octave bands at CHERRY001 during the winter of 2015.

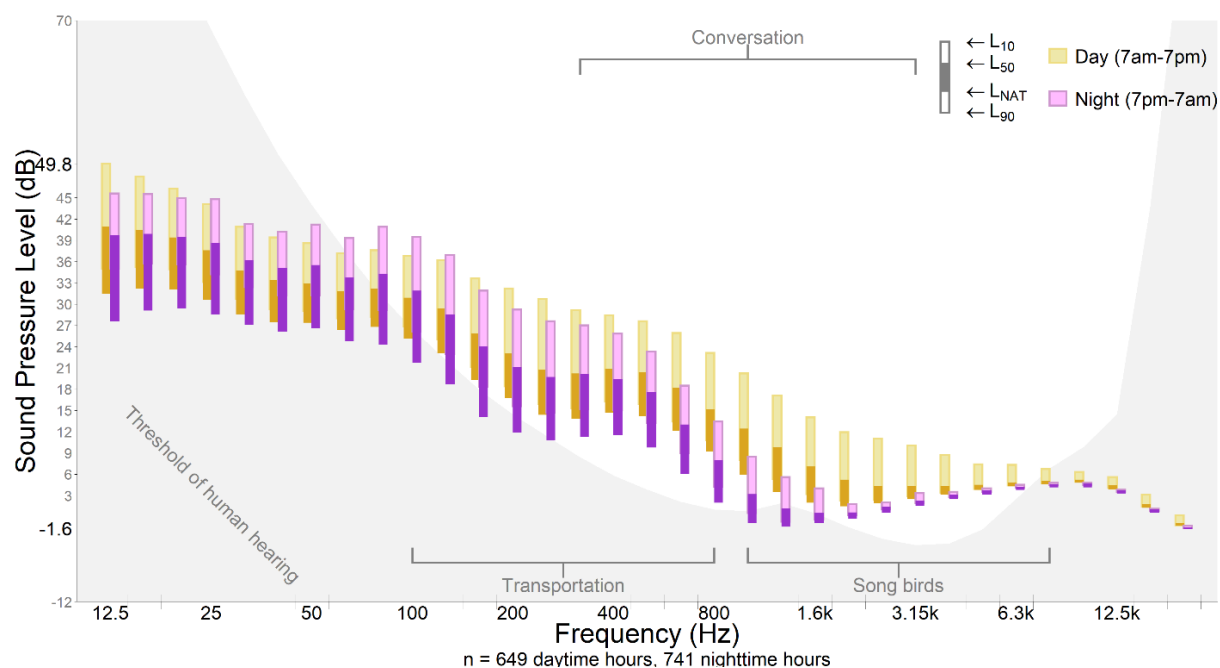


Figure 8. Day and night percentile sound pressure levels for 33 one-third octave bands at CHERRY001 during the spring of 2015.

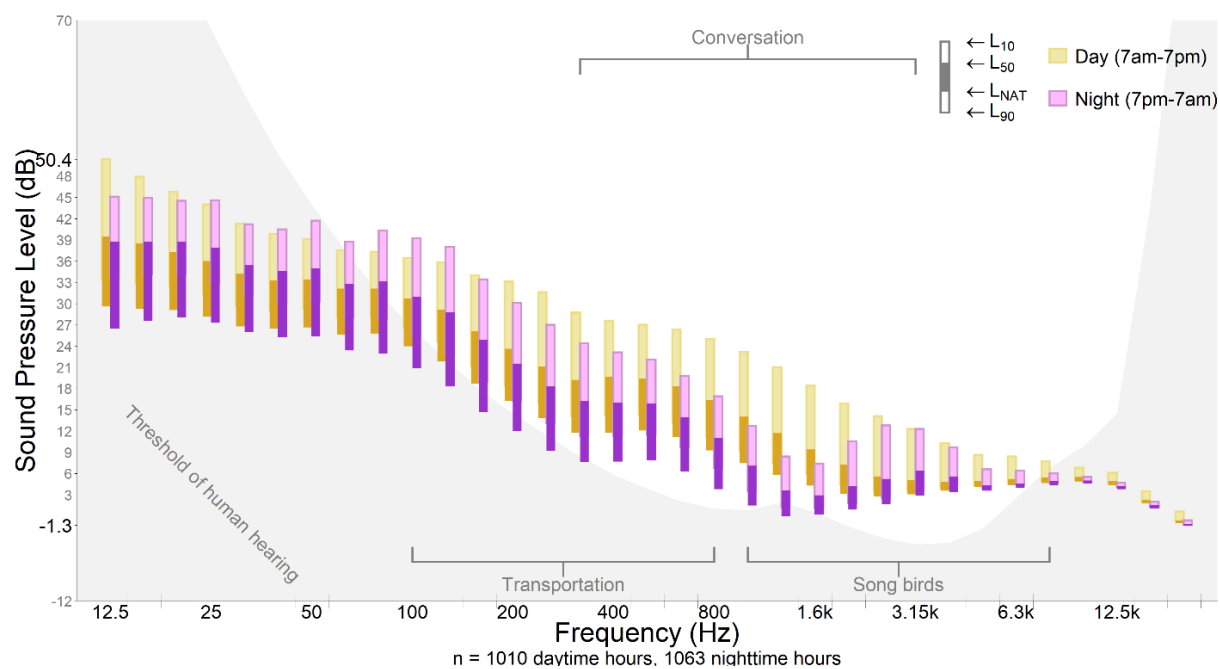


Figure 9. Day and night percentile sound pressure levels for 33 one-third octave bands at CHERRY001 during the summer of 2015.

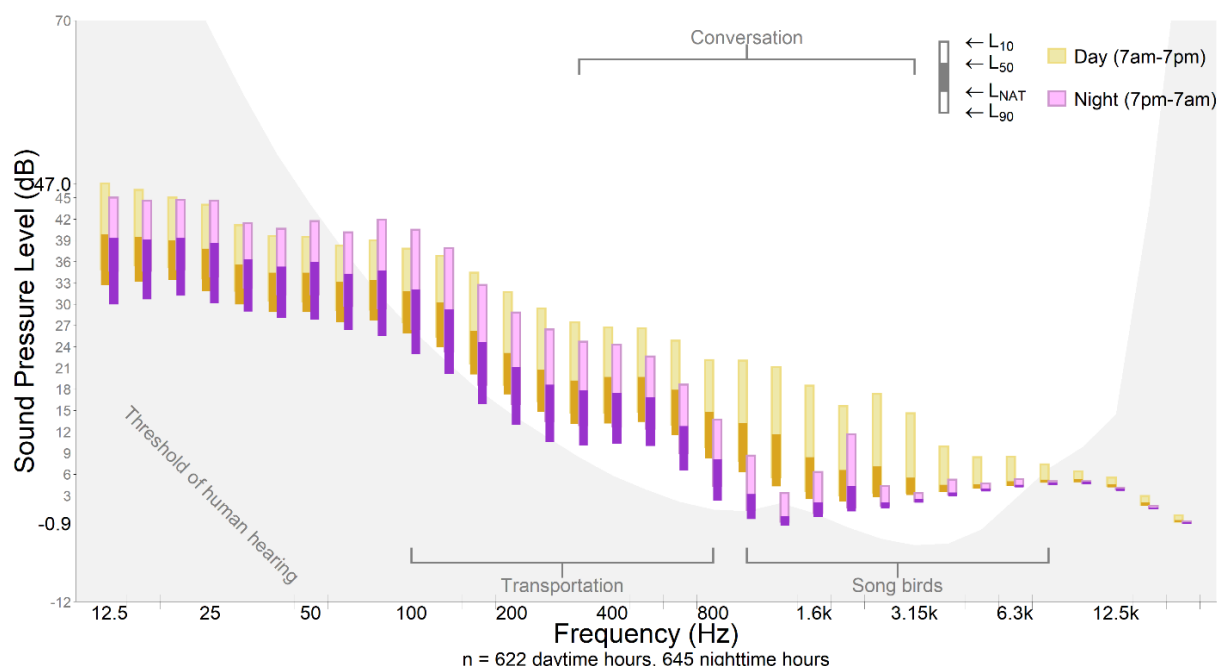


Figure 10. Day and night percentile sound pressure levels for 33 one-third octave bands at CHERRY001 during the fall of 2015.

Sound Level: Percentile Levels

Table 6 reports the A-weighted percentile sound levels (L_{A90} , $L_{A\text{nat}}$, L_{A50} , and L_{A10}) for the acoustical monitoring sites in WACA. These values are calculated from the hourly broadband (12.5 Hz–20 kHz) A-weighted 1-second time averaged sound levels ($L_{A\text{eq}, 1s}$). The top value in each cell focuses on the full frequency range, whereas the lower values use frequencies affected by transportation noise. Most human-caused noise is confined to a lower frequency range (20–1,250 Hz), 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 (Acoustical Society of America 2014). As described above, percentile sound levels (L_{Ax}) represent the sound level exceeded x percent of time during the given measurement period. For instance, in Table 6, the L_{A90} for WACA003 during the daytime in the summer of 2011 is 26.8 dB, a 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_{A10} for the same time period at this site is 43.2 dB, a level that has been exceeded 10% of the time, and 90% of the measurements are quieter than the L_{A10} .

Table 6. Median percentile sound levels for existing conditions in WACA, ($L_{Aeq, 1s}$), in dB re 20 μ Pa.

Site ID	Frequency (Hz)	Percentile levels (Daytime hours 0700 to 1900)				Percentile levels (Nighttime hours 1900 to 0700)			
		LA ₉₀	LA _{nat}	LA ₅₀	LA ₁₀	LA ₉₀	LA _{nat}	LA ₅₀	LA ₁₀
WACA003 Summer 2011	12.5–20,000	26.8	26.2	34.6	43.2	19.8	18.2	23.3	30.4
	20–1,250	22.0	21.3	27.8	35.7	17.6	15.2	21.7	29.3
WACA003 Fall 2012	12.5–20,000	20.5	20.4	24.2	31.7	17.8	17.0	21.5	28.1
	20–1,250	18.8	18.7	23.3	31.0	15.8	14.7	20.5	27.8
WACA003 Winter 2013	12.5–20,000	24.2	22.2	28.0	34.6	22.3	20.0	26.5	32.4
	20–1,250	23.6	21.3	27.6	34.3	21.5	18.7	26.3	32.2
WACA003 Spring 2013	12.5–20,000	25.0	24.1	30.5	38.0	19.6	18.1	23.4	30.2
	20–1,250	23.4	22.3	28.6	36.6	17.7	15.5	22.6	29.7
CHERRY001 Fall 2014	12.5–20,000	22.0	21.2	25.9	33.2	22.2	20.0	26.4	32.1
	20–1,250	18.9	18.1	22.5	30.4	16.2	13.9	20.8	27.3
CHERRY001 Winter 2015	12.5–20,000	25.4	24.0	29.2	35.6	23.0	20.3	26.6	33.0
	20–1,250	24.7	23.1	28.6	35.2	22.3	19.3	26.1	32.7
CHERRY001 Spring 2015	12.5–20,000	23.1	21.9	27.4	34.9	21.6	19.1	26.0	32.5
	20–1,250	22.3	20.7	26.9	34.4	20.6	17.7	25.2	32.1
CHERRY001 Summer 2015	12.5–20,000	23.1	21.1	27.9	35.7	23.4	20.4	28.1	34.6
	20–1,250	22.0	19.9	27.1	35.0	19.6	16.4	24.5	31.7
CHERRY001 Fall 2015	12.5–20,000	23.9	22.6	29.0	36.1	24.4	22.6	28.7	34.5
	20–1,250	22.7	21.1	27.5	34.2	19.7	17.5	24.4	31.4

Table 7 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 uses the full frequency range, whereas the lower value focuses on frequencies affected by transportation noise sources. The first, 35 dB ($L_{Aeq, 1s}$), 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 in sleeping humans (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 dB ($L_{Aeq, 1s}$) (Berglund et al. 1999). The third value, 52 dB ($L_{Aeq, 1s}$), is based on the EPA's speech interference threshold for speaking in a raised voice to an audience at 10 meters (EPA 1974). This threshold addresses the effects of sound on interpretive presentations in parks. The final value, 60 dB ($L_{Aeq, 1s}$), provides a basis for estimating impacts on normal voice communications at 1 meter. Visitors viewing scenic areas in the park would likely be conducting such conversations. The top value in each split-cell uses the full frequency range (12.5–20,000 Hz), whereas the bottom value focuses on frequencies affected by lower-frequency noise (20–1250 Hz). Most motorized human-caused noise is confined to the truncated, lower-frequency range, while many natural sounds, including insects and birds, are higher in pitch. Therefore, the truncated range (20–1250 Hz) is more appropriate for identifying impacts from anthropogenic noise in parks (Acoustical Society of America 2014).

Sound Level: Time Above

Table 7. Time above metrics for key sound levels at WACA sites.

Site ID	Frequency (Hz)	Time above sound level (% of daytime hours, 07:00 to 19:00)				Time above sound level (% of nighttime hours, 19:00 to 07:00)			
		35 dB*	45 dB*	52 dB*	60 dB*	35 dB*	45 dB*	52 dB*	60 dB*
WACA003 Summer 2011	12.5–20,000	58.0	18.5	4.4	0.1	7.6	0.6	0.1	0.0
	20–1,250	19.1	1.2	0.2	0.0	6.1	0.4	0.1	0.0
WACA003 Fall 2012	12.5–20,000	6.6	0.5	0.1	0.0	2.3	0.1	0.0	0.0
	20–1,250	5.4	0.4	0.1	0.0	2.0	0.1	0.0	0.0
WACA003 Winter 2013	12.5–20,000	16.5	1.1	0.2	0.0	12.1	0.5	0.1	0.0
	20–1,250	15.0	0.8	0.1	0.0	10.5	0.4	0.1	0.0
WACA003 Spring 2013	12.5–20,000	36.7	2.6	0.3	0.0	7.8	0.4	0.1	0.0
	20–1,250	29.9	1.9	0.2	0.0	6.9	0.3	0.1	0.0
CHERRY001 Fall 2014	12.5–20,000	10.6	0.9	0.2	0.0	11.1	0.4	0.1	0.0
	20–1,250	7.1	0.6	0.1	0.0	4.4	0.3	0.0	0.0
CHERRY001 Winter 2015	12.5–20,000	21.3	1.0	0.2	0.0	8.8	0.3	0.1	0.0
	20–1,250	18.4	0.9	0.2	0.0	8.6	0.3	0.0	0.0
CHERRY001 Spring 2015	12.5–20,000	13.3	1.0	0.2	0.0	9.0	0.4	0.1	0.0
	20–1,250	11.6	0.8	0.1	0.0	7.4	0.4	0.1	0.0
CHERRY001 Summer 2015	12.5–20,000	16.2	1.1	0.2	0.0	16.7	0.8	0.1	0.0
	20–1,250	13.3	0.8	0.2	0.0	6.6	0.3	0.1	0.0
CHERRY001 Fall 2015	12.5–20,000	16.9	2.0	0.2	0.0	22.5	0.6	0.1	0.0
	20–1,250	11.2	0.8	0.2	0.0	5.2	0.3	0.0	0.0

* dB re 20 μ Pa

Audibility of noise sources

Identifying the percent of time a noise source is audible is an important step in understanding the acoustic environment. Tables 8–16 show the mean percentage of time that trains and gunshots, as well as other all other sources of anthropogenic noise, were audible by hour. Results are presented for each season. Trained analysts examined eight days for each season, and audibility results are averaged over those eight days.

Figures 11–19 show these hourly audibility results in graphical format and compare overall noise audibility to that of individual noise sources such as trains and gunshots.

Table 8. Mean hourly percent time audible for each noise source at WACA003 during the summer of 2011.

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	7.8	5.0	1.1	5.6	2.8	0.6	4.4	12.2	24.4	25.0	16.7	22.2	22.8	12.2	13.9	25.0	27.8	25.0	19.4	33.3	22.8	16.7	13.3	10.0
Vehicle	2.2	0.0	0.0	0.0	0.0	2.8	7.8	3.9	3.3	7.2	5.6	3.9	6.7	4.4	2.8	2.8	0.0	1.1	0.0	0.0	0.6	0.0	1.1	0.0
Train	81.7	93.9	90.6	85.0	87.8	79.4	78.9	78.9	35.0	26.7	20.6	34.4	34.4	23.9	15.0	18.9	26.1	28.3	30.6	45.6	52.8	53.9	70.6	76.1
Grounds Care ^a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.1	6.1	4.4	3.3	1.7	2.8	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
People	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	1.7	1.1	0.0	0.0	0.0	1.1	0.0	0.0	8.3	9.4	1.7	0.6	0.0	0.0
Gunshot	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	1.1	1.7	1.7	0.0	0.0	0.0	0.0
Non-Natural Unknown ^b	15.6	10.6	23.9	23.3	26.1	23.9	26.7	25.6	45.6	45.0	47.8	35.0	43.9	41.1	41.1	33.9	31.1	30.0	24.4	20.0	26.1	26.1	23.3	13.3
Wind	7.8	11.1	6.1	4.4	3.9	3.3	1.7	5.6	28.3	45.0	49.4	45.6	56.1	62.2	77.8	72.2	53.3	48.3	56.1	33.9	35.6	32.8	32.2	33.3
Water	2.2	12.2	11.1	11.1	0.0	0.0	11.7	12.8	5.6	0.0	0.0	0.0	2.8	3.3	2.2	8.3	13.9	0.0	0.0	0.6	0.0	0.0	0.0	0.0
Thunder	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	12.2	8.9	5.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mammal	2.8	2.2	0.0	1.1	1.1	8.3	1.1	1.1	5.6	0.6	0.6	3.9	3.9	2.8	3.3	6.1	0.0	0.0	0.0	0.6	1.1	0.0	0.0	0.0
Bird	15.6	4.4	4.4	9.4	87.2	100.0	96.1	95.0	82.2	78.3	61.1	72.2	68.9	63.9	70.6	56.1	56.7	53.3	58.9	46.7	11.7	2.2	3.3	2.2
Insect	66.7	82.2	77.2	68.3	35.0	13.3	35.0	67.2	90.6	95.0	95.0	90.6	93.3	83.9	75.0	67.8	78.9	90.6	87.2	91.7	98.9	100.0	100.0	100.0
Animal	0.6	1.7	0.6	0.6	1.1	7.8	3.3	2.2	0.0	0.0	0.0	1.7	0.6	0.6	0.0	3.9	6.1	1.1	0.0	1.1	2.2	2.2	1.7	0.0
Natural Unknown ^c	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.6	2.8	2.2	0.6	0.6	0.6	0.0	0.0

^a Grounds Care denotes chainsaw noise.

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

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

Table 9. Mean hourly percent time audible for each noise source at WACA003 during the fall of 2012.

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	1.9	2.6	0.4	1.9	3.3	4.1	1.9	6.7	8.9	17.0	19.3	20.7	14.4	14.4	12.6	18.5	21.9	17.8	12.2	20.0	13.0	12.2	7.4	3.7
Vehicle	0.0	0.4	1.1	0.0	0.7	1.9	8.9	2.6	0.4	1.9	2.6	0.7	1.9	3.0	2.6	1.1	0.7	3.0	1.5	2.6	0.0	0.4	1.1	1.1
Train	88.1	87.0	88.5	87.8	87.0	87.4	87.4	87.8	86.3	79.6	69.6	46.3	44.8	33.0	20.4	27.0	43.3	54.1	80.7	78.1	83.0	74.8	86.3	91.1
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	0.0	0.7	1.1	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Gunshot	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.4	0.0	4.1	4.8	8.9	13.3	5.9	9.3	5.2	4.1	2.2	0.4	0.0	0.0	0.0	0.0	0.0
Non-Natural Unknown ^a	0.0	0.0	0.0	0.0	0.0	1.1	0.7	0.0	0.0	0.0	3.3	17.8	11.5	15.9	21.1	27.8	12.6	11.5	2.2	1.1	1.9	3.0	5.6	1.5
Wind	12.6	11.9	11.1	11.1	11.1	12.2	11.5	11.1	10.7	11.9	21.1	29.3	55.9	65.2	73.7	47.0	29.6	22.6	24.4	5.6	7.8	10.7	11.5	12.2
Thunder	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mammal	1.9	5.2	1.9	0.4	4.4	0.4	3.7	3.7	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	8.9	14.8	13.3	12.2	11.9	7.4
Bird	3.0	2.2	3.7	4.1	8.5	5.9	43.7	95.2	91.1	90.0	88.1	83.0	76.3	73.0	70.7	71.5	76.7	40.4	4.1	8.1	3.0	3.0	1.9	3.0
Insect	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.1	8.1	14.4	23.3	18.9	18.1	22.6	33.3	34.8	21.1	6.7	6.7	6.3	0.4	0.0	0.0
Animal	0.0	0.0	0.4	0.0	0.4	1.5	0.4	0.0	0.0	0.0	2.6	0.4	0.4	0.0	0.0	0.0	1.5	0.7	1.9	2.2	0.0	0.0	0.0	0.0
Natural Unknown ^b	0.4	0.0	0.0	0.4	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.4

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

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

Table 10. Mean hourly percent time audible for each noise source at WACA003 during the winter of 2013.

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	7.1	11.3	5.0	3.3	3.8	8.7	2.9	4.6	12.5	14.6	24.6	17.9	22.9	28.7	25.8	20.4	23.7	19.2	17.5	14.2	13.3	12.1	8.7	5.8
Vehicle	0.4	0.8	1.2	1.2	1.2	0.8	0.8	2.5	2.1	3.8	2.5	2.1	1.2	0.4	1.2	3.3	0.8	2.1	0.0	2.1	0.8	1.2	0.0	0.0
Train	85.8	90.8	89.2	95.0	92.9	84.2	95.4	95.0	92.9	91.7	79.6	83.7	79.6	72.1	75.4	81.2	75.8	75.0	82.1	85.8	87.1	93.3	97.5	89.2
People	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
Gunshot	0.0	0.0	0.0	0.0	0.0	1.2	0.4	0.4	1.2	4.2	2.9	4.2	6.2	0.4	0.4	1.2	1.2	0.8	0.4	0.0	0.0	0.0	0.0	0.0
Domestic Animal	0.0	0.0	2.5	0.8	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.0	0.0	0.0
Non-Natural Unknown ^a	17.9	12.9	15.8	12.1	5.0	10.8	11.3	6.2	5.8	2.9	3.8	7.5	5.8	9.2	11.3	4.2	6.7	14.2	6.2	5.0	2.5	4.6	1.2	12.1
Wind	0.8	8.7	12.5	3.8	24.6	15.0	17.1	8.3	1.7	12.9	20.0	23.7	32.1	20.0	30.0	23.7	15.8	12.5	12.5	12.5	12.1	11.3	4.2	9.6
Water	11.3	12.5	12.5	12.5	12.5	10.8	7.1	4.6	8.7	13.8	19.2	20.0	10.4	12.1	6.2	0.4	0.0	0.0	4.6	5.8	10.4	12.5	12.5	12.5
Mammal	2.5	1.2	4.2	2.5	0.0	0.0	0.8	0.4	2.1	1.2	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.8	1.2	0.0	2.5	2.5
Bird	0.0	0.8	2.5	2.9	0.4	1.2	2.1	63.3	84.2	63.8	55.0	67.1	52.1	44.6	45.4	52.9	55.8	26.2	3.3	3.8	3.8	5.0	5.0	1.2
Insect	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.2	1.2	0.4	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Natural Unknown ^b	1.2	1.2	1.2	1.2	2.5	2.5	2.5	0	1.2	2.9	1.7	2.5	2.1	2.9	3.8	2.9	4.6	3.8	3.8	3.8	2.9	1.7	5	6.7

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

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

Table 11. Mean hourly percent time audible for each noise source at WACA003 during the spring of 2013.

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	3.3	4.4	4.1	4.1	4.8	5.2	10.0	13.3	19.6	34.4	34.1	24.1	21.9	17.4	26.7	21.1	33.0	30.0	23.3	30.0	27.0	19.6	18.1	10.4
Vehicle	0.0	0.0	0.4	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.4	0.4	0.0	1.1	0.7	0.4	0.0	0.4	1.9	1.1	0.0	0.0	0.4	0.4
Train	87.0	91.1	96.3	95.2	97.4	97.8	95.6	95.9	86.3	51.5	44.4	43.0	43.0	44.1	37.8	43.7	24.1	33.0	32.6	44.4	62.6	73.7	61.9	75.6
People	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gunshot	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.7	4.1	7.0	8.1	4.8	6.3	0.4	2.6	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0
Domestic Animal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0
Non-Natural Unknown ^a	1.1	0.0	0.4	0.4	1.5	0.7	1.5	0.4	5.6	8.1	13.7	24.1	17.4	14.1	11.9	16.7	15.2	17.4	27.4	22.6	9.3	9.6	21.5	13.3
Wind	8.9	0.7	3.0	1.5	0.0	0.0	0.0	0.7	9.3	18.1	23.3	31.5	41.1	36.7	41.5	44.1	38.9	35.9	19.3	2.2	4.1	1.5	2.2	1.5
Mammal	0.4	0.0	0.4	1.1	0.7	0.4	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	1.9	0.0	0.7
Bird	8.1	3.3	1.5	4.1	8.9	27.8	74.1	93.0	81.5	68.9	68.5	61.1	58.1	37.4	35.9	35.9	29.3	32.6	17.4	11.5	3.7	4.1	1.5	5.9
Insect	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	1.1	1.5	2.6	2.6	7.8	2.6	1.9	2.6	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Animal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wind-Induced Natural	17.8	8.1	5.6	6.3	0.0	0.0	0.7	0.7	12.6	23.0	28.9	28.9	36.3	43.0	43.7	36.7	42.6	45.2	33.3	10.4	11.5	1.5	1.1	5.9
Natural Unknown ^b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.1	21.5	16.3	9.3	10.0	18.1	10.4	16.3	10.4	9.6	1.1	0.4	0.0	0.4	0.4	0.0

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

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

Table 12. Mean hourly percent time audible for each noise source at CHERRY001 during the fall of 2014.

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	4.8	5.6	4.8	5.9	3.3	4.4	7.4	11.9	12.6	35.2	34.8	21.5	28.5	20.4	31.9	27.8	28.9	29.3	13.0	15.6	23.3	8.5	7.8	5.9
Vehicle	15.9	15.2	11.5	17.4	26.3	23.7	22.2	15.2	18.1	6.3	5.2	5.2	10.7	10.4	12.6	24.8	20.7	26.3	30.0	23.7	24.8	16.7	11.1	15.6
Train	94.8	97.8	95.9	91.9	91.1	96.7	93.3	88.9	88.5	60.4	49.3	65.2	50.7	62.6	48.1	52.6	47.4	55.6	85.9	83.0	76.7	94.4	93.3	90.7
Motor	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	10.0	2.6	0.0	1.1
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	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Gunshot	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	1.5	11.5	17.8	20.4	31.5	30.7	27.4	17.8	10.7	6.7	5.9	0.4	0.0	0.0	0.0	0.0
Domestic Animal	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Non-Natural Unknown ^a	1.1	3.3	2.2	2.2	6.3	0.7	1.5	1.9	2.2	1.9	4.1	3.7	8.5	4.1	11.9	5.9	5.6	6.3	2.2	3.7	3.0	0.4	0.0	0.7
Wind	4.1	5.9	5.2	15.6	3.3	3.0	3.7	8.5	11.9	15.6	25.6	26.3	27.4	33.7	29.3	24.1	18.5	11.5	4.8	1.5	2.2	1.5	4.4	3.0
Water	0.0	0.0	0.0	2.6	0.0	0.0	0.0	3.0	4.4	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
Thunder	0.0	0.0	0.4	0.4	5.2	0.0	3.7	0.0	0.0	0.4	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mammal	4.4	5.2	14.1	15.6	4.8	7.4	4.1	3.7	1.1	0.0	0.0	0.0	0.4	0.0	0.4	0.7	0.7	0.4	4.4	8.9	3.0	4.8	3.3	7.0
Bird	4.8	9.3	3.0	4.1	4.8	21.1	75.6	99.3	96.3	97.4	94.4	90.0	70.0	78.9	71.5	74.8	78.5	58.1	17.4	5.2	4.4	4.4	2.2	3.7
Insect	19.3	17.0	13.3	10.0	9.6	19.3	5.9	17.4	49.6	75.9	83.7	92.6	87.0	82.6	75.6	81.1	89.6	83.3	75.9	73.3	57.8	38.1	33.7	14.4
Animal	0.7	1.5	0.7	0.7	0.4	0.7	0.4	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.4	1.5	2.2	0.0	0.7	0.7	0.4
Wind-Induced Natural	0.0	0.4	3.7	0.7	0.4	1.5	0.4	2.2	3.3	10.0	15.6	14.4	22.2	26.7	17.4	7.8	7.4	0.4	0.0	0.0	0.0	0.0	1.1	2.6
Natural Unknown ^b	0.0	0.4	0.4	0.0	0.7	0.7	0.0	0.0	0.4	0.0	0.0	0.7	0.4	0.4	0.4	0.7	0.0	0.0	0.0	0.4	0.0	0.4	0.0	0.0

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

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

Table 13. Mean hourly percent time audible for each noise source at CHERRY001 during the winter of 2015.

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	2.6	5.2	2.2	5.6	2.6	2.6	1.5	4.1	13.0	17.4	24.4	24.1	23.0	20.4	15.2	22.2	21.1	27.8	18.9	11.5	8.9	11.9	6.3	4.4
Vehicle	15.2	14.1	20.7	19.6	15.2	14.4	15.2	13.7	9.6	7.4	11.1	4.8	3.7	2.2	0.7	1.5	4.1	7.4	14.4	21.5	14.1	17.4	19.3	19.3
Train	98.9	97.4	98.9	98.1	98.9	91.5	95.6	93.3	84.8	83.0	73.7	70.4	61.9	75.2	70.4	68.1	64.4	75.2	79.6	91.1	92.2	85.9	93.3	96.7
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	0.7	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	0.0	0.0	0.0	0.4	1.1	3.7	5.6	9.6	8.9	4.4	5.9	0.7	1.1	7.8	0.0	0.0	0.0	0.0	0.7
Domestic Animal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Non-Natural Unknown ^a	0.0	0.4	1.1	0.4	0.0	0.0	0.4	0.0	0.4	3.0	1.5	0.0	0.0	0.0	0.7	0.4	1.5	1.5	6.3	1.5	0.7	7.8	2.6	0.0
Wind	0.7	1.9	3.0	1.1	1.9	4.1	7.8	5.2	7.8	18.9	32.2	34.1	39.3	37.0	44.8	40.7	41.5	17.4	11.9	14.8	10.7	0.4	0.0	5.6
Water	11.1	11.1	11.1	11.1	11.1	11.1	10.4	11.1	10.4	13.7	31.5	32.2	29.3	21.1	15.6	12.2	1.1	11.1	10.7	11.1	3.3	2.6	5.2	8.9
Thunder	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mammal	1.9	3.3	1.1	0.4	0.0	5.9	3.3	0.0	0.7	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.4	1.9	1.5	1.5	3.0	0.0	1.1	1.1
Bird	4.4	3.7	3.3	3.3	4.1	10.0	24.4	93.7	91.5	84.1	73.3	64.4	53.3	59.6	42.6	57.0	48.5	65.2	21.1	8.9	6.7	6.7	6.3	15.2
Insect	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.3	15.2	18.1	12.6	14.8	19.6	21.1	11.1	8.5	0.0	0.0	0.0	0.0	0.0	0.0
Animal	0.0	0.4	0.0	0.7	0.7	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.1	0.4	0.0	0.0	0.0	0.0	0.0
Natural Other	0.0	0.0	2.6	11.1	5.9	5.9	10.7	7.4	9.6	13.0	20.7	32.2	41.5	40.4	46.3	43.0	44.4	25.2	24.4	18.1	8.1	0.4	0.0	0.7
Natural Unknown ^b	0.0	0.7	0.7	0.7	0.0	1.9	1.9	1.5	0.4	1.1	2.2	1.9	2.6	3.0	1.5	1.9	2.2	0.0	0.4	0.7	0.4	0.4	0.4	0.0

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

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

Table 14. Mean hourly percent time audible for each noise source at CHERRY001 during the spring of 2015.

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	4.8	5.9	4.4	2.2	3.3	4.1	9.6	12.2	16.7	27.0	28.1	28.5	21.1	22.2	18.9	24.8	26.7	20.4	26.3	16.3	21.5	14.1	15.9	15.2
Vehicle	13.7	13.7	17.8	21.5	17.8	15.2	18.5	15.2	7.8	6.7	3.0	8.1	3.7	7.0	5.2	6.3	4.8	14.1	17.4	13.7	21.1	21.9	13.3	19.3
Train	96.7	98.1	97.0	95.6	98.1	94.4	90.4	90.7	85.9	73.0	73.3	62.6	75.9	68.5	74.8	67.0	56.3	55.2	53.0	58.9	60.0	88.1	84.8	85.9
Gunshot	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	2.2	1.9	5.6	10.4	16.3	10.0	14.8	4.4	4.1	0.4	0.0	0.7	0.0	0.0	0.0	0.0
Domestic Animal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Non-Natural Unknown ^a	4.4	0.7	3.0	5.2	4.4	6.7	4.1	3.7	0.0	3.3	0.7	5.6	1.9	4.8	4.4	2.2	3.3	3.0	4.8	4.8	9.3	0.7	4.4	3.0
Wind	14.4	13.3	8.9	7.8	4.8	3.0	3.7	4.4	20.7	22.2	26.3	24.8	30.4	24.1	28.1	28.5	38.5	36.3	23.7	23.7	22.2	9.3	9.6	4.4
Water	8.1	1.5	0.7	0.0	0.0	0.0	0.0	0.0	13.0	21.9	21.5	20.0	13.3	10.4	1.9	2.6	0.0	0.0	0.0	0.0	0.0	5.6	8.5	6.3
Mammal	0.0	0.0	0.0	0.0	0.4	1.9	1.9	2.6	0.4	1.1	0.0	1.1	0.0	1.1	0.0	0.0	0.0	0.0	1.1	0.7	0.4	3.3	0.4	1.1
Bird	15.9	11.9	5.2	5.6	25.2	60.4	86.7	96.3	88.9	80.0	70.4	69.3	70.0	68.5	68.9	56.7	40.0	42.6	31.1	24.4	28.9	21.1	30.0	17.0
Insect	11.1	7.0	4.1	0.0	0.0	0.0	0.7	10.4	35.2	53.7	60.0	65.6	66.7	69.3	64.8	66.7	47.4	52.2	47.4	33.3	33.3	33.0	33.3	33.3
Animal	0.4	1.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.4	0.4	1.9	0.7	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0
Wind-Induced Natural	25.2	15.6	10.4	5.2	0.0	0.0	0.7	8.1	18.5	23.7	21.9	19.3	24.1	22.6	26.3	25.6	33.3	31.9	20.4	23.0	17.0	0.4	4.1	0.7
Natural Unknown ^b	0.0	1.5	3.0	1.9	1.5	0.7	0.0	2.6	2.2	2.2	2.2	4.1	3.3	3.0	4.8	2.2	0.7	1.5	0.0	0.4	0.4	0.7	0.7	1.1

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

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

Table 15. Mean hourly percent time audible for each noise source at CHERRY001 during the summer of 2015.

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	9.6	6.3	10.0	8.5	2.2	10.4	11.1	18.5	25.2	32.6	38.5	35.2	23.0	18.9	19.3	21.9	29.3	22.2	25.9	18.1	24.4	17.4	16.3	17.0
Vehicle	15.6	13.0	2.6	7.8	7.0	10.7	13.3	18.9	4.8	4.8	2.6	1.9	1.9	3.7	5.9	2.6	2.6	7.8	16.7	16.7	17.8	22.2	13.3	17.4
Train	92.6	91.5	93.7	90.0	93.7	84.1	92.6	83.3	78.9	59.3	50.4	56.7	72.2	73.7	64.4	76.7	60.0	67.0	57.0	73.7	68.5	82.6	86.3	81.1
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	0.0	0.0	0.0	0.0	0.0	0.7	0.4	0.0	0.0	0.0	0.0
Gunshot	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	8.1	11.5	8.1	18.1	13.0	1.5	1.1	0.0	0.4	1.5	0.7	0.0	0.0	0.0	0.0
Domestic Animal	0.0	0.4	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Non-Natural Unknown ^a	0.4	10.7	1.1	4.1	5.6	7.8	1.5	3.3	4.1	8.9	12.6	4.4	5.2	4.8	9.3	1.1	6.3	7.4	12.2	9.3	7.0	5.9	0.7	3.7
Wind	12.2	13.3	13.0	16.7	14.8	10.0	3.0	4.8	13.3	27.8	35.2	32.2	39.6	46.3	47.0	30.7	27.0	27.0	22.6	20.4	19.6	9.3	13.0	13.3
Water	11.9	19.3	11.1	11.1	11.1	3.0	0.0	0.0	0.0	1.5	0.0	0.0	0.4	5.9	7.0	8.5	12.2	5.2	0.7	2.6	0.0	0.0	0.0	0.0
Thunder	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.0	5.2	3.0	10.4	3.7	11.9	0.7	0.0	0.0	0.0	0.0
Mammal	0.4	5.2	0.0	1.5	2.2	0.0	1.1	0.0	0.7	0.0	0.7	0.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0	3.0	0.4	0.4	0.4	0.0
Bird	4.1	6.7	8.1	12.2	68.9	98.9	98.5	96.3	96.3	88.5	79.6	85.2	73.7	69.3	66.7	61.5	54.4	73.7	77.8	74.1	42.2	15.9	8.1	14.8
Insect	82.2	81.9	89.3	79.6	43.3	11.5	18.1	27.8	48.1	66.3	65.9	71.1	47.0	44.1	38.1	53.7	57.0	54.4	53.7	44.1	74.4	93.3	89.6	81.9
Animal	0.0	0.4	0.0	0.7	0.0	0.4	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.4	0.0	0.0	0.0	0.4	0.4	0.0	1.1	0.0	0.0	0.0
Natural Other	0.7	0.0	1.5	1.5	6.3	5.9	0.0	0.0	2.6	11.9	10.7	18.5	24.4	27.8	24.1	19.6	11.9	6.7	5.2	13.7	3.3	1.5	0.4	0.0
Natural Unknown ^b	1.5	0.7	2.2	1.9	0.4	0.7	1.1	1.1	0.4	0.7	0.7	0	0.7	0.7	0	0.4	0	0.4	1.1	0.4	3.3	1.5	0.7	1.1

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

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

Table 16. Mean hourly percent time audible for each noise source at CHERRY001 during the fall of 2015.

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	6.7	5.0	2.1	5.0	2.9	3.3	8.3	6.7	14.2	30.0	33.7	28.7	27.5	32.1	23.3	26.7	22.1	30.0	20.4	16.3	27.9	12.5	8.3	8.3
Vehicle	16.3	12.5	13.8	8.3	18.8	22.1	27.9	20.4	12.1	6.2	4.6	5.8	2.1	4.6	4.2	5.0	6.7	20.0	20.0	27.5	21.2	21.2	18.8	22.9
Train	93.7	90.8	96.7	95.0	90.8	91.7	86.7	85.0	80.0	65.8	55.4	54.6	51.3	57.5	62.5	58.8	54.2	49.2	70.8	84.6	71.3	77.5	90.8	87.5
Grounds Care ^a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.8	2.1	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
People	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.4	0.0	0.0	0.8	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
Gunshot	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	5.0	12.5	18.3	15.8	20.8	19.6	9.2	2.1	2.9	1.2	0.4	0.0	0.0	0.4	0.0
Domestic Animal	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.4	0.0	2.1	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
Non-Natural Unknown ^b	0.8	0.4	0.0	0.0	0.0	0.0	0.4	7.5	2.9	2.1	8.3	7.1	9.6	9.2	11.3	11.7	10.4	8.3	4.2	0.8	2.5	2.5	1.7	0.8
Wind	2.9	2.1	2.1	5.4	3.3	6.2	2.5	0.8	7.5	18.3	15.4	23.3	19.6	20.4	25.0	17.5	21.2	8.3	4.6	1.2	10.0	10.8	12.1	5.8
Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	23.3	25.0	27.9	36.2	23.7	2.5	0.0	0.0	2.5	0.8	0.0	0.0	1.2	3.8	8.3
Thunder	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mammal	1.7	13.3	14.2	3.3	5.4	7.9	3.8	2.9	1.2	0.4	0.8	0.8	1.2	0.0	0.4	0.0	0.4	0.4	5.4	7.9	5.0	2.9	0.0	2.9
Bird	0.4	2.1	0.4	5.0	8.7	28.7	85.0	99.6	100.0	100.0	97.1	92.9	90.0	94.2	92.9	87.9	90.8	70.8	20.8	1.7	4.6	5.8	5.8	5.8
Insect	61.7	52.5	49.6	49.2	35.8	15.4	0.4	10.4	30.4	44.2	35.8	32.9	30.4	35.4	32.9	32.5	42.5	40.8	68.3	75.0	75.0	74.2	70.4	73.3
Animal	0.0	0.0	1.2	0.0	0.4	0.8	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.8	0.0	0.0	0.0	1.7	1.2	1.2	1.2	1.2	0.4
Wind-Induced Natural	3.3	5.4	5.0	1.2	1.7	7.9	1.2	0.0	14.6	28.7	28.7	48.8	40.4	27.9	36.2	34.6	35.8	22.9	8.3	1.7	0.0	0.8	1.7	0.0
Natural Unknown ^c	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	2.5	0.0	0.0	0.0	0.0	0.4

^a Grounds Care denotes chainsaw noise.

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

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

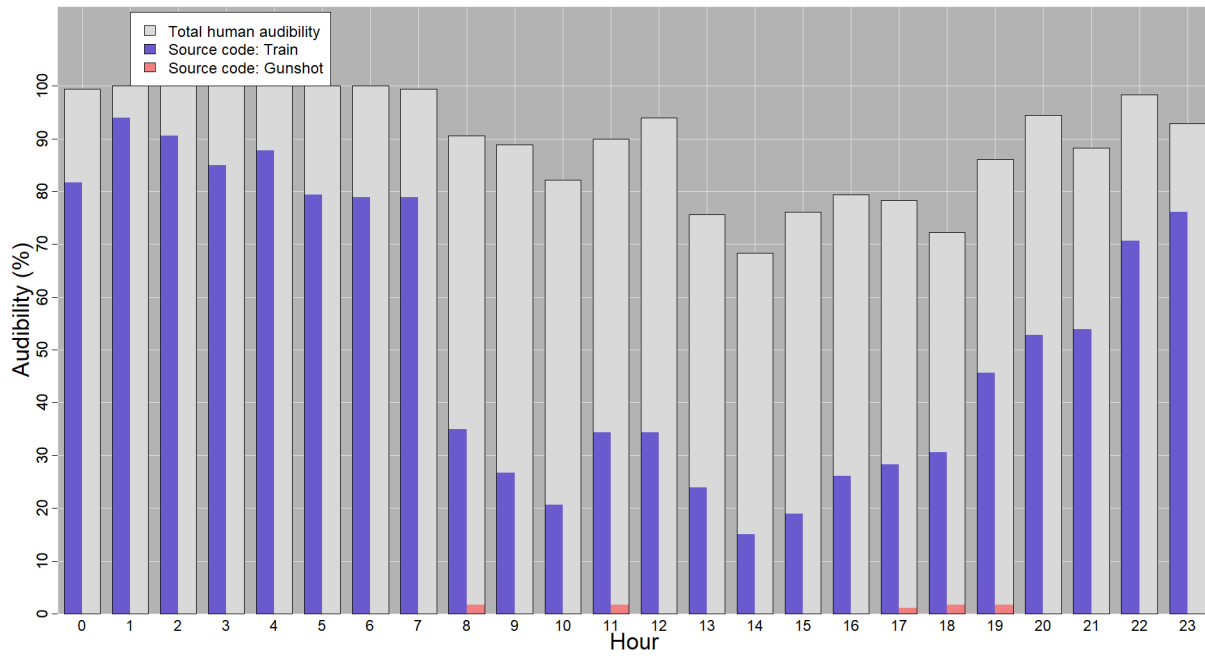


Figure 11. Comparison of hourly train, gunshot, and overall noise audibility at WACA003 during the summer of 2011.

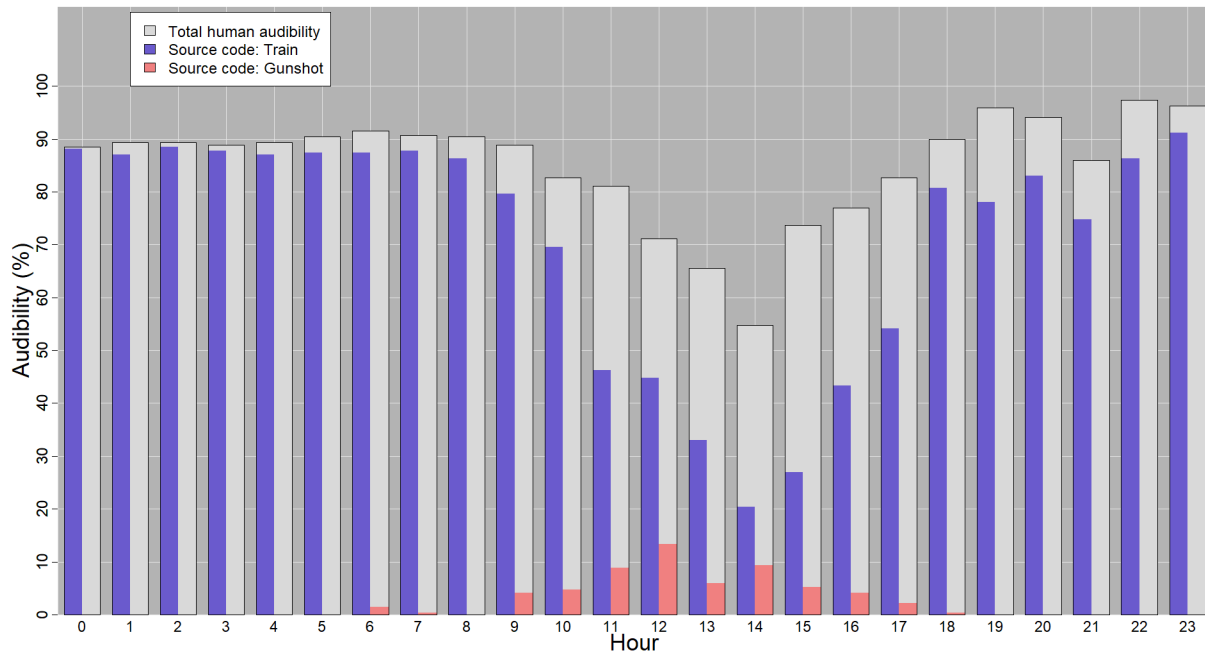


Figure 12. Comparison of hourly train, gunshot, and overall noise audibility at WACA003 during the fall of 2012.

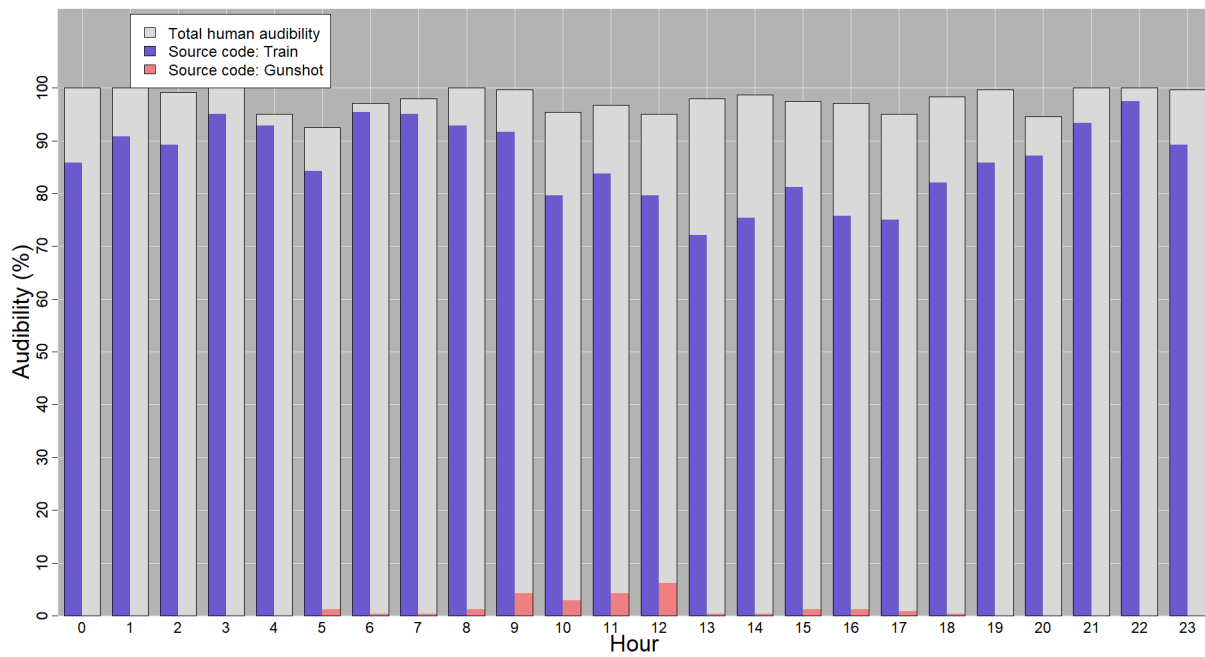


Figure 13. Comparison of hourly train, gunshot, and overall noise audibility at WACA003 during the winter of 2013.

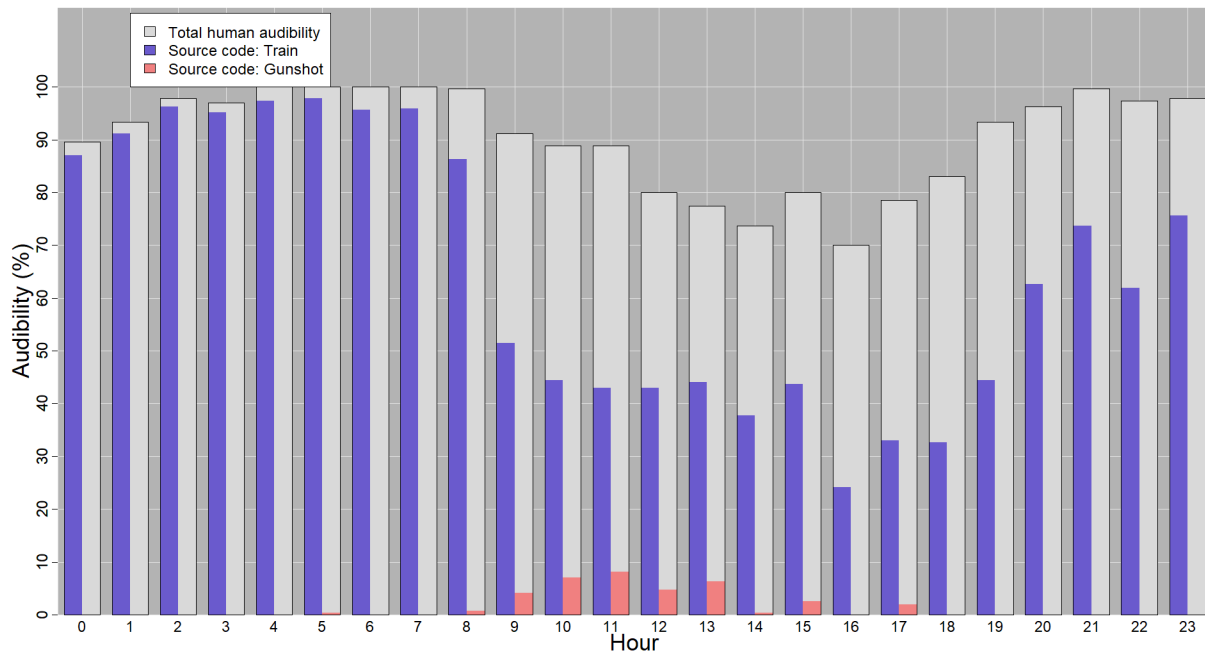


Figure 14. Comparison of hourly train, gunshot, and overall noise audibility at WACA003 during the spring of 2013.

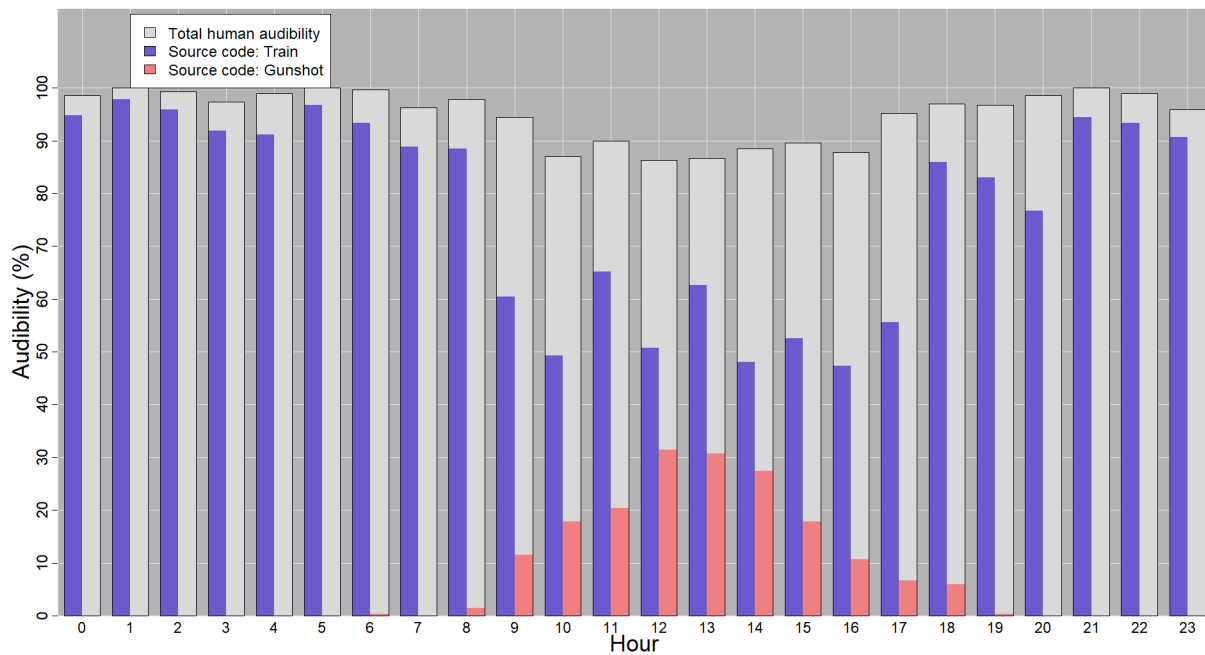


Figure 15. Comparison of hourly train, gunshot, and overall noise audibility at CHERRY001 during the fall of 2014.

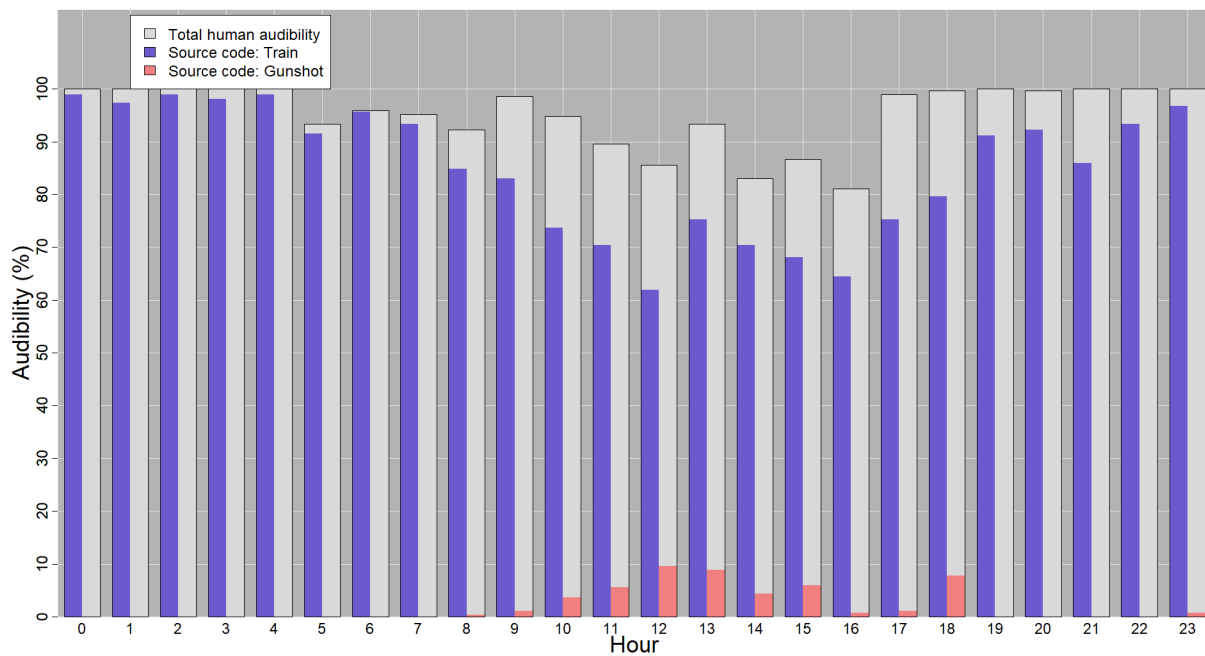


Figure 16. Comparison of hourly train, gunshot, and overall noise audibility at CHERRY001 during the winter of 2015.

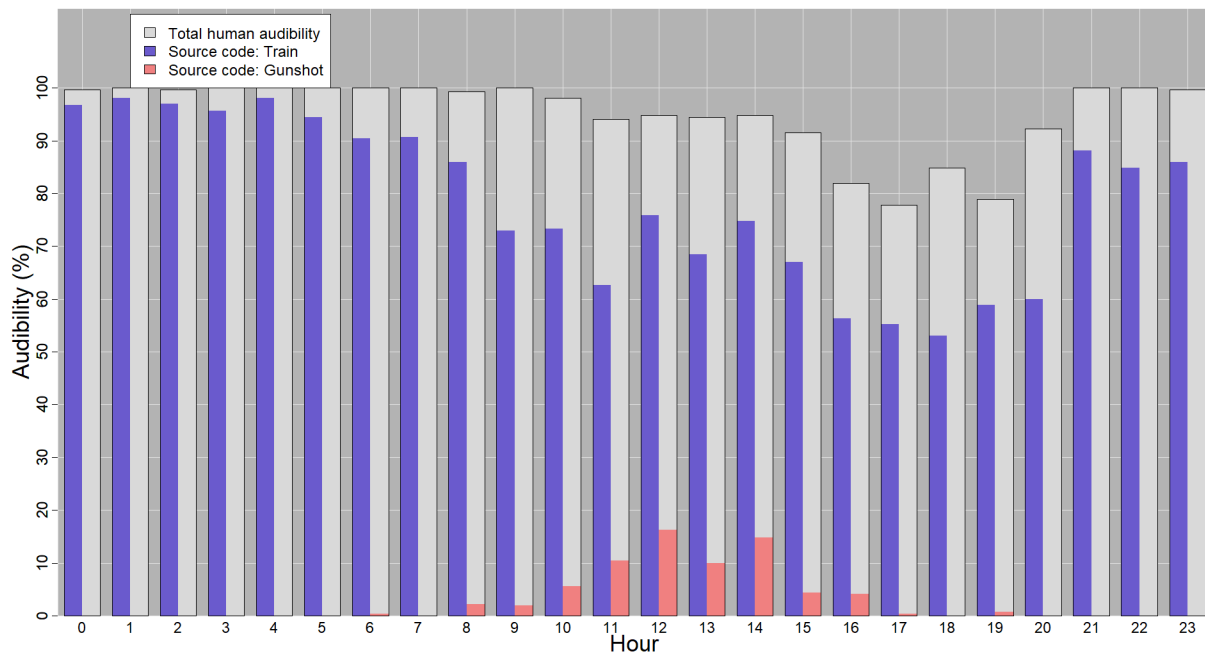


Figure 17. Comparison of hourly train, gunshot, and overall noise audibility at CHERRY001 during the spring 2015.

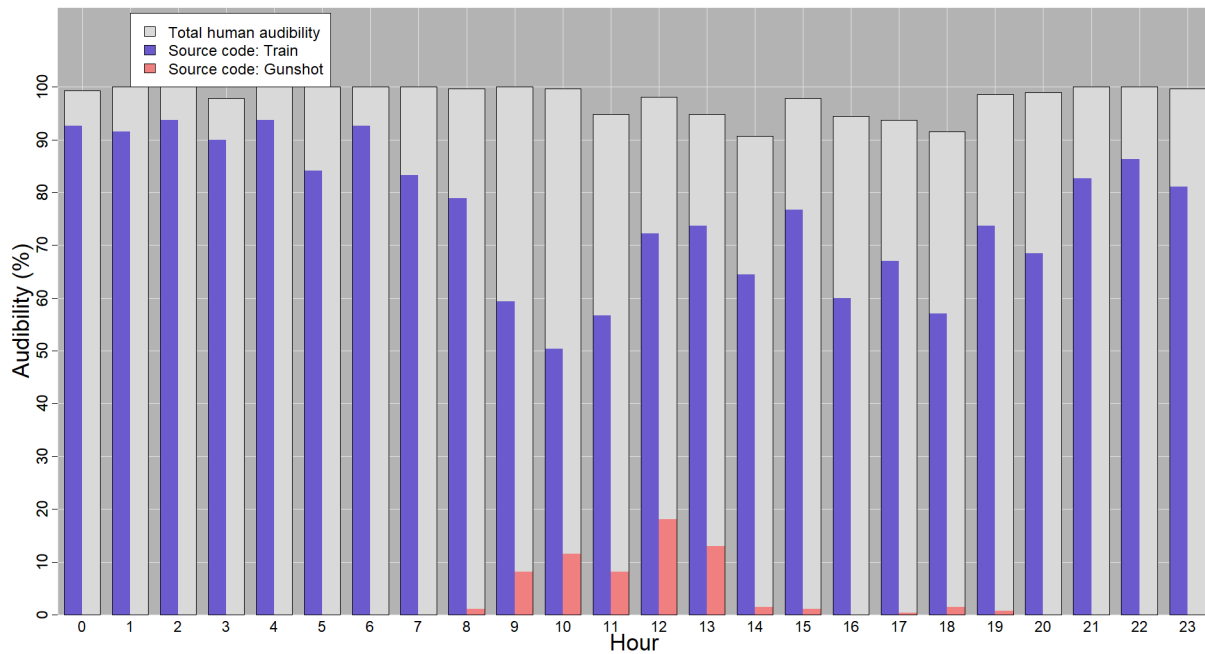


Figure 18. Comparison of hourly train, gunshot, and overall noise audibility at CHERRY001 during the summer of 2015.

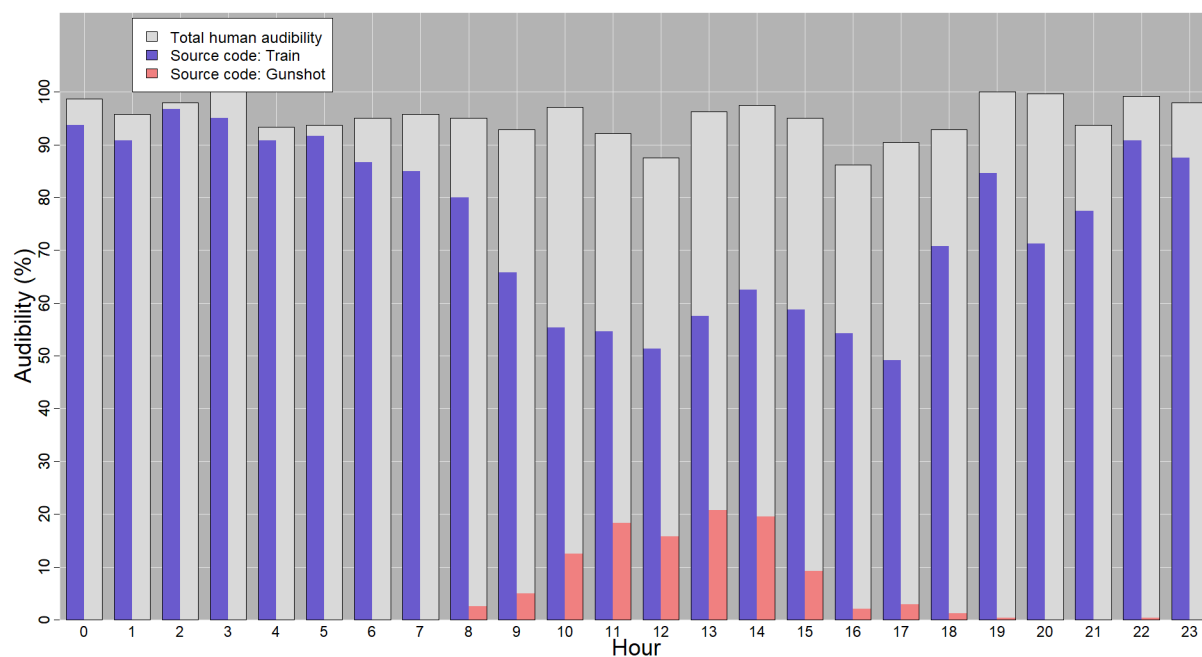


Figure 19. Comparison of hourly train, gunshot, and overall noise audibility at CHERRY001 during the fall of 2015.

Discussion

The purpose of this study was to assess current conditions of the acoustical environment at WACA. Monitoring results characterize existing and natural ambient sound levels within the park, which provide the park with baseline information and inform management decisions. Continuous audio, sound level data, and meteorological data were collected from two sites during a period from 2011 to 2015. At one site, WACA003, data were collected from 2011–2013 across all seasons, but due to vandalism, park staff established a new monitoring location nearby, CHERRY001. This site collected data across all seasons from 2014–2015. Taken together, the data from these locations contribute to a better understanding of the acoustical environment at WACA.

Results indicate that natural ambient sound levels (L_{Anat}) across each monitoring station were as follows: *For WACA003*: summer 2011 ranged from 26.2 dB during the daytime and 18.2 dB at night; fall 2012 ranged from 20.4 dB during the daytime and 17.0 dB at night; winter 2013 ranged from 22.2 dB during the daytime and 20.0 dB at night; spring 2013 ranged from 24.1 dB during the daytime and 18.1 dB at night. *For CHERRY001*: fall 2014 ranged from 21.2 dB during the daytime and 20.0 dB at night; winter 2015 ranged from 24.0 dB during the daytime and 20.3 dB at night; spring 2015 ranged from 21.9 dB during the daytime and 19.1 dB at night; summer 2015 ranged from 21.1 dB during the daytime and 20.4 dB at night; fall 2015 ranged from 22.6 dB during the daytime and 22.6 dB at night. Across all sites and seasons, nighttime natural ambient sound levels were generally lower than daytime natural ambient sound levels.

Comparing natural sound levels to median existing sound levels illustrates the degree to which noise is contributing to the acoustic environment. Existing ambient sound levels (L_{A50}) across each monitoring station were as follows: *For WACA003*: summer 2011 ranged from 34.6 dB during the daytime and 23.3 dB at night; fall 2012 ranged from 24.2 dB during the daytime and 21.5 dB at night; winter 2013 ranged from 28.0 dB during the daytime and 26.5 dB at night; spring 2013 ranged from 30.5 dB during the daytime and 23.4 dB at night. *For CHERRY001*: fall 2014 ranged from 25.9 dB during the daytime and 26.4 dB at night; winter 2015 ranged from 29.2 dB during the daytime and 26.6 dB at night; spring 2015 ranged from 27.4 dB during the daytime and 26.0 dB at night; summer 2015 ranged from 27.9 dB during the daytime and 28.1 dB at night; fall 2015 ranged from 29.0 dB during the daytime and 28.7 dB at night. In most cases, results show a considerable difference between L_{Anat} and L_{A50} , indicating that anthropogenic noise was prevalent during the day and night. However, overall sound levels were still fairly quiet, meaning noise was often present but did not necessarily dominate the acoustic environment. In fact, the natural ambient sound level during the monitoring period was considerably lower than most residential areas. 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). Note that noise levels have increased nationally with population growth since the EPA study (Suter 1991; Barber et al. 2010).

Despite the low overall sound levels, noise was often audible at WACA. The mean 24 hour time audible for noise was very consistent between sites and across seasons and years. At WACA003,

noise was present 89.8%, 85.2%, 97.8%, and 90.6% of the time during summer 2011, fall 2012, winter 2013, and spring 2013 respectively. At CHERRY001, noise was present 95.0%, 95.3%, 95.1%, 97.9%, and 95.1% of the time during fall 2014, winter 2015, spring 2015, summer 2015, and fall 2015 respectively. Noise from both sites largely originated from trains, aircraft, and vehicles, but also came from gunshots and voices from the nearby shooting range. Train noise was by far the most prominent noise source, especially during the nighttime hours, sometimes causing nighttime existing sound levels to exceed daytime levels. Gunshots were infrequently heard during every year and throughout each season, but were more prominent during the fall. They were most commonly audible midday (11:00–14:00), but as early as 05:00 and as late as 19:00.

Based on the results of this study, visitors to WACA are unlikely to experience a significant noise-free interval near the monitoring sites at any time during the year. Noise has the potential to affect a visitor's experience in parks by causing annoyance (Rapoza et al. 2015), reducing the perceived scenic beauty (Weinzimmer et al. 2014), or simply by limiting opportunities for solitude. Increased sound levels may also have wide ranging effects on wildlife such as reduced predatory success (Mason 2015), changes in vocal communication, or increased vigilance by keystone species (Shannon et al. 2014). In a review of literature addressing the effects of noise on wildlife published between 1990 and 2013, wildlife responses to noise were observed beginning at about 40 dB ($L_{Aeq, *}$).² Of the papers reviewed, 20% showed impacts to terrestrial wildlife at or below noise levels of 50 dB ($L_{Aeq, 1s}$) (Shannon et al. 2015). Wildlife response to noise was found to be highly variable between taxonomic groups. Mexican Spotted Owl, Golden Eagle, Northern Goshawk, and Peregrine Falcon have been identified by the park as species of interest. With respect to the effects of noise on these species, there is evidence that wildlife can suffer adverse behavioral and physiological changes from noise and other human disturbances (Delaney et al. 1999, Grubb et al. 2013), but our ability to translate that evidence into quantitative estimates of impact by species and noise stimulus is presently limited (Shannon et al. 2014).

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

Literature Cited

- Acoustical Society of America. 2014. Methods to Define and Measure the Residual Sound in Protected Natural and Quiet Residential Areas, Melville, NY. ANSI/ASA S3/SC1.100-2014.
- 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.
- Delaney, David K., et al. Effects of helicopter noise on Mexican spotted owls. *The Journal of Wildlife Management* (1999): 60–76.
- Environmental Protection Agency. 1974. Information on Levels of Noise Requisite to Protect the Public Health and Welfare with an Adequate Margin of Safety.
- Environmental Protection Agency. 1982. National Ambient Noise Survey. Office of Noise Abatement and Control, Washington, DC.
- Grubb, Teryl G., et al. Response of nesting northern goshawks to logging truck noise in northern Arizona. *The Journal of Wildlife Management* 77.8 (2013): 1618–1625.
- 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.
- Mason, J. T. 2015. The Impact of Anthropogenic Noise on Northern Saw-whet Owl (*Aegolius acadicus*) Hunting Behavior. Boise State University Theses and Dissertations. Paper 892. <http://scholarworks.boisestate.edu/td/892>
- 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, Colorado.
- National Park Service. 2006a. Management Policy 4.9: Soundscape Management.
- National Park Service. 2006b. Management Policy 8.2.3: Use of Motorized Equipment.
- National Park Service. 2013. Walnut Canyon National Monument: Acoustical monitoring 2010. Natural Resource Technical Report NPS/NRSS/NRTR—2013/763. National Park Service, Fort Collins, Colorado.
- Rapoza, A., Sudderth, E., & Lewis, K. 2015. The relationship between aircraft noise exposure and day-use visitor survey responses in backcountry areas of national parks. *The Journal of the Acoustical Society of America*, 138(4), 2090–2105.
- Shannon G, Angeloni LM, Wittemyer G, Fristrup KM, Crooks KR. 2014. Road traffic noise modifies behaviour of a keystone species. *Anim Behav.* 94:135–141.
- Suter, A. H. 1991. Noise and its Effects. Administrative Conference of the United States. 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
- Weinzimmer, D., Newman, P., Taff, D., Benfield, J., Lynch, E., & Bell, P. 2014. Human responses to simulated motorized noise in national parks. *Leisure Sciences*, 36(3), 251–267.

Appendix A. Site Photographs



Figure 20. Site photograph of CHERRY001 acoustical monitoring site during the summer deployment. A site photograph for WACA003 was not available at the time of publishing.

Appendix B. Comparison with 2010 monitoring data

Baseline acoustical data were collected at one site from July–August 2010 in Walnut Canyon National Monument (WACA) by partners from the U.S. Department of Transportation Volpe Center (NPS 2013). The purpose of this inventory was to help park managers and planners estimate the effects of future noise impacts, and to inform future park planning objectives such as an acoustic resource management plan, or an air tour management plan (ATMP). Since these data were collected, the monument has been exempted from the mandate to develop an ATMP or an air tour agreement because they have had zero reported air tours each year since 2013. Their current interim operating authority (IOA), or the number of annual air tours allowed, totals 48, which is also below the current 50 flight cutoff for the air tour management plan or agreement requirement.

The 2010 acoustic site (Table 17) was located in a different region of the park than WACA003 and CHERRY001, (Figure 1), on the northeast rim of the canyon (about 1.75 miles/ 1.6 km away), so acoustic conditions and noise source audibility are expected to differ between the three sites.

Table 17. WACA acoustical monitoring site information, 2010.

Site ID	Dates Deployed	Vegetation	Elevation (m)	Latitude	Longitude
WACA002	July 7–August 5, 2010	Pinyon-Juniper Shrubland	1,982	35.17731	–111.45950



Figure 21. Site photograph of WACA002, Northeast Rim, acoustical monitoring site during the 2010 deployment.

Table 18 compares audibility of noise sources and sound levels across the three sites. Data analysis protocols were different for the 2010 site, in that audibility of noise sources was calculated only for daytime hours, and train and gunshot were not identified as sound sources of interest at the time of analysis, so were not specifically called out. Still, some comparisons can be made between measurement efforts. At WACA002, aircraft were prominent sources of noise (audible 27% of daytime hours). Other human sounds were audible 49% of daytime hours, and these events were mostly attributed to vehicles. It is likely that the vehicle sounds originated from Interstate 40, as this site was located much closer to the highway than the subsequent sites. Natural sounds included wind, bird vocalizations, insects, and rain. Though WACA002 was located in a different part of the monument, daytime existing ambient sound levels were comparable to summer sound levels measured in other years. Median nighttime existing sound levels were slightly higher at this location, which is likely due to this site's proximity to the highway (note in Figure 22, that contributions from low frequencies, where vehicles produce sound, are greater at night than they are during the day). Audibility notes from the 2010 analysis indicate that both highway and train activity could be heard in evening and early morning hours. Median daytime natural ambient sound levels (L_{Anat}) were also comparable to other summer sites in the monument.

Table 18. Mean time audible for human-caused noise, aircraft, and vehicle noise sources, existing and natural ambient sound levels (dB re 20 μ Pa, A-weighted broadband, 12.5 Hz—20 kHz) at WACA003, and CHERRY001.

Site ID	Year	Season	Mean time audible for noise (% of 24 hour time period) ^a				Median Existing Ambient (L _{A50}) in dB ^b		Median Natural Ambient (L _{Anat}) in dB	
			All Noise	Gunshot	Train	Aircraft	Day ^c	Night ^c	Day	Night
WACA002	2010	Summer	— ^d	—	—	—	29.7	31.7	22.1	N/A
WACA003	2011	Summer	89.8	0.3	52.9	15.4	34.6	23.3	26.2	18.2
WACA003	2012	Fall	85.2	2.5	70.8	10.7	24.2	21.5	20.4	17.0
WACA003	2013	Winter	97.8	1.0	86.3	13.7	28.0	26.5	22.2	20.0
WACA003	2013	Spring	90.6	1.5	64.9	18.3	30.5	23.4	24.1	18.1
CHERRY001	2014	Fall	95.0	7.6	77.3	16.3	25.9	26.4	21.2	20.0
CHERRY001	2015	Winter	95.3	2.1	84.9	12.4	29.2	26.6	24.0	20.3
CHERRY001	2015	Spring	95.1	3.0	78.5	16.3	27.4	26.0	21.9	19.1
CHERRY001	2015	Summer	97.9	2.7	76.3	19.2	27.9	28.1	21.1	20.4
CHERRY001	2015	Fall	95.1	4.6	75.1	16.8	29.0	28.7	22.6	22.6

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

^b For comparison, nighttime sound level (L_{Aeq, 12 hr}) in a typical residential area is about 40 dB.

^c Day hours are 0700–1900; night hours are 1900–0700.

^d Audibility of different sources tracked for this dataset. Percent time audible of fixed wing aircraft and helicopters = 10.9, other aircraft sounds = 16.0, all other human sounds = 49.1.

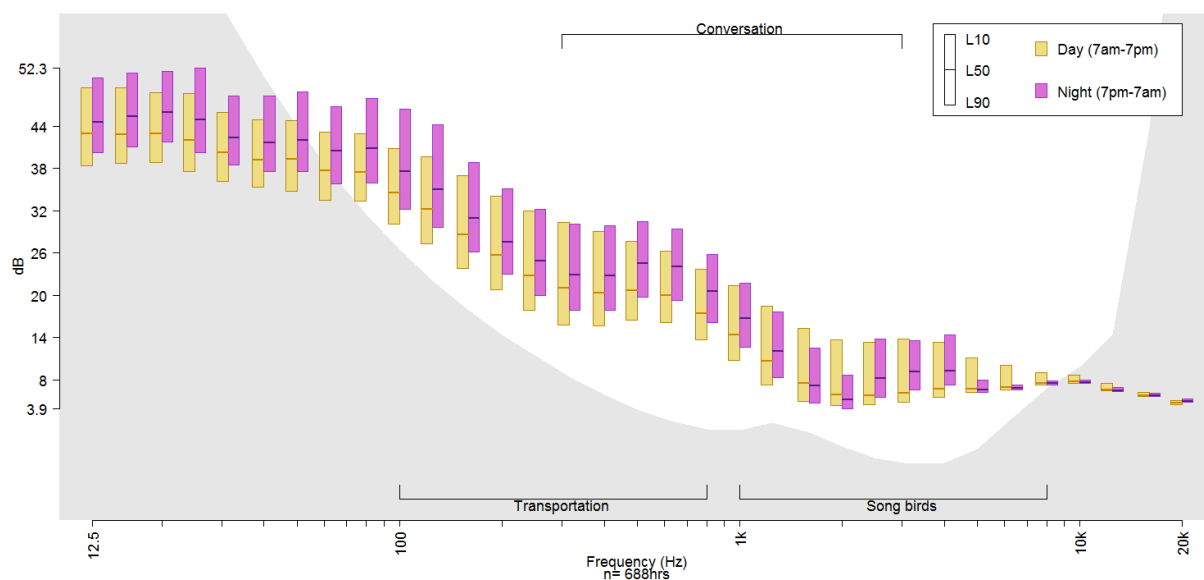


Figure 22. Day and night percentile levels for 33 one-third octave bands at WACA002.

Table 19 compares percent time above metrics for WACA002 to other sites. It shows that the 35 dB sound level was exceeded about 25% of the time during daytime hours and almost 30% of the time during nighttime hours, while other sound levels were rarely exceeded during the day or night. These results are in keeping with observed conditions at WACA003 during the summer, and similar to all other deployments in that the 45, 52, and 60 dB sound levels were rarely exceeded.

Table 19. Percent time above metrics for key sound levels at WACA sites.

Site ID	Frequency (Hz)	% Time above sound level: 0700 to 1900 (Day)				% Time above sound level: 1900 to 0700 (Night)			
		35 dB*	45 dB*	52 dB*	60 dB*	35 dB*	45 dB*	52 dB*	60 dB*
WACA002 Summer 2010	12.5–20,000	25.2	2.6	0.5	0.1	29.7	1.8	0.2	0.0
	20–1,250	22.8	2.3	0.5	0.1	27.5	1.5	0.2	0.0
WACA003 Summer 2011	12.5–20,000	58.0	18.5	4.4	0.1	7.6	0.6	0.1	0.0
	20–1,250	19.1	1.2	0.2	0.0	6.1	0.4	0.1	0.0
WACA003 Fall 2012	12.5–20,000	6.6	0.5	0.1	0.0	2.3	0.1	0.0	0.0
	20–1,250	5.4	0.4	0.1	0.0	2.0	0.1	0.0	0.0
WACA003 Winter 2013	12.5–20,000	16.5	1.1	0.2	0.0	12.1	0.5	0.1	0.0
	20–1,250	15.0	0.8	0.1	0.0	10.5	0.4	0.1	0.0
WACA003 Spring 2013	12.5–20,000	36.7	2.6	0.3	0.0	7.8	0.4	0.1	0.0
	20–1,250	29.9	1.9	0.2	0.0	6.9	0.3	0.1	0.0
CHERRY001 Fall 2014	12.5–20,000	10.6	0.9	0.2	0.0	11.1	0.4	0.1	0.0
	20–1,250	7.1	0.6	0.1	0.0	4.4	0.3	0.0	0.0
CHERRY001 Winter 2015	12.5–20,000	21.3	1.0	0.2	0.0	8.8	0.3	0.1	0.0
	20–1,250	18.4	0.9	0.2	0.0	8.6	0.3	0.0	0.0
CHERRY001 Spring 2015	12.5–20,000	13.3	1.0	0.2	0.0	9.0	0.4	0.1	0.0
	20–1,250	11.6	0.8	0.1	0.0	7.4	0.4	0.1	0.0
CHERRY001 Summer 2015	12.5–20,000	16.2	1.1	0.2	0.0	16.7	0.8	0.1	0.0
	20–1,250	13.3	0.8	0.2	0.0	6.6	0.3	0.1	0.0
CHERRY001 Fall 2015	12.5–20,000	16.9	2.0	0.2	0.0	22.5	0.6	0.1	0.0
	20–1,250	11.2	0.8	0.2	0.0	5.2	0.3	0.0	0.0

* dB re 20 µPa

Overall, acoustic conditions measured at WACA002 in 2010 were similar to those measured in subsequent years, with slight variations. These variations are expected in cases where acoustic monitoring sites are almost two miles apart, and located at different distances from key sound sources. With that being said, nighttime sound levels were slightly higher at WACA002 than other sites, likely due to the site's proximity to the highway corridor, as well as train tracks.

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

NPS 360/170309, June 2020

National Park Service
U.S. Department of the Interior



[Natural Resource Stewardship and Science](#)

1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525