



Great Smoky Mountains National Park

Acoustic Monitoring Report for Cades Cove and Cherokee Orchard Roadways, 2023



Acoustic Monitoring at Cades Cove.
NPS / KELSEY WHITE

Great Smoky Mountains National Park: Acoustic monitoring report for Cades Cove and Cherokee Orchard roadways, 2023

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Abstract

The Natural Sounds and Night Skies Division (NSNSD) received a request to collect baseline acoustical data on Great Smoky Mountains National Park (GRSM) roadways. Two acoustic monitoring stations were deployed during the summer (June/July) and winter (November/December) of 2023. The goal of the study was to conduct an acoustic inventory at these locations and to understand the degree to which vehicle noise in general, and specifically utility terrain vehicle (UTV) noise, may affect wildlife and visitor experience. In recent years, there has been an increase in the use of Utility Terrain Vehicles (UTVs) within GRSM. The park has reported an uptick in complaints from visitors, employees, and park partners regarding their use in popular areas such as Cades Cove and Roaring Fork Motor Nature Trail. As of 2024, GRSM does not regulate the use of these vehicles. Detailed sound source analysis shows road-based vehicles (all types combined) were audible an average of 57–59% of daytime hours during the summer season, while UTVs and motorcycles were audible 33–40% of daytime hours during the summer season. Hourly data show that the UTVs and motorcycles can be audible for 50% of a peak hour during the summer season and 10–20% of a peak hour during the winter season.

Glossary of Acoustical Terms

A-weighting: A-weighting is applied to sound levels in order to account for the sensitivity of the human ear (Harris, 1998). To approximate human hearing sensitivity, A-weighting discounts sounds below 1 kHz and above 6 kHz.

Acoustic Environment: A combination of all the physical sound resources within a given area. This includes natural sounds and cultural sounds, and non-natural human-caused sounds. The acoustic environment of a park can be divided into two main categories: intrinsic and extrinsic.

Acoustic Resources: Includes both natural sounds like wind, water, and wildlife and cultural and historic sounds like tribal ceremonies, quiet reverence, and battle reenactments.

Amplitude: The relative strength of a sound wave, described in decibels (dB). Amplitude is related to what we commonly call loudness or volume.

ANS Weighting: The Natural Sounds modification to A-weighting eliminates high-frequency sound (leaf rustle, equipment noise, and biological sounds) allowing for more accurate comparisons of low-frequency ambient sound levels across different land use types (e.g., urban, protected areas; ANSI S3/SC1.100, 2014 [R2020]). This frequency weighting scheme improves ambient sound level measurements in quiet environments.

Audibility: The ability of animals, including humans, with normal hearing, to hear a given sound. It can vary depending upon the frequency content and amplitude of sound and by hearing ability of individual animals.

Decibel (dB): A unit of sound energy. Sound levels are measured on a logarithmic scale relative to the reference sound pressure for atmospheric sources, 20 μ Pa. The logarithmic scale is a useful way to express the wide range of sound pressures perceived by the human ear. Every 10 dB increase represents a tenfold increase in energy. Therefore, a 20 dB increase represents a hundredfold increase in energy.

Existing ambient sound level (L_{A50}): Sound level ($L_{Aeq, 1s}$) exceeded 50% of the time (50th percentile) for a specified duration. This level is referred to as the existing ambient sound level and the preferred metric for chronic conditions, as it is insensitive to infrequent loud events or periods of silence.

Frequency: Related to the pitch of a sound, and defined as the number of times per second that the wave of sound repeats itself and is expressed in terms of hertz (Hz). Sound levels are often adjusted (“weighted”) to match the hearing abilities of a given animal. In other words, different species of animals and humans are capable 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.

Percentile sound levels (L_{A10} , L_{A50} , L_{A90}): Metrics used to describe A-weighted sound pressure levels (L), in decibels, exceeded 10, 50, and 90 percent of the time, respectively. Put another way, half the time the measured levels of sound are greater than the L_{A50} value, while 90 percent of the time the measured levels are higher than the L_{A90} value, and 10 percent of the time measured levels are higher than the L_{A10} value.

Day-Night average sound levels (L_{dn}): Day-Night Average Sound Level. Average equivalent sound level over a 24-hour period, with a 10-dB penalty added for sound levels between 10 p.m. and 7 a.m.

Energy Equivalent Sound Level (L_{Aeq}): The sound energy level averaged over the measurement period. Generally, refers to A-weighted 1-second time averaged sound levels measured between 12.5 Hz and 20 kHz. This is a standard measurement collected using NSNSD acoustic monitoring protocol for sound level meters. Sound levels measured over 1 second intervals are used to calculate summary statistics, specifically percent of the time a sound level of interest is exceeded.

Natural Ambient Sound Level ($L_{A_{nat}}$): The natural sound conditions in parks, which would exist in the absence of any human-caused noise sources. $L_{A_{nat}}$ is the preferred metric to represent baseline or reference conditions.

Noise Free Interval (NFI): The length of the continuous period of time during which no human-caused sounds are audible.

Time Above: Within a defined time period, the percent of the time sound levels ($L_{Aeq, 1s}$) are above a specified sound level ($L_{Aeq, 1s}$). Commonly used levels are 35, 45, 52 dB ($L_{Aeq, 1s}$).

Time Audible: The amount of time that various sound sources are audible to humans with normal hearing, commonly expressed in percent of day, or percent of daytime hours and nighttime hours. A sound may be above natural ambient sound pressure levels, but still not audible. Similarly, some sounds that are below the natural ambient can be audible. Time Audible is useful because of its simplicity. It is a measure that correlates well with visitor complaints of excessive noise and annoyance. Most noise sources are audible to humans at lower levels than virtually all wildlife species. Therefore, time audible is a protective proxy for wildlife. These data can be collected either by a trained observer (on-site listening) or by making high-quality digital recordings for later playback (off-site listening).

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

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

Sound vs. Noise: Sound and noise are often used interchangeably to describe an acoustic source. A common definition of noise is unwanted sound or sounds that interfere with a signal of interest (Harris 1998; Templeton 1997). However, noise is not a purely subjective designation. Any sound

that serves no function is noise. Most sounds produced by human transportation and other machinery are unintended and serve no function, therefore are noise regardless of the attitudes of the listener. While there are unintended sounds in nature, like the footfalls of an animal, these sounds provide vital cues for some receivers and are therefore considered sounds to the receiver, yet noise from the perception of the producer.

Soundscape: The human perception of physical sound resources.

Executive Summary

In 2022, the Natural Sounds and Night Skies Division (NSNSD) received a request to collect baseline acoustical data on Great Smoky Mountains National Park (GRSM) roadways. This request was in response to an increase in the use of Utility Terrain Vehicles (UTVs) within GRSM. Park staff have reported an uptick in complaints from visitors, employees, and park partners regarding their use in popular areas such as Cades Cove and Roaring Fork Motor Nature Trail. As of 2024, GRSM does not regulate the use of these vehicles. The goal of the study was to conduct an acoustic inventory at these locations to help park managers understand the degree to which vehicle noise, in general, and specifically utility terrain vehicle (UTV) noise, may affect wildlife and visitor experience. Two sites were sampled in this study: Cades Cove III (GRSM017) and Cherokee Orchard Road (GRSM018) during both winter and summer seasons. Both sites were located beside frontcountry traffic corridors known to be popular auto touring routes.

For these deployments, a calibrated sound level meter measured sound pressure level (SPL) continuously every second, an anemometer collected accompanying wind speed data, and a digital audio recorder collected audio recordings used to document sound sources.

In this document, “sound pressure level” refers to broadband (12.5 Hz–20,000 Hz), A-weighted, 1-second time averaged sound level ($L_{Aeq, 1s}$), and hereafter referred to as “sound level.” Sound levels are measured on a logarithmic scale relative to the reference sound pressure for atmospheric sources, 20 μ Pa. The logarithmic scale is a useful way to express the wide range of sound pressures perceived by the human ear. Sound levels are reported in decibels (dB). A-weighting is applied to sound levels in order to account for the response of the human ear (Harris 1998). To approximate human hearing sensitivity, A-weighting discounts sounds below 1 kHz and above 6 kHz. For reference, Table 1 provides examples of sound levels measured in parks compared to sound levels of common sound sources.

Table 1. Sound level examples.

Park Sound Sources	Common Sound Sources	Sound Level dB ^A
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 2m	100
Military jet at 100m AGL (YUCH)	Train horn at 1m	120

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

Table 2 reports the percent of time that measured sound levels ($L_{Aeq,1s}$) were above four key functional values during the monitoring periods. The first value, 35 dB ($L_{Aeq,1s}$), is used by the NPS as an indicator of overall quality of the acoustic environment. Beyond this level, noise begins to negatively affect the visitor experience in an otherwise natural acoustic environment (Pilcher et al., 2009; Watts et al., 2020; Betchkal et al., 2023). 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). As wildlife begin to exhibit signs of disturbance at noise levels as low as 40 dB (Shannon et al. 2016), 45 dB also represents a conservative estimate of negative effects on wildlife. The third value, 52 dB ($L_{Aeq,1s}$), is based on the EPA’s analysis of speech interference for an individual speaking in a raised voice to an audience at 10 meters (EPA 1974)—an acoustic level that would affect interpretive presentations in parks. The final value, 60 dB ($L_{Aeq,1s}$), marks the point at which normal voice communications at 1 meter begin to be interrupted (EPA 1974); sounds at or exceeding this level would affect conversation between visitors and/or staff.

Sound levels are often measured over narrow frequency bands (typically in one-third octave bands between 12.5 Hz and 20 kHz) because these smaller bands closely represent how humans distinguish between frequencies of sound. In this study, we examine how often sound levels exceeded key values in two frequency *ranges*. The top value in each split-cell of Table 2 uses the full frequency range (12.5 Hz–20 kHz) collected, whereas the bottom value focuses on frequencies affected by low-frequency noise sources (20–1,250 Hz). This Natural Sounds (NS) modification to A-weighting (referred to as ANS weighting, ANSI S3/SC1.100, 2014) eliminates high-frequency sound (leaf rustle, equipment noise, and biological sounds) allowing for more accurate comparisons of low-frequency ambient sound levels across different land use types (e.g., urban, protected areas; ANSI S3/SC1.100, 2014). This frequency weighting scheme improves ambient sound level measurements in quiet environments. For instance, in the full frequency range, the 35 dB ($L_{Aeq,1s}$) level was exceeded at GRSM017 93.8% of the time during the day and 59.3% of the time at night, but in the ANS range, the 35 dB functional sound level value was exceeded only 41.7% during the daytime and only 7.1% at night. Speech interruption occurs (between two people 1 meter apart) at 60 dB ($L_{Aeq,1s}$) and this level was rarely exceeded at either site.

Table 2. Time above metrics for GRSM017 and GRSM018.

Site	Frequency Range (Hz)	Time Above Sound Level (% of Daytime Hours, 07:00–19:00)				Time Above Sound Level (% of Nighttime Hours, 19:00–07:00)			
		35 dB ^A	45 dB ^A	52 dB ^A	60 dB ^A	35 dB ^A	45 dB ^A	52 dB ^A	60 dB ^A
GRSM017 Summer	Full (12.5–20,000)	93.8	16.2	1.6	0.1	59.3	2.1	0.2	0.0
	ANS (20–1,250)	41.7	6.1	0.8	0.0	7.1	0.7	0.1	0.0
GRSM017 Winter	Full (12.5–20,000)	32.1	3.4	0.5	0.0	6.3	0.6	0.1	0.0
	ANS (20–1,250)	23.2	2.4	0.3	0.0	4.8	0.5	0.1	0.0
GRSM018 Summer	Full (12.5–20,000)	100.0	39.9	8.4	0.9	100.0	10.1	1.1	0.1
	ANS (20–1,250)	100.0	29.2	5.3	0.5	100.0	2.9	0.4	0.0
GRSM018 Winter	Full (12.5–20,000)	100.0	15.6	2.2	0.1	100.0	0.6	0.1	0.0
	ANS (20–1,250)	100.0	12.0	1.4	0.1	100.0	0.5	0.0	0.0

^A dB LAeq, 1s re: 20 µPa.

After data collection was complete, technicians calculated how often noise sources were audible. At GRSM017, sound source analysis revealed that aircraft and road-based vehicles were primary sources of noise during both summer and winter. Other sources of identifiable noise included people (voices), as the historic Dan Lawson Cabin and a parking area are located nearby. Table 3 displays the percent time audible values for common noise sources, as well as ambient sound levels. It is of note that GRSM017 experienced “Vehicle Free Wednesdays” during the span of the summer deployment. This led to the inclusion of five days without vehicle noise from the Cades Cove Loop. At GRSM018 during the summer season, sound source analysis revealed that road-based vehicles and the HVAC system at a nearby NPS building are the primary sources of noise. Aircraft noise was less audible primarily due to sound masking from the HVAC system as well as a nearby creek. During the winter season at GRSM018, the HVAC system operates less frequently; road-based vehicles and aircraft are the primary sources of noise. Common natural sound sources within the park were birds, insects, rain, and wind blowing through vegetation. On occasion, coyotes were audible during the nighttime hours at both locations. At GRSM018, flowing water from a nearby stream was a constant companion as were the amphibians during late evening and early morning hours during summer.

Natural ambient sound levels (L_{Anat}) at GRSM017 ranged from 36.1 dB during the daytime to 33.9 dB at night during the summer season. During the winter season, the natural ambient ranged from 25.0 during the day to 20.0 at night. Existing ambient sound levels (L_{A50}) were higher, ranging from 40.6 dB during the day to 36.1 dB at night during the summer season at GRSM017, and 32.8 to 21.3 dB during the winter season (see Table 3). Natural ambient sound levels (L_{Anat}) at GRSM018 ranged from 40.7 dB during the daytime to 39.7 dB at night during the summer season. During the winter season, the natural ambient was relatively constant; 39.6 dB during the day and 39.8 dB at night. Existing ambient sound levels were higher, ranging from 43.7 dB during the day to 40.6 dB at night during the summer season at GRSM018. During the winter season at GRSM018, the natural ambient was again relatively constant; 40.6 dB during the day and 40.0 dB at night (see Table 3).

Of particular interest for this sound source inventory is the audibility of UTVs. These vehicles are generally louder and have more low-frequency content than standard passenger vehicles (autos, SUVs, and pickup trucks), making them audible at longer distances and for a longer duration. Detailed sound source analysis in Table 4 shows the time audible for UTVs, motorcycles, and standard passenger vehicles *during daytime hours (7 am to 7 pm)* when most visitation occurs. Road-based vehicles (all types combined) were audible on average 57% of daytime hours during the summer season at GRSM017 and 59% of daytime hours at GRSM018. During the winter season, time audible was slightly lower, 56% of daytime hours at GRSM017 and 42% of daytime hours at GRSM018.

Table 3. Mean time audible for human-caused, aircraft, and vehicle noise sources, existing and natural ambient sound levels (dB re 20 µPa, A-weighted broadband, 12.5 Hz–20 kHz) at GRSM017 and GRSM018 (where day is 07:00–19:00 and night is 19:00–7:00).

Site	Site Name	Season	Mean Time Audible for Noise (% of 24-Hour Time Period)			Median Existing Ambient (L_{A50}) in dB		Median Natural Ambient (L_{nat}) in dB	
			All Noise	Aircraft	Vehicle	Day	Night	Day	Night
GRSM017	Cades Cove III	Summer	66.1	32.3	34.5	40.6	36.1	36.1	33.9
GRSM017	Cades Cove III	Winter	59.7	38.0	28.3	32.8	21.3	25.0	20.0
GRSM018	Cherokee Orchard Road	Summer	75.4	9.1	35.5	43.7	40.6	40.7	39.7
GRSM018	Cherokee Orchard Road	Winter	38.5	14.1	22.7	40.6	40.0	39.6	39.8

^A Over a 24-hour period, based on eight days of analysis at each site during each season.

Table 4. Mean time audible for vehicle noise sources by vehicle type during daytime hours (7:00–19:00) at GRSM017 and GRSM018.

Site	Site Name	Season	Mean Time Audible for Noise (% of Daytime Hours)				
			All Vehicles	Standard Passenger	Motorcycles	UTVs	Unknown
GRSM017	Cades Cove III	Summer	57.4	10.3	8.0	25.0	8.0
GRSM017	Cades Cove III	Winter	55.8	35.7	2.1	6.1	9.0
GRSM018	Cherokee Orchard Road	Summer	58.8	13.9	13.1	26.9	4.3
GRSM018	Cherokee Orchard Road	Winter	42.4	12.0	11.6	14.5	3.5

Listening center technicians reported having difficulty discerning between UTV sounds and motorcycle sounds, as they have similar engines. Therefore, it is reasonable to combine audibility results for these vehicle types. UTV and motorcycles were audible 33% of daytime hours during the summer season at GRSM017 and 40% of daytime hours at GRSM018. During the winter season, time audible was much lower, 8% of daytime hours at GRSM017 and 26% of daytime hours at GRSM018. Hourly data shows these vehicles can be audible for 50% of a peak hour (hour of highest traffic) during the summer season and 10–20% of a peak hour during the winter season.

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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 and 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 inventory, understand, and 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.”

NPS Management Policies 2006 Chapter 4.9 provides direction for management of natural soundscapes:

“The National Park Service will preserve, to the greatest extent possible, the natural soundscapes of parks...”

“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 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 under Management Policies 2006 Chapter 8.2.3, “[t]he 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 2006c). However, the desired acoustic condition may also depend upon the resources and the values of the park. For instance, “culturally appropriate sounds are important elements of the national park experience in many parks” (NPS 2006b). In this case, “the Service will preserve soundscape resources and values of the parks to the greatest extent possible to protect opportunities for appropriate transmission of cultural and historic sounds that are fundamental components of the purposes and values for which the parks were established” (NPS 2006b).

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 2006c).

Director’s Order 47, Soundscape Preservation and Noise Management (2000) builds on the principles set out in Management Policies, directing park management how and when to consider acoustic resources. 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. An ATMP was developed for GRSM and became effective December 2, 2022.

Study Area

This report presents results from an acoustic inventory conducted in 2023 at Great Smoky Mountains National Park (GRSM). The focus of this inventory is to monitor soundscape conditions and capture data related to motor vehicle traffic, with a particular focus on utility terrain vehicles (UTV) and motorcycles, to inform Park Management Strategies. Two sites were sampled in this study: Cades Cove III (GRSM017) and Cherokee Orchard Road (GRSM018) (Figure 1, Table 5). These sites were located beside frontcountry traffic corridors known to be common auto touring routes. Sites were sampled during both summer and winter seasons.

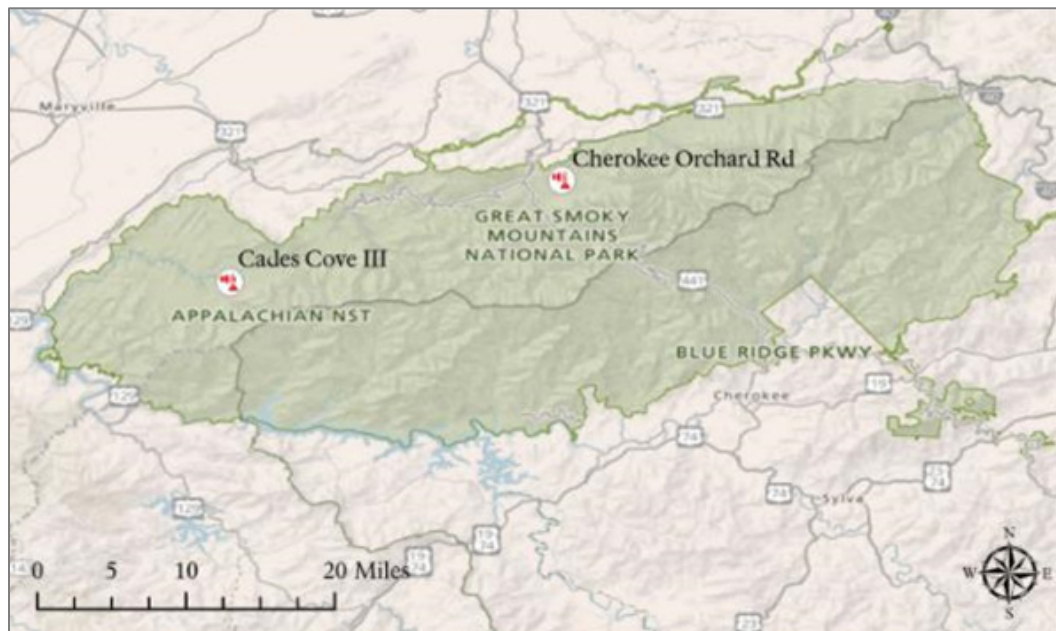


Figure 1. Map showing locations of GRSM017 and GRSM018 within Great Smoky Mountains National Park.

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Figures 2 and 3 show the location of the sites in map format. The Cades Cove site was located approximately 60 m from the Cades Cove Loop Rd, 35 m from the Dan Lawson Historical Cabin and 70 m from a parking area. An open field separates the site from the roadway. The Cherokee Orchard site was located approximately 35 m from Cherokee Orchard Rd. (part of the Roaring Forks Motor Nature Trail), a few meters from Twin Creeks trail and 35 m from the Twin Creeks NPS building.

Table 5. Metadata for acoustic monitoring at GRSM, 2023.

Site ID	Site Name	Dates Deployed	Vegetation	Elevation (m)	Latitude	Longitude
GRSM017	Cades Cove III	June 5–July 6, 2023 & November 27–December 27 2023	Temperate Broadleaf/Mixed	536	35.588006	–083.8216017
GRSM018	Cherokee Orchard Road	June 5–July 6, 2023 & November 27–December 27, 2023	Temperate Broadleaf/Mixed	600	35.6877093	–083.4991143

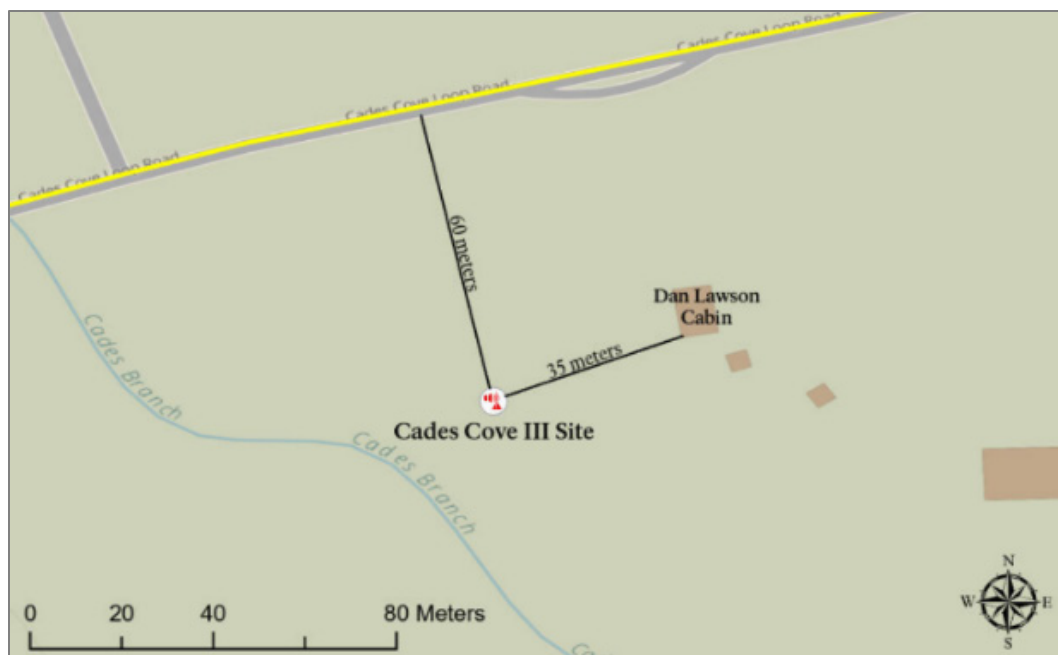


Figure 2. Cades Cove III (GRSM017) Location.
NPS / KELSEY WHITE

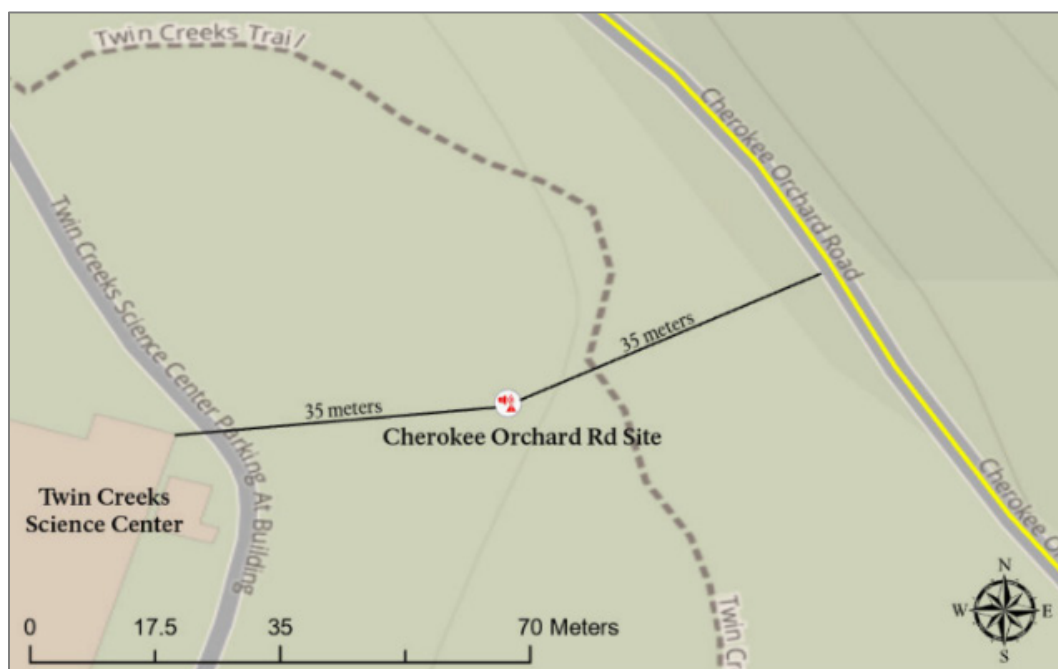


Figure 3. Cherokee Orchard Rd. (GRSM018) Location.
NPS / KELSEY WHITE

Methods

Automatic Monitoring

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

Acoustic monitoring equipment is used by many practitioners to determine noise levels in different environments, both indoors and outdoors. The NPS uses equipment like that used by other practitioners but has developed a unique configuration that stands up to the potentially harsh environment encountered in national parks (NPS 2013). The microphone with environmental shroud was set up on a tripod at 1.5 m, which approximates the average height of the human ear. The digital audio recorder recorded continuous audio throughout the entire monitoring period. An anemometer was attached to a tripod and placed approximately 2 m from the microphone to capture local wind conditions.

Each sampling station consisted of:

1. Type 1 sound level meter
2. Microphone with environmental shroud
3. Preamplifier
4. 12 V battery pack
5. Ultrasonic anemometer (wind speed and direction)
6. Wildlife Acoustics digital audio recorder

Each sampling station collected:

1. Flat-weighted, time-average sound level ($L_{Zeq, 1s}$) for each one-third octave frequency band, 12.5–20,000 Hz in dB re 20 μ Pa [collected by Type 1 sound level meter].
2. A-weighted, time-average sound level ($L_{Aeq, 1s [12.5-20000 \text{ Hz}]}$) in dB re 20 μ Pa [collected by Type 1 sound level meter].
3. Continuous meteorological data for wind speed [collected by anemometer].
4. Continuous digital audio recordings (.mp3, 96 kbps, 32 kHz)

Monitoring Period

To ensure that the data set accounts for daily differences and represents the typical range of conditions at a site, acoustic monitoring studies typically monitor a minimum of 25 days (NPS 2005). For this study, sites varied in monitoring periods due to equipment issues resulting in a range of 10–

29 full days of digital audio recordings and 21–30 full days of sound level data depending on which site/ season.

Calculation of Metrics

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

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

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

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

P_H represents 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 the Results section.

Off-Site Listening

Auditory analysis was used to calculate the audibility of sound sources at the monitoring locations. Staff at the U.S. Department of Transportation’s Volpe Center analyzed a subset of .mp3 samples (10 seconds every two minutes for eight days of audio for GRSM017 and GRSM018) 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). 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 the Results section.

Results

Frequency Content

To determine the influence that noise has on the acoustic environment, it is useful to examine percentile metrics across the frequency spectrum. 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 narrower bands, each encompassing one-third of an octave. These one-third octave 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 at GRSM017, summer and winter seasons, are shown in Figure 4 and Figure 5 respectively. Figure 6 and Figure 7 show the percentile sound levels at GRSM018, summer and winter seasons. For figures 4–7, the bold horizontal line indicates the existing (L_{50}) sound pressure levels. Sound levels depicted are not A-weighted.

Examining the sound energy in each one-third octave band (combined with digital audio recordings) allows acoustic technicians to determine what types of sounds are contributing to the overall sound level at a site. The grayed areas on these graphics represent sound levels outside of the typical range of human hearing. The percentile levels (L_x) are also shown for each one-third octave band. They represent the sound levels exceeded x percent of the measurement period. For example, L_{90} is the sound level that has been exceeded 90% of the time, and only the quietest 10% of the samples can be found below this point. On the other hand, the L_{10} is the sound level that has been exceeded 10% of the time, and 90% of the measurements are quieter than the L_{10} . The bold portion of the column represents the difference between L_{50} and L_{nat} . The height of this bold portion is a measure of the contribution of anthropogenic noise to the existing sound levels at this site. The 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.

At GRSM017, the high-frequency (4–5 kHz) peak indicates there is more bird and insect activity in summer. There is significant low-frequency energy (25 Hz–260 Hz) which is indicative of vehicular noise sources including UTVs and motorcycles. This low-frequency energy is more prevalent during daytime hours and in the summer season.

At GRSM018, there is also significant low-frequency energy. Here it may be indicative of both vehicular sources and the nearby HVAC unit. This energy more prevalent during daytime hours and in the summer season—times when both sources are expected to be present for longer periods of time.

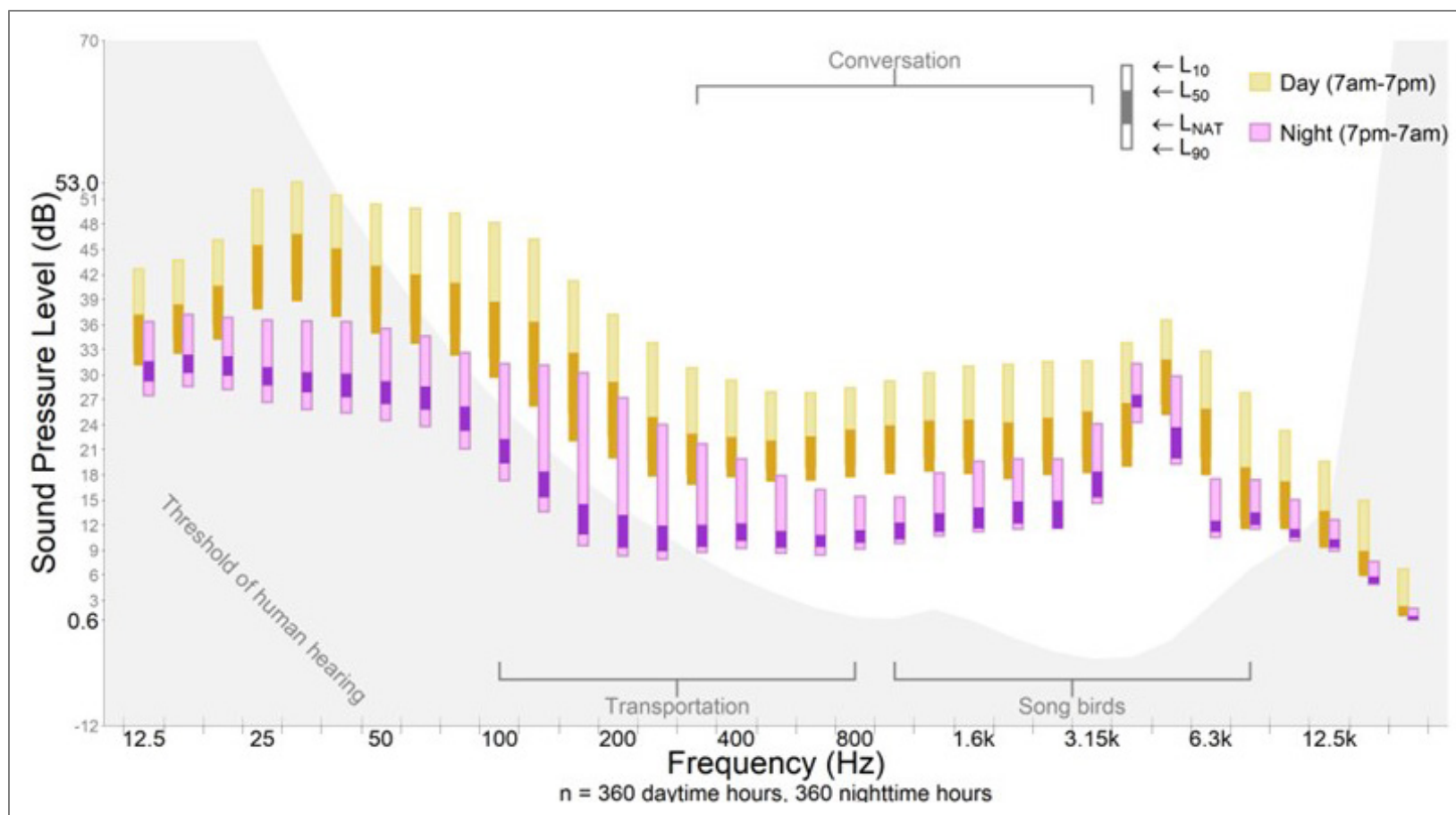


Figure 4. Day and night percentile sound pressure levels for 33 one-third octave bands at GRSM017, summer season.
NPS / NSNSD

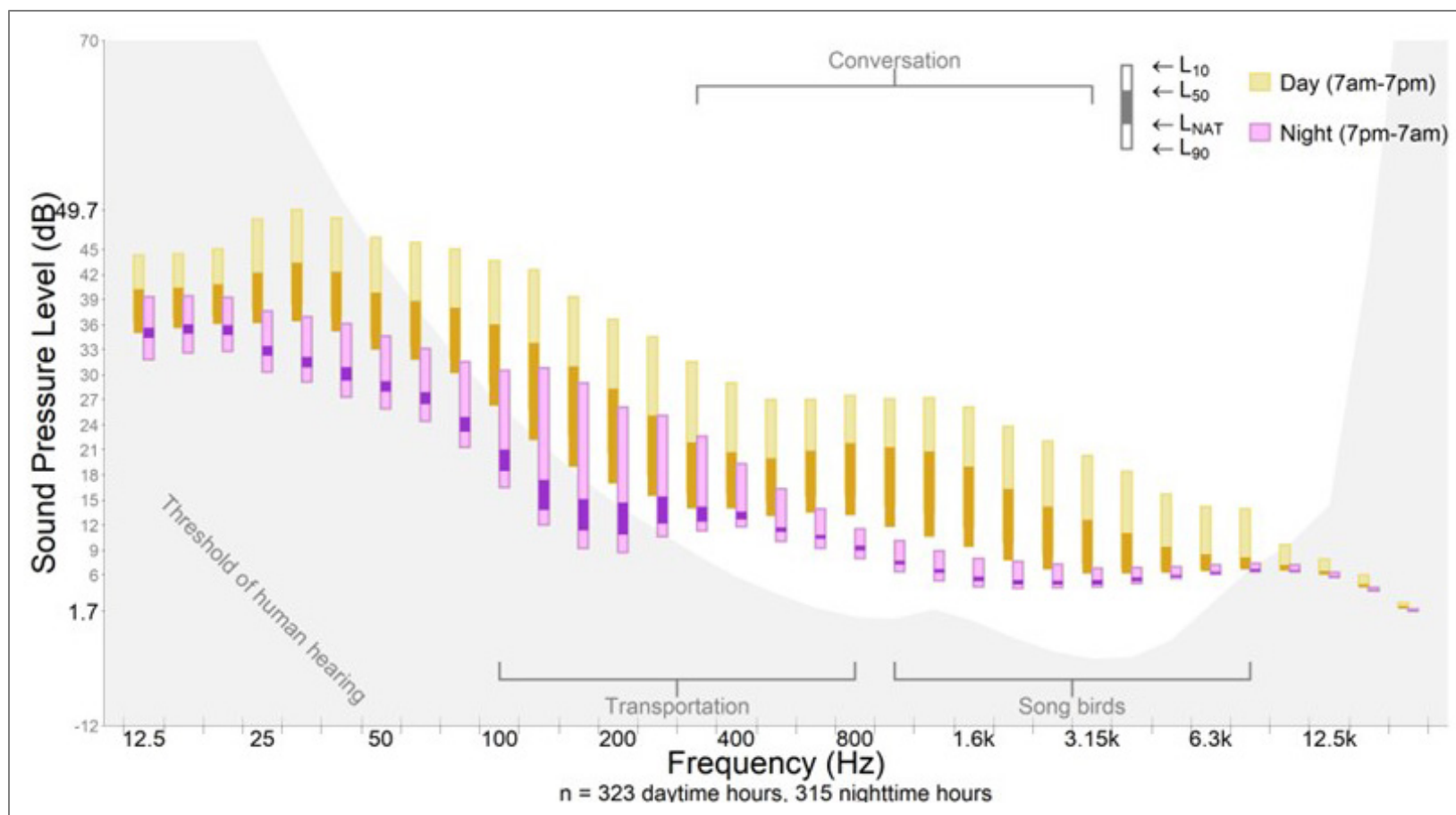


Figure 5. Day and night percentile sound pressure levels for 33 one-third octave bands at GRSM017, winter season.

NPS / NSNSD

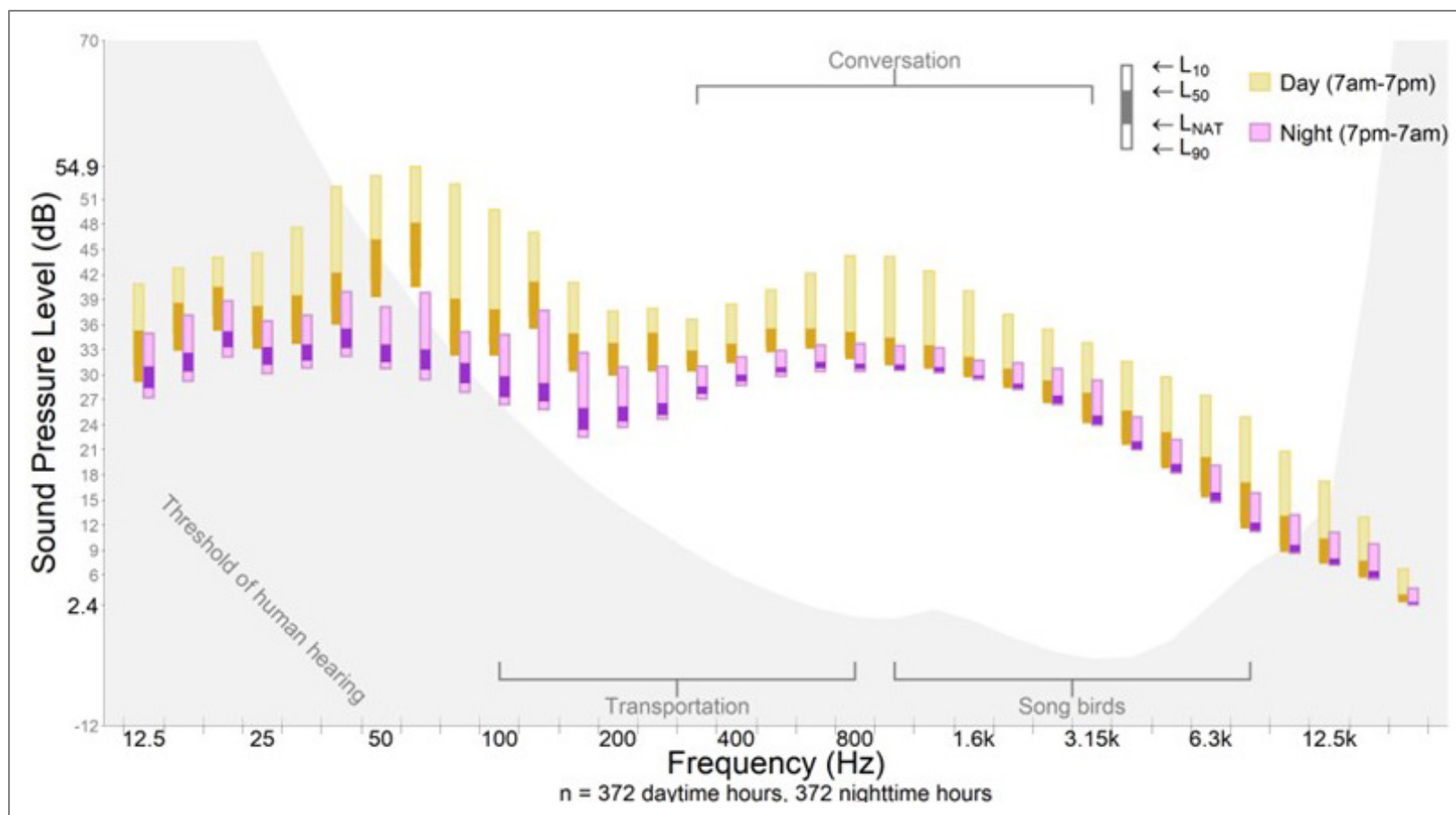


Figure 6. Day and night percentile sound pressure levels for 33 one-third octave bands at GRSM018, summer season.

NPS / NSNSD

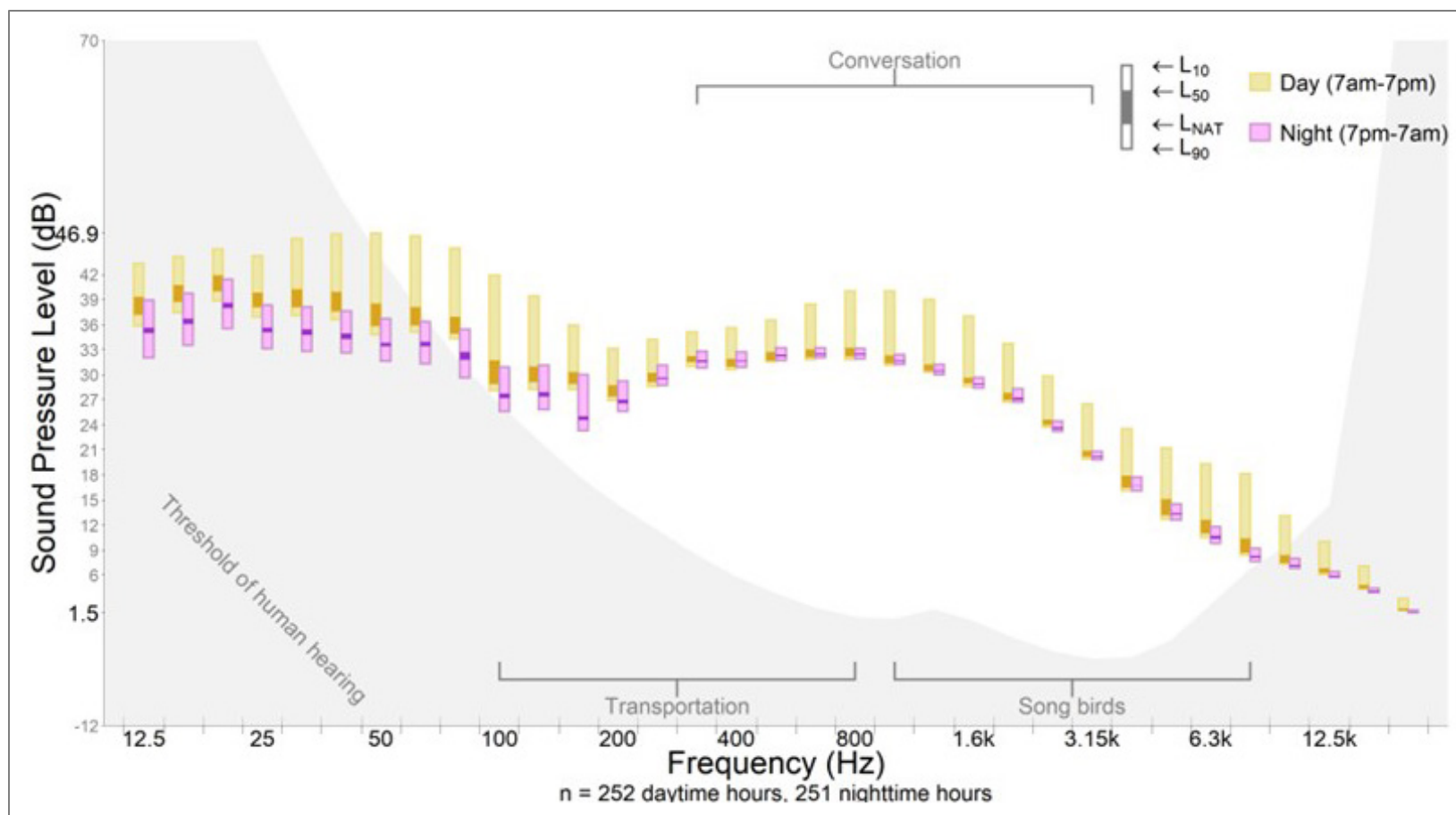


Figure 7. Day and night percentile sound pressure levels for 33 one-third octave bands at GRSM018, winter season.

NPS / NSNSD

Sound Level: Time Above

To understand how acoustic conditions in the park might affect visitors, measured sound levels are compared to sound levels of interest. Specifically, Table 6 reports the percent of time that measured sound levels ($L_{Aeq,1s}$) were above four key functional values during the monitoring periods (daytime and nighttime). The top value in each split-cell uses the full frequency range, whereas the bottom values report the percent of time ANS-weighted sound levels (20–1,250 Hz) are above functional values. Most motorized human-caused noise is confined to the truncated, lower-frequency range, while many natural sounds, including insects and birds, are higher in pitch. ANS weighting eliminates high-frequency sound (leaf rustle, equipment noise, and biological sounds) allowing for more accurate comparisons of low-frequency ambient sound levels across different land use types (e.g., urban, protected areas; ANSI S3/SC1.100, 2014). This frequency weighting scheme improves ambient sound level measurements in quiet environments. For instance, in the full frequency range, the 35 dB ($L_{Aeq,1s}$) level was exceeded at GRSM017 93.8% of the time during the day and 59.3% of the time at night, but in the 20–1,250 Hz range, the 35 dB functional sound level value was exceeded only 41.7% in daytime and 7.1% at night (Table 6). To understand how acoustic conditions in the park might affect visitors, measured sound levels are compared to sound levels of interest. Specifically, Table 5 reports the percent of time that measured sound levels ($L_{Aeq,1s}$) were above four key functional values during the monitoring periods (daytime and nighttime). The top value in each split-cell uses the full frequency range, whereas the bottom values report the percent of time ANS-weighted sound levels (20–1,250 Hz) are above functional values. Most motorized human-caused noise is confined to the truncated, lower-frequency range, while many natural sounds, including insects and birds, are higher in pitch. ANS weighting eliminates high-frequency sound (leaf rustle, equipment noise, and biological sounds) allowing for more accurate comparisons of low-frequency ambient sound levels across different land use types (e.g. urban, protected areas; ANSI S3/SC1.100, 2014 [2020]). This frequency weighting scheme improves ambient sound level measurements in quiet environments.

The first functional effect in Table 6 occurs around 35 dB ($L_{Aeq,1s}$), which is used by the NPS as an indicator of overall quality of the acoustic environment. Beyond this level, noise begins to negatively affect the visitor experience in an otherwise natural acoustic environment (Pilcher et al., 2009; Watts et al., 2020; Betchkal et al., 2023). When examining the GRSM017 summer data, the 35 dB ($L_{Aeq,1s}$) level is exceeded 93.8% of the time at the full frequency range. In comparison, the ANS level was lower at only 41.7%. This is likely due to the high insect and bird activity the Smokies experienced during this time. When examining the ANS frequencies through both sites and seasons the 35dB threshold is exceeded overall 23.2-100% of the time. GRSM017 winter experienced the lowest exceedance values in both frequency ranges.

Table 6. Time above metrics for GRSM017 and GRSM018.

Site	Frequency Range (Hz)	Time Above Sound Level (% of Daytime Hours, 07:00–19:00)				Time Above Sound Level (% of Nighttime Hours, 19:00– 07:00)			
		35 dB ^A	45 dB ^A	52 dB ^A	60 dB ^A	35 dB ^A	45 dB ^A	52 dB ^A	60 dB ^A
GRSM017 Summer	Full (12.5–20,000)	93.8	16.2	1.6	0.1	59.3	2.1	0.2	0.0
	ANS (20–1,250)	41.7	6.1	0.8	0.0	7.1	0.7	0.1	0.0
GRSM017 Winter	Full (12.5–20,000)	32.1	3.4	0.5	0.0	6.3	0.6	0.1	0.0
	ANS (20–1,250)	23.2	2.4	0.3	0.0	4.8	0.5	0.1	0.0
GRSM018 Summer	Full (12.5–20,000)	100.0	39.9	8.4	0.9	100.0	10.1	1.1	0.1
	ANS (20–1,250)	100.0	29.2	5.3	0.5	100.0	2.9	0.4	0.0
GRSM018 Winter	Full (12.5–20,000)	100.0	15.6	2.2	0.1	100.0	0.6	0.1	0.0
	ANS (20–1,250)	100.0	12.0	1.4	0.1	100.0	0.5	0.0	0.0

^A dB LAeq, 1s re: 20 µPa.

The second functional effect is expected to occur around 45 dB ($L_{Aeq,1s}$). As wildlife begin to exhibit signs of disturbance at noise levels as low as 40 dB (Shannon et al. 2016), 45 dB represents a conservative estimate of negative effects on wildlife. Both seasons exceeded this value to varying extents with GRSM017 ranging 2.4-6.1% (ANS) and GRSM018 moderately higher at 12-29.2%. Both seasons had a rare exceedance (less than 3% ANS) of this value during the night, where nocturnal behaviors would most likely be affected. The third value, 52 dB ($L_{Aeq,1s}$), is based on the EPA's analysis of speech interference for an individual speaking in a raised voice to an audience at 10 meters (EPA 1974)—an acoustic level that would affect interpretive presentations in parks. This was exceeded .3-5.3% of the daytime (ANS). The final value, 60 dB ($L_{Aeq,1s}$), marks the point at which normal voice communications at 1 meter begin to be interrupted. Notably, less than 1% of sound pressure level data collected at GRSM during the sampling period reached these levels at both frequencies.

Sound Level: Percentile Levels

To understand the range of acoustic conditions at the park, percentile sound levels are reported. In Figure 8 and Figure 9 below, the A-weighted percentile sound levels (L_{A90} , L_{Anat} , L_{A50} , and L_{A10}) are shown for GRSM017, summer and winter seasons; Figure 10 and Figure 11 show these percentile sound levels at GRSM018. The hourly percentile sound levels are calculated from the broadband (12.5 Hz–20 kHz) A-weighted, 1-second time averaged sound levels ($L_{Aeq,1s}$) within each hour of the day. For instance, in Figure 8, the L_{A50} (median) sound level for GRSM017 during the 14:00 hour is 40 dB. On the other hand, the sound level exceeded 10% of the time (L_{A10}) for the same hour at this site is 46.7 dB, meaning 90% of the measurement period is quieter than this level. Hours where the L_{A50} and the L_{Anat} differ the most are usually hours with the most human-caused noise. If we cross reference Table 6, we see that vehicles were audible on average about 57 % of this hour. The following bullets summarize a few additional points that can be gleaned from these figures combined with Table 6.

- At GRSM017 during summer, the hours between 9 am and 10 pm are most affected by noise; hours between midnight and 5 am least affected. Hourly L_{Anat} values range between 27.4 dBA (9 pm) and 40 dBA (8 am). Natural sounds during this peak 8 am hour are dominated by birds and insects.
- At GRSM017 during winter, results show the hours between 7 am and 5 pm are most affected by noise. Hourly L_{Anat} values are lower in winter, ranging between 19.5 dBA (8 and 9 pm) and 25.9 dBA (11 am and 4 pm). Natural sounds during these peak hours are dominated by birds, wind, and wind-induced sounds.
- At GRSM018 during summer, the hours between 8 am and 7 pm are most affected by noise; hours between 10 pm and 5 am least affected. Hourly L_{Anat} values range between 38.9 dBA (10 pm) and 42.4 dBA (3 am). Natural sounds during this peak 3 am hour are dominated by water flowing in the nearby creek and amphibians.
- During winter at GRSM018, human-caused noise has a much smaller influence. The hours between 10 am and 4 pm are most affected. Hourly L_{Anat} values range between 38.8 dBA (2

pm) and 40.7 dBA (7 am). Natural sounds during this peak 7 am hour are dominated by birds, water flowing in the nearby creek, and wind.

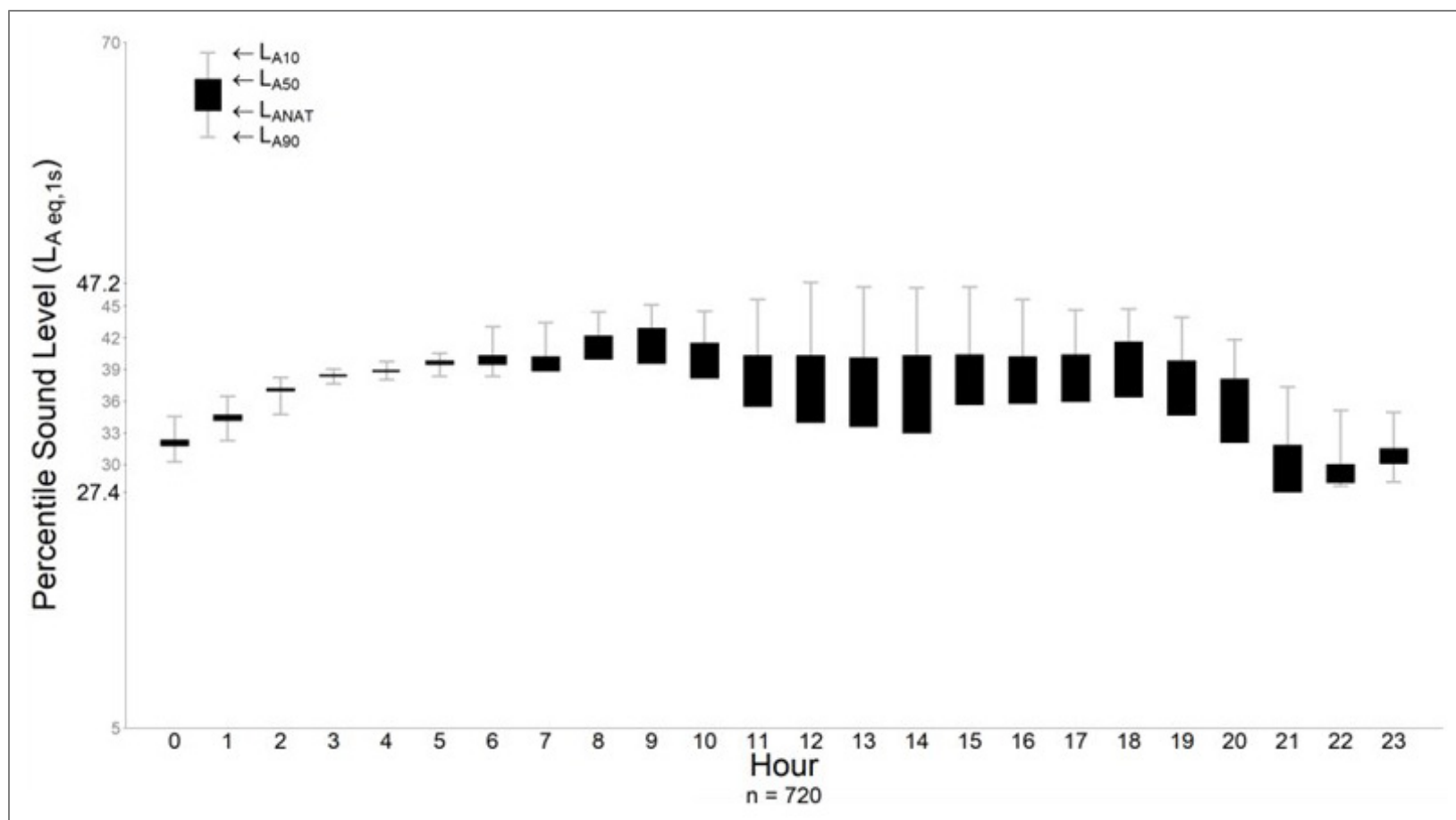


Figure 8. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at GRSM017, summer season.

NPS / NSNSD

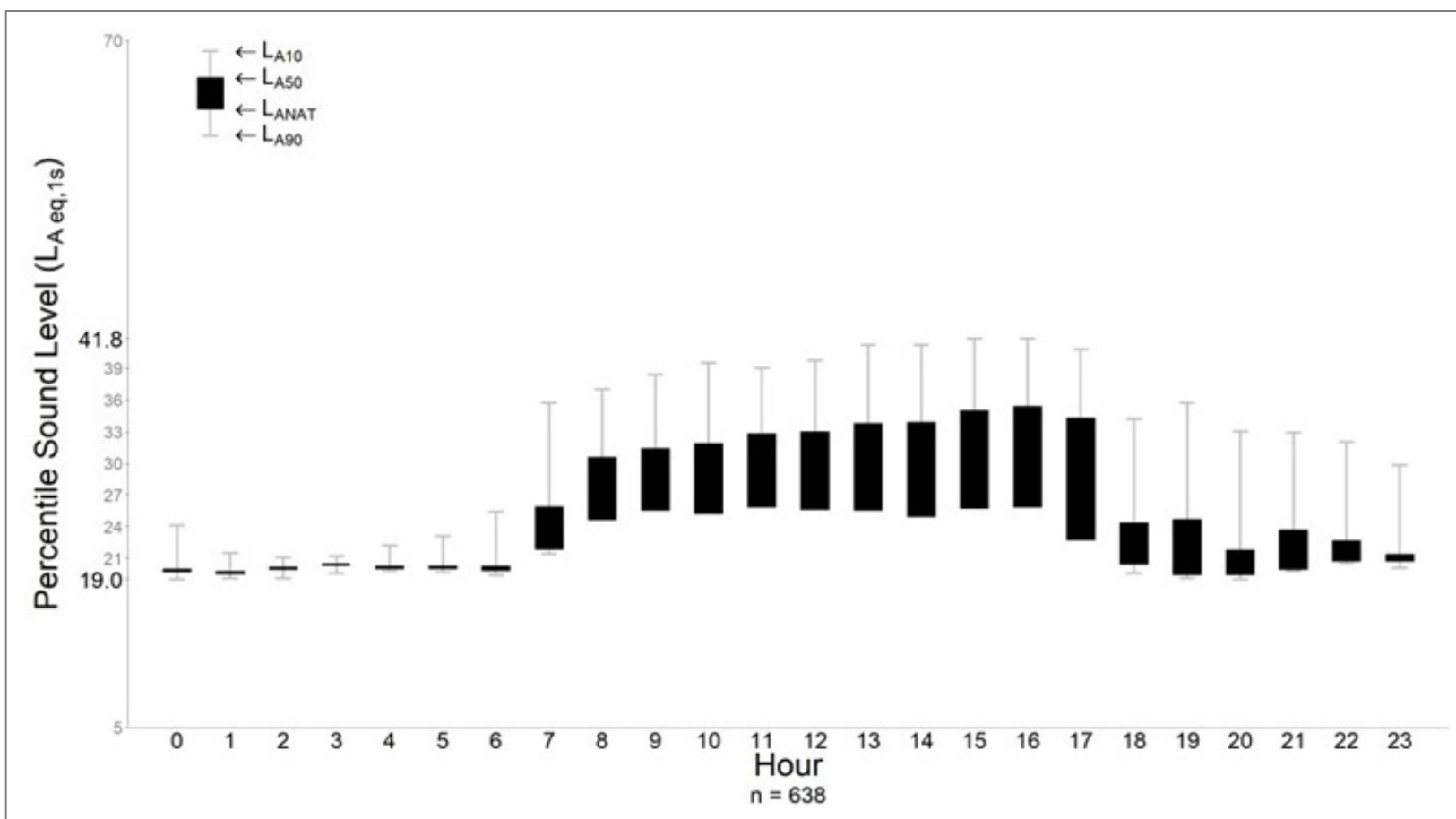


Figure 9. Median percentile sound levels ($L_{Aeq, 1s}$), in dB re 20 μ Pa, at GRSM017, winter season.

NPS / NSNSD

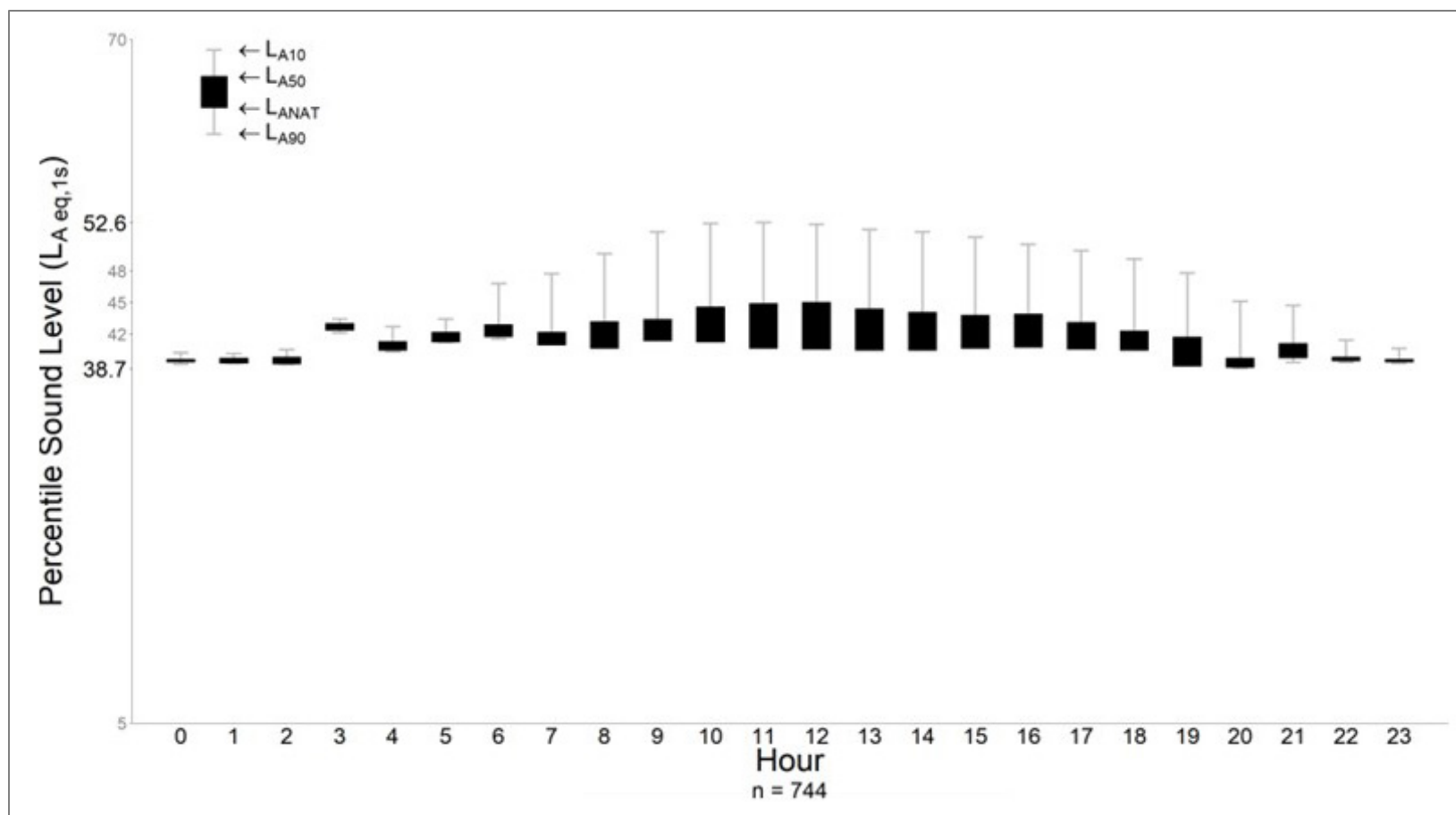


Figure 10. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at GRSM018, summer season.

NPS / NSNSD

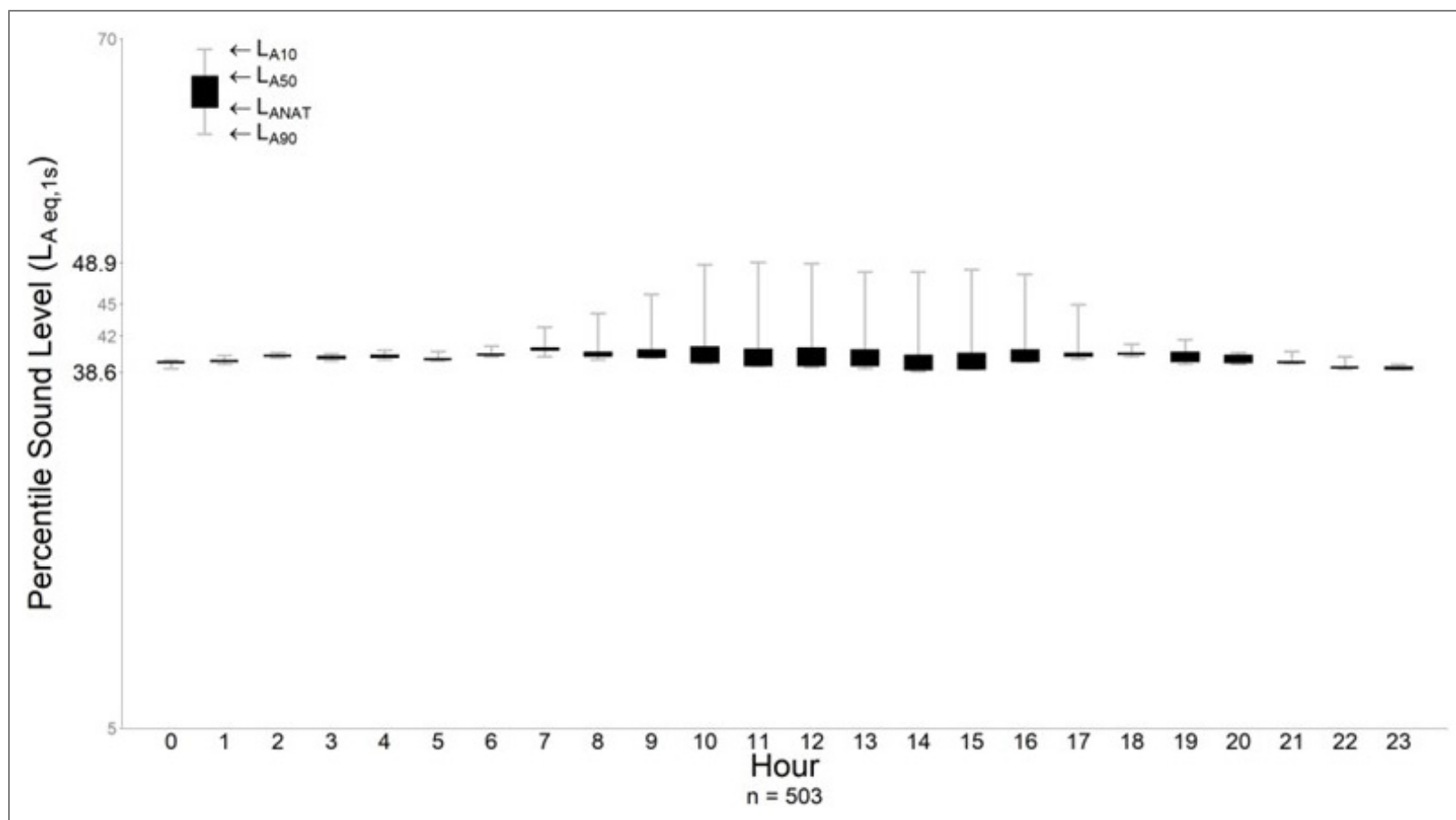


Figure 11. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at GRSM018, winter season.

NPS / NSNSD

Event Duration

Through off-site listening analysis, event duration for all audible sounds is calculated. Table 7 and Table 8 list audible natural sounds and noise sources during summer and winter seasons at GRSM017. Table 9 and Table 10 list audible natural sounds and noise sources during summer and winter seasons at GRSM018.

At GRSM017, noise was audible for an average of 66.1% of the day during summer and 59.7% during winter. At GRSM018, noise was audible on average 75.4% of the time during summer and 38.5% during winter (Table 3). At GRSM017, sound source analysis revealed that aircraft and road-based vehicles are a primary source of noise during both summer and winter. Other sources of identifiable noise included people (voices), as the historic Dan Lawson Cabin and a parking area are located nearby. At GRSM018 during the summer season, sound source analysis revealed that road-based vehicles and the HVAC system at a nearby NPS building (Twin Creeks) are the primary source of noise. Aircraft noise was less audible primarily due to sound masking from the HVAC system as well as a nearby creek. During the winter season at GRSM018, the HVAC system operates less frequently; road-based vehicles and aircraft are the primary sources of noise.

Table 7. Mean hourly percent time audible for each noise and sound source at GRSM017, summer season. n = 8 days of analysis.

Source Type	Sound Source	00h	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Non-natural	Aircraft	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	1.2	0.0	0.0	0.4	0.4	0.4	0.0	1.7	1.2	0.0	0.0
	Jet	20.8	9.6	4.6	1.2	3.8	17.5	26.7	42.9	46.7	51.7	42.5	27.1	23.3	27.1	25.8	24.2	26.2	27.9	22.9	33.3	30.8	46.7	47.1	46.3	20.8
	Propeller	1.7	2.5	0.0	0.4	0.8	1.2	2.5	5.8	2.5	5.0	9.6	12.9	7.5	3.8	6.2	6.2	6.2	2.5	4.6	3.3	0.8	2.9	4.2	3.8	1.7
	Helicopter	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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
	Vehicle	0.0	0.0	0.0	0.0	0.4	0.0	0.0	2.5	2.1	3.8	6.7	8.7	6.2	7.9	10.4	9.6	11.3	12.5	13.8	12.5	16.3	8.7	1.7	0.4	0.0
	Car	0.4	0.0	0.0	0.0	0.0	0.0	7.1	15.0	16.7	13.3	15.8	13.3	5.0	3.3	5.8	3.8	7.9	10.0	13.3	20.4	13.8	17.1	1.7	0.4	0.4
	Car alarm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.2	2.1	1.7	2.9	1.2	2.5	0.8	2.9	2.1	1.7	0.0	2.1	0.0	0.0	0.0
	Car door	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	5.0	10.4	12.1	3.8	10.8	6.2	7.1	6.2	7.9	5.0	2.9	3.8	5.4	0.0	0.0	0.0
	Car brake	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	0.8	0.4	0.8	1.2	0.8	0.0	0.4	0.0	0.0	0.0	0.0	0.0
	Motorcycle	0.0	0.4	0.8	0.0	0.0	0.0	0.4	1.2	2.1	1.7	5.8	12.1	14.6	14.2	8.3	10.4	7.1	12.1	6.2	9.2	7.5	3.3	0.0	0.0	0.0
	Truck	0.0	0.0	0.0	0.0	0.0	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
	UTV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.2	17.5	24.2	15.8	18.3	39.2	32.1	30.8	24.2	31.2	29.6	27.9	25.8	24.2	5.4	0.4	0.0	0.0
	Motors	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	0.0	0.0
	Grounds care	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	0.0
	People	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	2.1	0.4	0.4	0.4	0.0	0.4	0.0	0.4	0.0	1.2	0.0	0.4	0.4	0.4	0.0	0.0
	Voices	0.0	0.0	0.0	0.0	0.0	0.0	1.7	22.5	30.0	49.6	57.5	52.9	51.3	52.5	66.7	65.8	56.3	55.0	48.3	61.7	60.4	44.6	15.0	0.4	0.0
	Walking	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.4	0.0	0.0	0.8	0.0	0.4	0.8	0.4	0.8	0.8	1.7	0.8	1.7	2.5	0.4	0.4	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	0.4	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
	Gunshot	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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
	Bicycling	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	0.4	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	0.4	0.0	0.0	0.0	0.4	1.2	1.7	0.4	1.2	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0
	Non-natural Other	0.0	0.0	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	0.0	0.0	0.0	0.0	0.0	0.0
	Non-natural unknown	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	0.0	0.0
Natural	Wind	0.0	0.0	0.0	0.0	1.2	0.0	2.1	1.2	0.8	7.1	15.8	30.0	34.6	39.2	38.3	31.7	18.3	16.3	16.3	3.8	0.0	3.8	2.1	4.2	0.0
	Wind, light	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	10.4	12.5	7.9	4.6	3.8	9.2	10.4	5.0	0.8	0.0	0.4	0.0	0.0	0.4
	Wind, strong	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.8	0.0	0.0	3.3	11.3	21.2	26.2	21.2	14.2	8.3	9.6	2.5	0.4	0.0	0.0	0.0	0.0	0.0
	Rain, Fog Drip	13.8	15.0	12.5	10.8	12.1	12.5	2.5	0.8	0.0	0.4	0.0	0.0	0.0	0.0	0.0	9.2	5.0	0.4	8.3	10.0	4.2	9.2	8.7	9.6	13.8
	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	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0
	Squirrel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.4	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Chipmunk	0.0	0.0	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	0.4	0.0	0.0	0.0	0.0
	Coyote	3.8	0.0	0.0	2.1	0.8	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	0.0	0.0	0.0	1.2	2.1	3.8
	Birds	70.0	54.6	64.6	61.7	80.4	89.6	99.6	98.7	100.0	100.0	98.3	92.5	90.4	80.4	84.2	86.2	82.5	85.0	89.6	86.2	74.6	27.1	2.9	16.7	70.0
	Amphibians	0.0	0.0	0.4	0.0	0.0	0.8	0.0	0.0	0.0	0.4	0.4	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0
	Insects	62.5	73.8	75.4	67.1	67.9	65.0	55.8	62.1	87.5	99.6	95.8	88.3	65.0	57.9	70.0	76.2	95.8	98.3	99.2	99.6	98.3	99.6	92.9	85.4	62.5
	Animals	2.5	5.8	4.6	2.9	0.4	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.8	0.0	0.8	1.7	6.7	1.7	2.5
	Natural other	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.8	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0

Table 7 (continued). Mean hourly percent time audible for each noise and sound source at GRSM017, summer season. n = 8 days of analysis.

Source Type	Sound Source	00h	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Natural (continued)	Wind-induced natural	5.0	5.0	5.0	3.8	4.6	6.2	0.4	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	0.4	0.0	0.0	5.0
	Natural unknown	10.0	10.0	6.2	12.1	7.9	8.3	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	10.0
	Artifacts	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 8. Mean hourly percent time audible for each noise and sound source at GRSM017, winter season. n = 8 days of analysis.

Source Type	Sound Source	00h	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Non-natural	Aircraft	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.4	1.2	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
	Jet	15.8	8.7	6.7	3.3	8.3	16.3	22.5	52.1	41.7	50.0	35.4	29.2	33.7	26.7	30.0	36.7	36.2	41.3	56.3	64.2	51.3	64.2	50.8	34.6	15.8
	Propeller	0.0	0.4	2.9	0.0	0.0	0.0	0.0	3.3	1.7	3.8	7.5	6.7	8.3	9.2	9.2	6.2	8.3	6.7	6.7	3.8	3.3	0.8	2.9	1.2	0.0
	Helicopter	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	1.2	1.2	0.8	0.0	0.4	0.0	0.8	0.0	0.0	0.0	0.0
	Vehicle	0.0	0.0	0.8	0.0	0.0	0.0	0.8	0.0	1.7	13.8	5.8	8.3	18.3	14.2	10.8	10.4	9.6	13.3	1.2	0.4	2.1	0.4	0.0	0.0	0.0
	Car	0.4	0.0	0.0	0.0	0.0	0.0	0.8	16.3	47.5	26.7	42.1	39.6	26.2	26.7	35.0	50.0	56.3	53.3	8.7	0.0	0.8	1.2	0.4	0.4	0.4
	Car alarm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.8	0.8	4.2	0.4	1.7	0.8	0.8	0.8	1.2	0.0	0.0	0.0	0.0	0.0	0.0
	Car door	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.8	1.2	3.3	7.5	7.5	6.7	11.7	5.8	5.8	5.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0
	Car brake	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	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Motorcycle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.2	0.4	3.3	2.1	4.6	2.9	3.3	4.6	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Truck	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	UTV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	7.9	8.3	12.9	10.4	9.6	10.0	6.7	2.9	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Grounds Care	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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
	Dumpster / trashcan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	People	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.8	2.1	1.2	0.4	0.0	0.4	2.1	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	0.4	2.1	5.0	22.5	34.6	46.3	49.6	56.3	44.6	35.8	30.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0
	Walking	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.8	0.0	0.8	3.8	5.0	2.1	2.5	0.0	0.4	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	0.4	0.0	0.4	0.0	0.0	2.1	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	0.4	0.0	0.4	0.0	0.4	0.8	0.4	0.4	0.0	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	0.4	0.4	0.0	0.4	0.0	0.0	0.0	0.4	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0
	Non-natural unknown	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.0	1.2	0.4	0.0	0.0	0.8	0.0	0.4	0.0	0.0	1.7	0.0	0.0	0.0
Natural	Wind	1.7	2.9	0.8	1.7	2.5	2.1	0.0	0.0	0.0	0.4	1.7	1.7	5.4	5.8	4.6	1.2	2.9	0.8	0.8	0.0	0.0	0.0	0.4	0.8	1.7
	Wind, light	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.4	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.0
	Wind, strong	1.2	0.4	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	1.7	5.0	8.3	5.8	3.3	0.4	0.0	0.0	0.0	0.4	0.0	0.4	0.8	0.8	1.2
	Rain, fog drip	12.5	12.5	12.9	12.5	12.5	12.5	12.1	12.5	11.7	4.2	7.1	10.8	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5
	Squirrel	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	0.4	0.0	0.4	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4
	Chipmunk	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	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Coyote	0.8	0.0	1.2	2.1	3.3	3.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	2.9	4.2	3.8	1.7	3.3	1.7	0.8
	Birds	2.1	0.4	4.2	1.2	6.2	1.2	5.0	77.1	87.9	87.9	85.8	70.8	60.0	48.8	48.8	32.9	33.3	27.9	4.6	2.9	3.3	1.2	0.4	0.8	2.1

Table 8 (continued). Mean hourly percent time audible for each noise and sound source at GRSM017, winter season. n = 8 days of analysis.

Source Type	Sound Source	00h	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Natural (continued)	Amphibians	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	1.2	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Insects	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	3.3	7.5	0.4	0.0	0.0	0.4	0.0	0.4	0.0	0.0	0.0	0.0
	Animals	1.2	0.0	0.0	2.5	0.4	0.0	0.8	0.8	4.6	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.8	0.0	2.5	0.0	0.0	1.2
	Natural other	22.9	36.7	41.7	42.1	40.4	44.6	47.5	15.4	1.7	8.7	22.1	9.2	8.7	3.8	4.2	4.6	1.2	1.2	27.5	35.8	32.1	32.9	35.4	40.0	22.9
	Wind-induced natural	6.2	10.0	2.5	2.1	5.4	2.1	0.0	0.0	0.4	0.0	2.5	8.7	5.0	4.2	9.6	6.2	0.8	1.7	20.0	15.4	15.4	10.4	12.1	14.6	6.2
	Natural unknown	15.8	17.1	22.5	18.3	14.6	17.1	11.7	2.1	0.4	0.4	1.2	1.2	0.4	0.4	0.0	0.0	0.0	0.0	5.8	10.8	8.7	9.6	9.6	9.6	15.8
	Wind distortion	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	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
	Unknown	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	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

Table 9. Mean hourly percent time audible for each noise and sound source at GRSM018, summer season. n = 8 days of analysis.

Source Type	Sound Source	00h	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Non-natural	Aircraft	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Jet	3.3	3.3	0.8	1.2	0.8	0.8	4.6	8.3	6.7	10.0	6.7	7.9	6.7	3.8	6.7	6.2	5.8	11.3	7.5	17.5	20.0	16.3	14.6	10.0	3.3
	Propeller	0.4	0.0	0.0	0.8	0.0	0.0	0.8	4.2	0.8	0.4	2.9	2.5	2.9	2.5	0.8	2.1	2.5	3.3	2.1	1.2	0.8	0.4	1.2	0.8	0.4
	Helicopter	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.7	0.8	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0
	Vehicle	0.0	0.0	0.0	0.0	0.4	0.4	2.5	3.3	2.5	5.0	4.6	6.2	4.2	2.9	4.2	5.4	5.0	4.2	4.6	4.2	3.3	2.5	2.5	1.2	0.0
	Car	1.2	0.0	0.8	0.8	0.4	0.8	7.5	15.8	16.3	10.0	12.5	12.5	13.8	17.5	14.2	13.3	12.1	15.0	14.2	14.6	13.3	9.6	5.4	3.8	1.2
	Car alarm	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.4	0.4	0.4	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Car door	0.0	0.0	0.0	0.0	0.0	0.0	1.7	3.3	1.2	0.4	0.4	1.2	0.4	1.7	1.2	2.1	2.1	3.3	0.4	0.0	0.8	0.0	0.0	0.8	0.0
	Car brake	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	0.4	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Motorcycle	0.0	0.0	0.0	0.0	0.0	0.4	2.9	9.6	10.0	9.2	13.8	14.6	14.2	16.7	12.9	12.9	10.4	15.4	17.9	13.8	13.8	6.7	1.7	1.2	0.0
	Truck	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.8	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
	UTV	0.0	0.0	0.0	0.0	0.0	0.0	1.2	7.9	22.5	34.2	32.1	39.2	37.1	28.7	31.2	28.3	30.0	15.4	15.8	13.8	10.4	1.7	0.8	0.4	0.0
	People	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	0.4	1.7	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	0.4	0.0	1.2	2.9	3.3	5.8	5.4	3.8	2.5	3.8	5.4	1.7	6.7	2.5	3.8	0.0	0.0	0.0	0.0
	Walking	0.0	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	0.8	0.8	0.8	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	0.4	0.4	1.2	2.1	2.9	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	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
	Utilities (HVAC, Alarm, etc.)	40.4	40.8	44.2	70.4	58.8	67.5	65.0	56.7	55.0	48.3	47.5	42.1	36.7	50.4	55.0	61.3	61.7	60.4	62.9	38.8	10.8	15.4	17.1	23.3	40.4
	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	0.0	0.0	4.2	5.0	2.1	0.0	0.0	0.0	0.0
	Non-natural unknown	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	2.1	2.5	0.0	0.0	0.0	0.0	0.0	0.0
Natural	Wind	0.4	0.4	0.4	5.8	10.4	6.2	9.2	8.3	7.9	6.7	4.2	7.1	21.2	24.6	23.3	24.6	20.0	25.4	20.8	8.3	2.9	3.3	1.2	0.4	0.4
	Wind, light	0.0	0.0	0.0	0.0	1.7	1.2	1.2	0.8	0.8	0.4	0.0	0.0	0.4	0.4	1.2	0.0	2.1	3.8	2.1	0.0	0.0	0.8	0.0	0.0	0.0
	Wind, strong	0.0	0.0	0.0	0.0	0.0	0.4	0.0	1.7	0.0	0.0	0.0	1.2	1.2	2.5	3.3	1.2	1.2	2.1	1.7	0.0	0.0	0.0	0.0	0.0	0.0

Table 9 (continued). Mean hourly percent time audible for each noise and sound source at GRSM018, summer season. n = 8 days of analysis.

Source Type	Sound Source	00h	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Natural (continued)	Water	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	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8
	Rain, fog drip	25.0	25.0	25.0	17.9	12.9	14.2	16.7	10.4	8.7	11.7	6.7	7.5	0.8	6.7	14.6	7.5	17.1	7.1	14.6	12.9	9.6	13.3	13.3	22.1	25.0
	Flowing water	75.4	81.2	85.0	60.8	72.1	68.8	60.4	53.3	45.4	37.1	39.2	40.8	34.6	27.9	32.5	33.3	31.7	38.3	31.7	55.8	71.3	77.1	79.6	82.9	75.4
	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	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0
	Squirrel	0.0	0.0	0.0	0.0	0.0	0.0	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	1.2	2.1	0.0	0.0	0.0	0.0
	Chipmunk	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.7	1.7	0.4	0.0	0.0	2.9	0.8	0.0	0.0	0.4	0.0	0.8	0.4	0.4	0.0	0.0	0.0	0.0
	Coyote	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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
	Birds	0.4	1.2	2.9	2.5	5.0	47.5	99.6	96.7	98.7	98.7	96.7	90.0	87.5	86.2	85.8	92.5	89.2	92.5	81.2	90.8	88.7	20.4	0.4	0.8	0.4
	Amphibians	28.3	26.7	17.9	25.8	30.4	35.4	7.9	0.8	0.4	0.0	0.4	0.8	4.2	2.1	1.7	0.4	2.9	2.5	6.7	15.8	26.7	44.2	35.4	28.3	28.3
	Insects	1.2	2.9	1.2	0.8	0.8	1.2	0.4	0.4	0.0	0.4	0.8	0.0	0.4	0.8	1.7	5.8	1.7	1.2	1.2	1.7	2.9	2.9	1.2	0.4	1.2
	Animals	0.0	0.0	0.0	1.7	0.4	0.0	2.9	1.7	0.4	0.0	0.0	0.4	0.4	0.0	0.0	0.0	0.4	0.8	0.4	2.1	0.4	0.0	0.4	0.0	0.0
	Natural other	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
	Wind-induced natural	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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
	Artifacts	0.0	0.0	0.0	0.0	0.0	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	0.0	0.0	0.0	0.0	0.0
	Unknown	0.0	0.0	0.0	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

Table 10. Mean hourly percent time audible for each noise and sound source at GRSM018, winter season. n = 8 days of analysis.

Source Type	Sound Source	00h	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Non-natural	Aircraft	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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
	Jet	3.8	5.4	1.7	0.8	2.5	2.5	5.4	18.3	11.7	19.2	7.1	7.5	12.5	10.8	11.3	14.6	16.3	15.4	15.0	20.4	21.2	30.8	17.1	12.1	3.8
	Propeller	0.4	0.0	0.4	0.0	0.0	0.0	0.4	3.3	3.8	5.0	4.6	3.8	3.8	3.8	4.2	5.0	4.6	2.5	1.2	0.4	1.7	0.8	0.8	0.8	0.4
	Helicopter	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.4	0.8	0.0	0.0	0.0	0.0
	Vehicle	0.4	0.4	0.0	0.8	0.0	0.0	0.4	2.9	3.8	2.1	6.7	4.6	2.1	1.2	5.0	3.8	5.4	1.7	2.1	1.7	0.8	1.2	0.0	1.2	0.4
	Car	0.8	0.0	0.0	0.0	0.0	0.4	5.8	4.6	7.1	13.3	15.0	17.5	13.8	15.4	16.3	14.2	11.3	11.7	4.2	4.6	2.9	2.5	2.5	3.3	0.8
	Car alarm	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.4	0.8	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
	Car door	0.0	0.8	0.0	0.0	0.0	0.0	0.8	3.8	3.3	1.2	1.2	1.2	1.7	2.1	0.4	2.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Car brake	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Motorcycle	0.0	0.0	0.0	0.0	0.0	0.0	0.4	2.9	6.2	13.8	18.3	13.3	8.7	12.5	18.8	13.8	22.9	7.9	0.0	1.2	0.4	0.8	0.4	0.4	0.0
	Truck	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.4	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	0.0
	UTV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	7.5	14.2	20.0	20.4	22.1	21.7	20.0	21.2	16.3	8.7	0.8	0.0	0.0	0.4	0.4	0.0	0.0
	Grounds care	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	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
	Dumpster / Trashcan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.2	1.2	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	People	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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
	Voices	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	2.1	0.8	2.9	1.2	1.7	1.7	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Walking	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.8	1.2	0.4	0.4	1.2	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 10 (continued). Mean hourly percent time audible for each noise and sound source at GRSM018, winter season. n = 8 days of analysis.

Source Type	Sound Source	00h	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Non-natural (continued)	Dog	0.0	0.0	0.0	0.0	0.0	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
	Utilities (HVAC, Alarm, etc.)	0.8	0.4	1.7	12.9	22.5	12.5	12.9	6.2	3.8	5.8	4.2	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0	2.9	0.0	0.0	0.8	1.7	0.8
	Door	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	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
	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	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Wind-induced non-natural	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	0.0
	Non-natural unknown	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	0.0
Natural	Wind	11.7	15.0	10.4	1.2	2.1	4.6	7.1	4.2	2.9	7.9	4.6	6.7	10.0	9.6	12.1	11.7	6.7	5.4	10.4	0.0	0.8	0.0	0.0	0.0	11.7
	Wind, light	25.0	24.2	24.2	24.6	25.0	25.0	24.6	12.1	9.6	7.1	8.7	12.1	15.0	12.9	10.0	6.2	10.0	9.2	13.3	23.7	24.2	23.7	25.0	25.0	25.0
	Wind, strong	2.9	4.6	2.5	0.0	0.0	0.0	0.0	0.0	0.4	0.8	0.0	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9
	Water	0.0	0.0	0.0	0.0	0.0	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
	Rain, fog drip	0.0	0.0	0.4	0.0	0.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0	2.9	4.2	3.3	6.2	13.3	16.7	12.5	12.5	12.5	12.5	12.5	12.1	0.0
	Flowing water	62.1	62.5	64.2	75.0	75.0	75.0	73.3	80.0	83.3	80.4	77.1	73.3	61.3	57.1	56.3	57.5	51.3	60.8	62.5	62.5	62.5	62.5	65.0	75.0	62.1
	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	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0
	Squirrel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	2.5	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Chipmunk	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.3	7.1	5.8	0.0	1.2	5.0	0.4	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Birds	0.4	0.0	0.4	0.0	0.4	0.0	0.8	68.8	74.6	67.5	55.8	51.7	52.9	47.9	45.8	58.8	48.8	24.6	11.3	8.7	6.7	5.0	1.2	0.0	0.4
	Animals	0.4	0.0	0.0	0.8	0.0	0.0	0.0	0.8	1.2	3.3	1.7	0.0	1.7	10.8	2.5	0.0	5.0	0.4	0.0	0.4	0.0	0.0	0.0	0.0	0.4
	Natural other	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	0.4	0.8	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Wind-induced natural	5.4	7.1	9.2	12.9	13.8	7.5	14.6	6.7	3.8	1.2	6.2	23.7	30.8	33.7	35.8	26.2	17.5	10.0	10.0	9.6	4.2	8.7	8.3	10.4	5.4
	Natural Unknown	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	0.0

To further illustrate the audibility of road-based vehicles, Figure 12 and Figure 13 display average hourly audibility for all non-natural sources at GRSM017, summer and winter seasons respectively. Within each hourly total the shaded areas represent the portion of the total audibility attributed to UTVs, motorcycles, and all other vehicles. For example, in Figure 12 during the 07 hour, the time audible of all non-natural sources was 80%. Of that 80%, approximately 9% was attributed to UTVs, 1% to motorcycles, and 18% to other types of vehicles. Figure 14 and Figure 15 display these results for GRSM018, summer and winter seasons.

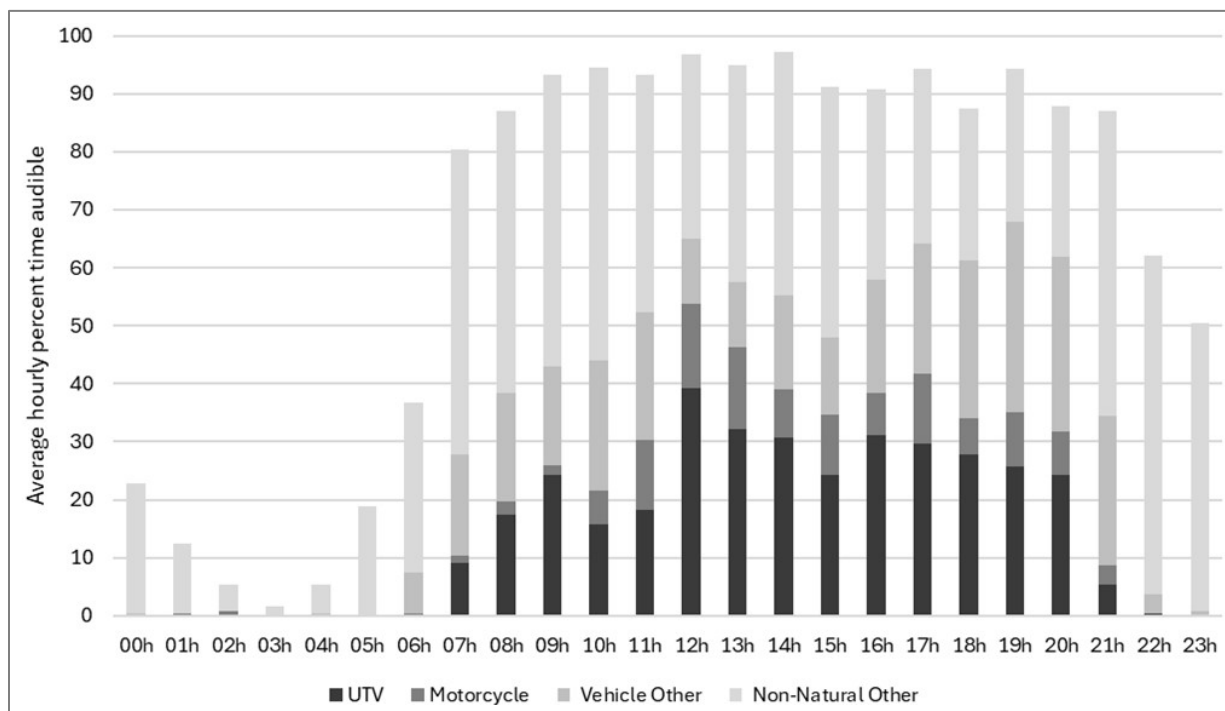


Figure 12. Average hourly percent time audible for UTV, Motorcycle, Vehicle, and Non-natural noise sources at GRSM017, summer season (n=8 days).

NPS / NSNSD

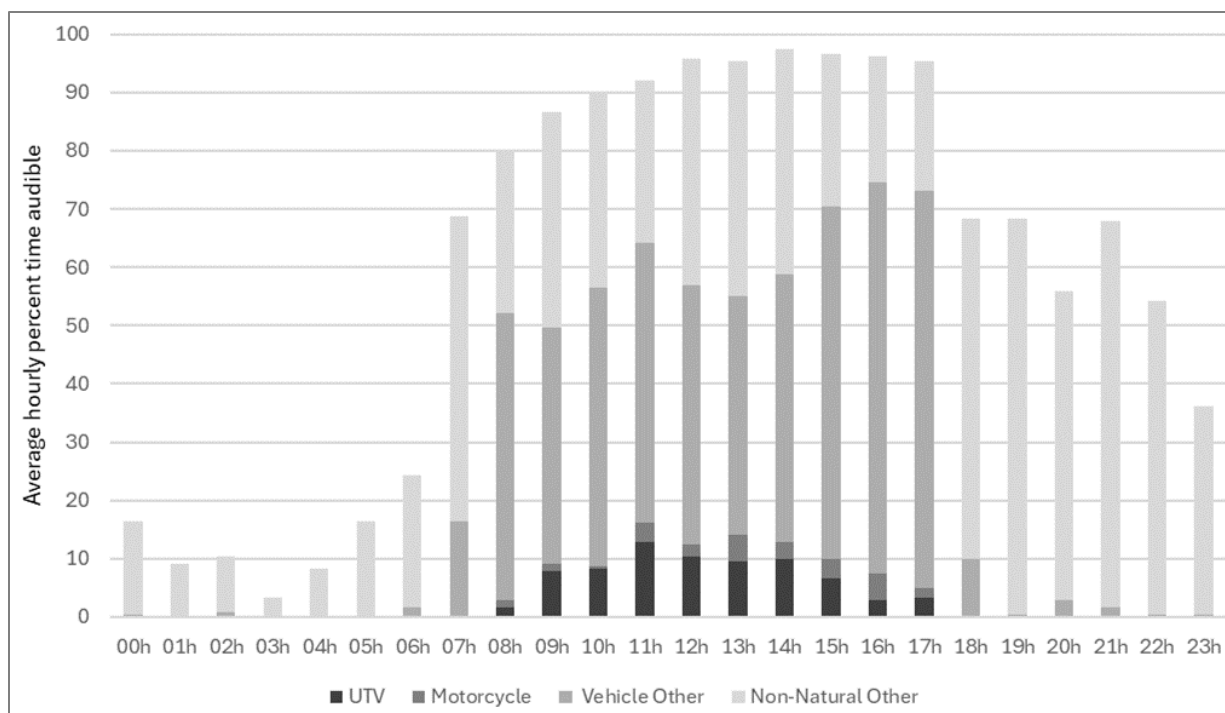


Figure 13. Average hourly percent time audible for UTV, Motorcycle, Vehicle, and Non-natural noise sources at GRSM017, winter season (n=8 days).

NPS / NSNSD

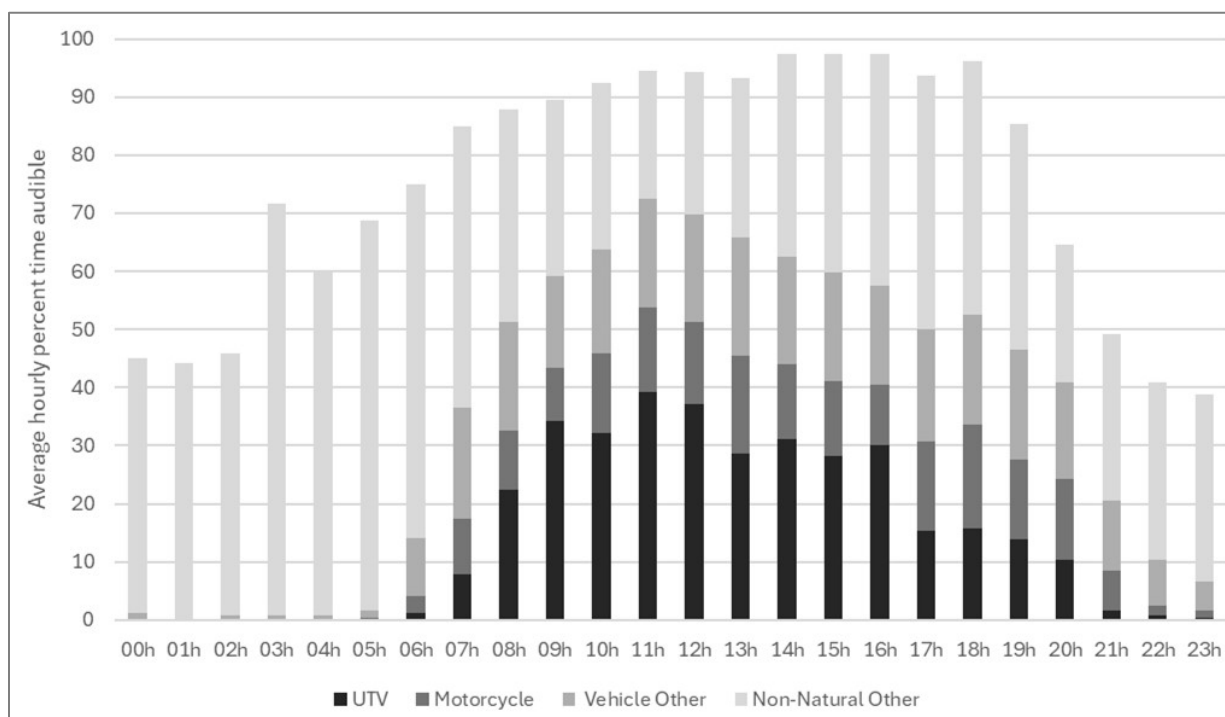


Figure 14. Average hourly percent time audible for UTV, Motorcycle, Vehicle, and Non-natural noise sources at GRSM018, summer season (n=8 days).

NPS / NSNSD

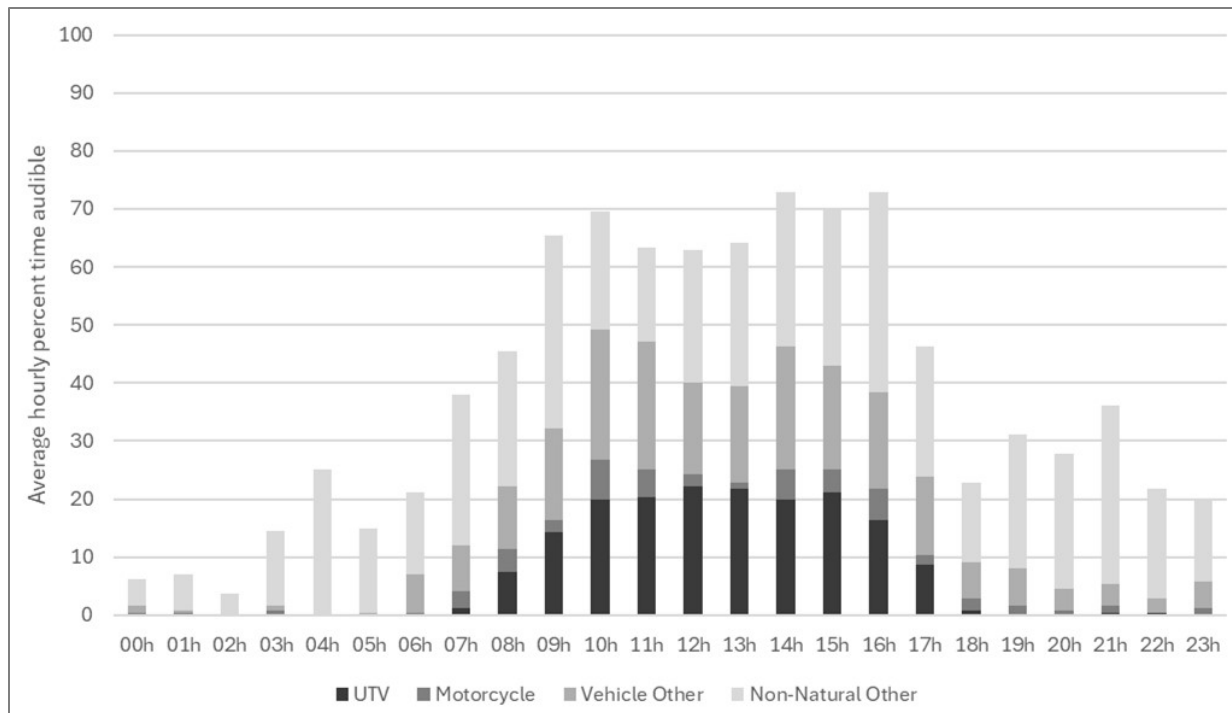


Figure 15. Average hourly percent time audible for UTV, Motorcycle, Vehicle, and Non-natural noise sources at GRSM018, winter season (n=8 days).

NPS / NSNSD

Discussion

Acoustic measurements allow parks to gain insight into levels of extrinsic noise and biological activity. The results can help estimate the influence of noise on park visitors and wildlife, as well as the condition of the acoustic environment. Monitoring results include existing ambient sound levels, calculations of sound source audibility through off-site listening, and estimates of natural ambient levels, all of which are intended to provide the park with baseline information and to inform management decisions. The purpose of this study was to monitor soundscape conditions and capture data related to motor vehicle traffic, with a particular focus on utility terrain vehicles (UTV) and motorcycles. These vehicles are generally louder and have more low-frequency content than standard passenger vehicles (autos, SUVs, and pickup trucks), making them audible at longer distances and for a longer duration. A detailed sound source analysis was conducted to determine time audible of UTVs, motorcycles and standard passenger vehicles. The site locations were chosen to assess the influence of noise on the acoustic environment at two frontcountry locations adjacent to “auto touring routes” where standard roadway vehicles, motorcycles and UTVs are allowed.

Based on the results of this study, visitors and wildlife within GRSM will experience exposure to consistent anthropogenic noise. During daytime hours (7 am to 7 pm) when most visitation occurs, road-based vehicles (all types combined) were audible 57% of daytime hours during the summer season at GRSM017 and 59% of daytime hours at GRSM018. During the winter season, time audible was slightly lower, 56% of daytime hours at GRSM017 and 42% of daytime hours at GRSM018. UTV and motorcycles were audible 33% of daytime hours during the summer season at GRSM017 and 40% of daytime hours at GRSM018. During the winter season, time audible was much lower, 8% of daytime hours at GRSM017 and 26% of daytime hours at GRSM 018. An examination of hourly data shows these vehicles can be audible for 50% of a peak hour during the summer season and 10–20% of a peak hour during the winter season. 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).

The information presented in this report will be used to inform park managers and planners when they make management decisions, but it will also serve as a permanent record of what the park sounded like in 2023. Sound level data as well as continuous digital audio recordings will be archived at the Natural Sounds and Night Skies Division office in Fort Collins, Colorado.

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