National Park Service
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Natural Resource Stewardship and Science

# Great Smoky Mountains National Park

## *Acoustic Monitoring Report 2016*

Natural Resource Report NPS/GRSM/NRR—2021/2267

**ON THE COVER**
View from Clingman's Dome
NPS

# Great Smoky Mountains National Park

*Acoustic Monitoring Report 2016*

Natural Resource Report NPS/GRSM/NRR—2021/2267

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# Contents

Page

Figures....iv

Tables....vi

Appendices....viii

Executive Summary....ix

2006–2016 Comparisons....xvi

Acknowledgments....xviii

Glossary of Acoustic Terms....xix

Introduction....1

National Park Service Natural Sounds and Night Skies Division....1

Soundscape Planning Authorities....1

Study Area....3

Methods....6

Automatic Monitoring....6

Monitoring Period....6

Calculation of Metrics....7

Off-Site Listening....7

Results....9

Frequency content....9

Sound level: Time Above....12

Sound Level: Percentile Levels....13

Event duration....15

Conclusions....28

Literature Cited....31

# Figures

Page

**Figure 1.** Acoustic monitoring sites in Great Smoky Mountains National Park, USA, 2006 and 2016. ..... ix

**Figure 2.** Acoustic monitoring system at Mt. Collins (GRSM001) in 2016. ..... x

**Figure 3.** Acoustic monitoring system at Parson Branch (GRSM002) in 2006. ..... xi

**Figure 4.** Acoustic monitoring system at Purchase Knob (GRSM004) in 2016. ..... xi

**Figure 5.** Acoustic monitoring system at Bullhead Trail (GRSM005) in 2016. ..... xii

**Figure 6.** Acoustic monitoring sites in Great Smoky Mountains National Park, USA, 2006 and 2016. ..... 5

**Figure 7.** Colorado State University student identifies sound sources using Acoustic Monitoring Toolbox (NPS) software. ..... 8

**Figure 8.** Day and night percentile sound pressure levels for 33 one-third octave bands at Mt. Collins (GRSM001) in 2016. ..... 10

**Figure 9.** Day and night percentile sound pressure levels for 33 one-third octave bands at Parson Branch (GRSM002) in 2016. ..... 10

**Figure 10.** Day and night percentile sound pressure levels for 33 one-third octave bands at Purchase Knob (GRSM004) in 2016. ..... 11

**Figure 11.** Day and night percentile sound pressure levels for 33 one-third octave bands at Bullhead Trail (GRSM005) in 2016. ..... 11

**Figure 12.** Median percentile sound levels ($L_{Aeq,\ 1s}$), in dB re 20 µPa, at Mt. Collins (GRSM001) in 2016. ..... 13

**Figure 13.** Median percentile sound levels ($L_{Aeq,\ 1s}$), in dB re 20 µPa, at Parson Branch (GRSM002) in 2016. ..... 14

**Figure 14.** Median percentile sound levels ($L_{Aeq,\ 1s}$), in dB re 20 µPa, at Purchase Knob (GRSM004) in 2016. ..... 14

**Figure 15.** Median percentile sound levels ($L_{Aeq,\ 1s}$), in dB re 20 µPa, at Bullhead Trail (GRSM005) in 2016. ..... 15

**Figure 16.** Hourly time audible for aircraft, vehicle, and other noise sources at Mt. Collins (GRSM001) in 2016. ..... 24

**Figure 17.** Hourly time audible for aircraft, vehicle, and all other noise sources at Parson Branch (GRSM002) in 2016. ..... 25

# Figures (continued)

Page

**Figure 18.** Hourly time audible for aircraft, vehicle, and all other noise sources at Purchase Knob (GRSM004) in 2016. ..... 26

**Figure 19.** Hourly time audible for aircraft, vehicle, and all other noise sources at Bullhead Trail (GRSM005) in 2016. ..... 27

**Figure 20.** Screen shot of Listening Center. ..... 33

**Figure 21.** Tracked aircraft routes over GRSM in the fall of 2019. ..... 34

**Figure 22.** Map of known air tour routes over Great Smoky Mountains National Park, USA. ..... 36

# Tables

Page

**Table 1.** Sound level examples. ..... xii

**Table 2.** Time above metrics for GRSM001, GRSM002, GRSM004, and GRSM005 in 2016. ..... xiii

**Table 3.** Mean time audible for human-caused noise, including aircraft, vehicles, and non-natural unknown. ..... xv

**Table 4.** Metadata for each acoustical monitoring site at GRSM in 2016. ..... 3

**Table 5.** Deployment and listening analysis dates for each acoustical monitoring site at GRSM in 2016. ..... 7

**Table 6.** Time above metrics for GRSM001, GRSM002, GRSM004, and GRSM005 in 2016. ..... 12

**Table 7.** Mean hourly time audible (%) for each natural sound source at Mt. Collins (GRSM001) in 2016, n=8 days. ..... 16

**Table 8.** Mean hourly time audible (%) for each noise source at Mt. Collins (GRSM001) in 2016, n=8 days. ..... 17

**Table 9.** Mean hourly time audible (%) for each natural sound source at Parson Branch (GRSM002) in 2016, n=8 days. ..... 18

**Table 10.** Mean hourly time audible (%) for each noise source at Parson Branch (GRSM002) in 2016, n=8 days. ..... 19

**Table 11.** Mean hourly time audible (%) for each natural sound source at Purchase Knob (GRSM004) in 2016, n=8 days. ..... 20

**Table 12.** Mean hourly time audible (%) for each noise source at Purchase Knob (GRSM004) in 2016, n=8 days. ..... 21

**Table 13.** Mean hourly time audible (%) for each natural sound source at Bullhead Trail (GRSM005) in 2016, n=7 days. ..... 22

**Table 14.** Mean hourly time audible (%) for each noise source at Bullhead Trail (GRSM005) in 2016, n=7 days. ..... 23

**Table 15.** Number of reported air tours on the 7 days for which audibility analysis was conducted at Bullhead Trail (GRSM005) in 2016. ..... 35

# Tables (continued)

Page

**Table 16.** Median existing and natural ambient sound levels (dB re 20 µPa, A-weighted broadband,12.5 Hz—20 kHz) at GRSM001, GRSM002, GRSM004, and GRSM005 (where day is 7:00–19:00 and night is 19:00–7:00) during summer. Measurements by Volpe from May 30–July 4, 2006 compared to data collected from June 6–July 19, 2016. ..... 37

**Table 17.** Time above metrics for daytime at GRSM001, GRSM002, GRSM004, and GRSM005 measured by Volpe from May 30–July 4, 2006 compared to data collected from June 6–July 19, 2016. ..... 38

**Table 18.** Time above metrics for nighttime at GRSM001, GRSM002, GRSM004, and GRSM005 measured by Volpe from May 30–July 4, 2006 compared to data collected from June 6–July 19, 2016. ..... 39

**Table 19.** Mean and median wind speed collected at weather stations and anemometers located at acoustic monitoring sites in Great Smoky Mountains National Park in 2006 and 2016 ..... 40

# Appendices

Page

Appendix A: Office Listening....33

Appendix B: Aircraft Tracking....34

Appendix C: Air Tours....35

Appendix D: Summer 2006 Data....37

# Executive Summary

This report presents acoustical data gathered at Great Smoky Mountains National Park (GRSM) in June and July of 2016. Data were collected at four sites to provide park managers with information about the acoustical environment, sources of noise, and the existing ambient sound levels within the park. These sites represent four of seven sites originally sampled during a noise measurement study undertaken in 2005 and 2006 by the U.S. Department of Transportation Volpe Center (Volpe) in cooperation with the NPS for the purposes of air tour planning (Figure 1; Lee *et al*. 2016).

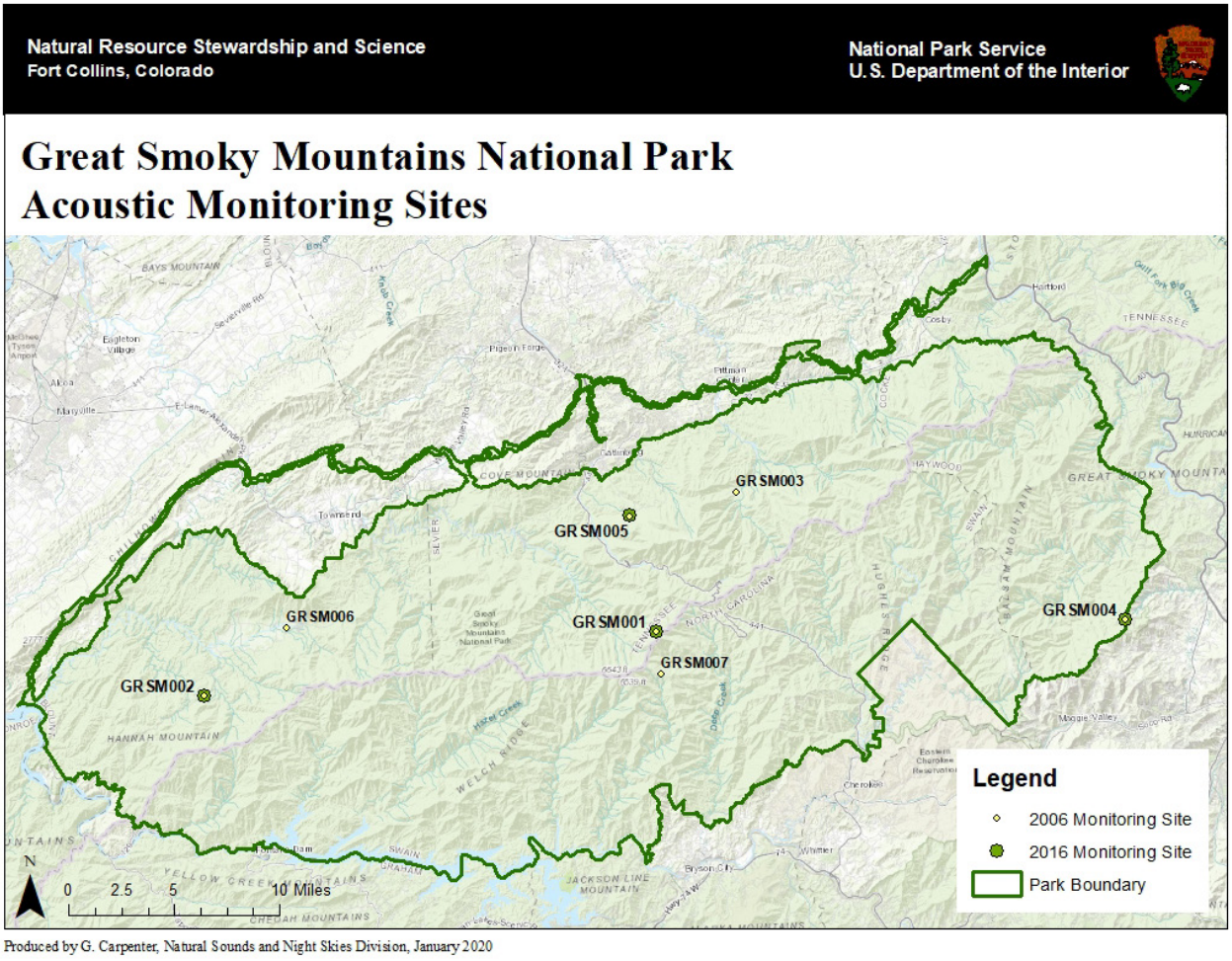


**Figure 1.** Acoustic monitoring sites in Great Smoky Mountains National Park, USA, 2006 and 2016.

The intent of site selection in the 2005–2006 Volpe study was to identify a minimum number of field sites that would allow for characterization of baseline ambient sound levels throughout the entire park (Lee *et al*. 2016). Acoustic zones were identified based on attributes that affect acoustics such as land cover and wind conditions. Sites were selected within zones such that measurements would represent acoustic conditions throughout the entire zone, or portions of the zone nearest a given site. Therefore, wide geographic coverage within the park was prioritized during site selection. The four acoustic zones and approximate percent park coverage were Hardwood Forest (52%), Spruce-Fir

Forest (25%), Pine-Oak Forest (20%), and Open Field Grass (1%). Final site selection within acoustic zones was made with additional criteria including Park/Resource Management Zones and Commercial Air Tour Flight Routes. Only four of the seven sites could be resampled in 2016 due to equipment and staffing shortages, however, those chosen represent a range of visitor and air tour usage within the predominant acoustic zones (Figures 2–5). Given the placement of monitoring sites, sound levels described in this document are more representative of what visitors would experience in the backcountry than at high visitor use areas.

**Figure 2.** Acoustic monitoring system at Mt. Collins (GRSM001) in 2016.

**Figure 3.** Acoustic monitoring system at Parson Branch (GRSM002) in 2006.

**Figure 4.** Acoustic monitoring system at Purchase Knob (GRSM004) in 2016.

**Figure 5.** Acoustic monitoring system at Bullhead Trail (GRSM005) in 2016.

In these deployments, sound pressure level was measured continuously every second by a calibrated sound level meter. Other equipment included an anemometer to collect wind speed and a digital audio recorder collecting continuous recordings to document sound sources. In this document, "sound pressure level" refers to broadband, A-weighted, 1-second time averaged sound level, hereafter referred to as "sound level." Sound levels are reported in decibels (dB). To approximate human hearing sensitivity, A-weighting is applied, which discounts sounds below 1 kHz and above 6 kHz (Harris, 1998). For reference, Table 1 provides examples of sound levels measured in parks compared to sound levels of common sources.

**Table 1.** Sound level examples.

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

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

Overall, median existing ambient sound levels ($L_{A50}$) at sites within GRSM ranged from 26.7–32.6 dB during the day and 22.8–33.4 dB at night. Table 2 reports the percent of time that sound levels were above four key values. Recent studies suggest that sound events as low as 35 dB can adversely affect blood pressure in sleeping humans (Haralabidis *et al*. 2008). Thirty-five dB is also the desired background sound level in classrooms (American National Standards Institute [ANSI] S12.60-2002). The second value addresses the World Health Organization's recommendations that noise levels inside bedrooms remain below 45 dB (Berglund et al. 1999). The third value, 52 dB, 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, provides a basis for estimating speech interference on normal voice communications at 1 meter.

**Table 2.** Time above metrics for GRSM001, GRSM002, GRSM004, and GRSM005 in 2016.

| Site ID | Site Name | 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* |
| GRSM001 | Mt. Collins | 12.5–20,000 | 11.99 | 1.76 | 0.20 | 0.00 | 6.43 | 0.59 | 0.09 | 0.00 |
| | Mt. Collins | 20–1,250 | 2.98 | 0.36 | 0.05 | 0.00 | 1.46 | 0.15 | 0.01 | 0.00 |
| GRSM002 | Parson Branch | 12.5–20,000 | 21.62 | 2.88 | 0.35 | 0.02 | 29.47 | 9.22 | 1.83 | 0.02 |
| | Parson Branch | 20–1,250 | 9.20 | 0.97 | 0.15 | 0.01 | 10.68 | 0.52 | 0.08 | 0.00 |
| GRSM004 | Purchase Knob | 12.5–20,000 | 42.00 | 9.20 | 1.91 | 0.22 | 48.85 | 6.33 | 1.43 | 0.39 |
| | Purchase Knob | 20–1,250 | 13.00 | 0.57 | 0.08 | 0.00 | 12.47 | 0.33 | 0.03 | 0.00 |
| GRSM005 | Bullhead Trail | 12.5–20,000 | 20.06 | 1.95 | 0.34 | 0.01 | 25.40 | 2.88 | 0.28 | 0.00 |
| | Bullhead Trail | 20–1,250 | 3.63 | 0.38 | 0.07 | 0.00 | 3.52 | 0.35 | 0.01 | 0.00 |

* dB $L_{Aeq, 1s}$ re 20 µPa

Sound levels are often measured over narrow frequency bands 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 bottom split cell is based upon a "Natural Sounds" subset which eliminates high-frequency sound (leaf rustle, equipment noise, and biologic sounds) allowing for more accurate comparisons of low-frequency ambient sound levels across different land use types (e.g. urban, protected areas). This frequency weighting scheme improves ambient sound level measurements in quiet environments.

After data collection was complete, trained technicians calculated how often noise[1] sources were audible. Sound source analysis revealed that noise was audible 35.6–76.0% of the time at study sites when averaged across all hours of the day (Table 3). The most common source of noise during this study period was non-natural unknown, often described by listeners as a "distant" or "running" motor. Oftentimes, low frequency motorized sources are clearly audible to an attentive listener, but distant enough that their specific origin cannot be identified. Natural ambient sound levels ($L_{Anat}$) ranged from 24.6–28.3 dB during the day and 21.5–28.4 dB at night. Increased natural ambient sound levels during the night at Purchase Knob were likely due to insect and bird activity in the evening hours (see Figure 5 above and Figures 6 and 7 in the Study Area section below).

[1]For the purposes of this document, we will refer to "noise" as any human-caused sound that masks or degrades natural sounds

**Table 3.** Mean time audible for human-caused noise, including aircraft, vehicles, and non-natural unknown. Median existing and natural ambient sound levels (dB re 20 µPa, A-weighted broadband,12.5 Hz—20 kHz) are also included. Data are from GRSM001, GRSM002, GRSM004, and GRSM005 (where day is 7:00–19:00 and night is 19:00–7:00) during summer 2016.

| | | Mean time audible for noise (% of 24-hour time period) | | | | | | | Median Existing Ambient ($L_{A50}$) in dB | | Median Natural Ambient ($L_{Anat}$) in dB | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site ID | Site Name | All Noise | All Aircraft | Jet | Propeller Aircraft | Helicopter | Vehicle | Non-Natural Unknown | Day | Night | Day | Night |
| GRSM001 | Mt. Collins | 35.6 | 12.8 | 0.0 | 0.7 | 0.0 | 4.1 | 17.8 | 26.7 | 22.8 | 24.6 | 21.5 |
| GRSM002 | Parson Branch | 67.5 | 44.2 | 39.2 | 5.1 | 0.0 | 1.0 | 20.5 | 30.7 | 28.5 | 26.4 | 25.1 |
| GRSM004 | Purchase Knob | 75.1 | 16.2 | 13.3 | 2.8 | 0.1 | 12.0 | 62.7 | 32.6 | 33.4 | 28.3 | 28.4 |
| GRSM005 | Bullhead Trail | 76.0 | 23.5 | 16.1 | 4.2 | 3.3 | 17.5 | 36.8 | 29.7 | 29.2 | 25.8 | 25.7 |

### 2006–2016 Comparisons

In 2006, noise events were documented by technicians present on site whereas in 2016 sources were documented off-site using recorded audio. A disadvantage of off-site listening is that binaural hearing and vision cannot be used to aid noise source identification. Consequently, in 2016 sources classified as "non-natural unknown" were audible as much as 62.7% of the time. This implies that audibility of other specified sources such as air tours are likely underestimated in this report.

Additionally, temporal differences in time above metrics and existing and natural ambient levels can be caused by factors such as relative equipment placement or environmental differences including change in wind speed (further details in Appendix D). Therefore, caution should be used when making comparisons between 2006 and 2016 sound levels.

From 2006 to 2016, changes in existing ambient sound levels generally correspond to differences in natural ambient sound levels. Increases were most pronounced in frequency bands associated with insects and songbirds, supporting rise in natural level as a cause for the rise in existing level. Subtracting the difference in natural ambient level between years, daytime median existing sound level decreased at Mt. Collins (1.9 dB) and Bullhead Trail (0.2 dB) and increased at Parson Branch (0.1 dB) and Purchase Knob (0.9 dB). According to the GRSM NRCA, these differences of < 1.5 dB increase indicate soundscapes are in good condition with declining trend (Bates *et al.* 2018). Existing levels at night increased more substantially at Parson Branch (4 dB) and Purchase Knob (6.3 dB), which may warrant significant concern according to the GRSM NRCA. However, as nighttime sound source identification did not occur in 2006, nighttime natural ambient level was not calculated. Therefore, the rise in existing ambient level may be attributed to rise in natural ambient level or to the environmental and instrumental factors discussed above.

**Mt. Collins (GRSM001)** had the lowest existing and natural ambient sound levels and time above metrics among sites in 2016. Overall, daytime audibility of man-made noise stayed virtually the same from 2006 (45.5%) to 2016 (45.4%), with maximum audibility (55.2%) occurring at the 16:00 hour in 2016. Daytime audibility of fixed wing aircraft and helicopters decreased from 2006 (12.9%) to 2016 (1.2%), however, daytime audibility of non-natural unknown sounds was 23.4% in 2016. Two air tours were flown that, based on the proximity of the route to this site, should have been identified but were not (blue route; Appendix B). Thus, some portion of the non-natural unknown audibility is likely attributable to those flights. Given the relatively low natural ambient level, impacts from man-made sources may be more pronounced in Spruce-Fir Forest than in other acoustic zones.

**Parson Branch (GRSM002)** had the highest time above metrics at night for the 45, 50, and 62 dB sound levels. Given the high energy in higher frequency bands, elevated time above metrics may have been due to insect activity. Overall, daytime audibility of man-made noise increased substantially from 2006 (64.0%) to 2016 (80.4%) with maximum audibility (93.3%) occurring at the 08:00 hour in 2016. Daytime audibility of fixed wing aircraft and helicopters decreased from 2006 (18.6%) to 2016 (8.1%), however, daytime audibility of non-natural unknown sounds was 18.3% in 2016. Commercial jets were audible as much as 72.6% of the time at this site.

**Purchase Knob (GRSM004)** had the highest time above metrics for all key sound levels during daytime in 2016, consistent with 2006. It had the highest day- and nighttime existing sound level in 2016 where it had the lowest for daytime in 2006. This may be partially attributed to Purchase Knob having the highest natural ambient sound level in 2016. Nonetheless, impacts from man-made noise increased considerably as the site had the lowest daytime audibility in 2006 (39.4%) and one of the highest in 2016 (77.5%), with maximum audibility (86.2%) occurring at the 11:00, 19:00 and 21:00 hours in 2016. This is likely due to the proximity of Purchase Knob to the park boundary. Daytime audibility of fixed wing aircraft and helicopters decreased from 13.8% in 2006 to 3.9% in 2016, however, daytime audibility of non-natural sounds was 62.7%.

**Bullhead Trail (GRSM005)** had neither the highest nor lowest time above metrics and existing and natural ambient sound levels among sites. However, Bullhead Trail had the greatest time audible among sites during the day in 2016 (84.9%), an increase from 2006 (59.0%), with maximum audibility (93.7%) occurring at the 09:00 hour in 2016. Daytime audibility of fixed wing aircraft and helicopters was 11.9% in 2016, up slightly from 9.5% in 2006, and daytime audibility of non-natural unknown sources was 36.8%.

# Acknowledgments

Acoustic data for this report were gathered by Scott McFarland.

# Glossary of Acoustic 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, & wildlife and cultural and historic sounds like tribal ceremonies, quiet reverence, and battle reenactments.

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

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

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

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

**Existing ambient sound level (LA50):** Sound level ($L_{Aeq,\ 1s}$) exceeded 50% of the time ($50^{th}$ percentile) for a specified duration. This level is referred to as the existing ambient sound level and the preferred metric for chronic conditions, as it is insensitive to infrequent loud events.

**Frequency:** Related to the pitch of a sound, and defined as the number of times per second that the wave of sound repeats itself and is expressed in terms of hertz (Hz). Sound levels are often adjusted ("weighted") to match the hearing abilities of a given animal. In other words, different species of animals and humans are capable or hearing (or not hearing) at different frequencies. Humans with normal hearing can hear sounds between 20 Hz and 20,000 Hz, and as low as 0 dB at 1,000 Hz. Bats, on the other hand, can hear sounds between 20 Hz and 200,000 Hz.

**Percentile sound levels (LA10, LA50, LA90):** 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 (Ldn):** 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 (LAeq):** The sound energy level averaged over the measurement period. Generally, refers to A-weighted 1-second time averaged sound levels measured between 12.5 Hz–20 kHz. This is a standard measurement collected using NSNSD acoustic monitoring protocol for sound level meters. Sound levels measured over 1 second intervals are used to calculate summary statistics, specifically percent of the time a sound level of interest is exceeded.

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

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

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

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

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

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

**Sound vs. Noise:** Sound and noise are often used interchangeably to describe an acoustic source. A common definition of noise is unwanted sound or sounds that interfere with a signal of interest (Harris 1998; Templeton 1997). However, noise is not a purely subjective designation. Any sound that serves no function is noise. Most sounds produced by human transportation and other machinery are unintended and serve no function, therefore are noise regardless of the attitudes of the listener. While there are unintended sounds in nature, like the footfalls of an animal, these sounds provide vital cues for some receivers and are therefore considered sounds to the receiver, yet noise from the perception of the producer.

**Soundscape:** The human perception of physical sound resources.

# Introduction

A 1998 survey of the American public revealed that 72 percent of respondents thought that providing opportunities to experience natural quiet and the sounds of nature was a very important reason for having national parks, while another 23 percent thought that it was somewhat important (Haas & Wakefield 1998). In another survey specific to park visitors, 91 percent of respondents considered enjoyment of natural quiet and the sounds of nature as compelling reasons for visiting national parks (McDonald *et al*. 1995). Acoustical monitoring provides a scientific basis for assessing the status of acoustic resources, identifying trends in resource conditions, quantifying impacts from other actions, assessing consistency with park management objectives and thresholds, 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 soundscapes[2] 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 unnatural sound will vary throughout a

[2] 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.

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, as amended, requires the Federal Aviation Administration (FAA), in cooperation with the NPS, to develop an Air Tour Management Plan (ATMP) or voluntary agreement 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.

# Study Area

This report covers results from an acoustic inventory conducted in 2016 at Great Smoky Mountains National Park (GRSM). Four sites were sampled in this study: Mt. Collins (GRSM001), Parson Branch (GRSM002), Purchase Knob (GRSM004), and Bullhead Trail (GRSM005) (Table 4). These represent four of seven sites originally sampled during a noise measurement study undertaken in 2005 and 2006 by the U.S. Department of Transportation Volpe Center in cooperation with the NPS for the purposes of air tour planning (Lee *et al*. 2016).

**Table 4.** Metadata for each acoustical monitoring site at GRSM in 2016.

| Site | Site Name | Dates Deployed | Visitor Use | Acoustic Zone | Elevation (m) | Latitude | Longitude |
|---|---|---|---|---|---|---|---|
| **GRSM001** | Mt. Collins | 6/15/2016–7/19/2016 | Low | Spruce-Fir Forest | 1804 | 35.59227 | −83.47372 |
| **GRSM002** | Parson Branch | 6/13/2016–7/14/2016 | Moderate | Pine-Oak Forest | 699 | 35.55861 | −83.85690 |
| **GRSM004** | Purchase Knob | 6/6/2016–7/12/2016 | low | Hardwood Forest | 1419 | 35.588540 | −83.077057 |
| **GRSM005** | Bullhead Trail | 6/14/2016–7/12/2016 | Moderate | Hardwood Forest | 865 | 35.672722 | −83.492531 |

The intent of site selection in the original 2005–2006 study was to identify a minimum number of field sites that would allow for characterization of baseline ambient sound levels throughout the entire park. Acoustic zones were identified based on attributes that affect acoustics such as land cover and wind conditions. Sites were selected within zones such that measurements taken would represent acoustic conditions throughout the entire zone. The four acoustic zones and approximate percent park coverage were Hardwood Forest (52%), Spruce-Fir Forest (25%), Pine-Oak Forest (20%), and Open Field Grass (1%). Each zone corresponds to an NLCD landcover type: Hardwood Forest – NLCD Deciduous Forest; Spruce-Fir Forest – NLCD Evergreen Forest; Pine-Oak Forest – NLCD Mixed Forest; Open Field Grass – NLCD Shrubland, Grasslands, Pasture/Hay, and Urban Grasses (Vogelmann et al. 2001). Final site selection within acoustic zones was made with additional criteria including Park/Resource Management Zones and Commercial Air Tour Flight Routes. Data from these sites were used to construct an acoustic conditions map across GRSM. A similar map was not created in the current study, but the same monitoring sites were used to compare local conditions, which may be extrapolated to describe conditions in nearby portions of acoustic zones. Three of the seven sites could not be monitored in 2016 due to equipment and staffing shortages, however, those chosen represent a range of visitor and air tour usage within the predominant acoustic zones.

Figure 6 shows the location of acoustic inventory sites in map format. The Mt. Collins site was located just off the Appalachian Trail near a backcountry shelter. The Parson Branch site was located near Parsons Branch road, a small, one-way dirt road that leads from Cades Cove to Highway 129. The area was considered to have moderate visitor use but Parsons Branch road was closed to motor

vehicle traffic during the survey period. The Purchase Knob site was located near the Cataloochee Divide Trail, 440 m from a remote science learning center, and 31 m from the park boundary. The Bullhead Trail site was located near the junction of the Bullhead and Old Sugarlands trails.

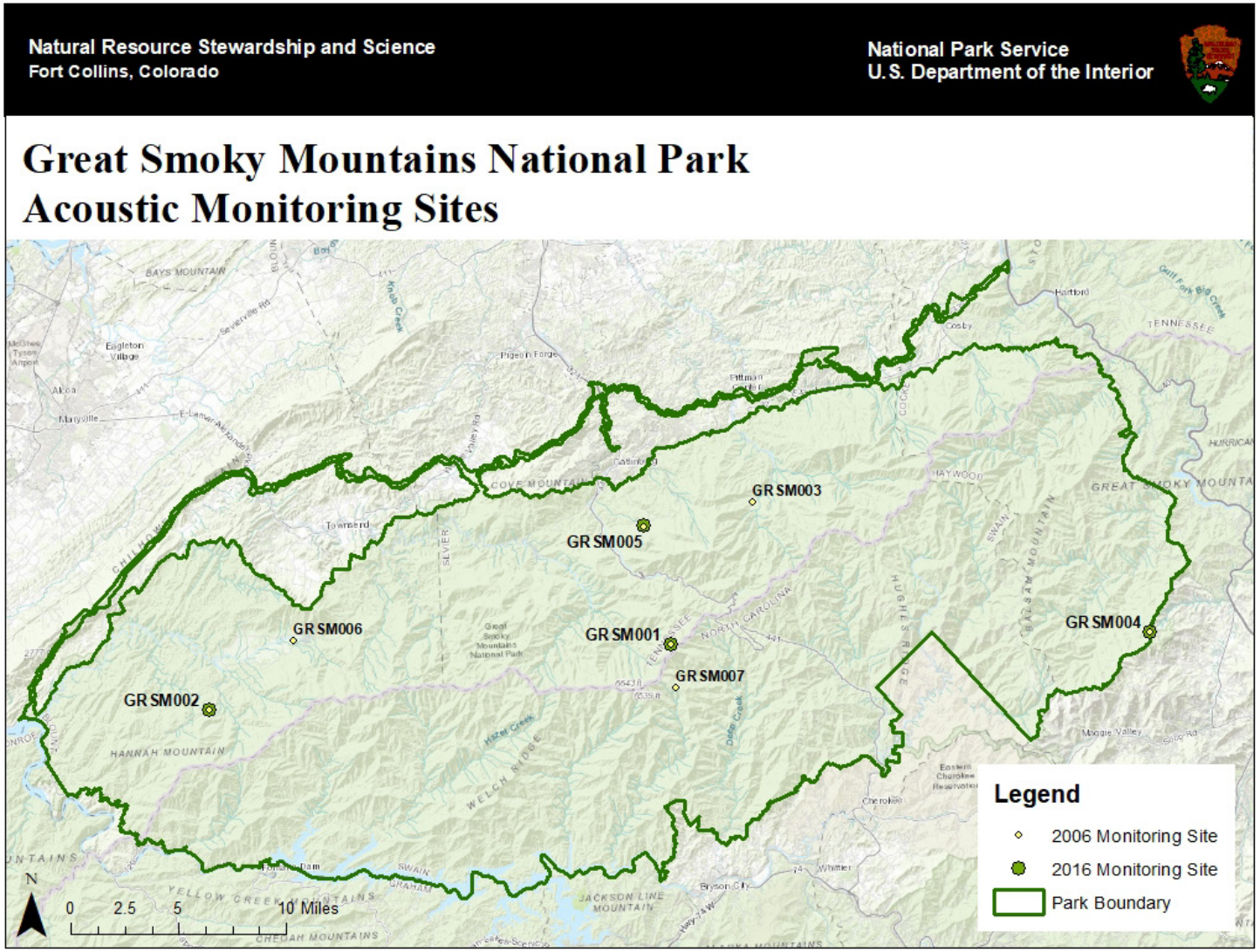


**Figure 6.** Acoustic monitoring sites in Great Smoky Mountains National Park, USA, 2006 and 2016.

# Methods

## Automatic Monitoring

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

Acoustical monitoring equipment is used by many industries to determine noise levels in different environments, both indoors and outdoors. NPS uses equipment that is similar to the equipment used by other industries but has developed a unique configuration that stands up to the potentially harsh environment encountered in national parks. The microphone with environmental shroud was set up on a tripod at 1.5 m, which approximates the average height of the human ear. The digital audio recorder recorded continuous audio through the entire monitoring period. An anemometer was attached to a tripod and placed approximately 10 feet from the microphone, to capture local wind conditions without recording possible sound from anemometer wind cup rotation.

The sampling station consisted of:

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

The sampling station collected:

- A-weighted 1 second time averaged sound level ($L_{Aeq, 1s}$) in dB re 20 µPa
- 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 30 days at each site between June 13–July 19, 2016. 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). Data were only gathered in the summer season in 2016 due to equipment and staffing shortages. However, paired with summer 2006 data these results may offer insight to within-season condition trends.

## Calculation of Metrics

The status of the acoustical environment can be characterized by sound level ($L_{A50}$, $L_{Anat}$, $L_{A90}$, $L_{A10}$, $L_{Aeq}$), 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 > 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. The $L_{A90}$ represents the sound pressure level that is exceeded 90% of the time, therefore, only 10% of the sound levels that occur are below the $L_{90}$. The inverse of this, $L_{A10}$, represents the sound pressure level that is exceeded 10% of time, therefore, 90% of the sound levels that occur are above the $L_{A10}$.

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

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

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

## Off-Site Listening

Off-site listening is normally done by listening to an audio recording and simultaneously visually analyzing a spectrogram (for more information on Listening Center software, see Appendix A). Auditory analysis was used to calculate the audibility of sound sources at the monitoring locations. Trained technicians at Colorado State University (Figure 7) listened to a subset of .mp3 audio samples (10 seconds every two minutes for eight days of audio) in order to identify durations of audible sound sources (Table 5).

**Table 5.** Deployment and listening analysis dates for each acoustical monitoring site at GRSM in 2016.

| Site | Site Name | Dates Deployed | Listening Analysis Dates |
|---|---|---|---|
| **GRSM001** | Mt. Collins | 6/15/2016–7/19/2016 | June 18, 19, 20, 22, 27, 28; July 2, 4 |
| **GRSM002** | Parson Branch | 6/13/2016–7/14/2016 | June 16, 17, 18, 23, 24, 25, 28; July 3 |
| **GRSM004** | Purchase Knob | 6/6/2016–7/12/2016 | June 19, 20, 25, 26, 28, 29; July 2, 3 |
| **GRSM005** | Bullhead Trail | 6/14/2016–7/12/2016 | June 15, 19, 24, 25, 26, 29; July 1 |

The total percent time noise was audible was then used to calculate the natural ambient sound level ($L_{Anat}$) for each hour (see Equation 1 above for more information) (Figure 7). 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 in the Results section.

**Figure 7.** Colorado State University student identifies sound sources using Acoustic Monitoring Toolbox (NPS) software.

# Results

## Frequency Content

In order to determine the effect that noise has on the acoustical environment, it is useful to examine percentile metrics across a frequency range. High frequency sounds (such as a cricket chirping) and low frequency sounds (such as flowing water) often occur simultaneously, so the frequency spectrum is split into 33 smaller ranges, each encompassing one-third of an octave. These smaller bands closely represent how humans distinguish between frequencies of sound. For each one-third octave band, sound level ($L_{eq,\,1s}$) was recorded once per second for the duration of the monitoring periods. The percentile sound levels for 33 one-third octave band frequencies over the day and night periods are shown in Figure 8–Figure 11.

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 areas of Figure 8–Figure 11 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 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.

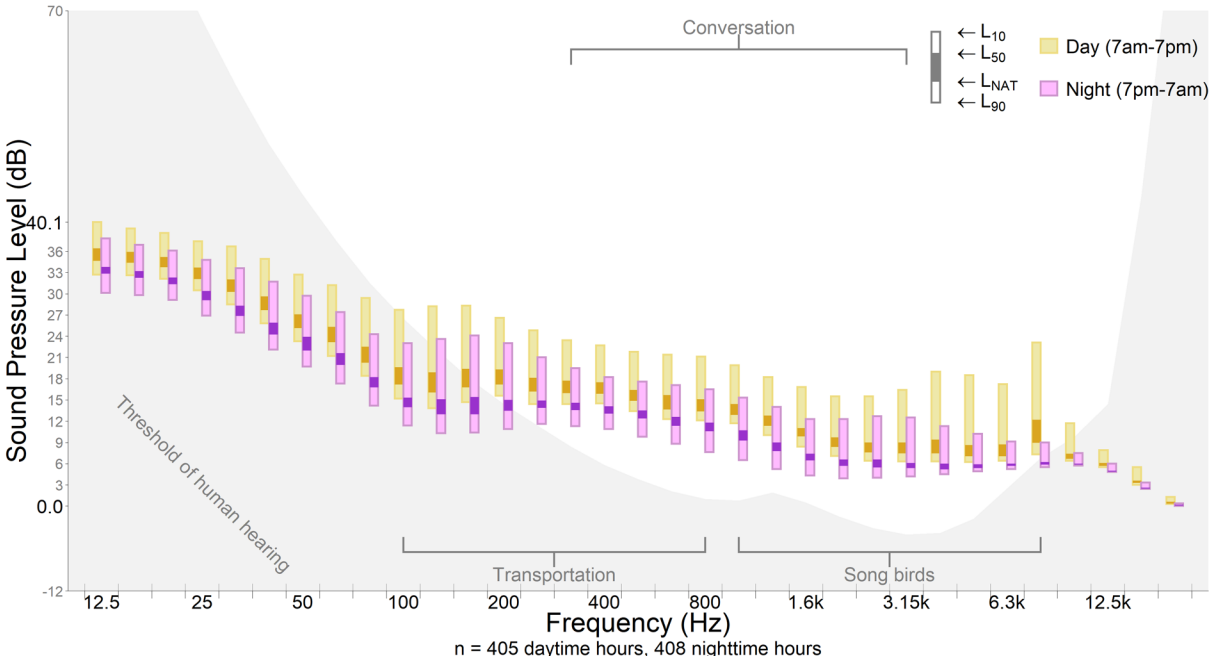


**Figure 8.** Day and night percentile sound pressure levels for 33 one-third octave bands at Mt. Collins (GRSM001) in 2016. Grayed areas represent sounds outside the typical range of human hearing.

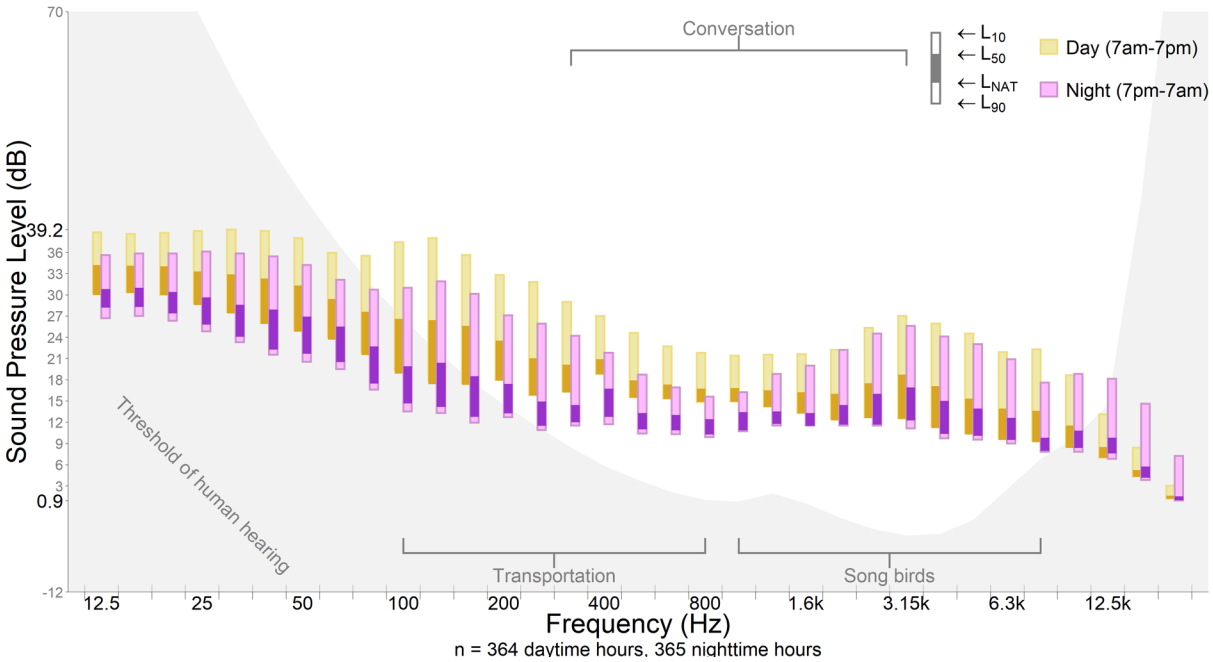


**Figure 9.** Day and night percentile sound pressure levels for 33 one-third octave bands at Parson Branch (GRSM002) in 2016. Grayed areas represent sounds outside the typical range of human hearing.

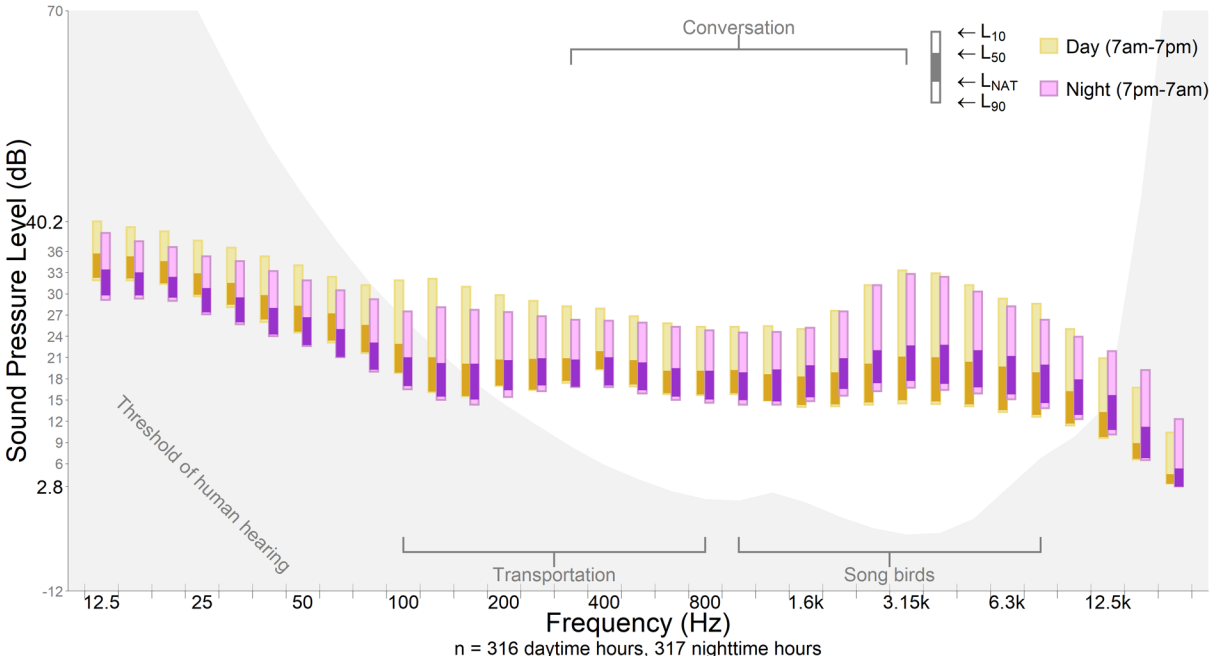


**Figure 10.** Day and night percentile sound pressure levels for 33 one-third octave bands at Purchase Knob (GRSM004) in 2016. Grayed areas represent sounds outside the typical range of human hearing.

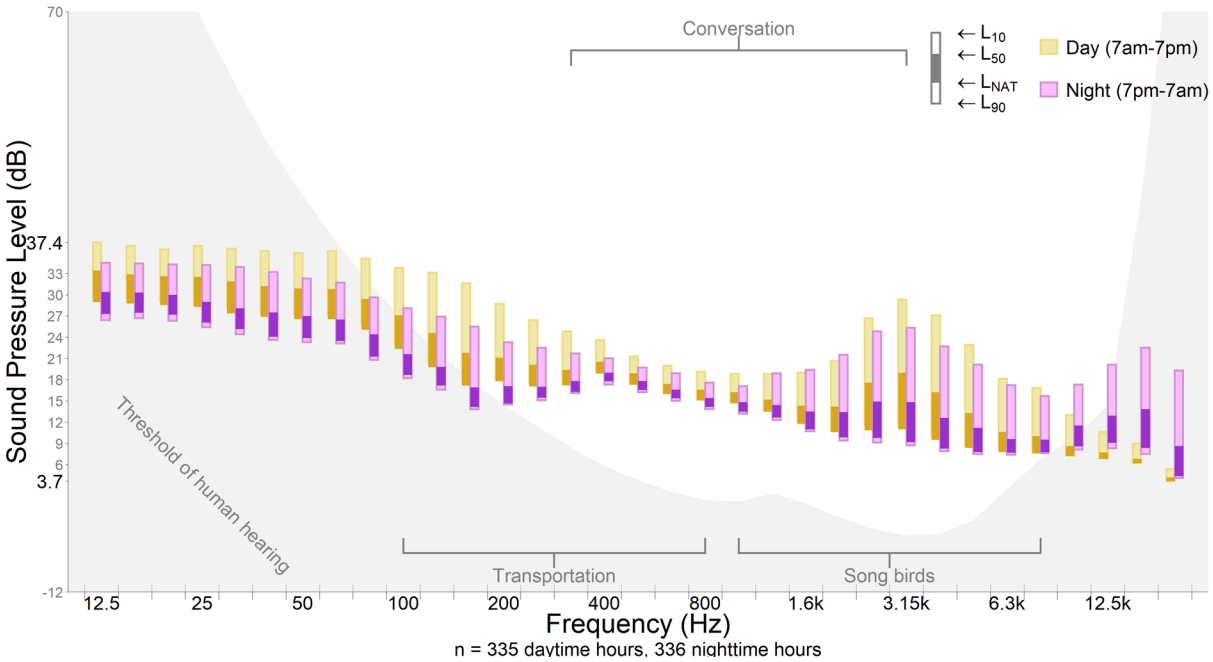


**Figure 11.** Day and night percentile sound pressure levels for 33 one-third octave bands at Bullhead Trail (GRSM005) in 2016. Grayed areas represent sounds outside the typical range of human hearing.

## 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 biologic sounds) allowing for more accurate comparisons of low-frequency ambient sound levels across different land use types (e.g. urban, protected areas; ANSI S3/SC1.100, 2014). This frequency weighting scheme improves ambient sound level measurements in quiet environments. For instance, in the full frequency range, the 35 dB ($L_{Aeq, 1s}$) level was exceeded at Mt. Collins 11.99% of the time during the day and 6.43% of the time at night, but in the 20–1,250 Hz range, the 35 dB functional sound level value was very rarely exceeded in daytime or nighttime (Table 6).

**Table 6.** Time above metrics for GRSM001, GRSM002, GRSM004, and GRSM005 in 2016.

| Site ID | Site Name | 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* |
| **GRSM001** | Mt. Collins | 12.5–20,000 | 11.99 | 1.76 | 0.20 | 0.00 | 6.43 | 0.59 | 0.09 | 0.00 |
| | Mt. Collins | 20–1,250 | 2.98 | 0.36 | 0.05 | 0.00 | 1.46 | 0.15 | 0.01 | 0.00 |
| **GRSM002** | Parson Branch | 12.5–20,000 | 21.62 | 2.88 | 0.35 | 0.02 | 29.47 | 9.22 | 1.83 | 0.02 |
| | Parson Branch | 20–1,250 | 9.20 | 0.97 | 0.15 | 0.01 | 10.68 | 0.52 | 0.08 | 0.00 |
| **GRSM004** | Purchase Knob | 12.5–20,000 | 42.00 | 9.20 | 1.91 | 0.22 | 48.85 | 6.33 | 1.43 | 0.39 |
| | Purchase Knob | 20–1,250 | 13.00 | 0.57 | 0.08 | 0.00 | 12.47 | 0.33 | 0.03 | 0.00 |
| **GRSM005** | Bullhead Trail | 12.5–20,000 | 20.06 | 1.95 | 0.34 | 0.01 | 25.40 | 2.88 | 0.28 | 0.00 |
| | Bullhead Trail | 20–1,250 | 3.63 | 0.38 | 0.07 | 0.00 | 3.52 | 0.35 | 0.01 | 0.00 |

* dB $L_{Aeq, 1s}$ re 20 µPa

The first functional value in Table 6 is 35 dB ($L_{Aeq,1s}$), which is designed to address the health effects of sleep interruption. Studies suggest that sound events as low as 35 dB can have adverse effects on blood pressure in sleeping humans (Haralabidis *et al*. 2008). This is also the desired background sound level in classrooms (ANSI S12.60-2002). The second sound level value, 45 dB ($L_{Aeq,1s}$), addresses the World Health Organization's recommendations that noise levels inside bedrooms

remain below 45 dB ($L_{Aeq,1s}$) (Berglund *et al*. 1999). The third sound level value, 52 dB ($L_{Aeq,1s}$), is based on the EPA's speech interference threshold for speaking in a raised voice to an audience at 10 meters (EPA 1974). This threshold addresses the effects of sound on interpretive presentations in parks. The final value, 60 dB ($L_{Aeq,1s}$), provides a basis for estimating impacts on normal voice communications at 1 meter. Visitors viewing scenic areas in the park would likely be conducting such conversations.

### Sound Level: Percentile Levels

To understand the range of acoustic conditions at the park, percentile sound levels are reported (Figure 12–Figure 15). The hourly percentile sound levels in these figures 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 12, the $L_{A50}$ (median) sound level for Mt. Collins during the 6:00 hour is 31.4 dB. Conversely, the sound level exceeded 10% of the time ($L_{A10}$) for the same hour at this site is 39.6 dB, meaning 90% of the measurement period is quieter. Hours where the $L_{A50}$ and the $L_{Anat}$ differ the most are usually hours with the most human-caused noise (in this case, impact levels are fairly consistent from 5:00–20:00).

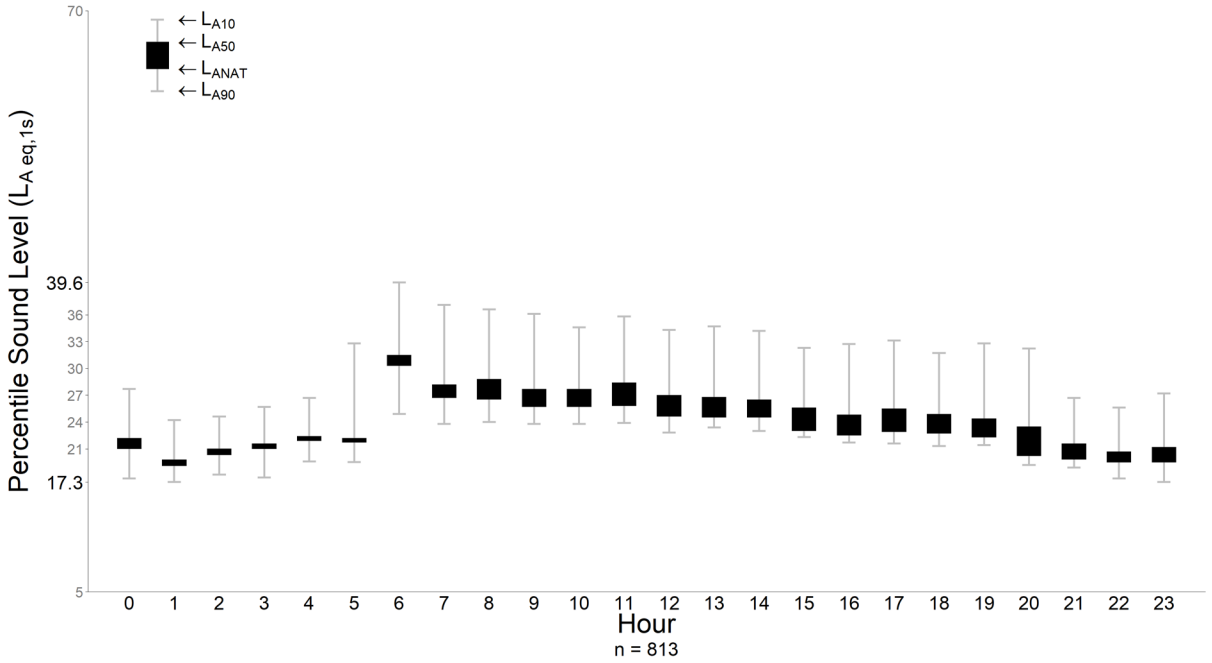


**Figure 12.** Median percentile sound levels ($L_{Aeq, 1s}$), in dB re 20 µPa, at Mt. Collins (GRSM001) in 2016.

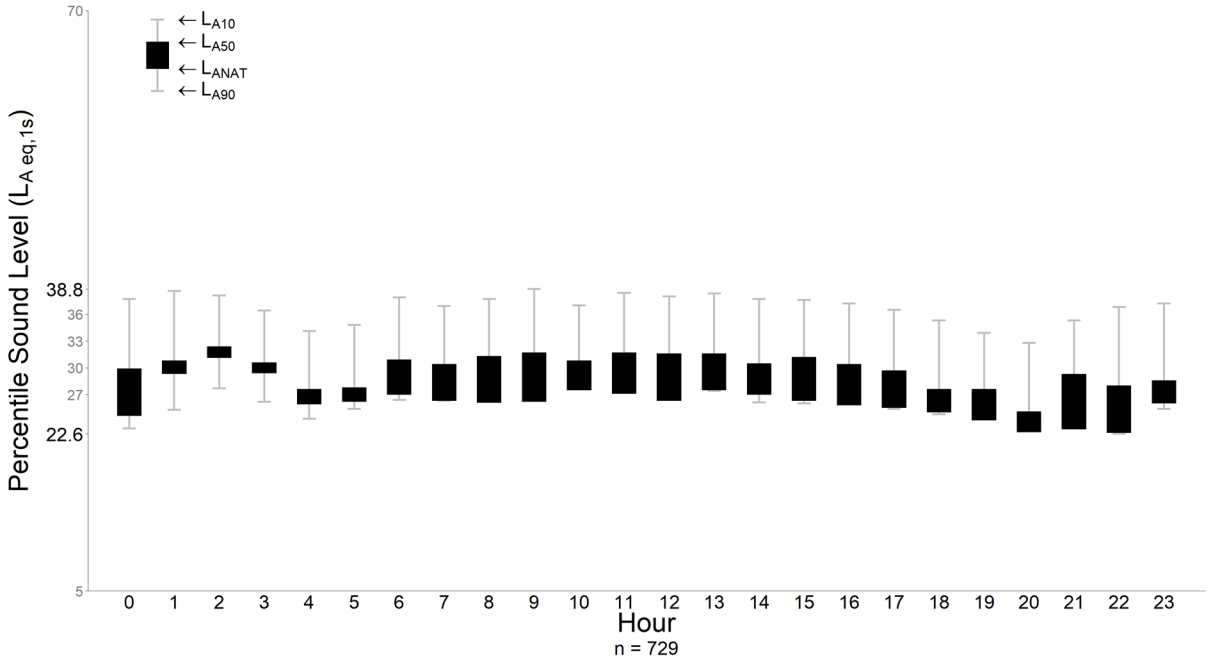


**Figure 13.** Median percentile sound levels ($L_{Aeq,\ 1s}$), in dB re 20 µPa, at Parson Branch (GRSM002) in 2016.

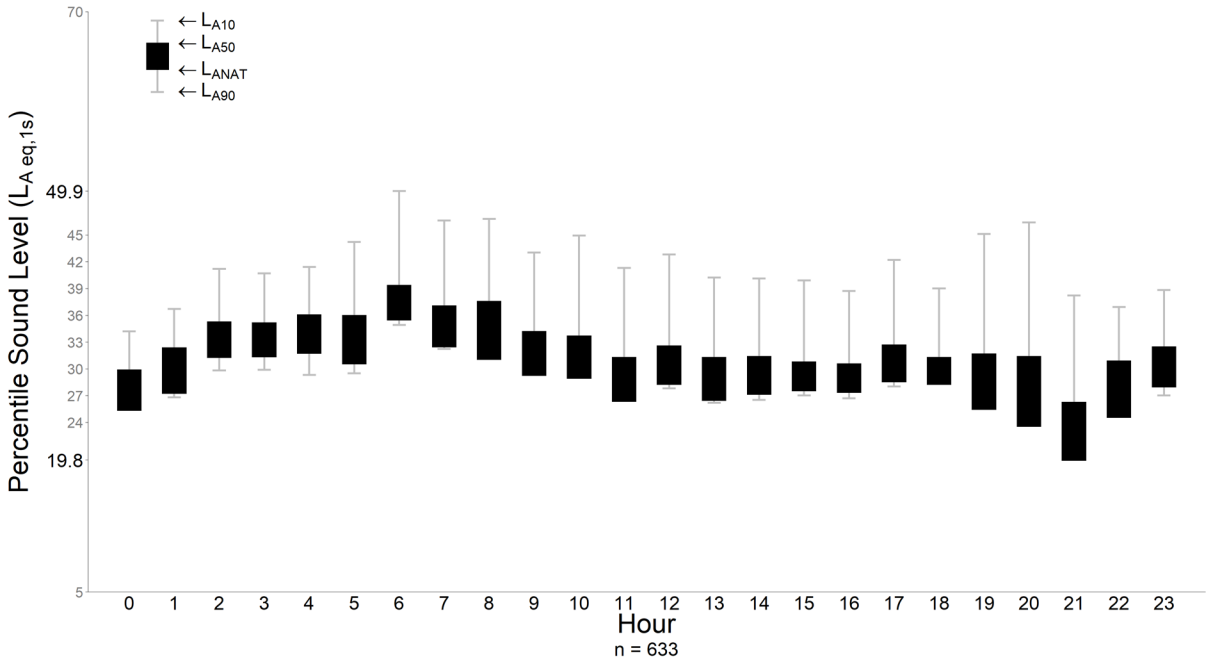


**Figure 14.** Median percentile sound levels ($L_{Aeq,\ 1s}$), in dB re 20 µPa, at Purchase Knob (GRSM004) in 2016.

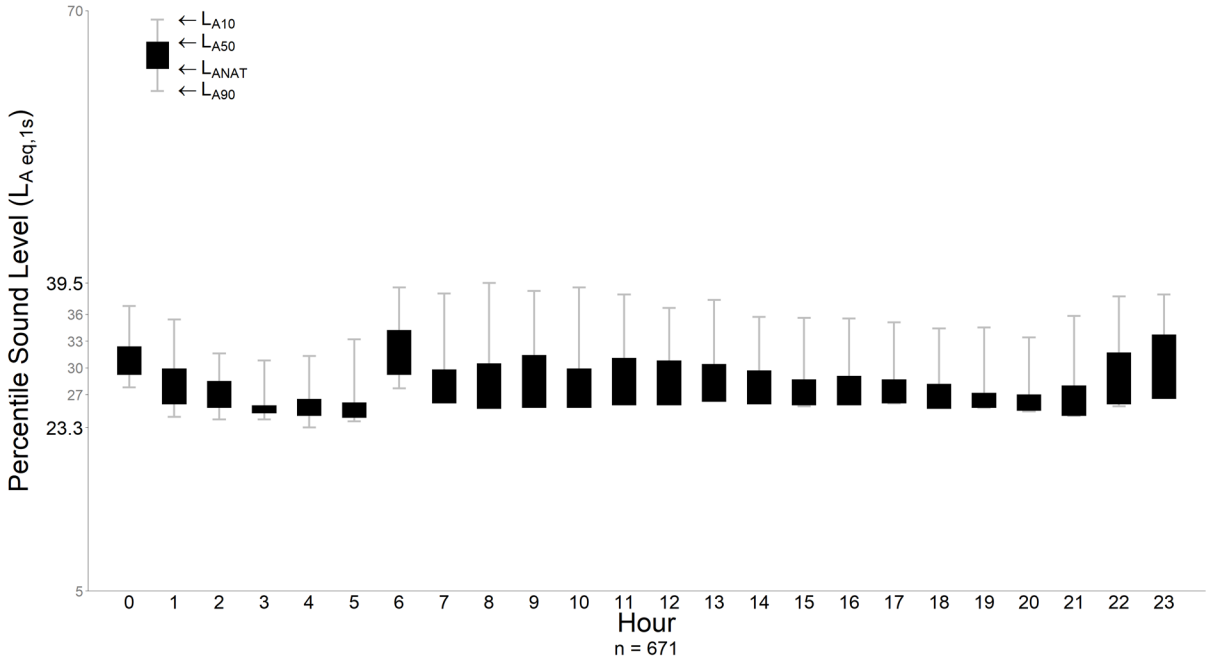


**Figure 15.** Median percentile sound levels ($L_{Aeq,\ 1s}$), in dB re 20 µPa, at Bullhead Trail (GRSM005) in 2016.

## Event Duration

Through off-site listening analysis, event duration for all audible sounds is calculated. Table 7–Table 14 list audible natural sounds and noise sources at Mt. Collins, Parson Branch, Purchase Knob, and Bullhead Trail. These tables contain only sound sources that were audible during listening analysis at each site, therefore, not all sound sources are represented in each table. Mean hourly audibility was calculated over eight days of analysis (see Table 5 for the exact days for each site). See Appendix A for more information on analysis procedures. Figure 16–Figure 19 display hourly audibility for all non-natural sources, as compared to audibility of two noise sources of interest: aircraft and vehicles.

**Table 7.** Mean hourly time audible (%) for each natural sound source at Mt. Collins (GRSM001) in 2016, n=8 days.

| Natural 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wind | 49.6 | 49.3 | 51.1 | 55.9 | 48.5 | 44.8 | 61.5 | 67.0 | 62.2 | 64.1 | 68.1 | 80.7 | 70.4 | 76.3 | 57.8 | 60.0 | 54.8 | 49.6 | 53.0 | 39.6 | 36.3 | 35.9 | 41.9 | 44.8 |
| Light Wind | 28.9 | 25.2 | 25.2 | 26.7 | 30.7 | 32.6 | 13.0 | 1.9 | 0.0 | 0.4 | 0.0 | 0.0 | 4.4 | 7.0 | 11.1 | 10.7 | 11.1 | 11.1 | 8.5 | 10.7 | 11.1 | 16.7 | 19.6 | 20.7 |
| Rain | 11.1 | 11.1 | 11.9 | 13.0 | 37.8 | 38.5 | 12.6 | 20.0 | 21.5 | 15.2 | 19.6 | 13.7 | 8.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.7 | 0.7 | 8.5 | 11.1 | 11.1 | 9.6 | 6.3 |
| Thunder | 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 | 0.0 |
| Mammal | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 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 |
| Bird | 0.0 | 0.0 | 0.0 | 0.4 | 0.7 | 28.1 | 99.6 | 99.6 | 98.9 | 96.3 | 97.0 | 95.9 | 92.6 | 94.8 | 90.7 | 88.1 | 88.9 | 89.3 | 92.2 | 92.6 | 95.9 | 34.1 | 0.0 | 0.4 |
| Insect | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.4 | 8.9 | 18.9 | 18.1 | 16.7 | 13.7 | 13.7 | 23.7 | 19.3 | 23.7 | 18.1 | 23.3 | 19.6 | 20.4 | 30.7 | 14.1 | 0.4 | 0.0 | 0.0 |
| Animal | 0.0 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.4 | 0.4 | 0.0 | 1.1 | 0.0 | 0.0 | 1.1 | 0.4 | 0.4 | 0.0 | 0.0 | 0.7 | 1.1 | 0.4 |
| Natural Other | 17.0 | 14.1 | 10.0 | 14.8 | 15.9 | 18.1 | 12.2 | 20.0 | 13.7 | 12.6 | 13.0 | 13.0 | 14.4 | 14.4 | 12.6 | 10.4 | 7.8 | 10.4 | 6.7 | 8.5 | 9.3 | 5.6 | 5.2 | 10.7 |
| Wind-induced Natural | 1.1 | 0.4 | 2.6 | 0.7 | 1.9 | 0.7 | 0.4 | 0.0 | 0.0 | 0.4 | 0.4 | 1.1 | 1.9 | 0.7 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 1.5 | 1.1 | 1.1 |
| Natural Unknown | 1.9 | 2.2 | 2.6 | 1.5 | 3.3 | 2.6 | 0.0 | 0.4 | 1.1 | 1.1 | 0.4 | 1.5 | 1.9 | 0.7 | 0.4 | 1.1 | 0.0 | 0.0 | 0.4 | 0.4 | 0.4 | 0.7 | 0.7 | 0.4 |

**Table 8.** Mean hourly time audible (%) for each noise source at Mt. Collins (GRSM001) in 2016, n=8 days.

| Noise 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 | 8.1 | 7.8 | 1.1 | 1.1 | 0.7 | 1.1 | 4.8 | 4.1 | 17.0 | 14.8 | 9.6 | 8.9 | 11.9 | 13.3 | 12.2 | 13.0 | 21.1 | 17.8 | 14.1 | 20.4 | 29.3 | 23.7 | 18.1 | 14.4 |
| Propeller Aircraft | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.7 | 0.4 | 0.4 | 1.1 | 0.4 | 0.7 | 1.1 | 1.5 | 1.5 | 0.7 | 1.5 | 1.1 | 1.9 | 3.3 | 0.0 | 1.5 | 0.0 | 0.0 |
| Vehicle | 1.5 | 1.5 | 0.0 | 0.0 | 0.4 | 0.7 | 1.9 | 1.5 | 3.7 | 4.4 | 6.3 | 7.0 | 8.9 | 4.1 | 9.6 | 10.4 | 9.6 | 5.6 | 7.8 | 3.7 | 2.2 | 3.0 | 2.2 | 2.2 |
| Alarm, Horn | 0.0 | 0.0 | 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 |
| 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 | 0.4 | 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 | 1.1 | 0.0 | 0.7 | 0.0 | 2.2 | 1.9 | 2.2 | 3.0 | 0.0 | 4.1 | 3.7 | 2.6 | 3.3 | 0.7 | 0.4 | 0.0 |
| Building Sounds | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 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 |
| 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 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 7.4 | 3.0 | 0.4 |
| Wind-induced Non-natural | 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 | 0.0 | 0.0 | 0.0 |
| Non-natural Unknown | 5.9 | 9.3 | 12.2 | 10.7 | 7.0 | 5.9 | 9.6 | 18.9 | 21.1 | 26.3 | 24.8 | 20.4 | 19.3 | 26.7 | 22.6 | 27.8 | 23.3 | 23.0 | 24.4 | 25.2 | 17.8 | 15.6 | 17.4 | 13.0 |
| Artifact | 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 | 0.0 |
| Field Personnel | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Unknown | 0.4 | 0.4 | 0.0 | 0.0 | 0.7 | 0.4 | 1.1 | 1.1 | 2.6 | 1.5 | 0.4 | 0.7 | 1.5 | 1.5 | 2.6 | 0.7 | 1.1 | 0.4 | 0.7 | 1.9 | 0.7 | 1.5 | 2.2 | 0.4 |

**Table 9.** Mean hourly time audible (%) for each natural sound source at Parson Branch (GRSM002) in 2016, n=8 days.

| Natural 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wind | 34.1 | 39.6 | 25.2 | 25.6 | 40.4 | 29.3 | 30.0 | 32.2 | 23.3 | 26.7 | 39.3 | 55.2 | 54.8 | 57.4 | 63.0 | 47.4 | 34.8 | 35.6 | 27.0 | 23.7 | 18.9 | 23.7 | 26.3 | 29.3 |
| Water | 36.7 | 44.1 | 31.9 | 27.0 | 10.0 | 17.8 | 18.9 | 16.7 | 13.7 | 12.2 | 7.4 | 11.1 | 12.6 | 15.2 | 10.4 | 10.0 | 9.3 | 8.5 | 14.4 | 14.8 | 18.1 | 27.0 | 32.6 | 28.1 |
| Rain | 10.4 | 16.3 | 32.6 | 35.2 | 35.6 | 30.7 | 25.6 | 19.6 | 6.3 | 6.3 | 7.8 | 11.1 | 13.3 | 15.2 | 15.6 | 11.1 | 7.0 | 5.9 | 8.9 | 13.7 | 14.4 | 17.4 | 8.9 | 12.6 |
| Flowing Water | 18.9 | 14.4 | 20.7 | 37.0 | 44.4 | 42.6 | 17.4 | 8.5 | 7.0 | 5.9 | 6.7 | 6.7 | 1.5 | 2.6 | 9.3 | 7.8 | 4.4 | 15.6 | 8.5 | 11.1 | 9.3 | 17.8 | 18.9 | 24.1 |
| Thunder | 1.1 | 10.4 | 15.2 | 5.2 | 0.7 | 0.7 | 0.0 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.4 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 |
| Mammal | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.7 | 4.1 | 1.5 | 1.9 | 1.5 | 1.9 | 0.7 | 0.0 | 0.0 | 0.0 | 0.4 | 1.5 | 0.4 | 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 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| Bird | 1.9 | 1.1 | 1.9 | 1.1 | 5.2 | 21.5 | 94.8 | 91.5 | 97.0 | 95.9 | 83.7 | 80.0 | 79.6 | 65.2 | 70.4 | 84.1 | 82.6 | 69.3 | 78.1 | 80.4 | 67.0 | 11.9 | 1.1 | 2.6 |
| Amphibian | 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 | 0.7 | 0.7 | 0.4 | 0.0 | 0.0 | 0.4 |
| Insect | 35.9 | 25.6 | 25.6 | 15.2 | 14.1 | 12.6 | 30.0 | 33.0 | 37.8 | 42.6 | 39.6 | 43.3 | 42.2 | 50.0 | 29.6 | 40.0 | 48.1 | 41.5 | 47.4 | 30.0 | 27.0 | 41.5 | 41.9 | 39.6 |
| Animal | 0.7 | 0.7 | 0.0 | 1.5 | 0.0 | 0.4 | 0.0 | 0.4 | 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 | 1.5 |
| Natural Other | 3.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Natural Unknown | 6.3 | 3.7 | 3.7 | 4.4 | 3.3 | 3.0 | 1.1 | 3.0 | 1.9 | 1.5 | 0.7 | 1.9 | 1.1 | 0.4 | 3.3 | 1.1 | 5.9 | 4.8 | 4.1 | 7.0 | 4.4 | 7.8 | 3.7 | 3.0 |

**Table 10.** Mean hourly time audible (%) for each noise source at Parson Branch (GRSM002) in 2016, n=8 days.

| Noise Source | 00h | 01h | 02h | 03h | 04h | 05h | 06h | 07h | 08h | 09h | 10h | 11h | 12h | 13h | 14h | 15h | 16h | 17h | 18h | 19h | 20h | 21h | 22h | 23h |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aircraft | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Jet | 26.7 | 9.3 | 5.2 | 0.7 | 7.8 | 5.2 | 24.4 | 21.5 | 72.6 | 63.3 | 57.8 | 40.7 | 67.4 | 48.1 | 41.9 | 48.5 | 56.7 | 53.0 | 47.8 | 61.1 | 54.4 | 55.2 | 34.1 | 37.0 |
| Propeller Aircraft | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.5 | 3.0 | 5.6 | 3.0 | 7.8 | 7.8 | 14.1 | 13.3 | 5.2 | 9.3 | 11.9 | 10.7 | 8.9 | 5.2 | 1.5 | 3.7 | 3.0 | 6.3 | 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 | 0.0 | 0.0 | 0.0 | 0.7 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Vehicle | 1.5 | 1.1 | 1.1 | 0.4 | 0.0 | 2.2 | 2.6 | 1.5 | 1.5 | 1.5 | 0.0 | 0.4 | 0.0 | 0.7 | 0.4 | 0.0 | 0.4 | 0.0 | 0.4 | 0.4 | 3.0 | 0.7 | 1.5 | 1.5 |
| Automobile | 0.0 | 0.0 | 0.0 | 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 |
| Grounds Care | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.1 | 0.0 | 0.7 | 0.0 | 0.0 | 0.0 | 0.7 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 1.5 | 0.0 | 0.0 | 0.0 |
| People | 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 |
| Voices | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 1.9 | 0.7 | 1.9 | 1.5 | 0.7 | 0.0 | 1.5 | 2.6 | 1.1 | 3.3 | 0.4 | 1.1 | 0.0 | 0.0 | 0.0 |
| Walking | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.7 | 1.1 | 0.0 | 0.0 | 0.4 | 0.7 | 0.0 | 1.1 | 0.4 | 0.0 | 0.4 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 |
| Dog | 0.0 | 0.0 | 0.0 | 0.4 | 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 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 |
| Horse | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.7 | 1.1 | 0.4 | 0.0 | 1.1 | 0.4 | 1.1 | 1.1 | 3.3 | 1.1 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| Construc-tion | 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 |
| Non-natural Other | 11.1 | 3.0 | 0.0 | 0.0 | 0.0 | 1.5 | 1.9 | 10.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.1 | 0.4 | 0.0 | 1.1 | 1.5 | 0.4 | 1.1 | 1.5 | 8.5 | 8.5 | 7.0 | 4.1 |
| Non-natural Unknown | 14.4 | 11.9 | 10.4 | 20.7 | 27.4 | 39.6 | 38.9 | 40.7 | 17.4 | 17.0 | 21.9 | 27.0 | 9.3 | 21.9 | 13.7 | 12.2 | 14.8 | 11.1 | 14.1 | 17.0 | 23.7 | 23.3 | 22.2 | 20.7 |
| Artifact | 0.7 | 1.1 | 4.8 | 0.7 | 3.0 | 0.7 | 0.7 | 0.0 | 0.0 | 0.0 | 0.7 | 0.0 | 0.0 | 0.0 | 0.7 | 0.0 | 0.0 | 0.4 | 0.7 | 1.5 | 0.4 | 0.0 | 0.0 | 0.7 |
| Field Personnel | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.9 | 0.0 | 0.0 | 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 | 0.4 | 0.4 | 0.4 | 0.4 | 0.0 | 0.7 | 0.7 | 0.4 | 0.4 | 0.4 | 0.7 | 0.0 | 0.0 | 0.0 | 0.7 | 0.4 | 1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 |

**Table 11.** Mean hourly time audible (%) for each natural sound source at Purchase Knob (GRSM004) in 2016, n=8 days.

| Natural 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wind | 29.2 | 40.0 | 49.2 | 48.3 | 50.0 | 42.5 | 18.3 | 15.8 | 12.1 | 8.3 | 8.7 | 10.4 | 10.4 | 15.0 | 14.2 | 11.3 | 14.2 | 12.5 | 1.7 | 0.8 | 0.0 | 4.6 | 14.2 | 27.5 |
| Wind, Light | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 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 |
| Wind, Strong | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.1 |
| Water | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Rain | 26.2 | 30.0 | 27.1 | 28.7 | 33.7 | 19.2 | 14.2 | 14.6 | 20.4 | 25.0 | 24.6 | 18.8 | 12.1 | 24.2 | 25.0 | 27.5 | 26.7 | 22.5 | 21.7 | 7.5 | 12.1 | 18.8 | 28.7 | 39.6 |
| Flowing Water | 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 |
| Thunder | 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 | 6.2 | 3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Mammal | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 | 0.0 | 1.2 | 1.7 | 0.4 | 8.3 | 7.9 | 2.5 | 8.7 | 5.0 | 0.0 | 3.8 | 0.8 | 3.8 | 0.4 | 0.4 | 0.4 | 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 | 0.0 | 0.0 | 0.0 | 0.0 | 3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Bird | 16.3 | 11.3 | 11.7 | 15.8 | 13.3 | 40.8 | 97.9 | 95.0 | 91.2 | 93.3 | 96.2 | 88.7 | 90.4 | 84.2 | 75.8 | 81.2 | 74.2 | 81.7 | 74.6 | 92.1 | 97.9 | 31.7 | 10.4 | 16.3 |
| Raven | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 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 |
| Insect | 9.2 | 3.8 | 2.1 | 1.2 | 3.3 | 2.5 | 16.7 | 24.6 | 17.1 | 24.6 | 32.9 | 42.5 | 49.2 | 42.1 | 54.6 | 45.8 | 35.0 | 52.1 | 55.4 | 37.5 | 17.9 | 12.5 | 15.0 | 10.4 |
| Animal | 12.1 | 10.8 | 10.4 | 7.1 | 10.8 | 6.2 | 11.7 | 23.7 | 16.3 | 19.6 | 15.0 | 15.8 | 17.9 | 14.6 | 20.4 | 14.2 | 11.3 | 15.8 | 10.0 | 11.3 | 13.3 | 27.5 | 27.1 | 17.9 |
| Natural Unknown | 7.1 | 9.6 | 5.4 | 7.1 | 9.6 | 10.4 | 3.3 | 3.3 | 3.3 | 7.1 | 6.7 | 12.1 | 12.9 | 7.1 | 10.4 | 10.0 | 12.5 | 10.4 | 5.4 | 8.7 | 0.4 | 5.0 | 2.5 | 2.1 |

**Table 12.** Mean hourly time audible (%) for each noise source at Purchase Knob (GRSM004) in 2016, n=8 days.

| Noise Source | 00h | 01h | 02h | 03h | 04h | 05h | 06h | 07h | 08h | 09h | 10h | 11h | 12h | 13h | 14h | 15h | 16h | 17h | 18h | 19h | 20h | 21h | 22h | 23h |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jet | 5.0 | 4.6 | 0.8 | 0.8 | 1.7 | 4.6 | 9.6 | 26.7 | 20.8 | 13.3 | 12.1 | 20.4 | 16.3 | 15.0 | 12.5 | 15.0 | 15.0 | 12.9 | 23.7 | 24.2 | 20.8 | 22.1 | 14.2 | 7.9 |
| Propeller Aircraft | 0 | 2.9 | 0 | 0 | 0 | 0 | 0.4 | 0 | 2.5 | 4.6 | 3.8 | 7.5 | 2.1 | 2.9 | 1.7 | 4.2 | 7.1 | 5.8 | 2.5 | 5.4 | 5.4 | 0.8 | 0.4 | 6.7 |
| Helicopter | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.2 | 0 | 0 | 0 | 0 | 0 |
| Vehicle | 17.5 | 14.6 | 7.5 | 7.5 | 12.5 | 10.4 | 17.1 | 15.4 | 15 | 12.9 | 14.6 | 8.3 | 7.1 | 10 | 8.7 | 9.6 | 2.9 | 7.9 | 7.5 | 8.3 | 14.2 | 19.2 | 17.9 | 20.4 |
| Motorcycle | 0 | 0 | 0 | 0 | 0 | 0.8 | 0 | 0 | 0.4 | 0.4 | 0.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Grounds Care | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.6 | 0 | 3.3 | 1.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Voices | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.4 | 0.4 | 3.3 | 8.3 | 0.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Gunshot | 0.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.8 | 5 | 0 |
| Dog | 0 | 0.8 | 6.2 | 1.7 | 0.4 | 1.2 | 0 | 0.4 | 0.4 | 2.5 | 1.7 | 3.3 | 2.5 | 0 | 0.4 | 0 | 0 | 1.2 | 0 | 1.2 | 0.4 | 1.2 | 2.5 | 0.8 |
| Non-natural Other | 0 | 0 | 0 | 0 | 0 | 0.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0.4 | 2.1 | 0.4 | 0 |
| Non-natural Unknown | 70 | 63.3 | 62.5 | 57.1 | 53.3 | 61.3 | 60.4 | 55 | 68.8 | 66.7 | 66.7 | 63.8 | 60 | 59.6 | 58.8 | 57.5 | 63.8 | 63.3 | 65 | 72.1 | 64.6 | 68.8 | 67.9 | 53.8 |
| Artifact | 2.9 | 1.2 | 0 | 3.8 | 2.9 | 1.7 | 3.3 | 1.7 | 0.4 | 0.8 | 0.8 | 0.8 | 0 | 0.8 | 0.4 | 0 | 1.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Wind distortion | 25.8 | 26.7 | 22.9 | 20 | 17.5 | 20.8 | 15.4 | 12.9 | 11.3 | 17.9 | 12.1 | 12.9 | 15 | 9.2 | 15.8 | 16.3 | 12.1 | 10.4 | 13.3 | 15.8 | 17.5 | 19.6 | 22.1 | 17.1 |
| Static interfer-ence – quiet | 1.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.4 | 0 | 0 | 0.8 | 5.4 |
| Static interfer-ence – loud | 0 | 0 | 0 | 0 | 0 | 1.7 | 9.2 | 2.9 | 4.2 | 0.8 | 1.2 | 0.4 | 1.7 | 3.3 | 0.4 | 4.6 | 2.1 | 1.7 | 0.8 | 5.8 | 4.2 | 1.2 | 0 | 0 |
| Unknown | 1.7 | 0.4 | 2.1 | 0.4 | 1.7 | 2.1 | 0 | 0.4 | 0.4 | 0 | 0.8 | 0.4 | 0 | 0.4 | 0.4 | 0.4 | 0 | 0 | 0 | 0 | 1.2 | 0.8 | 2.5 | 0.8 |

**Table 13.** Mean hourly time audible (%) for each natural sound source at Bullhead Trail (GRSM005) in 2016, n=7 days.

| Natural 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wind | 36.7 | 37.1 | 37.9 | 46.7 | 43.8 | 38.8 | 11.7 | 14.2 | 16.3 | 9.6 | 2.5 | 16.3 | 22.1 | 29.2 | 34.6 | 37.5 | 32.9 | 35 | 28.3 | 11.3 | 4.6 | 16.7 | 12.9 | 10 |
| Water | 12.1 | 22.1 | 26.7 | 30 | 16.7 | 12.5 | 3.8 | 2.5 | 4.2 | 7.9 | 9.6 | 8.7 | 9.2 | 10.4 | 7.5 | 6.7 | 10.8 | 9.2 | 9.6 | 14.2 | 16.3 | 18.3 | 13.3 | 23.3 |
| Rain | 27.9 | 23.3 | 30.4 | 30.4 | 17.5 | 6.2 | 0.8 | 0.4 | 10 | 13.3 | 13.3 | 14.2 | 11.3 | 11.3 | 10.8 | 6.7 | 3.8 | 6.2 | 4.2 | 7.1 | 0.8 | 1.2 | 3.8 | 6.2 |
| Thunder | 8.3 | 12.5 | 10.8 | 4.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.8 | 0 | 0 | 0 | 8.3 | 5.4 | 0 | 0 | 0.8 | 0.4 | 0 |
| Mammal | 0 | 0 | 0 | 0 | 0 | 0 | 0.4 | 2.1 | 5.4 | 0 | 0 | 0.4 | 0 | 0.8 | 0.8 | 2.5 | 0 | 0.4 | 0 | 0 | 0 | 0.4 | 0 | 0 |
| Bird | 7.1 | 12.5 | 4.2 | 13.3 | 27.5 | 64.6 | 99.6 | 95.4 | 94.2 | 98.3 | 99.6 | 97.9 | 93.3 | 88.3 | 75 | 75.8 | 72.1 | 74.2 | 72.9 | 74.6 | 79.6 | 46.3 | 27.1 | 13.8 |
| Insect | 35.8 | 45.8 | 48.8 | 29.6 | 19.2 | 20.8 | 7.1 | 9.6 | 7.9 | 14.6 | 18.3 | 11.3 | 13.3 | 16.7 | 13.3 | 15.8 | 17.5 | 17.5 | 10.8 | 11.7 | 14.6 | 59.6 | 58.8 | 55 |
| Animal | 0 | 0 | 1.7 | 0 | 0.8 | 0.4 | 1.2 | 0.4 | 0.8 | 0.8 | 0 | 0 | 0 | 0.4 | 0 | 0 | 0.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0.4 |
| Natural Unknown | 6.2 | 10.4 | 9.2 | 8.7 | 8.7 | 8.3 | 7.9 | 8.3 | 8.3 | 8.7 | 10 | 8.7 | 5.8 | 7.5 | 5 | 7.1 | 6.7 | 9.6 | 8.7 | 9.6 | 12.9 | 6.7 | 13.8 | 16.3 |

**Table 14.** Mean hourly time audible (%) for each noise source at Bullhead Trail (GRSM005) in 2016, n=7 days.

| Noise Source | 00h | 01h | 02h | 03h | 04h | 05h | 06h | 07h | 08h | 09h | 10h | 11h | 12h | 13h | 14h | 15h | 16h | 17h | 18h | 19h | 20h | 21h | 22h | 23h |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jet | 13.8 | 5.0 | 0.4 | 0.0 | 4.2 | 9.2 | 20.8 | 20.4 | 28.3 | 32.9 | 25.0 | 15.4 | 22.5 | 20.0 | 8.3 | 9.6 | 16.3 | 19.2 | 16.3 | 26.7 | 22.5 | 22.9 | 12.5 | 13.3 |
| Propeller Aircraft | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.8 | 3.3 | 8.3 | 7.1 | 10.8 | 9.6 | 6.2 | 7.5 | 5.8 | 8.3 | 6.7 | 5.0 | 4.6 | 6.2 | 2.9 | 2.9 | 1.7 | 0.8 | 0.8 |
| Helicopter | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 | 1.7 | 2.1 | 5.4 | 7.1 | 6.7 | 7.5 | 8.7 | 7.5 | 7.9 | 5.8 | 2.9 | 1.2 | 0.8 | 6.2 | 4.6 | 1.2 | 1.2 |
| Vehicle | 8.7 | 17.9 | 12.9 | 13.3 | 8.3 | 20.4 | 16.7 | 18.8 | 27.1 | 17.5 | 23.7 | 27.5 | 23.7 | 18.3 | 21.7 | 21.7 | 19.6 | 16.3 | 21.2 | 14.2 | 13.3 | 7.5 | 13.8 | 14.2 |
| Motorcycle | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 |
| ATV | 0.0 | 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 |
| 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 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 2.1 | 0.0 | 0.0 |
| Voices | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 1.2 | 0.4 | 3.3 | 2.1 | 2.9 | 5.8 | 2.9 | 2.5 | 3.3 | 2.5 | 3.3 | 2.1 | 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 | 2.1 | 0.0 | 2.1 | 0.4 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Building Sounds | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 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 |
| 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 | 0.8 | 6.7 | 9.2 | 0.8 | 5.4 | 5.8 | 6.7 | 6.7 | 4.2 | 13.8 | 10.8 | 10.0 |
| Non-natural Unknown | 45.8 | 46.7 | 36.2 | 39.2 | 52.9 | 39.6 | 33.3 | 35.8 | 30.0 | 30.0 | 32.9 | 41.7 | 34.6 | 36.7 | 31.7 | 33.7 | 33.7 | 31.7 | 29.6 | 30.8 | 28.3 | 30.8 | 47.1 | 50.0 |
| Wind distortion | 16.3 | 13.8 | 12.5 | 14.2 | 14.2 | 21.2 | 16.7 | 20.4 | 20.4 | 24.2 | 20.4 | 17.9 | 11.3 | 16.7 | 16.3 | 12.9 | 9.6 | 14.2 | 11.7 | 10.0 | 14.6 | 14.6 | 7.5 | 8.7 |
| Static interfer-ence | 2.9 | 2.5 | 1.7 | 1.7 | 0.8 | 0.4 | 2.1 | 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 | 0.8 | 5.4 | 9.2 | 11.7 |
| Field Personnel | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.1 | 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 | 0.4 | 0.0 | 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 | 0.4 | 0.0 | 0.0 |

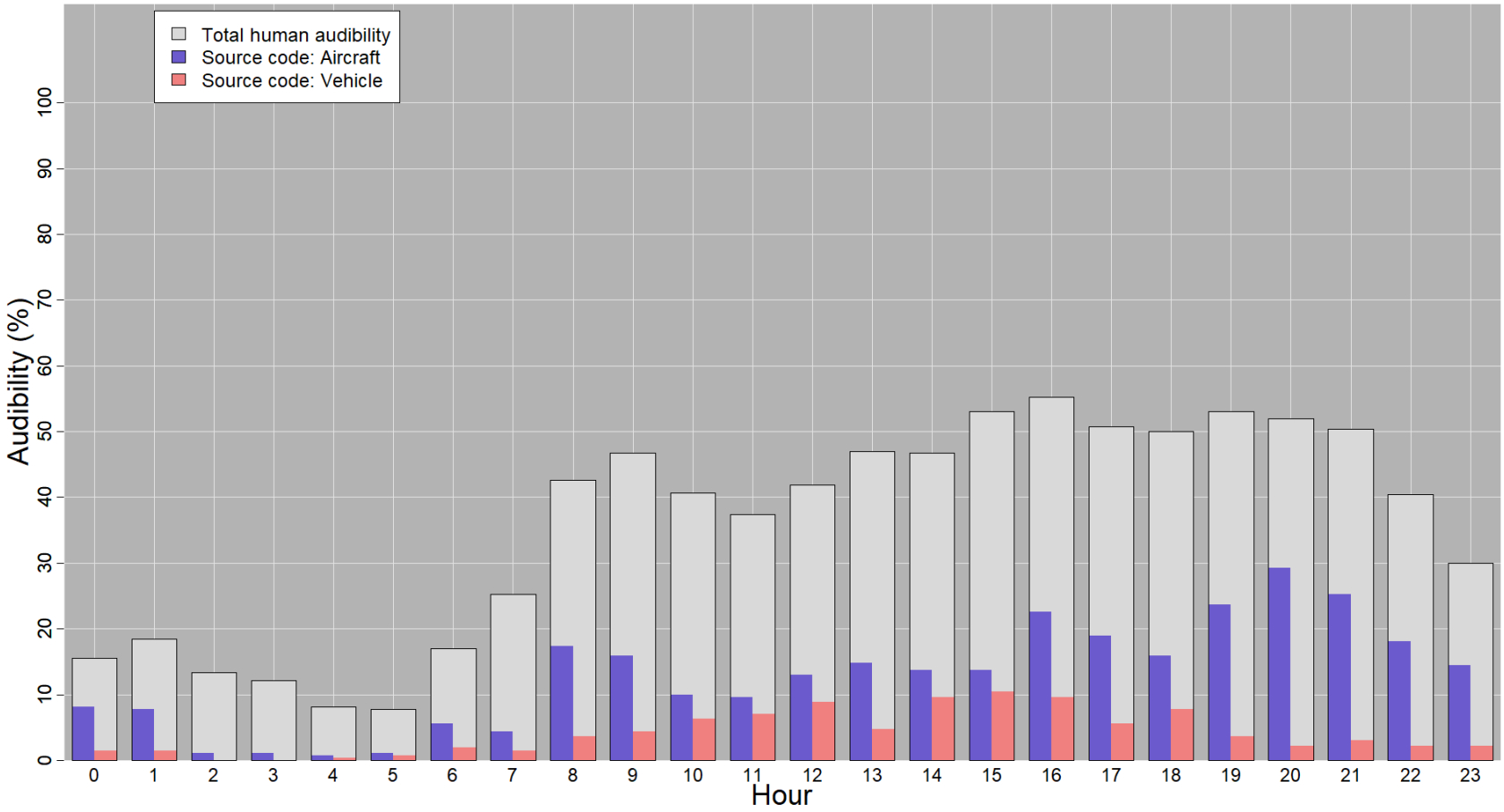


**Figure 16.** Hourly time audible for aircraft, vehicle, and other noise sources at Mt. Collins (GRSM001) in 2016.

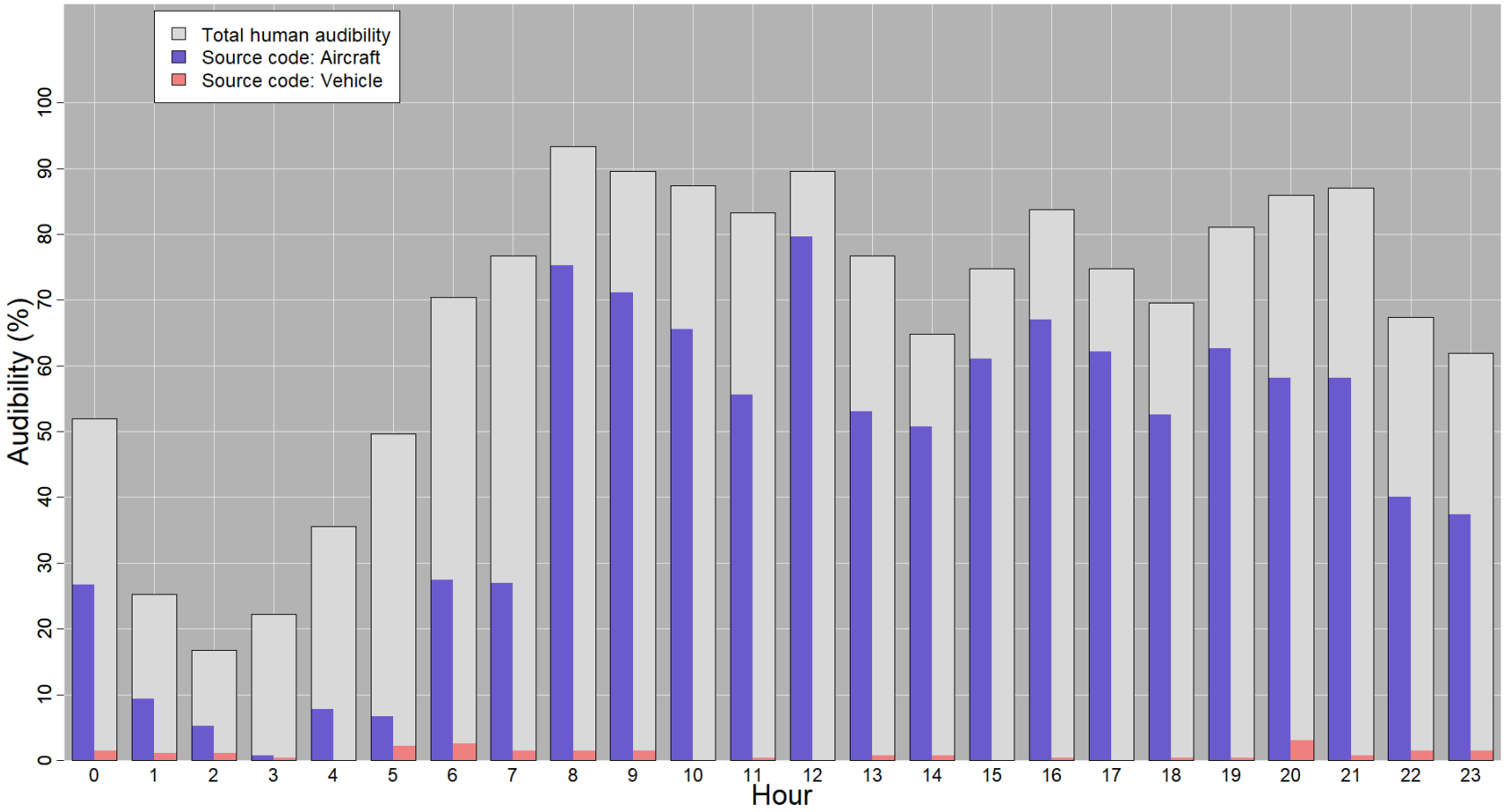


**Figure 17.** Hourly time audible for aircraft, vehicle, and all other noise sources at Parson Branch (GRSM002) in 2016.

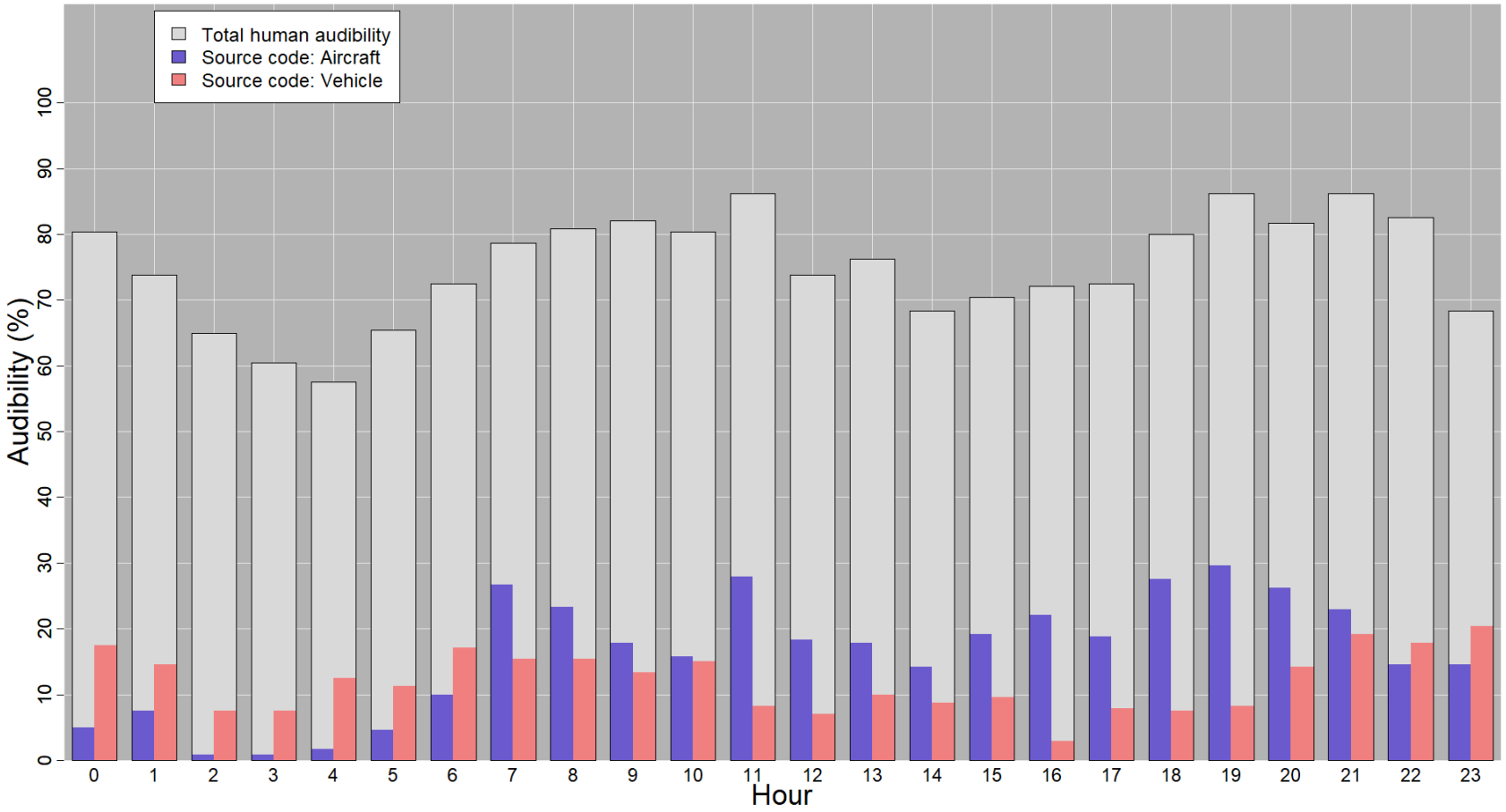


**Figure 18.** Hourly time audible for aircraft, vehicle, and all other noise sources at Purchase Knob (GRSM004) in 2016.

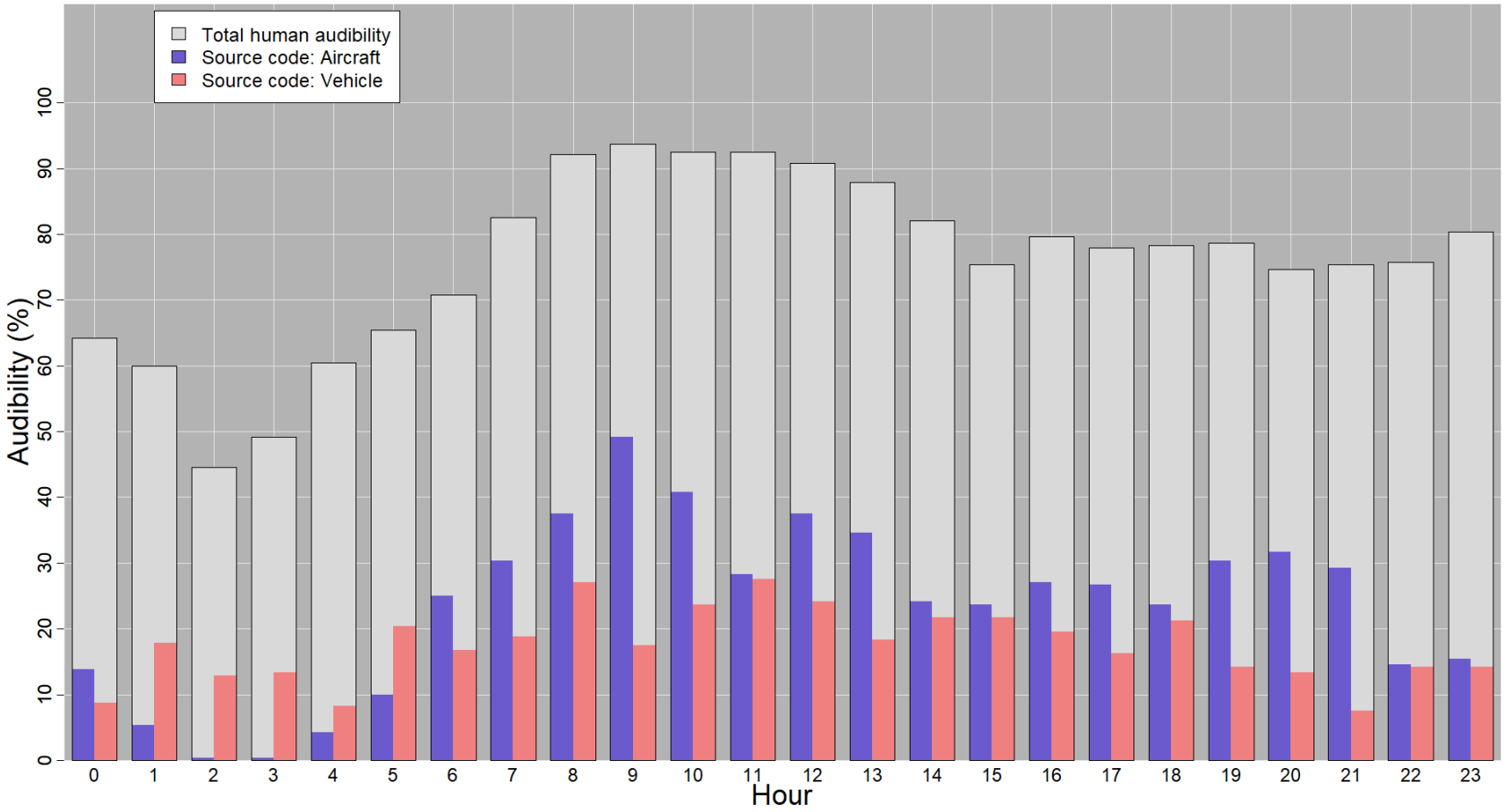


**Figure 19.** Hourly time audible for aircraft, vehicle, and all other noise sources at Bullhead Trail (GRSM005) in 2016.

# Conclusions

Acoustic monitoring allows parks to gain insight into levels of extrinsic noise and biologic activity. The results can help estimate the effects of noise on park visitors and wildlife alike. The study was successful in determining the acoustical conditions at GRSM in areas used by visitors in backcountry areas and popular hiking trails in 2016.

Results from Mt. Collins, Parson Branch, Purchase Knob, and Bullhead Trail included measures of existing ambient sound levels, calculations of sound source audibility through off-site listening, and estimates of natural ambient sound levels. Sound source analysis revealed that noise is audible about 35.6–76.0% of the time among study sites when averaged across all hours of the day. A non-natural unknown noise source was the most commonly heard noise during the 2016 monitoring period at Mt. Collins, Purchase Knob, and Bullhead Trail, with a 24-hour mean audibility of 17.8–62.7%, and was the second most commonly heard noise at Parson Branch with 24-hour mean audibility of 20.5% (Table 7–Table 14) Listeners often described this as the sound of a distant motor or a "low rumble" but could not discern whether the sound originated from an aircraft, vehicle, or other type of motor. This implies that audibility of other specified sources are likely underestimated herein.

Aircraft were the most commonly heard noise source during the 2016 monitoring period at Parson Branch with a 24-hour mean audibility of 44.2%. However, audibility was as high as 79.6% during the 12:00 hour. At this site, the most commonly heard type of aircraft was by far jets. This suggests that Parson Branch is located under a common flight path for high altitude commercial jets. Appendix B supports this conclusion. Data from the 2006 study also suggest that Parson Branch is highly influenced by aircraft noise. For example, the 2006 winter data reported a $L_{50}$ existing daytime ambient of 33.7 dB, while existing ambient without all aircraft noise during the daytime was 22.5 dB (Lee *et al.* 2016).

Aircraft were the second most commonly heard noise source at Mt. Collins, Purchase Knob, and Bullhead Trail, with a 24-hour mean audibility ranging from 12.8–23.5%. Bullhead Trail was unique with respect to aircraft, because helicopters were more frequently audible here than at any other site. This is likely because Bullhead Trail is located nearest to known air tour routes, which are conducted by helicopter (see Appendix C). Specifically, helicopter noise was audible 5.8–8.7% of the time between the hours of 1000 and 1600 (Table 14). Because air tour events are generally flown at a lower altitude than other flights, this results in a higher intensity of noise. Helicopters were also audible at Parson Branch and Purchase Knob although only during evening hours and < 2% of the time.

Natural sources such as wind, rain, thunder, birds, and insects were commonly audible at all GRSM sites in 2016. Specifically, recordings of yellow-billed cuckoo, Eastern whip-poor-will, barred owl, and thunder were collected during this monitoring period.

During the study period, computed natural ambient sound levels ranged from 24.6–28.3 dB ($L_{Anat}$) during the day and 21.5–28.4 dB ($L_{Anat}$) at night. Existing sound level (encompassing natural and noise sources) measurements ranged from 26.7–32.6 dB ($L_{A50}$) during the day and 22.8–33.4 dB

($L_{A50}$) at night. The site with the highest existing sound level was Purchase Knob with 32.6 dB ($L_{A50}$) during the day and 33.4 dB ($L_{A50}$) at night. Purchase Knob also had the highest computed natural sound level which may have contributed to the high existing sound level. However, the existing level at this site exceeded the natural level by the greatest margins of any site, 4.3 dB during the day and 5.0 dB at night. This is likely because Purchase Knob is closer to the park boundary than other sites therefore is subject to increased urban noise. The site with the lowest existing sound level was Mt. Collins with 26.7 dB ($L_{A50}$) during the day and 22.6 dB ($L_{A50}$) at night. While located only 0.25 mile from the Clingman's Dome access road, Mt. Collins may have been the quietest among sites as the area is densely vegetated and the mountain ridge separates it from nearby infrastructure. In contrast, sites such as Purchase Knob and Bullhead Trail have comparably less terrain shielding from terrestrial noise sources and are much closer in proximity to visitor facilities (approximately 0.25–1.5 miles). While Parson Branch is also a considerable distance from major roadways or visitor facilities (approximately 2.5 miles), the site has a 24-hour mean time audible of 67.5%, due largely to aircraft noise (see Appendix B for more details).

Temporal differences in time above metrics and existing and natural ambient levels can be caused by instrumental differences such as relative equipment placement or environmental differences such as change in wind speed (further details in Appendix D). Therefore, caution should be used when making comparisons between 2006 and 2016 studies.

From 2006 to 2016, changes in existing ambient sound levels generally correspond to differences in natural ambient sound levels. Increases were most pronounced in frequency bands associated with insects and songbirds, supporting rise in natural ambient sound level as a cause for the rise in existing ambient sound level. Subtracting the difference in natural ambient level between years, daytime existing ambient level decreased at Mt. Collins (1.9 dB) and Bullhead Trail (0.2 dB) and increased at Parson Branch (0.1 dB) and Purchase Knob (0.9 dB). According to the GRSM NRCA, these differences of < 1.5 dB increase indicate soundscapes are in good condition (Bates *et al.* 2018). Existing ambient sound levels at night increased more substantially at Parson Branch (4 dB) and Purchase Knob (6.3 dB), which may warrant significant concern according to the GRSM NRCA. However, as nighttime sound source identification did not occur in 2006, nighttime natural ambient sound level was not calculated. Therefore, the rise in existing ambient sound level may be attributed to rise in natural ambient sound level or to the limitations discussed in Appendix D.

Using unpublished raw data from the 2006 study, time above metrics were generated for daytime and nighttime at Mt. Collins, Parson Branch, Purchase Knob, and Bullhead Trail (Appendix D). Time above metrics in 2016 were similar to those measured in 2006 with a few exceptions. First, daytime measures at Purchase Knob in 2016 were nearly double those of 2006. Second, Parson Branch, Purchase Knob, and Bullhead Trail all revealed an increase of at least double for nighttime levels above 35 dB. This trend in nighttime levels continued for Parson Branch and Bullhead Trail for levels above 45 dB and 52 dB (Lee *et al*. 2016).

For a broader context of the acoustic conditions at GRSM, a comprehensive 1982 study of noise levels in residential areas found that nearly 87% of US residents were exposed to day-night sound levels (Ldn) over 55 dB, and an additional 53% were exposed to Ldn 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). Additionally, a nationwide study modeling daytime summer sound levels indicated that only 23% of the continental United States was predicted to have an existing ambient sound level above 40 dB ($L_{A50,\ 12\ hr}$), and only 1% of the continental U.S. was predicted to have an existing daytime ambient sound level above 50 dB ($L_{A50,\ existing}$) (Mennitt *et al*. 2013). Consider, though, that daily sound levels described in this report for Mt. Collins, Parson Branch, Purchase Knob, and Bullhead Trail can be influenced by both natural and non-natural sources.

Based on the results of this study, visitors to GRSM are unlikely to experience a significant noise-free interval near the monitoring sites, though noise is audible less in the early morning and late evening hours (Table 8, Table 10, Table 12, Table 14, and Figure 16–Figure 19). Noise audibility appeared to increase considerably at Parson Branch, Purchase Knob, and Bullhead Trail in 2016, while it remained similar to 2006 levels at Mt. Collins. 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 ($L_{Aeq,\ x}$). [3] Of the papers reviewed, 20% showed impacts to terrestrial wildlife at or below noise levels of 50 dB ($L_{Aeq,\ 1s}$) (Shannon *et al*. 2016).

The information presented in this report will be used to inform park managers and planners when they make management decisions, but it will also serve as a permanent record of what the park sounded like in 2016. Sound level data as well as continuous digital audio recordings are stored at the Natural Sounds and Night Skies Division office in Fort Collins, Colorado for archiving purposes.

[3] This metric is a composite of multiple metrics with varying time averaging metrics.

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# Appendix A: Office Listening

Office listening is a way to characterize the length and type of noise events occurring at a monitored site. The NSNSD protocol calls for 8 days of analysis per monitoring period. The Acoustical Monitoring Toolbox splits the audio files in to 10 second clips every two minutes per one day. This results in 16 hours' worth of data being analyzed per site. Each sound is assigned a number which is then put into the Listening Center program each time the listener hears the sound. These numbers are eventually used to compute the $L_{Anat}$ for the site.

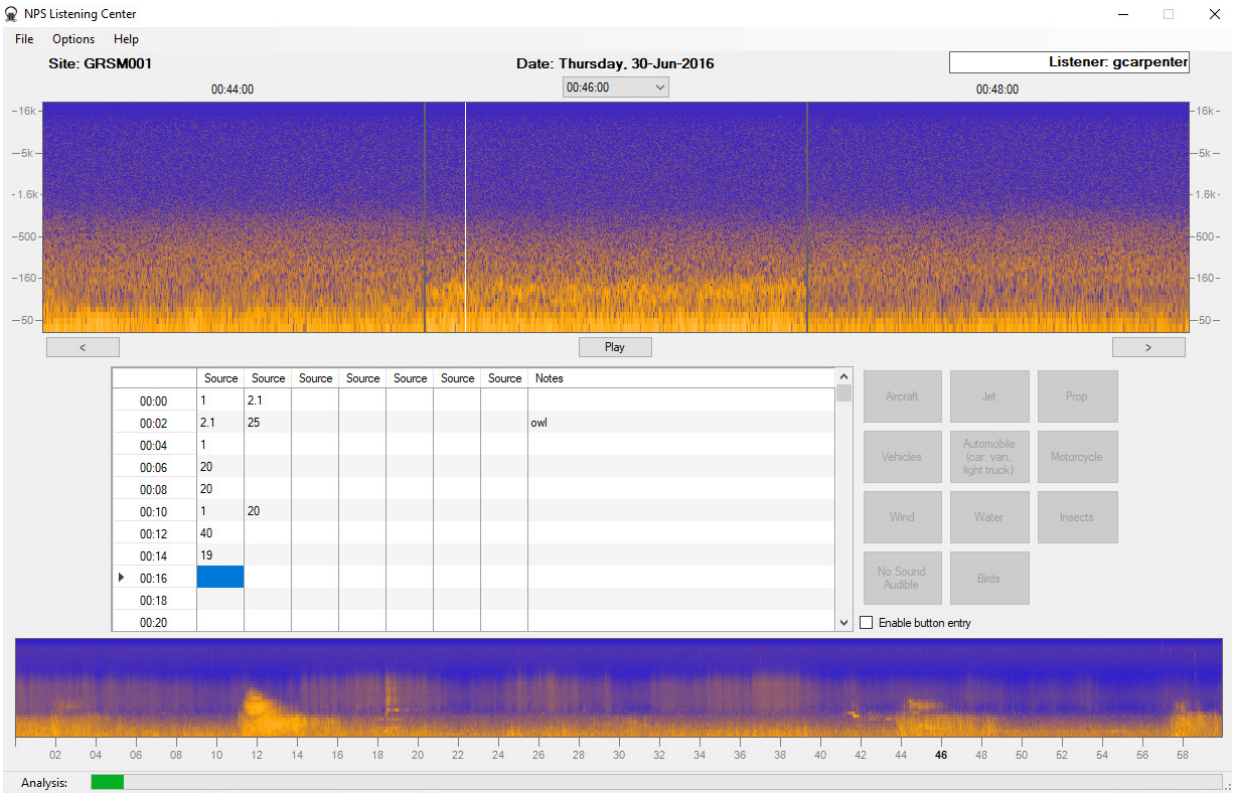


**Figure 20.** Screen shot of Listening Center. Three ten second samples are displayed side by side. Audible sound sources and annotations are recorded in the spreadsheet cells.

# Appendix B: Aircraft Tracking

In the fall of 2019, NSNSD launched an aircraft tracking study using newer technology called Automatic Dependent Surveillance-Broadcast (ADS-B). ADS-B is comprised of both an Out and In function. ADS-B Out uses GPS signals along with aircraft avionics to broadcasts a signal that relays real-time information to other aircraft and air traffic controllers, including latitude, longitude, altitude, and a unique identification code. ADS-B In is the technology that allows pilots to view real-time air traffic data inside the cockpit. Our work focuses only on ADS-B Out, which we shorthand in most places to "ADS-B." The ADS-B signal is un-encrypted and publicly accessible.

Data collected at GRSM during (non-sequential) 26 days between September 25 and November 6 indicates significant air traffic exists above GRSM. Figure 21 is a map which displays all the ADS-B data captured during the 26-day period. The routes in Figure 21 are set to 90% transparency, which results in a display that darker blue lines represent a higher concentration of aircraft routes over GRSM. Of relevance to this acoustical monitoring study is that Parson Branch is directly below a great concentration of routes arriving/departure the McGhee Tyson Airport (i.e., Knoxville; Figure 21). While these aircraft tracking data were collected several years after the acoustic measurements covered in this report, this information may provide insight into aircraft audibility results for all sites, particularly Parson Branch.

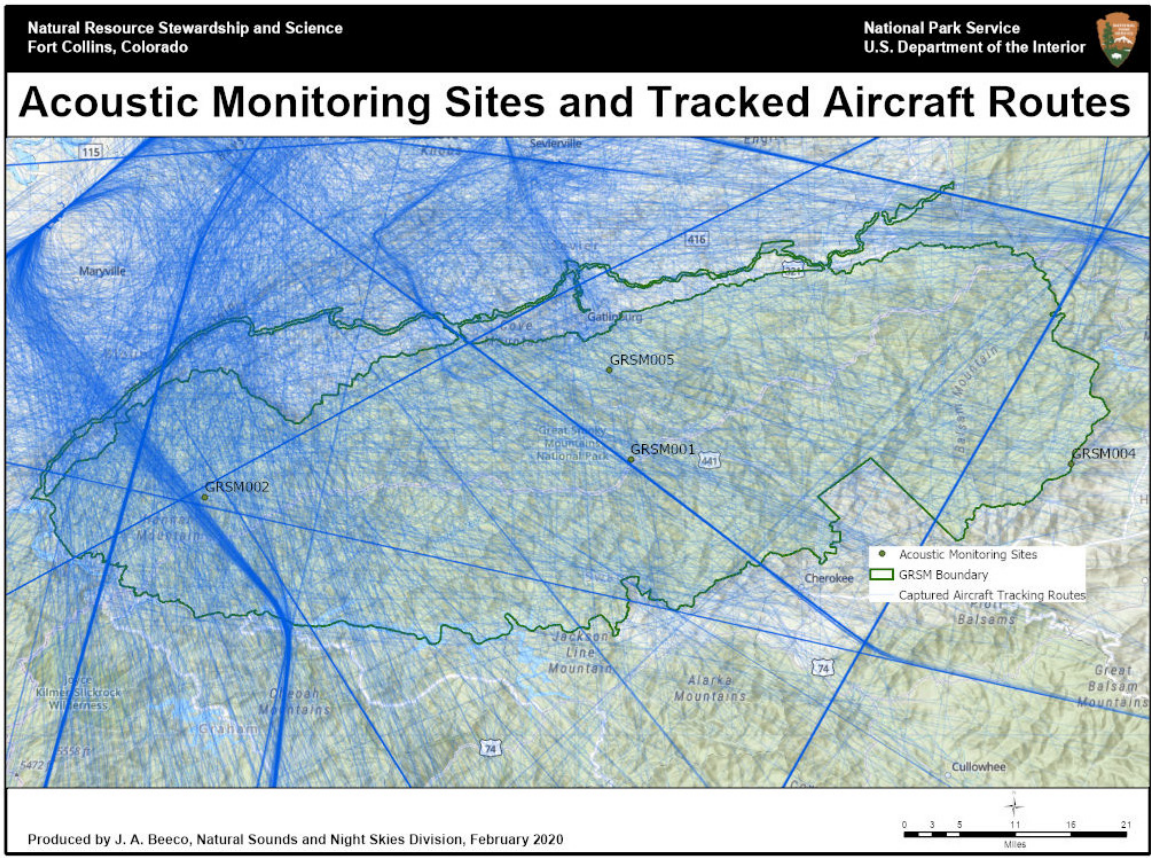


**Figure 21.** Tracked aircraft routes over GRSM in the fall of 2019.

# Appendix C: Air Tours

The National Park Air Tour Management Act (NPATMA) requires the Federal Aviation Administration (FAA) and the NPS to jointly manage air tours over NPS units. Currently, there are two operators who have interim operating authority (IOA) to conduct air tours over GRSM. The total amount of air tours per year is limited to 1,920 (Lignell, 2019). This amount of IOA is split between the two operators with Whirl'd Helicopter, Inc. having 1,800 IOA and Great Smoky Mountain Helicopters Inc. having 120 IOA.

Air tour reporting data from GRSM indicates that Whirl'd Helicopter Inc. has been an active operator of air tours over GRSM since reporting began in 2013, while Great Smoky Mountain Helicopters Inc. have been inactive over the past three years (2016–2018), providing zero tours. Reporting data for June and July of 2016 indicate a total of 169 air tours during these two months.

In the fall of 2019, NSNSD reached out to Whirl'd Helicopter, Inc. and Great Smoky Mountain Helicopter Inc. for their existing routes of air tours over GRSM to better understand the flight operations and types of aircraft used. Figure 22 displays the four routes that were provided. Reporting data for June and July of 2016 indicate that that 82% percent of flights occurred on the SNPF route. All air tours were conducted by helicopters.

The four acoustic monitoring points in this study have varying degrees of proximity to the air tour routes. Helicopters were heard more frequently during audibility analysis for Bullhead Trail than any other site. This is explained when comparing the route information provided by Whirl'd Helicopter Inc. to the acoustic monitoring locations because Bullhead Trail lies underneath three of the four routes, including the SNPF route. The specific dates that audibility was analyzed for Bullhead Trail were June 15, 19, 24, 25, 26, 29 and July 1. Table 15 displays the number of reported air tours at GRSM on the days of audibility analysis. Across all seven days the average number of tours was three. When referencing Table 14, the percent time audible for helicopters averaged 7.5% for the hours of 10:00am to 3:00pm.

**Table 15.** Number of reported air tours on the 7 days for which audibility analysis was conducted at Bullhead Trail (GRSM005) in 2016.

| Date | Number of Air tours |
|---|---|
| **June 15** | 5 |
| **June 19** | 1 |
| **June 24** | 3 |
| **June 25** | 2 |
| **June 26** | 2 |
| **June 29** | 4 |
| **July 1** | 4 |

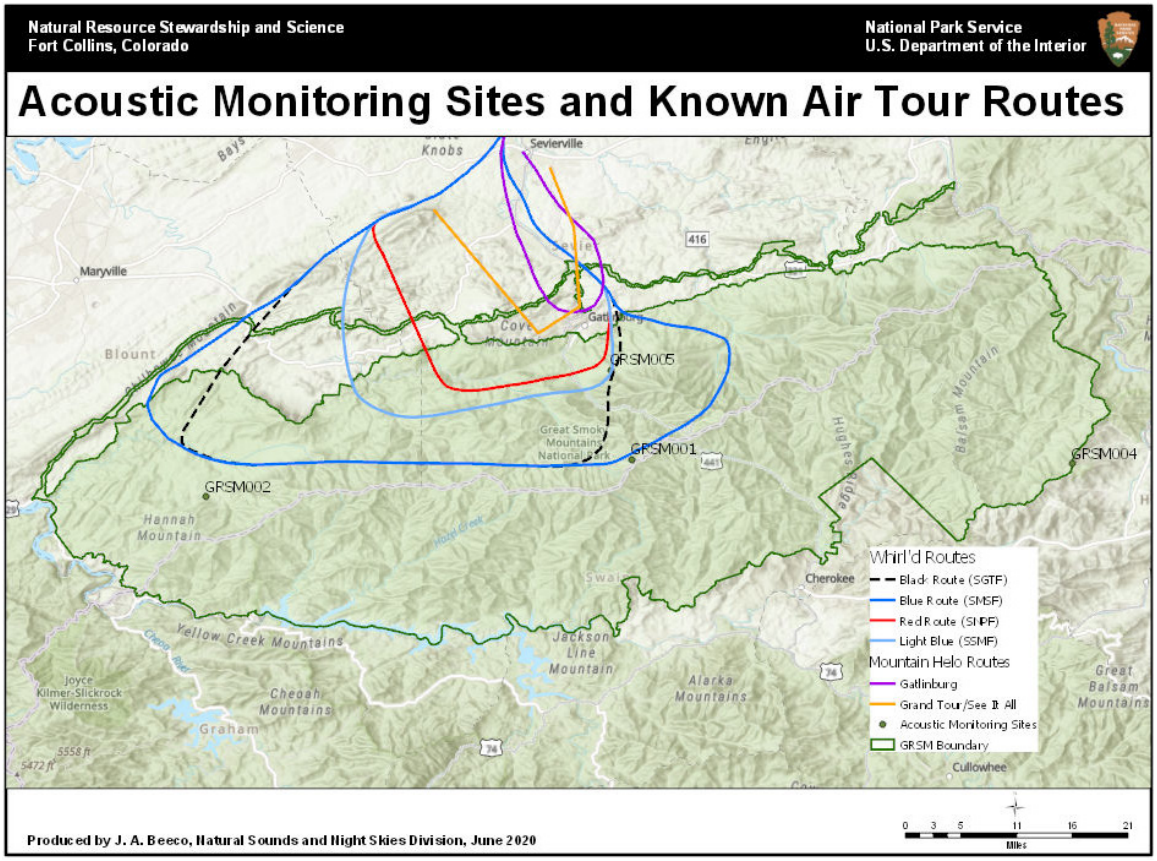


**Figure 22.** Map of known air tour routes over Great Smoky Mountains National Park, USA.

# Appendix D: Summer 2006 Data

Certain caveats apply when comparing 2006 and 2016 sound level data (Table 16–Table 18). Among natural sound sources, wind can have considerable influence on ambient sound level and time above metrics. On-site wind speed is typically collected by anemometer to help evaluate effects (Table 19). However, anemometer data were not collected at Mt. Collins, Purchase Knob, and Bullhead Trail in 2016 due to equipment error. Ambient temperature and humidity also affect propagation of soundwaves, so differences between years may affect sound levels recorded at the same location. Further, sound level measurements are sensitive to changes in immediate environment, therefore, any change in vegetation near equipment may have influenced sound levels between years. Additionally, sound levels recorded by a Larson Davis 831 sound level meter can drift by up to 3 dB over a 4-week period so differences in calibration regime may also contribute to differences in sound level (Lee 2020 pers. comm.). Volpe sound level meters were calibrated weekly, where those in the current study were calibrated every two weeks. Further differences could have emerged from differences in microphone sensitivity and different accessories, like wind screens. Considering these factors, temporal comparison of sound level metrics, including time above and ambient sound level (), should be made cautiously.

**Table 16.** Median existing and natural ambient sound levels (dB re 20 µPa, A-weighted broadband,12.5 Hz—20 kHz) at GRSM001, GRSM002, GRSM004, and GRSM005 (where day is 7:00–19:00 and night is 19:00–7:00) during summer. Measurements by Volpe from May 30–July 4, 2006 compared to data collected from June 6–July 19, 2016.

| | | Median Existing Ambient ($L_{A50}$) in dB | | | | Median Natural Ambient Daytime ($L_{Anat}$) in dB | |
|---|---|---|---|---|---|---|---|
| Site ID | Site Name | 2006 Day | 2006 Night | 2016 Day | 2016 Night | 2006 Day* | 2016 Day |
| **GRSM001** | Mt. Collins | 30.7 | 26.2 | 26.7 | 22.8 | 26.7 | 24.6 |
| **GRSM002** | Parson Branch | 30.7 | 24.5 | 30.7 | 28.5 | 26.3 | 26.4 |
| **GRSM004** | Purchase Knob | 29.8 | 27.1 | 32.6 | 33.4 | 26.4 | 28.3 |
| **GRSM005** | Bullhead Trail | 33.2 | 29.6 | 29.7 | 29.2 | 29.1 | 25.8 |

* Natural ambient estimated from audibility data collected in-situ and from office listening where in 2016 only office listening was used.

**Table 17.** Time above metrics for daytime at GRSM001, GRSM002, GRSM004, and GRSM005 measured by Volpe from May 30–July 4, 2006 compared to data collected from June 6–July 19, 2016.

| Site ID | Site Name | Frequency (Hz) | Time above sound level (% of daytime hours, 07:00 to 19:00) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 35 dB 2006* | 35 dB 2016* | 45 dB 2006* | 45 dB 2016* | 52 dB 2006* | 52 dB 2016* | 60 dB 2006* | 60 dB 2016* |
| **GRSM001** | Mt. Collins | 12.5–20,000 | 19.78 | 11.99 | 1.17 | 1.76 | 0.20 | 0.20 | 0.01 | 0.00 |
| | Mt. Collins | 20–1,250 | 11.13 | 2.98 | 0.65 | 0.36 | 0.10 | 0.05 | 0.01 | 0.00 |
| **GRSM002** | Parson Branch | 12.5–20,000 | 17.61 | 21.62 | 1.74 | 2.88 | 0.20 | 0.35 | 0.00 | 0.02 |
| | Parson Branch | 20–1,250 | 9.69 | 9.20 | 0.91 | 0.97 | 0.15 | 0.15 | 0.00 | 0.01 |
| **GRSM004** | Purchase Knob | 12.5–20,000 | 22.54 | 42.00 | 5.13 | 9.20 | 0.34 | 1.91 | 0.02 | 0.22 |
| | Purchase Knob | 20–1,250 | 12.08 | 13.00 | 0.35 | 0.57 | 0.07 | 0.08 | 0.00 | 0.00 |
| **GRSM005** | Bullhead Trail | 12.5–20,000 | 19.95 | 20.06 | 2.20 | 1.95 | 0.28 | 0.34 | 0.01 | 0.01 |
| | Bullhead Trail | 20–1,250 | 5.98 | 3.63 | 0.84 | 0.38 | 0.23 | 0.07 | 0.00 | 0.00 |

* dB $L_{Aeq, 1s}$ re 20 µPa

**Table 18.** Time above metrics for nighttime at GRSM001, GRSM002, GRSM004, and GRSM005 measured by Volpe from May 30–July 4, 2006 compared to data collected from June 6–July 19, 2016.

| Site ID | Site Name | Frequency (Hz) | Time above sound level (% of nighttime hours, 19:00 to 07:00) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 35 dB 2006* | 35 dB 2016* | 45 dB 2006* | 45 dB 2016* | 52 dB 2006* | 52 dB 2016* | 60 dB 2006* | 60 dB 2016* |
| **GRSM001** | Mt. Collins | 12.5–20,000 | 8.91 | 6.43 | 0.50 | 0.59 | 0.06 | 0.09 | 0.00 | 0.00 |
| | Mt. Collins | 20–1,250 | 3.66 | 1.46 | 0.14 | 0.15 | 0.01 | 0.01 | 0.00 | 0.00 |
| **GRSM002** | Parson Branch | 12.5–20,000 | 7.76 | 29.47 | 0.43 | 9.22 | 0.05 | 1.83 | 0.00 | 0.02 |
| | Parson Branch | 20–1,250 | 3.29 | 10.68 | 0.20 | 0.52 | 0.02 | 0.08 | 0.00 | 0.00 |
| **GRSM004** | Purchase Knob | 12.5–20,000 | 20.64 | 48.85 | 5.20 | 6.33 | 0.16 | 1.43 | 0.00 | 0.39 |
| | Purchase Knob | 20–1,250 | 12.15 | 12.47 | 0.15 | 0.33 | 0.02 | 0.03 | 0.00 | 0.00 |
| **GRSM005** | Bullhead Trail | 12.5–20,000 | 11.13 | 25.40 | 0.74 | 2.88 | 0.13 | 0.28 | 0.00 | 0.00 |
| | Bullhead Trail | 20–1,250 | 3.11 | 3.52 | 0.24 | 0.35 | 0.03 | 0.01 | 0.00 | 0.00 |

* dB $L_{Aeq, 1s}$ re 20 µPa

**Table 19.** Mean and median wind speed collected at weather stations and anemometers located at acoustic monitoring sites in Great Smoky Mountains National Park in 2006 and 2016. Anemometers failed at GRSM001, GRSM004, and GRSM005 in 2016.

| Site ID | Site Name | Nearest Weather Station | Distance from Weather Station to Site (km) | Scalar Wind Speed (m/s) | | | |
|---|---|---|---|---|---|---|---|
| | | | | 2006 Mean | 2006 Median | 2016 Mean | 2016 Median |
| **GRSM001** | Mt. Collins | Clingmans Dome | 4.1 | 3.4 | – | 2.4 | – |
| **GRSM004** | Purchase Knob | Clingmans Dome | 38.4 | – | 2.9 | – | 2.1 |
| **GRSM002** | Parson Branch | Cades Cove | 8.2 | 0.9 | 0.7 | 1.0 | 0.7 |
| **GRSM005** | Bullhead Trail | Cove Mountain | 9.5 | 3.2 | 2.8 | 3.2 | 2.8 |
| **GRSM001** | Mt. Collins | GRSM001 Anemometer | 0.0 | 0.2 | 0.1 | – | – |
| **GRSM002** | Parson Branch | GRSM002 Anemometer | 0.0 | 0.4 | 0.2 | 0.2 | 0.0 |
| **GRSM004** | Purchase Knob | GRSM004 Anemometer | 0.0 | 0.3 | 0.2 | – | – |
| **GRSM005** | Bullhead Trail | GRSM005 Anemometer | 0.0 | 0.3 | 0.2 | – | – |

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