



Cumberland Island National Seashore

Acoustic Monitoring Report 2022–2023



Acoustic monitoring at Terrapin Point Trail, Cumberland Island (CUIS001).
NPS / KELSEY WHITE

Cumberland Island National Seashore: Acoustic monitoring report 2022–2023

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Abstract

The Natural Sounds and Night Skies Division (NSNSD) received a request to collect baseline acoustical data on Cumberland Island National Seashore (CUIS). The goal of this project is to inform decisions related to fire management, land use, and future land development. These decisions will be formed to understand the degree to which noise could affect the natural environment and visitor experience. Three acoustic monitoring stations were deployed during spring 2022 (March/April) and winter 2022–2023 (December/January). Aircraft were found to be the predominant source of noise at all sites, audible between 50 and 56% of a 24-hour day. Other, less frequent sources of audible noise include watercraft and road/trail vehicles. Common natural sound sources within the park were birds, insects, animals foraging and wind blowing through vegetation. On occasion, wild horses and hogs were audible during both day and night hours at all locations.

Glossary of Acoustical Terms

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

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

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

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

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

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

Decibel (dB): A unit of sound energy. Sound levels are measured on a logarithmic scale relative to the reference sound pressure for atmospheric sources, 20 μ Pa. The logarithmic scale is a useful way to express the wide range of sound pressures perceived by the human ear. 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 (L_{A50}): Sound level ($L_{Aeq, 1s}$) exceeded 50% of the time (50th percentile) for a specified duration. This level is referred to as the existing ambient sound level and the preferred metric for chronic conditions, as it is insensitive to infrequent loud events or periods of silence.

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

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

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

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

Natural Ambient Sound Level (L_{Anat}): 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 period of one second.

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

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

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

Soundscape: The human perception of physical sound resources.

Executive Summary

The Natural Sounds and Night Skies Division (NSNSD) received a request to collect an inventory of baseline acoustical data on Cumberland Island National Seashore (CUIS). The goal of this study is to establish a baseline acoustic inventory of the park and understand how noise is affecting the soundscape, visitor experience, and cultural and natural resources. This baseline will also assist resource managers measure changes and provide mitigation where necessary. Three backcountry sites were sampled in this study: Terrapin Trail (CUIS001), South Cut Trail (CUIS002) and Lost Trail (CUIS003) during both spring and winter seasons.

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

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

Table 1. Sound level examples.

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

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

Table 2 reports the percent of time that measured levels at the monitoring locations were above four key sound level values. The first value, 35 dB ($L_{Aeq, 1s}$), is used by the NPS as an indicator of overall quality of the acoustic environment. Beyond this level, noise begins to negatively affect the visitor

experience in an otherwise natural acoustic environment (Pilcher et al. 2009; Watts et al. 2020; Betchkal et al. 2023). As wildlife begin to exhibit signs of disturbance at noise levels as low as 40 dB (Shannon et al. 2016), 45 dB represents a conservative estimate of negative effects on wildlife. The third value, 52 dB ($L_{Aeq, 1s}$), is based on the EPA’s analysis of speech interference for an individual speaking in a raised voice to an audience at 10 meters (EPA 1974)—an acoustic level that would affect interpretive presentations in parks. The final value, 60 dB ($L_{Aeq, 1s}$), marks the point at which normal voice communications at 1 meter begin to be interrupted (EPA 1974); sounds at or exceeding this level would affect conversation between visitors and/or staff.

Sound levels are often measured over narrow frequency bands (typically in one-third octave bands between 12.5 Hz–20,000 Hz) because these smaller bands closely represent how humans distinguish between frequencies of sound. In this study, we examine how often sound levels exceeded the key values mentioned above in two frequency ranges. The top value in each split-cell of Table 2 uses the full frequency range (12.5 Hz–20,000 Hz) collected, whereas the bottom value focuses on frequencies affected by low-frequency noise sources (20–1,250 Hz). The focus on low-frequency noise sources—a modification to A-weighting (referred to as A-weighted Natural Sounds (ANS) weighting, ASA/ANSI S3/SC1.100–2014 [2020])—eliminates high-frequency sounds such as leaves rustling, equipment noise, and bird calls, allowing for more accurate comparisons of low-frequency ambient sound levels across different land use types (e.g., urban, protected areas; ASA/ANSI S3/SC1.100–2014 [2020]). It also helps distinguish between ambient sound level measurements in quiet environments.

For instance, in the full frequency range, the 35 dB ($L_{Aeq, 1s}$) level was exceeded at CUIS001 84.7% of the time during the day and 37.1% of the time at night, but in the ANS range, the 35 dB functional sound level value was exceeded only 47.3% during the daytime and only 12.0% at night. Speech interruption occurs (between two people 1 meter apart) at 60 dB ($L_{Aeq, 1s}$) and this level was rarely exceeded at any site.

At all three of these backcountry locations, sound source analysis revealed that aircraft were the primary source of noise during both spring and winter, audible 50–56% of the time. Other, less frequent sources of audible noise include watercraft and vehicles. Table 3 displays the percentage of time audible values for common noise sources, as well as ambient sound levels. The overall audibility of noise at these backcountry locations over the 24-hour day was 50.4% to 57.8% during winter and 51.7% to 54.2% during spring.

Table 2. Time above metrics for CUIS001, CUIS002 and CUIS003.

Site ID	Frequency Range (Hz)	Time Above Sound Level (% of Daytime Hours, 07:00–19:00)				Time Above Sound Level (% of Nighttime Hours, 19:00–07:00)			
		35 dB ^A	45 dB ^A	52 dB ^A	60 dB ^A	35 dB ^A	45 dB ^A	52 dB ^A	60 dB ^A
CUIS001 Spring	Full (12.5–20,000)	84.7	13.3	1.3	0.1	37.1	3.5	0.2	0.0
	ANS (20–1,250)	47.3	3.9	0.4	0.0	12.0	0.7	0.1	0.0
CUIS001 Winter	Full (12.5–20,000)	32.7	3.7	0.4	0.0	29.0	0.9	0.0	0.0
	ANS (20–1,250)	20.9	2.8	0.4	0.0	4.5	0.4	0.0	0.0
CUIS002 Spring	Full (12.5–20,000)	88.4	16.9	2.1	0.2	43.5	4.8	0.3	0.0
	ANS (20–1,250)	47.9	3.4	0.5	0.0	12.7	0.6	0.1	0.0
CUIS002 Winter	Full (12.5–20,000)	38.8	3.8	0.6	0.0	24.8	0.5	0.0	0.0
	ANS (20–1,250)	25.1	2.6	0.4	0.0	6.5	0.4	0.0	0.0
CUIS003 Spring	Full (12.5–20,000)	94.1	20.9	2.7	0.2	43.0	2.9	0.3	0.0
	ANS (20–1,250)	49.9	4.3	0.7	0.1	23.0	0.6	0.1	0.0
CUIS003 Winter	Full (12.5–20,000)	50.5	3.4	0.6	0.0	43.2	0.8	0.0	0.0
	ANS (20–1,250)	39.7	2.7	0.5	0.0	29.0	0.5	0.0	0.0

^A dB L_{Aeq, 1s} re: 20 µPa**Table 3.** Mean time audible for human-caused, aircraft, and vehicle noise sources, existing and natural ambient sound levels (dB re 20 µPa, A-weighted broadband, 12.5 Hz-20 kHz) at CUIS001, CUIS002 and CUIS003 (where day is 07:00–19:00 and night is 19:00–07:00).

Site ID	Site Name	Season	Mean Time Audible for Noise (% Of 24-Hour Period) ^A			Median Existing Ambient (L _{A50}) In Db		Median Natural Ambient (L _{anat}) In Db	
			All Noise	Aircraft	Vehicle	Day	Night	Day	Night
CUIS001	Terrapin Trail	Spring	54.2	50.0	0.3	39.8	32.9	35.7	30.9
CUIS001	Terrapin Trail	Winter	57.1	54.4	0.3	32.7	30.0	29.1	29.1
CUIS002	South Cut Trail	Spring	52.6	50.9	0.2	40.1	34.0	36.5	31.7
CUIS002	South Cut Trail	Winter	57.8	55.9	1.6	33.4	30.0	29.3	29.1

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

Table 3 (continued). Mean time audible for human-caused, aircraft, and vehicle noise sources, existing and natural ambient sound levels (dB re 20 µPa, A-weighted broadband, 12.5 Hz-20 kHz) at CUIS001, CUIS002 and CUIS003 (where day is 07:00–19:00 and night is 19:00–07:00).

Site ID	Site Name	Season	Mean Time Audible for Noise (% Of 24-Hour Period) ^A			Median Existing Ambient (L _{A50}) In Db		Median Natural Ambient (L _{anat}) In Db	
			All Noise	Aircraft	Vehicle	Day	Night	Day	Night
CUIS003	Lost Trail	Spring	51.7	51.2	0.0	40.9	34.6	37.6	33.4
CUIS003	Lost Trail	Winter	50.4	50.2	0.1	35.2	34.1	32.5	33.4

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

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Introduction

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

National Park Service Natural Sounds and Night Skies Division

The Natural Sounds and Night Skies Division (NSNSD) helps parks manage sounds in a way that protects park resources and the visitor experience. The NSNSD addresses acoustic issues raised by Congress, NPS Management Policies, and NPS Director's Orders. The NSNSD works to protect, maintain, or restore acoustic 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 acoustic monitoring, data processing, park planning support, and comparative analyses of acoustic 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 wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." In addition to the NPS Organic Act, the Redwoods Act of 1978 affirmed that, "the protection, management, and administration of these areas shall be conducted in light of the high value and integrity of the National Park System and shall not be exercised in derogation of the values and purposes for which these various areas have been established, except as may have been or shall be directly and specifically provided by Congress."

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

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

"The Service will restore to the natural condition wherever possible those park soundscapes that have become degraded by unnatural sounds (noise) and will protect natural soundscapes from unacceptable impacts."

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

It should be noted that under Management Policies 2006 Chapter 8.2.3, “[t]he natural ambient sound level—that is, the environment of sound that exists in the absence of human-caused noise—is the baseline condition, and the standard against which current conditions in a soundscape [acoustic resource] will be measured and evaluated” (NPS 2006c). However, the desired acoustic condition may also depend upon the resources and the values of the park. For instance, “culturally appropriate sounds are important elements of the national park experience in many parks” (NPS 2006b). In this case, “the Service will preserve soundscape resources and values of the parks to the greatest extent possible to protect opportunities for appropriate transmission of cultural and historic sounds that are fundamental components of the purposes and values for which the parks were established” (NPS 2006b).

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

Director’s Order 47, Soundscape Preservation and Noise Management (2000) builds on the principles set out in Management Policies, directing park management how and when to consider acoustic resources. Through this order, parks are guided to manage noise by identifying noise sources, minimizing noise from park operations, considering the acoustic environment in park planning documents, and promoting park sounds and noise management through communication, education, and outreach.

Study Area

This report presents results from an acoustic inventory conducted in spring 2022 and winter 2022–2023 at Cumberland Island National Seashore (CUIS). Three sites were sampled in this study: Terrapin Trail (CUIS001), South Cut Trail (CUIS002) and Lost Trail (CUIS003) (Table 4). Figure 1 shows the location of the sites in map format. The Terrapin Trail site was located approximately 80m from the trailhead and road, within the CUIS wilderness area. The South Cut Trail site was located approximately 15m off a side road. The Lost Trail site was located approximately 0.6 mile down Lost Trail and 30m off trail.

Table 4. Metadata for acoustic monitoring at CUIS, 2022–2023.

Site ID	Site Name	Dates Deployed	Vegetation	Elevation (m)	Latitude	Longitude
CUIS001	Terrapin Trail	March 16 to April 20, 2022, and December 13, 2022, to February 1, 2023	(Sub) Tropical Moist Broadleaf	15	30.915099	-081.445856
CUIS002	South Cut Trail	March 16 to April 20, 2022, and December 14, 2022, to February 1, 2023	(Sub) Tropical Moist Broadleaf	10	30.887748	-081.435821
CUIS003	Lost Trail	March 16 to April 20, 2022, and December 14, 2022, to February 1, 2023	(Sub) Tropical Moist Broadleaf	17	30.865259	-081.431232

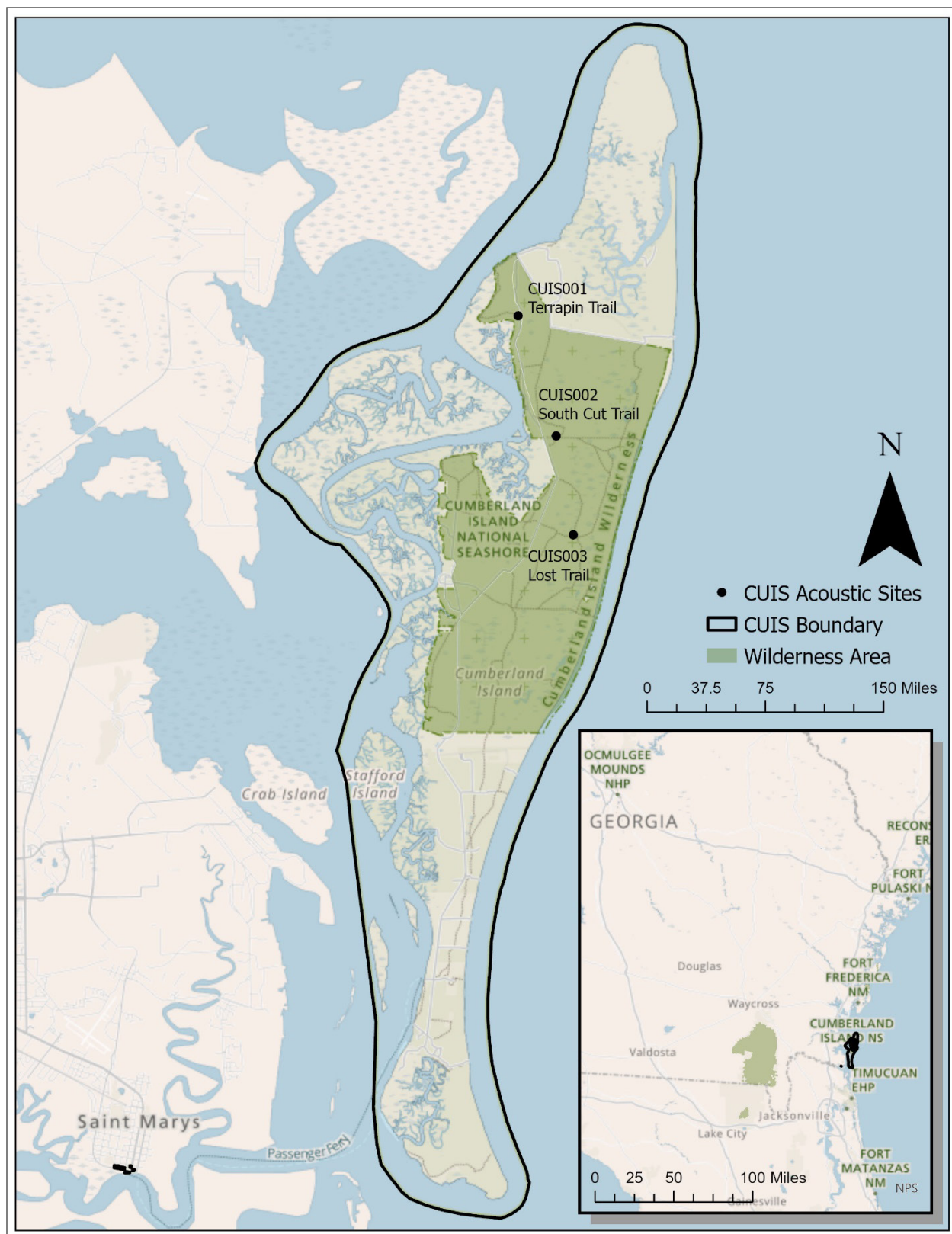


Figure 1. Study sites in Cumberland Island National Seashore.
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Methods

Automatic Monitoring

A Larson Davis sound level meter (SLM) type 831-A was deployed at one monitoring site. The SLM is a hardware-based, real-time analyzer which constantly records one-third octave band sound pressure level (SPL) data. This Larson Davis-based site met American National Standards Institute (ANSI) Type 1 standards (ANSI 1968 [R2023], 1983 [R2006], 1992 [2018]) for accurate survey-grade instrumentation. 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. The NPS uses equipment like that used by other practitioners but has developed a unique configuration that stands up to the potentially harsh environment encountered in national parks (NPS 2013). The microphone with environmental shroud was set up on a tripod at 1.5 m, which approximates the average height of the human ear. The digital audio recorder recorded continuous audio throughout the entire monitoring period. An anemometer was attached to a tripod and placed approximately 2 m from the microphone to capture local wind conditions.

Each sampling station consisted of:

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

Each sampling station collected:

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

Monitoring Period

To ensure that the data set accounts for seasonal and day-to-day differences, representative of typical conditions at a site, acoustic monitoring studies typically monitor a minimum of 25 days over two seasons (NPS 2005). Ideally, two seasons are identified by which season may produce the most noise

and least noise. For example, CUIS experiences the highest visitation in the spring and the lowest in the winter. Due to equipment issues, a range of 17–32 full days of digital audio recordings and 21–39 full days of sound level data are available depending on the site and season.

Calculation of Metrics

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

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

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

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

where:

P_H = 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 (07:00–19:00) and the median of the hourly L_{Anat} values for the nighttime (19:00–07:00) are displayed in graphical format in the following sections.

Off-Site Listening

Off-site auditory analysis is completed by listening to the audio record while simultaneously viewing its spectrogram representation. Staff at the U.S. Department of Transportation's Volpe Center analyzed a subset of .mp3 samples (10 seconds every two minutes for eight days of audio for each site) to identify durations of audible sound sources. Staff used the total percentage of time noise was audible to calculate the natural ambient sound level for each hour (see Equation 1 above). Bose Quiet Comfort Noise Canceling headphones were used for off-site audio playback to minimize limitations imposed by the office acoustical environment.

Results

Frequency Content

To determine the influence that noise has on the acoustic environment, it is useful to examine percentile metrics across the frequency spectrum. High-frequency sounds (such as a cricket chirping) and low-frequency sounds (such as flowing water) often occur simultaneously, so the frequency spectrum is split into 33 narrower bands, each encompassing one-third of an octave. These one-third octave bands closely represent how humans distinguish between frequencies of sound. For each one-third octave band, sound level ($L_{eq, 1s}$) was recorded once per second for the duration of the monitoring periods. The percentile sound levels for 33 one-third octave band frequencies over the day and night periods during spring season are shown in Figure 2, Figure 3, and Figure 4 at CUIS001, CUIS002, and CUIS003 respectively. Figure 5, Figure 6, and Figure 7 show the percentile sound levels during winter season at the three sites.

Examining the sound energy in each one-third octave band (usually, in combination 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 Figures 2 and 3 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 percentage of 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. For example, during the spring season, birds have significant bumps within the graph representing vocal activity in the 3.15–6.3 kHz ranges (daytime). During this same season, similar trends are noted on the nighttime bar suggesting notable insect activity as well. The low-frequency energy content at all locations, particularly during the daytime hours, is indicative of aircraft overflights. These trends can be further examined through off-site listening analysis, which will be discussed in the section below.

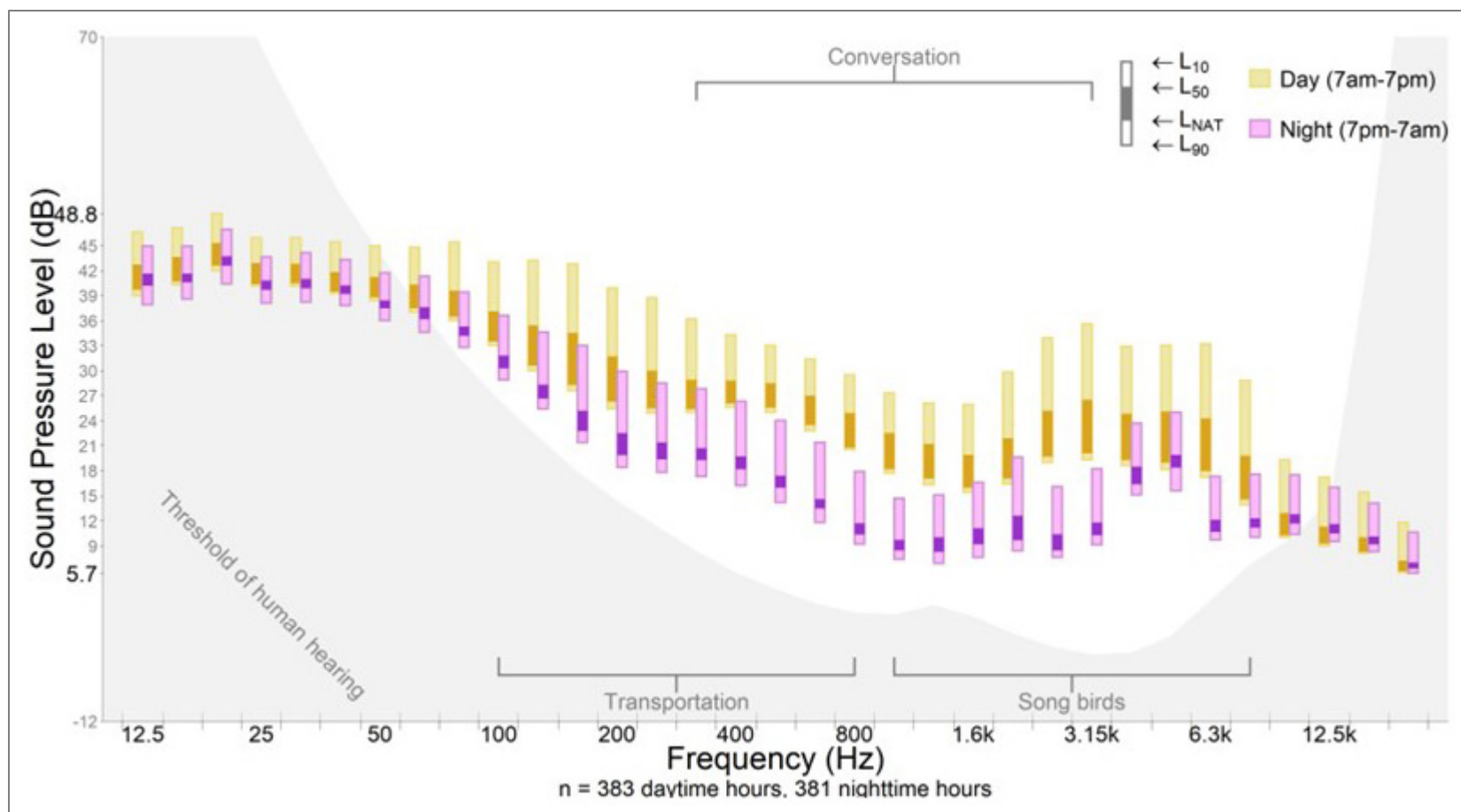


Figure 2. Day and night percentile sound pressure levels (unweighted) for 33 one-third octave bands at CUIS001, spring season.
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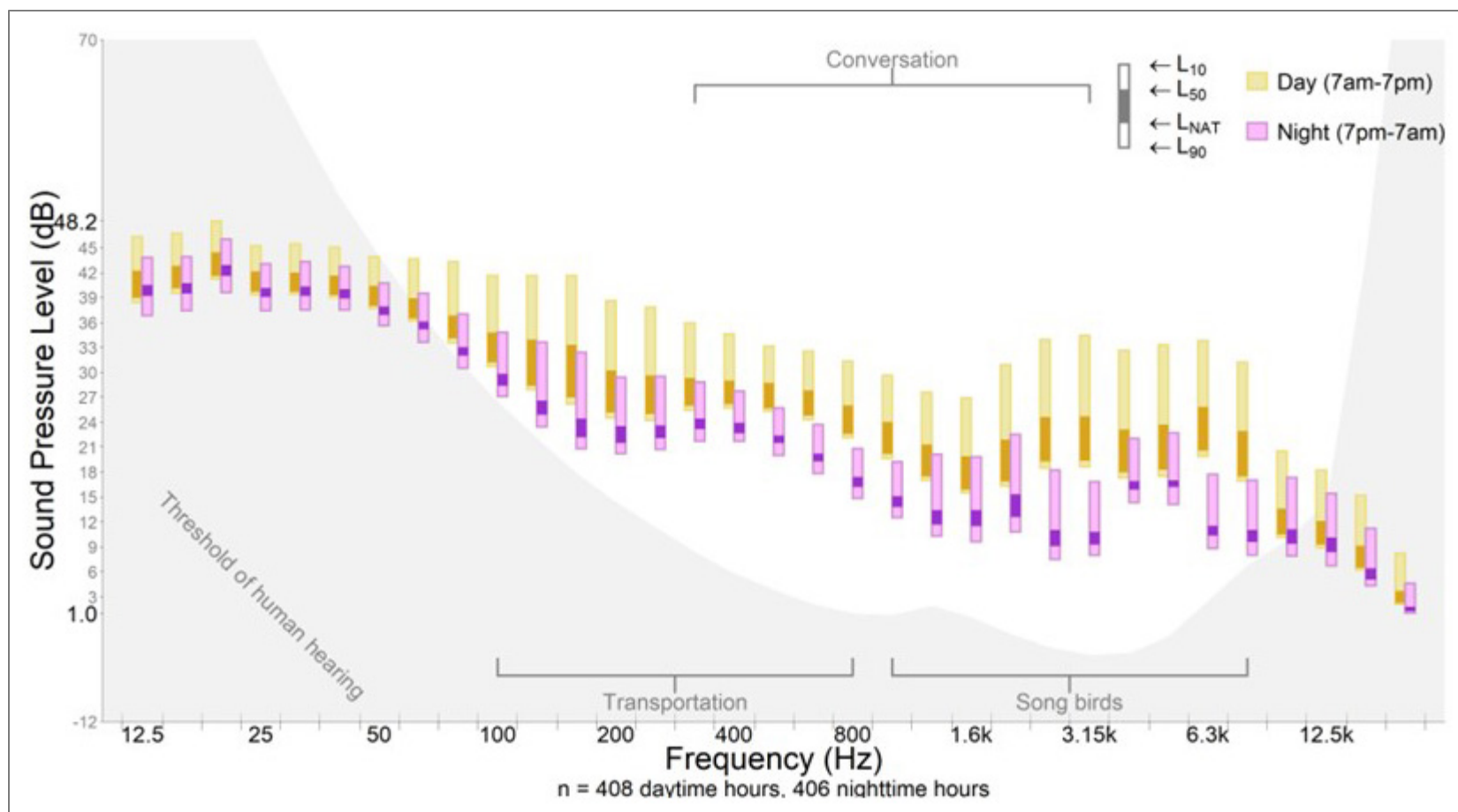


Figure 3. Day and night percentile sound pressure levels (unweighted) for 33 one-third octave bands at CUIS002, spring season.
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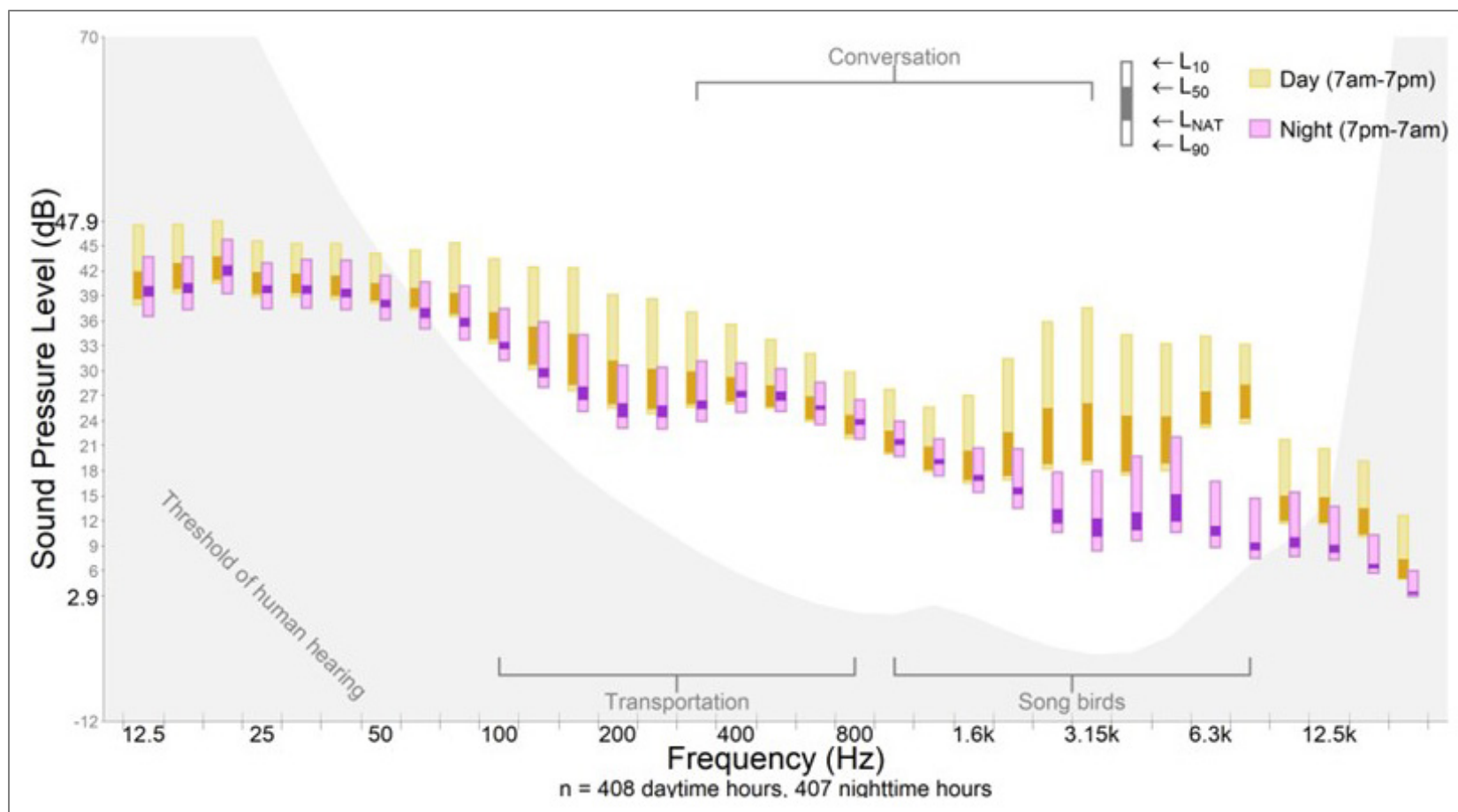


Figure 4. Day and night percentile sound pressure levels (unweighted) for 33 one-third octave bands at CUIS003, spring season.
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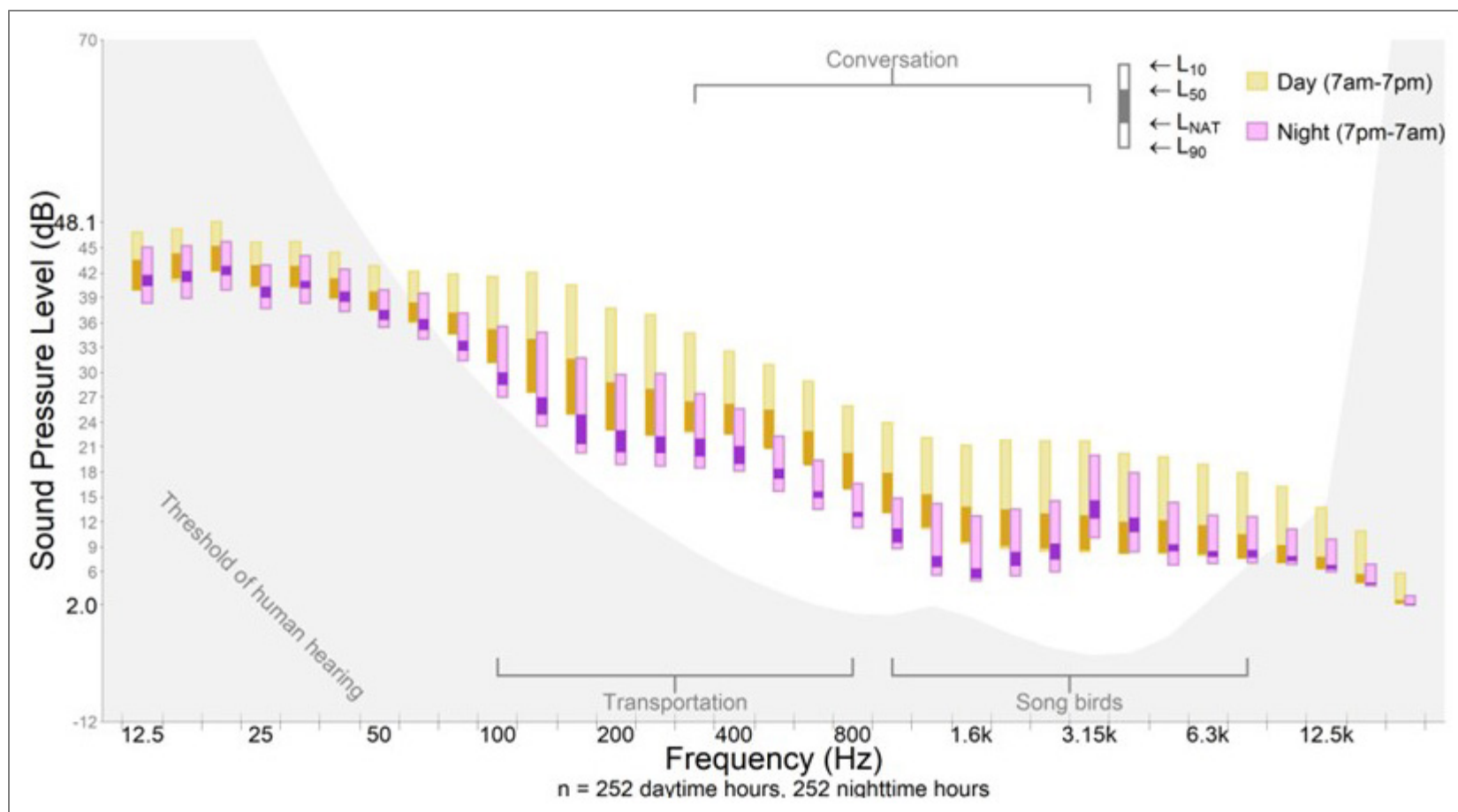


Figure 5. Day and night percentile sound pressure levels (unweighted) for 33 one-third octave bands at CUIS001, winter season.
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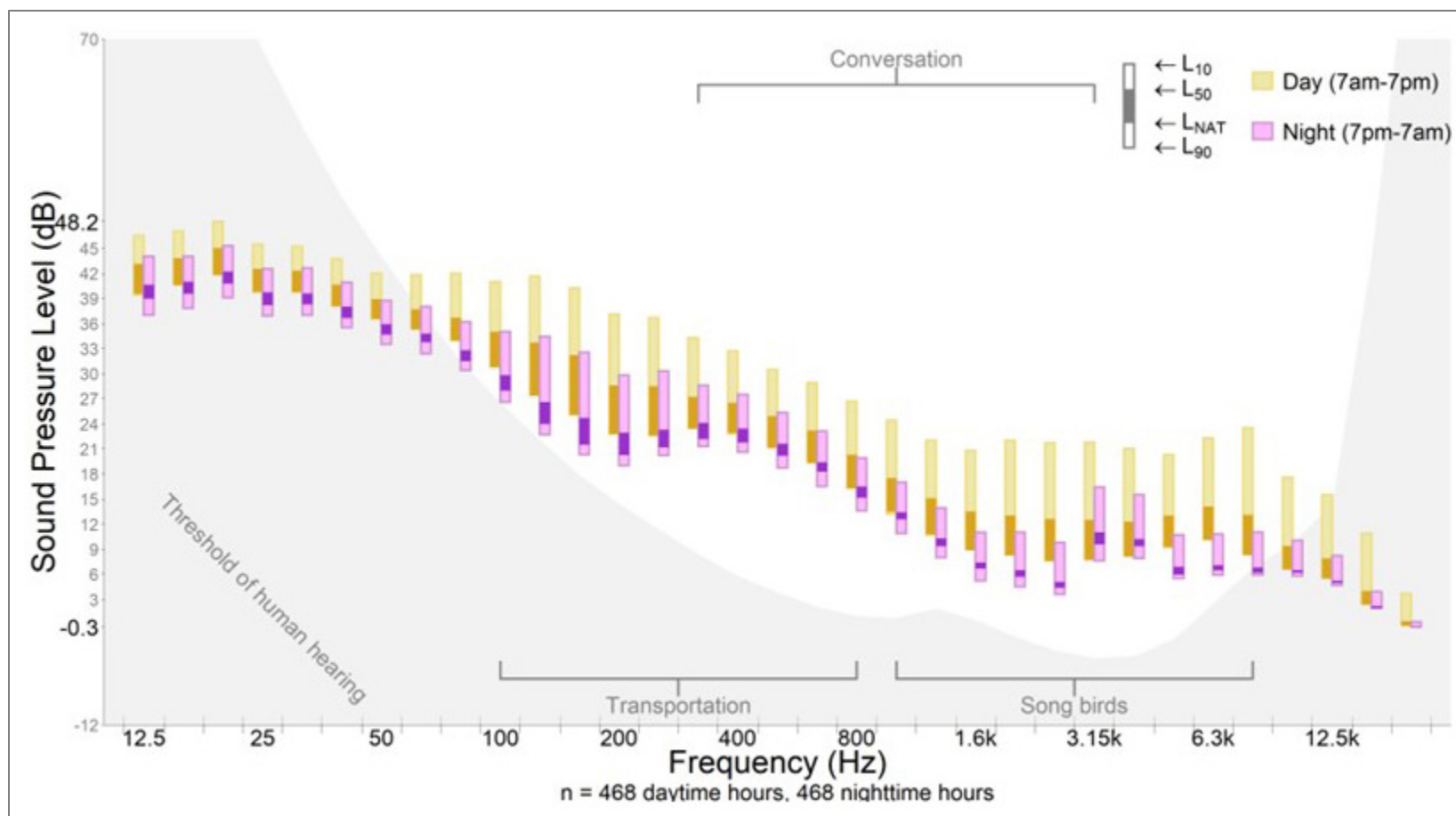


Figure 6. Day and night percentile sound pressure levels (unweighted) for 33 one-third octave bands at CUIS002, winter season.
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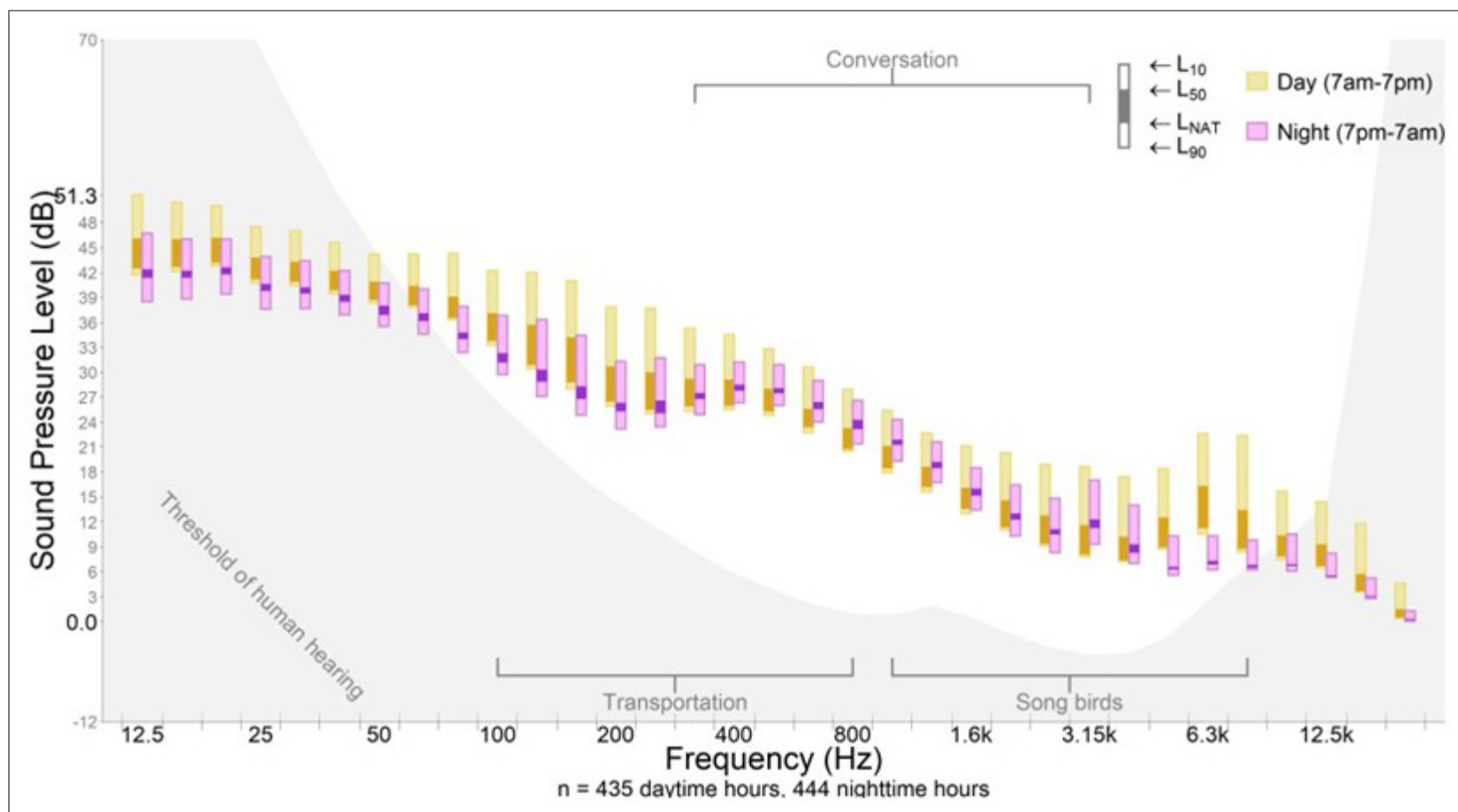


Figure 7. Day and night percentile sound pressure levels (unweighted) for 33 one-third octave bands at CUIS003, winter season.
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Sound Sources and Event Duration

Through off-site listening analysis at the Volpe Center, trained technicians identified audible sounds and calculated the percentage of time each sound is audible for each hour, over an 8-day listening period (a representative subset of the acoustic deployment) for each site/ season. A separate dataset representing the entire results—all identified sound sources, across all hours of the day—is published to the NPS DataStore (White 2025).

Sound source analysis shows that aircraft are the predominant source of noise at all sites, audible between 50 and 56% of the 24-hour day. Other, less frequent sources of audible noise include watercraft and road/trail vehicles. The mean 24-hour time audible of noise at CUIS001 was 54.2% during spring and 57.1% during winter. At CUIS002, noise was audible on average 52.6% of the time during spring and 57.8% during winter. At CUIS003, noise was audible on average 51.7% of the time during spring and 50.4% during winter. Common natural sound sources at all three sites within the park were birds, insects, animals foraging, and wind blowing through vegetation. Waves and surf from the nearby oceanfront could also be heard at times during high tide. On occasion, wild horses and hogs were audible during the day and night hours at all locations.

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 5 reports the percent of time that measured sound levels ($L_{Aeq,1s}$) were above four key functional values during the monitoring periods (daytime and nighttime). The top value in each split-cell uses the full frequency range, whereas the bottom values report the percent of time ANS-weighted sound levels (20–1,250 Hz) are above functional values. Most motorized human-caused noise is confined to the truncated, lower-frequency range, while many natural sounds, including insects and birds, are higher in pitch. ANS weighting eliminates high-frequency sound (leaf rustle, equipment noise, and biological sounds) allowing for more accurate comparisons of low-frequency ambient sound levels across different land use types (e.g. urban, protected areas; ANSI S3/SC1.100, 2014 [2020]). This frequency weighting scheme improves ambient sound level measurements in quiet environments.

The first functional effect in Table 5 occurs around 35 dB ($L_{Aeq,1s}$), which is used by the NPS as an indicator of overall quality of the acoustic environment. Beyond this level, noise begins to negatively affect the visitor experience in an otherwise natural acoustic environment (Pilcher et al., 2009; Watts et al., 2020; Betchkal et al., 2023). In this study, the 35 dB ($L_{Aeq,1s}$) effect level was exceeded the most at all three sites during the spring season (88.7–94.1%) at the full frequency range. In comparison the ANS levels ranged from 39.7–49.9%. This is likely due to the high biological activity the island experiences such as bird song. Spring is also expected to be higher in park visitation with low-frequency noise caused by vehicles and watercraft. Examining the ANS frequencies, the 35dB threshold is exceeded overall 20.9–49.9% of the time.

Table 5. Time above metrics for CUIS001, CUIS002 and CUIS003.

Site ID	Frequency Range (Hz)	Time Above Sound Level (% of Daytime Hours, 07:00–19:00)				Time Above Sound Level (% of Nighttime Hours, 19:00–07:00)			
		35 dB ^A	45 dB ^A	52 dB ^A	60 dB ^A	35 dB ^A	45 dB ^A	52 dB ^A	60 dB ^A
CUIS001 Spring	Full (12.5–20,000)	84.7	13.3	1.3	0.1	37.1	3.5	0.2	0.0
	ANS (20–1,250)	47.3	3.9	0.4	0.0	12.0	0.7	0.1	0.0
CUIS001 Winter	Full (12.5–20,000)	32.7	3.7	0.4	0.0	29.0	0.9	0.0	0.0
	ANS (20–1,250)	20.9	2.8	0.4	0.0	4.5	0.4	0.0	0.0
CUIS002 Spring	Full (12.5–20,000)	88.4	16.9	2.1	0.2	43.5	4.8	0.3	0.0
	ANS (20–1,250)	47.9	3.4	0.5	0.0	12.7	0.6	0.1	0.0
CUIS002 Winter	Full (12.5–20,000)	38.8	3.8	0.6	0.0	24.8	0.5	0.0	0.0
	ANS (20–1,250)	25.1	2.6	0.4	0.0	6.5	0.4	0.0	0.0
CUIS003 Spring	Full (12.5–20,000)	94.1	20.9	2.7	0.2	43.0	2.9	0.3	0.0
	ANS (20–1,250)	49.9	4.3	0.7	0.1	23.0	0.6	0.1	0.0
CUIS003 Winter	Full (12.5–20,000)	50.5	3.4	0.6	0.0	43.2	0.8	0.0	0.0
	ANS (20–1,250)	39.7	2.7	0.5	0.0	29.0	0.5	0.0	0.0

^A dB L_{Aeq}, 1s re: 20 µPa

The second functional effect is expected to occur around 45 dB ($L_{Aeq,1s}$). As wildlife begin to exhibit signs of disturbance at noise levels as low as 40 dB (Shannon et al. 2016), 45 dB represents a conservative estimate of negative effects on wildlife. Both seasons had a rare exceedance (less than 1% ANS) of this value during the night, where nocturnal behaviors would most likely be affected with less than 5% ANS during the day. The third value, 52 dB ($L_{Aeq, 1s}$), is based on the EPA's analysis of speech interference for an individual speaking in a raised voice to an audience at 10 meters (EPA 1974)—an acoustic level that would affect interpretive presentations in parks. The final value, 60 dB ($L_{Aeq, 1s}$), marks the point at which normal voice communications at 1 meter begin to be interrupted. Notably, less than 1% of sound pressure level data collected at CUIS during the sampling period reached these levels (52dB, 60dB ANS).

Sound Level: Percentile Levels

To understand the range of acoustic conditions at the park, percentile sound levels are reported. In Figure 8 and Figure 9 below, the A-weighted percentile sound levels (L_{A90} , L_{Anat} , L_{A50} , and L_{A10}) are shown for CUIS001, spring and winter seasons. Figure 10 and Figure 11 show these percentile sound levels at CUIS002, while Figure 12 and Figure 13 show these percentile sound levels at CUIS003. The hourly percentile sound levels are calculated from the broadband (12.5 Hz - 20 kHz) A-weighted, 1-second time averaged sound levels ($L_{Aeq, 1s}$) within each hour of the day. For instance, in Figure 8, the L_{A50} (median) sound level for CUIS001 during the 7:00 hour is 40.8 dB. On the other hand, the sound level exceeded 10% of the time (L_{A10}) for the same hour at this site is 46.5 dB, meaning 90% of the measurement period is quieter than this level. Hours where the L_{A50} and the L_{Anat} differ the most are usually hours with the most human-caused noise. If we cross reference supplemental data (White 2025) we see that aircraft were audible on average about 62.5% of this hour. The following bullets summarize a few additional points that can be gleaned from these figures.

- At CUIS001 during spring, the hours between 6 am and 10 pm are most affected by noise; hours between midnight and 5 am are least affected. Hourly L_{Anat} values range between 28.0 dBA (6 am) and 36.7 dBA (12 pm). Birds and wind dominated natural sounds during this peak hour. At CUIS001 during winter, results show the hours between 7 am and 10 pm most affected by noise. Hourly L_{Anat} values are lower in winter, ranging between 25.2 dBA (5 pm) and 30.9 dBA (1 am). Natural sounds during the peak hour are dominated by wind and insects.
- At CUIS002 during spring, the hours between 6 am and 10 pm are most affected by noise; hours between 11 pm and 5 am are least affected. Hourly L_{Anat} values range between 29.9 dBA (5 am) and 38.6 dBA (1 pm). Natural sounds during this peak 1 pm hour are dominated by wind and birds.
- During winter at CUIS002, results show the hours between 7 am and 11 pm are most affected by noise; hours between 12 am and 6 am are least affected. Hourly L_{Anat} values range between 25.8 dBA (5 pm) and 30.7 dBA (2 am). Natural sounds during this peak 2 am hour are dominated by wind and insects.
- At CUIS003 during spring, the hours between 6 am and 10 pm are most affected by noise; hours between 12 am and 5 am are least affected. Hourly L_{Anat} values range between 32.8

dBa (7 9m) and 38.7 dBA (1 pm). Natural sounds during this peak 1 pm hour are dominated by wind, insects and birds.

- During winter at CUIS003, results show the hours between 7 am and 11 pm are most affected by noise; hours between 12 am and 6 am are least affected. Hourly $L_{A_{nat}}$ values range between 30.6 dBA (10 am) and 35.2 dBA (7 pm). Natural sounds during this peak 10 am hour are dominated by wind and insects.

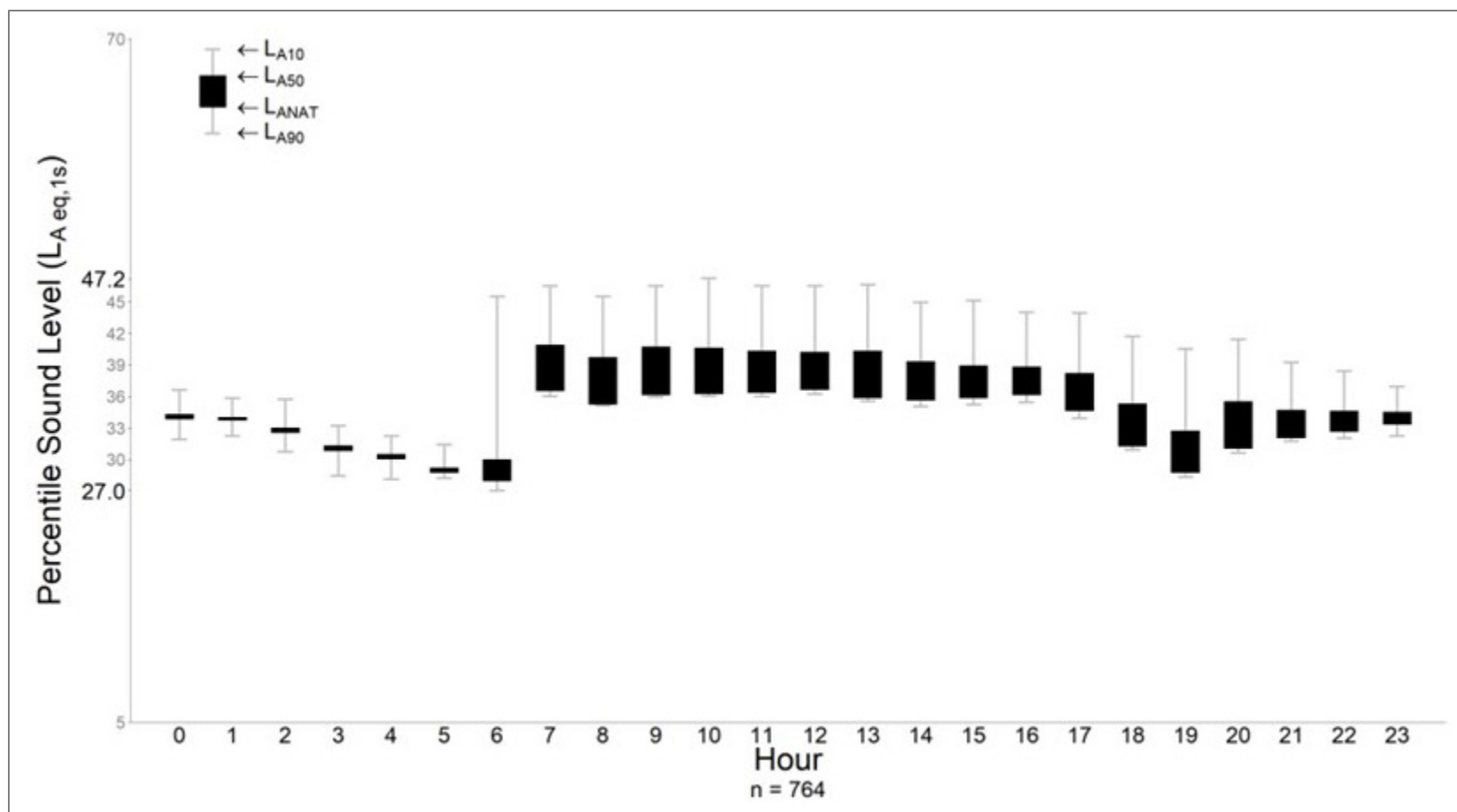


Figure 8. Median percentile sound levels ($L_{Aeq, 1s}$), in dB re 20 μ Pa, at CUIS001, spring season.

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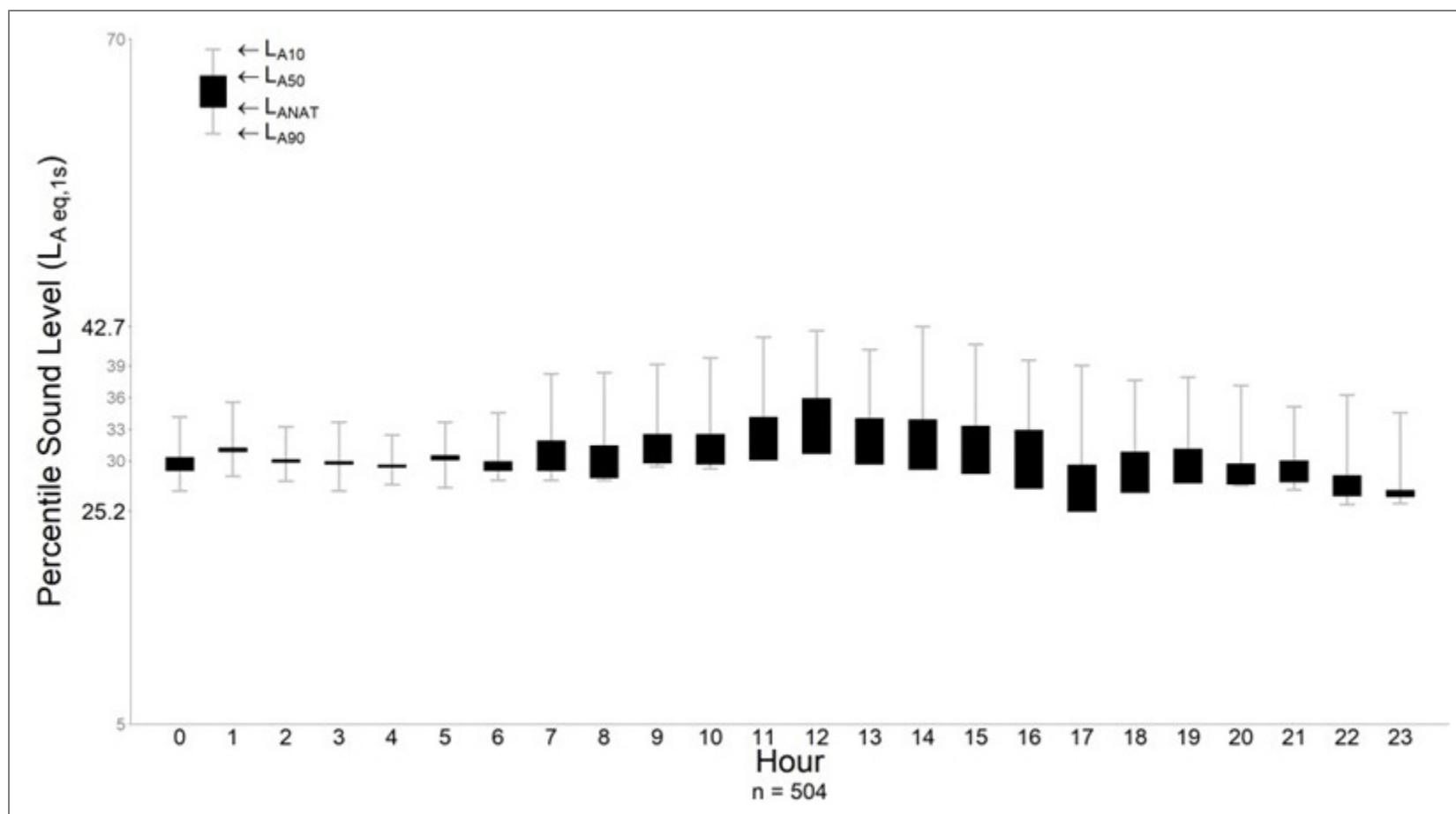


Figure 9. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at CUIS001, winter season.

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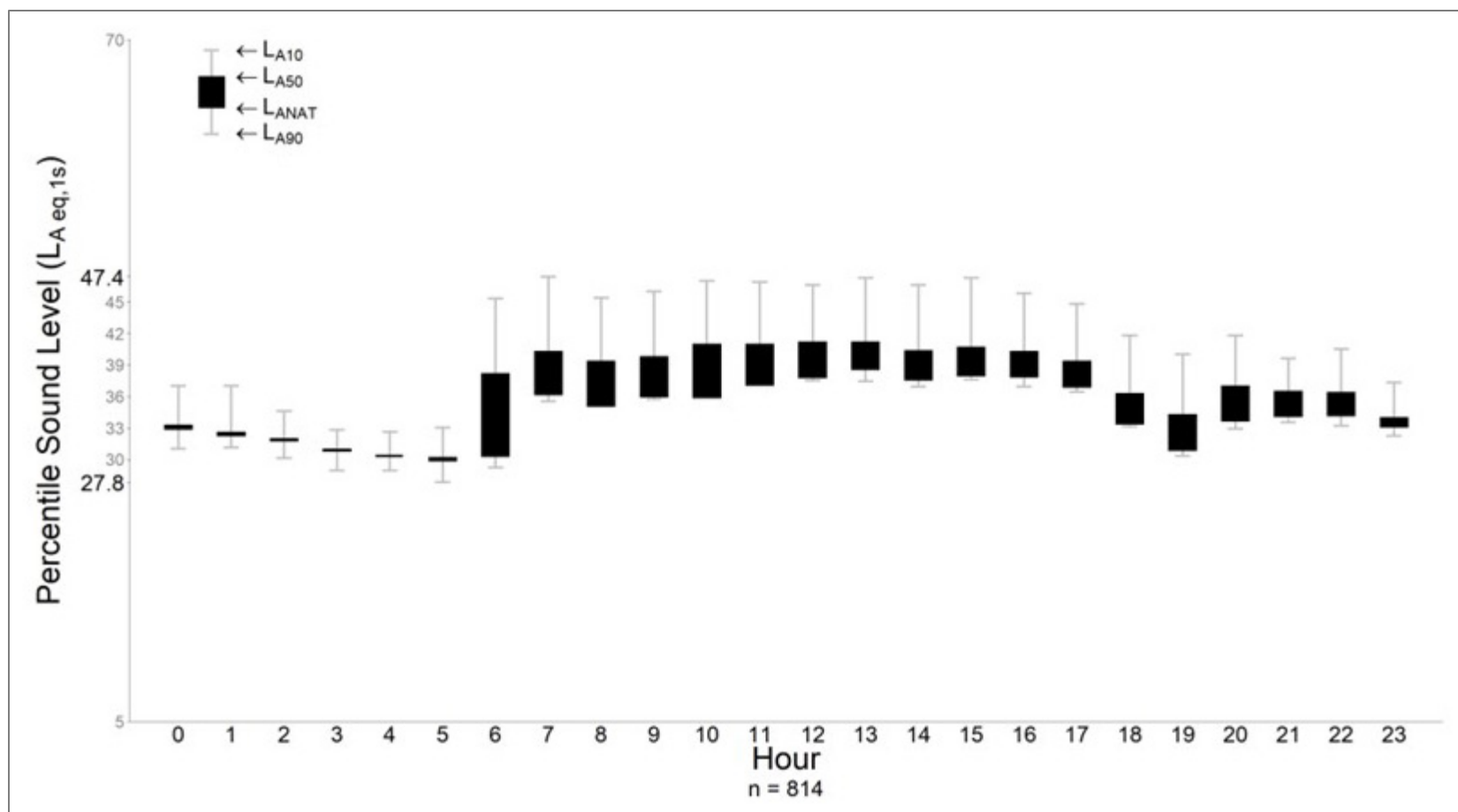


Figure 10. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at CUIS002, spring season.

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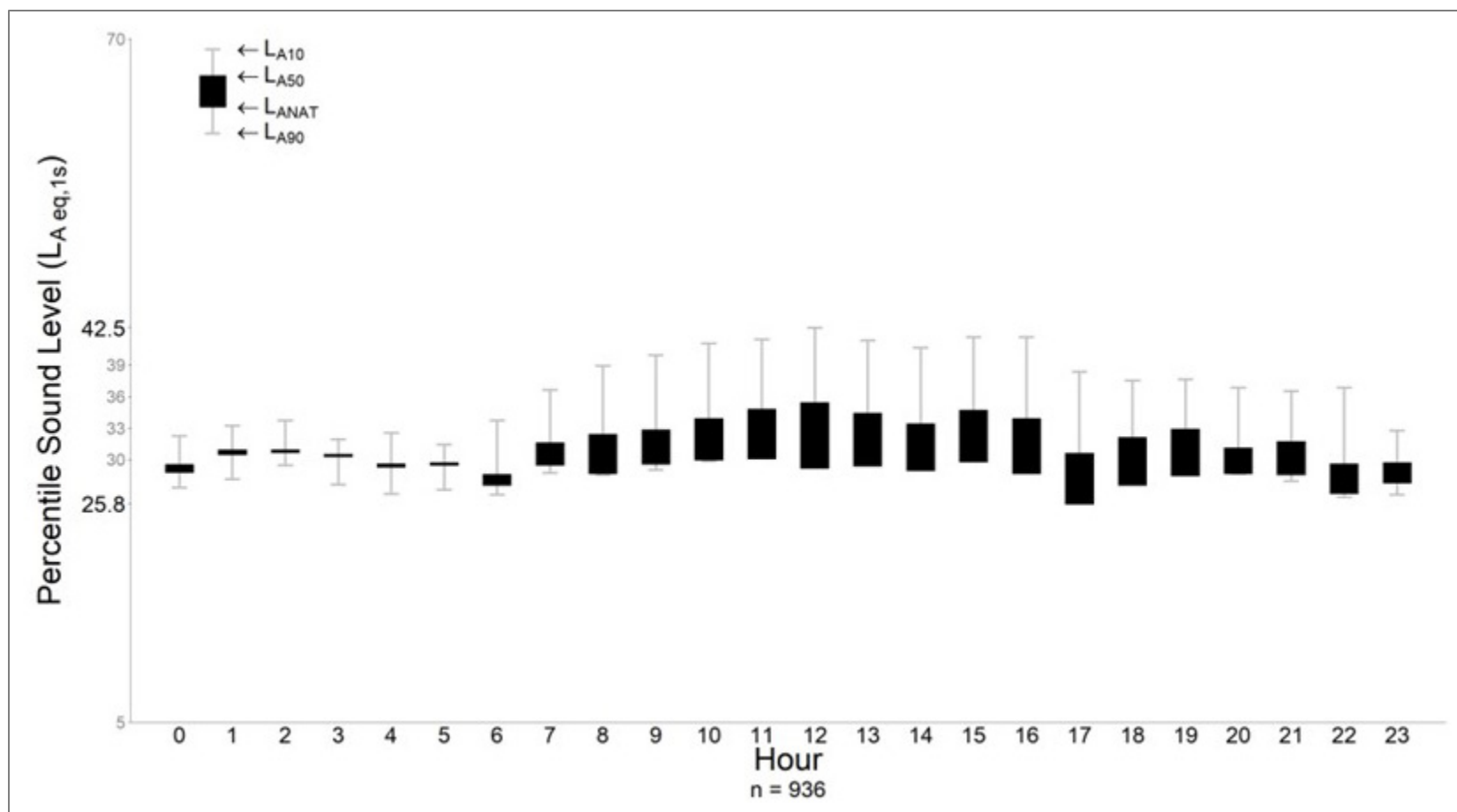


Figure 11. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at CUIS002, winter season.

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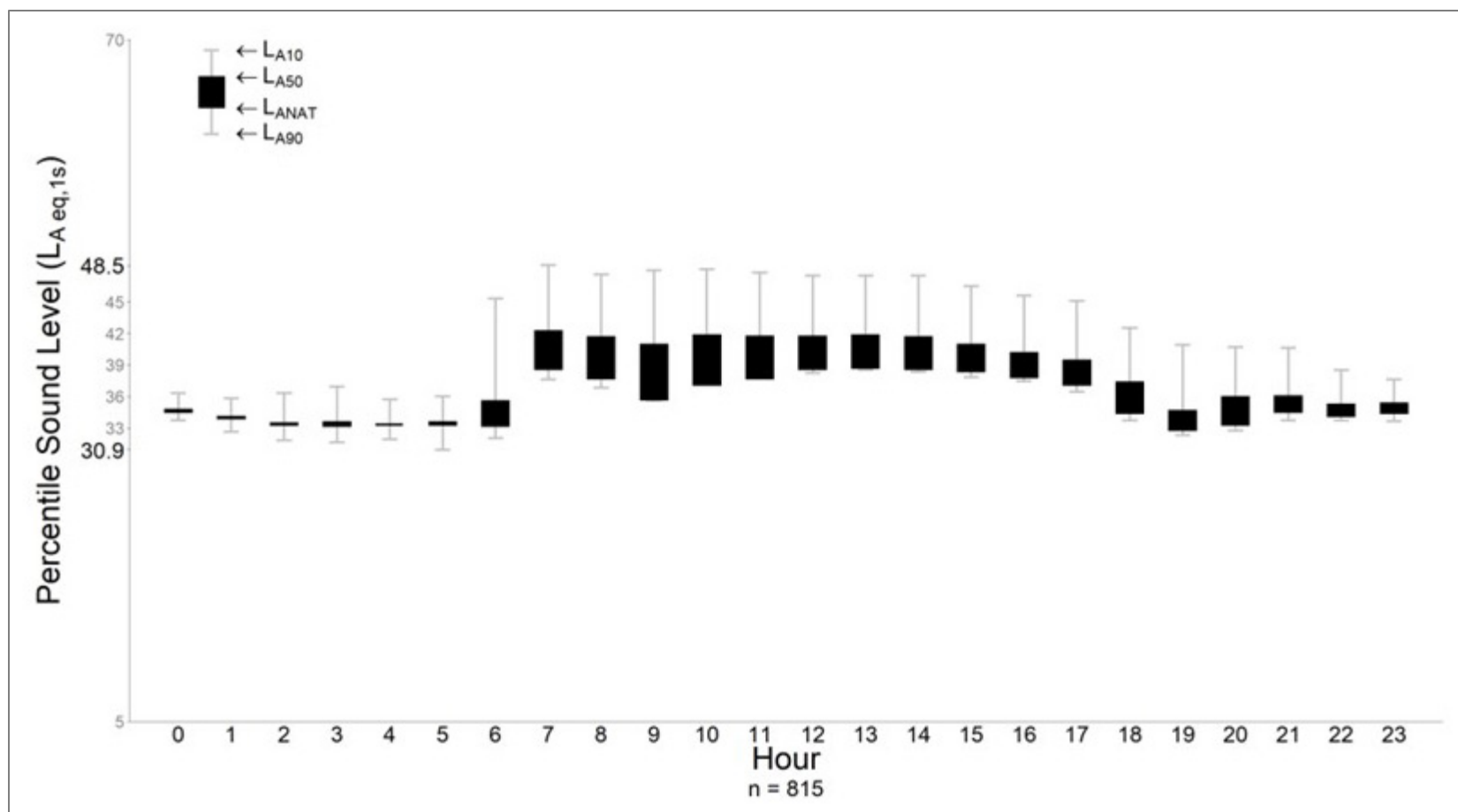


Figure 12. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at CUIS003, spring season.

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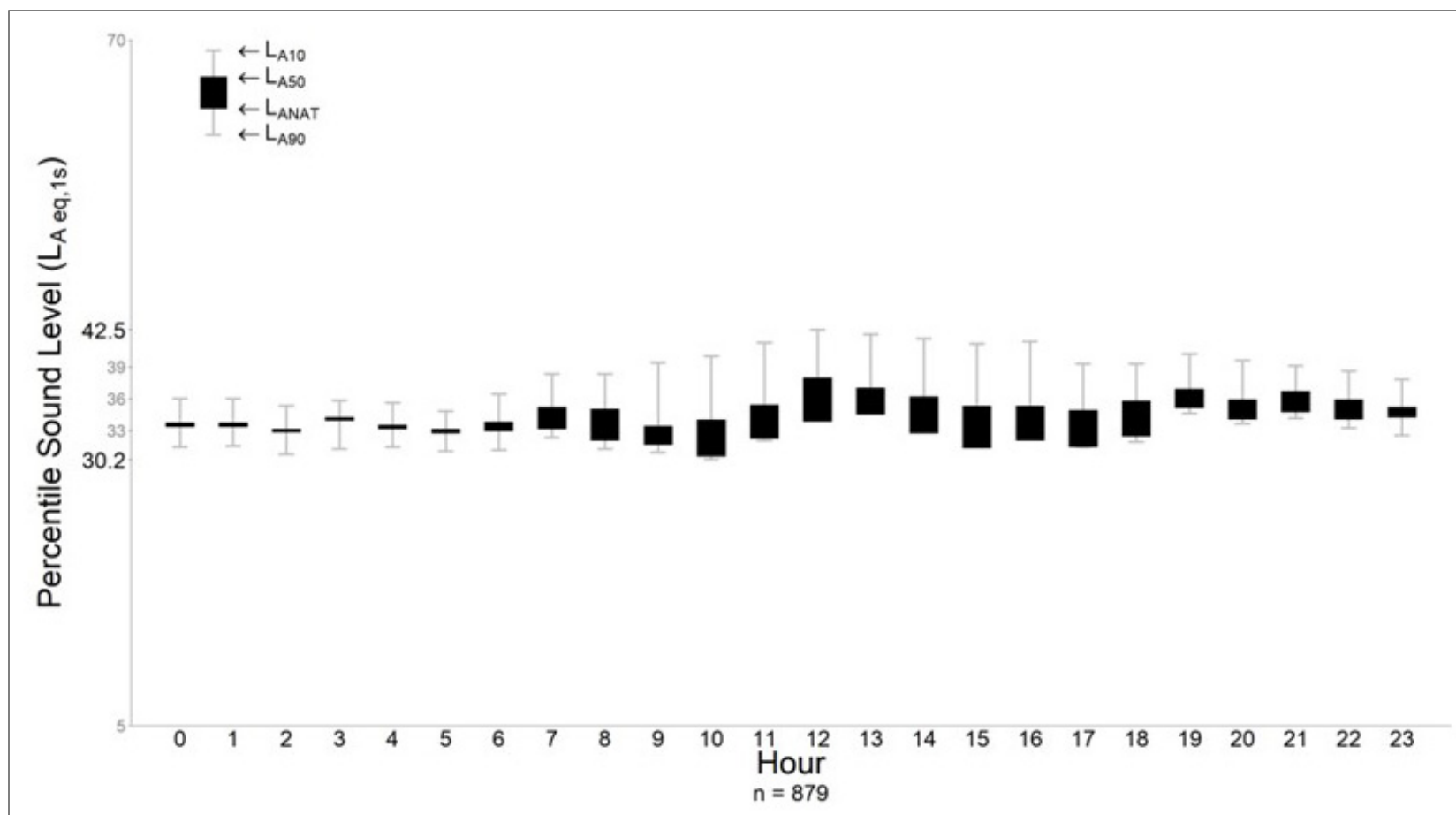


Figure 13. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at CUIS003, winter season.

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Conclusions

Acoustic measurements allow parks to gain insight into the acoustic environment of the park, including levels of extrinsic noise and biological activity. The results can help estimate the influence of noise on park visitors and wildlife, as well as the overall condition of the acoustic environment. The purpose of this study was to establish a baseline acoustic inventory of Cumberland Island National Seashore. Monitoring results include existing ambient sound levels, calculations of sound source audibility through off-site listening, and estimates of natural ambient levels, all of which are intended to provide the park with baseline information to inform management decisions. The site locations were chosen to assess the influence of noise on the acoustic environment at three backcountry locations.

Based on the results of this study, visitors and wildlife within CUIS will experience some exposure to anthropogenic noise—low-level, but consistent. Aircraft were audible over 50% of the days analyzed and the time above averages exceeded the 35dB threshold approximately 40% or higher each day. Noise has the potential to affect a visitor's experience in parks by causing annoyance (Rapoza et al. 2015), reducing the perceived scenic beauty (Weinzimmer et al. 2014), or simply by limiting opportunities for solitude. Increased sound levels may also have wide-ranging effects on wildlife such as reduced predatory success (Mason 2015), changes in vocal communication, or increased vigilance by keystone species (Shannon et al. 2014).

The results also suggest that CUIS has a rich soundscape, with the frequency analysis and event duration showing natural sounds (birds, insects, waves) dominating the soundscape through many hours. For example, birds have been analyzed at 100% of a given hour with many high occurrences through morning-day, while insects have been noted up to 96% of an hour at night.

The information presented in this report will be used to inform park managers and planners when they make management decisions and will also serve as a permanent record of what the park sounded like in 2022 and 2023. Sound level data as well as continuous digital audio recordings will be archived at the Natural Sounds and Night Skies Division office in Fort Collins, Colorado.

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