



Weir Farm National Historical Park

Acoustic Monitoring Report, 2022–2023



Acoustic monitoring at Weir Farm National Historical Park.
NPS / EMMA BROWN

Weir Farm National Historical Park: Acoustic monitoring report, 2022–2023

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Abstract

In 2021, the Natural Sounds and Night Skies Division (NSNSD) received a technical assistance request ([17694](#)) to collect baseline acoustical data at Weir Farm National Historical Park (WEFA) to develop appropriate measures for desired soundscape conditions. From March to April 2022, two acoustical monitoring systems were deployed at two study sites in the park, WEFA001 (Pond Trail) on the east side of Nod Hill Road, just off the Pond Trail, and WEFA002 (Meadow), on the west side of Nod Hill Road, in the Burlingham complex, on the border of the Weir Preserve. Equipment was also deployed from October to November of 2023 at the same locations. Combined, these two seasons of acoustic measurements provide park managers with baseline information about the acoustic environment, including existing ambient sound levels, time-above noise level metrics in the park, and audibility of a variety of sound sources. Vehicles and aircraft were the most frequently heard noise sources at both sites during both spring and fall measurement periods. However, there were a variety of noise sources present in the acoustic environment and there were hours of the day when these two sources contributed less than 50% of noise audibility. Grounds care (both from WEFA and surrounding private parcels), and trains were the next most prevalent noise sources. The springtime measurement period captured a highly active amphibian chorus (including Wood Frog *Rana sylvatica*, and Spring Peeper *Pseudacris crucifer*). Overall, across all sites and seasons, existing median ambient sound levels (L_{A50}) ranged from 38.2 dB – 40.9 dB during the daytime and 32.0 – 48.8 dB during the nighttime. When sound levels exceed 52 dBA, and if a speaker and audience are far apart, as they often are during interpretive programs (approx. 10 meters), speech interference begins to occur (EPA 1974). Over the two measurement periods, during the daytime, hourly L_{Aeq} sound levels exceeded this level less than 5.5% of the time.

List of Terms or Acronyms

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 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 [R2020]). 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 μ Pa. The logarithmic scale is a useful way to express the wide range of sound pressures perceived by the human ear. Every 10 dB increase represents a tenfold increase in energy. Therefore, a 20 dB increase represents a hundredfold increase in energy.

Existing ambient sound level (LA50): 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.

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}): 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 during which no human-caused sounds are audible.

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

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

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

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

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

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

Soundscape: The human perception of physical sound resources.

Executive Summary

This report presents acoustic data gathered by the Natural Sounds and Night Skies Division (NSNSD) at Weir Farm National Historical Park (WEFA, WEFA NHP) from March to April 2022 and October to November 2023. Data were collected at two sites (WEFA001 and WEFA002; Figure 1), with the goal of developing appropriate measures for desired soundscape conditions and understanding how often noise sources of interest (specifically aircraft and vehicles) are audible. WEFA001 (Pond Trail) was located on the east side of Nod Hill Road, just off the Pond Trail, and WEFA002 (Meadow), was located on the west side of Nod Hill Road, in the Burlingham complex, on the border of the Weir Preserve. For each of 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 was deployed to collect audio recordings to assist in sound source identification.

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 3 m	10
Leaves rustling (CANY)	Whispering	20
Crickets at 5 m (ZION)	Residential area at night	40
Conversation at 5 m (WHMI)	Car at 15 m, 30 mph	60
Cruiser motorcycle at 15 m (BLRI)	Curbside of busy street	80
Thunder (ARCH)	Jackhammer at 2 m	100
Military jet at 100 m 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 and Table 3 report 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 the level at which sleep can be interrupted. According to a study of night-time noise exposure, sound events as low as 35 dB can have adverse effects on blood pressure in sleeping humans (Haralabidis *et al.* 2008). This level, 35

dB, is also the desired maximum background sound level in classrooms (ANSI S12.60-2002 [R2012]). The second value addresses the World Health Organization's recommendations that noise levels inside bedrooms remain below 45 dB ($L_{Aeq, 1s}$) (Berglund et al. 1999). The third value, 52 dB ($L_{Aeq, 1s}$), is based on the EPA's 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 the types of interpretive presentations that occur in the park. During the sampling period at WEFA, sound levels exceeding 52 dB ($L_{Aeq, 1s}$) occurred no more than 5.5% of the time during the day and more often closer to 3% of the time. 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. Notably, less than 0.5% of daytime hourly L_{Aeq} sound levels measured at WEFA during the sampling periods reached this level.

Sound levels are often measured over narrow frequency bands (typically in one-third octave bands between 12.5 Hz – 20 kHz) because these smaller bands closely represent how humans distinguish between frequencies of sound. In this study, we examine how often sound levels exceeded the key values mentioned above in two frequency ranges. The top value in each split-cell of Tables 2 and 3 uses the full frequency range (12.5 Hz – 20 kHz) collected, whereas the bottom value focuses on frequencies affected by low frequency noise sources (20 – 1,250 Hz). 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 during the springtime measurement at WEFA001 91.01% of the time during the day and 85.85% of the time at night during the sampling period. In the 20 – 1,250 Hz range, the 35 dB functional sound level value was exceeded 71.01% of the time during the day and 25.87% of the time at night.

Overall, existing ambient sound levels (L_{A50}) at WEFA001 were 40.0 dB during the day and 48.8 dB at night during the springtime sampling period (Table 4). Oftentimes, nighttime sound levels are quieter than daytime. The reverse is true for this site, due largely to contributions from the amphibian chorus (including Wood Frog *Rana sylvatica*, and Spring Peeper *Pseudacris crucifer*). At WEFA002 during the spring, existing ambient sound levels (L_{A50}) were 38.2 dB during the day and 38.7 dB at night during the sampling period (Table 4). At both sites, nighttime sound levels were higher than daytime sound levels in the spring. However, the reverse was true during the fall season (Table 5). At WEFA001, existing ambient sound levels (L_{A50}) were 40.9 dB during the day and 34.2 dB at night, and at WEFA002 existing ambient sound levels (L_{A50}) were 40.2 dB during the day and 32.0 dB at night.

Table 2. Percent time above metrics for two Weir Farm NHP sites in the spring season.

Site ID	Frequency Range	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 ^A	45 dB ^A	52 dB ^A	60 dB ^A	35 dB ^A	45 dB ^A	52 dB ^A	60 dB ^A
WEFA001	Full (12.5 – 20,000 Hz)	91.01	20.62	3.25	0.21	85.85	56.80	35.60	11.44
	ANS (20 – 1,250 Hz) ^B	71.01	7.69	1.01	0.08	25.87	4.95	0.32	0.01
WEFA002	Full (12.5 – 20,000 Hz)	78.38	14.42	1.90	0.10	59.95	25.23	15.37	0.80
	ANS (20 – 1,250 Hz) ^B	66.80	5.90	0.73	0.06	20.70	1.86	0.19	0.00

^A dB L_{Aeq, 1s} re 20 µPa

^B The percent of time ANS-weighted sound levels (20 – 1,250 Hz) are above functional values.

Table 3. Percent time above metrics for two Weir Farm NHP sites in the fall season.

Site ID	Frequency Range	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 ^A	45 dB ^A	52 dB ^A	60 dB ^A	35 dB ^A	45 dB ^A	52 dB ^A	60 dB ^A
WEFA001	Full (12.5 – 20,000 Hz)	93.57	27.51	5.38	0.17	45.88	2.62	0.30	0.02
	ANS (20 – 1,250 Hz) ^B	76.04	13.61	1.34	0.10	15.81	1.23	0.20	0.01
WEFA002	Full (12.5 – 20,000 Hz)	89.53	19.95	1.94	0.13	38.28	2.64	0.29	0.01
	ANS (20 – 1,250 Hz) ^B	73.63	7.53	0.95	0.08	12.62	1.08	0.16	0.00

^A dB L_{Aeq, 1s} re 20 µPa

^B The percent of time ANS-weighted sound levels (20 – 1,250 Hz) are above functional values.

Table 4. Summary of spring noise sources and sound levels at two Weir Farm NHP sites. Included for each site are a) mean percent time audible for all human-caused noise, including the top three known noise sources, and b) existing (L_{A50}) and natural (L_{Anat}) ambient sound levels (dB re 20 μ Pa, A-weighted broadband, 12.5 Hz – 20 kHz) during the day (07:00–19:00) and night (19:00–07:00). The difference between the natural and existing ambient sound levels indicates the deviation from the natural condition.

Site ID	Site Description	Season	Mean Time Audible for Noise (% of 24-hour Time Period)				Median Existing Ambient (L_{A50}) in dB		Median Natural Ambient (L_{Anat}) in dB	
			All Noise	Aircraft	Motors	Vehicle	Day	Night	Day	Night
WEFA001	Pond Trail	Spring	83.2	28.3	5.7	47.7	40.0	48.8	35.3	39.7
WEFA002	Meadow	Spring	86.5	32.1	17.9	50.8	38.2	38.7	32.9	31.9

Table 5. Summary of fall noise sources and sound levels at two Weir Farm NHP sites. Included for each site are a) mean percent time audible for all human-caused noise, including the top three known noise sources, and b) existing (L_{A50}) and natural (L_{Anat}) ambient sound levels (dB re 20 μ Pa, A-weighted broadband, 12.5 Hz – 20 kHz) during the day (07:00–19:00) and night (19:00–07:00). The difference between the natural and existing ambient sound levels indicates the deviation from the natural condition.

Site ID	Site Description	Season	Mean Time Audible for Noise (% of 24-hour Time Period)				Median Existing Ambient (L_{A50}) in dB		Median Natural Ambient (L_{Anat}) in dB	
			All Noise	Aircraft	Motors	Vehicle	Day	Night	Day	Night
WEFA001	Pond Trail	Fall	67.4	21.8	19.3	22.3	40.9	34.2	37.8	31.9
WEFA002	Meadow	Fall	68.0	25.4	9.6	25.8	40.2	32.0	36.8	29.7

Sound source analysis revealed that road-based vehicles and aircraft were primary sources of noise at WEFA. Additionally, in spring, motor sounds, and in fall, a non-natural unknown sound was often audible. These events were identified by technicians as being distinctly non-natural, but their source could not be identified more precisely for a variety of reasons including signal strength and the presence of other masking sounds. Other sources of identifiable noise that occurred with relative frequency included grounds care and train sounds (rumble and train horns). Natural sound sources such as birdsong, amphibian and insect choruses, rain, and leaves rustling in the wind were also present in abundance.

Acknowledgments

Emma Brown gathered acoustic data for this report. Special thanks to WEFA personnel, especially Superintendent Linda Cook, and volunteer coordinators Bridget Craig and Laurel McKenzie for on-site logistical assistance. Thank you also to technicians at Colorado State University's Listening Lab for analyzing the spring dataset, as well as technicians at the Protected Areas Research Collaborative (PARC) Lab at Penn State for analyzing the fall dataset.

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

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

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

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

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

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

Further guidance is provided in 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 2006).

Director’s Order 47, Soundscape Preservation and Noise Management (2000), builds on the principles set out in Management Policies, directing park management on 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 covers results from a two-season acoustic inventory conducted from March to April 2022 and October to November 2023. Two acoustical monitoring systems were deployed at two study sites in the park, WEFA001 (Pond Trail) on the east side of Nod Hill Road just off the Pond Trail, and WEFA002 (Meadow) on the west side of Nod Hill Road in the Burlingham complex on the border of the Weir Preserve (Table 6; Figure 1; Appendix A).

Table 6. Metadata for acoustic monitoring at Weir Farm National Historical Park, spring 2022 and fall 2023.

Site	Site Name	Dates	Vegetation	Elevation (m)	Latitude	Longitude
WEFA001	Pond Trail	• 03/15/2022–04/14/2022 • 10/10/2023–11/13/2023	Wetlands	104	41.257556	-73.454632
WEFA002	Meadow	• 03/15/2022–04/14/2022 • 10/10/2023–11/13/2023	Temperate grasslands	197	41.255669	-73.458048

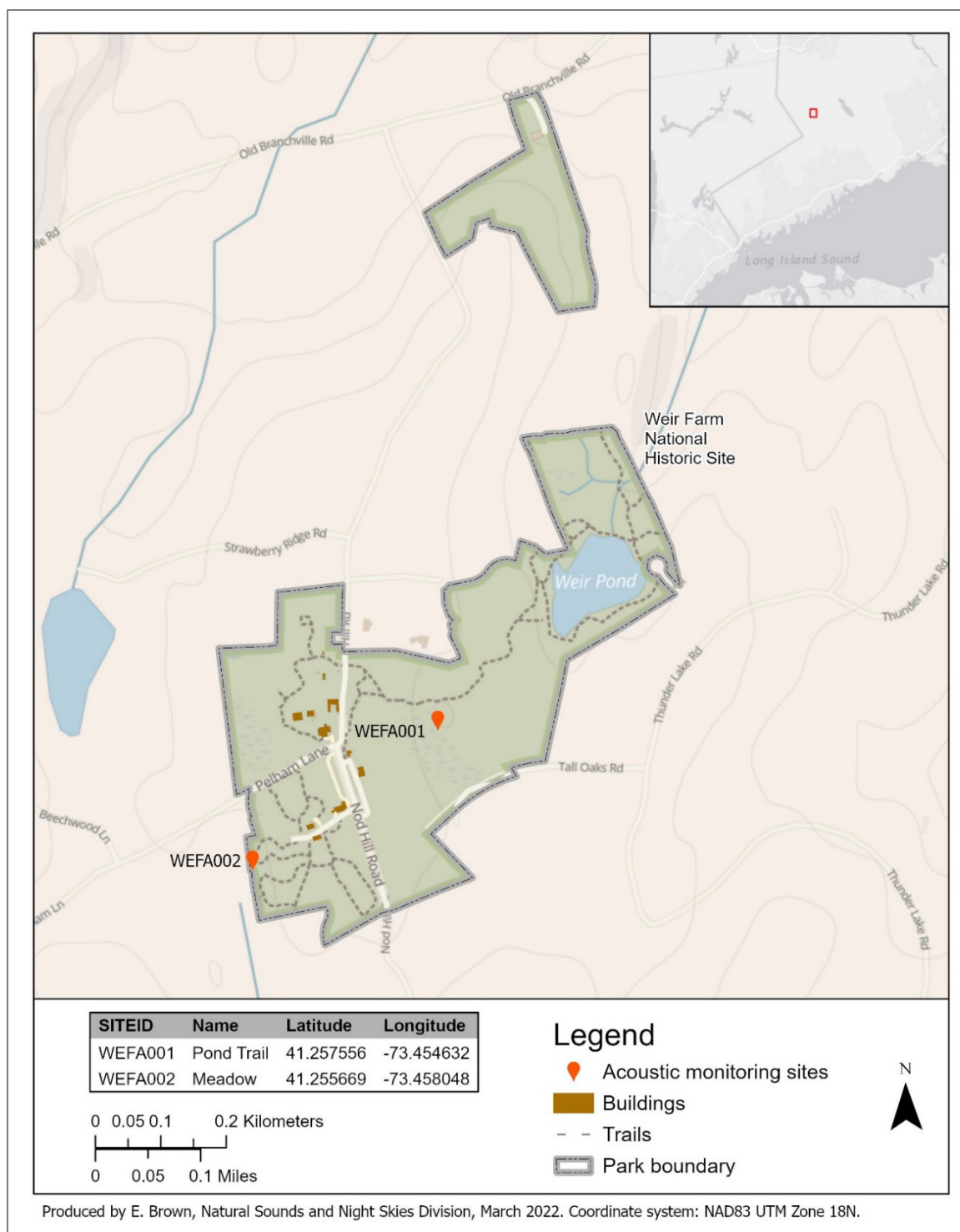


Figure 1. Study sites at Weir Farm National Historical Park, Connecticut, USA.
NPS / NATURAL SOUNDS AND NIGHT SKIES DIVISION

Methods

Automatic Monitoring

A Larson Davis sound level meter (SLM) type 831-A was deployed at each 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 [R2020], 1983 [R2006], 1992 [2018]) for accurate survey-grade instrumentation. The sound level meters provided the information needed to calculate metrics described below in Calculation of Metrics.

Acoustic monitoring equipment is used by many practitioners to determine noise levels in different environments, both indoors and outdoors. The NPS uses equipment like that used by other practitioners but has developed a unique configuration that withstands the potentially harsh environment encountered in national parks (National Park Service 2013). The microphone with environmental shroud was set up on a tripod at 1.5 m above the ground, which approximates the average height of the human ear. The digital audio recorder (SM Mini, Wildlife Acoustics, Maynard, MA, USA) recorded continuous audio throughout the entire monitoring period (see details below on the acoustic record). An anemometer was attached to a tripod and placed approximately 10 feet from the microphone to capture local wind conditions.

The 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)
6. Digital audio recorder

The sampling station was designed to collect:

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 – 20,000 Hz]) in dB re 20 μ Pa [collected by Type 1 sound level meter].
3. Continuous meteorological data for wind speed [collected by anemometer].
4. Continuous digital audio recordings [.wav file format, hourly files].

Monitoring Period

To ensure that the data set accounts for daily differences and represents the typical range of conditions at a site, acoustic monitoring studies typically monitor a minimum of 25 days (NPS 2005).

Calculation of Metrics

The status of the acoustic environment can be characterized by sound level metrics (L_{A50} , L_{Anat} , L_{A90} , L_{A10} , L_{Aeq}) frequency content, and sound source audibility (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 percent of the time. The L_{A50} represents the median sound level and is drawn from a full dataset (removing data with wind speed > 5 m/s to eliminate error from microphone artifacts). 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.

Audibility Analysis

Trained technicians listen to a sample set of audio recordings to identify noise sources and calculate how often noise sources were audible. Off-site listening is normally done by listening to an audio recording and simultaneously visually analyzing a spectrogram. Auditory analysis was used to calculate the audibility of sound sources at the monitoring locations. Technicians at Colorado State University's Listening Lab analyzed the spring dataset and technicians in the Protected Areas Research Collaborative (PARC) Lab at Penn State analyzed the fall dataset. In all cases, listeners reviewed a subset of digital audio samples (10 seconds every two minutes for eight days of audio for both sites) in order to identify durations of audible sound sources. Bose QuietComfort Noise Canceling headphones were used for off-site audio playback to minimize limitations imposed by the office acoustical environment. Staff used the total percent time noise was audible to calculate the natural ambient sound level for each hour. L_{Anat} is calculated as 100 minus the percentage of samples containing noise for a given hour, divided by two, plus the percentage of samples containing noise for that same hour. For the complete results of this thorough audibility analysis, see the Event duration section below, and associated documents in the NPS DataStore record.

Results

Frequency Content

To determine the effect 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 narrow bands closely represent how humans distinguish between frequencies of sound. The percentile sound levels for 33 one-third octave band frequencies over the day and night periods are shown in Figures 2 through 5.

Examining the sound energy in each one-third octave band (usually, in combination with digital audio recordings) allows acoustic technicians to determine which types of sounds are contributing to the overall sound levels at a site. The grayed areas of Figures 2 through 5 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 during 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 horizontal line within the column represents the L_{50} . 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.

Sound pressure level measurements can also be displayed as spectrograms, which visualize sound pressure energy across 1/3 octave frequencies over time. Typically, these spectrograms can be annotated to determine the number and duration of sound events such as jet overflights or vehicle traffic during a sampling period (Figure 6).

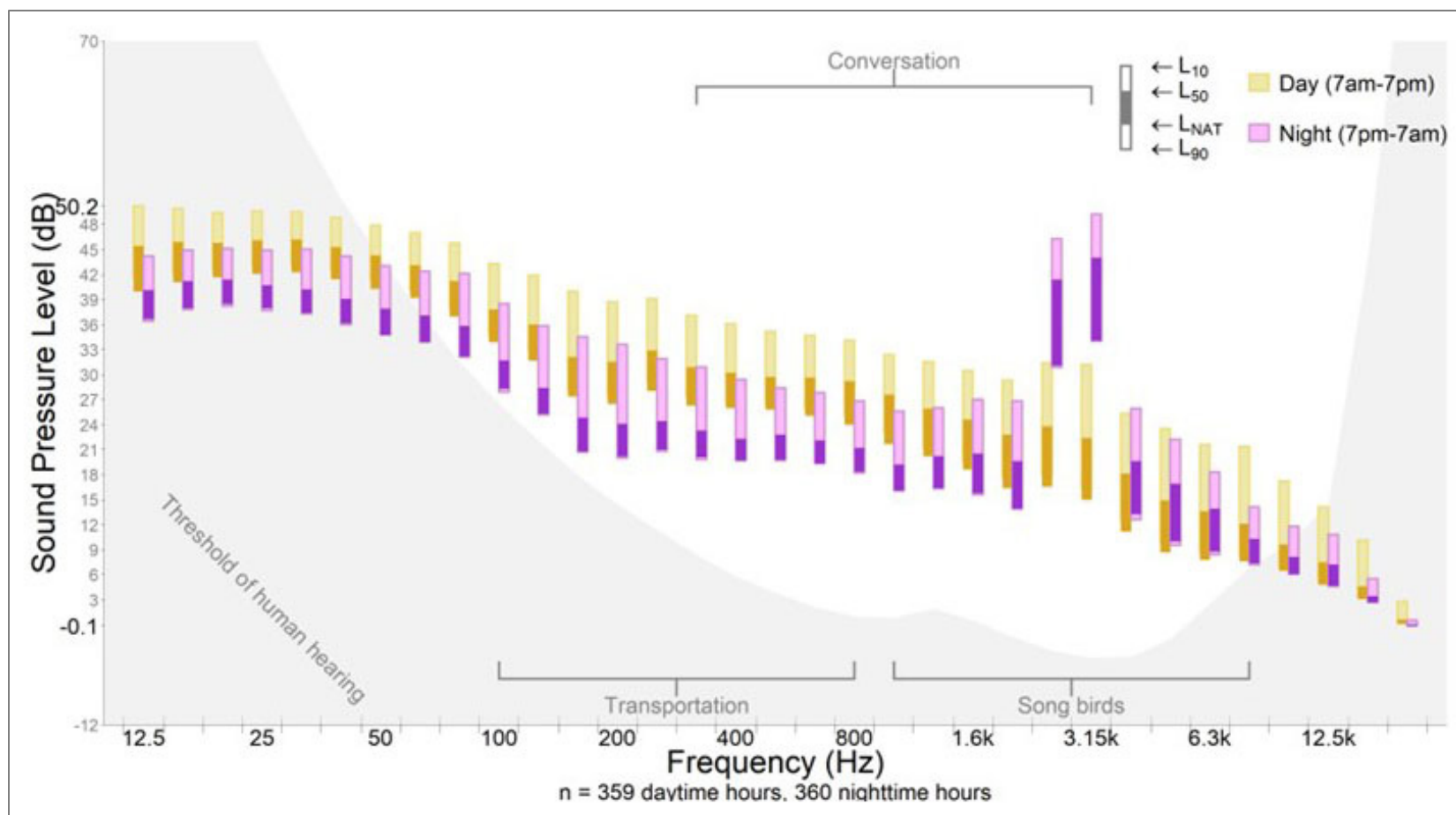


Figure 2. Day and night percentile sound pressure levels for 33 one-third octave bands at WEFA001 from March to April 2022. For each bar, the bold horizontal line indicates the existing (L₅₀) sound pressure levels. Sound levels depicted are not A-weighted.

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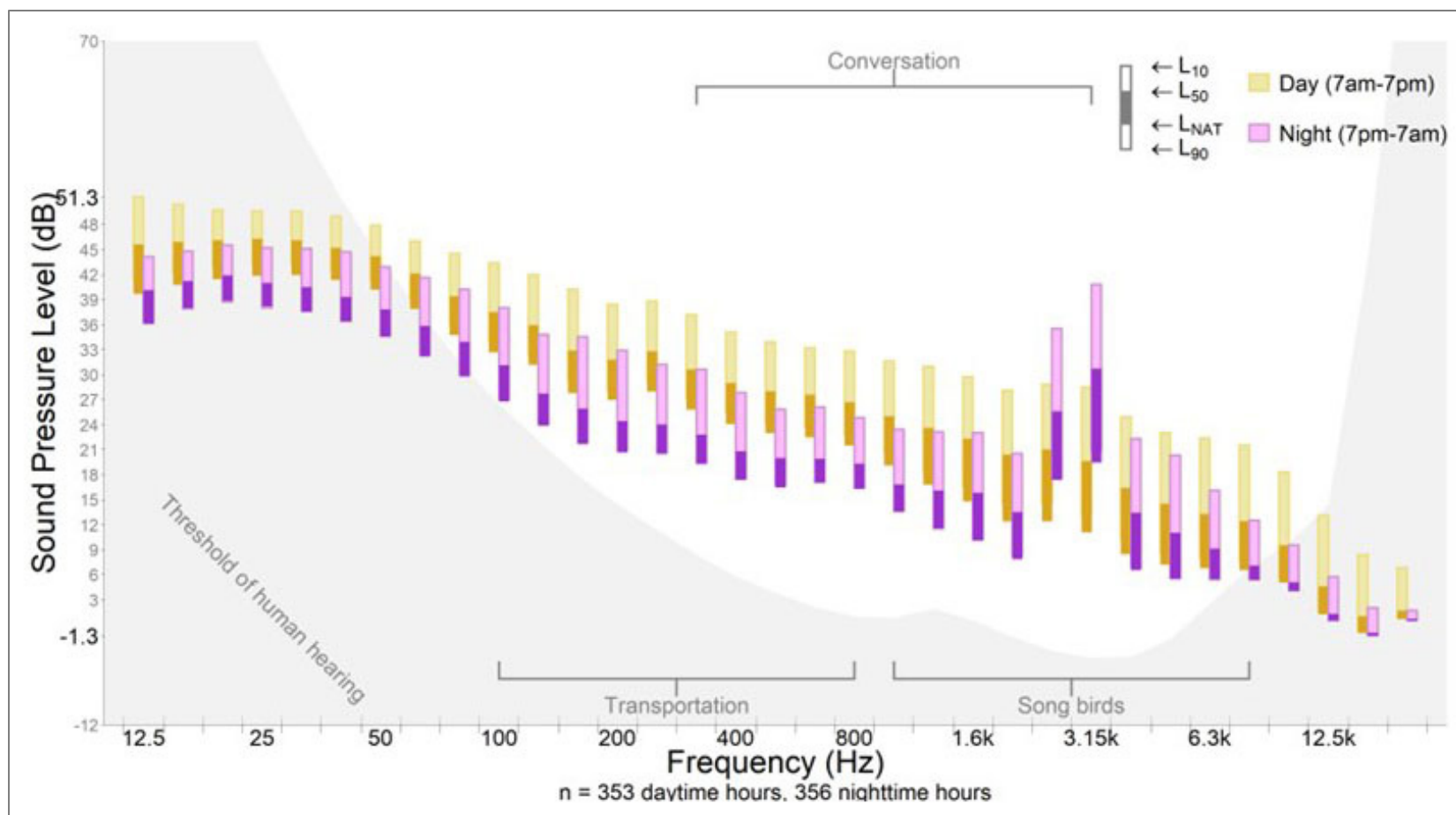


Figure 3. Day and night percentile sound pressure levels for 33 one-third octave bands at WEFA002 from March to April 2022. For each bar, the bold horizontal line indicates the existing (L₅₀) sound pressure levels. Sound levels depicted are not A-weighted.

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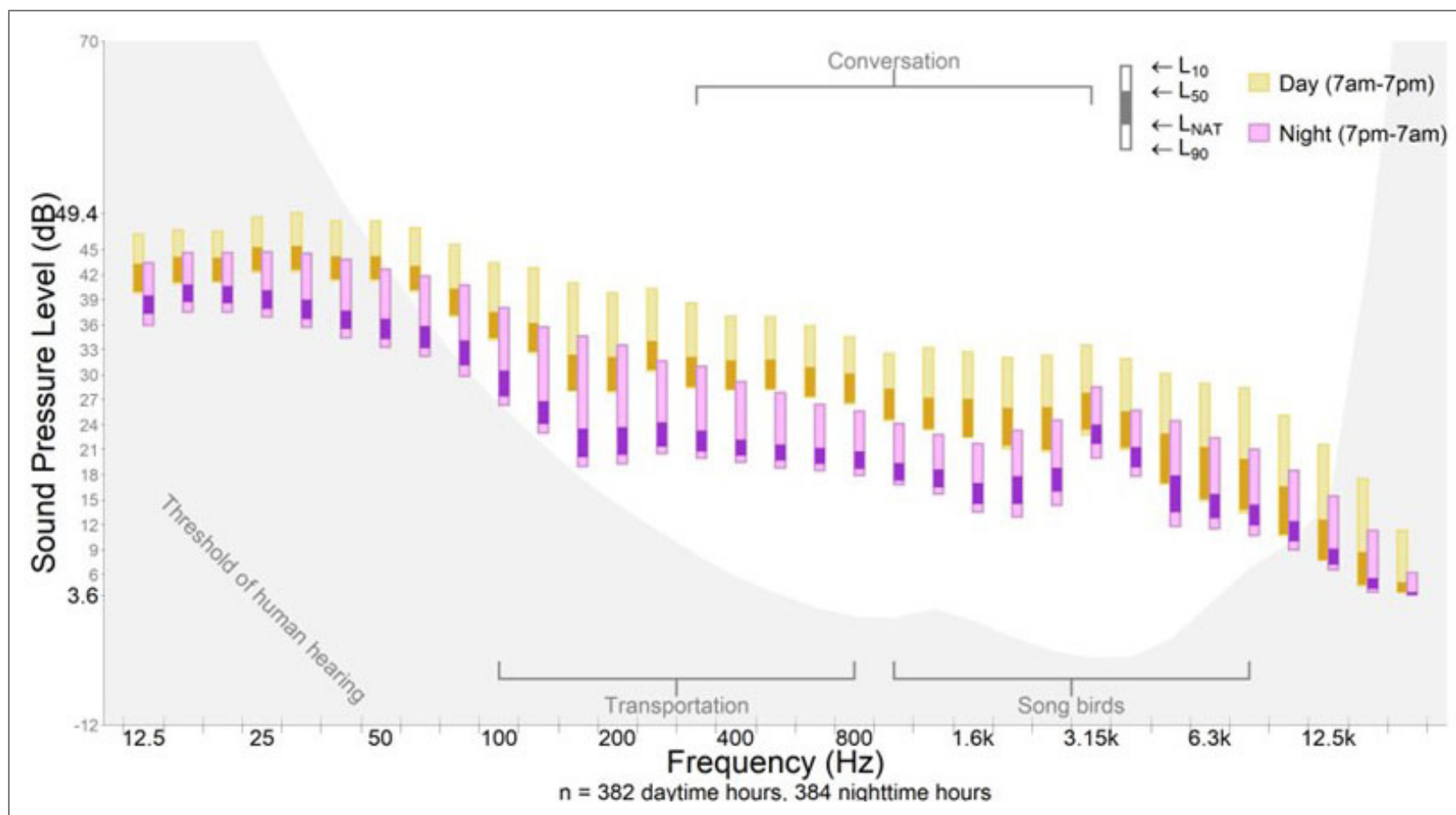


Figure 4. Day and night percentile sound pressure levels for 33 one-third octave bands at WEFA001 from October to November 2023. For each bar, the bold horizontal line indicates the existing (L₅₀) sound pressure levels. Sound levels depicted are not A-weighted.

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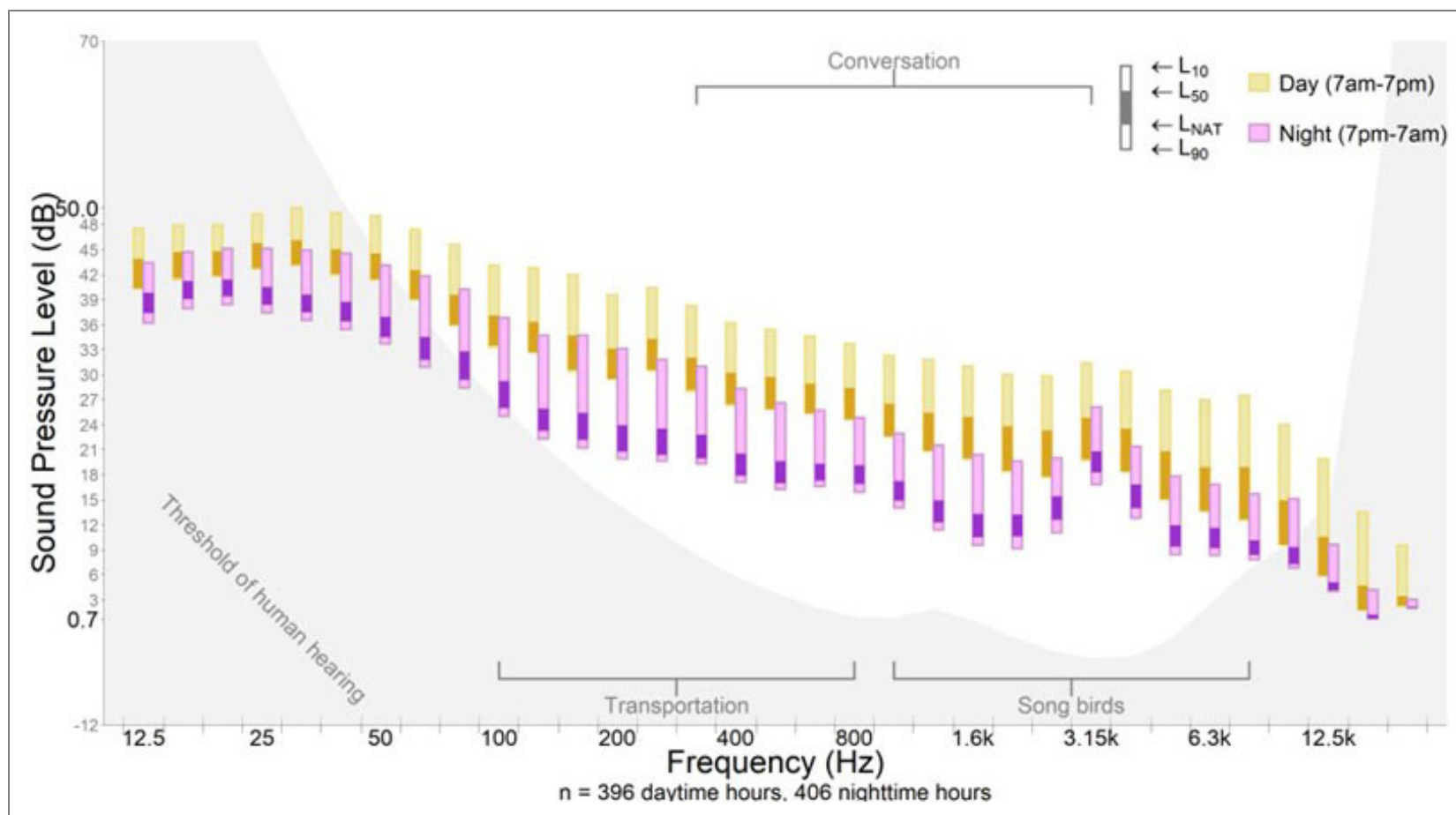


Figure 5. Day and night percentile sound pressure levels for 33 one-third octave bands at WEFA002 from October to November 2023. For each bar, the bold horizontal line indicates the existing (L_{50}) sound pressure levels. Sound levels depicted are not A-weighted.

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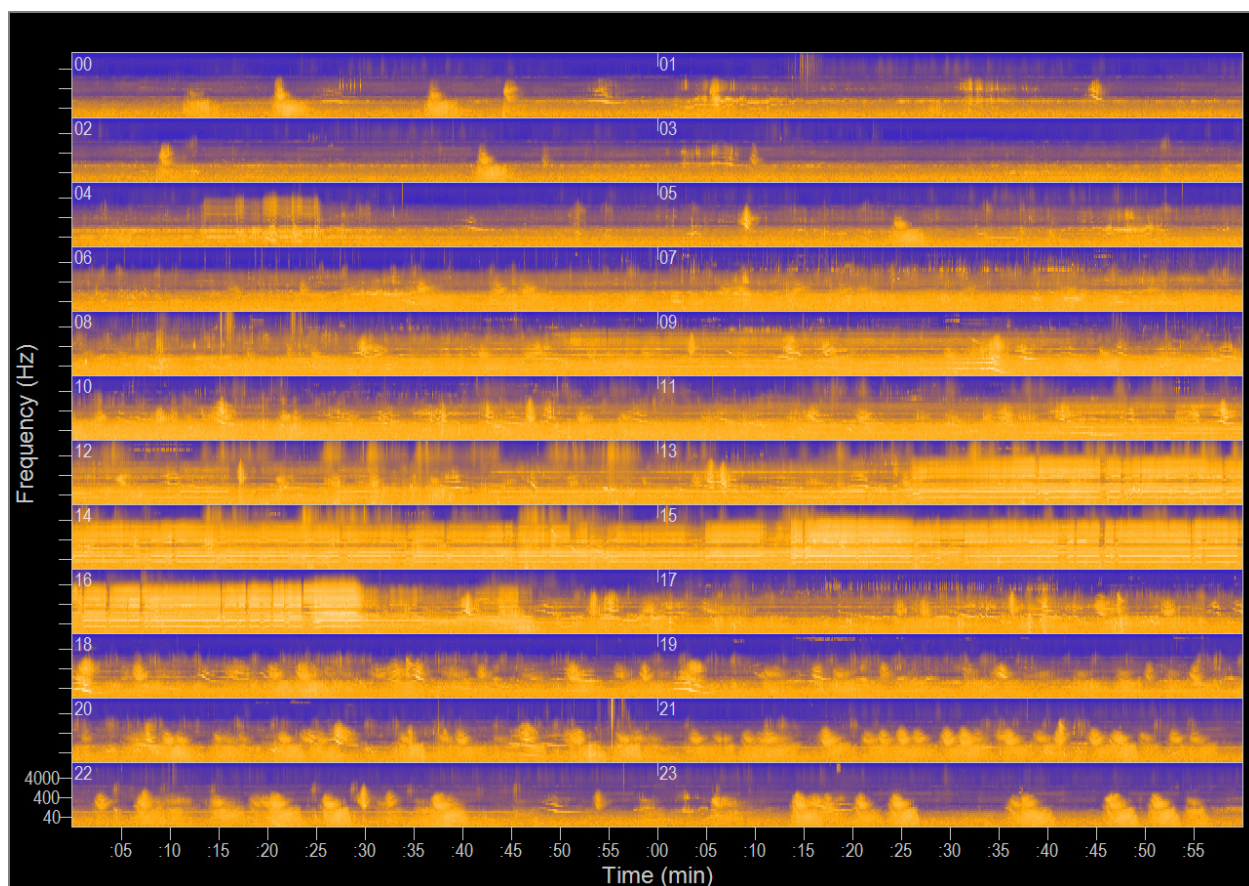


Figure 6. Example of a 24-hour spectrogram for WEFA001 on November 2, 2023. During this period, grounds care activities, such as leaf blowers and tree trimming, occurred in the middle hours of the day along with many jet overflights starting around 17:00. High-frequency signals from natural sources, such as birds and amphibians, are far less frequent in this season compared to the chorus audible during the spring season.

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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, Tables 7 and 8 report the percentage of time that measured sound levels ($L_{Aeq,1s}$) were above four key functional effect levels 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 percentage of ANS-weighted sound levels (20 – 1,250 Hz) that were above functional effect levels. Most motorized, human-caused noise is confined to the truncated, lower-frequency range, while many natural sounds, including insects and songbirds, are higher in pitch. ANS weighting eliminates high-frequency sounds (e.g., leaf rustle and biologic sounds) allowing for more accurate comparisons of low-frequency ambient sound levels across different land use types (e.g., urban and protected areas; ANSI S3/SC1.100, 2014 [R2020]). This frequency weighting scheme improves ambient sound level measurements in quiet environments.

Table 7. Percent time above metrics for two Weir Farm NHP sites in the spring season.

Site ID	Frequency Range	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 ^A	45 dB ^A	52 dB ^A	60 dB ^A	35 dB ^A	45 dB ^A	52 dB ^A	60 dB ^A
WEFA001	Full (12.5 – 20,000 Hz)	91.01	20.62	3.25	0.21	85.85	56.80	35.60	11.44
	ANS (20 – 1,250 Hz) ^B	71.01	7.69	1.01	0.08	25.87	4.95	0.32	0.01
WEFA002	Full (12.5 – 20,000 Hz)	78.38	14.42	1.90	0.10	59.95	25.23	15.37	0.80
	ANS (20 – 1,250 Hz) ^B	66.80	5.90	0.73	0.06	20.70	1.86	0.19	0.00

^A dB L_{Aeq, 1s} re 20 µPa

^B The percent of time ANS-weighted sound levels (20 – 1,250 Hz) are above functional values.

Table 8. Percent time above metrics for two Weir Farm NHP sites in the fall season.

Site ID	Frequency Range	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 ^A	45 dB ^A	52 dB ^A	60 dB ^A	35 dB ^A	45 dB ^A	52 dB ^A	60 dB ^A
WEFA001	Full (12.5 – 20,000 Hz)	93.57	27.51	5.38	0.17	45.88	2.62	0.30	0.02
	ANS (20 – 1,250 Hz) ^B	76.04	13.61	1.34	0.10	15.81	1.23	0.20	0.01
WEFA002	Full (12.5 – 20,000 Hz)	89.53	19.95	1.94	0.13	38.28	2.64	0.29	0.01
	ANS (20 – 1,250 Hz) ^B	73.63	7.53	0.95	0.08	12.62	1.08	0.16	0.00

^A dB L_{Aeq, 1s} re 20 µPa

^B The percent of time ANS-weighted sound levels (20 – 1,250 Hz) are above functional values.

The first functional effect in Tables 7 and 8 occurs around 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 [R2012]). In these studies, the 35 dB ($L_{Aeq,1s}$) effect level was exceeded at WEFA001 over 90% of the time in both seasons during the day, about 85% of the time at night during the spring, and only 45% of the time at night during the fall.

The second functional effect is expected to occur around 45 dB ($L_{Aeq,1s}$). This level addresses the World Health Organization's recommendations that noise levels inside bedrooms remain below 45 dB ($L_{Aeq,1s}$) (Berglund *et al.* 1999). The third value, 52 dB ($L_{Aeq,1s}$), is based on the EPA's 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. During the spring sampling period at WEFA, sound levels exceeding 52 dB ($L_{Aeq,1s}$) occurred a mere 3% of the time during the day and between 15% and 35% of the time during the night, likely due to contributions from amphibians. The final value, 60 dB ($L_{Aeq,1s}$), marks the point at which normal voice communications at 1 meter begin to be interrupted; sounds at or exceeding this level could begin to affect conversation between visitors and/or staff at WEFA. This level was exceeded very rarely at all sites and all seasons with the exception of the springtime sampling period, when spring peepers were particularly active at night.

Sound Level: Percentile Levels

Percentile sound levels help quantify the range of acoustic conditions at the park. Tables 9 and 10 list day and night A-weighted percentile sound levels for the spring and fall sampling periods at WEFA. Figures 7 through 10 show hourly summaries for the A-weighted percentile sound levels (L_{A90} , L_{Anat} , L_{A50} , and L_{A10}), 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, during the spring measurement period at WEFA001, L_{A50} (median) sound level peaked during the 17:00 hour at about 57 dB. On the other hand, the quietest L_{A90} values were during the early morning hours of 2:00 to 3:00.

Table 9. Summary of noise sources and sound levels at two Weir Farm NHP sites in the spring season. Included for each site are maximum (L_{Amax}), sound level exceeded 10 percent of the time (L_{A10}), existing (L_{A50}), natural (L_{Anat}), sound level exceeded 90 percent of the time (L_{A90}), and minimum (L_{Amin}) ambient sound levels (dB re 20 μ Pa, A-weighted broadband, 12.5 Hz – 20 kHz) during the day (07:00 – 19:00) and night (19:00 – 07:00). The difference between the natural and existing ambient sound levels indicates the deviation from the natural condition.

Site ID	Time	L_{A10}	L_{A50}	L_{Anat}	L_{A90}
WEFA001	Day	45.7	40.0	35.3	36.1
	Night	53.9	48.8	39.7	40.1
WEFA002	Day	44.5	38.2	32.9	34.0
	Night	46.5	38.7	31.9	32.3

Table 10. Summary of noise sources and sound levels at two Weir Farm NHP sites in the fall season. Included for each site are maximum (L_{Amax}), sound level exceeded 10 percent of the time (L_{A10}), existing (L_{A50}), natural (L_{Anat}), sound level exceeded 90 percent of the time (L_{A90}), and minimum (L_{Amin}) ambient sound levels (dB re 20 μ Pa, A-weighted broadband, 12.5 Hz – 20 kHz) during the day (07:00 – 1900) and night (19:00 – 07:00). The difference between the natural and existing ambient sound levels indicates the deviation from the natural condition.

Site ID	Time	L_{A10}	L_{A50}	L_{Anat}	L_{A90}
WEFA001	Day	46.2	40.9	37.8	37.6
	Night	39.4	34.2	31.9	30.8
WEFA002	Day	45.0	40.2	36.8	36.6
	Night	38.5	32.0	29.7	28.8

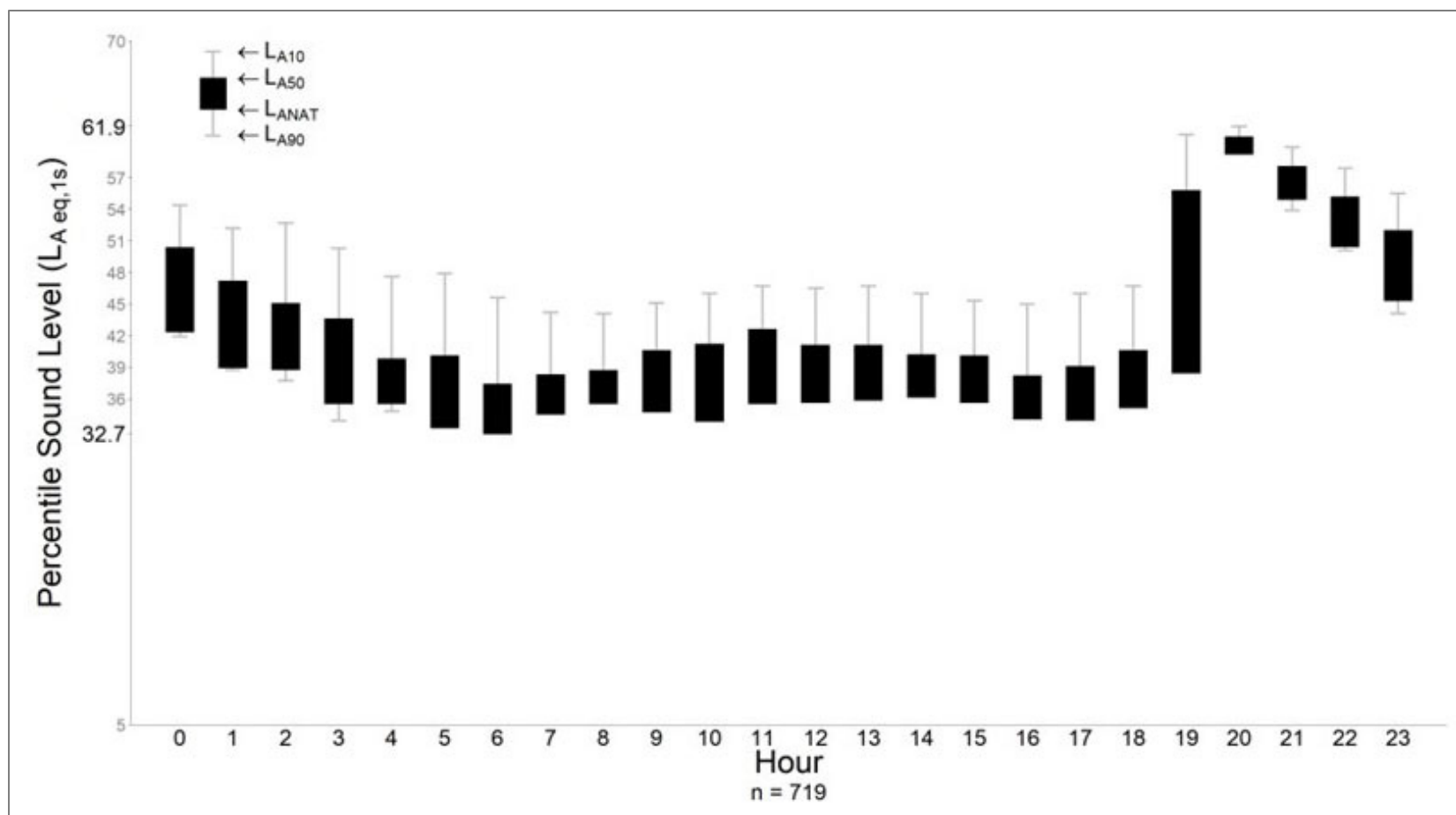


Figure 7. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at WEFA001 from March to April 2022.
 NPS / NATURAL SOUNDS AND NIGHT SKIES DIVISION

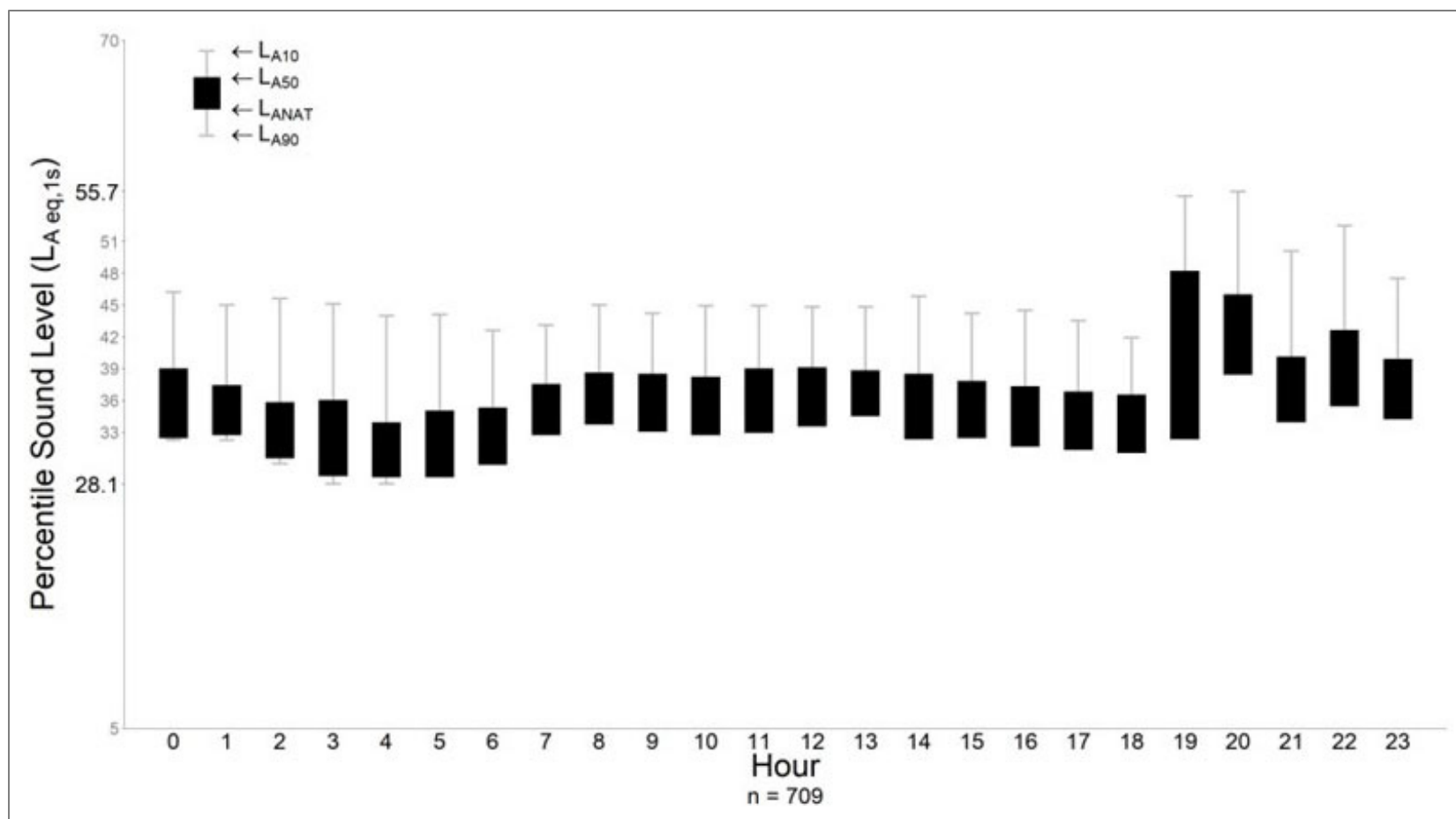


Figure 8. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at WEFA002 from March to April 2022.

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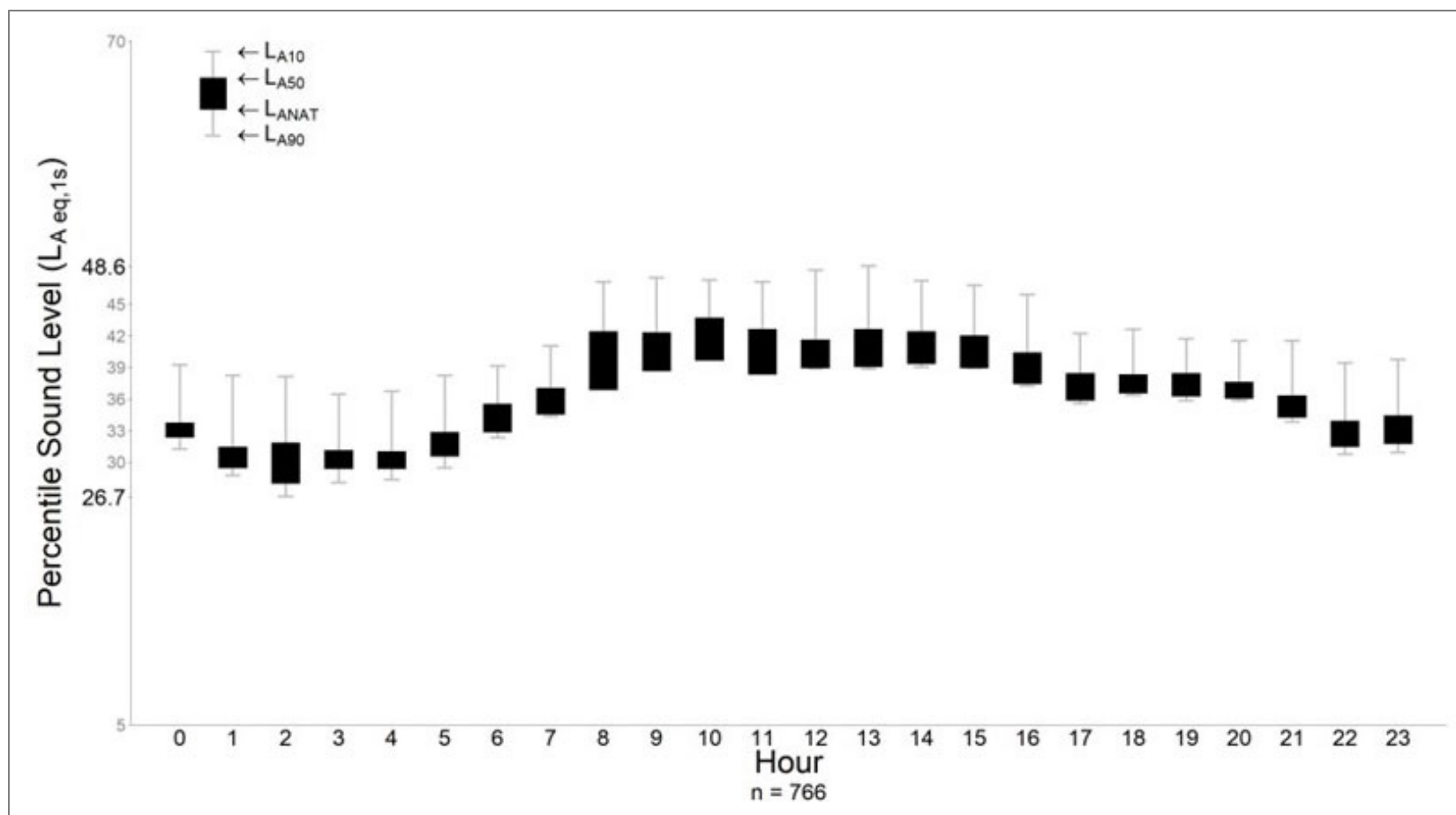


Figure 9. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at WEFA001 from October to November 2023.
 NPS / NATURAL SOUNDS AND NIGHT SKIES DIVISION

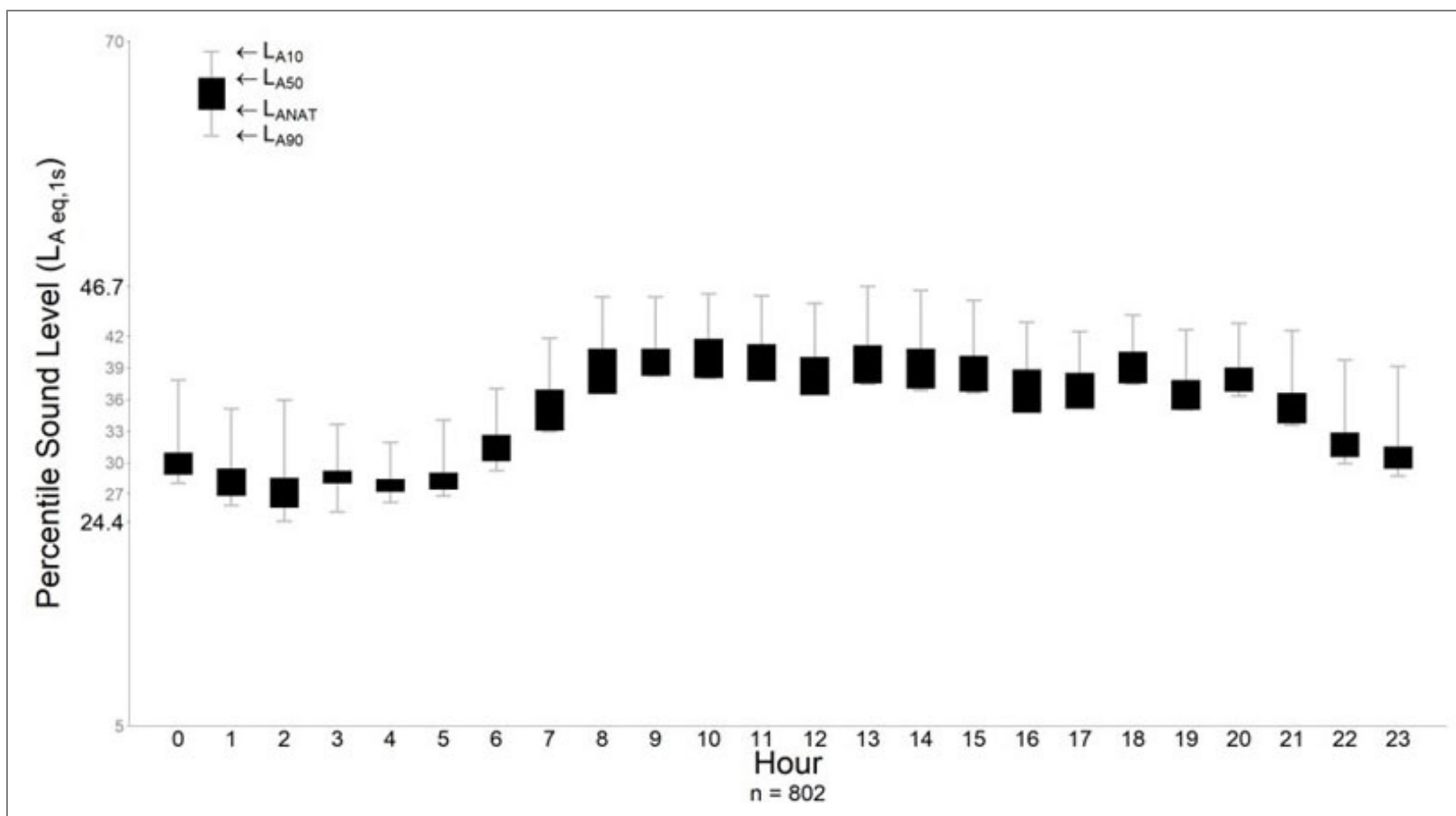


Figure 10. Median percentile sound levels ($L_{Aeq, 1s}$), in dB re 20 μ Pa, at WEFA002 from October to November 2023.
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Hours where the L_{A50} and the L_{Anat} differ the most are usually hours with the most human-caused noise. The larger the span of the black bars, the greater the difference of the existing sound level from natural conditions. At the WEFA sites in all seasons, human-caused impacts were fairly consistent across hours, with slightly less impact noted during the fall season.

Event Duration

Figures 11 through 14 show the percent of time audible at each of the location sites. A full record of hourly audibility for all sound sources across all sites and seasons is available in comma-separated tabular format on the [NPS Datastore](#).

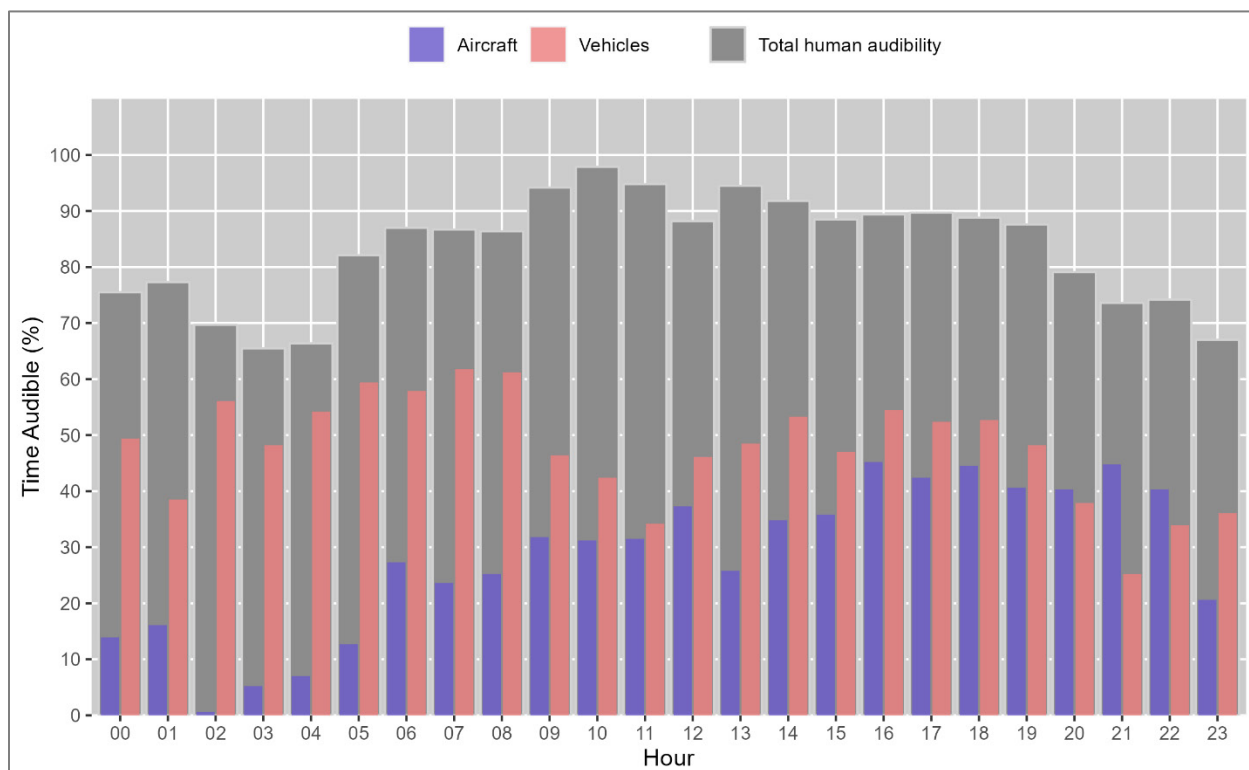


Figure 11. Hourly time audible for vehicles and aircraft sources at WEFA001 from March to April 2022.
NPS / NATURAL SOUNDS AND NIGHT SKIES DIVISION

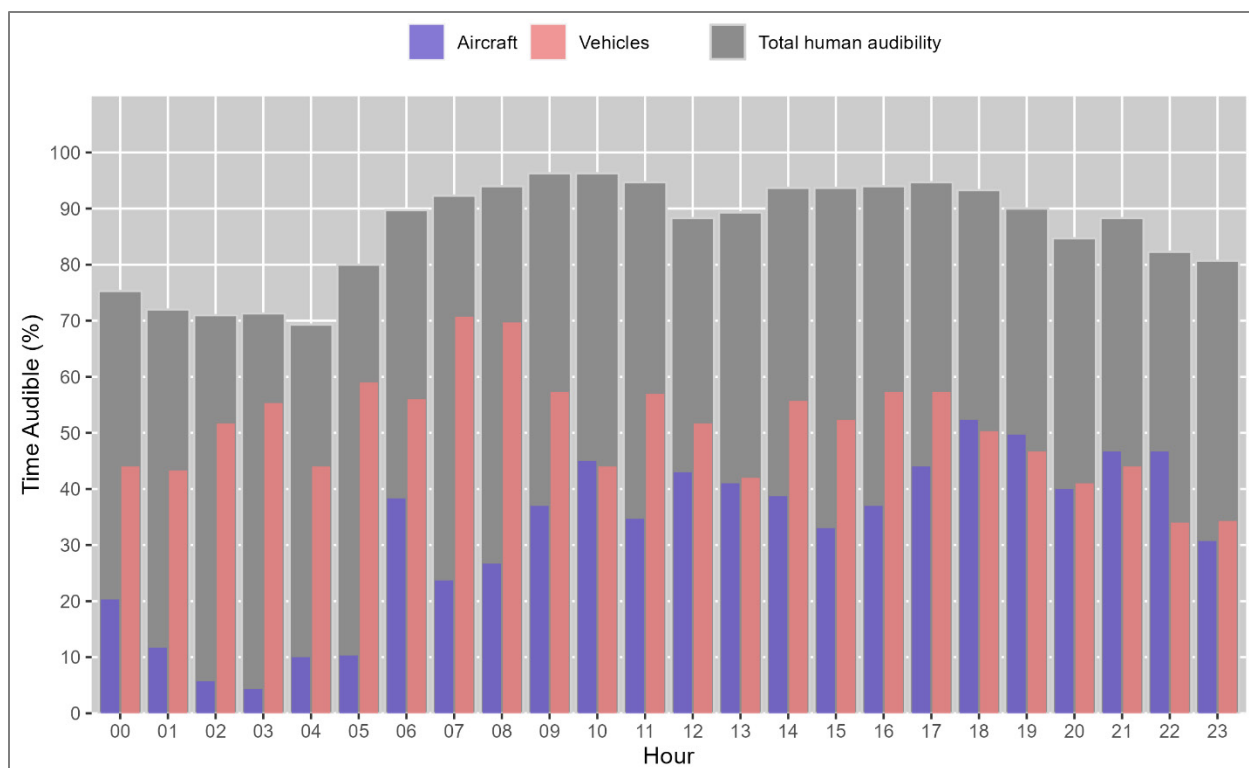


Figure 12. Hourly time audible for vehicles and aircraft sources at WEFA002 from March to April 2022.
NPS / NATURAL SOUNDS AND NIGHT SKIES DIVISION

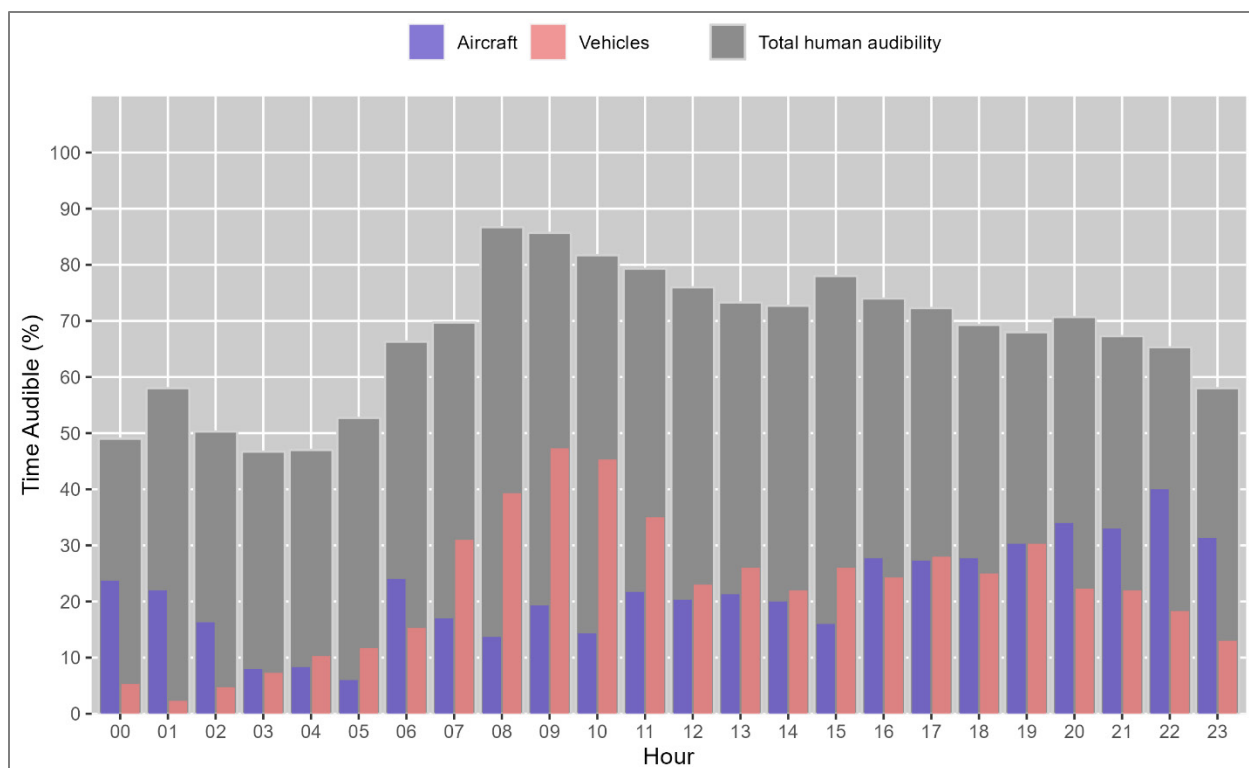


Figure 13. Hourly time audible for vehicles and aircraft sources at WEFA001 from October to November 2023.

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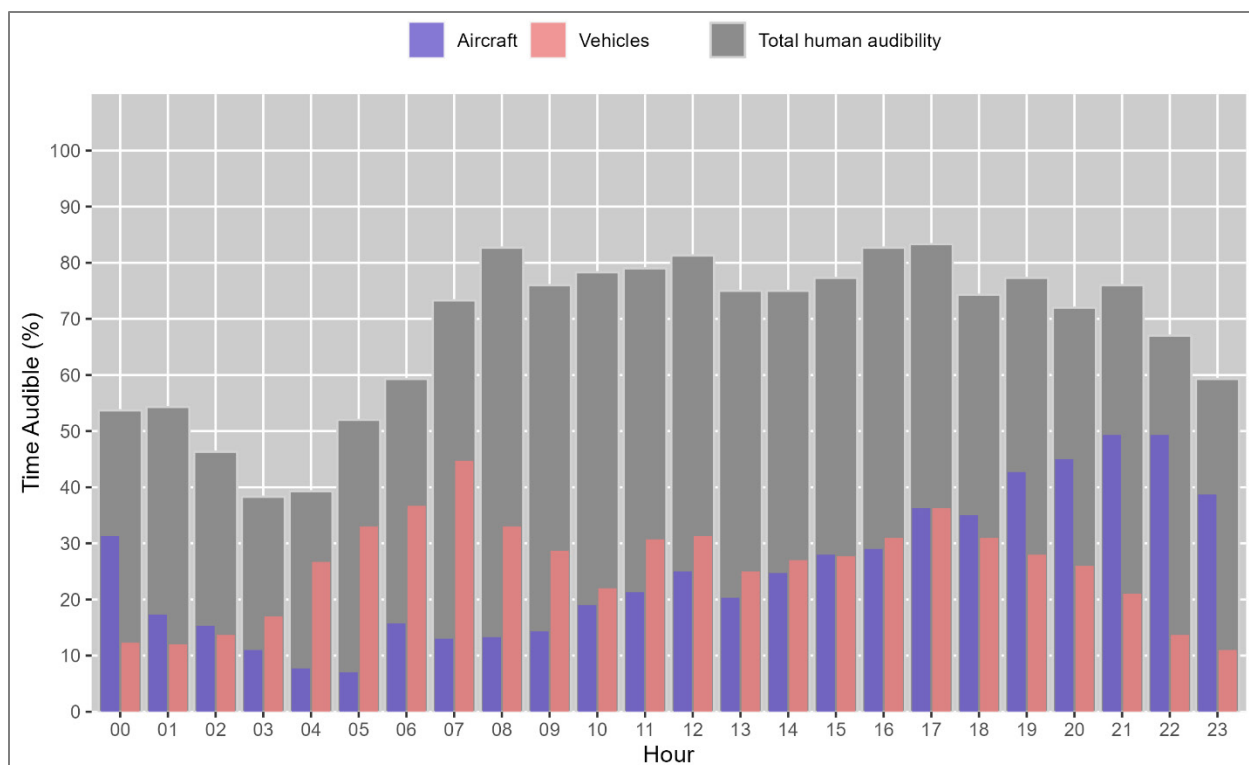


Figure 14. Hourly time audible for vehicles and aircraft sources at WEFA002 from October to November 2023.

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Conclusions

Acoustic measurements allow 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, as well as the condition of the acoustic environment and cultural landscape. This study arose out of Weir Farm National Historical Park's interest in developing appropriate measures for desired soundscape conditions. Of particular interest were sounds that contribute to the natural and cultural historic acoustic environment, as well as vehicles and aircraft. To carry out this study, two acoustical monitoring systems were deployed in the park from March to April 2022 and October to November of 2023. WEFA001 (Pond Trail) was placed on the east side of Nod Hill Road, just off the Pond Trail, and WEFA002 (Meadow) was placed on the west side of Nod Hill Road, in the Burlingham complex, on the border of the Weir Preserve. Results included measures of existing ambient sound levels, calculations of sound source audibility through off-site listening, and estimates of natural ambient sound levels.

Sound levels frequently exceeded 35 dB during the daytime (between 78% and 94% of the time) at both sites across both seasons. The 35 dB functional effect level was exceeded less often at night, particularly during the fall season, when this level was only exceeded between 35 – 45% of the time (Tables 7 and 8). Speech interference occurs when noise interferes with human speech. If sound levels exceed 52 dBA, and if a speaker and audience are far apart, as they often are during interpretive programs (approx. 10 meters), speech interference begins to occur. This functional effect level was exceeded during the daytime between 2 and 3% of the time at the springtime sites, and between 2 and 5% of the time at the fall sites. This suggests that near the two measurement sites (Pond Trail and Meadow), an interpreter's speech would rarely be interrupted by noise during daytime programming. However, many of the historic structures featured on the park's interpretive tours are closer to Nod Hill and Pelham roads, and interruptions would increase with proximity to roads.

Median sound levels (L_{A50}) at WEFA001 were comparable to those measured at WEFA002 during the daytime in all seasons (they ranged from 38.2 – 40.9 dB), but notably, nighttime sound levels at WEFA001 during the spring were 14.6 dB higher than fall conditions, due to spring peeper and wood frog activity (Tables 7 and 8, Figure 7). For a broader context for the acoustic conditions at WEFA, 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 ($L_{A50, 12 \text{ hr}}$), and only 1% of the continental U.S. was predicted to have an existing daytime ambient sound level above 50 dB (L_{A50}) (Mennitt et al. 2013). Consider, though, that daily sound levels measured at WEFA were influenced by both natural and non-natural sources.

Natural ambient sound levels (L_{Nat}) were calculated to be between 3 and 5 dB quieter than L_{A50} sound levels (Tables 9 and 10). Functionally, this increase in background sound level caused by noise would reduce the listening area of humans or wildlife in the park by between 50 and 68%. Noise also 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) and tranquility (Watts *et al.* 2020),

and by limiting opportunities for solitude or a wilderness experience at this park. Increased sound levels may also have wide-ranging effects on wildlife such as reduced predatory success (Mason 2015), changes in vocal communication, and 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} , as a composite of multiple metrics with varying time-averaging). 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).

Off-site listening in a subset of data revealed that some sources of human-caused noise was audible at least 70% of each hour during the spring season, and sometimes over 90% of the time (Figure 11 and Figure 12). During the fall season, noise was audible less often overall, but did exceed 80% audibility during some hours, particularly during morning hours between 0800 and 1000 (Figure 13 and Figure 14). Audibility of noise at this level increases the margin of error in estimating the natural ambient sound level, particularly during the hours where audibility exceeded 90%.

The most common sources of noise at this site were vehicles and aircraft, which is logical given the park's proximity to New York metro area airports as well as Danbury Municipal Airport, and the fact that Nod Hill Road bisects the park. Grounds care was also frequently audible, and while WEFA carries out maintenance and grounds care activities, it is worth noting that the park is located in a suburban environment, and a portion of these grounds care noise events originated from neighboring parcels. Train rumble and whistle from the Metro-North Railroad New Haven Line commuter rail were also audible at both sites for some portion of every hour in all seasons. Though the frequency of activity at the station may have changed over time, this sound was probably a part of the acoustic environment during Julian Alden Weir's time on the farm, as the Branchville station has been used for passenger and/or freight service since the mid-19th century.

Finally, in addition to noise, diverse natural sounds were heard during the measurement periods. Bird, insect, and amphibian choruses were audible. Wind, rustling leaves, rain, and mammal vocalizations (e.g. squirrel, coyote) were also noted. The information presented in this report will be used to inform park managers and planners, and it will also serve as a permanent record of sound levels measured at WEFA during spring 2022 and fall of 2023. Sound level data and digital audio recordings will be archived with the Natural Sounds and Night Skies Division office in Fort Collins, Colorado, and detailed sound source analysis results will be included as associated files on this report's NPS DataStore reference page.

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Appendix A: Site Photos

Figures 15 and 16 are photos of each sampling site location.



Figure 15. WEFA001, Pond Trail site.
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Figure 16. WEFA002, Meadow site.
NPS / EMMA BROWN

National Park Service
U.S. Department of the Interior



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Natural Resource Stewardship and Science

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