



Tule Springs Fossil Beds National Monument

Acoustic Monitoring Report 2019–2020



Acoustic monitoring in Tule Springs Fossil Beds National Monument
NPS / NATURAL SOUNDS PROGRAM

Tule Springs Fossil Beds National Monument: Acoustic monitoring report 2019–2020

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Contents

	Page
Figures.....	iv
Tables.....	v
Abstract.....	vi
Acknowledgments.....	vii
List of Terms or Acronyms.....	viii
Executive Summary	xi
Introduction.....	1
National Park Service Natural Sounds and Night Skies Division.....	1
Soundscape Planning Authorities.....	1
Focal Park Unit.....	2
Study Area.....	3
Methods.....	4
Automatic Monitoring.....	4
Monitoring Period	5
Calculation of Metrics	5
Off-Site Listening and Spectrogram Analysis.....	5
Results.....	7
Frequency content	7
Sound level: Time Above.....	9
Sound Level: Percentile Levels	10
Event duration	12
Listening Center Software.....	12
Conclusions.....	15
Literature Cited	18
Appendix A: Site Photos.....	21
Appendix B: Modeled Impact Levels	23

Figures

	Page
Figure 1. Study sites in Tule Springs Fossil Beds National Monument, Nevada, USA.	xi
Figure 2. A Colorado State University student identifies sound sources using Acoustic Monitoring Toolbox (NPS) software.	6
Figure 3. Day and night percentile sound pressure levels for 33 one-third octave bands at TUSK001 in winter, 2019–2020.	8
Figure 4. Day and night percentile sound pressure levels for 33 one-third octave bands at TUSK002 in winter, 2019–2020.	9
Figure 5. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at TUSK001 in Winter, 2019–2020.	11
Figure 6. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at TUSK002 in winter, 2019–2020.	12
Figure 7. Hourly time audible for the top noise sources and all noise sources at TUSK001 in winter, 2019–2020.	13
Figure 8. Hourly time audible for the top noise sources and all noise sources at TUSK002 in winter, 2019–2020.	14
Figure 9. TUSK001, South Unit site.	21
Figure 10. TUSK002, North Unit site.	22
Figure 11. Map of predicted existing acoustic levels in TUSK for an average summer day.	24
Figure 12. Map of predicted natural acoustic sound levels in TUSK for an average summer day.	25
Figure 13. Map of predicted acoustic impact levels in TUSK for an average summer day.	26

Tables

	Page
Table 1. Sound level examples.....	xii
Table 2. Percent time above metrics for acoustic records collected in Tule Springs Fossil Beds National Monument (TUSK) in Winter, 2019–2020.	xiii
Table 3. Summary noise sources and sound levels at Tule Springs Fossil Beds National Monument (TUSK) in Winter, 2019–2020.....	xiv
Table 4. Metadata for acoustical monitoring sites at Tule Springs Fossil Beds National Monument, in 2019.....	3
Table 5. Percent time above metrics for acoustic records collected in Tule Springs Fossil Beds National Monument (TUSK) in Winter, 2019.	10
Table 6. Summary of summer sound levels at Tule Springs Fossil Beds National Monument (TUSK) in Winter, 2019.....	11

Abstract

This study arose from a Tule Springs Fossil Beds National Monument (TUSK) technical assistance request titled “Soundscape Monitoring”, which identified the need for baseline acoustic surveys in the newly created park. Therefore, across one season in 2019, the Natural Sounds and Night Skies Division (NSNSD) gathered acoustical data at two sites in TUSK to provide park managers with information about the acoustical environment, sources of noise, and the natural and existing ambient sound levels within the park. On average, noise was present from 77 to 100 percent of the time across the two sites. The most common sources of noise were vehicles, aircraft, and unknown non-natural sounds. The maximum percent time audible for any detailed noise source were vehicles at site TUSK001, audible for 94% of a 24-hr period. Unknown non-natural noise was most audible at site TUSK002 (38%), followed by vehicles (37%). Overall, existing ambient sound levels (L_{A50}) at sites within TUSK ranged from 27.3–31.9 dB during the day and 21.1–28.2 dB at night during the sampling period. Natural ambient sound levels (L_{Anat}) at sites within TUSK ranged from 21.7–26.8 dB during the day and 18.1–23.9 dB at night, although these measurements were likely influenced by the high prevalence of noise. In total, these results suggest that the TUSK acoustic environment is influenced by lower level, but very consistent noise. As a supplement, a geospatial sound model predicts existing and natural ambient sound levels at TUSK are 34.0 (dBA) and 21.4 (dBA), respectively.

Acknowledgments

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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.

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.

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.

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.

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.

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.

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.

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.

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.

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).

Executive Summary

This report presents acoustic data gathered by the Natural Sounds and Night Skies Division (NSNSD) at Tule Springs Fossil Beds National Monument (TUSK) across one season in 2019. Data were collected at two sites (Figure 1) to provide park managers with information about the acoustical environment, sources of noise, and the natural and existing ambient sound levels within the park. In these deployments, sound pressure level (SPL) was measured continuously every second by a calibrated sound level meter. Other equipment included an anemometer to collect wind speed and a digital audio recorder collecting continuous recordings to document sound sources. In this document, “sound pressure level” refers to broadband (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 is 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.

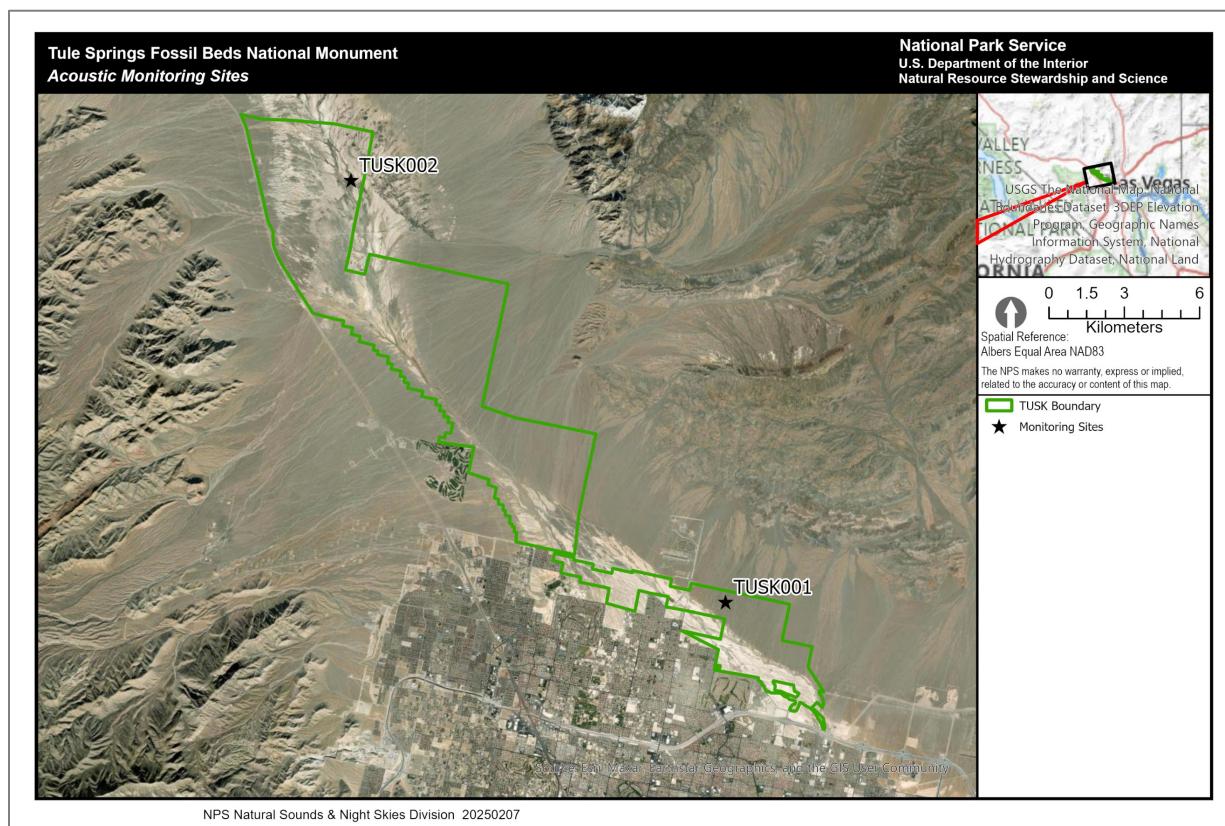


Figure 1. Study sites in Tule Springs Fossil Beds National Monument, Nevada, USA.

NPS / NSNSD

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.

Overall, existing ambient sound levels (L_{A50}) at sites within TUSK ranged from 27.3–31.9 dB during the day and 21.1–28.2 dB at night during the sampling period. 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). Moreover, sound events as low as 35 dB can adversely affect sleeping humans (Haralabidis et al. 2008). This level, 35 dB, is also the desired 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). As wildlife begin to exhibit signs of disturbance at noise levels as low as 40 dB (Shannon et al. 2016), 45 dB also represents a conservative estimate of negative effects on wildlife. The third value, 52 dB ($L_{Aeq,1s}$), is based on the EPA’s speech interference level for speaking in a raised voice to an audience at 10 meters (EPA 1974). This value addresses the effects of sound on interpretive presentations in parks. The final value, 60 dB ($L_{Aeq,1s}$), 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.

Table 2. Percent time above metrics for acoustic records collected in Tule Springs Fossil Beds National Monument (TUSK) in Winter, 2019–2020. Sound level functional values are displayed in decibels (dB $L_{Aeq, 1s}$ re 20 μ Pa).

Site Name	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	45 dB	52 dB	60 dB	35 dB	45 dB	52 dB	60 dB
TUSK001	Full (12.5–20,000)	33.38	2.76	0.84	0.21	7.69	0.09	0.01	0
TUSK001	ANS (20–1,250)	33.16	2.75	0.84	0.20	7.59	0.09	0.01	0
TUSK002	Full (12.5–20,000)	11.61	1.05	0.16	0.00	1.80	0.09	0.00	0
TUSK002	ANS (20–1,250)	11.38	1.06	0.07	0.00	1.56	0.04	0.00	0

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 key values in two frequency ranges. For each site in Table 2, the top row uses the full frequency range (12.5 Hz–20 kHz) collected, whereas the bottom row focuses on frequencies affected by low frequency noise sources (20–1,250 Hz). This Natural Sounds modification to A-weighting (referred to as A-weighted Natural Sounds (ANS) weighting, ASA/ANSI S3/SC1.100-2014 [2020]) 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; ASA/ANSI S3/SC1.100-2014 [2020]). This frequency weighting scheme improves ambient sound level measurements in quiet environments. For instance, in the full frequency range, the 35 dB ($L_{Aeq, 1s}$) level was exceeded at TUSK001 33.38% of the time during the day and 7.69% of the time at night. The results were very similar in the 20–1,250 Hz range, suggesting most of the contributions in both ranges are from lower frequency sounds. Speech interruption (between two people 1 meter apart) occurs at 60 dB ($L_{Aeq, 1s}$) and this level was rarely exceeded at any of the sites.

After data collection was complete, trained technicians calculated how often noise sources were audible. See Methods section for protocol details, equipment specifications, and metrics calculations. Sound source analysis revealed that noise was audible about ~77–100% of the time during the sampling period at study sites when averaged across all hours of the day (Table 3). The most common identifiable noise sources observed during this study were aircraft, vehicles, and gunshots. Natural sources such as wind, coyotes, songbirds, and insects were also commonly audible. Natural ambient sound levels (L_{Anat}) ranged between 21.7–26.8 dB during the day and 18.1–23.9 dB at night. Caution should be used when utilizing L_{Anat} , because the pervasiveness of noise during the study period reduced the amount of time that L_{Anat} could be calculated. Thus, while L_{Anat} is reported, the estimation of natural ambient is susceptible to higher error at TUSK. Modeled natural sound levels in Appendix C may provide a better representation of the noise impacts.

Table 3. Summary noise sources and sound levels at Tule Springs Fossil Beds National Monument (TUSK) in Winter, 2019–2020. Included for each site are a) mean percent time audible for all human-caused noise, including the top two 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–20,000 Hz) during the day (0700–1900) and night (1900–0700). The difference between the natural and existing ambient sound levels indicates the deviation from the natural condition.

Site Name	a.) Mean time audible for noise (% of 24-hour time period)				b.) Median Existing Ambient (L_{A50}) in dB		Median Natural Ambient (L_{Anat}) in dB	
	Noise	Aircraft	Non- natural Unknown	Vehicles	Day	Night	Day	Night
TUSK001	99.6	9.7	4.8	93.8	31.9	28.2	26.8	23.9
TUSK002	77.4	18.5	38.1	36.6	27.3	21.1	21.7	18.1

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 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.

Focal Park Unit

Tule Springs Fossil Beds National Monument (TUSK) was established as the 405th unit of the national park system on December 19, 2014 (NPS 2019). The monument conserves, protects, enhances, and interprets late Pleistocene fossils, their geologic context, and other scientific values in the upper Las Vegas Wash through education, research, community collaboration, and appropriate public use. In 2018, a technical assistance request (TAR) was submitted to NSNSD (TAR 10372) for baseline soundscape data. This request stated that it was important to have this data for planning purposes as TUSK was a new park, and that it was important to preserve the original soundscapes of the park prior to encroaching development. Further, TUSK wanted to use soundscape data to determine wildlife management plans and to better understand visitor use patterns. This study describes the outcome of this request.

Study Area

This report covers results from an acoustic inventory conducted in the winter season of 2019 at TUSK (Table 4). Two sites were selected to represent a range of visitation, noise source, and park region. In early December 2019, TUSK001 was deployed in southern TUSK near suburban development and TUSK002 was deployed in the more remote northern part of the park. The set of acoustic inventory sites spanned approximately 25 km (Figure 1).

Table 4. Metadata for acoustical monitoring sites at Tule Springs Fossil Beds National Monument, in 2019.

Site	Site Name	Dates	Vegetation	Wilderness	Elevation (m)	Latitude	Longitude
TUSK001	South Unit	12/02/2019–1/25/2020	Desert	No	728	36.33017	-115.1902
TUSK002	North Unit	12/05/2019–1/25/2020	Desert	No	888	36.45004	-115.3927

Methods

Automatic Monitoring

A Larson Davis sound level meter (SLM) type 831-A was deployed at 2 monitoring sites. 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 meter provided the information needed to calculate metrics described below in Calculation of Metrics.

Acoustic monitoring equipment is used by many practitioners to determine noise levels in different environments, both indoors and outdoors. The NPS has developed a unique configuration of standard acoustic monitoring equipment that stands up to 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 recorded continuous audio through 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:

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

The sampling station was designed to collect:

- 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].
- 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].
- Continuous meteorological data for wind speed [collected by anemometer].
- Continuous digital audio recordings.

Monitoring Period

It is typical to monitor a minimum of 25 days to capture daily differences within a sampling period that occur at each site within a reasonable margin of error (NPS 2005). For this study, the monitoring period ranged from 51 to 54 days. For both sites, there was a full SPL record but the audio record was missing data from 12/24/2019 through 1/10/2020.

Calculation of Metrics

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

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

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

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

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 (0700–1900) and the median of the hourly L_{Anat} values for the nighttime (1900–0700) are displayed in graphical format in the following sections.

Off-Site Listening and Spectrogram Analysis

Off-site analysis is completed by listening to the audio record while simultaneously viewing its spectrogram representation (for more information on Listening Center software, see Appendix A). Auditory analysis was used to calculate the audibility of sound sources at each location. Trained technicians at Colorado State University (Figure 2) listened back to 10 days of the audio record. Technicians considered only a subsample of each day representing the first 10 seconds of every two-minute period. Within each subsample every audible sound source was categorized. This allowed the temporal extent of audibility for each source type to be estimated. The total percent time noise was audible was then used to calculate the natural ambient sound level (L_{Anat}) for each hour (see Equation 1 above for more information). For any off-site audio playback listening techniques, Bose Quiet

Comfort Noise Canceling headphones were used to minimize limitations imposed by the office acoustical environment.



Figure 2. A Colorado State University student identifies sound sources using Acoustic Monitoring Toolbox (NPS) software.

NPS / NSNSD

Results

Frequency content

To determine the effect that noise has on the acoustic environment, it is useful to examine percentile metrics across a frequency range. High frequency sounds (such as a cricket chirping) and low frequency sounds (such as flowing water) often occur simultaneously, so the frequency spectrum is split into 33 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 Figure 3 and Figure 4.

Examining the sound energy in each one-third octave band (combined with digital audio recordings) allows acoustic technicians to determine what types of sounds are contributing to the overall sound levels at a site. The grayed areas of Figure 3 and Figure 4 represent sound levels outside of the typical range of human hearing. The percentile levels (L_x) are also shown for each one-third octave band. They represent the sound levels exceeded x percent of the measurement period. For example, L_{90} is the sound level that has been exceeded 90% of the time, and only the quietest 10% of the samples can be found below this point. On the other hand, the L_{10} is the sound level that has been exceeded 10% of the time, and 90% of the measurements are quieter than the L_{10} . The bold portion of the column represents the difference between L_{50} and L_{nat} . The height of this bold portion is a measure of the contribution of anthropogenic noise to the existing sound levels at this site. The size of this portion of the column is directly related to the percent time that human caused sounds are audible. When bold portions of the column do not appear the natural and existing sound levels were either very close to each other or were equal. The typical frequency levels for transportation, conversation, and songbirds are presented on the figure as examples for interpretation of the data. These ranges are estimates and are not vehicle-, species-, or habitat-specific.

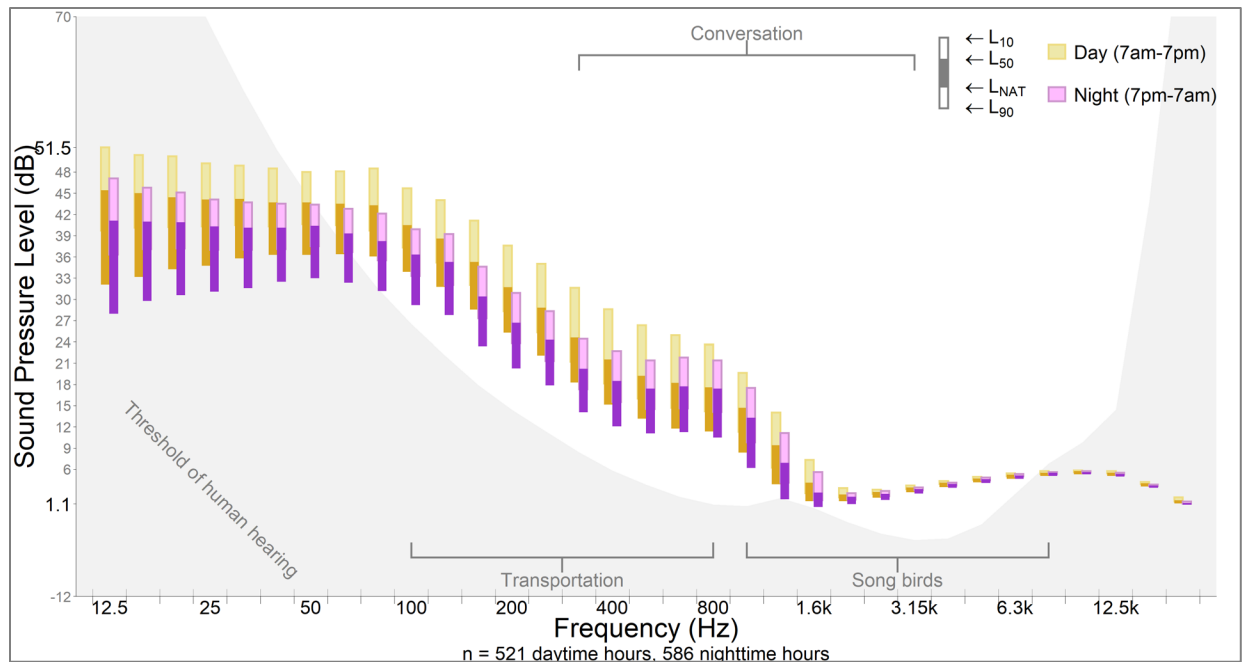


Figure 3. Day and night percentile sound pressure levels for 33 one-third octave bands at TUSK001 in winter, 2019–2020. For each bar, the bold color indicates the range of existing (L_{50} ; upper) and natural (L_{nat} ; lower) sound pressure levels. Sound levels depicted are not A-weighted. Note that the high level of noise increases the margin of error in estimating the natural ambient sound level. L_{nat} may be inaccurate due to the pervasiveness of noise at this site.

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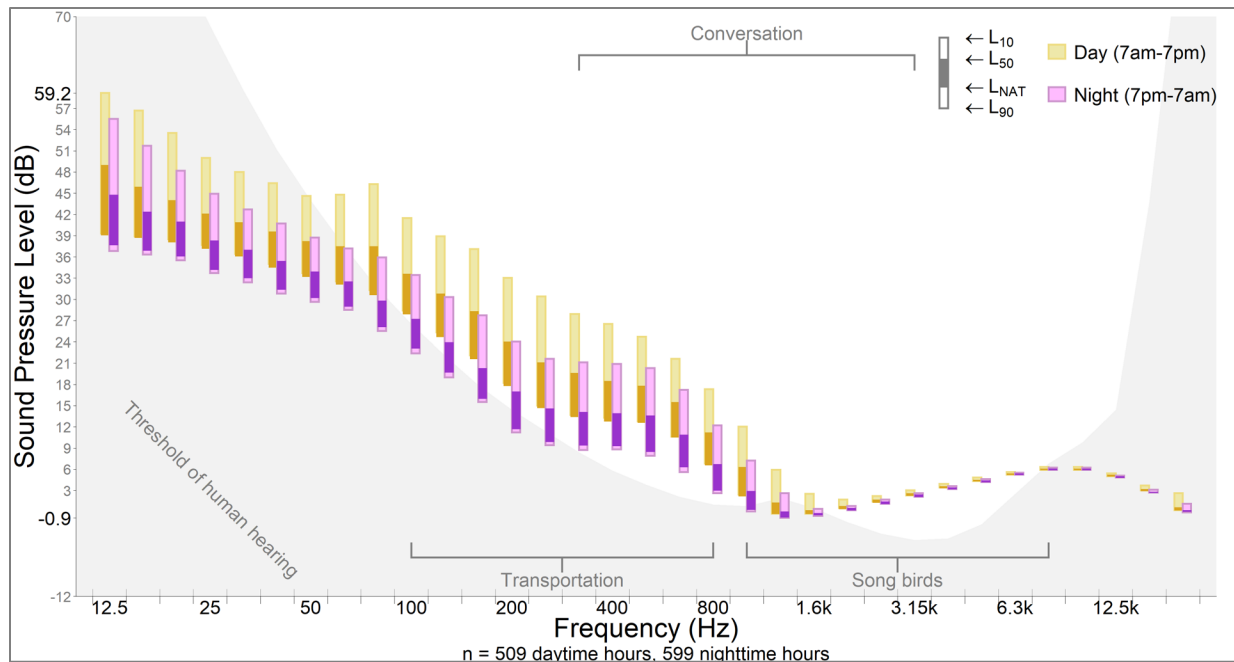


Figure 4. Day and night percentile sound pressure levels for 33 one-third octave bands at TUSK002 in winter, 2019–2020. For each bar, the bold color indicates the range of existing (L_{50} ; upper) and natural (L_{nat} ; lower) sound pressure levels. Sound levels depicted are not A-weighted. Note that the high level of noise increases the margin of error in estimating the natural ambient sound level. L_{nat} may be inaccurate due to the pervasiveness of noise at this site.

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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, Table 5 reports the percent of time that measured sound levels ($L_{Aeq,1s}$) were above four key functional effect levels during the monitoring periods (daytime and nighttime).

For each site, the top row in Table 5 uses the full frequency range, whereas the bottom row reports the percentage of the sample with ANS-weighted sound levels (20–1,250 Hz) above functional effect thresholds. 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 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.

Table 5. Percent time above metrics for acoustic records collected in Tule Springs Fossil Beds National Monument (TUSK) in Winter, 2019. Sound level functional values are displayed in decibels (dB $L_{Aeq, 1s}$ re 20 μ Pa).

Site Name	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	45 dB	52 dB	60 dB	35 dB	45 dB	52 dB	60 dB
TUSK001	Full (12.5–20,000)	33.38	2.76	0.84	0.21	7.69	0.09	0.01	0
TUSK001	ANS (20–1,250)	33.16	2.75	0.84	0.20	7.59	0.09	0.01	0
TUSK002	Full (12.5–20,000)	11.61	1.05	0.16	0.00	1.80	0.09	0.00	0
TUSK002	ANS (20–1,250)	11.38	1.06	0.07	0.00	1.56	0.04	0.00	0

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). Moreover, sound events as low as 35 dB can adversely affect sleeping humans (Haralabidis et al. 2008). This is also the desired background sound level in classrooms (ANSI S12.60-2002 [R2012]). For application to the present study, the 35 dB ($L_{Aeq, 1s}$) effect level was exceeded at TUSK001 33.38% of the time during the day and 7.69% of the time at night in the full frequency range. In the 20–1,250 Hz range, the 35 dB functional sound level value was exceeded similarly in both times of day, which indicates that much of the sound energy was from lower frequency noise sources. The second functional effect is expected to occur around 45 dB ($L_{Aeq, 1s}$). It addresses the World Health Organization’s recommendations that noise levels inside bedrooms remain below 45 dB ($L_{Aeq, 1s}$) (Berglund et al. 1999). As wildlife begin to exhibit signs of disturbance at noise levels as low as 40 dB (Shannon et al. 2016), 45 dB also represents a conservative estimate of negative effects on wildlife. The third functional effect is expected to occur around 52 dB ($L_{Aeq, 1s}$), based on the EPA’s speech interference threshold for speaking in a raised voice to an audience at 10 meters (EPA 1974). This threshold addresses the effects of sound on interpretive presentations in parks. The final functional effect at 60 dB ($L_{Aeq, 1s}$) provides a basis for estimating impacts on normal voice communications at 1 meter. Visitors viewing scenic areas in the park regularly conduct such conversations.

Sound Level: Percentile Levels

Percentile sound levels help quantify the range of acoustic conditions at the park. Table 6 lists day and night A-weighted percentile sound levels for the sampling period at TUSK. Figures 5 and 6 show hourly summaries for the A-weighted percentile sound levels (L_{A90} , $L_{A_{nat}}$, 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, in Figure 5, the L_{A50} (median) sound level for TUSK001 during the 8:00 hour is 36.8 dB. On the other hand, the sound level exceeded 10% of the time (L_{A10}) for the same hour at this site is 39.4 dB, meaning 90% of the measurement period is quieter. Hours where the L_{A50} and the $L_{A_{nat}}$ differ the most are usually hours with the most human-caused noise, as shown with site TUSK002 at 14:00 and 15:00 (Figure 6). The larger the span of the black bars, the

greater the difference of the existing sound level from estimated natural conditions. At TUSK002, existing sound levels are closest to estimated natural conditions in the early morning hours but depart from estimated natural conditions for most of the day (Figure 6). In general, higher natural ambient sound levels occurred in the late morning hours and were largely due to wind (Figures 5–6, Pennsylvania State University 2024).

Table 6. Summary of summer sound levels at Tule Springs Fossil Beds National Monument (TUSK) in Winter, 2019. Included for each site are 90th percentile (L_{A10}), existing (L_{A50}), natural (L_{Anat}), and 10th percentile (L_{A90}) ambient sound levels (dB re 20 μ Pa, A-weighted broadband, 12.5 Hz–20 kHz) during the day (0700–1900) and night (1900–0700). Note that the high level of noise increases the margin of error in estimating the natural ambient sound level. L_{Anat} may be inaccurate due to the pervasiveness of noise at this site.

Site Name	Time	L_{A10}	L_{A50}	L_{Anat}	L_{A90}
TUSK001	Day	37.3	31.9	26.8	28.9
TUSK001	Night	31.1	28.2	23.9	26.0
TUSK002	Day	33.9	27.3	21.7	22.2
TUSK002	Night	26.5	21.1	18.1	17.7

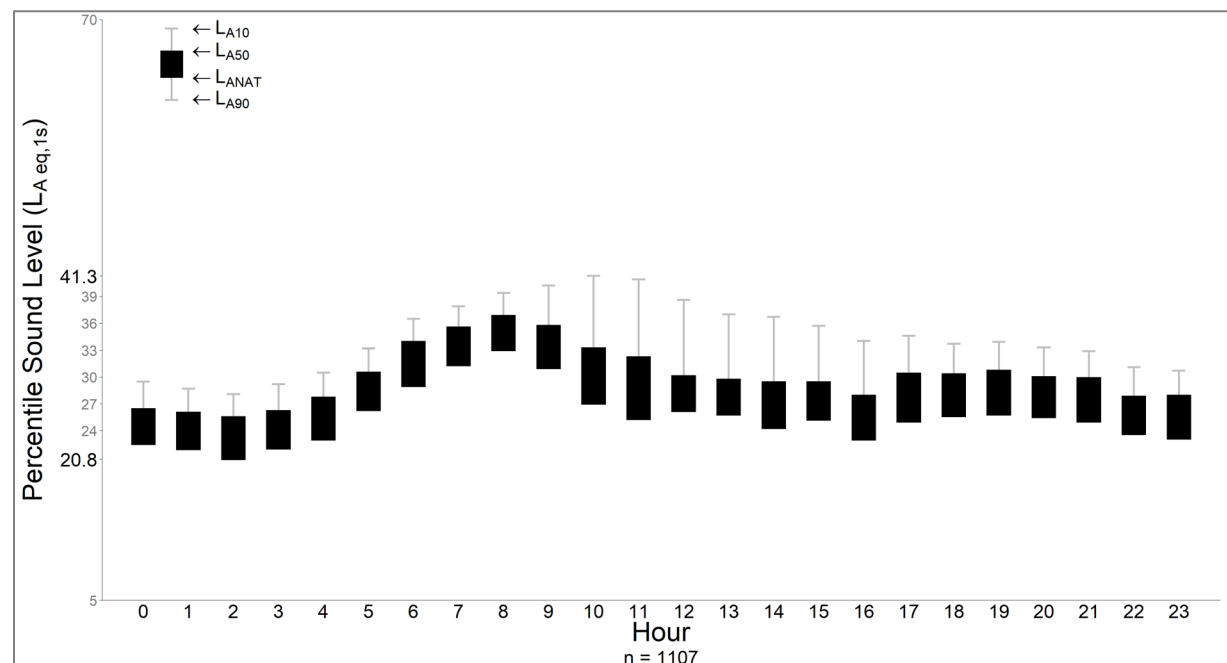


Figure 5. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at TUSK001 in Winter, 2019–2020. Note that the high level of noise increases the margin of error in estimating the natural ambient sound level. L_{Anat} may be inaccurate due to the pervasiveness of noise at this site.

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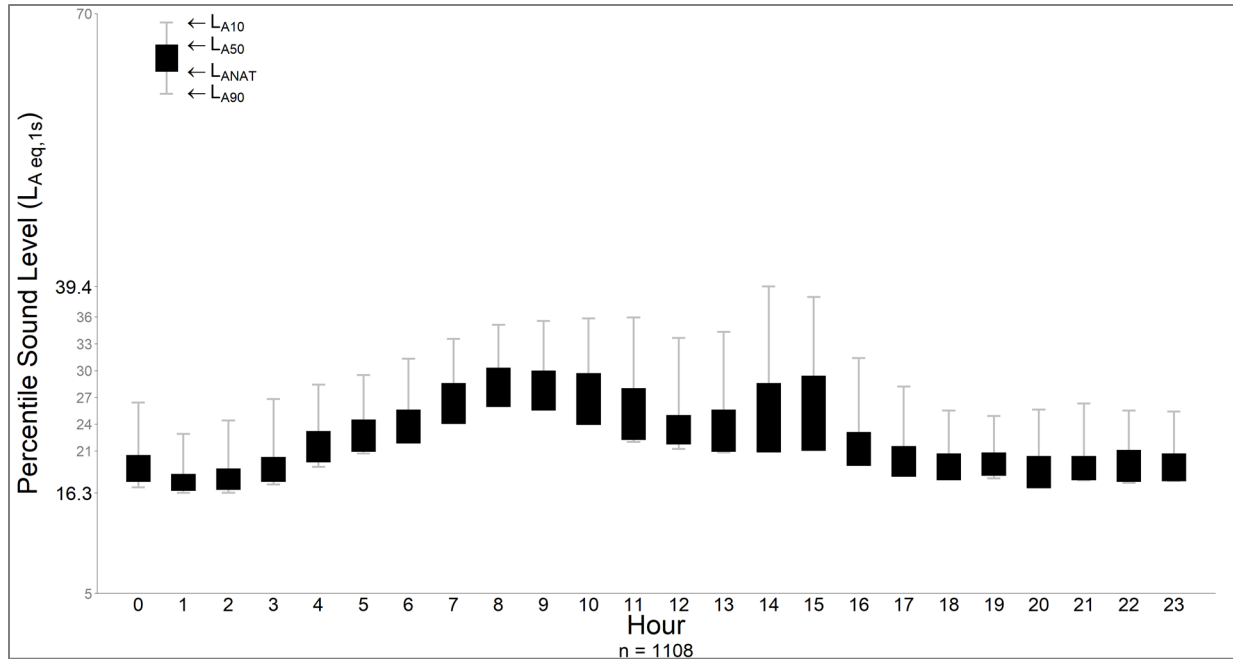


Figure 6. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at TUSK002 in winter, 2019–2020. Note that the high level of noise increases the margin of error in estimating the natural ambient sound level. L_{Anat} may be inaccurate due to the pervasiveness of noise at this site.

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Event duration

Listening Center Software

Through off-site listening analysis, event duration for all audible sounds is calculated and averaged over the listening period. For both sites, mean hourly audibility was obtained for each hour of the day over 10-day listening period (Pennsylvania State University 2024). Hourly audibility is also displayed for all non-natural sources, while also highlighting the top two sources at each site (Figure 7–Figure 8). For example, at TUSK001, noise was audible nearly 100% of the time across all hours of the day. During that time, vehicles were audible throughout the day with a slight decrease from 10:00–16:00 (Figure 7). At TUSK002, noise was audible at least 60% of time across all hours of the day, and the primary contributors were vehicles and unknown non-natural sounds (Figure 8).

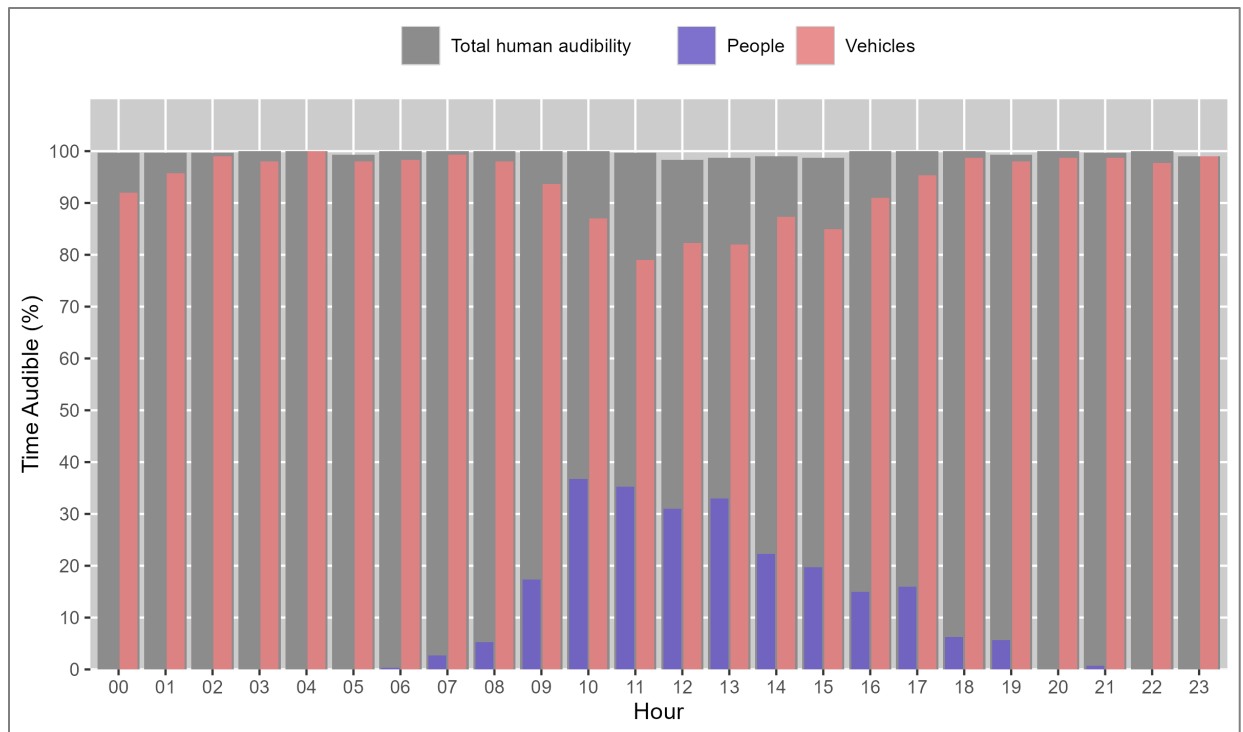


Figure 7. Hourly time audible for the top noise sources and all noise sources at TUSK001 in winter, 2019–2020.

NPS / NSNSD

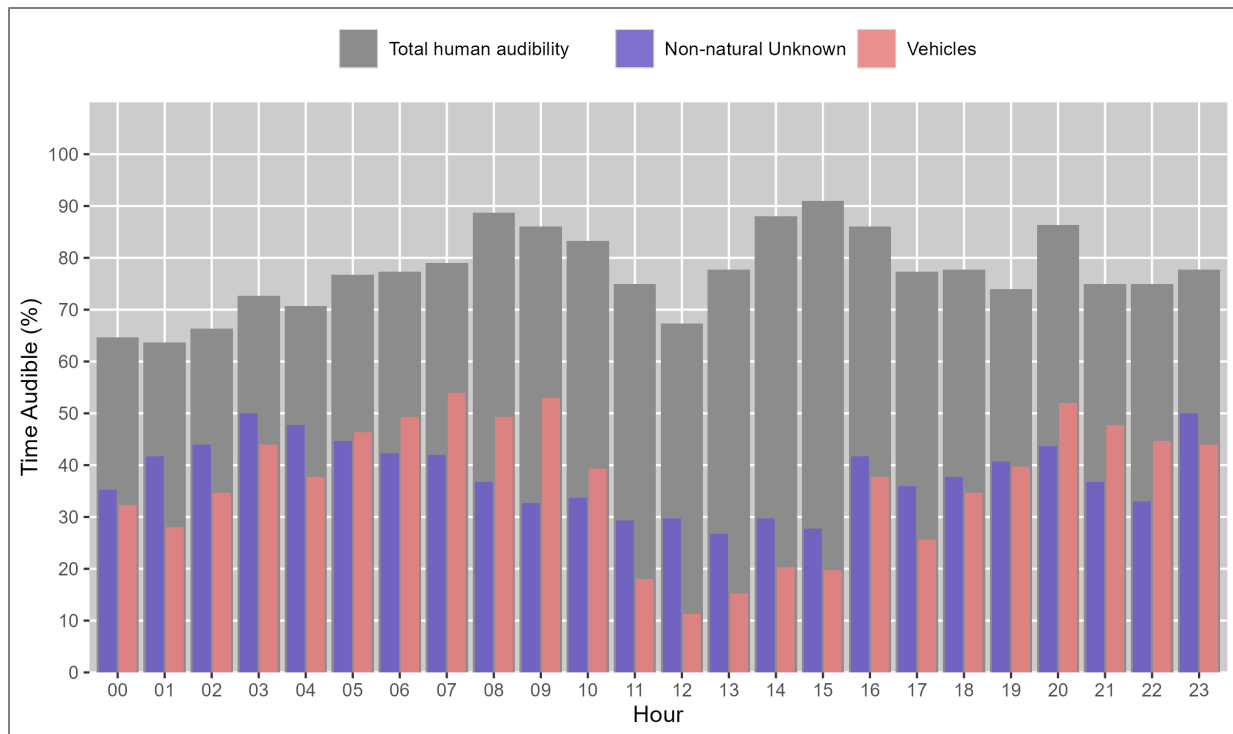


Figure 8. Hourly time audible for the top noise sources and all noise sources at TUSK002 in winter, 2019–2020.

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Conclusions

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) and tranquility (Watts et al. 2020), and by limiting opportunities for solitude or a wilderness experience at the 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 ($L_{Aeq, 1s}$, 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).

This study arose from a technical assistance request from TUSK, which identified the need to improve understanding of the park's acoustic environment. Soundscape data were identified as a need to document baseline conditions and to help evaluate threats from encroaching development. Acoustic measurements allow parks to gain insight into levels of extrinsic noise and biological activity. The results can help estimate the effects of noise on park visitors and wildlife, as well as the condition of the acoustic environment.

To carry out this study, two monitoring sites were placed in distinct areas of the monument that captured varied noise levels, sources, and patterns that exist across TUSK. Results included measures of existing ambient sound levels, calculations of sound source audibility through off-site listening, and estimates of natural ambient sound levels.

At TUSK001, functional effect thresholds were exceeded at the most sensitive sound threshold, 35 dB ($L_{Aeq, 1s}$), 33% of the day and 8% of the night in the ANS-weighted frequency ranges (Table 5). These results are like those in the full frequency range, which indicates that most of the sound energy contributing to this threshold is from lower frequency noise sources. Sound levels at this site were higher than TUSK002, and existing median sound levels (L_{A50}) were 5.1 dB higher than natural sound levels (L_{Anat}) during the day and 4.3 dB higher at night (Table 6). Off-site listening in a subset of data revealed that noise was audible nearly 100% of each hour, every day (Figure 7). The primary noise source was coded as "Vehicles", a source that is not surprising given the proximity of this site to suburban infrastructure. The second most common source was coded as "People", which followed activity patterns of a typical human workday (Figure 7). In addition, gunshots were commonly audible from 7:00–16:00, peaking at 30–40% of each hour from 10:00–13:00 (Pennsylvania State University 2024). Gunshots audible from this site are from a firing range within 1.5 miles to the northwest. Of the two sites, TUSK001 had the highest natural sound level. The energetic contributions to natural sound levels at the site were from wind and birds (Pennsylvania State University 2024).

At TUSK002, functional effect thresholds were exceeded at the most sensitive sound threshold, 35 dB ($L_{Aeq, 1s}$), 11% of the day and 2% of the night in the ANS-weighted frequency ranges (Table 5). These results are like those in the full frequency range, which indicates that most of the sound energy

contributing to this threshold is also from lower frequency noise sources. Sound levels at this site were the lowest of the two sites, and existing median sound levels (L_{A50}) were 5.6 dB higher than natural sound levels (L_{Anat}) during the day and 4.3 dB higher at night (Table 6). Off-site listening in a subset of data revealed that noise was audible from 64–91% of the time across all hours of the day (Figure 8). The primary noise source was “Vehicles” and likely from nearby Highway 95, which parallels the western border of TUSK. The second highest noise source was “Non-natural Unknown”. This source is utilized by off-site listeners when a noise cannot be identified. In general, this unidentified noise source followed the same patterns as vehicles so the origin could be related to the highway as well. Aircraft noise was more audible at TUSK002 than TUSK001, with peak audibility occurring from 13:00–15:00. Finally, gunshots are audible at TUSK002, following similar hourly patterns as TUSK001, but at no more than 6% audibility in any given hour. There is no shooting range at this site but prohibited target shooting often occurs in the area. Of the two sites, TUSK002 had the lowest natural sound level. The energetic contributions to natural sound level at the site was primarily from wind (Pennsylvania State University 2024).

As previously noted, this study reports L_{Anat} despite location specific conditions that partially reduce the accuracy of the sound level calculation. Baseline natural sound levels rely on less frequent noise (target of < 70% audibility) than what exists in TUSK. Because noise was audible for 99% of the day at TUSK001 and 77% of the day at TUSK002, the L_{Anat} reported likely has a higher margin of error than actual baseline conditions. To supplement the measured L_{Anat} results, Appendix B includes modeled sound levels and suggests that the median modeled whole-park noise impact is 5.4 dBA greater than the measured noise impact. For long acoustic records with many repeated values (e.g., at the natural ambient sound level) percentiles offer robust estimates of sound level (Tang and Phillips 2016). However, prevalent noise at TUSK severely censors observations of L_{Anat} and suggests these reported figures overestimate the actual value.

Based on the results of this study, visitors to TUSK likely experience noise throughout their visit. In general, noise at all sites is present during daytime and nighttime hours. The location of TUSK in relation to busy roads, suburban development, and a firing range contributed to the presence of noise at most hours.

Finally, in addition to noise, natural sounds from wildlife, while limited, were audible in the park. Dawn and dusk bird choruses were limited at both sites, and coyotes were the only other common audible animal sound. The lack of animal-derived natural sounds is likely due to monitoring during the winter. Further acoustic analysis, such as artificial intelligence techniques like BirdNET, could generate species lists and daily call patterns from this dataset. In fact, NSNSD worked on another TAR that deployed this technology with acoustic monitoring over multiple seasons and provided unverified bird species information back to TUSK (<https://irma.nps.gov/STAR/Summary/Edit/32069>).

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 what the park sounded like in the winter of 2019–2020.

Sound level data as well as continuous digital audio recordings will be archived with the Natural Sounds and Night Skies Division office in Fort Collins, Colorado.

Literature Cited

- American National Standards Institute (ANSI). 1968. Audiometer Standard 3.6. American National Standards Institute, New York, NY. ANSI/ASA S3.6-2018 (R2023)
- American National Standards Institute (ANSI). 1983. Specification for Sound Level Meters 1.4. American National Standards Institute, New York, NY. ASA/ANSI S1.4-1983 (R2006)
- American National Standards Institute (ANSI). 1992. Quantities and procedures for description and measurement of environmental sound. Part 2: Measurement of long-term, wide-area sound. Accredited Standards Committee S12, Noise. New York, NY. ANSI/ASA S12.9-1992/Part 2 (R2018)
- American National Standards Institute (ANSI). 1994. Outdoor Measurement Of Sound Pressure Level, New York, NY. ANSI/ASA S12.18-1994 (R2009)
- American National Standards Institute (ANSI). 2002. Acoustical Performance Criteria, Design Requirements, And Guidelines For Schools. Melville, NY. ANSI/ASA S12.60-2002 (R2021).
- American National Standards Institute (ANSI). 2014. Methods to Define and Measure the Residual Sound in Protected Natural and Quiet Residential Areas, Melville, NY. ANSI/ASA S3/SC1.100-2014 (R2020)
- Berglund, B., T. Lindvall, and D. H. Schwela (Eds.). 1999. HWO. Guidelines for community noise. World Health Organization, Geneva.
- Betchkal, D. H., J. A. Beeco, S. J. Anderson, B. A. Peterson, and D. Joyce. 2023. Using aircraft tracking data to estimate the geographic scope of noise impacts from low-level overflights above parks and protected areas. *Journal of Environmental Management*, 348. <https://doi.org/10.1016/j.jenvman.2023.119201>
- Betchkal, D.H. and A.W. Hug. 2024. Influence of atmospheric state on variability of long-term sound level measurements in a subalpine valley. In preparation. Environmental Protection Agency.
1974. Information on Levels of Noise Requisite to Protect the Public Health and Welfare with an Adequate Margin of Safety.
- Environmental Protection Agency. 1982. National Ambient Noise Survey. Office of Noise Abatement and Control, Washington, DC.
- Haas, G.E., and T. J. Wakefield. 1998. National parks and the American public: A national public opinion survey on the national park system. Washington D.C. and Fort Collins, CO.: National Parks and Conservation Association and Colorado State University.

- Haralabidis Alexandros, S., K. Dimakopoulou, F. Vigna-Taglianti, M. Giampaolo, A. Borgini, M. L. Dudley, G. Pershagen, G. Bluhm, D. Houthuijs, W. Babisch, M. Velonakis, K. Katsouyanni, and L. Jarup. 2008. Acute effects of night-time noise exposure on blood pressure in populations living near airports. *European Heart Journal Advance Access*. Published online February 12, 2008.
- Harris, C. M. 1998. *Handbook of Acoustical Measurements and Noise Control*, 3rd ed. McGraw-Hill, New York.
- McDonald, C. D., R. M. Baumgarten, and R. Iachan. 1995. Aircraft management studies: National Park Service Visitors Survey. HMMH Report No. 290940.12; NPOA Report No. 94-2, National Park Service, U.S. Department of the Interior.
- Mennitt, Daniel, et al. 2013. Mapping sound pressure levels on continental scales using a geospatial sound model. *Proceedings of Inter-Noise*. 1–11.
- National Park Service. 2005. Acoustic and soundscape studies in National Parks: Draft, Fort Collins, Colorado.
- National Park Service. 2006a. Management Policy 4.9: Soundscape Management.
- National Park Service. 2006b. Management Policy 8.2.3: Use of Motorized Equipment.
- National Park Service. 2013. Acoustic monitoring training manual. Draft, https://www.nps.gov/subjects/sound/upload/NSNSDTrainingManual_AcousticalAmbientMonitoring-508.pdf
- National Park Service. 2019. Foundation Document, Tule Springs Fossil Beds National Monument. https://www.nps.gov/tusk/learn/management/upload/TUSK_FD_508-2.pdf
- National Park Service. 2021. Geospatial Soundscapes Modeling. <https://www.nps.gov/media/video/view.htm?id=89BBDB21-E2F0-4625-AD19-920728CF807E>
- Pennsylvania State University. 2024. Tule Springs Fossil Beds National Monument Acoustic Monitoring Report: Off-site Listening Results. National Park Service. Pennsylvania State University <https://doi.org/10.57830/2308241>
- Pilcher, E.J., P. Newman, P, and R. E. Manning. 2009. Understanding and Managing Experiential Aspects of Soundscapes at Muir Woods National Monument. *Environmental Management* 43: 425–435. <https://doi.org/10.1007/s00267-008-9224-1>
- Poling, J. and D.H. Betchkal. 2023. Use of the noise-free interval (NFI) metric to assess the disturbances of airborne vessel noise at Glacier Bay National Park. In *INTER-NOISE and NOISE-CON Congress and Conference Proceedings* (Vol. 266, No. 2, pp. 991–1002). Institute of Noise Control Engineering.

- Rapoza, A., Sudderth, E., & Lewis, K. 2015. The relationship between aircraft noise exposure and day-use visitor survey responses in backcountry areas of national parks. *The Journal of the Acoustical Society of America*, 138(4), 2090–2105.
- Shannon G, Angeloni LM, Wittemyer G, Fristrup KM, Crooks KR. 2014. Road traffic noise modifies behaviour of a keystone species. *Anim Behav.* 94:135–141.
- Shannon G., M. F. McKenna, L. M. Angeloni, K. R. Crooks, K. M. Fristrup, E. Brown, K. A. Warner, M. D. Nelson, C. White, J. Briggs, S. McFarland, G. Wittemyer. 2016. A synthesis of two decades of research documenting the effects of noise on wildlife. *Biological Reviews* 91(4), 982–1005.
- Templeton, D. (Ed.). 1997. *Acoustics in the built environment: advice for the design team*. Architectural Press, Oxford
- Watts, G., Pearse, J., Delikostidis, I., Kissick, J., Donohue, B., & Dalley, J. (2020). Tranquillity mapping in New Zealand national parks—a pilot study. *Noise Mapping*, 7(1), 303–315.
<https://doi.org/10.1515/noise-2020-0025>
- Weinzimmer, D., Newman, P., Taff, D., Benfield, J., Lynch, E., & Bell, P. 2014. Human responses to simulated motorized noise in national parks. *Leisure Sciences*, 36(3), 251–267.

Appendix A: Site Photos

This appendix displays images of acoustic monitoring systems and sites at TUSK (Figures 9–10).



Figure 9. TUSK001, South Unit site.
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Figure 10. TUSK002, North Unit site.
NPS / NSNSD

Appendix B: Modeled Impact Levels

NSNSD developed a model (Mennitt et al. 2014, NPS 2021) that predicts the median sound level using measurements made in hundreds of national park sites as well as 109 explanatory variables such as location, climate, land cover, hydrology, wind speed, and proximity to noise sources such as roads, railroads, and airports. The resulting model can predict sound levels anywhere in the contiguous United States and estimate how much lower these sound levels would be in the absence of human activities. Each pixel in the graphic shown in Figures 11–13 represents 270 m and represents the acoustic conditions on a typical summer day.

Within TUSK, the model predicted an existing L_{50} of 32.3 dBA (Figure 11) and a natural L_{50} of 21.4 dBA (Figure 12). The modeled difference between the existing and predicted natural sound level ($L_{50\text{impact}}$) at TUSK is shown in Figure 13 and provides a measure of how much anthropogenic noise is increasing the existing sound level above the natural sound level on an average summer day in the park. Across TUSK, the mean modeled sound level impact is 10.7 dBA (ranging from 8.2 dBA in the least impacted areas to 23.4 dBA in the most impacted areas).

For translating sound level impacts into functional effects (for human visitors and resident wildlife), an increase in background sound level of 3 dB produces an approximate decrease in listening area of 50%. In other words, by raising the sound level at TUSK by just 3 dB, the ability of listeners to hear the sounds around them is effectively cut in half. Furthermore, an increase of 7 dB leads to an approximate decrease in listening area of 80%. An increase of 10.7 dBA would reduce the listening area for wildlife and visitors by 91.5%. For example, if a predator can hear a potential prey animal in an area of 100 square feet in a setting with natural ambient sounds, that animal's ability to hear would be reduced to 9.5 square feet if the sound levels were increased by the modeled average impact of 10.7 dBA.

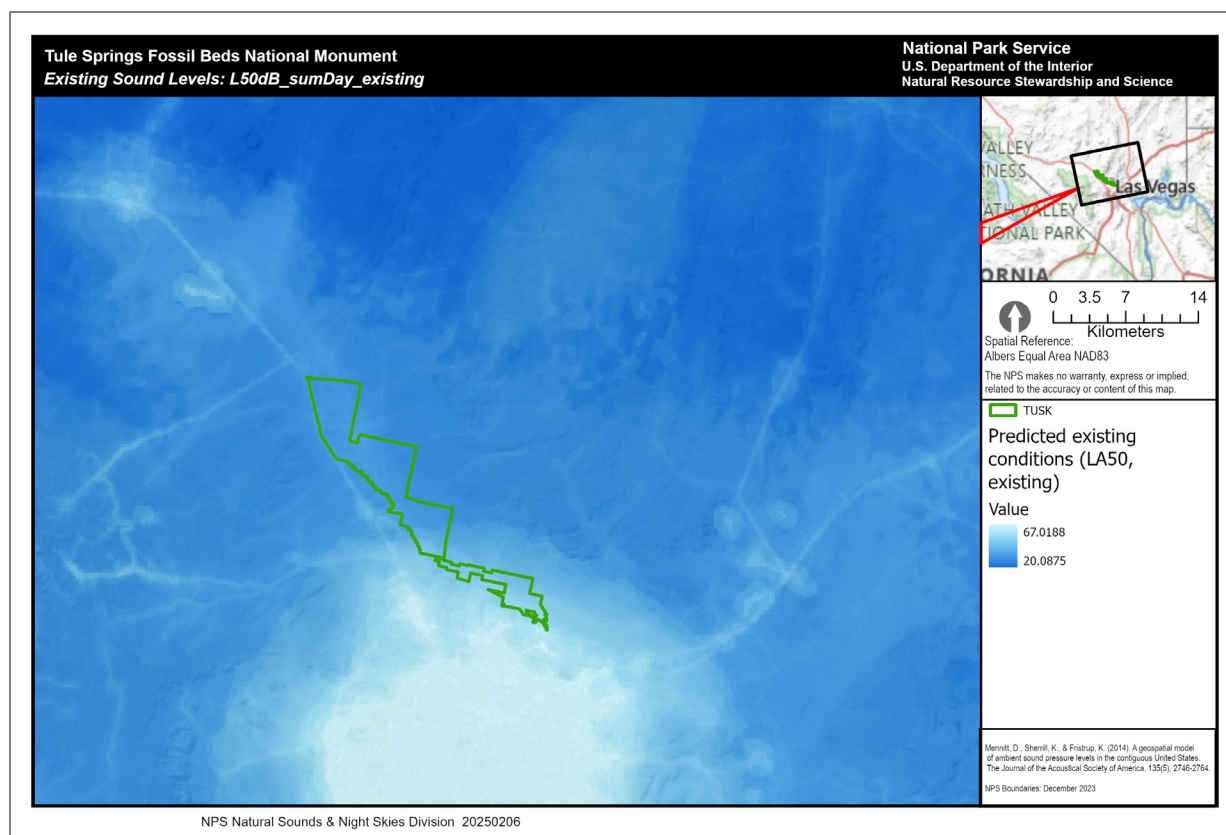


Figure 11. Map of predicted existing acoustic levels in TUSK for an average summer day.
NPS / NSNSD

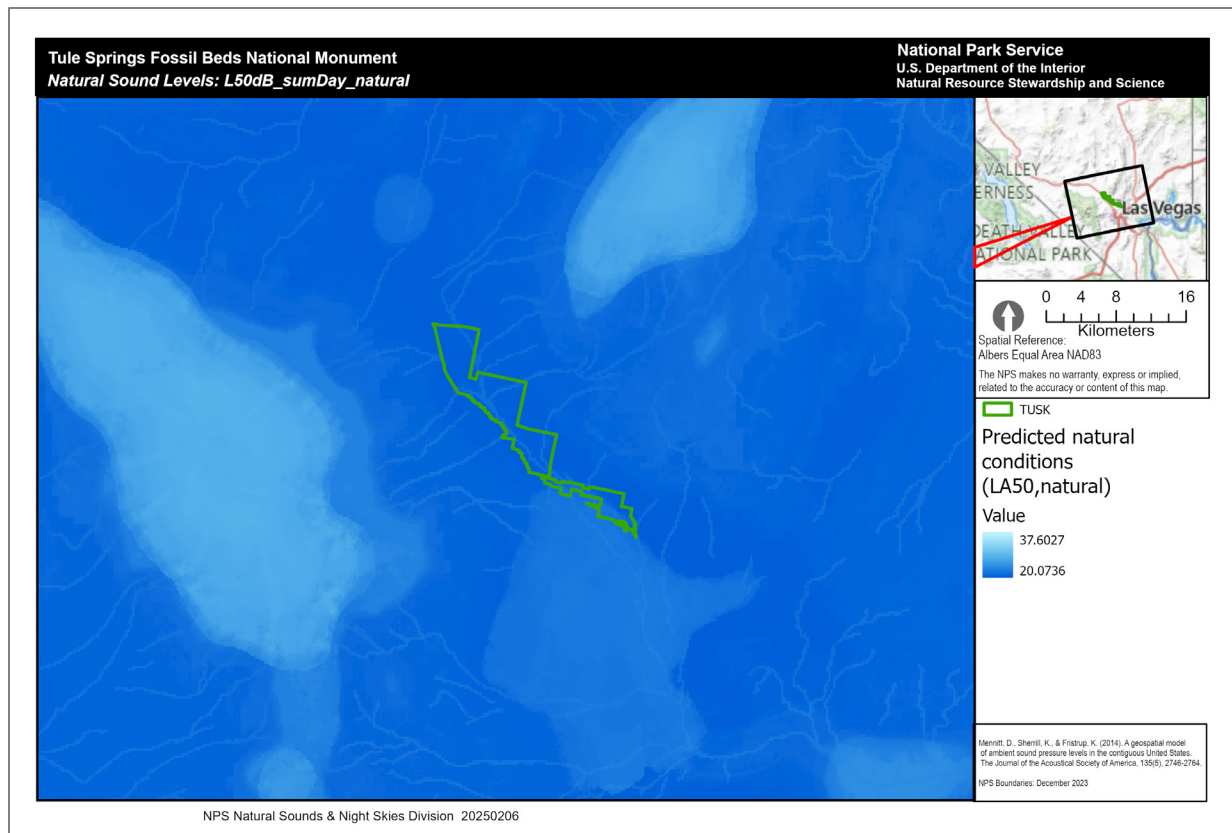


Figure 12. Map of predicted natural acoustic sound levels in TUSK for an average summer day.
 NPS / NSNSD

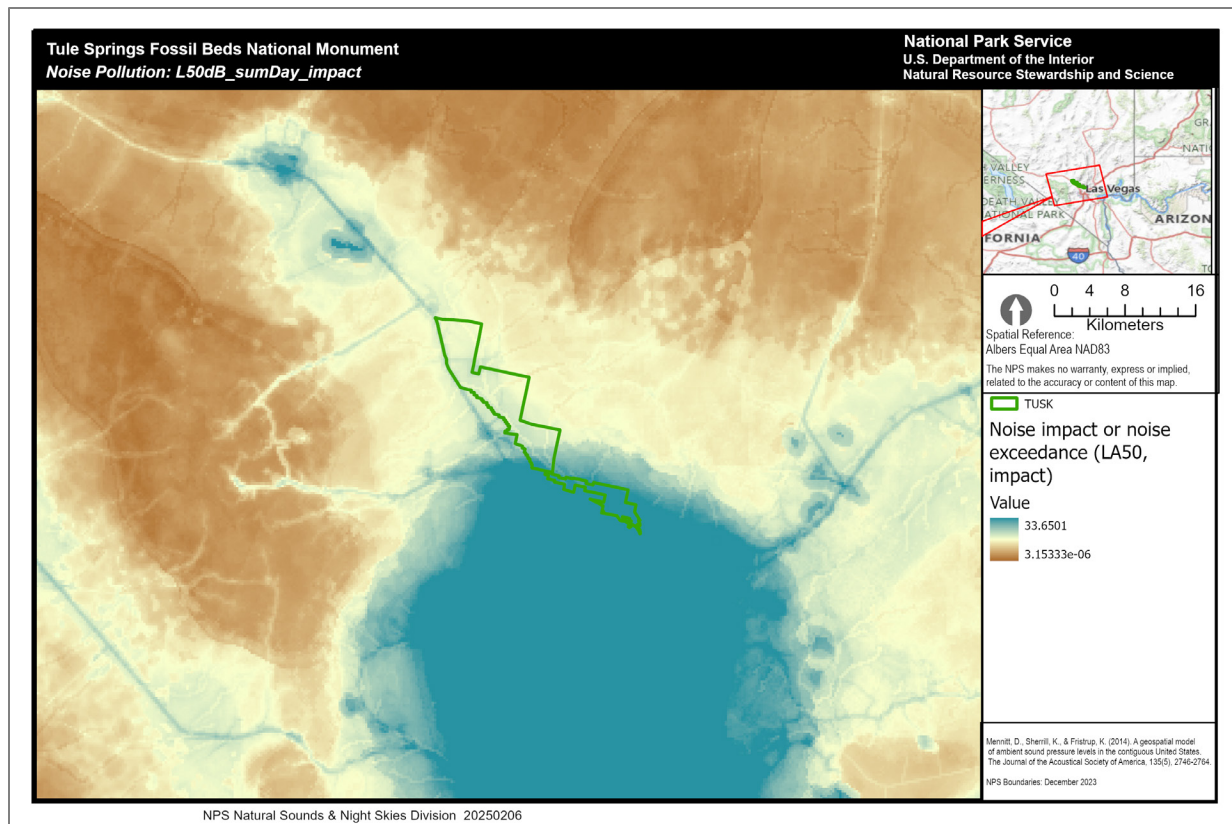


Figure 13. Map of predicted acoustic impact levels in TUSK for an average summer day.
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U.S. Department of the Interior



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