National Park Service
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Natural Resource Stewardship and Science

Fort Union Trading Post National Historic Site

Acoustic Monitoring Report

Natural Resource Report NPS/NRSS/NSNS/NRR—2016/1305

ON THE COVER
Fort Union Trading Post National Historic Site Visitor Center
Photograph by: Dr. Jacob R. Job, NPS

Fort Union Trading Post National Historic Site

Acoustic Monitoring Report

Natural Resource Report NPS/NRSS/NSNS/NRR—2016/1305

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U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
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Contents

Figures

Tables

Appendices

Executive Summary

In 2015, the Natural Sounds and Night Skies Division (NSNSD) received a request to collect baseline acoustical data at Fort Union Trading Post National Historic Site (FOUS). Between August and September 2015, one sound monitoring system was deployed for approximately 20 days. Results indicate that background sound pressure levels without human noise present (natural ambient sound level; L_{nat}) at FOUS001 ranged from 39.7 dBA during the daytime to 36.9 dBA at night. With human noise present (existing ambient sound level; L_{50}), sound pressure levels were higher, ranging from 42.2 dBA during the day to 40.7 dBA at night. The goal of the study was to establish a baseline inventory of the soundscape (collection of all sound and noise sources in an area) at FOUS. This inventory will be used to establish indicators and standards of soundscape quality that will support the park and NSNSD in developing a comprehensive approach to protecting the acoustic environment through soundscape management planning. Results of this study will help the park identify major sources of noise within the park, as well as provide an understanding of the acoustic environment as a whole for use in potential future comparative studies.

For the purposes of this document, we will refer to "noise" as any human-caused sound that masks or degrades natural sounds (Lynch et al. 2011). The most common sources of noise at FOUS include vehicles and trains, while noise generated within the park minimal. Table 1 displays percent time audible values for the major noise sources identified during the monitoring period, as well as existing and natural ambient sound levels (see above). Ambient sound pressure levels were measured continuously every second over the 20 day monitoring period by a calibrated, Type 1, Larson Davis 831 sound level meter. Percent time audible metrics were calculated by trained technicians after monitoring was complete. See Methods section for protocol details and equipment specifications. Median existing (L_{50}) and natural (L_{nat}) ambient metrics are also reported for daytime (7 am–7 pm) and nighttime (7 pm–7 am). See Methods section for detailed information on how these metrics are calculated. Sound pressure levels were partly comprised of noise in the frequencies typically attributed to transportation noise sources (20–1250 Hz), indicating that human activity affects the acoustical environment at FOUS.

Table 1. Mean percent time audible for extrinsic, vehicles, trains, and aircraft; existing and natural ambient sound levels at FOUS001.

		Mean percent time audible (in 24 hour time period)a				Median Existing Ambient (L50) in dBAb		Median Natural Ambient (Lnat) in dBA	
Site ID	**Site Description**	**All Extrinsic**	**Vehicle**	**Train**	**Aircraft**	**Dayc**	**Night**	**Day**	**Night**
FOUS001	Middle Terrace Bench	74.5	42.8	29.2	1.2	42.2	40.7	39.7	36.9

[a] Over a 24-hour period, based on eight days of analysis.

[b] For comparison, nighttime sound level in a typical residential area is about 40 dBA.

[c] Day hours are 0700–1900; night hours are 1900–0700.

In determining the current conditions of an acoustical environment, it is informative to examine how often sound pressure levels exceed certain values. **Error! Not a valid bookmark self-reference.** reports the percent of time that measured levels at FOUS001 were above four key values. The first value, 35 dBA, is designed to address the health effects of sleep interruption. Recent studies suggest that sound events as low as 35 dB can have adverse effects on blood pressure while sleeping (Haralabidis et al. 2008). This is also the desired background sound level in classrooms (ANSI S12.60–2002). The second value addresses the World Health Organization's recommendations that noise levels inside bedrooms remain below 45 dBA (Berglund et al. 1999). The third value, 52 dBA, is based on the Environmental Protection Agency'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 dBA, provides a basis for estimating impacts on normal voice communications at 1 meter. Visitors viewing scenic areas in the park would likely be conducting such conversations. The top value in each split-cell focuses on frequencies affected by transportation noise (20–1250 Hz), whereas the bottom values use the full frequency range (12.5–20,000 Hz) collected. 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. Therefore, the truncated range (20–1250 Hz) is more appropriate for identifying impacts from anthropogenic noise in parks (Acoustical Society of America 2014).

Table 2. Percent time above metrics for FOUS001.

Site ID	Frequency (Hz)	% Time above sound level: 0700 to 1900 (Day)				% Time above sound level: 1900 to 0700 (Night)			
		35 dBA	45 dBA	52 dBA	60 dBA	35 dBA	45 dBA	52 dBA	60 dBA
FOUS001	20-1250	42.2	6.0	1.8	0.4	27.1	6.6	2.7	0.6
	12.5-20,000	94.1	35.8	2.2	0.4	73.1	36.0	4.3	0.7

Acknowledgments

The author of this report wishes to express his sincere gratitude to all who helped make this a successful study, including the employees at FOUS who helped with deployment of the monitoring station, Colorado State University Listening Lab students Henry Joyner and Sean Williams for their work in the off-site acoustical data analysis, and Kathryn Nuessly for her help with the deployment of the monitoring station, as well as feedback on the final report with Emma Brown.

Introduction

A 1998 survey of the American public revealed that 72 percent of respondents thought that providing opportunities to experience natural quiet and the sounds of nature was a very important reason for having national parks, while another 23 percent thought that it was somewhat important (Haas & Wakefield 1998). In another survey specific to park visitors, 91 percent of respondents considered enjoyment of natural quiet and the sounds of nature as compelling reasons for visiting national parks (McDonald et al. 1995). Acoustical monitoring provides a scientific basis for assessing the current status of acoustic resources, identifying trends in resource conditions, quantifying impacts from proposed 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 National Park Service's Natural Sounds and Night Skies Division (NSNSD) helps parks manage sounds in a way that balances access to the park with the expectations of park visitors and the protection of park resources. The NSNSD addresses acoustical issues raised by Congress, National Park Service (NPS) Management Policies, and NPS Director's Orders. The NSNSD works to protect, maintain, or restore acoustical environments throughout the National Park System. Its goal is to provide coordination, guidance, and a consistent approach to soundscape protection with respect to park resources and visitor use. The program also provides technical assistance to parks in the form of acoustical monitoring, data processing, park planning support, and comparative analyses of acoustical environments.

Soundscape Planning Authorities

The National Park Service Organic Act of 1916 states that the purpose of national parks is "… to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." In addition to the NPS Organic Act, the Redwoods Act of 1978 affirmed that, "the protection, management, and administration of these areas shall be conducted in light of the high value and integrity of the National Park System and shall not be exercised in derogation of the values and purposes for which these various areas have been established, except as may have been or shall be directly and specifically provided by Congress."

Direction for management of natural soundscapes[1] is represented in 2006 Management Policy 4.9:

> The Service will restore to the natural condition wherever possible those park soundscapes that have become degraded by unnatural sounds (noise), and will protect natural soundscapes from unacceptable impacts. Using appropriate management planning, superintendents will identify what levels and types of unnatural sound constitute acceptable impacts on park

[1] The 2006 Management Policy 4.9 and related documents refer to "soundscapes" instead of "acoustic resources." When quoting from this authority, it is advisable to note that the term often refers to resources rather than visitor perceptions.

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

Study Area

In 1966, Fort Union Trading Post National Historic Site (FOUS) was established along the Missouri River near the town of Williston, North Dakota to preserve and interpret the site, landscape, archeology, and history of the American Fur Company's Fort Union trading post, which operated from 1828 to 1867. During the summer of 2015, one acoustic monitoring station was deployed in the park. The site was located ~100 m to the west of the entrance road to the park and ~215 m to the south of Route 327 in Montana. Table 3 shows site information for the monitoring station, while Figure 1 shows the location of the acoustic monitoring station.

Table 3. FOUS acoustical monitoring site.

Site ID	Site Name	Dates Deployed	Vegetation	Elevation (m)	Latitude	Longitude
FOUS001	Middle Terrace Bench	8/27/2015 – 9/16/2015	Tall grass and deciduous forest	574.5	48.000909	-104.047505

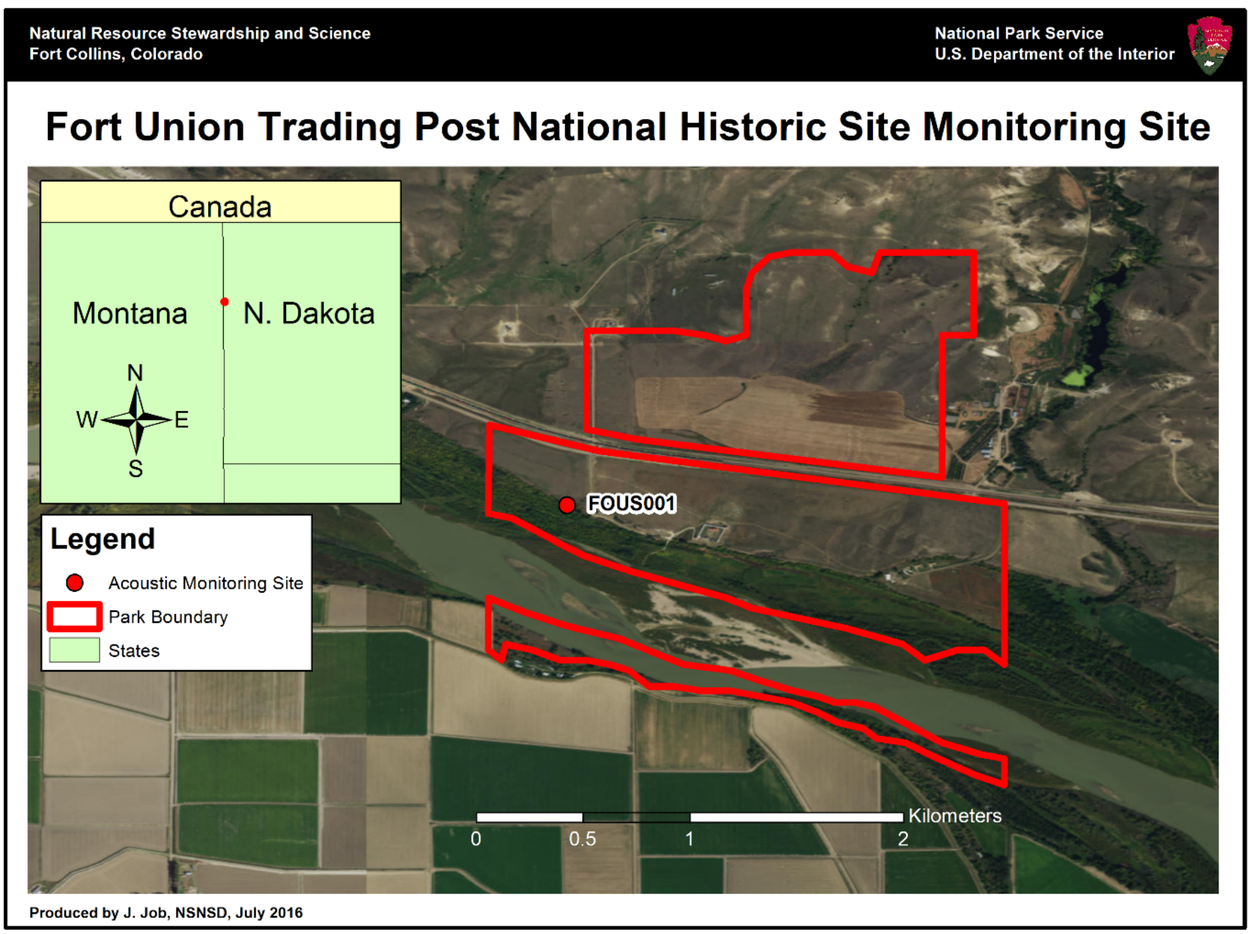

Figure 1. Location of acoustic monitoring site at Fort Union Trading Post National Historic Site.

Methods

Automatic Monitoring

A Larson Davis 831 sound level meter (SLM) was employed over the 20 day monitoring period at the FOUS site. The Larson Davis SLM is a hardware-based, real-time analyzer which constantly records one second sound pressure level (SPL) and 1/3 octave band data. These systems met American National Standards Institute (ANSI) Type 1 standards. Additionally, these sound level meters provided the information needed to calculate metrics described below in Calculation of Metrics.

The sampling station consisted of:

- Microphone with wind and rain protection shroud (see Appendix A Figure 6)
- Preamplifier
- 3.2 V LiFe rechargeable battery packs (9 packs)
- Anemometer (wind speed and direction)
- MP3 recorder

The sampling station collected:

- SPL data in the form of A-weighted decibel readings (dBA) every second
- Continuous digital audio recordings
- One-third octave band data every second ranging from 12.5 Hz–20,000 Hz
- Continuous meteorological data for wind speed

Calculation of Metrics

The current status of the acoustical environment can be characterized by spectral measurements, durations, and overall sound levels (intensities). The NSNSD uses descriptive figures and metrics to interpret these characteristics. Two fundamental descriptors are existing ambient (L_{50}) and natural ambient (L_{nat}) sound levels. These are both examples of exceedance levels, where each L_x value refers to the sound pressure level that is exceeded x% of the time. The L_{50} represents the median sound pressure level and is comprised of spectra (in dB) drawn from a full dataset (removing data with wind speed > 5m/s to eliminate error from microphone distortion). The natural ambient (L_{nat}) is an estimate of what the ambient level for a site would be if all extrinsic (anthropogenic sources) were removed. Unlike the existing ambient, the natural ambient is comprised of spectra drawn from a subset of the original data.

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

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

and P_H is the percentage of samples containing extrinsic or anthropogenic sounds for the hour. For example, if human caused sounds are present 30% of the hour, x = 65, and the L_{nat} 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_{nat} values for the daytime hours (0700–1900) and the median of the hourly L_{nat} values for the nighttime (1900–0700) are displayed in Figure 2 in the results section. Additionally, this figure separates the data into 33 one-third octave bands.

Off-Site Listening/Auditory Analysis

Auditory analysis was used to calculate the audibility of sound sources at FOUS. A trained technician at Colorado State University analyzed a subset of .mp3 samples (10 seconds every two minutes for eight days of audio) in order to identify durations of audible sound sources. Staff used the total percent time extrinsic sounds were audible to calculate the natural ambient sound level for each hour (see Equation 1 above for more information). Bose Quiet Comfort Noise Canceling headphones were used for off-site audio playback to minimize limitations imposed by the office acoustic environment. For the complete results of this thorough audibility analysis, see Table 6 in the Off-Site Data Analysis section below.

Results

Off-Site Data Analysis

Metrics

In order to determine the effect that extrinsic noise audibility has on the acoustical environment, it is useful to examine the median hourly exceedance metrics. The dB levels for 33 one-third octave band frequencies over the day and night periods are shown in Figure 2. High frequency sounds (such as a cricket chirping) and low frequency sounds (such as flowing water) often occur simultaneously, so the frequency spectrum is split into 33 smaller ranges, each encompassing one-third of an octave. For each one-third octave band, dB level was recorded once per second for the duration of the monitoring period. Recording the sound intensity of 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 pressure level of a site. The grayed area of the graph represents sound levels outside of the typical range of human hearing. The exceedance levels (L_x) are also shown for each one-third octave band. They represent the dB level exceeded x percent of the time. For example, L_{90} is the dB level that has been exceeded 90% of the time, and therefore is a measure of the some of the lowest sound levels that may be experience and only the quietest 10% of the samples can be found below this point. On the other hand, the L_{10} is the dB level that has been exceeded only 10% of the time, and therefore is a measure of elevated sound levels and 90% of the measurements are quieter than the L_{10}. The bold portion of the column represents the difference between L_{50} (existing ambient) and L_{nat} (natural ambient). The height of this bold portion is a measure of the contribution of anthropogenic noise to the existing ambient 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 ambient levels were either very close to each other, or were equal.

L_{nat} and L_{50} are bordered above by L_{10} and below by L_{90}, which essentially mark the median (L_{50}), maximum (L_{90}), and minimum (L_{10}) sound pressure levels over the 20 day monitoring period. 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.

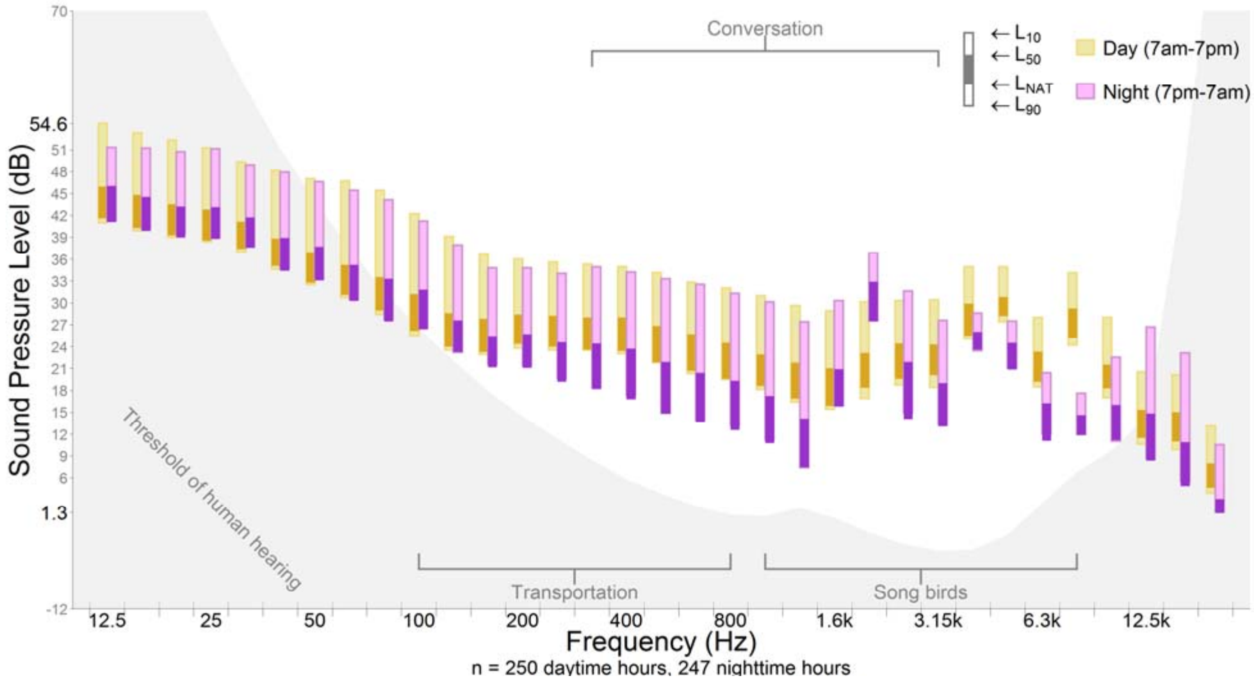

Figure 2. Day and night dB levels for 33 one-third octave bands at FOUS001.

Table 4 reports the L_{90}, L_{nat}, L_{50}, and L_{10} values for the sites measured at FOUS. The top value in each cell focuses on frequencies affected by transportation noise, whereas the lower values use the conventional full frequency range. Most human-caused noise is confined to the truncated, lower-frequency range, while many loud natural sounds, including insects and birds, are higher in pitch. Therefore, the truncated range is more appropriate for identifying noise levels in parks (Acoustical Society of America 2014).

Table 4. Exceedance levels for existing conditions in FOUS.

Site	Frequency (Hz)	Exceedance levels (dBA): 0700 to 1900 hours (Day)				Exceedance levels (dBA): 1900 to 0700 hours (Night)			
		L_{90}	L_{nat}	L_{50}	L_{10}	L_{90}	L_{nat}	L_{50}	L_{10}
FOUS001	20-1,250	28.3	28.6	33.3	41.4	23.2	23.0	29.3	40.1
	12.5-20,000	39.0	39.7	42.2	46.4	37.0	36.9	40.7	46.9

In determining the current conditions of an acoustical environment, it is important to examine how often sound pressure levels exceed certain values. Table 5 reports the percent of time that measured levels were above four key values during the monitoring period (daytime and nighttime). The top value in each split-cell focuses on frequencies affected by transportation noise whereas the lower values use the conventional full frequency range. The first, 35 dBA, is designed to address the health effects of sleep interruption. Recent studies suggest that sound events as low as 35 dB can have adverse effects on blood pressure while sleeping (Haralabidis et al. 2008). This is also the desired background sound level in classrooms (ANSI S12.60-2002). The second value addresses the World

Health Organization's recommendations that noise levels inside bedrooms remain below 45 dBA (Berglund et al. 1999). The third value, 52 dBA, is based on the EPA's speech interference threshold for speaking in a raised voice to an audience at 10 meters (EPA 1974). This threshold addresses the effects of sound on interpretive presentations in parks. The final value, 60 dBA, provides a basis for estimating impacts on normal voice communications at 1 meter. Visitors viewing scenic areas in the park would likely be conducting such conversations. The top value in each split-cell focuses on frequencies affected by transportation noise (20–1250 Hz), whereas the bottom values use the full frequency range (12.5–20,000 Hz) collected. 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. Therefore, the truncated range (20–1250 Hz) is more appropriate for identifying impacts from anthropogenic noise in parks (Acoustical Society of America 2014).

Table 5. Percent time above metrics for existing conditions in FOUS.

Site	Frequency (Hz)	% Time above sound level: 0700 to 1900 (Day)				% Time above sound level: 1900 to 0700 (Night)			
		35 dBA	**45 dBA**	**52 dBA**	**60 dBA**	**35 dBA**	**45 dBA**	**52 dBA**	**60 dBA**
FOUS001	20-1250	42.2	6.0	1.8	0.4	27.1	6.6	2.7	0.6
	12.5-20,000	94.1	35.8	2.2	0.4	73.1	36.0	4.3	0.7

Audibility

Audibility results are presented below. Table 6 shows the mean percentage of time that all noise sources were audible, based on eight days of off-site auditory analysis. Figures 3 and 4 show hourly audibility results and compare overall noise audibility to that of vehicles and trains.

Table 6. Mean hourly percent time audible for each noise source at FOUS001. N=8 days off-site sound source analysis.

Sound Source	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Aircraft	0.4	0.4	0.8	0.0	0.0	0.4	1.2	0.0	0.0	6.7	1.2	1.2	1.2	1.7	0.8	3.8	4.6	1.2	1.7	0.0	0.4	1.2	0.4	0.4
Vehicle	46.3	40.8	39.6	44.6	35.8	57.1	57.5	56.3	62.1	62.1	52.1	44.6	27.9	25.4	31.7	33.7	40.8	39.2	39.6	38.8	44.6	34.6	42.1	29.2
Watercraft	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0
Train	33.7	39.6	39.6	41.7	52.9	40.8	37.1	42.1	38.3	30.4	31.7	20.4	17.5	11.3	19.6	25.4	13.3	32.5	24.2	25	18.3	20.4	18.8	27.1
Grounds care	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	4.2	0.0	0.0	0.0	9.6	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0
People	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0	0
Domestic animal	1.2	0.4	0.0	0.0	0.0	1.2	0.0	0.8	0.0	0.0	0.4	0.0	0.0	0.0	1.2	0.0	0.0	0.0	2.1	1.7	1.2	1.7	0.8	0.8
Building sounds	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0	0
Construction	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0
Non-natural other[a]	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0
Non-natural unknown[b]	1.7	8.3	5.4	6.7	12.1	10.8	9.2	9.6	4.2	4.6	2.5	2.5	0.8	3.8	2.5	7.9	5.0	8.3	11.3	9.2	6.7	5.4	5.8	8.3
Non-natural total	80.4	83.7	82.1	87.5	95.8	98.3	90.4	98.3	97.1	86.7	73.3	62.5	41.3	47.9	54.6	63.3	61.3	75.4	73.8	72.1	69.2	62.1	65.8	64.2

[a] Non-natural other sound sources are uncommon sound sources produced by humans.

[b] Non-natural unknown sound sources are associated with human activity, but their exact identity is unclear.

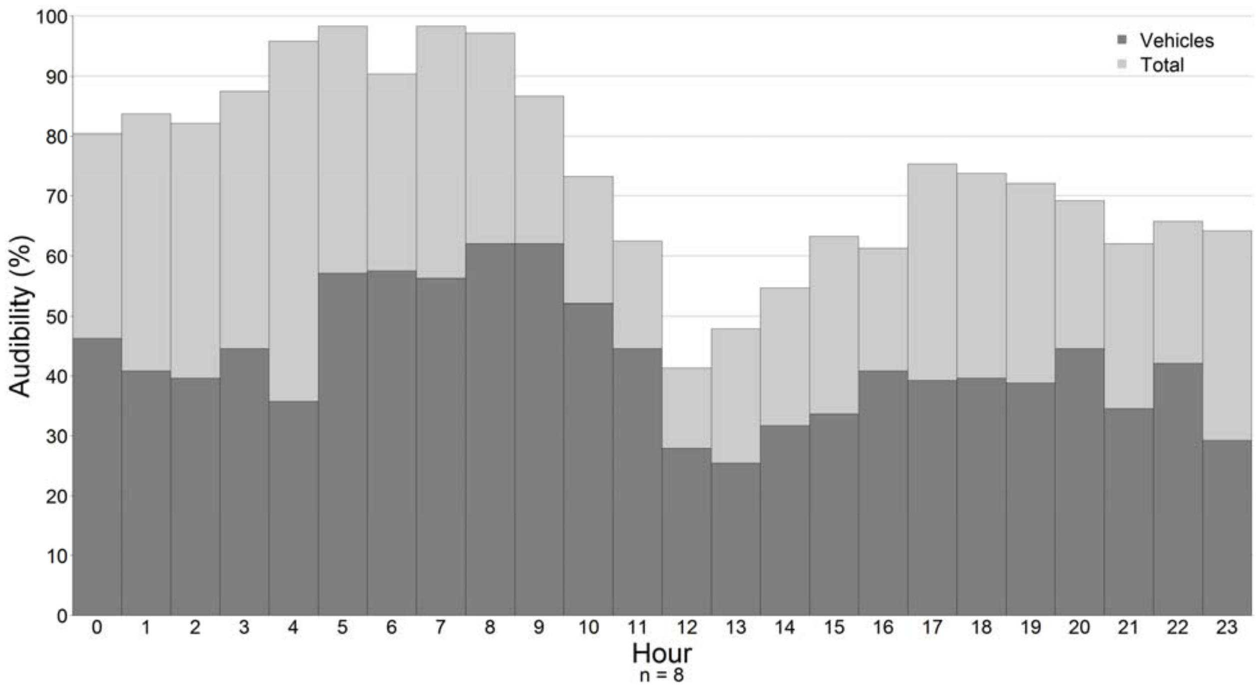

Figure 3. Comparison of hourly vehicle and overall noise audibility at FOUS001. N=8 days off-site sound source analysis.

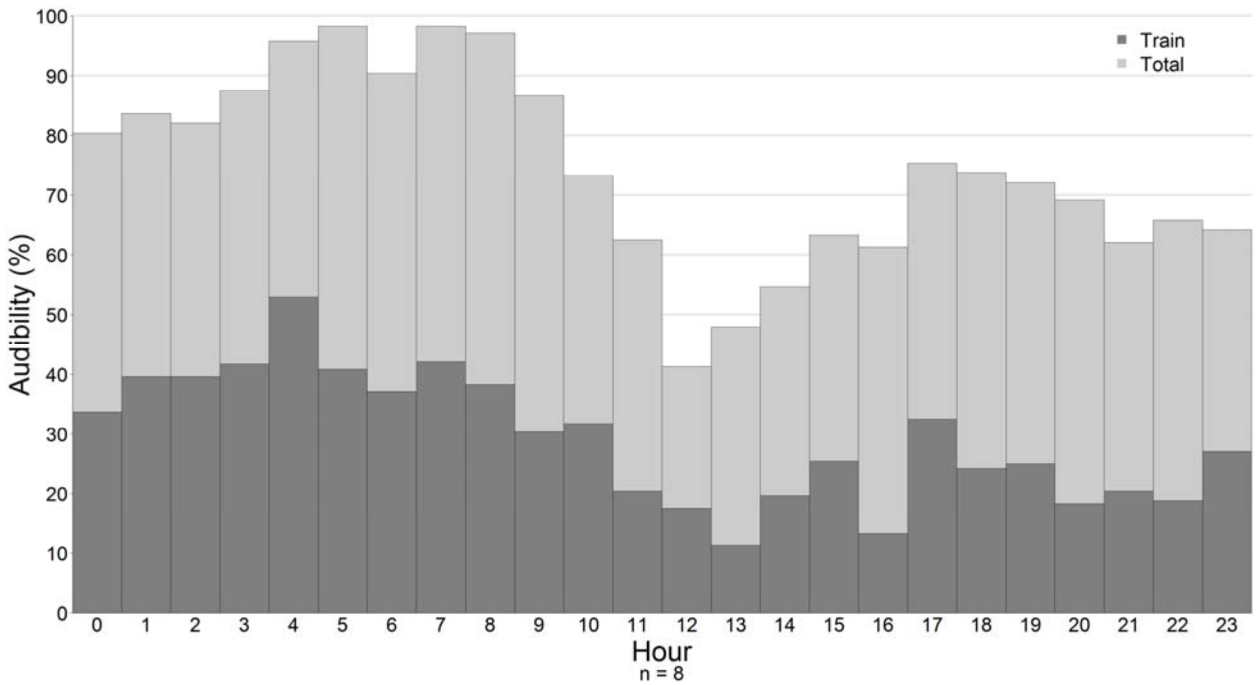

Figure 4. Comparison of hourly train and overall noise audibility at FOUS001. N=8 days off-site sound source analysis.

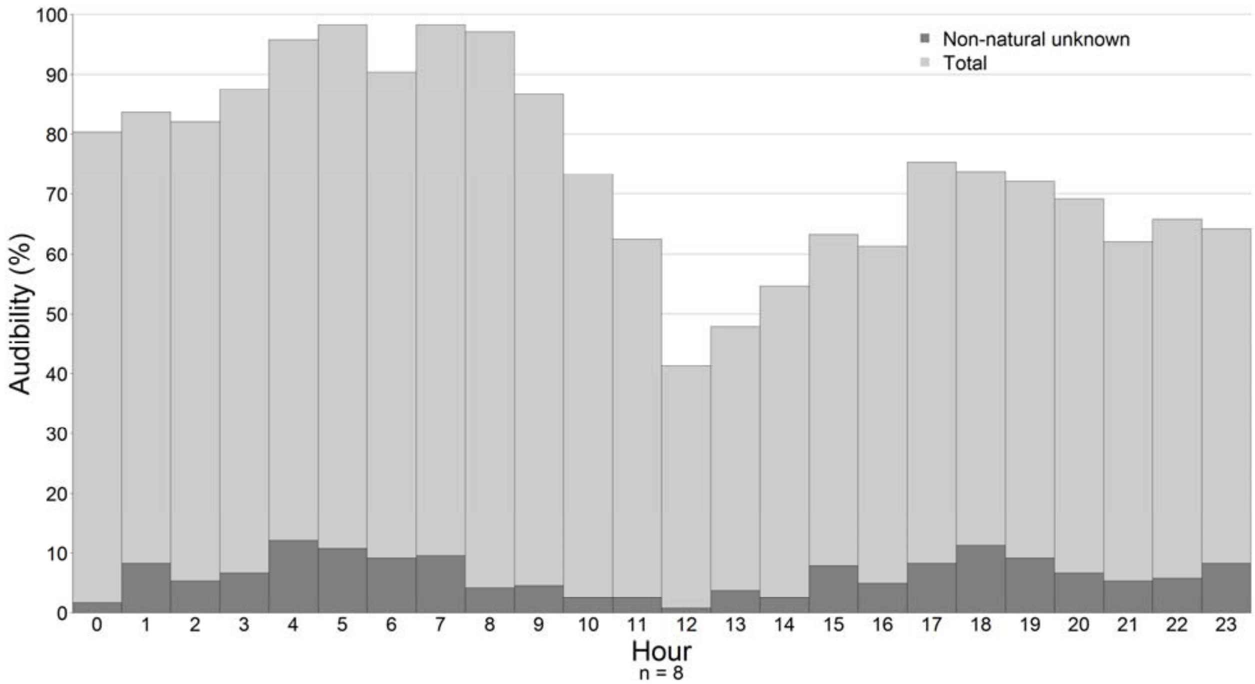

Figure 5. Comparison of hourly non-natural unknown noise sources and overall noise audibility at FOUS001. N=8 days off-site sound source analysis.

Discussion

The purpose of this study was to assess current conditions of the acoustical environment at FOUS. Monitoring results characterize existing sound levels and estimate natural ambient sound levels within the park. The results are intended to provide the park with baseline information, as well as to inform management decisions. Sound pressure level data, meteorological data, and continuous audio were collected from one site for approximately 20 days. The acoustical monitoring station was chosen to best assess the effects of noise from nearby highways and train tracks.

Results indicate that the natural ambient sound level (L_{nat}) at FOUS001 ranged from 39.7 dBA during the daytime to 36.9 dBA at night. Existing ambient sound levels (L_{50}) were higher, ranging from 42.2 dBA during the day to 40.7 dBA at night. For comparison, a comprehensive 1982 study of noise levels in residential areas found that nearly 87% of US residents were exposed to day-night sound levels (L_{dn}) over 55 dB, and an additional 53% were exposed to L_{dn} over 60 dB (EPA 1982). Noise levels have increased nationally with population growth since the EPA study (Suter 1991; Barber et al. 2010). Therefore, the results imply that the natural ambient sound level during the monitoring period was considerably quieter than most residential areas.

Despite the low overall sound pressure levels, noise still exists at FOUS. The mean 24 hour percent time audibility of anthropogenic noise was 74.5% and a detailed analysis of audibility at the monitoring site found that vehicles and trains contributed the most significant instances of noise. Non-natural unknown noise sources were present 6.4% of the time. The acoustic technicians felt that these sources were likely distant vehicles, but were conservative in their designation. In Figure 5, the peaks in these sources during the time periods typically associated with morning and evening rush hour support the idea that at least a portion of these sources could be attributed to vehicles. The likelihood that a portion of the vehicle noise is attributed to energy development is high considering the amount of development in the area; however due to the nature of the acoustic analysis, the acoustic technicians were not able to positively attribute this noise to energy development. From these results, it is unlikely that a visitor to FOUS can experience a significant time period completely free from anthropogenic noise. Furthermore, increased sound levels may have wide ranging effects on wildlife such as reduced predatory success (Mason 2015) and increased vigilance by keystone species (Shannon et al. 2014), partly due to the reduction in effective listening area (Appendix C).

Overall sound pressure levels were in part comprised of noise found in the frequencies typically attributed to transportation-based noise sources (20–1250Hz; dBT), indicating that human activity is affecting the acoustical environment of the park. These sources include those mentioned in the paragraph above, in addition to those in Table 6. The additional noise sources in Table 6 were few and occurred on a limited basis, indicating that noise sources generated within the park likely contributed very little to the overall soundscape. The difference in sound pressure levels between transportation-based noise sources (dBT) and all sound sources (dBA) is considerable, indicating other sound sources were present. Vocalizing insects were audible 92.8% of the time, including

95.1% of daytime hours and 90.4% of nighttime hours. The prevalence of vocalizing insects likely significantly contributed to overall A-weighted[2] sound pressure levels.

[2] See definition for dB in Glossary for more information regarding A-weighting

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Appendix A: Site Photographs

Figure 6. FOUS001, ‘Middle Terrace Bench’ acoustical monitoring site.

Appendix B: Glossary of Acoustical Terms

Term	Definition
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	Include both natural sounds like wind, water, & wildlife and cultural and historic sounds like tribal ceremonies, quiet reverence, and battle reenactments.
Amplitude	The relative strength of a sound wave, described in decibels (dB). Amplitude is related to what we commonly call loudness or volume.
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 an individual animal's hearing ability.
Decibel (dB)	A unit of sound energy. Every 10 dB increase represents a tenfold increase in energy. Therefore, a 20 dB increase represents a hundredfold increase in energy. When sound levels are adjusted for human hearing they are expressed as dBA.
Extrinsic Sound	Any sounds not forming an essential part of the park unit, or a sound originating from outside the park boundary. This could include voices, radio music, or jets flying thousands of feet above the park.
Frequency	Related to the pitch of a sound, it is defined as the number of times per second that the wave of sound repeats itself and is expressed in terms of hertz (Hz). Sound levels are often adjusted ("weighted") to match the hearing abilities of a given animal. In other words, different species of animals and humans are capable or hearing (or not hearing) at different frequencies. Humans with normal hearing can hear sounds between 20 Hz and 20,000 Hz, and as low as 0 dB at 1,000 Hz. Bats, on the other hand, can hear sounds between 20 Hz and 200,000 Hz.
Intrinsic Sound	Belongs to a park by the park's very nature, based on its purposes, values, and establishing legislation. Intrinsic sounds can include natural, cultural, and historic sounds that contribute to the acoustical environment of the park.
L50, L90	Metrics used to describe sound pressure levels (L), in decibels, exceeded 50 and 90 percent of the time, respectively. Put another way, half the time the measured levels of sound are greater than the L50 value, while 90 percent of the time the measured levels are higher than the L90 value.
Ldn	Day-Night Average Sound Level. Average equivalent sound level over a 24-hour period, with a 10-dB penalty added for sound levels between 10 p.m. and 7 a.m.
Leq	Energy Equivalent Sound Level. The sound energy level averaged over the measurement period.
Lnat (Natural Ambient Sound Level)	The natural sound conditions in parks which exist in the absence of any human-produced noise.
Noise Free Interval (NFI)	The length of the continuous period of time during which no human-caused sounds are audible.
Percent Time Above Natural Ambient	The amount of time that various sound sources are above the natural ambient sound pressure levels in a given area. It is most commonly used to measure the amount of time that human-caused sounds are above natural ambient levels. This measure is not specific to the hearing ability of a given animal, but a measure of when and how long human-caused sounds exceed natural ambient levels.

Term	**Definition**
Percent Time Audible	The amount of time that various sound sources are audible to humans with normal hearing. 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. Percent 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 percent time audible is a protective proxy for wildlife. These data can be collected by either 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	The NSNSD differentiates between the use of sound and noise, since these definitions have been used inconsistently in the literature. Although noise is sometimes incorrectly used as a synonym for sound, it is in fact sound that is undesired or extraneous to an environment. Humans perceive sound as an auditory sensation created by pressure variations that move through a medium such as water or air and are measured in terms of amplitude and frequency (Harris 1998; Templeton 1997).
Soundscape	The human perception of physical sound resources.

Appendix C: Modeled Impact Levels

NSNSD developed a model (Mennitt et al. 2014) 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 U.S., and it can also estimate how much lower these sound levels would be in the absence of human activities. The modeled difference between the existing and predicted natural sound level (L_{50} impact) at FOUS is shown in Figure 7, and it 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. At FOUS, the mean modeled sound level impact is 3.6 dBA, and this value represents a close approximation of expected impact levels at a randomly chosen point within the park. Each pixel in the graphic shown in Figure 7 represents 270 m. For reference in 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 in FOUS 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%, and an increase of 10 dB decreases listening area by approximately 90%.

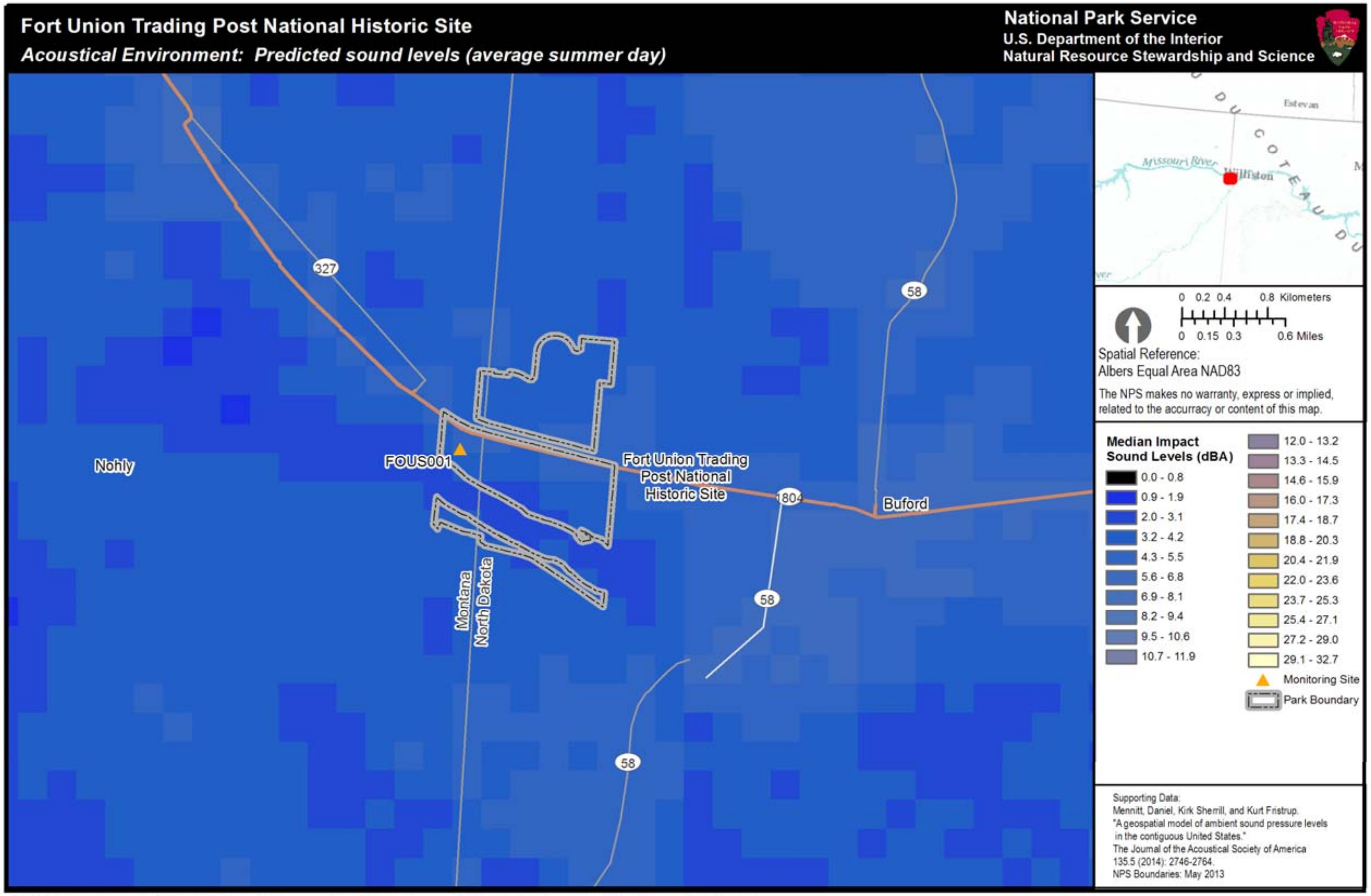

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Figure 7. Modeled median sound level impacts in the area immediately surrounding FOUS and the nearby region (inset). Map of predicted acoustic impact levels in the park for an average summer day. The color scale indicates how much man-made noise increases the sound level (in A-weighted decibels, or dBA), with 270 m resolution. Black or dark blue colors indicate low impacts while yellow or white colors indicate greater impacts. Note that this graphic may not reflect recent localized changes such as new access roads or development. The mean acoustic impact level at the park is 3.6 dBA.

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