National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Rock Creek Park

Acoustic Monitoring Report

Natural Resource Report NPS/NRSS/NSNS/NRR—2016/1189

ON THE COVER
Rock Creek Acoustic Monitoring Site– Photo by Kate Gentry

Rock Creek Park

Acoustic Monitoring Report

Natural Resource Report NPS/NRSS/NSNS/NRR—2016/1189

Scott D. McFarland

National Park Service
Natural Sounds and Night Skies Division
1201 Oakridge Drive, Suite 100
Fort Collins, Colorado 80525

March 2016

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

Data in this report were collected analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

This report is available in digital format from the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/). To receive this report in a format optimized for screen readers, please email irma@nps.gov.

Please cite this publication as:

McFarland, S. M. 2016. Rock Creek Park: Acoustic monitoring report. Natural Resource Report NPS/NRSS/NSNS/NRR—2016/1189. National Park Service, Fort Collins, Colorado.

NPS 821/132201, March 2016

Contents

Figures

Page

Tables

Page

Appendices

Page

Executive Summary

In 2012, the Natural Sounds and Night Skies Division (NSNSD) received a request to collect baseline acoustical data at Rock Creek Park (ROCR). In January 2013 one acoustical monitoring system was deployed for approximately 30 days by park staff and researchers from George Mason University. The goal of the monitoring was to establish a baseline inventory of the soundscape at ROCR. 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 evaluate the potential effects of various man-made sound sources as well as identify the major sources of noise within the park.

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 ROCR are aircraft and vehicles. Table 1 displays percent time audible values for each of these common noise sources during the monitoring period, as well as ambient sound levels. Ambient sound pressure levels were measured continuously every second over the 30 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 – 7am). See Methods section for detailed information on how these metrics are calculated

Table 1. Mean percent time audible for extrinsic, aircraft, and vehicle sounds; existing and natural ambient sound levels.

		Mean percent time audible (in 24 hour time period)[a]			Median Existing Ambient (L_{50}) in dBA[b]		Median Natural Ambient (L_{nat}) in dBA	
Site ID	**Site Description**	**All Extrinsic**	**Aircraft**	**Vehicle**	**Day[c]**	**Night**	**Day**	**Night**
ROCR001	Pinehurst	96.44	32.42	71.68	38.8	34.9	34.8	32.5

[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. Table 2 reports the percent of time that measured levels 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 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 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.

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
ROCR001	20-1250	88.36	7.68	1.06	0.1	52.61	2.02	0.35	0.06
	12.5-20,000	92.4	8.59	1.49	0.1	54.76	2.52	0.47	0.05

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 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) was established in 2011 and 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, 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

Rock Creek Park (ROCR) was established in 1890 and is located in Washington D.C. During the winter of 2013 one acoustic monitoring station was deployed in the park. The monitoring site was located in a relatively undeveloped location within the park away from major noise sources (e.g. traffic corridors). Significant portions of the park are much closer to major sources of noise; therefore, results should only be considered indicative of the immediate area surrounding the monitoring location. Table 3 shows site information for the monitoring station, and Figure 1 shows the locations of the acoustic monitoring stations.

Table 3. ROCR acoustical monitoring site

Site	Site Name	Dates Deployed	Vegetation	Elevation (m)	Latitude	Longitude
ROCR001	Pinehurst	01/08/2013-02/08/2013	Temperate Broadleaf/Mixed	108	38.975375	-77.046316

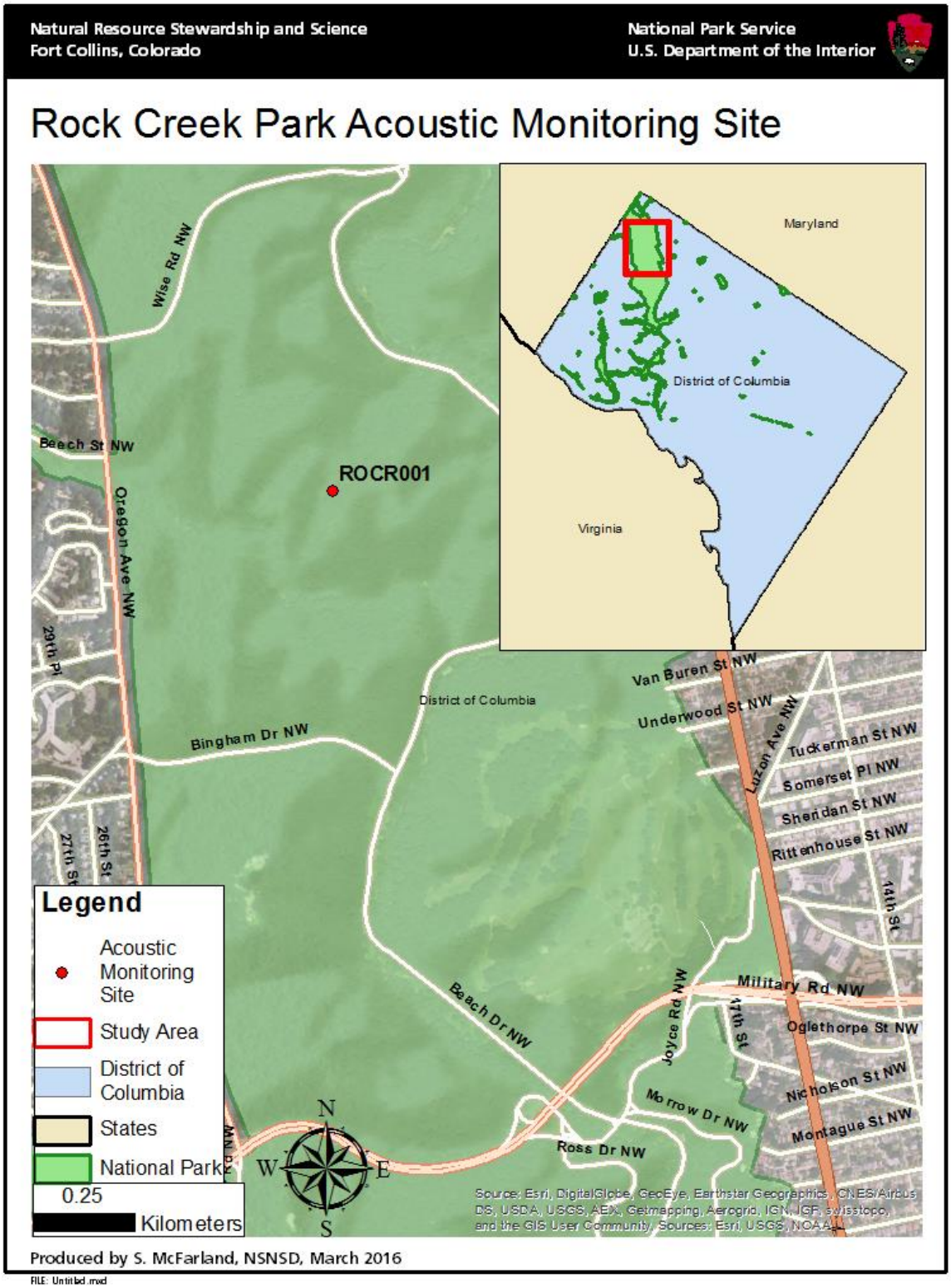

Figure 1. Location of acoustic monitoring site at Rock Creek Park

Methods

Automatic Monitoring

One Larson Davis 831 sound level meter (SLM) was employed over a thirty day monitoring period at the ROCR 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. This Larson Davis-based site met American National Standards Institute (ANSI) Type 1 standards.and provided the information needed to calculate metrics described below in Calculation of Metrics.

The sampling station consisted of:

- Microphone with environmental shroud
- Preamplifier
- 3.2 V LiFe rechargeable battery packs (9 packs)
- Anemometer (wind speed and direction)
- Temperature and humidity probe
- 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 including wind speed, direction, temperature, and relative humidity

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 or 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):

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

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 ROCR. Trained technicians 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 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 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} (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}) sounds pressure levels over the 30 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.

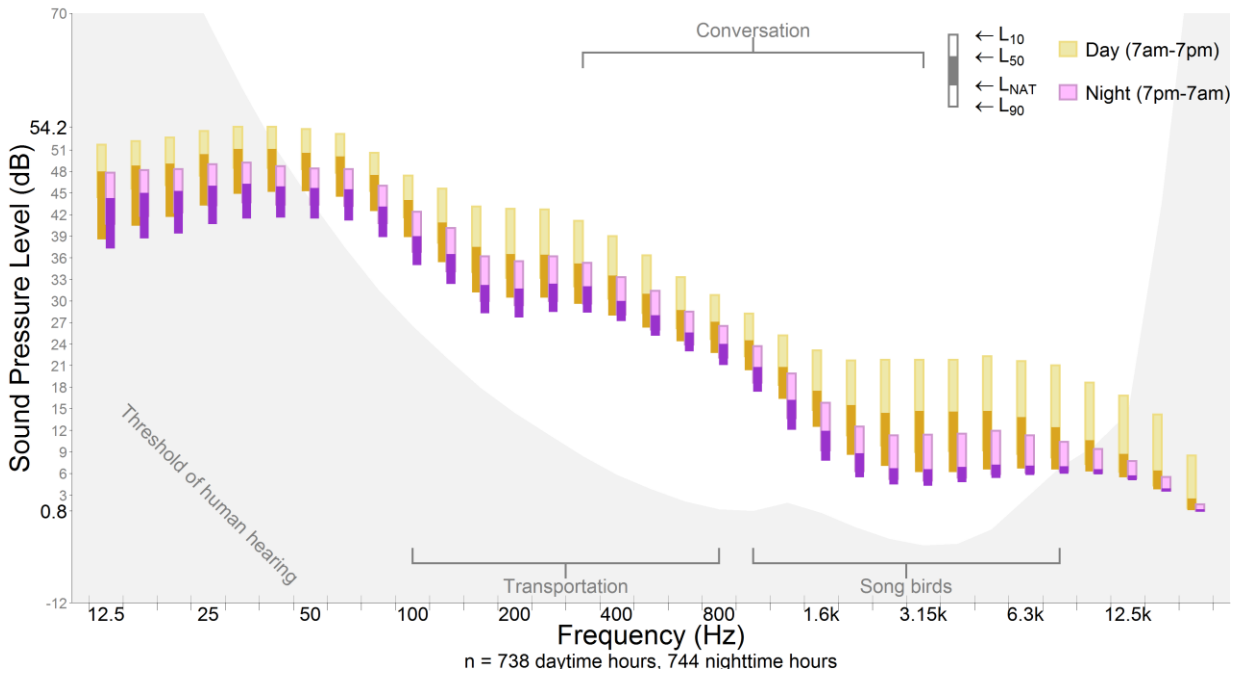

Figure 2. Day and night dB levels for 33 one-third octave bands at ROCR001

Table 4 reports the L_{90}, L_{nat}, L_{50}, and L_{10} values for the site measured at ROCR. 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 ROCR

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}
ROCR001	20-1,250	36.0	34.4	38.3	43.5	32.9	32.0	34.6	37.7
	12.5-20,000	36.6	34.8	38.8	44.1	33.3	32.5	34.9	38.4

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, 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 ROCR

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
ROCR001	20-1250	88.36	7.68	1.06	0.1	52.61	2.02	0.35	0.06
	12.5-20,000	92.4	8.59	1.49	0.1	54.76	2.52	0.47	0.05

Audibility

Audibility results are presented below in Table 6. The table shows the mean percentage of time that all noise sources were audible, based on eight days of off-site auditory analysis. Figure 3 shows hourly audibility results and compares overall noise audibility to the audibility of aircraft while Figure 4 shows hourly audibility results and compares overall noise audibility to the audibility of vehicles.

Table 6. Mean hourly percent time audible for each noise source at ROCR001. 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	6.2	5.4	4.6	9.2	10.4	14.2	33.3	38.8	40.4	46.3	47.5	39.2	42.9	36.2	47.1	46.3	45.8	46.3	44.6	42.5	43.8	30.8	35	21.2
Vehicle	84.2	86.7	83.7	84.6	92.1	86.7	61.7	67.5	68.8	64.2	64.2	67.1	64.2	70.8	61.7	60.4	60.4	59.6	64.2	69.6	68.3	76.2	71.3	82.1
Train	0.4	1.2	0	2.9	1.7	1.2	0.8	1.2	0.4	1.2	0	0.8	0.8	0.4	1.2	0.8	1.2	0.4	0	0.4	0.4	0	0.4	0
People	0	0	0	0	0	0	0	0.4	3.8	0.4	2.5	1.7	7.1	3.3	4.2	0.4	3.3	2.5	0.8	0	0	0.4	0	0.4
Dog	1.2	0	0	0	0	0.8	0.4	0.4	0	0	1.2	0.4	0	0.4	0	0	0	0.4	0.4	2.1	0.4	0.4	0.8	0
Construction	0	0	0	0	0	0	0	0	0.4	0.8	0.8	3.3	0.4	0.4	0.4	0	0	0	0	0	0.4	0	0	0.4
Non-Natural Other	0	0	0	0	0	0	0.4	0	0	0	0.4	1.2	0.4	0	0	0	0	0	0	0	0	0	0	0
Non-Natural Unknown	1.7	0.8	1.2	1.2	1.2	0.8	2.5	1.2	5.8	9.2	13.3	10.4	11.3	5	4.2	7.5	2.5	1.7	0	0.8	0.4	0	0.4	0.4

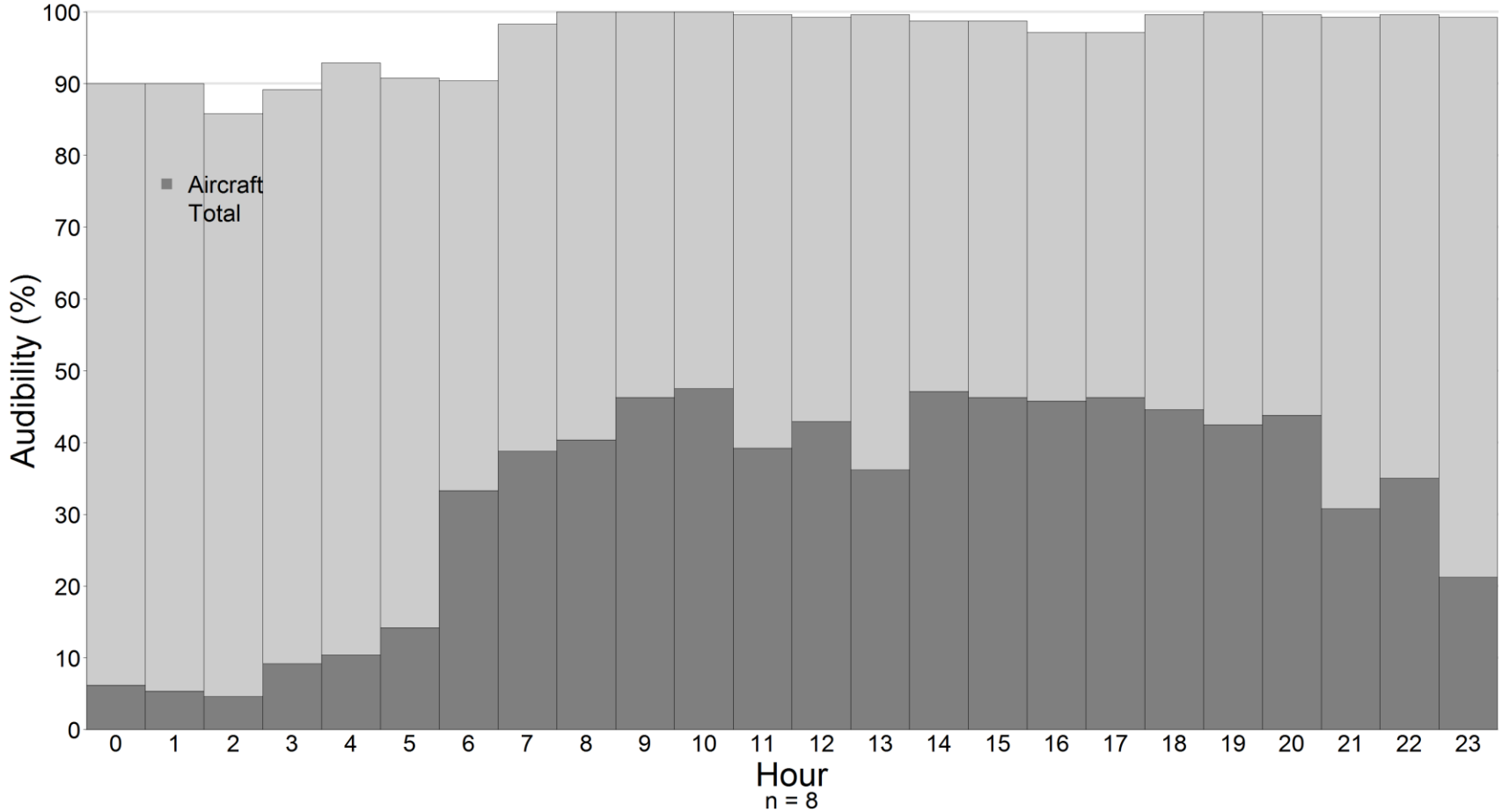

Figure 3: Comparison of hourly aircraft audibility and overall noise audibility at ROCR001

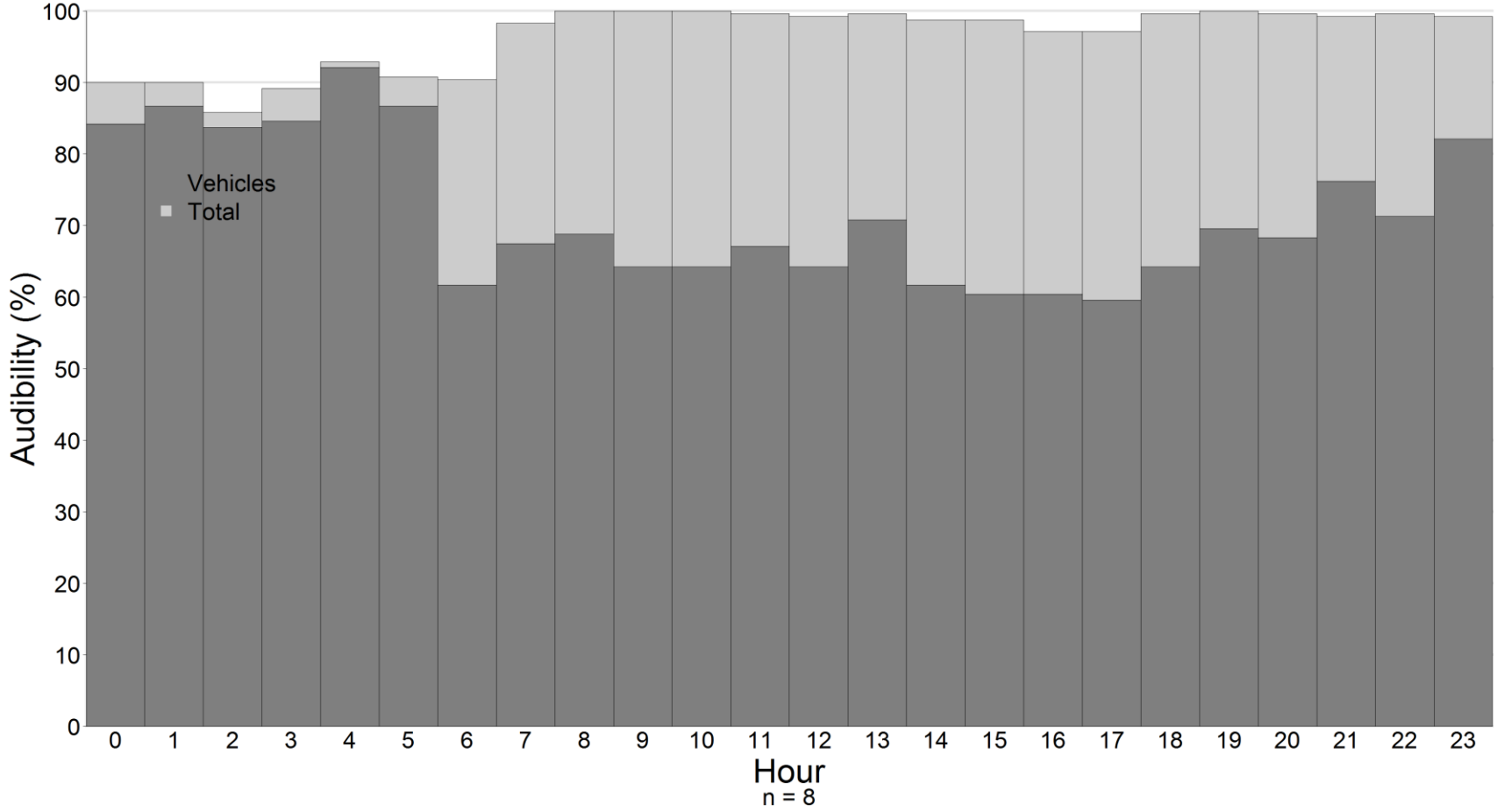

Figure 4: Comparison of hourly vehicle audibility and overall noise audibility at ROCR001

Discussion

The purpose of this study was to assess current conditions of the acoustical environment at ROCR. Monitoring results characterize existing sound levels and estimate natural ambient sound levels within the park, which 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 30 days.

Results indicated that the natural ambient sound level (L_{nat}) ranged between from 34.8 dBA during the daytime and to 32.5 dBA at night. Existing ambient sound levels (L_{50}) were higher, ranging from 38.8 dBA during the day to 34.9 dBA at night. Although the difference between natural ambient and existing ambient may seem small, an increase of just 3dB in the natural ambient is equivalent to a doubling of the acoustic intensity and leads to a 50% reduction in listening area (Barber et al. 2010). 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).

Despite the relatively low overall sound levels, noise still exists in the ROCR acoustical environment. The mean 24 hour percent time audibility of anthropogenic noise at the acoustic monitoring site was 96.44% and a detailed analysis of audibility at the site found that two major noise sources, aircraft (32.42%) and vehicles (71.68%), contributed the most significant amounts of noise. From these results, it is unlikely that any visitor to ROCR will experience any time period free from anthropogenic noise while within the park.

Since much of the park is close to major sources of noise, the results from this study should only be considered indicative of conditions in the immediate area surrounding the monitoring location. The results from the single acoustic monitoring station should not be used to indicate the state of the acoustic environment in other locations of the park. A broader analysis of the acoustic environment has been completed using modeling and the results this analysis is included in Appendix B.

ROCR provides a relative acoustic sanctuary for both humans and wildlife when contrasted to its developed surroundings and the ambient levels within portions of the park are significantly quieter than most residential areas. Therefore, it is important to recognize the low ambient sound levels within the park and take steps to protect the acoustic environment from further degradation while working towards mitigating current impacts from both internal and external sources.

Literature Cited

Acoustical Society of America. 2014. Methods to Define and Measure the Residual Sound in Protected Natural and Quiet Residential Areas, Melville, NY. ANSI/ASA S3/SC1.100-2014.

Barber J.R., C. Crooks, and K. Fristrup. 2010. The costs of chronic noise exposure for terrestrial organisms. Trends in Ecology and Evolution 25:180–189.

Berglund, B., T. Lindvall, and D. H. Schwela (Eds.). 1999. HWO. Guidelines for community noise. World Health Organization, Geneva.

Environmental Protection Agency. Information on Levels of Noise Requisite to Protect the Public Health and Welfare with an Adequate Margin of Safety, March 1974.

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., et. al. 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.

Lynch, E., D. Joyce, and K. Fristrup. 2011. An assessment of noise audibility and sound levels in U.S. National Parks. Landscape Ecology 26: 1297-1309.

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, D., K. Sherrill, and K. Fristrup. 2014. A geospatial model of ambient sound pressure levels in the contiguous United States. Journal of the Acoustical Society of America 135:2746-2764.

National Park Service. 2005. Acoustic and Soundscape Studies in National Parks: Draft. Fort Collins, CO: NPS Natural Sounds and Night Skies Division.

National Park Service. 2006a. Management Policy 4.9: Soundscape Management.

National Park Service. 2006b. Management Policy 8.2.3: Use of Motorized Equipment.

Suter, A. H. Noise and its Effects. Administrative Conference of the United States, 1991. Available at: http://www.nonoise.org/library/suter/suter.htm (accessed 17 January 2014)

Templeton, D (Ed.). 1997. Acoustics in the built environment: advice for the design team. Architectural Press, Oxford

Appendix A: 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 dB(A).
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.
L_{50}, L_{90}	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 L_{50} value, while 90 percent of the time the measured levels are higher than the L_{90} value.
L_{dn}	Day-Night Average Sound Level. Average equivalent sound level over a 24-hour period, with a 10-dB penalty added for sound levels between 10 p.m. and 7 a.m.
L_{eq}	Energy Equivalent Sound Level. The sound energy level averaged over the measurement period.
L_{nat} (Natural Ambient Sound Level)	The natural sound conditions in parks which exist in the absence of any human-produced noise.
Listening Area	The area of a circle whose radius is the alerting distance.
Noise Free Interval (NFI)	The length of the continuous period of time during which no human-caused sounds are audible.

Term	Definition
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.
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 B: 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 ROCR is shown in Figure 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. At ROCR, the mean modeled sound level impact is 14.1 dBA or about 25 times the acoustic intensity. 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 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 ROCR 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%.

> *The results from the acoustic monitoring station are not directly comparable to those from the model due to two major factors. The first factor is L50 levels within the park vary drastically and are correlated to the distance from major roads. The acoustic monitoring site was located in one of the quietest locations in the park whereas the model predicts the average over the entire park. The second important factor in variance between the model and measured results is due to seasonal differences. The model predicts summer season day time levels only and the acoustic monitoring occurred in winter.

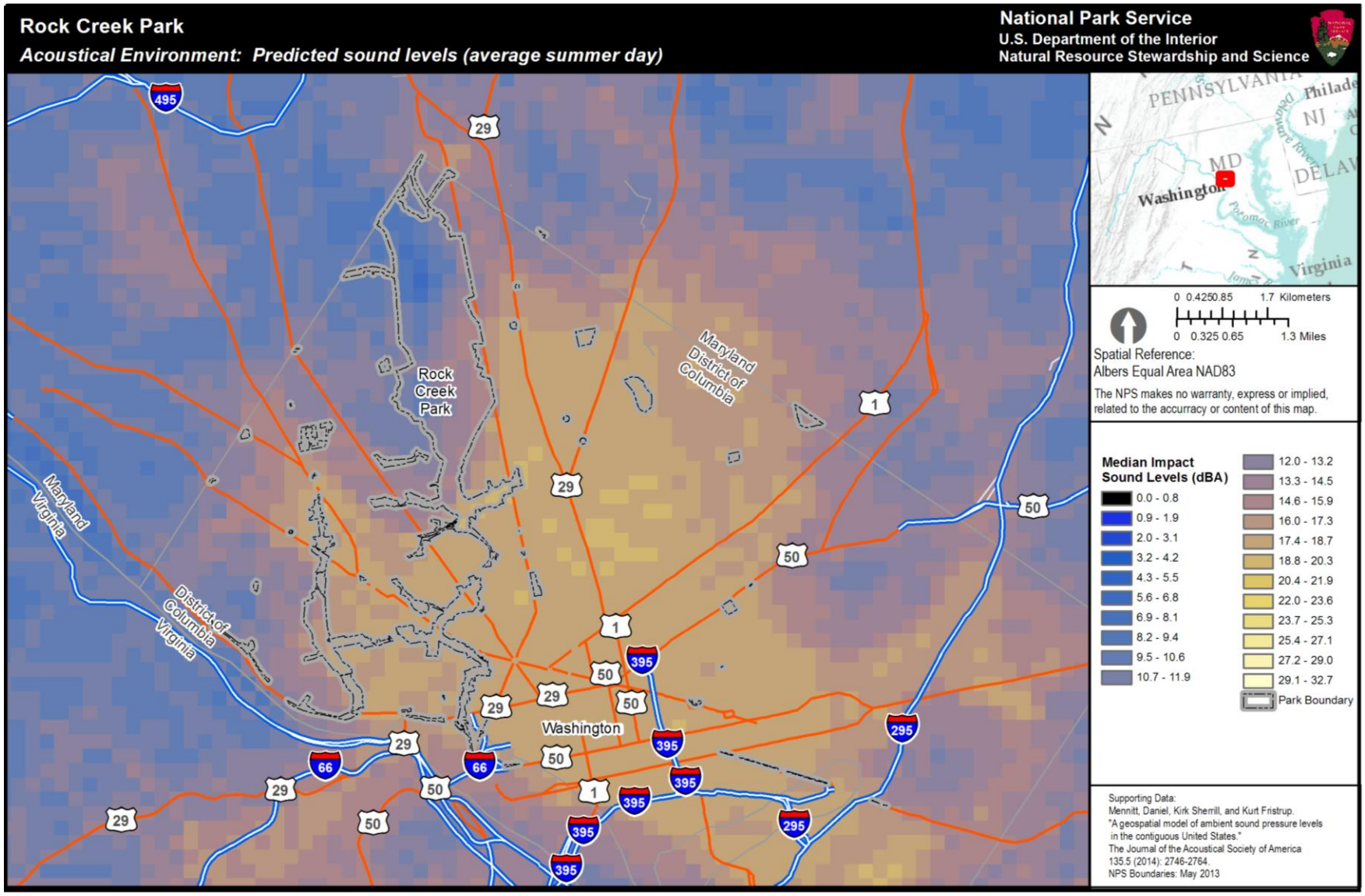

Figure 5. Modeled median sound level impacts in the area immediately surrounding ROCR and in the nearby region (inset)

Appendix C: Acknowledgements

The Natural Sounds and Night Skies Division would like to thank Bill Yeaman from the Resource Management Division of ROCR and Katherine Gentry of George Mason University for their efforts with deploying, monitoring, and retrieving the acoustic system. Their collaboration and support was instrumental in collecting the data for this study.

NPS 328/126978, October 2014

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov