



# Fort Raleigh National Historic Site

## *Acoustic Monitoring Report*

Natural Resource Report NPS/NRSS/NSNS/NRR—2015/1067





**ON THIS PAGE**

FORA002 Acoustic Monitoring System  
Photograph by: NPS

**ON THE COVER**

FORA001 Acoustic Monitoring System  
Photograph by: NPS

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# **Fort Raleigh National Historic Site**

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Natural Resource Report NPS/NRSS/NSNS/NRR—2015/1067

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## Executive Summary

In 2011, the Natural Sounds and Night Skies Division received a request to collect baseline acoustical data at Fort Raleigh National Historic Site (FORA). During the month of September 2011, two acoustical monitoring systems were deployed for approximately 30 days. The goal of the technical assistance request was to complete a baseline soundscape inventory. This inventory will be used to establish indicators and standards of soundscape quality that will support the park in developing a comprehensive approach to soundscape management planning.

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 FORA include vehicles, aircraft, and motors. 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, motor, vehicle, and people sounds; existing and natural ambient sound levels.

Site ID	Site Description	Mean percent time audible (in 24 hour time period) <sup>a</sup>					Median Existing Ambient ( $L_{50}$ ) in dBA <sup>b</sup>		Median Natural Ambient ( $L_{nat}$ ) in dBA	
		All Extrinsic	Aircraft	Motors	Vehicle	People	Day <sup>c</sup>	Night	Day	Night
FORA001	VC Parking	92.60	12.70	78.59	10.60	2.29	43.5	46.1	38.5	46.1
FORA002	Park Housing	71.66	13.27	53.11	6.50	2.46	42.1	45.8	38.3	44.5

<sup>a</sup> Over a 24-hour period, based on eight days of analysis.

<sup>b</sup> For comparison, nighttime sound level in a typical residential area is about 40 dBA.

<sup>c</sup> 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.

**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
FORA001	20-1250	78.77	17.18	2.92	0.48	30.70	1.41	0.31	0.07
	12.5-20,000	98.36	42.81	16.35	1.67	100.00	65.98	5.58	1.83
FORA002	20-1250	76.79	9.85	1.47	0.26	29.24	1.48	0.28	0.05
	12.5-20,000	91.16	27.04	6.00	0.66	99.94	60.46	4.69	0.93

## 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) 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<sup>1</sup> 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 natural soundscapes. The frequencies, magnitudes, and durations of acceptable levels of

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<sup>1</sup> 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.

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

Fort Raleigh National Historic Site preserves and protects outstanding natural, cultural, and archaeological resources in North Carolina associated New World English settlements. During the fall of 2011, two acoustical monitoring stations were deployed at FORA. The sites (FORA001 and FORA002) were selected to represent the typical acoustical conditions of the park. Table 3 shows site information for the monitoring stations, and Figure 1 shows the locations of the acoustic monitoring stations. See Figure and Figure in Appendix A for site photos.

**Table 3.** FORA acoustical monitoring sites

Site	Site Name	Dates Deployed	Vegetation	Elevation (m)	Latitude	Longitude
FORA001	Fort Donelson Ravine	9/2/11-11/15/11	Temperate Broadleaf/Mixed	16	35.93815	-75.70839
FORA002	Fort Heiman	9/2/11-11/15/11	Temperate Broadleaf/Mixed	3	35.93855	-75.71715



# Acoustic Monitoring: Fort Raleigh National Historic Site

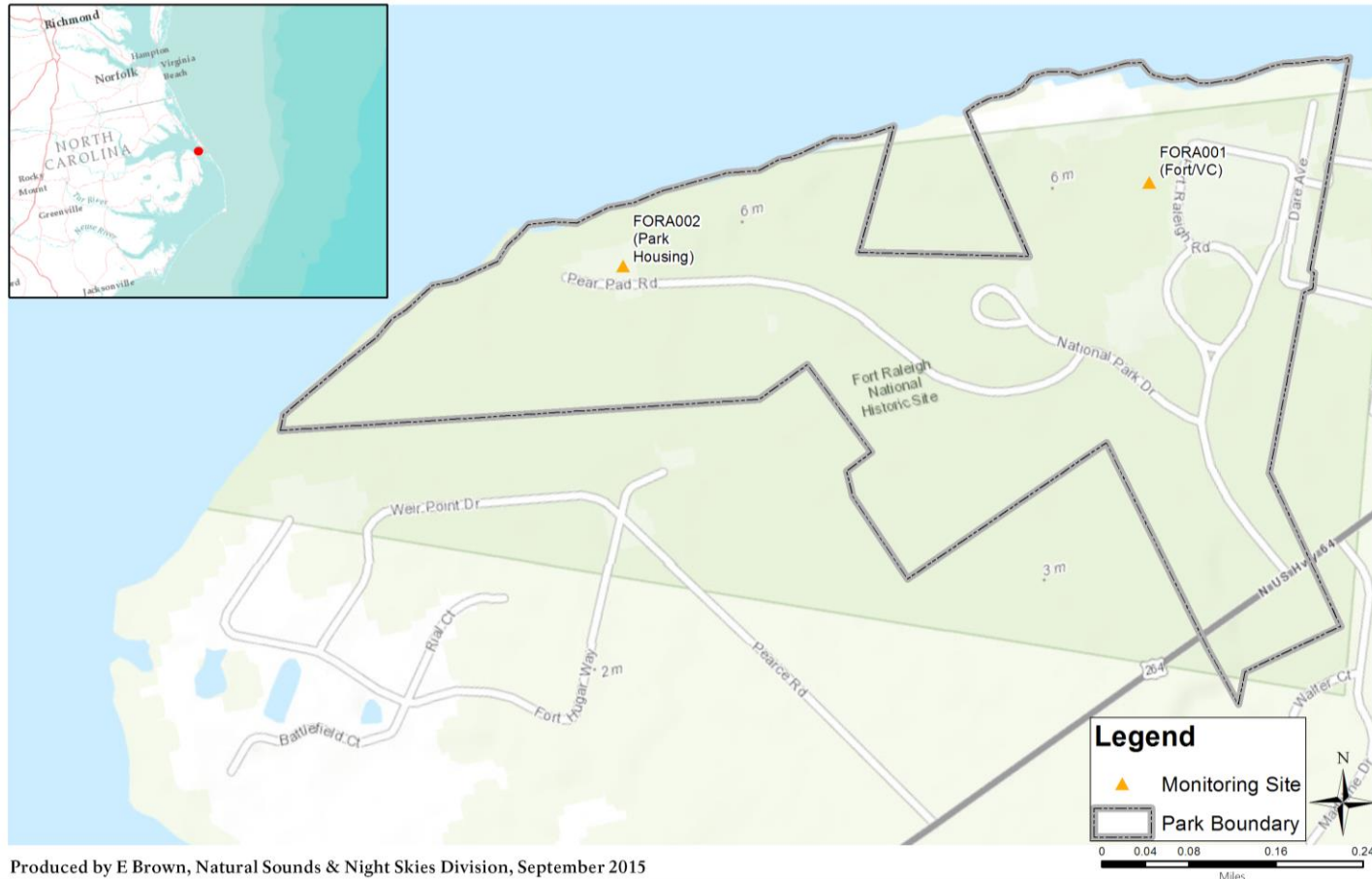


Figure 1. Location of acoustic monitoring sites at Fort Raleigh National Historic Site

# Methods

## Automatic Monitoring

Two Larson Davis 831 sound level meters (SLM) were employed over the thirty day monitoring period at the FORA sites. 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 Larson Davis-based sites met American National Standards Institute (ANSI) Type 1 standards. These sound level meters provided the information needed to calculate metrics described below in Calculation of Metrics.

The sampling stations consisted of:

- Microphone with environmental shroud
- Preamplifier
- 9 3.2 V LiFe rechargeable battery packs
- Anemometer (wind speed and direction)
- Temperature and humidity probe
- MP3 recorder

The sampling stations 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 exceedence 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):

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

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.

### On-Site Listening

While the sound level meter provides information about how loud or quiet the acoustical environment is at a given time, we need .mp3 recordings or on-site listening sessions to know *what* or *who* is making the sound. On-site listening is the practice of placing an observer near the acoustical monitoring station with a handheld personal digital assistant (PDA; or in this case, an Apple iPod Touch device). The observer listens for a designated period of time (in this case, one hour), and identifies all sound sources and their durations. On-site listening takes full advantage of human binaural hearing capabilities, and closely matches the experience of park visitors. Logistic constraints prevent comprehensive sampling by this technique, but selective samples of on-site listening provide a basis for relating the results of off-site listening to the probable auditory perception of events by park visitors and wildlife. On-site listening sessions are also an excellent screening tool for parks initiating acoustical environment studies. They produce an extensive inventory of sound sources, require little equipment or training, and can help educate park staff and volunteers.

Thus, four periods of on-site listening at both FORA001 and FORA002 were conducted in order to discern the type, timing, and duration during sound-level data collection. As recommended by NSNSD protocol (NPS 2005), these sessions lasted for one hour each. Staff recorded the beginning and ending times of all audible sound sources using custom-designed software. These on-site listening sessions provided the basis for the calculation of metrics including the period of time between noise events (average noise free interval [NFI]), percent time each sound source was audible, and maximum, minimum, and mean length (in seconds) of sound source events. The results of these on-site listening sessions are summarized in **Error! Reference source not found.** and **Error! Reference source not found.**

### Off-Site Listening/ Auditory Analysis

Auditory analysis was used to calculate the audibility of sound sources at FORA. 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 and Table in the Off-Site Data Analysis section below.



# Results

## On-site Listening

Table 5. Summary of on-site audible sound sources for FORA002 n=4 hour-long sessions. Events are measured in minutes:seconds.

and **Error! Reference source not found.** display the results of the four on-site listening sessions at FODRA001 and FORA002, respectively. Each audible sound source is listed in the first column. Percent time audible, or PA, is the second column. The third column, Max Event, reports the maximum event length among the sessions for each sound source. Likewise, Mean Event and Min Event columns report the mean and minimum length of events, respectively. SD reports the standard deviation among event lengths, and the Count column reports the number of times that each sound source was audible. Max Event, Mean Event, Min Event, and SD Event are reported in minutes:seconds. The last row in the table, noise free interval (NFI), is a metric which describes the length of time between extrinsic or human-caused events (when only natural sounds were audible). NFI is also reported in minutes:seconds. These on-site listening tables are essentially a sound inventory of each site. They reveal the sounds one is likely to hear at or near this location. Table 5. Summary of on-site audible sound sources for FORA002 n=4 hour-long sessions. Events are measured in minutes:seconds.

**Table 5.** Summary of on-site audible sound sources for FORA002 n=4 hour-long sessions. Events are measured in minutes:seconds.

Sound Source Description	PA	Max Event	Mean Event	Min Event	SD Event	Count
Jet	4	2:05	1:06	0:17	0:38	8
Jet, Military	0	0:37	0:37	0:37	0:01	
Aircraft, Propeller	69	21:22	3:39	0:01	4:27	45
Helicopter	0	0:33	0:33	0:33	0:01	
Automobile (car, van, light	5	1:20	0:29	0:01	0:19	24
Alarm, Horn	0	0:33	0:12	0:01	0:15	4
Vehicle Door	0	0:12	0:02	0:00	0:03	29
Motorcycle	0	0:31	0:22	0:14	0:12	2
Outboard	0	0:34	0:34	0:34	0:01	
Grounds Care	2	1:25	0:24	0:00	0:32	10
People, Voices	2	1:04	0:19	0:01	0:22	15
People, Walking	0	0:27	0:13	0:06	0:09	5
Bicycling	0	0:05	0:05	0:05	0:00	2
Dog	0	0:26	0:18	0:05	0:12	3
Wind	17	12:41	4:26	0:50	4:05	9
Waves (natural)	97	42:41	10:33	0:11	11:26	22
Squirrel	9	7:04	0:38	0:01	1:15	35
Bird	44	6:54	0:56	0:01	1:16	113
Insect	97	59:53	16:38	0:25	20:32	14
Animal (Natural)	0	0:01	0:01	0:01	0:01	

Natural Other	0	0:25	0:25	0:25	0:01	
Cracking or Popping Tree	0	0:03	0:02	0:01	0:01	4
All Aircraft	71.7	2:05	1:06	0:17	0:38	
All Road Vehicles	6	0:37	0:37	0:37	0:01	
All Watercraft	0.2	21:22	3:39	0:01	4:27	
All Non-natural Sources	75.5	0:33	0:33	0:33	0:01	
All Natural Sources	99.9	1:20	0:29	0:01	0:19	
Noise Free Interval	24.5	0:33	0:12	0:01	0:15	59

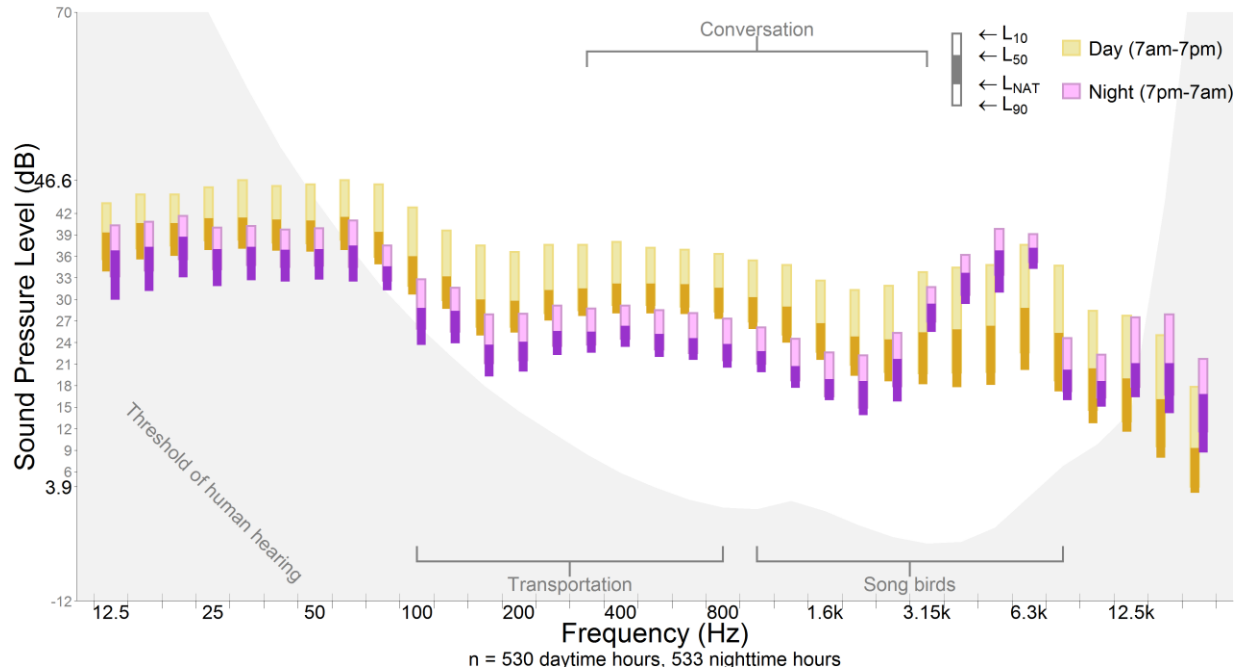
## Off-Site Data Analysis

### Metrics

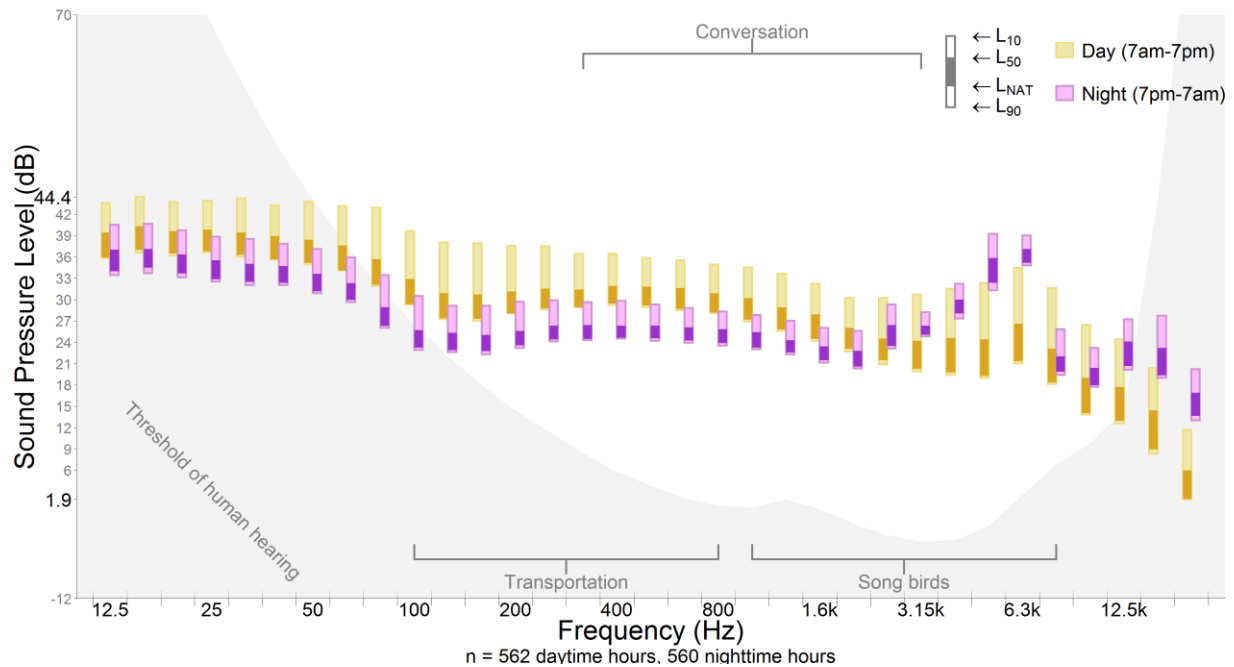
In order to determine the effect that extrinsic noise audibility has on the acoustical environment, it is useful to examine the median hourly exceedence metrics. The dB levels for 33 one-third octave band frequencies over the day and night periods are shown in Figure 2 (FORA001) and Figure 3 (FORA002). 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 exceedence 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. It can be useful to review each one-third octave band on these figures to predict the audibility of one sound or the masking of another. Notice that songbirds and transportation noise are audible at different frequency spectrums. There may be times when transportation sounds are louder than the songbirds. In this case, bird sounds would not be masked because their song is audible at a different frequency. If both of these sounds are within similar or overlapping frequency ranges, and

one sound is louder than the other, then the quieter sound could be masked. For example, vehicle noise, wind, and aircraft have overlapping frequency components and may mask one another.



**Figure 2.** Day and night dB levels for 33 one-third octave bands at FORA001



**Figure 3.** Day and night dB levels for 33 one-third octave bands at FORA002

Table reports the  $L_{90}$ ,  $L_{nat}$ ,  $L_{50}$ , and  $L_{10}$  values for the sites measured at FORA. 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.

**Table 6.** Exceedance levels for existing conditions in FORA

Site	Frequency (Hz)	Exceedance levels (dBA): 0700 to 1900 hours (Day)				Exceedance levels (dBA): 1900 to 0700 hours (Night)			
		$L_{90}$	$L_{nat}$	$L_{50}$	$L_{10}$	$L_{90}$	$L_{nat}$	$L_{50}$	$L_{10}$
FORA001	20-1,250	35.6	34.7	39.1	44.6	29.6	28.7	31.6	35.2
	12.5-20,000	39.3	38.5	43.5	50.2	44.6	43.7	46.1	47.8
FORA002	20-1,250	35.3	35.5	38.1	43.2	30.9	31.0	32.8	36.1
	12.5-20,000	38.1	38.3	42.1	47.8	44.3	44.5	45.8	47.9

In determining the current conditions of an acoustical environment, it is important to examine how often sound pressure levels exceed certain values. Table 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.

**Table 7.** 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
FORA001	20-1250	78.77	17.18	2.92	0.48	30.70	1.41	0.31	0.07
	12.5-20,000	98.36	42.81	16.35	1.67	100.00	65.98	5.58	1.83
FORA002	20-1250	76.79	9.85	1.47	0.26	29.24	1.48	0.28	0.05
	12.5-20,000	91.16	27.04	6.00	0.66	99.94	60.46	4.69	0.93

***Audibility***

Audibility results are presented below. Table and Table show the mean percentage of time that all noise sources were audible, based on eight days of off-site auditory analysis. Figures 4-11 show hourly audibility results and compare overall noise audibility to four sources of interest: aircraft, motors, vehicles, and watercraft.

**Table 8.** Mean hourly percent time audible for each noise source at FORA001. 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	0.8	8.3	2.1	0.4	2.9	2.9	2.1	4.2	10.4	11.3	20.4	16.3	25.8	22.1	17.9	20	17.1	17.1	19.2	17.5	24.6	19.2	15.4	6.7
Vehicles	9.2	2.5	2.5	3.3	2.9	17.1	27.9	29.6	16.3	11.7	5.4	7.1	10.4	10	16.7	21.7	7.1	5.4	4.6	5.8	14.2	12.1	6.7	4.2
Motor	90	86.2	89.2	99.2	97.5	87.9	78.3	79.6	65.8	70.4	71.7	76.2	64.6	66.7	61.3	72.1	75.4	80	76.2	62.1	78.7	79.6	86.2	91.2
Grounds Care	0	0	0	0	0	0	0	5.8	11.3	10.4	11.7	23.3	7.9	12.9	19.2	20.8	9.2	12.9	0.8	0	0	0	0	0
People	1.7	2.9	0	0	0.4	0	0.4	2.5	2.5	1.2	3.3	4.2	7.5	9.6	3.3	3.8	3.3	4.6	12.1	4.6	3.3	4.6	0.4	0.4
Dog	2.9	2.5	1.7	0.8	1.7	0.8	0.8	0.4	0.8	0.4	0	0	0	0	0	0	0.8	0.4	5.4	2.1	11.3	10.8	9.6	1.7
Door Opening/Closing	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	0	0	0	0	0	0	0	0	0	0
Construction	0	0	0	0	0	0	1.2	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-natural Unknown	0.8	0.4	0	0	0	0.4	0	0	0.4	0	0.4	0	0.4	0.4	0	0.4	0	0	0.4	0	0.8	0	0	0

**Table 9.** Mean hourly percent time audible for each noise source at FORA002. 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	2.1	6.7	0.4	0	0.8	1.2	5.8	4.6	13.8	14.2	22.1	22.5	20	16.3	26.2	21.7	23.3	20	13.8	17.9	21.7	25.4	9.2	8.7
Vehicles	10	6.2	5	3.3	3.8	5.8	7.5	10.4	7.5	2.9	2.5	3.3	5.4	5	7.1	6.2	9.2	6.2	11.3	5.4	10.4	6.7	10.8	4.2
Watercraft	1.2	0	0	0	0	0	1.2	0.8	4.6	2.5	1.2	1.2	0.4	0	0	1.2	2.1	3.3	2.9	2.9	0.4	0	1.2	0
Motor	66.3	61.7	53.3	40.4	31.2	37.9	45.4	62.1	65	58.3	46.7	45	47.5	51.3	49.6	43.3	45	51.7	63.8	52.5	60.4	61.3	60.8	74.2
Grounds Care	0	0	0	0	0	0	2.1	0.8	5.8	1.2	1.2	2.9	1.2	5.8	1.2	1.2	1.7	1.2	0	0	0	0	0	0
People	2.1	1.2	0.4	0	0	0	1.2	3.8	1.2	2.5	1.7	5.4	6.2	7.5	5	7.9	2.1	4.6	1.7	1.7	0.8	0.4	1.2	0.4
Dog	1.7	0	0.4	0	0	0	0	0	0.4	0.8	0.8	0	0	0.4	0	0.4	4.2	3.8	2.5	1.7	2.9	0.8	1.2	1.2
Door Opening/Closing	0.4	0	0	0.4	0	0	0	1.2	1.2	1.2	0	0.4	1.2	0.4	0.8	1.2	0.4	1.2	0	0	0	0	0.4	0.4
Non-natural Unknown	0.8	0	0.8	0.4	1.7	1.2	0.4	0	0.4	0	0.4	0	0	0	0.4	0	0.4	0.4	0	0	0.4	0	2.1	0.4

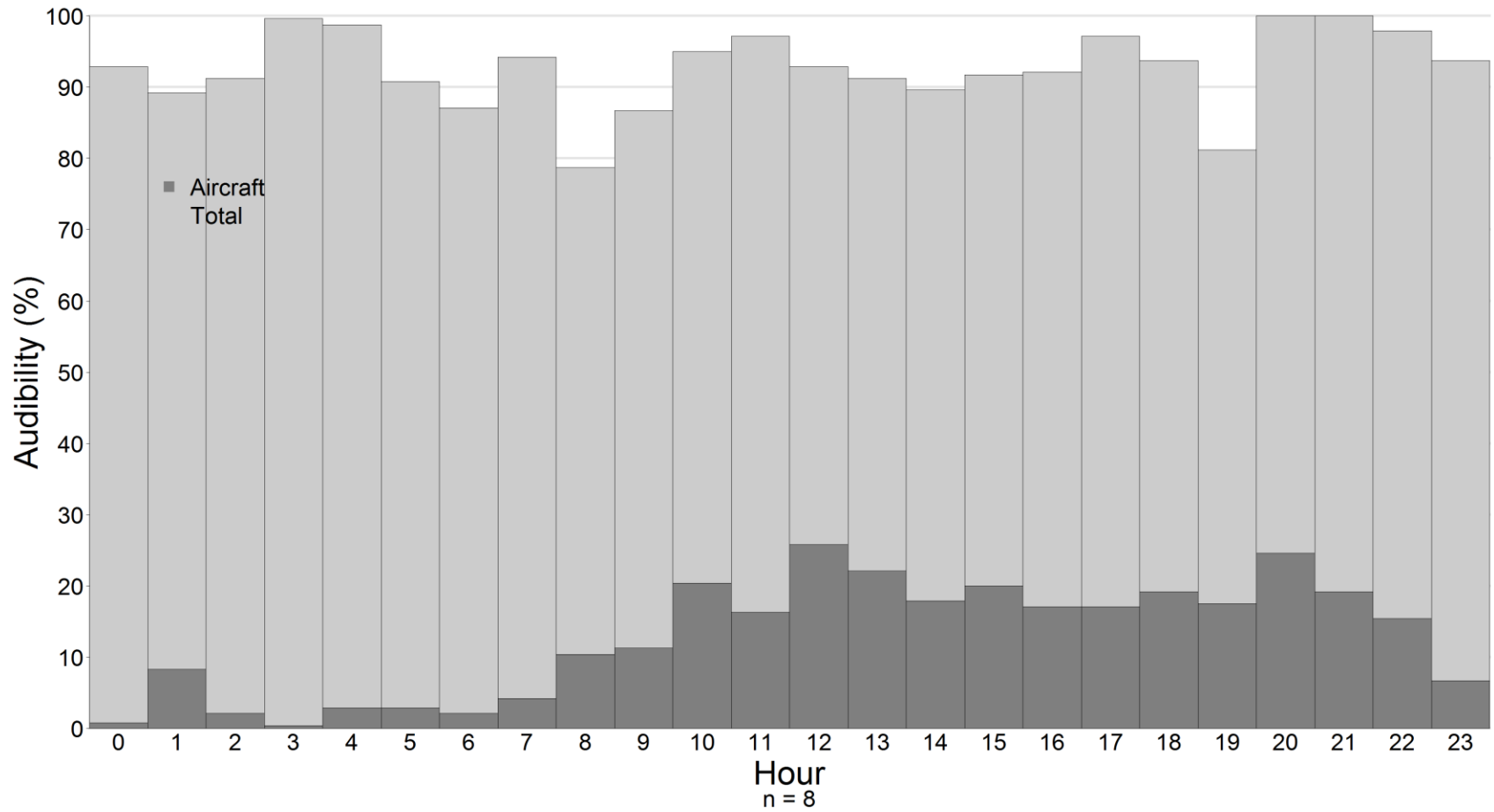


Figure 4. Comparison of hourly aircraft audibility and overall noise audibility at FORA001

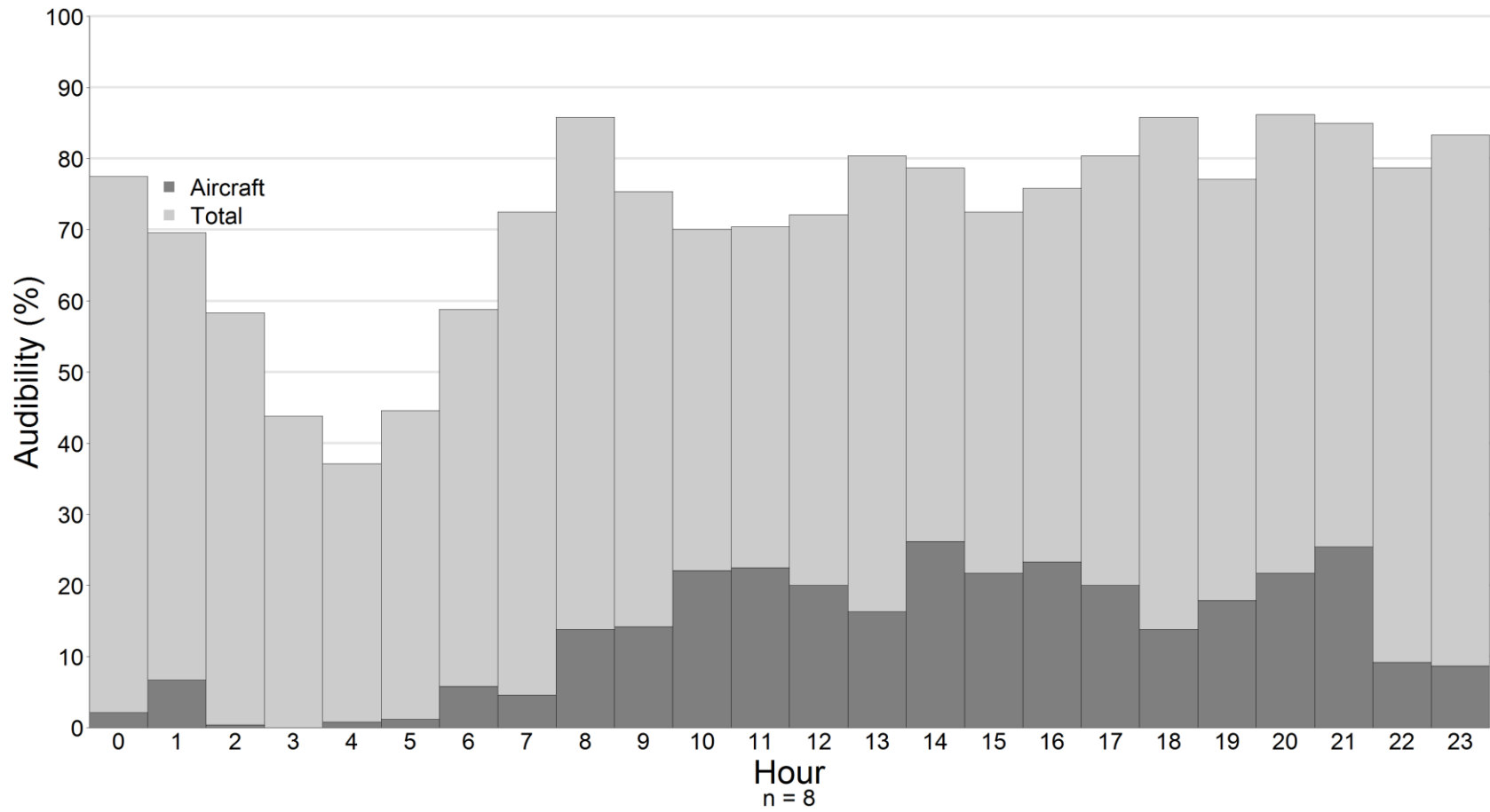


Figure 5. Comparison of hourly aircraft audibility and overall noise audibility at FORA002



## Discussion

The purpose of this study was to assess current conditions of the acoustical environment in the park. 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 two sites, one near the Visitor Center and the other near park housing, for approximately 30 days. The acoustical monitoring station locations were chosen because their vegetation and biologic activity were representative of the rest of the park.

Results indicated that the natural ambient sound level ( $L_{nat}$ ) at these sites ranged between 38.3 dBA during the daytime and 46.1 dBA at night. Existing ambient sound levels ( $L_{50}$ ) were slightly higher, ranging from 42.1 dBA during the day to 46.1 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.

Noise still exists in FORA's acoustical environment, however. Despite the relatively quiet overall sound levels, anthropogenic noise was audible 78-100% of the time at FORA001, and 37-86% of the time at FORA002. A detailed analysis of audibility at these sites found that motor noise was the most commonly heard noise. Sources of motor noise may include a variety of equipment, vehicles, building HVAC systems, aircraft etc. that can be difficult to identify through listening alone due to vagueness of the signal or confounding potential sources. Aircraft and vehicles also contributed significant amounts of noise to the acoustical environment. Other sounds heard frequently during the monitoring period included dogs, people, and grounds care.

Off-site analysis focused primarily on anthropogenic sources of sound, and as such, the results do not reflect natural sound sources in the acoustic environment. However, on-site analysis revealed a relatively active natural acoustic environment at FORA. Based on eight total hours of daytime listening, birds were audible 57% of the time at FORA001 and 44% of the time at FORA002. Squirrels, insects, and other animals, as well as wind and rain, all contributed to the natural acoustic environment of the park and were audible over 99% of the time.

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## Appendix A: Site Photos



Figure 6. FORA001, Visitor Center acoustical monitoring site



**Figure 7.** FORA002, Park Housing acoustical monitoring site

## Appendix B: Glossary of Acoustical Terms

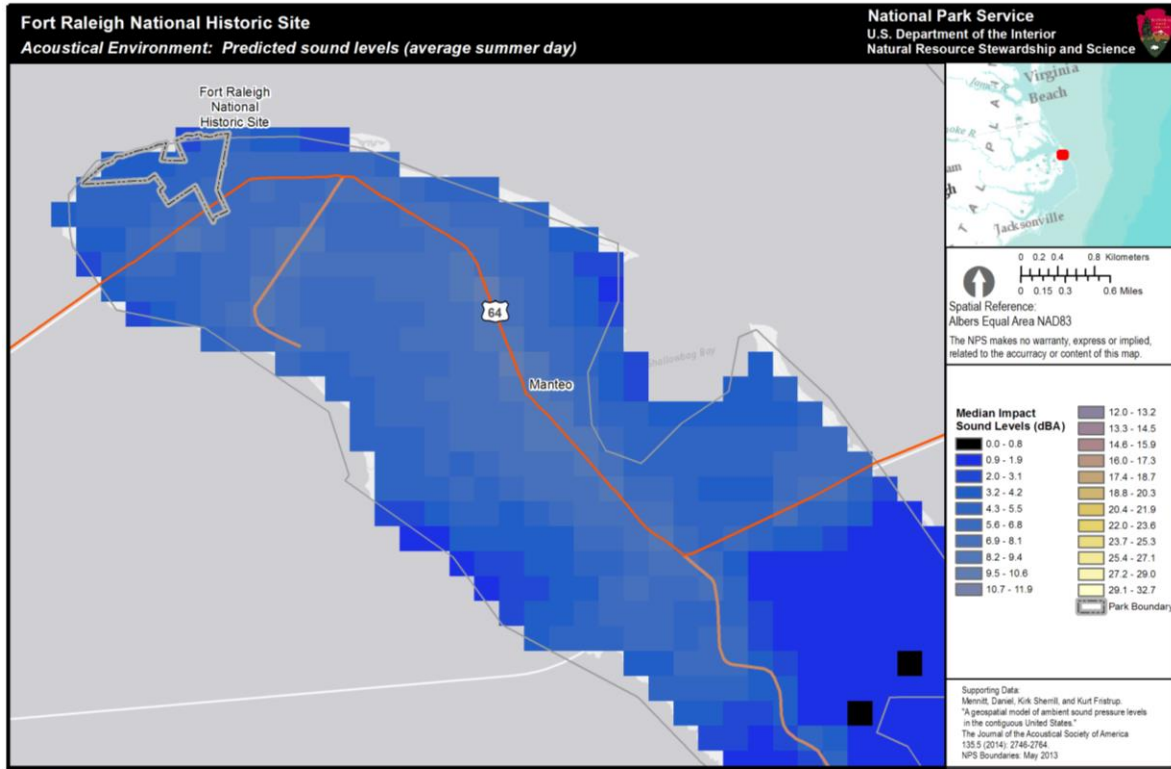
Term	Definition
Acoustic Environment	A combination of all the physical sound resources within a given area. This includes natural sounds and cultural sounds, and non-natural human-caused sounds. The acoustic environment of a park can be divided into two main categories: intrinsic and extrinsic.
Acoustic 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 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 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.
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.
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 <i>sound</i> and <i>noise</i> , since these definitions have been used inconsistently in the literature. Although <i>noise</i> is sometimes incorrectly used as a synonym for sound, it is in fact sound that is undesired or extraneous to an environment. Humans perceive <i>sound</i> 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 FORA 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 FORA, the mean modeled sound level impact is 5.0 dBA, and this value represents a close approximation of expected impact levels at a randomly chosen point within the park. Moreover, this modeled metric is very close to the measured difference between daytime natural and existing ambient sound levels at FORA, which is 5.0 dBA at FORA001 and 3.8 dBA at FORA002. 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 FORA 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%.



**Figure 8.** Map of predicted acoustic impact levels in the park and nearby region (inset) 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 meter 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.



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