



Pictured Rocks National Lakeshore

Acoustical Monitoring 2012

Natural Resource Technical Report NPS/NRSS/NRTR—2013/787



ON THE COVER

View from atop the Pictured Rocks

Photograph courtesy of Pictured Rocks National Lakeshore

Pictured Rocks National Lakeshore

Acoustical Monitoring Report 2012

Natural Resource Technical Report NPS/NRSS/NRTR—2013/787

Natural Sounds and Night Skies Division

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Executive Summary

In 2012, the Natural Sounds and Night Skies Division (NSNSD) received a request to collect baseline acoustical data at Pictured Rocks National Lakeshore (PIRO). From July 2012 to September 2012 three acoustical monitoring systems were deployed in the park. These stations were configured to collect sound pressure level data and continuous audio recordings for approximately thirty days but remained deployed for an additional month due to logistics of retrieval. One station, PIRO003/Au Sable Dunes, failed to record any data due to an equipment failure. The baseline data collected during this period for the remaining two sites will help managers and planners assess the current condition of the acoustical environment in different areas of the park. The measured existing and natural ambient conditions may also be used as a baseline for noise modeling efforts.

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). Sources of noise at PIRO include vehicles on nearby roads, watercraft, and aircraft. 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 calibrated, Type 1, Larson Davis 831 sound level meters. 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 all extrinsic sounds, aircraft, watercraft, and vehicles

Site ID	Site Description	Mean percent time audible (in 24 hour time period)				Median Existing Ambient (L_{50}) in dBA		Median Natural Ambient (L_{nat}) in dBA	
		All Extrinsic	Aircraft	Watercraft	Vehicles	Day	Night	Day	Night
PIRO001	Miners Castle	62.6	2.7	42.0	1.4	36.3	35.6	33.0	34.3
PIRO002	Beaver Basin	30.8	5.4	12.4	2.2	39.2	40.6	38.2	40.2

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, 2008). 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. Kayakers, hikers, or 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				% Time above sound level: 1900 to 0700			
		35dBA	45dBA	52dBA	60dBA	35dBA	45dBA	52dBA	60dBA
PIRO001	20-1250	35.6	0.4	0.0	0.0	36.2	0.1	0.0	0.0
	12.5-20,000	62.8	2.9	0.1	0.0	56.0	2.2	0.1	0.0
PIRO002	20-1250	70.2	4.0	0.0	0.0	73.1	15.7	0.0	0.0
	12.5-20,000	81.1	10.7	1.4	0.0	77.6	26.4	0.2	0.0

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 soundscapes¹ 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

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.

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

It should be noted that “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

Known for its scenic limestone cliffs, Pictured Rocks National Lakeshore (PIRO) was established to preserve a portion of the Great Lakes shoreline for its geographic, scientific, scenic, and historic features, provide opportunities for public benefit in recreation, education, enjoyment, and inspiration, and protect the character and use of the shoreline zone while allowing economic utilization of the inland buffer zone renewable resources. The park itself consists of two jointly managed units (Shoreline Zone, owned by the National Park Service, and the Inland Buffer Zone, a mixture of State of Michigan, Forestland Group, and other private lands) for a total of 73,235 acres. PIRO receives just under 600,000 visits per year. Three sites were selected for acoustic monitoring because they were representative of high (PIRO001) and low (PIRO002) use areas in the park. The third site (PIRO003) experienced equipment failure, and no data were recovered. Table 3 shows site information for each monitoring station, and Figure 1 shows locations of acoustic monitoring stations.

Table 3. Study areas

Site	Site Name	Dates Deployed	Vegetation	Elevation (m)	Latitude	Longitude
PIRO001	Miners Castle	7/24/2012 – 9/16-2012	Mixed deciduous, grasses	246	46.48867	-86.55622
PIRO002	Beaver Basin	7/26/2012 – 9/16/2012	Mixed deciduous, grasses	203	46.56924	-86.36867
PIRO003	Au Sable Dunes	7/24/2012 – 9/16/2012	Sand Dunes, Dispersed Scrub Pine	241	46.66251	-86.02761



2012 Acoustic Monitoring Locations

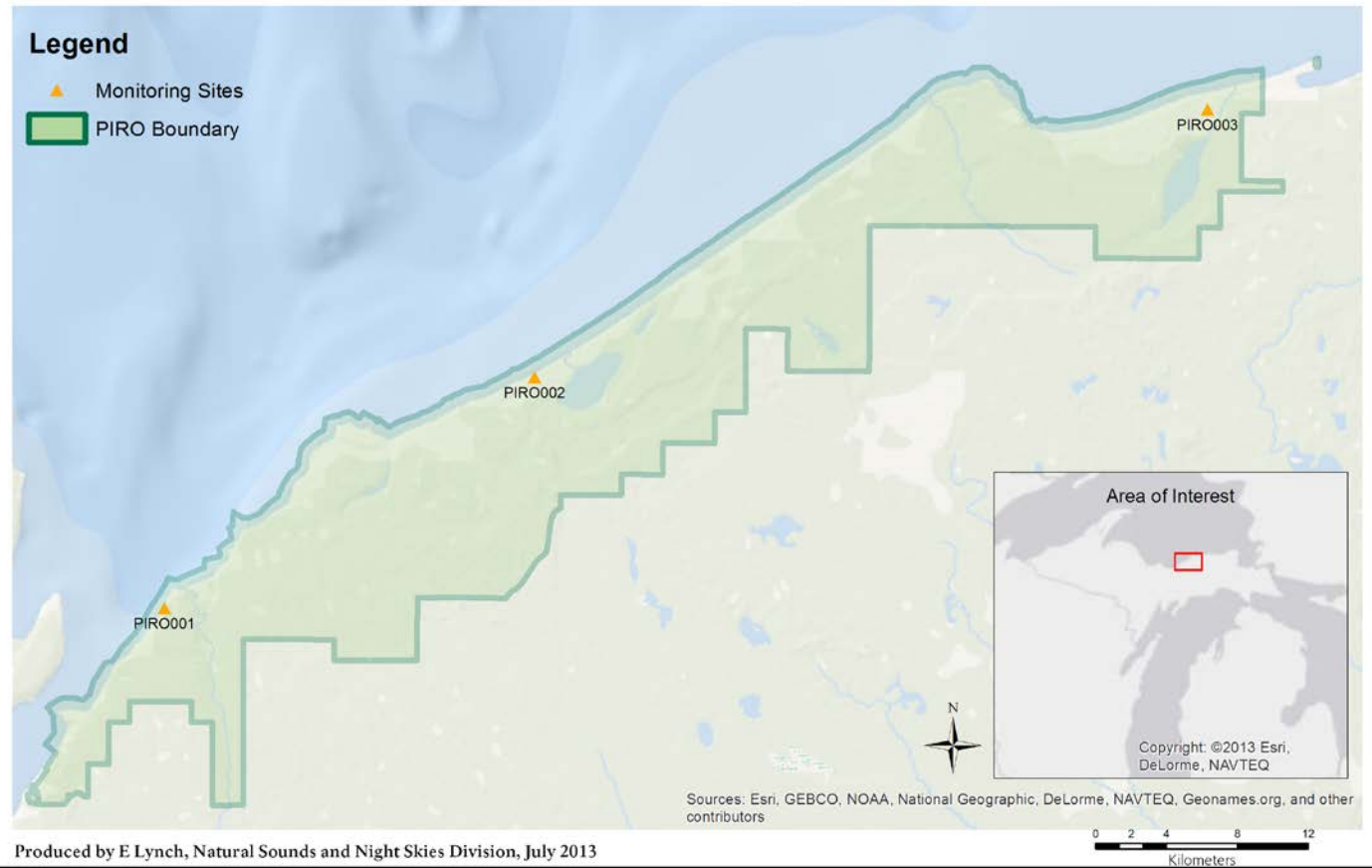


Figure 1. Location of acoustic monitoring sites

Methods

Automatic Monitoring

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

The sampling stations consisted of:

- Microphone with environmental shroud
- Preamplifier
- 8 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 levels 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 and Figure 3 in the results section. Additionally, these figures separate 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). 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 PIRO001, two periods of on-site listening at PIRO002, and three periods of on-site listening at PIRO003 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 generally began at the top or middle of an hour and lasted for one hour. Staff recorded the beginning and ending times of all audible sound sources using custom-designed PDA 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 Table 4, Table 5, and Table 6.

Off-Site Listening/ Auditory Analysis

Auditory analysis was used to calculate the audibility of sound sources at PIRO. 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 below 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 9 and Table 10 in the Off-Site Data Analysis section below.

Results

On-site Listening

Table 4 - Table 6 display the results of the four on-site listening sessions at PIRO001, two on-site listening sessions at PIRO002, and three sessions from PIRO003. 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 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 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 4. Summary of on-site audible sound sources for PIRO001 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	2	3:24	2:10	0:56	1:45	2
Aircraft, Propeller	2	4:09	4:09	4:09	0:01	1
Vehicle	1	1:16	0:30	0:01	0:36	4
Motorcycle	2	3:25	1:57	1:09	1:16	3
Watercraft	73	47:22	9:10	0:16	11:23	19
Outboard, 2-stroke	0	0:01	0:01	0:01	0:01	1
People	0	0:03	0:03	0:03	0:01	1
People, Voices	5	6:15	0:54	0:02	1:38	14
Wind	59	58:47	4:33	0:03	13:29	31
Wind, Light	19	42:48	22:16	1:43	29:03	2
Rain/Fog Drip	16	31:52	19:32	7:12	17:27	2
Waves (natural)	98	59:56	58:41	55:22	2:13	4
Mammal	0	0:11	0:06	0:01	0:07	2
Squirrel	3	2:40	0:41	0:00	1:07	11
Chipmunk	1	0:33	0:09	0:00	0:12	8
Coyote	0	0:03	0:03	0:03	0:01	1
Bird	47	44:20	2:11	0:01	6:25	52
Raven	0	0:14	0:07	0:00	0:10	2
Duck	0	0:09	0:09	0:09	0:01	1
Reptile	0	0:02	0:01	0:00	0:01	5
Insect	1	0:28	0:07	0:00	0:08	12
Geothermal / Mass	0	0:09	0:03	0:00	0:05	3
Natural Other	0	0:06	0:03	0:01	0:03	3
All Aircraft	3.5	0:00	0:00	0:00	0:00	
All Road Vehicles	3.3	0:00	0:00	0:00	0:00	
All Watercraft	72.5	0:00	0:00	0:00	0:00	
All Non-natural Sources	78	0:00	0:00	0:00	0:00	
All Natural Sources	98.5	0:00	0:00	0:00	0:00	
Noise Free Interval	22	11:03	2:12	0:01	2:43	24

Table 5. Summary of on-site audible sound sources for PIRO002 n=2 hour-long sessions. Events are measured in minutes: seconds.

Sound Source Description	PA	Max Event	Mean Event	Min Event	SD Event	Count
Jet	1	1:11	1:11	1:11	0:01	1
Watercraft	50	54:15	8:29	0:37	20:11	7
People, Voices	3	1:53	1:10	0:31	0:41	3
Wind	0	0:13	0:13	0:13	0:01	1
Wind, Light	50	59:52	59:52	59:52	0:01	1
Waves (natural)	100	59:55	59:46	59:37	0:13	2
Mammal	0	0:15	0:15	0:15	0:01	1
Chipmunk	0	0:02	0:01	0:01	0:01	3
Bird	9	3:33	1:20	0:01	1:33	8
Insect	0	0:03	0:02	0:01	0:01	4
Natural Other	0	0:01	0:01	0:01	0:01	1
All Aircraft	1	0:00	0:00	0:00	0:00	
All Watercraft	49.5	0:00	0:00	0:00	0:00	
All Non-natural Sources	49.8	0:00	0:00	0:00	0:00	
All Natural Sources	99.8	0:00	0:00	0:00	0:00	
Noise Free Interval	50.2	31:54	7:32	0:13	11:21	8

Table 6. Summary of on-site audible sound sources for PIRO003 n=3 hour-long sessions. Events are measured in minutes: seconds.

Sound Source Description	PA	Max Event	Mean Event	Min Event	SD Event	Count
Vehicle	31	5:42	1:20	0:05	1:28	42
Motorcycle	1	2:24	2:24	2:24	0:01	1
Watercraft	20	21:30	8:51	0:07	10:03	4
People, Voices	1	0:56	0:20	0:01	0:31	3
Wind	66	59:55	59:50	59:45	0:07	2
Wind, Light	33	59:50	59:50	59:50	0:01	1
Rain/Fog Drip	33	59:52	59:52	59:52	0:01	1
Waves (natural)	14	13:03	12:59	12:55	0:06	2
Bird	15	6:48	0:34	0:01	1:07	47
Insect	61	59:45	6:50	0:01	17:33	16
All Road Vehicles	32.6	0:00	0:00	0:00	0:00	
All Watercraft	19.7	0:00	0:00	0:00	0:00	
All Non-natural Sources	52.2	0:00	0:00	0:00	0:00	
All Natural Sources	99.8	0:00	0:00	0:00	0:00	
Noise Free Interval	47.8	13:40	1:50	0:08	2:37	47

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 and Figure 3. 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. Notice in Figure 3 that contributions of songbirds are prominent in daytime hours, and that nighttime sound levels in the same frequencies are quieter. 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.

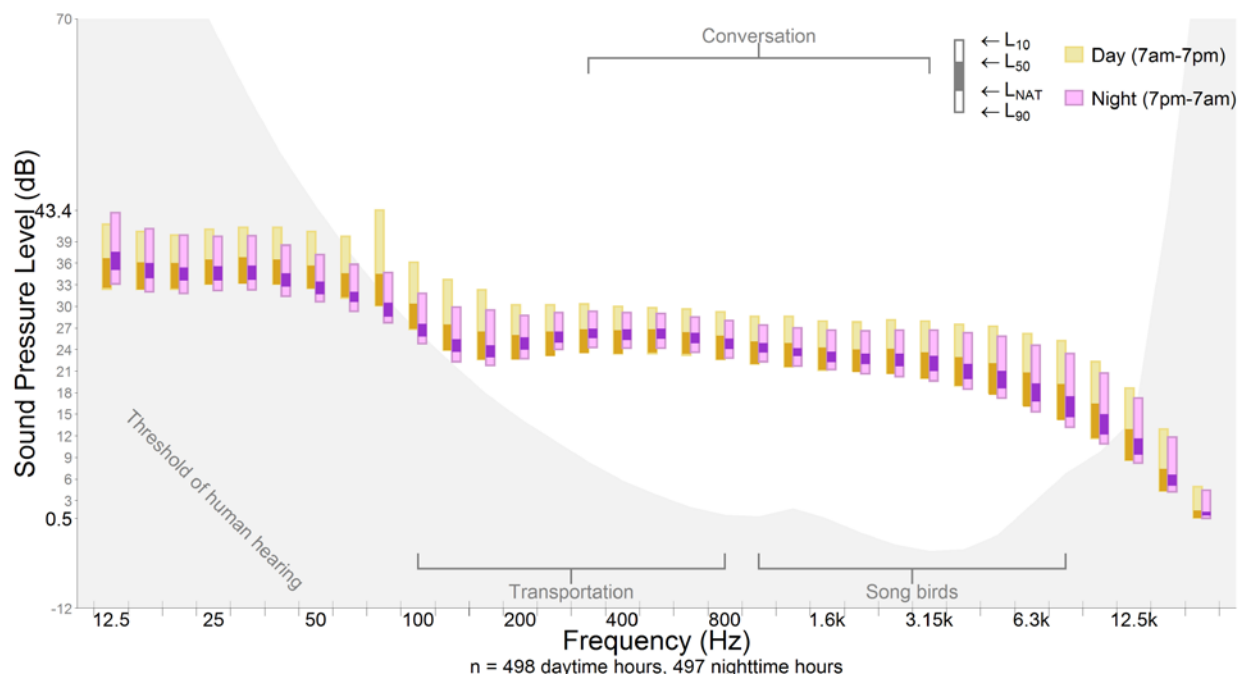


Figure 2. Day and night dB levels for 33 one-third octave bands at PIRO001

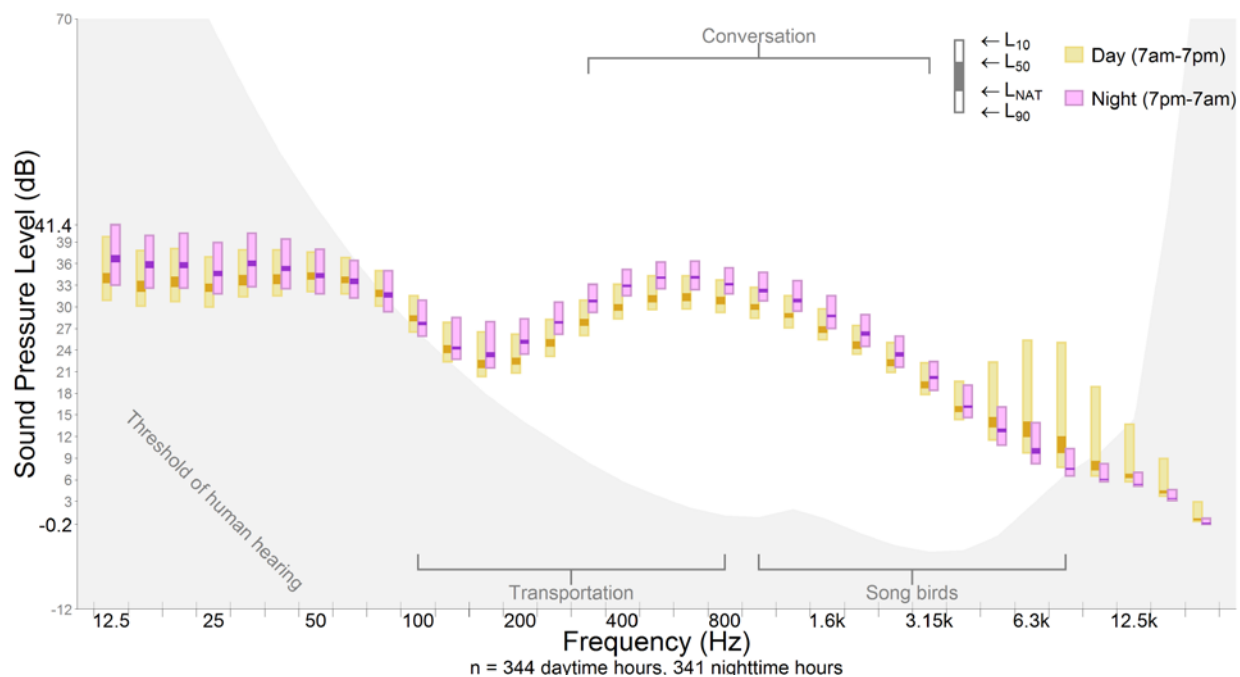


Figure 3. Day and night dB levels for 33 one-third octave bands at PIRO002

Table 7 reports the L_{90} , L_{nat} , L_{50} , and L_{10} values for the sites measured at PIRO. 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 7. Exceedence levels for existing conditions in PIRO

Site	Frequency (Hz)	Exceedence levels (dBA): 0700 to 1900 hours (Day)				Exceedence levels (dBA): 1900 to 0700 hours (Night)			
		L_{90}	L_{nat}	L_{50}	L_{10}	L_{90}	L_{nat}	L_{50}	L_{10}
PIRO001	20-1,250	30.0	30.1	33.3	36.6	30.2	31.6	32.8	35.1
	12.5-20,000	32.8	33.0	36.3	39.8	33.1	34.3	35.6	38.6
PIRO002	20-1,250	35.4	36.6	37.4	39.8	38.1	39.3	39.6	41.7
	12.5-20,000	37.1	38.2	39.2	43.1	38.9	40.2	40.6	43.0

In determining the current conditions of an acoustical environment, it is important to examine how often sound pressure levels exceed certain values. Table 8 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). 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. Hikers and visitors viewing scenic vistas in the park would likely be conducting such conversations.

Table 8. Percent time above metrics

Site	Frequency (Hz)	% Time above sound level: 0700 to 1900				% Time above sound level: 1900 to 0700			
		35dBA	45dBA	52dBA	60dBA	35dBA	45dBA	52dBA	60dBA
PIRO001	20-1250	35.6	0.4	0.0	0.0	36.2	0.1	0.0	0.0
	12.5-20,000	62.8	2.9	0.1	0.0	56.0	2.2	0.1	0.0
PIRO002	20-1250	70.2	4.0	0.0	0.0	73.1	15.7	0.0	0.0
	12.5-20,000	81.1	10.7	1.4	0.0	77.6	26.4	0.2	0.0

Audibility

Audibility results are presented below. Table 9 and Table 10 show the mean percentage of time that all noise sources were audible, based on eight days of auditory analysis. Figure 4 and Figure 5 show hourly audibility results and compare overall noise audibility to one source of interest: watercraft.

Table 9. Mean hourly percent time audible for each noise source at PIRO001. 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	0.0	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	0.7	0.0	0.4	0.0	0.0
Jet	1.1	1.5	12.6	6.7	1.9	0.4	0.7	0.0	0.7	0.7	0.7	1.1	0.4	0.4	1.5	0.7	0.4	3.7	4.1	3.7	6.3	2.2	3.3	5.6
Propeller	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	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Helicopter	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.4	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0
Vehicle	0.4	1.1	0.0	0.7	0.7	5.2	0.7	0.0	0.0	0.0	0.4	1.9	0.0	0.4	0.7	0.4	0.4	1.5	4.1	1.5	2.6	1.9	4.4	1.1
Automobile	0.0	0.0	0.0	0.4	0.0	1.1	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	0.4	0.0	0.0
Motorcycle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0
Watercraft	2.6	3.7	6.7	1.9	0.4	0.0	22.2	40.4	33.3	37.0	54.8	56.3	63.7	70.0	69.3	71.9	69.6	66.3	55.9	59.6	44.4	34.8	4.4	7.4
Outboard	1.9	0.4	0.0	0.0	0.0	1.9	10.4	10.4	10.7	12.2	6.7	6.7	9.3	8.9	8.5	7.0	5.6	5.9	5.2	6.3	4.8	0.0	0.0	0.0
Jet Ski (PWC)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.9	0.7	0.0	1.5	1.1	0.4	1.1	0.4	1.5	0.0	0.7	0.7	0.0	0.0	0.0
Boat wake on shore	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	1.9	0.0	0.0	0.4	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Motor	0.0	0.0	0.0	0.0	4.1	11.1	10.4	6.7	10.0	10.0	11.1	8.1	8.9	2.6	0.0	0.0	0.0	3.0	2.6	3.0	6.7	4.4	6.7	2.6
Voices	0.0	0.0	0.0	0.0	0.0	0.0	1.1	3.0	0.0	5.2	3.7	8.1	6.3	5.9	7.0	7.8	5.9	5.2	2.2	1.5	10.4	1.5	0.0	0.0
Portable audio devices	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	1.9	0.0	0.0	0.7	0.0	0.0	0.0	0.7	0.4	0.0	0.0	0.0
Dog	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.4	2.2	0.0	1.1	0.0	0.0	1.1	0.7	0.4	0.0	0.0
Non-natural other	25.6	16.3	14.1	10.7	14.1	6.7	8.1	3.0	11.9	3.0	9.3	3.0	0.7	0.4	0.0	4.8	7.0	4.8	0.7	0.0	5.6	7.4	11.5	5.9
Non-natural unknown	12.2	23.0	26.3	26.3	26.3	28.5	20.4	11.9	16.3	16.3	6.7	8.5	8.9	8.9	3.3	3.7	7.4	9.6	11.9	10.4	19.6	29.3	36.3	25.2
Total non-natural sources	31.1	33	40.7	39.3	35.9	34.8	53.3	64.8	66.7	68.1	80.7	77	86.7	87.4	81.1	83.7	80	80.7	75.2	74.8	74.4	60.7	51.5	39.6

Table 10. Mean hourly percent time audible for each noise source at PIRO002. 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	0.7	0.0	3.0	1.5	0.4	0.4	1.9	0.7	0.7	1.1	1.1	0.7	0.7	1.5	1.5	3.7	3.0	6.7	3.7	6.3	6.3	4.1	5.6	1.9
Jet	0.7	1.1	8.1	1.5	0.0	0.0	1.1	0.0	0.7	0.0	0.0	1.1	3.0	3.0	1.1	1.9	2.2	3.7	3.3	5.9	5.9	3.3	2.6	5.2
Propeller	0.0	0.0	1.9	0.7	0.0	1.9	0.7	0.0	1.1	0.0	0.4	1.1	3.0	0.0	0.0	1.9	0.4	0.7	0.7	1.9	0.0	0.0	0.4	0.0
Helicopter	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vehicle	1.5	4.1	2.2	1.1	3.0	0.7	0.4	0.7	1.5	1.5	2.2	7.4	2.6	5.2	4.1	2.2	1.9	1.9	1.1	0.7	0.7	1.5	0.4	0.0
Vehicle alarm	0.4	1.9	0.4	0.0	0.0	0.0	0.4	0.4	0.4	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.4	0.0	0.4	0.0	0.0	0.0
Watercraft	0.0	0.0	0.0	4.1	8.9	13.7	8.5	16.3	21.1	11.9	14.8	15.9	15.2	15.6	10.7	15.9	22.6	25.2	21.5	14.8	24.1	7.4	6.7	0.4
Jet Ski (PWC)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	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
Motor	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.7	0.0	0.4	0.4	0.4	0.0	0.0	1.1	3.3	1.5	0.0	0.7	1.5	0.0	0.0	0.0
Voices	0.0	0.7	0.4	0.4	0.4	0.0	0.0	2.2	1.1	3.7	2.6	4.1	12.2	10.4	10.7	10.7	18.5	12.2	17.8	8.9	2.2	4.4	4.1	0.4
Walking	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	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Dog	0.0	0.0	0.4	0.7	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	0.4	0.0	0.0
Non-natural unknown	10.4	9.3	7.8	8.5	10.0	8.9	7.0	4.1	11.1	14.8	11.5	8.5	8.1	8.5	10.4	9.3	9.3	10.0	9.3	13.0	11.1	12.2	10.4	8.1
Total non- natural sources	13.3	15.6	23	18.5	22.6	23	17.8	22.2	33.3	28.5	29.6	34.1	37.4	39.6	34.4	40	51.5	52.6	45.2	44.8	44.8	26.3	25.9	15.6

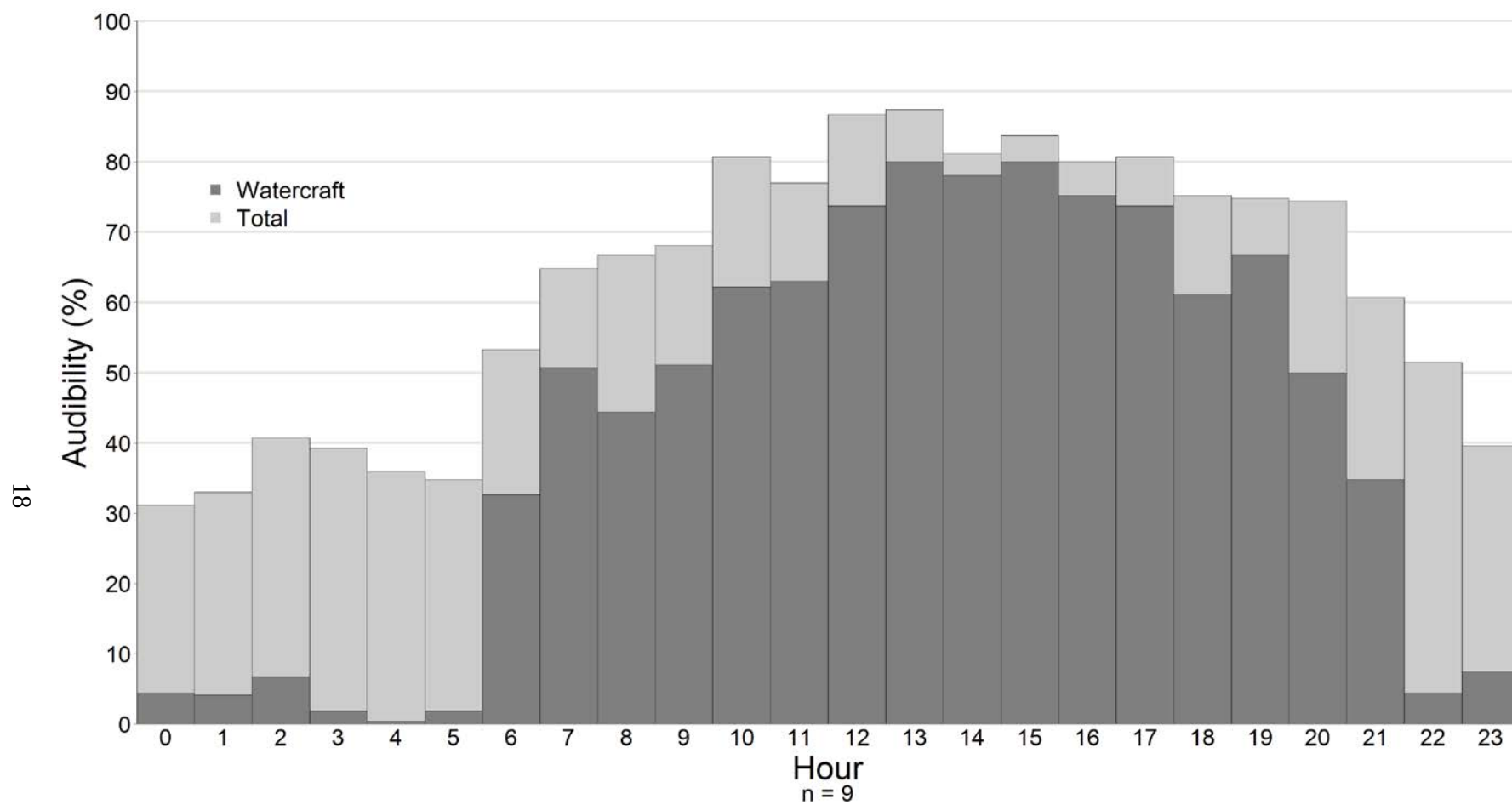


Figure 4. Comparison of hourly watercraft audibility and overall noise audibility at PIRO001

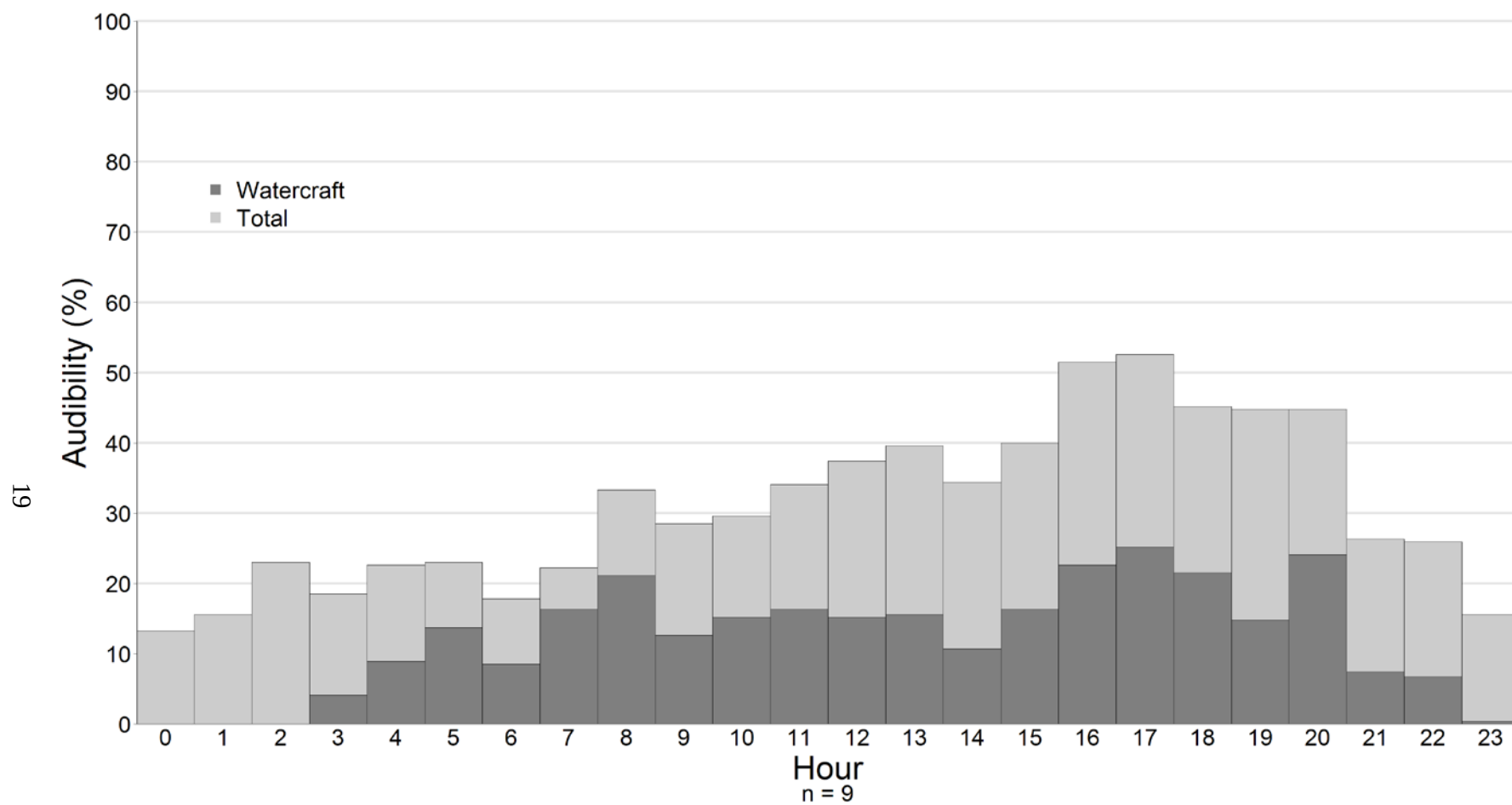


Figure 5. Comparison of hourly watercraft audibility and overall noise audibility at PIRO002

Discussion

The purpose of this study was twofold: to assess current conditions of the acoustical environment in the park, and to provide baseline sound levels for the purpose of noise modeling. Sound pressure level data, meteorological data, and continuous audio were collected from a high-use area (Miners Castle, PIRO001) and a low-use area (Beaver Basin, PIRO002).

Results indicated that the natural ambient sound levels at these sites ranged between 33.0 and 38.2 dBA during the daytime, and 34.3 and 40.2 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 over 55 dB (and an additional 53% was exposed to day-night sound levels over 60 dB)(EPA 1982). Therefore, the results imply that the natural ambient sound level during the monitoring period was considerably quieter than most residential areas.

However, noise still exists in PIRO's acoustical environment. A detailed analysis of audibility at this site found that the three major noise sources (watercraft, aircraft, and vehicles) contributed significant amounts of noise to the acoustical environment (ranging from about 30 to 62 % average audibility in a 24 hour period). Human voices were also audible, to a lesser degree (~5% average audibility in a 24 hour period). These are the sources of noise which have the potential to mask the natural and cultural sounds that provide a sense of place at Pictured Rocks National Seashore.

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