National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Saint Croix National Scenic Riverway

Acoustic Monitoring Report

Natural Resource Report NPS/NRSS/NSNS/NRR—2014/890

ON THIS PAGE
Saint Croix River between Soderbeck Landing and Sandrock Cliffs
Photograph by: Misty D. Nelson

ON THE COVER
Saint Croix River between Sandrock Cliffs and Highway 70 Landing
Photograph by: Misty D. Nelson

Saint Croix National Scenic Riverway

Acoustic Monitoring Report

Natural Resource Report NPS/NRSS/NSNS/NRR—2014/890

Misty D. Nelson

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

December 2014

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 high-priority, current natural resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability.

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.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

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:

Nelson, M. D. 2014. Saint Croix National Scenic Riverway: Acoustic monitoring report. Natural Resource Report NPS/NRSS/NSNS/NRR—2014/890. National Park Service, Fort Collins, Colorado.

NPS 630/127399, December 2014

Contents

Figures

Tables

Appendices

Executive Summary

In 2011, the Natural Sounds and Night Skies Division (NSNSD) received a request to collect baseline acoustical data at Saint Croix National Scenic Riverway (SACN). During the months of June and July, 2011, one acoustical monitoring system was deployed for 34 days. The purpose of the 2011 monitoring effort was to characterize existing sound levels, estimate natural ambient sound levels, and identify audible sound sources prior to the re-opening of Zavoral Gravel Mine in Scandia, Minnesota. In 2014, SACN submitted an additional Technical Assistance Request (TAR) to NSNSD. During the months of July and August, 2014, two acoustical monitoring systems were deployed for approximately 40 days each. The goal of the 2014 TAR was to compare acoustic conditions at the 2011 monitoring site, and also to collect baseline acoustical data at an additional site on the upper Riverway near a mine for sand used in hydraulic fracturing located just outside the park boundary in Burnett County, Wisconsin. Results of this study will provide information on environmental impacts associated with the mines, and will help inform future management 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). The most common sources of noise at SACN include aircraft, people (e.g., voices, portable audio devices), vehicle traffic on nearby roads, and boats. Table 1 displays percent time audible values for each of these common noise sources during the monitoring period, as well as ambient sound levels. Results from 2011 monitoring are included for comparison. 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. In 2011, daytime values of both L_{50} and L_{nat} at SACN001 were higher than nighttime values, likely due to increased bird activity during daylight hours. During the 2014 monitoring period, L_{50} and L_{nat} values at both SACN001 and SACN002 were only slightly higher during the day than at night, likely as a result of nocturnal insect sounds.

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

Site ID	Site Description	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	
		All Extrinsic	Aircraft	People	Vehicles	Water-craft	Day[c]	Night	Day	Night
SACN001 (2011)	Swing Bridge Island	56.1	13.7	2.6	16.9	10.0	39.4	29.8	35.1	26.6
SACN001 (2014)	Swing Bridge Island	95.9	10.5	6.8	83.9	4.2	33.3	31.5	28.6	27.9
SACN002 (2014)	River Mile s91.7, MN side	84.3	9.7	7.8	68.1	3.9	35.4	34.0	32.4	31.8

[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. Paddlers on the river 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 (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
SACN001 (2011)	20-1250	13.84	1.83	0.31	0.03	5.37	0.64	0.13	0.02
	12.5-20,000	79.40	24.70	9.96	2.63	30.65	10.94	4.57	1.32
SACN001 (2014)	20-1250	13.88	1.71	0.35	0.05	7.84	0.88	0.14	0.01
	12.5-20,000	38.06	2.43	0.48	0.06	27.24	1.79	0.26	0.04
SACN002 (2014)	20-1250	11.31	1.09	0.26	0.08	1.77	0.24	0.04	0.00
	12.5-20,000	51.64	5.37	1.00	0.17	33.05	6.38	0.65	0.07

Acknowledgments

This report would not have been possible without the input of J. Medland and E. Brown. R. Haass, J. Medland, and J. Snyder assisted with field data collection.

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[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 natural soundscapes. The frequencies, magnitudes, and durations of acceptable levels of

---

[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.

> 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

Saint Croix National Scenic Riverway (SACN) was established to preserve, protect, restore, enhance, and interpret the riverway's exceptional natural and cultural resources for the enjoyment of present and future generations. The park itself is a thin ribbon of protected land that includes the St. Croix and Namekagon rivers and about ¼ mile of land on either side. Land within this strip is a combination of NPS, state, and local government ownership and privately-owned lands over which the NPS has purchased easements. The 255 mile long Riverway runs through two states, 11 counties, 7 state parks, 3 state forests, county forests, and over 1500 parcels of private land. It is also designated as a National Wild and Scenic River. During the summer of 2011, one long-term acoustical monitoring station was deployed at SACN, and during the summer of 2014, two stations were deployed. The sites (SACN001 and SACN002) were selected to represent the typical acoustical conditions of the park, and also because of their proximity to sand and gravel mines near the park boundary. Table 3 shows site information for the monitoring stations, and Figure 1 shows the locations of the acoustic monitoring stations. See Figures 12 and 13 in Appendix A for site photos.

Table 3. SACN long-term acoustical monitoring sites

Site	Site Name	Vegetation	Dates Deployed	Elevation (m)	Latitude	Longitude
SACN001	Swing Bridge Island	Riparian	6/22/11-7/27/11	227	45.26050	-092.75419
			7/17/14-8/28/14	249	45.25783	-092.75619
SACN002	River Mile s91.7, Minnesota side	Riparian	7/15/14-8/27/14	238	45.79947	-092.76707

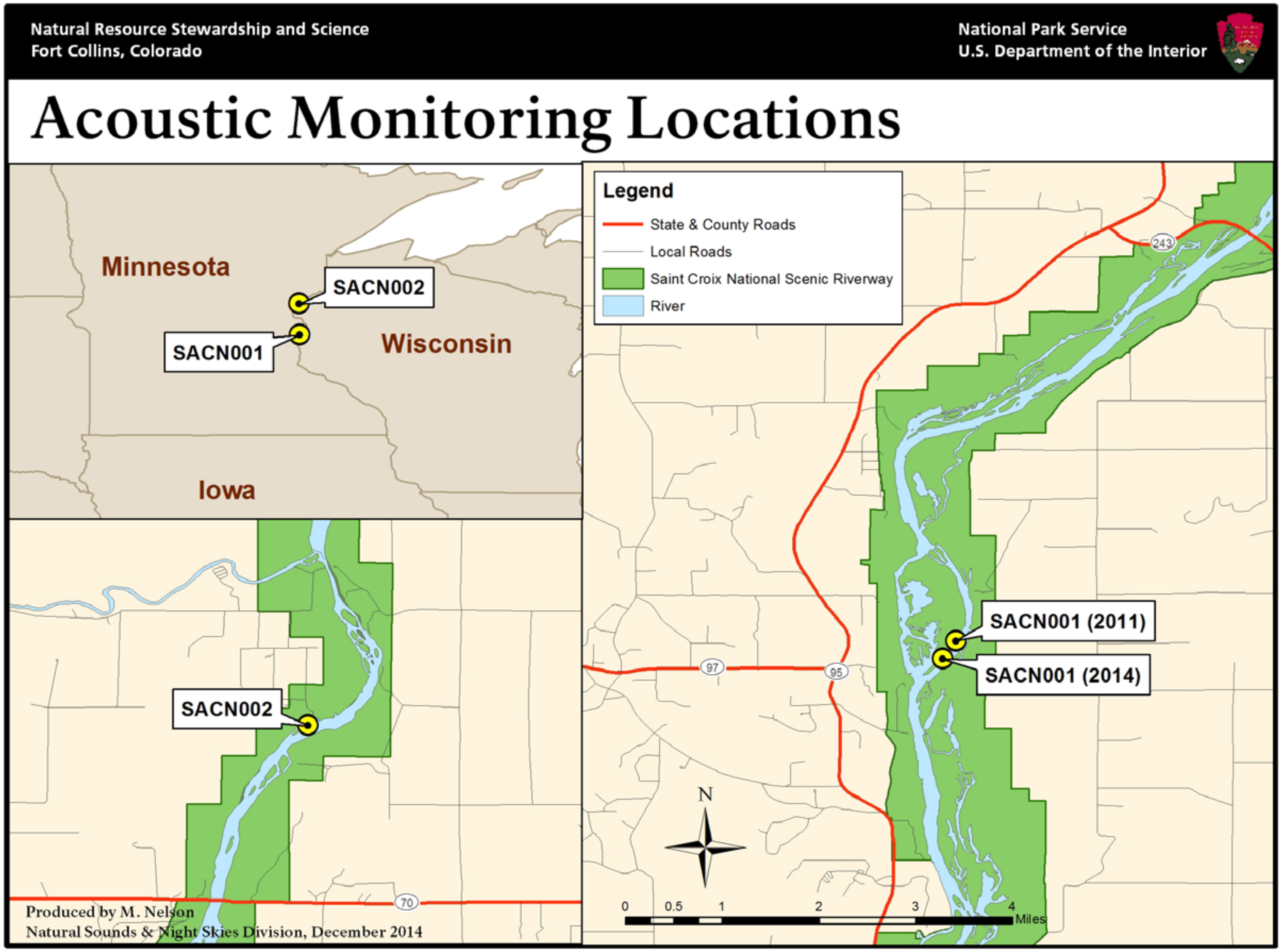

Figure 1. Location of acoustic monitoring sites at Saint Croix National Scenic Riverway

Methods

Automatic Monitoring

Two Larson Davis 831 sound level meters (SLM) were employed over the thirty day monitoring period at the SACN 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 Figures 2, 3, and 4 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; 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, two periods of on-site listening at SACN001 were conducted in 2011, three periods at SACN001 in 2014, and four periods at SACN002 in 2014, 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 Table 4 and Table 5.

Off-Site Listening/ Auditory Analysis

Auditory analysis was used to calculate the audibility of sound sources at SACN. Trained NSNSD staff 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 the Off-Site Data Analysis section below.

Results

On-site Listening

Tables 4, 5, and 6 display the results of the on-site listening sessions at SACN001 and SACN002. 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 4. Summary of on-site audible sound sources for SACN001 n=2 hour-long sessions (2011). Events are measured in minutes:seconds.

Sound Source	PA	Max Event	Mean Event	Min Event	SD Event	Count
Aircraft	0.0	00:02	00:02	00:02	00:01	1
Jet	17.0	02:30	01:05	00:06	00:43	19
Helicopter	4.0	02:05	01:35	00:48	00:41	3
Vehicle	81.0	24:40	03:37	00:03	06:03	28
Vehicle Door	0.0	00:02	00:02	00:02	00:01	1
Motorcycle	0.0	00:09	00:06	00:04	00:03	3
Watercraft	2.0	02:36	01:24	00:12	01:42	2
Grounds Care	6.0	06:35	03:24	00:12	04:31	2
Wind	0.0	00:04	00:04	00:04	00:01	1
Wind, Light	0.0	00:16	00:16	00:16	00:01	1
Bird	100.0	59:55	59:45	59:35	00:14	2
Insect	0.0	00:06	00:05	00:04	00:01	6
Natural Other	94.0	59.53	22:41	03:42	22:04	5
All Aircraft	21.2					
All Road Vehicles	80.7					
All Watercraft	2.3					
Total Non-natural	94.9					
Noise-Free Interval		01:04	00:22	00:01	00:21	17

Table 5. Summary of on-site audible sound sources for SACN001 n=3 hour-long sessions (2014). Events are measured in minutes:seconds.

Sound Source	PA	Max Event	Mean Event	Min Event	SD Event	Count
Jet	2.5	01:26	00:53	00:19	00:31	5
Propeller	9.2	03:36	01:50	00:31	01:14	9
Helicopter	0.6	01:06	01:06	01:06		1
Vehicle	96.2	43:19	17:19	00:40	14:47	10
Vehicle Alarm	0.2	00:17	00:07	00:02	00:08	3
Watercraft	3.8	03:36	00:59	00:16	01:11	7
Pontoon Boat/Houseboat	1.8	03:19	03:19	03:19		1
Non-motorized Craft	2.6	01:23	00:47	00:22	00:24	6
Boat Wake (on shore)	0.1	00:16	00:16	00:16		1
Motor	4.9	06:12	02:55	01:00	02:52	3
Grounds Care	7.8	06:00	02:21	00:03	02:17	6
People	4.8	01:41	00:43	00:14	00:28	12
Talking	2.9	00:57	00:35	00:13	00:17	9
Gunshot	0	00:02	00:01	00:01	00:01	3
Dog	0.4	00:47	00:47	00:47		1
Human, Unknown	0.1	00:10	00:10	00:10		1
Wind	92.9	00:00	20:53	03:14	19:15	8
Squirrel	20.2	18:30	04:02	00:34	06:15	12
Bird	98.7	00:00	29:36	05:04	21:24	6
Insect	2.7	00:31	00:05	00:01	00:06	56
Natural, Other	22.3	01:44	00:23	00:02	00:23	104
All Aircraft	12.2					
All Vehicles	96.2					
All Watercraft	8.3					
All People	7.8					
Total Non-natural	98.1					
Noise-Free Interval		01:34	00:41	00:01	00:39	5

Table 6. Summary of on-site audible sound sources for SACN002 n=4 hour-long sessions (2014). Events are measured in minutes:seconds.

Sound Source	PA	Max Event	Mean Event	Min Event	SD Event	Count
Jet	15.1	05:46	02:16	00:18	01:22	16
Aircraft	1.2	02:46	02:46	02:46		1
Jet	8.2	03:20	02:11	00:48	00:54	9
Propeller	14.2	06:01	03:07	00:46	01:55	11
Vehicle	2.2	01:18	00:36	00:14	00:24	9
Alarm, Horn	0.7	00:25	00:15	00:02	00:09	7
Outboard	3	02:07	01:49	01:06	00:29	4
Non-motorized Craft	5.7	04:01	02:17	00:33	01:10	6
Motor	2	01:22	00:56	00:15	00:27	5
Grounds Care	8.1	09:05	01:46	00:03	02:45	11
Lawnmower	19.4	16:26	07:45	02:40	04:45	6
Voices	12.8	12:56	01:48	00:02	03:03	17
Gunshot	0.3	00:07	00:02	00:01	00:01	24
Domestic Animal	0	00:03	00:03	00:03		1
Dog	0	00:02	00:02	00:02		2
Wind	73.9	59:53	05:43	00:21	12:28	31
Water	79.8	00:00	47:53	11:35	24:12	4
Flowing Water	15.5	15:29	06:12	02:44	04:49	6
Bird	99.9	00:00	59:57	59:52	00:04	4
Insect	10.1	00:53	00:09	00:01	00:09	171
All Aircraft	23.6					
All Vehicles	2.9					
All Watercraft	8.8					
All Grounds care	26					
All People	13					
Total Non-natural	55.6					
Noise-Free Interval		11:51	02:36	00:02	03:04	41

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 (SACN001, 2011), Figure 3 (SACN001, 2014), and Figure 4 (SACN002, 2014). 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 2 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. For example, vehicle noise, wind, and aircraft have overlapping frequency components and may mask one another.

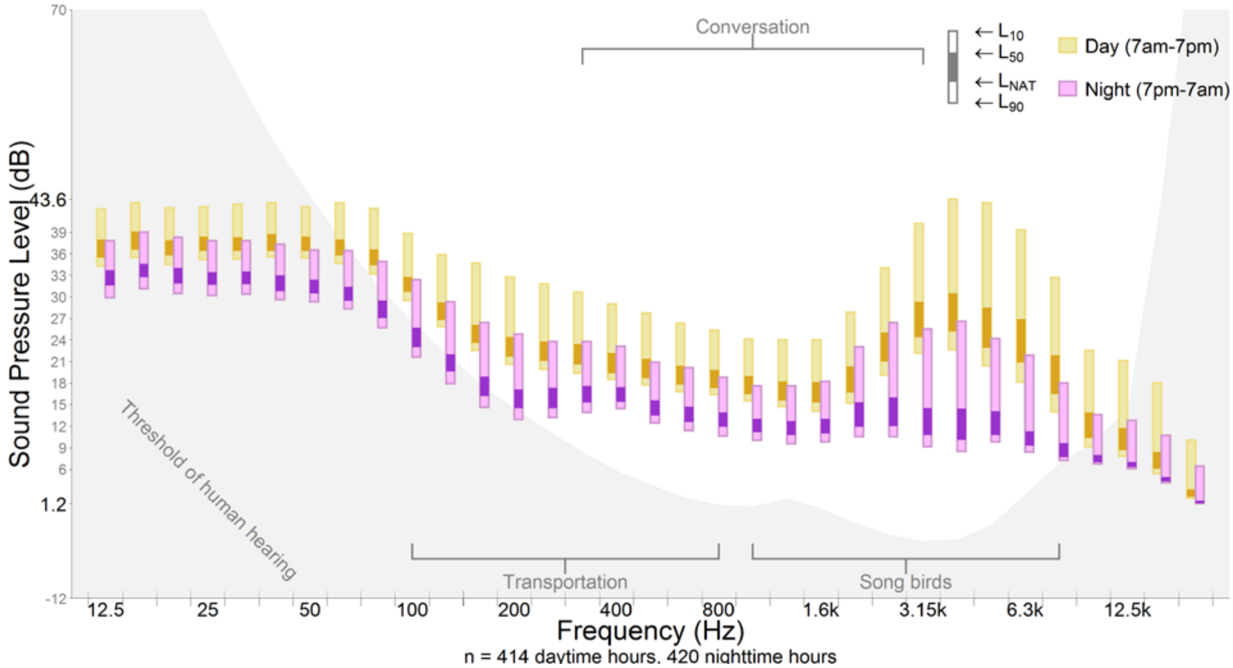

Figure 2. Day and night dB levels for 33 one-third octave bands at SACN001 summer 2011

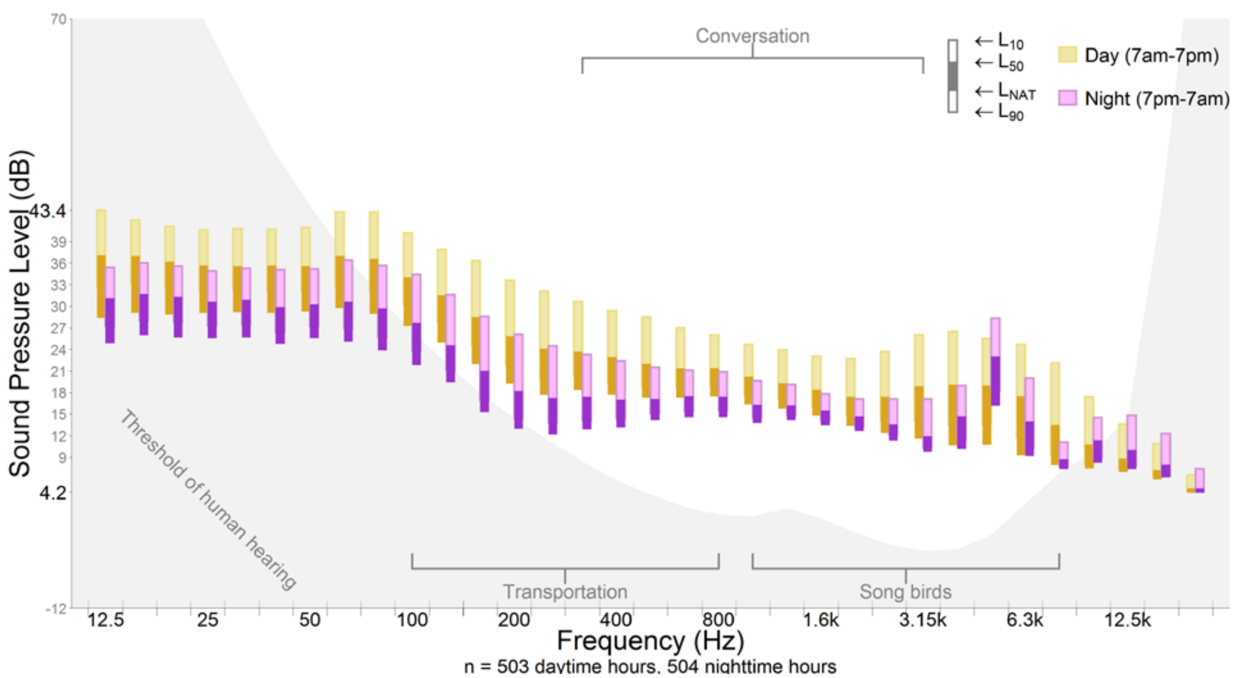

Figure 3. Day and night dB levels for 33 one-third octave bands at SACN001 summer 2014

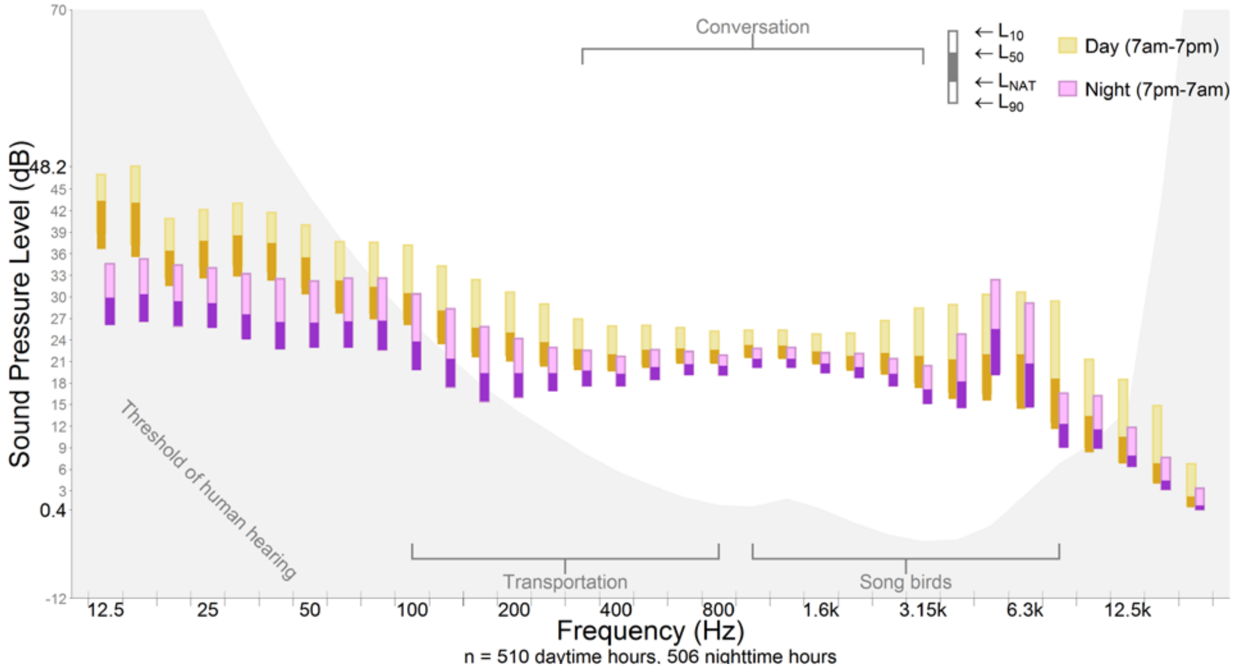

Figure 4. Day and night dB levels for 33 one-third octave bands at SACN002 summer 2014

Table 7 reports the L_{90}, L_{nat}, L_{50}, and L_{10} values for the sites measured at SACN. 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 SACN

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}
SACN001 (2011)	20-1,250	26.0	26.9	29.2	35.5	20.4	21.5	23.6	28.5
	12.5-20,000	33.4	35.1	39.4	50.5	25.5	26.6	29.8	37.5
SACN001 (2014)	20-1,250	27.2	25.8	30.1	36.0	23.1	22.3	25.3	30.0
	12.5-20,000	30.2	28.5	33.3	39.0	29.4	28.2	32.0	36.3
SACN002 (2014)	20-1,250	29.1	28.7	30.7	33.8	26.8	26.7	28.1	29.7
	12.5-20,000	32.8	32.4	35.4	40.7	31.7	31.6	34.3	38.7

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). 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 8. 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
SACN001 (2011)	20-1250	13.84	1.83	0.31	0.03	5.37	0.64	0.13	0.02
	12.5-20,000	79.40	24.70	9.96	2.63	30.65	10.94	4.57	1.32
SACN001 (2014)	20-1250	13.88	1.71	0.35	0.05	7.84	0.88	0.14	0.01
	12.5-20,000	38.06	2.43	0.48	0.06	27.24	1.79	0.26	0.04
SACN002 (2014)	20-1250	11.31	1.09	0.26	0.08	1.77	0.24	0.04	0.00
	12.5-20,000	51.64	5.37	1.00	0.17	33.05	6.38	0.65	0.07

Audibility

Audibility results are presented below. Tables 9, 10, and 11 show the mean percentage of time that all noise sources were audible, based on eight days of off-site auditory analysis. Figures 5-16 show hourly audibility results and compare overall noise audibility to four sources of interest: aircraft, people, vehicles, and watercraft.

Table 9. Mean hourly percent time audible for each noise source at SACN001 in 2011. 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**
Jet	1.2	2.5	3.3	4.2	7.1	3.3	3.8	18.8	7.1	9.2	18.8	10.8	4.6	13.3	12.1	13.8	15.8	8.7	5.8	23.7	11.3	4.2	11.7	3.3
Propeller	0	0	0	0	0.4	2.9	1.7	0.4	5.8	9.6	11.3	10.4	6.7	9.2	5.4	6.2	8.7	6.2	11	8.3	1.2	0.8	2.5	0
Helicopter	0	0	0	0	0	0	0	0	0	0	0.8	0	0	0	0	0	0	0	0	0.8	0	0	0	0.8
Vehicle, unknown	0	0	0	1.7	0.8	0	0	0	0	0	0	0.4	0	0	0.4	0.8	0	0.8	0.4	0.4	0.4	2.1	0	0
Automobile	37	29	19	23	32	18	30	28.7	18	8.3	4.2	7.9	7.1	6.2	6.2	5.4	3.8	3.3	6.2	7.1	10.4	19	14.6	25
Vehicle alarm, horn	0	0	0	0	0	0	0	0	0.4	0.4	0	0	2.9	9.6	2.9	0	0	0	0	0	0	0	0	0
Vehicle door	0	0	0	0	0	0	0.4	0	0	0	0	0	0	0	0	0	0	0	0.4	0	0	0	0	0
Motorcycle	0	0	0	0	0	0.8	0	0.4	0	0.4	0	0	0	0	0.4	0.8	0.4	0.8	0.4	0.8	0	1.2	0	0.4
Truck	0	0	1.2	0	0	0	0	0.4	0	0	0	0	0	0	0.4	0.4	0	0	0	0	0	0	0	0.8
Watercraft, unknown	0	0.8	2.9	0.4	1.2	7.9	3.8	8.7	13	8.7	17.1	15.8	13	13.8	17.5	12.9	8.3	22	20	19.6	17.5	11	2.1	2.1
Watercraft, non-motorized	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
Train	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.2	1.2	0	0	0	0	0	0	0
Train rumble	0	0	0	0	0	0	0	0	0	0	1.2	1.7	1.7	1.7	0	4.6	5	2.9	3.8	2.1	1.2	8.7	2.9	0
Train whistle	0.4	0	0	0	0	0	0	0	0	0	0	0.8	0	0.4	0	0.8	1.2	0.8	0.4	0	0.4	0.8	0.8	0
Generator	0	0	0	0	0	0	0	0	0	0	0	0	1.7	0	0	0	0	0	0	0	0	0	0	0
Grounds care	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
People	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	0	0	0.4	0	0	0	0	0
Voices	0	0	0	0	0	0	0	0	0	0	0.4	0.4	2.5	2.1	3.3	2.9	3.3	3.8	1.2	2.5	1.7	2.1	0.8	0
Portable audio devices	0	0	0	0	0	0	0	0	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.8
Fireworks	0.4	0	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.7	4.2	4.6	16.3	5
Domestic dog	1.7	0.4	2.9	0.4	0	0.4	0.4	0	0	0	1.2	0	0	0	0	0	0.4	0	0	0	0.8	0	1.7	2.5
Construction	0	0	0	0	0	0	0	0	0	0	0	0.8	0.4	0.8	2.5	4.6	2.1	2.5	0	0	0.8	0	0	0
Non-natural unknown	1.7	5.8	7.1	4.2	7.5	18	12	12.1	15	12	10.4	12.9	15	15.4	14.6	16.7	7.5	16	12	17.1	27.9	10	16.7	11
Total Aircraft	**1.2**	**2.5**	**3.3**	**4.2**	**7.5**	**6.2**	**5.5**	**19.2**	**13**	**19**	**30.9**	**21.2**	**11**	**22.5**	**17.5**	**20**	**24.5**	**15**	**17**	**32.8**	**12.5**	**5**	**14.2**	**4.1**
Total People	**0.4**	**0**	**0.4**	**0**	**0**	**0**	**0**	**0**	**0.4**	**0**	**0.4**	**0.4**	**2.5**	**2.1**	**3.3**	**3.3**	**3.3**	**3.8**	**1.6**	**4.2**	**5.9**	**6.7**	**17.1**	**5.8**
Total Vehicles	**37**	**29**	**20**	**25**	**33**	**19**	**31**	**29.5**	**18**	**9.1**	**4.2**	**8.3**	**10**	**15.8**	**10.3**	**7.4**	**4.2**	**4.9**	**7.4**	**8.3**	**10.8**	**22**	**14.6**	**26**
Total Non-natural	**41**	**38**	**36**	**34**	**49**	**52**	**52**	**67.9**	**59**	**48**	**62.9**	**59.6**	**53**	**66.7**	**62.1**	**63.3**	**53.3**	**64**	**60**	**78.7**	**72.9**	**60**	**64.2**	**48**

Table 10. Mean hourly percent time audible for each noise source at SACN001 in 2014. 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
Jet	0.8	0.4	1.2	3.8	2.5	0.8	2.5	5.8	0.4	2.1	7.9	2.9	3.3	7.5	2.5	9.6	9.2	5	4.6	18.3	18.8	4.2	8.3	2.9
Propeller	0	0	0	0	0	0	2.5	3.3	7.5	14.2	21.2	12.5	9.6	8.7	7.1	8.7	6.7	9.6	8.3	2.9	2.1	0.4	2.1	0
Helicopter	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	0	0	0	0	0	0	0	0.4	0.4
Vehicles	91.7	89.2	76.2	80	91.7	96.7	92.9	92.5	92.1	80.8	68.8	70.4	75	81.7	80.8	78.3	80.4	82.9	83.3	78.3	82.5	89.6	89.6	87.5
Alarm, Horn	0	0	0	0	0	0	0	0.8	0.4	0	0	0	0	0	0	0.8	0	0	0	0	0	0	0	0
Outboard Watercraft	2.5	0	0	0	0	0.8	2.9	1.2	5	5.8	5.8	10	10.4	3.8	4.6	5	2.1	6.2	9.2	7.5	6.2	2.1	0.8	0
Non-motorized Watercraft	0	0	0	0	0	0	0	0	0.4	0	0.8	1.7	0.8	0.8	0.8	0	0.8	0.4	0.4	0.8	0	0	0	0
Boat Wake (on shore)	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
Trains	2.5	0	0	0	0	0	0	0	0	0	0	0	2.5	0	0	0	0	0	0	0	0	0	0	0
Train Rumble	0	0	11.3	3.8	0	0	0	0	0	0	0	8.3	6.7	0	0	5.8	5	0	0	0	0	0	0	0
Train Whistle	0	0	1.2	0.4	0	0	0	0	0	0	0	1.2	2.5	0	0	1.2	1.2	0	0	0	0	0	0	0
Motors	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	0
People	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	2.9	0.4	0	0	0	0	0	0	0	0
Voices	0.8	0.4	0.4	0	0	0.4	0.8	0.4	1.7	4.2	5.4	7.9	12.9	12.5	23.3	15	21.2	15.4	6.7	7.9	10.4	7.9	1.2	0.4
Walking	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
Portable Audio Devices	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.8	0	0
Gunshot	0	0	0	0	0	0	0	0	0	0	0	0.4	0	0	0.4	0	0.4	1.7	0	1.2	0.4	0	0	0
Dog	7.1	4.6	6.7	1.7	1.2	0.4	0.4	0.4	0	0	0	0.4	0.4	0	0.8	2.5	1.2	0.4	0	0.8	1.2	3.3	3.3	6.7
Construction	0	0	0	0	0	0	0	0	0	0	0	0.4	0	0	0	0	0	0	0	0	0	0	0	0
Non-natural Other	0	0	0	0	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.1	0.8	0
Non-natural Unknown	0	0	0	0	0	0	1.2	0	0	0	0	0	0	0	0	0	0.4	0	1.7	0.4	0	0.4	0	0
Total Aicraft	**0.8**	**0.4**	**1.2**	**3.8**	**2.5**	**0.8**	**5.0**	**9.2**	**7.9**	**16.3**	**28.7**	**15.4**	**12.9**	**16.3**	**10.0**	**18.3**	**15.4**	**14.6**	**12.5**	**21.2**	**20.8**	**4.6**	**10.8**	**3.3**
Total People	**0.8**	**0.4**	**0.4**	**0**	**0**	**0.4**	**0.8**	**0.4**	**1.7**	**4.2**	**5.4**	**8.3**	**12.9**	**12.5**	**24.2**	**15.0**	**21.7**	**17.1**	**6.7**	**9.2**	**10.8**	**8.7**	**1.2**	**0.4**
Total Vehicles	**91.7**	**89.2**	**76.2**	**80.0**	**91.7**	**96.7**	**92.9**	**92.5**	**92.1**	**80.8**	**68.8**	**70.4**	**75.0**	**81.7**	**80.8**	**79.2**	**80.4**	**82.9**	**83.3**	**78.3**	**82.5**	**89.6**	**89.6**	**87.5**
Total Watercraft	**2.5**	**0**	**0**	**0**	**0**	**0.8**	**2.9**	**1.2**	**5.4**	**5.8**	**6.7**	**11.7**	**11.3**	**4.6**	**5.4**	**5.0**	**2.9**	**6.7**	**9.6**	**8.3**	**6.2**	**2.1**	**0.8**	**0**
Total Non-natural	**97.5**	**90.4**	**88.3**	**87.0**	**93.7**	**97.1**	**98.7**	**99.6**	**99.6**	**99.2**	**99.2**	**98.3**	**97.5**	**96.7**	**93.3**	**97.5**	**95.4**	**96.2**	**97.5**	**97.9**	**98.7**	**95.4**	**97.1**	**90.0**

Table 11. Mean hourly percent time audible for each noise source at SACN002. 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	0.4	0	0	0	0.8	0	0	0	0	0
Jet	2.1	4.6	4.2	9.6	4.2	1.2	0.4	0.8	0	3.8	5.4	6.7	7.1	8.3	6.7	4.6	5	2.1	7.9	7.5	11.7	10.4	4.6	2.9
Propeller	0.8	0	0	0	0	0	0	5	5	11.3	11.7	12.1	7.9	8.7	7.9	12.5	8.3	4.2	4.6	0.8	5	1.2	1.7	0
Vehicles	65.8	52.1	66.7	56.3	70.8	85	74.6	58.3	51.3	33.7	31.7	35	44.6	34.6	32.1	35.8	33.7	50.4	55.4	69.2	51.7	74.6	71.3	73.8
Alarm, Horn	0	0	0	0	0	0	0	5	1.2	1.7	2.5	2.1	3.3	2.9	4.2	4.6	1.7	2.5	2.9	0	0	0	0	0
Heavy Equipment	0	0	0	0	0	0	7.1	35	36.2	32.5	28.7	29.2	27.5	26.2	30.8	23.7	28.7	17.5	8.7	0	0	0	0	0
Outboard Watercraft	0	0	0	0	0	0	0	0.4	0.4	8.7	7.5	6.2	0.8	6.2	2.1	1.7	5	3.8	6.7	5.4	11.7	0.4	0.8	0
Non-motorized Watercraft	0	0	0	0	0	0	0	0	0	0	0	0.4	2.1	2.1	3.3	5.4	4.6	2.9	4.6	1.2	0	0	0	0
Train Rumble	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
Train Whistle	0	0	0	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Motors	0.8	3.8	1.2	1.2	1.2	0.8	6.7	0	0	3.8	0	0	0.4	0	0	0	0	0	0	0	0	0	0	0
Grounds Care	0	0	0	0	0	0	0	0.4	0	0	5.4	1.7	0	0.4	0	0	0	0	0	1.7	3.8	1.7	3.3	3.8
Lawnmower	0	0	0	0	0	0	0	0	0	3.8	12.9	0	0	0	0	0	8.7	6.2	4.6	0.4	6.2	0.8	0	0
Voices	1.7	0.8	0	0	0	0	0.8	0.4	0.4	2.5	9.2	3.8	13.3	11.7	15	14.2	14.2	15.4	19.6	9.6	9.6	5	6.2	4.6
Portable Audio Devices	2.1	0	0	0	0	0	0	0.8	0.8	0.8	7.1	0	0	0.4	5.4	0	2.1	4.6	0	1.7	5	0.8	0	9.6
Gunshot	0	0	0	0	0	0	0	0.4	0.4	0	0	0.4	0	0	0.4	0	0	0	0	0	0.8	0.8	0	0
Domestic Animals	0	0	0	0	0	0	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dog	2.5	1.2	1.2	0	2.5	0.8	0.8	0.8	0.4	0	0.4	0	0	0	0	0	0	0	0.8	0	1.2	0.4	0.4	0.8
Construction	0	0	0	0	0	0	0	0.8	0.4	0	0	0.4	0.4	0.4	0.8	0.8	0	0	0	0	0	0	0	0
Non-natural Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.8	0.8	0	0
Non-natural Unknown	0	0	0	0	0	0	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Aircraft	**2.9**	**4.6**	**4.2**	**9.6**	**4.2**	**1.2**	**0.4**	**5.8**	**5.0**	**15.0**	**17.1**	**18.8**	**15.0**	**17.1**	**15.0**	**17.1**	**13.3**	**6.2**	**13.3**	**8.3**	**16.7**	**11.7**	**6.2**	**2.9**
Total People	**3.8**	**0.8**	**0**	**0**	**0**	**0**	**0.8**	**1.7**	**1.7**	**3.3**	**11.3**	**4.2**	**13.3**	**12.1**	**20.0**	**14.2**	**14.6**	**17.1**	**19.6**	**11.3**	**13.8**	**6.7**	**6.2**	**10.4**
Total Vehicles	**65.8**	**52.1**	**66.7**	**56.3**	**70.8**	**85.0**	**81.2**	**92.1**	**86.7**	**65.8**	**60.4**	**63.8**	**71.3**	**60.4**	**62.9**	**58.8**	**62.5**	**67.1**	**63.3**	**69.2**	**51.7**	**74.6**	**71.3**	**73.8**
Total Watercraft	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0.4**	**0.4**	**8.7**	**7.5**	**6.7**	**2.1**	**8.3**	**5.0**	**7.1**	**9.6**	**6.7**	**11.3**	**6.7**	**11.7**	**0.4**	**0.8**	**0**
Total Non-natural	**72.5**	**60.0**	**71.3**	**67.1**	**76.2**	**87.0**	**87.9**	**97.5**	**90.8**	**93.3**	**98.7**	**87.9**	**87.5**	**85.4**	**88.7**	**82.9**	**90.0**	**85.0**	**88.3**	**84.2**	**87.9**	**89.6**	**79.2**	**83.7**

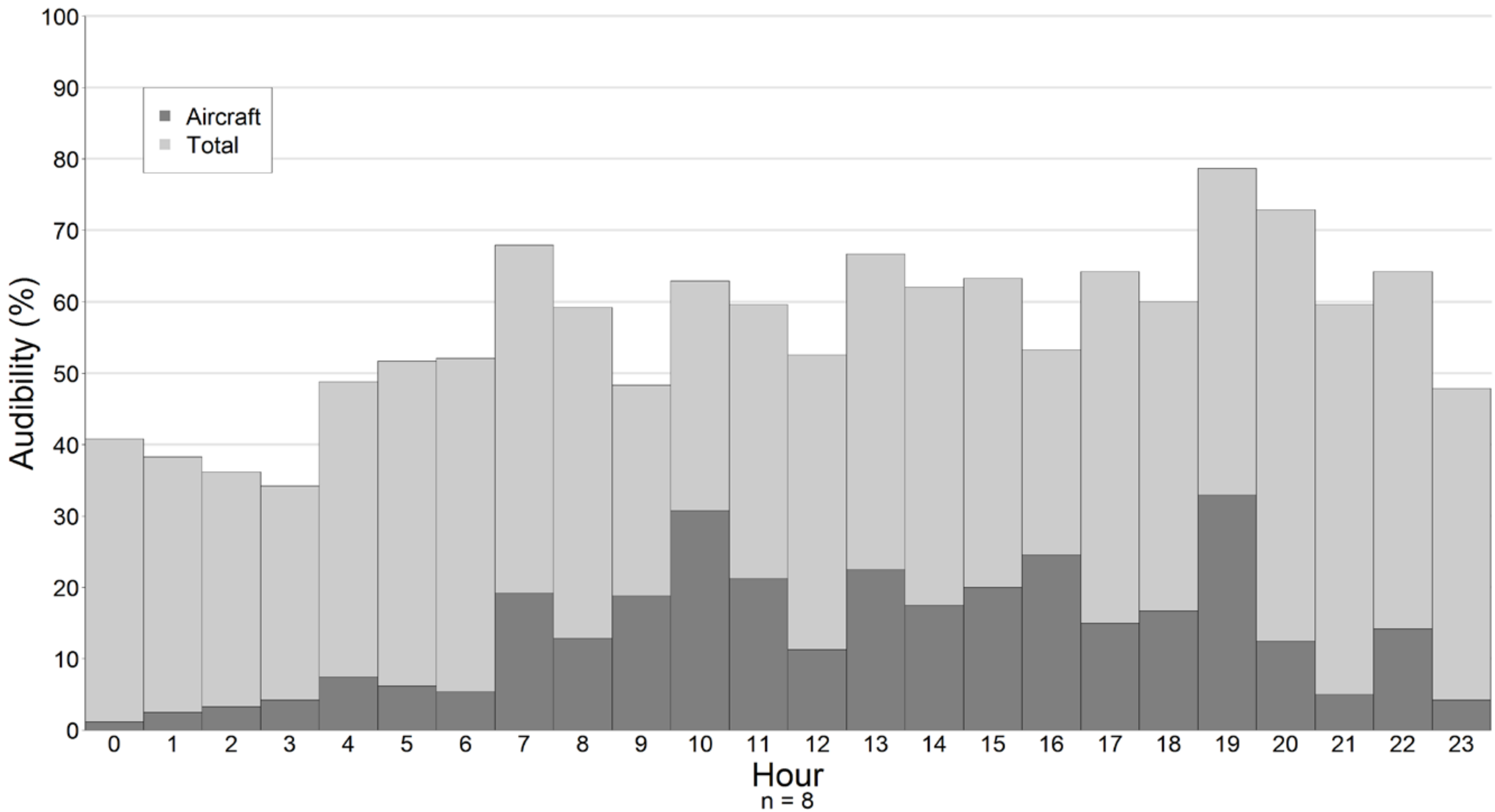

Figure 5. Comparison of hourly aircraft audibility and overall noise audibility at SACN001 summer 2011

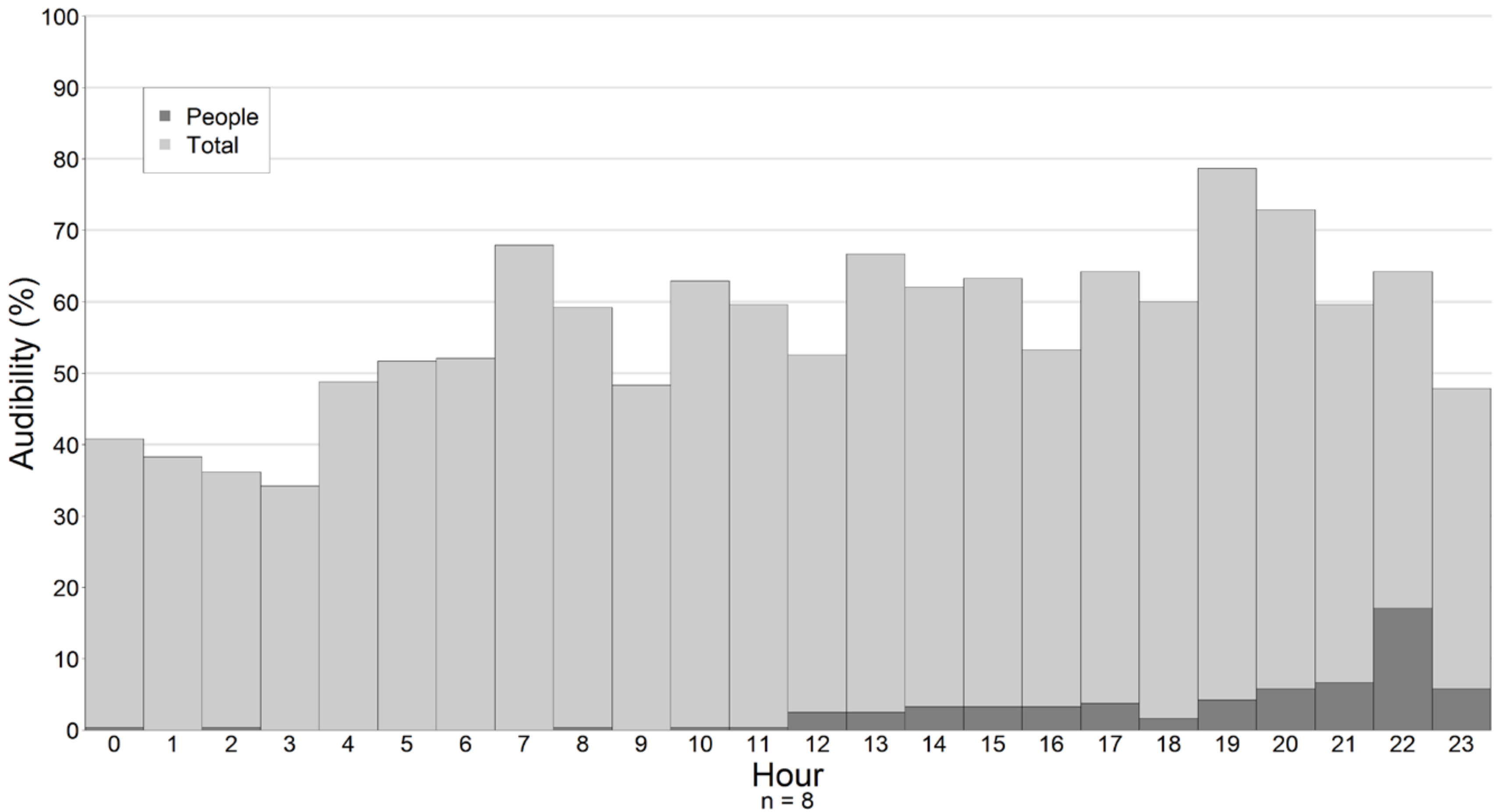

Figure 6. Comparison of hourly people audibility and overall noise audibility at SACN001 summer 2011

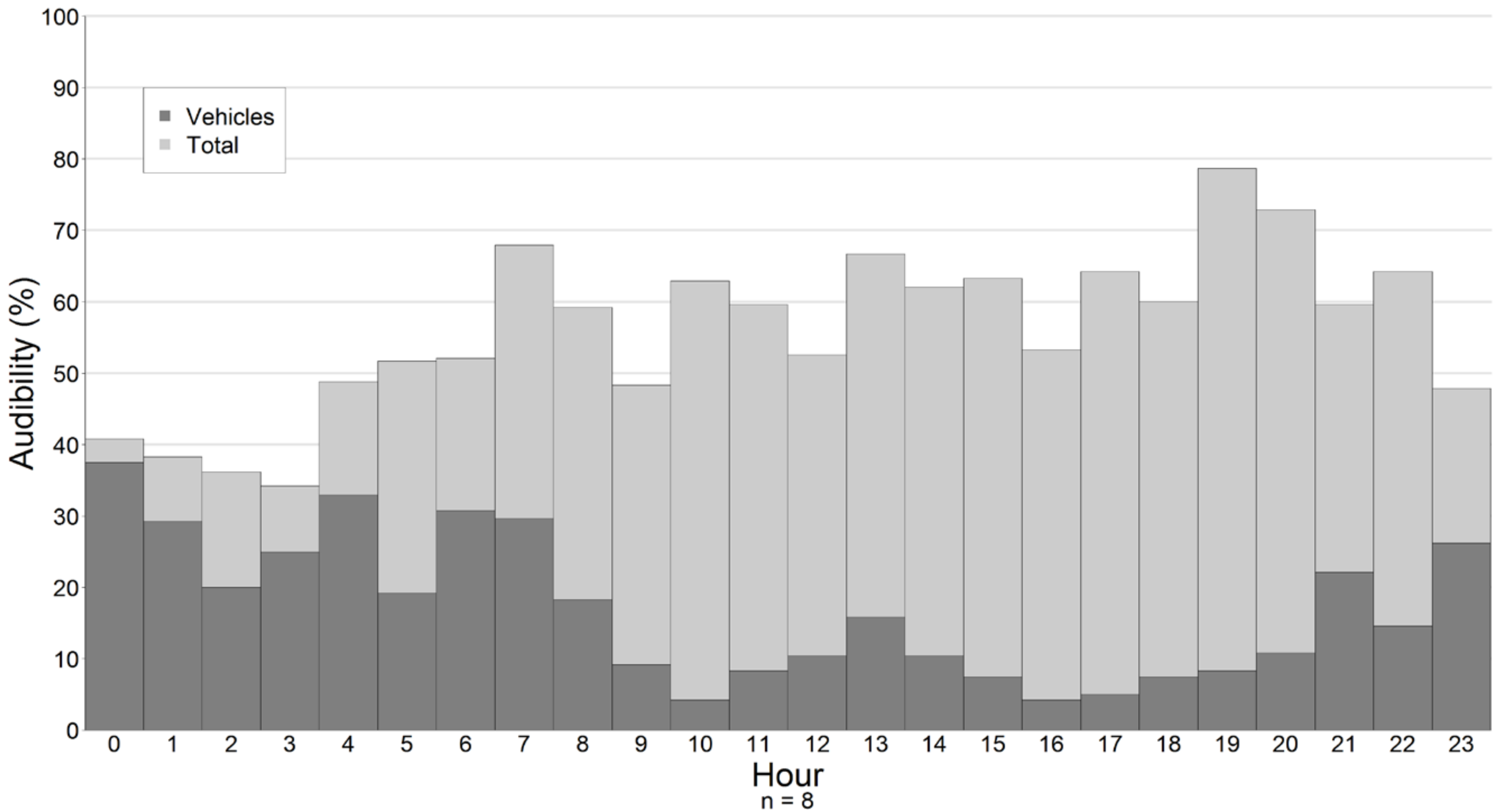

Figure 7. Comparison of hourly vehicle audibility and overall noise audibility at SACN001 summer 2011

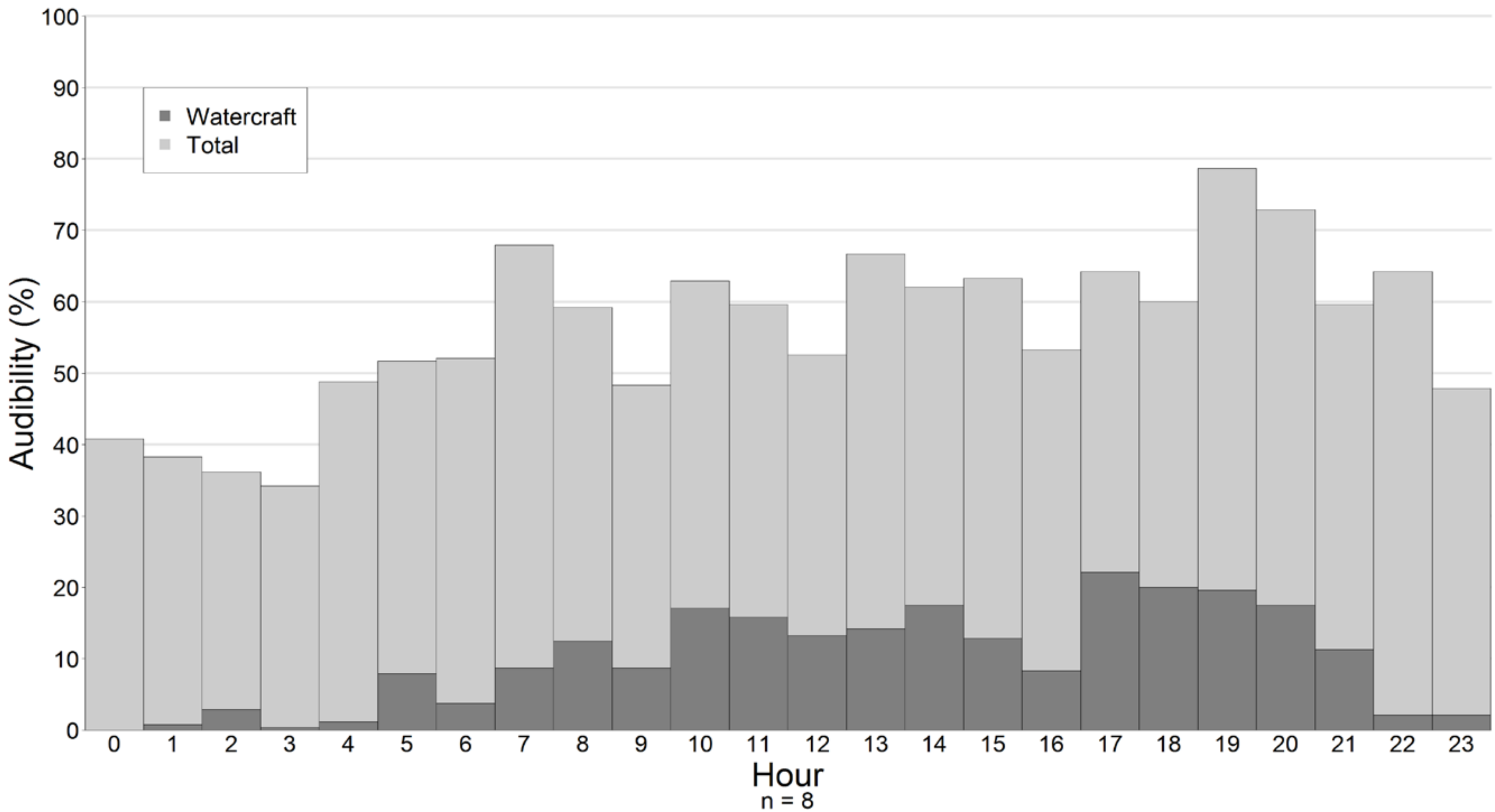

Figure 8. Comparison of hourly watercraft audibility and overall noise audibility at SACN001 summer 2011

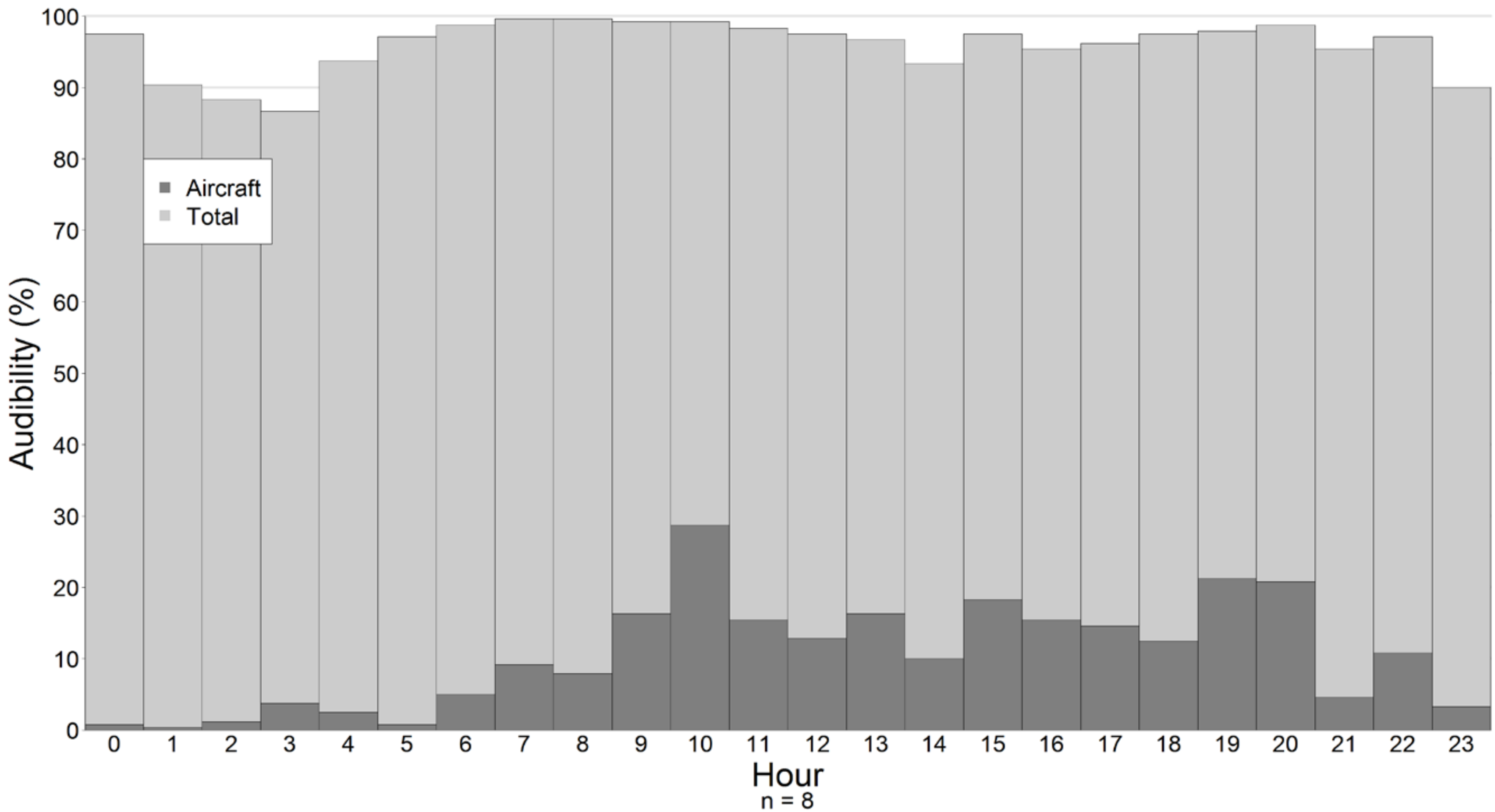

Figure 9. Comparison of hourly aircraft audibility and overall noise audibility at SACN001 summer 2014

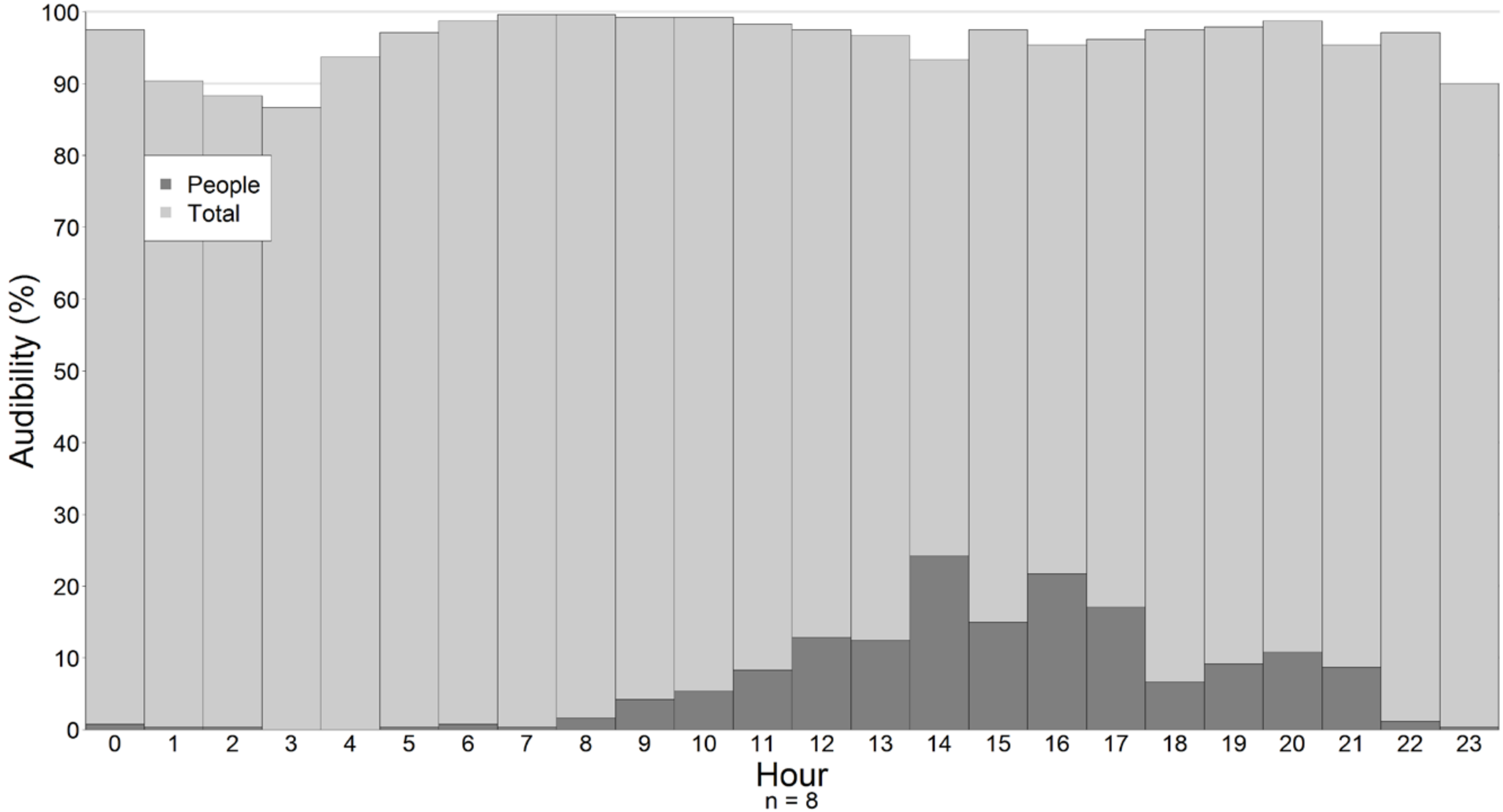

Figure 10. Comparison of hourly people audibility and overall noise audibility at SACN001 summer 2014

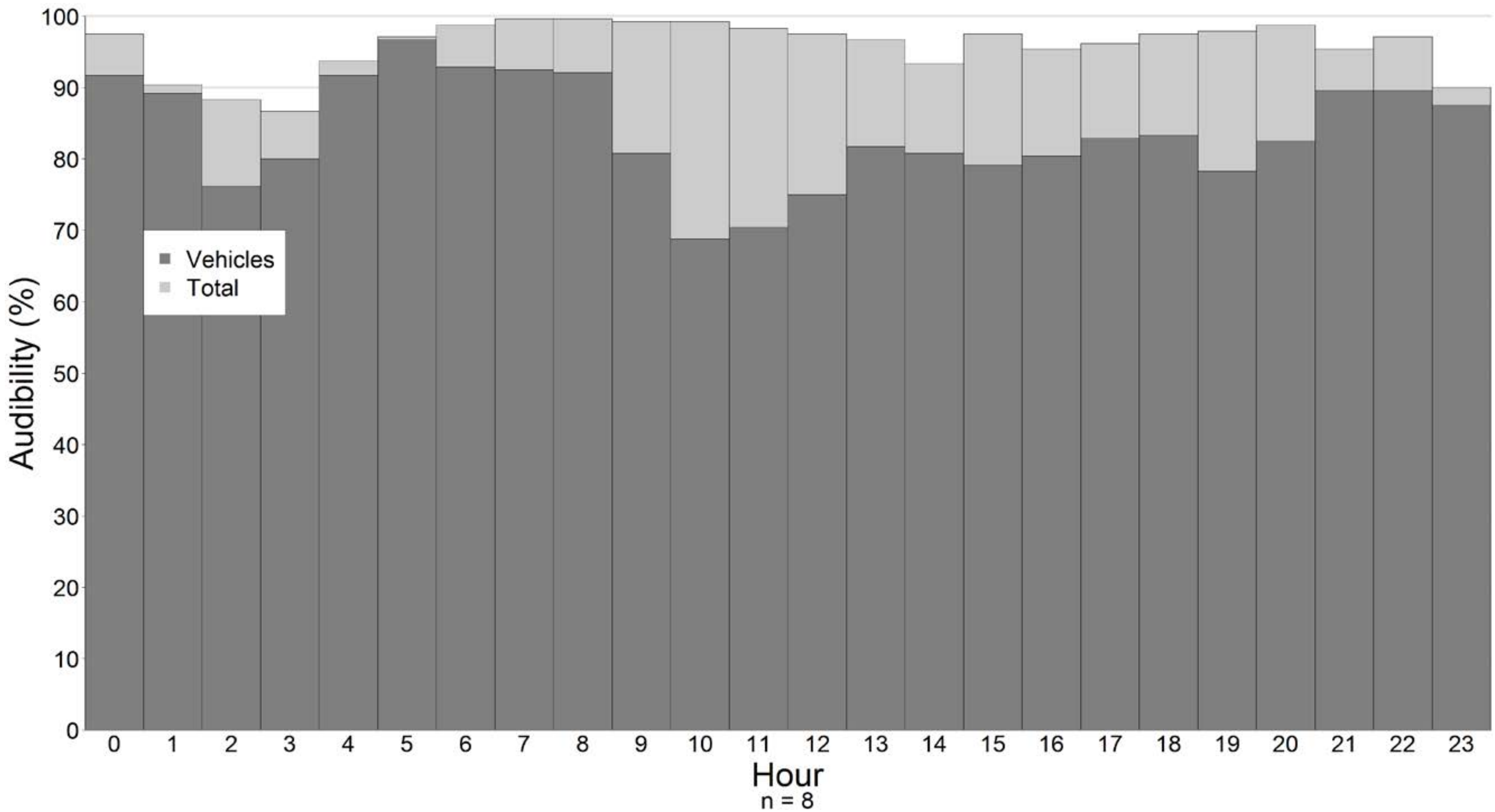

Figure 11. Comparison of hourly vehicle audibility and overall noise audibility at SACN001 summer 2014

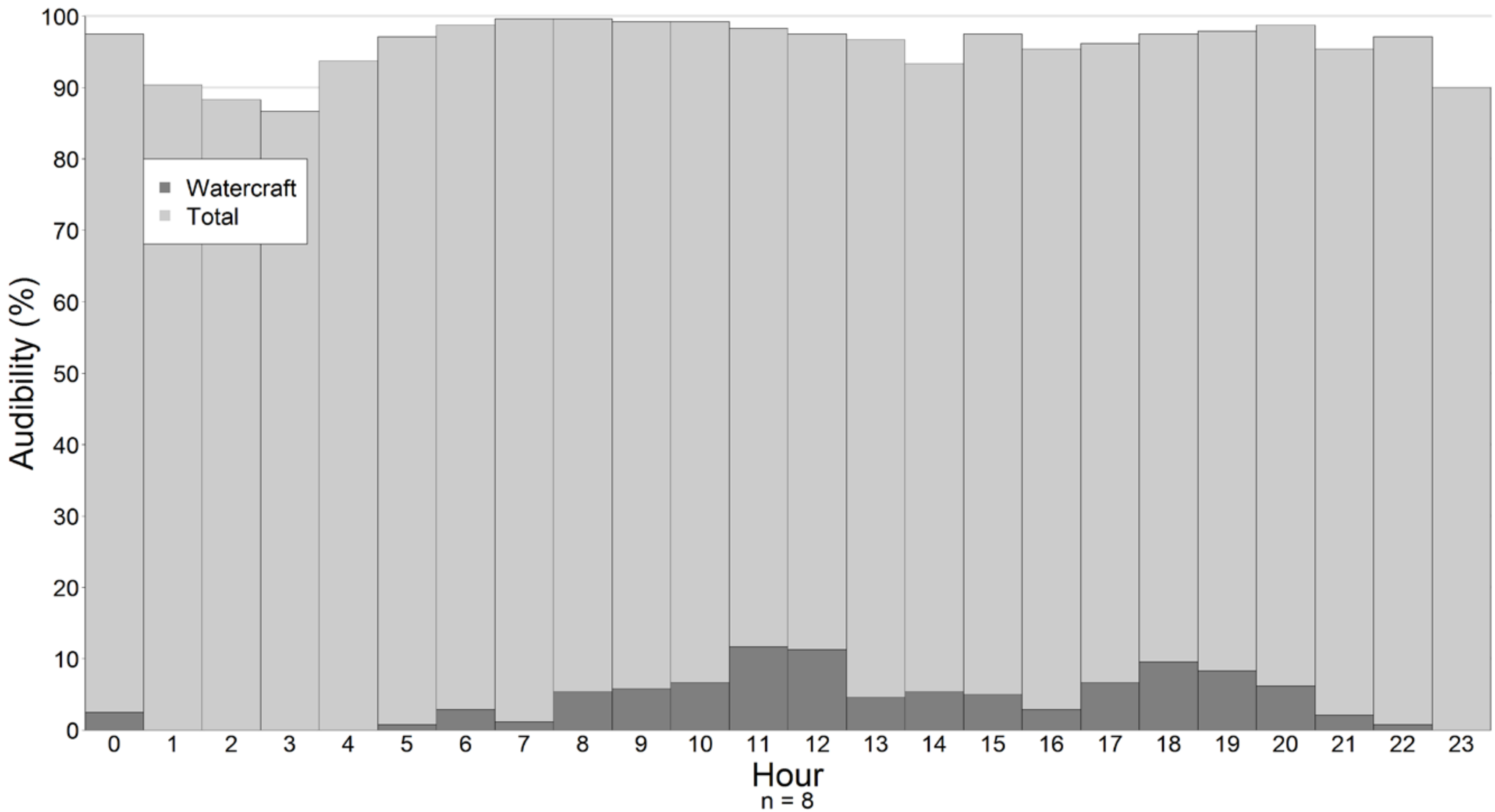

Figure 12. Comparison of hourly watercraft audibility and overall noise audibility at SACN001 summer 2014

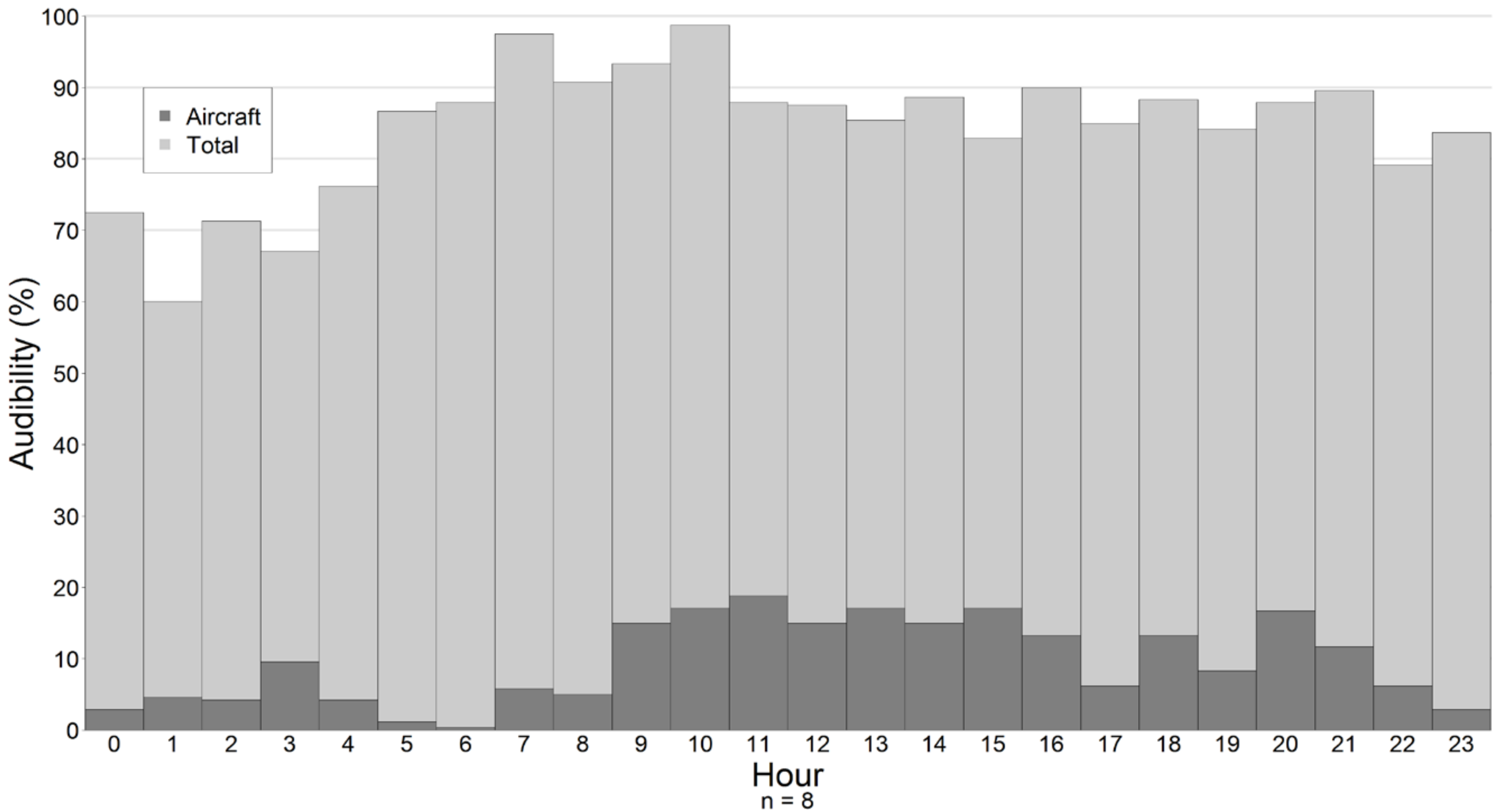

Figure 13. Comparison of hourly aircraft audibility and overall noise audibility at SACN002 summer 2014

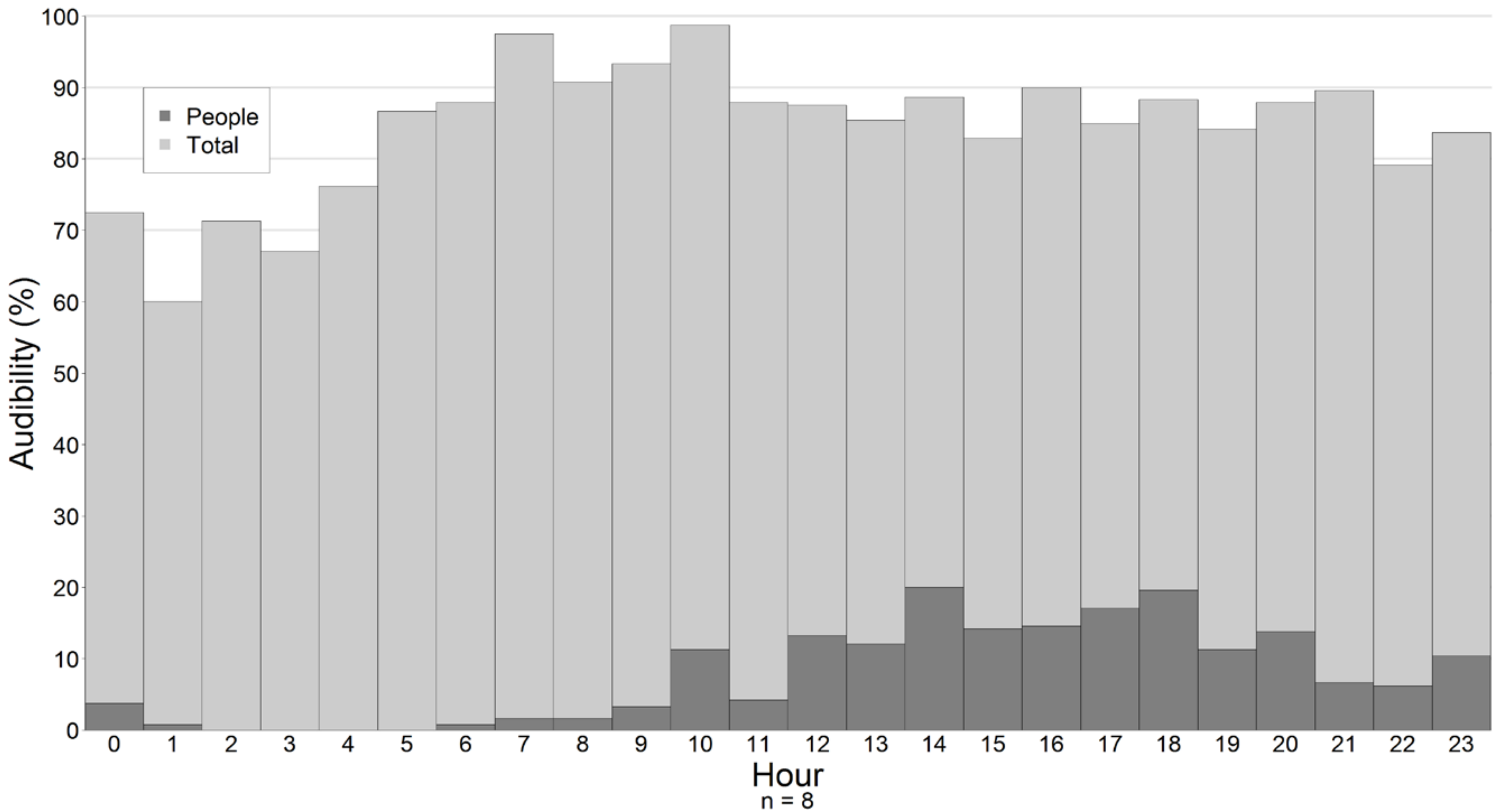

Figure 14. Comparison of hourly people audibility and overall noise audibility at SACN002 summer 2014

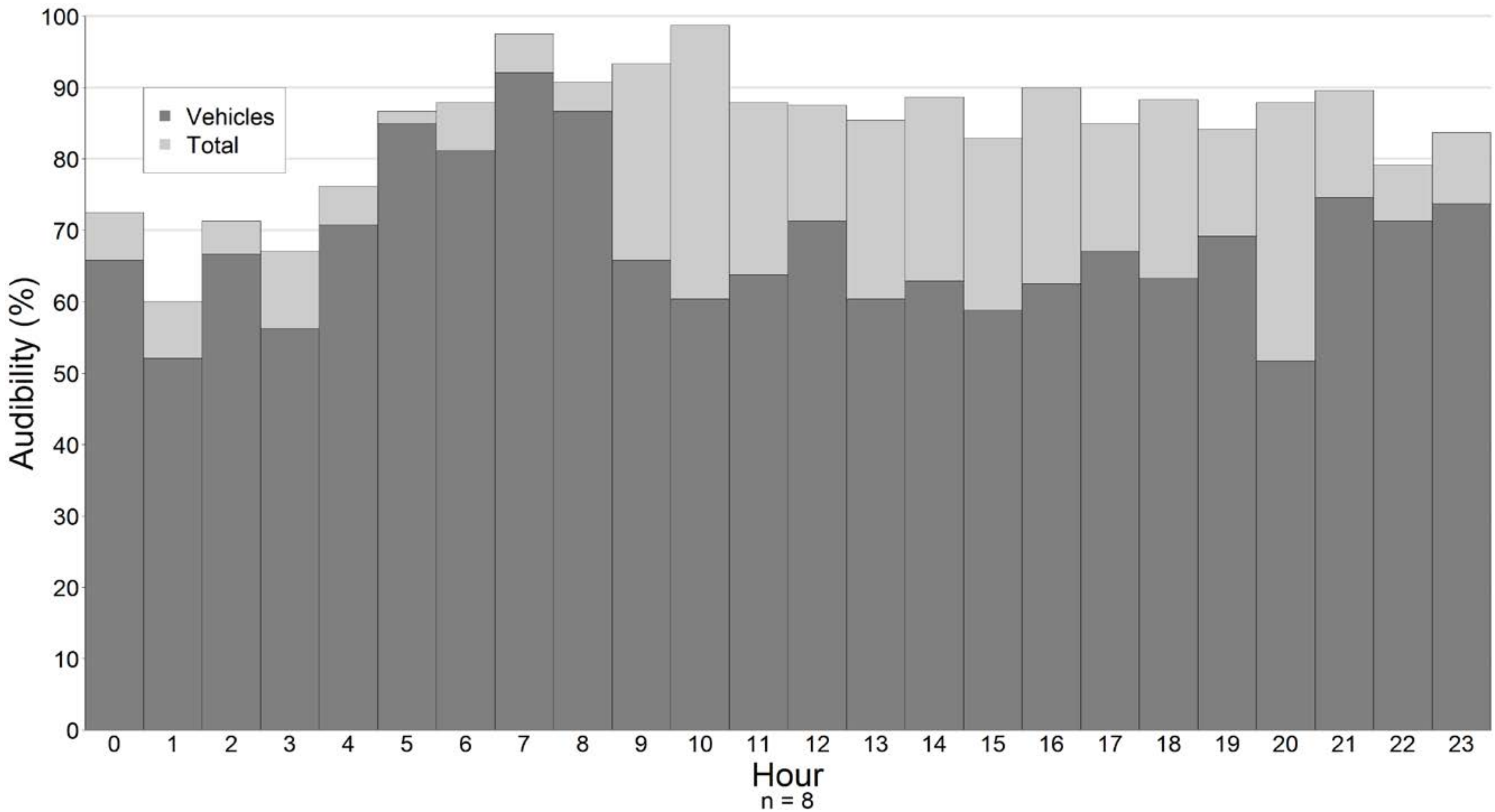

Figure 15. Comparison of hourly vehicle audibility and overall noise audibility at SACN002 summer 2014

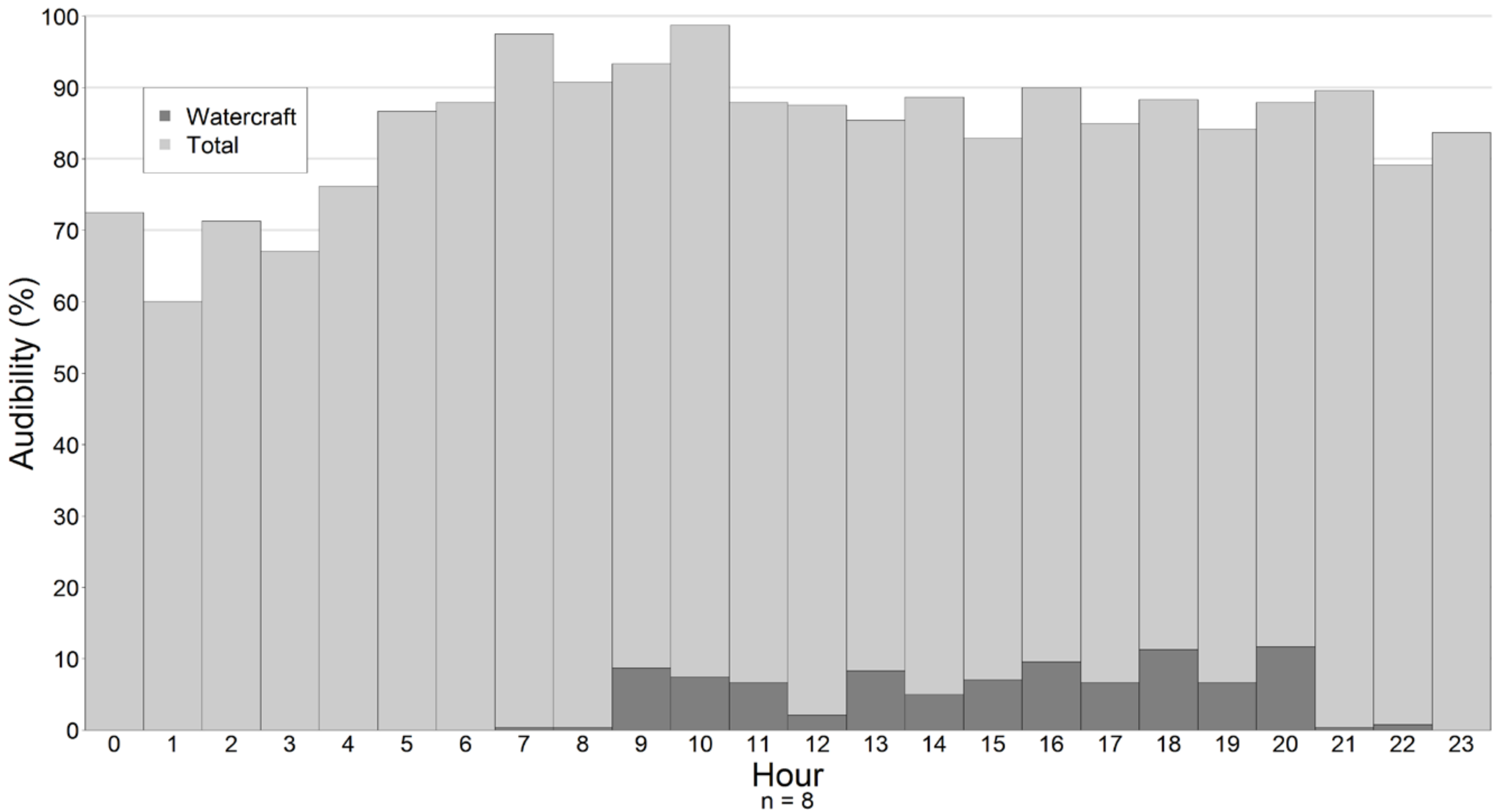

Figure 16. Comparison of hourly watercraft audibility and overall noise audibility at SACN002 summer 2014

Discussion

The purpose of this study was to assess current conditions of the acoustical environment in the park, and to compare those values with previously collected data. 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 for approximately 40 days from two sites, one on Swing Bridge Island (where data were also collected in 2011), and one near River Mile s91.7 between Soderbeck and Highway 70 landings. The acoustical monitoring station locations were chosen because their vegetation and biologic activity were representative of the rest of the park, and also because of their proximity to sand and gravel mining operations.

Results from 2014 monitoring indicated that the natural ambient sound level (L_{nat}) at these sites ranged between 28 dBA at SACN001 and 32 dBA at SACN002. There was little difference between daytime and nighttime L_{nat} values at either location, likely due to increased insect activity at night. Existing ambient sound levels (L_{50}) were slightly higher, ranging from 32.0 dBA at SACN001 during the night to 35.4 dBA at SACN002 during the day. 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 SACN's acoustical environment, however. Despite the relatively quiet overall sound levels, anthropogenic noise was audible 88-100% of any given hour of the day at SACN001, and 60-99% of the time at SACN002. A detailed analysis of audibility at these sites found that four major noise sources (aircraft, people, vehicles, and watercraft) contributed significant amounts of noise to the acoustical environment. During the 2014 monitoring period, the most common source of anthropogenic noise at SACN was vehicles, which could be heard 70-90% of the time at SACN001 and 52-92% at SACN002, and at all hours of the day and night. This is primarily from traffic on nearby roads, but it should be noted that noise likely associated with heavy equipment operation at the sand mine near SACN002 was audible up to 36% of the time between the hours of 6 a.m. and 7 p.m. Aircraft were audible up to 29% of the time at SACN001 and up to 19% of the time at SACN002 during both day and night, although aircraft were more commonly heard during daylight hours. Noise associated with people, including voices, portable audio devices, gunshots, and footsteps, could be heard up to 24% of the time at both sites, and was most common during the afternoon and evening hours. Watercraft noise (including outboard motors and non-motorized craft) was audible 12% of the time or less at both SACN001 and SACN002, and occurred primarily during daylight hours. Other sources of noise heard commonly during the monitoring period included barking dogs, lawnmowers, and trains (particularly at SACN002).

The acoustic environment at SACN001 has changed in several ways between 2011 and 2014. Daytime L_{nat} and L_{50} values decreased by 6.6 dBA and 6.1 dBA, respectively. Interestingly, nighttime values of L_{nat} and L_{50} increased by 1.6 dBA and 2.2 dBA, respectively. Percent time above metrics were also higher in 2011 when compared to 2014. It is worth noting that these differences in both exceedance levels and percent time above values are only reflected in the full frequency range, not the truncated low frequency values commonly associated with transportation noise. This suggests that the differences are likely a result of changes in biological sound sources, such as more daytime birdsong in 2011, and more insect sounds at night in 2014. Despite the fact that low frequency metrics remained fairly constant between 2011 and 2014, the overall audibility of anthropogenic sounds, and traffic noise in particular, showed a marked increase. In 2011, vehicle sounds were audible 4-37% of the time, compared to 70-90% of the time in 2014. Unfortunately, these results do not address one of the primary objectives of the repeat monitoring effort, which was to compare the acoustic environment before and after re-opening of the Zavoral Gravel Mine. Although the mine has been approved since 2011, it was not in operation during the 2014 monitoring period.

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 along the Riverway. Based on nine total hours of daytime listening, birds were audible virtually 100% of the time at both SACN001 and SACN002. It is interesting to note that the overall levels of birdsong were substantially higher in 2011 than in 2014; conversely, insect sounds were more common in 2014 than they were in 2011. In addition to birds and insects, flowing water, wind, and rain all contributed to the natural acoustic environment of the park.

Literature Cited

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: Site Photos

Figure 17. SACN001, Swing Bridge Island long-term acoustical monitoring site

Figure 18. SACN002, River Mile s91.7, MN side long-term 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 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.
Noise Free Interval (NFI)	The length of the continuous period of time during which no human-caused sounds are audible.
Percent Time Above Natural Ambient	The amount of time that various sound sources are above the natural ambient sound pressure levels in a given area. It is most commonly used to measure the amount of time that human-caused sounds are above natural ambient levels. This measure is not specific to the hearing ability of a given animal, but a measure of when and how long human-caused sounds exceed natural ambient levels.

Term	Definition
Percent Time Audible	The amount of time that various sound sources are audible to humans with normal hearing. A sound may be above natural ambient sound pressure levels, but still not audible. Similarly, some sounds that are below the natural ambient can be audible. Percent Time Audible is useful because of its simplicity. It is a measure that correlates well with visitor complaints of excessive noise and annoyance. Most noise sources are audible to humans at lower levels than virtually all wildlife species. Therefore percent time audible is a protective proxy for wildlife. These data can be collected by either a trained observer (on-site listening) or by making high-quality digital recordings for later playback (off-site listening).
Sound Exposure Level (SEL)	The total sound energy of the actual sound during a specific time period. SEL is usually expressed using a time period of one second.
Sound Pressure	Minute change in atmospheric pressure due to passage of sound that can be detected by microphones.
Sound vs.Noise	The NSNSD differentiates between the use of *sound* and *noise*, since these definitions have been used inconsistently in the literature. Although *noise* is sometimes incorrectly used as a synonym for sound, it is in fact sound that is undesired or extraneous to an environment. Humans perceive *sound* as an auditory sensation created by pressure variations that move through a medium such as water or air and are measured in terms of amplitude and frequency (Harris, 1998; Templeton, 1997).
Soundscape	The human perception of physical sound resources.

Appendix C: Modeled Impact Levels

NSNSD developed a model (Mennitt et al. 2014) that predicts the median sound level using measurements made in hundreds of national park sites as well as 109 explanatory variables such as location, climate, land cover, hydrology, wind speed, and proximity to noise sources such as roads, railroads, and airports.

The resulting model can predict sound levels anywhere in the contiguous U. S., and it can also estimate how much lower these sound levels would be in the absence of human activities. The modeled difference between the existing and predicted natural sound level (L_{50} impact) at SACN is shown in Figure 14, 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 SACN, the mean modeled sound level impact is 1.7 dBA, and this value represents an approximation of expected impact levels at a randomly chosen point within the park. This modeled metric is somewhat lower than the measured difference between daytime natural and existing ambient sound levels at SACN in 2014, which is 4.7 dBA at SACN001 and 3.0 dBA at SACN002. The difference between the modeled and measured values may be explained by the fact that 2014 data were collected in relatively high impact areas of the park, and may not be representative of more remote stretches of river. Each pixel in the graphic shown in Figure 19 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 SACN 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%.

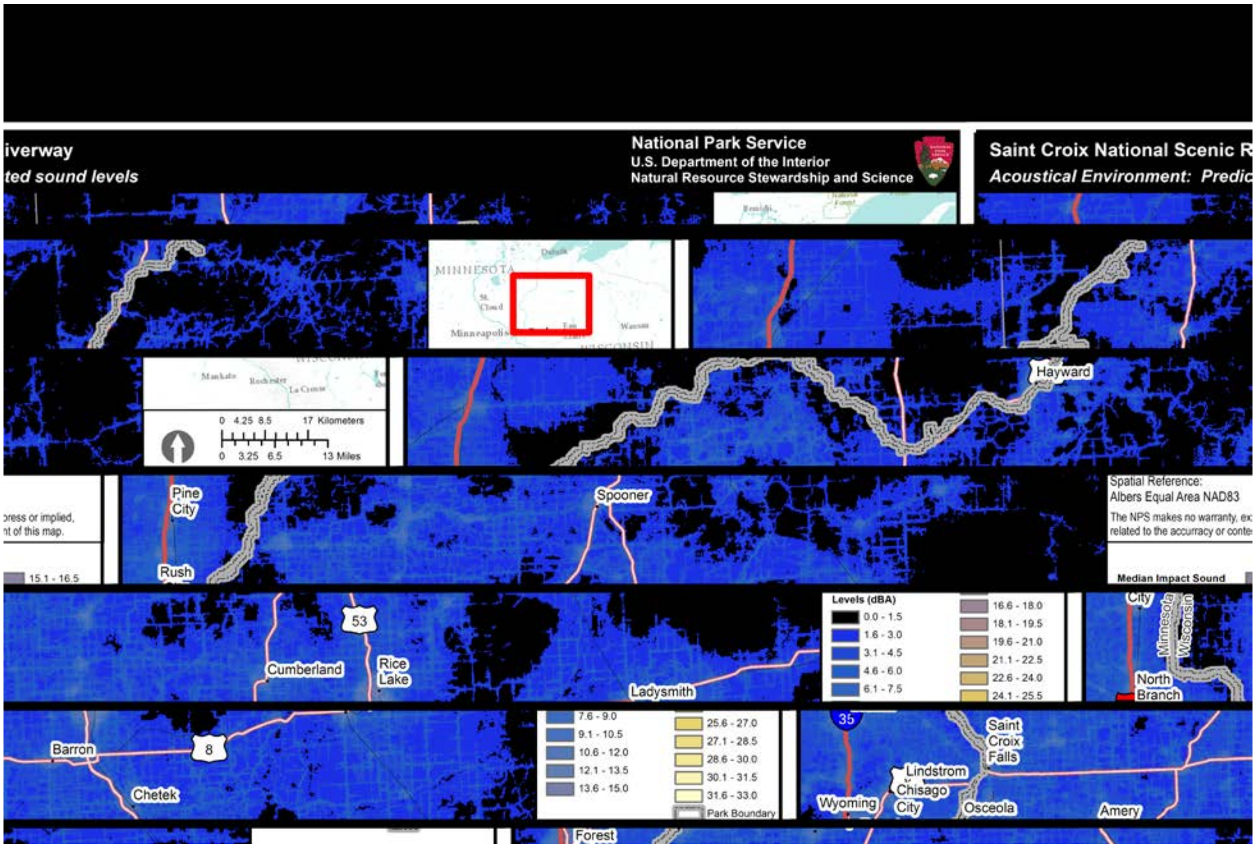

Figure 19. Modeled median sound level impacts in the area surrounding SACN

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 630/127399, December 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

EXPERIENCE YOUR AMERICA ™