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Natural Resource Stewardship and Science

Saguaro National Park

Acoustic Monitoring Report

Natural Resource Report NPS/NRSS/NSNSD/NRR—2016/1347

ON THE COVER
Saguaro National Park Backcountry
Photograph by: NPS

Saguaro National Park

Acoustic Monitoring Report

Natural Resource Report NPS/NRSS/NSNSD/NRR—2016/1347

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Executive Summary

In 2011, the Natural Sounds and Night Skies Division (NSNSD) gathered information about sound levels and predominant sound sources at Saguaro National Park (SAGU) in anticipation of the 2011 BioBlitz event held at the park. One type 1 acoustical monitoring system was deployed for approximately 40 days between July and August 2011. In 2016, SAGU park staff monitored three additional sites throughout the park using NSNSD protocols for calibrating digital audio recordings and NSNSD equipment design. Two of the monitoring stations were deployed for approximately 25 days in February, and the other station was deployed for approximately 20 days during April. This report summarizes results from 2016 data collection efforts, and cites results of 2011 data collection for comparison.

The goal of these studies was to establish a baseline inventory of the soundscape at SAGU. This inventory will be used to establish indicators and standards of soundscape quality that will support the park and NSNSD in developing a comprehensive approach to protecting the acoustic environment through soundscape management planning. Results will help the park identify major sources of noise within the park, as well as provide a baseline understanding of the acoustical environment as a whole for use in potential future comparative studies. Specifically, acoustical data will be used to evaluate the condition of SAGU soundscape in the park's Natural Resource Condition Assessment (NRCA) and to establish a baseline condition for the acoustic environment, which is required for the park's wilderness character monitoring protocol (Engebretson 2012).

The natural ambient sound level is the condition that would exist in the absence of any anthropogenic noise (e.g. mechanical, electrical, and other non-natural sounds). Results (Table 1) indicate that median natural ambient sound levels (L_{nat}) were as follows: 'North Coyote Wash' (SAGU001), 23.7 dBA during the daytime and 40.1 dBA at night; 'Discovery Trail' (SAGU002), 19.2 dBA during the daytime and 18.1 dBA at night; 'Tanque Verde Ridge Trail' (SAGU003), 19.8 dBA during the daytime and 17.8 dBA at night; and 'Steel Tank' (SAGU004), 26.9 dBA during the daytime and 25.7 dBA at night. Median existing ambient sound levels (L_{50}) include both natural and anthropogenic sound, and were higher at all sites: SAGU001, 25.6 dBA during the day and 41.4 dBA at night; SAGU002, 25.8 dBA during the day and 20.4 dBA at night; SAGU003, 22.7 dBA during the day and 21.3 dBA at night; and SAGU004, 27.8 dBA during the day and 26.4 dBA at night. For comparison, Table 2 presents park sound sources and other common sound sources with their corresponding A-weighted decibel values (dBA). Results imply that the median natural ambient sound level during the monitoring period was considerably quieter than most residential areas, and in some cases, were quieter than a whisper.

Table 1. Mean percent time audible for extrinsic (e.g., anthropogenic sourced), vehicles, aircraft, and non-natural unknown sounds, and existing and natural ambient sound levels at the SAGU monitoring sites.

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	Vehicle	Aircraft	Non-natural uknown[c]	Day[d]	Night	Day	Night
SAGU001	North Coyote Wash	35.3	4.0	16.6	n/a	25.6	41.4	23.7	40.1
SAGU002	Discovery Trail	99.8	62.8	8.3	95.3	25.8	20.4	19.2	18.1
SAGU003	Tanque Verde Ridge Trail	98.2	32.1	6.2	95.3	22.7	21.3	19.8	17.8
SAGU004	Steel Tank	48.0	7.4	9.5	31.3	27.8	26.4	26.9	25.7

[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] Non-natural unknown sound sources are associated with human activity, but their exact identity is unclear. At SAGU002 and SAGU003, the source of interest was a consistent, low frequency rumble that was likely either road/highway noise or noise from a distant gravel processing plant.

[d] Day hours are 0700-1900; night hours are 1900-0700.

Table 2. Sound pressure level examples, as measured in national parks

Park Sound Sources	Common Sound Sources	dBA
Volcano crater (HALE)	Human breathing at 3m	10
Leaves rustling (CANY)	Whispering	20
Crickets at 5m (ZION)	Residential area at night	40
Conversation at 5m (WHMI)	Busy restaurant	60
Snowcoach at 30m (YELL)	Curbside of busy street	80
Thunder (ARCH)	Jackhammer at 2m	100
Military jet at 100m AGL(YUCH)	Train horn at 1m	120

In determining the current conditions of an acoustical environment, it is informative to examine how often sound pressure levels exceed certain values. Table 3 reports the percent of time that measured levels at the monitoring sites at SAGU were above four key values. The first value, 35 dBA, is designed to address the health effects of sleep interruption. Recent studies suggest that sound events as low as 35 dB can have adverse effects on blood pressure while sleeping (Haralabidis et al. 2008). This is also the desired background sound level in classrooms (ANSI S12.60-2002). The second value addresses the World Health Organization's recommendations that noise levels inside bedrooms remain below 45 dBA (Berglund et al. 1999). The third value, 52 dBA, is based on the EPA's speech interference level for speaking in a raised voice to an audience at 10 meters (EPA 1974). This value

addresses the effects of sound on interpretive presentations in parks. The final value, 60 dBA, provides a basis for estimating impacts on normal voice communications at 1 meter. Visitors viewing scenic areas in the park would likely be conducting such conversations. Results show that sound levels exceed 35 dBA at all sites during the day, and less commonly at night. SAGU001 is an exception, but nighttime sound levels were likely influenced by an active insect chorus.

Table 3. Percent time above metrics for the monitoring sites at SAGU.

Site ID	Frequency (Hz)	% Time above sound level: 0700 to 1900 (Day)				% Time above sound level: 1900 to 0700 (Night)			
		35 dBA	45 dBA	52 dBA	60 dBA	35 dBA	45 dBA	52 dBA	60 dBA
SAGU001	12.5-20,000	13.6	3.0	1.1	0.3	84.8	21.5	1.2	0.0
SAGU002	12.5-6,300	9.2	1.3	0.2	0.0	1.9	0.1	0.0	0.0
SAGU003	12.5-6,300	3.9	0.6	0.2	0.0	2.6	0.1	0.0	0.0
SAGU004	12.5-6,300	11.4	2.6	0.8	0.1	2.7	0.6	0.2	0.0

Despite the low overall sound pressure levels, noise still exists at SAGU. In this document we refer to “noise” as any human-caused sound that masks or degrades natural sounds (Lynch et al. 2011). The mean 24 hour percent time audibility of anthropogenic noise was 35.3% and 48.0% at SAGU001 and SAGU004 respectively. Noise was very prominent at SAGU002 and SAGU003, at 99.8% and 98.2% of the time respectively.

Analysis of audibility at the monitoring sites found that vehicles and aircraft significantly contributed to the acoustic environment in the park. Vehicle noise was especially prominent at SAGU002 and SAGU003, while aircraft noise was highly prevalent at all sites, especially SAGU001. A non-natural unknown noise source, which could be described as a constant, low amplitude and low frequency rumble and likely to be either road/highway noise or noise from a distant gravel processing plant, was highly prevalent at SAGU002 and SAGU003.

Based on these results, it is unlikely that a visitor to SAGU can experience a significant time period completely free from anthropogenic noise, with this possibility being highly unlikely at SAGU002 and SAGU003. Furthermore, the presence of persistent noise and increased sound levels may have wide ranging effects on wildlife such as reduced predatory success (Mason 2015) and increased vigilance by keystone species (Shannon et al. 2014).

Acknowledgments

The author of this report wishes to express his sincere gratitude to all who helped make this a successful study. This includes employees at SAGU who helped with deployment of the monitoring stations, especially Anna Iwaki and Lauren Nichols, and Colorado State University Listening Lab students Abigail Crowder, Tabitha Gulley, Henry Joyner, Rachael Tindal, and Sean Williams, as well as Jessica Briggs for their work in the off-site/SPLAT acoustical data analysis. Emma Brown and Don Swann provided feedback on the final report.

Introduction

The NPS Visitor

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 actions within and outside of the park, 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 protects park resources and the visitor experience. The NSNSD addresses acoustical issues raised by Congress (such as air tour management), 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, noise modeling, park planning support, and comparative analyses and interpretation 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 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 2006).

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 2006). However, the desired acoustical condition may also depend upon the resources and the values of the park. For instance, Management Policies 5.3.1.7 Cultural Soundscapes, states that "culturally appropriate sounds are important elements of the national park experience in many parks." 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 2006).

Further guidance is provided in 2006 Management Policies 4.1.4 Partnerships, 4.1.5 Restoration of Natural Systems, 8.2 Visitor Use, 8.2.2 Recreational Activities, 8.2.3 Use of Motorized Equipment, and 8.4 Overflights and Aviation Uses (NPS 2006).

Directors Order 47, Preservation of the Acoustic Environment and Noise Management (2015) builds on the principles set out in Management Policies, but goes on to direct how and when to consider acoustic resources in park management. Through this order, parks are guided to manage noise by: identifying noise sources, minimizing noise from park operations, considering the acoustic environment in park planning documents, and promoting park sounds and noise management through communication, education, and outreach.

National Parks Air Tour Management Act (NPATMA) was passed on April 5, 2000 to regulate commercial air tour operations for each unit of the National Park System, or abutting tribal land, where such operations occur or are proposed. The Act required the Federal Aviation Administration (FAA), in cooperation with the NPS, to develop an Air Tour Management Plan (ATMP) for each unit of the National Park System to provide acceptable and effective measures to mitigate or prevent the significant adverse impacts, if any, of commercial air tour operations upon natural and cultural resources and visitor experiences. In 2012, NPATMA was amended to allow the FAA and NPS to enter into voluntary agreements with a commercial air tour operator as an alternative to an ATMP.

Study Area

Saguaro National Park (SAGU) was formally established in 1994, although before then it had been a national monument since 1933. During the summer of 2011, one acoustic monitoring station was deployed in the park, while three other stations were deployed during the winter and spring of 2016. SAGU002 was deployed in the park's west unit, while all other sites were deployed in the east unit. Table 3 shows site information for the monitoring station and Figure 1 shows the location of the acoustic monitoring stations.

Table 4. SAGU acoustical monitoring sites.

Site ID	Site Name	Dates Deployed	Vege-tation	Elevation (m)	Latitude	Longitude
SAGU001	North Coyote Wash	7/2/2011-8/11/2011	Desert	3144	32.14231	-110.67907
SAGU002	Discovery Trail	2/3/2016-2/29/2016	Desert	735	32.26036	-111.21025
SAGU003	Tanque Verde Ridge Trail	2/2/2016-2/29/2016	Desert	1077	32.15564	-110.718809
SAGU004	Steel Tank	4/4/2016-4/24/2016	Desert	946	32.21953	-110.68043

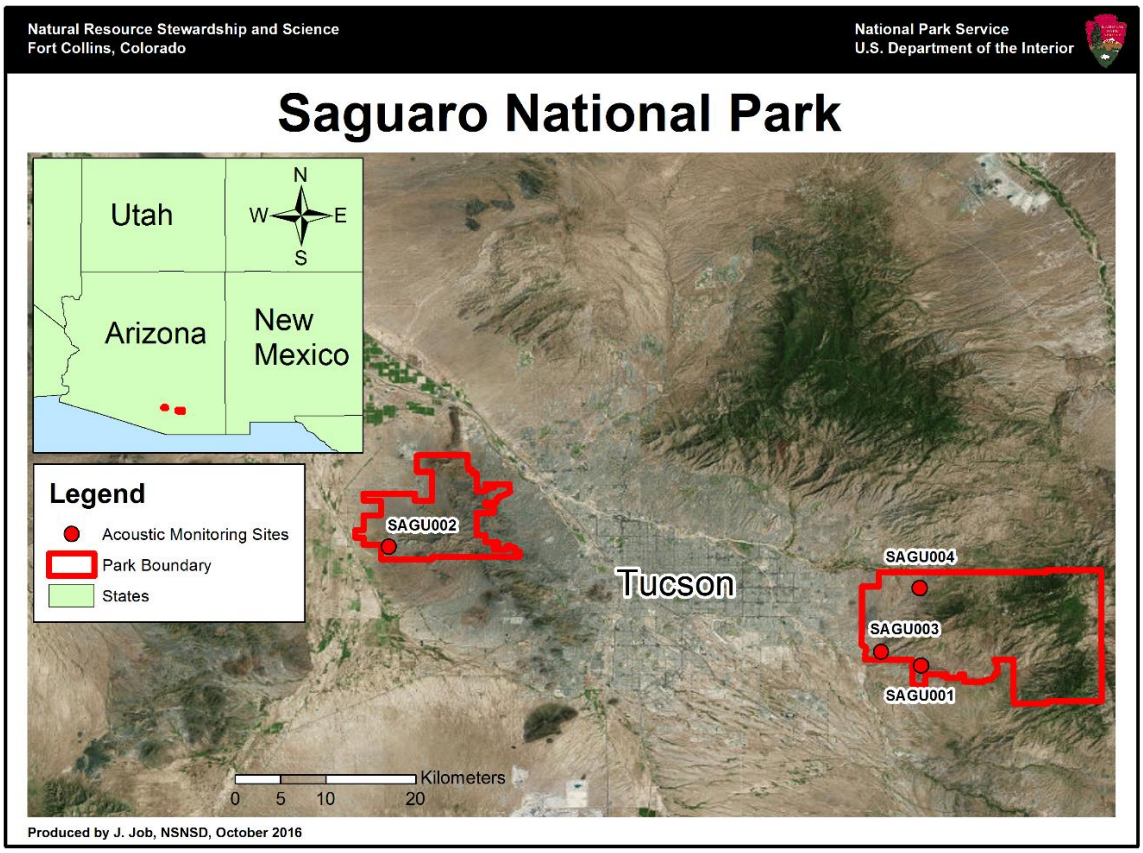

Figure 1. Location of acoustic monitoring sites at Saguaro National Park.

Methods

Automatic Monitoring

Roland R05 digital audio recorders (Roland Corporation, Los Angeles, CA) were employed at each of the monitoring stations. Audio recordings were converted to sound pressure level files using protocol described in Mennitt (2012). Sound pressure level files provided the information needed to calculate metrics described below in Calculation of Metrics.

The sampling stations consisted of:

- Digital audio recorder with environmental shroud
- 3.2 V LiFe rechargeable battery pack

The sampling stations collected:

- Continuous digital audio recordings

After the monitoring period, the continuous digital audio recordings were processed to produce:

- Hourly one-third octave band sound pressure level measurements ranging from 25 Hz – 6.3 kHz

Calculation of Metrics

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

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

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

and P_H is the percentage of samples containing extrinsic or anthropogenic sounds for the hour. For example, if human caused sounds are present 30% of the hour, x = 65, and the L_{nat} is equal to the L_{65}, or the level exceeded 65% of the time.

Off-Site Listening/SPLAT and Auditory Analysis

An analysis of sound pressure level (SPL) data was conducted for data collected at SAGU001 using the custom built software Sound Pressure Level Annotation Tool (SPLAT). SPLAT converts sound pressure level measurements for each of the 33 octave bands into a visual representation of the acoustical environment, called a spectrogram (Figure 2). Noise sources with unique visual signatures on a spectrogram were annotated within SPLAT by a trained technician, gathering information about the timing, duration, frequency, and amplitude of these sources. The technician focused on annotating all sources of noise (e.g. aircraft, vehicles, trains, people, etc.).

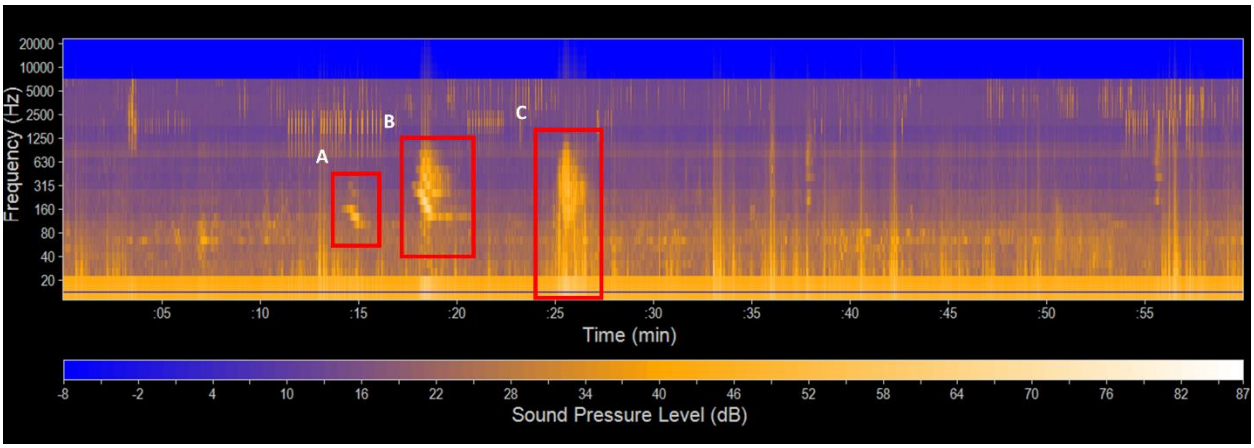

Figure 2. Example spectrogram in SPLAT, used to annotate the presence of aircraft overflights (propeller aircraft: labels ‘A’ and ‘B’; jet aircraft: label ‘C’).

Auditory analysis was used to calculate the audibility of sound sources at the remaining monitoring sites (SAGU002, SAGU003, and SAGU004). Trained technicians at Colorado State University analyzed a subset of .mp3 samples (10 seconds every two minutes for eight days of audio) in order to identify durations of audible sound sources. Staff used the total percent time extrinsic sounds were audible to calculate the natural ambient sound level for each hour (see Equation 1 above for more information). Bose Quiet Comfort Noise Canceling headphones were used for off-site audio playback to minimize limitations imposed by the office acoustical environment. For the complete results of this thorough audibility analysis, see Tables 7-9 in the Off-Site Data Analysis section below.

Results

Off-Site Data Analysis

Metrics

Table 4 reports the L_{90}, L_{nat}, L_{50}, and L_{10} values for the sites measured at SAGU. These exceedance levels represent the sound 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 sound level that has been exceeded 10% of the time, and 90% of the measurements are quieter than the L_{10}.

Table 5. Exceedance levels for existing conditions in SAGU.

Site ID	Frequency (Hz)	Exceedance levels (dBA): 0700 to 1900 hours (Day)				Exceedance levels (dBA): 1900 to 0700 hours (Night)			
		L_{90}	L_{nat}	L_{50}	L_{10}	L_{90}	L_{nat}	L_{50}	L_{10}
SAGU001	12.5-20,000	20.8	23.7	25.6	36.5	38.7	40.1	41.4	44.2
SAGU002	12.5-6,300	21.8	19.2	25.8	33.2	18.6	18.1	20.4	26.2
SAGU003	12.5-6,300	20.7	19.8	22.7	28.0	19.1	17.8	21.3	25.2
SAGU004	12.5-6,300	26.2	26.9	27.8	34.4	25.2	25.7	26.4	29.0

In determining the current conditions of an acoustical environment, it is important to examine how often sound pressure levels exceed certain values. Table 5 reports the percent of time that measured levels were above four key values during the monitoring period (daytime and nighttime). The top value in each split-cell focuses on frequencies affected by transportation noise whereas the lower values use the conventional full frequency range. The first, 35 dBA, is designed to address the health effects of sleep interruption. Recent studies suggest that sound events as low as 35 dB can have adverse effects on blood pressure while sleeping (Haralabidis et al. 2008). This is also the desired background sound level in classrooms (ANSI S12.60-2002). The second value addresses the World Health Organization's recommendations that noise levels inside bedrooms remain below 45 dBA (Berglund et al. 1999). The third value, 52 dBA, is based on the EPA's speech interference threshold for speaking in a raised voice to an audience at 10 meters (EPA 1974). This threshold addresses the effects of sound on interpretive presentations in parks. The final value, 60 dBA, provides a basis for estimating impacts on normal voice communications at 1 meter. Visitors viewing scenic areas in the park would likely be conducting such conversations.

Table 6. Percent time above metrics for existing conditions in SAGU.

Site ID	Frequency (Hz)	% Time above sound level: 0700 to 1900 (Day)				% Time above sound level: 1900 to 0700 (Night)			
		35 dBA	45 dBA	52 dBA	60 dBA	35 dBA	45 dBA	52 dBA	60 dBA
SAGU001	12.5-20,000	13.6	3.0	1.1	0.3	84.8	21.5	1.2	0.0
SAGU002	12.5-6,300	9.2	1.3	0.2	0.0	1.9	0.1	0.0	0.0
SAGU003	12.5-6,300	3.9	0.6	0.2	0.0	2.6	0.1	0.0	0.0
SAGU004	12.5-6,300	11.4	2.6	0.8	0.1	2.7	0.6	0.2	0.0

Figures 3 – 6 depict median hourly sound levels for each site. For each hour, L_{10}, L_{50}, L_{nat}, and L_{90} are shown graphically. The black box for each hour represents the difference between L_{50} (existing ambient) and L_{nat} (natural ambient). The height of this black box is a measure of the contribution of anthropogenic noise to the existing ambient sound levels at this site. The size of this box is directly related to the percent time that human caused sounds were audible during the study period.

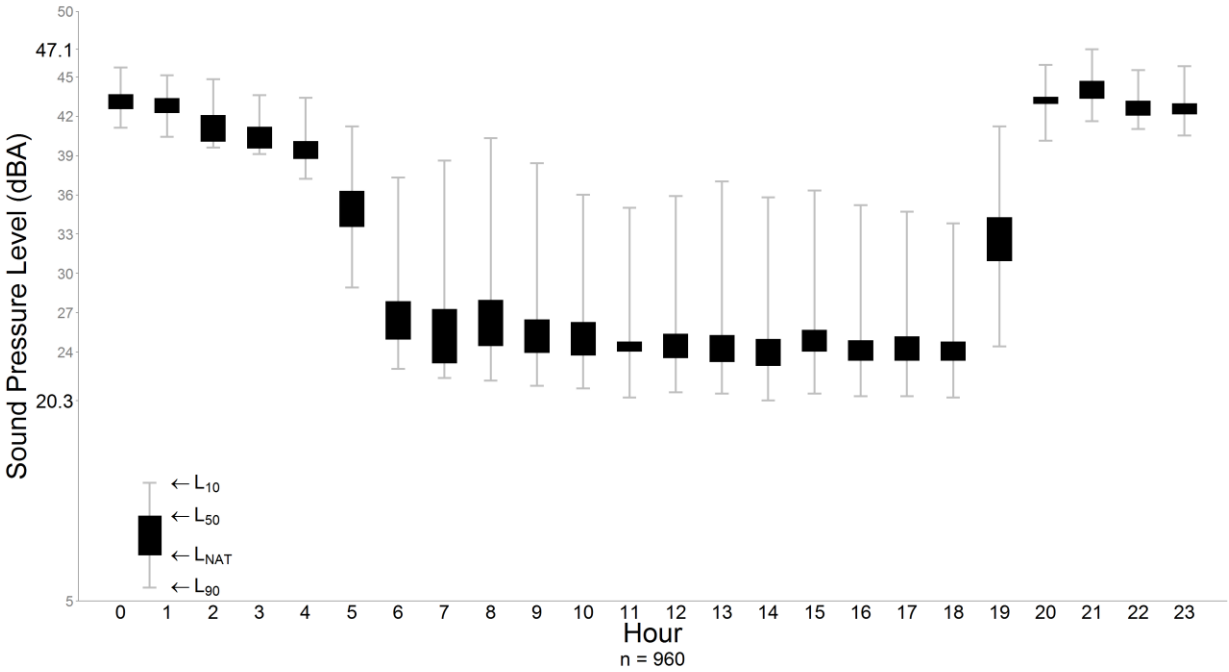

Figure 3. Median hourly sound pressure levels at SAGU001

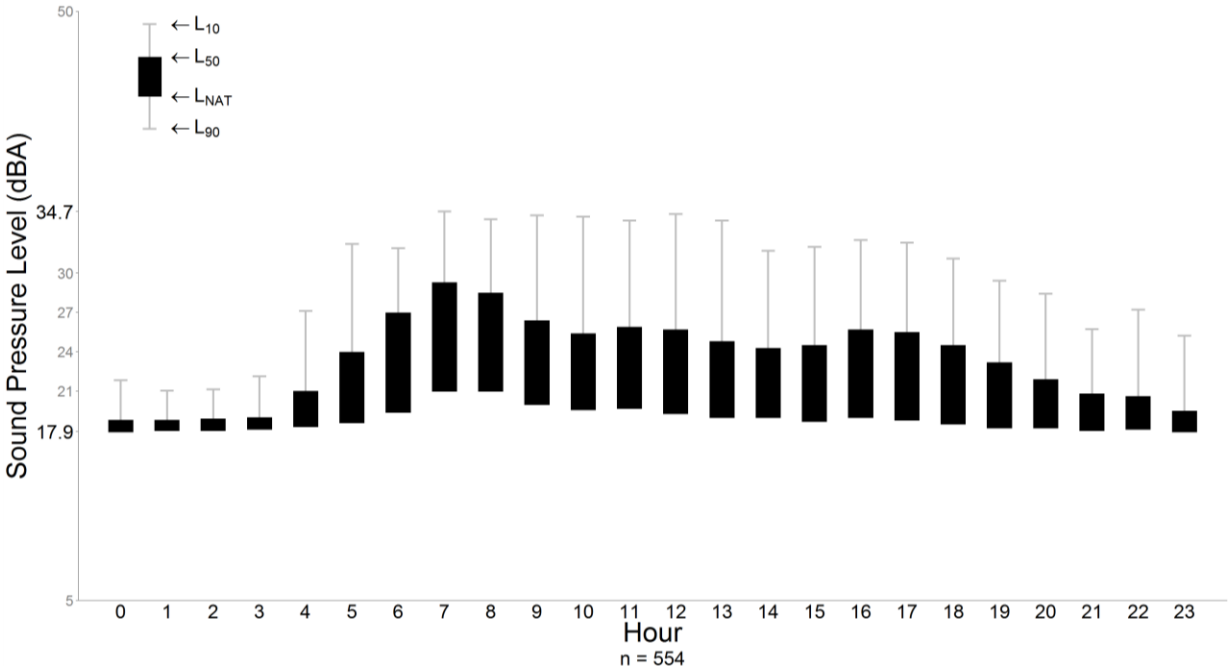

Figure 4. Median hourly sound pressure levels at SAGU002

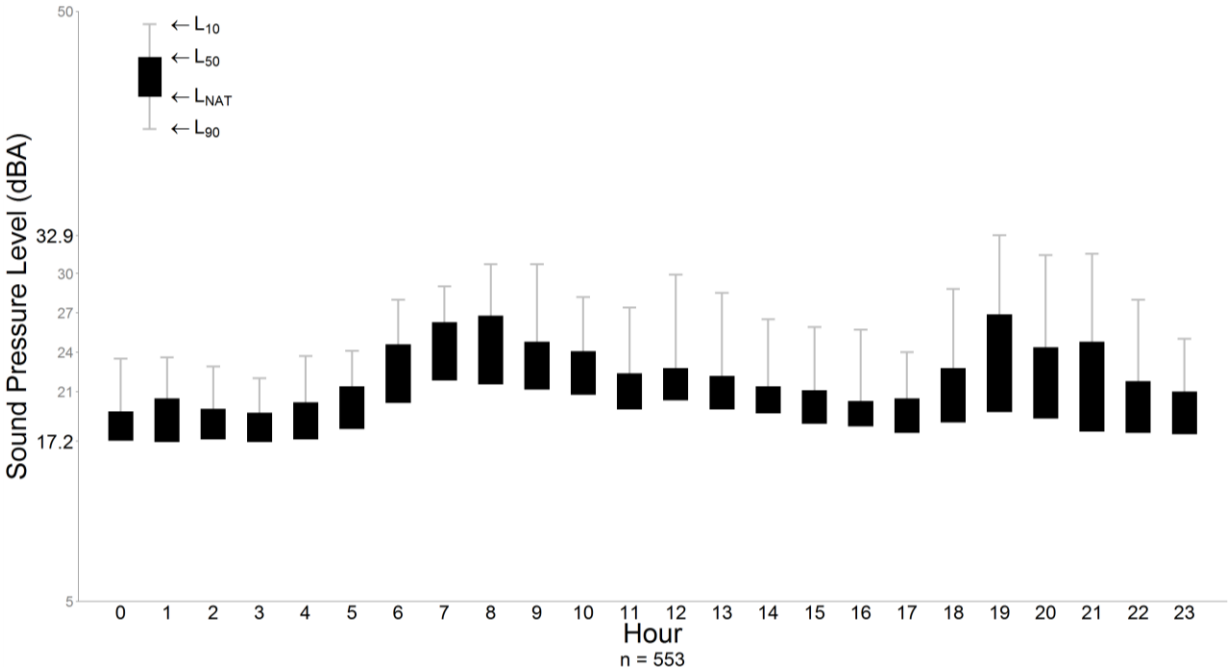

Figure 5. Median hourly sound pressure levels at SAGU003

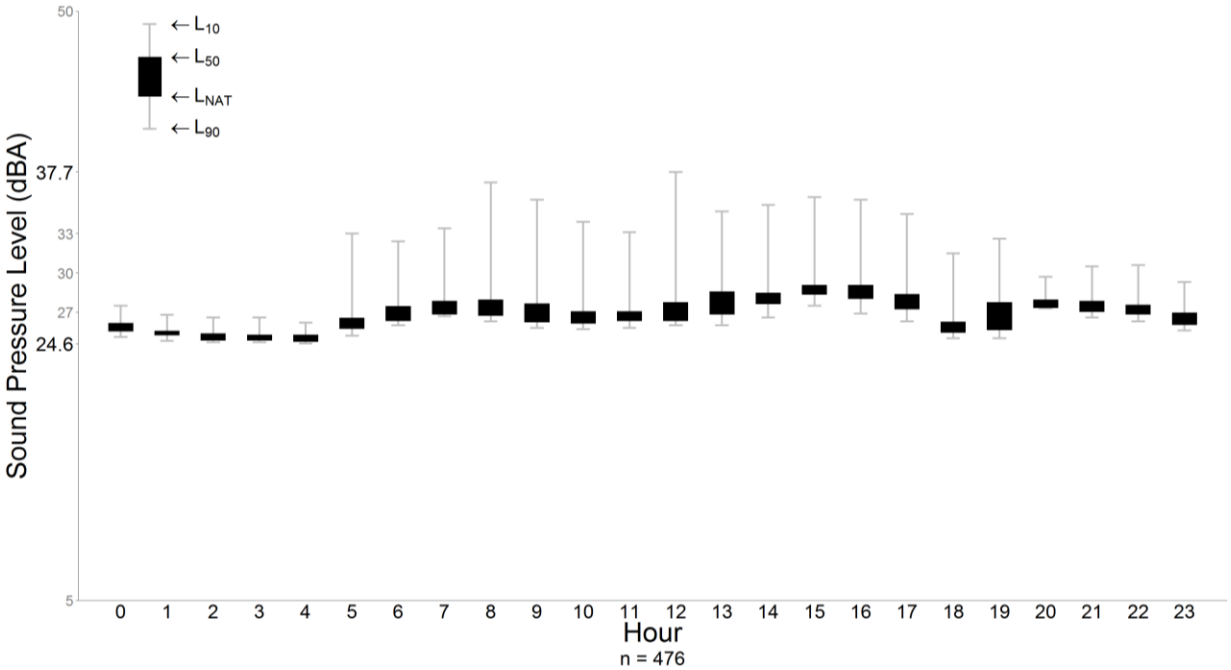

Figure 6. Median hourly sound pressure levels at SAGU004

Audibility

Audibility results are presented below. Table 6 shows the mean percentage of time that all noise sources were audible at SAGU001, as determined by eight days of SPLAT analysis. Table 7-9 show the mean percentage of time all noise sources were audible each remaining site, as determined by eight days of off-site auditory analysis. Figure 7 - Figure 10 show hourly audibility results and compares overall noise audibility to that of a noise source of interest. Figure 11 shows aircraft and vehicle event counts at SAGU001 as detected during daytime (0700-1900) and nighttime hours (1900-700), as well as during an entire 24hr period.

Table 7. Mean hourly percent time audible for each noise source at SAGU001. N=8 days SPLAT analysis.

Sound Source	**00h**	**01h**	**02h**	**03h**	**04h**	**05h**	**06h**	**07h**	**08h**	**09h**	**10h**	**11h**	**12h**	**13h**	**14h**	**15h**	**16h**	**17h**	**18h**	**19h**	**20h**	**21h**	**22h**	**23h**
Aircraft	2.0	1.1	3.7	1.5	0.4	10.1	18.8	31.3	41.1	37.5	31.0	16.0	26.3	31.1	21.5	21.1	12.4	18.7	13.9	17.3	11.4	11.8	8.8	9.0
Vehicle	8.8	1.7	1.7	4.0	3.9	8.6	13.9	6.0	2.6	3.4	0.6	0.2	1.0	0.0	0.0	0.4	3.0	0.0	1.1	1.9	7.4	12.9	7.8	4.7
Train	36.8	47.0	60.6	60.7	53.4	23.3	20.2	35.2	15.7	0.0	0.0	0.0	0.0	1.3	0.0	0.0	9.5	9.0	7.8	16.6	16.6	14.4	24.5	18.5
People	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	2.7	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 8. Mean hourly percent time audible for each noise source at SAGU002. 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	1.1	0.0	0.0	0.0	0.0	0.4	1.1	8.9	10.0	14.8	18.1	20.4	12.2	14.4	13.7	17.8	11.1	7.4	10.4	9.3	10.7	4.1	8.1	5.9
Vehicle	39.6	33.7	28.9	30.7	67.8	86.3	88.5	88.1	86.7	74.1	60.4	61.9	57.0	53.3	57	67	65.6	71.5	78.5	70.4	63.0	68.9	61.5	47.0
People	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	1.1	1.9	1.1	0.0	1.1	0.7	0.0	1.1	1.1	0.0	0.0	0.0	0.0	0.7
Domestic dogs	14.1	23.3	19.6	11.1	3.7	1.9	3.0	2.6	0.4	0.4	1.1	0.0	0.0	0.4	0.0	0.0	0.0	0.7	0.0	1.9	3.3	8.1	9.6	12.2
Non-natural unknowna	99.6	100.0	100.0	100.0	100.0	100.0	99.3	96.7	93.7	91.9	89.6	92.2	93.7	90.4	92.6	94.1	92.6	91.9	93.7	94.8	93.3	96.7	93.3	96.3

[a] Non-natural other sound sources are associated with human activity, but their exact identity is unclear. The source of interest at this site was a consistent, low frequency rumble that could have been either road/highway traffic noise or noise from a distant (~12 miles) gravel processing plant.

Table 9. Mean hourly percent time audible for each noise source at SAGU003. 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	1.1	3.0	0.4	1.9	0.0	5.9	4.4	6.7	5.2	11.9	10.0	10.4	12.2	8.1	11.1	5.2	9.3	6.7	6.7	7.8	5.2	6.7	5.2	2.6
Vehicle	21.5	21.5	24.4	28.1	32.6	35.6	51.5	47.0	50.0	28.5	25.9	21.9	20.7	19.3	24.4	31.9	27.4	31.5	46.3	40.0	44.8	35.9	32.6	27.0
Train	0.0	0.0	0.0	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.4	0.4	0.4	0.0	0.0	0.4
People	0.4	1.1	2.2	0.0	0.0	0.0	0.0	1.9	3.3	1.5	1.1	4.1	1.1	0.0	4.8	3.3	2.2	0.0	0.0	0.4	0.0	0.0	0.4	0.0
Domestic dogs	2.6	0.7	1.1	1.9	0.4	0.0	2.2	11.1	5.2	6.3	5.6	3.0	1.9	2.2	0.4	1.5	2.2	11.5	14.8	24.1	11.9	6.7	1.5	1.9
Construction	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.0	0.0	0.0
Non-natural unknown[a]	99.3	99.6	100	99.6	100.0	99.3	97.4	94.4	97.8	94.1	91.1	93.3	81.5	87.8	89.3	94.4	89.6	97	97.4	98.5	98.1	97.0	97.4	94.4

[a] Non-natural unknown sound sources are associated with human activity, but their exact identity is unclear. The source of interest at this site was a consistent, low frequency rumble that could have been either road/highway traffic noise or noise from a distant (~8 miles) gravel processing plant.

Table 10. Mean hourly percent time audible for each noise source at SAGU004. 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	3.3	5.9	3.3	2.2	2.6	3.0	14.1	4.1	14.1	20.4	16.3	17.8	24.4	12.6	10.7	11.1	8.1	9.3	11.5	12.2	9.6	3.7	5.9	1.5
Vehicle	8.1	5.9	5.2	5.2	4.4	5.2	7.0	18.5	4.4	5.6	3.7	0.7	1.9	4.1	3.0	4.1	3.7	7.0	8.5	11.1	17.4	11.5	20.4	10.0
People	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.4	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0
Domestic dogs	4.4	4.8	1.9	1.1	2.6	4.8	2.2	2.6	0.0	0.0	0.7	0.4	1.5	0.4	0.4	0.0	0.4	2.6	1.5	9.6	12.6	4.4	3.0	6.7
Non-natural unknown[a]	27.8	27.8	38.1	33.0	33.0	38.9	37.4	47.8	29.6	25.2	20.4	20.0	22.2	25.2	14.1	18.5	16.3	20.4	21.5	34.4	39.3	30.4	30.7	32.6

[a] Non-natural unknown sound sources are associated with human activity, but their exact identity is unclear. The source of interest at this site was a somewhat consistent, low frequency rumble that was likely road/highway traffic noise.

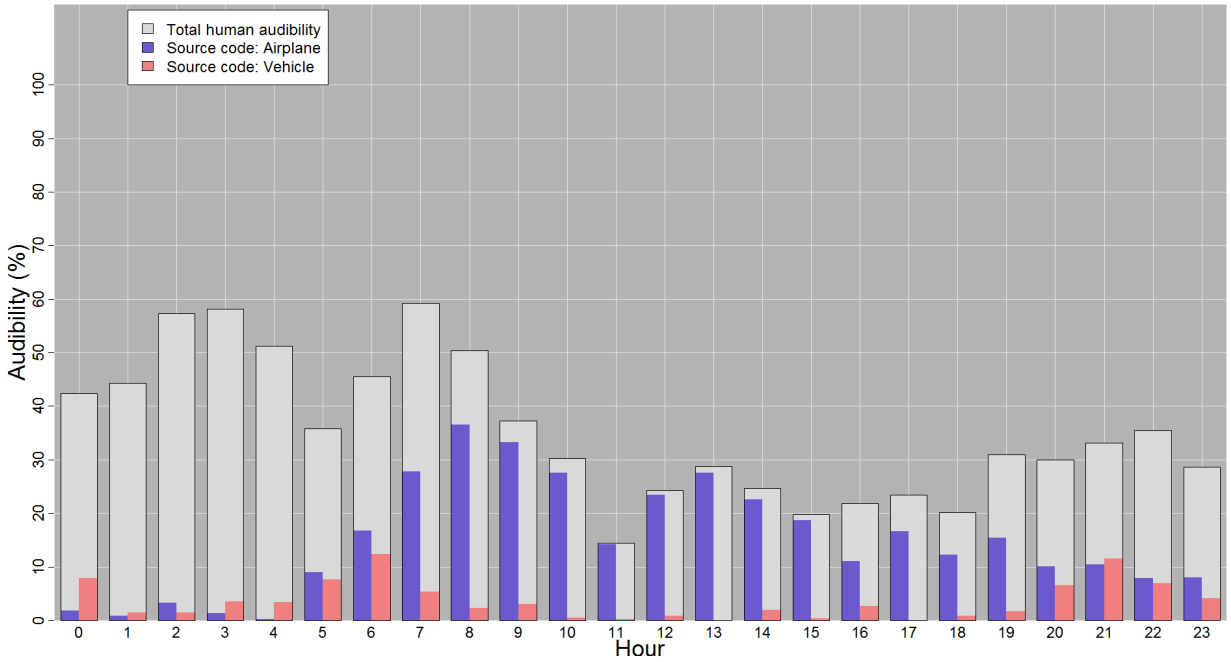

Figure 7. Comparison of hourly vehicle, aircraft, and overall noise audibility at SAGU001. N=8 days SPLAT analysis.

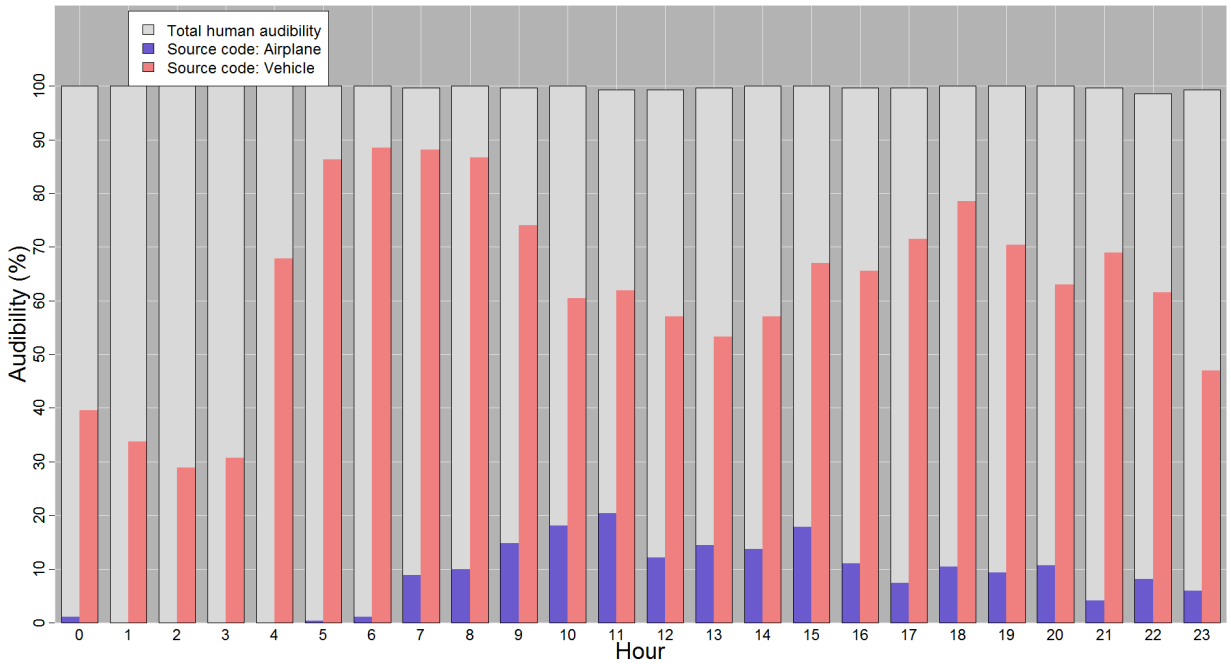

Figure 8. Comparison of hourly vehicle, aircraft, and overall noise audibility at SAGU002. N=8 days off-site sound source analysis.

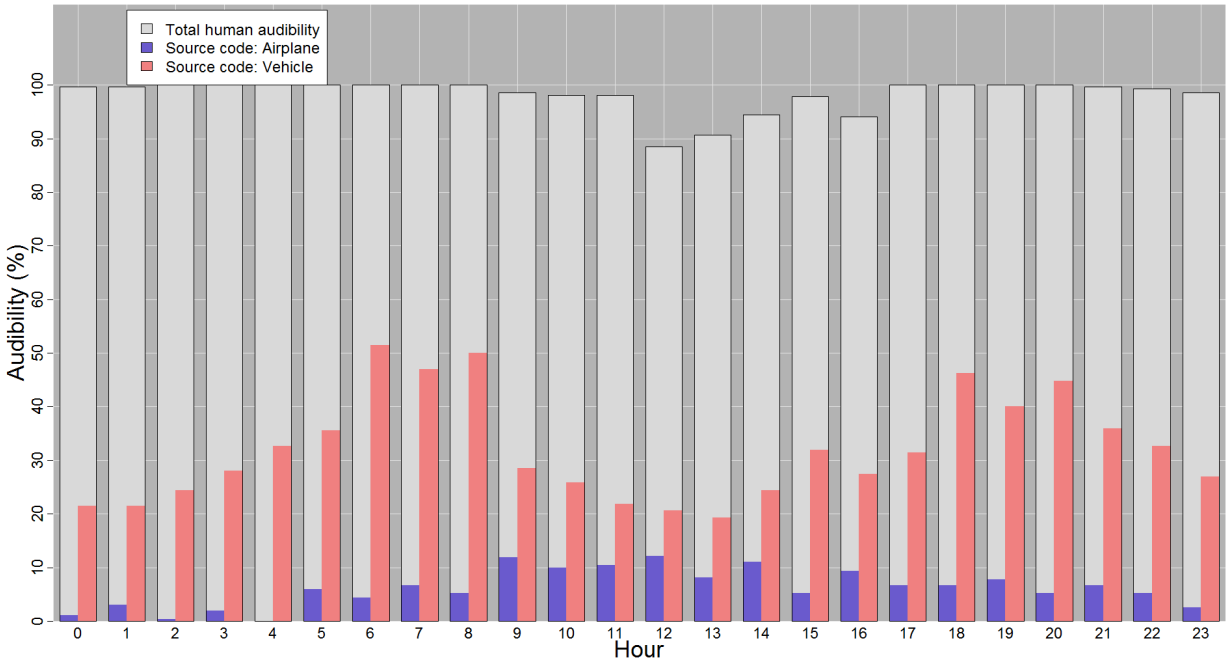

Figure 9. Comparison of hourly vehicle, aircraft, and overall noise audibility at SAGU003. N=8 days off-site sound source analysis.

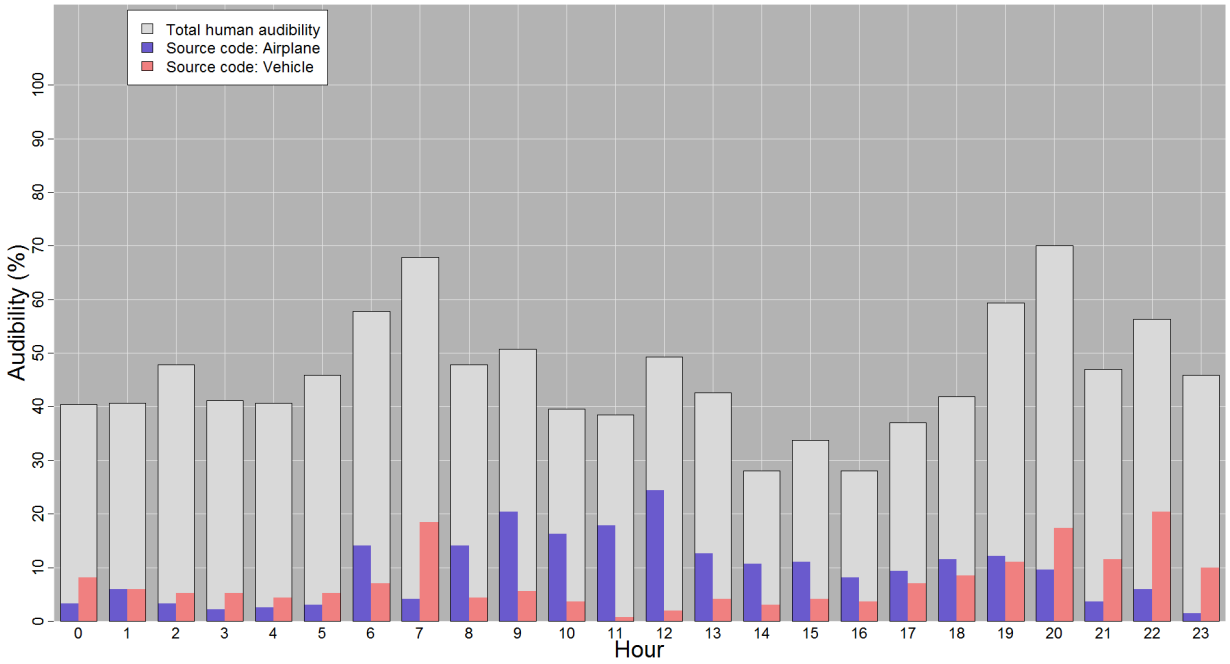

Figure 10. Comparison of hourly vehicle, aircraft, and overall noise audibility at SAGU004. N=8 days off-site sound source analysis.

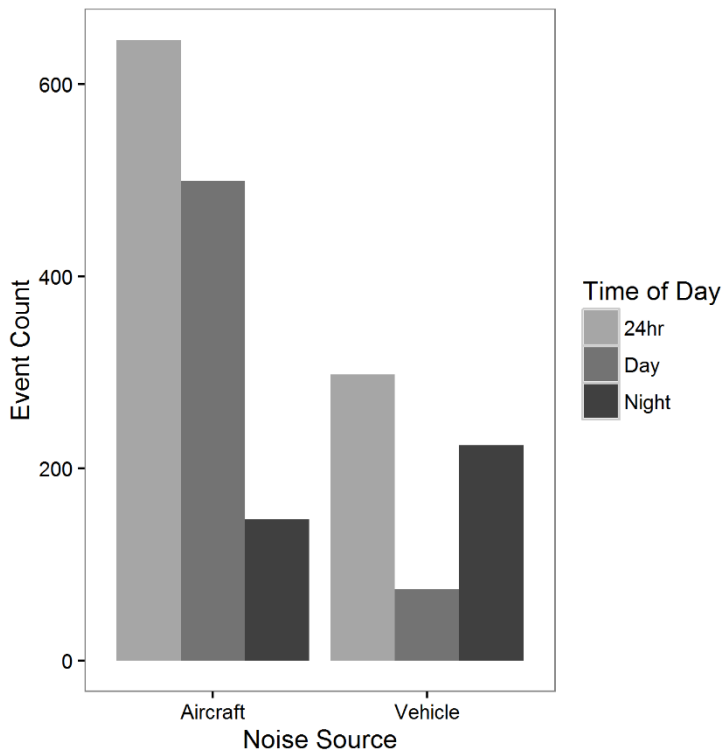

Figure 11. Total aircraft and vehicle event count over 8 days SPLAT analysis at SAGU001.

Discussion

The purpose of this study was to assess the acoustical environment at SAGU. Monitoring results characterize existing sound levels and estimate natural ambient sound levels within the park. The results, along with those collected in 2006 from three separate acoustical monitoring sites also within the park, are intended to provide the park with baseline information, as well as to inform management decisions. Continuous audio were collected in 2011 from one site, and in 2016 from three sites, each for approximately 20-40 days. Acoustical monitoring stations in 2016 were chosen to best assess the effects of noise, such as that from nearby highways and major roads, and aircraft overflights, while the site in 2011 was chosen to assess overall noise in the area. Acoustical data will be used to evaluate the condition of SAGU soundscape in the park's Natural Resource Condition Assessment (NRCA) and to establish a baseline condition for the acoustic environment, which is required for the park's wilderness character monitoring protocol.

Results indicate that natural ambient sound levels (L_{nat}) were as follows: 'North Coyote Wash' (SAGU001) ranged from 23.7 dBA during the daytime and 40.1 dBA at night, 'Discovery Trail' (SAGU002) ranged from 19.2 dBA during the daytime and 18.1 dBA at night, 'Tanque Verde Ridge Trail' (SAGU003) ranged from 19.8 dBA during the daytime and 17.8 dBA at night, and 'Steel Tank' (SAGU004) ranged from 26.9 dBA during the daytime and 25.7 dBA at night. Existing ambient sound levels (L_{50}) were higher, and were as follows: SAGU001 ranged from 25.6 dBA during the day to 41.4 dBA at night, SAGU002 ranged from 25.8 dBA during the day to 20.4 dBA at night, SAGU003 ranged from 22.7 dBA during the day to 21.3 dBA at night, and SAGU004 ranged from 27.8 dBA during the day to 26.4 dBA at night. For comparison, a comprehensive 1982 study of noise levels in residential areas found that nearly 87% of US residents were exposed to day-night sound levels (L_{dn}) over 55 dB, and an additional 53% were exposed to L_{dn} over 60 dB (EPA 1982). Noise levels have increased nationally with population growth since the EPA study (Suter 1991; Barber et al. 2010). Therefore, the results imply that the natural ambient sound level during the monitoring period was considerably quieter than most residential areas.

Despite the low overall sound pressure levels, noise still exists at SAGU. Though the mean 24 hour percent time audibility of anthropogenic noise was 35.3% and 48.0% at SAGU001 and SAGU004 respectively, noise was very prominent at SAGU002 and SAGU003 99.8% and 98.2% of the time respectively. A detailed analysis of audibility at the monitoring sites found that vehicles and aircraft significantly contributed to the noise environment. Vehicle noise was especially prominent at SAGU002 and SAGU003 (Tables 7 & 8), while aircraft was highly prevalent at all sites, but especially SAGU001 (Tables 6-9; Figure 11). A non-natural unknown noise source was highly prevalent at SAGU002 and SAGU003 (Tables 7 & 8). The source could be described as a constant, low amplitude and low frequency rumble that was likely either road/highway noise or noise from a distant gravel processing plant, but the acoustic technicians could not positively identify the source (thus the 'Non-natural unknown' designation). One of the technicians visited the park in August 2016 near these monitoring sites and correspondence with park staff suggested that the unknown noise source was likely produced by operations at a gravel pit plant (located ~19 km from SAGU002 and ~13 km from SAGU003). Finally, domestic dogs were heard at all sites except SAGU001 (not

detected using SPLAT analysis), especially during the early morning, evening, and nighttime hours (Tables 7-9). From these results, it is unlikely that a visitor to SAGU can experience a significant time period completely free from anthropogenic noise, with this possibility being highly unlikely at SAGU002 and SAGU003. Furthermore, the presence of persistent noise and increased sound levels may have wide ranging effects on wildlife such as reduced predatory success (Mason 2015) and increased vigilance by keystone species (Shannon et al. 2014).

Natural ambient sound levels (L_{nat}) and existing ambient sound levels (L_{50}) at SAGU001 were considerably higher during nighttime hours (1900-0700) than during daytime hours (0700-1900) (Table 4). This was due to the presence of vocalizing insects at night at this site. Though vocalizing insects are likely present at the other monitoring sites, monitoring at SAGU001 was conducted during the summer (July), while all monitoring was conducted during the winter (February) and spring (April), times when these insects do not appear to be active, and thus likely explaining why these sites did not exhibit a similar increase in nighttime levels.

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Appendix A: Site Photographs

Figure 12. SAGU001, ‘North Coyote Wash’ type 1 acoustical monitoring site. Site photographs were not collected at the other SAGU acoustical monitoring sites.

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 (L50 impact) at SAGU is shown in 13, 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 SAGU, the mean modeled sound level impact is 4.2 dBA, and this value represents a close approximation of expected impact levels at a randomly chosen point within the park. Each pixel in the graphic shown in Figure 13 represents 270m. 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 SAGU by just 3 dB, the ability of listeners to hear the sounds around them is effectively cut in half. Furthermore, an increase of 7 dB leads to an approximate decrease in listening area of 80%, and an increase of 10 dB decreases listening area by approximately 90%.

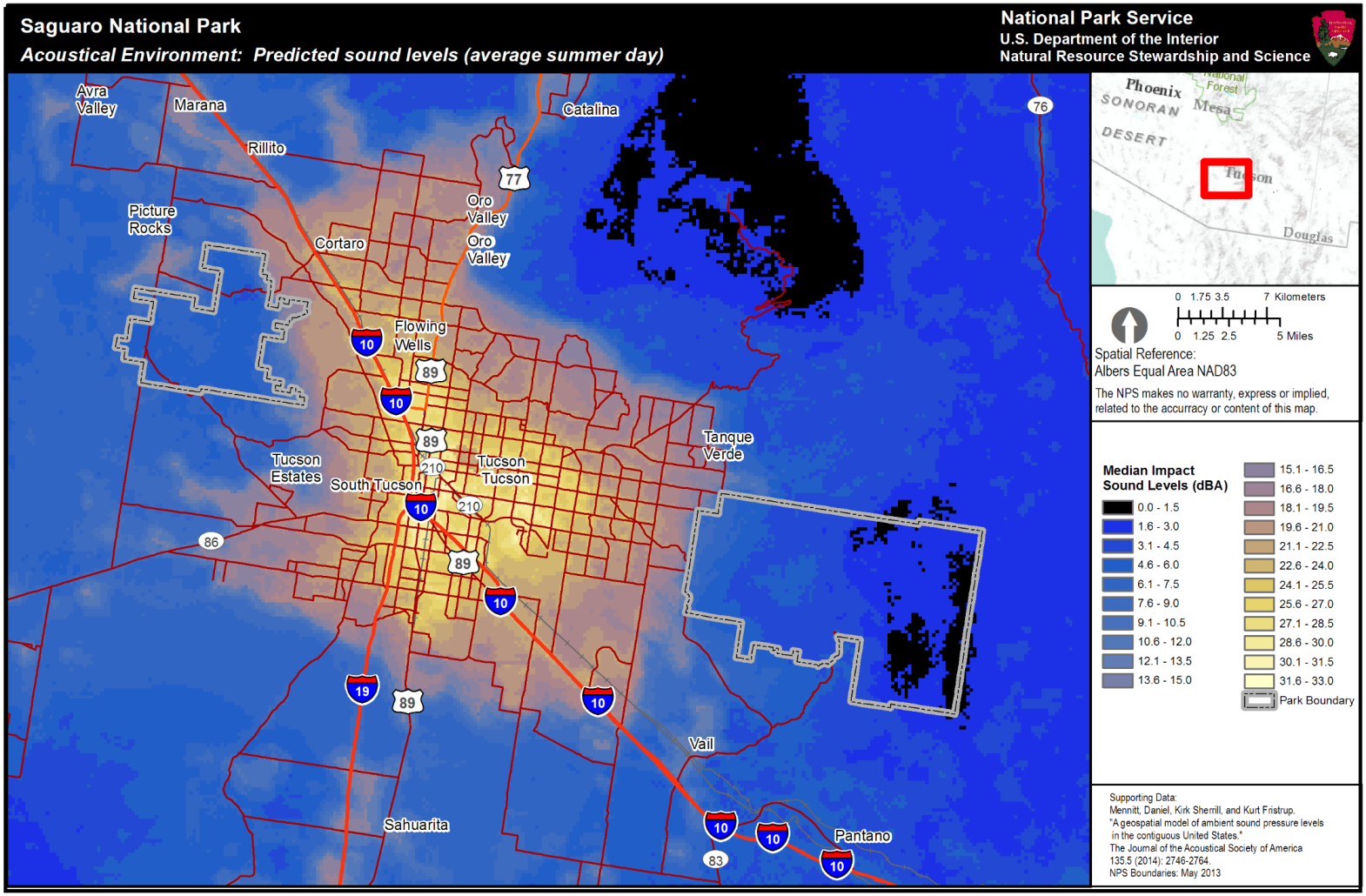

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Figure 13. Modeled median sound level impacts in the area immediately surround SAGU and the nearby region (inset). Map shows predicted acoustic impact levels in the park for an average summer day. The color scale indicates how much man-made noise increases the sound level (in A-weighted decibels, or dBA), with 270 m resolution. Black or dark blue colors indicate low impacts while yellow or white colors indicate greater impacts. Note that this graphic may not reflect recent localized changes such as new access roads or development. The mean acoustic impact level at the park is 4.2 dBA.

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.

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