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Natural Resource Stewardship and Science

North Cascades National Park Service Complex

Acoustical Monitoring Report Data Year 2015

Natural Resource Report NPS/NOCA/NRR—2017/1544

ON THE COVER
Acoustic monitoring equipment near Cascade Pass, North Cascades National Park Service Complex
Courtesy of NPS

North Cascades National Park Service Complex

Acoustical Monitoring Report Data Year 2015

Natural Resource Report NPS/NOCA/NRR—2017/1544

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Contents

Figures

Page

Tables

Page

Executive Summary

Natural sounds are integral to ecosystem function; they are one of the resources and values that National Park Service (NPS) managers are responsible for protecting and preserving. The NPS evaluates federal actions that may impact the human and natural environment of units within the national park system. The acoustic environment, like air, water or wildlife, is a valuable resource that can be substantially degraded by inappropriate sound levels and frequencies. Intrusive sounds (noise) are of concern to NPS managers because they can impede the ability to accomplish the NPS mission of resource protection and public enjoyment. This is especially important when assessing wilderness character within individual park units, which park managers are charged to preserve and protect by the 1964 Wilderness Act. Anthropogenic noise may also disrupt ecosystem processes by interfering with predator prey relationships and the ability of wildlife to communicate, establish territory, reproduce, support and protect offspring (Siemers and Schaub 2011, Schroeder et al. 2012, McClure et al. 2013, Shannon et al. 2016). People visit national parks to see, hear and experience myriad phenomena associated with specific natural and cultural environments. Yet, in many cases, those environments are being increasingly impacted by anthropogenic noise altering their experience (Lynch et al. 2011, Buxton et al. 2017).

In 2015 North Cascades National Park Complex (NOCA) began a long-term monitoring program to track trends in the acoustic environment as one metric in the park's Wilderness Character monitoring program; this report summarizes the data collected at these sites for 2015. NOCA is located approximately 95 kilometers north and 70 kilometers east of Seattle, Washington; the northern boundary of the complex shares a border with Canada. NOCA is 2,752 km^2 (680,000 acres) in size and 94% designated wilderness. Data was collected at Ruby Arm (NOCA003) on Ross Lake for the months of July and August, Cascade Pass (NOCA006) for the month of July and Boundary Camp (NOCA007) for the month of August (Figure 1). Table 1 describes the locations and characteristics of the monitoring sites. These sites were also monitored in 2007 (NOCA003) and 2008 (NOCA006 and NOCA007); data for those years will be reported alongside current 2015 data (NPS 2007, NPS 2008). These three sites were chosen due to reasonable access, record of data and location within designated wilderness (NOCA006 and NOCA007) and Ross Lake National Recreation Area (NOCA003).

Table 1. Locations and characteristics of acoustic monitoring sites at NOCA.

Site	Site Name	Deployment Dates	Vegetation	Elevation (m)	Lat/Long
NOCA003	Ruby Arm	2015-06-28 to 2015-07-28 2015-08-05 to 2015-09-04	Lodgepole Pine	514	48.734632/ -121.035196
NOCA006	Cascade Pass	2015-06-29 to 2015-07-29	Subalpine	1677	48.332617/ -121.047343
NOCA007	Boundary Camp	2015-08-03 to 2015-09-03	Silver Fir	1422	48.892548 -121.513506

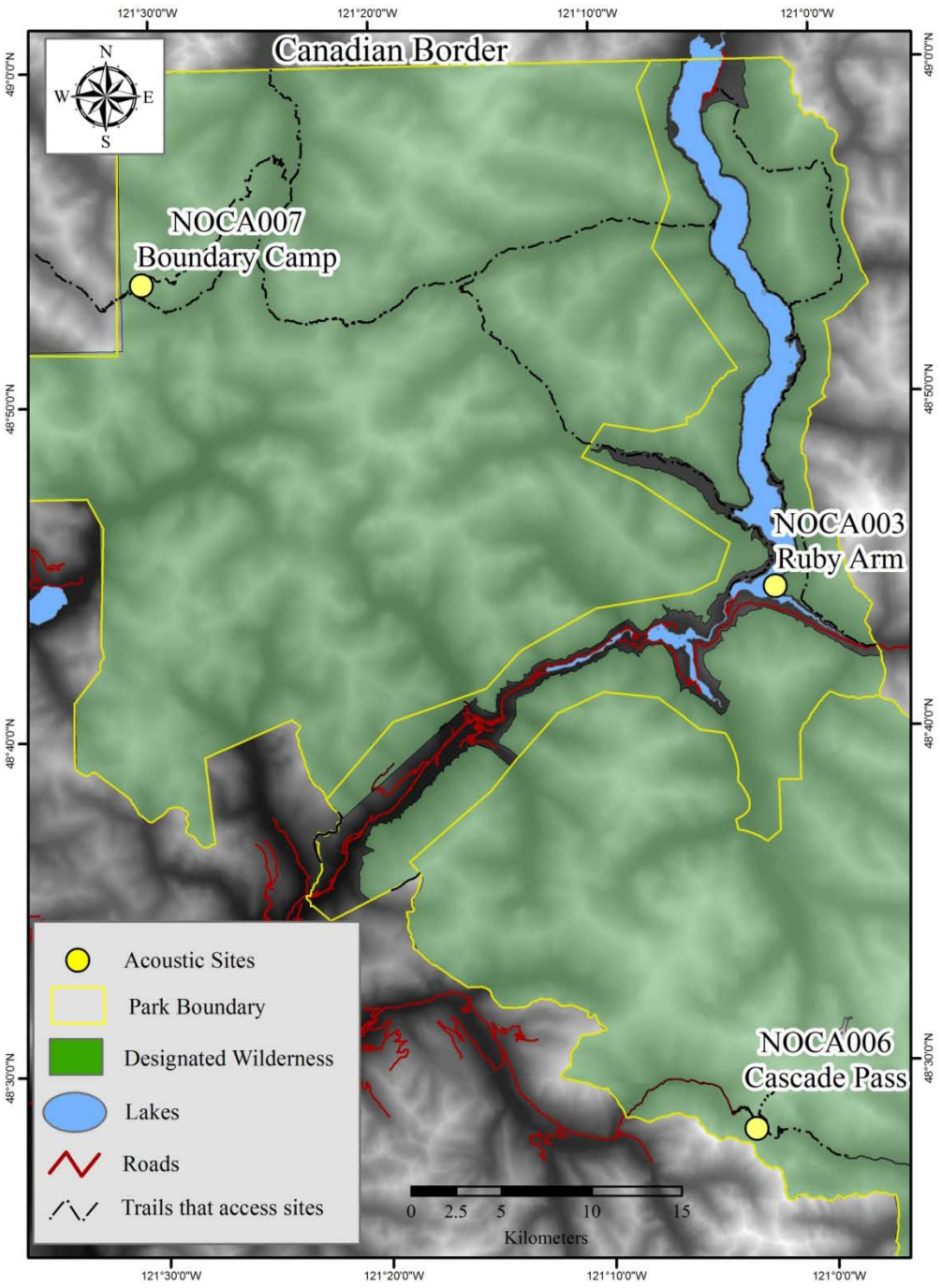

Figure 1. Locations of acoustic monitoring sites within North Cascades National Park Service Complex (NOCA). Grey area inside park boundary is non-wilderness.

This report summarizes acoustic metrics as well as data on multiple noise sources recorded during the monitoring period. Each system was deployed for a minimum of 25 days to collect continuous audio and sound pressure level (SPL) data; the metrics presented in this report are calculated from that data. The equipment deployed makes 33 SPL measurements for each second for a set of frequency bands that span the range of human hearing (12.5 – 20,000 Hz). These 33 measurements

approximate the capacity of human listeners to independently sense signals in various parts of the audible spectrum. The SPL is measures in decibels (dB), a logarithmic scale where 0 dB represents the threshold of human hearing at 1 kHz. Microphone measurements can also be adjusted according to a weighed scale (A-weighting) so they resemble the response of the human ear (Harris 1998).

The logarithmic dB scale can be difficult to interpret, and the functional effect of a seemingly small change in SPL can be greater than anticipated. When noise interferes with hearing natural sounds, the noise *masks* the natural sounds, and this affects the extent of the listening area. For example, if the natural ambient SPL is 30 dB, and transportation noise raises the ambient to 33 dB (a 3 dB increase), the listening area for humans (and many birds and mammals) is reduced by 50%. Increasing the ambient SPL an additional 3 dB (to 36 dB) would reduce the listening area by half again, to 25% of the initial area. Chronic noise exposure resulting in reduced listening area may interfere with predator prey relationships and the ability of wildlife to communicate, forage, establish territory, and reproduce (Barber 2010). Note, however, that changes in SPL do not proportionately translate to changes in perceived loudness. The rate of change of loudness is complex and dependent on the stimulus itself and other environmental factors (e.g., SPL, frequency, bandwidth, duration, background). Table 2 presents park sound sources and other common sound sources with their corresponding A-weighted decibel levels (dBA).

Table 2. Sound pressure level examples.

Park Sound Sources	Common Sound Sources	dBA
Volcano crater (Haleakala National Park)	Human breathing at 3m	10
Leaves rustling (Canyonlands National Park)	Whispering	20
Crickets at 5m (Zion National Park)	Residential area at night	40
Conversation at 5m (Whitman National Historic Site	Busy restaurant	60
Cruiser motorcycle at 15m (Blue Ridge Parkway)	Curbside of busy street	80
Thunder (Arches National Park)	Jackhammer at 12 m	100
Military jet at 100m Above Ground Level (Yukon-Charley Rivers National Preserve)	Train horn at 1m	120

The A-weighted median existing ambient statistics (also called L_{50}) describe average sound levels for daytime and nighttime periods at each site. The A-weighted median natural ambient statistics below (also called L_{nat}) describe natural ambient levels for daytime and nighttime periods at each site. L_{nat} is an estimate of the remaining sound energy over a particular time period when all extrinsic or anthropogenic noises are removed from the existing ambient (Table 3). For this study the default definition of day is used for data processing, which is 7am to 7pm, while night is 7pm to 7am.

Table 3. The A-weighted medium existing ambient and A-weighted median natural ambient statistics for NOCA sites. Additional statistics shown; data from previous years for comparison.

	Mean A-weighted Existing Ambient (dBA) (L_{50})		Mean A-Weighted Natural Ambient (dBA) (L_{Nat})	
Site	**Day**	**Night**	**Day**	**Night**
NOCA003 - July 2015	35.8	35.7	31.3	33.7
NOCA003 - August 2015	35.7	35.4	ND*	ND
NOCA003 - Summer 2007	35.5	28.4	32.5	32.5
NOCA006 - July 2015	37.6	37.1	37.9	37.1
NOCA006 - Summer 2008	35.1	35.3	34.6	35.2
NOCA007 - August 2015	26.2	23.3	26.0	23.2
NOCA007 - Summer 2008	29.8	30.2	29.7	30.2

*ND – Not Determined. Since NOCA003 recorded for so few hours in August; L_{nat} was not possible to determine.

In determining the current conditions of an acoustic environment, it is informative to examine how often SPLs exceed certain levels. Table 4 summarizes SPL levels that relate to human health and speech. These values are relevant to various aspects of the visitor experience including camping in front-country and backcountry sites, communication between staff and visitors, and informal communication. Additionally, human responses can often serve as a proxy for potential impacts to other vertebrates because humans have hearing that is more sensitive at low frequencies than many species (Dooling and Popper 2007, Fay 1988).

Table 4. Effects at discrete acoustic levels.

SPL (dBA)	Relevance
35	Blood pressure and heart rate increase in sleeping humans (Haralabidis et al., 2008)[1] Desired background sound level in classrooms (ANSI S12.60 2002)
45	World Health Organization's recommendation for maximum noise levels inside bedrooms (Berglund, Lindvall, and Schwela 1999)
52	Speech interference for interpretive programs (U.S. Environmental Protection Agency 1974)
60	Speech interruption for normal conversation (U.S. Environmental Protection Agency 1974)

1 The authors of Haralabidis use both dB and dBA in this paper and LAeq (an A-weighted Measurement), since A weighting is the industry standard we assumed their decibel measurements are A-weighted for the referenced data.

Table 5 reports the percent of time that measured levels were above the four key levels mentioned above during the (daytime and nighttime) monitoring period at NOCA sites. Data from 2007 and 2008 is presented for comparison.

Table 5. Percent time above sound pressure levels for NOCA sites, previous data for comparison.

	% Time above sound level: 0700-1900				% Time above sound level: 1900-0700			
Site	**35dBA**	**45dBA**	**52dBA**	**60dBA**	**35dBA**	**45dBA**	**52dBA**	**60dBA**
NOCA003 July-2015	56.1	14.8	1.4	0.0	52.3	4.4	0.2	0.0
NOCA003 August-2015	55.8	11.9	1.3	0.0	48.6	3.8	0.2	0.0
NOCA003 Summer-2007	55.9	9.7	<1	0	24.1	1.2	<1	0
NOCA006 July-2015	84.7	1.5	0.2	0.0	78.7	0.9	0.1	0
NOCA006 Summer-2008	52.8	1.9	0.1	0.0	51.6	1.2	0.3	0.0
NOCA007 August-2015	4.7	0.4	0.0	0.0	0.5	0.1	0.0	0.0
NOCA007 Summer 2008	0.5	0.1	0.0	0.0	1.9	0.1	0.0	0.0

Noise source characterization, including mean percent time audible of noise sources, was determined through standard Night Skies and Natural Sounds Division's (NSNSD) protocols for off-site data analysis (NPS 2013, Turina et al. 2013). The primary sources of human-caused sounds at these three sites were vehicles, aircraft and motorboats (Table 6). Noise audibility ranged from almost 60% at NOCA003 in 2015 to 7.5% at NOCA006 in 2015. At NOCA003, the most common noise source was watercraft, while at NOCA006 and NOCA007 the most common noise source was aircraft. All of these activities occur extremely close to, or in the case of aircraft use, over, designated wilderness.

Since this is the first year of this monitoring project, little can be stated about data trends. What can be noted from previous data is that there have been acoustic shifts at all sites. For NOCA003, overall mean A-weighted existing ambient was slightly higher while overall mean percent time audible of extrinsic sounds have increased since 2007. Site NOCA006 experienced an overall decrease in mean % time audible of noise sources with a slight increase in mean A-weighed and natural ambient since 2008. Site NOCA007 showed the opposite trend as NOCA006; this site had an increase in mean % time audible of noise sources but overall mean A-weighted existing ambient and natural ambient decreased since 2008.

As part of the Wilderness Character Monitoring Protocol, these metrics and observations will be reported yearly while a broader discussion of the data as a whole will be presented periodically in a Natural Resource Technical Report format.

Table 6. The percent time audible for noise at NOCA sites. Data from previous years for comparison were applicable.

	Mean % time audible				
Site	**Extrinsic**	**Aircraft**	**Vehicle**	**Watercraft**	**Motor Sounds**
NOCA003 July 2015	59.3	5.1	33.0	27.3	-
NOCA003 August 2015	ND[1]	ND	ND	ND	-
NOCA003 Summer 2007	36.7	0.9	ND	ND	35.7
NOCA006 July 2015	7.3	7.1	.1	NA	-
NOCA006 Summer 2008	16.3	15.6	0	NA	-
NOCA007 August 2015	11.0	10.0	NA	NA	-
NOCA007 Summer 2008	8.4	8.3	NA	NA	-

[1]ND = Not determined NA = Not applicable to the site. For 2007 NOCA003 data, vehicle and watercraft were not distinguished and labelled as “Motor Sounds” in the reporting, therefore the only direct comparisons that can be made between 2007 and 2015 is mean percent time audible for extrinsic sounds. NOCA003 data from August 2015 did not have enough hours logged to facilitate off-site listening analysis that is necessary for mean percent time audible.

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List of Acoustic Terms

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 - Includes 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, humans and different species of animals 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 acoustic environment of the park.

L50, L90 - 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 L50 value, while 90 percent of the time the measured levels are higher than the L90 value.

Ldn - 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.

Leq - Energy Equivalent Sound Level. The sound energy level averaged over the measurement period.

Lnat (Natural Ambient Sound Level) - The natural sound conditions in parks which exist in the absence of any human-produced noise.

Percent Time Above Natural Ambient - The amount of time that various sound sources are above the natural ambient sound pressure levels in a given area. It is most commonly used to measure the amount of time that human-caused sounds are above natural ambient levels. This measure is not specific to the hearing ability of a given animal, but a measure of when and how long human-caused sounds exceed natural ambient levels.

Percent Time Audible - The amount of time that various sound sources are audible to humans with normal hearing. A sound may be above natural ambient sound pressure levels, but still not audible. Similarly, some sounds that are below the natural ambient can be audible. Percent Time Audible is useful because of its simplicity. It is a measure that correlates well with visitor complaints of excessive noise and annoyance. Most noise sources are audible to humans at lower levels than virtually all wildlife species. Therefore percent time audible is a protective proxy for wildlife. These data can be collected by either a trained observer (on-site listening) or by making high-quality digital recordings for later playback (off-site listening).

Sound Exposure Level (SEL) - The total sound energy of the actual sound during a specific time period. SEL is usually expressed using a time period of one second.

Sound Pressure - Minute change in atmospheric pressure due to passage of sound that can be detected by microphones.

Sound vs. Noise - The NSNSD differentiates between the use of sound and noise, since these definitions have been used inconsistently in the literature. Although sound is sometimes incorrectly used as a synonym for noise, it is in fact noise 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 the physical sound resource.

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 and 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). Acoustic 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 Program

The NPS Natural Sounds Program (NSP) Office was established in 2000 to help 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 NSP addresses acoustical issues raised by Congress, NPS Management Policies, and NPS Directors Orders. An important element of this mission is working with the Federal Aviation Administration (FAA) to implement the National Parks Air Tour Management Act. Congress mandated that FAA and NPS jointly develop Air Tour Management Plans (ATMPs) for more than 106 parks where commercial air tours operate. The program also provides technical assistance to parks in the form of acoustic monitoring, data processing, park planning support, and comparative analyses of acoustic environments throughout the national park system.

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 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 acoustic 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 2006). 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.

Directors Order 47, Soundscape Preservation and Noise Management (2000) 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.

North Cascades National Park Complex Planning Authorities

The Ross Lake National Recreation Area General Management Plan (GMP) (2012) recognizes the importance of protecting the acoustic environment of this NPS unit. The plan states that "The NPS will actively manage Ross Lake National Recreation Area (NRA) for natural soundscapes. As part of this effort, the NPS will expand the soundscapes program to create a complete inventory of ambient sounds and implement an ongoing monitoring program to assess changes in the soundscape. The NPS will identify unacceptable sources of human-caused noise and sound levels and look for ways (such as enforcement of existing noise standards and increased education along the North Cascades

Highway) to protect natural soundscapes when feasible" (NPS 2012). This monitoring effort supports these goals outlined in the GMP; the study collects acoustic data for July and August in the Ross Lake NRA at site NOCA003. Sites NOCA006 and NOCA007 provide data from within the Stephen Mather Wilderness and have bearing on the North Cascades Wilderness Management Plan, which the park is currently drafting.

The park also began the development of a "Wilderness Character Baseline Assessment" in 2015; one wilderness character measure that was adopted in this draft plan is to track the long-term trends in "Percent time externally derived noise is audible in Wilderness". This measure directly relies on the results obtained and reported through this acoustics monitoring program, with the 2015 results serving as the starting baseline of conditions for this measure. The protocol for annual acoustic sampling methods, locations of sampling, and analysis of data will continue to form the basis for reporting on trends for this wilderness character measure. Data collected annually will be analyzed and provided to the park's Wilderness Coordinator for incorporation into that monitoring program.

Study Area

North Cascades National Park (501,458 acres), Ross Lake National Recreation Area (116,798 acres), and Lake Chelan National Recreation Area (62,902 acres) are collectively known as the North Cascades National Park Complex (Figure 2). NOCA contains over 680,000 acres of the heart of the North Cascades ecosystem, 94% of which is designated as the Stephen Mather Wilderness. The ecosystem is host to wide ranges in rainfall, temperature regimes, and elevation, which together result in a great diversity of habitat types. Four broadly defined vegetation zones are found within the North Cascades: lowland forest, montane forest, subalpine parkland, and the alpine zone. Temperate marine conditions are found generally west of the Ross Lake, while areas east of Ross Lake lie in the semi-arid continental zone due to orographic barriers. The Ross Lake drainage comprises a transitional zone where vegetal and climatic characteristics are intermediate between the mild, wet conditions and the semi-arid conditions.

NOCA is bisected by the North Cascades Scenic Highway, otherwise known as State Route 20. The highway draws large volumes of traffic during the summer months. Recreationists, truck drivers, and other users travel the highway to cross the Cascades, driving cars, RVs, motorcycles and tractor-trailers. For 2015 the Ross Lake National Recreation Area logged 772,579 visitors and the highway counter at the eastern entrance recorded 222,378 vehicles (NPS 2015). Seattle City Light (SCL) is a municipal electric utility for the City of Seattle that owns approximately 1,129 acres of land and has limited rights on approximately 19,300 acres of federal land under the terms of two Federal Energy Regulatory Commission (FERC) licenses, one for the Skagit River Hydroelectric Project (FERC Number 553) and a second license for the substantially smaller Newhalem Creek Hydroelectric Project (FERC Number 2705). The Skagit River Hydroelectric Project includes three dams and their facilities: Ross, Diablo and Gorge Dam. Ross lake is the largest of the three reservoirs, covering over 12,300 acres with 135 miles of shoreline. Ross Lake has limited access but is very popular among both motorized and non-motorized boat operators. A NPS concession service, Ross Lake Resort, operates during the summer and fall visitor season. Services include renting non-motorized and motorized boats (2-stroke engines) as well as running frequent shuttles just above Ross Dam as well as up and down Ross Lake.

While all acoustic sites for this study are located within wilderness (Figure 1), only NOCA003 is located within the Ross Lake National Recreation Area (Figure 2). These three sites were chosen due to reasonable access, record of data and location within designated wilderness (NOCA006 and NOCA007) and Ross Lake Recreation Area (NOCA003). This data pertains both to wilderness character monitoring as well as monitoring outlined by the Ross Lake Recreation Area General Management Plan (GMP).

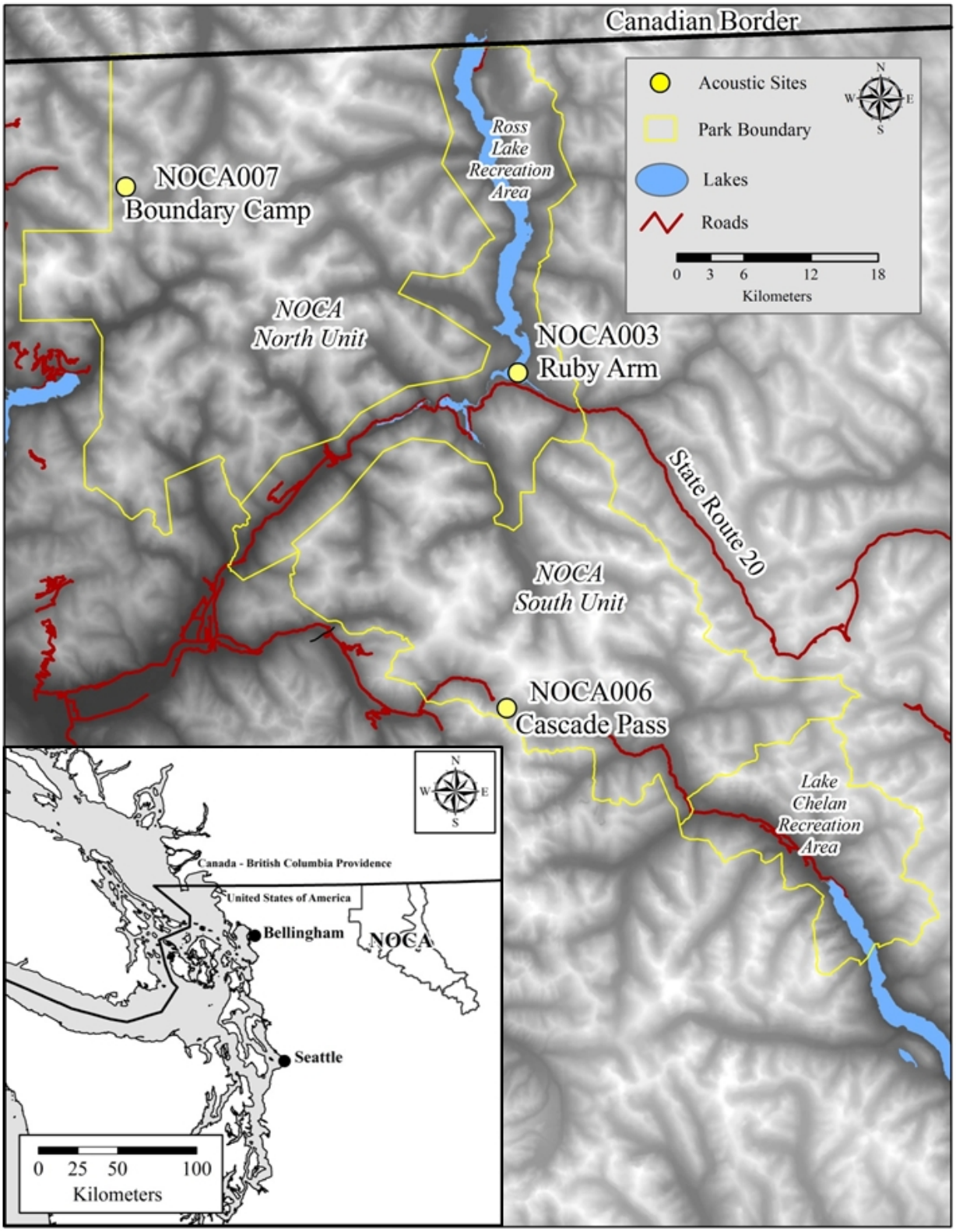

Figure 2. Locations of acoustic monitoring sites within North Cascades National Park Service Complex (NOCA). Insert map shows location of NOCA in Washington State.

Methods

Automatic Monitoring

Larson Davis 831 sound level meters (SLM) were employed over the monitoring period at each of the NOCA sites. The Larson Davis SLM is a hardware-based, real-time analyzer that constantly records one second sound pressure level and 1/3 octave band data. These Larson Davis instruments met American National Standards Institute (ANSI) Type 1 standards. The sound level meters provided the information needed to calculate metrics described below in the "Calculation of Metrics" section.

- The sampling stations consisted of:
- Microphone with environmental shroud
- Preamplifier
- 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 status of the acoustical environment can be characterized by spectral measurements, durations, and overall sound levels. The NSNSD uses descriptive figures and metrics to interpret these characteristics. A fundamental descriptor is existing ambient (L_{50}) sound levels. Existing ambient or L_{50} is an example of an exceedance level, where an L_x level refers to the SPLs that are 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 A-weighted median natural ambient statistics below (also called L_{nat}) describe natural ambient levels for daytime and nighttime periods at each site. L_{nat} is an estimate of the remaining sound energy over a particular time period when all extrinsic or anthropogenic noises are removed from the existing ambient (L_{50}).

Off-Site Listening/Analysis

Auditory and visual analysis was used to calculate the audibility of sound sources at NOCA along with percent time audible metrics for noise (NPS 2013, Turina et al. 2013). Staff at NOCA analyzed per protocol 8 days of data collected from the sound pressure level meter and MP3 recorder deployed at each site for noise source characterization. From the SPL data, spectrograms were created with the accompanying recorded audio (Figures 3, 4 and 5). Spectrograms are plots that display sound level as a function of time and frequency. Since aircraft have a recognizable sound signature, they are visually identifiable on spectrograms. Individual events can be isolated and analyzed. For every noise event, the user is able to record beginning and end times, frequencies spanned, maximum sound pressure level, and sound exposure level (SEL). This dataset also included continuous audio that can be played for events with questionable sound signatures. This method uses a platform created for sound pressure level annotation referred to as Sound Pressure Level Annotation Tool (SPLAT) by NSNSD. Bose Quiet Comfort Noise Canceling headphones were used for off-site audio playback to minimize limitations imposed by the office acoustic environment.

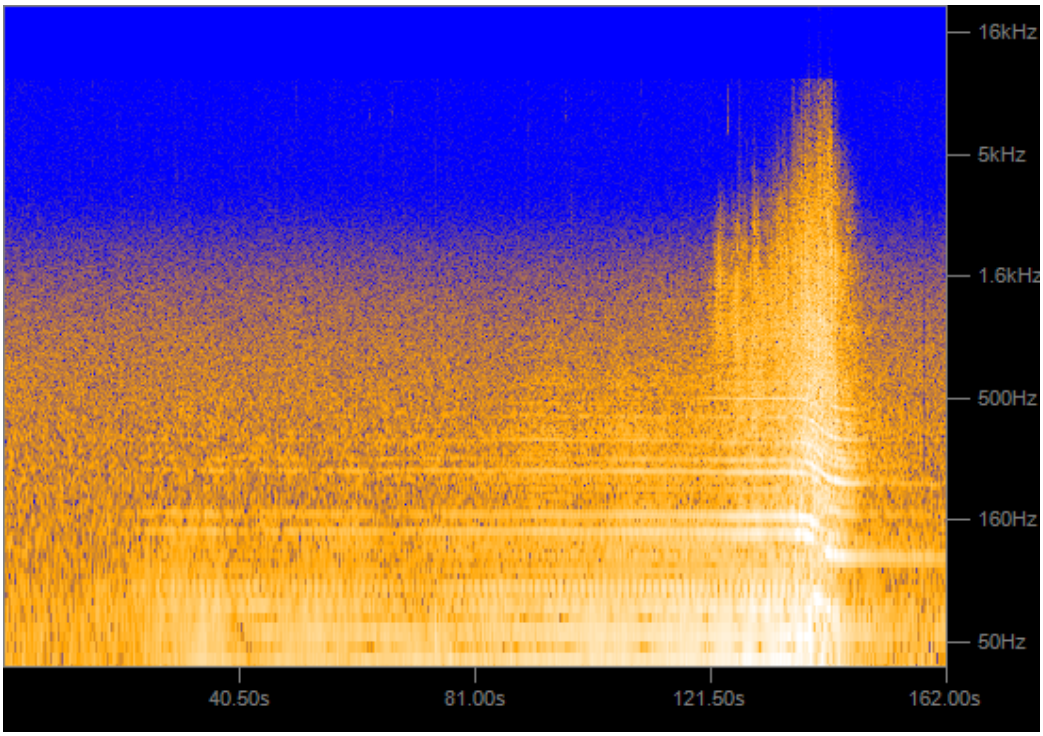

Figure 3. Spectrogram sample taken from NOCA006 shows the acoustic signature of a helicopter. Time is on the X-axis in seconds, frequency is in hertz (Hz) on the Y axis.

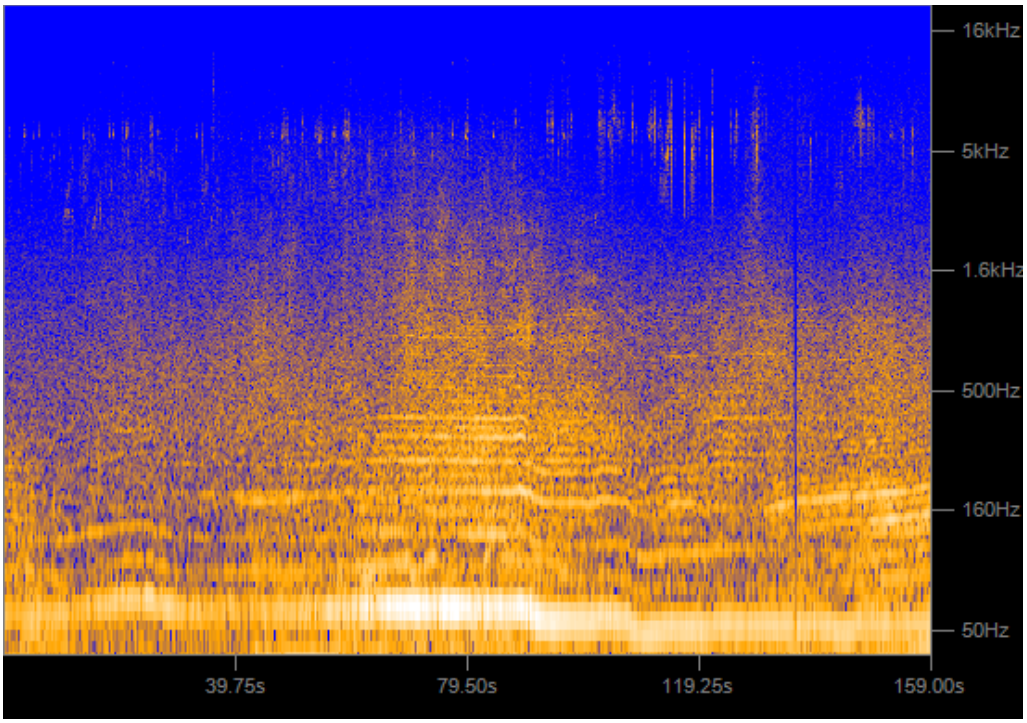

Figure 4. Spectrogram sample from NOCA003 shows the acoustic signature of a motorboat from 6/30/2015 at 1046. The high frequency notes near the top of the spectrogram on the right are from birds. Time is on the X-axis in seconds, frequency is in hertz (Hz) on the Y axis.

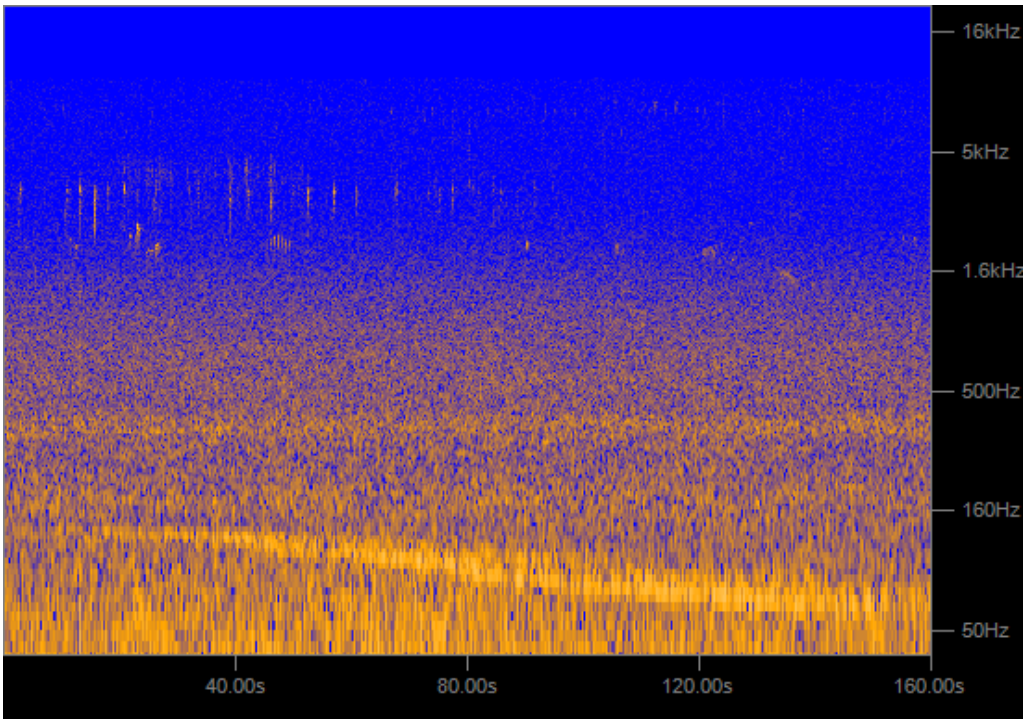

Figure 5. Spectrogram sample from NOCA007 shows the acoustic signature of a small plane from 8/16/2015 at 0927. The high frequency notes near the top of the spectrogram are from bird song. Time is on the X-axis in seconds, frequency is in hertz (Hz) on the Y axis.

Results

At each site, sound pressure level measurements were taken, along with digital audio recordings and meteorological data. The equipment makes 33 SPL measurements each second for a set of frequency bands that span the range of human hearing (12.5 – 20,000 Hz). These 33 measurements approximate the capacity of human listeners to independently sense signals in different parts of the audible spectrum. The SPL is measured in decibels (dB), a logarithmic scale where 0 dB represents the threshold of human hearing at 1 kHz. Microphone measurements were adjusted according to a weighted scale (A-weighting) such that they resemble the response of the human ear (Harris 1998). The logarithmic dB scale can be difficult to interpret, and the functional effect of a seemingly small change in SPL can be greater than anticipated. When noise interferes with hearing natural sounds, the noise *masks* the natural sounds, and this affects the extent of the listening area. For example, if the natural ambient SPL is 30 dB, and transportation noise raises the ambient to 33 dB (a 3 dB increase), the listening area for humans (and many birds and mammals) is reduced by 50%. Increasing the ambient SPL an additional 3 dB (to 36 dB) would reduce the listening area by half again, to 25% of the initial area. Chronic noise exposure resulting in reduced listening area may interfere with predator prey relationships and the ability of wildlife to communicate, forage, establish territory, and reproduce (Barber 2010). Note, however, that changes in SPL do not proportionately translate to changes in perceived loudness. The rate of change of loudness is complex and dependent on the stimulus itself and other environmental factors (e.g., SPL, frequency, bandwidth, duration, background). Table 2 presents park sound sources and other common sound sources with their corresponding A-weighted decibel levels (dBA).

The time above metric indicates the amount of time that the sound level exceeds specified decibel levels. In determining the current conditions of an acoustical environment, the NPS examines how often sound pressure levels exceed certain decibel levels that relate to human health and speech. The NPS uses these levels for making comparisons, but they should not be construed as thresholds of impact. Table 4 summarizes sound levels that relate to human health and speech. The first decibel 11 level, 35 dBA, addresses the health effects of sleep interruption (Haralabidis et al. 2008). The second level addresses the World Health Organization's recommendations that noise levels inside bedrooms remain below 45 dBA (Berglund et al. 1999). The third level, 52 dBA, is based on the Environmental Protection Agency's speech interference threshold for speaking in a raised voice to an audience at 10 meters (Environmental Protection Agency 1974). This level addresses the effects of sound on interpretive presentations in parks. The final level, 60 dBA, provides a basis for estimating impacts on normal voice communications at 1 m (3 ft). Hikers and visitors viewing scenic vistas in the park would likely be conducting such conversations. Human responses can serve as a proxy for potential impacts to other vertebrates because humans have hearing that is more sensitive at low frequencies than many species (Dooling and Popper 2007, Fay 1988).

NOCA Acoustical Data

The systems collected SPL data for 719 (NOCA006), 409 (NOCA007), 656 (NOCA003-July) and 250 (NOCA003-August) hours. Site NOCA003 was inaccessible in August for site maintenance due

to a fire within NOCA that closed access to State Route 20. The low amount of data hours for the month of August at NOCA003 made off-site analysis not possible.

By comparing the amount of time that sound levels are above certain specified levels, variations in levels can be observed over time (or between sites). Table 7 reports the percent of time that measured levels were above the discrete acoustic levels of 35, 45, 52 and 60 dBA at NOCA003, NOCA006 and NOCA007.

Table 7. Percent time above sound pressure levels for wilderness sites, previous data for comparison.

	% Time above sound level: 0700-1900				% Time above sound level: 1900-0700			
Site	**35dBA**	**45dBA**	**52dBA**	**60dBA**	**35dBA**	**45dBA**	**52dBA**	**60dBA**
NOCA003 July	56.1	14.8	1.4	0.0	52.3	4.4	0.2	0.0
NOCA003 August	55.8	11.9	1.3	0.0	48.6	3.8	0.2	0.0
NOCA003 Summer-2007	55.9	9.7	<1	0	24.1	1.2	<1	0
NOCA006 July-2015	84.7	1.5	0.2	0.0	78.7	0.9	0.1	0
NOCA006 Summer-2008	52.8	1.9	0.1	0.0	51.6	1.2	0.3	0.0
NOCA007 August-2015	4.7	0.4	0.0	0.0	0.5	0.1	0.0	0.0
NOCA007 Summer 2008	0.5	0.1	0.0	0.0	1.9	0.1	0.0	0.0

Off-site Listening Analysis

Presented in this section are the results from in-depth off-site analysis. Sound sources were further examined and identified using percent time audible metrics. The percent of time that extrinsic sounds were heard at each site is reported along with mean A-weighted existing ambient (dBA) and mean A-weighted natural ambient (dBA) are used to quantify the impacts of noise (Table 8). The A-weighted median existing ambient statistics (also called L_{50}) describe average sound levels for daytime and nighttime periods at each site. The A-weighted median natural ambient statistics below (also called L_{nat}) describe natural ambient levels for daytime and nighttime periods at each site. L_{nat} is an estimate of the remaining sound energy over a particular time period when all extrinsic or anthropogenic noises are removed from the existing ambient.

Noise source characterization, including mean % time audible of noise sources, was determined through standard NSNSD protocols for off-site data analysis (Turina et al. 2013). Noise audibility ranged from almost 60% at NOCA003 in 2015 to 7.5% at NOCA006 in 2015. At NOCA003, the

most common noise source was watercraft, while at NOCA006 and NOCA007 the most common noise source was aircraft. All of these activities occur extremely close to, or in the case of aircraft use, over, designated wilderness. For site NOCA003, data in 2007 did not distinguish motor sounds into vehicle vs. motorboat. Therefore a direct comparison between the data sets is not feasible, however extrinsic sounds as a whole can be compared, as can the mean A-weighted ambient metric.

Table 8. The percent time audible for extrinsic sounds at Ruby Arm (NOCA003), Cascade Pass (NOCA006) and Boundary Camp (NOCA007). Mean A-weighted existing ambient and Mean A-weighted natural ambient also shown; data from previous years for comparison.

	Mean % time audible[1]					Mean A-weighted Existing Ambient (dBA) (L_{50})		Mean A-Weighted Natural Ambient (dBA) (L_{Nat})	
Site	**Extrinsic**	**Aircraft**	**Vehicle**	**Watercraft**	**Motor**	**Day**	**Night**	**Day**	**Night**
NOCA003 July 2015	59.3	5.1	33.0	27.3	-	35.8	35.7	31.3	33.7
NOCA003 August 2015	ND	ND	ND	ND	-	35.7	35.4	ND	ND
NOCA003 Summer 2007	36.7	0.9	ND	ND	35.7	35.5	28.4	32.5	32.5
NOCA006 July 2015	7.3	7.1	.1	NA	-	37.6	37.1	37.9	37.1
NOCA006 Summer 2008	16.3	15.6	0	NA	-	35.1	35.3	34.6	35.2
NOCA007 August 2015	11.0	10.0	NA	NA	-	26.2	23.3	26.0	23.2
NOCA007 Summer 2008	8.4	8.3	NA	NA	-	29.8	30.2	29.7	30.2

[1]ND = Not determined NA = Not applicable to the site.

Since this is the first year of monitoring study, little can be stated about data trends. What can be noted from previous data is that there have been acoustic shifts at all sites. For NOCA003, overall mean A-weighted existing ambient was slightly higher while overall extrinsic sounds have increased. Site NOCA006 experienced an overall decrease in mean percent time audible of noise sources with a slight increase in mean A-weighed and natural ambient. Site NOCA007 showed the opposite trend as NOCA006; this site had an increase in mean percent time audible of noise sources but overall mean A-weighted existing ambient and natural ambient decreased.

Over the course of this monitoring these acoustic metrics and observations will be reported yearly. A broader discussion of the data as a whole will be periodically presented in a Natural Resource Technical Report format.

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