



Lake Clark National Park

Acoustic Monitoring Report, Coastal Deployments 2018–2023



Acoustic monitoring in Lake Clark National Park.
NPS / DAN YOUNG

Lake Clark National Park: Acoustic Monitoring Report, Coastal Deployments 2018–2023

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Abstract

This report documents acoustic conditions at three coastal sites in Lake Clark National Park (LACL) to support development of the LACL Coastal Management Plan and to establish a baseline for future monitoring. The study addresses how increasing motorized access associated with visitor use influences natural soundscapes in areas that concentrate both wildlife activity and visitor experience. Acoustic data were collected during 2018, 2019, and 2023 using standardized National Park Service monitoring protocols and were analyzed to characterize existing ambient sound levels, estimate natural ambient sound levels, and quantify the audibility of human-caused noise sources. Results indicate that natural soundscapes along the LACL coast are shaped primarily by wind, surf, and biological activity, but are periodically fragmented by discrete noise events associated with transportation corridors, particularly aircraft and watercraft. Across three sites, noise was audible for approximately 14–29% of an average day, with aircraft representing the most commonly heard source. Differences between existing and estimated natural ambient sound levels were generally small in magnitude but occurred in patterns that reflect repeated and spatially concentrated access routes rather than diffuse background change. These findings demonstrate that acoustic conditions at coastal portals into the park are closely coupled to transportation patterns and are therefore responsive to shifts in visitation, technology, and access practices. The results also provide a physical description of habitat conditions in areas important to brown bears and other wildlife that rely on auditory cues for foraging, communication, and predator avoidance. Together, these data establish an acoustic reference condition for the southeastern coastal portion of LACL and offer park managers a framework for evaluating how future changes in access may influence both visitor experience and ecological function. The dataset further serves as a permanent record of soundscape conditions during the study period and contributes to long-term documentation of environmental change in the park.

List of Terms

A-weighting: A-weighting is applied to sound levels to account for the sensitivity of the human ear (Harris 1998). To approximate human hearing sensitivity, A-weighting discounts sounds below 1 kHz and above 6 kHz.

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, and 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.

ANS Weighting: The Natural Sounds modification to A-weighting eliminates high-frequency sound (leaf rustle, equipment noise, and biologic sounds) allowing for more accurate comparisons of low-frequency ambient sound levels across different land use types (e.g., urban, protected areas; ANSI S3/SC1.100, 2014 [R2020]). This frequency weighting scheme improves ambient sound level measurements in quiet environments.

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 hearing ability of individual animals.

Decibel (dB): A unit of sound energy. Sound levels are measured on a logarithmic scale relative to the reference sound pressure for atmospheric sources, 20 μ Pa. The logarithmic scale is a useful way to express the wide range of sound pressures perceived by the human ear. Every 10 dB increase represents a tenfold increase in energy. Therefore, a 20 dB increase represents a hundredfold increase in energy.

Existing ambient sound level (L_{A50}): Sound level ($L_{Aeq, 1s}$) exceeded 50% of the time (50th percentile) for a specified duration. This level is referred to as the existing ambient sound level and the preferred metric for chronic conditions, as it is insensitive to infrequent loud events.

Frequency: Related to the pitch of a sound, defined as the number of times per second that the wave of sound repeats itself and expressed in terms of hertz (Hz). Sound levels are often adjusted (“weighted”) to match the hearing abilities of a given animal. In other words, different species of animals and humans are capable of hearing (or not hearing) at different frequencies. Humans with normal hearing can hear sounds between 20 Hz and 20,000 Hz, and as low as 0 dB at 1,000 Hz. Bats, on the other hand, can hear sounds between 20 Hz and 200,000 Hz.

Percentile sound levels (L_{A10} , L_{A50} , L_{A90}): Metrics used to describe A-weighted sound pressure levels (L), in decibels, exceeded 10, 50, and 90 percent of the time, respectively. Put another way, half the time the measured levels of sound are greater than the L_{A50} value, while 90 percent of the time the measured levels are higher than the L_{A90} value and 10 percent of the time measured levels are higher than the L_{A10} value.

Day-Night average sound levels (L_{dn}): Average equivalent sound level over a 24-hour period, with a 10 dB penalty added for sounds occurring between 10 p.m. and 7 a.m.

Energy Equivalent Sound Level (L_{Aeq}): The sound energy level averaged over the measurement period. Generally, refers to A-weighted 1-second time averaged sound levels measured between 12.5–20,000 Hz. This is a standard measurement collected using the NPS Natural Sounds and Night Skies Division (NSNSD) acoustic monitoring protocol for sound level meters. Sound levels measured over 1-second intervals are used to calculate summary statistics, specifically percent of the time a sound level of interest is exceeded.

Natural Ambient Sound Level (L_{Anat}): The natural sound conditions in parks, which would exist in the absence of any human-caused noise sources. L_{Anat} is the preferred metric to represent baseline or reference conditions.

Noise Free Interval (NFI): The duration of a continuous period during which no human-caused sounds are audible.

Time Above: Within a defined period, the percent of the time sound levels ($L_{Aeq, 1s}$) are above a specified sound level ($L_{Aeq, 1s}$). Commonly used levels are 35, 45, 52, 60 dB ($L_{Aeq, 1s}$).

Time Audible: The amount of time that various sound sources are audible to humans with normal hearing, commonly expressed in percent of day, or percent of daytime hours and nighttime hours. 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. 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, time audible is a protective proxy for wildlife. These data can be collected either by 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 1 second.

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

Sound vs. Noise: Sound and noise are often used interchangeably to describe an acoustic source. A common definition of noise is unwanted sound or sounds that interfere with a signal of interest

(Harris 1998; Templeton 1997). However, noise is not a purely subjective designation. Any sound that serves no function is noise. Most sounds produced by human transportation and other machinery are unintended and serve no function, therefore are noise regardless of the attitudes of the listener. While there are unintended sounds in nature, like the footfalls of an animal, these sounds provide vital cues for some receivers and are therefore considered sounds to the receiver, yet noise from the perception of the producer.

Soundscape: The human perception of physical sound resources.

Spectrogram: A visual, raster (matrix) representation of how the frequency of sound energy within an acoustic record changes over time. The display shows time on the horizontal axis, frequency on the vertical axis, and uses shading or color value to indicate amplitude. In the field of environmental sound monitoring, spectrograms are commonly used to identify sound sources, detect patterns, and study wildlife and environmental sounds.

Executive Summary

From brown bears feeding on salt marsh sedges along Cook Inlet, to still lake surfaces framed by the volcanic Chigmit Mountains, a visit to the southeastern coastal area of Lake Clark National Park (LACL) offers the potential for a truly scenic experience in the Alaskan wild. The LACL coast represents the convergence of marine, riparian, and alpine systems—supporting some of the park’s most visible wildlife concentrations and increasingly sought-after visitor experiences. These coastal portals are accessed primarily by aircraft and watercraft and are embedded within a mosaic of public, private, and Tribal lands that shape travel routes and patterns of use.

Park staff note that changes in visitation are driving corresponding changes in motorized transportation and associated noise. To understand these changes, this report presents acoustical data gathered at three sites along the LACL coast (Figure 1). The initial data collection effort occurred in 2018 and 2019, followed by a more expansive, season-long effort in 2023. These sequential monitoring data were gathered to provide park managers with information about the acoustical environment, sources of noise, and the existing ambient sound levels on the coast. In doing so, they support the park’s statutory purpose to maintain scenic beauty and wildlife habitat, including the preservation of natural acoustic conditions.

In these deployments, sound pressure level (SPL) was measured continuously every second by a calibrated sound level meter. Other equipment included an anemometer to log wind speed, a paired thermometer and hygrometer to log temperature and relative humidity and a digital audio recorder collecting continuous recordings to document sound sources. Throughout this document, “sound pressure level” refers to broadband (12.5–20,000 Hz), A-weighted, 1-second time averaged sound level ($L_{Aeq, 1s [12.5-20,000 \text{ Hz}]}$), and hereafter referred to as “sound level.” Sound levels are measured on a logarithmic scale relative to the reference sound pressure for atmospheric sources, 20 μPa . The logarithmic scale is a useful way to express the wide range of sound pressures perceived by the human ear. Sound levels are reported in decibels (dB). A-weighting is applied to sound levels to account for the response of the human ear (Harris 1998). To approximate human hearing sensitivity, A-weighting discounts sounds below 1 kHz and above 6 kHz. For reference, Table 1 provides examples of sound levels measured in parks compared to sound levels of common sources.



Figure 1. Coastal study sites in Lake Clark National Park, Alaska, USA. Indicated are the boundary of the park (bold black line), Visitor Use Areas used to report commercial use (fine), and the Designated Wilderness area (hatched).

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Table 1. Sound level examples.

Park Sound Sources	Common Sound Sources	Sound Level dB ^A
Volcano crater (HALE)	Human breathing at 3 m	10
Leaves rustling (CANY)	Whispering	20
Crickets at 5 m (ZION)	Residential area at night	40
Conversation at 5 m (WHMI)	Car at 15 m, 30 mph	60
Cruiser motorcycle at 15 m (BLRI)	Curbside of busy street	80
Thunder (ARCH)	Jackhammer at 2 m	100
Military jet at 100 m AGL (YUCH)	Train horn at 1 m	120

^A dB re 20 μ Pa A-weighted broadband (12.5–20,000 Hz); sound level measured over varied measurement durations and at the distances indicated.

Overall, existing ambient sound levels (L_{A50}) at the coastal sites within LACL ranged from 33.4–38.4 dB during the day and 31.9–41.0 dB at night. Table 2 reports the percent of time that measured levels at the monitoring locations were above four key sound level values. The first value, 35 dB ($L_{Aeq, 1s}$), addresses the health effects of sleep interruption. Recent studies suggest that sound events as low as 35 dB can have adverse effects on blood pressure in sleeping humans (Haralabidis et al. 2008). This level, 35 dB, 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 dB ($L_{Aeq, 1s}$) (Berglund et al. 1999). The third value, 52 dB ($L_{Aeq, 1s}$), 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 and group safety communication in bear country. The final value, 60 dB ($L_{Aeq, 1s}$), provides a basis for estimating speech interference on normal voice communications at 1 meter. Visitors viewing scenic areas in the park would likely be conducting such conversations.

Sound levels are often measured over narrow frequency bands (typically in one-third octave bands between 12.5–20,000 Hz) because these smaller bands closely represent how humans distinguish between frequencies of sound. In this study, we examine how often sound levels exceeded key values in two frequency ranges. The top value in each split-cell of Table 2 uses the full frequency range (12.5–20,000 Hz) collected, whereas the bottom value focuses on frequencies affected by low frequency noise sources (20–1,250 Hz). This Natural Sounds modification to A-weighting (referred to as ANS weighting, ASA/ANSI S3/SC1.100-2014) eliminates high-frequency sound (leaf rustle, equipment noise, and biologic sounds) allowing for more accurate comparisons of low-frequency ambient sound levels across different land use types (e.g., urban, protected areas; ASA/ANSI S3/SC1.100-2014). This frequency weighting scheme improves ambient sound level measurements in quiet environments. For instance, in the full frequency range, the 35 dB ($L_{Aeq, 1s}$) level was exceeded at LACLCHBA2023 (Chinitna Bay) 43.02% of the time during the day and 28.11% of the time at night, but in the 20–1,250 Hz range, the 35 dB functional sound level value was exceeded only 30.60% of the day and 12.20% of the night. Speech interruption (between two people 1 meter apart) occurs at 60 dB ($L_{Aeq, 1s}$) and this level was rarely exceeded at any of the sites.

After data collection was complete, trained technicians calculated how often noise sources were audible. See Methods section for protocol details, equipment specifications, and metric calculations. Sound source analysis revealed that noise was audible about 14–29% of the time during the sampling period at study sites when averaged across all hours of the day (Table 3). The most common noise sources observed during this study were aircraft and vehicles. Characteristic sounds of the LACL coast included surf, seabirds, songbirds, eagles, and occasionally bear vocalizations. Natural ambient sound levels (L_{Anat}) ranged between 32.6–36.9 dB during the day and 31.8–40.2 dB at night. Increased natural ambient sound levels during day and night varied by location and were likely caused by wind and daily atmospheric cycles interacting with powerful sources of flowing water (streams, lake waves, oceanic surf).

Table 2. Percent time above metrics for acoustic records from three coastal sites in LACL.

Site	Frequency (Hz)	Time above sound level (% of daytime hours, 07:00 to 19:00)								Time above sound level (% of nighttime hours, 19:00 to 07:00)							
		≥35 dB ^A 2018 ^C	≥35 dB ^A 2023	≥45 dB ^A 2018	≥45 dB ^A 2023	≥52 dB ^A 2018	≥52 dB ^A 2023	≥60 dB ^A 2018	≥60 dB ^A 2023	≥35 dB ^A 2018	≥35 dB ^A 2023	≥45 dB ^A 2018	≥45 dB ^A 2023	≥52 dB ^A 2018	≥52 dB ^A 2023	≥60 dB ^A 2018	≥60 dB ^A 2023
Chinitna Bay	12.5–20,000	52.8	43.0	4.2	3.6	1.9	1.1	0.6	0.3	36.0	28.1	1.5	1.0	0.1	0.2	0.0	0.3
	20–1,250 ^B	37.6	30.6	3.5	2.6	1.8	1.0	0.5	0.3	14.3	12.2	0.4	0.2	0.1	0.0	0.0	0.0
Crescent Lake	12.5–20,000	47.9	85.7	17.7	20.3	8.5	8.5	3.0	3.1	12.9	75.3	1.1	3.7	0.2	0.9	0.0	0.2
	20–1,250 ^B	41.4	72.7	16.4	15.7	8.2	7.2	2.9	2.9	8.2	63.2	0.5	1.4	0.1	0.4	0.0	0.1
Silver Salmon Creek	12.5–20,000	64.0	63.6	11.9	6.9	2.2	1.7	0.5	0.5	92.2	84.3	20.3	4.0	0.4	0.1	0.0	0.0
	20–1,250 ^B	61.6	53.1	10.5	4.8	2.1	1.6	0.5	0.5	90.5	75.5	17.1	1.0	0.2	0.1	0.0	0.0

^A dB LAeq, 1s re 20 µPa.

^B The percent of time ANS-weighted sound levels (20–1,250 Hz) are above functional values.

^C The acoustic monitoring record at Silver Salmon Creek was established in 2019.

Table 3. Summary acoustic metrics at three coastal sites in LACL. Reported for each site are mean daily time audible for primary noise sources (% of 24-hour time period), existing ambient (LA50), and natural ambient (LAnat) sound levels during the day (07:00–19:00) and night (19:00–07:00). Time audible and LAnat are calculated based on sound source identification from spectrogram annotation.

Site	Mean time audible for noise (% of 24-hour time period)								Median Existing Ambient (LA50) in dB ^A				Median Natural Ambient (LAnat) in dB ^A			
	Noise 2018 ^B	Noise 2023	Aircraft 2018	Aircraft 2023	Watercraft 2018	Watercraft 2023	Vehicles 2018	Vehicles 2023	Day 2018	Day 2023	Night 2018	Night 2023	Day 2018	Day 2023	Night 2018	Night 2023
Chinitna Bay	19.5	15.4	18.2	12.7	0.3	2.8	1.1	0.2	34.9	33.4	31.9	32.1	34.0	32.6	31.8	31.9
Crescent Lake	25.2	28.5	12.6	15.8	12.9	13.3	0.0	0.0	34.8	38.4	33.1	36.6	32.6	36.4	33.0	36.4
Silver Salmon Creek	17.3	13.9	13.2	11.5	2.5	1.5	2.0	1.0	37.0	37.6	40.4	38.9	35.6	36.9	40.2	38.8

^A dB LAeq, 1s re 20 µPa, 12.5–20,000 Hz.

^B The acoustic monitoring record at Silver Salmon Creek was established in 2019.

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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 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 protects park resources and the visitor experience. The NSNSD addresses acoustic issues raised by Congress, NPS Management Policies, and NPS Director's Orders. The NSNSD works to protect, maintain, or restore acoustic 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 acoustic monitoring, data processing, park planning support, and comparative analyses of acoustic 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 wildlife 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."

NPS Management Policies 2006 Chapter 4.9 provides direction for management of natural soundscapes:

The National Park Service will preserve, to the greatest extent possible, the natural soundscapes of parks...

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 2006a).

It should be noted that under Management Policies 2006 Chapter 8.2.3, “[t]he 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 2006c). The desired acoustic condition also depends 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).

Further guidance is provided in Management Policies 2006 §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.

Director’s Order 47, Soundscape Preservation and Noise Management (2000) builds on the principles set out in Management Policies, directing park management how and when to consider acoustic resources. 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.

Focal Park Unit

Established in 1980, Lake Clark National Park and Preserve (LACL) protects 4,030,015 acres (16,309 km²) of land set aside by Congress “to protect the watershed necessary for the perpetuation of the red salmon fishery in Bristol Bay; to maintain unimpaired the scenic beauty and quality of portions of the Alaska Range and the Aleutian range, including active volcanoes, glaciers, wild rivers, lakes, waterfalls, and alpine meadows in their natural state; and to protect habitat for populations of fish and wildlife including but not limited to caribou, Dall sheep, brown/grizzly bears, bald eagles, and peregrine falcons” (NPS 2009). As stated above, the maintenance of scenic beauty—in part as auditory scenes (Bregman 1994; Weinzimmer et al. 2014)—is among LACL’s statutory purposes. It is also clear that LACL was established to protect wildlife habitat from pollutants such as

anthropogenic noise, which has been shown to interfere with communication, increase physiological stress, and displace animals from affected landscapes (Barber et al. 2010; Francis and Barber 2013; Shannon et al. 2016).

The LACL Resource Stewardship Strategy (RSS) issued in 2009 includes the strategic stewardship goal, “improve understanding of the park’s natural landscape and physical processes” which recognized as a priority the need for an acoustic inventory and subsequent monitoring, stating, “natural sounds are vital to park ecosystems and are a valued part of the visitor experience. Aircraft traffic is generally considered to be the biggest impact to natural soundscapes in the park. Anecdotal observations indicate increased aircraft traffic over [LACL], particularly at locations that concentrate use...an acoustic inventory of key areas will be conducted to provide a benchmark in time. Subsequent monitoring will be conducted to assess changes in the acoustic environment” (NPS 2017). This report is the first to describe the results of the LACL acoustic inventory, focused on a coastal subset of sites.

Coastal Management Plan Study Sites

The data summarized in this report are key coastal sites selected from the 2018–2025 park-wide acoustic inventory to inform the nascent LACL Coastal Management Plan (NPS 2024): Chinitna Bay, Crescent Lake, and Silver Salmon Creek. All three places are remote, wild landscapes without road access, where coastal brown bears are central characters in the seasonal rhythm and where marine, freshwater, and terrestrial systems intersect. All three also serve as major transportation portals for visitors arriving to LACL. Points of origin for these sites are Anchorage, the Kenai Peninsula (Homer/Kenai/Soldotna), and to a lesser extent, Port Alsworth.

Chinitna Bay is located on the southern coastal boundary of the park and comprises privately owned lands, lands owned by the National Park Service, and lands owned by Alaska Native Village Corporations. Bear viewing is the primary visitor activity at Chinitna Bay, with the salt marsh, nearshore community, and creeks in Chinitna Bay supporting a high density of brown bears throughout the summer. Wheeled fixed-wing aircraft are the primary means of arrival from points of origin.

Crescent Lake is located inland from the coastline and is comprised of privately owned lands, lands owned by the National Park Service, and lands owned by Alaska Native Village Corporations. Bear-viewing and sport fishing are the primary visitor activities at Crescent Lake, with boat use supporting both activities. Multiple species of salmon use Crescent Lake and provide food for brown bears and fishing opportunities for visitors. Float-equipped fixed-wing aircraft are the primary means of arrival from points of origin.

Silver Salmon Creek is located on the central coast of the park and is comprised of a mix of private and National Park Service-owned lands. Multiple private inholdings are operated as lodges providing services to park visitors. Bear viewing is the primary visitor activity at Silver Salmon Creek, with the salt marsh and creek providing high quality habitat that supports bear use throughout the summer and early fall. Wheeled fixed-wing aircraft are the primary means of arrival from points of origin.

The purpose of the LACL Coastal Management Plan is “to improve visitor experiences at key coastal sites while protecting resources and responding to changing conditions.” One such change was “a substantial increase in seasonal visitation” along the LACL coast. For example, visitation to Chinitna Bay “increased nearly tenfold over the last 15 years from 724 to 7,197 visitors annually from June to September” and visitation to Silver Salmon Creek “tripled from 2,173 to 6,365” visitors over the same period. Presently, regional-scale transportation to coastal sites occurs almost entirely via aircraft capable of transporting ≤ 11 visitors at a time. Day visitors arriving via tour vessel are an emerging pattern. Local motorized transportation at each site occurs via both small, motorized watercraft and overland vehicles (including ATVs and larger multi-passenger vehicles) which operate on the beach and/or trails.

Study Area

This report pertains to three coastal transportation portals selected from the wider acoustic inventory of LACL conducted from 2018–2025 (Table 4). An initial inventory record of each portal site was made during the summer visitation season of 2018 or 2019. A season-long monitoring record was made in 2023. The sampling locations span 60 km (37 miles) of the LACL coastline (Figure 1). All three sites exist within non-wilderness Visitor Use Areas of the same name (NPS 2023). Each site location is also mapped at a finer 1:64,000 scale in Appendix B.

The Alaska Vegetation Classification system (Viereck et al. 1992) was used to categorize landcover (Table 4). At LACLCHBA Chinitna Bay, the microphone was surrounded by open white/Sitka spruce woodland (1.A.3.c, 1.A.3.b), and at LACLCRES Crescent Lake, open tall alder scrub (II.B.2.b). At LACLSISA Silver Salmon Creek, the backshore is dry graminoid herbaceous vegetation dominated by beach rye (III.A.1.a). Cardinal photographs of each microphone deployment are provided in Appendix A.

Table 4. Selected acoustic monitoring deployments at three coastal transportation portals in LACL.

Site	Deployment	Sample Dates	Vegetation	Latitude	Longitude	Elevation (m)
Chinitna Bay	LACLCHBA2018	6/21–7/04	I.A.3.c, I.A.3.b	59.86716	–153.11869	9
	LACLCHBA2023	5/21–9/29	I.A.3.b	59.86716	–153.11869	9
Crescent Lake	LACLCRES2018	9/9–9/20	II.B.2.b	60.35855	–152.85919	145
	LACLCRES2023	6/17–9/14	II.B.2.b	60.35855	–152.85919	145
Silver Salmon Creek	LACLSISA2019	6/28–9/2	III.A.1.a	59.97542	–152.67127	6
	LACLSISA2023	5/23–8/16	III.A.1.a	59.97542	–152.67127	6

Methods

Automatic Monitoring

A Larson Davis sound level meter (SLM) type 831-A was deployed at each monitoring site. The SLM is a hardware-based, real-time analyzer which constantly records one-third octave band sound pressure level (SPL) data. The accurate, survey-grade SLM met American National Standards Institute (ANSI) Type 1 standards (ANSI 1968 [R2020], 1983 [R2006], 1992 [2018]). The sound level meter provided the information needed to calculate metrics described below in Calculation of Metrics.

Acoustic monitoring equipment is used by many practitioners to determine noise levels in different environments, both indoors and outdoors. The NPS uses equipment like other practitioners but has developed a unique configuration that stands up to the potentially harsh environment encountered in national parks (NPS 2013). The microphone with environmental shroud was set up on a tripod approximately 1.5 m above the ground, which approximates the average height of the human ear. The digital audio recorder recorded continuous audio through the entire monitoring period. An anemometer was attached to a tripod and placed adjacent to the microphone to capture local wind conditions.

The sampling station consisted of:

1. Type 1 sound level meter
2. Microphone with environmental shroud
3. Preamplifier
4. 12 V and 3 V battery packs
5. Anemometer / Wind Vane (wind speed and direction)
6. Thermometer / Hygrometer (temperature and relative humidity)
7. Digital audio recorder

The sampling station was designed to collect:

1. Flat-weighted, time-averaged sound level ($L_{Zeq, 1s}$) for each one-third octave frequency band, 12.5–20,000 Hz in dB re 20 μ Pa [collected by Type 1 sound level meter].
2. A-weighted, time-average sound level ($L_{Aeq, 1s [12.5-20,000 \text{ Hz}]}$) in dB re 20 μ Pa [collected by Type 1 sound level meter].
3. Continuous meteorological data [collected by anemometer, vane, thermometer, and hygrometer].
4. Continuous digital audio recordings.

Monitoring Period

It is typical to sample the acoustic environment for a minimum of 25 days to capture daily differences within a reasonable margin of error (NPS 2005). For this study, acoustical data were collected in 2018/2019 and again in 2023. In 2018/2019, data were collected at Chinitna Bay, Crescent Lake, and Silver Salmon Creek for 14, 12, and 41 days as part of a park-wide acoustic inventory. In 2023, data were collected for 78, 88, and 76 days as part of a more comprehensive season-long sample.

Calculation of Metrics

The status of the acoustical environment can be characterized by percentile sound level (L_{A90} , L_{Anat} , L_{A50} , L_{A10}), frequency content, event durations, and their timing. NPS uses descriptive figures and metrics to interpret these characteristics.

Three fundamental descriptors of the ambient (background) acoustical environment are existing ambient (L_{A50}), natural ambient (L_{Anat}) and residual ambient (L_{A90}) sound levels. These are all examples of percentile levels, where each L_x value refers to the sound level that is exceeded $x\%$ of the time. All are calculated from the full dataset (removing data with wind speed >5 m/s to eliminate error from microphone artifacts). The L_{A50} represents the median sound level and is the preferred metric to represent prevailing acoustic conditions. The natural ambient (L_{Anat}) is an estimate of what the sound levels for a site would be if all human-caused noise sources were removed. L_{Anat} is the preferred metric to represent baseline or reference resource conditions. The L_{A90} represents the 10th percentile sound level and is the preferred metric to quantify active space, the spatial extent of audibility for a specific source type.

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

$$x = \frac{100 - P_H}{2} + P_H,$$

where

P_H = percentage of samples containing noise for the hour.

For example, if human caused sounds are present 30% of the hour, $x = 65$, and the L_{Anat} 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_{Anat} values for the “daytime” hours (07:00–19:00) and the median of the hourly L_{Anat} values for the “nighttime” (19:00–07:00) are displayed in graphical format in the following sections.

Spectrogram Analysis

The entire acoustic record from each site was annotated visually using the NPS-developed software, Sound Pressure Level Annotation Tool (SPLAT, Figure 2). Trained technical staff with the NPS and the U.S. Department of Transportation used SPLAT to draw bounding boxes at the beginning and

end of noise events using visual cues from the sound pressure energy, time, and frequency of a spectrogram (for more information on SPLAT software, see Appendix C). From the drawn bounding boxes, noise event counts (i.e., the number of boxes), noise duration (i.e., the length of each box), and the sound exposure level metric (SEL; i.e., the logarithmically summed total energy within each boundary) were obtained. The total percent of time noise was audible was then used to calculate the natural ambient sound level (L_{Anat}) for each hour (see Equation 1 above). In addition, the noise-free interval (NFI) metric was generated. The NFI represents the length of time that passes between the end of one noise event and the beginning of the next. Over the entire sampling period, the median NFI describes how a typical opportunity for solitude has been fragmented by noise (Haver et al. 2023; Miller 2008; Poling and Betchkal 2023).

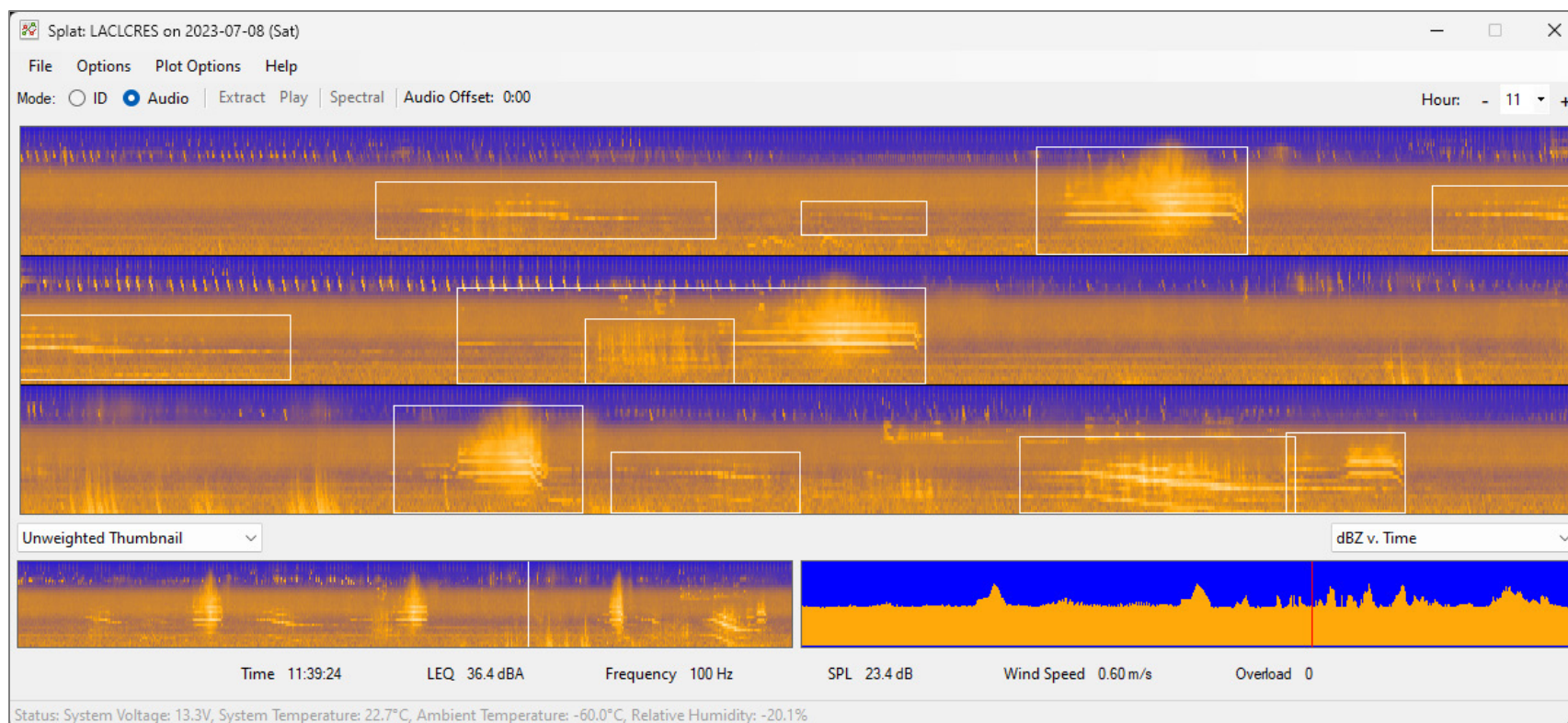


Figure 2. Spectrogram annotations (white bounding rectangles) created using NPS Sound Pressure Level Annotation Tool software.
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Results

Frequency Content

To determine the effect that noise has on the acoustic environment, it is useful to examine percentile metrics across a frequency range. High frequency sounds (such as gulls calling) and low frequency sounds (such as flowing water) often occur simultaneously, so the frequency spectrum is split into 33 narrower bands, each encompassing one-third of an octave. These narrow bands closely represent how humans distinguish between frequencies of sound. The percentile sound levels for 33 one-third octave band frequencies over the day and night periods are shown in Figures 3–8.

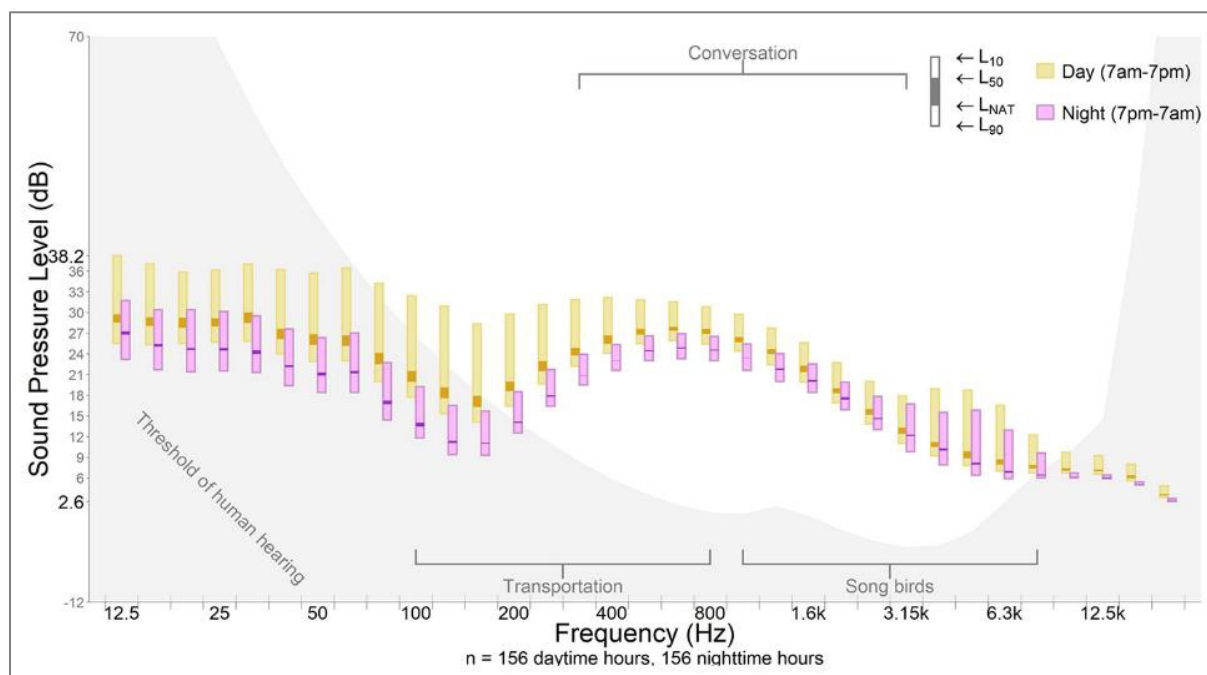


Figure 3. Day and night percentile sound pressure levels for 33 one-third octave bands at Chinitcha Bay (LACLCHBA) from 06/21–07/04/2018. For each bar, the bold color indicates the range of existing (L_{50} ; upper) and natural (L_{nat} ; lower) sound pressure levels. The sound levels depicted are not A-weighted.

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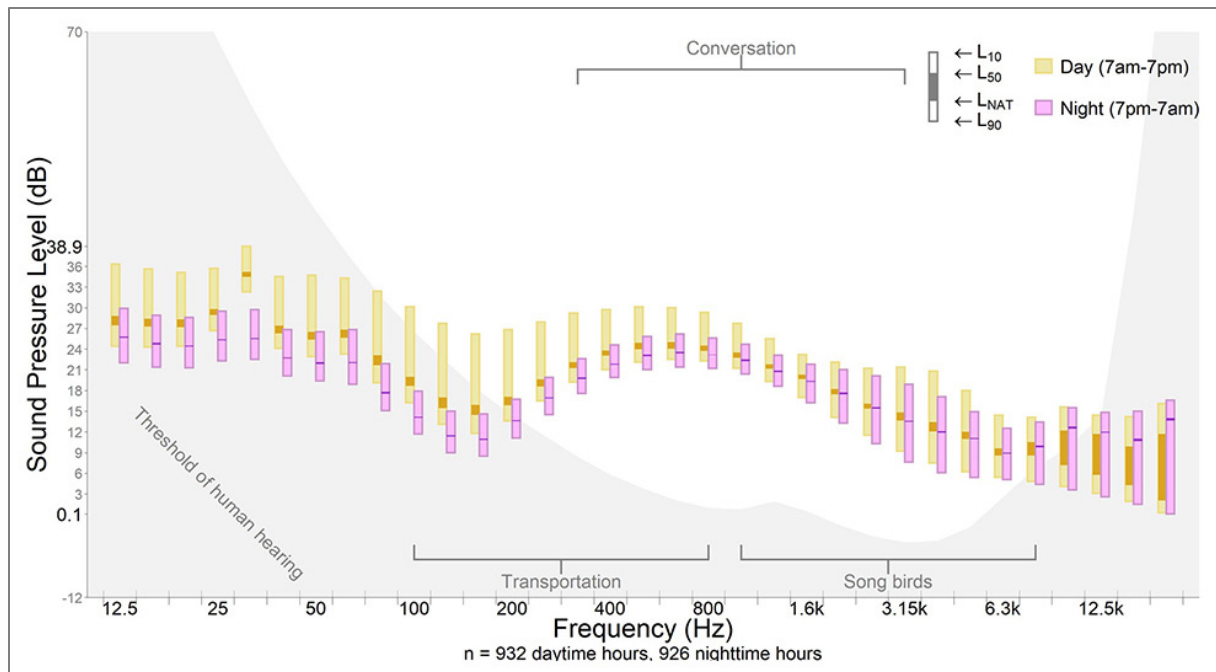


Figure 4. Day and night percentile sound pressure levels for 33 one-third octave bands at Chinitna Bay (LACLCHBA) from 05/21–09/29/2023. For each bar, the bold color indicates the range of existing (L₅₀; upper) and natural (L_{nat}; lower) sound pressure levels. The sound levels depicted are not A-weighted.
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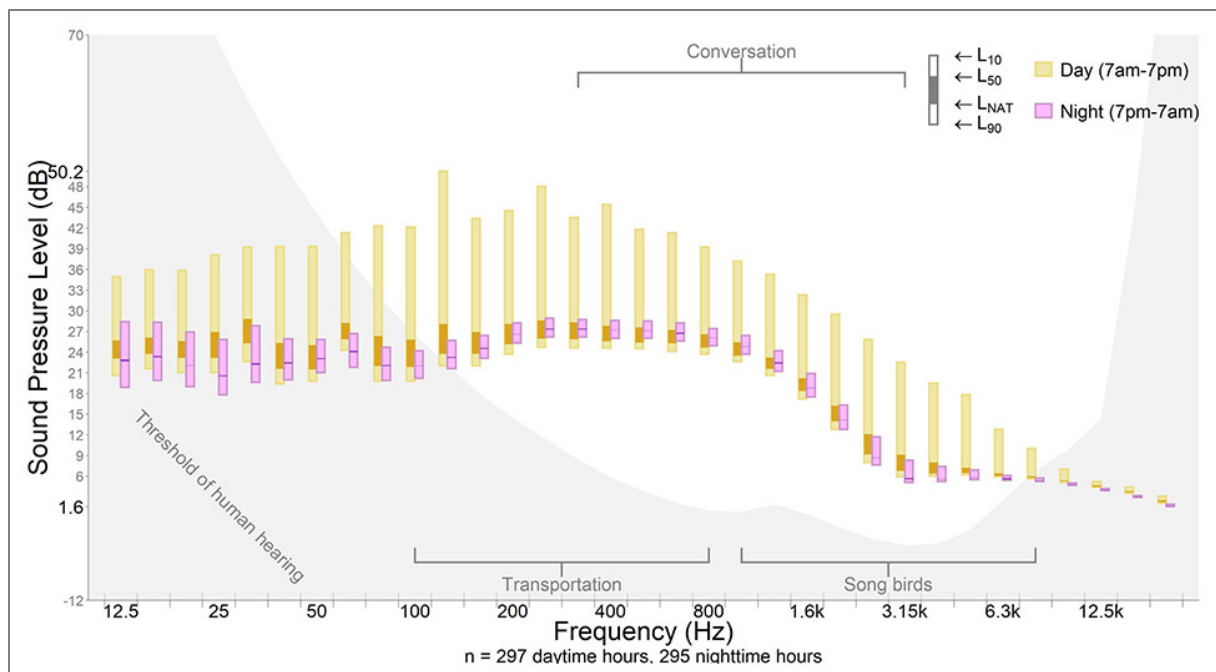


Figure 5. Day and night percentile sound pressure levels for 33 one-third octave bands at Crescent Lake (LALCRES) from 09/09–09/20/2018. For each bar, the bold color indicates the range of existing (L₅₀; upper) and natural (L_{nat}; lower) sound pressure levels. The sound levels depicted are not A-weighted.
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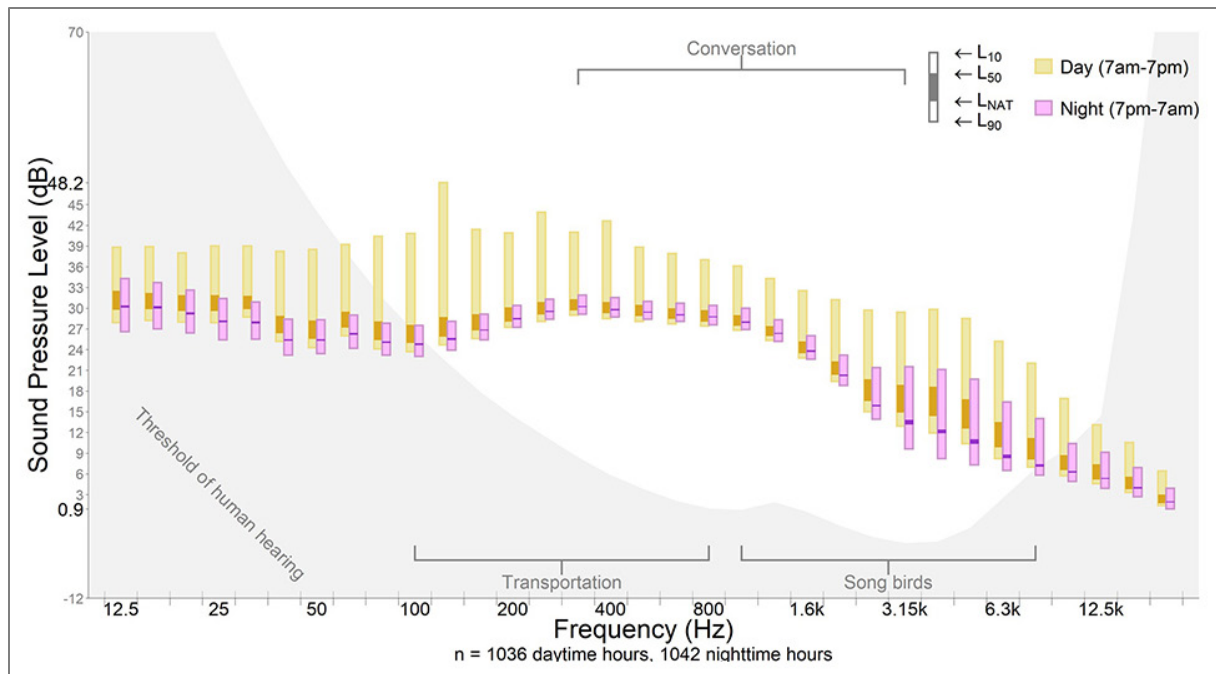


Figure 6. Day and night percentile sound pressure levels for 33 one-third octave bands at Crescent Lake (LACLRES) from 06/17–09/14/2023. For each bar, the bold color indicates the range of existing (L₅₀; upper) and natural (L_{nat}; lower) sound pressure levels. The sound levels depicted are not A-weighted.
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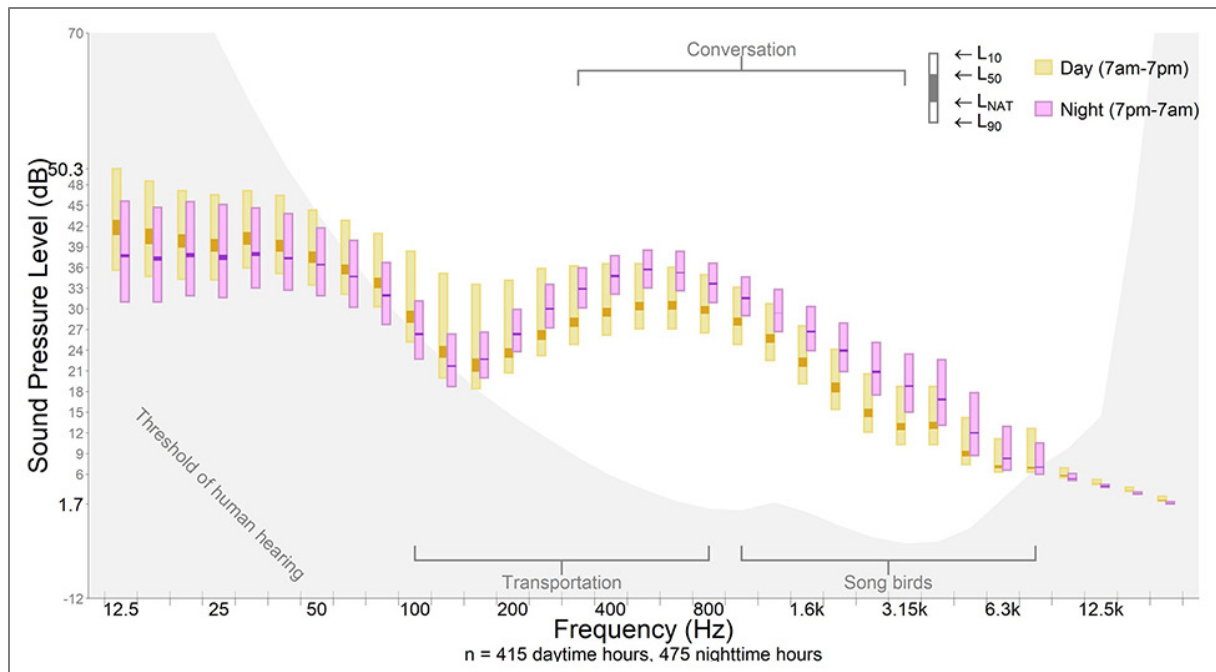


Figure 7. Day and night percentile sound pressure levels for 33 one-third octave bands at Silver Salmon Creek (LACLSISA) from 06/28–09/02/2019. For each bar, the bold color indicates the range of existing (L₅₀; upper) and natural (L_{nat}; lower) sound pressure levels. Sound levels depicted are not A-weighted.
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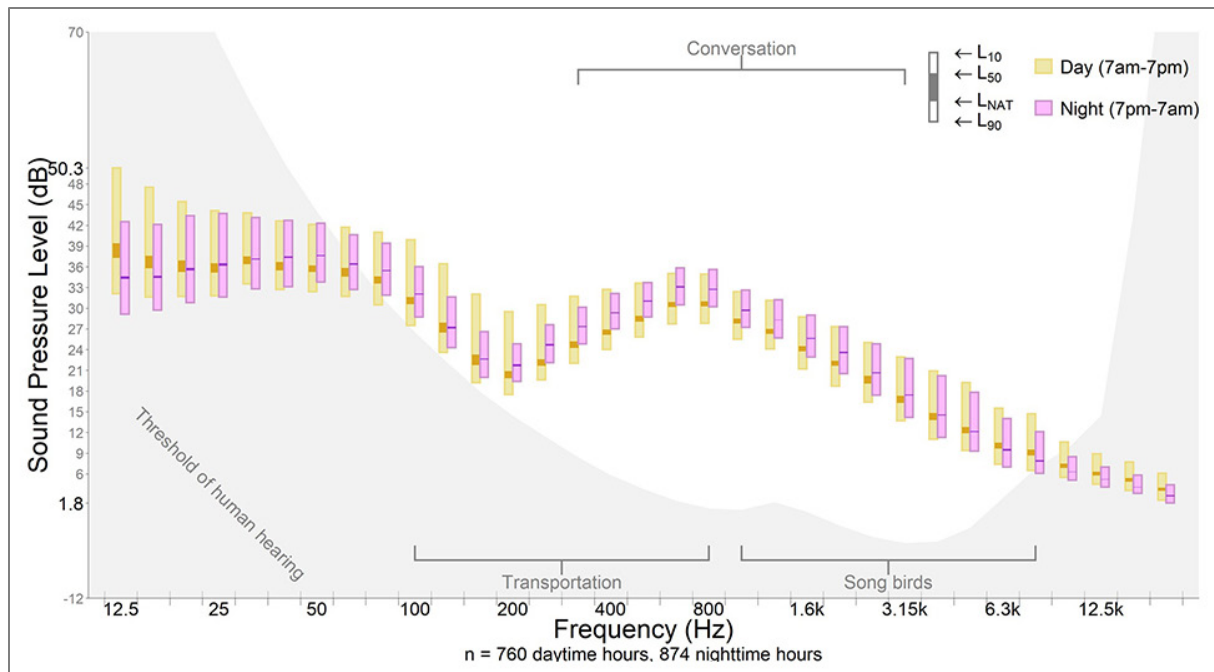


Figure 8. Day and night percentile sound pressure levels for 33 one-third octave bands at Silver Salmon Creek (LACLSISA) from 05/23–08/16/2023. For each bar, the bold color indicates the range of existing (L_{50} ; upper) and natural (L_{nat} ; lower) sound pressure levels. Sound levels depicted are not A-weighted. *NPS / NATURAL SOUNDS AND NIGHT SKIES DIVISION*

Examining the sound energy in each one-third octave band (combined with digital audio recordings) allows analysts to determine what types of sounds are contributing to the overall sound levels at a site. The grayed areas of Figures 3–8 represent sound levels outside of the typical range of human hearing. The percentile levels (L_x) are also shown for each one-third octave band. They represent the sound levels exceeded x percent of the measurement period. For example, L_{90} is the sound 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} . The bold portion of the column represents the difference between L_{50} and L_{nat} . The height of this bold portion is a measure of the contribution of anthropogenic noise to the existing sound levels at this site. The size of this portion of the column is directly related to the percent of time that human caused sounds are audible. When bold portions of the column do not appear the natural and existing sound levels were either very close to each other or were equal. 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.

Each of the sites has a different diurnal pattern. At Chinitna Bay, the residual ambient sound level (L_{90}) increases in the daytime relative to the night. At Crescent Lake, residual ambient sound level is not meaningfully differentiated by time of day. At Silver Salmon Creek, residual ambient sound level decreases in the daytime relative to the night.

Sound Level: Time Above

To understand how acoustic conditions in the park might affect visitors, measured sound levels are compared to sound levels of interest. Specifically, Table 5 reports the percent of time that measured sound levels ($L_{Aeq, 1s}$) were above four key functional effect levels during the monitoring periods (daytime and nighttime). The top value in each split-cell uses the full frequency range, whereas the bottom values report the percentage of the sample that ANS-weighted sound levels (20–1,250 Hz) were above functional effect thresholds. Most motorized human-caused noise is confined to the truncated, lower-frequency range, while many natural sounds, including insects and birds, are higher in pitch. ANS weighting eliminates high-frequency sound (leaf rustle and biologic sounds) allowing for more accurate comparisons of low-frequency ambient sound levels across different land use types (e.g., urban, protected areas; ANSI S3/SC1.100, 2014). This frequency weighting scheme improves ambient sound level measurements in quiet environments.

The first functional effect in Table 5 occurs around 35 dB ($L_{Aeq, 1s}$), which represents a threshold for health effects related to sleep interruption. Studies suggest that sound events as low as 35 dB can have adverse effects on blood pressure in sleeping humans (Haralabidis et al. 2008). This is also the desired background sound level in classrooms (ANSI S12.60-2002), where attention and focus are paramount. For example, in the present study, the 35 dB ($L_{Aeq, 1s}$) effect level was exceeded at LACLCHBA2018 52.84% of the time during the day and 36.01% of the time at night in the full frequency range. In the 20–1,250 Hz range, the 35 dB functional sound level value was exceeded 37.56% of the daytime and 14.33% of the nighttime. The second functional effect is expected to occur around 45 dB ($L_{Aeq, 1s}$), aligning with the World Health Organization's recommendation that noise levels inside bedrooms remain below this threshold (Berglund et al. 1999). The third functional effect is expected to occur around 52 dB ($L_{Aeq, 1s}$), based on the EPA's speech interference threshold for communication in a raised voice to an audience at 10 meters (EPA 1974). This threshold highlights the implications of sound on interpretive presentations in parks and ensuring group safety communication in bear country. Finally, the fourth functional effect occurs at a sound level of 60 dB ($L_{Aeq, 1s}$) and represents a threshold for estimating impacts on normal voice communications at 1 meter.

Table 5. Percent time above metrics for acoustic records collected in Lake Clark National Park (LACL).

Site	Frequency (Hz)	Time above sound level (% of daytime hours, 07:00 to 19:00)								Time above sound level (% of nighttime hours, 19:00 to 07:00)							
		≥35 dB ^A 2018 ^C	≥35 dB ^A 2023	≥45 dB ^A 2018	≥45 dB ^A 2023	≥52 dB ^A 2018	≥52 dB ^A 2023	≥60 dB ^A 2018	≥60 dB ^A 2023	≥35 dB ^A 2018	≥35 dB ^A 2023	≥45 dB ^A 2018	≥45 dB ^A 2023	≥52 dB ^A 2018	≥52 dB ^A 2023	≥60 dB ^A 2018	≥60 dB ^A 2023
Chinitna Bay	12.5–20,000	52.8	43.0	4.2	3.6	1.9	1.1	0.6	0.3	36.0	28.1	1.5	1.0	0.1	0.2	0.0	0.3
	20–1,250 ^B	37.6	30.6	3.5	2.6	1.8	1.0	0.5	0.3	14.3	12.2	0.4	0.2	0.1	0.0	0.0	0.0
Crescent Lake	12.5–20,000	47.9	85.7	17.7	20.3	8.5	8.5	3.0	3.1	12.9	75.3	1.1	3.7	0.2	0.9	0.0	0.2
	20–1,250 ^B	41.4	72.7	16.4	15.7	8.2	7.2	2.9	2.9	8.2	63.2	0.5	1.4	0.1	0.4	0.0	0.1
Silver Salmon Creek	12.5–20,000	64.0	63.6	11.9	6.9	2.2	1.7	0.5	0.5	92.2	84.3	20.3	4.0	0.4	0.1	0.0	0.0
	20–1,250 ^B	61.6	53.1	10.5	4.8	2.1	1.6	0.5	0.5	90.5	75.5	17.1	1.0	0.2	0.1	0.0	0.0

^A dB L_{Aeq, 1s} re 20 µPa.

^B The percent of time ANS-weighted sound levels (20–1,250 Hz) are above functional values.

^C The acoustic monitoring record at Silver Salmon Creek was established in 2019.

Sound Level: Percentile Levels

To understand the range of acoustic conditions at the park, percentile sound levels are reported (Table 6, Figures 9–14). In each figure, the A-weighted percentile sound levels (L_{A90} , L_{Anat} , L_{A50} , and L_{A10}) for a microphone deployment are shown by hour of the day. The hourly percentile sound levels are calculated from the broadband (12.5–20,000 Hz) A-weighted, 1-second time averaged sound levels ($L_{Aeq, 1s}$). For instance, in Figure 9, the L_{A50} (median) sound level for LACLCHBA2018 during the 10:00 hour is 35.5 dB. On the other hand, the sound level exceeded 10% of the time (L_{A10}) for the same hour at this site is 50.6 dB, meaning 90% of the measurement period is quieter. Hours where the L_{A50} and the L_{Anat} differ the most are usually hours with the most human-caused noise, as shown with site LACLCRES2023 (Figure 12). The greater the height of a black bar, the greater the divergence of the existing sound level from natural conditions. In general, existing sound levels are closest to natural conditions at night and in the early morning but depart from natural conditions for much of the day and evening (Figure 12).

The same diurnal patterns observed in Figures 3–8 are revealed more clearly in Figures 9–14. At Chinitna Bay, the residual ambient sound level (L_{90}) increases in the daytime relative to the night. At Crescent Lake, residual ambient sound level is not meaningfully differentiated by time of day. At Silver Salmon Creek, residual ambient sound level decreases in the daytime relative to the night.

Table 6. Summary of summer season sound level metrics at three coastal LACL monitoring sites. Metrics reported for each deployment are the 10th percentile (L_{A90}), natural ambient (L_{Anat}), existing ambient (L_{A50}), and 90th percentile (L_{A10}) sound levels (dB re 20 μ Pa, A-weighted broadband, 12.5–20,000 Hz) during the day (07:00–19:00) and night (19:00–07:00).

Site	Time	L_{A90}		L_{Anat}		L_{A50}		L_{A10}	
		2018	2023	2018	2023	2018	2023	2018	2023
Chinitna Bay	Day	32.7	30.2	34.0	32.6	34.9	33.4	39.5	38.8
	Night	30.5	29.0	31.8	31.9	31.9	32.1	34.9	35.6
Crescent Lake	Day	30.3	35.6	32.6	36.4	34.8	38.4	50.0	48.2
	Night	32.1	35.4	33.0	36.4	33.1	36.6	34.5	38.7
Silver Salmon Creek	Day	33.7	34.5	36.3	36.9	37.6	37.6	43.0	42.5
	Night	38.4	36.5	41.0	38.8	41.0	38.9	43.8	41.7

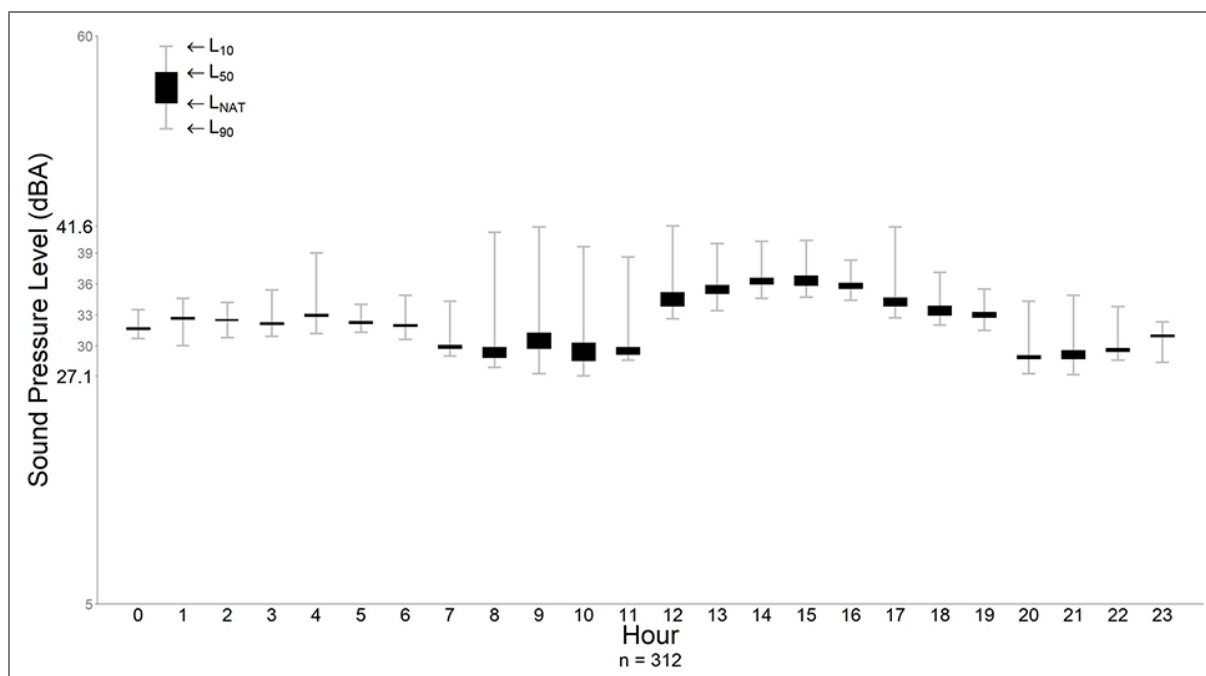


Figure 9. Median percentile sound levels ($L_{Aeq, 1s}$), in dB re 20 μ Pa, at Chinitna Bay (LACLCHBA) from 06/21–07/04/2018.

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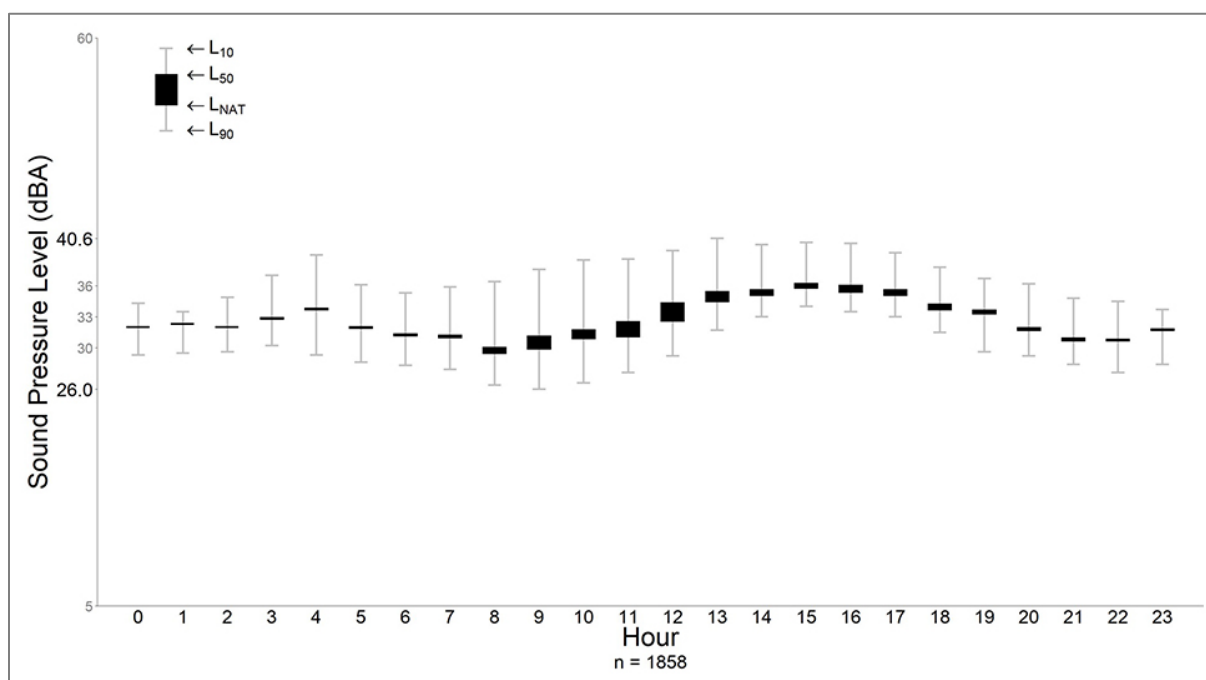


Figure 10. Median percentile sound levels ($L_{Aeq, 1s}$), in dB re 20 μ Pa, at Chinitna Bay (LACLCHBA) from 05/21–09/29/2023.

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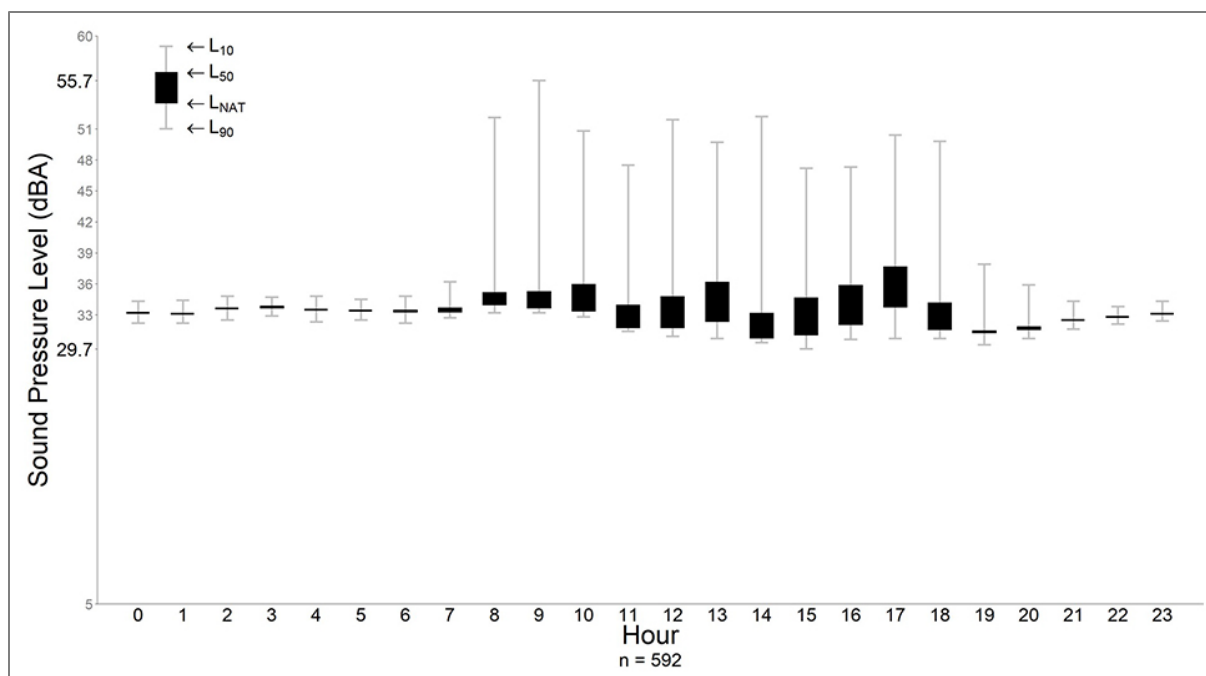


Figure 11. Median percentile sound levels ($L_{Aeq, 1s}$), in dB re 20 μ Pa, at Crescent Lake (LACLRES) from 09/09–09/20/2018.

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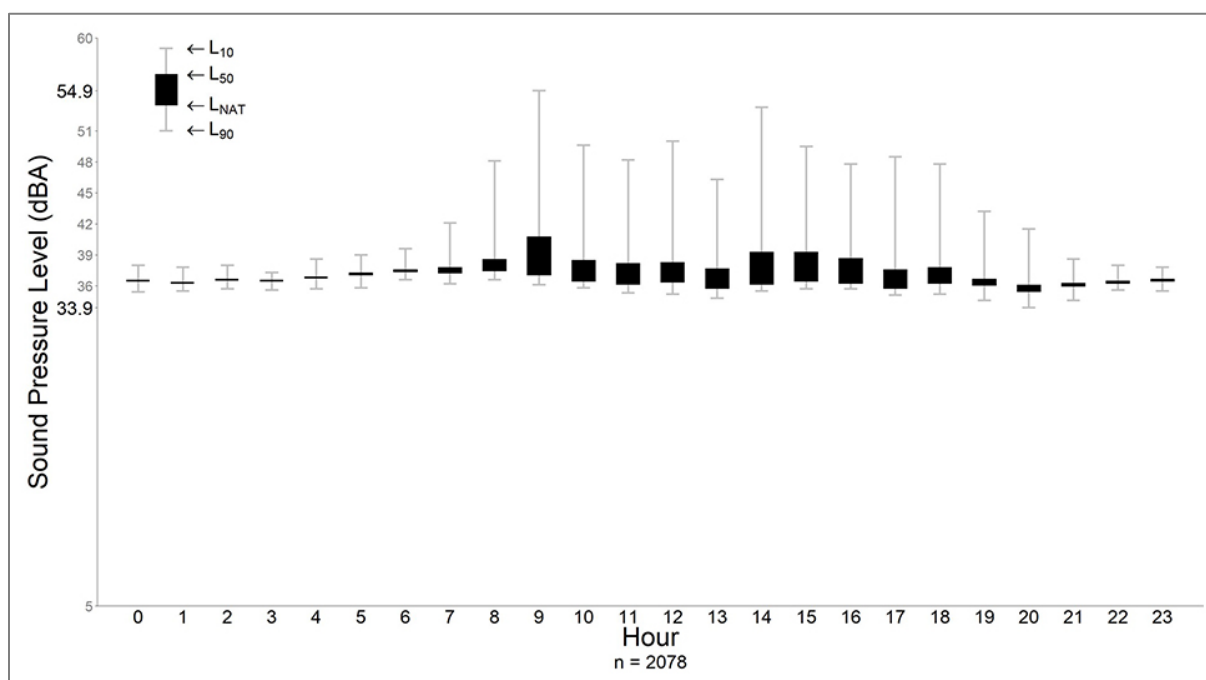


Figure 12. Median percentile sound levels ($L_{Aeq, 1s}$), in dB re 20 μ Pa, at Crescent Lake (LACLRES) from 06/17–09/14/2023.

NPS / NATURAL SOUNDS AND NIGHT SKIES DIVISION

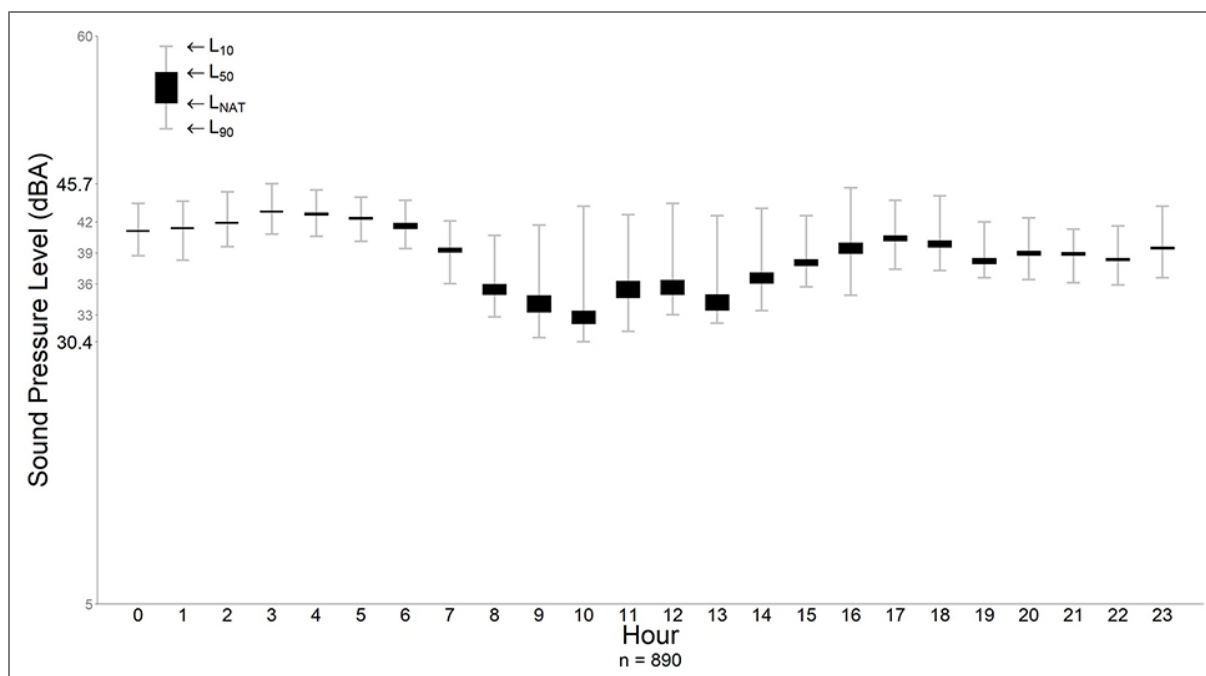


Figure 13. Median percentile sound levels ($L_{Aeq, 1s}$), in dB re 20 μ Pa, at Silver Salmon Creek (LACLSISA) from 06/28–09/02/2019.

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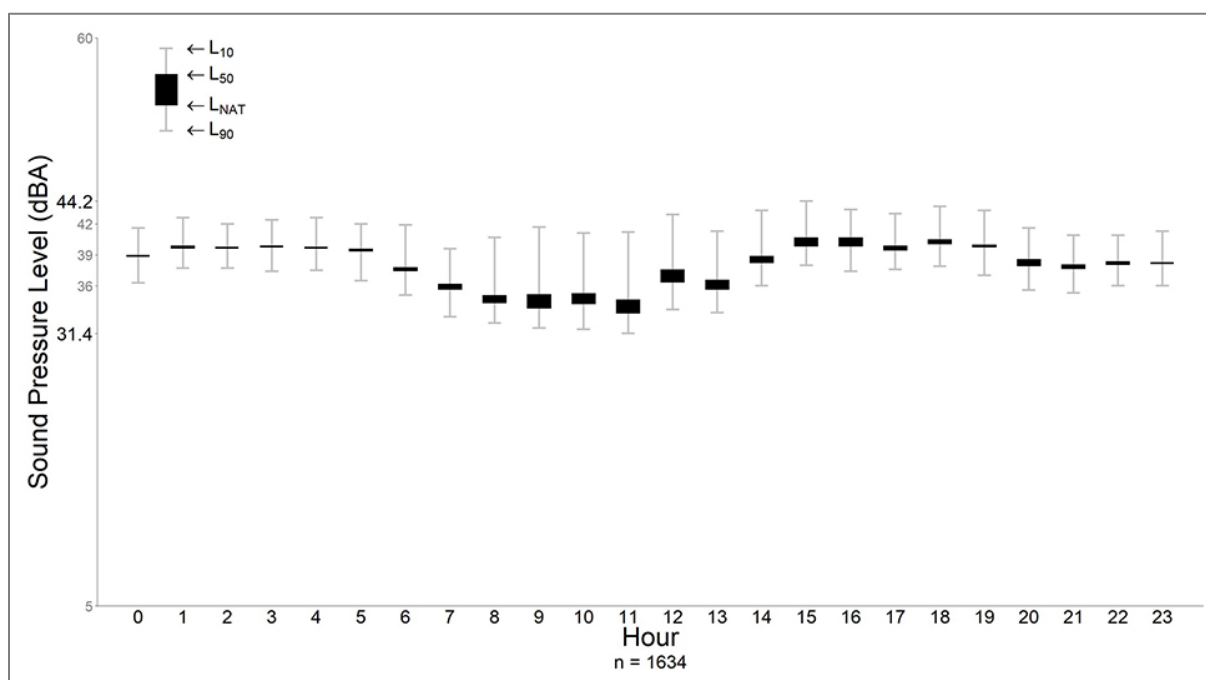


Figure 14. Median percentile sound levels ($L_{Aeq, 1s}$), in dB re 20 μ Pa, at Silver Salmon Creek (LACLSISA) from 05/23–08/16/2023.

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Event-Based Audibility: Duration, Timing, Event Rate and Exposure

Spectrogram analysis enables the duration and timing of all audible noise events in an acoustic record to be quantified. See Methods, Appendix C for more information on the technique. For each deployment, overall hourly audibility is displayed for all non-natural sources, while also highlighting three noise sources of special managerial focus: aircraft, overland vehicles, and watercraft (Figures 15–20). Additionally, for each deployment the duration, daily event rate and SEL of each noise source heard is tabulated (Tables 7–12). To assess the cumulative effects of noise from all categories and meet the requirements of the LACL Wilderness Character Monitoring Plan (NPS 2025), NFI and SEL for each deployment are provided in Table 13. As a measure of uncertainty, each tabular result includes a 95% confidence interval around the reported metric.

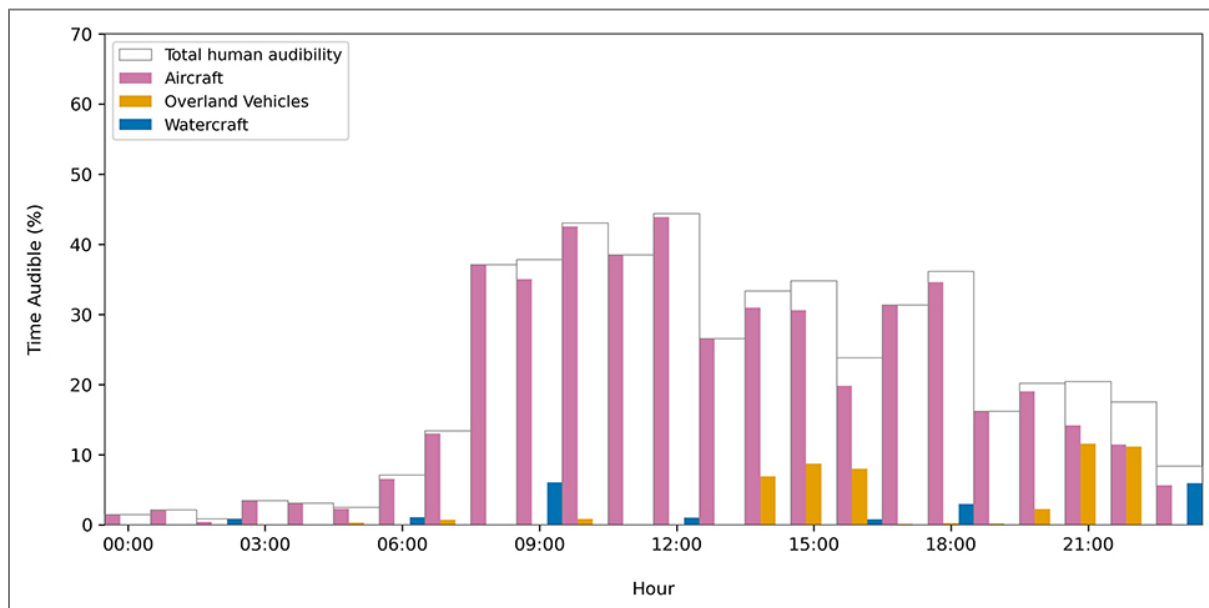


Figure 15. Hourly time audible for the top noise sources and all noise sources at Chinitna Bay (LACLCHBA) from 06/21–07/04/2018.

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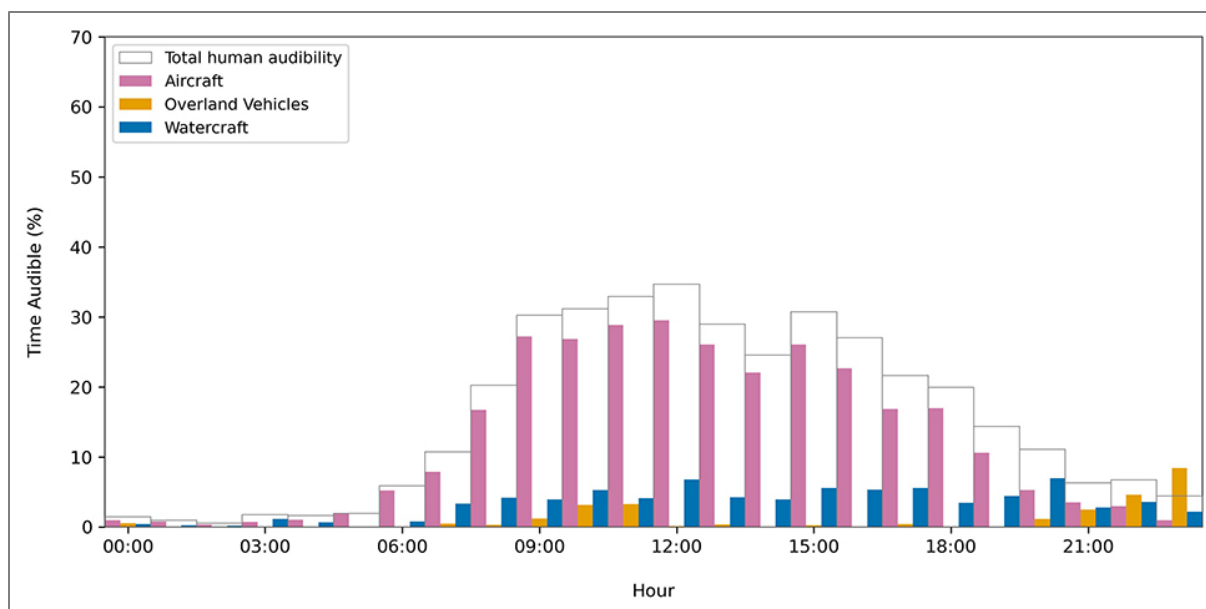


Figure 16. Hourly time audible for the top noise sources and all noise sources at Chinitna Bay (LACLCHBA) from 05/21–09/29/2023.

NPS / NATURAL SOUNDS AND NIGHT SKIES DIVISION

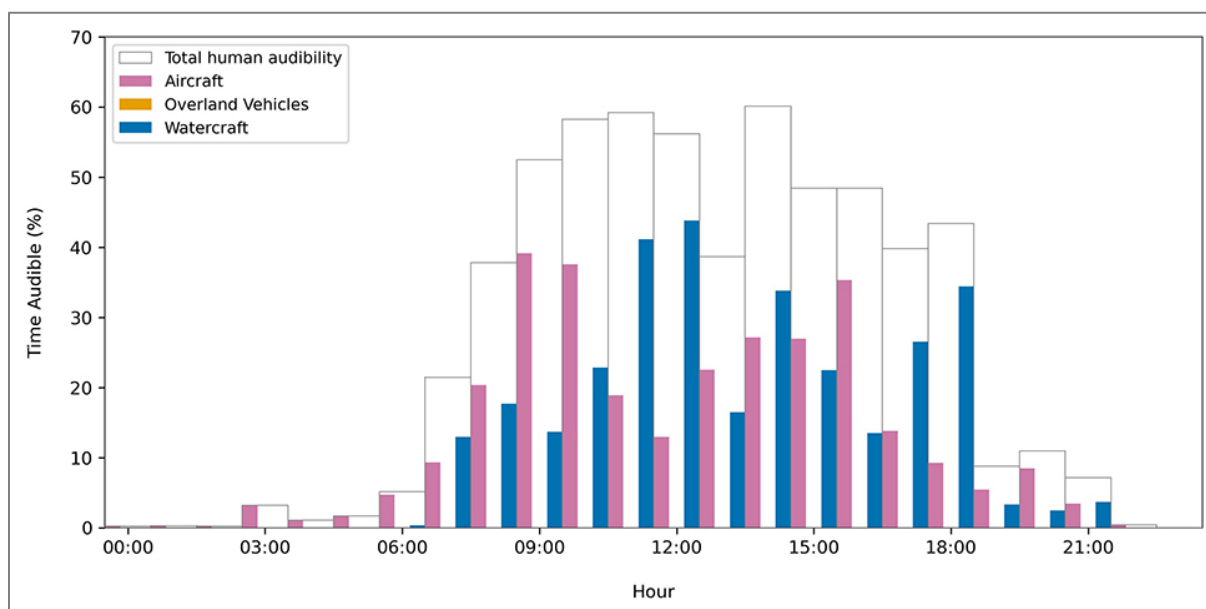


Figure 17. Hourly time audible for the top noise sources and all noise sources at Crescent Lake (LACLGRES) from 09/09–09/20/2018.

NPS / NATURAL SOUNDS AND NIGHT SKIES DIVISION

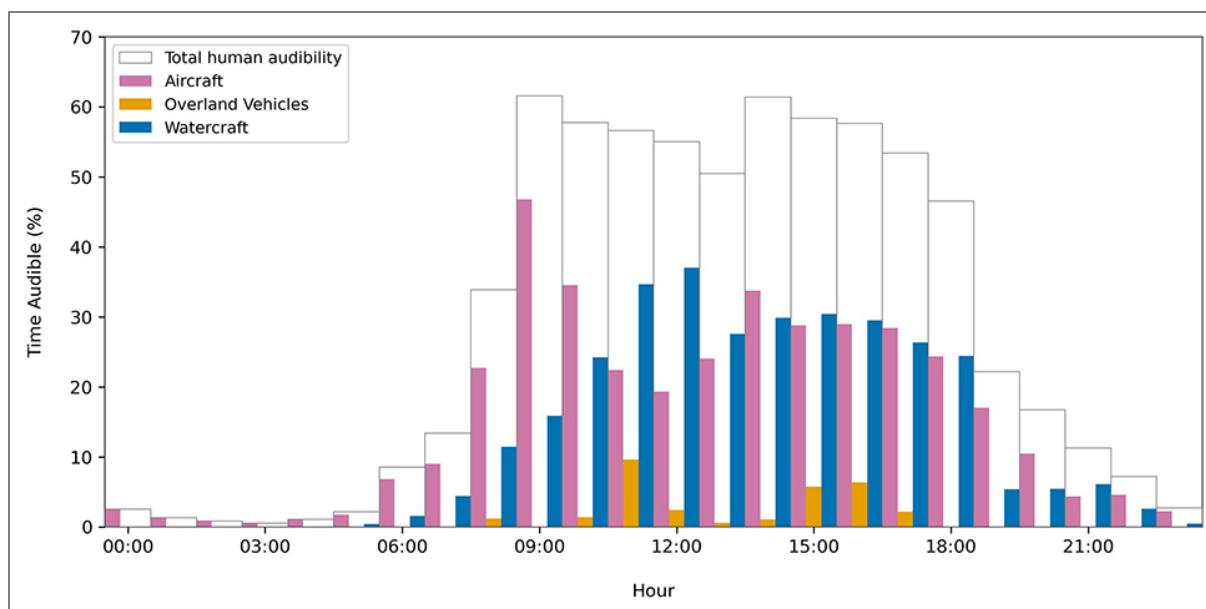


Figure 18. Hourly time audible for the top noise sources and all noise sources at Cresent Lake (LACLCRES) from 06/17–09/18/2023. The “Overland Vehicles” source category also includes heavy equipment sources which were unique to this deployment.

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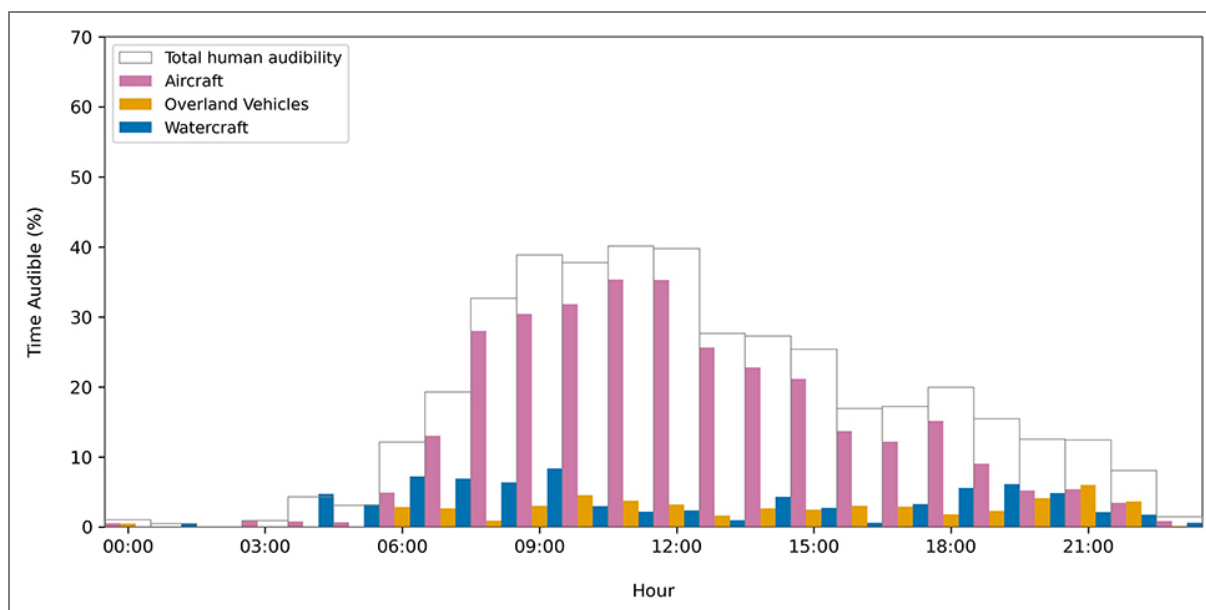


Figure 19. Hourly time audible for the top noise sources and all noise sources at Silver Salmon Creek (LACLSISA) from 06/28–09/02/2019.

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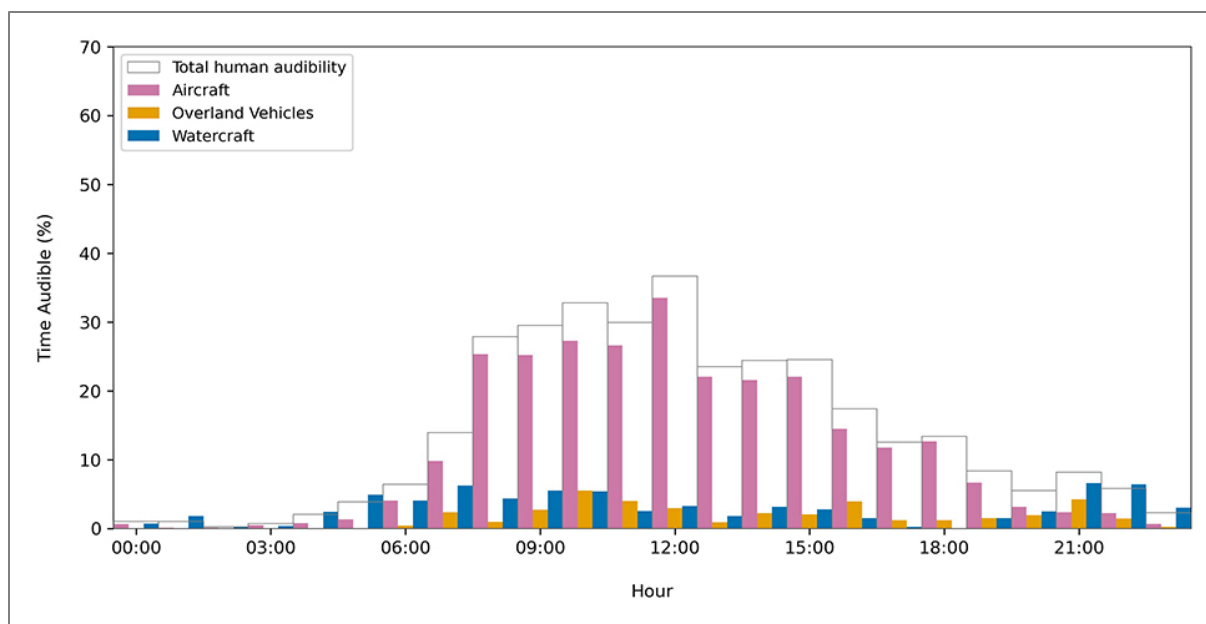


Figure 20. Hourly time audible for the top noise sources and all noise sources at Silver Salmon Creek (LACLSISA) from 05/23–08/16/2023.

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Table 7. Spectrogram annotation results for Chinitna Bay (LACLCHBA2018, n = 14 days). Bootstrapped 95% confidence intervals are provided as a measure of uncertainty.

Sound Source	Daily Event Rate (Mean)	Event Duration (Mean; mm:ss)	Sound Exposure Level (Median; dB)
Propeller Aircraft	41.8 ± 4.2	05:52 ± 00:28	62.4 ± 1.0
Helicopter	5.5 ± 2.6	08:17 ± 01:26	63.0 ± 1.7
Jet	4.6 ± 1.2	02:33 ± 00:18	57.8 ± 1.8
Overland Vehicle	3.4 ± 3.2	05:18 ± 02:01	57.2 ± 2.8
Watercraft	0.7 ± 0.5	07:32 ± 02:32	58.7 ± 3.5

Table 8. Spectrogram annotation results for Chinitna Bay (LACLCHBA2023, n = 78 days). Bootstrapped 95% confidence intervals are provided as a measure of uncertainty.

Sound Source	Daily Event Rate (Mean)	Event Duration (Mean; mm:ss)	Sound Exposure Level (Median; dB)
Propeller Aircraft	18.7 ± 3.0	05:34 ± 00:12	63.0 ± 0.4
Watercraft	2.9 ± 0.8	09:31 ± 02:14	58.4 ± 0.8
Jet	2.6 ± 0.6	02:27 ± 00:07	54.9 ± 0.9
Helicopter	0.9 ± 0.3	06:01 ± 01:06	68.8 ± 3.2
Overland Vehicle	0.5 ± 0.3	03:59 ± 01:01	56.1 ± 2.1

Table 9. Spectrogram annotation results for Cresent Lake (LACLCRES2018, n = 12 days). Bootstrapped 95% confidence intervals are provided as a measure of uncertainty.

Sound Source	Daily Event Rate (Mean)	Event Duration (Mean; mm:ss)	Sound Exposure Level (Median; dB)
Watercraft	46.0 ± 4.6	04:20 ± 00:20	74.3 ± 1.2
Propeller Aircraft	35.2 ± 3.5	05:41 ± 00:39	66.9 ± 2.1
Jet	2.4 ± 1.1	02:07 ± 00:07	56.6 ± 1.8
Helicopter	0.2 ± 0.3	04:04 ± 01:07	71.9 ± 5.4

Table 10. Spectrogram annotation results for Cresent Lake (LACLCRES2023, n = 88 days). Bootstrapped 95% confidence intervals are provided as a measure of uncertainty.

Sound Source	Daily Event Rate (Mean)	Event Duration (Mean; mm:ss)	Sound Exposure Level (Median; dB)
Watercraft	45.1 ± 3.1	04:25 ± 00:08	70.0 ± 0.8
Propeller Aircraft	36.0 ± 2.3	05:14 ± 00:12	66.3 ± 0.5
Jet	7.2 ± 0.8	01:59 ± 00:06	58.7 ± 0.4
Helicopter	6.4 ± 0.7	06:01 ± 00:16	81.7 ± 0.6
Grounds Care	0.5 ^A	03:33 ^A	70.8 ^A
Heavy Equipment	0.4 ± 0.3	10:32 ± 03:30	65.0 ± 4.4
Overland Vehicle	0.2 ± 0.1	01:49 ± 00:31	59.7 ± 8.1
Drone	0.1 ^A	00:55 ^A	53.9 ^A

^A Rarely observed. Insufficient observations available to estimate confidence intervals.

Table 11. Spectrogram annotation results for Silver Salmon Creek (LACLSISA2019, n = 41 days). Bootstrapped 95% confidence intervals are provided as a measure of uncertainty.

Sound Source	Daily Event Rate (Mean)	Event Duration (Mean; mm:ss)	Sound Exposure Level (Median; dB)
Propeller Aircraft	23.5 ± 5.2	05:04 ± 00:13	70.0 ± 0.6
Overland Vehicle	10.0 ± 3.1	01:46 ± 00:07	57.0 ± 0.6
Watercraft	2.1 ± 1.0	12:02 ± 02:43	62.2 ± 1.6
Jet	1.3 ± 0.5	02:01 ± 00:07	60.8 ± 1.8
Helicopter	0.7 ± 0.3	04:37 ± 00:56	76.4 ± 1.1

Table 12. Spectrogram annotation results for Silver Salmon Creek (LACLSISA2023, n = 76 days). Bootstrapped 95% confidence intervals are provided as a measure of uncertainty.

Sound Source	Daily Event Rate (Mean)	Event Duration (Mean; mm:ss)	Sound Exposure Level (Median; dB)
Propeller Aircraft	31.4 ± 3.5	04:43 ± 00:10	68.9 ± 0.6
Overland Vehicle	5.0 ± 1.5	02:35 ± 00:29	58.1 ± 0.6
Jet	2.1 ± 0.4	01:56 ± 00:06	60.0 ± 1.0
Helicopter	0.4 ± 0.2	06:14 ± 01:52	75.8 ± 3.7
Watercraft	1.9 ± 0.7	13:23 ± 03:11	62.4 ± 1.3

Table 13. Median Noise-Free Interval (NFI) and Sound Exposure Level (SEL) results for coastal sites in LACL. Bootstrapped 95% confidence intervals are provided as a measure of uncertainty.

Site	Median NFI (MM:SS)		Median SEL (dB)	
	2018	2023	2018	2023
Chinitna Bay	14:19 ± 00:24	15:20 ± 00:19	61.6 ± 0.7	61.4 ± 0.4
Crescent Lake	08:13 ± 00:19	06:42 ± 00:06	70.1 ± 2.2	67.8 ± 0.4
Silver Salmon Creek	10:32 ± 00:14	12:33 ± 00:13	64.5 ± 0.6	66.1 ± 0.4

Conclusions

Acoustic measurements provide parks with quantitative information on physical geography, biological activity and anthropogenic noise. These results support evaluation of potential effects on visitor experience and wildlife habitat. The LACL Acoustic Inventory was initiated in response to the park's Resource Stewardship Strategy, which identified the need for baseline acoustic surveys (NPS 2017). Data summarized in this report were selected from the broader park-wide inventory to inform the LACL Coastal Management Plan (NPS 2024), whose purpose is "to improve visitor experiences at key coastal sites while protecting resources and responding to changing conditions."

The analyses presented here include measures of existing ambient sound levels, calculations of natural ambient sound levels, and estimates of sound source audibility derived from off-site listening. Together, these results describe how motorized travel through key transportation portals alters acoustic conditions relative to natural baselines. They also provide a physical characterization of habitat conditions in coastal areas that are of particular importance to bears. In combination, these findings establish an acoustic baseline against which future changes in transportation patterns, visitation, and environmental conditions may be evaluated.

Coastal Overview

Chinitna Bay, Silver Salmon Creek, and Crescent Lake have naturally energetic acoustic environments, with L_{Anat} ranging from 31.8 to 41.0 dB (Table 6). Consistent with their coastal Alaskan geography at the convergence of marine, riparian, and alpine systems, each site is shaped by the natural sounds of flowing water (creeks, surf, lake waves) and wind moving through vegetation. These sources appear in the measurements as elevated sound levels in the 200–3150 Hz bands in Figures 3–8. In a subset of the acoustic records, bird vocalizations increase sound level in the 2000–6300 Hz bands in Figures 3, 4, 6, and 7.

Visitor transportation through these sites is multi-modal. Arrival from points of origin occurs primarily by aircraft, and to a lesser extent, watercraft. Local motorized transport is by watercraft and overland vehicles. Across all three locations, propeller aircraft and watercraft are the most frequently audible noise sources (Figures 15–20, Tables 3, 7–12), with aircraft noise audible for more than 10% (02:40:00) of an average day. At Crescent Lake in particular, the cumulative effects of multi-modal transportation are pronounced: aircraft noise was audible for 14% (03:21:36) of an average day and watercraft noise for 12% (02:52:48), combining to an overall noise audibility of 27% (06:28:48).

With the exception of tour vessels, the transportation system serving the LACL coast is dominated by low-capacity vehicles (<15 passengers each). One consequence of this pattern is that accommodating relatively modest visitation ($\leq 8,000$ visitor use days annually) results in an average of 41 noise events per day at Chinitna Bay, 90 at Crescent Lake, and 39 at Silver Salmon Creek (Tables 7–12). These events fragment the acoustic environment into typical NFIs of approximately 14–15 minutes at Chinitna Bay, 6–8 minutes at Crescent Lake, and 10–12 minutes at Silver Salmon Creek (0.24, 0.12, and 0.18 hours, respectively), corresponding to the 31st, 8th and 13th percentiles of acoustic records measured to date in Alaska (Poling and Betchkal 2023).

Another capacity-related result emerges when noise energy is expressed on a per-passenger basis. It is reasonable to assume that SEL values are driven primarily by the low-capacity fixed-wing aircraft events (see Table 17 in Appendix D). Assuming an average of six passengers per flight, the noise energy radiated into these coastal locations is approximately 10.2–11.7 dB per visitor (Table 13). For comparison, roadway-proximal estimates for large-capacity tour buses and private vehicles are 1.7 and 21.2 dB per visitor, respectively (Betchkal et al. 2025). Together, these results indicate that relatively low visitation levels can produce substantial and persistent alteration of acoustic conditions due to reliance on low-capacity motorized transport.

Site-Specific Conclusions

At LACLCHBA in 2018, functional effect thresholds were exceeded 4% of daytime hours at the 45 dB ($L_{Aeq, 1s}$) effect threshold and 2% of hours at the 52 dB effect threshold (Table 5). Existing median sound levels (L_{A50}) were 0.9 dB higher than natural sound levels (L_{Anat}) during the day, reducing the listening area by 19% (Table 3, Figure 3). Spectrogram annotation of the acoustic record revealed that noise was audible 19.5% of the day (Table 3). Noise events fractured the acoustic environment into noise-free intervals with a median duration of 14 minutes (Table 13). Noise occurred mostly from 07:00 – 22:00 (Figure 9), largely due to aircraft, and to a lesser extent, overland vehicles (Table 7, Figure 15).

At LACLCHBA in 2023, functional effect thresholds were exceeded 4% of daytime hours at the 45 dB ($L_{Aeq, 1s}$) effect threshold and 1% of hours at the 52 dB effect threshold (Table 5). Existing sound levels (L_{A50}) were 0.8 dB higher than natural sound levels (L_{Anat}) during the day, reducing the listening area by 17% (Table 3, Figure 4). Spectrogram annotation of the acoustic record revealed that noise was audible 15.4% of the day (Table 3). Noise events fractured the acoustic environment into noise-free intervals with a median duration of 15 minutes (Table 13). Noise occurred mostly from 07:00 – 22:00 (Figure 10), largely due to aircraft and watercraft (Table 8, Figure 16).

At LACLCRES in 2018, functional effect thresholds were exceeded 18% of daytime hours at the 45 dB ($L_{Aeq, 1s}$) effect threshold and 8% of hours at the 52 dB effect threshold (Table 5). Existing sound levels (L_{A50}) were 2.2 dB higher than natural sound levels (L_{Anat}) during the day, reducing the listening area by 40% (Table 3, Figure 5). Spectrogram annotation of the acoustic record revealed that noise was audible 25.2% of the day (Table 3). Noise events fractured the acoustic environment into noise-free intervals with a median duration of 8 minutes (Table 13). Noise occurred mostly from 07:00 – 20:00 (Figure 11), largely due to watercraft and aircraft (Table 9, Figure 17).

At LACLCRES in 2023, functional effect thresholds were exceeded 20% of daytime hours at the 45 dB ($L_{Aeq, 1s}$) effect threshold and 9% of hours at the 52 dB effect threshold (Table 5). Existing sound levels (L_{A50}) were 2.0 dB higher than natural sound levels (L_{Anat}) during the day, reducing the listening area by 37% (Table 3, Figure 6). Spectrogram annotation of the acoustic record revealed that noise was audible 28.5% of the day, which is the highest of any site included in this report (Table 3). Noise events fractured the acoustic environment into noise-free intervals with a median duration of 7 minutes (Table 13). Noise occurred mostly from 07:00 – 20:00 (Figure 12), largely due to aircraft and watercraft (Table 10, Figure 18).

At LACLSISA in 2019, functional effect thresholds were exceeded 12% of daytime hours at the 45 dB ($L_{Aeq, 1s}$) effect threshold and 2% of hours at the 52 dB effect threshold (Table 5). Existing sound levels (L_{A50}) were 1.4 dB higher than natural sound levels (L_{Anat}) during the day, reducing the listening area by 28% (Table 3, Figure 7). Spectrogram annotation of the acoustic record revealed that noise was audible 17.3% of the day (Table 3). Noise events fractured the acoustic environment into noise-free intervals with a median duration of 11 minutes (Table 13). Noise occurred mostly from 06:00 – 20:00 (Figure 13), largely due to aircraft, and to a lesser extent, watercraft and overland vehicles (Table 11, Figure 19).

At LACLSISA in 2023, functional effect thresholds were exceeded 7% of daytime hours at the 45 dB ($L_{Aeq, 1s}$) effect threshold and 2% of hours at the 52 dB effect threshold (Table 5). Existing sound levels (L_{A50}) were 0.7 dB higher than natural sound levels (L_{Anat}) during the day, reducing the listening area by 15% (Table 3, Figure 8). Spectrogram annotation of the acoustic record revealed that noise was audible 13.9% of the day (Table 3). Noise events fractured the acoustic environment into noise-free intervals with a median duration of 13 minutes (Table 13). Noise occurred mostly from 06:00 – 21:00 (Figure 14), largely due to aircraft, and to a lesser extent, watercraft and overland vehicles (Table 12, Figure 20).

Management Implications

This study documents the acoustic environment of three key transportation portals on the southeastern coast of LACL and establishes a quantitative baseline for evaluating future change. Across all sites, natural soundscapes are shaped by flowing water, wind, and biological activity, reflecting the convergence of marine, riparian, and alpine systems. At the same time, motorized access introduces recurrent and spatially concentrated noise into areas that support high levels of wildlife use and are central to visitor experience.

Results demonstrate that even relatively modest visitation levels can produce frequent and persistent alteration of acoustic conditions due to reliance on low-capacity aircraft, watercraft, and overland vehicles. Sound levels and audibility metrics provide a means of evaluating how transportation systems intersect with resource conditions and experiential values identified in the LACL Coastal Management Plan (see Appendix D: Coastal Management Plan Threshold Analysis). They are a complement to the social science information that has also been collected for planning purposes (Brownlee et al. 2020).

The data presented here establish a record of acoustic conditions during the 2018, 2019, and 2023 seasons. This record can support future comparisons as visitation patterns, transportation technologies, and environmental conditions evolve. Continued monitoring would allow the park to assess trends in noise exposure and to evaluate the effects of management actions or operational changes intended to protect acoustic resources while accommodating visitor use.

Literature Cited

- American National Standards Institute (ANSI). 1968. Audiometer Standard 3.6. American National Standards Institute, New York.
- American National Standards Institute (ANSI). 1983. Electroacoustics – Sound Level Meters – Part 1: Specifications. Accredited Standards Committee S1, Acoustics Standards Secretariat. Acoustical Society of America, New York, New York.
- American National Standards Institute (ANSI). 1992. Quantities and procedures for description and measurement of environmental sound. Part 2: Measurement of long-term, wide-area sound. Accredited Standards Committee S12, Noise. Acoustical Society of America, New York, New York.
- American National Standards Institute (ANSI). 2014. Methods to Define and Measure the Residual Sound in Protected Natural and Quiet Residential Areas, Melville, NY. ANSI/ASA S3/SC1.100-2014.
- 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, editors. 1999. WHO. Guidelines for community noise. World Health Organization, Geneva.
- Betchkal, D.H., and V.L. Ward. 2018. Glacier Bay National Park and Preserve: Acoustic Resource Management Framework. Table 2. Natural Sounds and Night Skies Division. Denali Park, Alaska. <https://irma.nps.gov/DataStore/Reference/Profile/2252058>
- Betchkal, D.H., S.E. Hayes, and B.C. Miller. 2025. A Comparison of Operational Noise Conditions on the Denali Park Road. Science Report. NPS/SR—2025/355. National Park Service. Fort Collins, Colorado. <https://doi.org/10.36967/2315605>
- Bregman, A.S. 1994. Auditory Scene Analysis. MIT Press, Cambridge, MA.
- Brownlee, M.T., R.L. Sharpe, D. Dagan, S. Jackson, and J. Nettles. 2020. Evaluation of the Bear Viewing Experience and Associated Thresholds at Katmai National Park and Preserve and Lake Clark National Park and Preserve, 2017–2020, Research Report. Clemson University. Clemson, South Carolina. <https://irma.nps.gov/DataStore/Reference/Profile/2278505>
- ElectricAirMobility News. 2024. Electra EL9 hybrid-electric eSTOL aircraft. ElectricAirMobility.news, 23 November 2024. <https://www.electricairmobility.news/2024/11/23/electra-el9-hybrid-electric-estol-aircraft/>

- Environmental Protection Agency (EPA). 1974. Information on Levels of Noise Requisite to Protect the Public Health and Welfare with an Adequate Margin of Safety.
- Fletcher, R. 2013. Practical methods of optimization. John Wiley & Sons.
- Francis, C.D., and J.R. Barber. 2013. A framework for understanding noise impacts on wildlife: an urgent conservation priority. *Frontiers in Ecology and the Environment* 11(6), pp. 305–313.
- 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, A.S., K. Dimakopoulou, F. Vigna-Taglianti, M. Giampaolo, A. Borgini, M.L. Dudley, G. Pershagen, G. Bluhm, D. Houthuijs, 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.
- Haver, S.M., K.B. Gustafson, and C.M. Gabriele. 2023. Rapid assessment of vessel noise events and quiet periods in Glacier Bay National Park and Preserve using a convolutional neural net. *Environmental Data Science*, 2, p. e14.
- 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.
- Miller, N.P. 2008. US National Parks and management of park soundscapes: A review. 4.1.1 Measurement of source audibility and level. *Applied Acoustics* 69, no. 2 (2008): 83.
- National Park Service (NPS). 2005. Acoustic and soundscape studies in National Parks: Draft, Fort Collins, Colorado.
- National Park Service (NPS). 2006a. Management Policy 4.9: Soundscape Management.
- National Park Service (NPS). 2006b. Management Policy 5.3.1: Protection and Preservation of Cultural Resources.
- National Park Service (NPS). 2006c. Management Policy 8.2.3: Use of Motorized Equipment.
- National Park Service (NPS). 2009. Foundation Document, Lake Clark National Park. Accessed from: <https://npshistory.com/publications/foundation-documents/lac-l-fs-2009.pdf>

- National Park Service (NPS). 2013. Acoustic Monitoring Training Manual. Draft. Natural Resource Stewardship and Science, Fort Collins, CO. Accessed from:
https://www.nps.gov/subjects/sound/upload/NSNSDTrainingManual_AcousticalAmbientMonitoring-508.pdf
- National Park Service (NPS). 2017. Resource Stewardship Strategy Summary. Lake Clark National Park and Preserve. LACL 188/139863. Anchorage, AK.
- National Park Service (NPS). 2023. Visitor Use Areas – Interior Region 11 – Alaska: VUA map of Lake Clark National Park and Preserve (LACL). Accessed from:
<https://irma.nps.gov/DataStore/Reference/Profile/2298483>
- National Park Service (NPS). 2024. Lake Clark National Park and Preserve Coastal Management Plan Newsletter. Anchorage, AK. Accessed from:
<https://parkplanning.nps.gov/showFile.cfm?sfid=722114&projectID=122146>
- National Park Service (NPS). 2025. Jay S. Hammond Wilderness: Wilderness Character Building Blocks for Wilderness Stewardship. U.S. Department of Interior, Lake Clark National Park and Preserve.
- Poling, J., and D.H. Betchkal. 2023. Use of the noise-free interval (NFI) metric to assess the disturbances of airborne vessel noise at Glacier Bay National Park. In INTER-NOISE and NOISE-CON Congress and Conference Proceedings (Vol. 266, No. 2, pp. 991–1002). Institute of Noise Control Engineering.
- Rapoza, A., E. Sudderth, and K. Lewis. 2015. The relationship between aircraft noise exposure and day-use visitor survey responses in backcountry areas of national parks. *The Journal of the Acoustical Society of America*, 138(4), 2090–2105.
- Rothman, K.J., S. Greenland, and T.L. Lash. 2008. *Modern epidemiology* (Vol. 3). Wolters Kluwer Health/Lippincott Williams & Wilkins. Philadelphia, Pennsylvania.
- Shannon, G., M.F. McKenna, L.M. Angeloni, K.R. Crooks, K.M. Fristrup, E. Brown, K.A. Warner, M.D. Nelson, C. White, et al. 2016. A synthesis of two decades of research documenting the effects of noise on wildlife. *Biological Reviews* 91(4), 982–1005.
- Templeton, D., editor. 1997. *Acoustics in the built environment: advice for the design team*. Architectural Press, Oxford.
- Viereck, L.A., C.T. Dyrness, A.R. Batten, and K.J. Wenzlick. 1992. *The Alaska Vegetation Classification*. General Technical Report PNW-GTR-286. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, Oregon.
- Weinzimmer, D., P. Newman, D. Taff, J. Benfield, E. Lynch, and P. Bell. 2014. Human responses to simulated motorized noise in national parks. *Leisure Sciences*, 36(3), 251–267.

Appendix A: Site Photos

Figures 21–26 show cardinal photographs of the sampling sites used in this study.



Figure 21. LACLCHBA2018, Chinitna Bay acoustic monitoring site.
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Figure 22. LACLCHBA2023, Chinitna Bay acoustic monitoring site.
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Figure 23. LACLCRES2018, Crescent Lake acoustic monitoring site.
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Figure 24. LACLCRES2023, Crescent Lake acoustic monitoring site.
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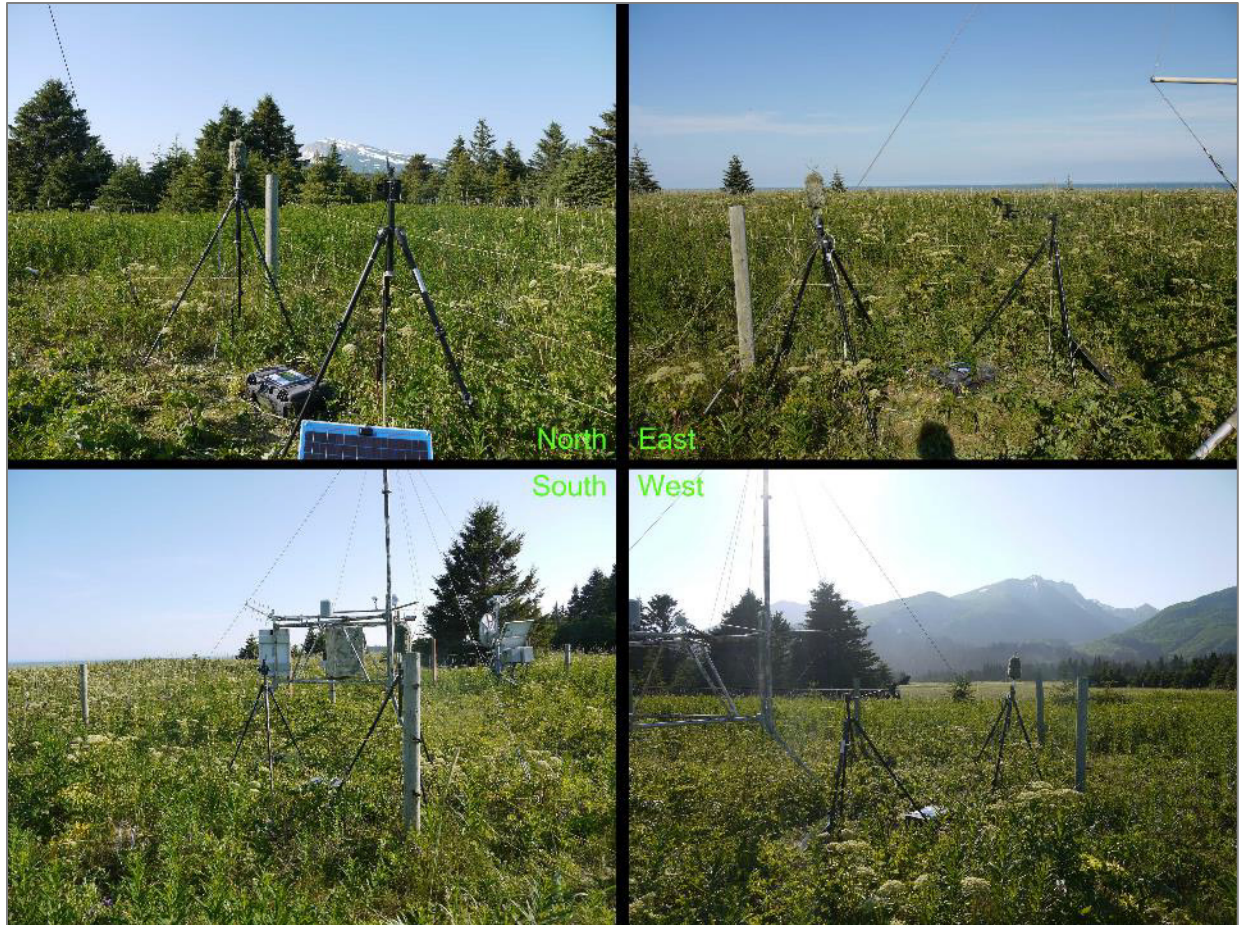


Figure 25. LACLSISA2019, Silver Salmon Creek acoustic monitoring site.
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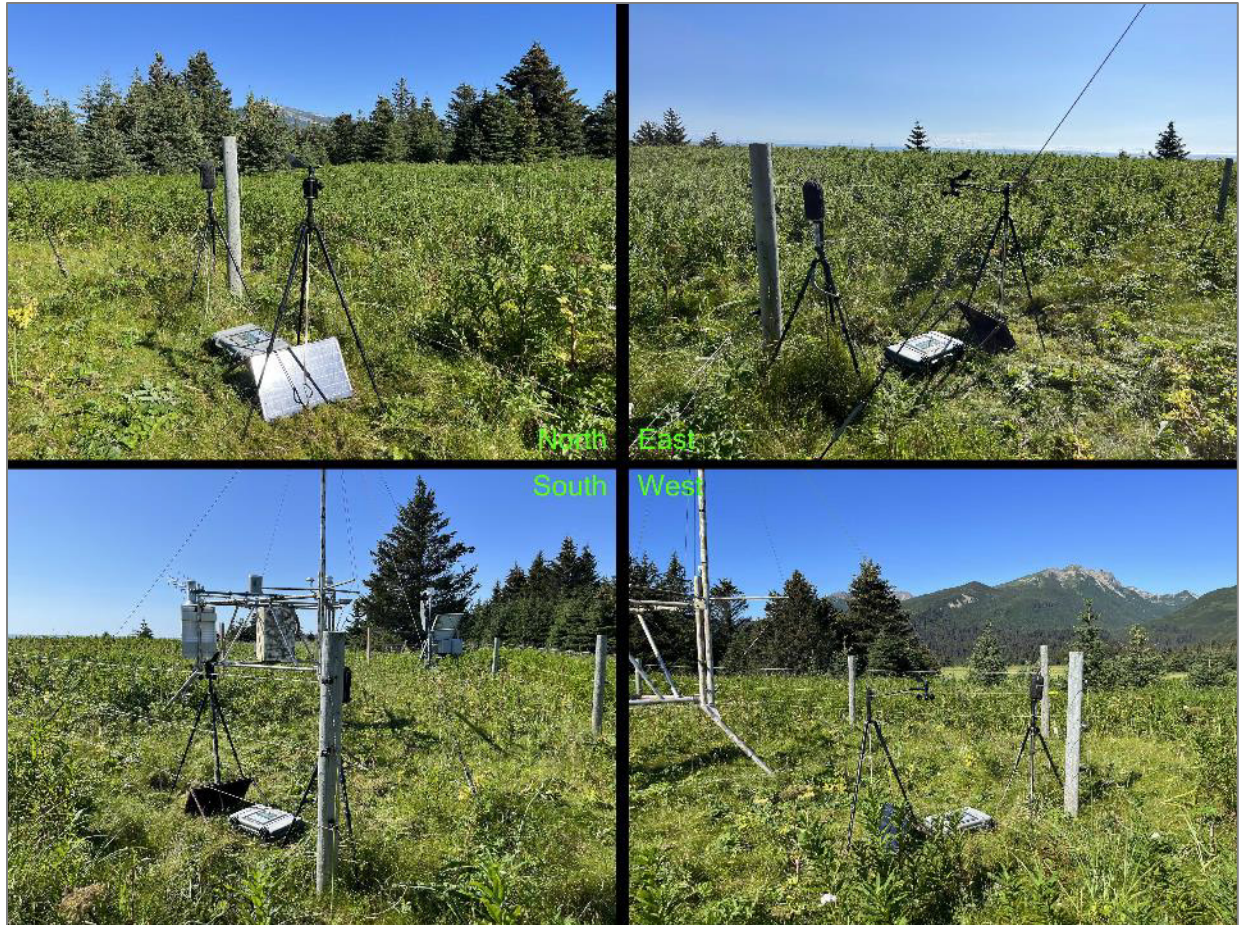


Figure 26. LACLSISA2023, Silver Salmon Creek acoustic monitoring site.
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Appendix B: Site Maps

This appendix presents additional maps to contextualize the locations of the coastal acoustic monitoring sites detailed in this report (Figures 27–29). The maps are visualized at a scale of 1:64,000 to reveal the microphone placement within the wider scope of the portal and its transportation geography. Each map also includes an inset showing the coarse-scale location of the portal in LACL, the administrative boundary of the park (bold black line), Visitor Use Reporting zones (fine black lines labelled by name; NPS 2023), Designated Wilderness (hatches), and satellite imagery with shaded relief.

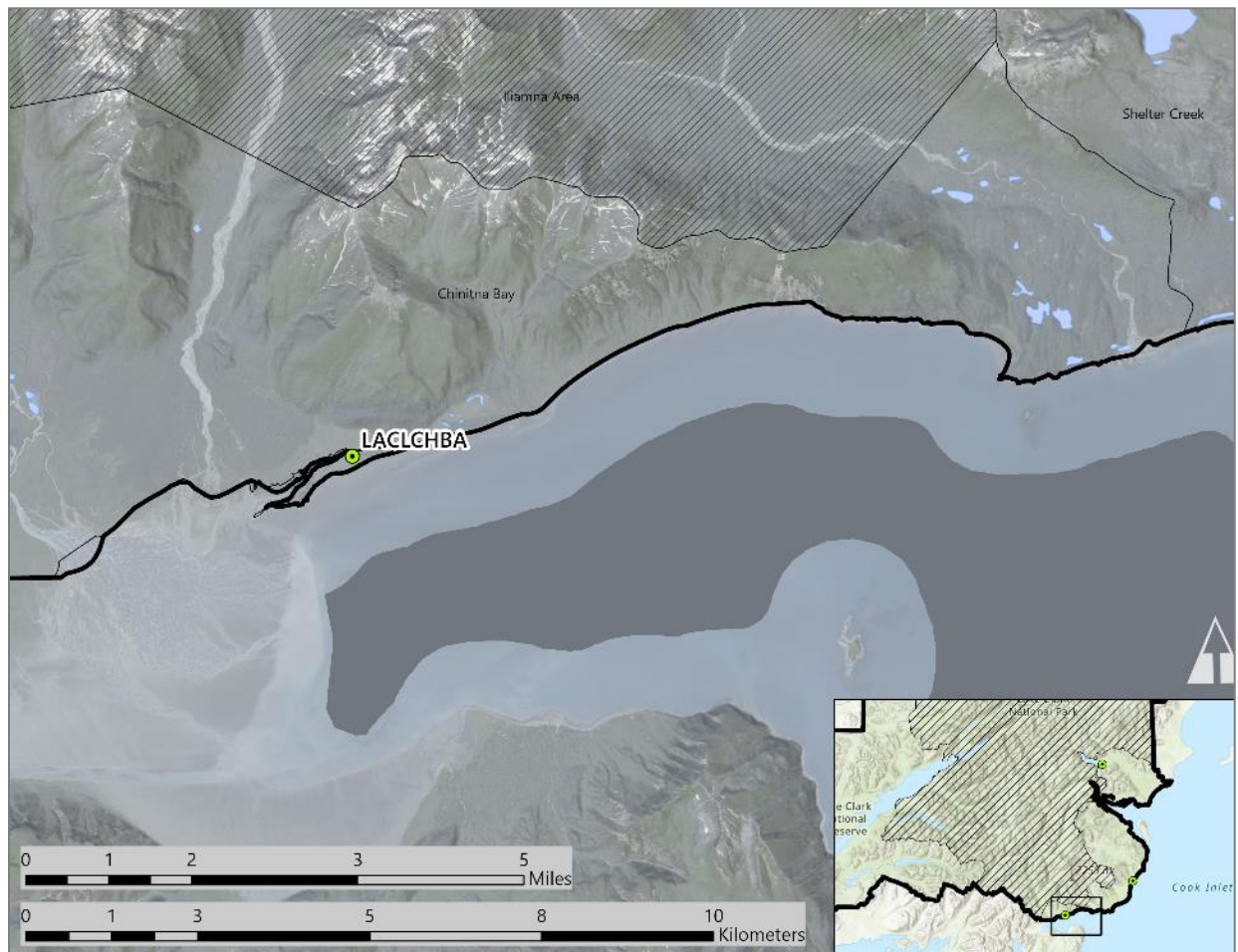


Figure 27. The location of the LACLCHBA Chinitna Bay acoustic monitoring site (green point) at a 1:64,000 scale. Also indicated are the boundary of the park (bold black line), Visitor Use Areas used to report commercial use (fine), and the Designated Wilderness area (hatched).

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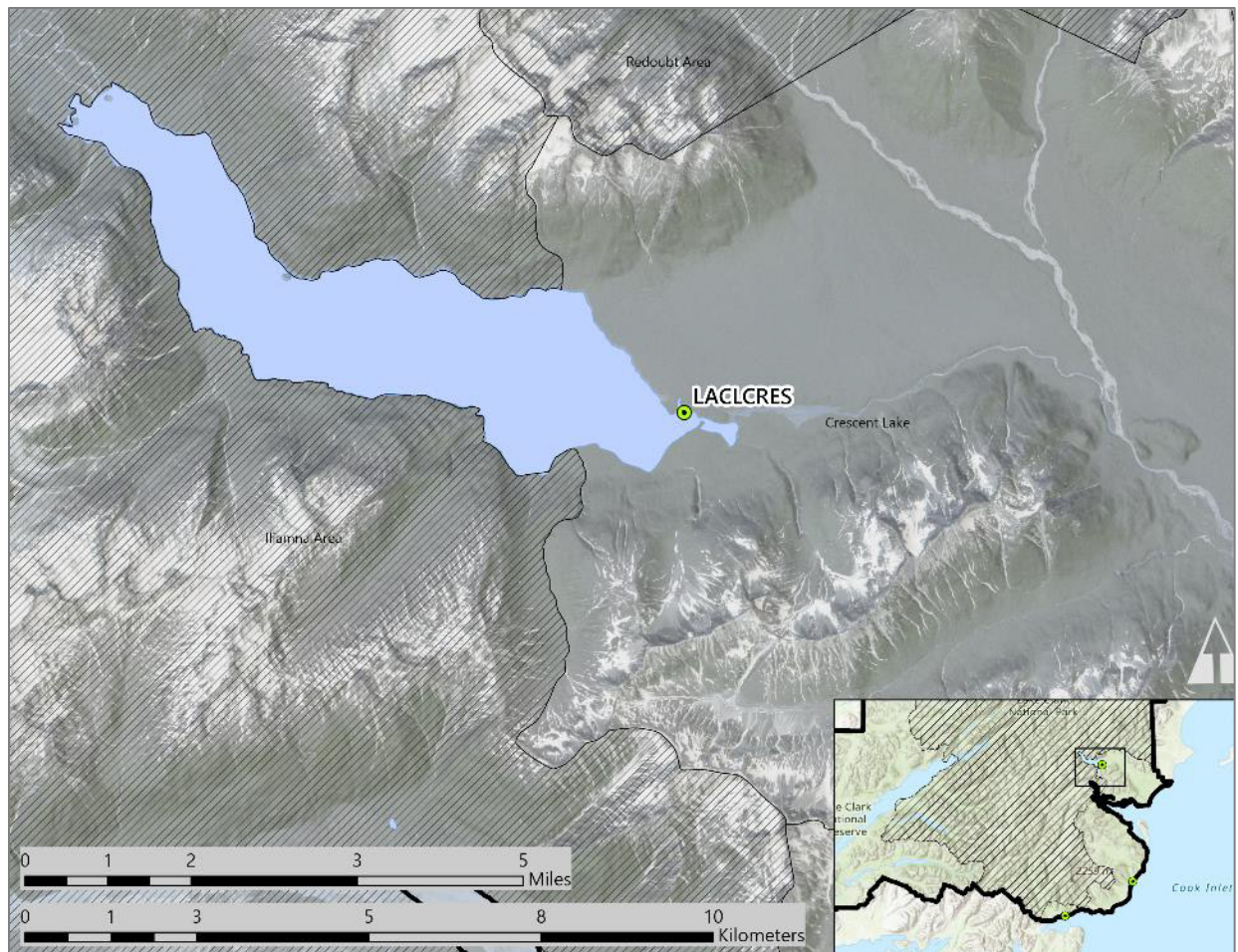


Figure 28. The location of the LACLGRES Crescent Lake acoustic monitoring site (green point) at a 1:64,000 scale. Also indicated are the boundary of the park (bold black line), Visitor Use Areas used to report commercial use (fine), and the Designated Wilderness area (hatched).

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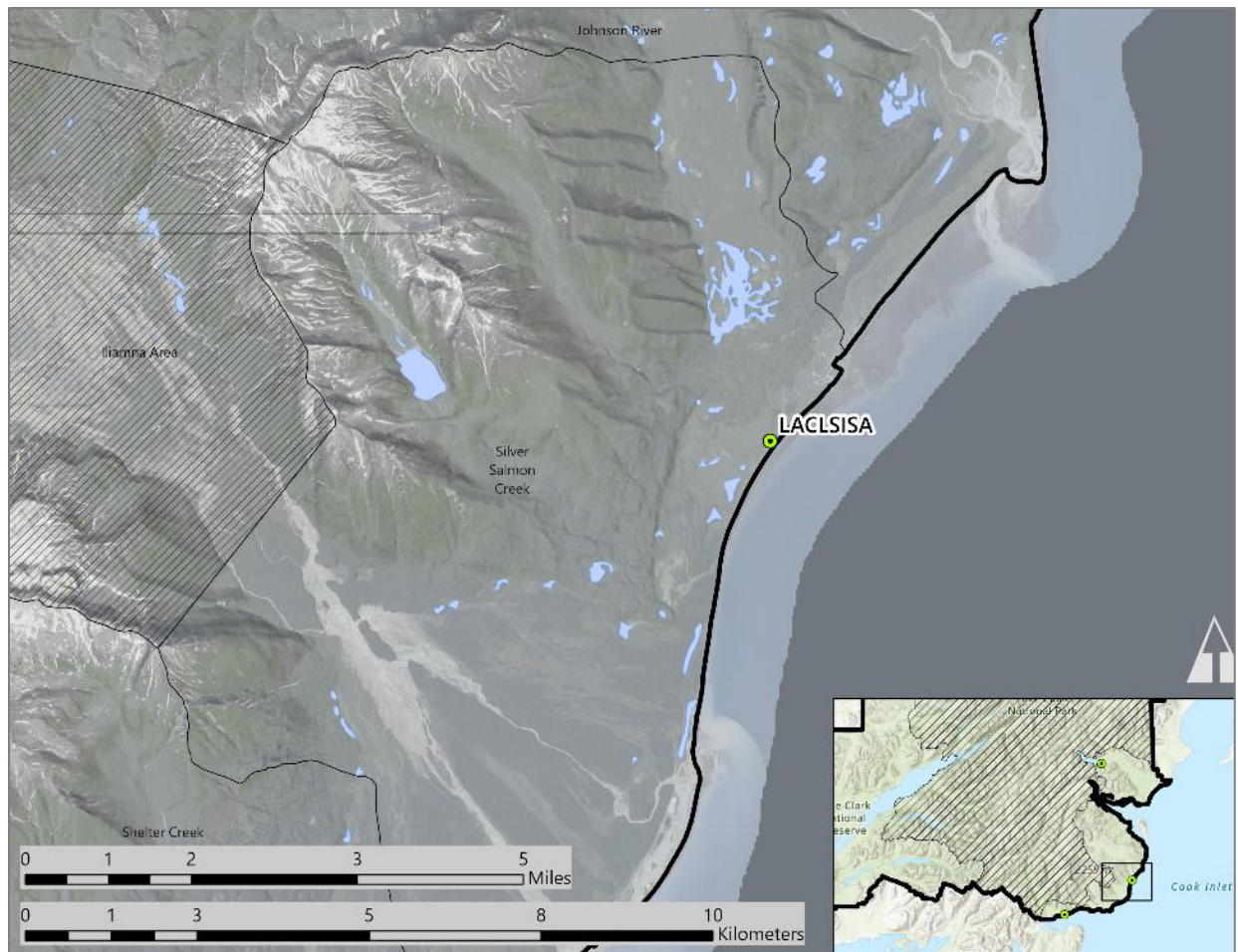


Figure 29. The location of the LACLISA Silver Salmon Creek acoustic monitoring site (green point) at a 1:64,000 scale. Also indicated are the boundary of the park (bold black line), Visitor Use Areas used to report commercial use (fine), and the Designated Wilderness area (hatched).

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Appendix C: Spectrogram Annotation Examples

To aid future identification efforts, this appendix includes representative spectrograms of the noise sources audible at LACL’s coastal acoustic monitoring sites—specifically aircraft (jet, propeller, helicopter), overland beach vehicles, watercraft, generators, grounds care and drones. These diagnostic examples were drawn from the overall set of audible noise events across all deployments ($n = 19,849$). Each figure in this Appendix resembles Figure 2, with a vertical frequency axis spanning from 12.5 to 20,000 Hertz and a horizontal time axis scaled to each noise event (Figures 30–46). The spectrograms share a common sound level ($L_{Zeq,1s}$) scale from -20 to 90 dB, with quiescent conditions shown in blue (low brightness) and energetic conditions shown in yellow/white (high brightness).

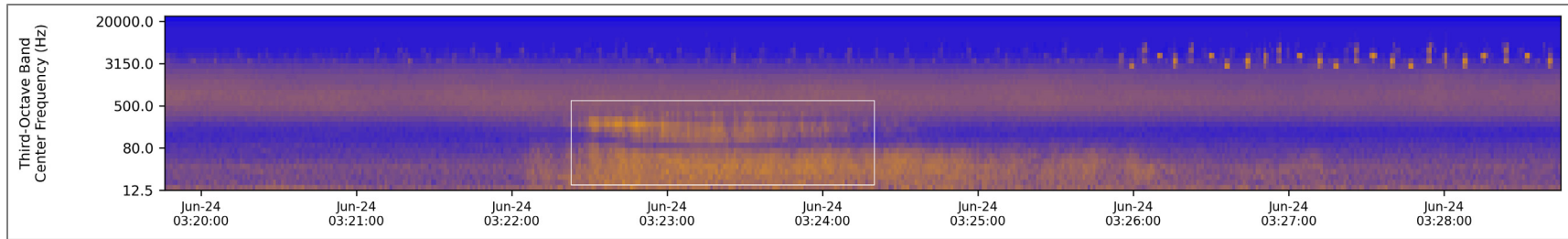


Figure 30. A commercial jet overflight audible at LACLCHBA, beginning 03:22 on 2018-06-24 (white rectangle). Turbulent air exiting the jet engine radiates sound across many spatial scales, causing a diffuse morphology on the spectrogram. This jet also exhibits characteristic destructive interference patterns visible as concave-upward, low value (blue) curves.

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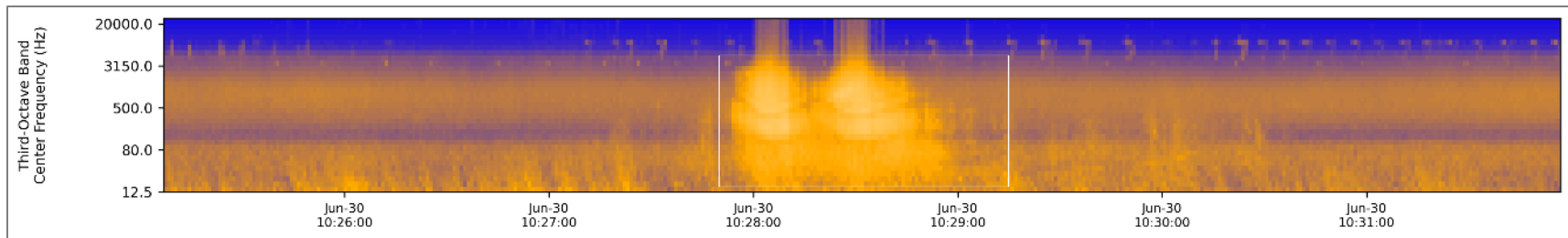


Figure 31. Two audible military jet overflights audible at LACLSISA, beginning 10:27 on 2019-06-30 (white rectangle). The aircraft are flying in close formation, with corresponding morphological overlap to form a single noise event. Both jets also exhibit characteristic destructive interference patterns visible as concave-upward, relatively low value (purple) curves.

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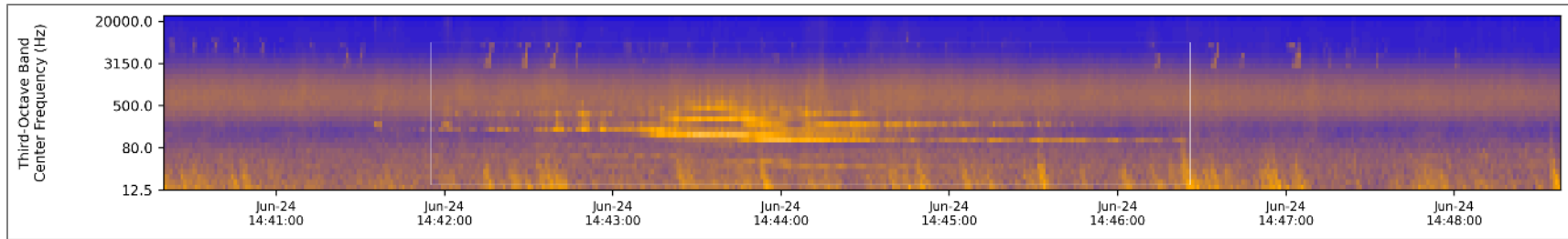


Figure 32. A fixed-wing propeller aircraft overflight audible at LACLCHBA, beginning 14:41 on 2018-06-24 (white rectangle). Tonal noise is radiated at the fundamental propeller blade passage frequency and integer multiples, appearing on the spectrogram as bright horizontal striations.
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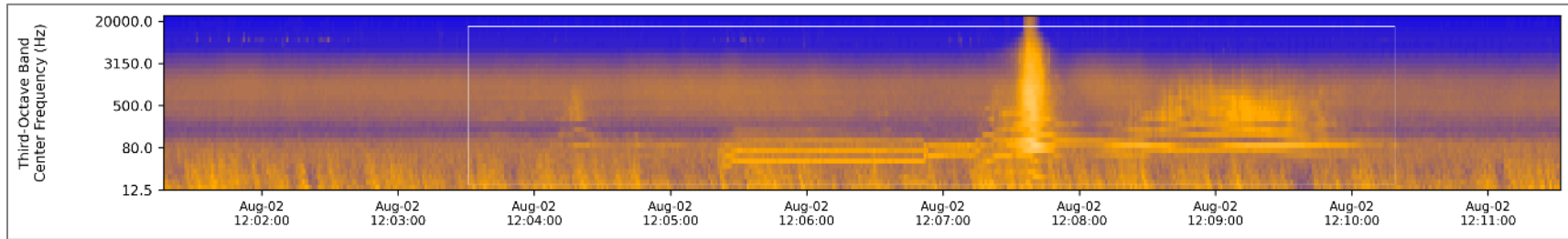


Figure 33. A fixed-wing propeller aircraft takeoff audible at LACLSISA, beginning 12:01 on 2019-08-02 (white rectangle). Taxiing operations on the beach are followed by a rapid increase in propeller speed and sound level during takeoff (12:07), followed by turnout and departure (12:08).
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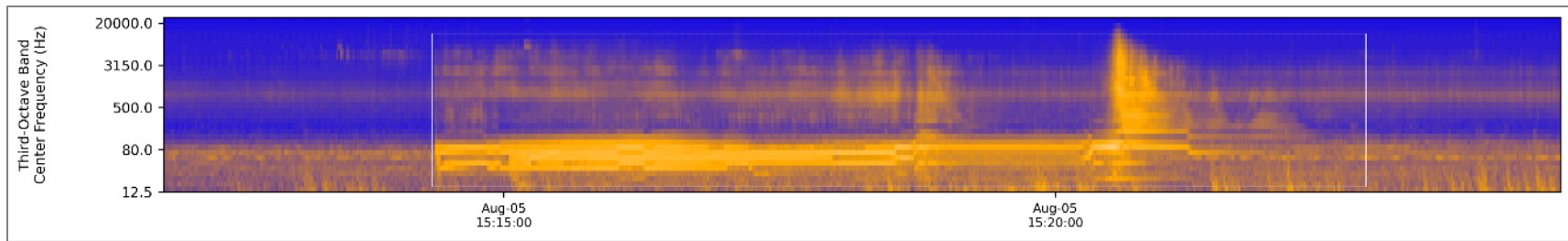


Figure 34. A fixed-wing propeller aircraft takeoff audible at LACLSISA, beginning 15:41 on 2023-08-05 (white rectangle). The aircraft idles and taxis along the beach past the microphone for over five minutes, then takes off (15:20) and departs.

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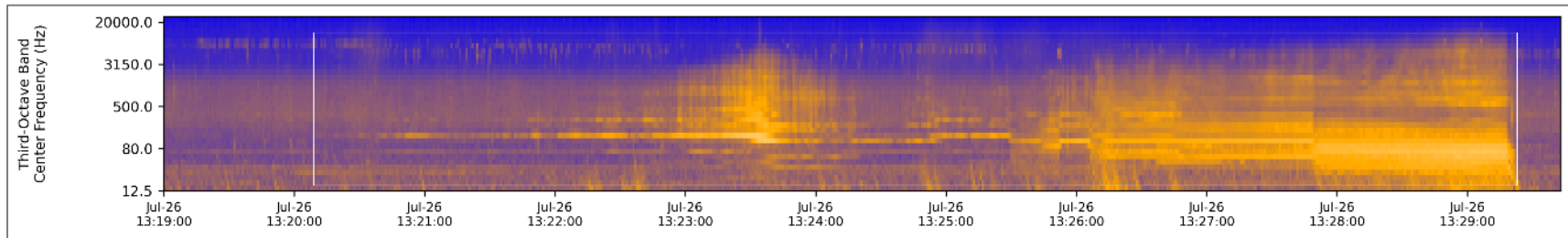


Figure 35. A floatplane landing audible at LACLCRES, beginning 13:20 on 2023-07-26 (white rectangle). At first the event appears as an overflight, then the aircraft turns (13:25), followed by approach and taxiing over the lake surface (13:26) after which the pilot abruptly cuts the engine.

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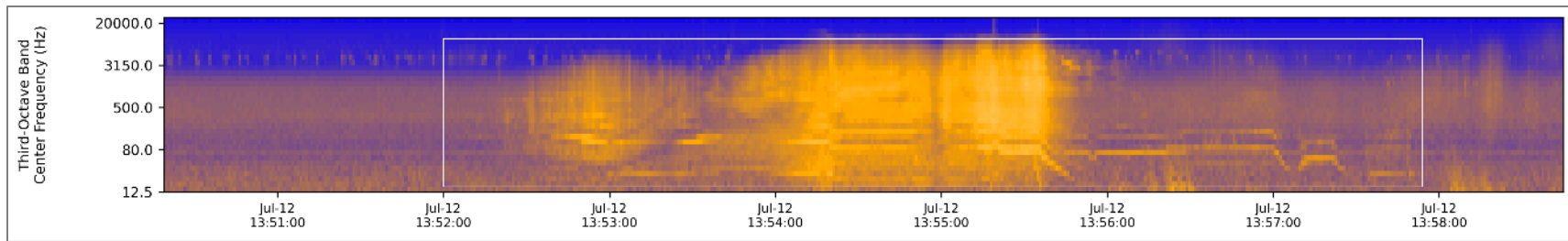


Figure 36. A floatplane landing audible at LACLCRES, beginning 13:52 on 2023-07-12 (white rectangle). The aircraft is equipped with a turbine engine, which is heard characteristically “spinning down” (13:55:40).

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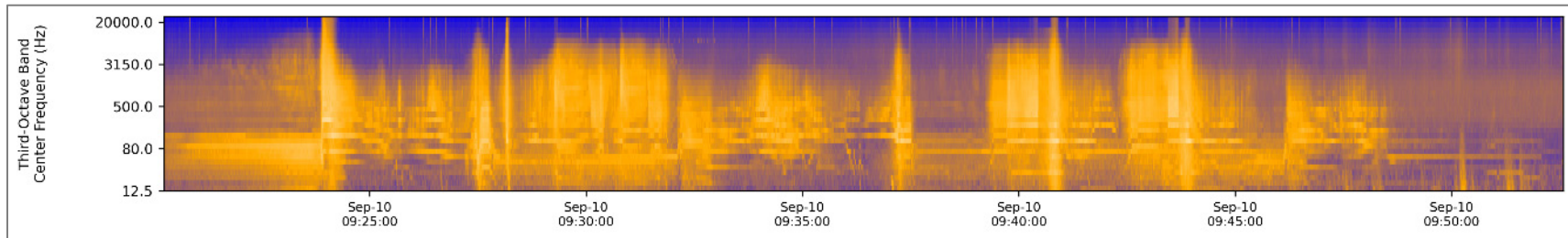


Figure 37. An extended sequence of overlapping aircraft noise observed at LACLCRES, beginning 09:20 on 2023-09-10. Similarly extensive periods of dense, chaotic noise occur at the other LACL coastal portal sites as well.

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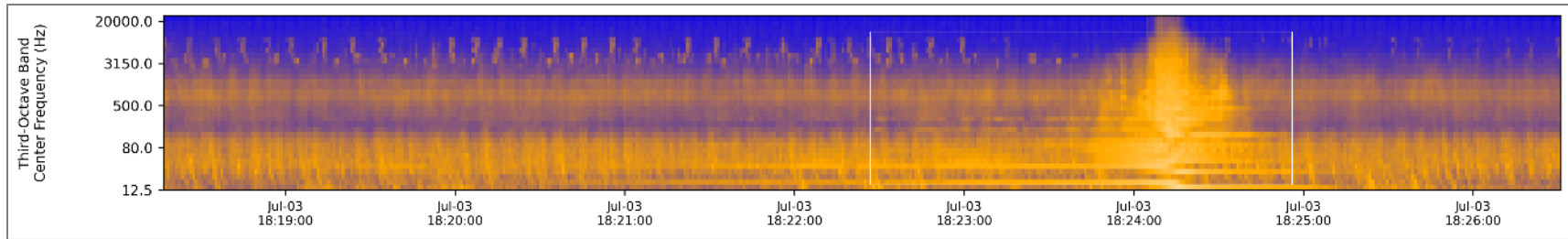


Figure 38. A helicopter overflight audible at LACLSISA, beginning 18:22 on 2023-07-03 (white rectangle). Low frequencies are dominated by the relatively large-scale main rotor system. The most energetic portion of the event occurs at 18:24:20, reflecting the tendency for helicopters to radiate more noise in the direction of flight.

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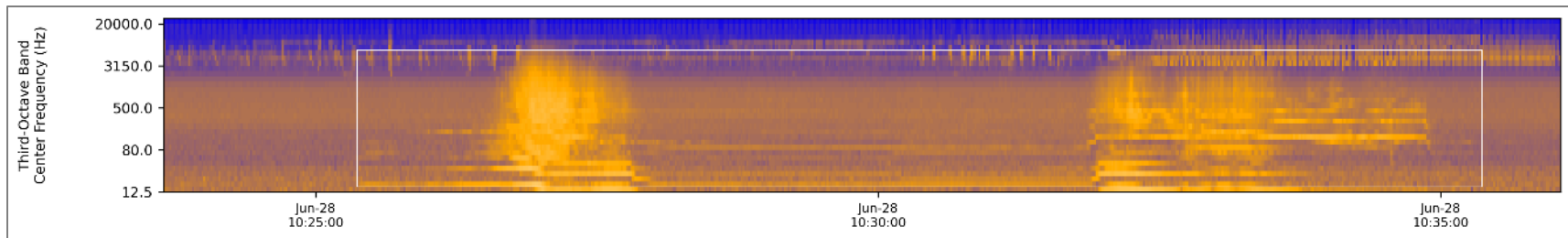


Figure 39. A helicopter operation audible at LACLCRES, beginning 10:25 on 2023-06-28 (white rectangle). The aircraft approaches, lands and reduces rotor speed (10:28), then idles with the rotors spinning for several minutes before lifting off again (10:32) and departing.

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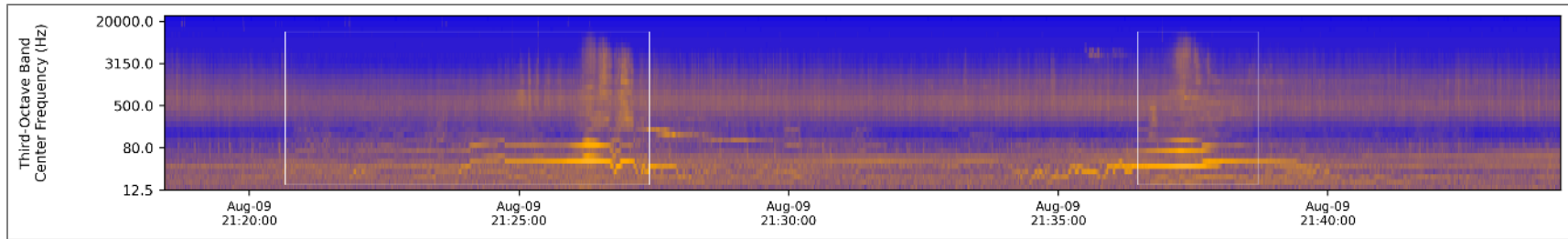


Figure 40. Two All-Terrain Vehicle (ATV) pass-by events audible at LACLSISA, beginning 21:20 on 2019-08-09 (white rectangles). ATVs use fewer cylinders than conventional road vehicles, so they radiate tonal noise at a lower fundamental frequency, here in the 40 Hz band. The second harmonic at 80 Hz is also characteristically energetic. Both pass-by events also include rasping, high-frequency noise above 400 Hz, attributable to the exhaust system.

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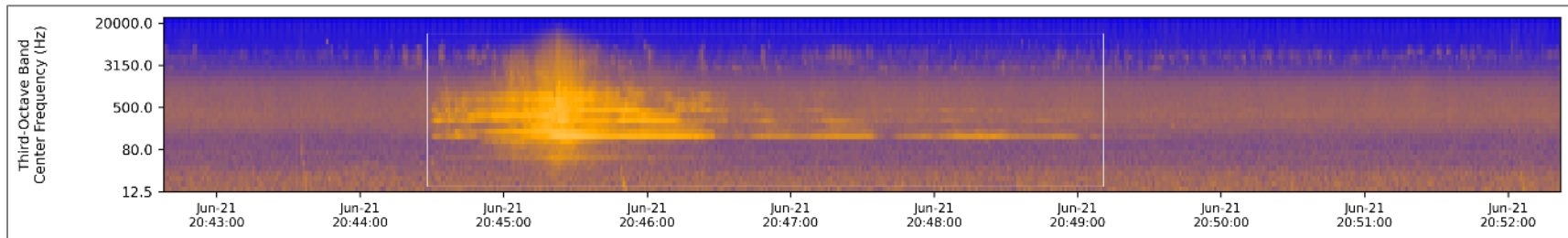


Figure 41. An 18-foot, flat-bottomed skiff equipped with a 25-horsepower outboard motor audible at LACLCRES, beginning 20:42 on 2023-06-21 (white rectangle). Dense harmonic noise is apparent above the 100 Hz band. Because the outboard is mounted on the transom, the noise is strongest behind the vessel.

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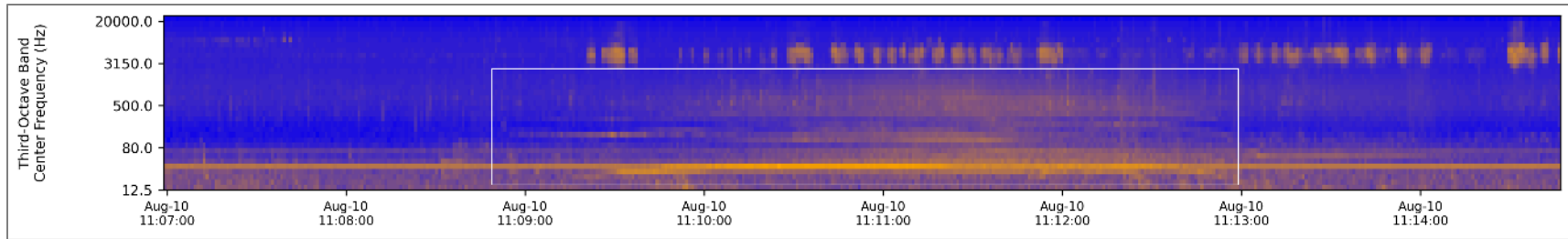


Figure 42. A large, ocean-going vessel audible at LACLCHBA, beginning 11:08 on 2023-08-10 (white rectangle). The propeller system of large vessels produces an inaudible, low frequency tone, here in the 31.5 Hz band. In this case, weakly tonal hydrodynamic and auxiliary machinery noise (e.g., electric generators, pumps, compressors) primarily determine the audible duration of the event.

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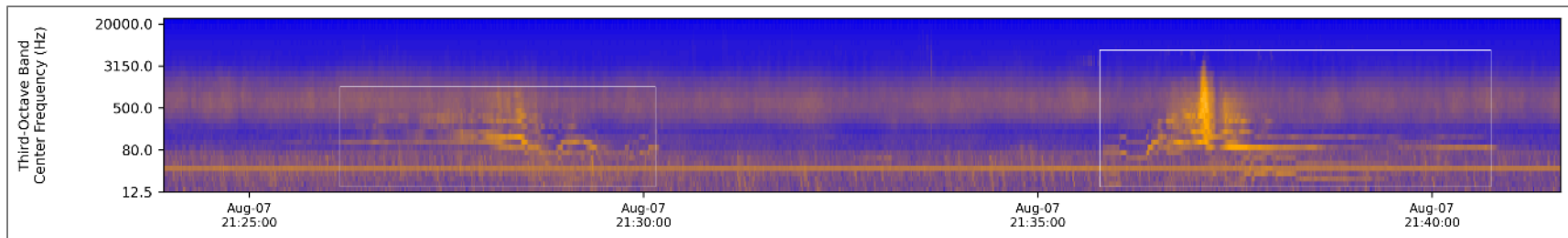


Figure 43. A motorboat audible at LACLCHBA, beginning 21:26 on 2023-08-07 (white rectangles). The watercraft approaches, changes speed (21:28:30) and stops (21:30). Travel resumes (21:36), followed by an increase to cruising speed (21:36:30) and eventual departure.

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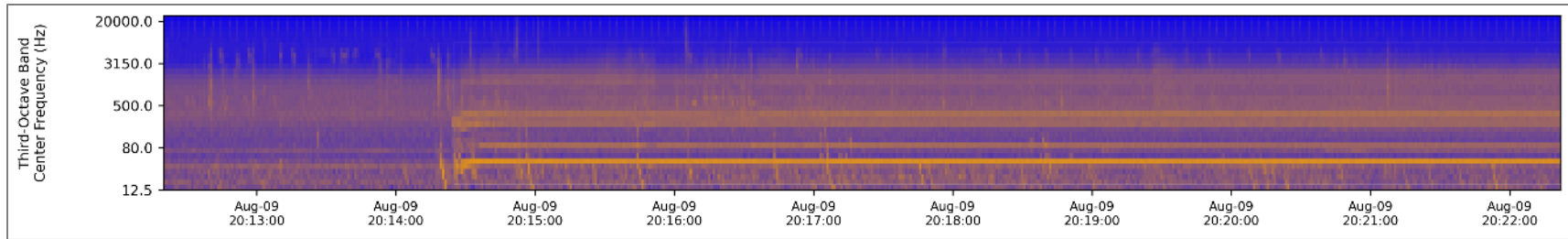


Figure 44. A generator audible at LACLCRES, beginning 20:14 on 2023-08-09 (white rectangle; audibility continues beyond frame). Generator noise is largely time invariant. The fundamental and second harmonics are observed within the 40 and 80 Hz bands, respectively. Dense harmonics within the 200–2000 Hz bands are most audible.

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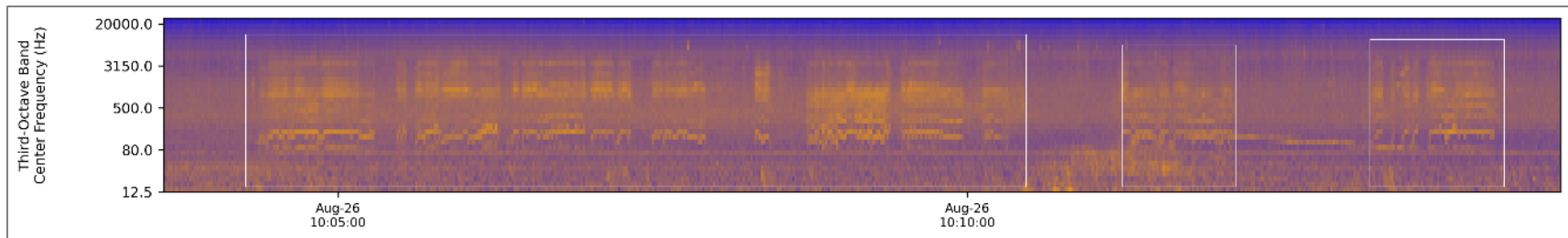


Figure 45. A sequence of power tool use audible at LACLCRES, beginning 10:04 on 2023-08-26 (white rectangles). Grounds care noise is morphologically diverse but often includes fine-scale temporal modulations associated with tools overcoming variable mechanical resistance (i.e., sanding, sawing, drilling).

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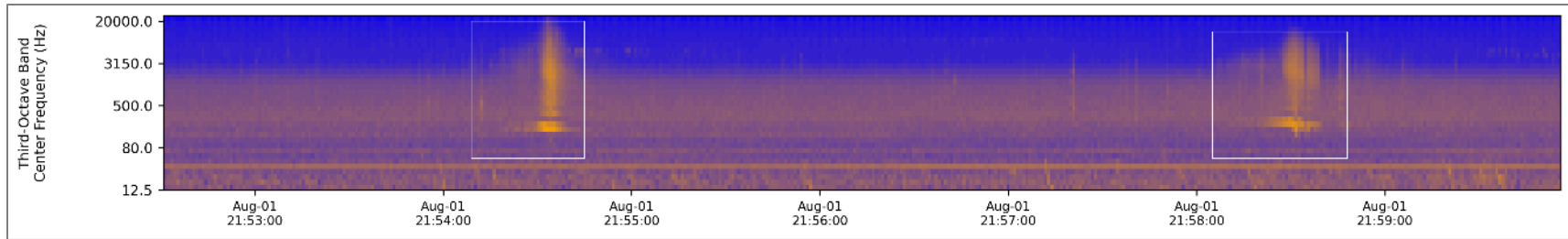


Figure 46. Two drone overflights audible at LACLCRES, beginning 21:54 on 2023-08-01 (white rectangles). The characteristic fan-like hum of the drone is caused by dense propeller harmonics above the 150 Hz band.

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Appendix D: Coastal Management Plan Threshold Analysis

This appendix serves as a technical primer on two scientific management thresholds recommended for inclusion in the LACL Coastal Management Plan (NPS 2024). The purpose of the plan is “to improve visitor experiences at key coastal sites while protecting resources and responding to changing conditions.” One such change was “a substantial increase in seasonal visitation” along the LACL coast. Presently, regional-scale transportation to coastal portals occurs almost entirely via small aircraft capable of transporting ≤ 11 visitors at a time. Day visitation via vessel is an emerging pattern. Local motorized transportation at each site occurs via small motorized watercraft and/or overland vehicles.

Indicators of the Acoustic Environment

Any reasonable indicator of the acoustic environment must relate to both (1) a park’s establishing legislation and (2) a functional effect of noise on the enjoyment of park resources (Betchkal and Ward 2018). LACL was established by Congress “to protect the watershed necessary for the perpetuation of the red salmon fishery in Bristol Bay; to maintain unimpaired the scenic beauty and quality of portions of the Alaska Range and the Aleutian range, including active volcanoes, glaciers, wild rivers, lakes, waterfalls, and alpine meadows in their natural state; and to protect habitat for populations of fish and wildlife including but not limited to caribou, Dall sheep, brown/grizzly bears, bald eagles, and peregrine falcons.” So, the maintenance of scenic beauty—in part as auditory scenes (Bregman 1994; Weinzimmer et al. 2014)—is clearly among LACL’s statutory purposes.

Determination of Functional Effect Thresholds

Rapoza et al. (2015) and Brownlee et al. (2020) provide useful insight into the functional effects of noise on visitor enjoyment of acoustic resources. Rapoza et al. demonstrated the effect of sound exposure level (SEL) on visitor annoyance due to noise. Brownlee et al. demonstrated the effect of time audible (TA) on visitor acceptability of noise. These studies are complimentary because their respective indicators describe different dimensions of the same acoustic environment; SEL is an energy-based metric, while TA is a duration-based metric (Betchkal and Ward 2018). Planning thresholds were derived from both studies using the same analytical method, nonlinear curve fitting (Fletcher 2013):

- A curve (such as a sigmoid or spline, also known as a “social norm curve”) is fit to the visitor response data, resulting in a closed-form equation which relates the acoustic indicator to the mean visitor response.
- The second derivative of the curve describes the acceleration of visitor attitude with respect to resource condition.
- The resource condition corresponding to the fastest acceleration of visitor attitude represents the ideal management threshold. Such a threshold appropriately cues noise management at the condition where visitors find the acoustic environment is most quickly becoming unacceptable/annoying. This arrests resource degradation before it becomes wholly unacceptable/annoying.

Planning thresholds were fit to Rapoza et al. using a cubic spline (Figure 47) and Brownlee et al. using a sigmoid curve (Figure 48), establishing an A-weighted SEL = 75 dB and TA = 10 minutes per hour as visitor-supported thresholds (vertical gold bars).

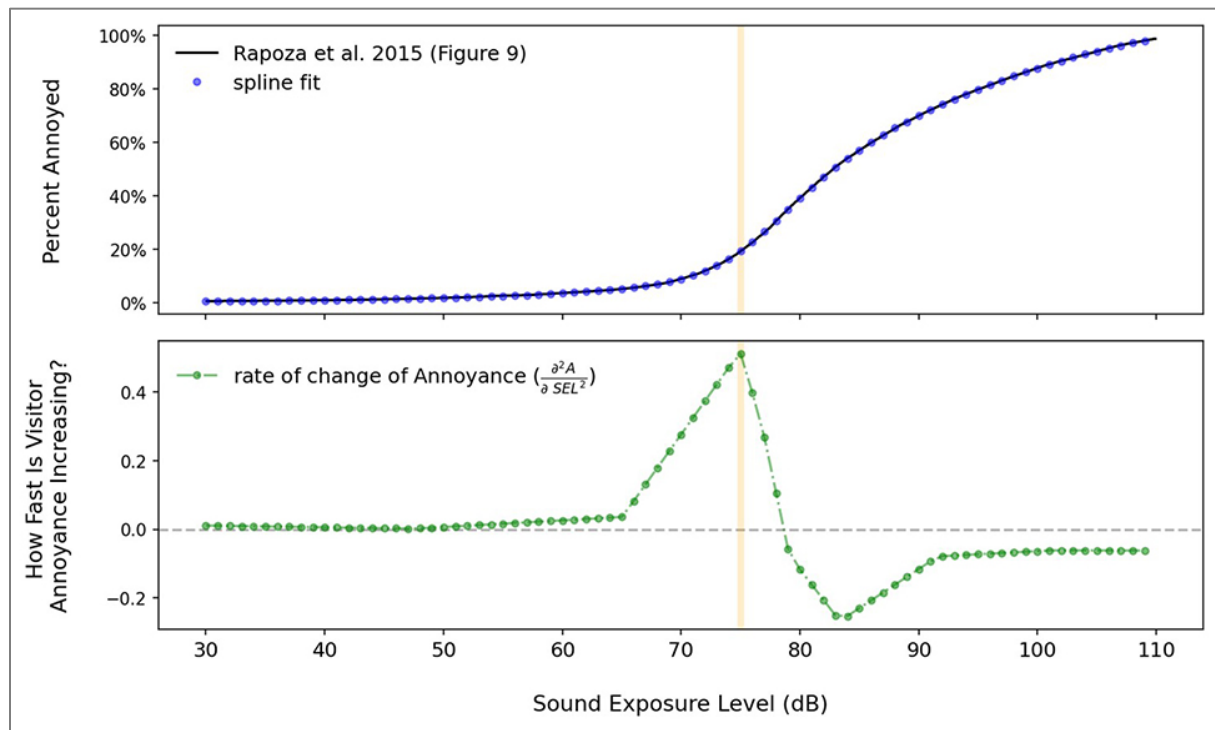


Figure 47. Top: Visitor perceived annoyance as a function of overflight sound exposure level (reproduced using data from Rapoza et al. 2015; black curve) fit with a cubic spline (blue points). Bottom: The second derivative of the spline has a distinct local maximum at the ideal management threshold (green line and points) where annoyance due to noise increases the fastest at an A-weighted Sound Exposure Level of 75 dB (vertical gold bar).

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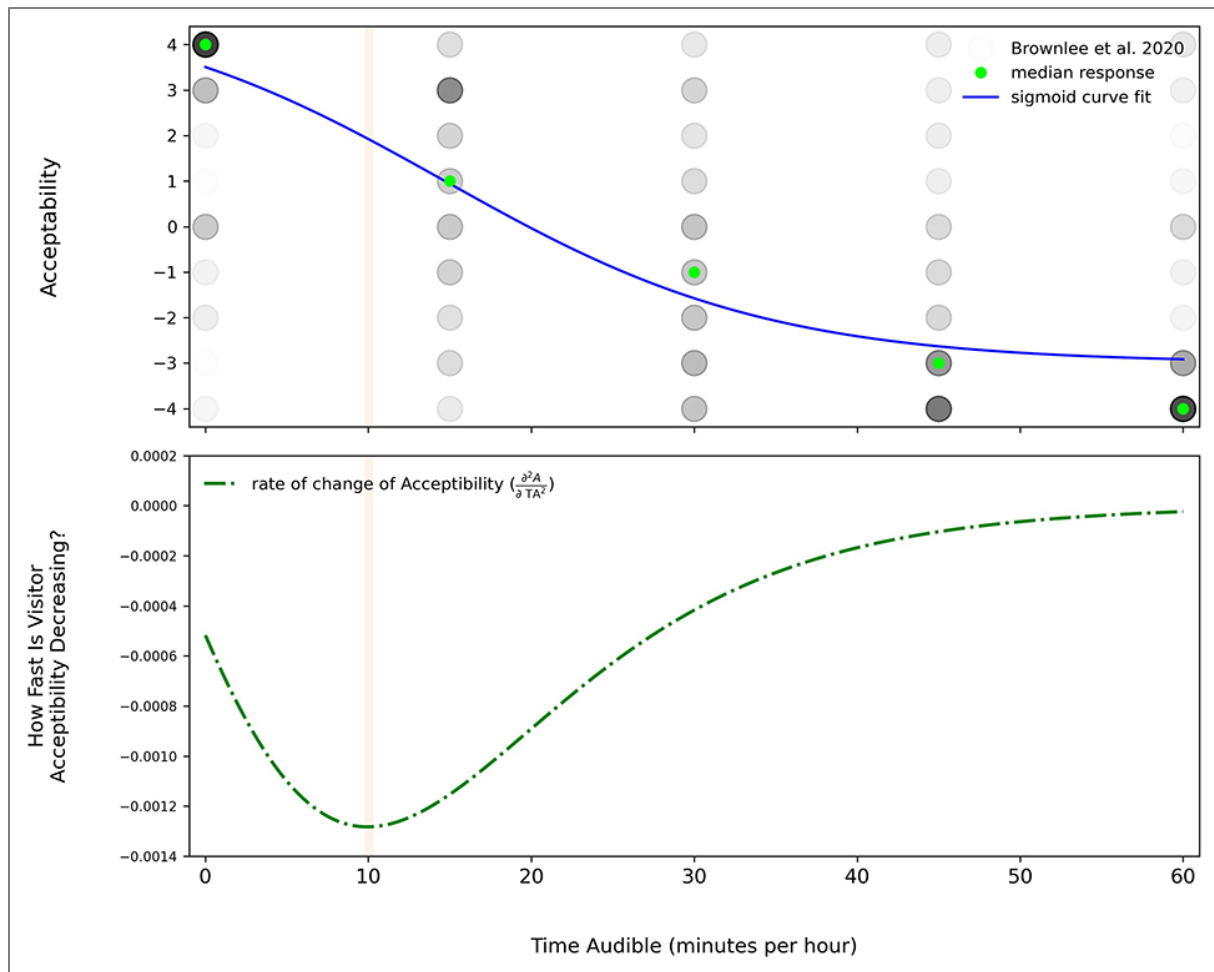


Figure 48. Top: Visitor acceptability response as a function of Time Audible (reproduced using data from Brownlee et al. 2020; transparent grayscale points; median response in green for emphasis) fit with a sigmoid curve (blue line). Bottom: The second derivative of the spline has a distinct local minimum at the ideal management threshold (green line) where acceptability of the acoustic environment decreases the fastest at a Time Audible of 10 minutes per hour (vertical gold bar).

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Threshold Exceedance Under Retrospective Conditions

The previous section establishes two acoustic thresholds for visitor use monitoring of LACL’s coastal portals, which may be expressed in the abstract as follows:

1. **Energy:** The number of noise events $SEL > 75$ dB shall not exceed X events per day.
2. **Time:** The number of hours with $TA > 10$ minutes shall not exceed Y hours per day.

Despite changing visitation conditions in LACL, it is informative to analyze retrospective compliance with each standard (Tables 14–15) using existing datasets from LACLCHBA and LACLSISA, which total to 208 days of observation. (LACLCRES is not within the proposed spatial scope of the plan, so it is excluded.) Because both standards are assessed at a daily timescale, the joint probability of compliance may be estimated by reporting the proportion of observation-days

where both standards are met (Table 16). To maximize joint compliance, it is recommended that the park set $(X, Y) = 18$ events, 15 hours per day.

Table 14. Retrospective compliance with the energy-based acoustic standard using existing measurements at relevant LACL coastal portals (n = 208 days). Compliance is calculated for various event rates, X.

Daily Event Rate, X	Retrospective Days Compliant with Energy Standard (%)
10	50%
12	60%
13	70%
16	80%
18	90%
30	100% ^A

^A The maximum (100th percentile) is a volatile metric not recommended for planning purposes. It is included for reference purposes only.

Table 15. Retrospective compliance with the time-based acoustic standard using existing measurements at relevant LACL coastal portals (n = 208 days). Compliance is calculated for various temporal quotas, Y.

Daily Quota, Y (Hours)	Retrospective Days Compliant with Time Standard (%)
11	50%
12	60%
13	70%
14	80%
15	90%
18	100% ^A

^A The maximum (100th percentile) is a volatile metric not recommended for planning purposes. It is included for reference purposes only.

Table 16. Retrospective joint probability of compliance with both the energy- and time-based standards using existing measurements at relevant LACL coastal portals (n = 208 days).

Metric	# Events	Energy Standard Event Rate, X					
		10	12	13	16	18	30 ^A
Time Standard Quota, Y	11	0.35	0.39	0.43	0.51	0.54	0.58
	12	0.40	0.46	0.50	0.59	0.62	0.67
	13	0.44	0.51	0.58	0.68	0.72	0.78
Time Standard Quota, Y (continued)	14	0.47	0.56	0.63	0.75	0.78	0.86
	15	0.49	0.59	0.66	0.79	0.84 ^B	0.92
	18 ^A	0.51	0.62	0.70	0.84	0.90	1.00

^A The maximum (100th percentile) is a volatile metric not recommended for planning purposes.

^B The optimal, stable joint probability occurs at (X,Y) = (18 events,15 hours).

For the acoustic environments of coastal LACL the time-based indicator of quality, TA, acts to preserve what remains of the quiet, scenic character for a portion of each day. Because it considers noise from all sources, it is a cumulative measure of the capacity to enjoy acoustic resources. To meet the standard, managers should concentrate on defending already quiet hours at night and in the early morning from becoming increasingly noisy. This is consistent with the motivation to minimize visitor annoyance (maximize acceptability) during tranquil times of day that serve to facilitate human experiences of scenery and wildlife habitat.

In contrast, the energy-based indicator of quality, SEL, responds only to events that transmit a considerable energy dose into the environment. The Standardized Incidence Ratio (SIR; Rothman et al. 2008) metric quantifies the contribution of a specific noise source category, *i*, to the binary outcome SEL >75 dB, while accounting for how often the category occurs. The SIR calculation takes the form of a ratio. The numerator of the ratio is the product of the non-compliant event count in a specific category and the overall event count across all categories. The denominator of the ratio is the product of the non-compliant event count across all categories and the overall event count in the specific category:

$$SIR_i = \frac{n_{(>75 \text{ dB}, i)} n_{tot}}{n_{(>75 \text{ dB})} n_i}$$

When $SIR > 1$, the specified source contributes more to compliance success than expected from its prevalence, and vice versa. SIR was calculated for jet aircraft, propeller aircraft, helicopter, overland vehicle, and watercraft sources at LACLCHBA and LACLSISA (Table 17). It is immediately clear that fixed-wing propeller aircraft contribute over four times the number of events SEL >75 dB than would be expected given their prevalence. For this reason, managing to the SEL standard will require more attention to fixed-wing propeller aircraft than any other source. This further suggests that one viable mitigation strategy to increase transportation capacity while maintaining resource conditions would be to explore the use of quieter electric aircraft now entering the market (for example the Electra EL-9; ElectricAirMobility News 2024). In addition to being quieter than conventional small

aircraft, these modern designs are also more performative – which suggests safety benefits to off-airport operations along the LACL coast.

Table 17. Calculated values of the Standardized Incidence Ratio for all noise event categories prevalent on the LACL coast.

Source Category, <i>i</i>	Proportion of Spectrogram Annotations	Proportion of Annotations with SEL >75 dB	Standardized Incidence Ratio (SIR)
Propeller Aircraft	71.9%	93.7%	4.426
Helicopter	2.7%	3.9%	0.184
Watercraft	6.9%	1.3%	0.063
Jet Aircraft	6.6%	0.6%	0.028
Overland Vehicle	12.0%	0.4%	0.020

National Park Service
U.S. Department of the Interior



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