National Park Service
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Natural Resource Stewardship and Science

Katmai National Park and Preserve

Acoustic Inventory 2015 - 2017

Natural Resource Report NPS/NRSS/NSNSD/NRR—2020/2080





ON THIS PAGE
Verdant cliffs tower over the islands of Amalik Bay – scenery typical of Katmai's wild and rugged coastline.
(NPS / JESSICA WESTBROOK)

ON THE COVER
Low-angle October light illuminates an acoustic recording system operating in the Valley of Ten-Thousand Smokes, near the base of snow-capped Mount Griggs. (NPS / ROBERT PETERSON)

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Davyd Halyn Betchkal[1]

[1]National Park Service
Denali Park, AK

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Executive Summary

In 2015, the Natural Sounds and Night Skies Division (NSNSD) received a request to collect baseline acoustic data at Katmai National Park and Preserve (KATM). Fifteen acoustic monitoring systems were deployed across the park and preserve during the summers of 2015 - 2017. The stations were configured to collect sound pressure level data and continuous audio recordings for approximately thirty days. Acoustic measurements are objective, continuous, and spatially explicit, and are made using methods that can easily be reviewed by the public. The baseline data collected during this period will help managers and planners assess the current condition of the acoustic environment at KATM. In conjunction with other information, the results of this study may help inform the Katmai Backcountry and Wilderness Management Plan. The measured existing and natural ambient conditions may also be used as a baseline for long-term monitoring and noise modeling efforts.

Katmai's landscapes are remarkably wild and unforgiving. Pinned between the Bering Sea and the Gulf of Alaska, the Aleutian Range is well-known for its unrelenting wind, active volcanoes, coastal cliffs, and thundering waterfalls. The drama of the mountainous coastline contrasts strongly with the interior, a placid, expansive country containing numerous lakes that have been nourished by the cascading energy of salmon runs since time immemorial. The keystone of Katmai's Wilderness character is solitude. The experience of natural quiet is a rare and powerful thing in our noisy and fast-paced world. Fittingly, Katmai's foundation statement describes 'Natural Soundscapes' as a fundamental resource and value of wilderness recreation (NPS 2009).

Transportation to and within KATM has always been a complex issue (Nagle 2013). Because of its wilderness protections and vast size, the primary sources of noise in the KATM backcountry are the aircraft and vessels in which visitors must arrive. Because of the obvious association between noise and portals, previous efforts (NPS 1988, Groth et al. 2007) have focused exclusively on these areas. In contrast, this report provides an unprecedented look at the sonic consequences of Katmai's transportation network in backcountry areas beyond portals. While it primarily describes the *effects* of transportation, the report also provides some insights into the *causes* of impacts.

In particular, the results suggest distinct patterns in the distribution of noise impacts. In particular, noise issues along the coast arise from a combination of long-duration vessel noise – especially from marine generators – and moderate-duration, high-amplitude aircraft noise. Although interior areas experience similarly intense impacts, they are principally associated with aircraft noise alone. In general, the routing habits of aviators can have outsized impacts on wilderness character in areas that are typically thought of (and managed) as being extremely remote and difficult to reach.

When considering the current conditions of an acoustic environment, it can be informative to examine how often sound pressure levels (SPLs) exceed certain values. Table i generalizes the effects of SPL on humans and wildlife as documented in the scientific literature. These values are relevant to various aspects of the visitor experience, including camping, communication at distance (for example when spaced out along a trail), and communication during normal conversation. Human

responses can serve as a proxy for potential impacts to other vertebrates because human hearing is more sensitive at low frequencies than that of many species (Dooling and Popper, 2007; Fay, 1988).

Table i. Generalized effects of specific sound pressure levels on humans and wildlife.

Noise level	Metric	Relevance
35	$LA_{eq,1s}$	Blood pressure and heart rate increase in sleeping humans (Haralabidis et al., 2008), maximum recommended background noise level inside classrooms (ANSI Standard S12.60)
40	LA_{eq*}	Decline in species diversity (Proppe et al. 2013, Shannon et al. 2015)
45	$LA_{eq,1s}$	World Health Organization's recommendation for maximum noise levels inside bedrooms (Berglund et al. 1999)
52	$LA_{eq,1s}$	Speech interference for interpretive programs or time-sensitive safety communication during backcountry travel (U.S. Environmental Protection Agency 1974)
60	$LA_{eq,1s}$	Speech interruption for normal conversation (U.S. Environmental Protection Agency 1974)

* This metric is a composite of measurements with varying time averages.

For a given frequency range, the percent-time-above metric indicates the percentage of time during which conditions exceed a specified SPL threshold. Table ii reports the percent of time that SPLs measured at various locations at Katmai were above the values listed in Table i. Although these values are useful for making comparisons, they should not be construed as thresholds of impact. The top value in each split-cell of Table ii reports the percent-time-above for the 20 – 1,250 Hz range. This low frequency range is useful because it includes frequencies that are typical of transportation noise (but also natural sounds like water and wind) while excluding higher-frequency bird and insect sounds. The bottom percent-time-above value in each split-cell is calculated using the full 12.5 – 20,000 Hz frequency range measured at each site.

Table ii. Time-above metrics for all sites

Site	Frequency (Hz)	Time above sound level: 07:00 to 19:00 (%)				Time above sound level: 19:00 to 07:00 (%)			
		35 dB	45 dB	52 dB	60 dB	35 dB	45 dB	52 dB	60 dB
Amalik Bay	20-1250	44.5	3.2	0.6	0.1	26.7	0.5	0.0	0.0
	12.5-20,000	22.0	1.3	0.2	0.1	15.2	0.0	0.0	0.0
American Creek	20-1250	17.6	3.7	1.4	0.4	7.2	0.5	0.1	0.0
	12.5-20,000	30.8	7.1	2.2	0.5	15.2	2.1	0.3	0.0
Contact Lake	20-1250	2.9	0.3	0.1	0.0	2.8	0.1	0.0	0.0
	12.5-20,000	1.7	0.3	0.1	0.0	0.8	0.0	0.0	0.0
Crosswinds Lake	20-1250	21.3	8.9	4.1	1.1	4.7	0.3	0.0	0.0
	12.5-20,000	18.8	8.6	4.0	0.9	0.9	0.1	0.0	0.0
Douglas River	20-1250	39.7	1.6	0.3	0.0	63.8	4.6	0.0	0.0
	12.5-20,000	52.9	5.2	0.5	0.0	73.2	9.3	0.3	0.0
Dumpling Point	20-1250	7.2	1.7	0.6	0.2	9.1	0.1	0.0	0.0
	12.5-20,000	13.5	2.0	0.7	0.2	20.2	0.5	0.0	0.0
East Kulik Lake	20-1250	87.6	29.2	0.3	0.0	76.3	24.3	0.2	0.0
	12.5-20,000	75.9	16.9	0.0	0.0	67.5	15.6	0.0	0.0
Hallo Bay	20-1250	45.5	3.3	1.1	0.4	57.3	0.9	0.0	0.0
	12.5-20,000	66.0	7.3	1.5	0.4	66.9	6.9	0.2	0.0
Jo-Jo Lake	20-1250	31.4	2.3	0.1	0.0	29.7	2.9	0.1	0.0
	12.5-20,000	48.9	8.6	1.4	0.1	37.7	11.4	1.4	0.0
Kamishak River	20-1250	5.8	1.5	0.6	0.1	0.4	0.0	0.0	0.0
	12.5-20,000	13.9	1.9	0.7	0.1	3.1	0.1	0.0	0.0
Katmai Bay	20-1250	84.9	8.8	0.1	0.0	96.7	18.4	0.5	0.0
	12.5-20,000	80.6	4.6	0.1	0.0	94.1	10.6	0.1	0.0
Pfaff Mine	20-1250	21.9	1.3	0.1	0.0	14.8	1.6	0.0	0.0
	12.5-20,000	18.7	0.5	0.1	0.0	12.7	0.5	0.0	0.0
Savonoski Lake	20-1250	29.8	1.1	0.1	0.0	15.9	0.2	0.0	0.0
	12.5-20,000	64.9	9.6	1.4	0.0	34.8	4.3	0.2	0.0
Swikshak Lagoon	20-1250	47.3	2.8	0.8	0.2	52.3	1.8	0.1	0.0
	12.5-20,000	36.9	1.8	0.7	0.1	45.3	0.3	0.0	0.0
Valley of 10k Smokes	20-1250	13.3	0.7	0.1	0.0	7.7	0.1	0.0	0.0
	12.5-20,000	12.1	0.3	0.0	0.0	7.2	0.1	0.0	0.0

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List of Acoustic Terms

Acoustic Environment - A combination of all the physical sound resources within a given area. This includes natural sounds and cultural sounds, and non-natural human-caused sounds. The acoustic environment of a park can be divided into two main categories: intrinsic and extrinsic.

Acoustic Resources - Includes both natural sounds like wind, water, & wildlife and cultural and historic sounds like tribal ceremonies, quiet reverence, and battle reenactments.

Amplitude - The acoustic pressure energy carried by a sound wave, described in decibels (dB). Amplitude is related to what we commonly call loudness or volume.

Audibility - The ability of animals with normal hearing, including humans, to hear a given sound. It can vary depending upon the frequency content and amplitude of sound and by an individual animal's hearing ability.

Decibel (dB) - A unit of sound energy. Every 10 dB increase represents a tenfold increase in energy. Therefore, a 20 dB increase represents a hundredfold increase in energy. When sound levels are adjusted for human hearing, they are expressed as dBA.

Extrinsic Sound - Any sounds not forming an essential part of the park unit, or a sound originating from outside the park boundary. This could include voices, radio music, or aircraft flying thousands of feet above the park.

Frequency - Related to the pitch of a sound, it is defined as the number of times per second that the wave of sound repeats itself and is expressed in terms of hertz (Hz). Sound levels are often adjusted ("weighted") to match the hearing abilities of a given animal. In other words, humans and different species of animals are capable 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. Some bats, on the other hand, can hear sounds between 20 Hz and 200,000 Hz.

Intrinsic Sound - Belongs to a park by the park's very nature, based on its purposes, values, and establishing legislation. Intrinsic sounds can include natural, cultural, and historic sounds that contribute to the acoustic environment of the park.

LA_{50}, LA_{90} - Metrics used to describe a set of A-weighted sound pressure levels (L) exceeded 50 and 90 percent of the time, respectively. Put another way, half the time the measured levels of sound are greater than the LA_{50} value, while 90 percent of the time the measured levels are higher than the LA_{90} value.

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

LA_{nat} (Natural Ambient Sound Level) - The natural sound conditions in parks, which exist in the absence of any human-produced noise. These measures are typically reported in

Noise Free Interval (NFI) - The length of time that passes between the end of one noise event and the beginning of the next. Over a long period of observation, the median of many NFIs describes how the typical opportunity for solitude has been fragmented by noise. The opportunity to experience an NFI of any particular length is strongly dependent on the noise event rate.

Percentile level: - The sound level or time-average sound level that is equaled or exceeded for X percent of the total measurement period, reported with the duration of the total measurement period.

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

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

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

Sound vs. Noise - The NPS differentiates between the use of sound and noise, since these definitions have been used inconsistently in the literature. Humans perceive sound as an auditory sensation created by pressure variations that move through a medium such as water or air and are measured in terms of amplitude and frequency (Harris, 1998; Templeton, 1997). This includes a broad range of phenomena. Noise is a smaller subset of all sounds: those that are undesired or extraneous to an environment.

Soundscape - The human perception of the physical sound resource.

Introduction

"Understanding patterns in terms of the processes that produce them is the essence of science, and is the key to the development of principles for management" (Levin 1992).

This report details an acoustic inventory conducted throughout Katmai National Park and Preserve (KATM) by automated measurement. Acoustic measurements are objective, continuous, and spatially explicit, and they employ methods easily reviewed by the public. This effort in KATM represents the 12th largest acoustic inventory effort in National Park Service (NPS) history. The results describe KATM's acoustic environments at a regional scale. They also describe the impacts of noise on acoustic resources.

The initial push for acoustic inventories on NPS-managed lands began with Director's Order #47 (DO-47; NPS 2000). In 2000, Robert Stanton issued this order, which directs park managers to identify baseline soundscapes and related measures. DO-47 states that "natural sounds are intrinsic elements of the environment that are often associated with parks and park purposes…They are inherent components of 'the scenery and the natural and historic objects and the wild life' protected by the NPS Organic Act." DO-47 directed park managers to "(1) measure baseline acoustic conditions, (2) determine which existing or proposed human-made sounds are consistent with park purposes, (3) set acoustic management goals and objectives based on those purposes, and (4) determine which noise sources are impacting the park and need to be addressed by management." Furthermore, it requires park managers to "(1) evaluate and address self-generated noise, and (2) constructively engage with those responsible for other noise sources that impact parks to explore what can be done to better protect parks" (NPS 2000).

National Soundscape Planning Authorities

The NPS "preserves unimpaired the natural and cultural resources and values of the National Park System for the enjoyment, education, and inspiration of this and future generations" (see *https://www.nps.gov/aboutus/index.htm*). The Redwoods Act of 1978 provides further insight into the NPS mission:

> "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 1978).

Direction for management of natural soundscapes[1] is represented in NPS Management Policies 2006 § 4.9:

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

It should be noted that Management Policies 2006 § 8.2.3: Use of Motorized Equipment states,

> "the natural ambient sound level—that is, the environment of sound that exists in the absence of human-caused noise—is the baseline condition, and the standard against which current conditions in a soundscape [acoustic resource] will be measured and evaluated" (NPS 2006b).

However, the desired acoustic condition may also depend upon the resources and the values of the park. For instance, "culturally appropriate sounds are important elements of the national park experience in many parks" (NPS 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).

Katmai-Specific Soundscape Planning Authorities

The signing of the Alaska Natural Interest Lands Conservation Act (ANILCA) in 1980 designated the Katmai Wilderness, a diverse 3.3-million-acre portion of the Aleutian Range encompassing rugged mountains, lakes, and coastline. The Katmai Foundation Statement interprets ANILCA §

[1] The 2006 Management Policy 4.9 and related documents refer to "soundscapes" instead of "acoustic resources." When quoting from this authority, it is advisable to note that the term often refers to resources rather than visitor perceptions.

202(2), describing ‘Natural Soundscapes’ as a fundamental resource and value of wilderness recreation (NPS 2009).

In 1988 the Katmai Wilderness Recommendation EIS presented an additional 0.6 million acres of land to Congress for wilderness designation (NPS 1988). One of the key benefits park managers focused on when recommending these lands was *solitude*. The NPS assured the public that due to the wilderness recommendation, “the naturalness of designated areas would be preserved indefinitely, and abundant opportunities for solitude and primitive recreation would be available.” Thirty years later the inventory data included in this report provide quantitative insights into how the NPS might continue such preservation goals into the future.

Methods

Study Area and Site Selection

NPS staff deployed acoustic monitoring systems to 15 locations across Katmai National Park and Preserve during the summers of 2015 - 2017, as shown in Table 1 and Figure 1.

Table 1. Sites sampled during the summers of 2015 - 2017.

Site Name	Site Code	Year	Elevation (m)	Latitude	Longitude	Days Sampled*	Wilderness
Amalik Bay	AMBA	2017	37	58.10639	-154.60167	14*	Eligible
American Creek	AMCR	2016	112	58.82051	-155.66612	28	Designated
Contact Lake	TACT	2017	581	58.20800	-155.96103	29	Designated
Crosswinds Lake	CROS	2017	909	59.20414	-154.97101	29	Eligible
Douglas River	DORI	2016	4	58.98351	-153.53938	16*	Designated
Dumpling Point	DUPO	2016	241	58.60343	-155.84497	25	Designated
East Kulik Lake	EKUL	2017	661	58.89650	-154.80084	14*	Eligible
Hallo Bay	HALO	2016	≤ 1	58.42707	-154.06105	35	Designated
Jo-Jo Lake	JOJO	2016	44	58.61685	-155.22643	34	Designated
Kamishak River	KAMI	2017	19	58.99634	-154.15538	24*	Designated
Katmai Bay	KABA	2016	≤ 1	58.02355	-154.90401	46	Designated
Pfaff Mine	PFMI	2015	1938	59.11098	-154.83687	44	Eligible
Savonoski Lake	SAVO	2017	254	58.59578	-154.75061	27	Designated
Swikshak Lagoon	SWLA	2015	18	58.60592	-153.76837	33	Designated
Valley of Ten-Thousand Smokes	VTTS	2015	1704	58.31635	-155.22972	59	Designated

* One month of continuous data is the sampling goal; this goal was not achieved at some sites due to equipment failure, animal disturbance, insufficient solar radiation, or access scheduling. In these cases an acoustic profile was compiled using the available data.

The inventory is designed to provide a spatially widespread sample of KATM. One benefit of this is that it allows us to sample a broad range of variability in observed conditions. Widespread sampling may also allow for spatial inference into the processes that produce noise. Inventory sites were deliberately spaced *close enough together* to reveal patterns in resource impact on a landscape scale. They were also spaced *far enough apart* (except possibly Crosswinds Lake / Pfaff Mine) such that no two sites are within the reach of a typical motorized noise footprint. This spacing ensures spatial independence for relatively energetic sources, meaning that they will never be simultaneously detected by two microphones at once (Betchkal and Ward 2018).

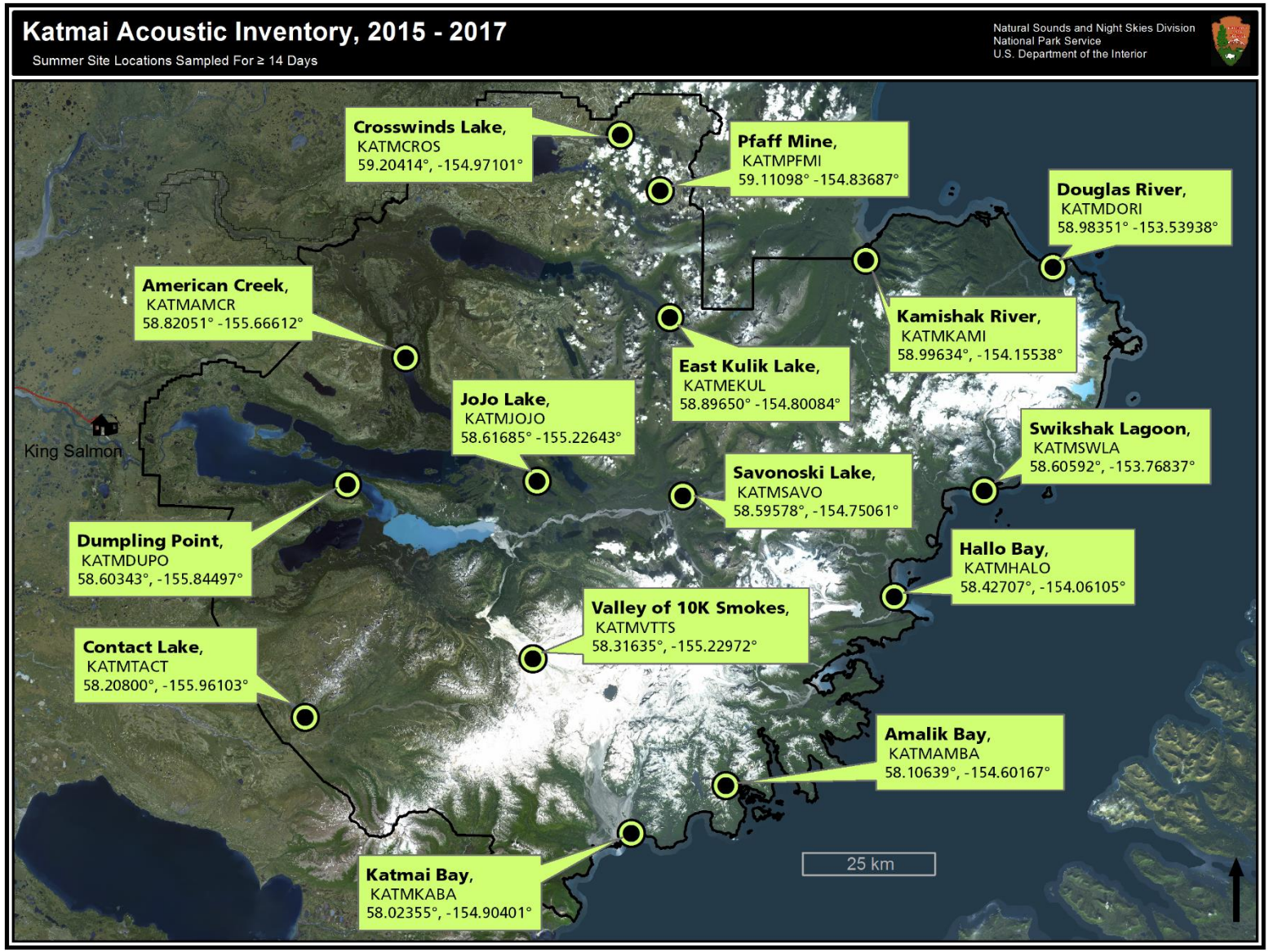


Figure 1. Acoustic inventory sites in Katmai National Park and Preserve during the summers of 2015 - 2017.

A sample of convenience was implemented for the first year of the inventory. Accessibility and the seasonality of visitor use levels were both considered when selecting sites, under the constraint that sites should be as far apart as possible. The access method for 2015 was a Cessna 185 on wheels, a method which limited sites to areas near airstrips, beaches, river bars, or open gravels where landings were practical.

The second and third year of the inventory implemented a modified Generalized Random Tessellation Stratified (GRTS) design, which spatially disperses samples in a statistically efficient manner. GRTS works by minimizing the variance in the area of polygons called *Voronoi cells* surrounding each point (Stevens and Olsen 2004). The underlying mathematics of GRTS allowed us to collect a spatially-balanced, non-random sample while respecting access constraints. The entire sampling implementation process used at Katmai involved the following steps:

1. Generate an exhaustive list of accessible site locations.
2. Decide how many stations can be reasonably deployed during the initial time period. Deploy these initial stations to accessible locations located as far apart as possible.
3. Create a Voronoi tessellation using the coordinates of the stations.
4. Pick the next iteration of samples by selecting accessible sites at either the edges or vertices of a Voronoi cell, prioritizing sites that reduce large cells towards the typical size of other cells (minimizing variability as per GRTS.) These samples will be deployed during the next time period.
5. Repeat steps 1-5 until the median size of the Voronoi cells is similar to or slightly larger than the detection area of the noise source at issue.

Figure 2 shows how the inventory process progressed at Katmai. The typical sampling location has 993 ± 211 km^2 (median ± median absolute deviation) of Katmai's area closer to it than any other point. In comparison, Katmai's total area divided by the number of sites is 1104 km^2. Based on these numbers, the error in the spatial balance can be estimated as follows:

$$Percent\ Error = 100 * \frac{Implemented\ Value - Theoretical\ Value}{Theoretical\ Value} = 100 * \frac{993 - 1104}{1104} = -10.1\%$$

The error in spatial balance was primarily associated with the infeasibility of accessing the high Aleutian Range. The close proximity of the Crosswinds Lake and Pfaff Mine sites also contributed error. The third source of error was the lack of sites along the western boundary of the park and preserve, such as the western shores of Nonvianuk, Kukaklek, or Naknek Lakes.

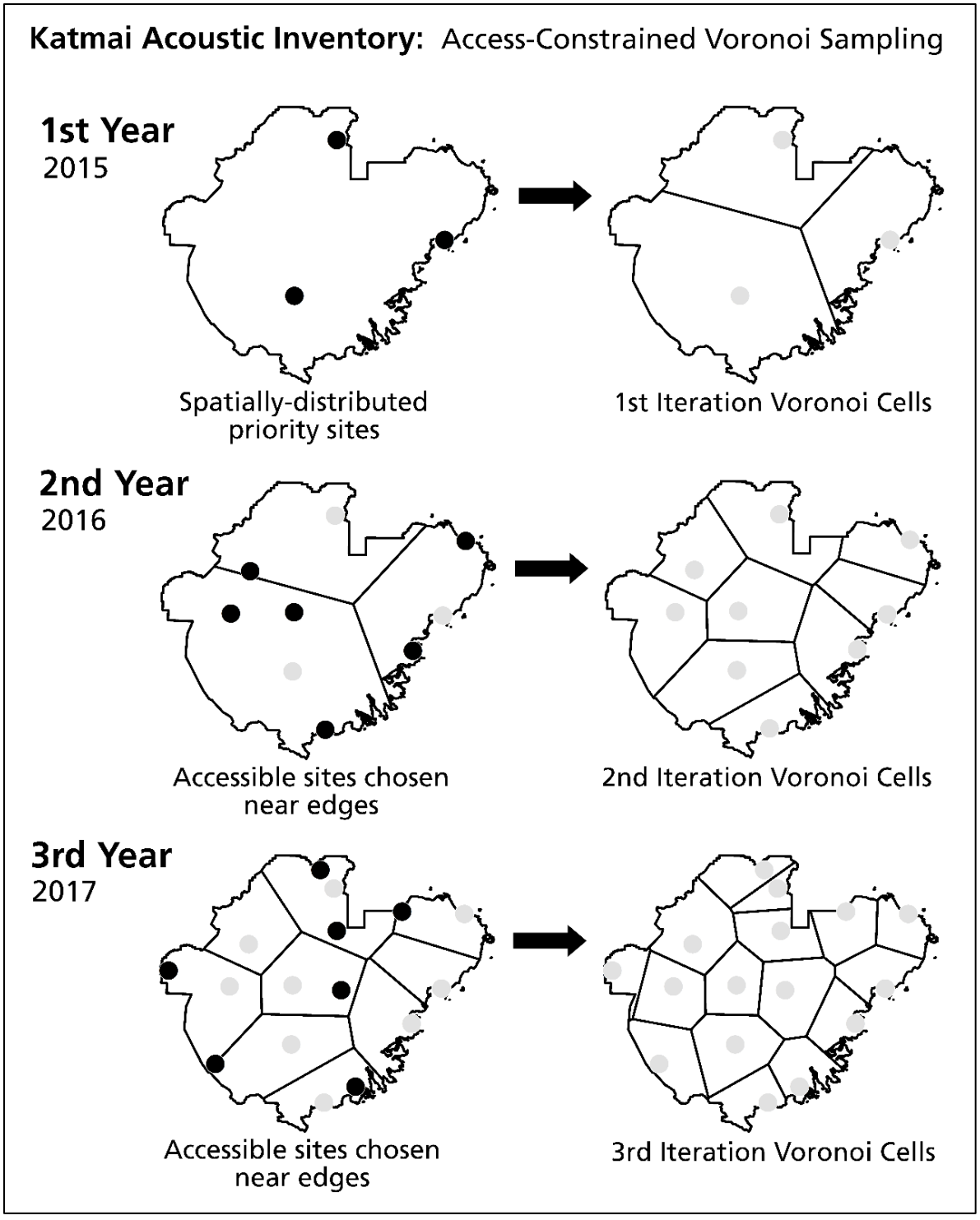


Figure 2. The Voronoi sampling process used for the acoustic inventory of Katmai National Park and Preserve. The diagram shows how Voronoi cells can help guide access-constrained sampling so that the final sample is spatially balanced. By the third iteration it is possible to see how variability in area around each site is minimized by this technique.

Automated Measurement

Sampling was conducted with the Larson Davis 831 sound level meter (SLM), a hardware-based real-time analyzer which constantly records one-second sound pressure levels (SPL) and 1/3 octave band data and exports them to a USB storage device. Larson Davis-based sites meet American National Standards Institute (ANSI) Type 1 standards (ANSI 1968, 1992). To supplement the SPL data, Roland R-05 field recorders capture 96 kbps MP3 recordings via the Larson Davis 831 audio output.

Each Larson Davis sampling station consists of:

- Microphone with environmental shroud and windscreen
- Preamplifier
- Roland R05 MP3 recorder
- Solar panel and batteries
- Anemometer/Wind Vane
- Temperature and Relative Humidity Probe *(not included in 2015)*

Each station collected:

- SPL data in the form of A-weighted sound pressure levels every second (LAeq, 1s)
- 1/3 octave band data every second ranging from 12.5 Hz – 20,000 Hz
- Continuous 96 kilobit-per-second digital audio recordings

Visual Analysis of Spectrograms

For each monitoring site, staff visually analyzed the acoustic record to identify the frequency and duration of mechanized sound sources. Hourly time-audible statistics are then used to calculate natural ambient sound level estimates.

Figure 3, below, shows sound pressure levels (SPL) from one hour at an acoustic monitoring site at Katmai National Park. Each row shows SPL values from low frequency (12.5 Hz, bottom of line) to high frequency (20 kHz, top of line). Values are represented with a color scale, where dark blue is quiet and yellow/white is loud. Thus, individual events stand out against the blue background, appearing as yellow areas. The image is read like text, following each row from left to right and proceeding from top to bottom.

The SPL spectrogram allows us to visually identify and tag acoustic events. Source type, start time, duration, amplitude metrics, and spectral information are cataloged for each annotated event. For

example, the blue box in Figure 3 annotates a propeller overflight recorded in the Valley of Ten-Thousand Smokes.

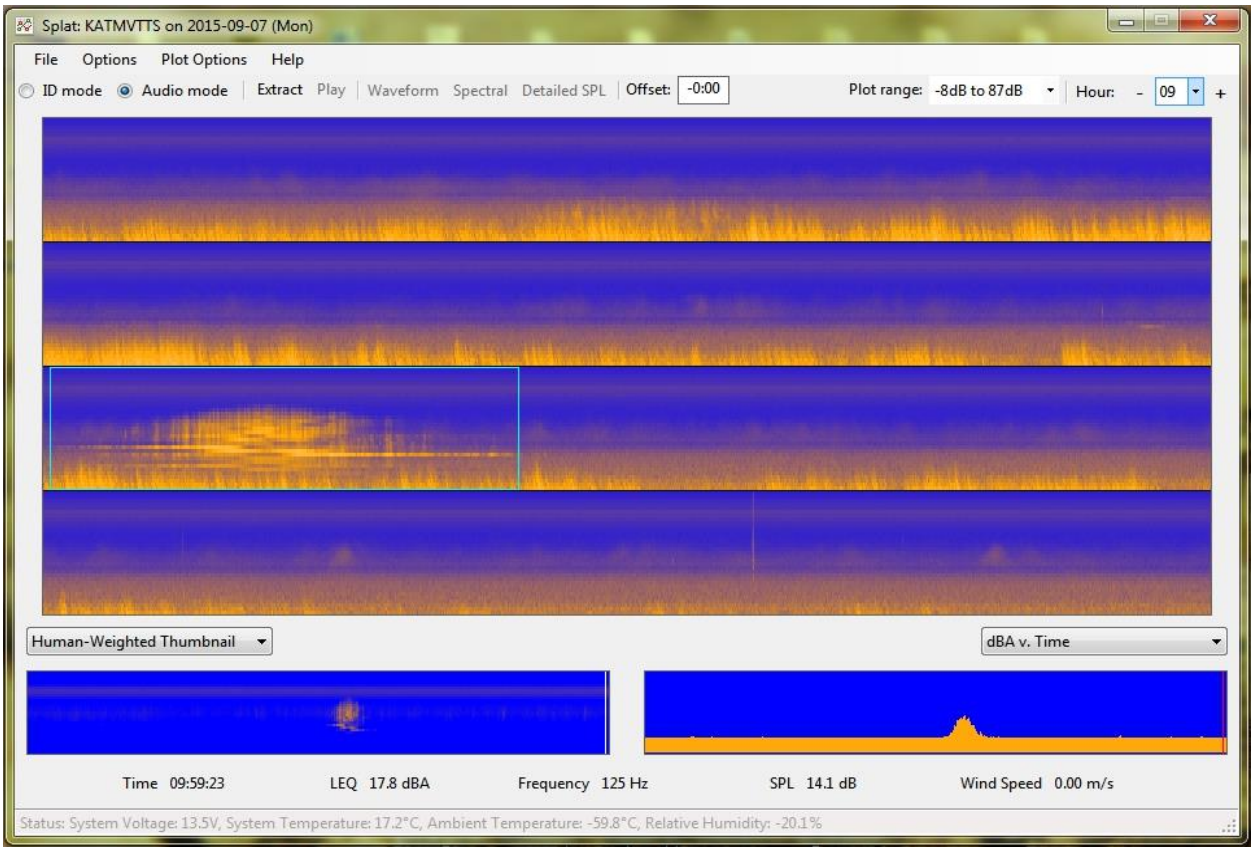


Figure 2. Spectrogram plot from the Valley of Ten-Thousand Smokes inventory site including an annotated propeller aircraft noise event.

Calculation of Natural Ambient Level, LA_{nat}

The following steps were utilized to calculate LA_{nat}:

1. NPS staff calculate the proportion P_H of all samples containing extrinsic sounds for each hour of the day by listening to samples and/or visually analyzing daily spectrograms.
2. P_H is used to complete this formula for every hour in the dataset: $x = \frac{1 - P_H}{2} + P_H$
3. Hourly x_H values are entered into a database of all octave band information. Example: if extrinsic sounds are audible 50% of the time (P_H =0.5), then x_H is 0.75.

LA_{nat} is computed as the sound level that is exceeded 100*x_H percent of the time. In practice, LA_{nat} is calculated by sorting the relevant sound level measurements and using x_H to extract the appropriate order statistic).

This procedure approximates the sound levels that would have been measured in the absence of extrinsic noise. The procedure is guaranteed to produce an estimate that is equal to or below the existing ambient sound levels; this calculation has produced consistent results for most backcountry sites analyzed by the NPS Natural Sounds Program (Lynch et al. 2011).

Results and Discussion

Park-wide Summary

The following tables summarize the entire inventory dataset. Table 2 gives existing and natural ambient sound statistics in A-weighted decibels. The median existing ambient level (LA50, LA90) describes the typical SPL as it is directly observed (including both natural and anthropogenic sounds). Natural ambient level (LAnat) estimates the SPL without the contribution of anthropogenic sounds. Table 2 also shows exceedance metrics LA10 and LA90, which mark the 90th and 10th percentiles of sound pressure level, respectively. These metrics describe the typical range of SPL fluctuations due to both human and natural sources over the sample period.

Table 2 provides summary noise metrics, including overall time audible for non-jet aircraft, median number of non-jet aircraft events per day, and maximum SPLs for non-jet aircraft. It also includes a source-independent metric, the 24-hour median Noise Free Interval . Table 3 provides similar measures for watercraft.

When interpreting SPL data, it should be noted that the decibel scale is logarithmic. As such, a six decibel increase in sound pressure level is equivalent to a doubling of sound pressure (Sound Pressure can be conceptualized as the amount of force applied to a unit area or the amount of energy contained within a unit volume).

Table 2. Median natural and existing ambient sound levels and aircraft statistics for all sites.

Site Name	Year	LA10*	LAnat*	LA50*	LA90*	Median Noise Free Interval*	Time Audible, Aircraft	Median Aircraft per Day	Median Aircraft Max SPL*
Amalik Bay	2017	37.5	30.8	32.5	28.6	0.12	5.8	5	51.6
American Creek	2016	38.1	24.4	26.8	21.5	0.11	23.0	45	51.6
Contact Lake	2017	28.6	22.0	22.1	19.5	0.36	5.4	10	51.2
Crosswinds Lake	2017	38.2	22.8	24.6	20.0	0.08	19.2	49	55.7
Douglas River	2016	40.9	37.4	37.5	34.2	0.84	1.7	3	53.2
Dumpling Point	2016	32.9	25.5	26.3	22.8	0.13	16.8	32	40.3
East Kulik Lake	2017	44.0	41.1	41.3	38.2	0.45	4.5	13	45.7
Hallo Bay	2016	42.1	36.2	37.4	33.9	0.05	5.6	11	62.5
Jo-Jo Lake	2016	39.3	31.7	31.9	27.3	0.35	5.7	10	44.2
Kamishak River	2017	32.4	23.0	24.4	20.3	0.12	8.6	16	52.8
Katmai Bay	2016	44.6	41.1	41.1	37.6	0.95	0.7	2	55.6
Pfaff Mine	2015	35.1	30.3	30.5	27.3	0.25	5.6	21	34.1
Savonoski Lake	2017	42.0	35.2	35.4	30.1	1.06	2.5	5	48.9

*LA_{nat}, LA_{10}, LA_{50}, LA_{90}, and SPL in dB Noise-Free Interval in hours.

Table 2 (continued). Median natural and existing ambient sound levels and aircraft statistics for all sites.

Site Name	Year	LA10*	LAnat*	LA50*	LA90*	Median Noise Free Interval*	Time Audible, Aircraft	Median Aircraft per Day	Median Aircraft Max SPL*
Swikshak Lagoon	2015	39.4	35.0	35.2	32.3	0.28	4.6	10	52.6
Valley of Ten-Thousand Smokes	2015	30.3	23.8	23.8	20.9	0.82	1.7	4	40.6

*LA_{nat}, LA_{10}, LA_{50}, LA_{90}, and SPL in dB Noise-Free Interval in hours.

Table 3. Median statistics for watercraft, where observed.

Site Name	Year	Time Audible (%)	Events Per Day	Max $LA_{eq, 1s}$ (dB)
Amalik Bay*	2017	27.9	7	48.8
American Creek	2016	0.1	5.5	38.4
Douglas River**	2016	1.0	4	39.9
Dumpling Point	2016	2.1	4	47.4
Hallo Bay**	2016	0.2	3	48.3
Kamishak River	2017	4.7	14	47.9
Katmai Bay	2016	0.2	1.5	41.6

*Marine generators contribute to time audible.

As described in the section Study Area and Site Selection, above, the inventory was deliberately designed to allow for spatial inferences into the processes that produce noise. It is useful to visualize geographic relationships within the data using maps. One such map is shown in Figure 4, and many more are included in Appendix B. Figure 4 visually represents the “median aircraft per day” column from Table 2. It shows the typical number of propeller aircraft noise events experienced daily during each sampling period.

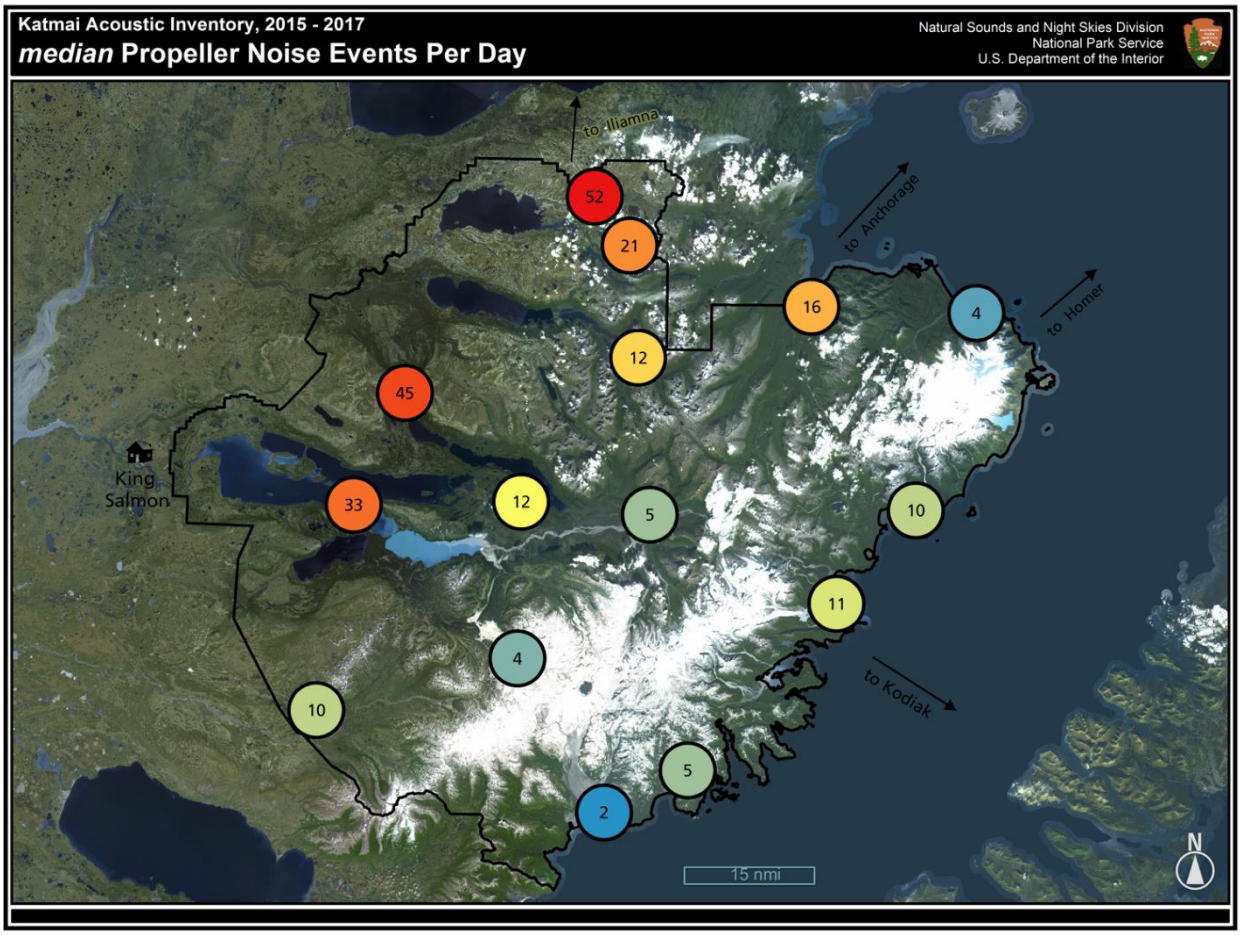


Figure 4. Map showing the median number of propeller noise events per day at inventory sites.

Site-Specific Summaries

The following sections of this report present specific results for each inventory site, as well as metadata. Detailed information about the position of the microphone is emphasized to provide contextual information that may influence the way the data are interpreted and to inform long-term monitoring at these sites.

Each section summarizes SPL observations and information on the timings, durations, and Amplitudes of annotated noise events. Discussion of unique Intrinsic Sounds or important explanatory observations are also included to help management understand the acoustic environment on the local scale.

Amalik Bay

Location Description: A low rocky bench above the western shore of Geographic Harbor – the protected inner portion of Amalik Bay. Site is about 35 (line-of-sight) meters from the ocean at low tide (Figures 5 and 6). The mountains surrounding the site form a deep bowl, reaching an elevation of 900 meters within 2 km.

Coordinates: 58.10639°, -154.60167° (WGS84)

Elevation: 13 meters (42 feet)

Sampling Period: 29-July-2017 to 12-August-2017

Management Unit: Katmai National park, Eligible Wilderness, near National Historic Landmark

Ecotypes: Barrier Range Mountains – South, Viereck Class III.A.2.b *Bluejoint Herb*

Access: DeHavilland DHC-2 on floats

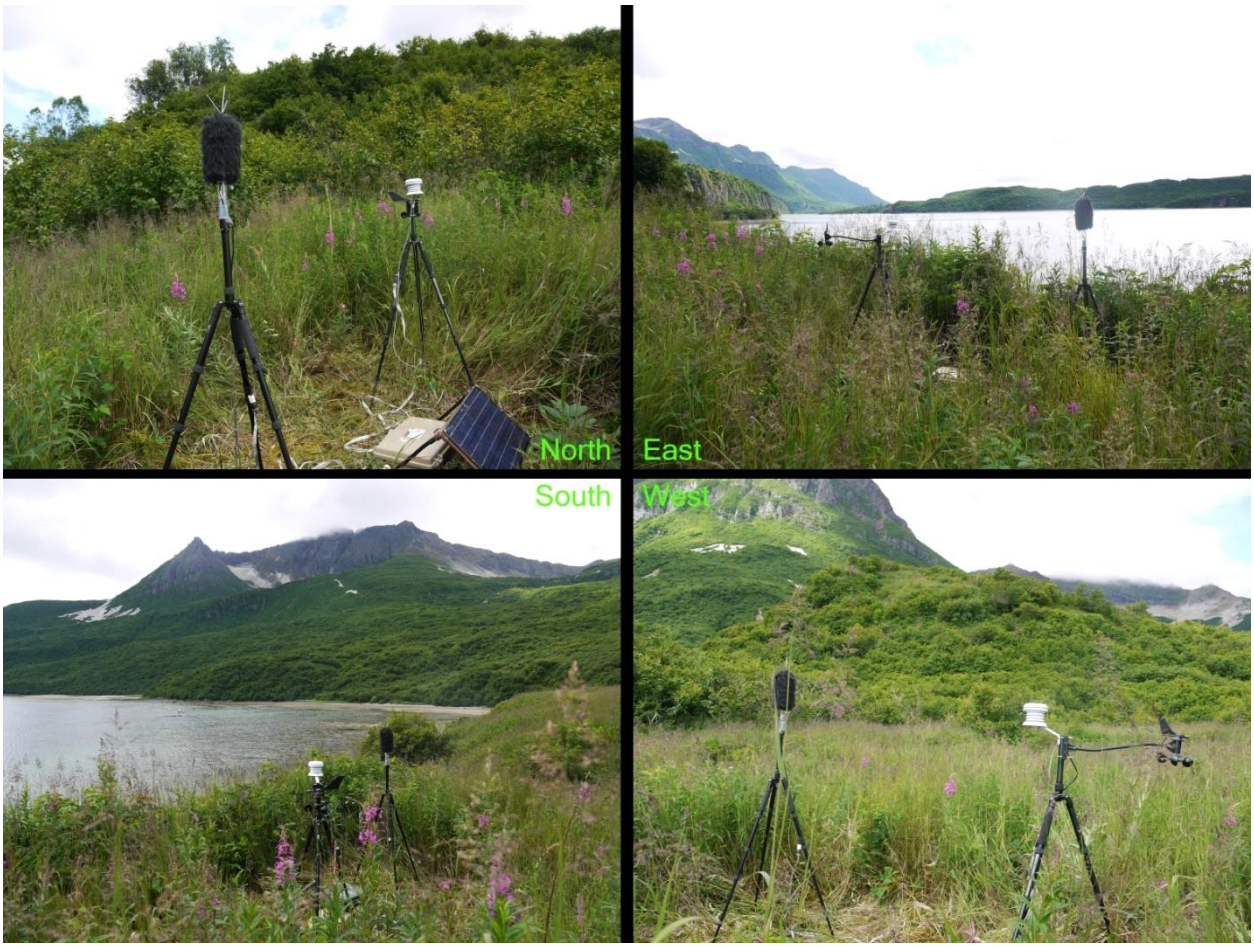


Figure 5. Cardinal photographs from the Amalik Bay inventory site.

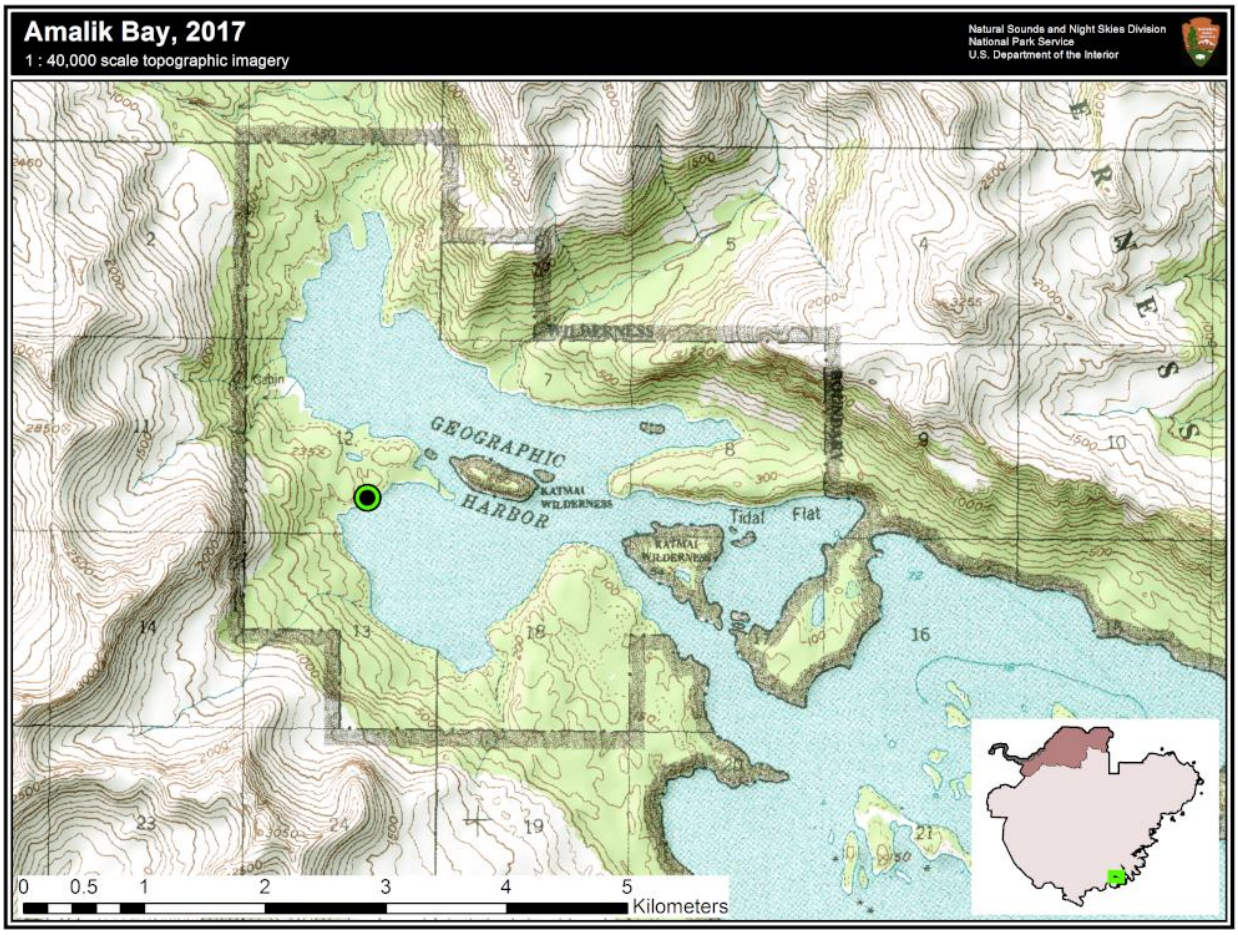


Figure 6. Topographic map of Amalik Bay at a 1:40,000 scale. The inset map in the lower-right corner indicates the location of the frame within Katmai. Light brown areas represent park land and darker brown areas show preserve land.

Summary: The densely-vegetated shoreline landscape of the Amalik Bay inventory site had a time-averaged natural ambient sound pressure level (LA_{nat}) of 30.8 dB. The 90th percentile of sound pressure levels (LA_{10}) was 37.5 dB, and the 10th percentile (LA_{90}) was 28.6 dB, a difference of 8.9 dB. Though the beach is protected, wave energy was prominently audible at times – most often for 1 to 3 hours during the mid-day. The dissipation of energy by fireweed and grass on windy days likely contribute to the considerable high-frequency energy at the site (see Figure 7). Dense surface vegetation was typical of many of locations sampled in this inventory; for examples, see Douglas River, Kamishak River, and Savonoski Lake.

Jet aircraft noise (Figures 8–12) event rates at the site were relatively high for KATM (time audible = 3.1% of entire record); this is likely due to great circle routes from Anchorage to Asia that overlap the southern portion of the park, as occurs in Katmai Bay. Median propeller noise event rates were among the lowest in the park, at five per day.

In comparison, watercraft – and especially marine generators – were far more impactful at Amalik Bay (time audible = 27.9% of entire record). One boat's generator was audible from 21:00 on

08/04/2017 through 07:00 on 08/06/2017 - 35 hours of continuous noise. This event represents the longest unbroken event (created by a transportation source) documented by a sound station in Alaska Region parks to date. Marine generator signatures appear on the spectrogram as long-duration signals in the 20 to 63 Hz bands; however, they are usually only audible when there is also energy present in the 120 Hz band or greater. Generators were visible on the spectrogram for much of the Amalik Bay record, but they were usually inaudible, suggesting that areas of the bay closer to places where boats anchor may be impacted by significantly longer periods of marine generator noise.

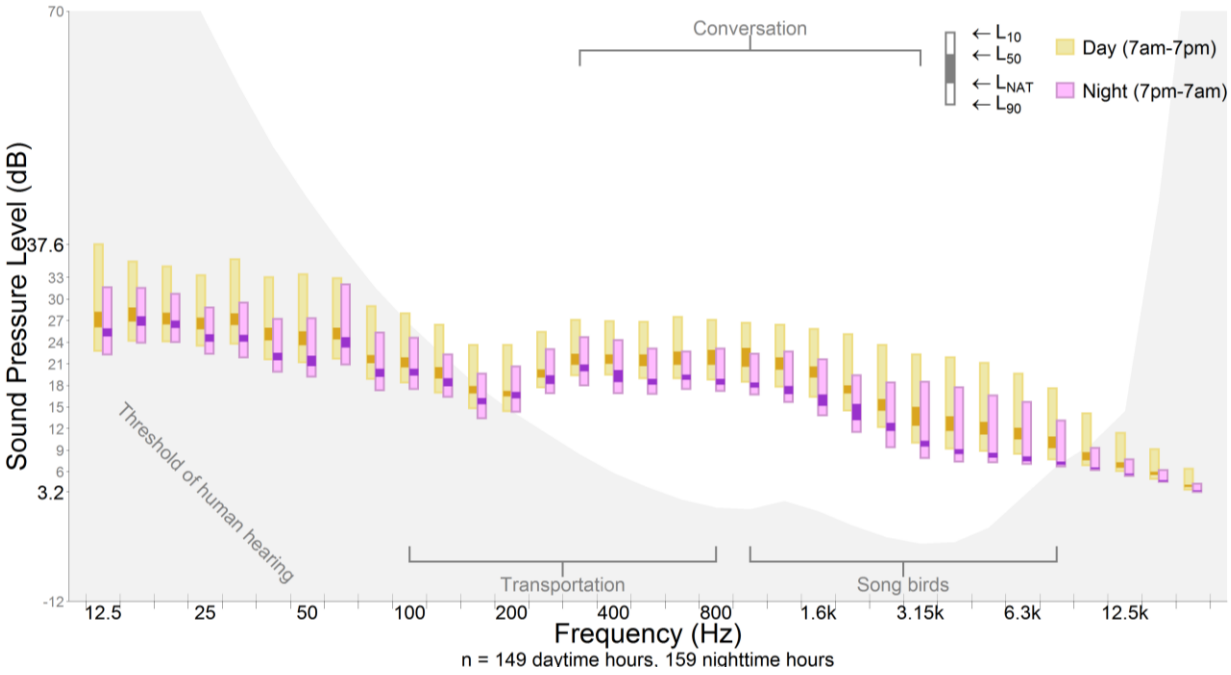


Figure 7. Spectral percentile levels for Amalik Bay, 2017.

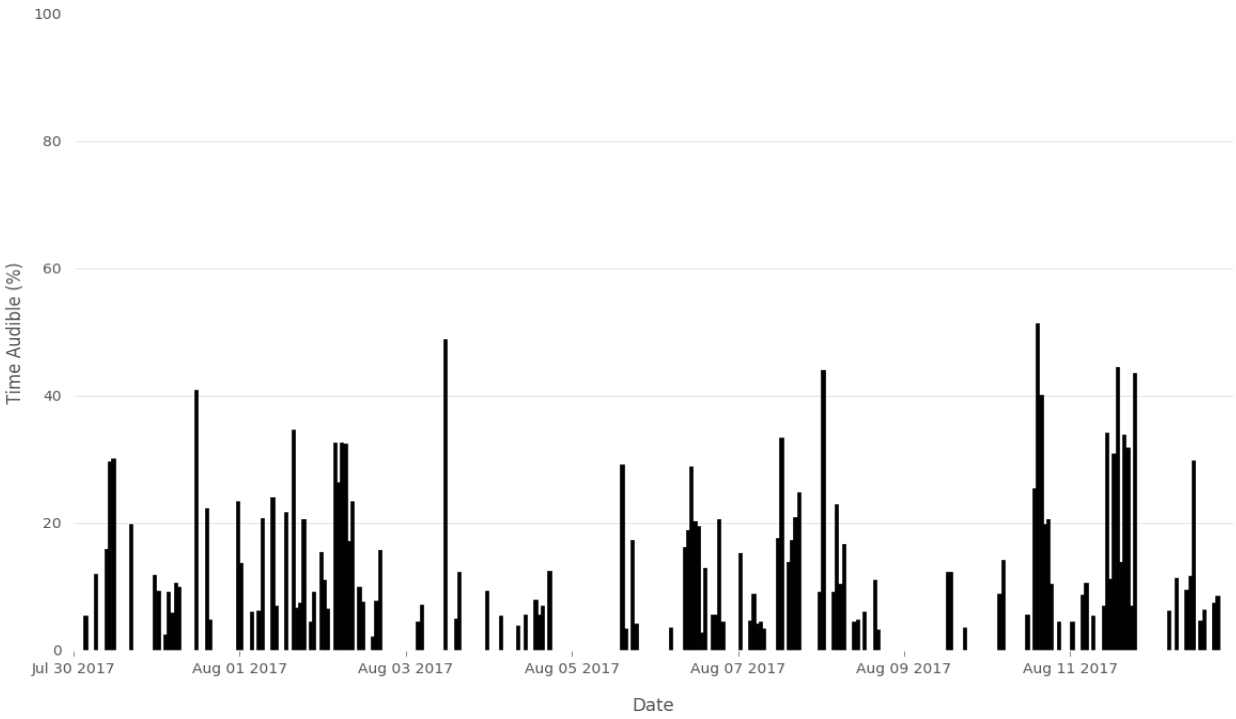


Figure 8. Audibility of aircraft noise by hour at Amalik Bay, 2017.

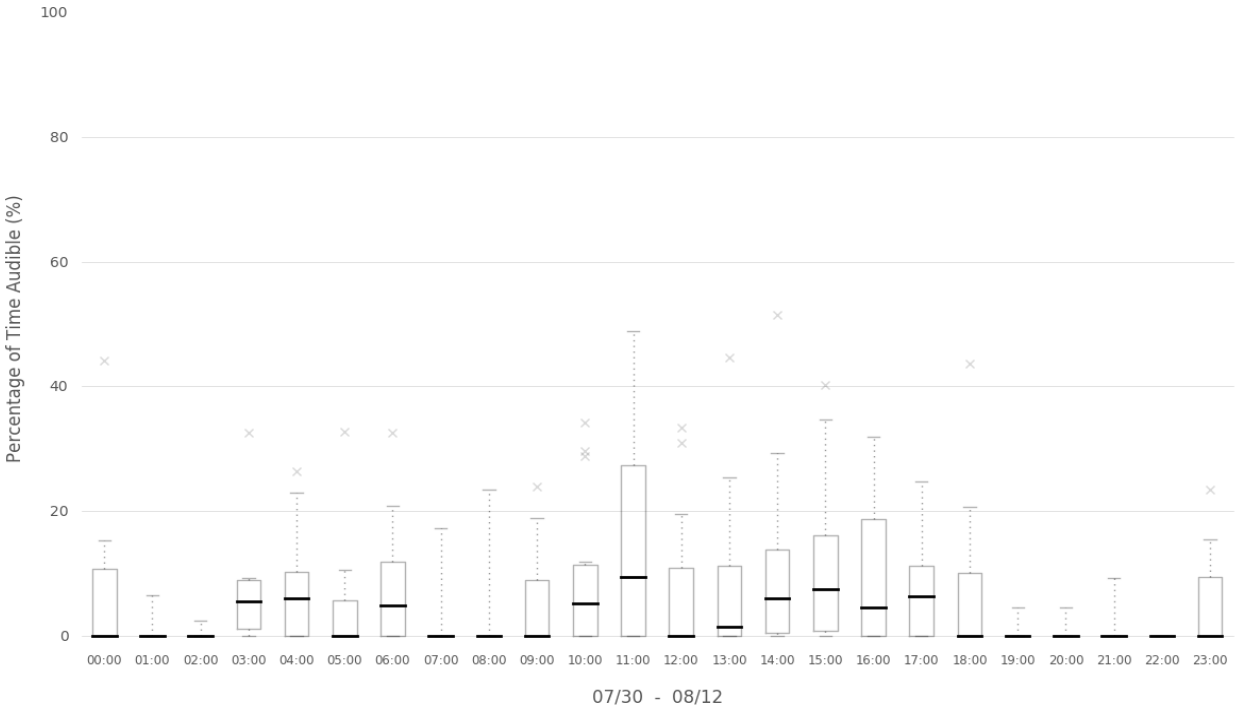


Figure 9. Audibility of aircraft noise for an average day, by hour, at Amalik Bay, 2017. The bold line indicates the median (50th percentile) value, the top of the box is the 75th percentile, and the bottom is the 25th percentile. The dashed flyers show 1.5x the interquartile range. Values outside this range are considered outliers and marked with an ‘x’.

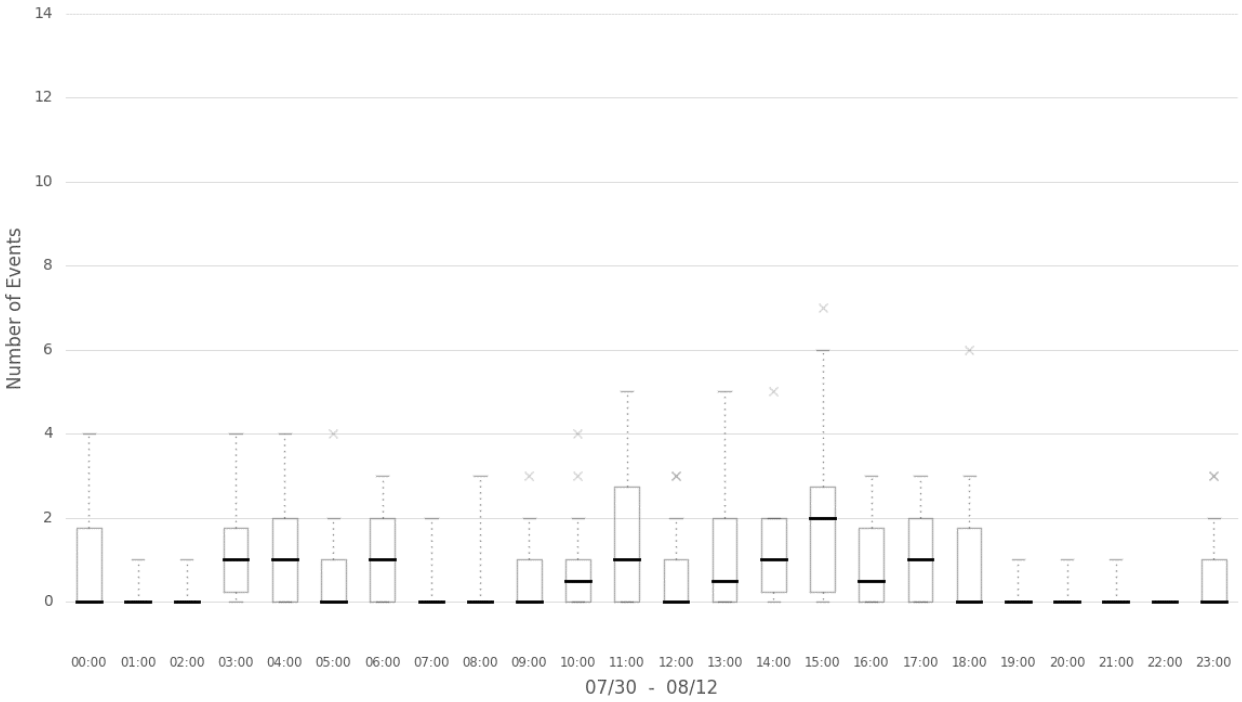


Figure 10. Rates of detection for aircraft noise events by hour at Amalik Bay, 2017.

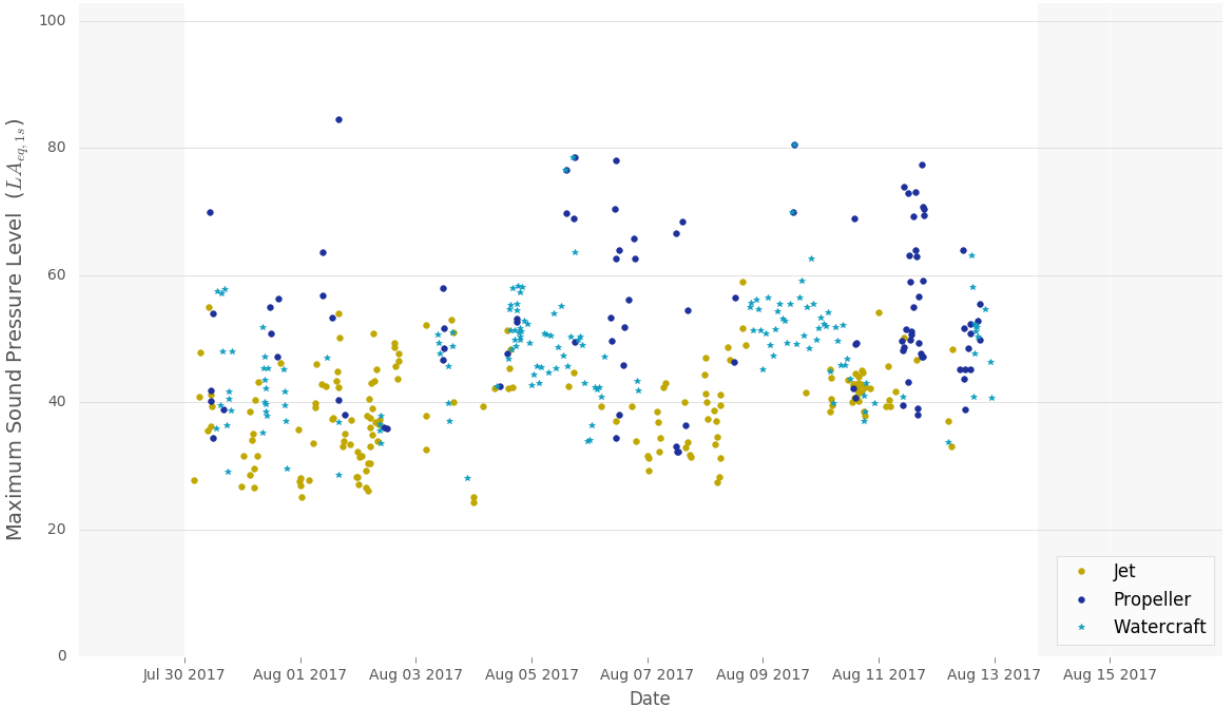


Figure 11. Maximum one-second sound pressure levels for each noise event detected at Amalik Bay, 2017.

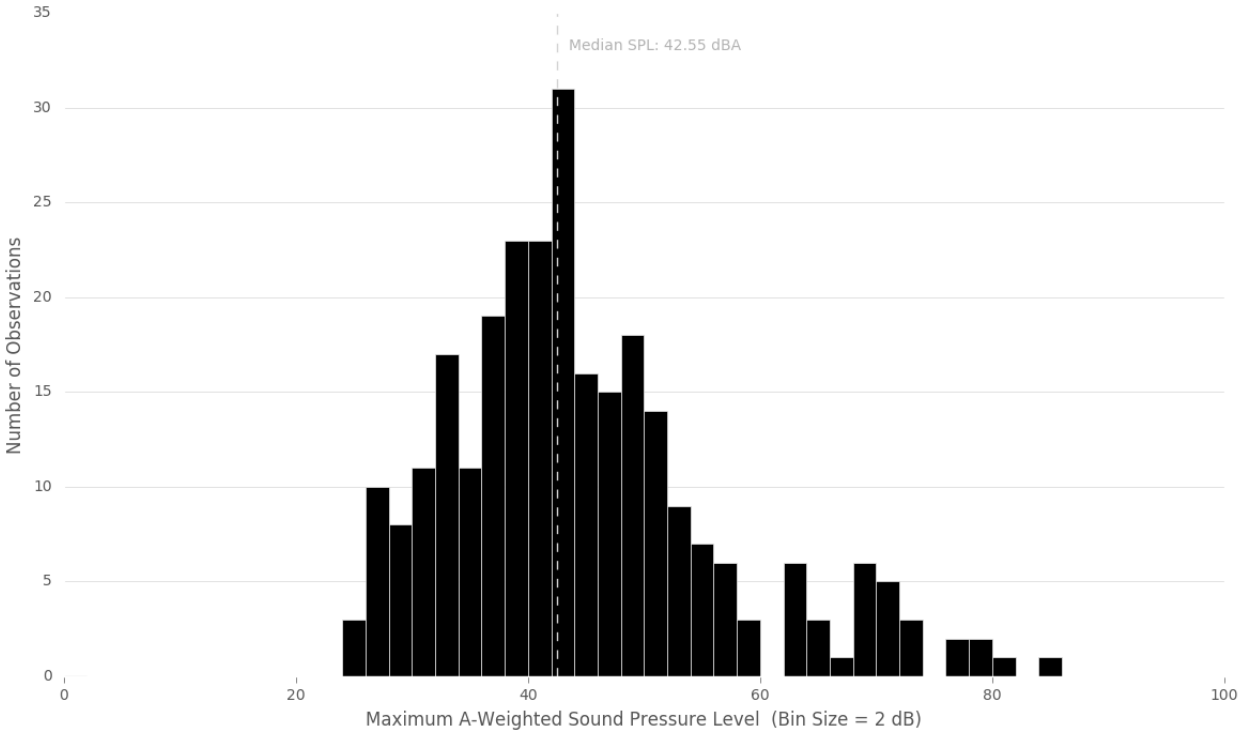


Figure 12. Histogram of maximum one-second LA_{eq} sound pressure levels for aircraft noise events detected at Amalik Bay, 2017.

American Creek

Location Description: The site was located at the top of a small knoll 1.5 km upstream from the mouth of American Creek where it empties into Coville Lake (Figures 13 and 14). The knoll was surrounded on most sides by wetland habitat of emergent grasses.

Coordinates: 58.82051°, -155.66612° (WGS84)

Elevation: 58 meters (190 feet)

Sampling Period: 22-June-2016 to 21-July-2016

Management Unit: Katmai National Park, Designated Wilderness

Ecotypes: Coville Lake Deposits, Viereck Class I.B.1.d. *Closed Paper Birch Forest*

Access: DeHavilland DHC-2 on floats



Figure 3. Cardinal photographs from the American Creek inventory site.

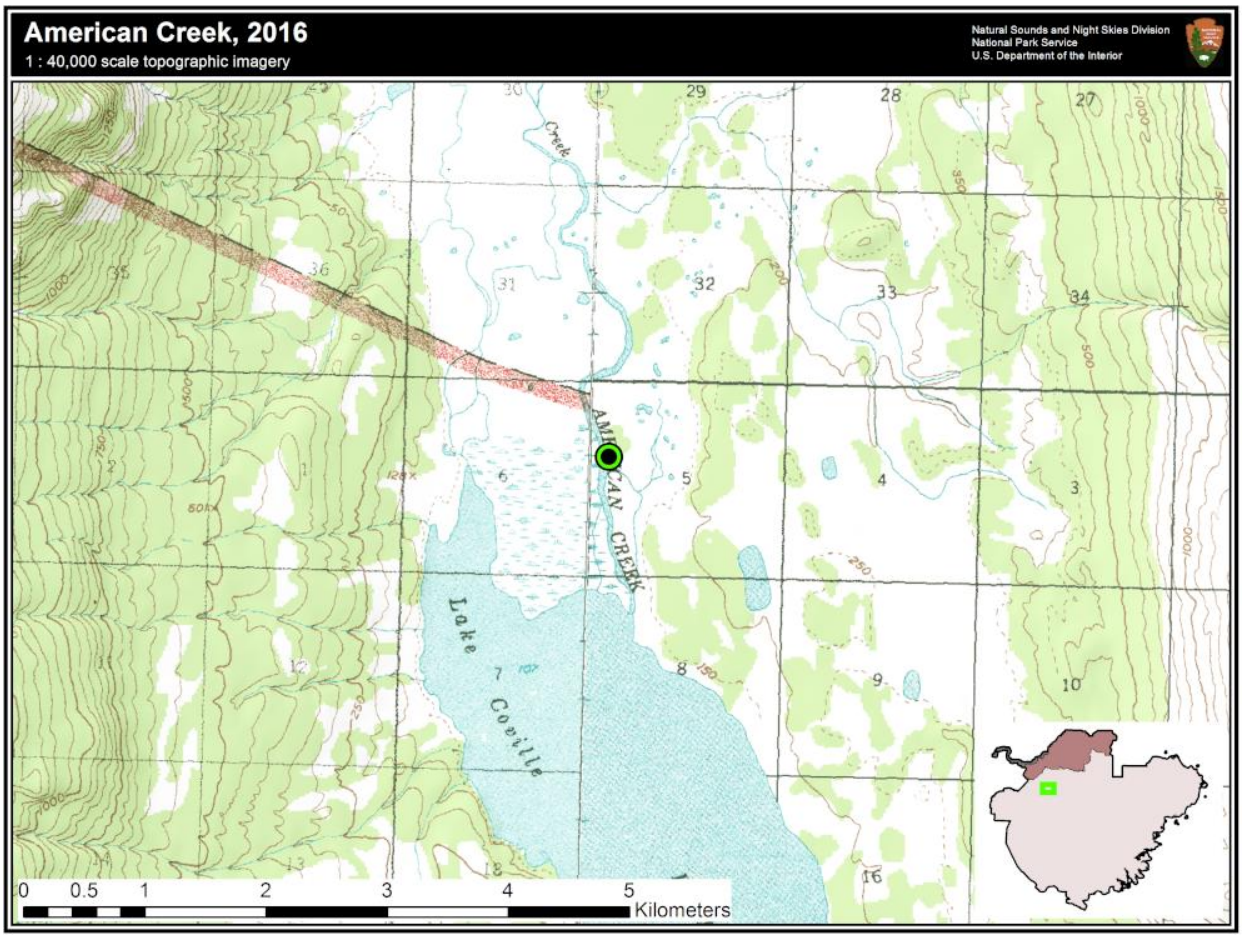


Figure 4. Topographic map of the American Creek site at 1:40,000 scale. The inset map in the lower-right corner indicates the location of the frame within Katmai. Light brown areas represent park land and darker brown areas show preserve land.

Summary: The canopied forest landscape of the American Creek inventory site had a time-averaged natural ambient sound pressure level (LA_{nat}) of 24.4 dB. Close to the mouth of American Creek, the water is slow-moving and inaudible on the record. As a result, it contributes little to this ambience. The 90th percentile of sound pressure levels (LA_{10}) was 38.1 dB, and the 10th percentile (LA_{90}) was 21.5 dB, resulting in a large difference of 16.6 dB. This difference is likely associated with the influence of chronic noise (time audible = 23.1% of entire record), which was easily extensive enough to influence long-term summary metrics like LA_{10} (Figure 15).

Avian song was a prominent component of American Creek's acoustic environment during the June/July sampling period. Mallard, Arctic Tern, Lesser Yellowlegs, Wilson's Snipe, Black-billed Magpie, Alder Flycatcher, Lincoln's Sparrow, Orange-crowned Warbler, Yellow Warbler, and Myrtle Warbler were all observed on the audio record.

The landscape in the vicinity of the site contains prominent human modifications, including a cleared campsite, a food cache, and a social trail. However, during deployment no people approached the equipment. At least four watercraft (owned by a variety of lodges) are stored directly below and

adjacent to the site location. During site install a jet boat was seen and heard operating on Colville Lake, at least 1.8 km away. Despite their presence, watercraft only contribute moderately to noise impacts at American Creek (median 6 noise events per day, time audible = 0.1% of entire record).

By contrast, propeller aircraft (Figures 16–20) contribute chronic noise impacts (median 45 noise events per day, time audible = 19.9% of entire record). While on site, staff observed several propeller takeoffs. By the time the aircraft were airborne they were at the same altitude as the recording equipment. They resulted in maximum SPLs of 78 - 80 dB ($LA_{eq,\ 1s}$) at the equipment. Such events were a common occurrence at American Creek, as shown in Figure 19 and the right-skewed histogram in Figure 20.

Patterns in hourly time audible reveal the expected timing of commercial day flights to the area (R. Peterson, personal comm.), with strong peaks at 08:00 and 16:00 (Figure 17). The temporal extent of noise at American Creek suggests that it is among the most impacted sites sampled thus far in the NPS Alaska Region, comparable to the most impacted sites in Denali (see *Ruth Glacier* in Withers and Hults 2006, *Toe of the Tokositna* in Withers 2010, *Triple Lakes Trail* in Withers 2012, *North Triple Lakes* in Betchkal 2013) and an impacted site in Glacier Bay (*Hutchins Bay* in Lynch 2012).

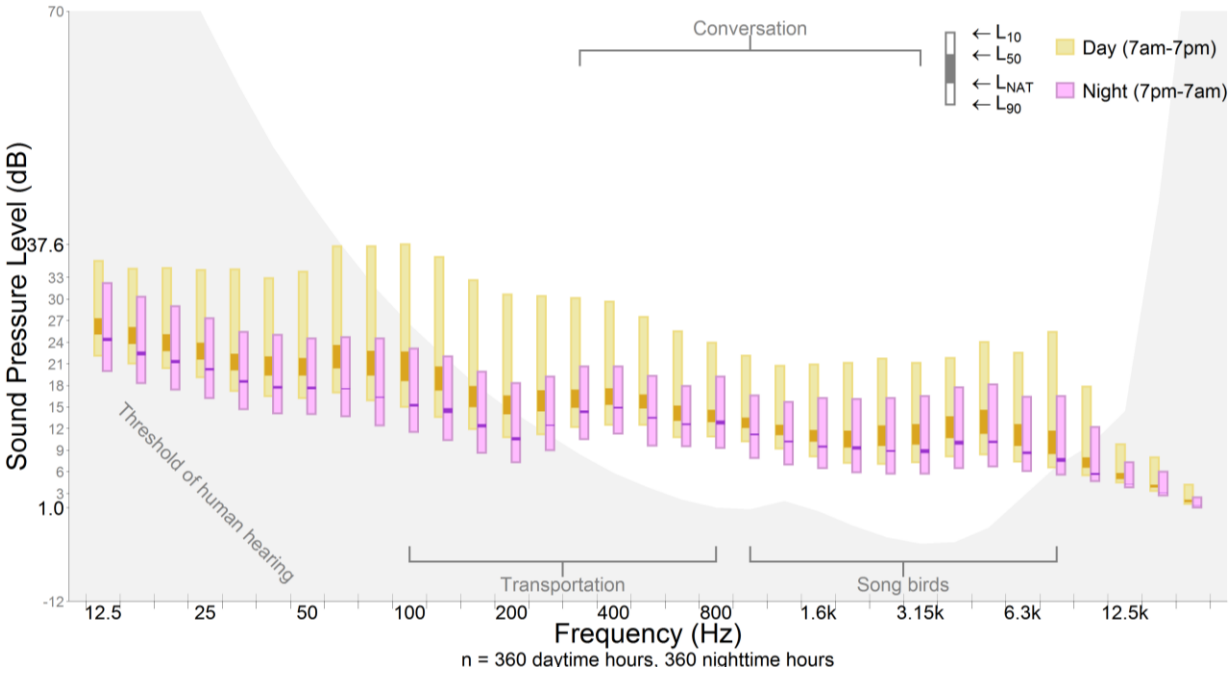


Figure 15. Spectral percentile levels for American Creek, 2016.

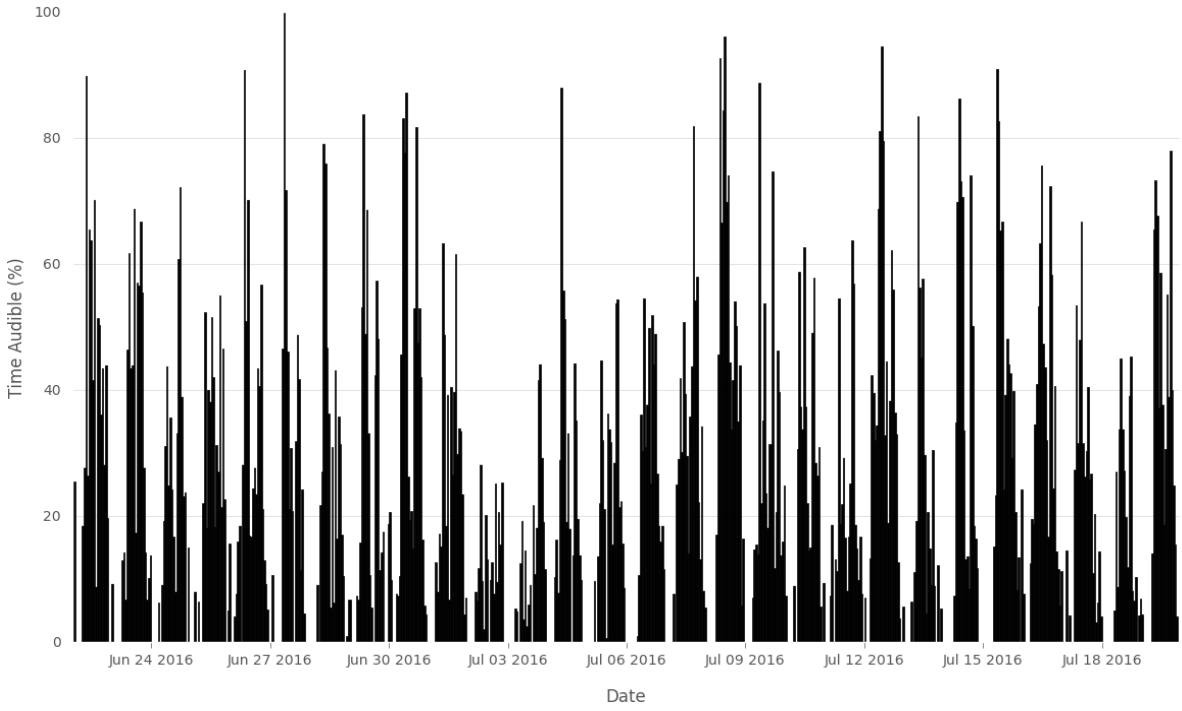


Figure 16. Audibility of aircraft noise by hour at American Creek, 2016.

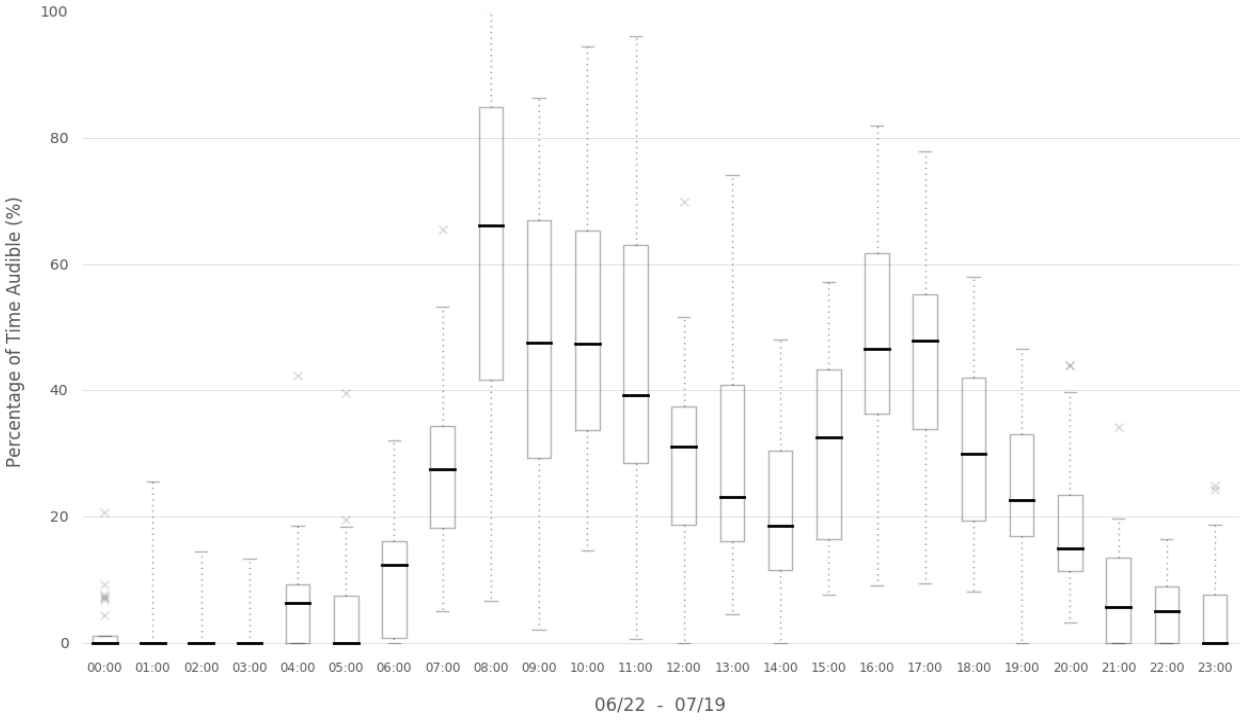


Figure 17. Audibility of aircraft noise for an average day, by hour, at American Creek, 2016. The bold line indicates the median (50th percentile) value, the top of the box is the 75th percentile, and the bottom is the 25th percentile. The dashed flyers show 1.5x the interquartile range. Values outside this range are considered outliers and marked with an ‘x’.

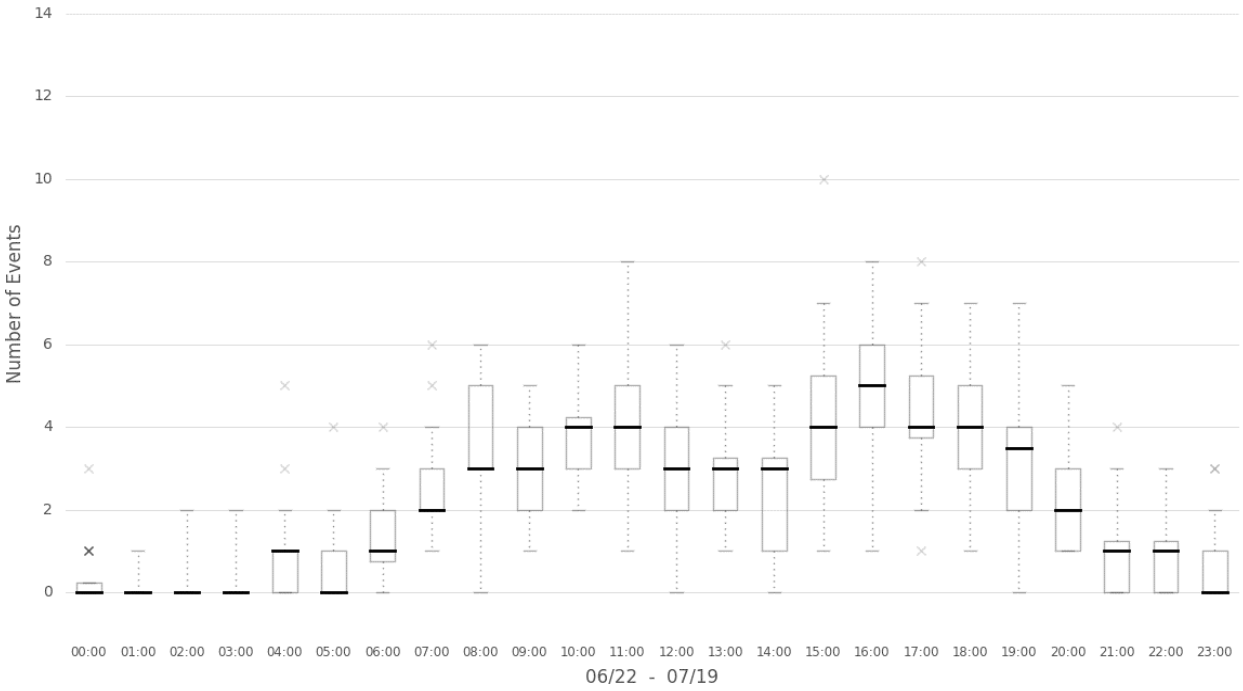


Figure 18. Rates of detection for aircraft noise events by hour at American Creek, 2016.

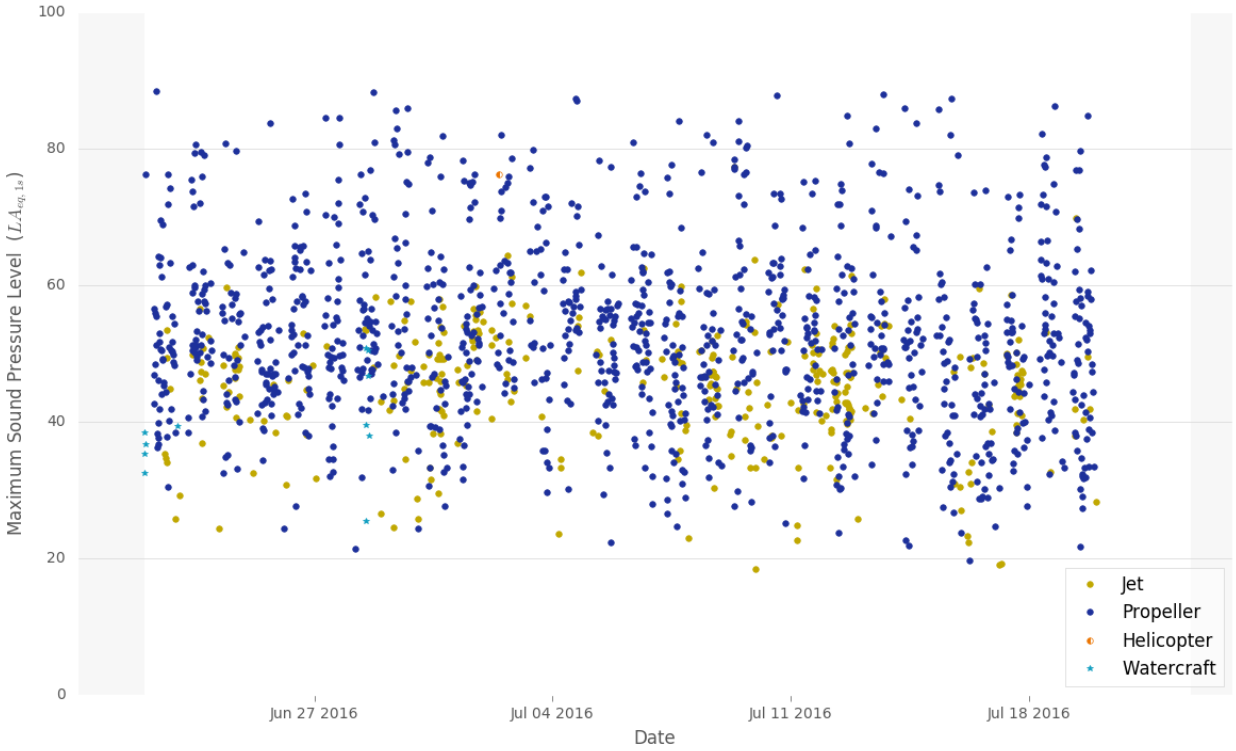


Figure 19. Maximum one-second sound pressure level for each noise event detected at American Creek, 2016.

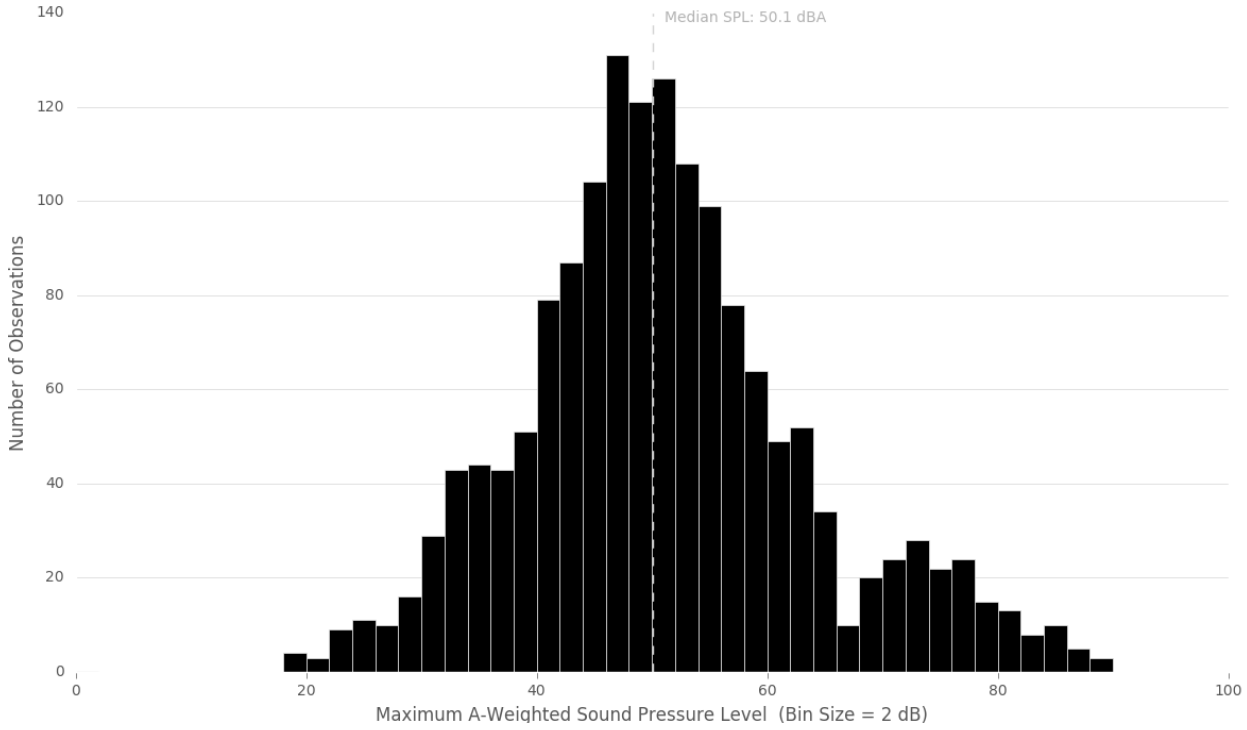


Figure 20. Histogram of maximum one-second sound pressure levels for aircraft noise events detected at American Creek, 2016.

Contact Lake

Location Description: The site was located about 2.4 km west of the gravel airstrip on Contact Creek and 6.1 km northeast of Katmai's boundary where it adjoins Becharof National Wildlife Refuge (Figures 21 and 22). At a local scale, the site is on the southwest shore of Contact Lake. It is protected from wind behind a low earthen mound. Immediately adjacent to the site is a wetland with emergent vegetation.

Coordinates: 58.20800°, -155.96103° (WGS84)

Elevation: 178 meters (583 feet)

Sampling Period: 28-June-2017 to 26-July-2017

Management Unit: Katmai National Park, Designated Wilderness

Ecotypes: Lowland Outwash and Drift Deposits, Viereck Class III.A.3.b. *Wet Graminoid Herbaceous*

Access: DeHavilland DHC-2 on floats



Figure 21. Cardinal photographs from the Contact Lake inventory site.

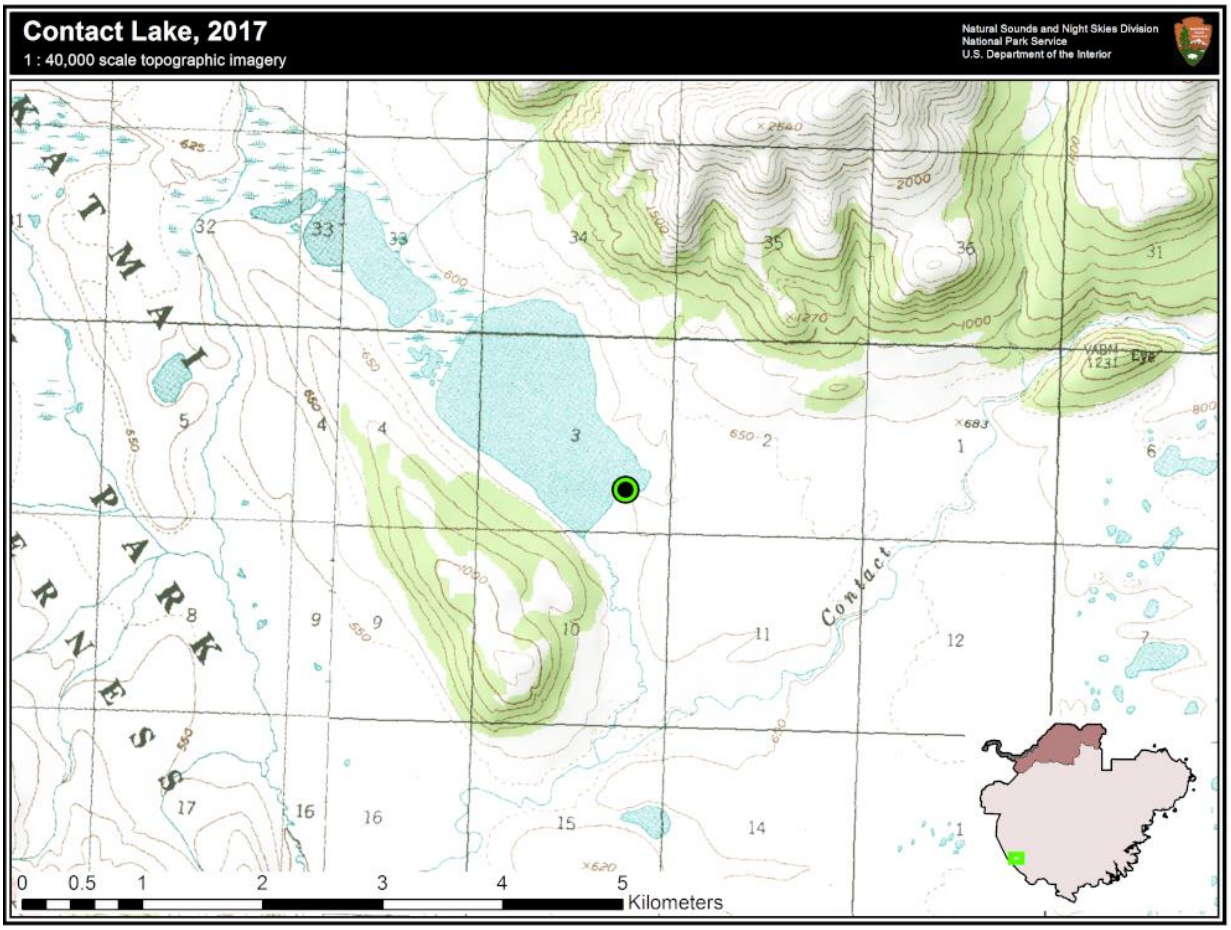


Figure 5. Topographic map of Contact Lake at a 1:40,000 scale. The inset map in the lower-right corner indicates the location of the frame within Katmai. Light brown areas represent park land and darker brown areas show preserve land.

Summary: The open wetland landscape of the Contact Lake inventory site had a time-averaged natural ambient sound pressure level (LA_{nat}) of 22.0 dB. The 90th percentile of sound pressure levels (LA_{10}) was 28.6 dB, and the 10th percentile (LA_{90}) was 19.5 dB, a difference of 9.1 dB. Contingent on atmospheric conditions, Contact Creek was sometimes audible from 2.1 km away. The energy of flowing water is evident as a minor peak centered on the 500 Hz band in Figure 23. Despite the influence of running water and the exposed nature of the site, Contact Lake was the least energetic natural acoustic environment documented during the inventory.

Avian species heard on the record included Wilson's Snipe, Lesser Yellowlegs, Arctic Tern, Savannah Sparrow, and American Tree Sparrow. Other unidentified waterfowl and shorebird species were also heard.

Aircraft noise data are shown in Figures 24-28. Float plane takeoffs with maximum one-second SPLs ($LA_{eq, 1s}$) in the 70 – 100 dB range occurred on the lake during the sampling period (Figure 27, Figure 28). Takeoffs represent 23% of propeller aircraft noise events at Contact Lake. The remaining events

were less energetic landings and overflight events. Contact Lake was noisier in the evening, as shown in Figure 25 and Figure 26.

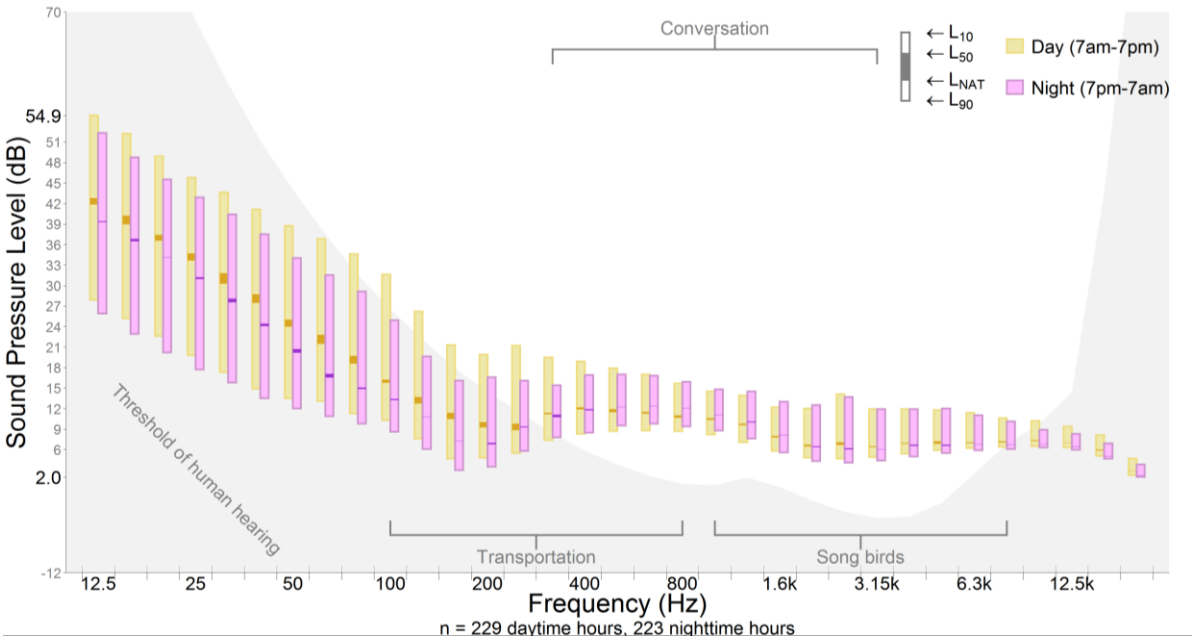


Figure 23. Spectral percentile levels for Contact Lake, 2017.

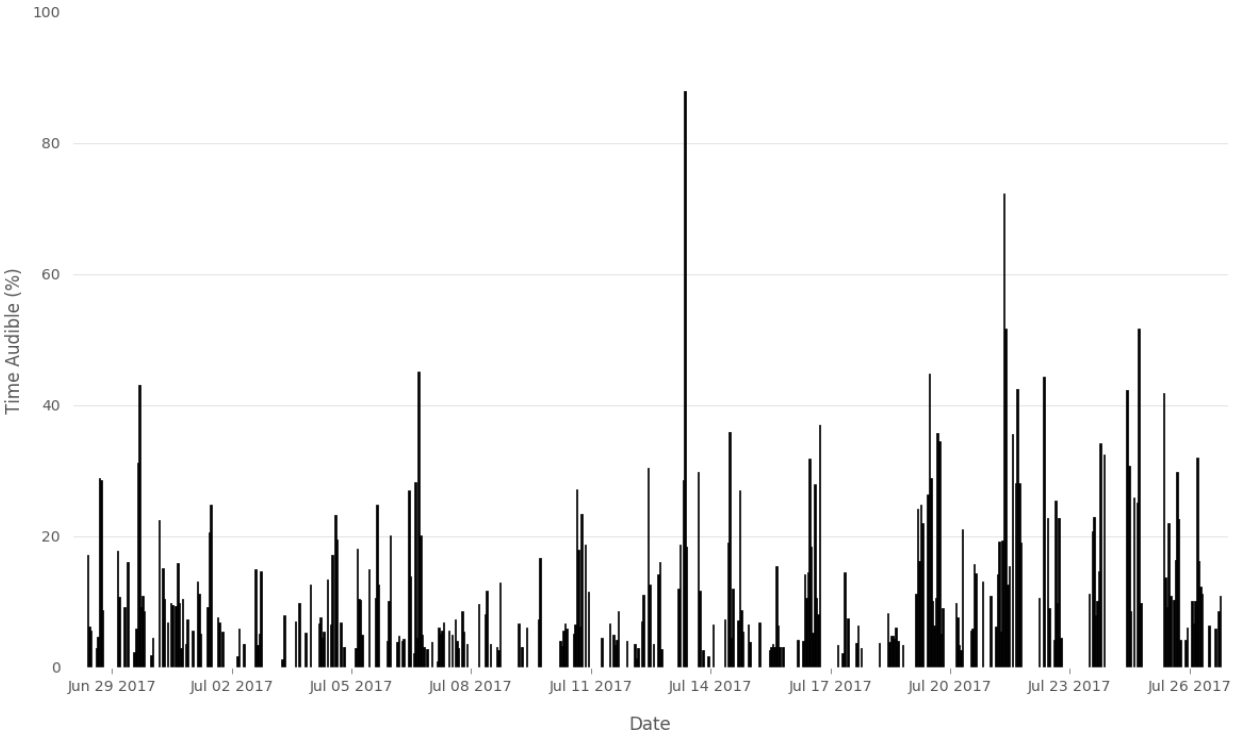


Figure 24. Audibility of aircraft noise by hour at Contact Lake, 2017.

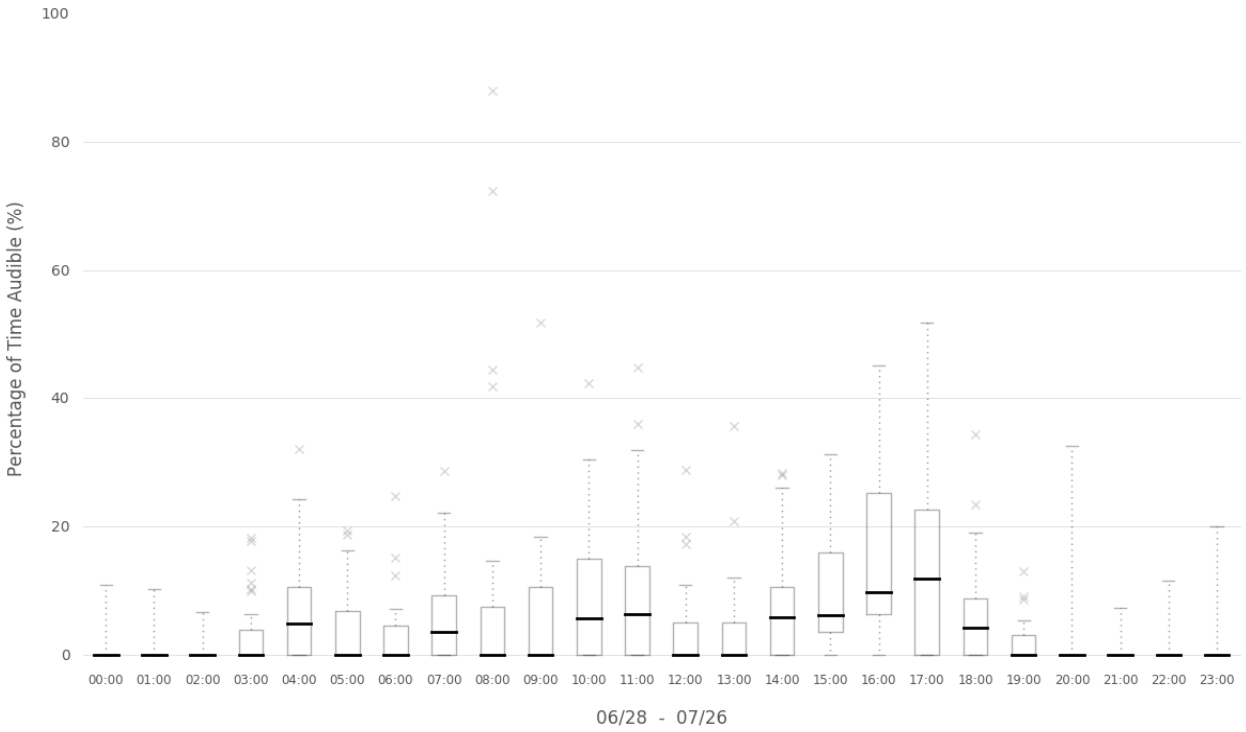


Figure 25. Audibility of aircraft noise for an average day, by hour, at Contact Lake, 2017. The bold line indicates the median (50th percentile) value, the top of the box is the 75th percentile, and the bottom is the 25th percentile. The dashed flyers show 1.5x the interquartile range. Values outside this range are considered outliers and marked with an ‘x’.

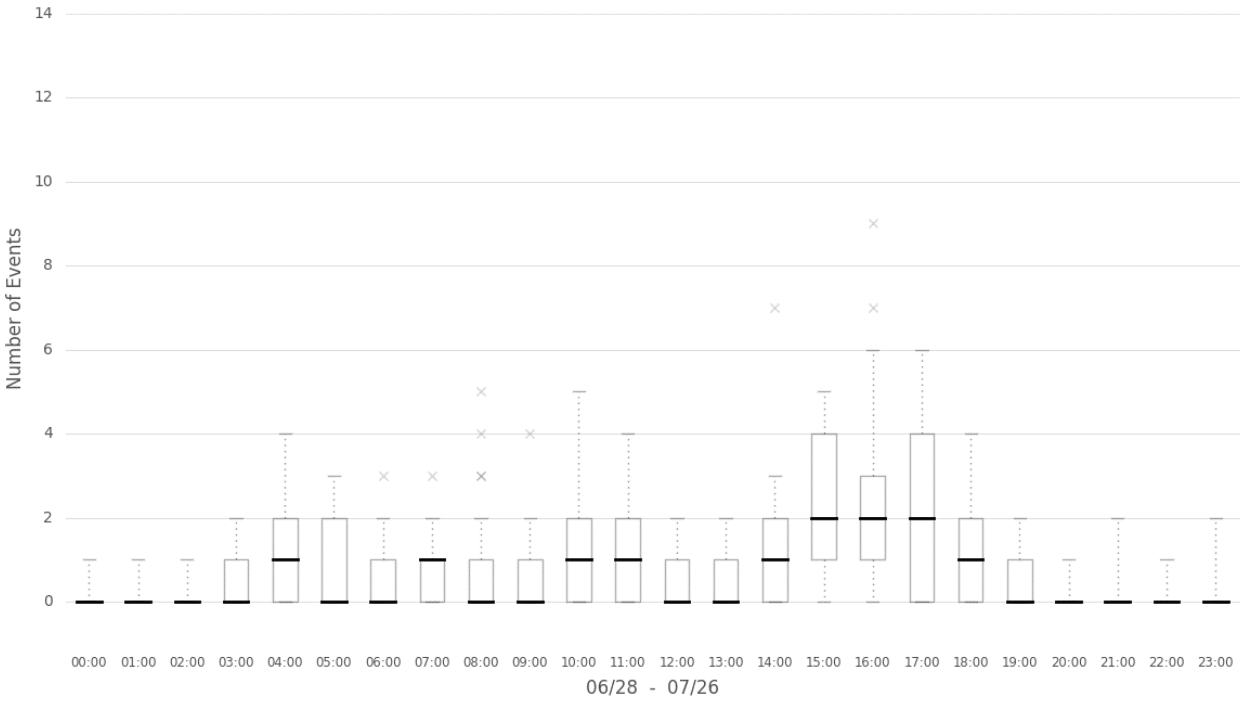


Figure 26. Rates of detection for aircraft noise events by hour at Contact Lake, 2017.

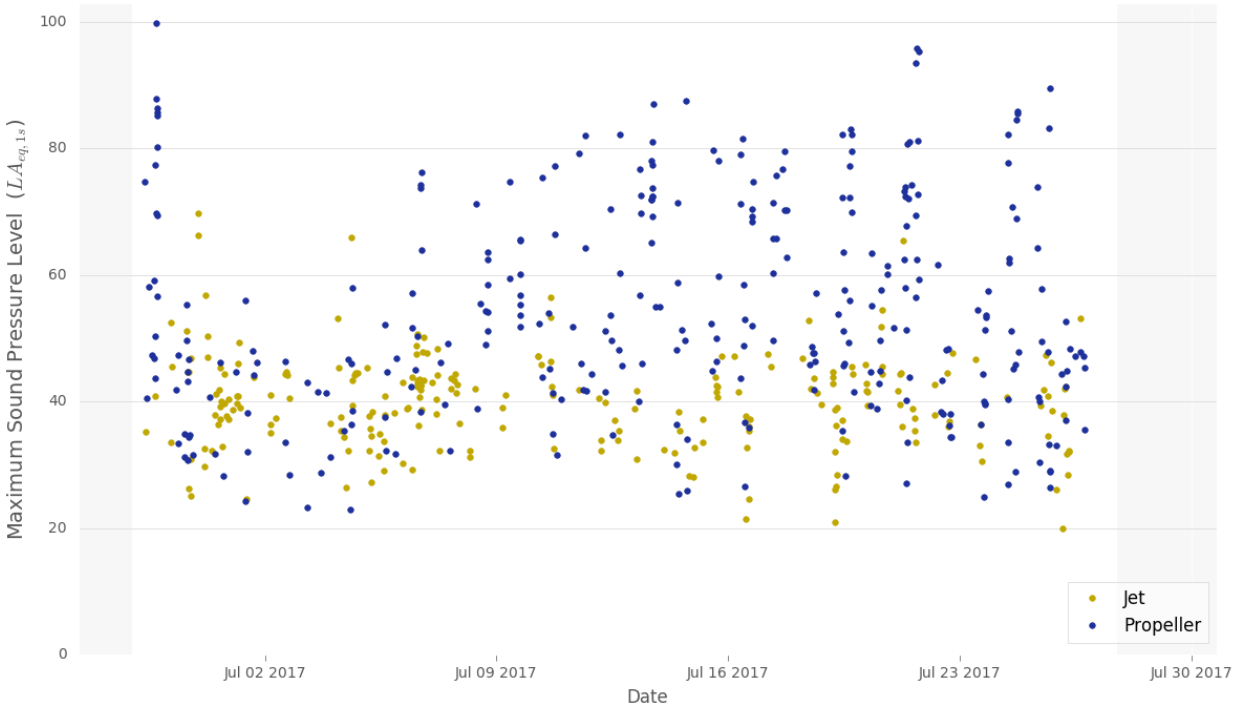


Figure 27. Maximum one-second sound pressure level for each noise event detected at Contact Lake, 2017.

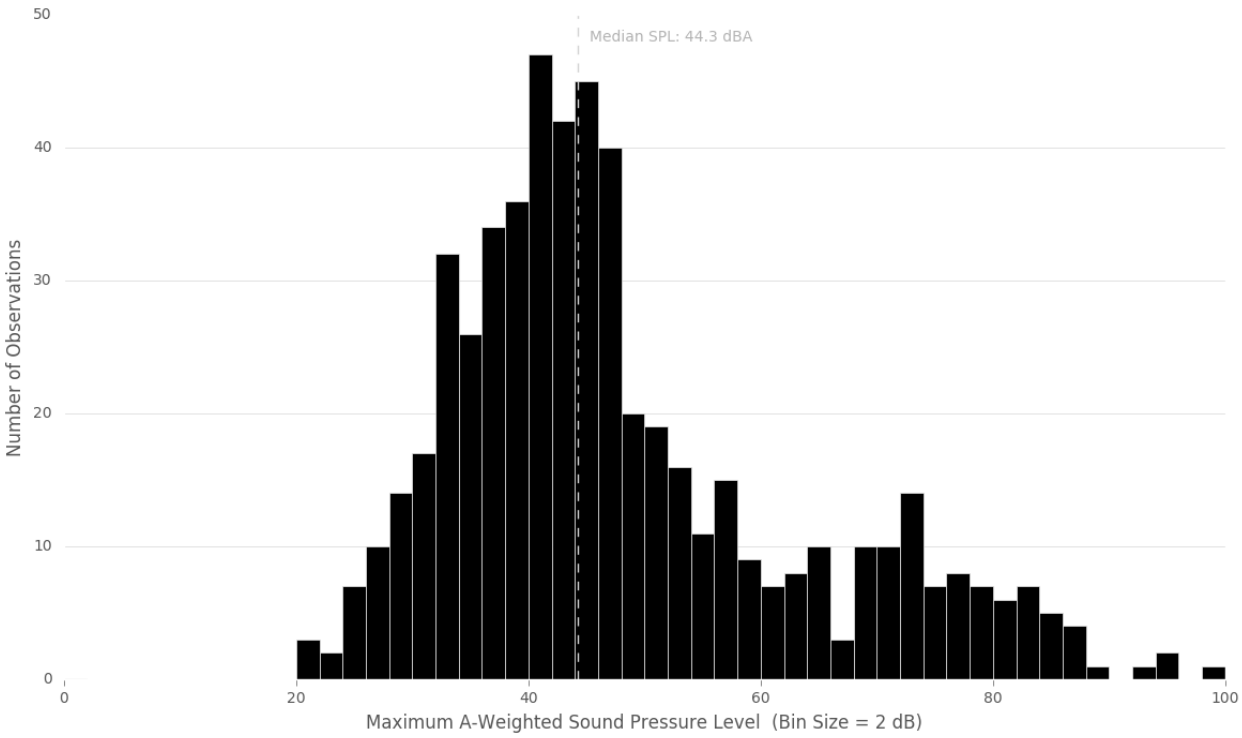


Figure 28. Histogram of maximum one-second sound pressure levels for aircraft noise events detected at Contact Lake, 2017.

Crosswinds Lake

Location Description: This site was located 28 meters south of Crosswinds Lake, and 60 – 280 meters south of floatplane mooring areas along the eastern shoreline (Figures 29 and 30). The confluence of Funnel and Moraine creeks is about 0.9 km to the north.

Coordinates: 59.20414°, -154.97101° (WGS84)

Elevation: 294 meters (964 feet)

Sampling Period: 29-July-2017 to 26-August-2017

Management Unit: Katmai National Preserve, Eligible Wilderness

Ecotypes: Kukaklek Lake Moraines, Viereck Class II.C.2.e. *Open Low Ericaceous – Shrub Bog Scrub* and III.C.2.b. *Folicose and Fruticose Lichen*

Access: DeHavilland DHC-2 on floats



Figure 6. Cardinal photographs from the Crosswinds Lake inventory site.

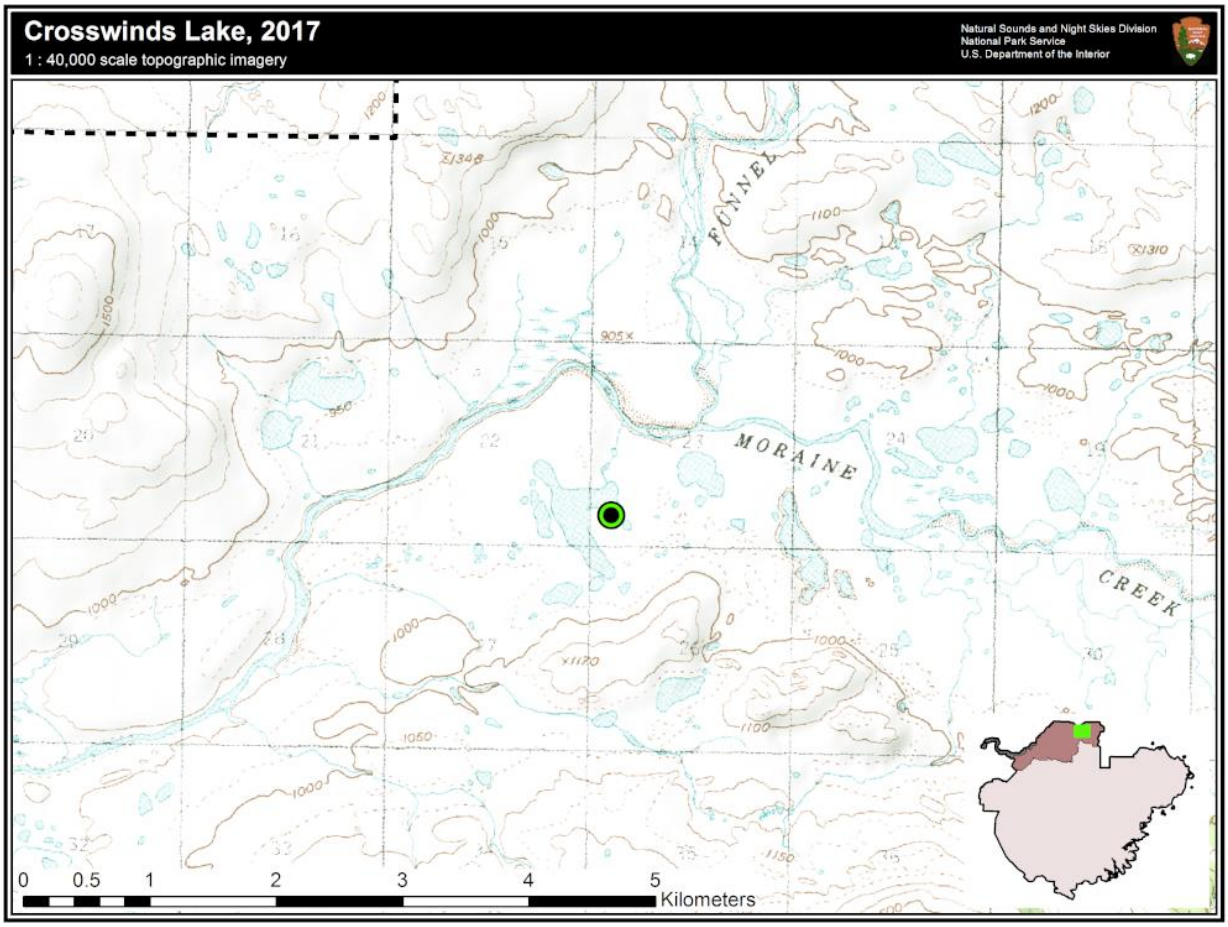


Figure 7. Topographic map of the Crosswinds Lake site at 1:40,000 scale. The dashed black line shows the unit boundary. The inset map in the lower-right corner indicates the location of the frame within Katmai. Light brown areas represent park land and darker brown areas show preserve land.

Summary: The open, pond-pocked landscape of the Crosswinds Lake inventory site had a time-averaged natural ambient sound pressure level (LA_{nat}) of 22.8 dB. The 90th percentile of sound pressure levels (LA_{10}) was 38.2 dB, and the 10th percentile (LA_{90}) was 20.0 dB, making for a very large difference of 18.2 dB. This is due to both wind and the influence of chronic noise, the latter of which was easily extensive enough (time audible = 19.2% of entire record) to influence long-term summary metrics like LA_{10} (Figure 31).

Common Loon and Red-throated Loon were both typical natural sounds of the area.

Aircraft noise data are shown in Figures 32-37. Transportation patterns at the Moraine and Funnel Creek confluence were previously studied from 08/09/2006 through 08/21/2006 (Groth et al 2007). As part of a research project on bear-human interactions, NPS observers documented a total of 301 propeller aircraft events, including takeoffs, landings, and overflights, in the area (the authors suggest this should be considered an undercount). The median number of observed events per day was 25. Over the same date range in 2017, the Crosswinds Lake sound station documented a total of 622

propeller aircraft events, and a median of 50 events per day. This is approximately a doubling of the event rate, with the greatest increases after 10:00, as shown in Figure 35.

Current noise event timing is highly bimodal, with peaks occurring between 08:00 and 10:00 and again between 15:00 and 16:00 (Figure 33, Figure 35). For these hours, noise is audible for approximately half of the time.

Along the shore of Crosswinds Lake, takeoff events produced one-second SPLs (LA_{eq}, 1s) that exceeded 70 dB. Seven percent of all propeller events exceeded 90 dB at the site, and a few exceed 110 dB (Figure 36). It is possible that other areas along the shoreline of Crosswinds Lake experience even higher noise levels.

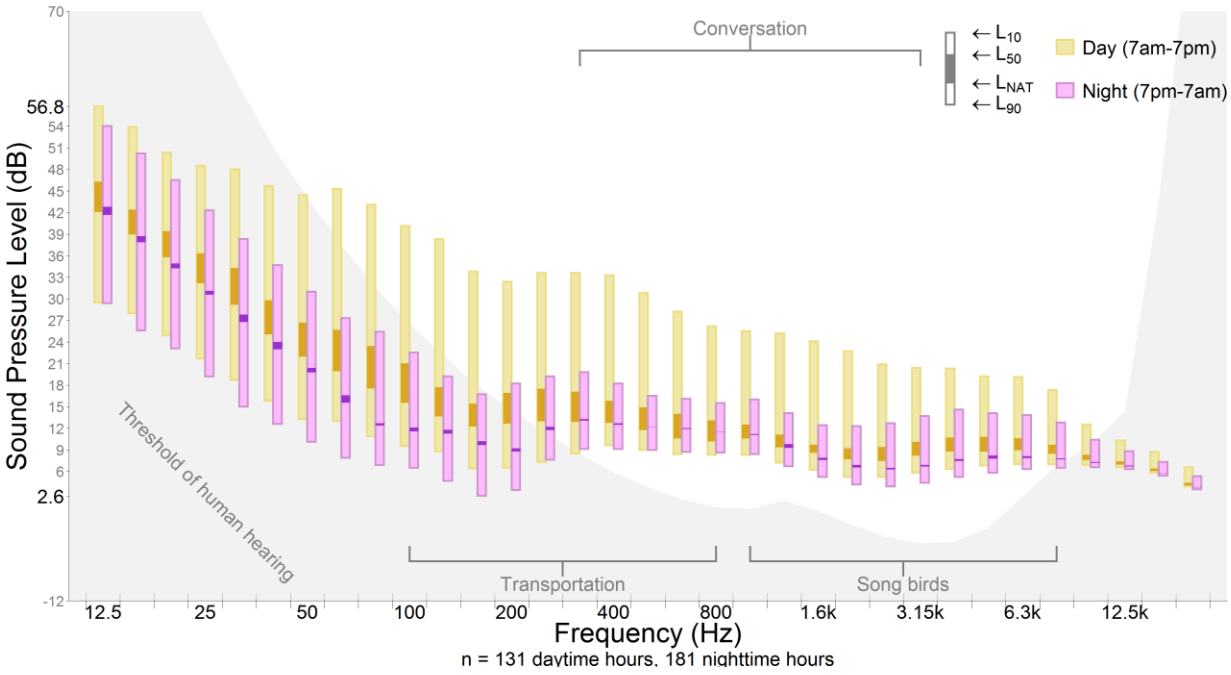


Figure 8. Spectral percentile levels for Crosswinds Lake, 2017.

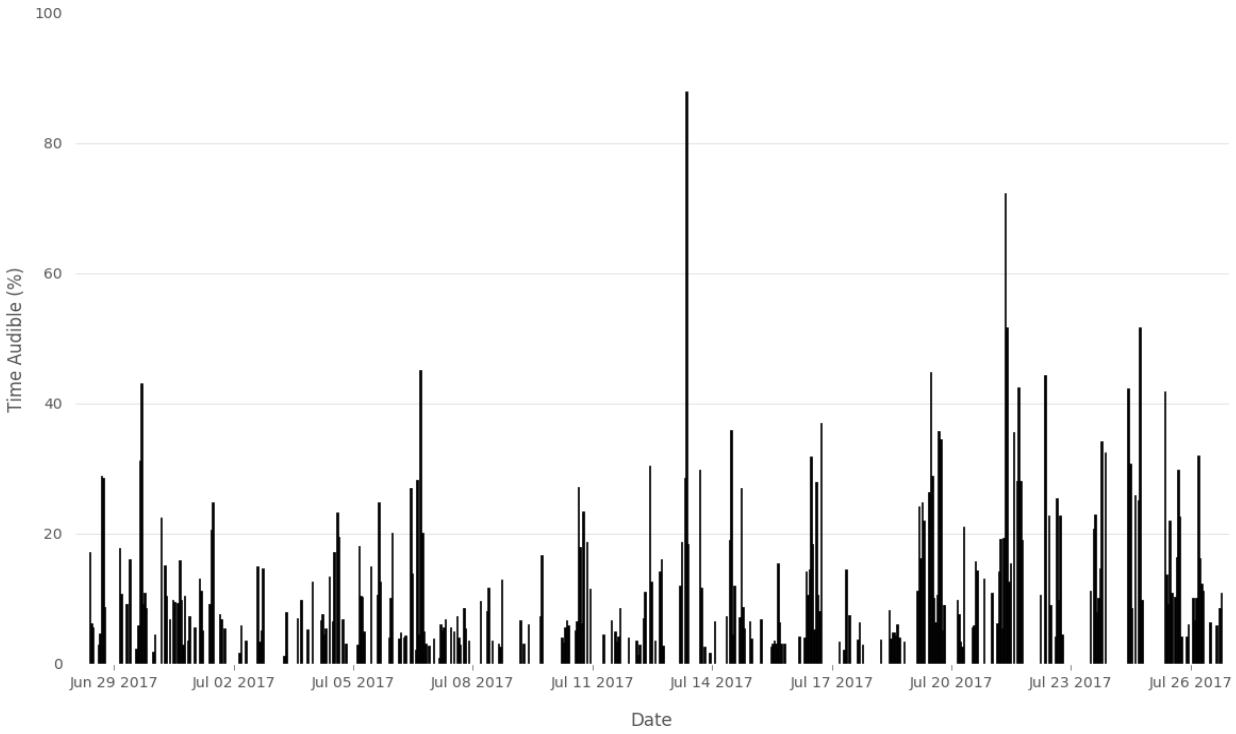


Figure 9. Audibility of aircraft noise by hour at Crosswinds Lake, 2017.

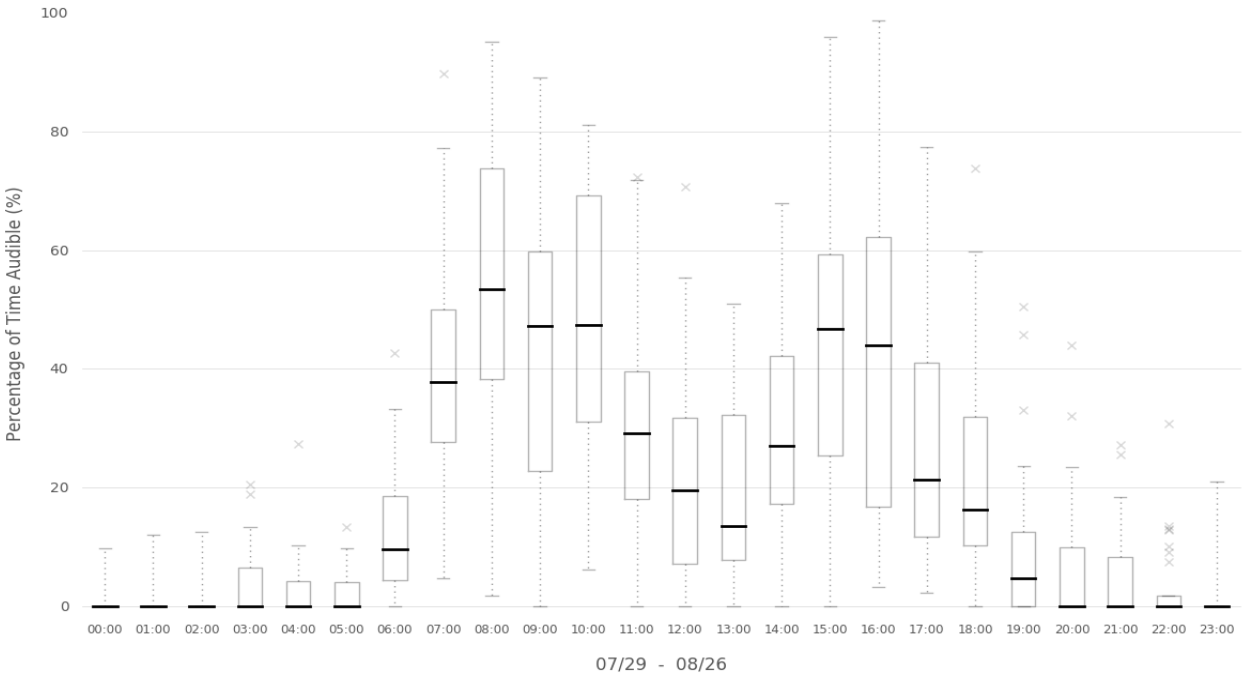


Figure 10. Audibility of aircraft noise for an average day, by hour, at Crosswinds Lake, 2017. The bold line indicates the median (50th percentile) value, the top of the box is the 75th percentile, and the bottom is the 25th percentile. The dashed flyers show 1.5x the interquartile range. Values outside this range are considered outliers and marked with an ‘x’.

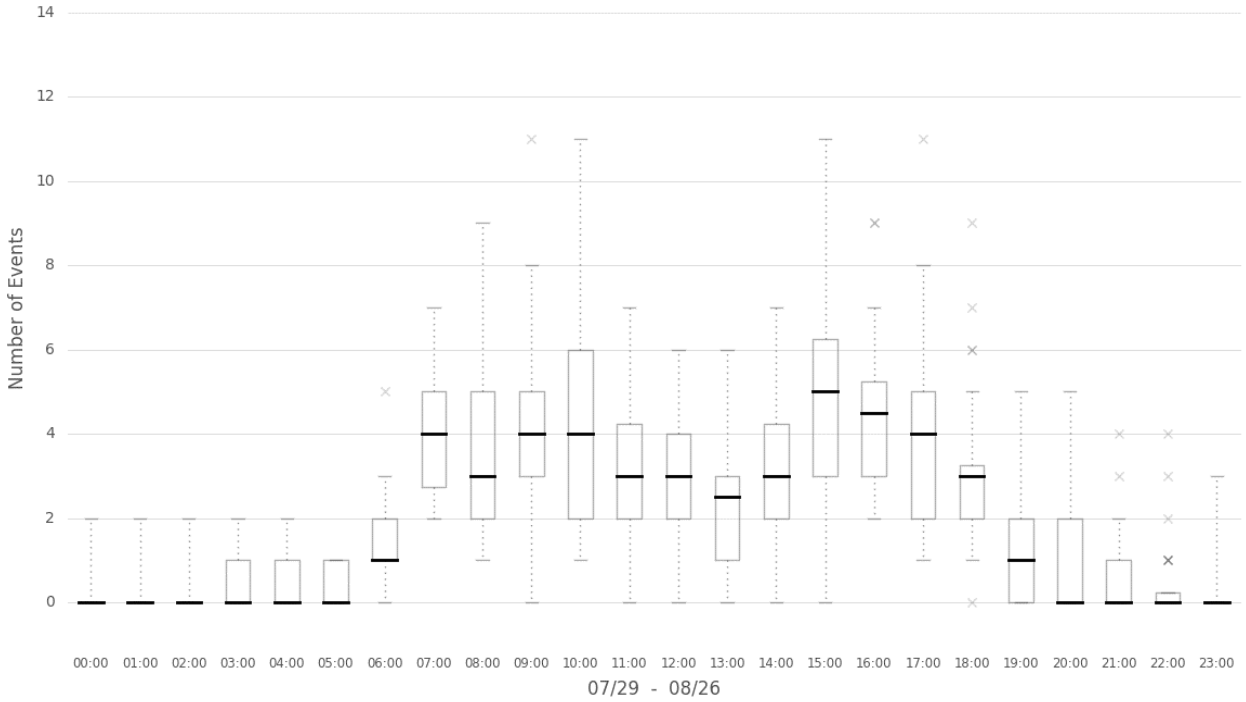


Figure 11. Rates of detection for aircraft noise events by hour at Crosswinds Lake, 2017.

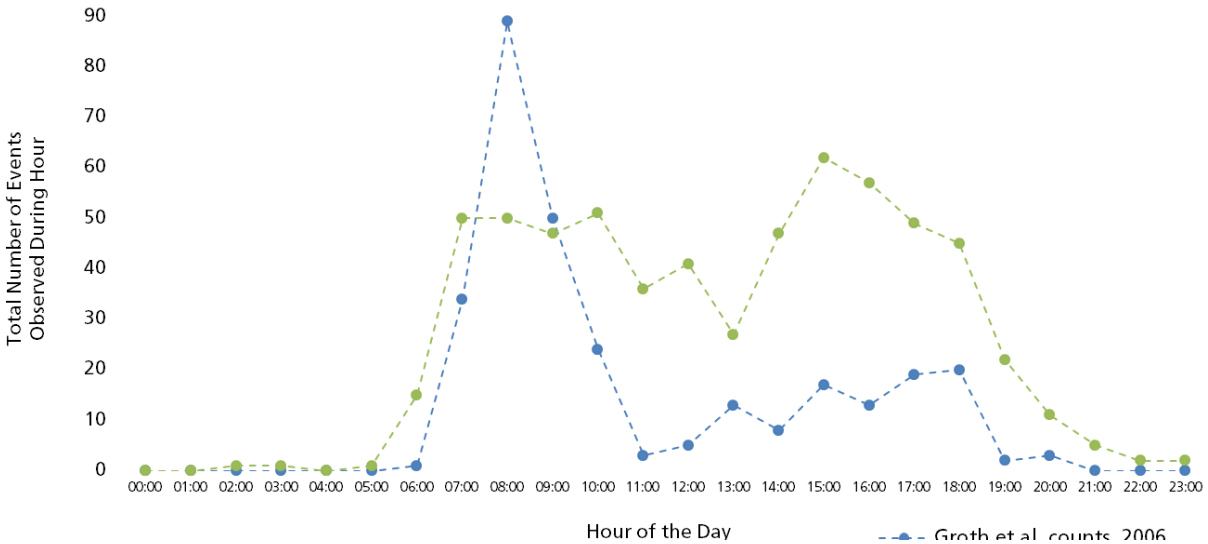


Figure 12. Total number of propeller aircraft events observed by hour at the Moraine and Funnel Creek confluence, 2006 and 2017. Data were collected onsite by NPS observers in 2006 (Groth et al. 2007) and by automated methods at Crosswinds Lake in 2017. Both years represent samples from 08/09 through 08/21, which is a subset of the 2017 data.

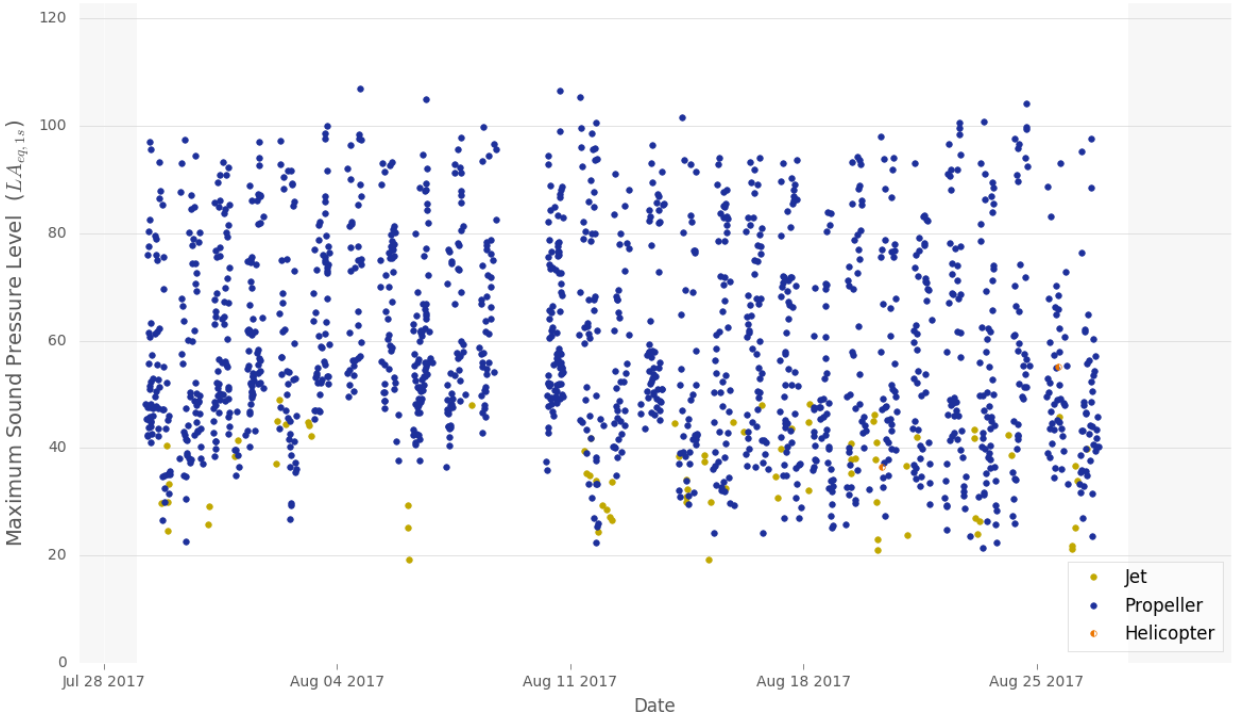


Figure 13. Maximum one-second sound pressure level for each noise event detected at Crosswinds Lake, 2017.

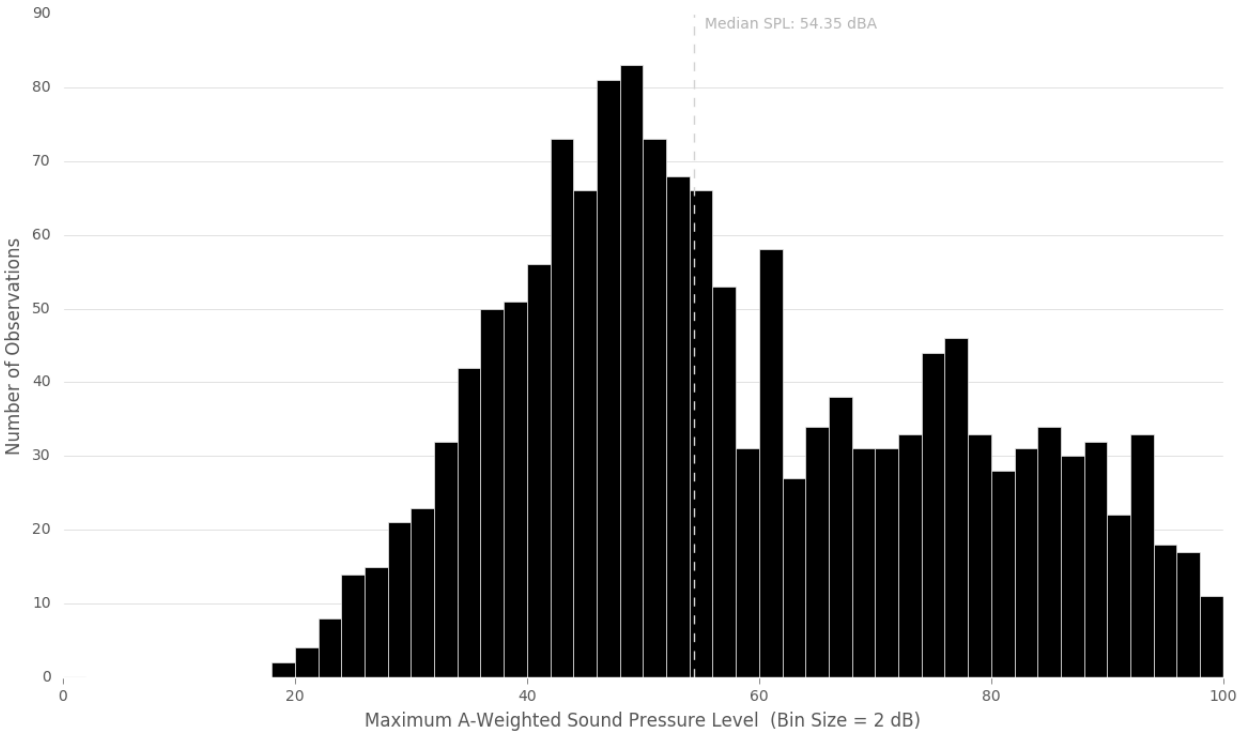


Figure 14. Histogram of maximum one-second sound pressure levels for aircraft noise events detected at Crosswinds Lake, 2017.

Douglas River

Location Description: Site was located on the southern coast of Kamishak Bay near the mouth of the Douglas River (Figures 38 and 39). Site was installed about 88 meters from the backshore, which is 30 – 90 meters from the surf zone. Low bluffs ring the site to the east and southeast at about 1.3 km distance.

Coordinates: 58.98351°, -153.53938° (WGS84)

Elevation: 8 meters (26 feet)

Sampling Period: 30-July-2016 to 14-August-2016

Management Unit: Katmai National Park, Designated Wilderness

Ecotypes: Shelikof Strait Lowlands, Viereck Class III.B.2.b. *Mesic Herbaceous Fireweed*

Access: Cessna 185 on wheels



Figure 15. Cardinal photographs from the Douglas River inventory site.

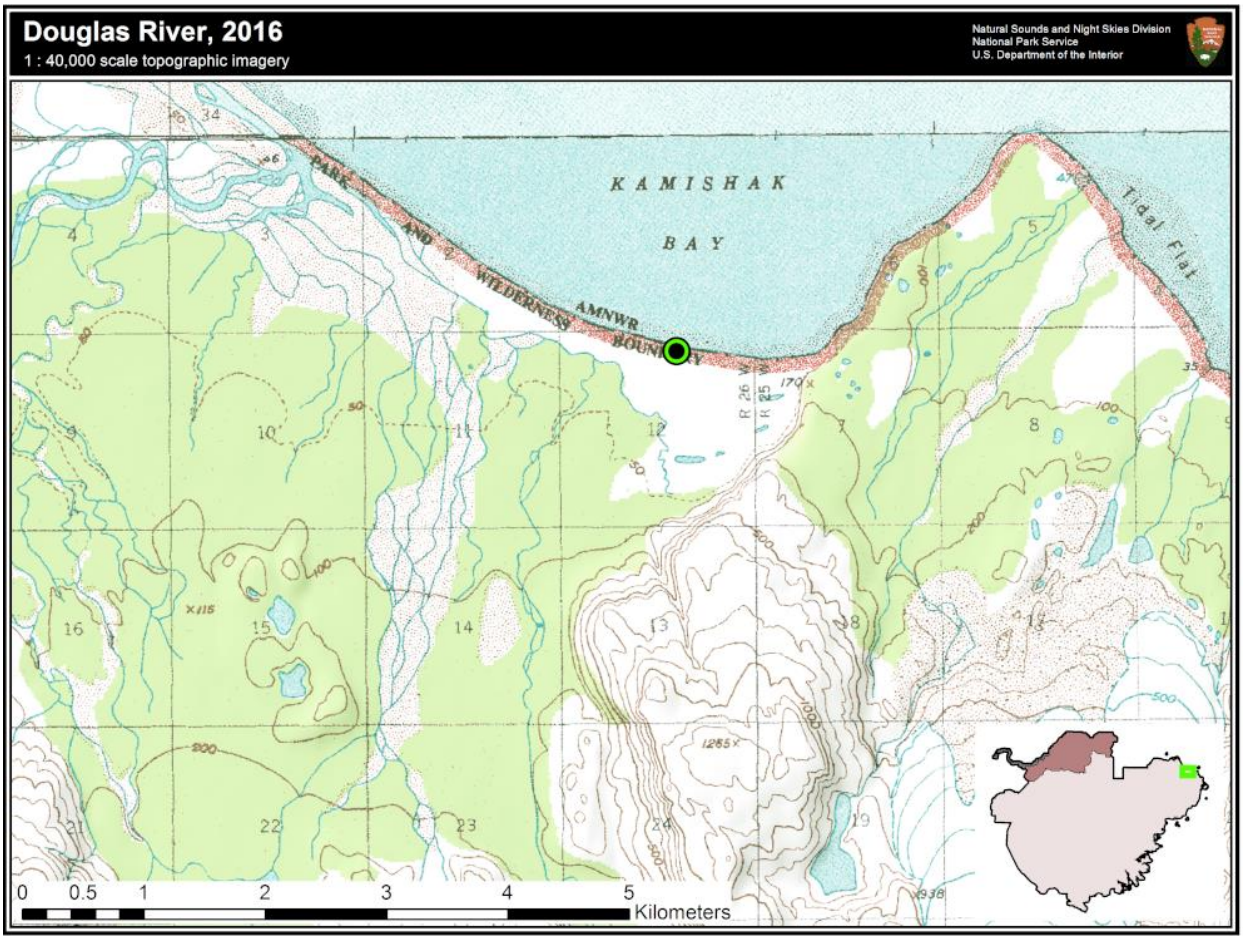


Figure 16. Topographic map of the Douglas River site at a 1:40,000 scale. The inset map in the lower-right corner indicates the location of the frame within Katmai. Light brown areas represent park land and darker brown areas show preserve land.

Summary: The coastal lowland landscape of the Douglas River inventory site had a time-averaged natural ambient sound pressure level (LA_{nat}) of 37.4 dB. The 90th percentile of sound pressure levels (LA_{10}) was 40.9 dB, and the 10th percentile (LA_{90}) was 34.2 dB, a difference of 6.7 dB (Figure 40). Waves interacting with the coarse gravel shoreline were clearly audible, contributing to the relatively energetic natural ambience at the site.

Biological sounds were relatively scarce in this July/August sample. Common Raven, Red-Throated Loon, and numerous seabirds and shorebirds were commonly heard avian species. Grasshopper stridulation was also detected.

Aircraft noise data are shown in Figures 41–45. The Douglas River side had very few noise events (median 5 per day), but those that did occur were often very loud (for example, max $LA_{eq,\,1s} > 80$ dB.) Three takeoff events were observed during the 16-day sampling period. An NPS pilot corroborated our observations that landings were taking place in the area, informing us that CUA operators often land on a flat section about a mile away from the site location. The same pilot has

also observed operators flying low over the area looking for bears, not finding any, and departing (C. Ricks, personal comm).

Vessels were audible off the coast, as were marine generators (time audible = 1.0% of entire record). The entire marine impact at the site was from a single vessel over a period of three days (Figure 44); over that time period, the vessel was audible about 5% of the time.

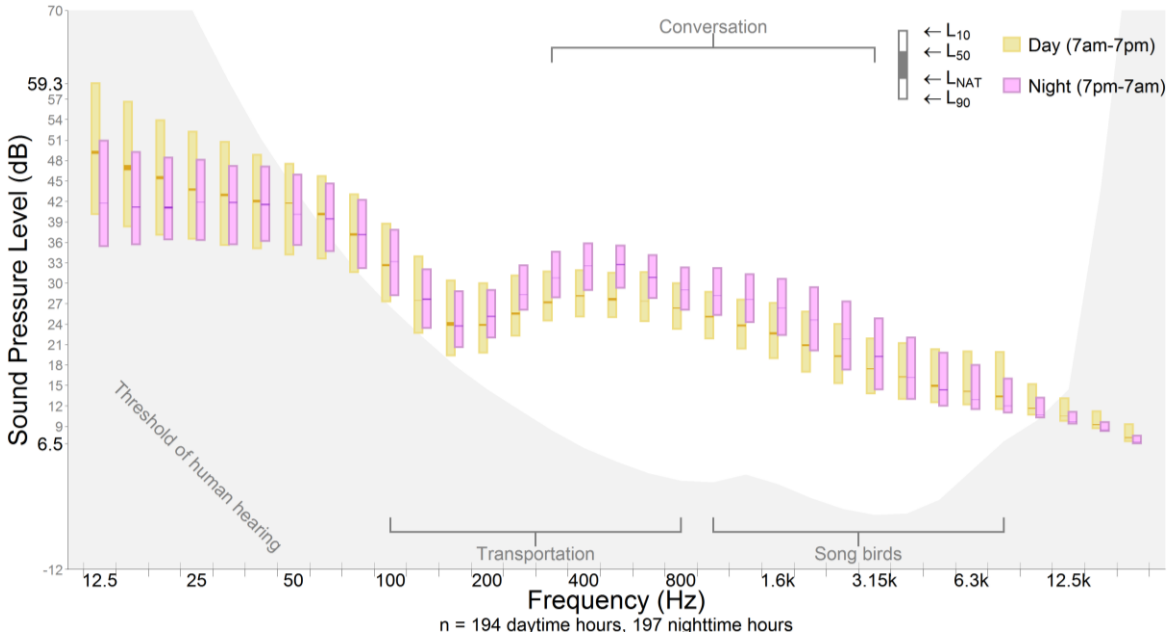


Figure 17. Spectral percentile levels for Douglas River, 2016.

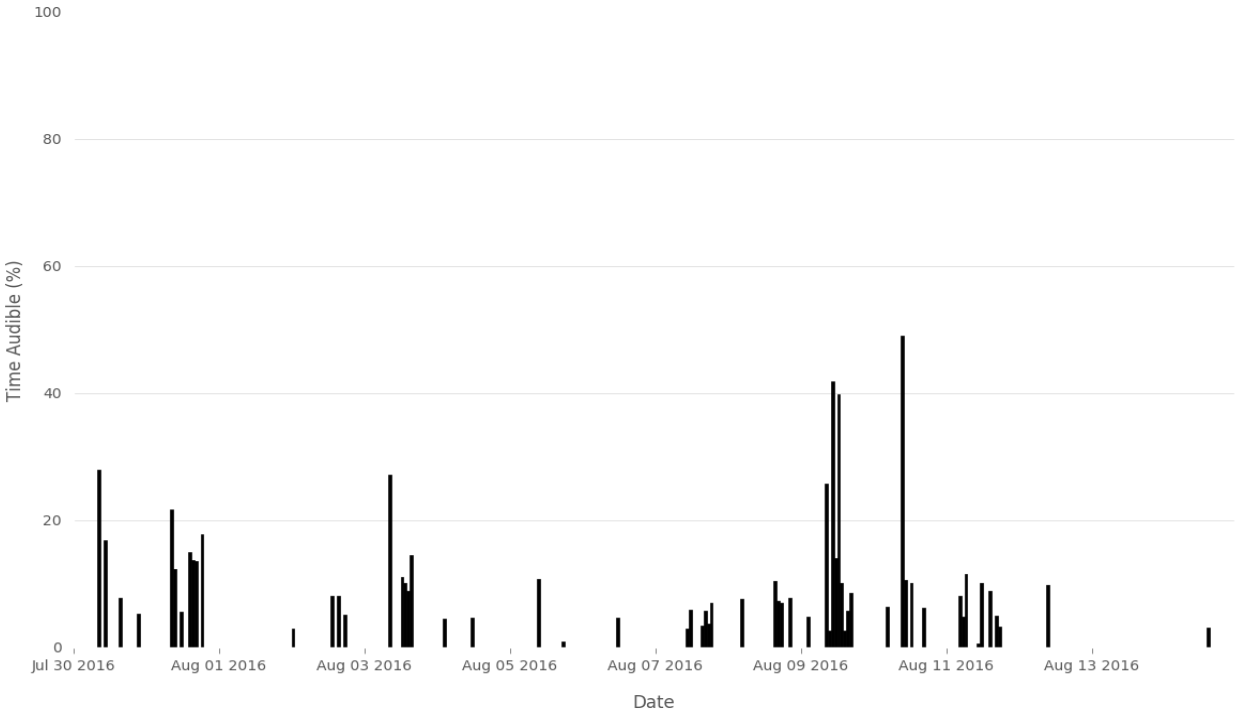


Figure 18. Audibility of aircraft noise by hour at Douglas River, 2016.

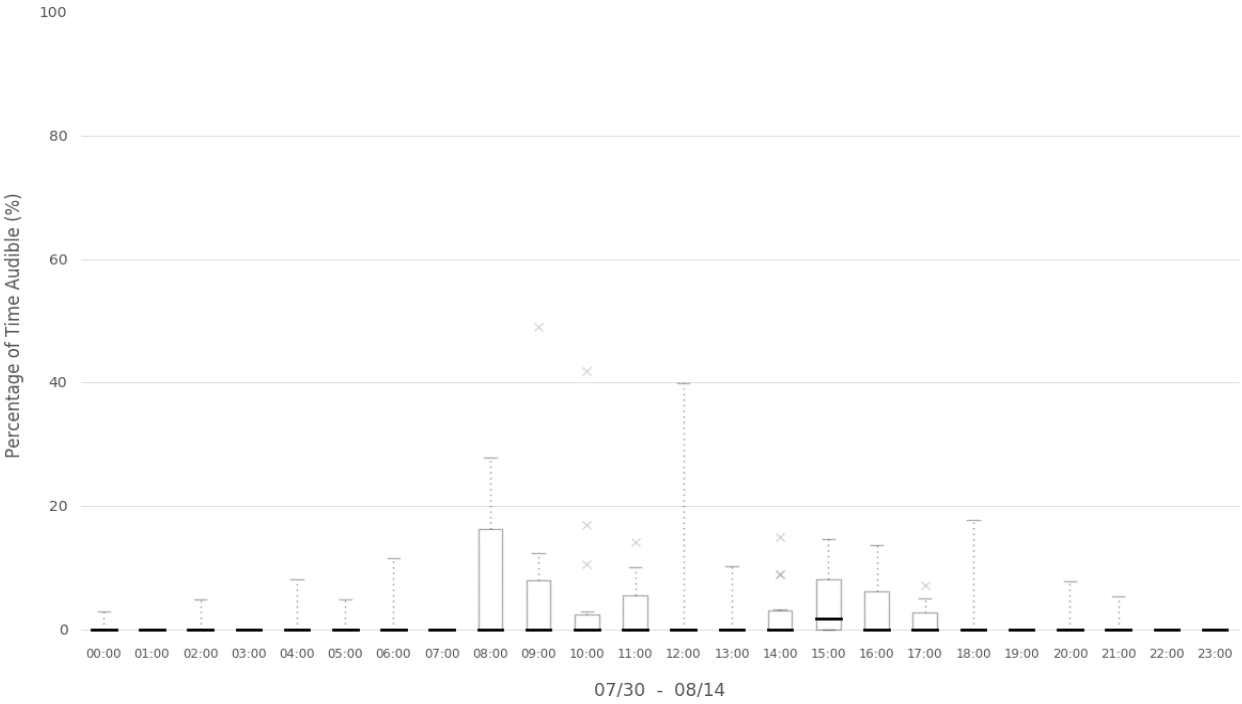


Figure 19. Audibility of aircraft noise for an average day, by hour, at Douglas River, 2016. The bold line indicates the median (50th percentile) value, the top of the box is the 75th percentile, and the bottom is the 25th percentile. The dashed flyers show 1.5x the interquartile range. Values outside this range are considered outliers and marked with an ‘x’.

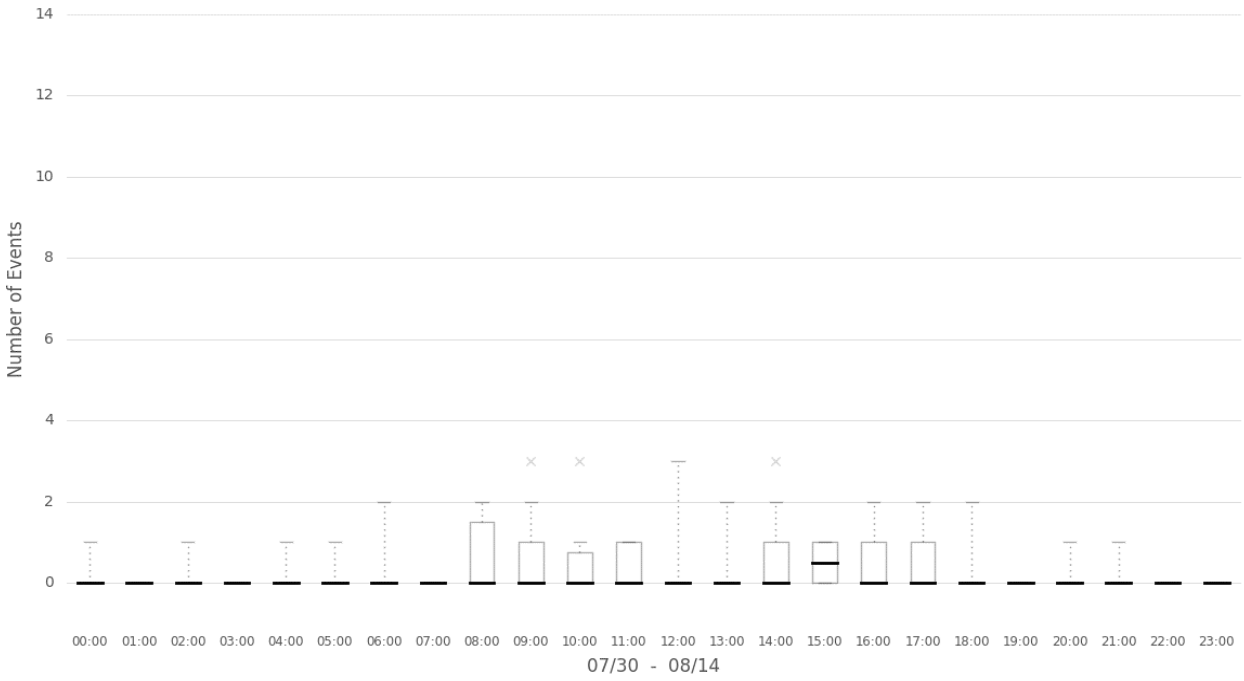


Figure 20. Rates of detection for aircraft noise events by hour at Douglas River, 2016.

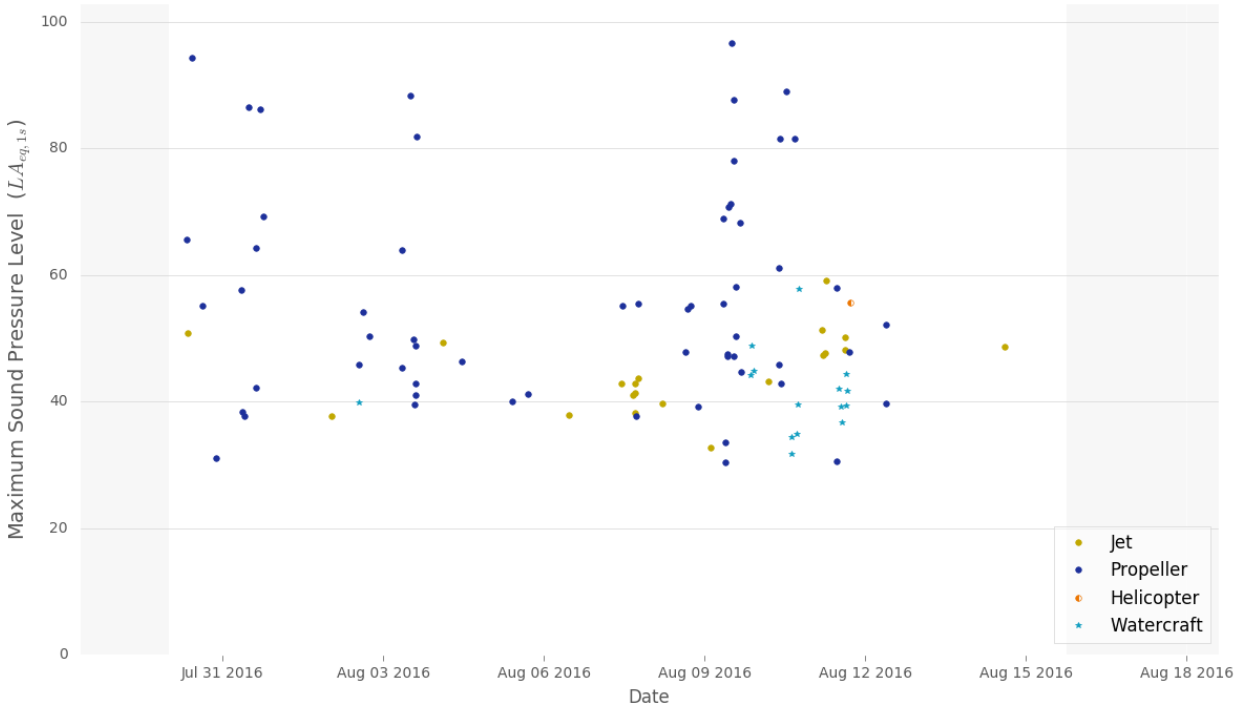


Figure 21. Maximum one-second sound pressure level for each noise event detected at Douglas River, 2016.

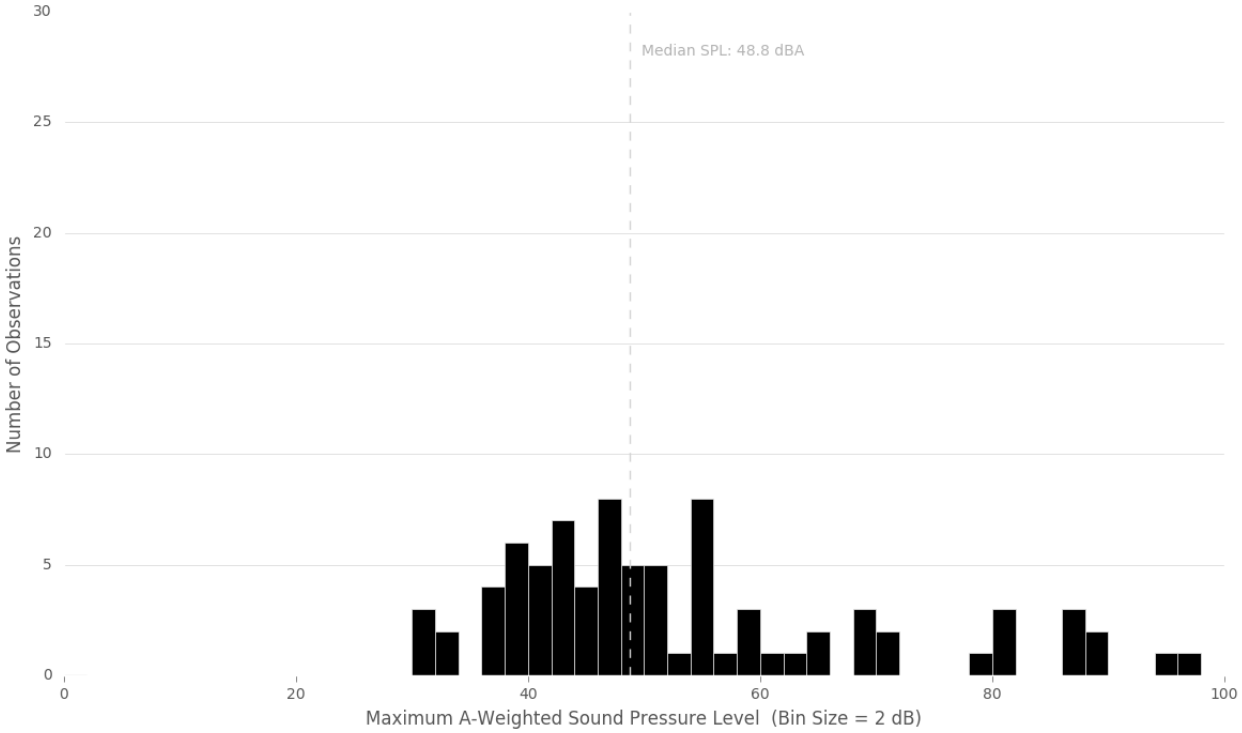


Figure 22. Histogram of maximum one-second sound pressure levels for aircraft noise events detected at Douglas River, 2016.

Dumpling Point

Location Description: Site was located on the initial slope of Dumpling Mountain, about 93 meters (line-of-sight) from Naknek Lake and 60 meters (vertically) above it (Figures 46 and 47). Site is located about 6 km from Brooks Camp.

Coordinates: 58.60343°, -155.84497° (WGS84)

Elevation: 77 meters (252 feet)

Sampling Period: 31-July-2016 to 24-August-2016

Management Unit: Katmai National Park, Designated Wilderness

Ecotypes: Lakes Region Hills, Viereck Class I.C.3.a. *Mixed Spruce - Paper Birch Woodland*

Access: boat (NPS Palayaq) from Lake Camp



Figure 23. Cardinal photographs of the Dumpling Point inventory site.

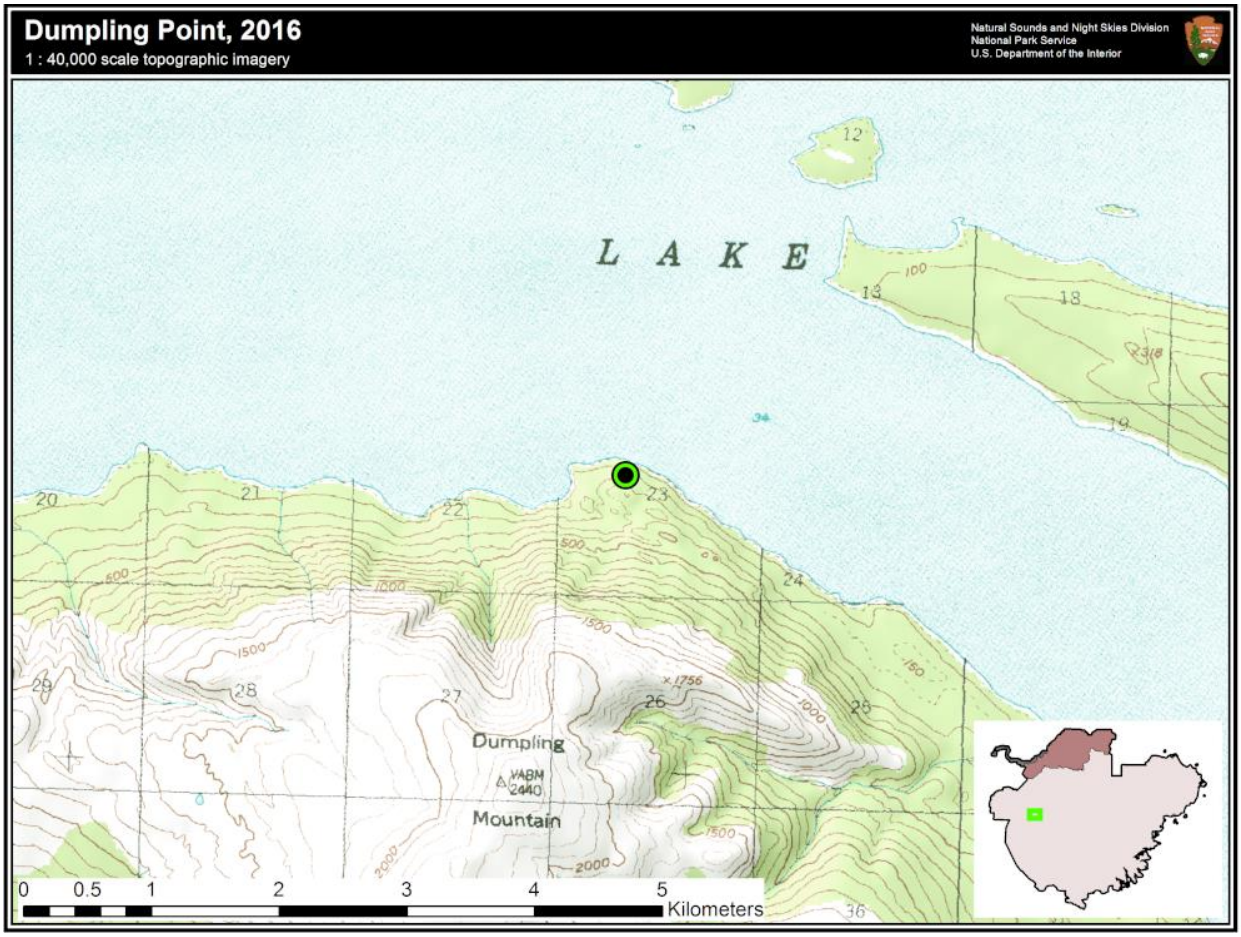


Figure 24. Topographic map of Dumpling Point at 1:40,000 scale. The inset map in the lower-right corner indicates the location of the frame within Katmai. Light brown areas represent park land and darker brown areas show preserve land.

Summary: The steep lakeside landscape of the Dumpling Point inventory site had a time-averaged natural ambient sound pressure level (LA_{nat}) of 25.5 dB. The 90th percentile of sound pressure levels (LA_{10}) was 32.9 dB, and the 10th percentile (LA_{90}) was 22.8 dB, a difference of 10.1 dB (Figure 48). Waves were just audible from the site location at times.

Biological sounds were few, likely because of the late-season sampling period. Common Raven, Bald Eagle, Black-capped Chickadee, and Common Redpoll were detected.

Aircraft noise data are shown in Figures 49–53. Dumpling Point had the third most propeller aircraft noise (time audible = 14.7% of entire record) of any inventory site, after the American Creek and Crosswinds Lake sites. Though no takeoffs were detected, overflights often exceeded $LA_{eq,\ 1s}$ of 60 dB (Figure 53). This is likely due to Dumpling Point's proximity Brooks Camp. Departing aircraft may still be climbing past the site under higher power settings. In addition, the cultural tolerance of flight in poor visibility and clouds – with pilots navigating close to the ground – may also play a role in the observation of louder overflight events.

Dumpling Point was notable as the inventory site with the most helicopter events (n = 9 events, time audible = 0.18% of entire record, Appendix B, Figure APP B.14). Two other sites in the west-central area of the park (Valley of Ten-Thousand Smokes and Jo-Jo Lake) have similar rates of helicopter noise.

Vessels were also heard throughout the record (time audible = 2.1% of entire record). They can be identified on the spectrogram by their broadband signal, usually superimposed with short transients associated with wake and/or hull slapping. Vessel noise events vary considerably in length, presumably depending on vessel speed. Overall, vessel events are much longer than aviation events (median 07:20 ± 03:28 for vessels versus 04:53 ± 01:47 for aircraft).

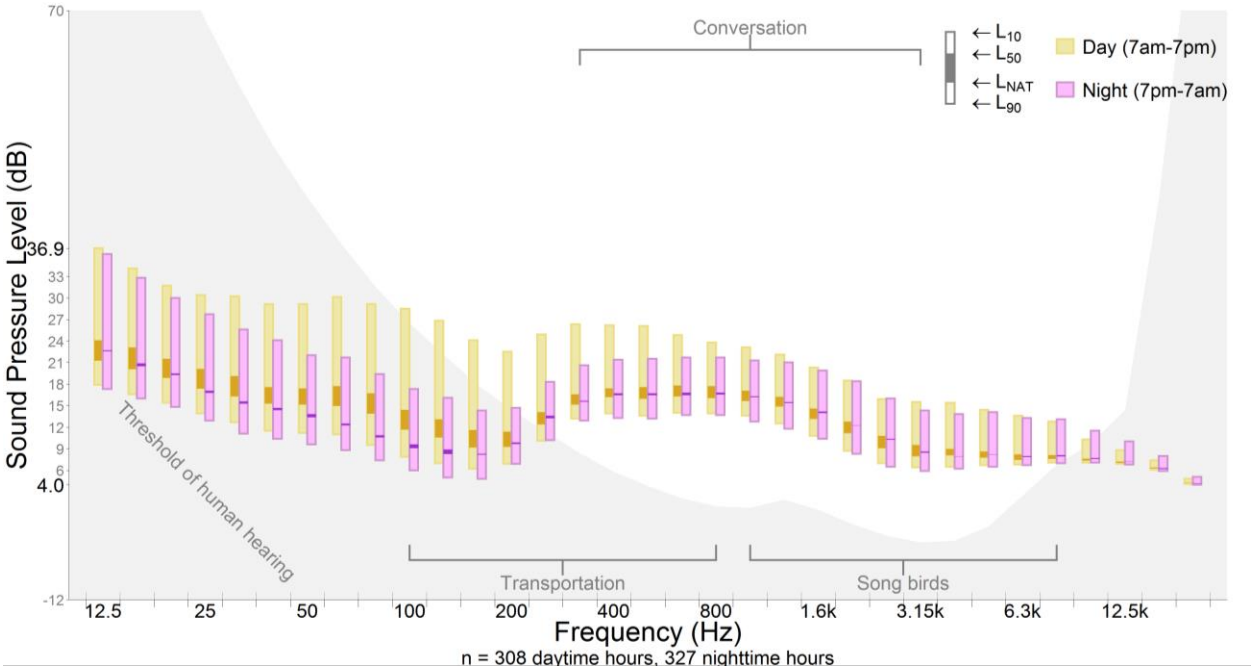


Figure 25. Spectral percentile levels for Dumpling Point, 2016.

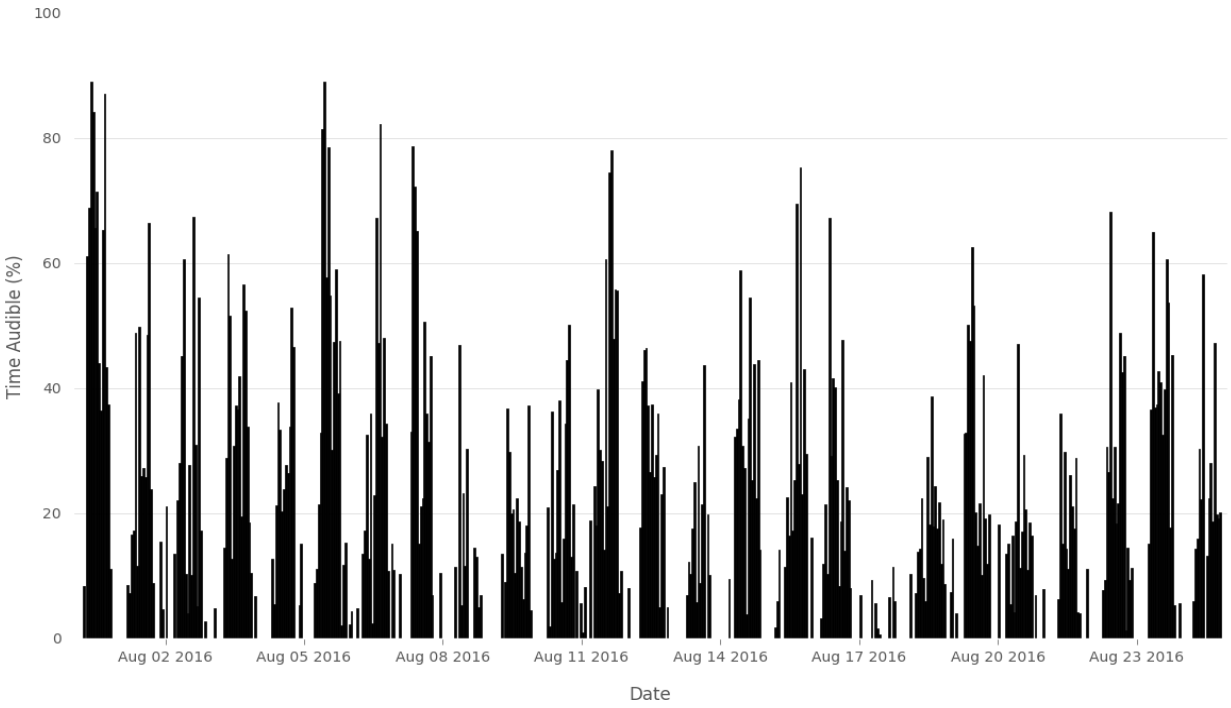


Figure 26. Audibility of aircraft noise by hour at Dumpling Point, 2016.

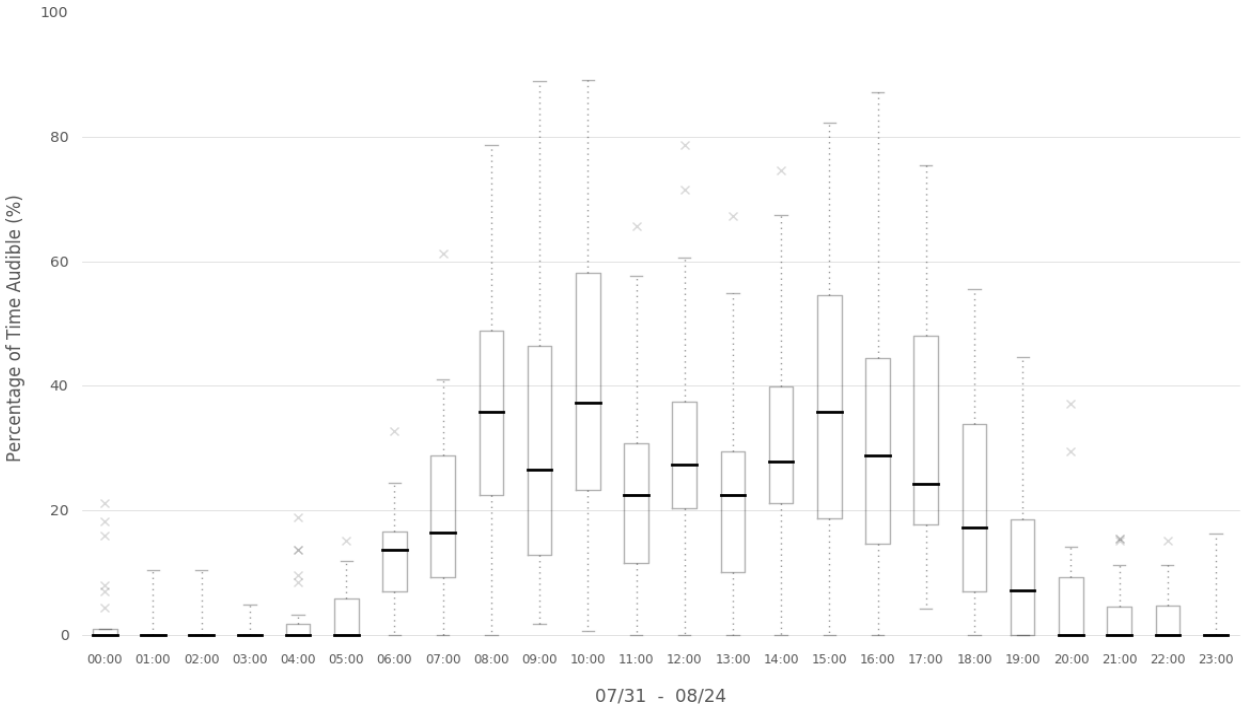


Figure 27. Audibility of aircraft noise for an average day, by hour, at Dumpling Point, 2016. The bold line indicates the median (50th percentile) value, the top of the box is the 75th percentile, and the bottom is the 25th percentile. The dashed flyers show 1.5x the interquartile range. Values outside this range are considered outliers and marked with an ‘x’.

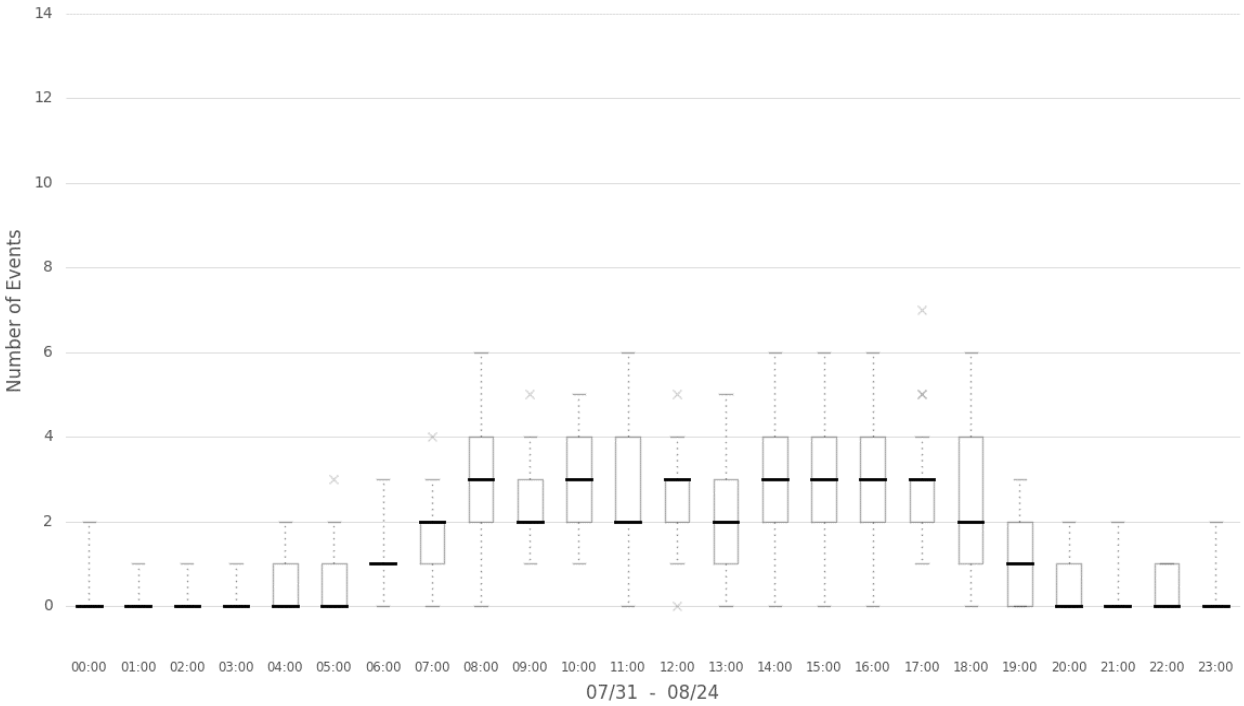


Figure 28. Rates of detection for aircraft noise events by hour at Dumpling Point, 2016.

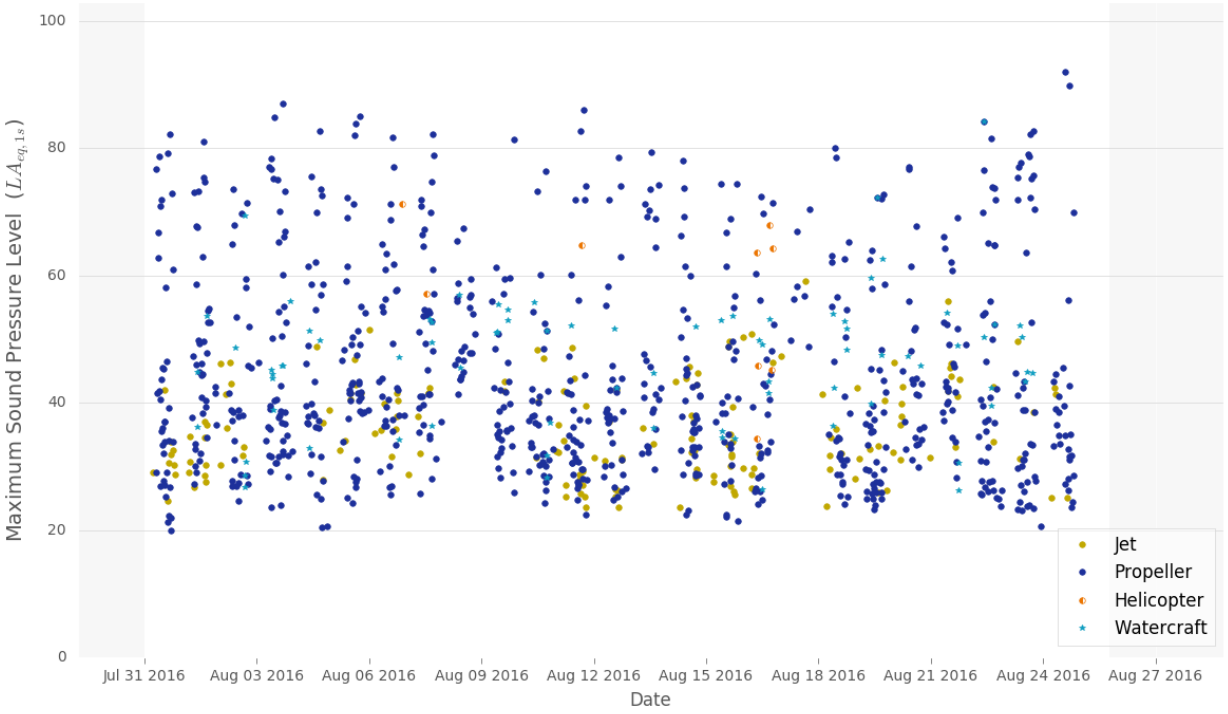


Figure 29. Maximum one-second sound pressure level for each noise event detected at Dumpling Point, 2016.

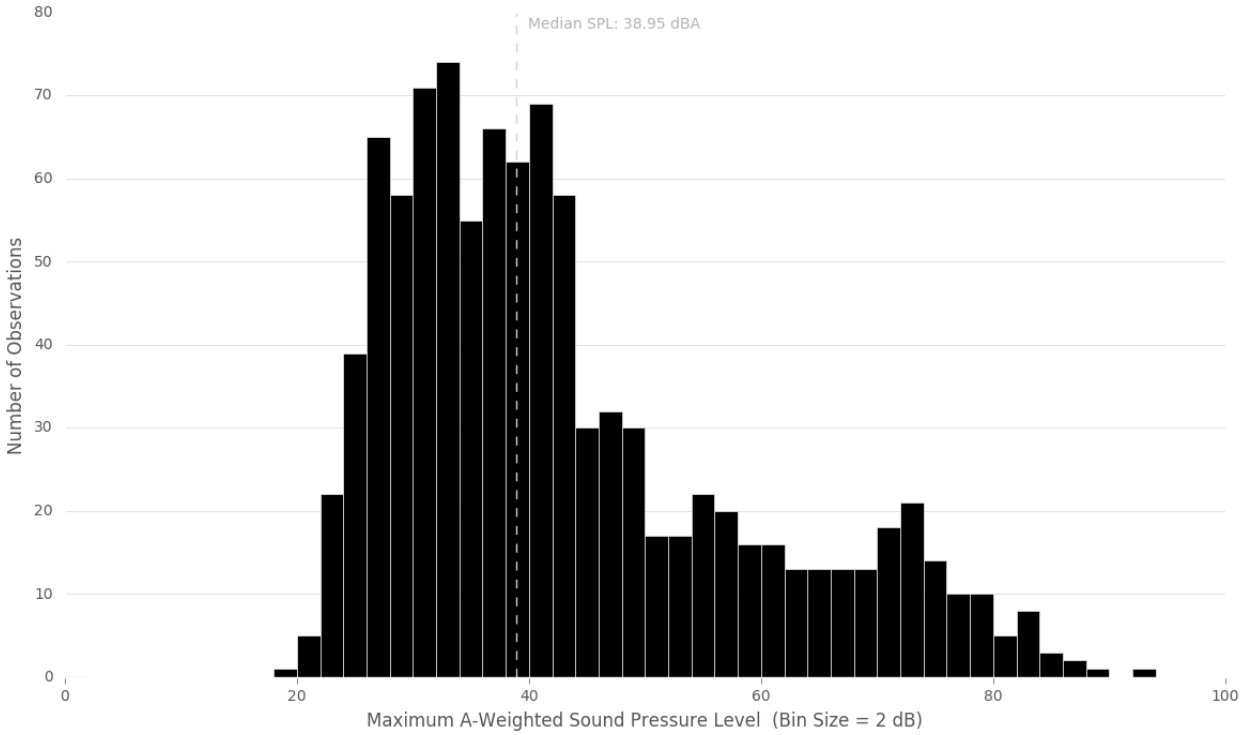


Figure 30. Histogram of maximum one-second sound pressure levels for aircraft noise events detected at Dumpling Point, 2016.

East Kulik Lake

Location Description: Site was located 10 meters inland from the southeast shore of Kulik Lake (Figures 54 and 55). Terrain within the local vicinity was flat and sandy with tall, sparse shrubs and trees. Sub-alpine mountains rise steeply from the lake in all directions, bordering the site closely to the east and south.

Coordinates: 58.89650°, -154.80084° (WGS84)

Elevation: 201 meters (659 feet)

Sampling Period: 07-July-2017 to 20-July-2017

Management Unit: Katmai National Park, Eligible Wilderness

Ecotypes: Walatka Mountains, Viereck Class II.B.2.a. *Open Tall Willow Scrub*

Access: DeHavilland DHC-2 on floats



Figure 31. Cardinal photographs from the East Kulik Lake inventory site.

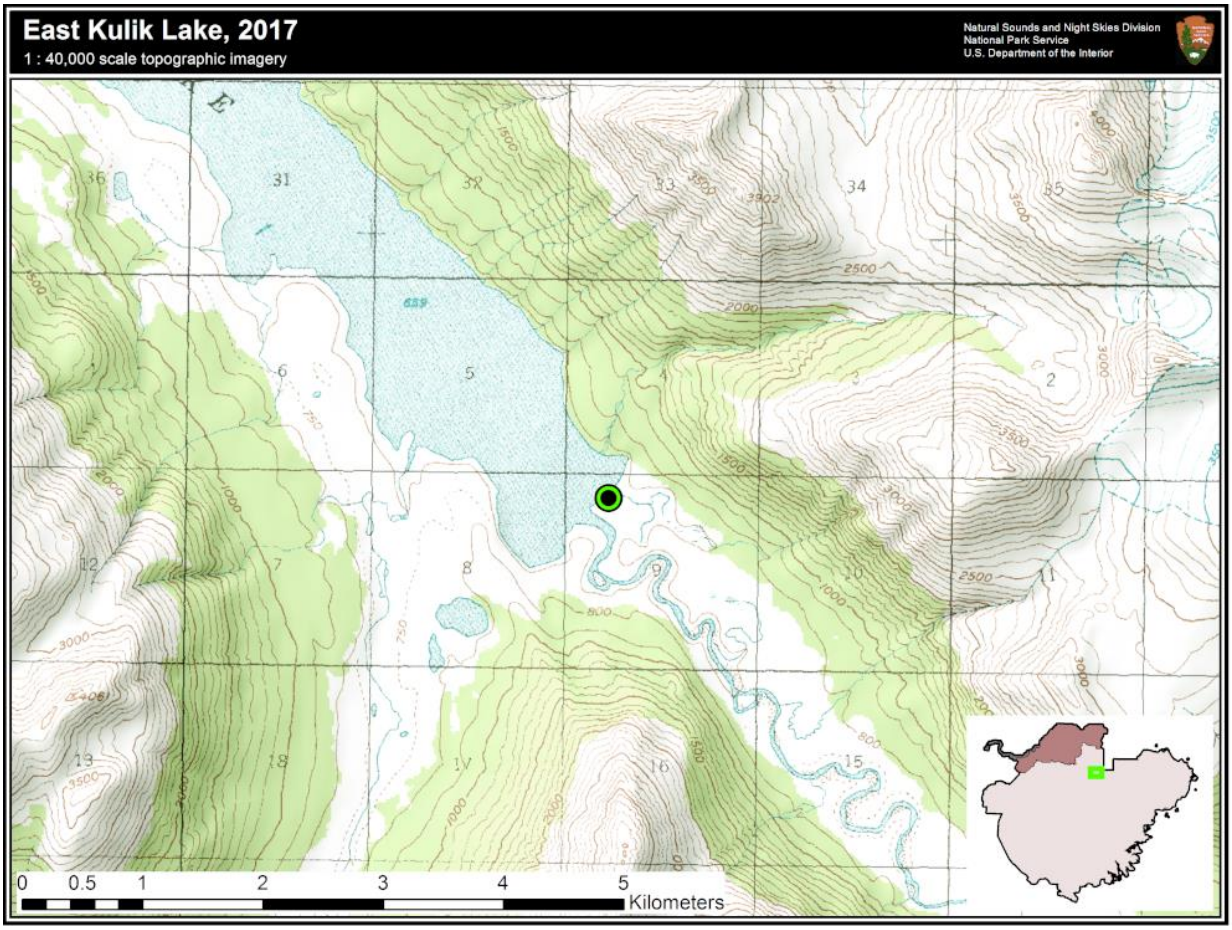


Figure 32. Topographic map of East Kulik Lake at 1:40,000 scale. The inset map in the lower-right corner indicates the location of the frame within Katmai. Light brown areas represent park land and darker brown areas show preserve land.

Summary: The secluded lakeside landscape of the East Kulik Lake inventory site had a time-averaged natural ambient sound pressure level (LA_{nat}) of 41.1 dB; it is tied with Katmai Bay as the most naturally-energetic acoustic environment sampled in KATM. The 90th percentile of sound pressure levels (LA_{10}) was 44.0 dB, and the 10th percentile (LA_{90}) was 38.2 dB, a difference of 5.8 dB. Many small streams drain the mountainsides surrounding East Kulik Lake. The plot of 1/3rd octave band spectra (Figure 56) reveals a prominent peak between the 160 and 3150 Hz bands, the expected spectral pattern for turbulent flowing water (Saleh 2002). Waves and wind were also significant natural sources of acoustic energy.

Aircraft noise data are shown in Figures 57–61. Unlike many of the other inventory sites, no propeller aircraft noise at East Kulik Lake exceeded $LA_{eq,\ 1s}$ of 80 dB (Figure 60). A non-skewed distribution of maximum $LA_{eq,\ 1s}$ values (Figure 61) suggests that East Kulik Lake is currently impacted only by overflights traversing the area. The narrowness of the histogram in Figure 61 suggests that the flight routes audible from the site location are either spatially-constrained, behaviorally-constrained, or both (compare to Hallo Bay, which experiences a wide range of maneuvers (Figure 61). The steep terrain surrounding the East Kulik Lake site contributes to the

patterns visible in Figure 61. It acts as an acoustic barrier for distant flight routes and ultimately limits the variability of observed events.

Geographically, the East Kulik Lake site along with Jo-Jo Lake and Kamishak River appear to represent a contour for propeller aircraft noise (see Appendix B, Figure APP B.6 and Figure APP B.7). Moving east from them towards the Aleutian Range propeller aircraft noise impacts are likely to decrease, while moving west impacts are expected to increase.

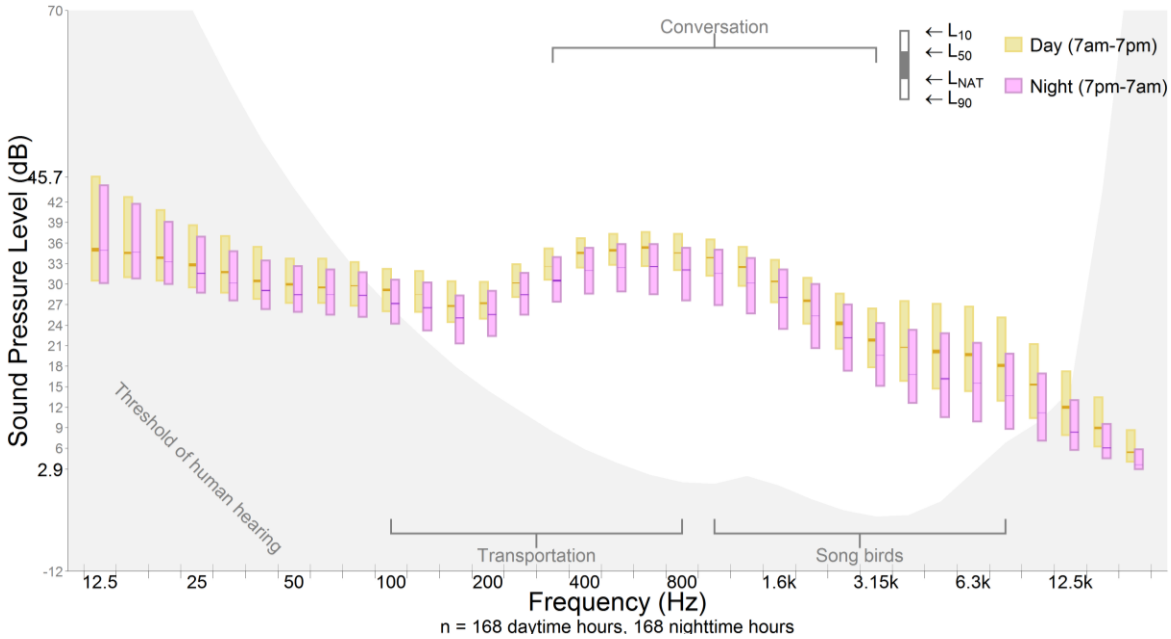


Figure 33. Spectral percentile levels for East Kulik Lake, 2017.

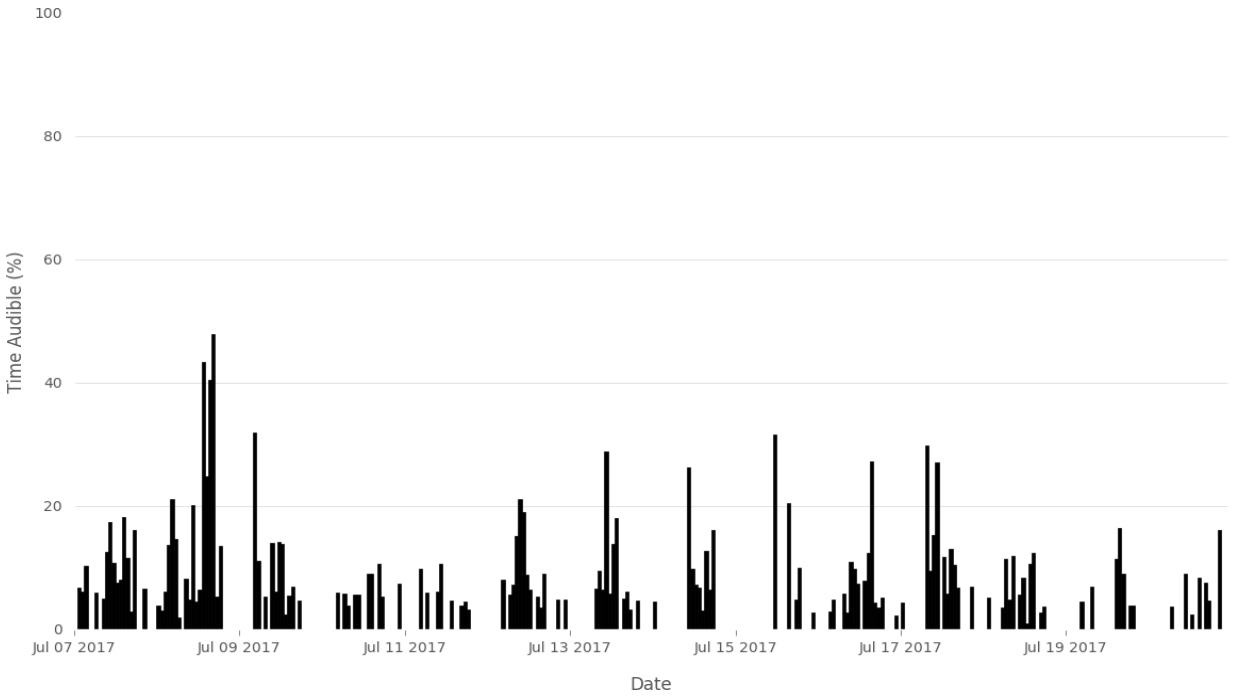


Figure 34. Audibility of aircraft noise by hour at East Kulik Lake, 2017.

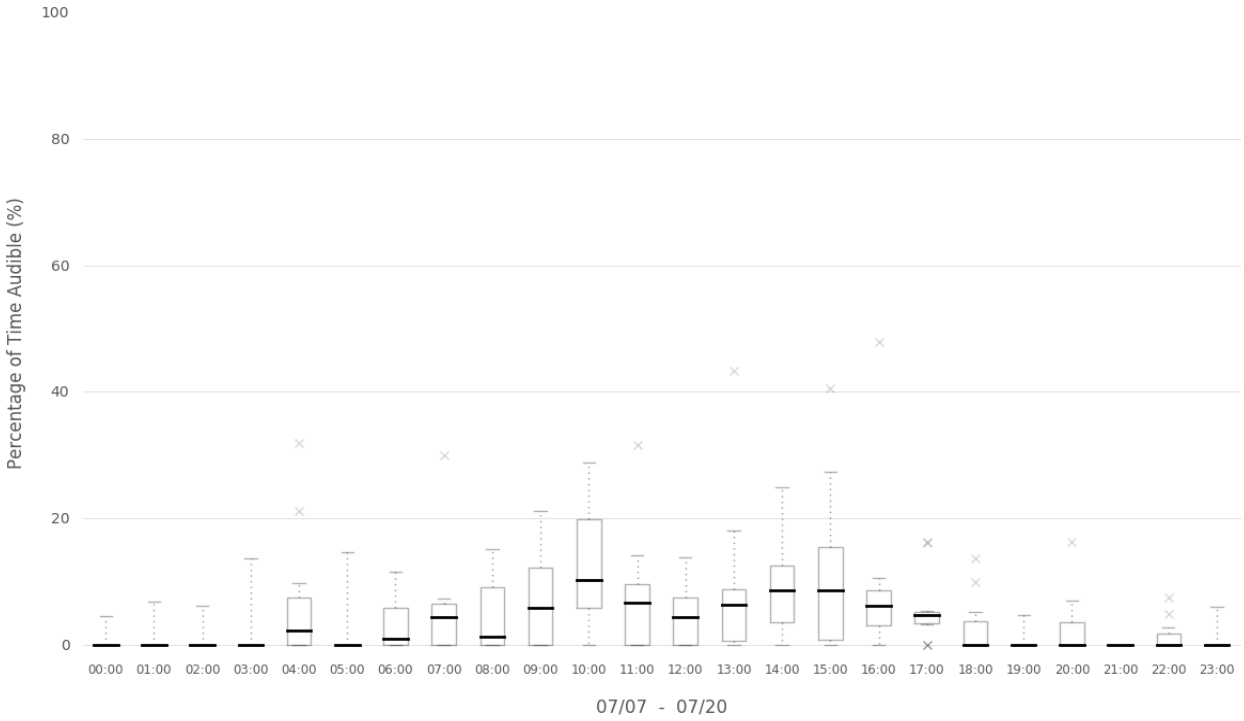


Figure 35. Audibility of aircraft noise for an average day, by hour, at East Kulik Lake, 2017. The bold line indicates the median (50th percentile) value, the top of the box is the 75th percentile, and the bottom is the 25th percentile. The dashed flyers show 1.5x the interquartile range. Values outside this range are considered outliers and marked with an ‘x’.

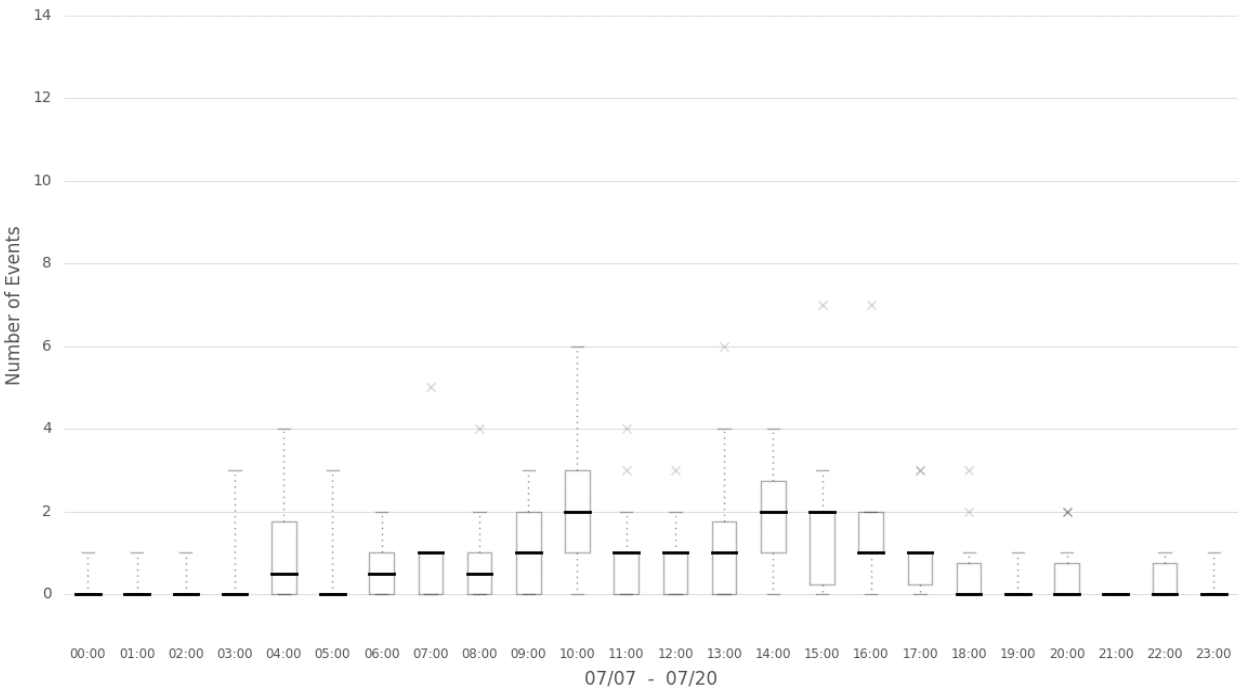


Figure 36. Rates of detection for aircraft noise events by hour at East Kulik Lake, 2017.

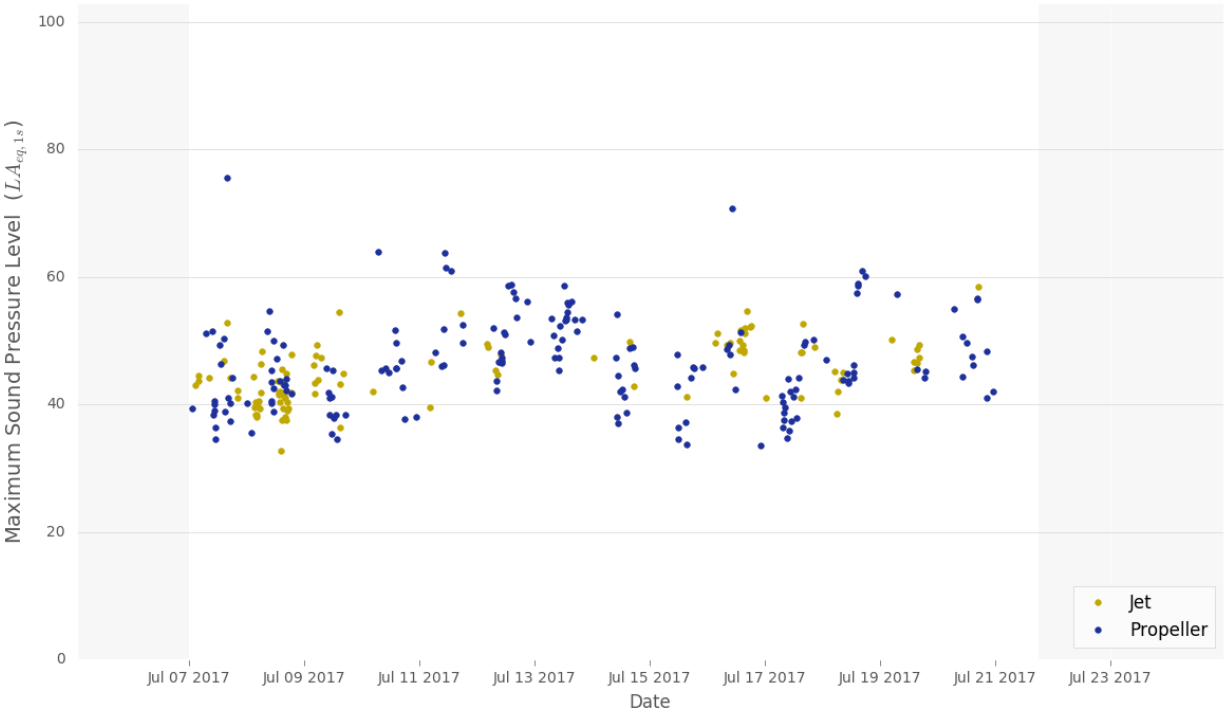


Figure 37. Maximum one-second sound pressure level for each noise event detected at East Kulik Lake, 2017.

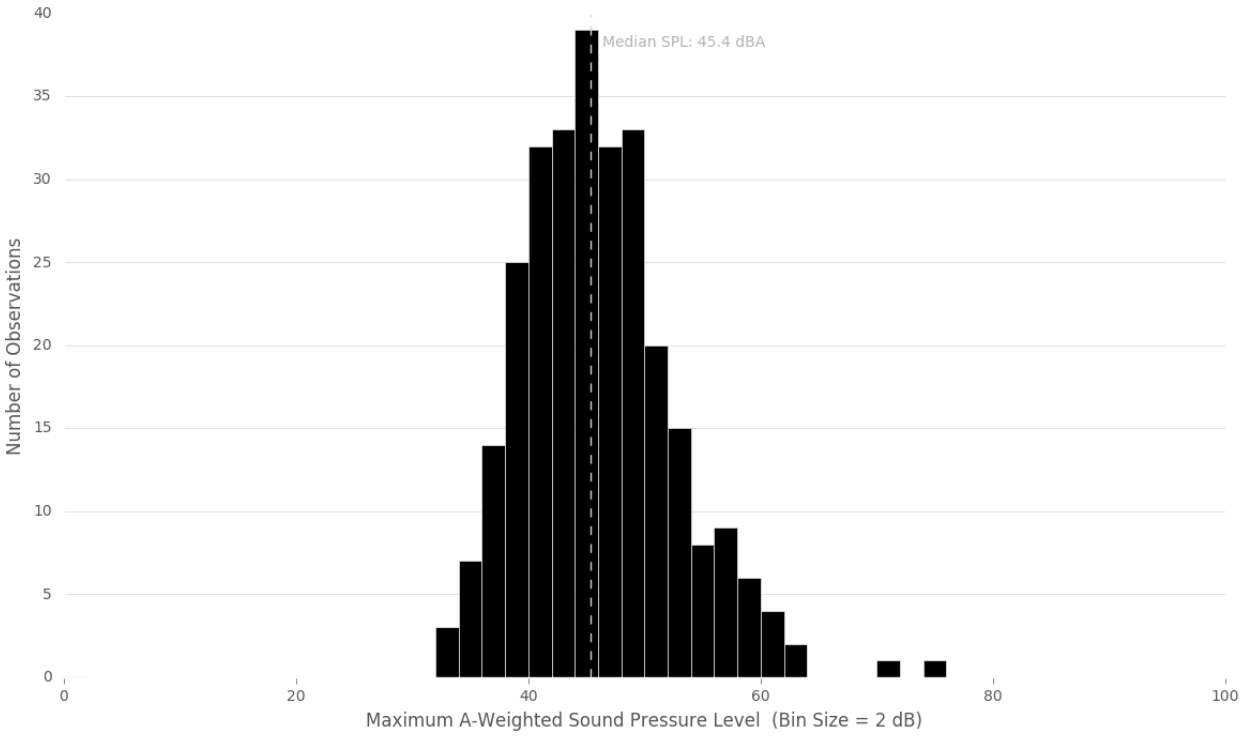


Figure 38. Histogram of maximum one-second sound pressure levels for aircraft noise events detected at East Kulik Lake, 2017.

Hallo Bay

Location Description: Site was placed near the tip of a long spit at the southern end of Hallo Bay (Figures 62 and 63). About 50 meters north of the site is a lagoon formed by Hallo Creek. A small eddy in the creek about 1.7 km from the site serves as a float pond. (For aerial photograph see Appendix C, Figure APP C.5). At high tide the site was about 80 – 90 meters from the ocean.

Coordinates: 58.42707°, -154.06105° (WGS84)

Elevation: 12 meters (41 feet)

Sampling Period: 23-June-2016 to 27-July-2016

Management Unit: Katmai National Park, Designated Wilderness

Ecotypes: Shelikof Strait Lowlands, Viereck Class III.A.1.a. *Dry Graminoid Herbaceous Elymus*

Access: Cessna 185 on wheels



Figure 39. Cardinal photographs of the Hallo Bay inventory site.

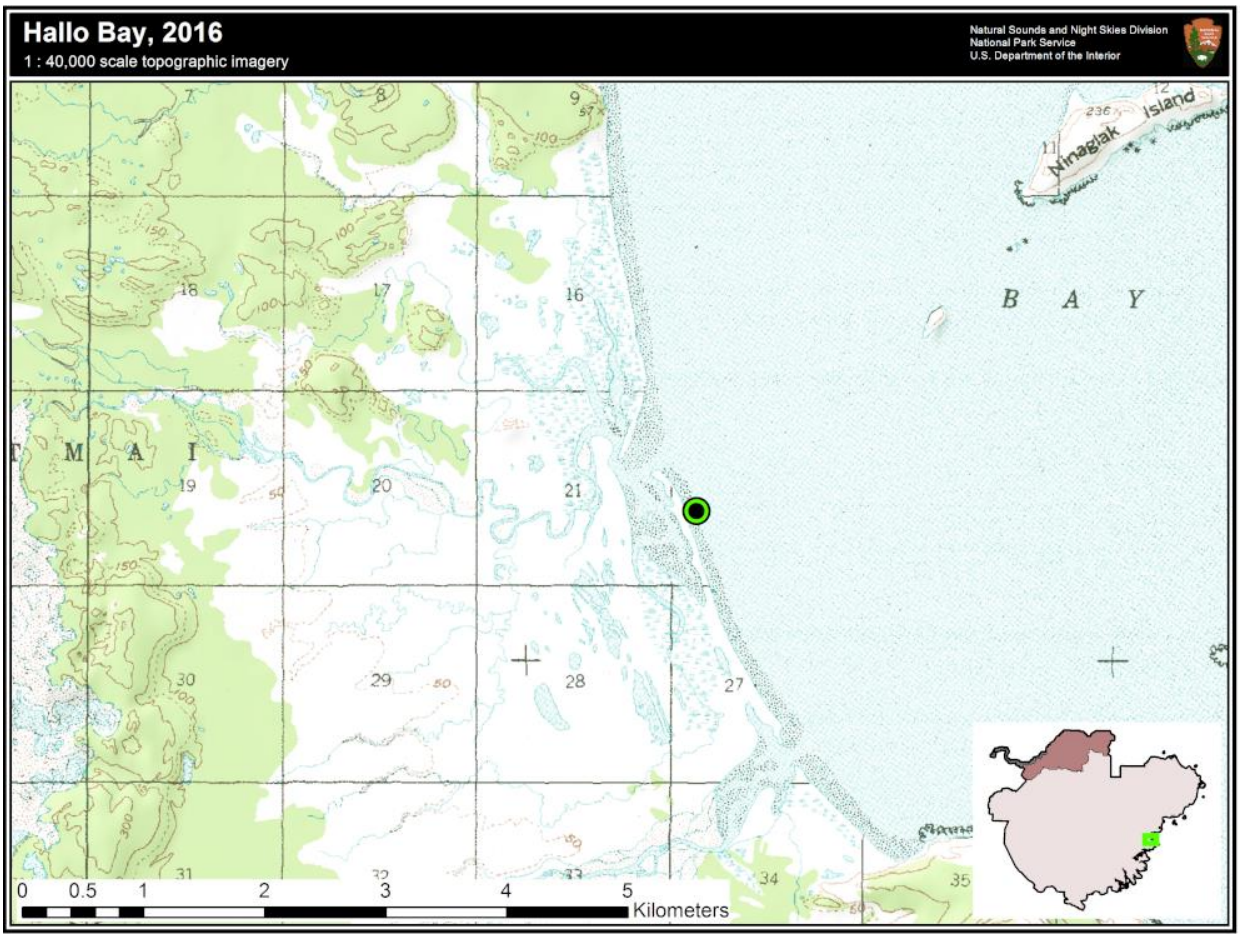


Figure 40. Topographic map of Hallo Bay at 1:40,000 scale. The inset map in the lower-right corner indicates the location of the frame within Katmai. Light brown areas represent park land and darker brown areas show preserve land.

Summary: The coastal landscape of the Hallo Bay inventory site had a time-averaged natural ambient sound pressure level (LA_{nat}) of 36.2 dB. The 90th percentile of sound pressure levels (LA_{10}) was 42.1 dB, and the 10th percentile (LA_{90}) was 33.9 dB, a difference of 8.2 dB (Figure 64). Waves and wind are both important contributors to this naturally energetic acoustic environment.

Avian sounds detected at the site include Bald Eagle, Common Raven, Semipalmated Plover, and Glaucous-winged Gull. Bears were also occasionally heard.

Aircraft noise data are shown in Figures 65–69. While on site, landing float planes passed almost directly overhead within 30-50 meters of the microphone. With such proximity, it should not be surprising that the station documented takeoff events with maximum $LA_{eq,\,1s}$ greater than 100 dB (Figure 68). Wheel planes were observed landing and taking off from a beach about 4.4 km north of the site. Turn-outs during takeoff were varied and spanned most of the Hallo Bay airspace. Variable flight routes create varied impacts, as seen in the broadly-distributed histogram of Figure 69 (compare to East Kulik Lake, Figure 61). Relative to the western areas of KATM, propeller aircraft

impacts at Hallo Bay (median 11 per day, time audible = 5.3% of entire record) were much less acute.

During installation, boats were anchored in the bay approximately 2 to 4 km from the site. Additionally, a small skiff was observed heading towards Ninagiak Island, inaudible over the sound of the outgoing tide. Boats had a temporally widespread impact (time audible = 26.2% of the entire record).

Pervasive watercraft noise and moderate aircraft noise at Hallo Bay combine to produce substantial impacts; the site has the shortest median noise-free interval of any in the Katmai inventory (0.05 hours, Appendix B, Figure APP B.3). It also had the second highest cumulative time audible of all sites in the inventory, after Amalik Bay (Appendix B, Figure APP B.11).

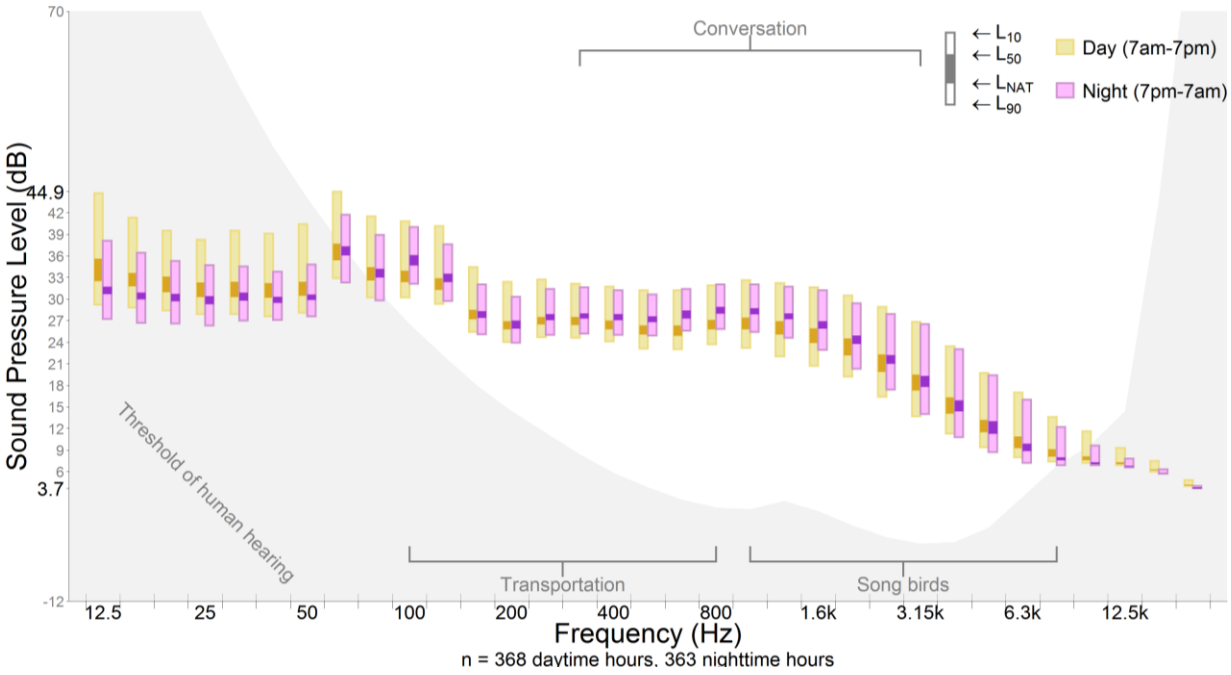


Figure 41. Spectral percentile levels for Hallo Bay, 2016.

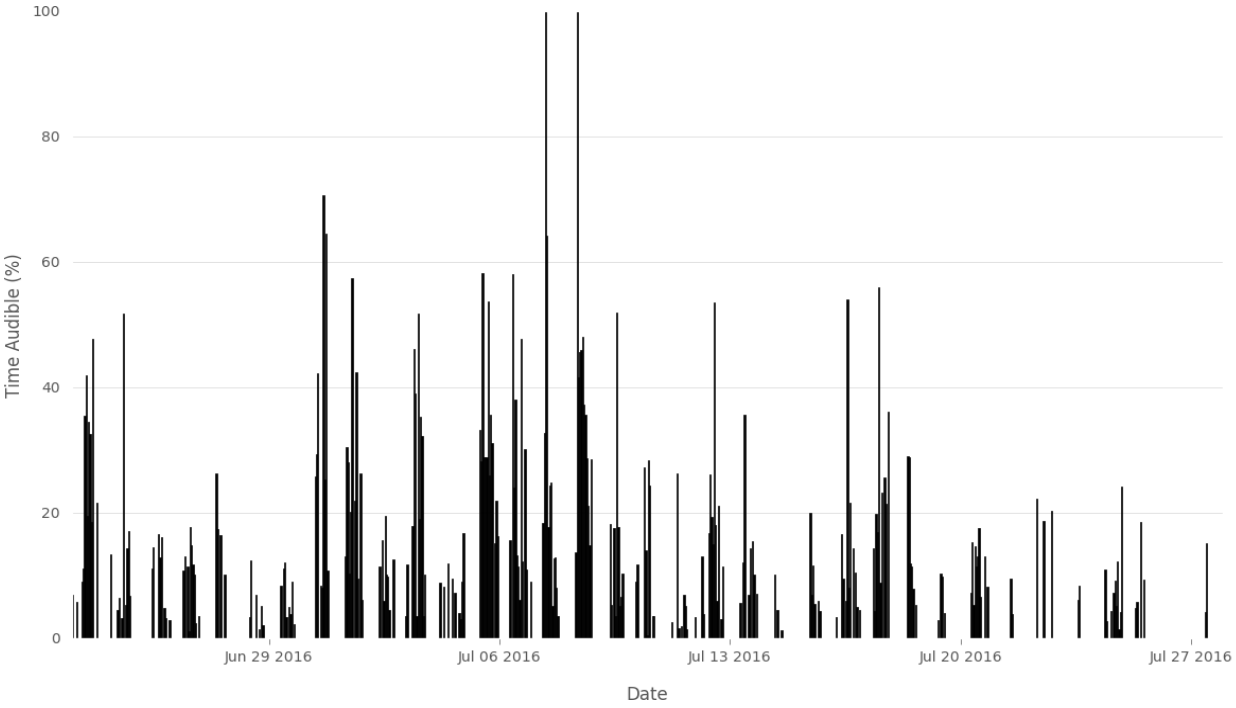


Figure 42. Audibility of aircraft noise by hour at Hallo Bay, 2016.

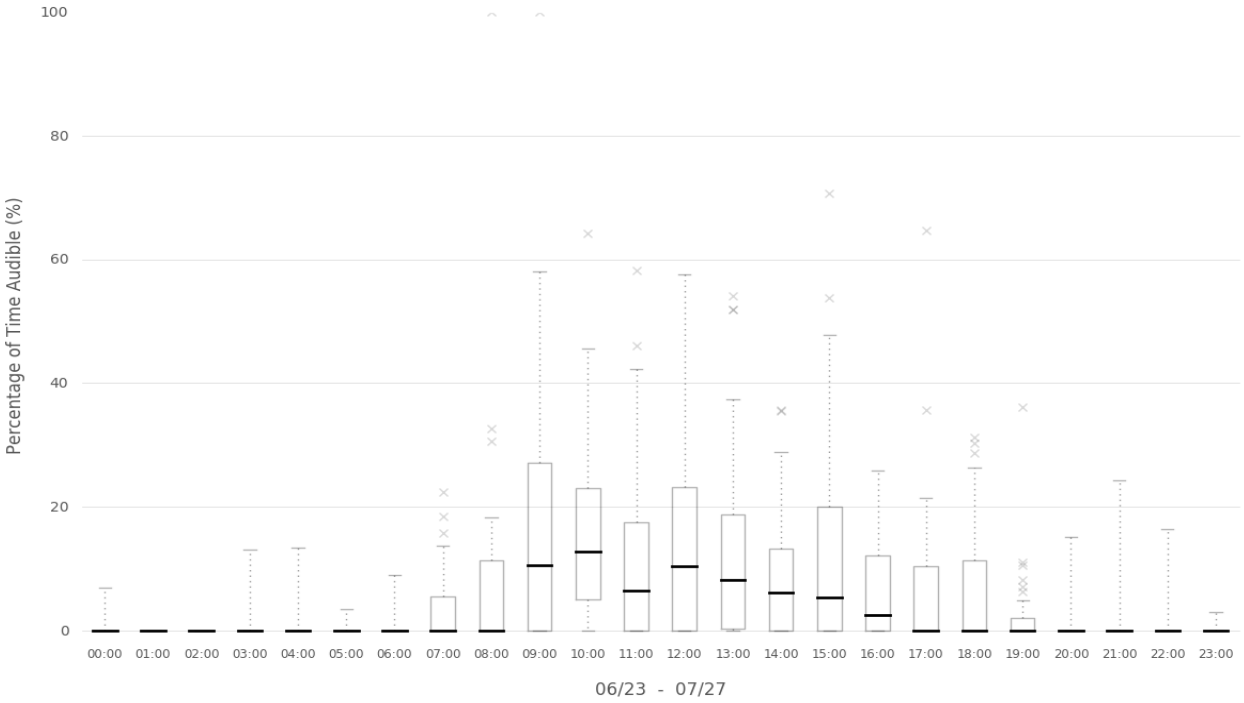


Figure 43. Audibility of aircraft noise for an average day, by hour, at Hallo Bay, 2016. The bold line indicates the median (50th percentile) value, the top of the box is the 75th percentile, and the bottom is the 25th percentile. The dashed flyers show 1.5x the interquartile range. Values outside this range are considered outliers and marked with an ‘x’.

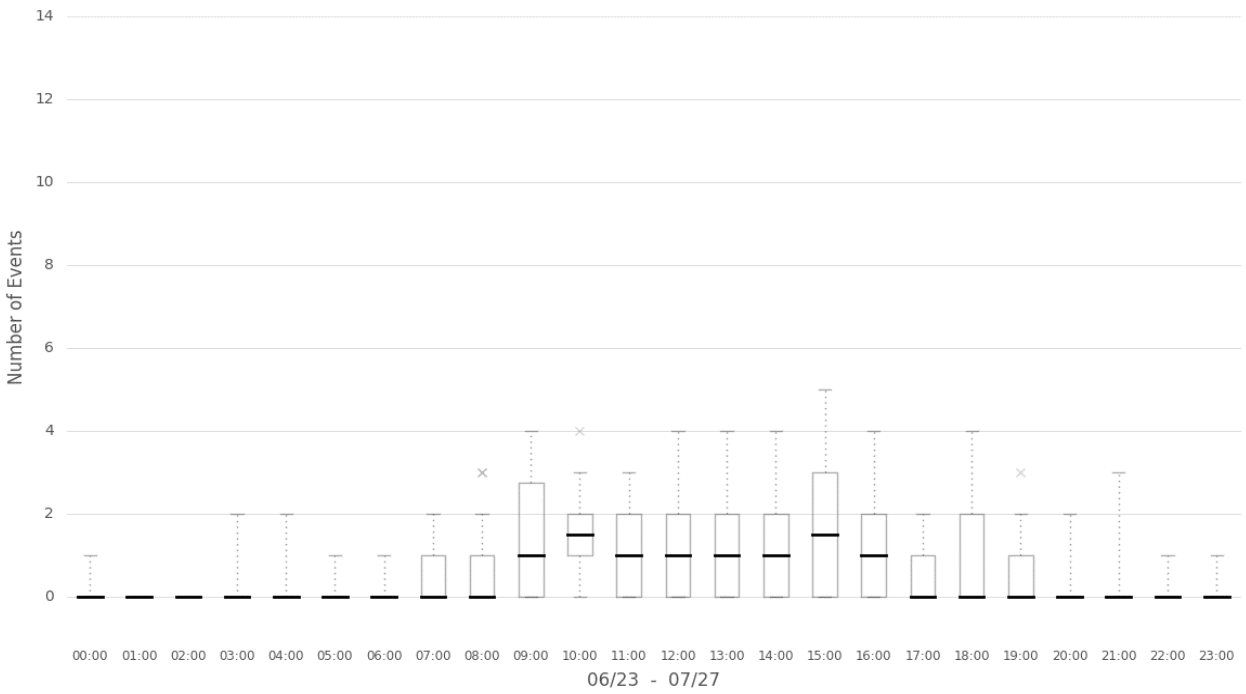


Figure 44. Rates of detection for aircraft noise events by hour at Hallo Bay, 2016.

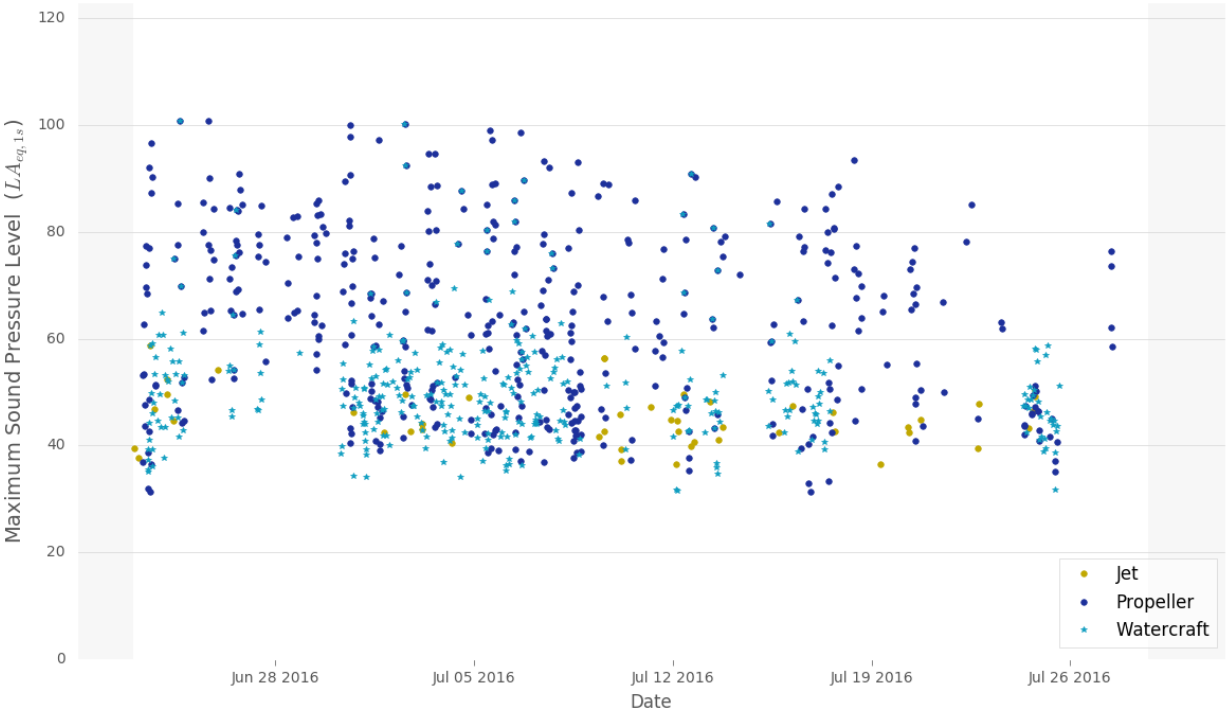


Figure 45. Maximum one-second sound pressure level for each noise event detected at Hallo Bay, 2016.

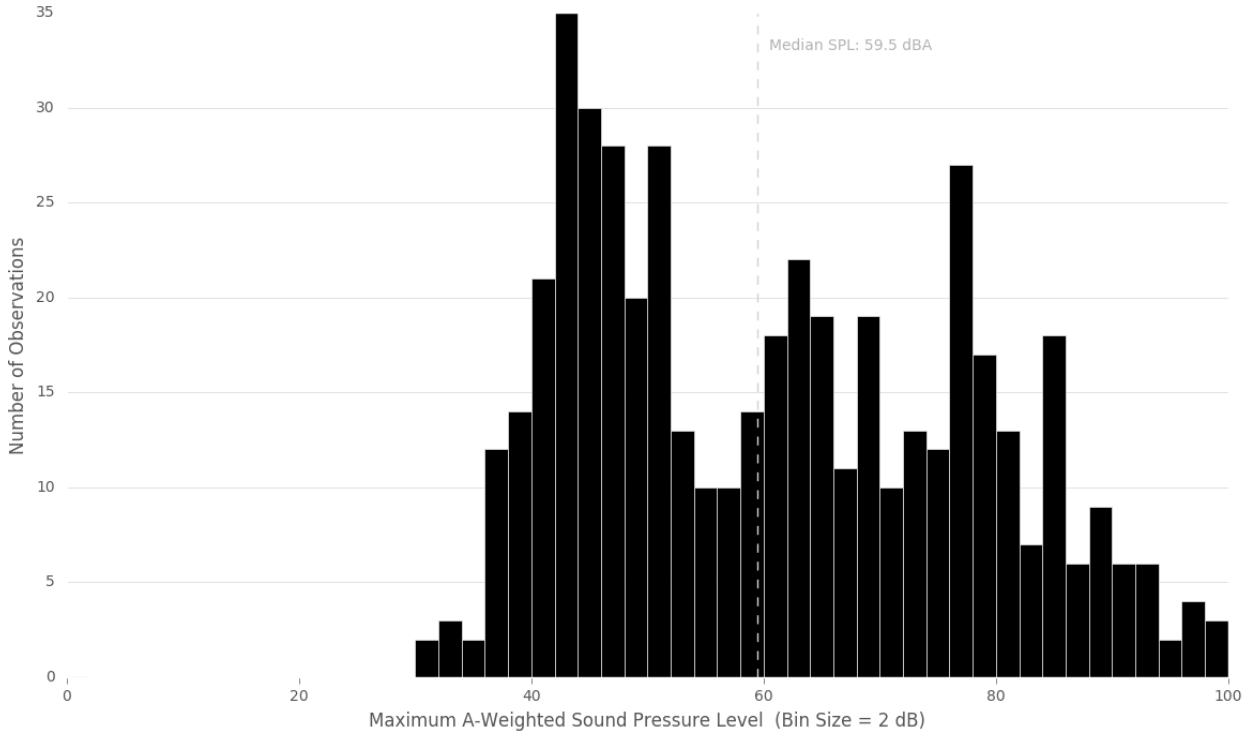


Figure 46. Histogram of maximum one-second sound pressure levels for aircraft noise events detected at Hallo Bay, 2016.

Jo-Jo Lake

Location Description: Site was located on a small island within Jo-Jo Lake (Figures 70 and 71). The site is separated by ridges from Lake Grosvenor to the east and the Savonoski River to the south. The microphone was located within 2 meters of the lake on a small projecting point of land.

Coordinates: 58.61685°, -155.22643° (WGS84)

Elevation: 18 meters (60 feet)

Sampling Period: 22-June-2016 to 25-July-2016

Management Unit: Katmai National Park, Designated Wilderness

Ecotypes: Lakes Region Spruce Covered Moraines, Viereck Class III.B.2.b *Mesic Forb Herbaceous Fireweed* and III.B.2.c *Mesic Forb Herbacious Large Umbel*

Access: DeHavilland DHC-2 on floats



Figure 47. Cardinal photographs of the Jo-Jo Lake inventory site.

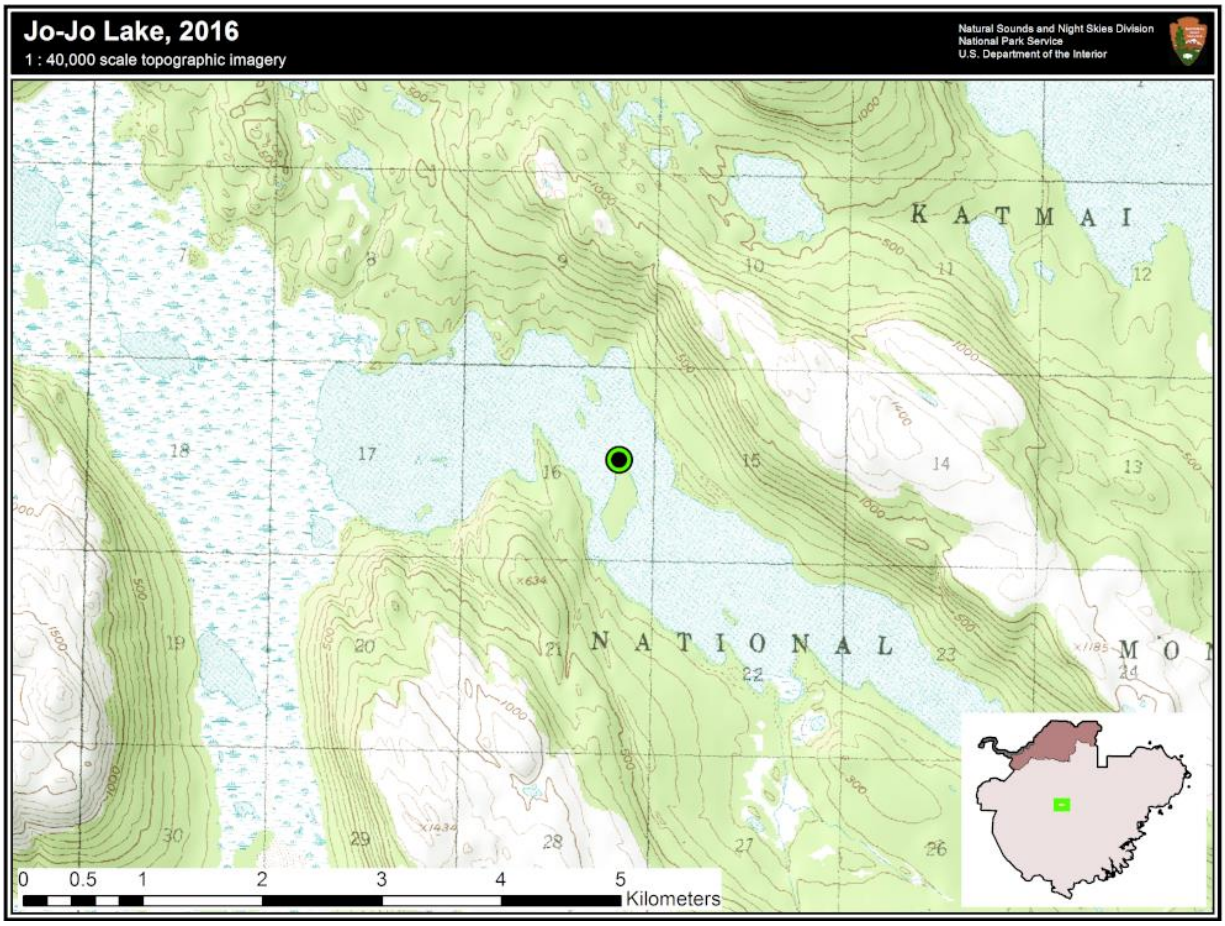


Figure 48. Topographic map of Jo-Jo Lake at 1:40,000 scale. The inset map in the lower-right corner indicates the location of the frame within Katmai. Light brown areas represent park land and darker brown areas show preserve land.

Summary: The Jo-Jo Lake inventory site had a time-averaged natural ambient sound pressure level (LA_{nat}) of 31.7 dB. The 90th percentile of sound pressure levels (LA_{10}) was 39.3 dB, and the 10th percentile (LA_{90}) was 27.3 dB, a difference of 12.0 Db (Figure 72). Small waves are important natural sources of acoustic energy at this site – within the span of a few hours they can change the values of $LA_{eq,\ 1s}$ from 17 dB to as high as 37 – 38 dB. The acoustic environment can be reverberant under certain atmospheric conditions, creating long trailing echoes on sounds.

Avian sounds were common during this June/July sample. Trumpter Swan, Common Loon, Barrow's Goldeneye, Swainson's Thrush, American Robin, Golden-crowned Sparrow, and Black-capped Chickadee were all detected on the record.

Avian noise data are shown in Figures 73–77. As is the case at East Kulik Lake, the non-skewed distribution of maximum $LA_{eq,\ 1s}$ values at Jo-Jo Lake (Figure 77) suggest that propeller noise events represent aircraft in 'cruising' flight along one (or a few) typical routes. Geographically, the Jo-Jo Lake site, along with East Kulik Lake and Kamishak River, appear to represent a contour for propeller aircraft noise (see Appendix B, Figure APP B.6 and Figure APP B.7). Moving east from

them towards the Aleutian Range propeller aircraft noise impacts are likely to decrease, while moving west impacts are expected to increase.

Jo-Jo Lake was one of six sites where helicopters were heard (time audible = 0.05% of entire record, n = 4 events). Two nearby sites in the west-central area of the park (Dumpling Point and Valley of Ten-Thousand Smokes) have similar rates of helicopter noise (Appendix B, Figure APP B.14).

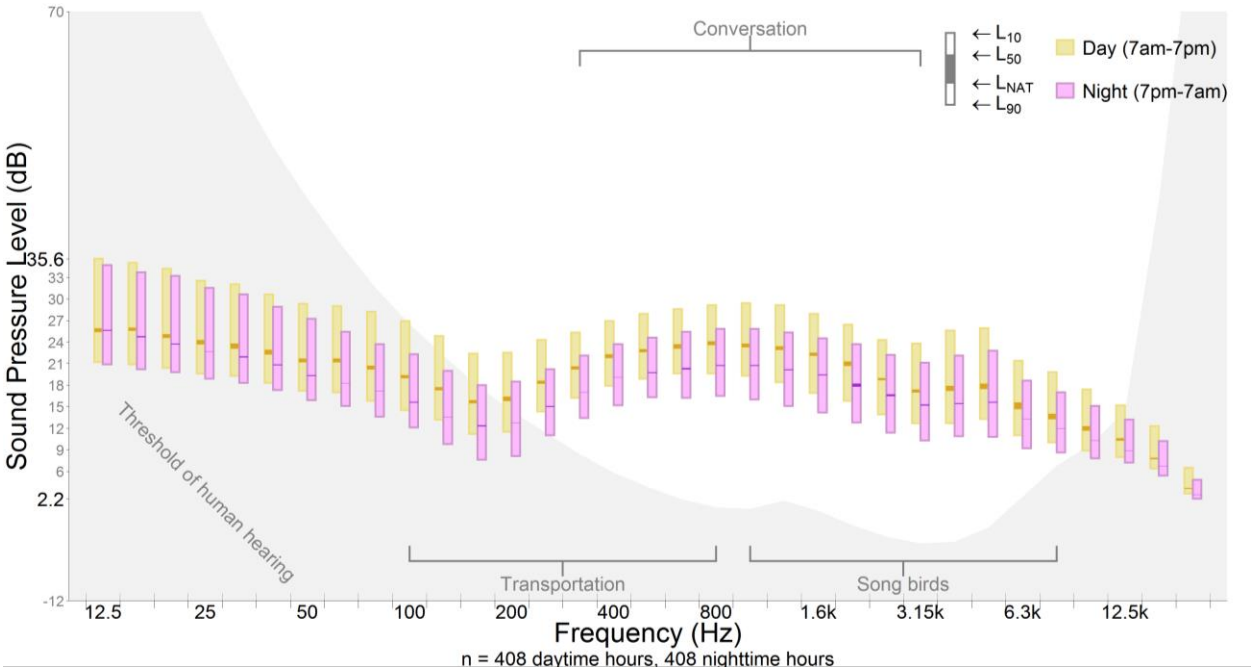


Figure 49. Spectral percentile levels for Jo-Jo Lake, 2016.

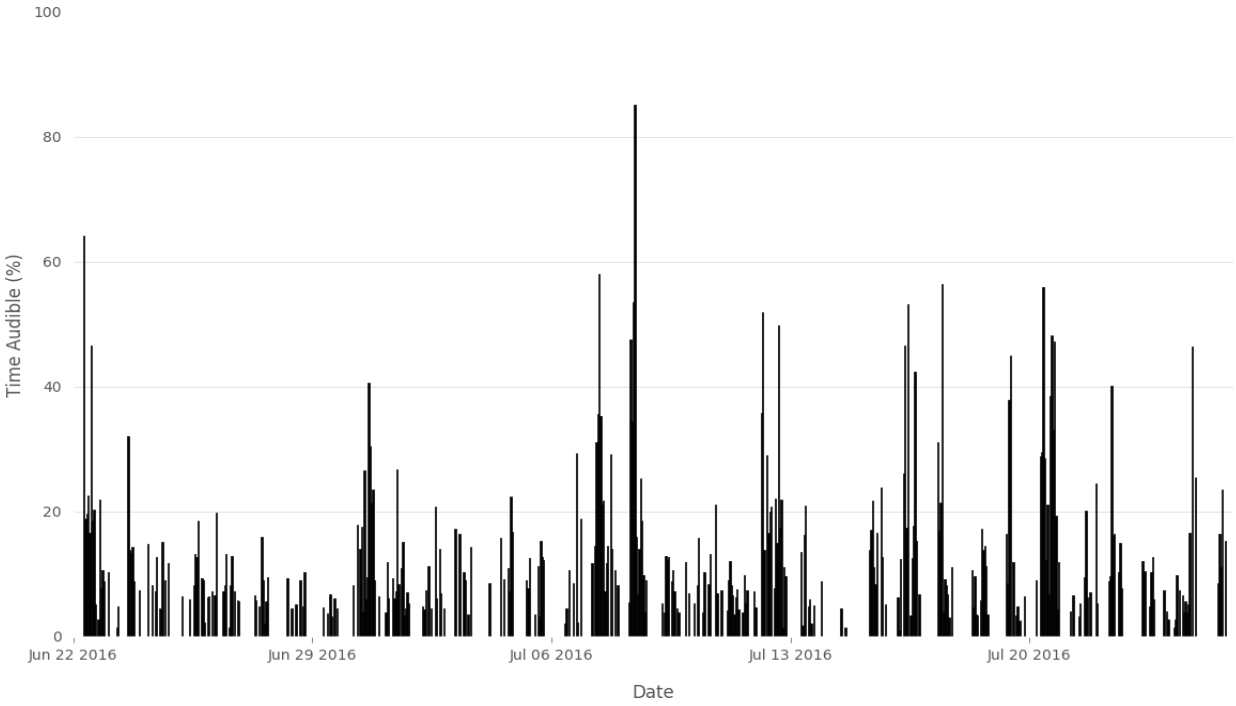


Figure 50. Audibility of aircraft noise by hour at Jo-Jo Lake, 2016.

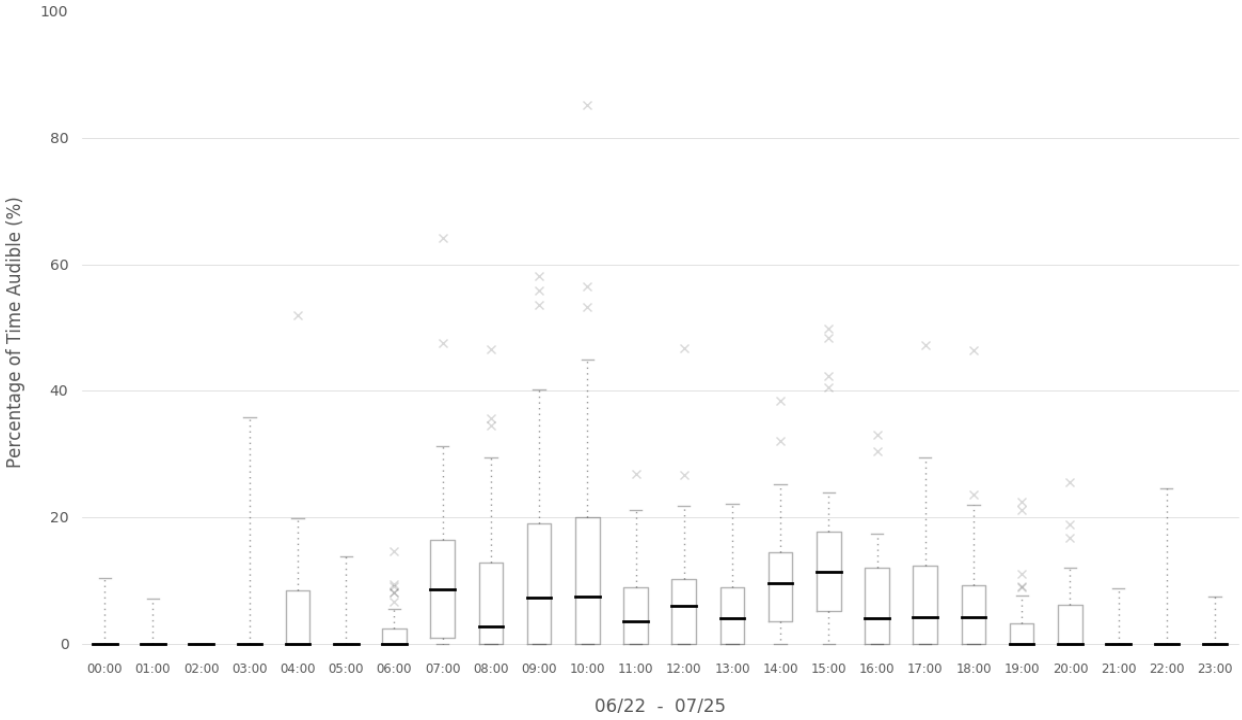


Figure 51. Audibility of aircraft noise for an average day, by hour, at Jo-Jo Lake, 2016. The bold line indicates the median (50th percentile) value, the top of the box is the 75th percentile, and the bottom is the 25th percentile. The dashed flyers show 1.5x the interquartile range. Values outside this range are considered outliers and marked with an ‘x’.

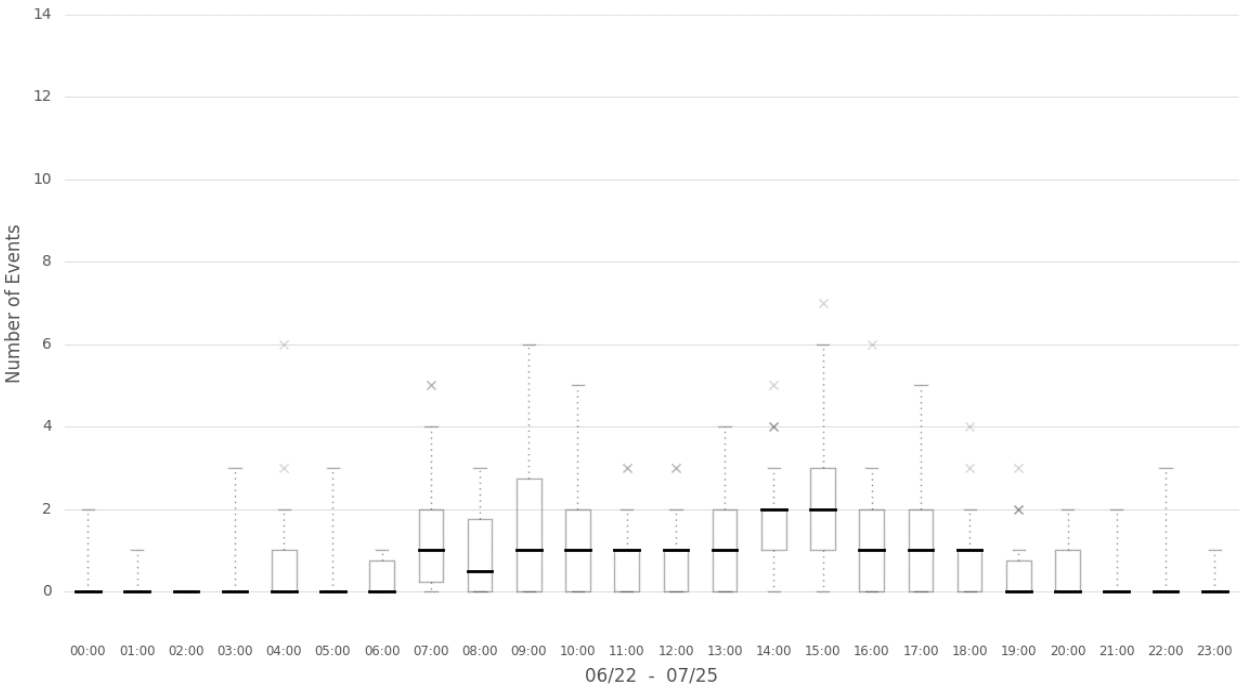


Figure 52. Rates of detection for aircraft noise events by hour at Jo-Jo Lake, 2016.

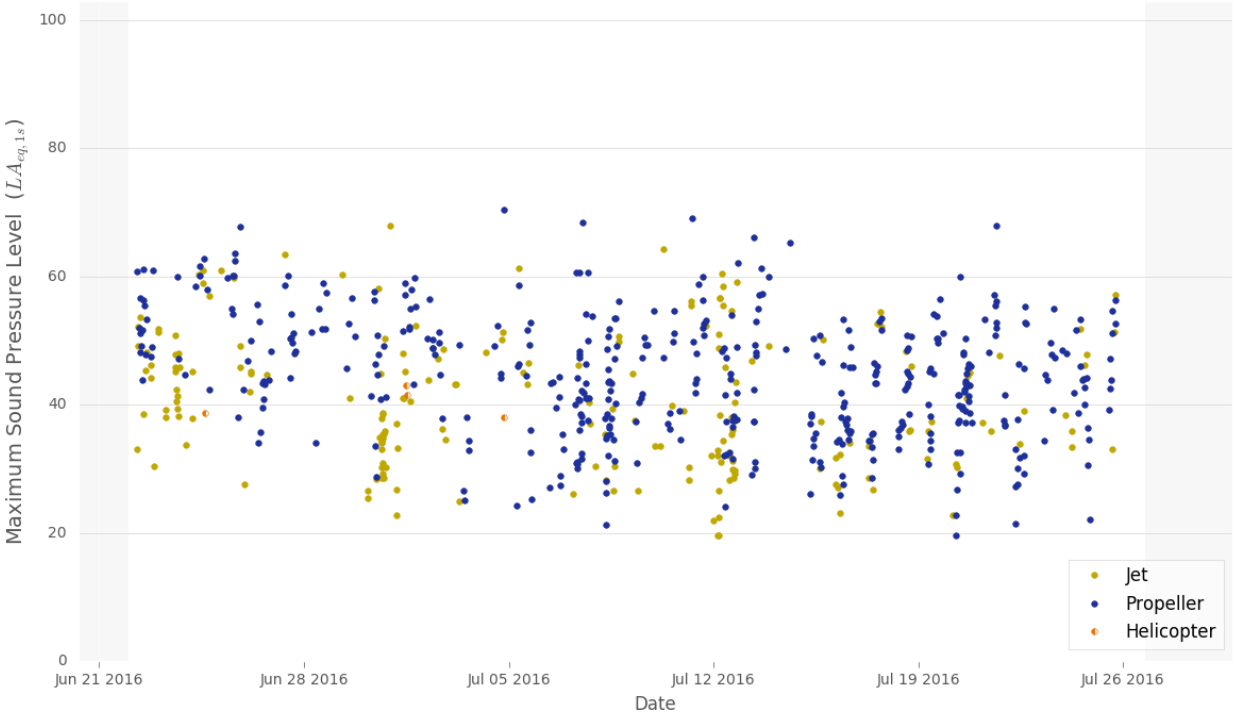


Figure 53. Maximum one-second sound pressure level for each noise event detected at Jo-Jo Lake, 2016.

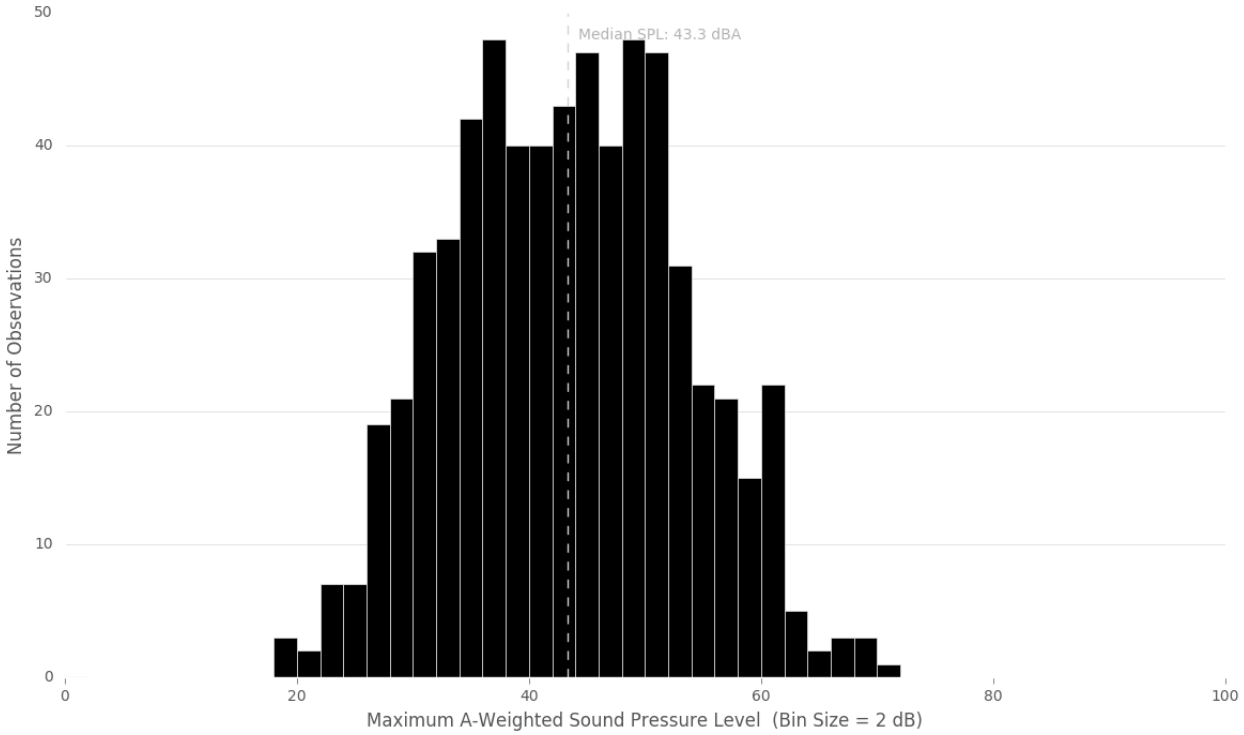


Figure 54. Histogram of maximum one-second sound pressure levels for aircraft noise events detected at Jo-Jo Lake, 2016.

Kamishak River

Location Description: Site was located on an expansive floodplain 70 meters east of the Kamishak River, about 3 km upstream from Akumwarvik Bay and 0.3 km upstream from the park boundary (Figures 78 and 79). Low, densely-vegetated coastal mountains rise 2.5 km to the east.

Coordinates: 58.99634°, -154.15538° (WGS84)

Elevation: 13 meters (42 feet)

Sampling Period: 29-July-2017 to 21-August-2017

Management Unit: Katmai National Park, Designated Wilderness

Ecotypes: Shelikof Strait Lowlands, Viereck Class III.A.2.a *Bluejoint meadow*

Access: DeHavilland DHC-2 on floats



Figure 55. Cardinal photographs of the Kamishak River inventory site.

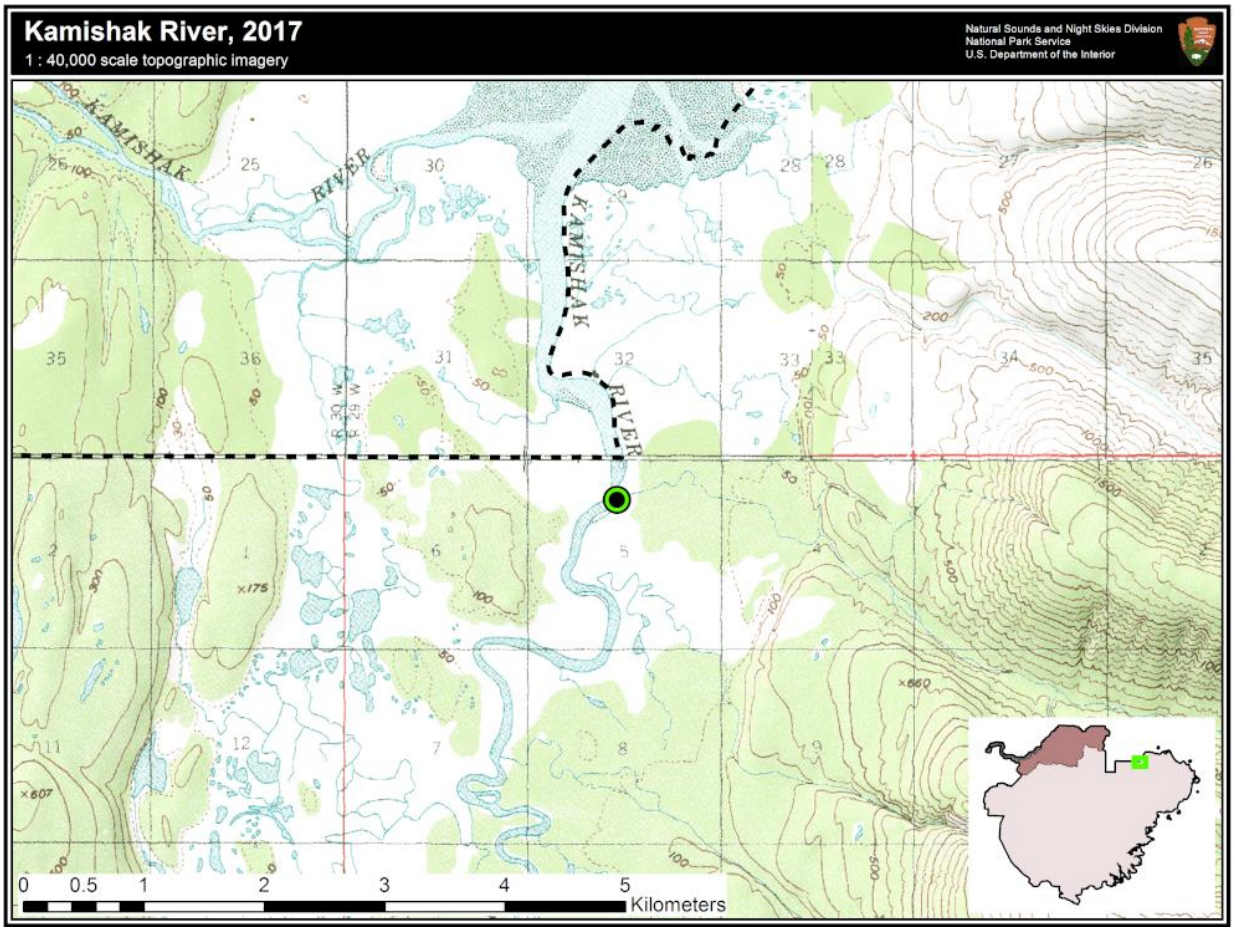


Figure 56. Topographic imagery of the Kamishak River at 1:40,000 scale. The dashed black line shows the park boundary. The inset map in the lower-right corner indicates the location of the frame within Katmai. Light brown areas represent park land and darker brown areas show preserve land.

Summary: The coastal lowland landscape of the Kamishak River inventory site had a time-averaged natural ambient sound pressure level (LA_{nat}) of 23.0 dB. The 90th percentile of sound pressure levels (LA_{10}) was 32.4 dB, and the 10th percentile (LA_{90}) was 20.3 dB, a large difference of 12.1 dB. The Kamishak River itself was inaudible from the site location during install, but flowing water was audible from other sources (see the minor peak in the 500 Hz 1/3rd octave band, Figure 80.)

Aircraft noise data are shown in Figures 81–85. During installation we observed both float planes and motorboats anchored about 0.8 km from the site just outside of the park boundary (Appendix C, Figure APP C.10). KATM staff suggested that the boats were kept there for the entire summer season (R. Peterson, personal comm). They were detected regularly on the record (time audible = 4.7%). Kamishak Bay had the highest rate of watercraft noise for any site in the inventory (median = 14 events per day). Motorboats were especially active in mid-to-late August (Figure 84).

Takeoffs were also prominent, producing $LA_{eq,\ 1s}$ that exceed 70 dB (Figure 84). The influence of takeoffs is also apparent in the strongly right-skewed maximum LA_eq, 1s histogram (Figure 85).

Noise event timing is highly bimodal with peaks at 08:00 and 15:00 (Figure 82, Figure 83), suggesting day-flights.

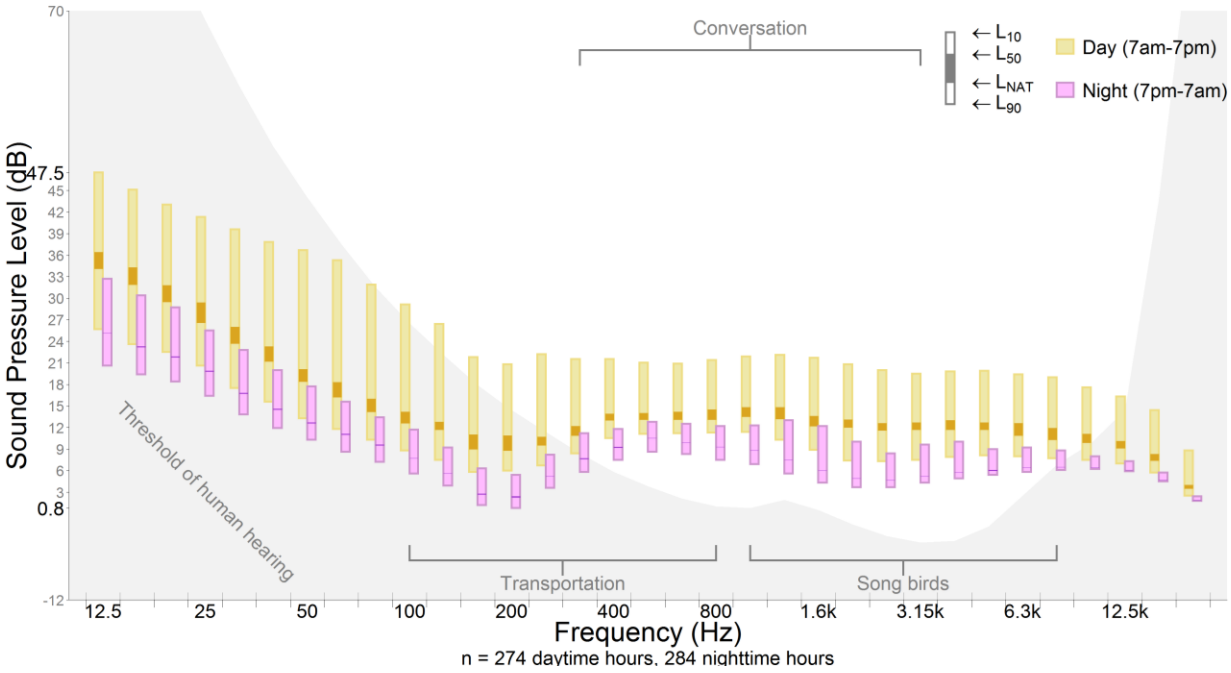


Figure 57. Spectral percentile levels for Kamishak River, 2017.

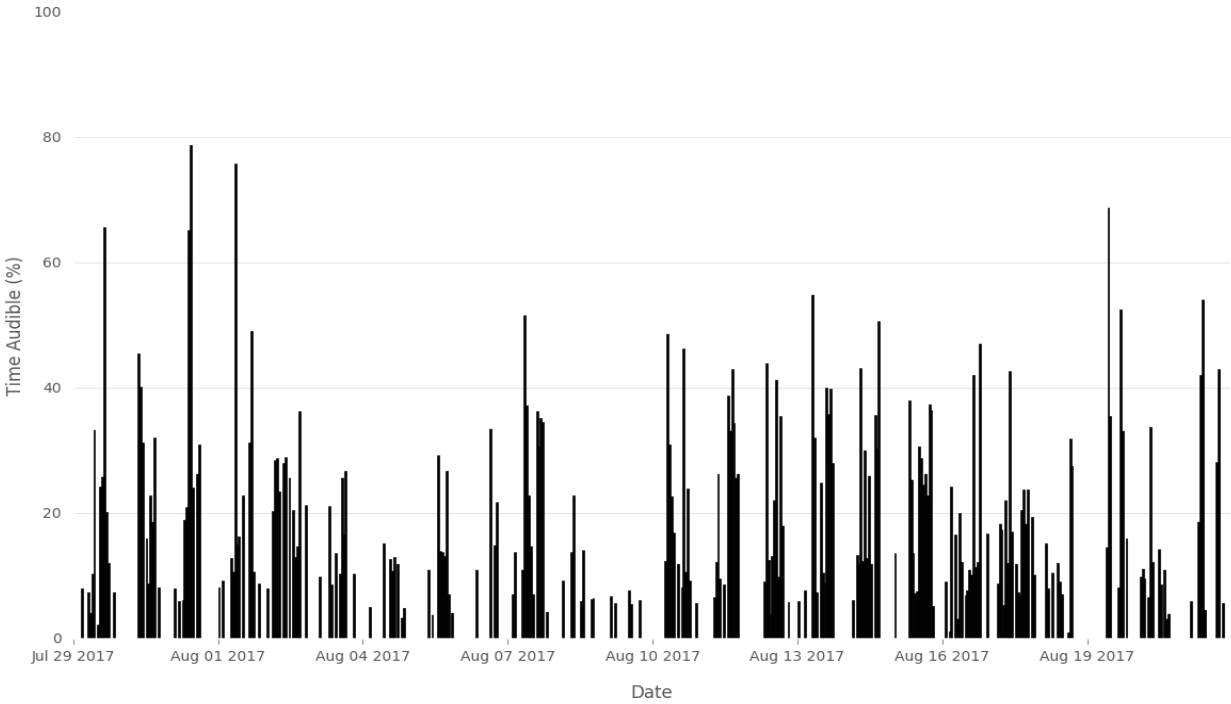


Figure 58. Audibility of aircraft noise by hour at Kamishak River, 2017.

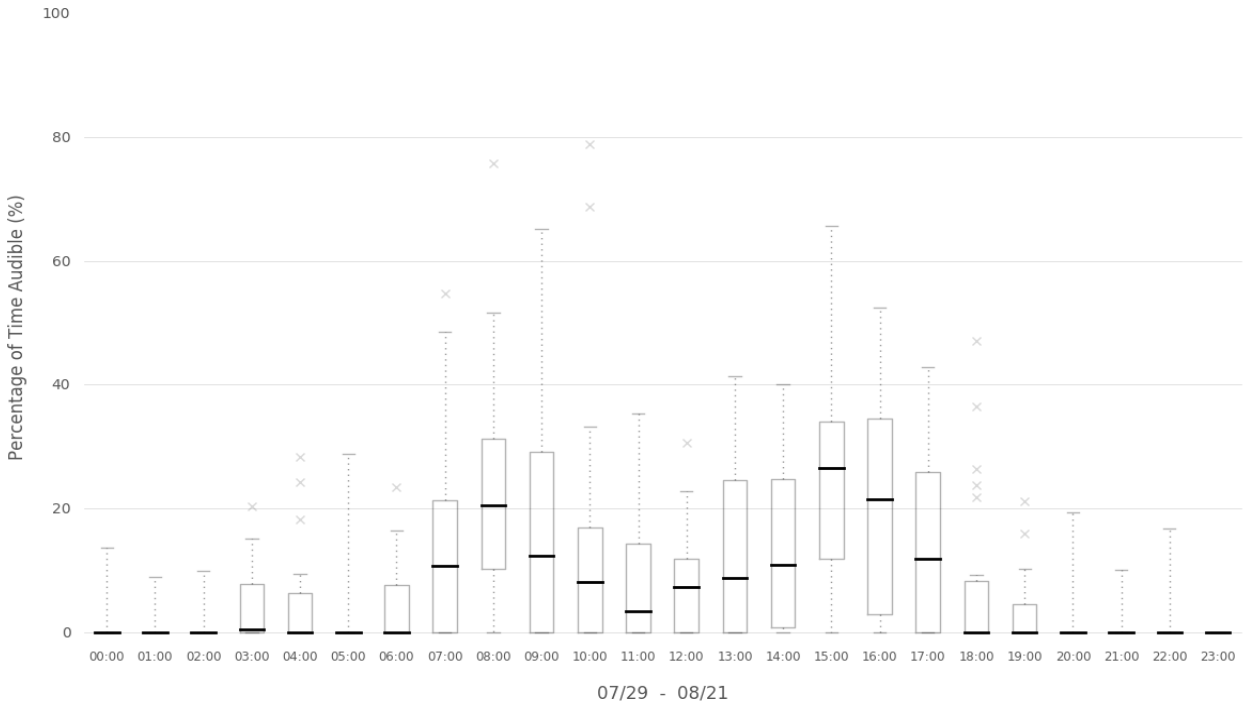


Figure 59. Audibility of aircraft noise for an average day, by hour, at Kamishak River, 2017. The bold line indicates the median (50th percentile) value, the top of the box is the 75th percentile, and the bottom is the 25th percentile. The dashed flyers show 1.5x the interquartile range. Values outside this range are considered outliers and marked with an ‘x’.

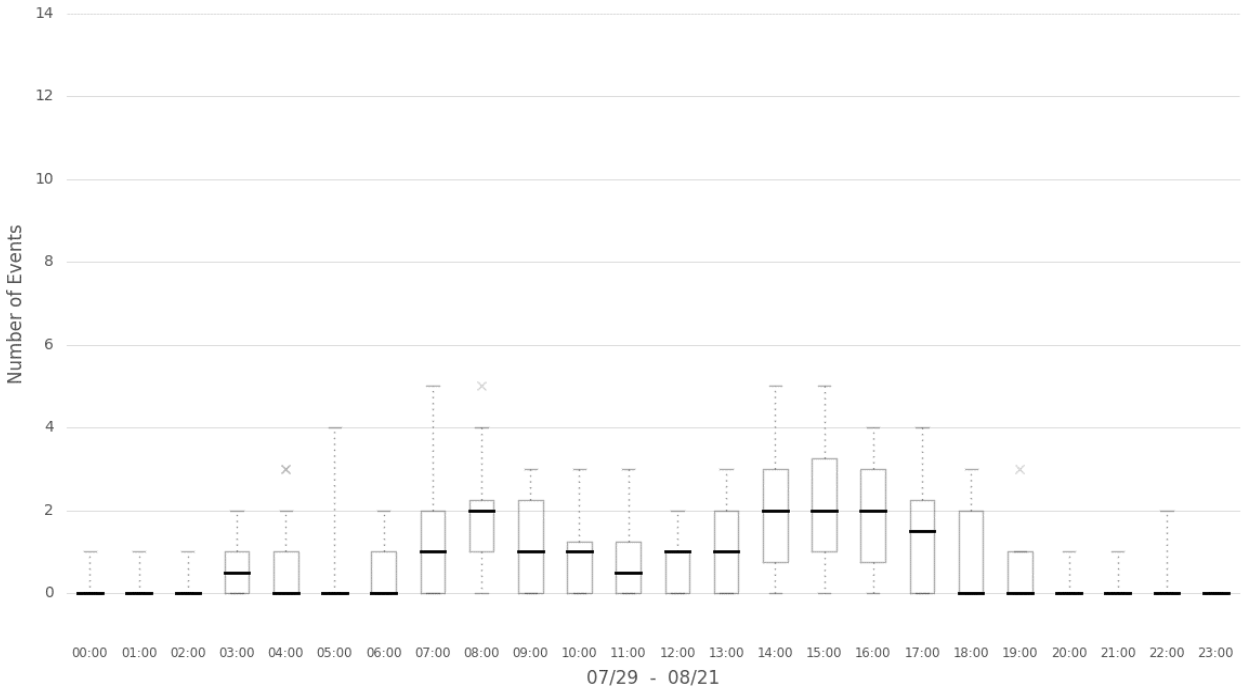


Figure 60. Rates of detection for aircraft noise events by hour at Kamishak River, 2017.

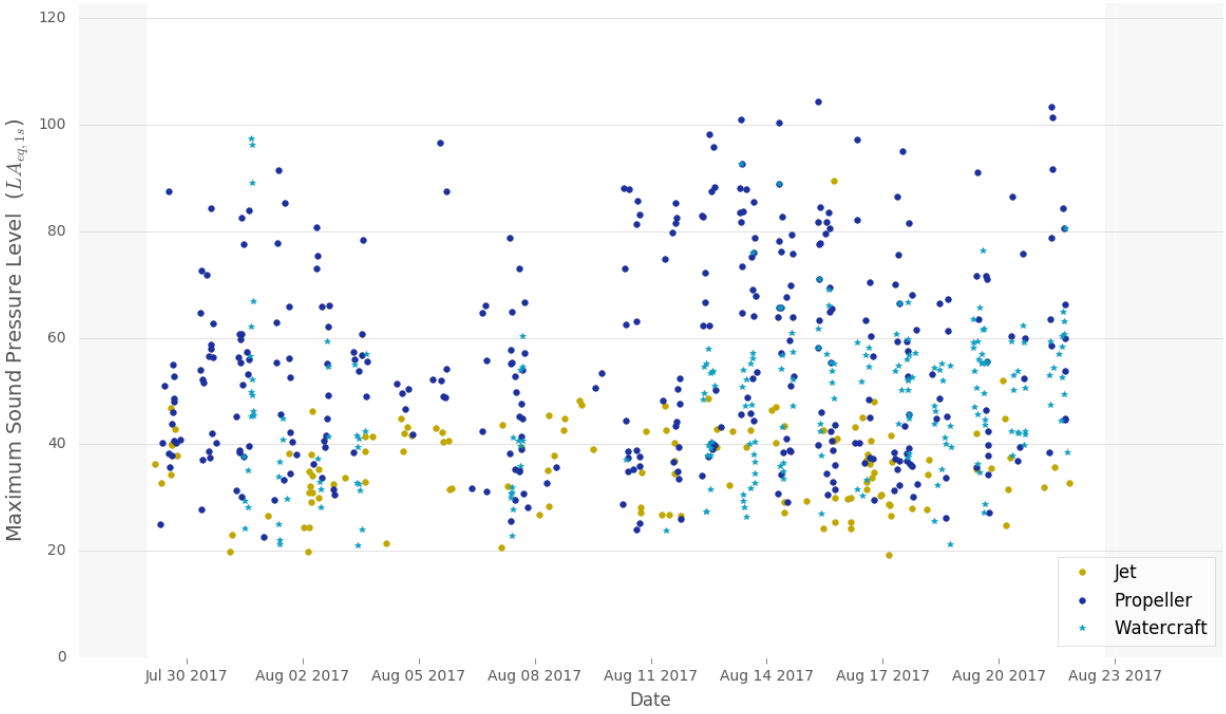


Figure 61. Maximum one-second sound pressure level for each noise event detected at Kamishak River, 2017.

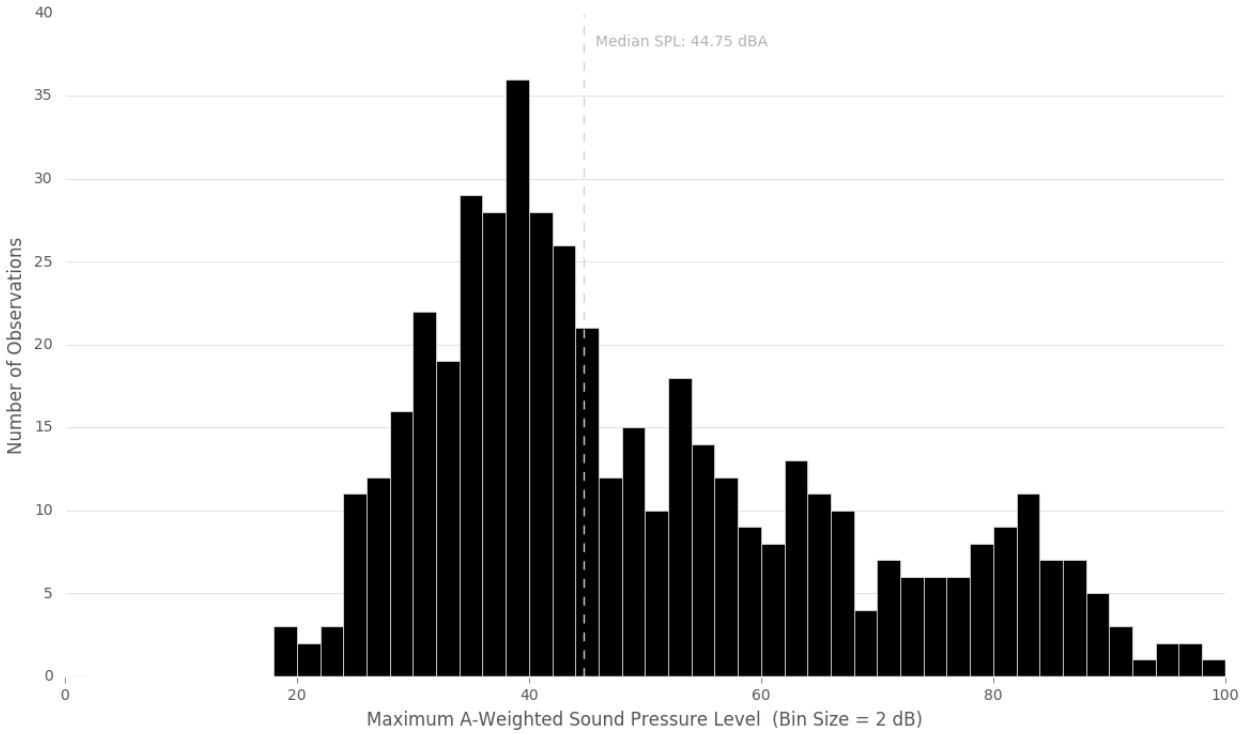


Figure 62. Histogram of maximum one-second sound pressure levels for aircraft noise events detected at Kamishak River, 2017.

Katmai Bay

Location Description: Site was located on the protected portion of the Katmai Bay beach, set about 100 – 200 meters back from the surf zone where the transition from loose sand to vegetation begins (Figures 86 and 87). Fully-vegetated dunes form a low barrier between the site and the Katmai River. These are located about 0.8 km to the northwest. The location is 2 km west of the historic Katmai Village.

Coordinates: 58.02355°, -154.90401° (WGS84)

Elevation: 7 meters (22 feet)

Sampling Period: 29-July-2016 to 12-September-2016

Management Unit: Katmai National Park, Designated Wilderness

Ecotypes: Katmai River Floodplain, Viereck Class III.A.I.a *Dry Graminoid Herbaceous Elymus*

Access: Cessna 185 on wheels



Figure 63. Cardinal photographs of the Katmai Bay inventory site.

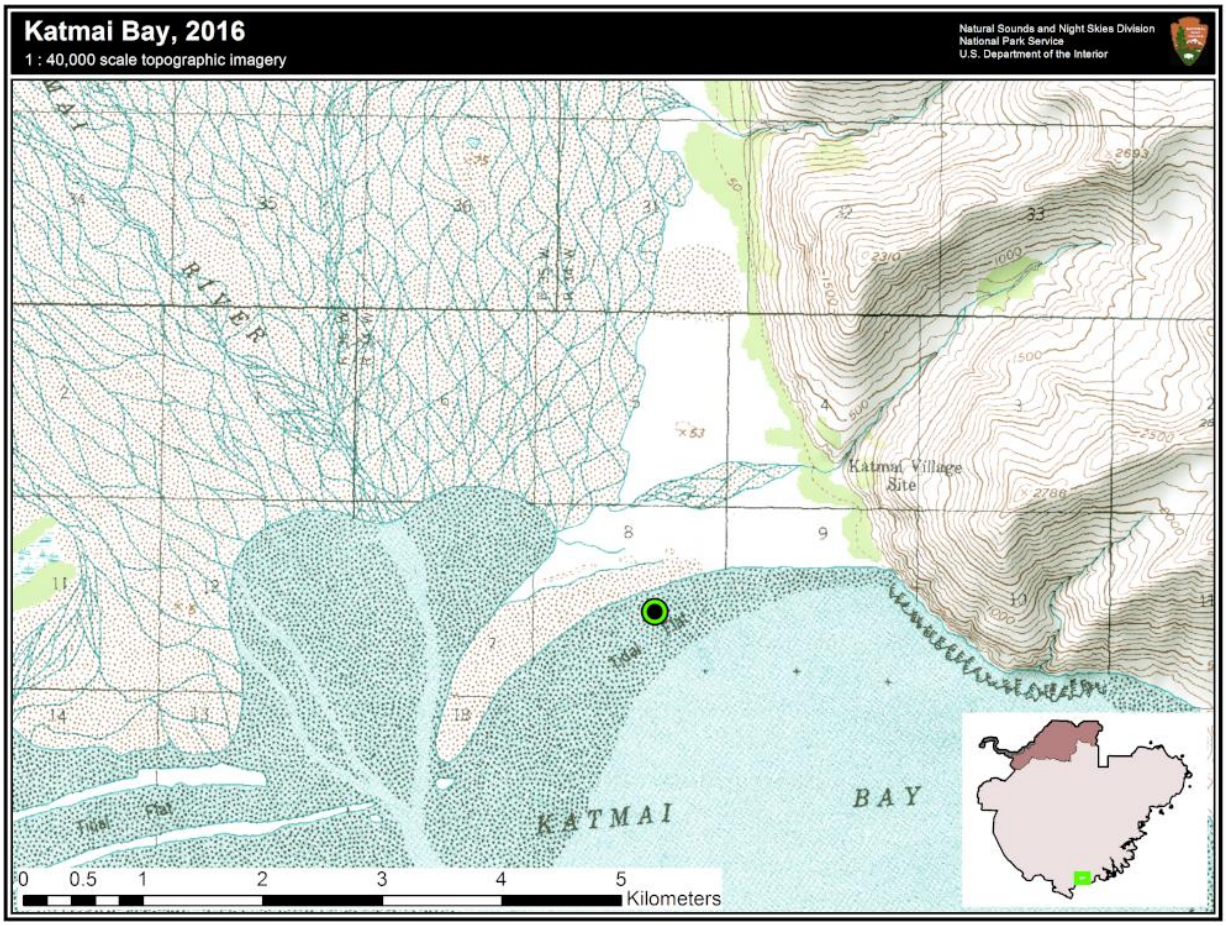


Figure 64. Topographic map of Katmai Bay at 1:40,000 scale. Since the map was created the shoreline has moved south and dunes have filled the areas formerly mapped as tidal flats. The inset map in the lower-right corner indicates the location of the frame within Katmai. Light brown areas represent park land and darker brown areas show preserve land.

Summary: The coastal landscape of the Katmai Bay inventory site had a time-averaged natural ambient sound pressure level (LA_{nat}) of 41.1 dB. The 90th percentile of sound pressure levels (LA_{10}) was 44.6 dB, and the 10th percentile (LA_{90}) was 37.6 dB, a difference of 7.0 dB (Figure 88). Waves and long periods of high winds (median speed 1.6 m/s) both contribute to the natural ambience. The site is tied with East Kulik Lake as the most naturally-energetic acoustic environment sampled in KATM.

Biological sounds were scarce in this July/August/September sample. Common Raven and Bald Eagle were commonly heard. Seabirds were audible from the headlands 2.3 km east of site (Appendix C, Figure APP C.9). Bears were documented visiting the site on several occasions, though they showed very little interest in the equipment – simply smelling the windscreen and moving on.

Aircraft noise data are shown in Figures 89–93. Katmai Bay has the distinction of being the least human-impacted site sampled during the inventory. It had a very low noise event rate (median 4 per day), and unlike Douglas River events were mainly low-amplitude. This is because 80% of noise

events were high-altitude jet aircraft. Anchorage is one of the largest air-cargo ports in the United States, equidistant from Asia, Europe, and the west coast of the Lower 48. Many of the great-circle routes to Asia pass over Lake Clark and Katmai. One clue that these aircraft are following regular, routine routes is that the histogram of maximum one-second SPLs in Figure 93 is very *narrow* (in fact, one of the narrowest ever measured in Alaska). For comparison see *Healy Ridge*, Withers and Hults 2006. This suggests similar aircraft following similar routes through a geographically proximal airspace. These conditions are similar to those found in Amalik Bay.

Due to a prevalence of jets, the audibility of aircraft events peaks between 02:00 and 03:00 (Figure 91), a time when visitors are not usually active. Katmai Bay never had noise audible for more than 20% of an hour (12 minutes), and many hours had no noise at all (Figure 89). Katmai Bay has a high proportion of long noise-free intervals: 29% exceed 3 hours (Appendix B, Figure APP B.20, see also Valley of Ten-Thousand Smokes). Compare this to Hallo Bay, where 37% of hours exceed 12 minutes of noise, and only 4% of noise-free intervals exceed 3 hours. Or alternatively, to American Creek, where 44% of all hours exceed 12 minutes of noise, and only 2% of noise-free intervals exceed 3 hours.

Watercraft events were uncommon (time audible = 0.2% of the entire record). As was the case at the Douglas River site, most of the events occurred over the course of a single day (specifically, 09/02/16).

The Katmai Bay site was near the Katmai Village site, which has important cultural and historic significance. This may change what sounds are considered intrinsic to the location. Additionally, quietude may facilitate the appreciation of such historical aspects of wilderness character.

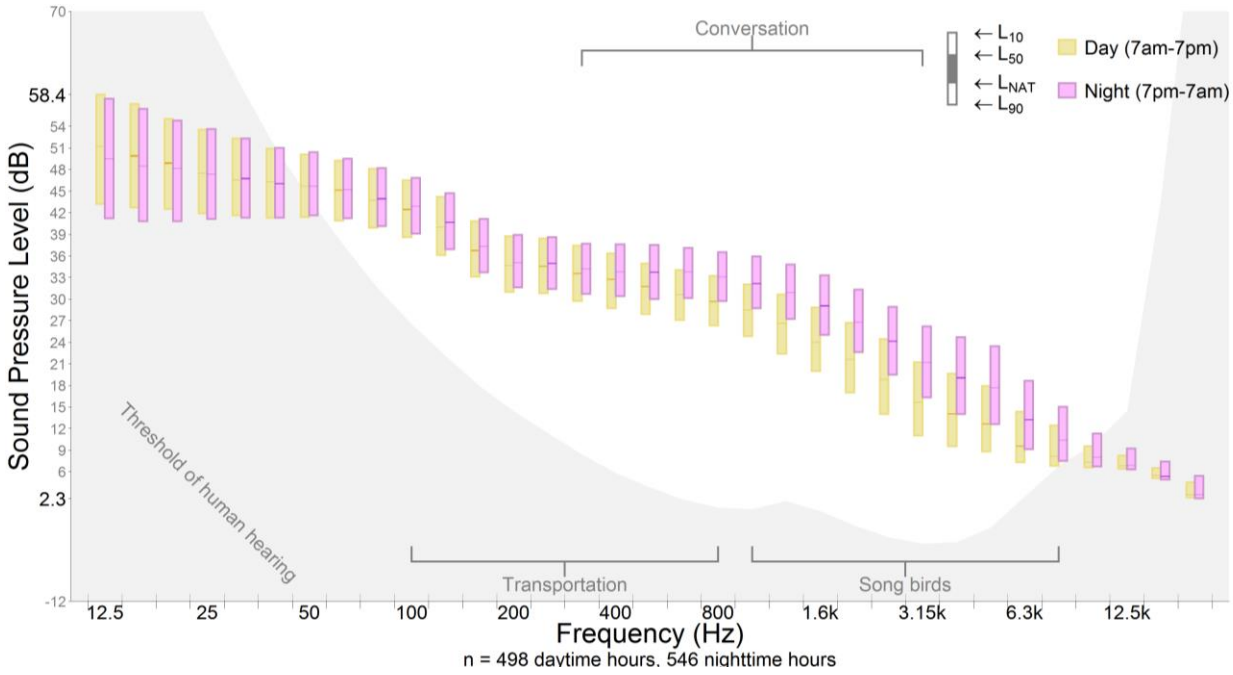


Figure 65. Spectral percentile levels for Katmai Bay, 2016.

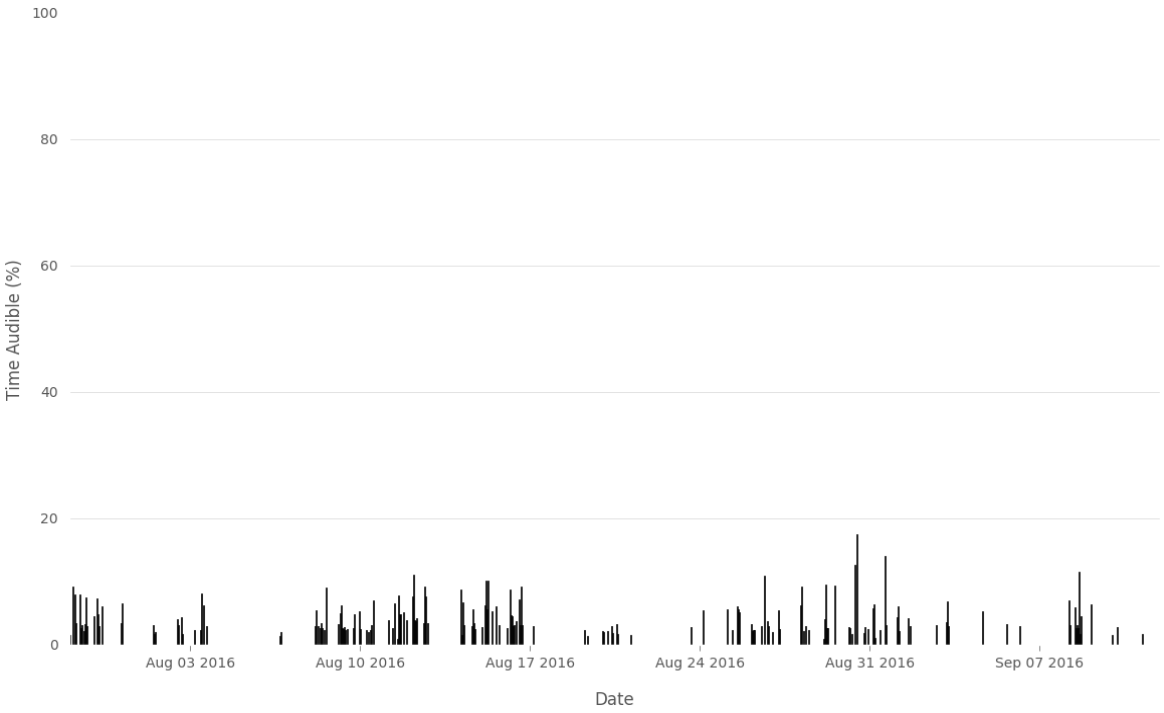


Figure 66. Audibility of aircraft noise by hour at Katmai Bay, 2016.

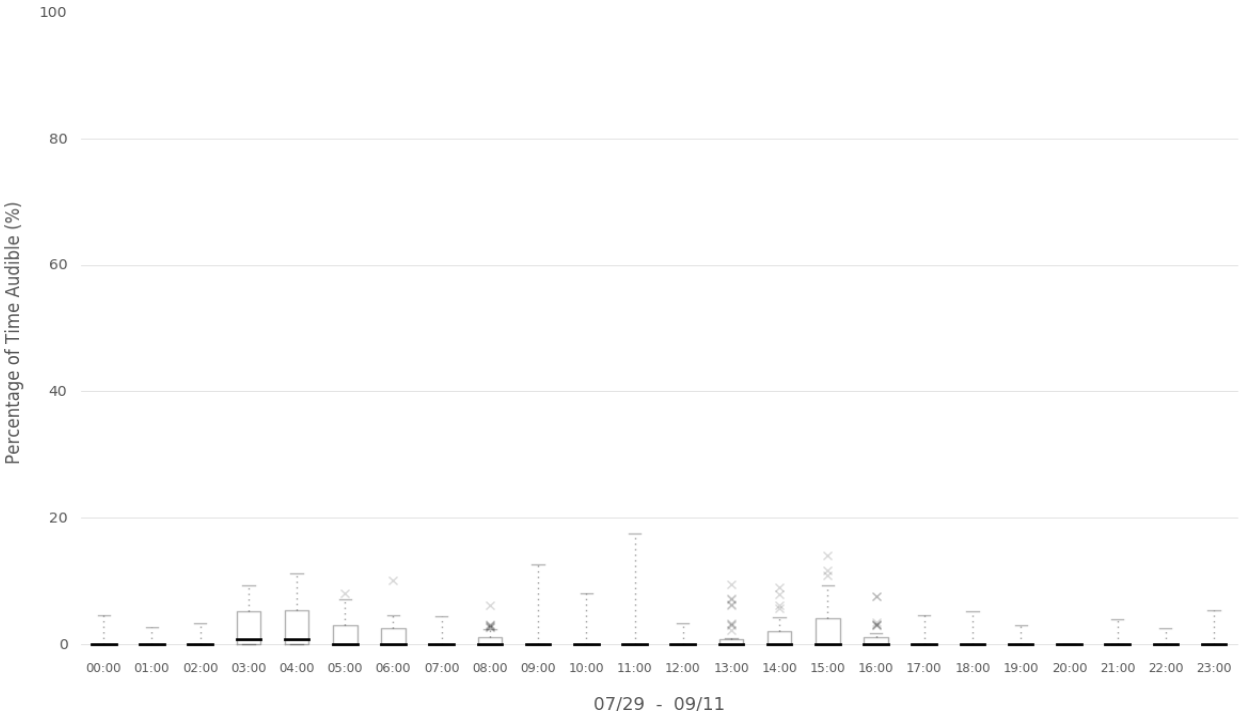


Figure 67. Audibility of aircraft noise for an average day, by hour, at Katmai Bay, 2016. The bold line indicates the median (50th percentile) value, the top of the box is the 75th percentile, and the bottom is the 25th percentile. The dashed flyers show 1.5x the interquartile range. Values outside this range are considered outliers and marked with an ‘x’.

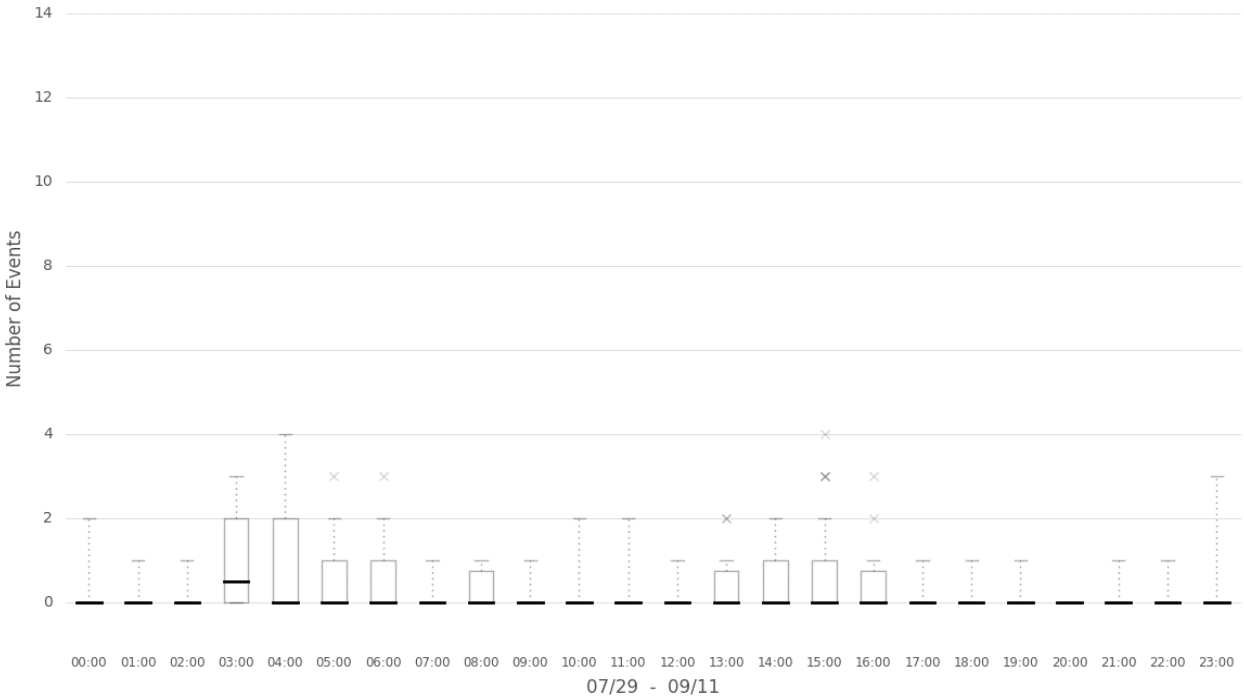


Figure 68. Rates of detection for aircraft noise events by hour at Katmai Bay, 2016.

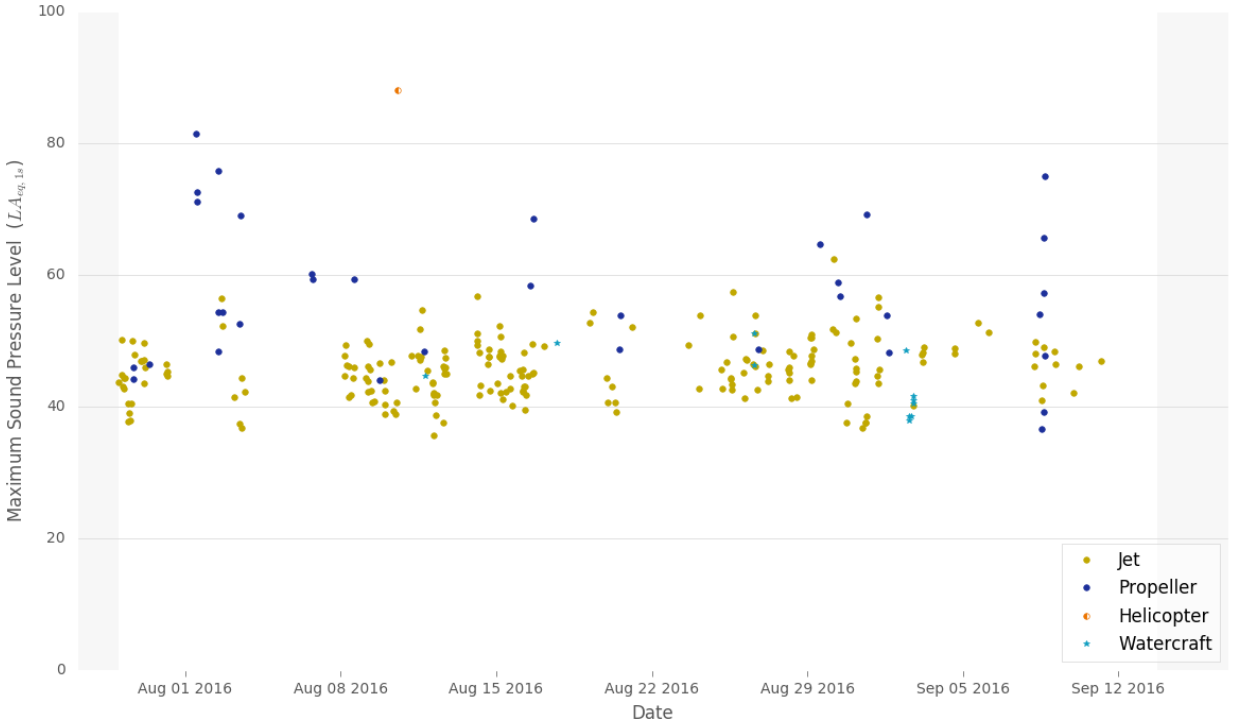


Figure 69. Maximum one-second sound pressure level for each noise event detected at Katmai Bay, 2016.

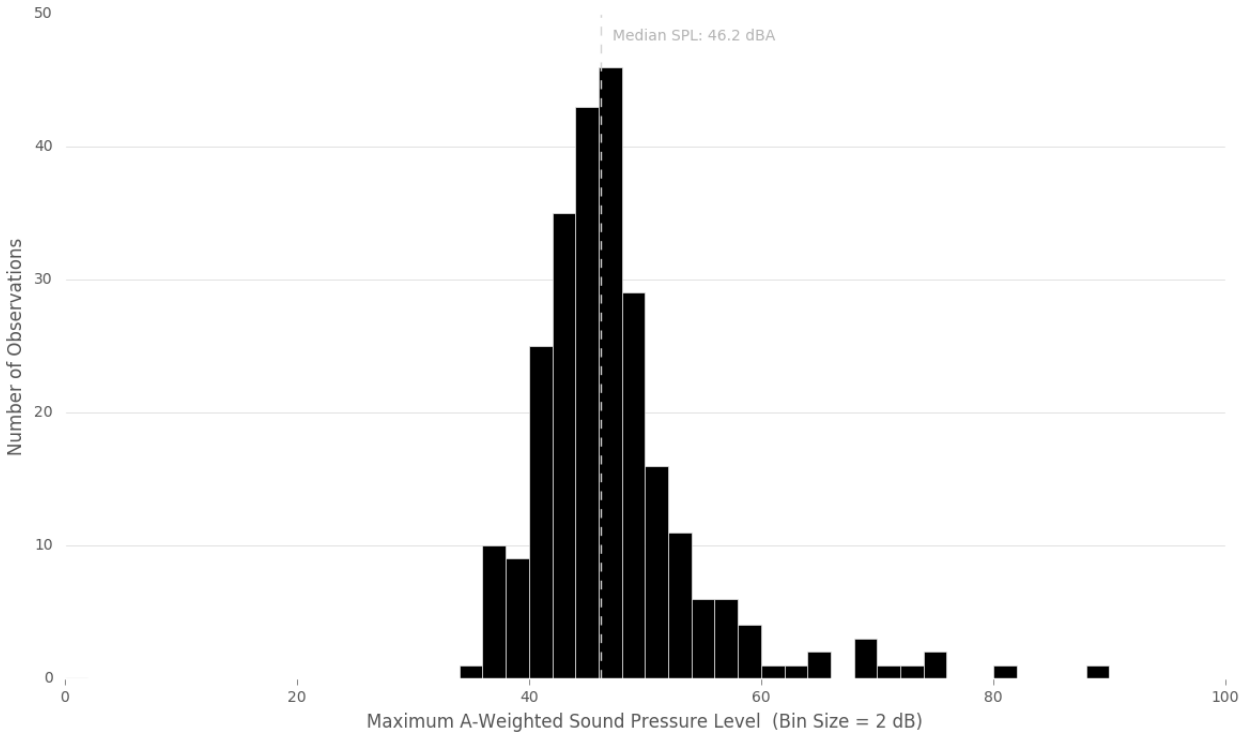


Figure 70. Histogram of maximum one-second sound pressure levels for aircraft noise events detected at Katmai Bay, 2016.

Pfaff Mine

Location Description: Site was located on a low tundra bench near the Pfaff airstrip, about 6.4 km upstream (north-east) from Battle Lake (Figures 94 and 95). The location is about 8.5 km east of the Battle Lake Cabins and 13.2 km south-east of the confluence of Funnel and Moraine creeks.

Coordinates: 59.11098°, -154.83687° (WGS84)

Elevation: 600 meters (1967 feet)

Sampling Period: 29-July-2015 to 07-October-2015

Management Unit: Katmai National Preserve, Eligible Wilderness

Ecotypes: Walatka Mountains, Viereck Class III.B.1.c *Alpine Herbs* and III.C.2.b *Foliose and Fruticose Lichen*

Access: Cessna 185 on wheels

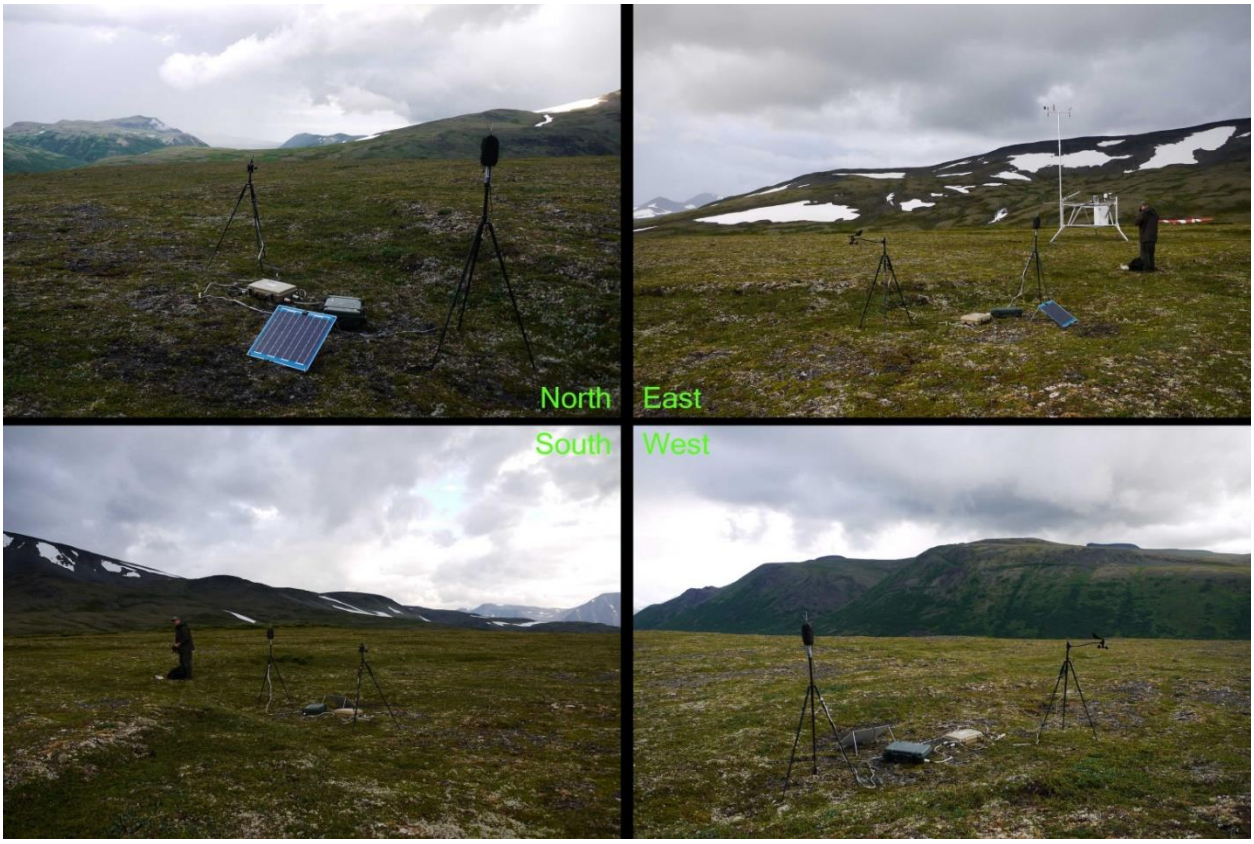


Figure 71. Cardinal photographs of the Pfaff Mine inventory site.

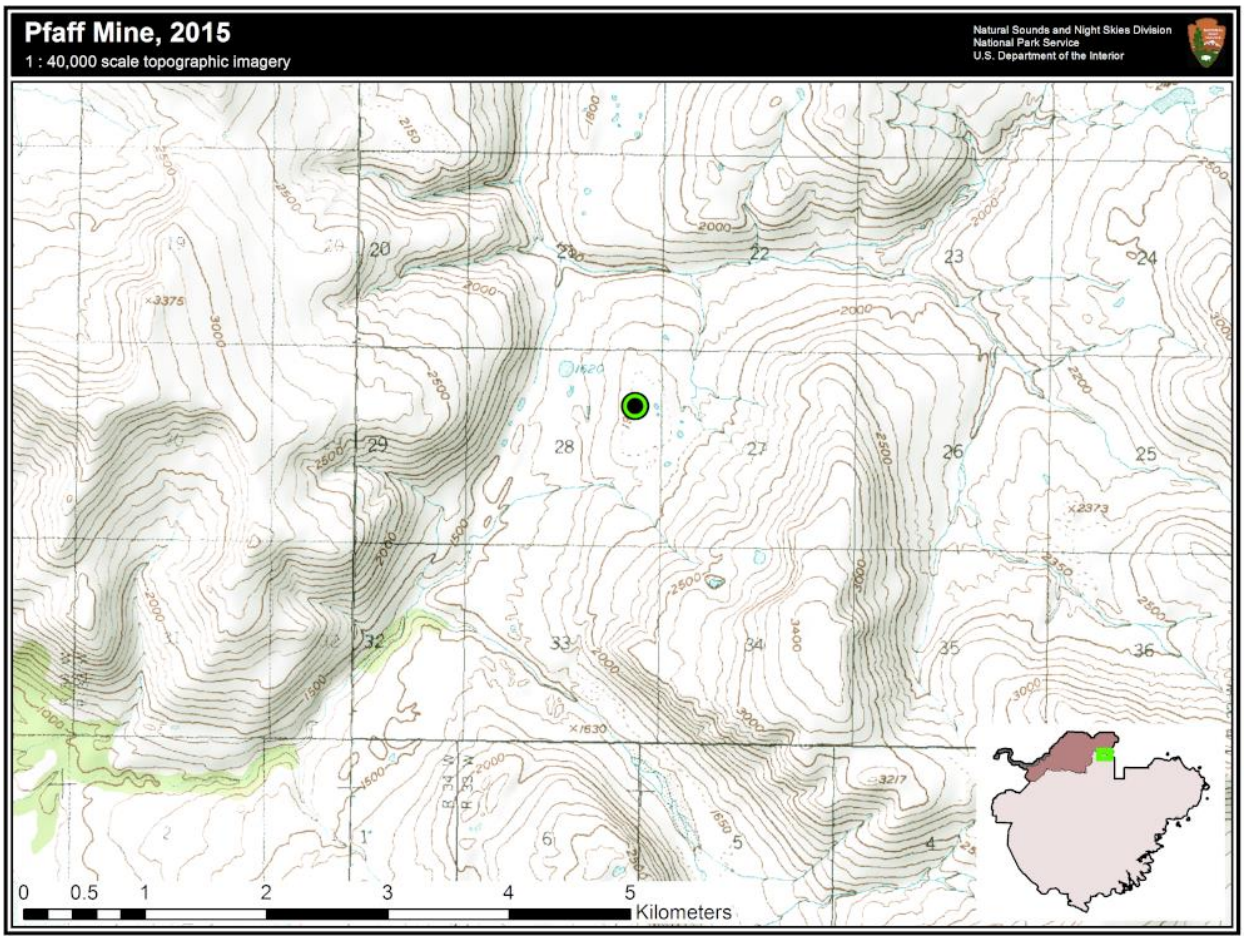


Figure 72. Topographic map of the Pfaff Mine area at 1:40,000 scale. The inset map in the lower-right corner indicates the location of the frame within Katmai. Light brown areas represent park land and darker brown areas show preserve land.

Summary: The open tundra landscape of the Pfaff Mine inventory site had a time-averaged natural ambient sound pressure level (LA_{nat}) of 30.3 dB. The 90th percentile of sound pressure levels (LA_{10}) was 35.1 dB, and the 10th percentile (LA_{90}) was 27.3 dB, a difference of 7.8 dB. A strong pseudonoise artifact from wind-generated turbulence is apparent on the 1/3rd octave band plot (**Figure 73**) as a linearly descending series below 200 Hz.

Biological sounds were scarce in this July/August/September sample. Common Raven and Rock Ptarmigan were two characteristic callers at the Pfaff Mine site. Caribou also were detected on several occasions, identifiable by the sound of tendons clicking around their sesamoid bone.

Aircraft noise data are shown in Figures 97–101. The station was deployed 85 meters downslope from the Pfaff airstrip in plain sight of the runway (Figure 84, east quadrant). Despite this, only one takeoff event was documented (07/31/15 at 10:22, Figure 100). It's maximum $LA_{eq,\ 1s}$ exceeded 90 dB.

Noise events primarily occurred around 08:00, but a minor afternoon peak around 16:00 is also detectable (Figure 98, Figure 99). This is similar to the timing of events at many sites throughout Katmai, including nearby Crosswinds Lake. The Crosswinds Lake site is 13 km away from Pfaff Mine – the closest spacing of any site pair. Pfaff Mine has half the daily rate of propeller noise events (Pfaff median 21, Crosswinds median 52), but *much* less afternoon traffic than Crosswinds Lake. Consider time audible during the 08:00 (Crosswinds 53%, Pfaff 17%) and 16:00 (Crosswinds 43%, Pfaff 3%), respective peaks. Pfaff has a third as much traffic during the 08:00 hour, and *one-seventeenth* as much traffic during the 16:00 hour. This implies that most afternoon approaches/departures to Crosswinds Lake do not pass within the detection radius of Pfaff Mine. This is a clear demonstration of the influence flight routing has on wilderness character.

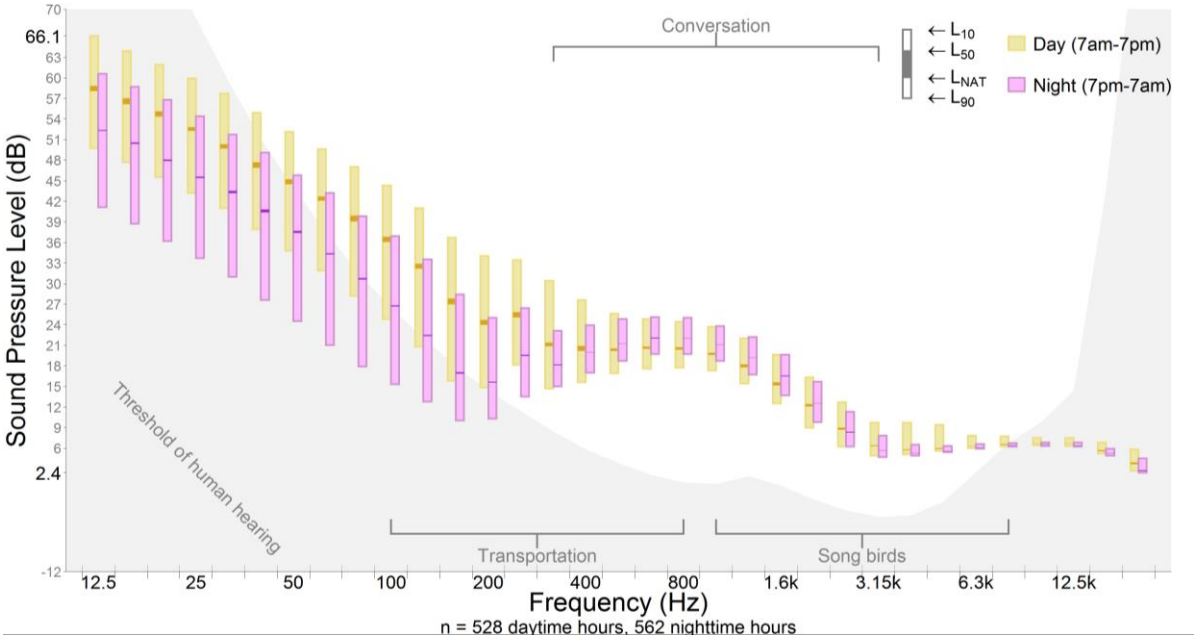


Figure 73. Spectral percentile levels for Pfaff Mine, 2015.

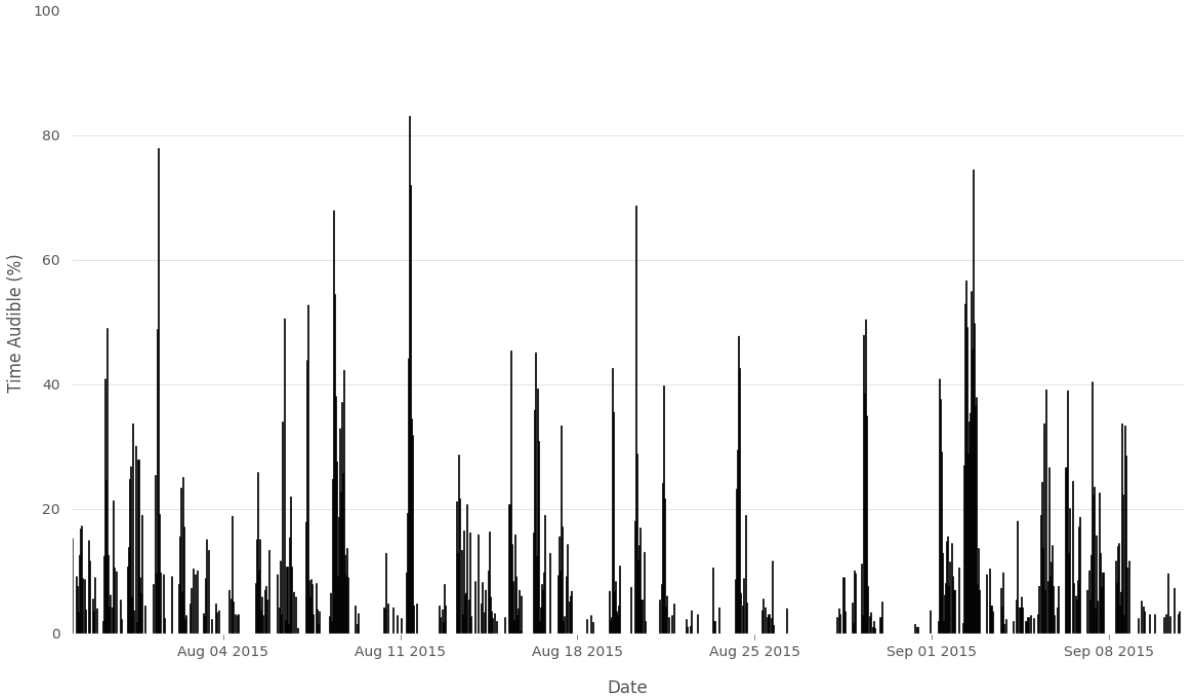


Figure 74. Audibility of aircraft noise by hour at Pfaff Mine, 2015.

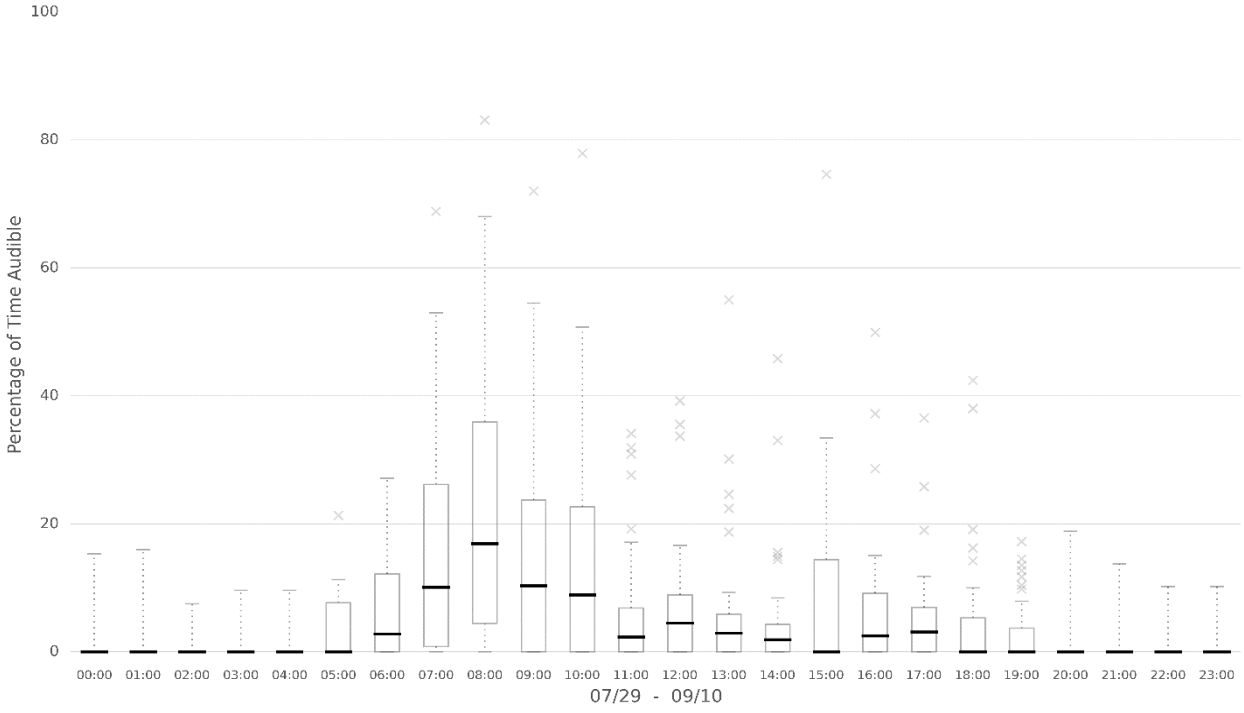


Figure 75. Audibility of aircraft noise for an average day, by hour, at Pfaff Mine, 2015. The bold line indicates the median (50th percentile) value, the top of the box is the 75th percentile, and the bottom is the 25th percentile. The dashed flyers show 1.5x the interquartile range. Values outside this range are considered outliers and marked with an ‘x’.

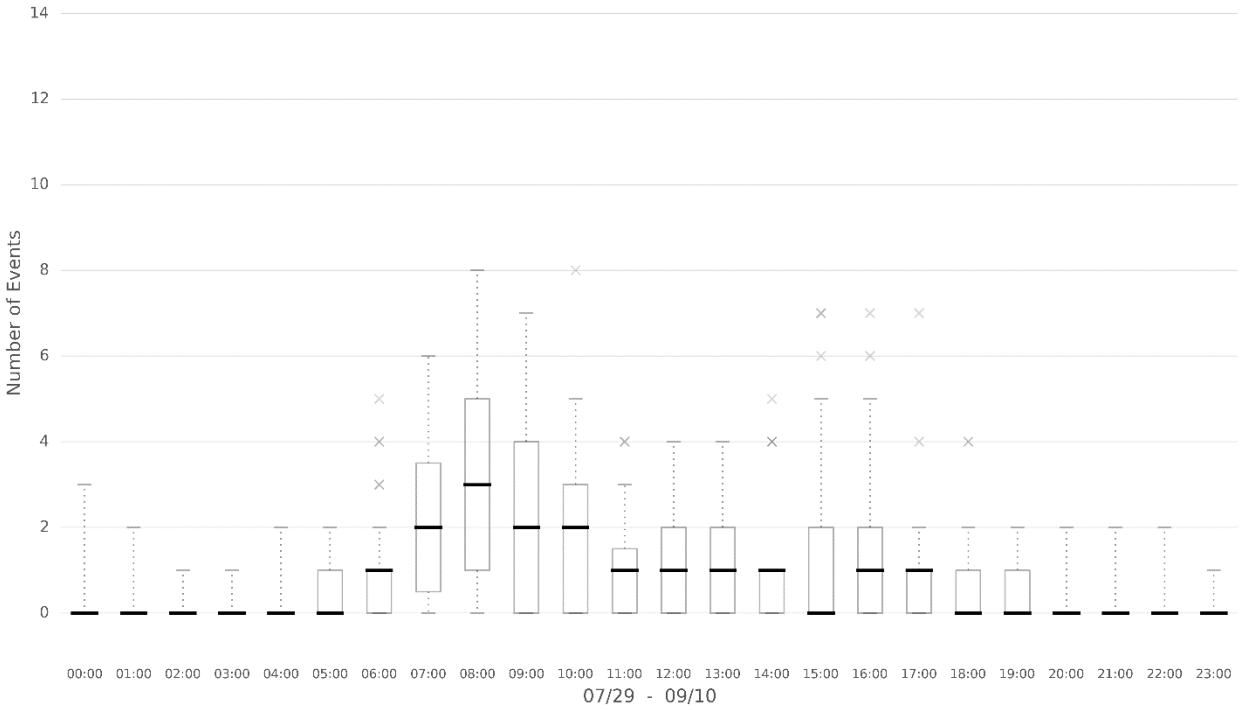


Figure 76. Rates of detection for aircraft noise events by hour at Pfaff Mine, 2015.

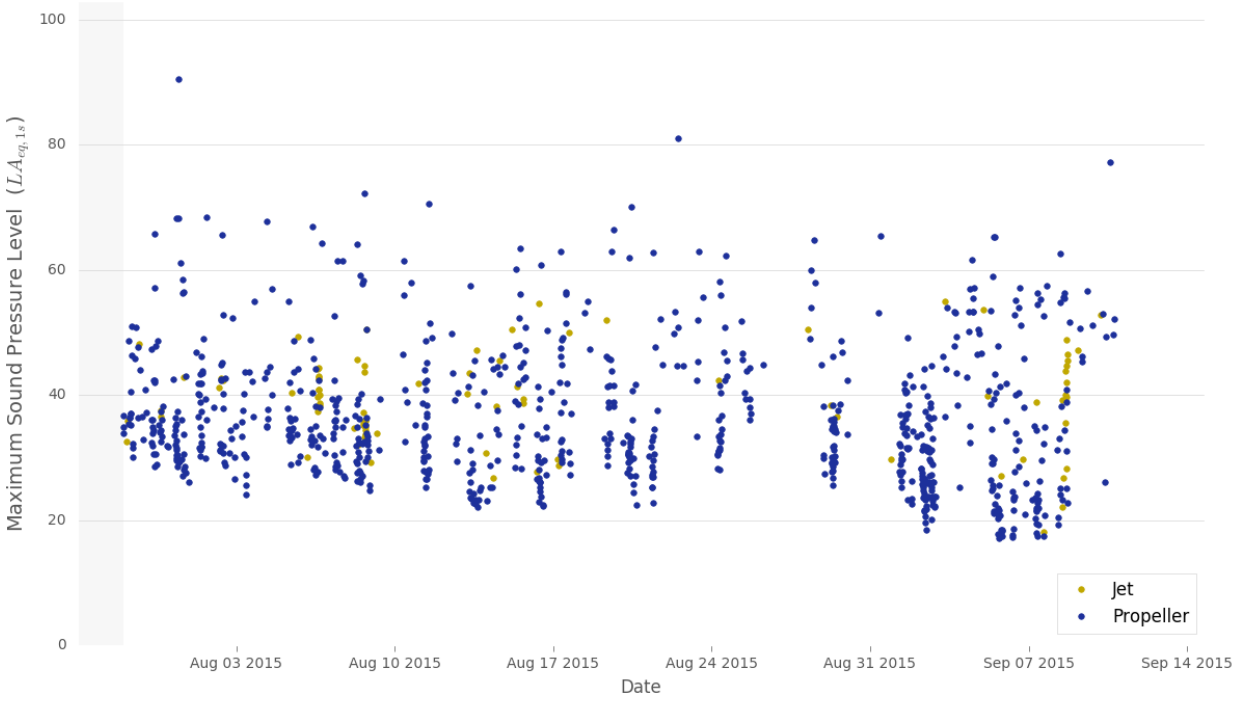


Figure 77. Maximum one-second sound pressure level for each aircraft event detected at Pfaff Mine, 2015.

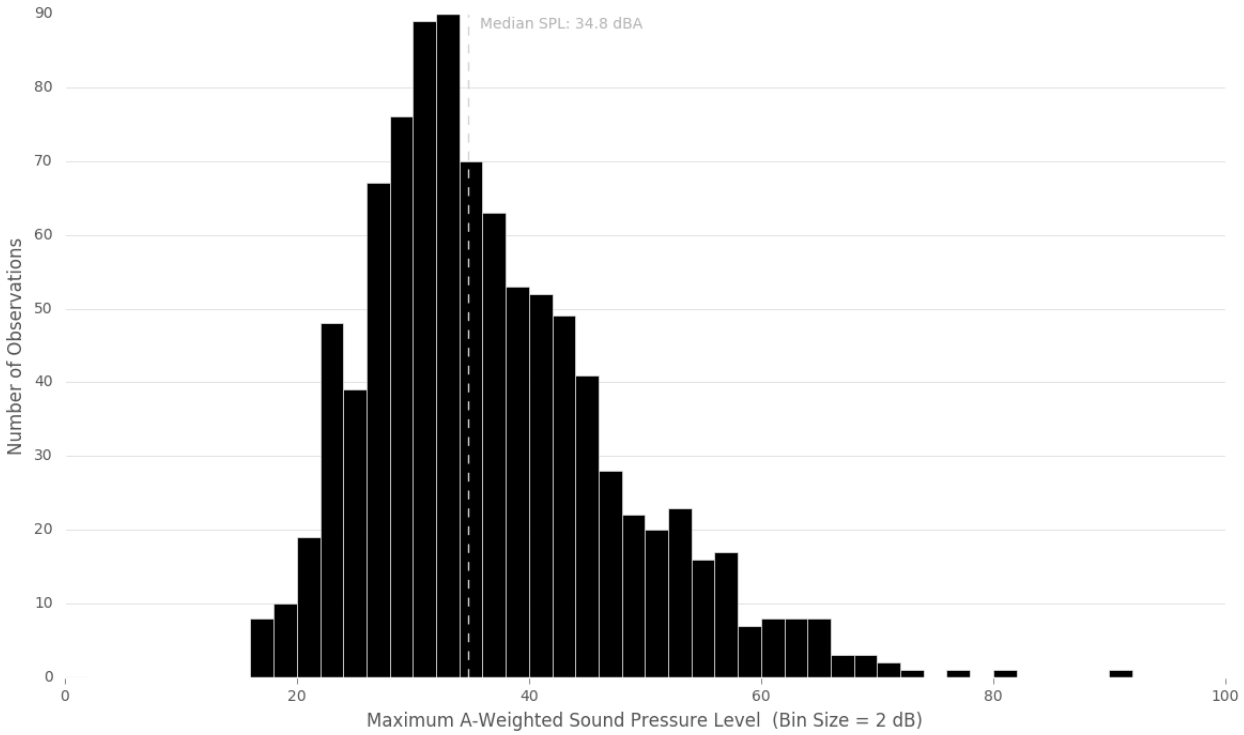


Figure 78. Histogram of maximum one-second sound pressure levels for aircraft noise events detected at Pfaff Mine, 2015.

Savonoski Lake

Location Description: Site was located on the northeastern shoreline of Savonoski Lake approximately 1 km from the Savonoski River. The site is about 25 km west of Savonoski Pass, a common flight route traversing the Aleutian Range from King Salmon to Hallo Bay (Figures 102 and 103).

Coordinates: 58.59578°, -154.75061° (WGS84)

Elevation: 84 meters (275 feet)

Sampling Period: 28-June-2017 to 24-July-2017

Management Unit: Katmai National Park, Designated Wilderness

Ecotypes: Savonoski River Floodplain and Terraces, Viereck Class I.B.2.c *Open Balsam Poplar Forest*

Access: DeHavilland DHC-2 on floats



Figure 79. Cardinal photographs of the Savonoski Lake inventory site.

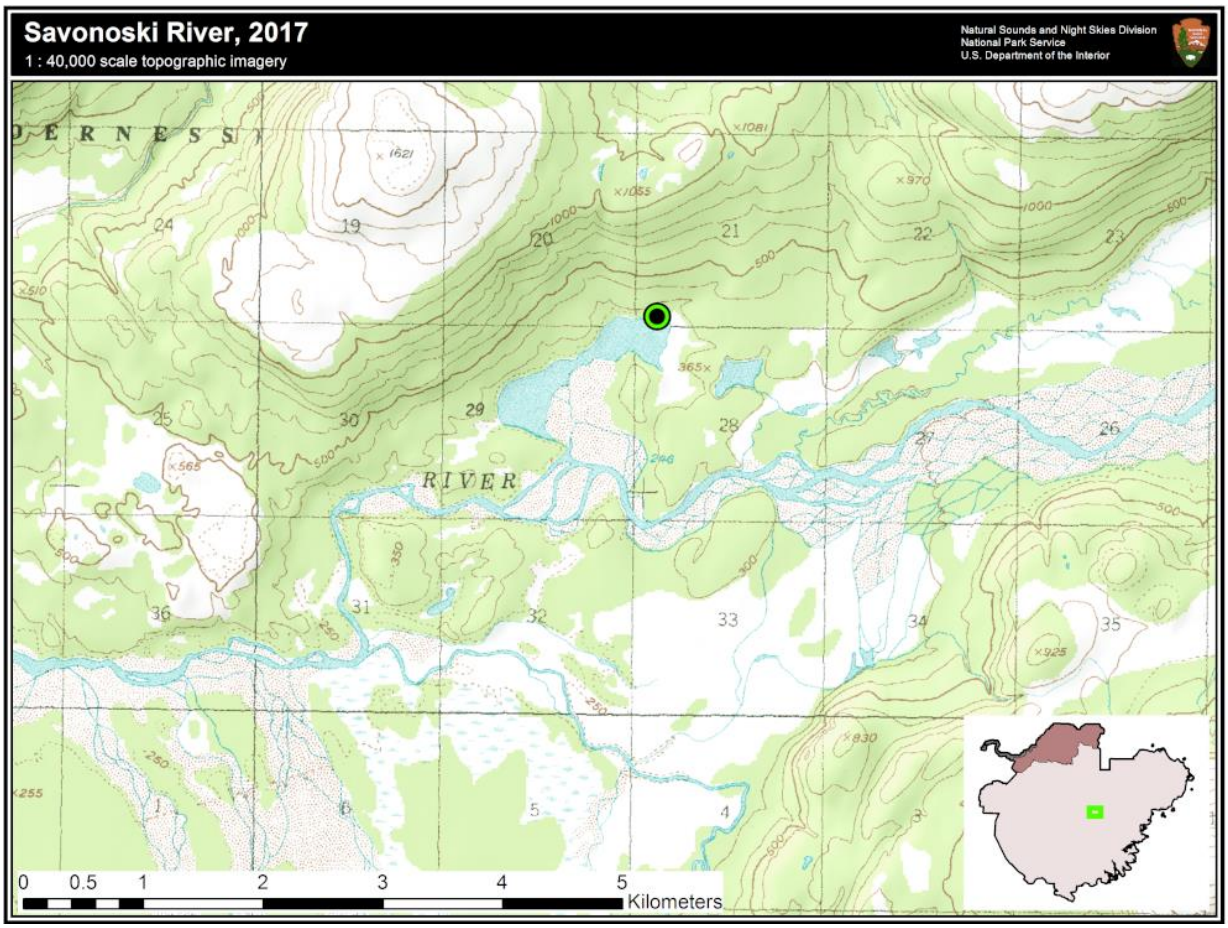


Figure 80. Topographic map of Savonoski Lake at 1:40,000 scale. The inset map in the lower-right corner indicates the location of the frame within Katmai. Light brown areas represent park land and darker brown areas show preserve land.

Summary: The forested lakeside landscape of the Savonoski Lake inventory site had a time-averaged natural ambient sound pressure level (LA_{nat}) of 35.2 dB. The 90th percentile of sound pressure levels (LA_{10}) was 42.0 dB, and the 10th percentile (LA_{90}) was 30.1 dB, a difference of 11.9 dB. Savonoski Lake had a canopy of balsam poplar about 12 meters tall. Canopied forest is a rare feature for Alaskan acoustic inventory sites (but shared by American Creek). Leaf motion created considerable energy above the 1000 Hz band, as can be seen in Figure 104.

Avian vocalizations were common in this June/July sample. Varied Thrush, Swainson's Thrush, Lincoln's Sparrow, Golden-crowned Sparrow, Orange-crowned Warbler, Black-capped Chickadee, Wilson's Warbler were all detected on the record.

Aircraft noise data are shown in Figures 105–109. Savonoski Pass – a route traversing the Aleutian Range from coast to interior – is 25 km west of the site. Despite this, propeller aircraft impacts were relatively low at Savonoski Lake (median 5 noise events per day, time audible = 1.3%). As is the case for East Kulik Lake, the non-skewed distribution of maximum $LA_{eq,\ 1s}$ values at Savonoski Lake

(Figure 109) suggest that propeller noise events represent aircraft in ‘cruising’ flight along one (or a few) typical routes.

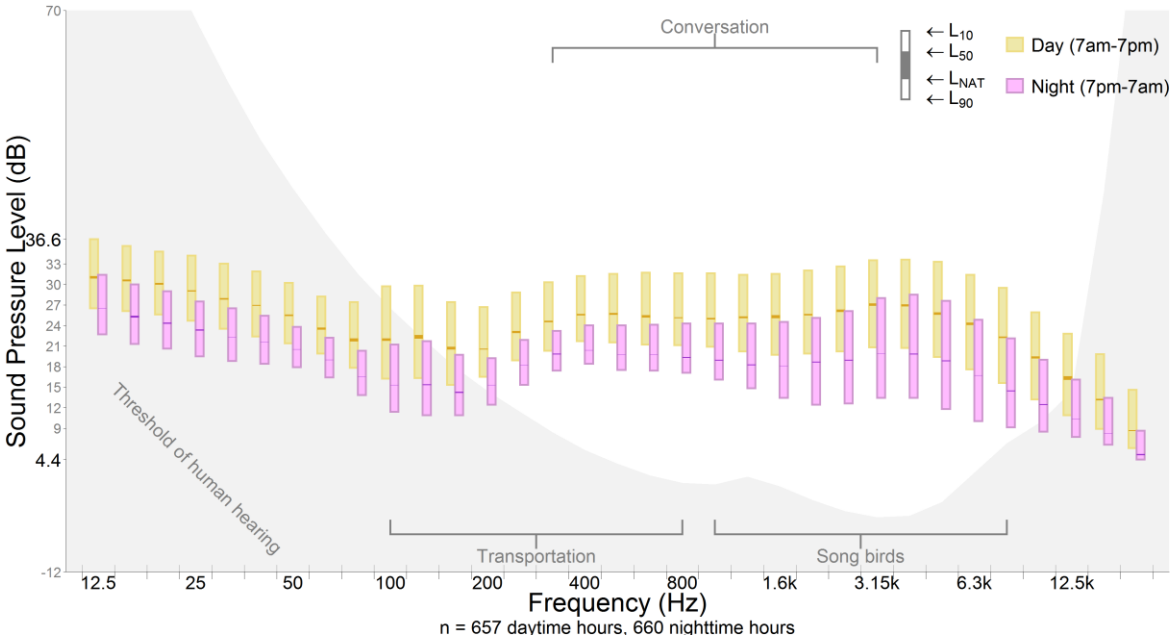


Figure 81. Spectral percentile levels for Savonoski Lake, 2017.

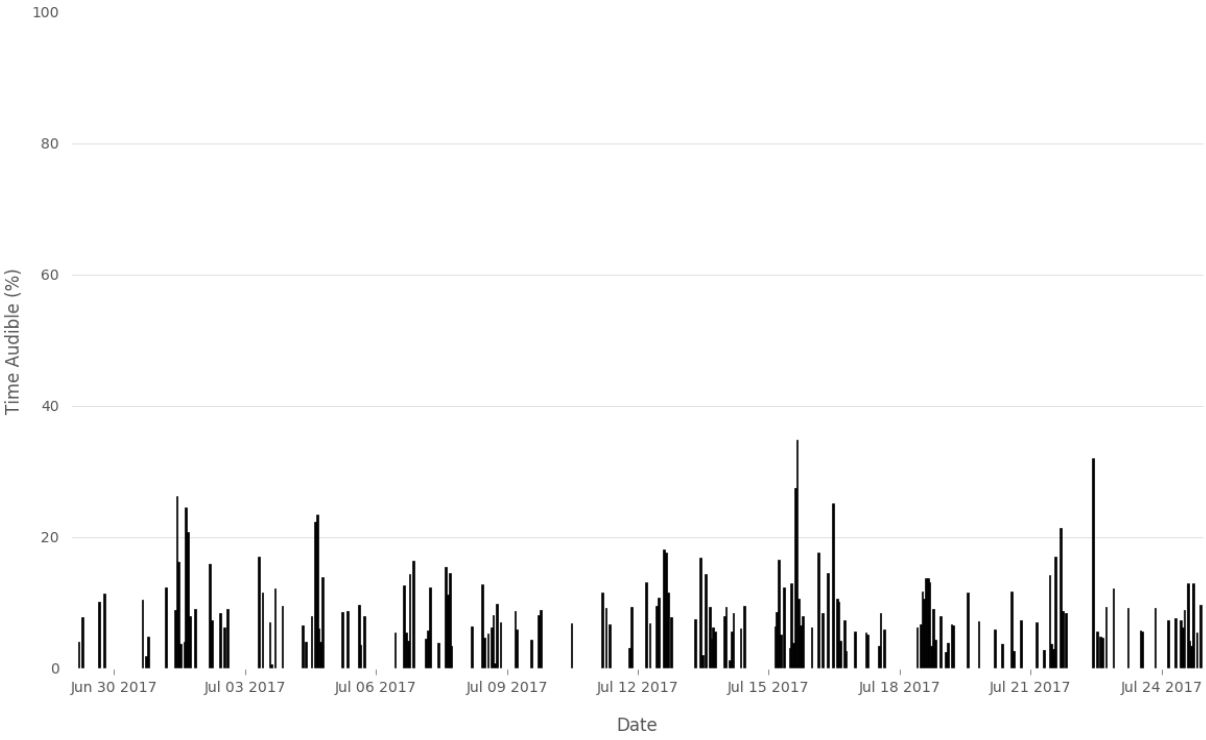


Figure 82. Audibility of aircraft noise by hour at Savonoski Lake, 2017.

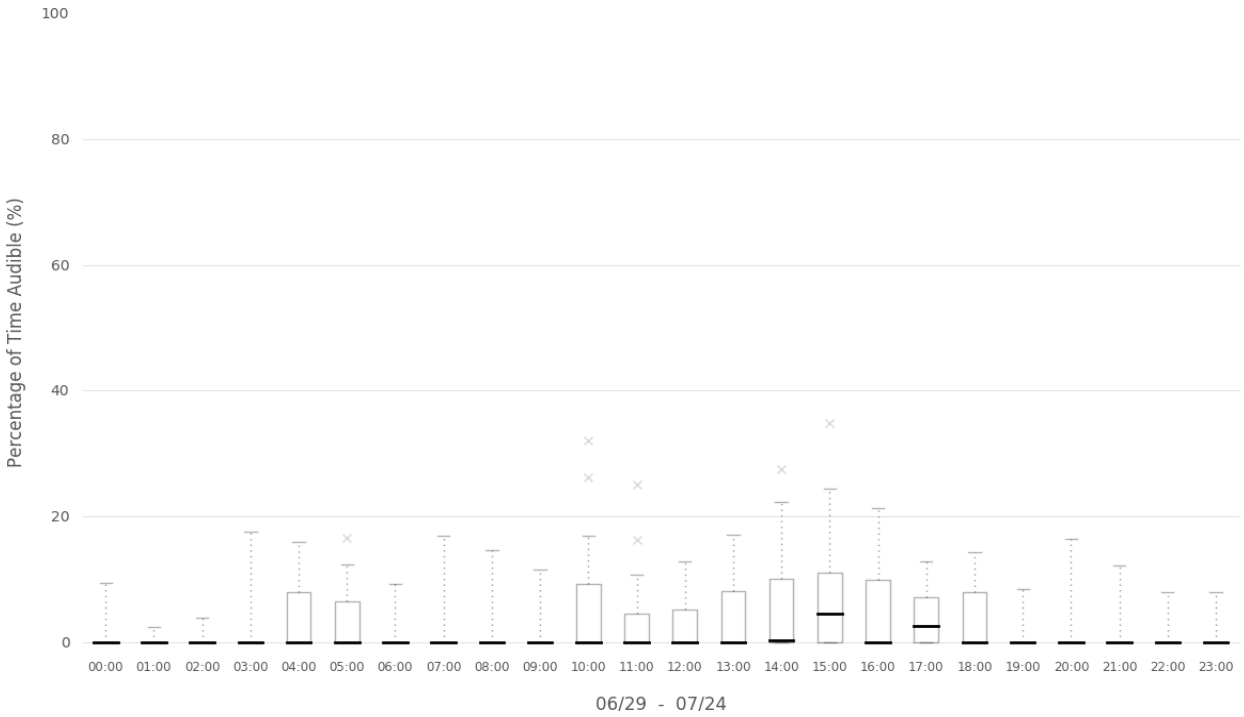


Figure 83. Audibility of aircraft noise for an average day, by hour, at Savonoski Lake, 2017. The bold line indicates the median (50th percentile) value, the top of the box is the 75th percentile, and the bottom is the 25th percentile. The dashed flyers show 1.5x the interquartile range. Values outside this range are considered outliers and marked with an ‘x’.

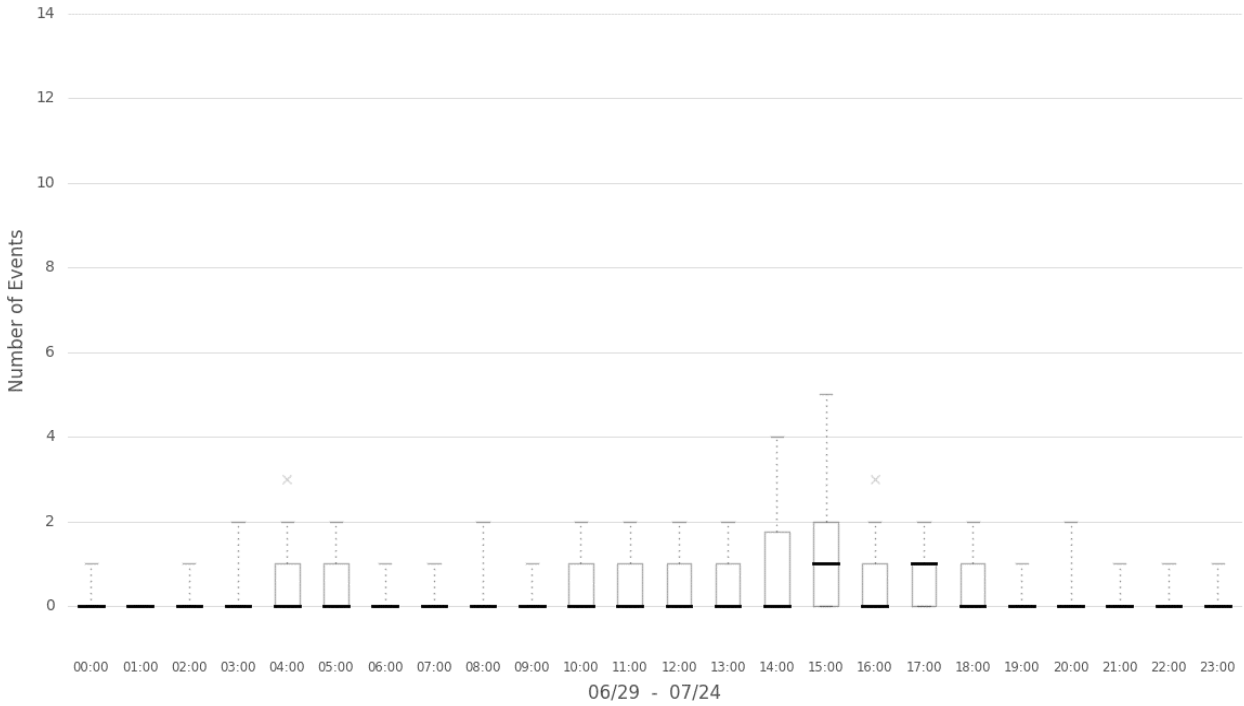


Figure 84. Rates of detection for aircraft noise events by hour at Savonoski Lake, 2017.

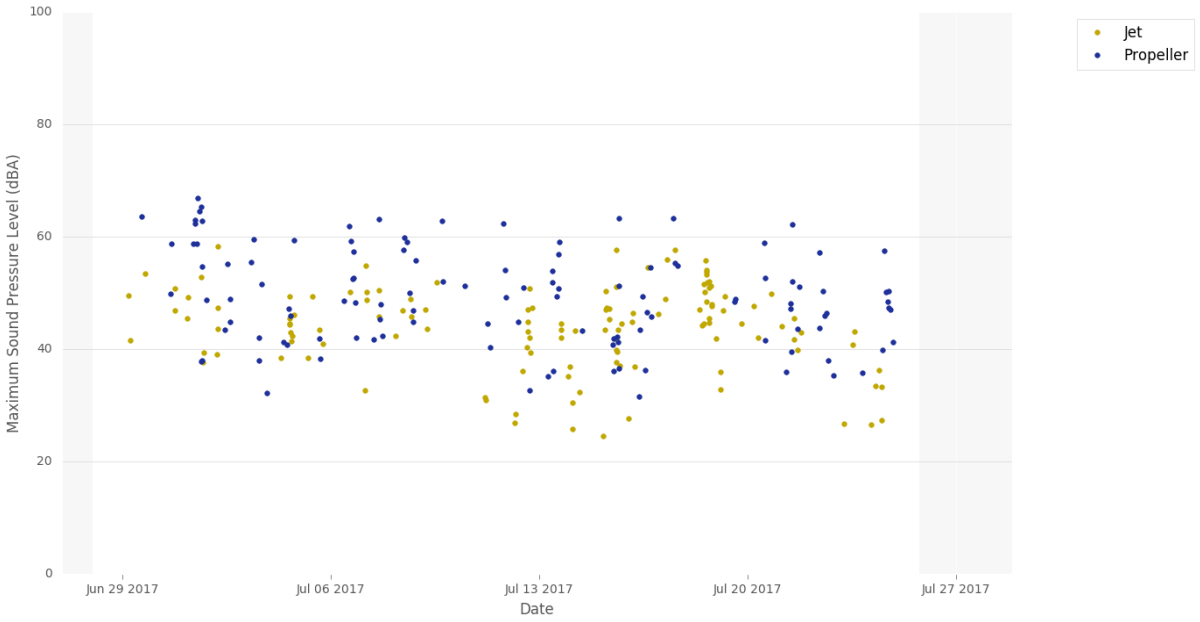


Figure 85. Maximum one-second sound pressure level for each aircraft event detected at Savonoski Lake, 2017.

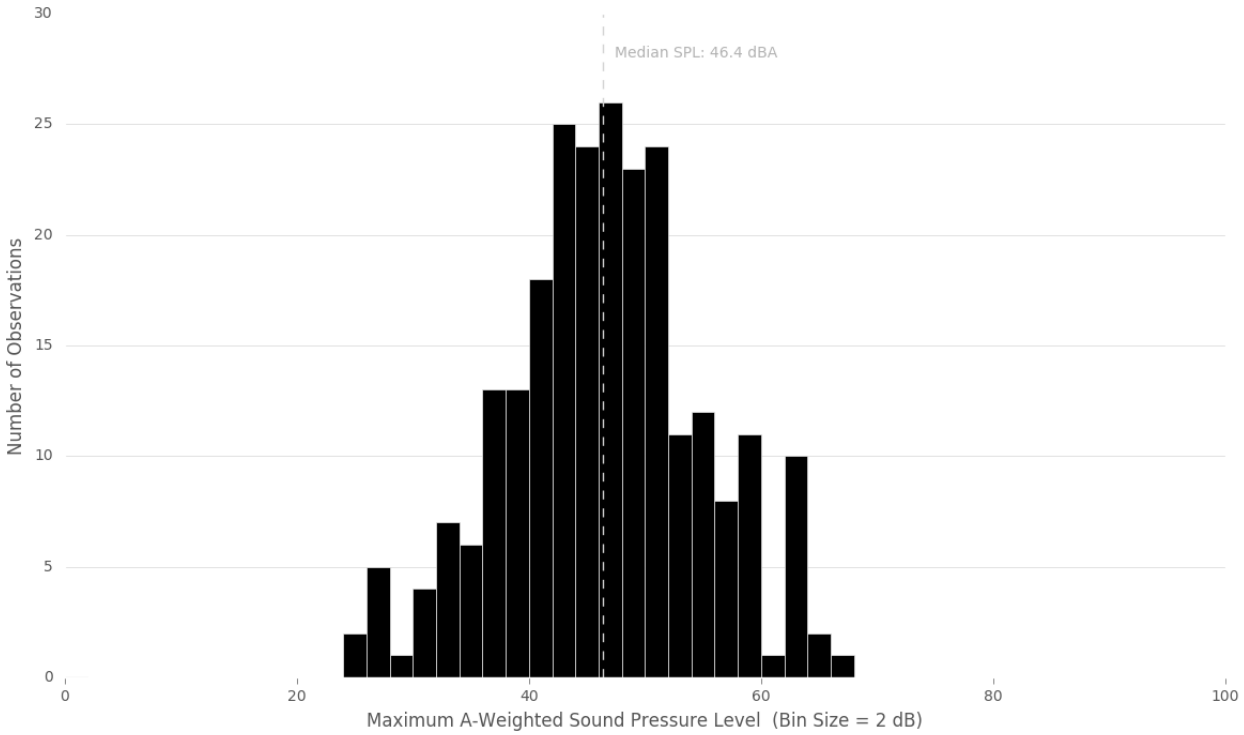


Figure 86. Histogram of maximum one-second sound pressure levels for aircraft noise events detected at Savonoski Lake, 2017.

Swikshak Lagoon

Location Description: Site was located in alder shrubland near Swikshak Lagoon, the oceanic terminus of the Swikshak River (Figures 110 and 111). Site was placed about 115 meters north-west of the Swikshak Patrol Cabin, 315 meters from the shoreline, and about 8.8 km from the Hallo Bay Bear Camp.

Coordinates: 58.60592°, -153.76837° (WGS84)

Elevation: 26 meters (85 feet)

Sampling Period: 29-July-2015 to 31-August-2015

Management Unit: Katmai National Park, Designated Wilderness

Ecotypes: Shelikof Strait Lowlands, Viereck Class II.B.2.b *Open Tall Alder Scrub*

Access: Cessna 185 on wheels



Figure 87. Cardinal photographs of the Swikshak Lagoon inventory site.

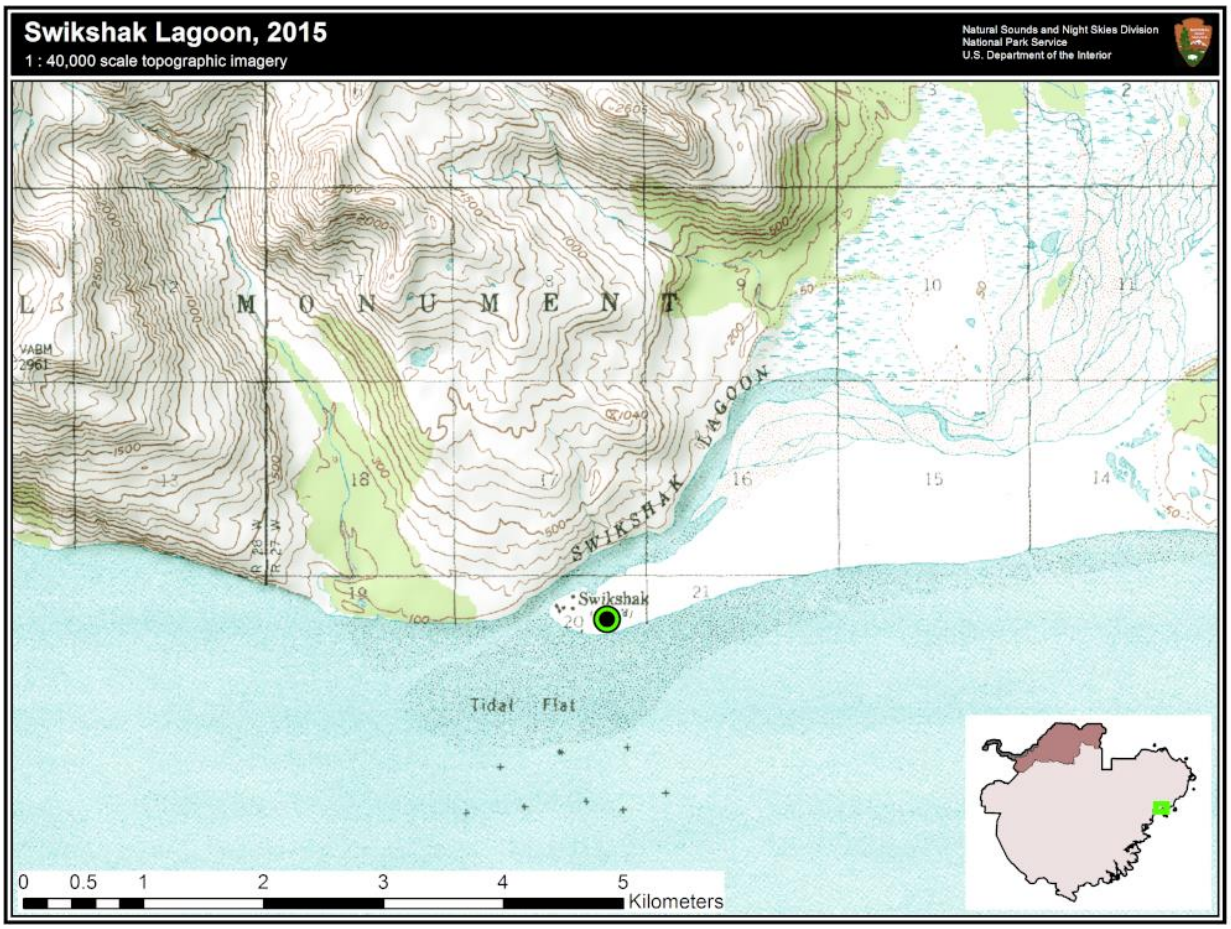


Figure 88. Topographic map of Swikshak Lagoon at a 1:40,000 scale. The inset map in the lower-right corner indicates the location of the frame within Katmai. Light brown areas represent park land and darker brown areas show preserve land.

Summary: The lush coastal landscape of the Swikshak Lagoon inventory site had a time-averaged natural ambient sound pressure level (LA_{nat}) of 35.0 dB. The 90th percentile of sound pressure levels (LA_{10}) was 39.4 dB, and the 10th percentile (LA_{90}) was 32.3 dB, a difference of 7.1 dB. The plot of 1/3rd octave band spectra (Figure 112) reveals a prominent peak between the 200 and 1600 Hz bands. This is associated with waves impacting the coarse, rocky shoreline. Alder foliage rustling in the wind contributed energy above the 2000 Hz band.

Black-billed Magpie, Black-capped Chickadee, Golden-crowned Sparrow, Great-horned Owl, Common Redpoll, Hermit Thrush, and an assortment of unidentified seabirds and shorebirds were all heard on the record.

Aircraft noise data are shown in Figures 113–117. During site install we witnessed eight separate low-altitude propeller overflights hugging the coast en route to Hallo Bay or other coastal locations. This appears to have been a particularly busy day, as the median propeller event rate is 10 per day (Appendix B, Figure APP B.10), and typically the busiest time of day is 09:00 (Figure 114). Regardless, the mechanism of impact is consistent: noise at Swikshak Lagoon primarily results from

overflights to coastal portals. No takeoffs were detected during the sample. The above observations allow us to group Swikshak Lagooon with sites like East Kulik Lake, Jo-Jo Lake, Savonoski Lake, Dumpling Point, (and to some degree, Pfaff Mine) – all of them are impacted by the Katmai transportation network but are not active portals themselves. It is important to remember that *most* locations in the Katmai wilderness fall into this category. Popular portal destinations represent constrained spatial extents, but the impact of noise from the network connecting them is spatially vast, and thus very impactful (Toubman 2016, pg 31 - 32). Only by managing beyond portals can acoustic resources be protected in a holistic sense.

Neither watercraft nor helicopters were detected during the sampling period.

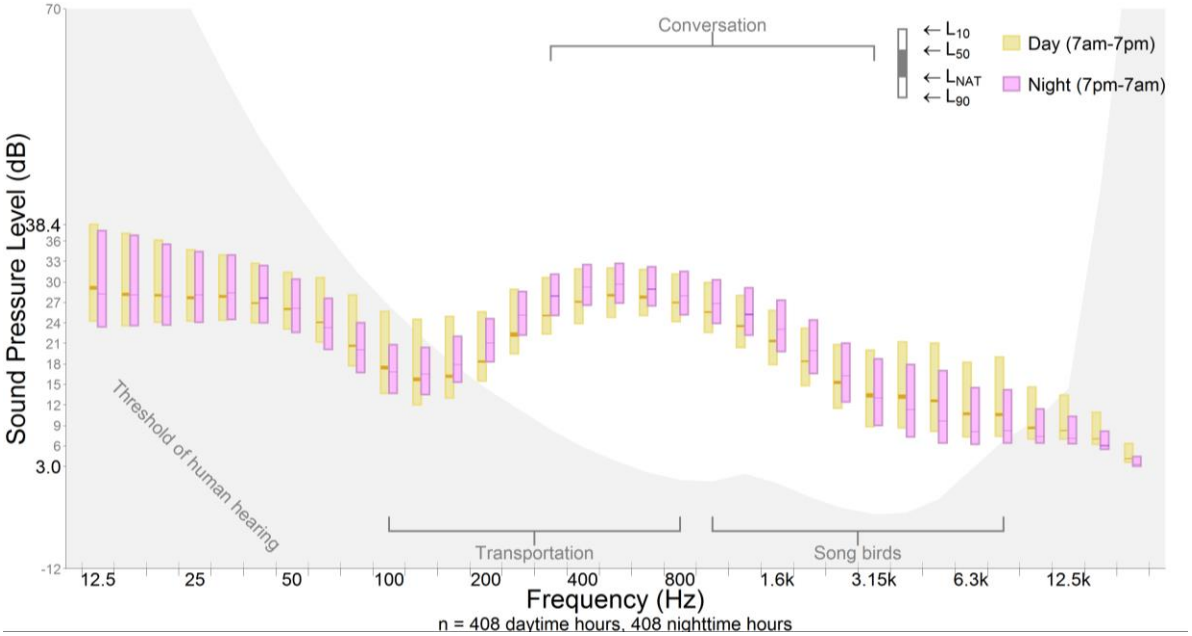


Figure 89. Spectral percentile levels for Swikshak Lagoon, 2015.

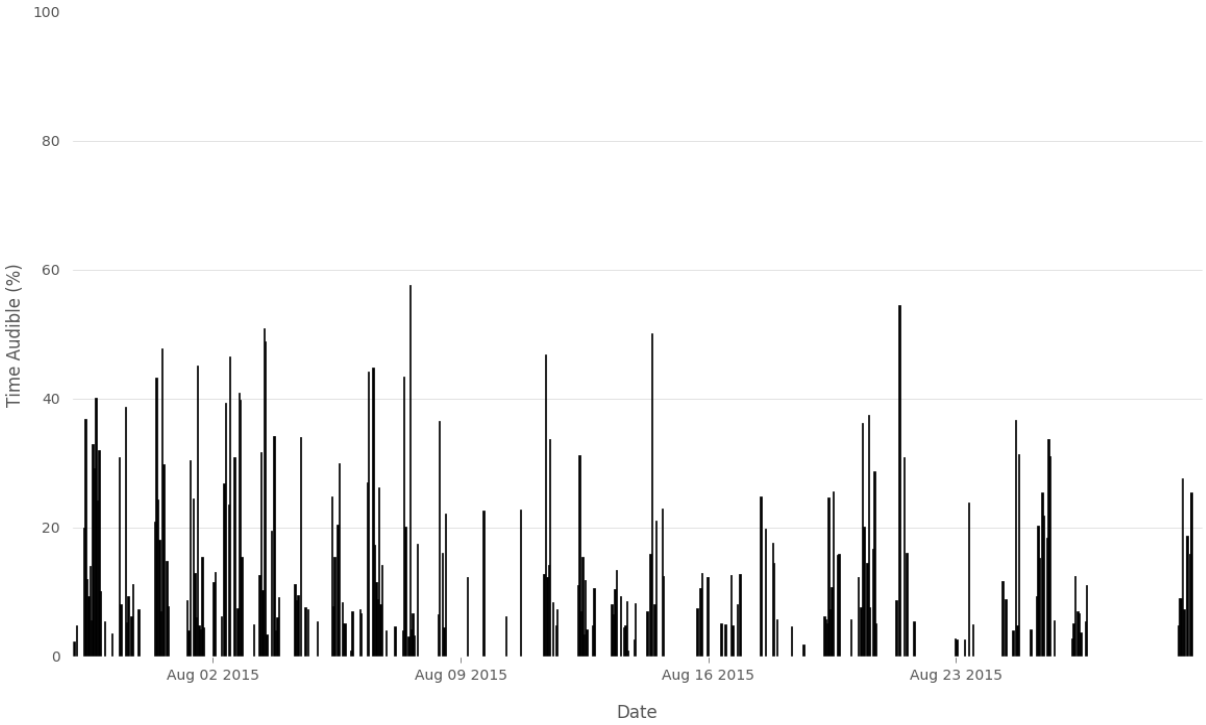


Figure 90. Audibility of aircraft noise by hour at Swikshak Lagoon, 2015.

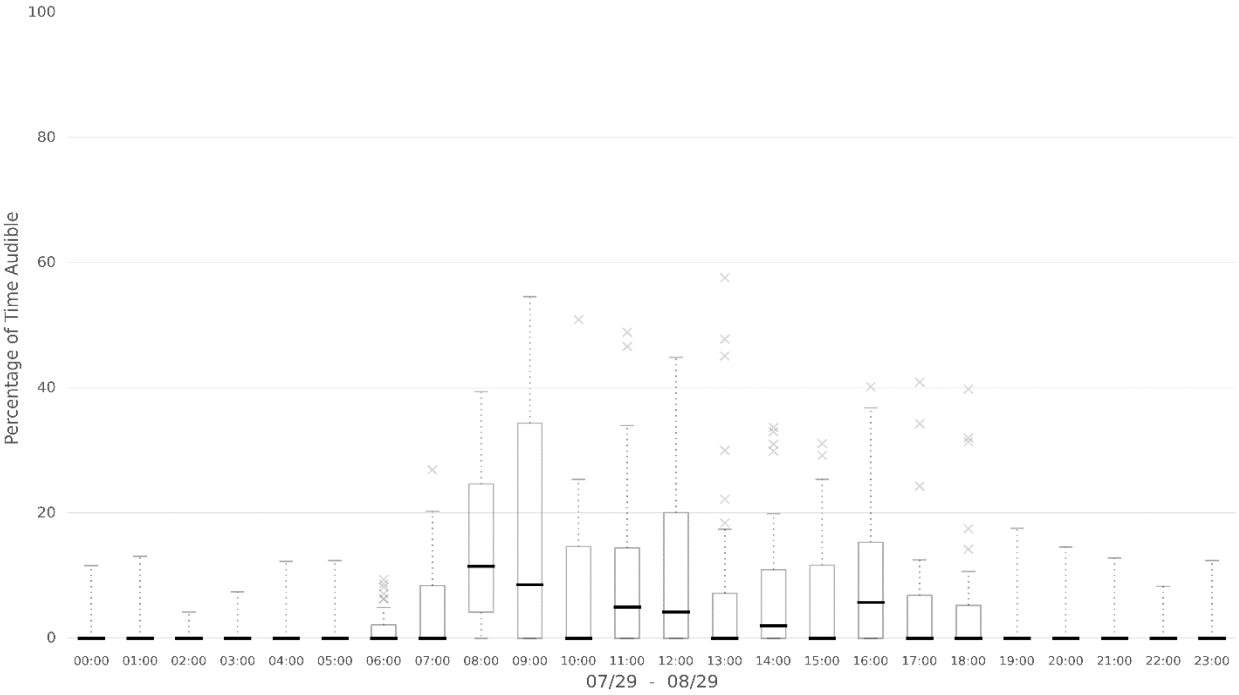


Figure 91. Audibility of aircraft noise for an average day, by hour, at Swikshak Lagoon, 2015. The bold line indicates the median (50th percentile) value, the top of the box is the 75th percentile, and the bottom is the 25th percentile. The dashed flyers show 1.5x the interquartile range. Values outside this range are considered outliers and marked with an ‘x’.

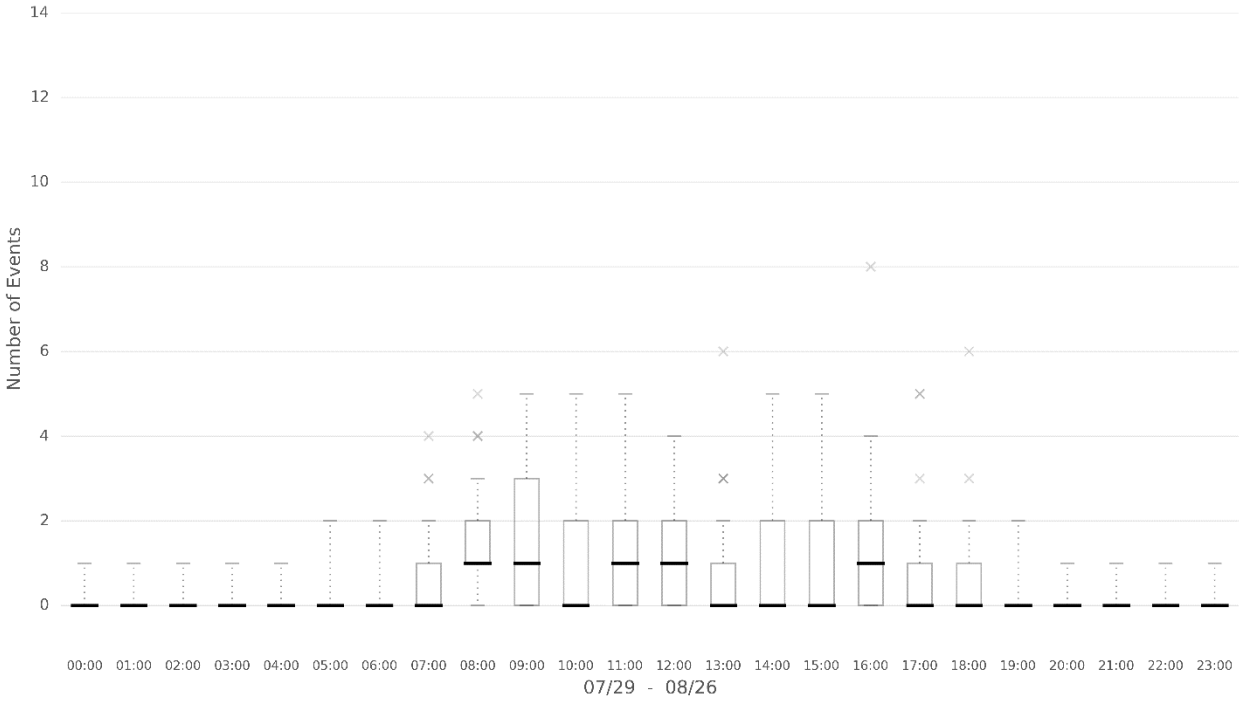


Figure 92. Rates of detection for aircraft noise events by hour at Swikshak Lagoon, 2015.

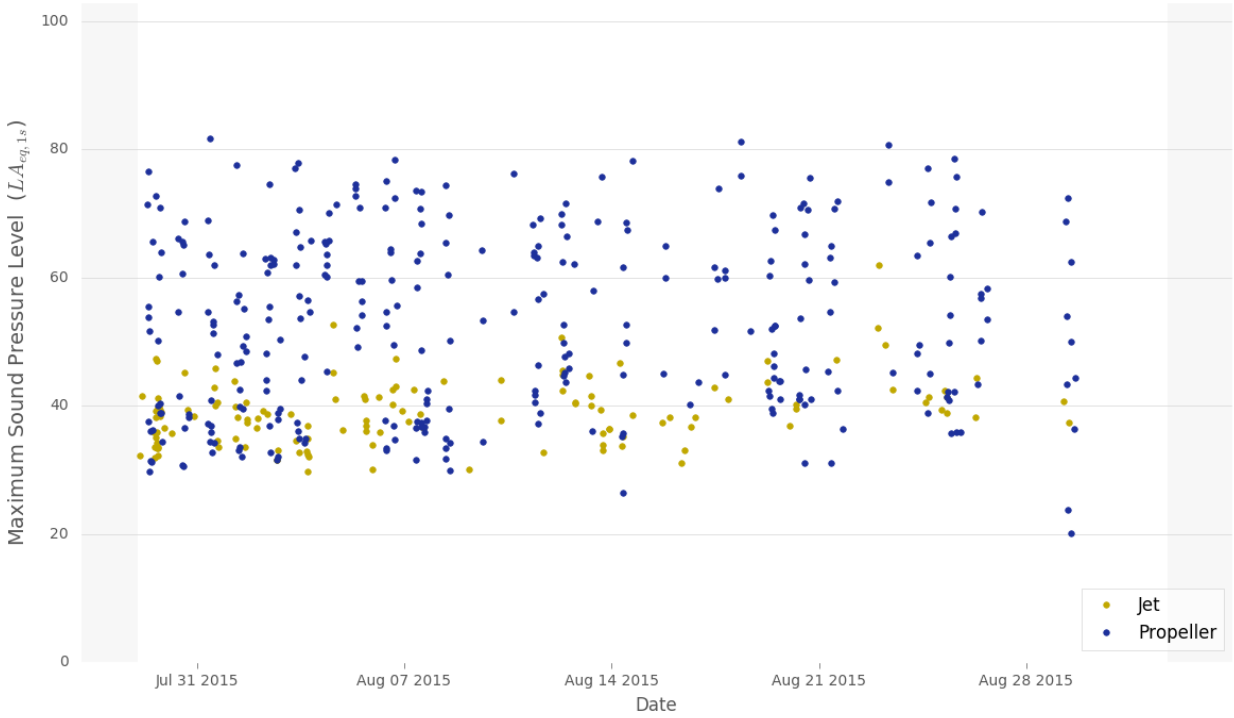


Figure 93. Maximum one-second sound pressure level for each aircraft event detected at Swikshak Lagoon, 2015.

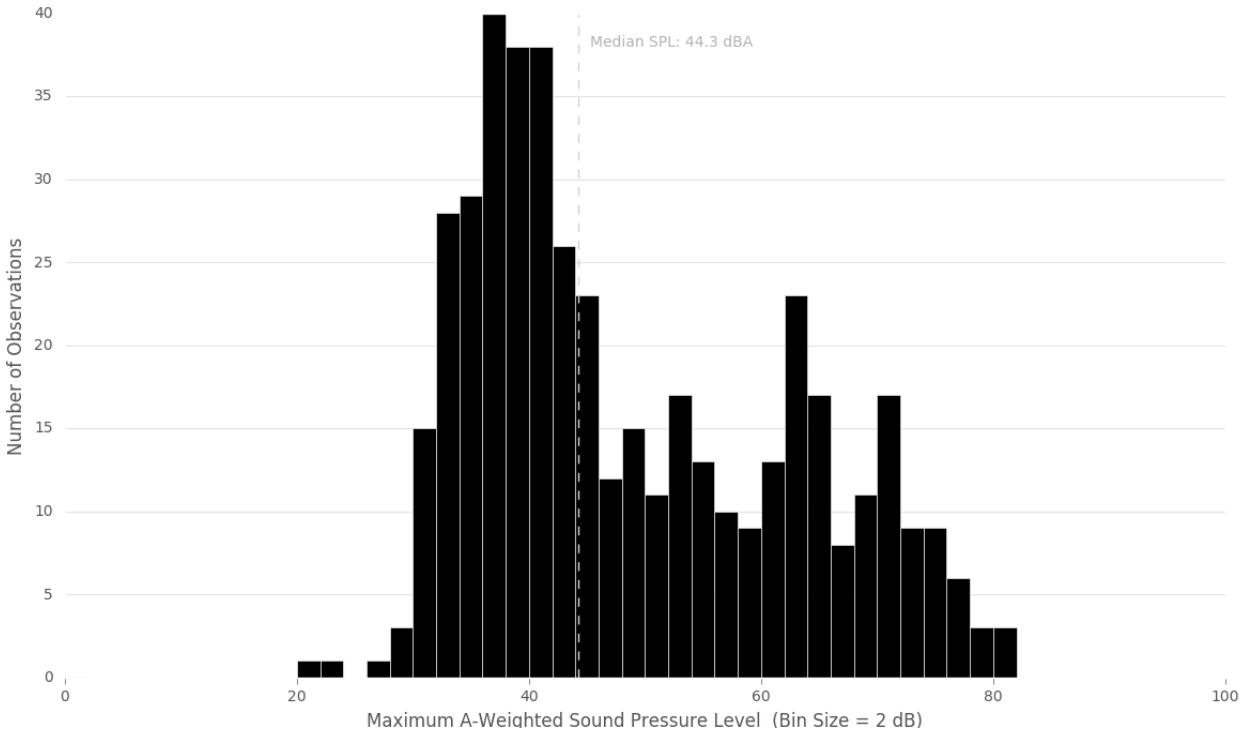


Figure 94. Histogram of maximum one-second sound pressure levels for aircraft noise events detected at Swikshak Lagoon, 2015.

Valley of Ten-Thousand Smokes

Location Description: Site was located on the windswept ash deposits of the Valley of Ten-Thousand Smokes (Figures 118 and 119). This site was positioned approximately 10.6 km up-valley from the terminus of the Valley Road and 3.0 km down-valley from the Baked Mountain huts.

Coordinates: 58.31635°, -155.22972° (WGS84)

Elevation: 508 meters (1666 feet)

Sampling Period: 29-July-2015 to 25-September-2015

Management Unit: Katmai National Park, Designated Wilderness

Ecotypes: Valley of Ten Thousand Smokes, no vegetation at site location

Access: Cessna 185 on wheels



Figure 95. Cardinal photographs of the Valley of Ten-Thousand Smokes inventory site.

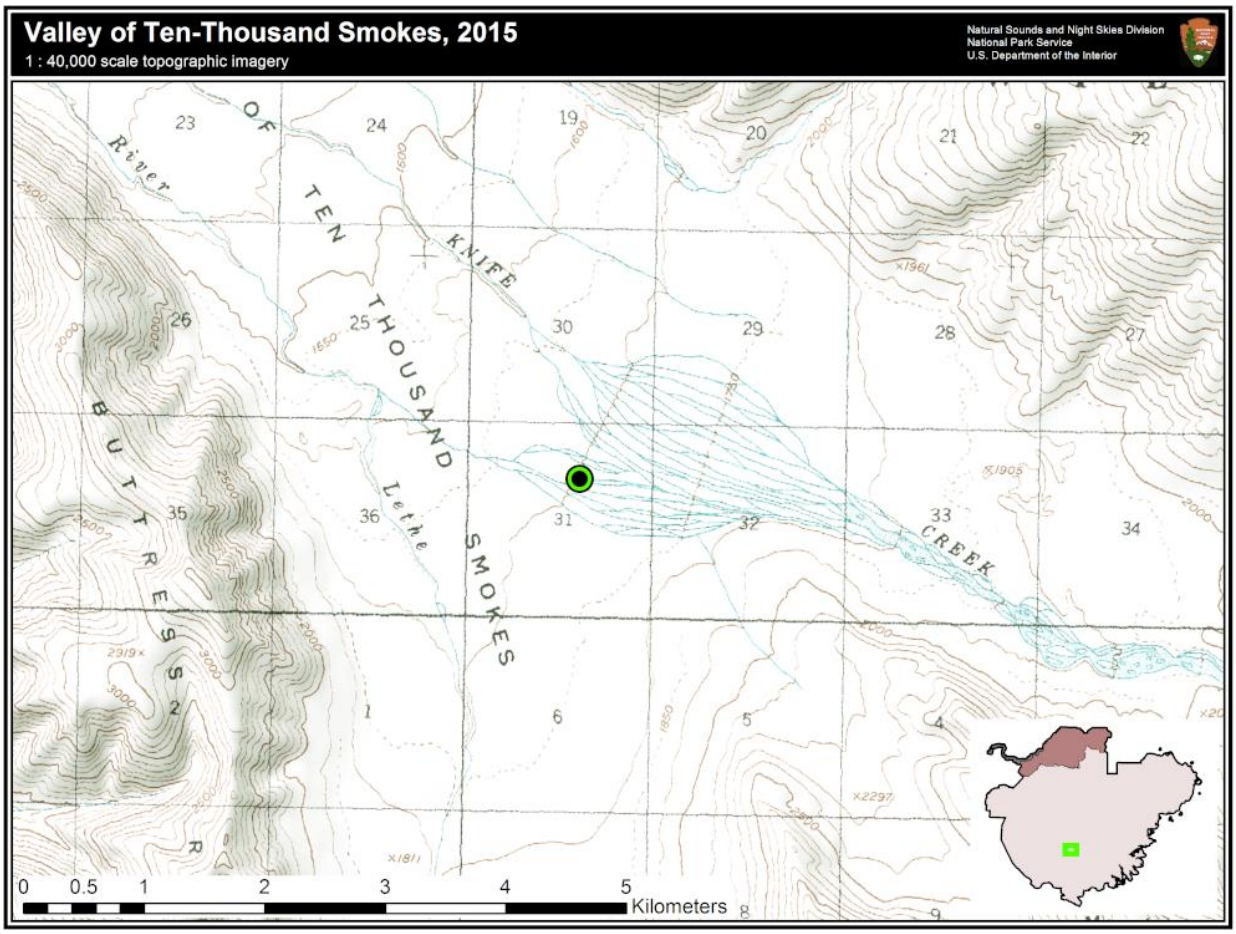


Figure 96. Topographic imagery for Valley of Ten-Thousand Smokes at a 1:40,000 scale. The inset map in the lower-right corner indicates the location of the frame within Katmai: light brown areas are Park land, and darker brown areas Preserve.

Summary: The austere volcanic landscape of the Valley of Ten-Thousand Smokes inventory site had a time-averaged natural ambient sound pressure level (LA_{nat}) of 23.8 dB. The 90th percentile of sound pressure levels (LA_{10}) was 30.3 dB, and the 10th percentile (LA_{90}) was 20.9 dB, a difference of 9.4 dB. A strong pseudonoise artifact from wind-generated turbulence is apparent on the 1/3rd octave band plot (Figure 120) as a linearly descending series below 200 Hz. Median windspeed at the Valley of Ten-Thousand Smokes site was 2.2 meters per second.

Water is almost continuously audible at the site – presumably from Knife Creek. The near-vertical walls of Knife Creek and the River Lethe are unique acoustic features of the valley. The precipitous chasm acts as an acoustic low-pass filter, giving these distant watercourses their characteristic 'hollow' or 'distant' sound. Only until approached to within a few meters of the lip are all the high-frequency components audible.

Biological sounds are scarce in the valley, but infrequent call notes of birds and the wingbeats of insects were occasionally detected. Overall the acoustic environment is austere.

The Valley of Ten-Thousand Smokes site has relatively few noise impacts, a quality shared by Katmai Bay, Douglas River, and Savonoski Lake. It is particularly notable for having a high proportion of long noise-free intervals: 29% exceed 3 hours (Appendix B, Figure APP B.21). The valley is the most popular backpacking destination in Katmai, and is of profound natural and scenic value.

Aircraft noise data are shown in Figures 121–125. Aviation impacts do occur given the fact that the upper end of the valley forms Katmai Pass, one of two major passes through the high mountains of the Aleutian Range. Despite this, the overall rate of propeller aircraft traffic is fairly low (median propeller noise event rate = 6 per day), suggesting the pass is not used as a major flight corridor. Amplitude impacts are more subdued than at sites with takeoff events, but several events did exceed $LA_{eq,\ 1s}$ of 80 dB (Figure 124).

Helicopters were heard relatively often in the Valley of Ten-Thousand Smokes (time audible = 0.07% of entire record, n = 23). Most of the events occurred in a dense cluster between 07/30 and 08/02, suggesting that they may have been administrative in nature. The other two sites in the west-central area of the park (Dumpling Point and Jo-Jo Lake) have similar rates of helicopter noise (Appendix B, Figure APP B.15).

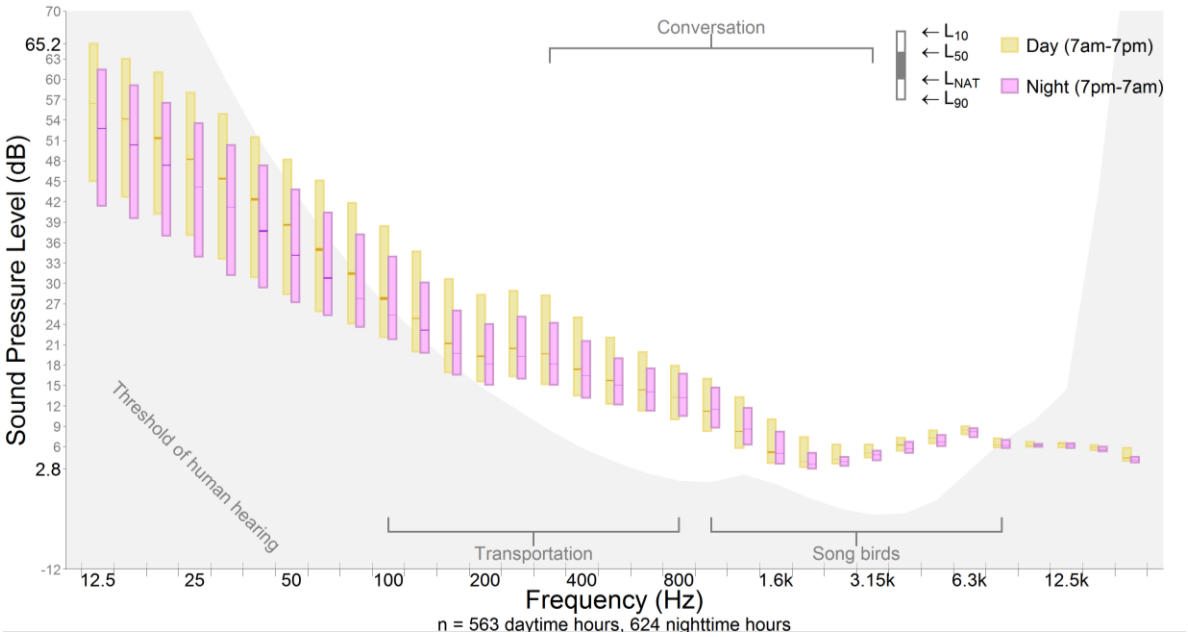


Figure 97. Spectral percentile levels for the Valley of Ten-Thousand Smokes site, 2015.

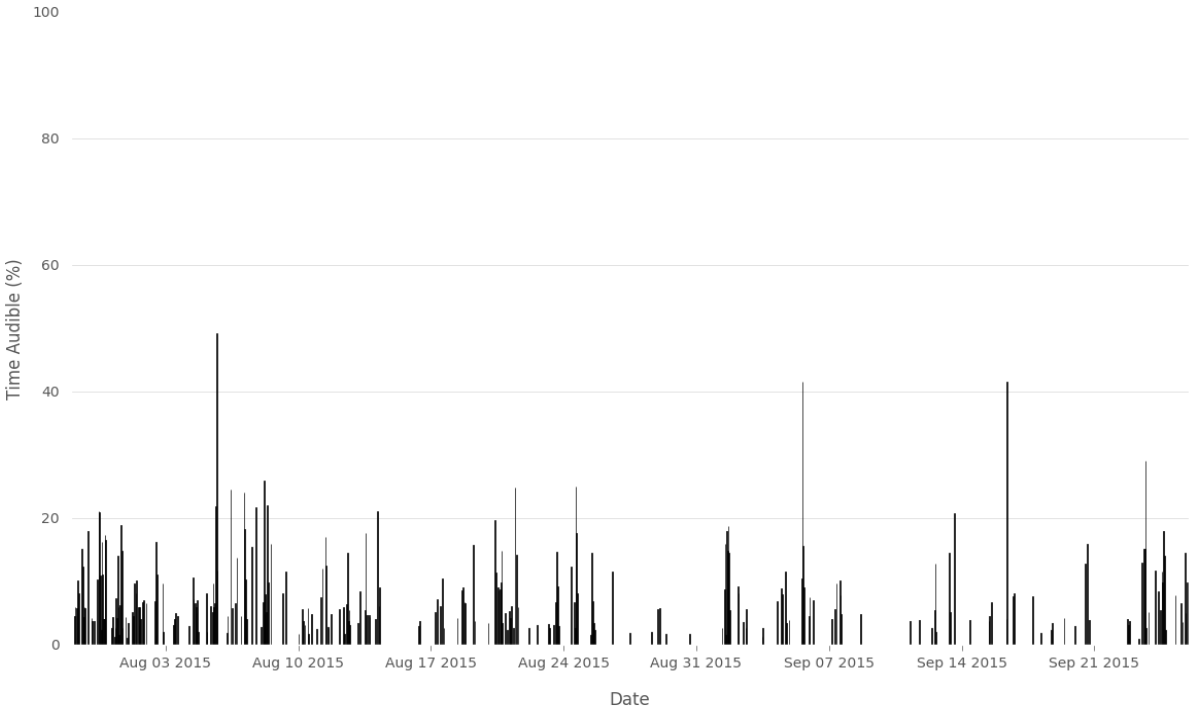


Figure 98. Audibility of aircraft noise by hour at Valley of Ten-Thousand Smokes, 2015.

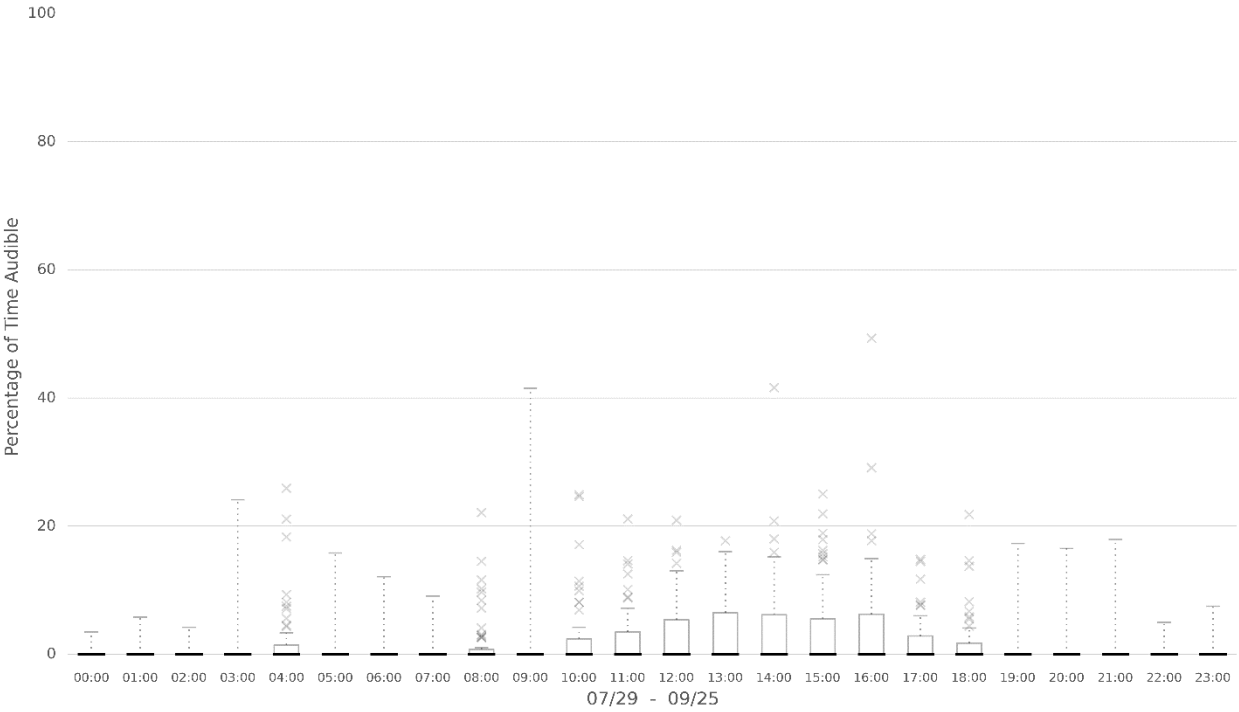


Figure 99. Audibility of aircraft noise for an average day, by hour, at Valley of 10k Smokes, 2015. The bold line indicates the median (50th percentile) value, the top of the box is the 75th percentile, and the bottom is the 25th percentile. The dashed flyers show 1.5x the interquartile range. Values outside this range are considered outliers and marked with an ‘x’.

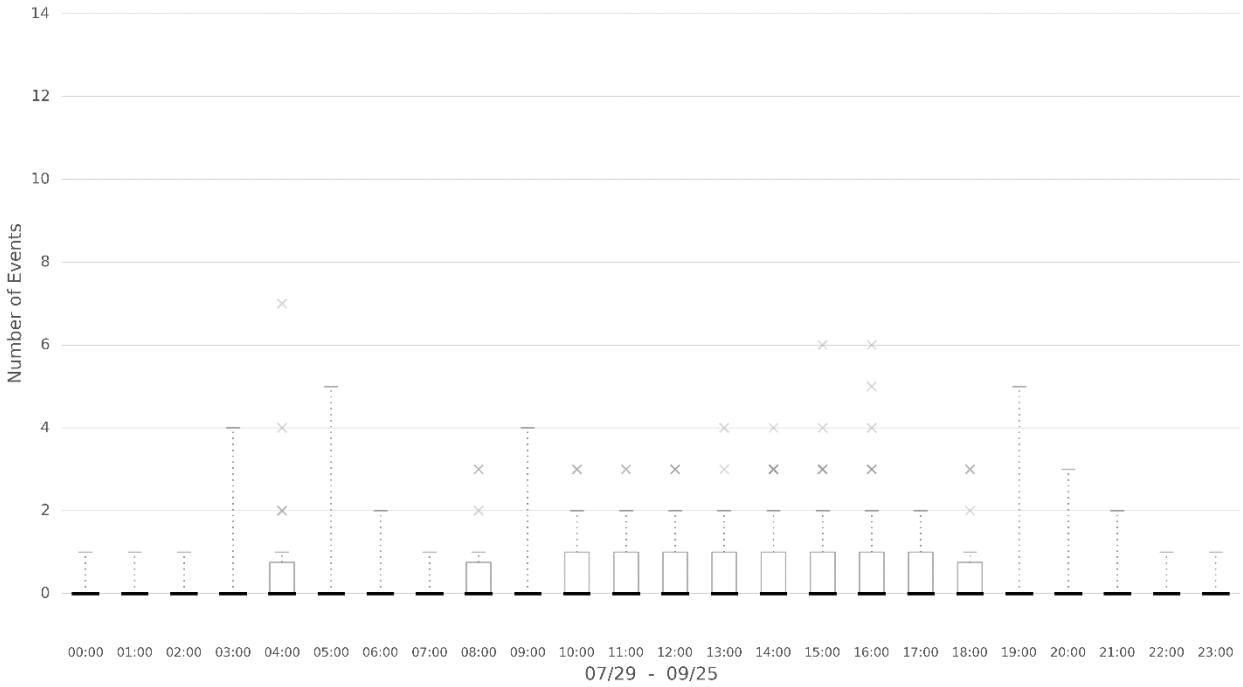


Figure 100. Rates of detection for aircraft noise events by hour at Valley of Ten-Thousand Smokes, 2015.

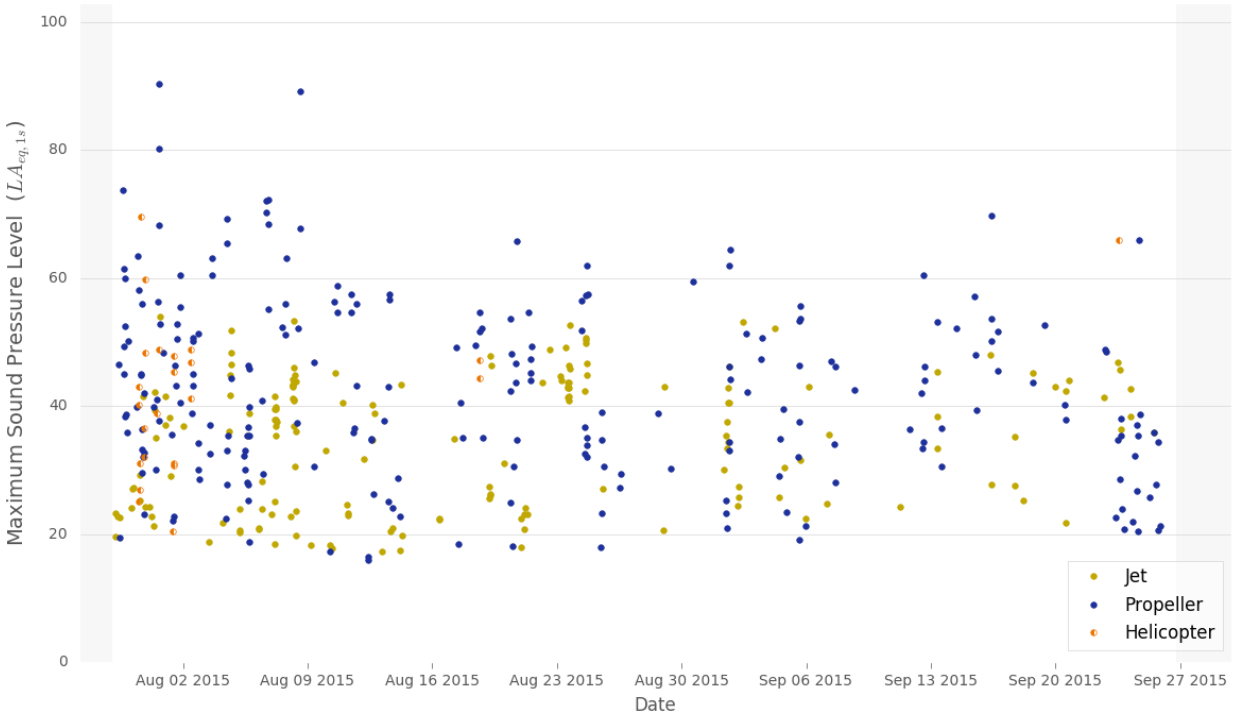


Figure 101. Maximum one-second sound pressure level for each aircraft event detected at Valley of Ten-Thousand Smokes, 2015.

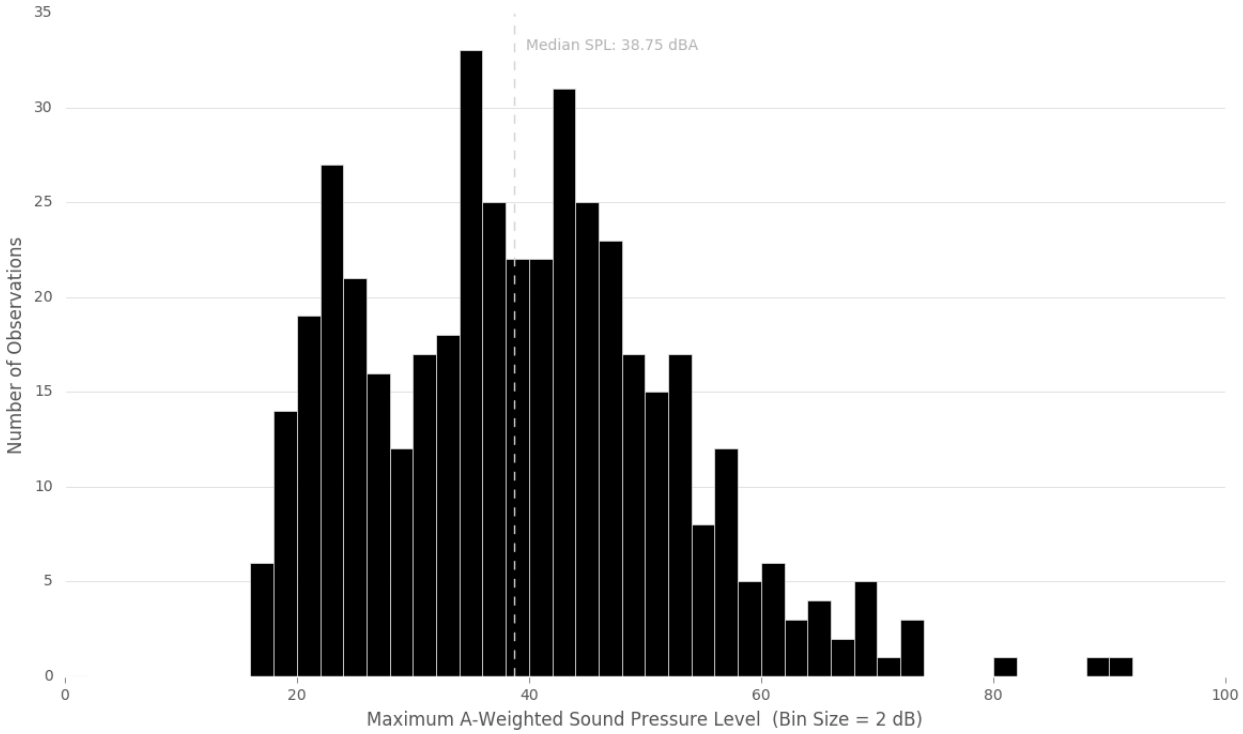


Figure 102. Histogram of maximum one-second sound pressure levels for aircraft noise events detected at Valley of Ten-Thousand Smokes, 2015.

Conclusions and Future Work

Given the large volume of data collected as part of this effort, numerous conclusions can be drawn from the results. These are broken into two primary categories: conclusions about the acoustic resources of Katmai, and conclusions related to noise impacts.

Acoustic Resources

This study produced information on the acoustic environment at fifteen sites within Katmai National Park and Preserve. These data are first and foremost descriptions of the natural ecosystem. The original definition of an ecosystem proposed by Sir Arthur Tansley plainly states that, "*we cannot separate [organisms] from their special environment, with which they form one physical system"* (Tansley 1935). The ecological paradigm of acoustics conceptualizes all naturally-produced sources of sound at a location as part of such a physical system. This includes both identifiable nearby natural sounds, such as gull calls or bear grunts, and the diffuse aggregation of distant or faint sounds referred to as *natural ambient energy*, or natural ambience.

Like most units in Alaska, the natural acoustic environments of Katmai are austere. The Aleutian Range is characterized by the sounds of *dissipation* – continuous flowing water overlaid by episodes of wind and rain. Along coastline or lakeshores, waves are a fourth keynote sound. In May and June these fundamental physical processes are supplemented by a diversity of avian vocalizations. In July, choruses fade until the sounds of life become mere punctuation: sparse, functional messages. The guttural vocalizations of bears, the strident calls of gulls and kittiwakes, or the flight calls of ravens are voices shared by many acoustic environments throughout Katmai. Because these regionally-characteristic sounds are arresting to the listener, they are easy to imagine as having an outsized impact on long-term summary statistics. However, their contributions are small relative to the energy released by long-term physical processes such as flowing rivers, tides, and storms.

Natural ambient levels throughout Katmai fall within the commonly observed range for NPS lands in Alaska (median LA_{nat} KATM = 30.8 ± 5.7 dB, median LA_{nat} Alaska non-KATM = 28.1 ± 7.3 dB). A notable difference between KATM and the broader Alaskan dataset is that there were relatively few naturally "low-energy" (quiescent) environments documented in KATM. The least-energetic natural environment sampled was at Contact Lake (LA_{nat} = 22.0 dB), which falls in the 14^{th} percentile region-wide. Quiescent summer conditions are most often observed in flat, lowland areas with characteristically stable atmospheric conditions (see *Lower Slippery Creek* Withers 2011, *Birch Creek* Betchkal 2013) or at high altitude beyond the influence of flowing water (see *Lower Dall Glacier* Withers and Betchkal 2013, *Upper Eldridge Glacier* Betchkal 2015). The fact that naturally quiescent sites were not observed in KATM does not mean they do not exist. Because Pfaff Mine – a subalpine site – was the highest elevation site sampled, the inventory excluded potential quiescent environments in KATM's alpine regions. This said, the strong winds of the Aleutian Range may preclude long-term levels any lower than we encountered during this effort.

Impacts to Acoustic Resources

The management of acoustic resources in Katmai presents a rare challenge. As the fifth largest area of designated wilderness in the United States, the park must protect wilderness character for the

public at a vast scale. Transportation to the park is typically via aircraft, or less often by boat. Simple transportation networks involving these noise sources may be benign to manage, but three factors combine to make Katmai's network more complex:

1. Katmai's notoriety as a world-class tourism destination creates high-volume traffic
2. Multiple points-of-destination spread out flight routes – and thus noise – in space
3. Multiple points-of-origin (Anchorage, Homer, King Salmon, Iliamna, Kodiak, private lodges, etc.) also spread out noise in space

These factors interact to create widespread noise impacts both in terms of duration and amplitude. In addition to describing impacts within the local area surrounding each site, this inventory also provides insight into transportation processes on a park-wide scale.

In particular, the results suggest a helpful simplification for management purposes. Noise issues along the coast arise from the superposition of long-duration vessel noise – especially from marine generators – over moderate-duration, high-amplitude aircraft noise. Interior areas can experience similarly intense impacts, but these are (essentially) due to aircraft noise alone.

Because aircraft are more powerful acoustic sources than watercraft (and less constrained in space), they impact the park over a much wider spatial area. Thus, the interior experiences acute, spatially widespread impacts, while the coast tends to experience local impacts. Such clear indications of scale give planners advance knowledge about the kinds of management goals and monitoring efforts that are appropriate for Katmai. (For a planning-oriented digest related to scale, see Betchkal and Ward 2018, pg 31 - 34).

Coastal Subzone

The Amalik Bay and Hallo Bay sites both experienced audible noise for over 30% of the entire record, well over the median for sites sampled nationwide (including frontcountry areas, Lynch 2011). These sites also have very short median noise-free intervals. The impacts at these two sites are primarily driven by long-duration vessel noise. The Kamishak River site, though perhaps not typically considered a ‘coastal’ location, follows much the same formula as Amalik Bay. Watercraft (in this case small motorboats) and takeoffs combine to create considerable noise impacts. Without the presence of marine generators, conditions at Kamishak Bay do have much lower overall time audible than Amalik Bay, but in terms of noise free interval the impacts are comparable.

In contrast, the Swikshak Lagoon site was primarily impacted by overflights – in this case, overflights following the coastline towards more southerly destinations. The connectedness of noise impacts in space is easy to overlook when management is narrowly focused on portal areas alone. Transportation networks may terminate in portals, but they create noise impacts along their entire extent. Therefore, an understanding of the spatial connections between portals is crucial for successful noise management.

Interior / Lake Subzone

The Crosswinds Lake and American Creek sites both documented exceptionally noisy portals where the original opportunities for solitude have been all but lost. They represent the highest noise event rates in Katmai (Crosswinds Lake median 53 / max 95 per day, American Creek median 56 / max 90 per day). These rates correspond to very short median noise-free intervals (Crosswinds Lake 3 minutes, American Creek 7 minutes). Because propeller aircraft events are shorter than vessel events, noise audibility is lower than at coastal sites, but still exceeded 19% of the entire record at both locations. In addition to their status as portals, both sites are underneath flight paths connecting King Salmon to Anchorage via Cook Inlet or Lake Clark Pass.

The third-most impacted site in the park is Dumpling Point. Although it is removed from the influence of King Salmon – Anchorage transportation routes and south of many of the lodges which operate within the lake region, it experiences considerable noise from both aircraft (time audible = 14.7% of entire record) and vessels (time audible = 2.1% of entire record). These unavoidably signal the proximity of development at Brooks Camp, diminishing wilderness character in an otherwise solitude-rich landscape.

Finally, it is worth noting that helicopters – though not currently a major impact – were most likely to be detected on a transect between King Salmon and the Valley of Ten-Thousand Smokes (at the Dumpling Point, Jo-Jo Lake, and Valley of Ten-Thousand Smokes sites, Appendix B, Figure APP B.15).

Aleutian Range Subzone

The south-central portions of the park (and probably much of the high Aleutian Range) have truly special intact quietude. Sites at Katmai Bay, the Valley of Ten-Thousand Smokes, and Savonoski Lake represent the most pristine acoustic environments sampled as part of the inventory (see Appendix B, Figure APP B.21).

The acoustic conditions in all areas of the park – and especially these areas – are important components of wilderness quality (NPS Management Policies § 6.3.7). NPS Management Policies 2006 directs parks to monitor trends in wilderness resources to identify the need for management action (NPS Management Policies § 6.3.6.2). Continuing to actively manage for non-degradation of this resource is surprisingly similar to the artistry involved in producing a film soundtrack: *"You have to imagine the hundred musicians on stage in order for their silence to mean anything. You have to work with the psychic pressure exerted by the instruments or sounds that are not playing"* (Murch 2005). We live in a world full of motorized noise, but in parks our policy ultimately calls for the protection of resources, prohibiting the "impairment of park resources and values, unless a particular law directly and specifically provides otherwise" (NPS Management Policies 2006 § 1.4.3, 1.4.4).

Data from south-central portions of the park also provide inference into the volume of propeller traffic crossing the Aleutian Range. Savonoski Lake and Valley of Ten-Thousand Smokes both represent gateways to major passes: Savonoski Pass and Katmai Pass, respectively. These sites experience remarkably similar noise impacts (median propeller noise events per day 5 and 4

respectively, maximum propeller noise events per day 12 and 13). The most extreme interpretation – that all these events are one-way flights (not round-trip) that traverse a pass (rather than flying somewhere else) suggests that on a typical day about ten propeller aircraft traverse the Aleutian Range through the two best passes available. This makes sense considering that routes arriving from the north/northeast (i.e., Anchorage, Iliamna, or Homer) do not need to cross the higher mountains of the range to arrive at King Salmon, Brooks Camp, or any of the various lodges in the Katmai lake region. Only routes connecting interior points-of-origin to Hallo Bay or Amalik Bay (or Kodiak, beyond) would require the use of Savonoski Pass or Katmai Pass. Administrative flights more often use the former.

Future Work

In addition to the fifteen sites reported here, NPS staff deployed a station at Lake Camp in 2017. This station experienced equipment malfunctions which corrupted the data, rendering them unusable. The Katmai Wilderness Recommendation EIS suggested that the western end of Naknek Lake was the "most visited" area of the park due to the number of watercraft entering through the Naknek River (NPS 1988.), which means a repeat attempt at data collection is likely merited. Deploying a station at Lake Camp would also describe the volume of air traffic headed from King Salmon towards Brooks Camp, helping contextualize observations at the Dumpling Point site. A sample collected at Lake Camp in future years would round out the work of this inventory.

NPS staff collected short-duration acoustic measurements at Brooks Camp during the summer of 2010 (Appendix A). These could be complimented by more precise, focused acoustic measurements of specific administrative noise sources (i.e., the fish freezer, generator, etc.) such that mitigation opportunities could be explored.

Acoustic models could be developed for specific landscapes of management concern. Models are a concrete, mechanistic compliment to acoustic measurements. If well-calibrated by field observations, they can be helpful in predicting the effect of management action over broad areas. Acoustic models of takeoffs from Crosswinds Lake / Just Enough Lake, Hallo Bay, American Creek, or Brooks Camp all would be useful to contextualize the results of this inventory. Parks in the Alaska Region are beginning to stipulate that aircraft concessionaire partners provide flight tracks of their operations. Denali implemented such provisions in recent concessions contracts. An analysis procedure is available to reduce and join flight tracking data to acoustic data (https://github.com/dan-walsh/flightsounds), speeding the assessment of commercial noise impacts.

As mentioned in the introduction to this report, Director's Order #47 calls on parks to create acoustic goals. Conducting an *Extent Necessary Determination* as per §4(d)(5) of the Wilderness Act may be a helpful managerial exercise that could inform the creation of acoustic goals that are consistent with KATM's foundational purposes. Once acoustic goals have been set, KATM could develop and enact a statistically-robust long-term monitoring plan. This would help revisit the measurements made in this report and protect acoustic resources into the future.

Literature Cited

American National Standards Institute (ANSI). 1968. Audiometer Standard *3.6*. American National Standards Institute, 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.

Berglund, B., Lindvall, T. and Schwela, D.H., 1999. Guidelines for community noise: World Health Organization. Geneva, Switzerland.

Betchkal, D. 2013. Acoustic monitoring report, Denali National Park and Preserve – 2011. Natural Resource Data Series. NPS/DENA/NRDS—2013/474. National Park Service. Fort Collins, Colorado. Published Report-2194377.

Betchkal, D. 2015. Acoustic monitoring report, Denali National Park and Preserve – 2013. Natural Resource Data Series NPS/DENA/NRDS—2015/989. National Park Service, Fort Collins, Colorado.

Betchkal, D. and Ward VL. 2018. Glacier Bay National Park and Preserve: Acoustic Resource Management Framework. Natural Sounds and Night Skies Division. Denali Park, AK.

Dooling, R.J. and Popper, A.N., 2007. The effects of highway noise on birds. Sacramento, CA: The California Department of Transportation Division of Environmental Analysis, 74.

Environmental Protection Agency (EPA.), 1974. Information on levels of environmental noise requisite to protect public health and welfare with an adequate margin of safety (Vol. 74, No. 4). U.S. Environmental Protection Agency, National Park Service, Washington, D.C.

Fay, R. R. 1988. Hearing in Vertebrates: A Psychophysics Databook. Winnetka, IL: Hill-Fay Associates

Groth EM and Others. 2007. Visitor and bear use of Moraine and Funnel Creeks, Katmai National Preserve, 2006. National Park Service. King Salmon, Alaska.

Haralabidis, A.S., Dimakopoulou, K., Vigna-Taglianti, F., Giampaolo, M., Borgini, A., Dudley, M.L., Pershagen, G., Bluhm, G., Houthuijs, D., Babisch, W. and Velonakis, M., 2008. Acute effects of night-time noise exposure on blood pressure in populations living near airports. European heart journal, 29(5), pp.658-664.

Harris, C. M. (1998). Handbook of Acoustical Measurements and Noise Control, 3rd ed. McGrawHill, New York.

Levin, S.A., 1992. The problem of pattern and scale in ecology: the Robert H. MacArthur award lecture. Ecology, 73(6), pp.1943-1967.

Lynch, E., D. Joyce, and K. Fristrup. 2011. An assessment of noise audibility and sound levels in US National Parks. Landscape Ecology 26:1297–1309.

Lynch, E. 2012. Glacier Bay National Park and Preserve: Acoustical monitoring 2011. Natural Resource Technical Report NPS/NRSS/NRTR—2012/XXX. National Park Service, Fort Collins, Colorado.

Murch, W., 2005. Silence. http://transom.org/2005/walter-murch/ Accessed 14 May 2011.

Nagle, J.C., 2016. Enjoying Katmai. Alaska L. Rev., 33, p.65.

National Park Service. 1978. Redwood Act (92 Statute 163).

National Park Service (NPS). 1988. Katmai National Park and Preserve Final EIS for the Wilderness Recommendation. U.S. Department of the Interior, National Park Service, Anchorage, Alaska.

National Park Service (NPS). 2000. Director's Order #47. Soundscape Preservation and Noise Management. U.S. Department of the Interior, National Park Service, Washington, D.C.

National Park Service (NPS). 2006a. Management policy 4.9: Soundscape management in Management policies 2006. U.S. Department of the Interior, National Park Service, Washington, D.C.

National Park Service (NPS). 2006b. Management policy 8.2.3: Use of motorized equipment in Management policies 2006. U.S. Department of the Interior, National Park Service, Washington, D.C.

National Park Service (NPS). 2009. Katmai National Park and Preserve Foundation Statement. National Park Service, Anchorage, Alaska.

Proppe, D.S., Sturdy, C.B., St Clair, C.C., 2013. Anthropogenic noise decreases urban songbird diversity and may contribute to homogenization. Global change biology, 19(4), pp.1075-1084.

Saleh, J., 2002. Fluid Flow Handbook: Chapter 31 – Turbulent Flow. McGraw-Hill Professional.

Shannon, G., McKenna, M.F., Angeloni, L.M., Crooks, K.R., Fristrup, K.M., Brown, E., Warner, K.A., Nelson, M.D., White, C., Briggs, J., McFarland, S., 2015. A synthesis of two decades of research documenting the effects of noise on wildlife. Biological Reviews.

Stevens Jr, D.L., Olsen, A.R., 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association, 99(465), pp.262-278.

Tansley, A.G., 1935. The use and abuse of vegetational concepts and terms. Ecology, 16(3), pp.299.

Templeton, D. (Ed.). 1997. Acoustics in the built environment: advice for the design team. Architectural Press, Oxford.

Toubman J and Others. 2016. Winter road plowing in Denali National Park and Preserve: Monitoring 2014-2015. Natural Resource Report. NPS/DENA/NRR—2016/1277. National Park Service. Fort Collins, Colorado.

United States Public Law 96-487 (16 U.S. C. 3101 - 3233) Alaska National Interest Lands Conservation Act, §202(2). 1980.

Withers, J., and C. Hults. 2006. Denali National Park and Preserve soundscape annual report 2006. Denali Park, Alaska.

Withers, J. 2010. Acoustic monitoring report, Denali National Park and Preserve - 2008. Natural Resource Data Series NPS/CAKN/NRDS—2010/091. National Park Service, Fort Collins, Colorado.

Withers, J. 2011. Acoustic monitoring report, Denali National Park and Preserve - 2007. Natural Resource Data Series NPS/CAKN/NRDS—2011/136. National Park Service, Fort Collins, Colorado.

Withers, J. 2012. Acoustic monitoring report, Denali National Park and Preserve - 2009. Natural Resource Data Series NPS/DENA/NRDS—2012/271. National Park Service, Fort Collins, Colorado.

Withers, J., and D. Betchkal. 2013. Acoustic monitoring report, Denali National Park and Preserve – 2010. Natural Resource Data Series NPS/DENA/NRDS—2013/441. National Park Service, Fort Collins, Colorado.

Appendix A – Brooks Camp Acoustic Inventory, 2010

Background

Brooks Camp is a non-wilderness area of the park that represents a concentrated area of visitation and use by both bears and people (Figure APP A.1). Katmai staff collected short-duration acoustic measurements throughout Brooks Camp in the summer of 2010. This appendix provides metadata and cursory summaries of the effort so that park managers and the public are aware of the data (Tables APP A.1 through APP A.3). A detailed analysis is not included.

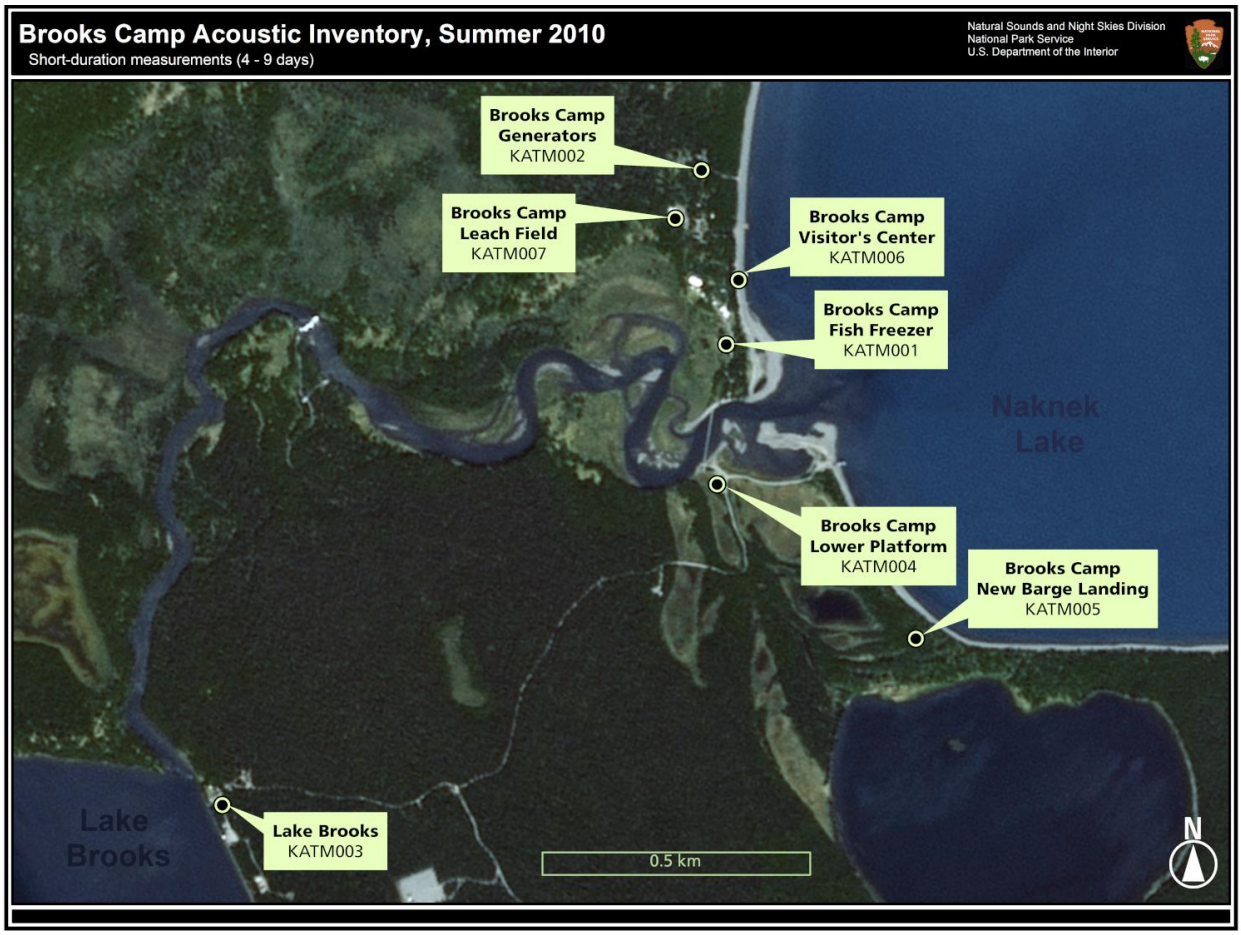


Figure APP A.1. Acoustic inventory sites at Brooks Camp sampled during the summer of 2010.

Table APP A.1. Short-duration sites sampled at Brooks Camp during the summer of 2010.

Site Name	Site Code	Year	Elevation (m)	Latitude	Longitude	Days Sampled
Brooks Camp Fish Freezer	001	2010	50	58.55485	-155.77807	7
Brooks Camp Generators	002	2010	61	58.55775	-155.77902	5
Lake Brooks	003	2010	75	58.54693	-155.79388	4
Brooks Camp Lower Platform	004	2010	48	58.55251	-155.77825	5
Brooks Camp New Barge Landing	005	2010	48	58.55002	-155.77172	5
Brooks Camp Visitor Center	006	2010	46	58.55593	-155.77773	6
Brooks Camp Leach Field	007	2010	59	58.55693	-155.77982	9

Table APP A.2. Percent time above metrics for all sites

Site	Frequency (Hz)	% Time above sound level: 0700 to 1900				% Time above sound level: 1900 to 0700			
		35dB	45dB	52dB	60dB	35dB	45dB	52dB	60dB
Fish Freezer	20-1250 (T)	77.4	13.4	3.5	0.7	50.3	21.9	0.8	0.0
	12.5-20,000	92.3	29.4	6.8	1.9	66.2	29.8	15.1	0.2
Generators	20-1250 (T)	100.0	100.0	100.0	1.3	100.0	100.0	100.0	0.0
	12.5-20,000	100.0	100.0	100.0	2.5	100.0	100.0	100.0	0.0
Lake Brooks	20-1250 (T)	43.0	18.6	9.7	4.0	3.2	0.3	0.0	0.0
	12.5-20,000	64.5	25.2	13.2	5.1	20.2	1.0	0.2	0.0
Lower Platform	20-1250 (T)	46.3	11.6	3.5	0.6	2.2	0.3	0.1	0.0
	12.5-20,000	55.6	24.4	7.8	1.1	9.5	0.7	0.2	0.1
New Barge Landing	20-1250 (T)	25.2	5.7	2.0	0.5	10.1	0.2	0.1	0.0
	12.5-20,000	48.7	12.2	3.4	0.9	31.6	1.8	0.2	0.0
Visitor Center	20-1250 (T)	19.5	5.5	1.8	0.7	3.1	0.1	0.0	0.0
	12.5-20,000	31.7	6.6	2.8	0.8	26.2	4.8	0.2	0.0
Leach Field	20-1250 (T)	99.9	8.2	2.3	0.5	100.0	0.2	0.0	0.0
	12.5-20,000	100.0	12.6	3.5	0.9	100.0	0.4	0.1	0.0

Table APP A.3. Median natural and existing ambient sound levels and aircraft statistics for all sites.

Site Name	L10*	L50*	L90*
Fish Freezer	47.3	41.1	37.2
Generators	56.3	55.3	54.7
Lake Brooks	49.8	35.6	29.5
Lower Platform	45.1	33.7	29.9
New Barge Landing	42.7	33.9	30.0
Visitor Center	38.6	30.1	27.0
Leach Field	43.1	40.6	40.0

*L_{10}, L_{50}, L_{90}, and SPL in dBA.

Appendix B – Inventory Maps

This section includes maps of results that depict geographic relationships between inventory sites(Figures APP B.1 through APP B.24).

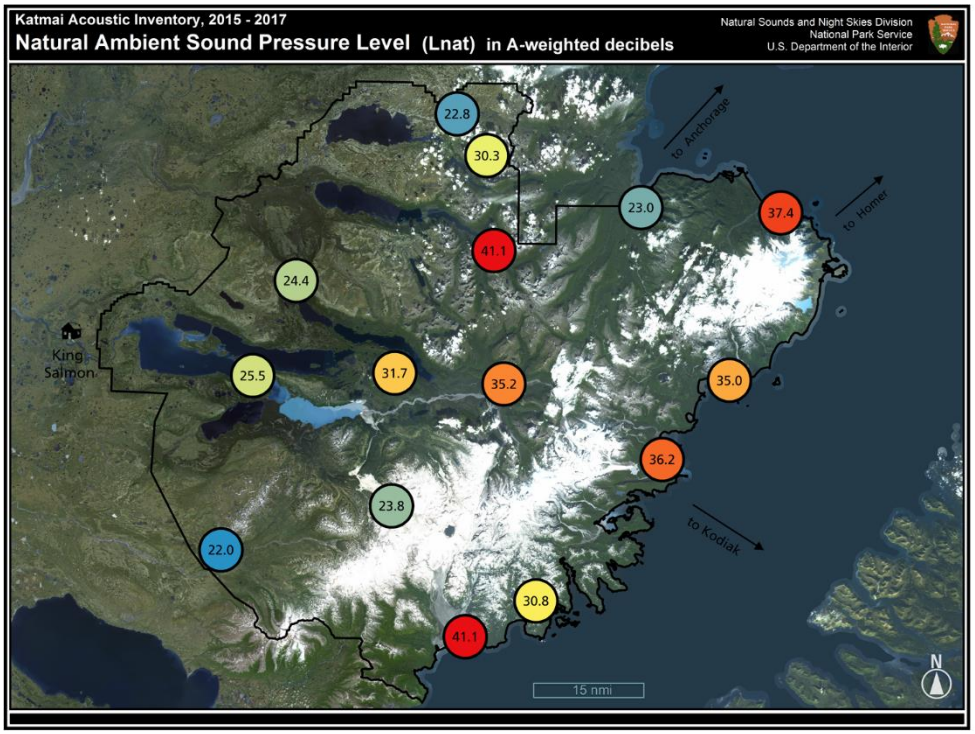


Figure APP B.1. Map showing the natural ambient sound pressure levels measured at inventory sites.

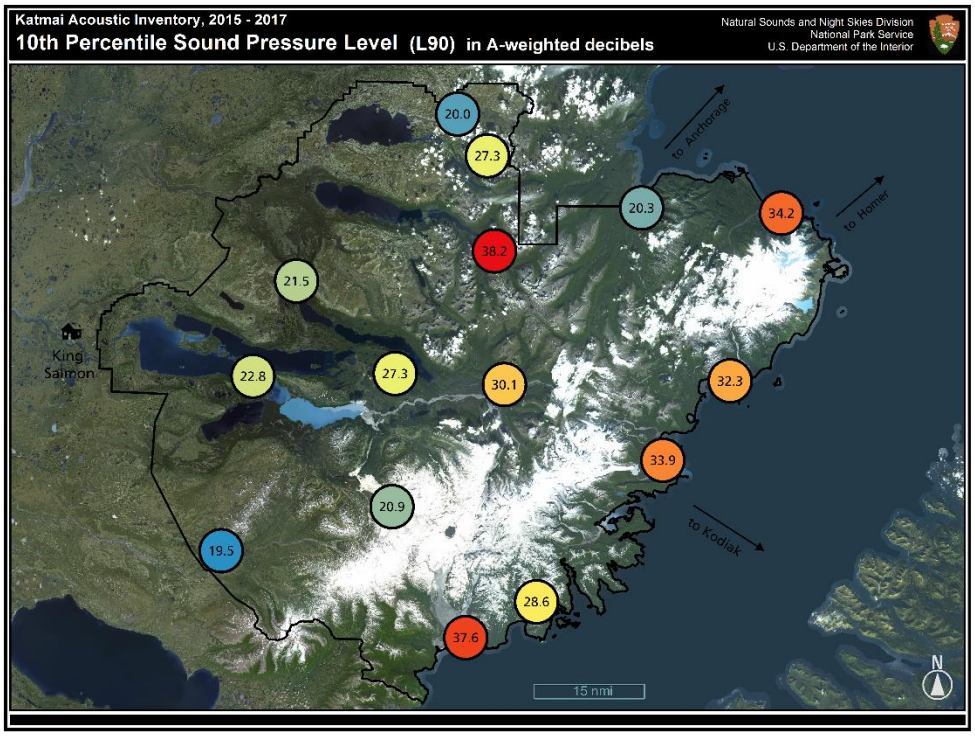


Figure APP B.2. Map showing the 10th percentile sound pressure level (L90) at inventory sites. This value serves as an estimate of the natural 'floor' of the acoustic environment, or in rarer cases, higher floors associated with instrumentation noise.

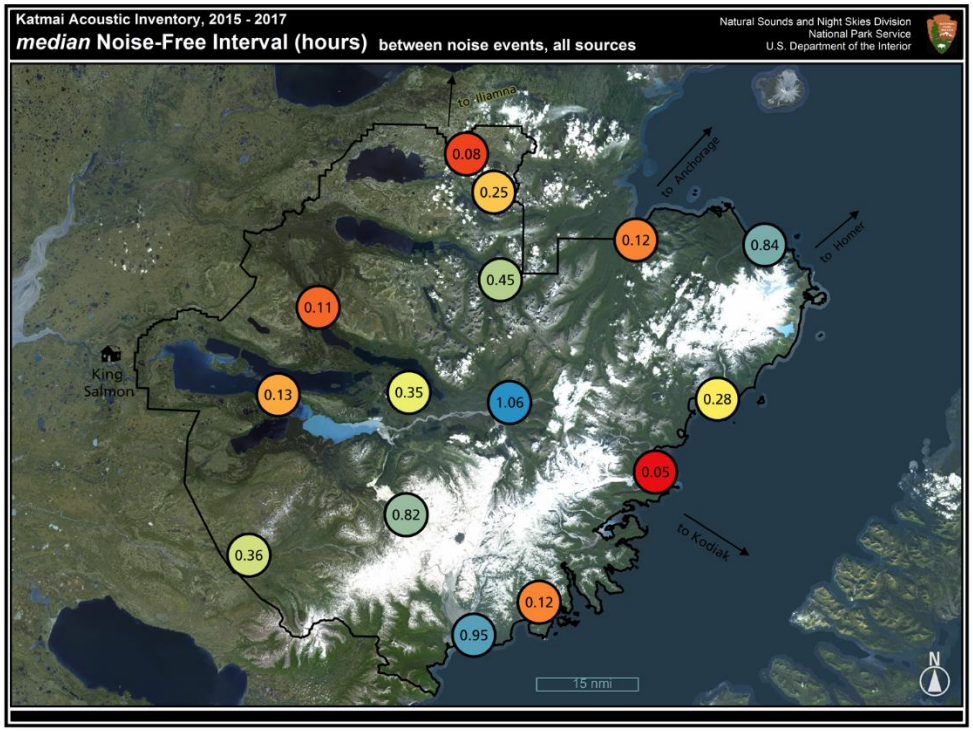


Figure APP B.3. Map showing duration of the median noise free interval (in hours) between noise events of all source types.

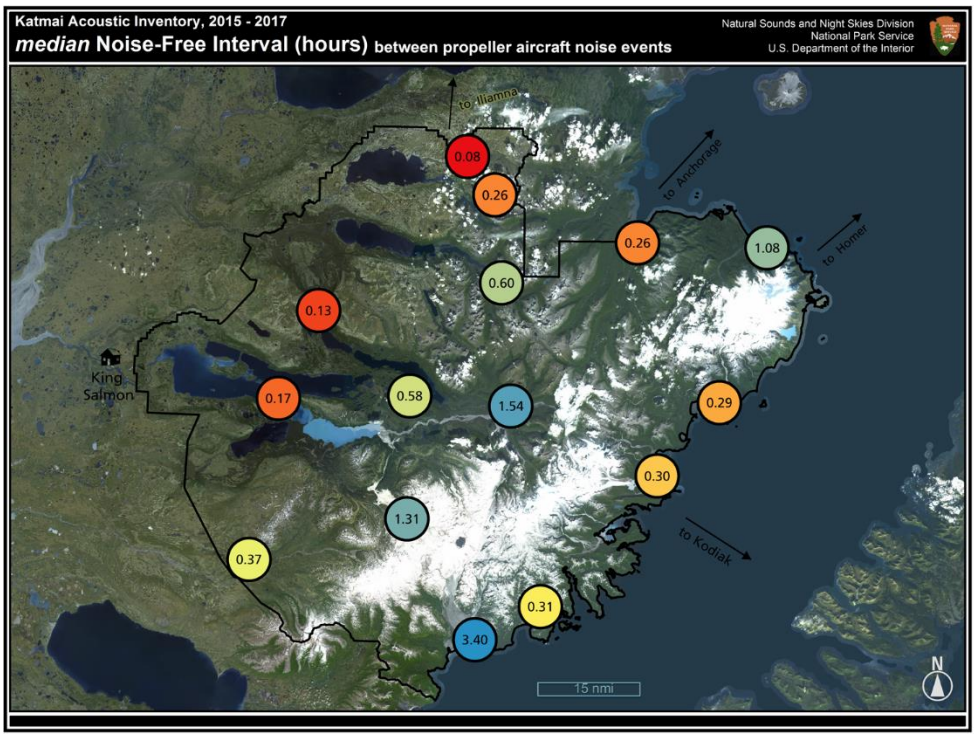


Figure APP B.4. Map showing duration of the median noise free interval (in hours) between propeller aircraft noise events.

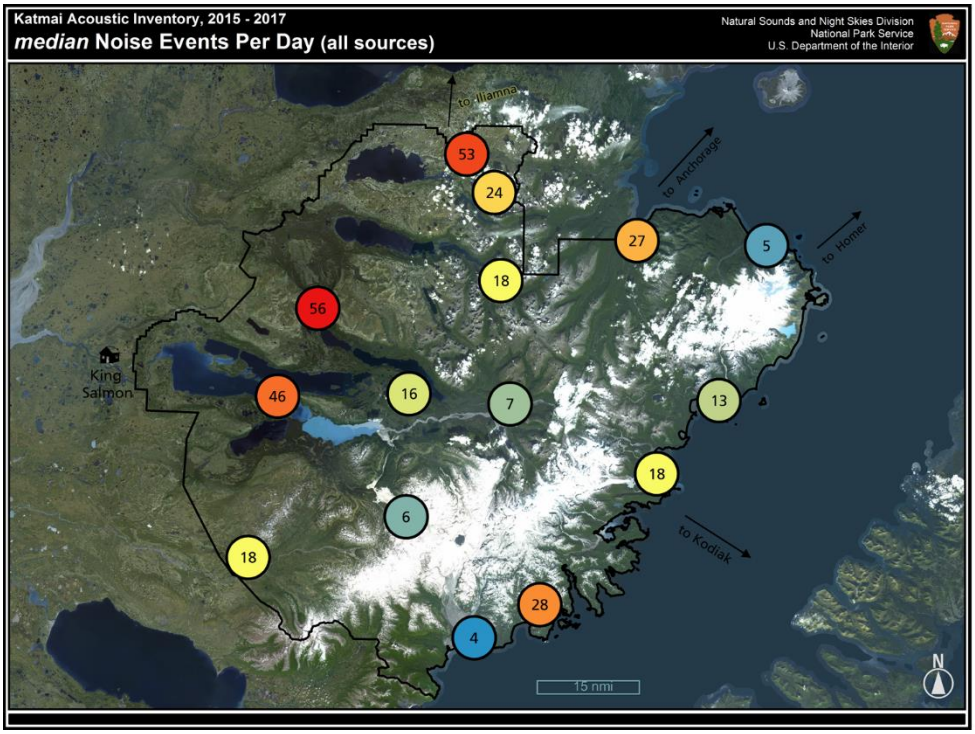


Figure APP B.5. Map showing the median number of noise events per day, all source types.

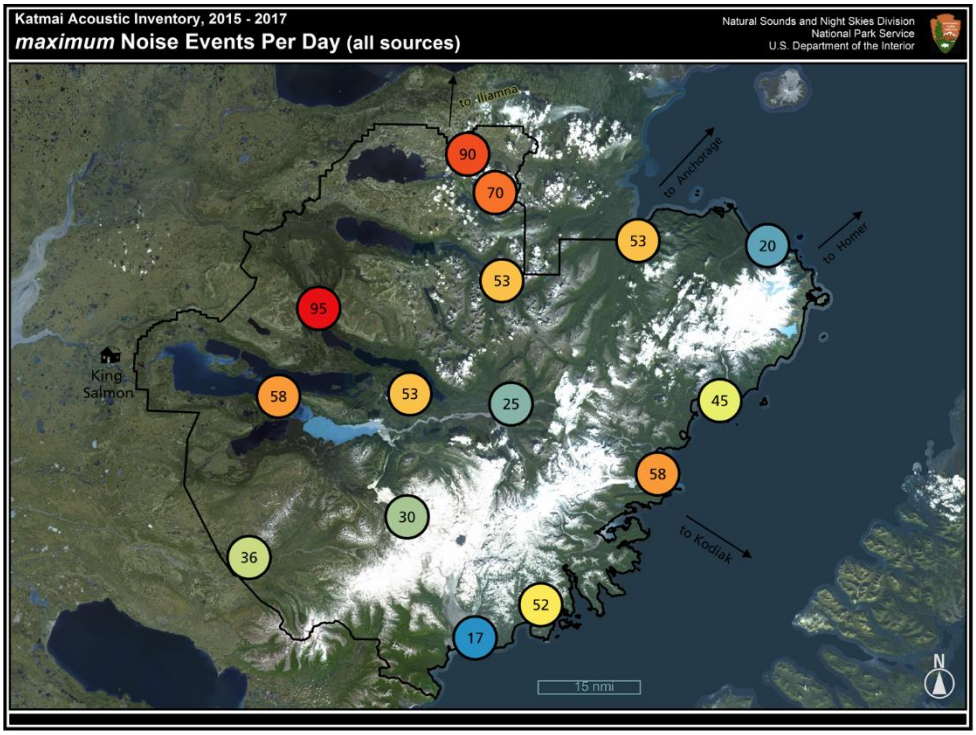


Figure APP B.6. Map showing the maximum number of noise events per day, all source types.

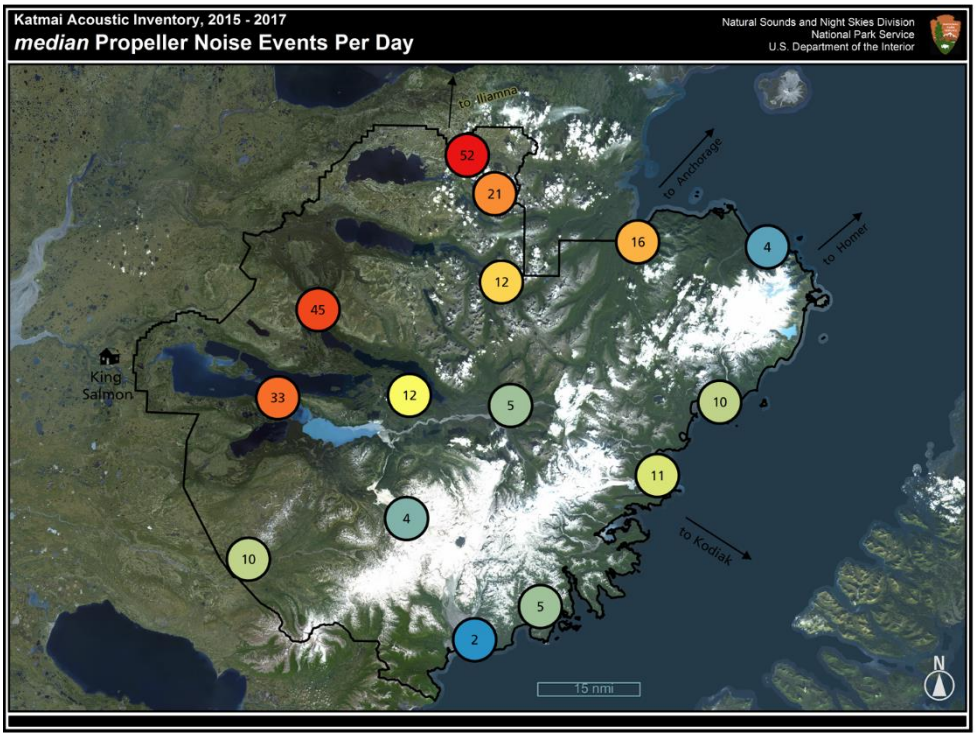


Figure APP B.7. Map showing the median number of propeller aircraft noise events per day.

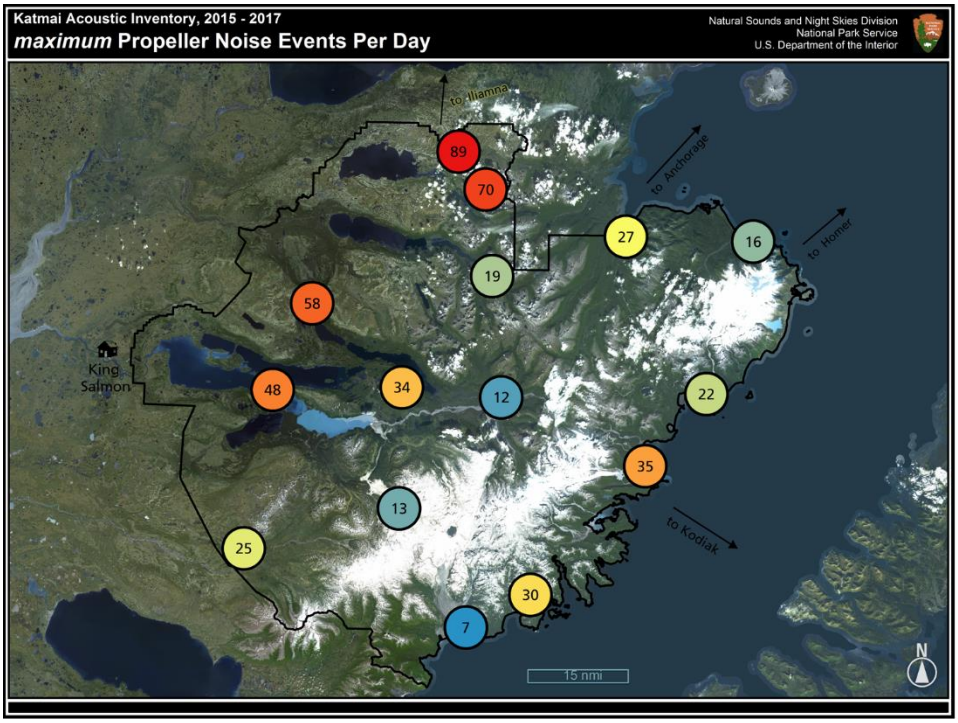


Figure APP B.8. Map showing the maximum number of propeller aircraft noise events per day.

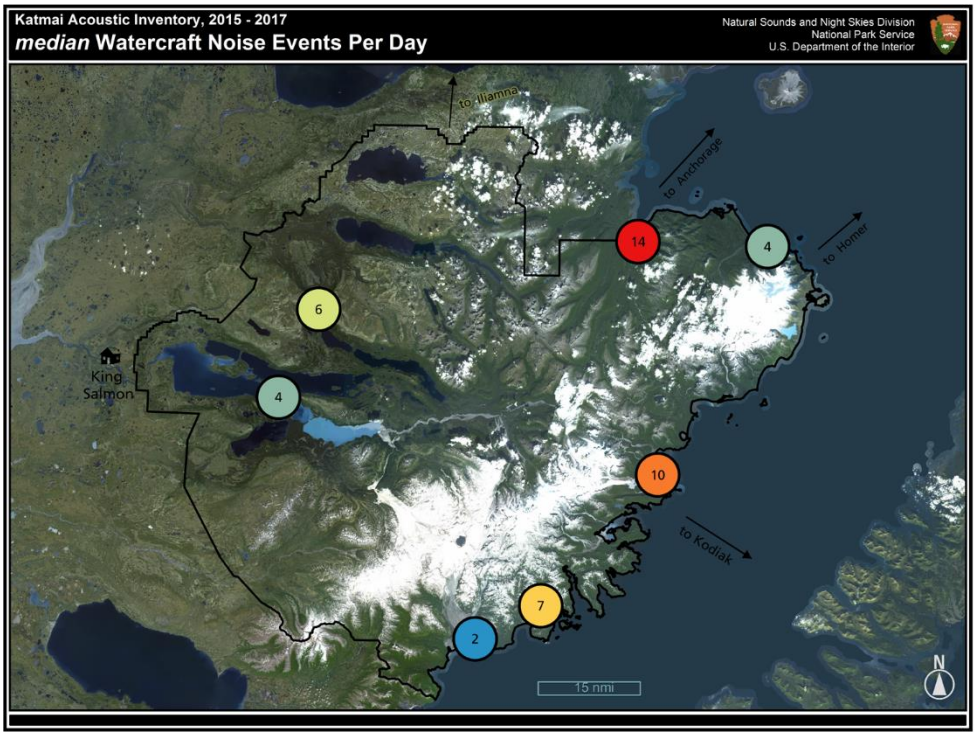


Figure APP B.9. Map showing the median number of watercraft aircraft noise events per day.

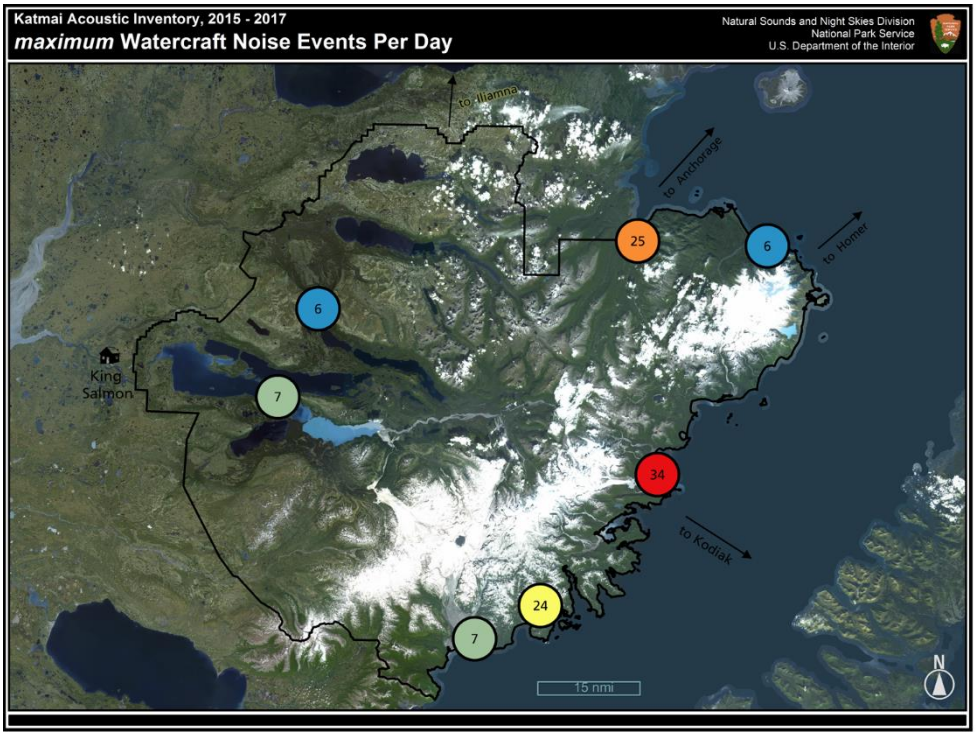


Figure APP B.10. Map showing the maximum number of watercraft aircraft noise events per day.

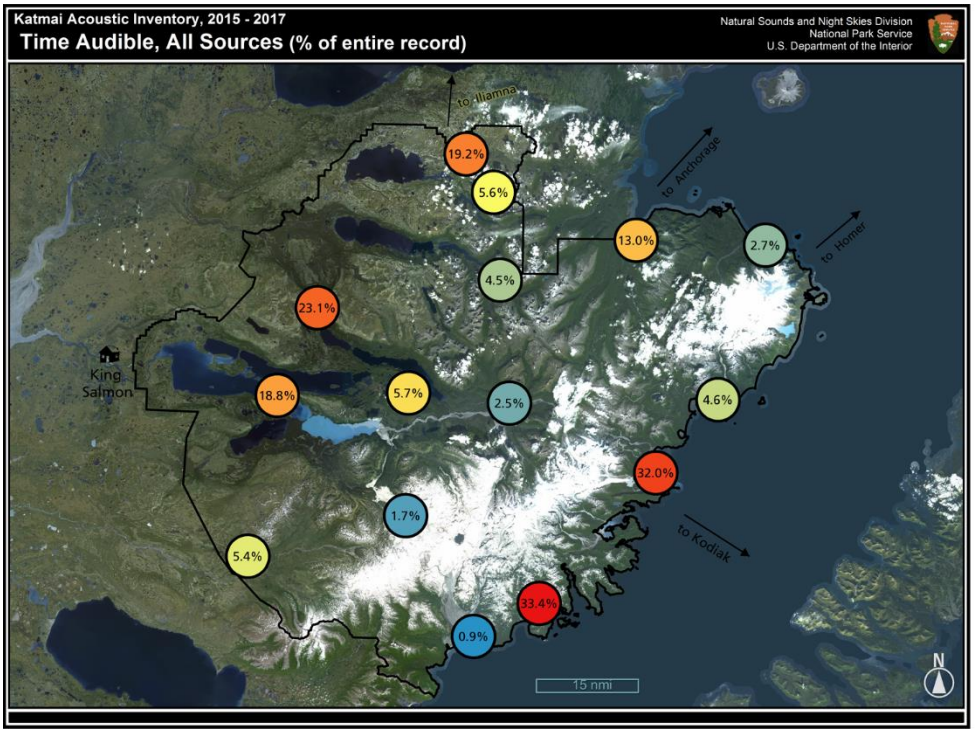


Figure APP B.11. Map showing time audible (percent of entire record) for all noise sources combined.

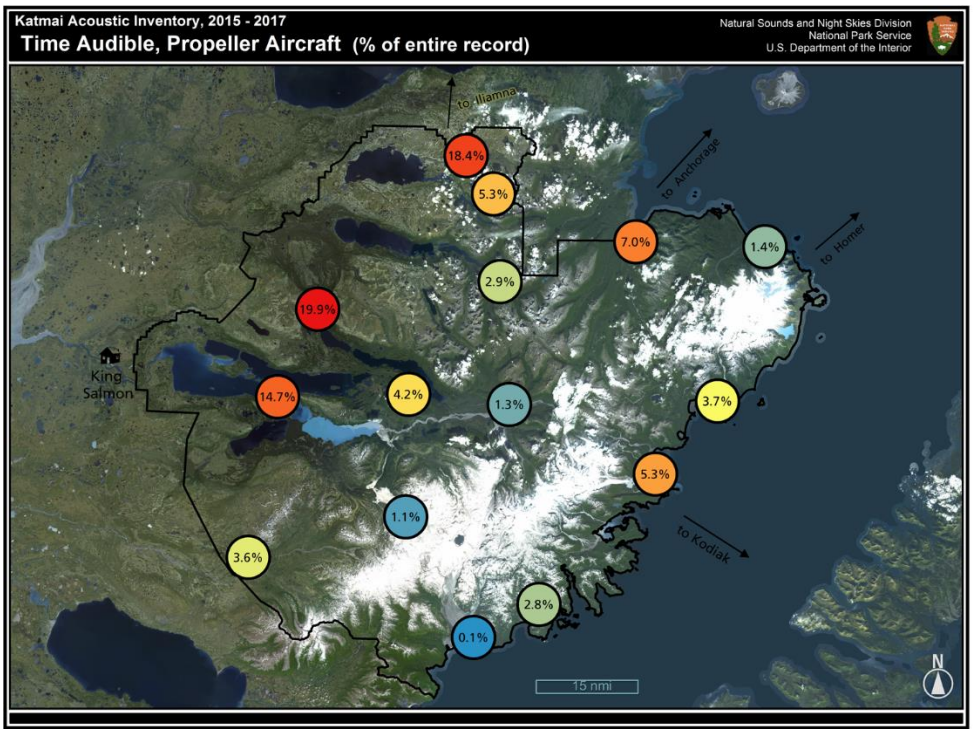


Figure APP B.12. Map showing time audible (percent of entire record) for propeller aircraft noise.

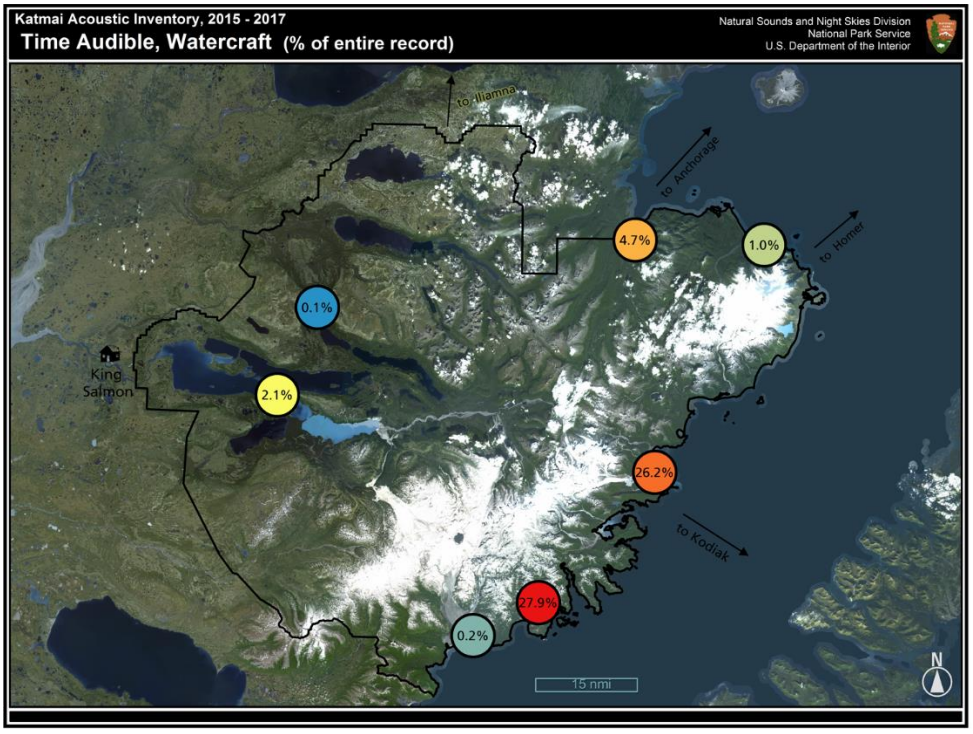


Figure APP B.13. Map showing time audible (percent of entire record) for watercraft noise.

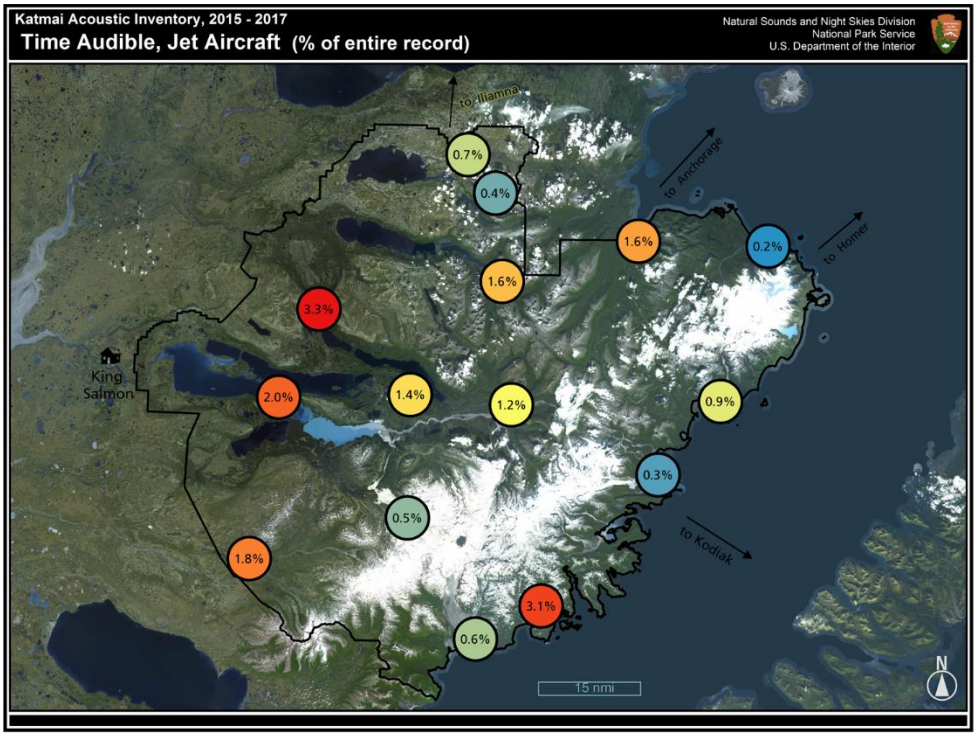


Figure APP B.14. Map showing time audible (percent of entire record) for jet aircraft noise.

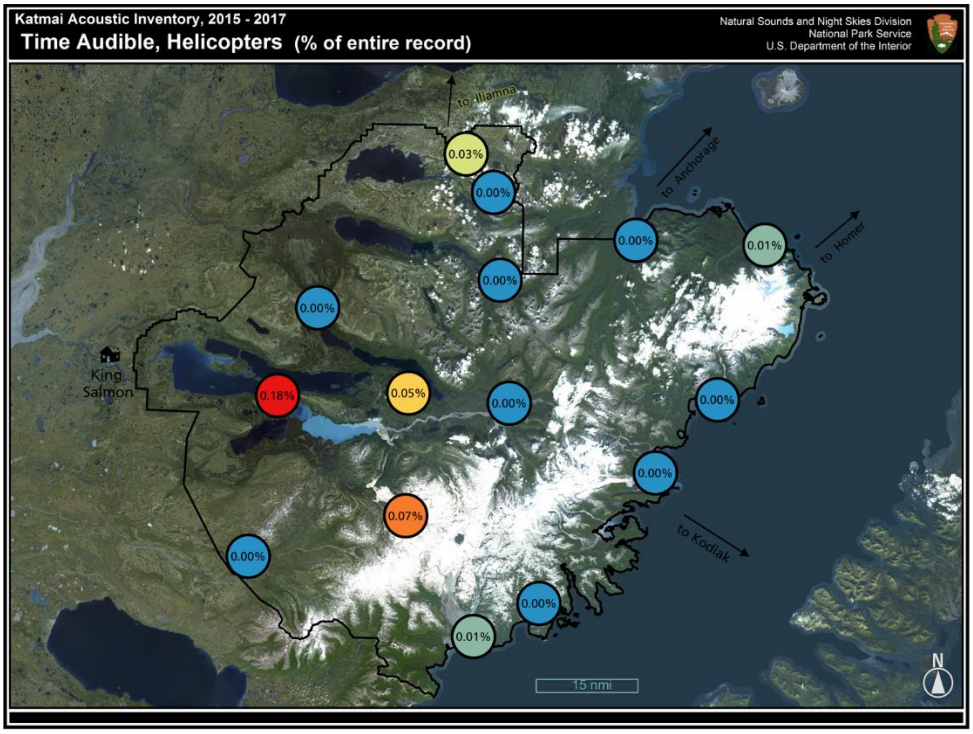


Figure APP B.15. Map showing time audible (percent of entire record) for helicopter noise.

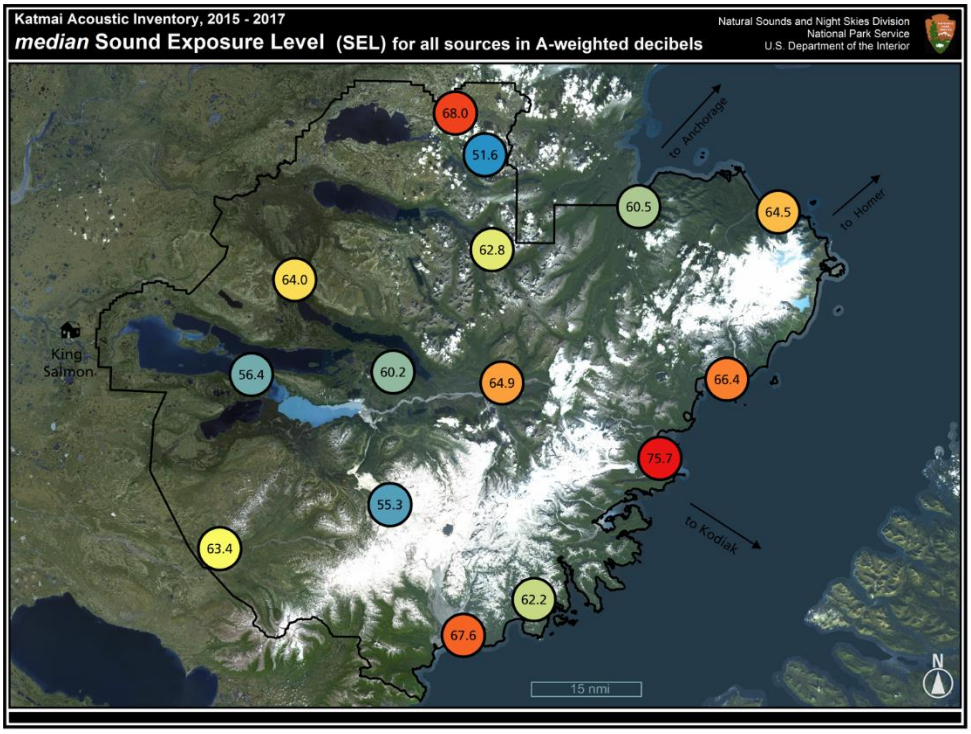


Figure APP B.16. Map showing median sound exposure level for all noise source types combined.

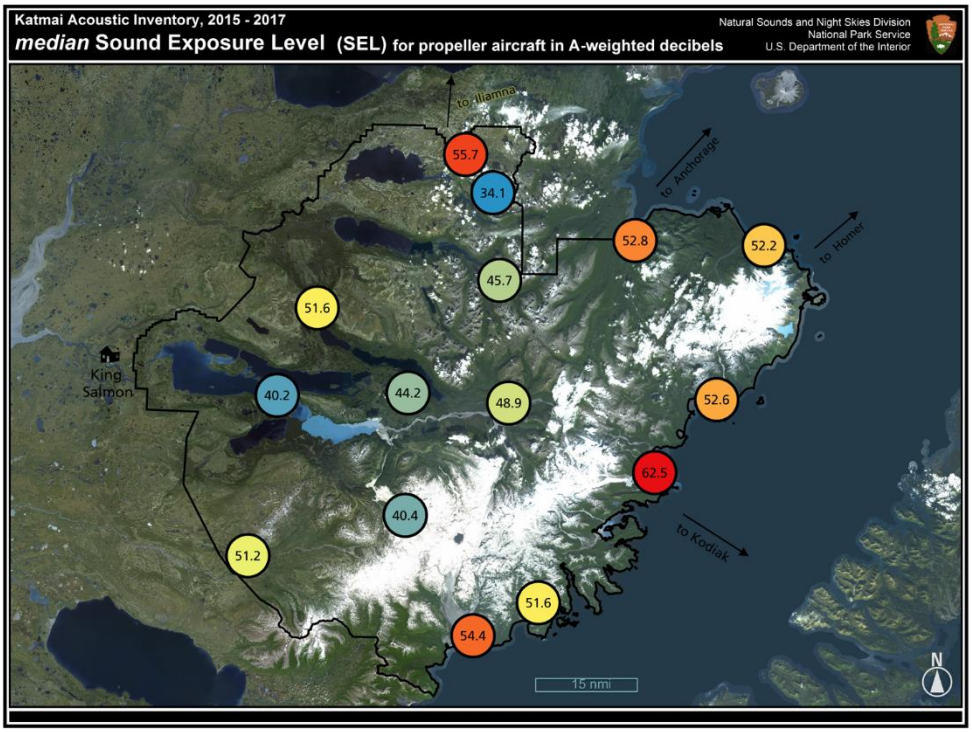


Figure APP B.17. Map showing median sound exposure level for propeller aircraft noise events.

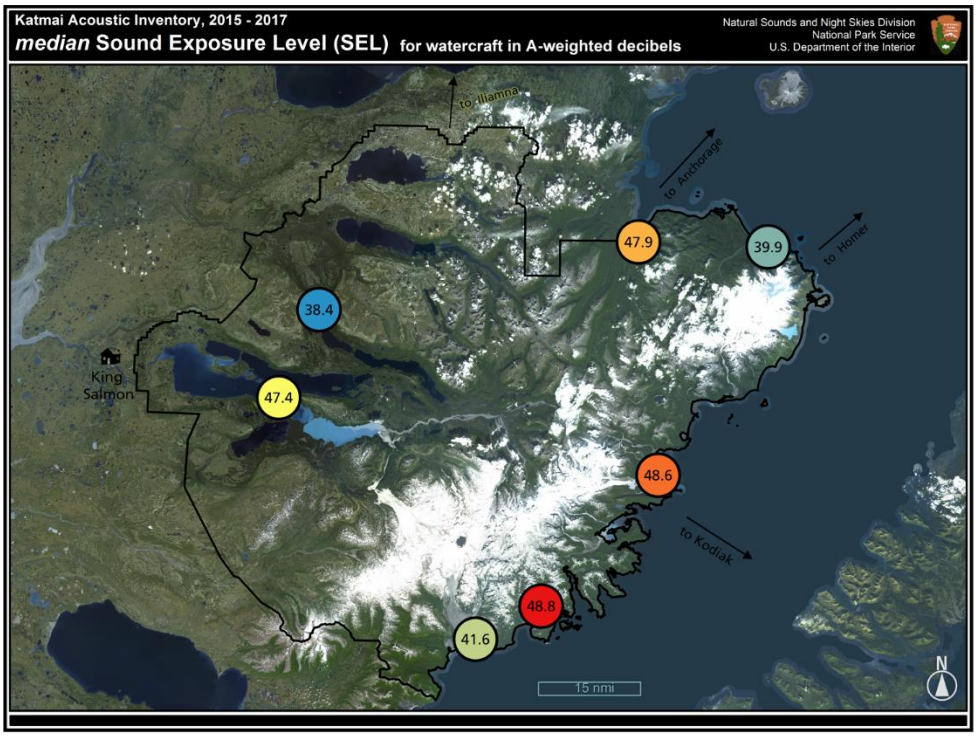


Figure APP B.18. Map showing median sound exposure level for watercraft noise events.

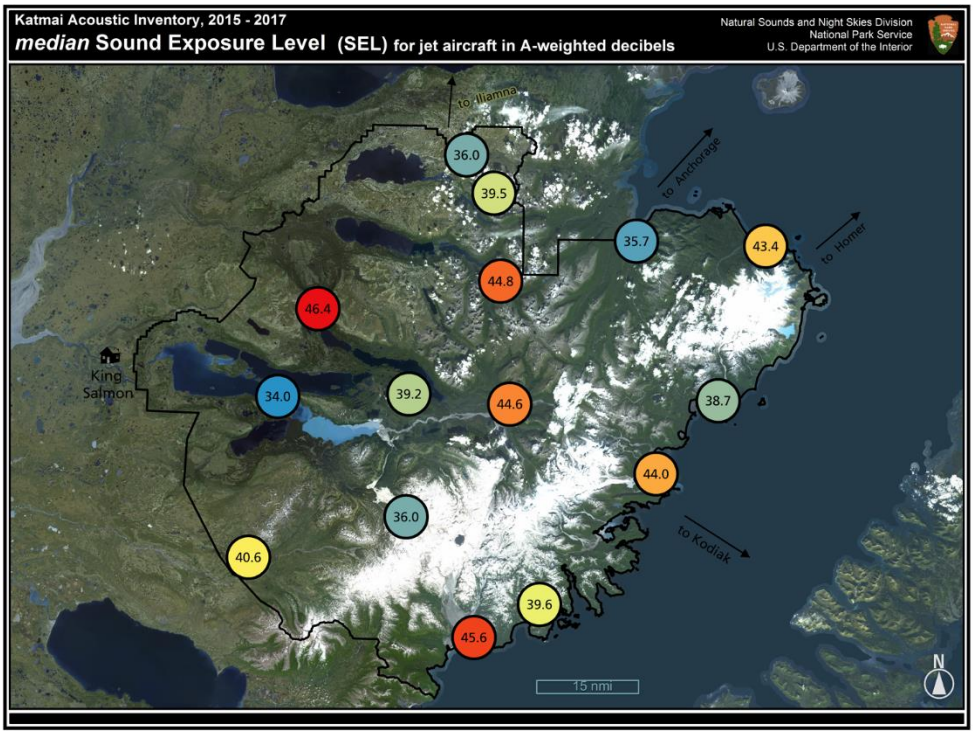


Figure APP B.19. Map showing median sound exposure level for jet aircraft noise events.

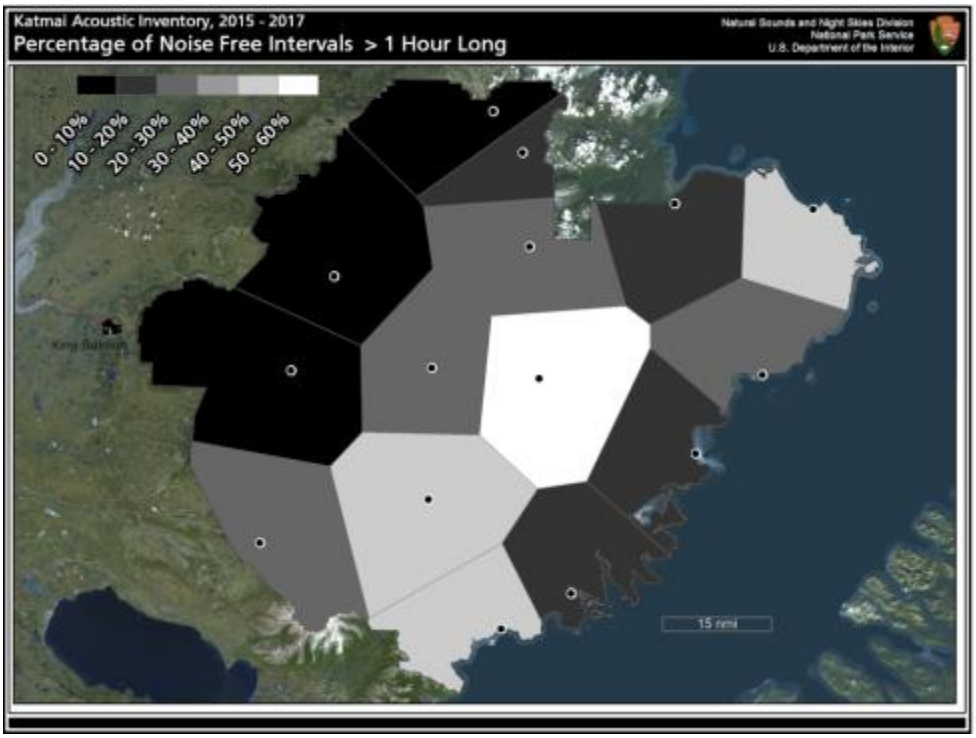


Figure APP B.20. Map showing percentage of noise-free intervals greater than one hour in length. The shaded areas around each site contain every point closer to the site in the center of each area than to any other site (i.e., Voronoi cells).

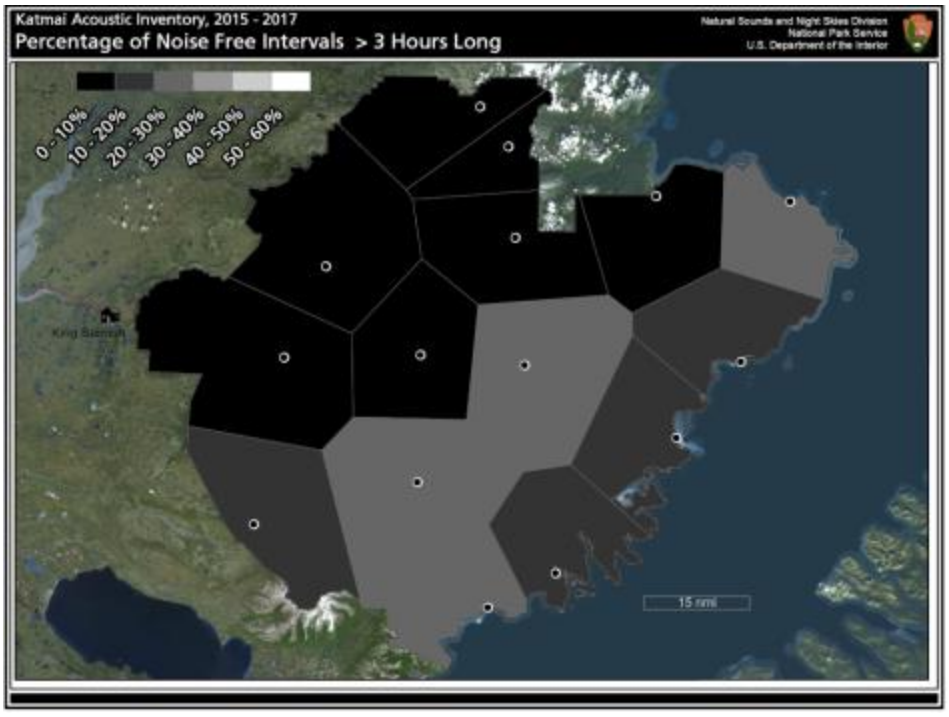


Figure APP B.21. Map showing percentage of noise-free intervals greater than three hours in lenfth. The shaded areas around each site contain every point closer to the site in the center of each area than to any other site (i.e., Voronoi cells).

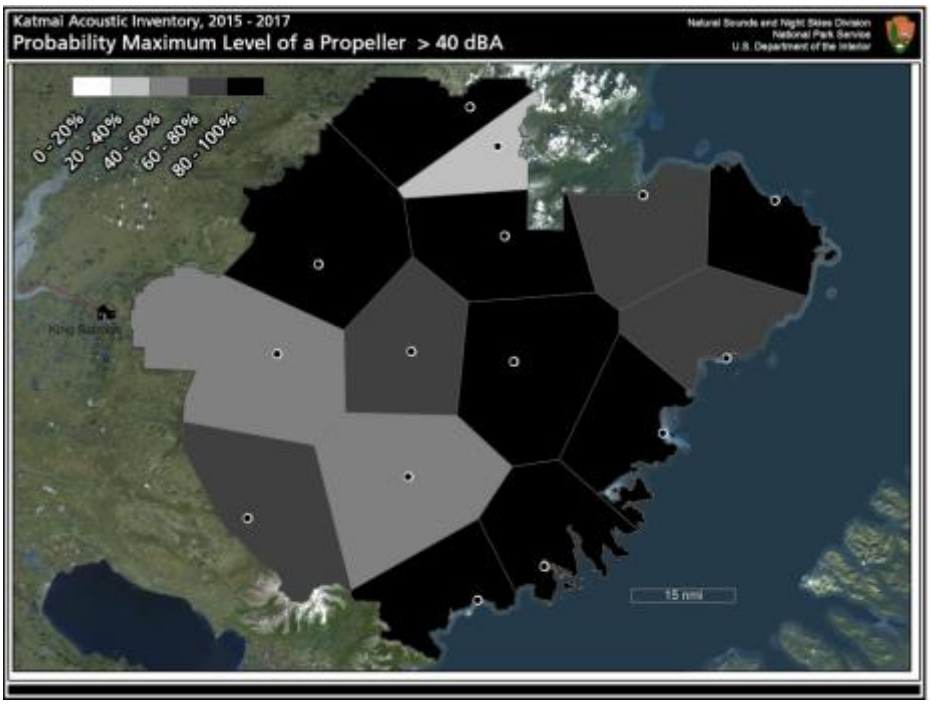


Figure APP B.22. Map showing percentage of propeller noise events with maximum $L_{Aeq, 1s}$ greater than 40 dBA. The shaded areas around each site contain every point closer to the site in the center of each area than to any other site (i.e., Voronoi cells).

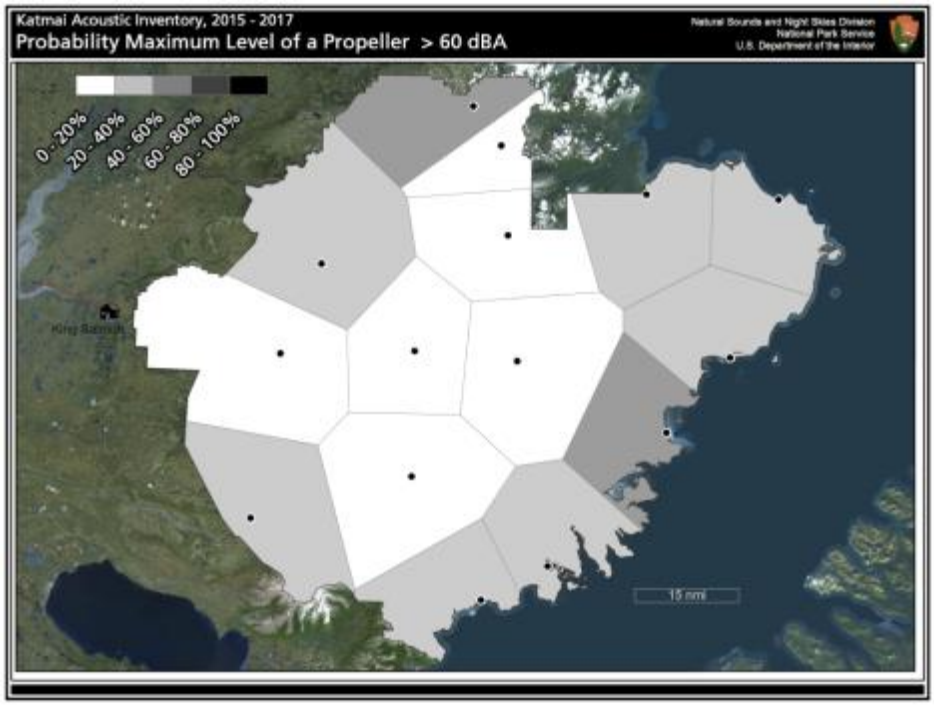


Figure APP B.23. Map showing percentage of propeller noise events with maximum $L_{Aeq, 1s}$ greater than 60 dBA. The shaded areas around each site contain every point closer to the site in the center of each area than to any other site (i.e., Voronoi cells).

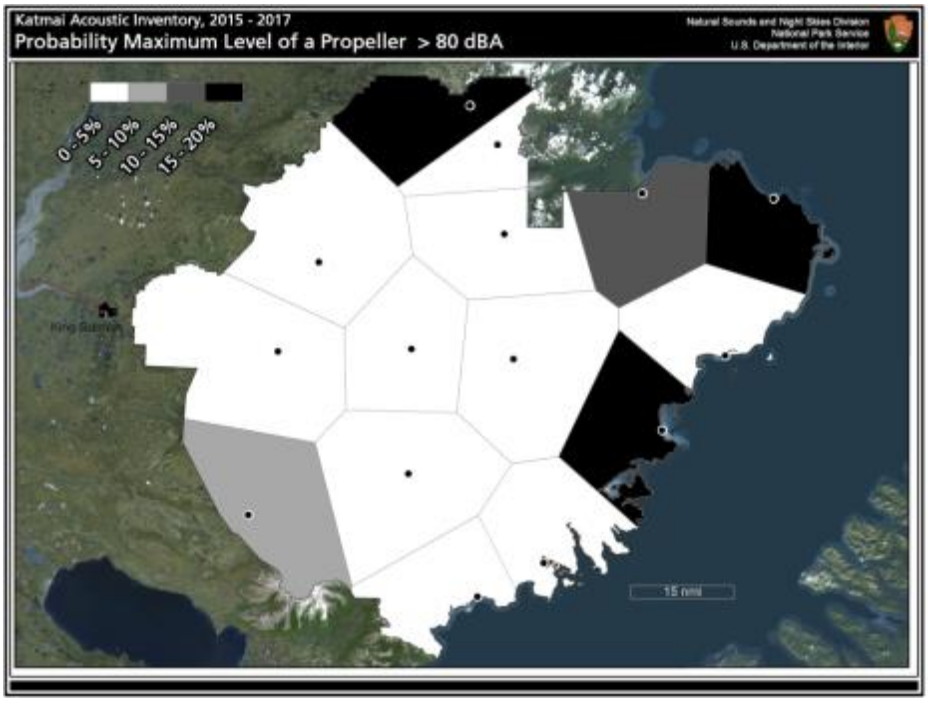


Figure APP B.24.Map showing percentage of propeller noise events with maximum $L_{Aeq, 1s}$ greater than 60 dBA. The shaded areas around each site contain every point closer to the site in the center of each area than to any other site (i.e., Voronoi cells). Note that scale ranges from 0 – 20 percent.

Appendix C – Reference Photographs and Maps

Figures APP C.1 through APP C.10 are reference photographs.



Figure APP C.1. View from the American Creek site location out over wetlands towards Collvile Lake. The closest proximity of the lake is 1.7 km from the site. During install staff saw (and heard) jet boats operating on the lake.



Figure APP C.2. Example of boat storage near the American Creek site.



Figure APP C.3. Annotated photograph of the approach to the Dumpling Point acoustic inventory site. Photograph shows a view of the site location in open mixed forest 60 meters above the shoreline of Naknek Lake. The gravel beach in the foreground was used to land the NPS boat.

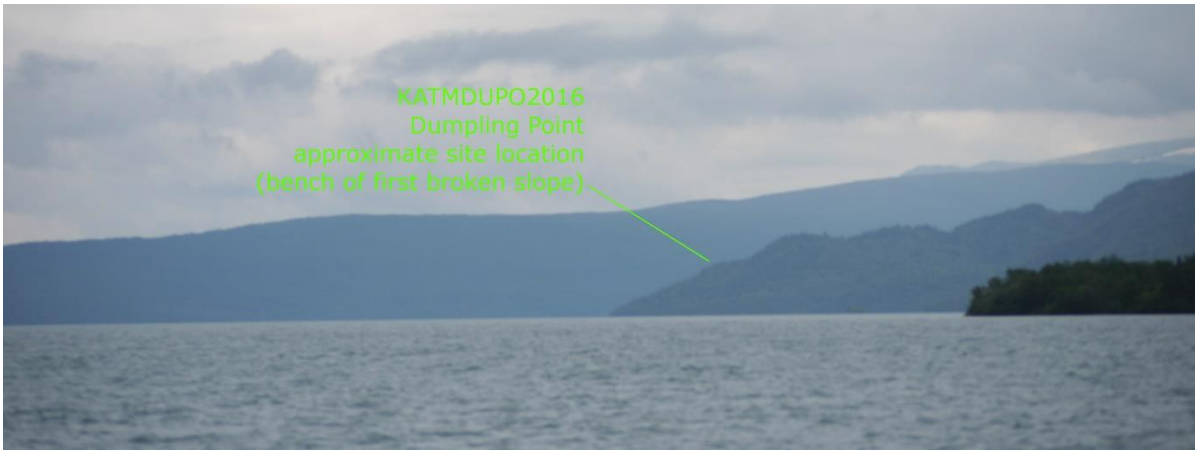


Figure APP C.4. Annotated photograph of the Dumpling Point acoustic inventory site location. The view looks west along Naknek Lake and shows the site location in profile.

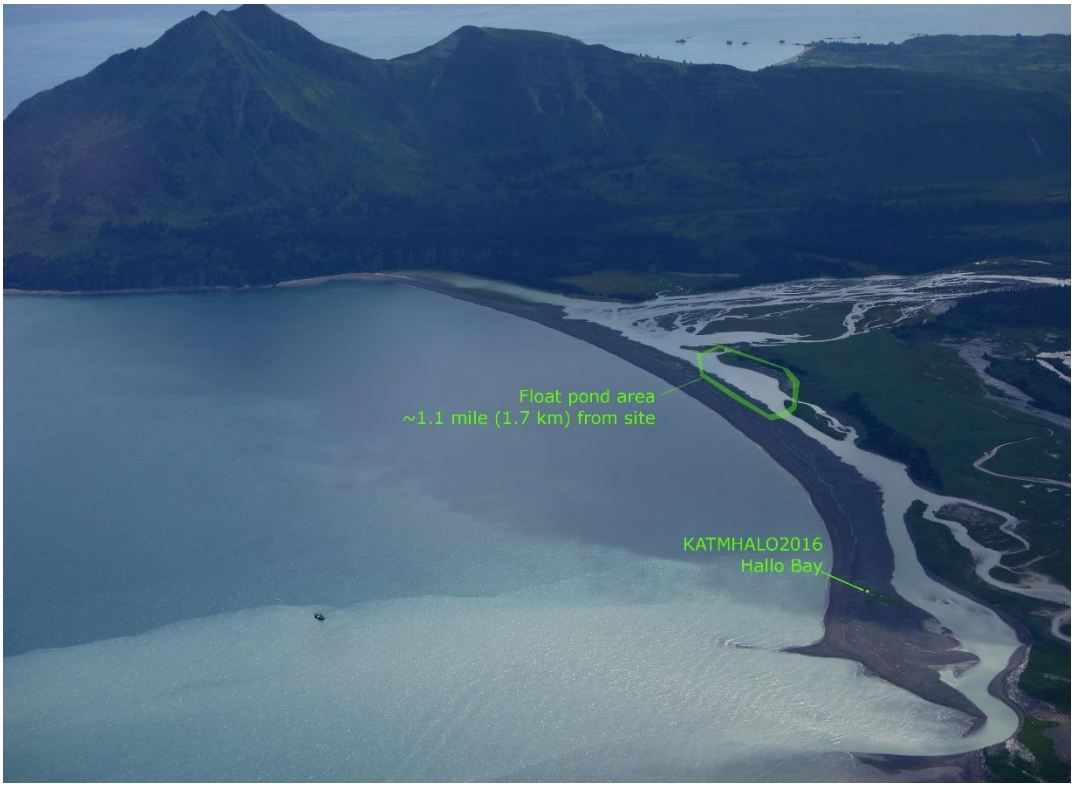


Figure APP C.5. Annotated aerial photograph of the Hallo Bay acoustic inventory site. The spit separates the bay from Hallo Creek. A floatplane landing area is located about 1.7 kilometers upstream from the site. The steep scarp of Cape Nukshak forms the midground of the photograph.



Figure APP C.6 Annotated aerial photograph of the Swikshak Lagoon acoustic inventory site.

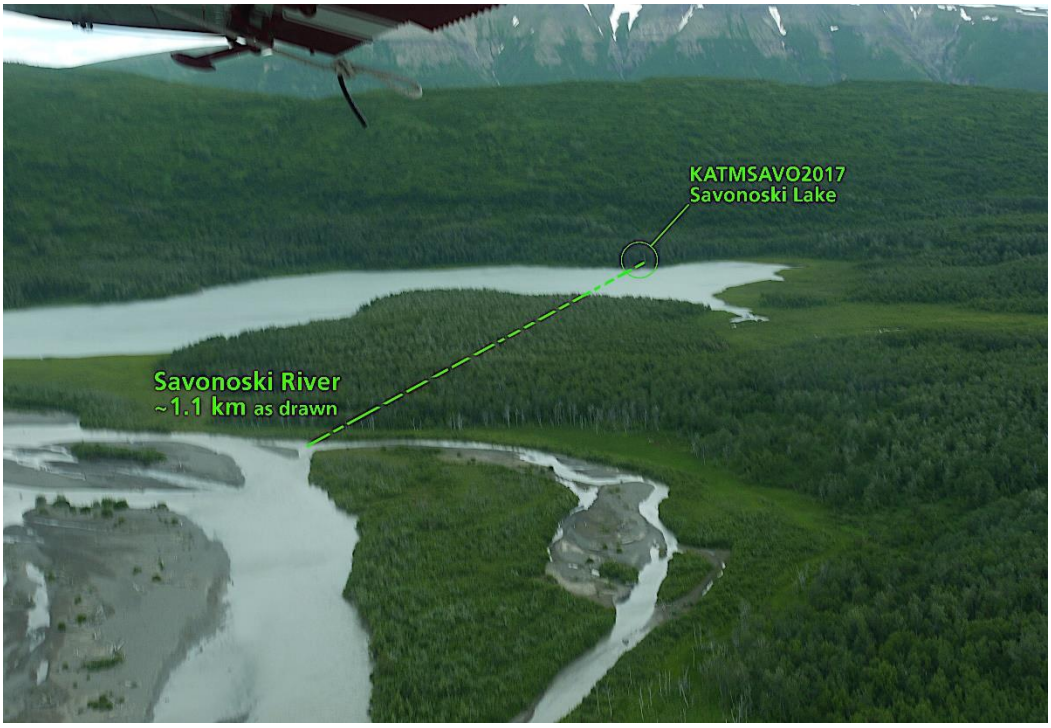


Figure APP C.7. Annotated aerial photograph of the Savonoski Lake acoustic inventory site. Photograph shows the close proximity of the lake to the Savonoski River. The annotated line represents a horizontal distance of 1.1 km northeast. Site was located in a stand of balsam poplar trees along the northern shore of the lake.



Figure APP C.8. Annotated aerial photograph of the Katmai Bay acoustic inventory site.



Figure APP C.9. View towards seabird colony on cliffs 2 km west of the Katmai Bay site. Calls were readily audible from the site location. This view also looks approximately towards the (former) Katmai Village.

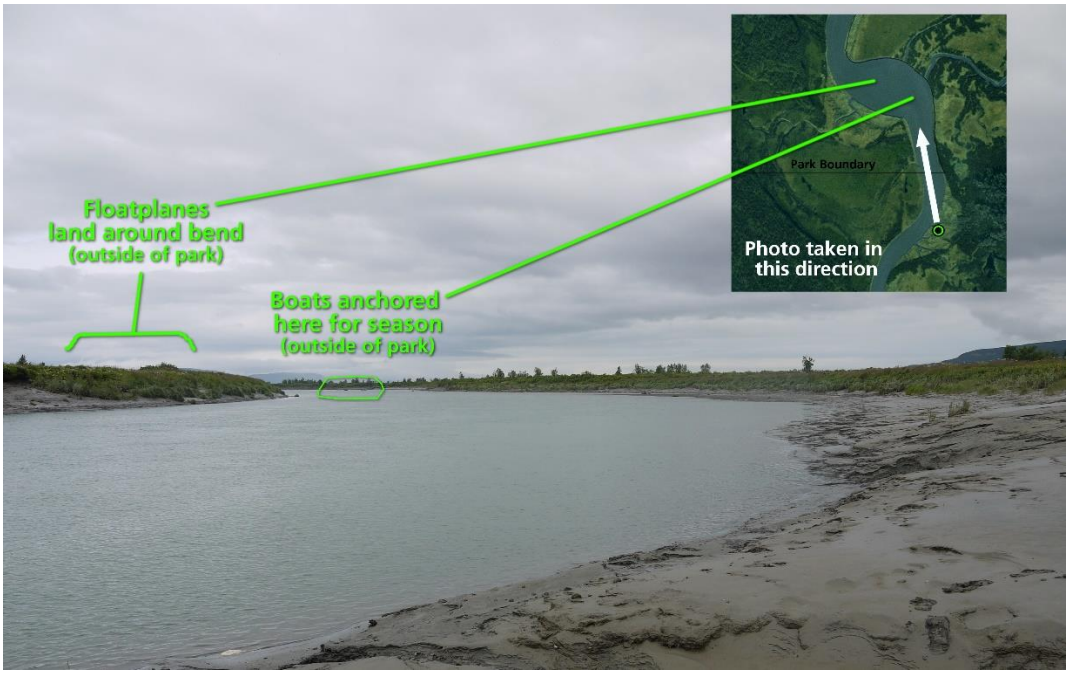


Figure APP C.10. Annotated downstream view along the banks of the Kamishak River. Photograph was taken approximately 70 meters west of the Kamishak River site. Text indicates floatplane landing area and boat anchorage, both outside of the park. Inset map shows photograph location and orientation with respect to the river and park boundary, which is 0.3 km distant.

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

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Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO