National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Acoustic Monitoring Report, Denali National Park and Preserve – 2012

Natural Resource Data Series NPS/DENA/NRDS—2013/589

ON THE COVER
A soundscape monitoring system collects data on Sushana Ridge, overlooking the Teklanika River in Denali National Park.
NPS Photo by Davyd Betchkal

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November 2013

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Data Series is intended for the timely release of basic data sets and data summaries. Care has been taken to assure accuracy of raw data values, but a thorough analysis and interpretation of the data has not been completed. Consequently, the initial analyses of data in this report are provisional and subject to change.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data. Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

This report is available from the Denali National Park and Preserve website (http://www.nps.gov/dena/naturescience/index.htm), and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/). To receive this report in a format optimized for screen readers, please email irma@nps.gov.

Please cite this publication as:

Betchkal, D. 2013. Acoustic monitoring report, Denali National Park and Preserve – 2012. Natural Resource Data Series NPS/DENA/NRDS—2013/589. National Park Service, Fort Collins, Colorado.

NPS 184/122929, November 2013

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Executive Summary

In 2012, park staff deployed acoustic monitoring systems to 11 locations in Denali National Park and Preserve. The purpose of this monitoring effort was to inventory the ambient acoustic conditions and amount of non-natural sound in Denali National Park as called for in the 2006 Backcountry Management Plan. Data collected included ANSI-certified Type 1 sound pressure levels every second and continuous MP3 audio recordings throughout the sampling period. These data serve as a permanent record of existing acoustical conditions at these locations for the summer or winter of 2012.

Table i shows summarized results of 2012 monitoring, including ambient and natural ambient sound statistics in dBA (A-weighted decibels,) average percentage of time audible, number of events per day, and the average maximum sound pressure level (SPL) for aircraft sound sources. Aircraft are specifically reported because they are the most prominent extrinsic sounds occurring in Denali's backcountry. (An extrinsic sound is defined as any sound not forming an essential part of the park purpose.) Median ambient (L_{50}) describes the acoustical environment as measured, including both natural and extrinsic sounds. Natural ambient (L_{nat}) estimates what the acoustical environment would be without the contribution of extrinsic sounds. Table i also shows exceedence metrics L_{10} and L_{90}, which mark the 90^{th} and 10^{th} percentiles of sound pressure level, respectively.

When interpreting sound pressure level data, it should be noted that the decibel scale is logarithmic. As such, a six decibel increase in sound pressure level is a doubling of sound energy.

Table i. Ambient acoustic metrics and median aircraft statistics for 2012 sites*.

Site Name	L10	Lnat	L50	L90	% Time Audible, Aircraft	# Aircraft/Day	Aircraft Max SPL
Bison Gulch [1]	27.27	**	21.61	19.36	**	**	**
Bull River	44.76	43.56	43.61	42.71	1.9	15.6	53.75
Cathedral Mountain	27.76	24.61	24.67	24.61	5.2	22.5	44.54
Dunkle Hills [1]	22.99	15.64	16.06	14.64	5.5	18.2	32.93
Hines Creek [1]	22.43	16.52	16.73	15.58	6.9	23.3	34.99
Kichatna Mountains	46.76	44.61	44.61	43.36	1.7	8.5	51.68
McKinley River	21.49	18.70	18.76	17.70	2.3	5.8	31.25
Sushana Ridge	30.47	23.41	23.63	19.97	3.5	13.5	46.28
Toe of the Kanikula Glacier	43.06	40.91	41.00	39.83	9.3	26.3	51.37
Upper West Branch Toklat	40.74	38.09	38.16	36.12	3.8	19.9	50.04
Upper Yentna Glacier	27.70	25.11	25.17	23.26	1.3	5.3	31.88

*L_{nat}, L_{10}, L_{50}, L_{90}, and SPL in A-weighted decibels.

[1] : Winter season site.

**Because the purpose of the Bison Gulch monitoring station was to collect baseline data prior to restart of the Healy Unit 2 power plant, conventional analyses were not conducted for this site.

A twelfth site was attempted near the headwaters of Carlson Creek south of McGonagall Mountain. Due to a problem with the wiring polarity of the solar panel, the station's batteries failed after about two days of use. Two days of data do not cover the range of variability in acoustic conditions at this location, which are influenced by wind, cloud cover, flight schedules, et cetera. For that reason, the decision was made to drop this small dataset from subsequent analyses and redeploy the station in 2013.

Patterns of anthropogenic noise at successful locations were readily apparent upon analysis, typifying each particular soundscape. The highest rates of air traffic were measured at the Toe of the Kanikula – which detected 26 events on a typical day. By contrast, the site at Upper Yentna Glacier which was 40 km north-west and distant from flight paths between Mt. McKinley and Talkeetna, detected 5 events per day. This relatively-intact condition of solitude is shared by most nearby monitoring locations in the west-central portion of the park. (For detailed information on this especially intact soundscape, see Withers 2010, Withers 2012, Withers and Betchkal 2013, and Betchkal 2013. Of interest are the Highpower Creek, Herron Glacier, Herron River, North Vertical Access Benchmark, and Upper Dall Glacier, and Upper Yentna Glacier monitoring locations.)

Two additional sites, Cathedral Mountain and Upper West Branch Toklat, were resampled in 2012 – revisiting soundscapes originally sampled in 2007 and 2009. The sites were specifically chosen to assess the effect of a new aviation best practice suggested by the Denali Aircraft Overflights Advisory Committee during the spring of 2012. Data from Upper West Branch Toklat quantified changes in soundscape condition close to the spine of the Alaska Range – away from which traffic was asked to move - and Cathedral Mountain assessed whether the same traffic displacement caused conditions to degrade along the road corridor. Overall, little effect from the best practice was observed along the spine of the range. However, events were about 4 decibels quieter on average, suggesting that operators may have flown considerably higher than in previous years. Similarly, little change was noticed along the road corridor. Table ii compares results from the four data sets:

Table ii. Monitoring effects of the spring-2012 Denali Aircraft Overflights Advisory Committee Voluntary Best Practice. Shaded columns indicate Denali Backcountry Management Plan Standards.

Site Name	Lnat	% Time Audible, Aircraft	% Time Audible, Vehicles	% Time Standard	Events Standard	SPL Standard
Cathedral Mountain, 2007	39.30	3.6%	3.7%	32%	100%	100%
Cathedral Mountain, 2012	24.61	5.2%	15.4%	37%	80%	66%
Upper West Branch Toklat, 2009	32.77	3.7%	-	28%	100%	89%
Upper West Branch Toklat, 2012	38.09	3.8%	-	26%	83%	68%

*L_{nat} in A-weighted decibels.

During the winter months, records from the Hines Creek sampling location were collected to inform an environmental assessment related to plowing the park road to Savage Overlook. Data from the station predicted that noise could be audible for up to 8 miles from the road. A second winter site at Bison Gulch collected baseline data from which to compare conditions upon the restart of the Healy Unit 2 coal-fired power plant, scheduled for 2015.

Acknowledgments

Everyone knows that nature abhors a vacuum. Perhaps that is why operations in the National Park Service require a strong team effort. The seventh season of Denali's Soundscape Inventory was certainly no exception.

Many of the difficulties with soundscape fieldwork are related to moving heavy, awkward, or fragile components over the landscape. Despite that, 2012 was a record year for non-motorized access. I'd like to thank Kristin Knight-Pace and her Backcountry Ranger staff – John Brueck, Christina Thompson, Chris Dunn, Diana Liles, and Sam Hooper - for their major effort in the installation, maintenance, and removal of the Bull River, Upper West Branch of the Toklat River, and Carlson Creek stations. Sarah Hayes, Jennifer Johnston, Bennie Johnson, Mariah Richards, Joe Flower, Henry Ring, Mark Paulson, Andrew Ackerman, Jon Fish, Jenny Yaeger-Fish, Nancy Bale, Claire Pywell, Chris Baur, Rob Burrows, Kim Arthur, and participants of the 'Composing in the Wilderness' seminar all helped move or maintain sound stations on foot. (That's a total of *33* individuals who assisted with non-motorized transport!)

Gilbert Garcia, Forrest Ford, Joe Riechert, Chris Kim, Andy Hermansky, Jan Bennett (AMD) and Chris Ramsey (Pollux Aviation) were invaluable for their assistance in the air. Thanks to Jennifer Raffaeli and Sarah Hayes of the Denali Kennels and Rangers Jeff Duckett, Ralph Anderson, and Sharon Olsen for their assistance with the winter stations at Hines Creek and Dunkle Hills.

I received technical assistance from the Natural Sounds and Night Skies Division office many times during the year, especially from Dr. Kurt Fristrup, Damon Joyce and Emma Lynch. I also received technical insights from Jon Paynter, who was always ready to teach GIS wizardry. Tom Meier made pertinent suggestions towards the design of a new solar panel system.

Patient, insightful and thorough critiques of plans, analysis technique, and data graphics came throughout the season from Dave Schirokauer, Bennie Johnson, Andrew Ackerman, Andrea Blakesley, Pete Webster, Rob Burrows, Dan Abbe, Denny Capps, and Kristin Knight-Pace.

Introduction

Natural sound is both a resource in its own right as well as an important quality of the Denali Wilderness. Therefore, the widespread influence of motorized noise on visitor experience is a key concern of park management. Denali's Backcountry Management Plan (BCMP), finalized in 2006, established indicators and standards for the natural sound environment and called for monitoring to evaluate whether the standards are being satisfied. Soundscape measurements are objective and employ monitoring methods easily reviewed by the public, which will provide strong support for future management decisions. Without these data, the park will have little information to make management guidelines or support management decisions that may affect the quality of Denali's soundscape.

The initial push for Denali to begin soundscape inventories began with Director's Order 47 (DO-47; NPS 2000). Robert Stanton issued the order in 2000 directing 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).

The primary purpose behind the Denali soundscape inventory has been to measure the level of influence motorized noise has on the park's natural soundscape and wilderness character. This involves not only careful attention to noise sources, but thorough documentation of all the sounds that characterize a given landscape. Only by understanding the natural context within which acoustic intrusions occur can Denali assess the effects of noise – both on the wildlife of the park and the experience of wilderness. It is the aim of this research to provide a baseline from which such effects can be monitored successfully.

Soundscape Planning Authorities

The National Park Service (NPS) Organic Act of 1916 states that the purpose of national parks is "… to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." (NPS 1916) In addition to the NPS Organic Act, the Redwoods Act of 1978 affirmed that, "the protection, management, and administration of these areas shall be conducted in light of the high value and integrity of the National Park System and shall not be exercised in derogation of the values and purposes for which these various areas have been established, except as may have been or shall be directly and specifically provided by Congress." (NPS 1978)

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

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

It should be noted that the Management Policy 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).

Sampling Plan

Denali's soundscape sampling plan was designed from the Long Term Ecological Monitoring (LTEM) grid (NPS 2006c). The number of points sampled in the coarse grid is driven by the number of acoustic monitoring stations available (six were available in 2012), and the length of time each station should be established at each location. To properly characterize the natural soundscape, stations should be established such that at least one month of continuous data is collected at each site during the field/tourist season (Ambrose and Burson 2004). Six sites are deployed on the LTEM sampling grid each year, with 60 grid points to be sampled overall (Figure 1). Two additional stations are available to allow park managers to collect data at sites of specific interest which may not fall on a grid point. In addition, opportunistic sampling may be attempted during the winter months as permitted by funding, personnel, and ease of access to provide some indication of acoustic conditions outside the field/tourist season and to determine winter use patterns.

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[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.

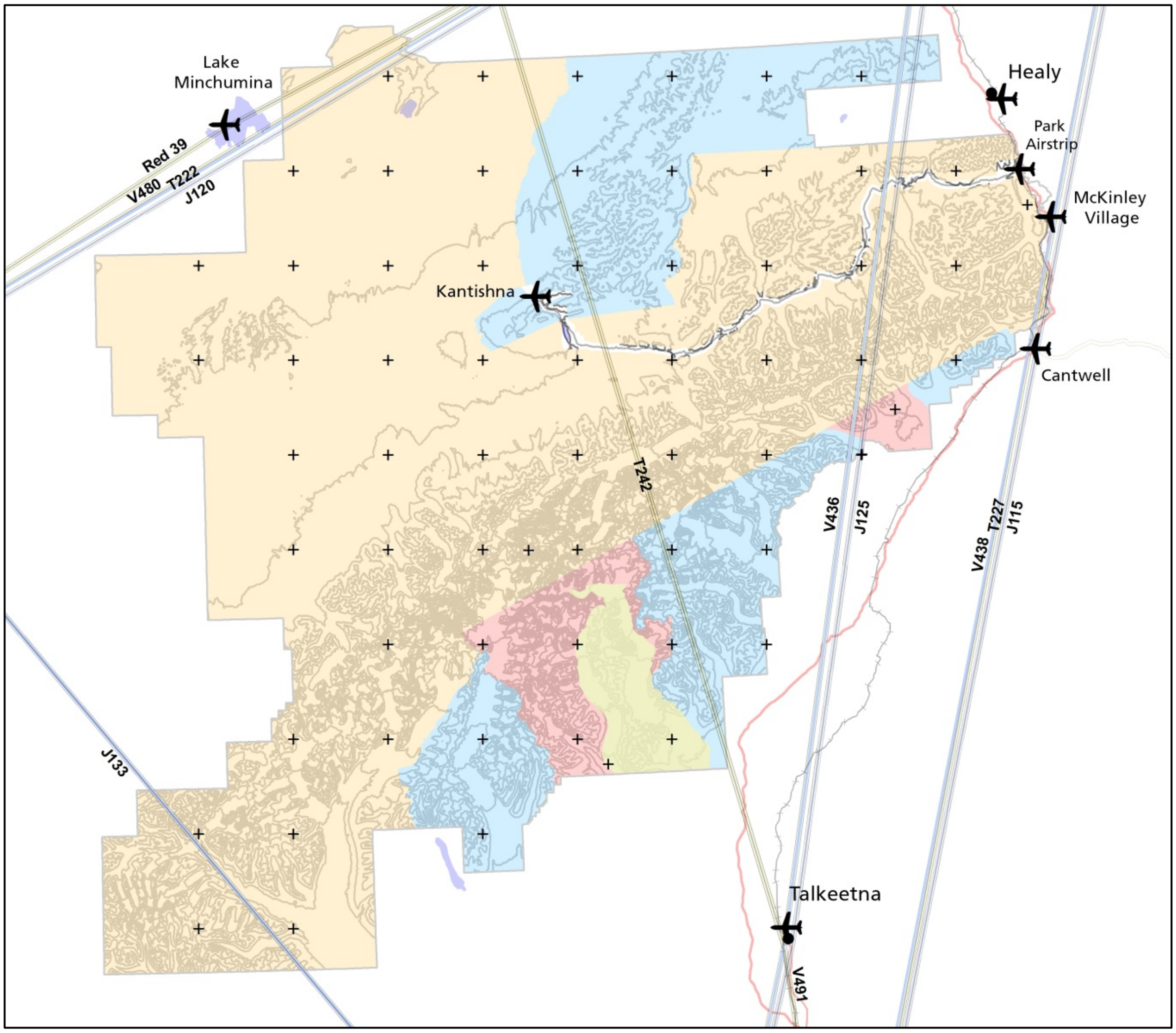


Figure 1. Map showing the Long Term Ecological Monitoring grid of 60 points to be sampled. As a frame of reference, major transportation features are indicated as well. FAA flight routes are indicated as blue and yellow lines, along with their alpha-numeric code. The main airports of the area are shown as black aircraft symbols.

Study Area

Park staff deployed acoustic monitoring systems to eleven locations in Denali National Park in 2012, as shown in Table 1 and Figure 2.

Table 1. Sites sampled in 2012.

Site Location	Elevation (meters)	Latitude	Longitude	Sampling Period*
Bison Gulch [1]	1028	63.79981	-148.98702	Feb-24 to Apr-11
Bull River	1081	63.39192	-149.62902	Jul-14 to Aug-11
Cathedral Mountain	1162	63.57477	-149.61148	Jul-23 to Sept-08
Dunkle Hills [1]	828	63.26703	-149.54225	Feb-02 to Apr-15
Hines Creek [1]	861	63.71061	-149.07915	Nov-28 to Mar-23
Kichatna Mountains	637	62.34868	-152.44975	May-19 to Jun-18
McKinley River	276	63.61935	-151.63177	Jul-20 to Sept-11
Sushana Ridge	1211	63.74123	-149.58362	May-14 to Jul-04
Toe of the Kanikula Glacier	352	62.70562	-150.91173	May-19 to Jul-09
Upper West Branch of the Toklat	1215	63.40903	-150.03513	Jul-28 to Sept-13
Upper Yentna Glacier	1575	62.88545	-151.64183	May-19 to Jun-18

[1] Winter season site.

*One month of continuous data is the sampling goal, but some sites do not achieve this goal due to equipment failure, animal tampering, insufficient solar radiation, or access scheduling. If a full month of data was not collected, an acoustic profile is compiled using the available data.

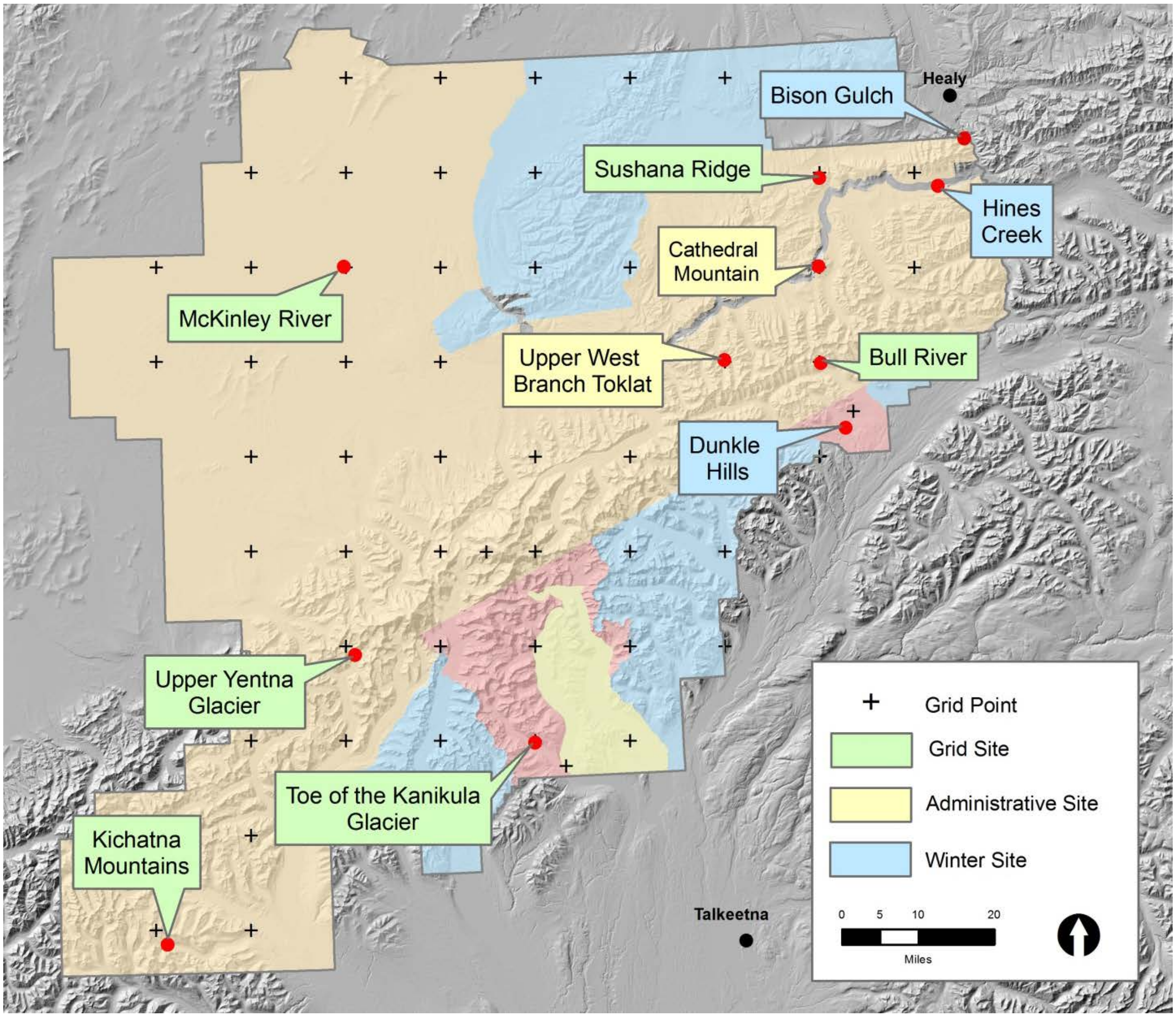


Figure 2. Acoustic monitoring sites in Denali National Park, 2012.

Methods

Automated Monitoring

The Larson Davis 831 sound level meter (SLM) is a hardware-based, real-time analyzer which constantly records one second sound pressure level (SPL) and 1/3 octave band data, and exports these data to a USB storage device. These Larson Davis-based sites met American National Standards Institute (ANSI) Type 1 standards (ANSI 1968, 1992). To supplement the SPL data, Roland R-05 field recorders capture 64kpbs mp3 recordings via the Larson Davis 831 audio output.

Each Larson Davis sampling station consists of:

- Microphone with environmental shroud and Rycote windscreen
- Preamplifier
- Roland R05 mp3 recorder
- Solar panel and batteries
- Anemometer/Wind Vane/Temperature and Relative Humidity Probe

Each station collected:

- SPL data in the form of A-weighted decibel readings (dBA) every second
- 1/3 octave band data every second ranging from 12.5 Hz – 20,000 Hz
- Continuous 64 kilobit-per-second digital audio recordings

Visual Analysis

For each monitoring site, staff visually analyzed collected SPL samples in order to identify the frequency and durations of mechanized sound sources. See Appendix C for further information on visual analysis. Hourly time audible statistics are then used to calculate natural ambient sound level estimates (see Calculation of Metrics below).

Audibility Analysis

For each monitoring site, staff analyzed a subset of the audio record— the first five seconds of every five minute interval of the day, starting at 00:00. The purpose of the analyses was to identify natural and quiet sound sources which are difficult to reliably identify though visual analysis. Listening headphones are calibrated with a 94 dB, 1000 Hz tone which was recorded at the time of data collection. This approximates a playback volume similar to what would be heard if the observer were actually listening at the sample site. This audibility data results in an estimate of total percent time audible and makeup of the natural and anthropogenic components of the soundscape.

Calculation of Metrics

Several metrics are calculated in order to provide some detail about the characteristics of the acoustical environment. The current status of the acoustical environment can be characterized by a number of measurements. These include sound pressure levels for each 1/3 octave band from 12.5 Hz to 20,000 Hz, overall broad-band sound pressure levels, and percent time audible durations for various sound sources. Two fundamental descriptors of the acoustic environment are existing ambient and natural ambient sound levels which are presented as exceedence levels (L_x). Equivalent to percentiles, exceedence levels represent the dBA exceeded x percent of the time during the given measurement period. For example, measured in dBA, the existing ambient (L_{50}) is the sound level exceeded 50% of the time, or median sound level. It is the uncensored composite of all sounds at a site, both human caused and natural. The natural ambient (L_{nat}) estimates the acoustic environment without the contribution of anthropogenic sounds. L_{10} and L_{90} are also presented which describe the sound levels exceeded 10% and 90% of the time, respectively.

The differences between L_{50} and L_{nat} values allow NPS to answer the following questions:

1. What are the listening opportunities in the absence of human development and activities?
2. How are these listening opportunities compromised by increased sound levels due to extrinsic noise?

To calculate L_{nat}, the following method is utilized:

- NPS staff calculates the percentage, P_H, of all samples containing extrinsic sounds for each hour of the day both by listening to samples, or visually analyzing daily spectrograms.
- P_H is used to complete this formula for every hour in the dataset: $x = \frac{1 - P_H}{2} + P_H$
- 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.
- L_{nat} is computed as the sound level that is exceeded 100*x_H percent of the time.
- (In practice, L_{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, and the results of this calculation have produced consistent results at most backcountry sites analyzed by the NPS Natural Sounds Program (Lynch et al. 2011).

Results

The following tables are summaries of the 2012 data. Presented are the existing and natural ambient sound statistics in A-weighted decibels, average percentage of time audible, number of events per day, and maximum sound pressure level for aircraft (in Table 2) and other motorized sound sources (in Table 3). The 24-hour average noise-free interval describes the typical amount of time between motorized events throughout the entire day. The median existing ambient level (L_{50}) describes the acoustic environment as it is directly observed, including both natural and extrinsic sounds. Natural ambient (L_{nat}) estimates the magnitude of acoustic energy at the location without the contribution of extrinsic sounds. This table also shows exceedence metrics L_{10} and L_{90}, which mark the 90^{th} and 10^{th} percentiles of sound pressure level, respectively.

When interpreting sound pressure level (SPL) data, it should be noted that the decibel scale is logarithmic. As such, a six decibel increase in sound pressure level is 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 mean aircraft statistics for all sites.

Site Name	L10*	Lnat*	L50*	L90*	Avg. Noise Free Interval*	% Time Audible, Aircraft	# Aircraft/ Day	Aircraft Max SPL*
Bison Gulch [1]	27.27	**	21.62	19.36	**	**	**	**
Bull River	44.76	43.56	43.61	42.71	1.51	1.9	15.6	53.75
Cathedral Mountain	27.76	24.61	24.67	24.61	1.02	5.2	22.5	44.54
Dunkle Hills [1]	22.99	15.64	16.06	14.64	1.51	5.5	18.2	32.93
Hines Creek [1]	22.43	16.52	16.73	15.58	0.99	6.9	23.3	34.99
Kichatna Mountains	46.76	44.61	44.61	43.36	2.78	1.7	8.5	51.68
McKinley River	21.49	18.70	18.76	17.70	4.21	2.3	5.8	31.25
Sushana Ridge	30.47	23.41	23.63	19.97	1.79	3.5	13.5	46.28
Toe of the Kanikula Glacier	43.06	40.91	41.00	39.83	0.74	9.3	26.3	51.37
Upper West Branch Toklat	40.74	38.09	38.16	36.12	1.20	3.8	19.9	50.04
Upper Yentna Glacier	27.70	25.11	25.17	23.26	4.62	1.3	5.3	31.88

*L_{nat}, L_{10}, L_{50}, L_{90}, and SPL in dBA. Noise-Free Interval in hours. [1] : Winter season site.

** Because the purpose of the Bison Gulch monitoring station was to collect baseline data concerning the Healy Unit 2 power plant, conventional analyses were not conducted for this site.

Table 3. Mean BCMP statistics* for vehicles at all sites.

Site Name	Vehicle Type	% Time Audible, Vehicles	# Vehicles/ Day	Vehicle Max SPL
Cathedral Mountain	Buses, Trucks	3.7	10.5	25.42
Dunkle Hills 1	Snowmachines	2.0	4.6	30.48
Hines Creek 1	Maintainance Equipment and Highway Traffic	2.9	5.2	22.55

*SPL in dBA. [1] : Winter season site.

A twelfth site was attempted near the headwaters of Carlson Creek south of McGonagall Mountain. Due to a problem with the polarity of the solar panel, the station's batteries failed after about two days of use. Two days of data do not cover the range of variability in acoustic conditions likely experienced at this location, which are influenced by wind, cloud cover, flight schedules, etc. For that reason, the decision was made to drop this small dataset from subsequent analyses and redeploy the station in 2013.

The following summaries and figures represent the reduced data for each of the 2012 sites. These include percent audibility for natural sounds and mechanized noise, temporal audibility of sources, hourly natural ambient and exceedence sound levels, and figures which speak directly to the soundscape indicators and standards outlined in Denali's Backcountry Management Plan: percentage of time audible, number of events per day, and maximum sound pressure level (NPS 2006c).

Bison Gulch

Location Description: On the Healy Ridge, approximately 1.5 – 2.5 km west of the Parks Highway and approximately 6-7 km from the Healy Unit 2 power plant.

Purpose/Project: This station collected baseline data with which to understand the natural ambient sound pressure level in the area, allowing management to monitor the type of sound energy radiated into the park by the Healy Unit 2 coal plant during operating conditions.

Coordinates: 63.799813°, -148.987017 ° (WGS84)

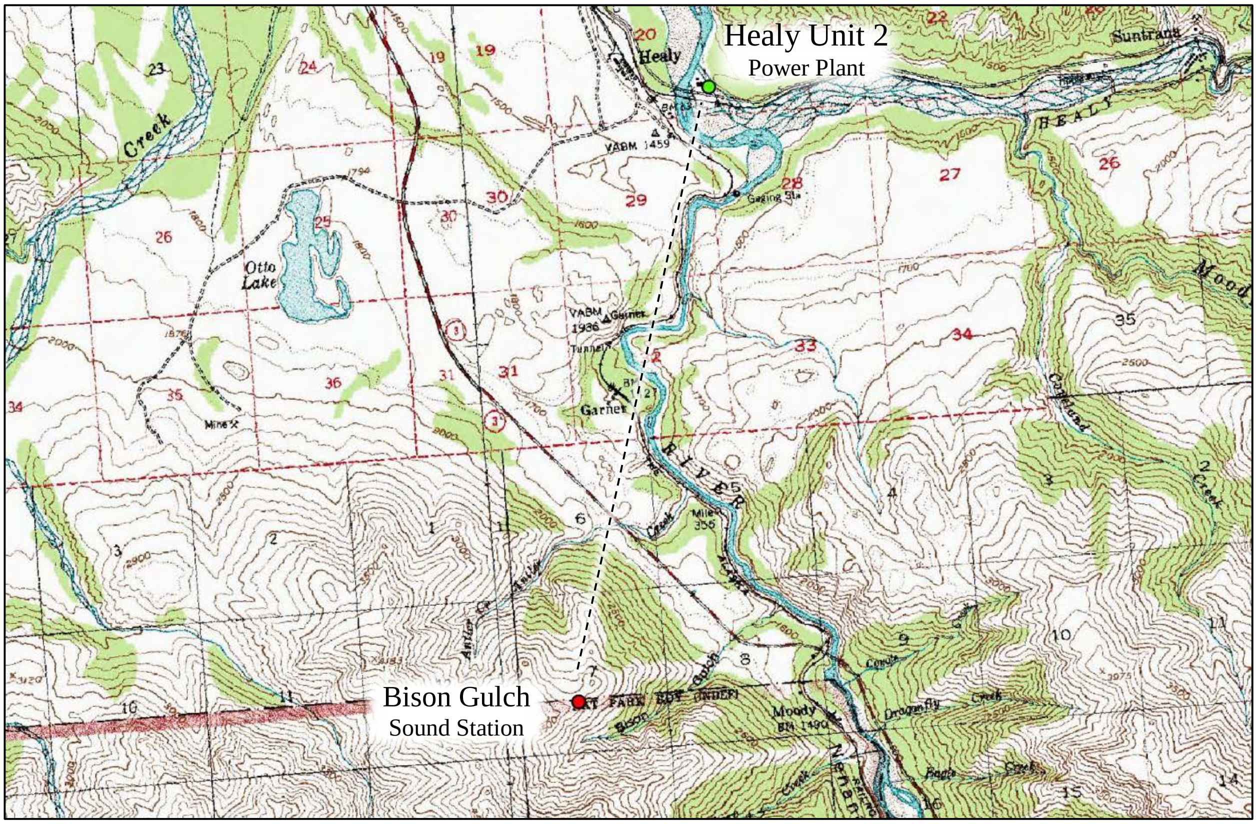
Elevation: 1028 meters

BCMP Management Area: OP1 (Low Natural Sound Disturbance)

Park Ecoregion: Alaska Range Front Range

Sampling Period: 24-February-2012 to 11-April-2012

Access: Foot



Summary/Notes: The purpose of the Bison Gulch sampling location was to collect baseline data that describe current ambient sound pressure conditions in the area. These levels can subsequently be used to compare soundscape conditions when the Healy Unit 2 power plant restarts (Figure 3). This need arises directly from Director's Order 47 which asks parks to '*determine the nature and level of impacts*' to the soundscape, as well as assess '*the appropriate and inappropriate sources of noise*'. Moreover, an understanding of permanent, fixed-location sound sources would be a novel study towards the interpretation of soundscape standards in the Backcountry Management Plan.

The specific noise of concern is created by the motion of an induced draft boiler fan and radiated from the smoke stack of the facility. During the original period of operation for the plant, a 1998 study by Mullins Acoustics determined the fan to have a blade passage frequency of 159 Hz and a first harmonic frequency of 318 Hz. Therefore the 160 and 315 Hz 1/3rd octave bands are of most importance to monitor (Mullins 1998).

Because of its unique purpose, conventional analyses were not conducted for this site. Instead, two graphics (Figure 4 and Figure 5) detailing the acoustic ambience have been included in this report for future reference and comparison.

Figure 3. A line of sight photograph from the Bison Gulch station north-east towards the Healy Unit 2 Power Plant, with a circle indicating the location of the sound source. Also indicated is the proximity of the station to the George Parks Highway.

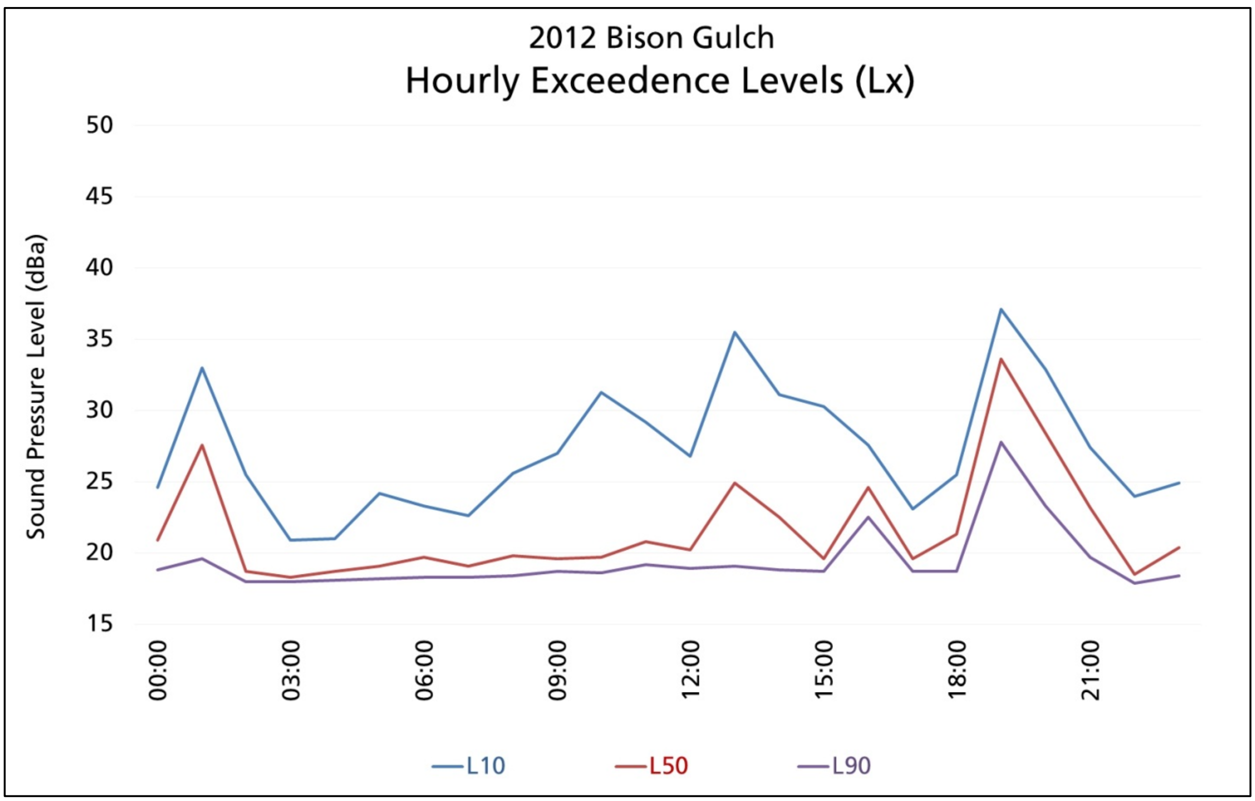


Figure 4. Exceedence levels for Bison Gulch.

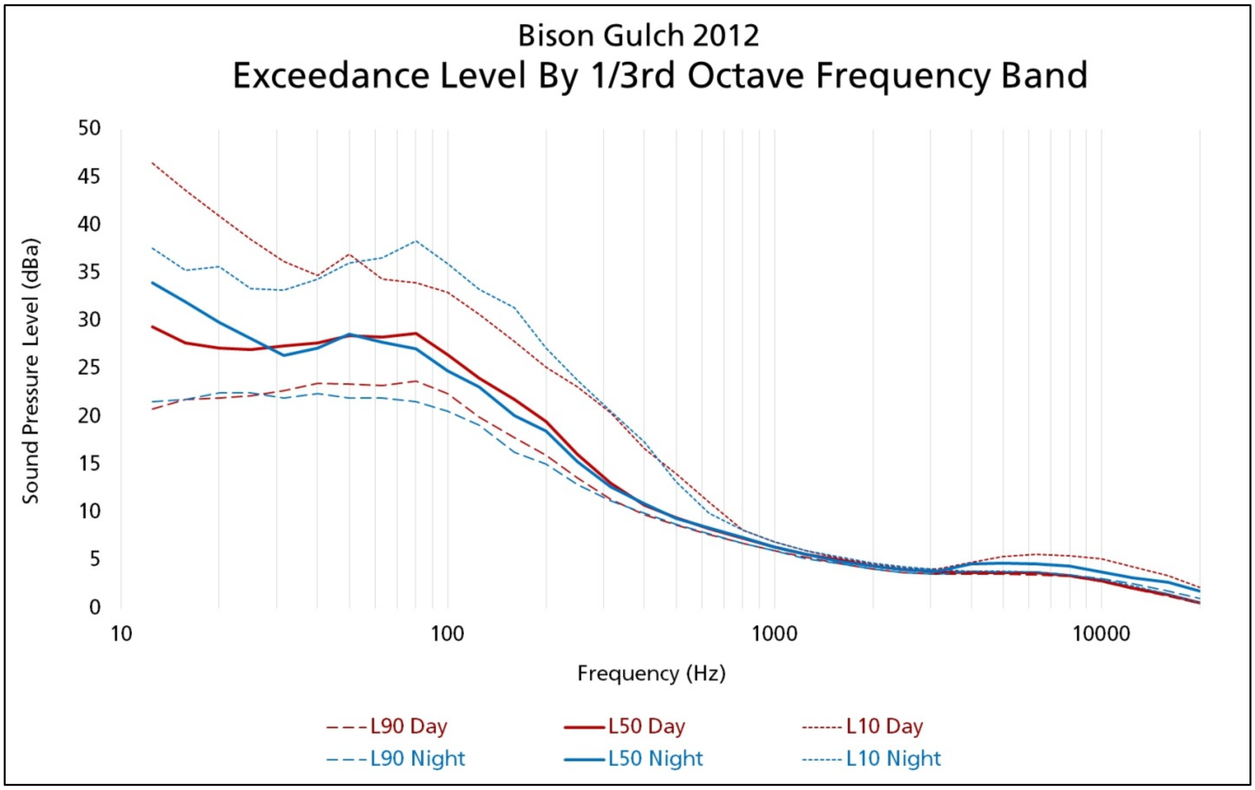


Figure 5. Exceedance Level by 1/3rd Octave Frequency Band at Bison Gulch.

Bull River

Location Description: On a tundra bench above the western 'horn' of the Bull River, adjacent to Easy Pass.

Purpose/Project: Location randomly chosen from the LTEM grid as part of the long-term Denali Soundscape inventorying and monitoring sampling plan.

Coordinates: 63.39192°, -149.62902° (WGS84)

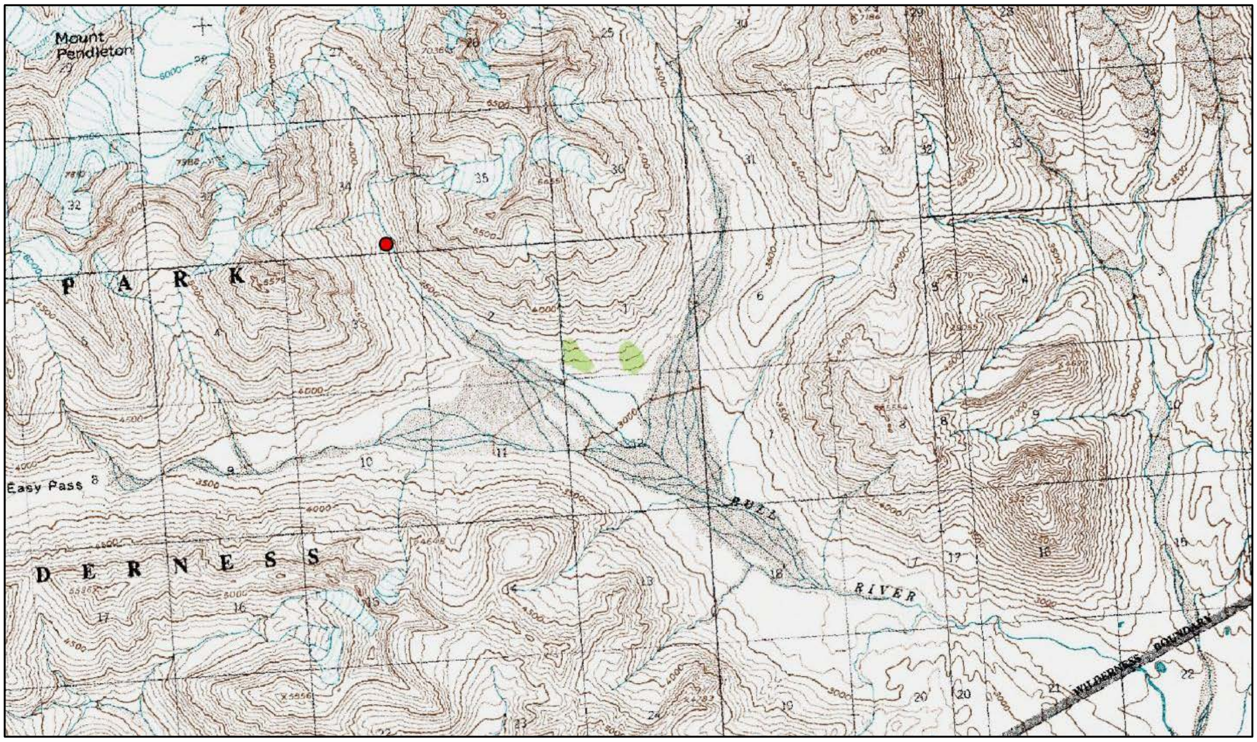
Elevation: 1081 meters

Sampling Period: 14-July-2012 to 11-August-2012

BCMP Management Area: OP1 (Low Natural Sound Disturbance)

Park Ecoregion: Alaska Range South Central Mountains

Access: Foot

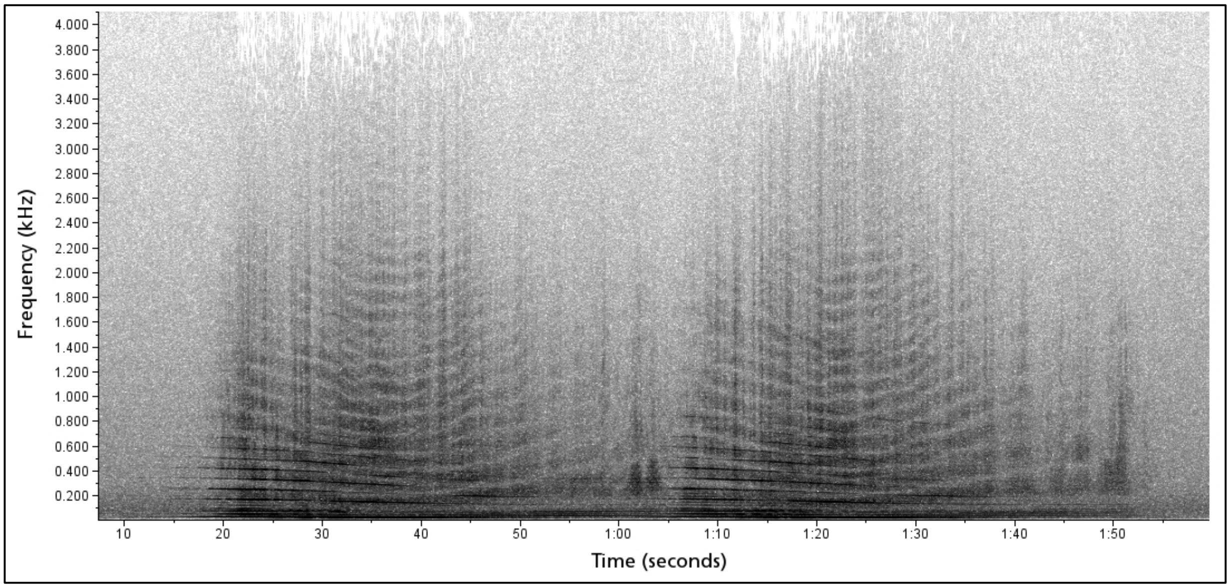


Summary: The purpose of the Bull River location was to collect data at one of the long-term ecological monitoring (LTEM) grid points, as outlined in the above sampling plan. LTEM grid point #136 was located in congressionally-designated Denali Wilderness (former Mt. McKinley National Park.) The monitoring location was accessible by foot from the Dunkle Mine road.

The tumultuous headwaters of the Bull River dissipate powerful, broadband acoustic energy. At 43.56 dBA, Bull River had the 5th loudest time-averaged natural ambient level of any site sampled in the park (Figure 6; In other words, it was in the 92nd percentile of sites parkwide.) Overall, the audio impression within the influence of the river was time-invariant and austere; a steady record of earth-shaping force. Over this energy it was sometimes even difficult to distinguish wind or rain.

Animals were not commonly observed on the audio record at this location (Figure 9). This was probably due to several factors. First, the masking influence of the water, limiting the distance over which sounds could be detected (Figure 7 and Figure 8). Second, the sampling period started just after the main pulse of bird song in Denali, which tapers out in early July. Collared pika (*Ochotona collaris*) were detected at the site, but infrequently. It is still interesting to note their presence, as they were also observed at several other locations in 2012— Cathedral Mountain, Toe of the Kanikula Glacier, and on the Upper West Branch of the Toklat River.

During station setup (between 16:00 and 17:15 on 07/14/2013) two ERA helicopters were observed flying west-bound towards Easy Pass. From subsequent spectrogram analysis it became apparent that pairs of helicopter overflights were common during the 09:00 and 16:00 hours. Inflated audibility and event counts spread generally around these times; a pattern clearly visible in Figure 10 and Figure 13.



Spectrogram 1. A pair of ASTAR 350 B2 helicopters pass the Bull River sound station. Maximum sound pressure level measured for the events was 64.9 and 51.6 dBA, sequentially. The spectrogram begins at 16:30:42 on 07/19/2012.

The most commonly heard sounds at this site were water (audible 100.0% of the time), wind (27.1%), and rain (2.6%). Human made sound was audible 1.9% of the time on average. This is equivalent to 27.4 minutes each day, or approximately 8 overflights a day. Conditions exceeded the BCMP percent audible standard 17% of the time, number of events per day 82% of the time, and maximum SPL 100% of the time.

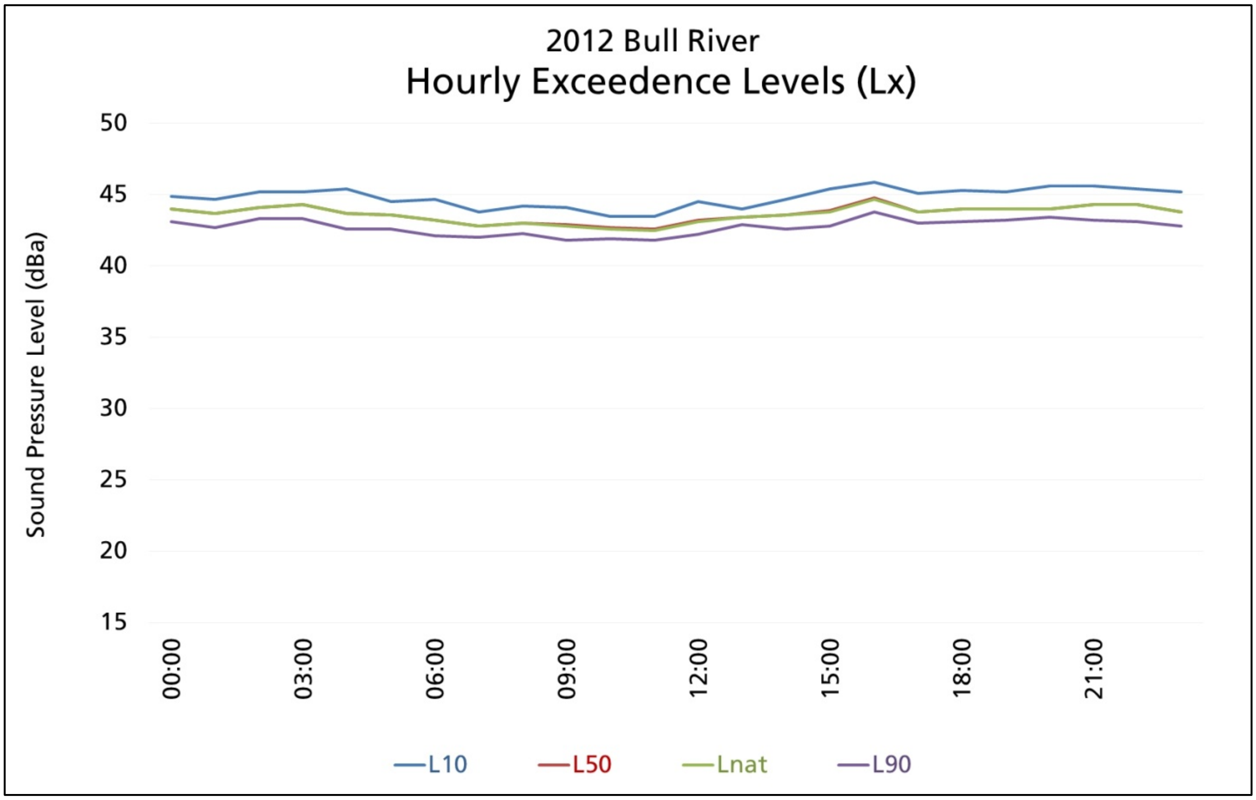


Figure 6. Exceedence levels for Bull River.

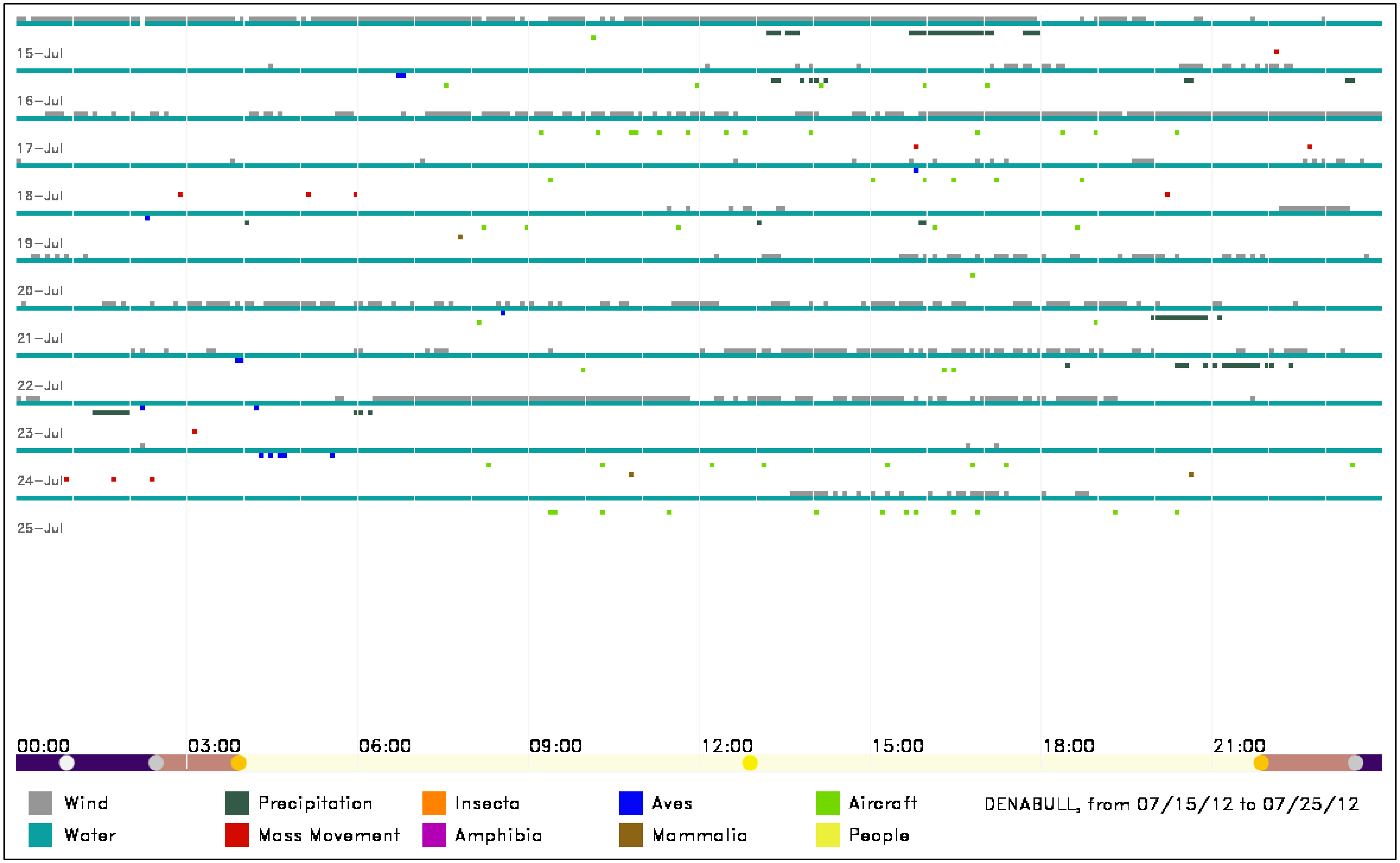


Figure 7. Temporal audibility of sound sources at Bull River, based on five seconds of audio every five minutes. The bar along the time axis indicates the average light conditions during the sampling period. The orange circles are sunrise/sunset, and the gray circles are the beginning and end of civil twilight.

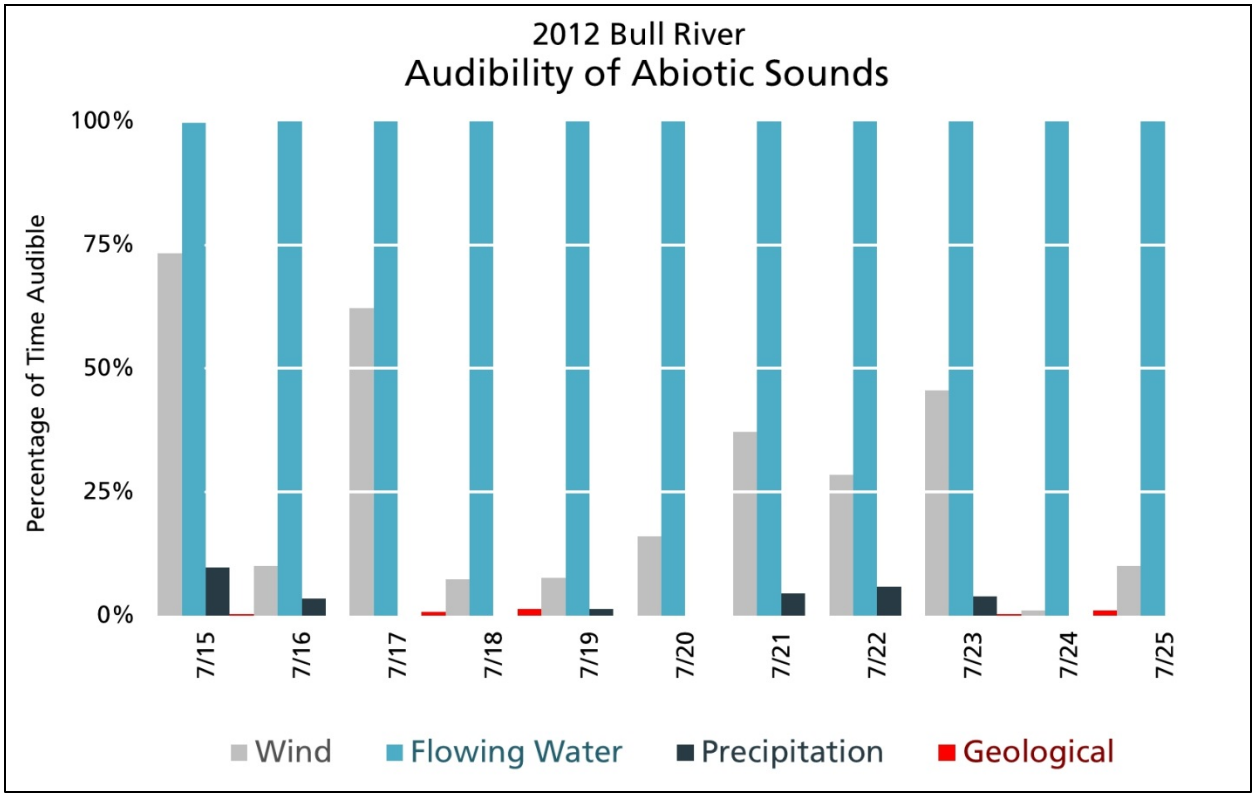


Figure 8. Audibility of abiotic sounds at Bull River.

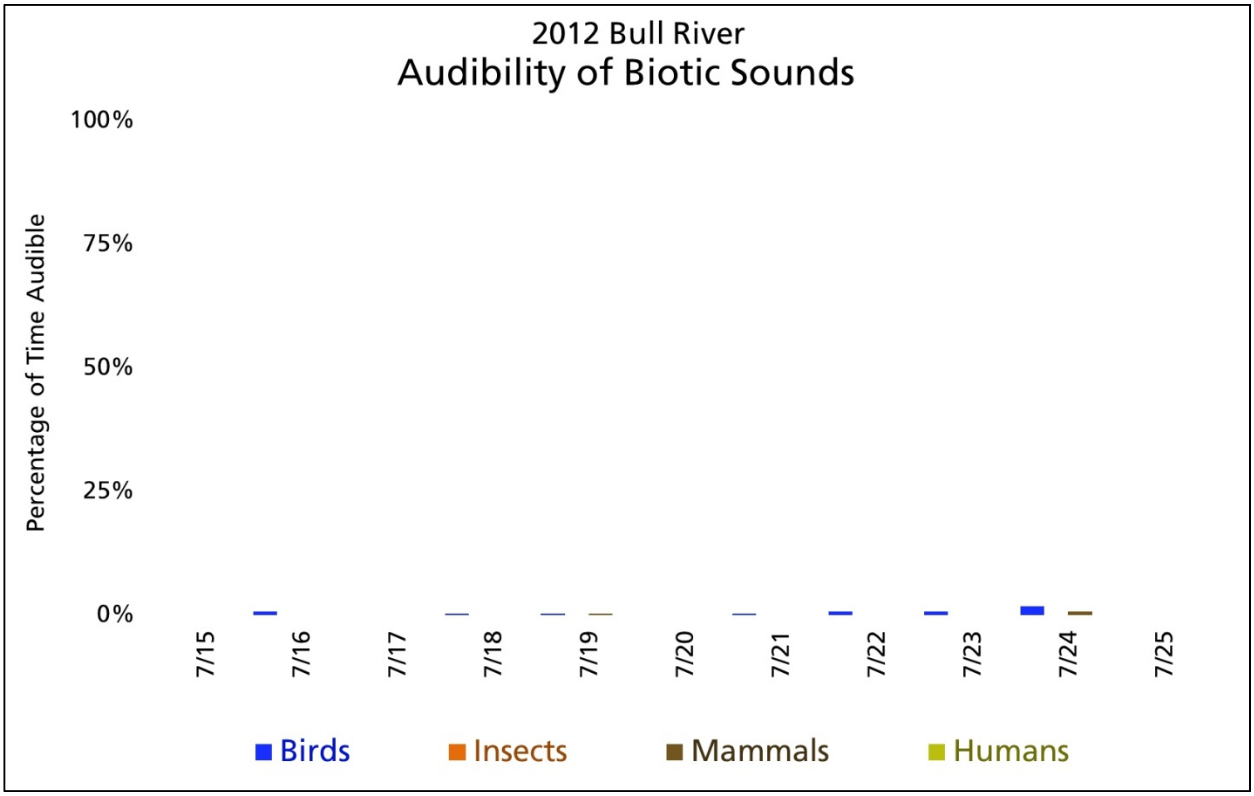


Figure 9. Audibility of biotic sounds at Bull River.

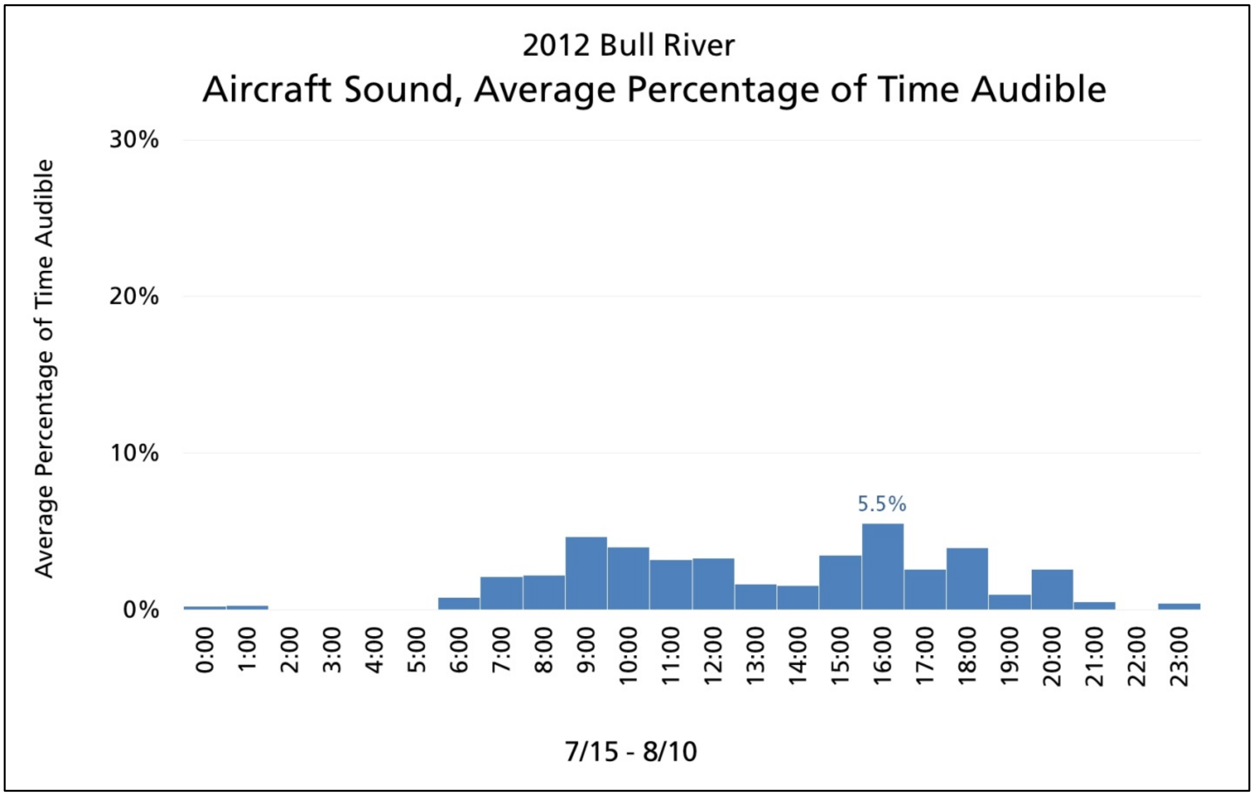


Figure 10. Audibility of aircraft noise for an average day, by hour, at Bull River.

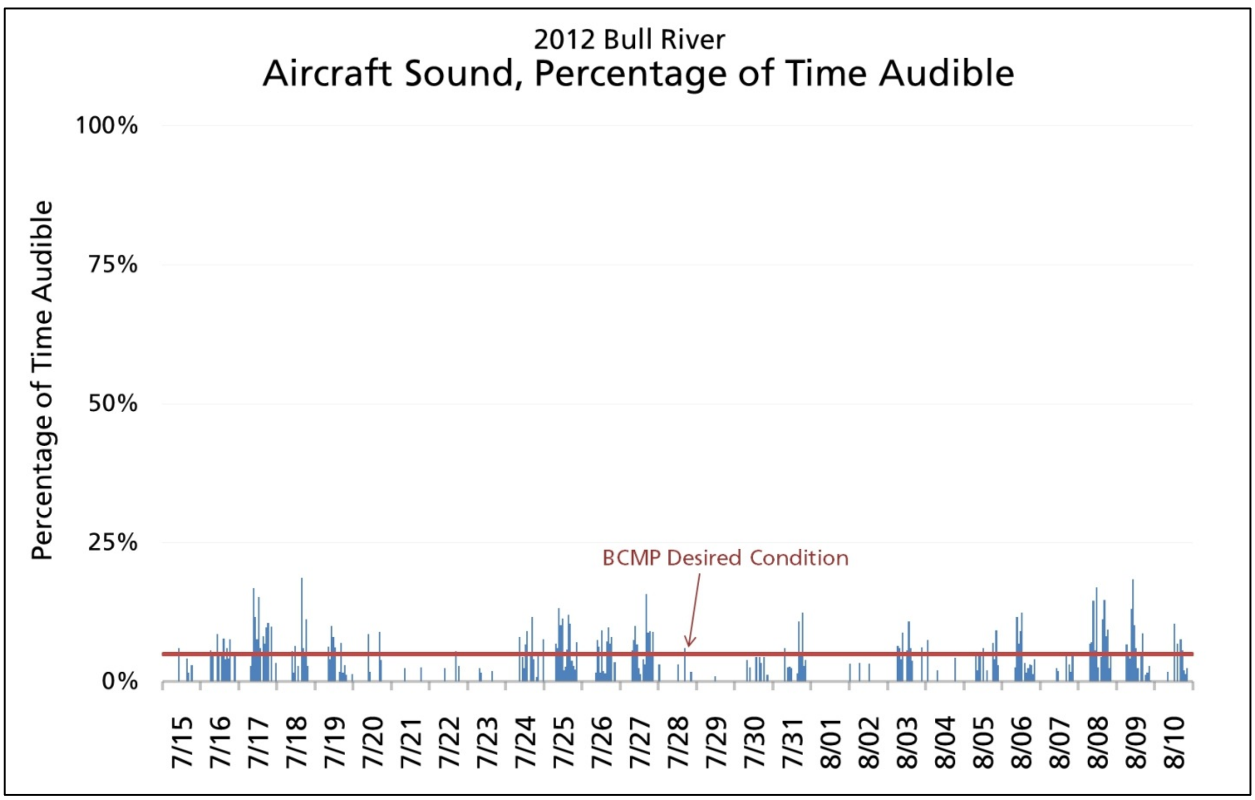


Figure 11. Audibility of aircraft noise at Bull River.

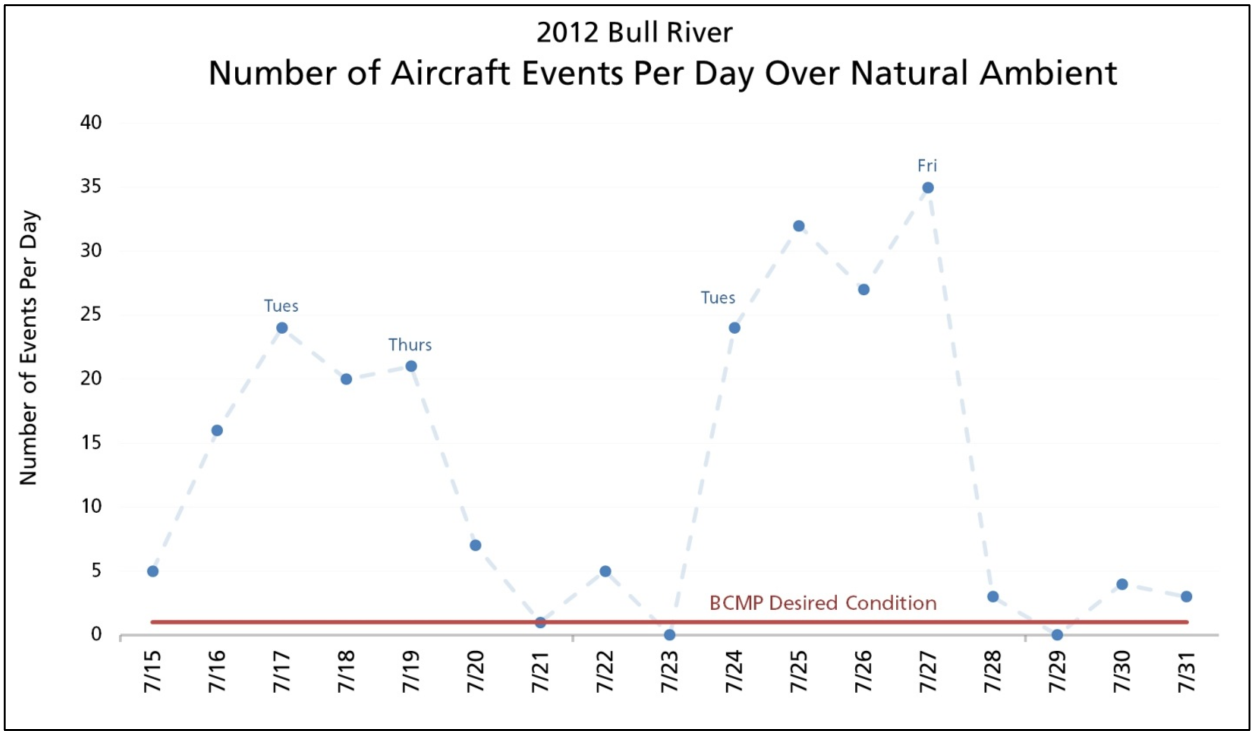


Figure 12. Number of aircraft noise events detected per day at Bull River.

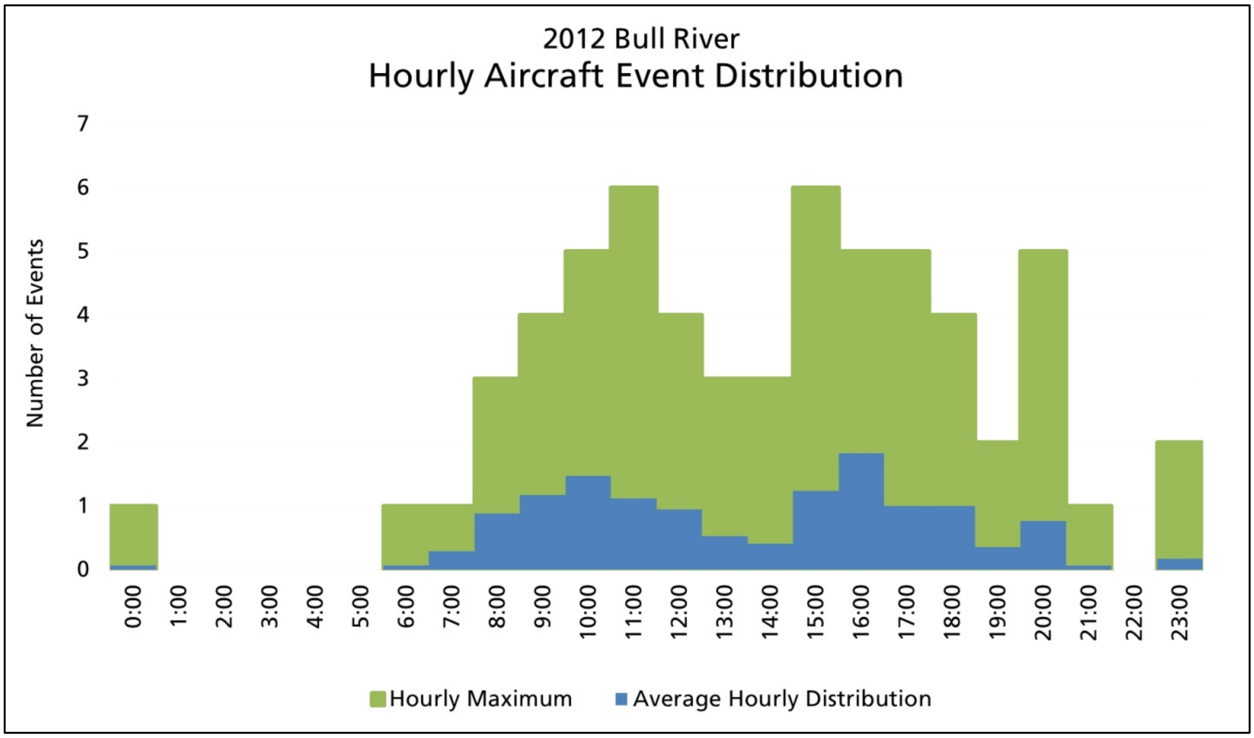


Figure 13. Hourly average and maximum rates of detection for aircraft noise events at Bull River.

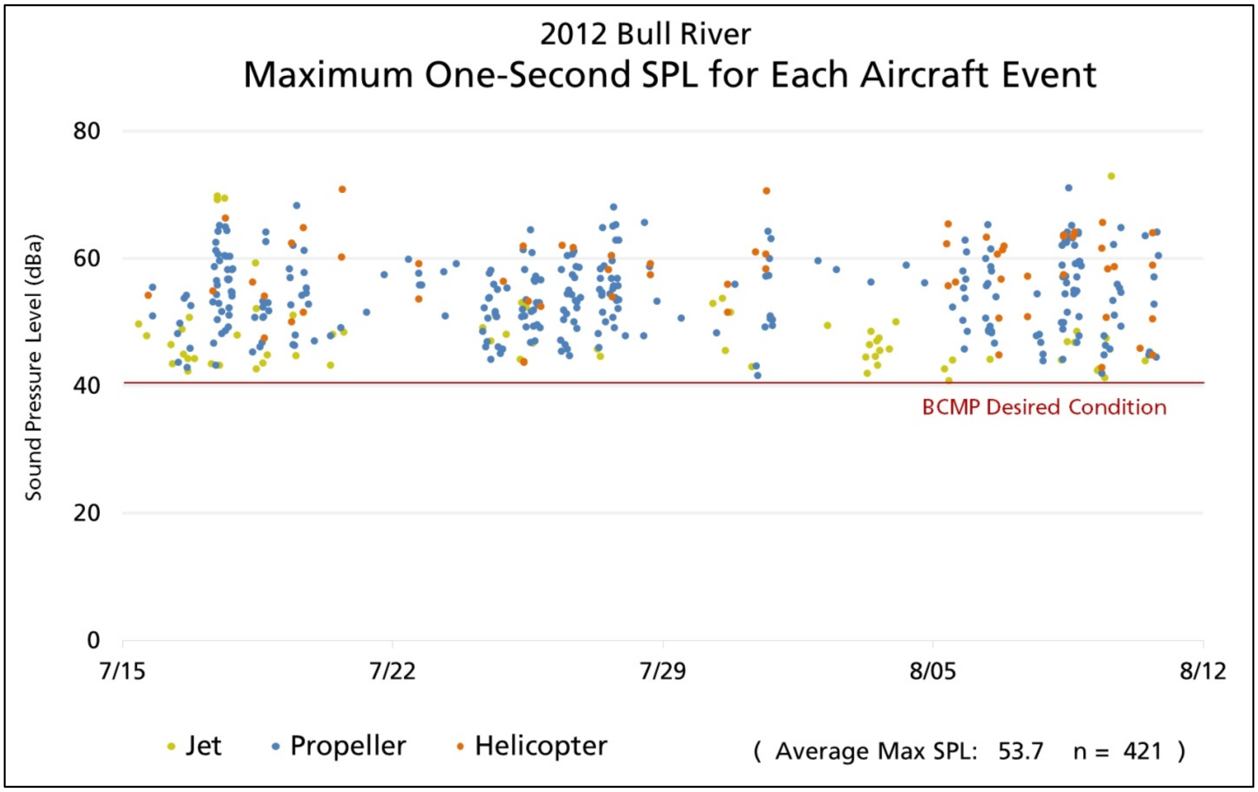


Figure 14. Maximum one-second sound pressure level for each aircraft event identified at Bull River.

Cathedral Mountain

Location Description: On the western slope of Cathedral Mountain, about 1 kilometer from the park road.

Purpose/Project: This location was chosen from the list of previously sampled locations within popular hiking regions of the park. Specifically, it was chosen to monitor soundscape conditions along the park road corridor in response to an aviation best practice enacted during the summer of 2012.

Coordinates: 63.57477°, -149.61148° (WGS84)

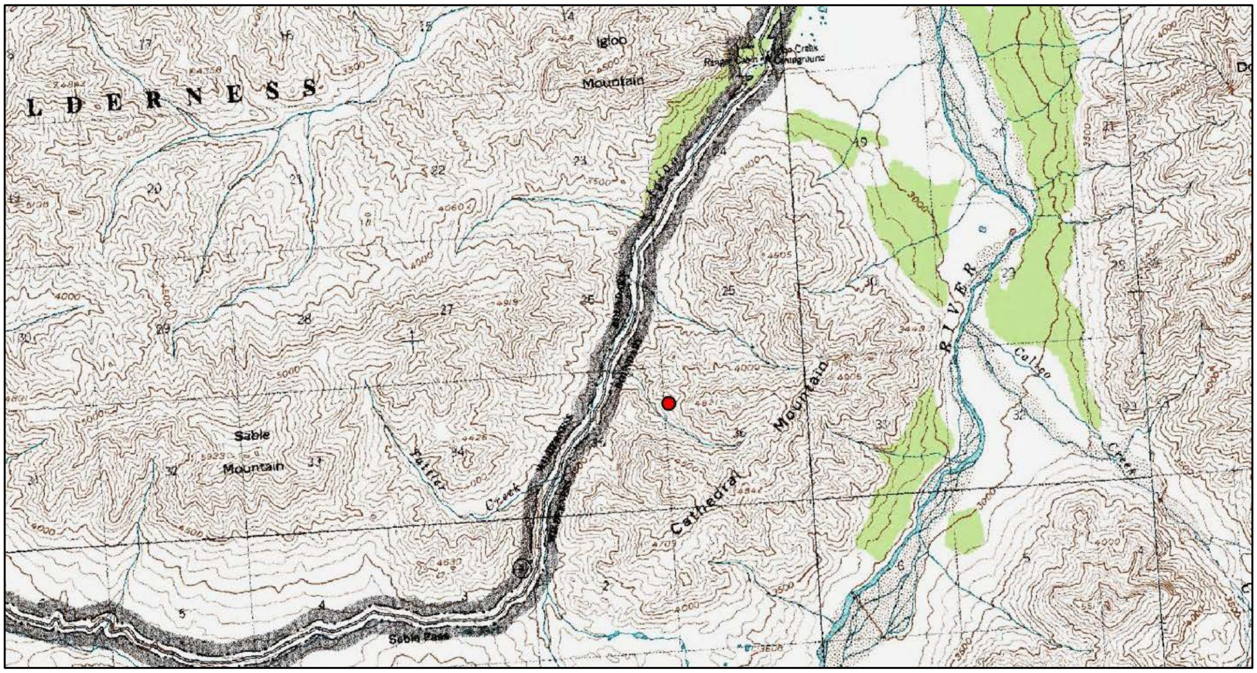
Elevation: 1162 meters

Sampling Period: 23-July-2012 to 08-September-2012

BCMP Management Zone: OP1 (Low Natural Sound Disturbance)

Park Ecoregion: Alaska Range Interior Mountains and Valleys

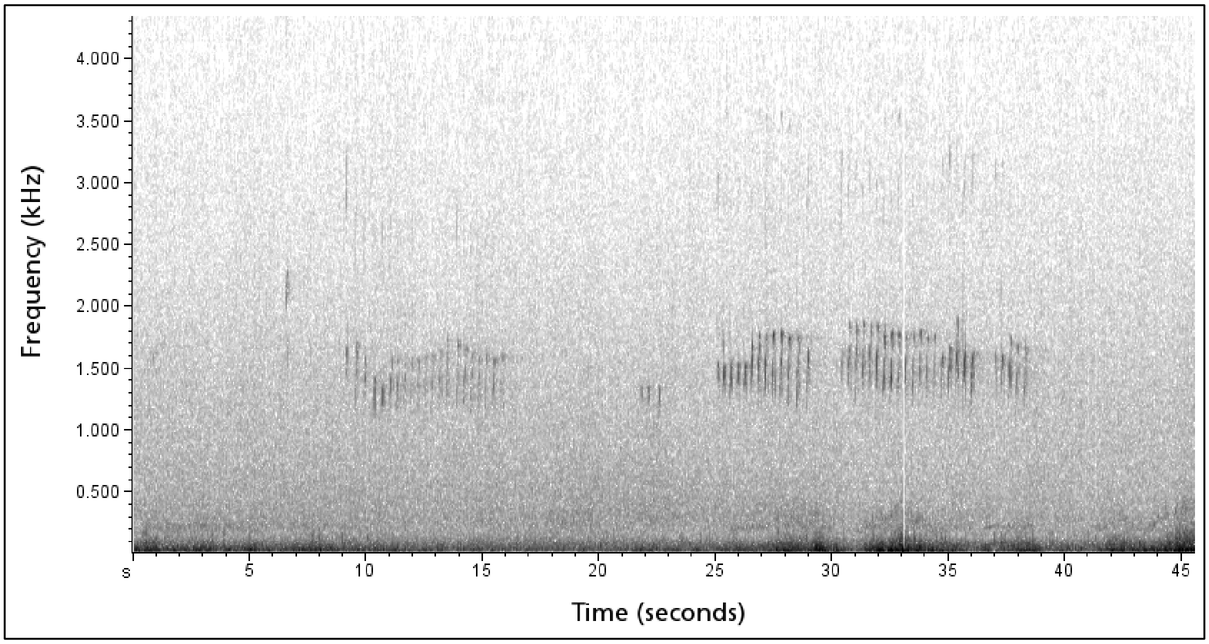
Access: Foot



Summary: The purpose of the Cathedral Mountain location was to monitor whether soundscape conditions along the park road corridor changed in response to an aviation best practice enacted during the summer of 2012. In order to detect change, a previous study of the soundscape along the road corridor had to exist – a practicality that made Cathedral's previous sampling during 2007 ideal (for a detailed record of these baseline data, see Withers 2011).

With a time-averaged natural ambient level of 24.61 dBA, Cathedral is in the 36th percentile of sites parkwide. In this open alpine environment, long periods of powerful winds were counterpoised with shorter intervals of stillness. Median wind speed at this site was loosely yet linearly related to the natural ambient level, with the overall median of 2.4 meters per second corresponding to a sound pressure level of 33 ± 7 dBA.

An interesting addition to Denali's sound library from this location were calls of the Golden Eagle (*Aquila chrysaetos*; Spectrogram 2). A species not known for frequent vocalization, a detection of the high-pitched yelping calls of the bird are good indication that adults are tending to young in the area. Considering that eagles are predators of small mammals it should be no surprise that local populations of arctic ground squirrel (*Spermophilus parryii*) and collared pika were both active with alarm calls throughout the sampling period. Small mammals were audible for about 12.4% of an average day, with pikas more active during twilight or near-twilight. This is the highest detection rate of mammals in the inventory thus far.



Spectrogram 2. Faint, yelping calls of a Golden Eagle (*Aquila chrysaetos*) near the Cathedral Mountain sound station. The spectrogram begins at 07:00:21 on 07/30/2012.

Park road traffic was prominently audible at Cathedral, as expected for a site within a kilometer of the route. Most of the noise was due to daytime traffic, and specifically the buses that traverse the park road carrying visitors. Traffic rates were the highest from 08:00 through 12:00, and again near 16:00. During such times, engines were audible for about 5 minutes (8% of the hour) on average (**Figure 21**). Throughout the early portion of this record, vehicle traffic was faintly but consistently audible during the nighttime as well— with most events occurring at even intervals between 22:00 through 06:00. Most of the nighttime traffic was due to six large trucks with side-dumping trailers contracted to perform construction work.

The most commonly heard sounds at this site were wind (audible 54.9% of the time), silence (26.2%), mammals (12.2% - mostly arctic ground squirrels), and insects (8.6%). Human made sound was audible 8.9% of the time. Vehicles – mainly buses, road construction equipment, and road maintenance equipment - were audible 3.7% of the time. Aircraft were audible 5.2% of the time. (This is equivalent to 74.9 minutes of aircraft sound each day, or about 21 overflights a day.) Conditions exceeded the BCMP percent audible standard 37% of the time, number of events per day 80% of the time, and maximum SPL 66% of the time.

For comparison with the earlier sampling period, the data collected from 05/19/2007 through 06/16/2007 – a considerably earlier sampling period than 2012 – showed the most commonly heard sounds at this site were silence (audible 38.7% of the time), wind (36.6%), mammals (20.0%), and birds (14.2%). Human made sound was audible 19.0% of the time. Road vehicles were audible 15.4% of the time. This figure estimates that nearby road construction during 2007 inflated the amount of time motorized noise was audible in the area by a considerable margin – over 10% of a typical day – a serious detriment to the local soundscape. On the other hand, aircraft sound was audible 3.6% of the time on average, which was slightly less than observed in 2012. In 2007, conditions exceeded the BCMP percent audible standard 32% of the time, number of events per day 100% of the time, and maximum SPL 91% of the time (for detailed information on the original dataset, see Withers 2011). **Table 4** compares acoustic metrics for the two sampling periods.

Table 4. Comparison of soundscape conditions at Cathedral Mountain, 2007 and 2012. Shaded columns indicate Denali Backcountry Management Plan Standards.

Year	% Time Aircraft	% Time Vehicles	% Time Standard	Events Standard	SPL Standard	% Time Wind	% Time Silence	% Time Mammal	% Time Insects
2007	3.6%	3.7%	32% of all hours	100% of all days	100% of all events	36.6%	38.7%	20.0%	3.9%
2012	5.2%	15.4%	37%	80%	66%	54.9%	26.2%	12.2%	8.6%

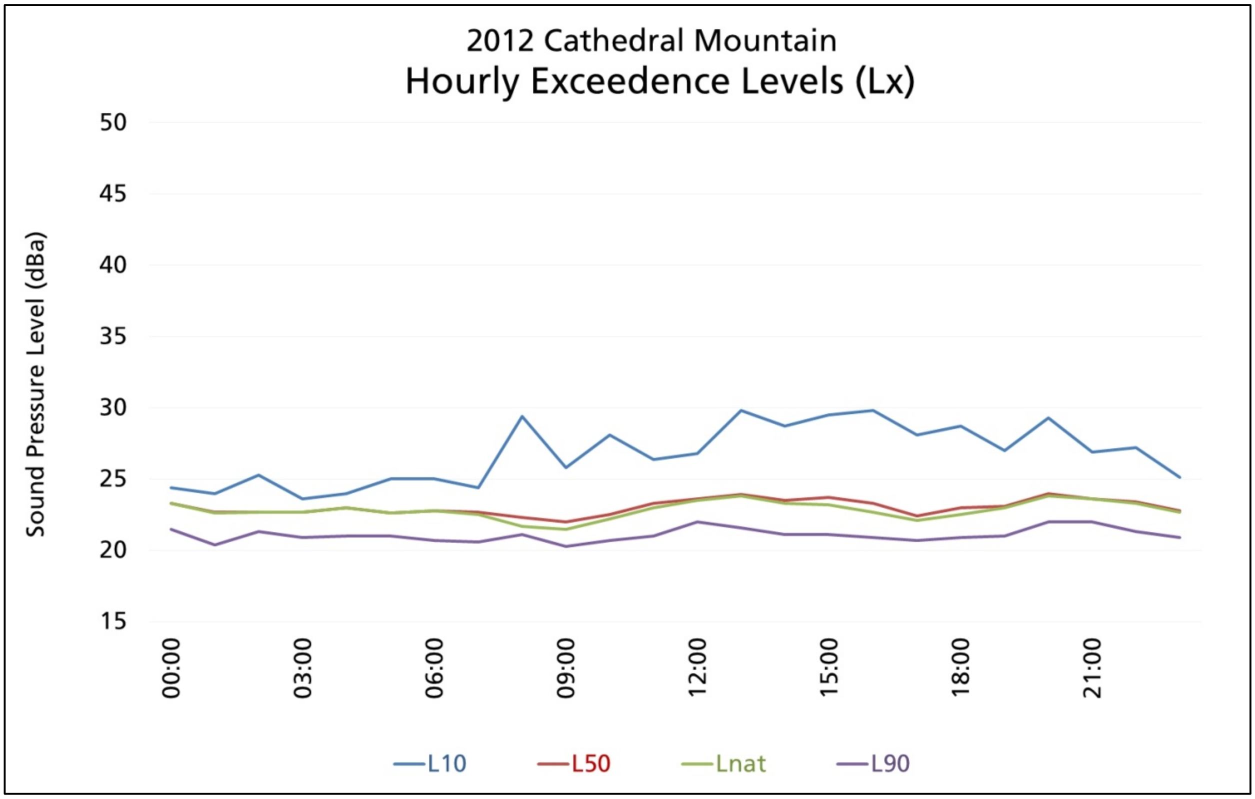


Figure 15. Exceedence levels for Cathedral Mountain.

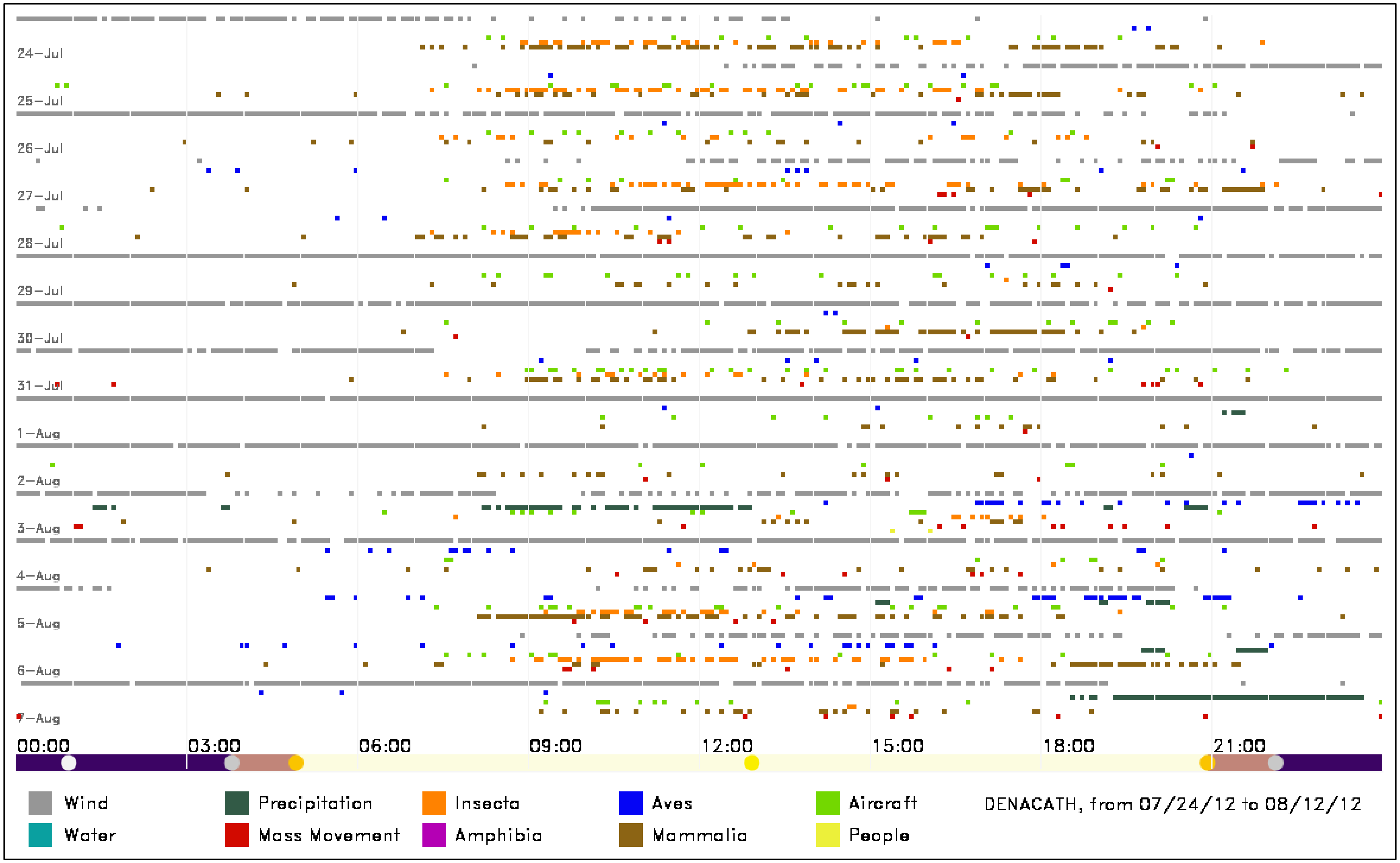


Figure 16. Temporal audibility of sound sources at Cathedral Mountain, based on five seconds of audio every five minutes. The bar along the time axis indicates the average light conditions during the sampling period. The orange circles are sunrise/sunset, and the gray circles are the beginning and end of civil twilight.

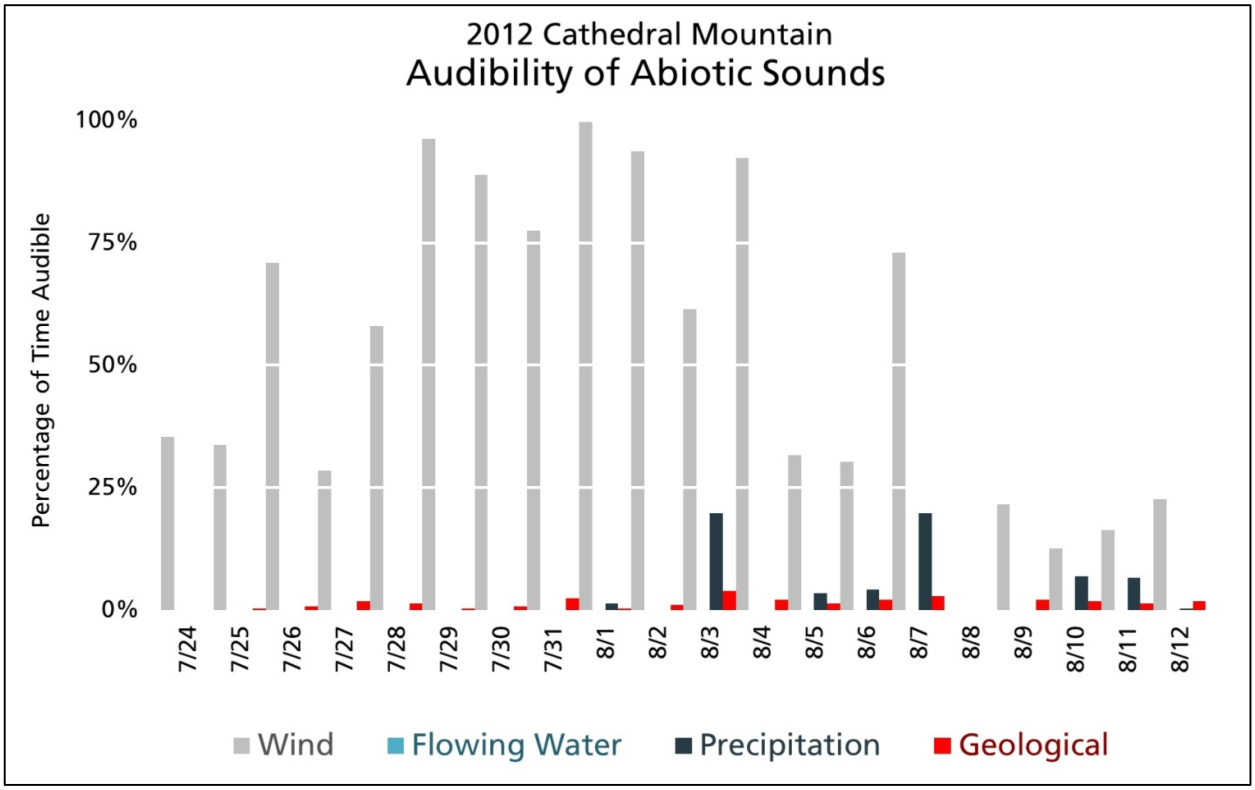


Figure 17. Audibility of abiotic sounds at Cathedral Mountain.

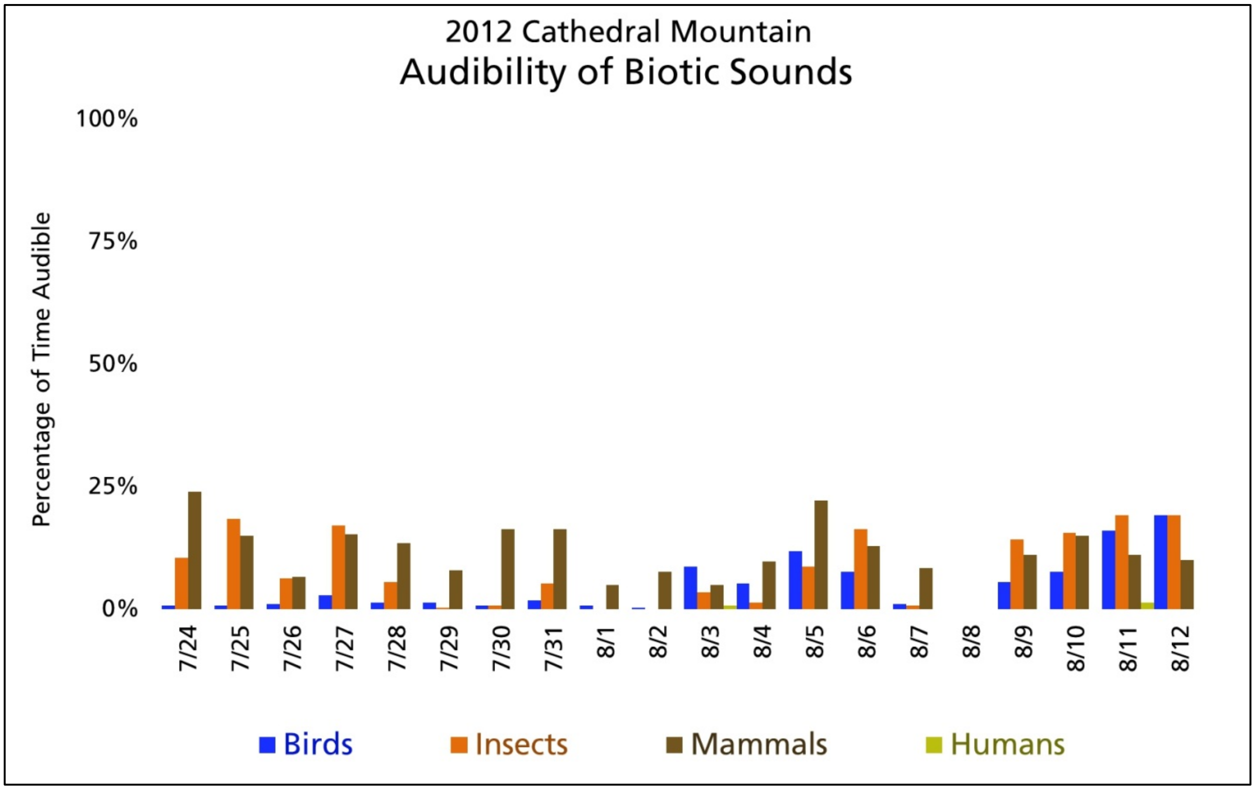


Figure 18. Audibility of biotic sounds at Cathedral Mountain.

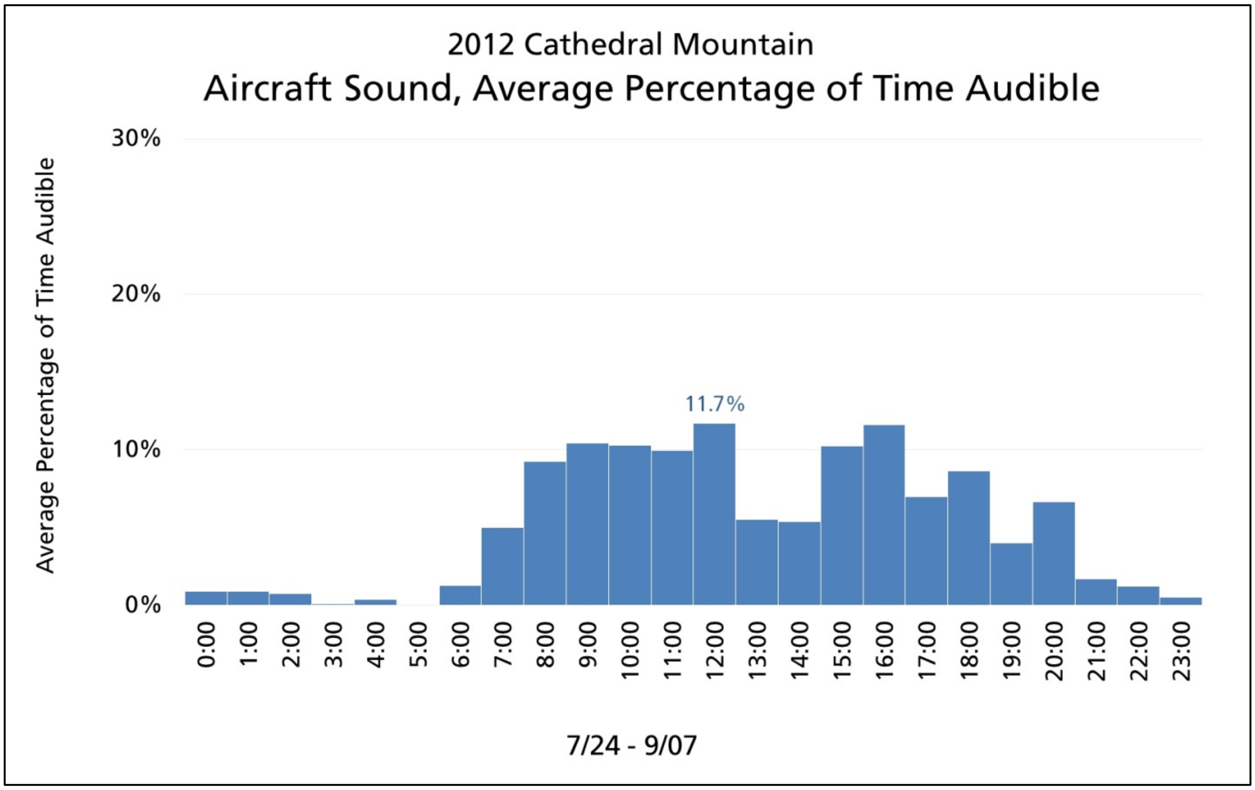


Figure 19. Audibility of aircraft noise for an average day, by hour, at Cathedral Mountain.

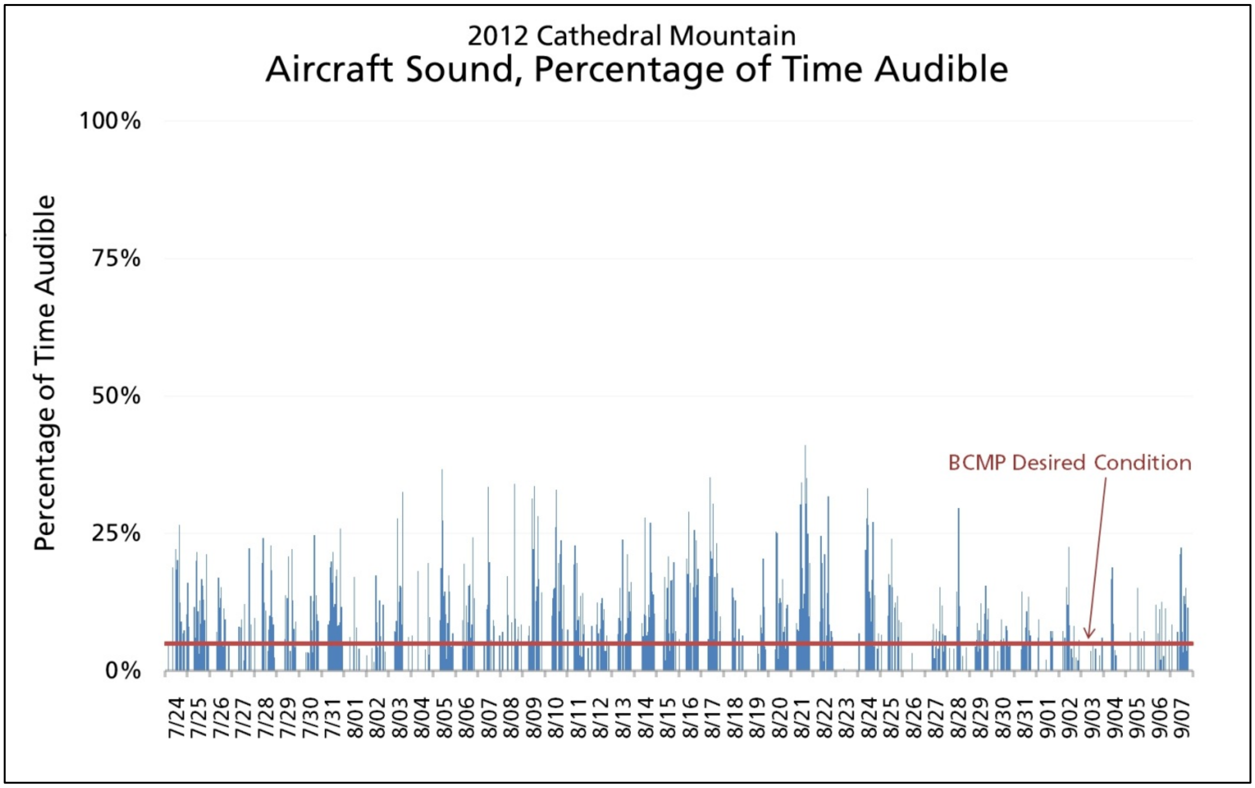


Figure 20. Audibility of aircraft noise at Cathedral Mountain.

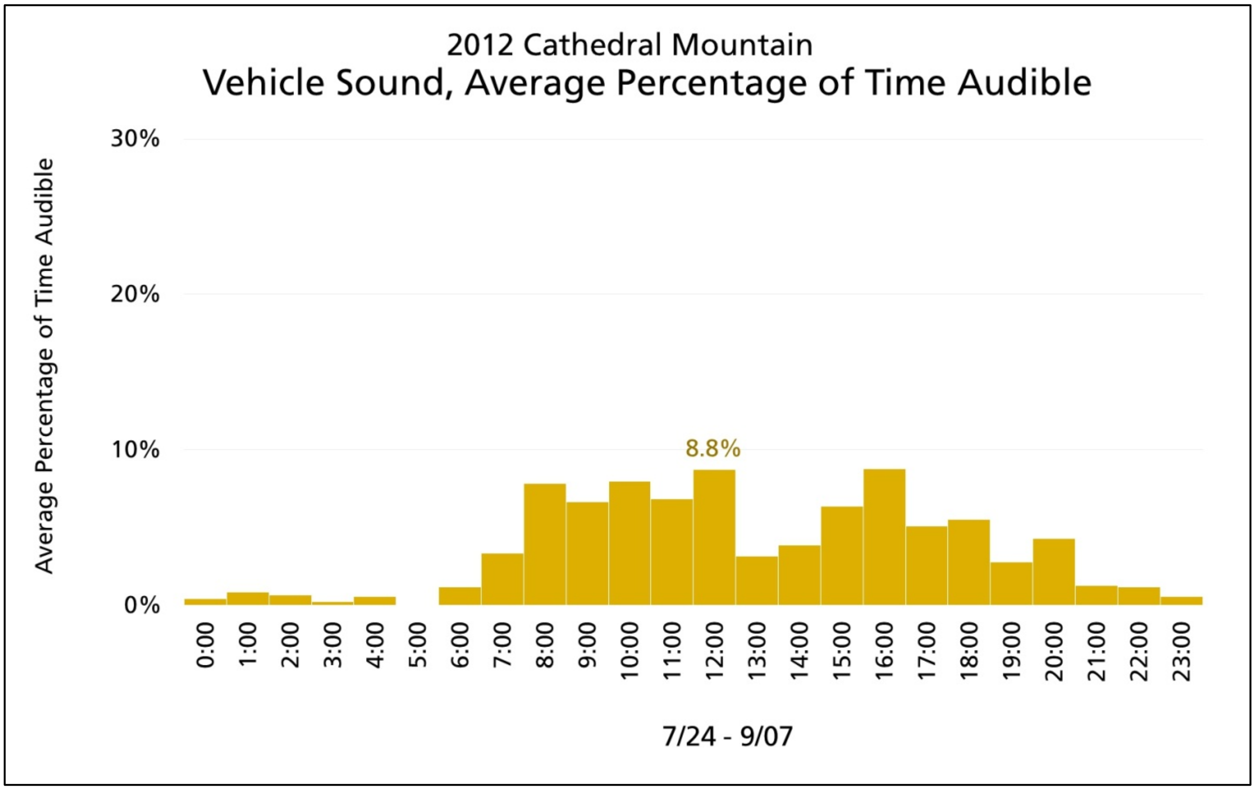


Figure 21. Audibility of vehicle noise for an average day, by hour, at Cathedral Mountain.

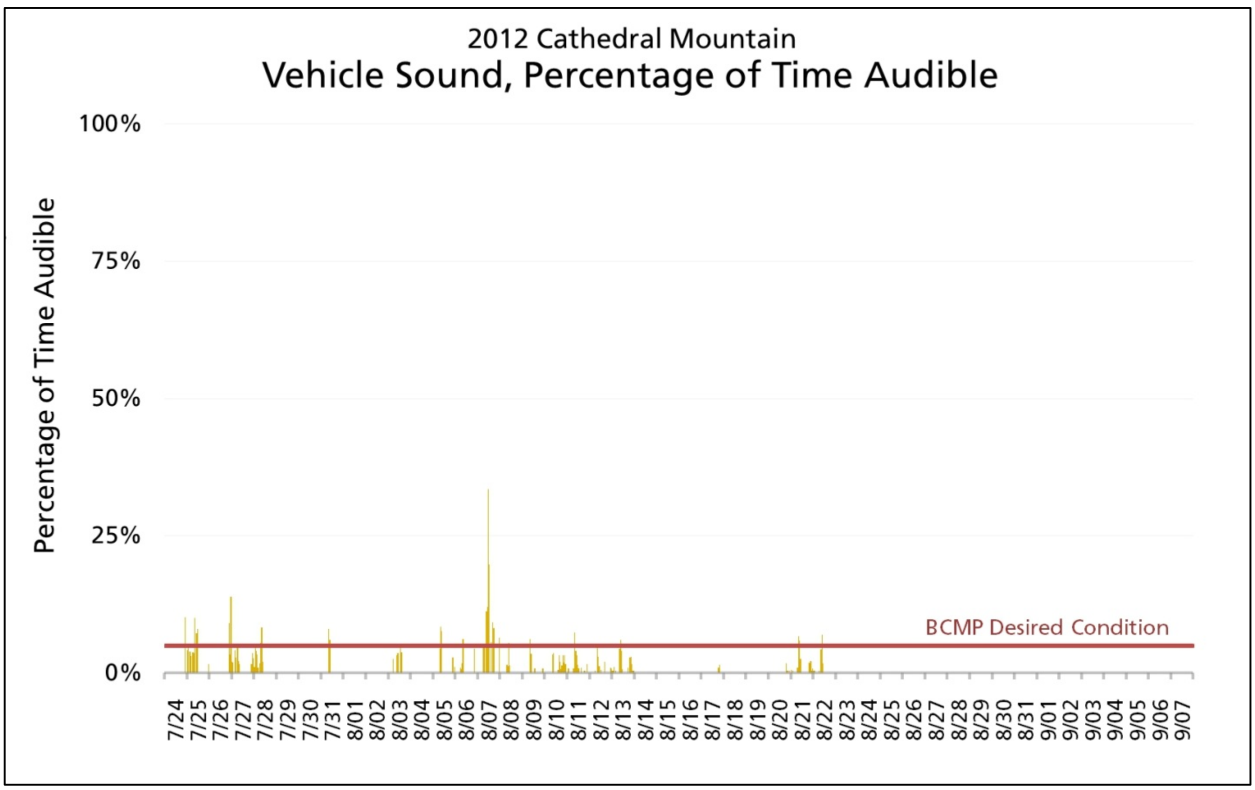


Figure 22. Audibility of vehicle noise at Cathedral Mountain.

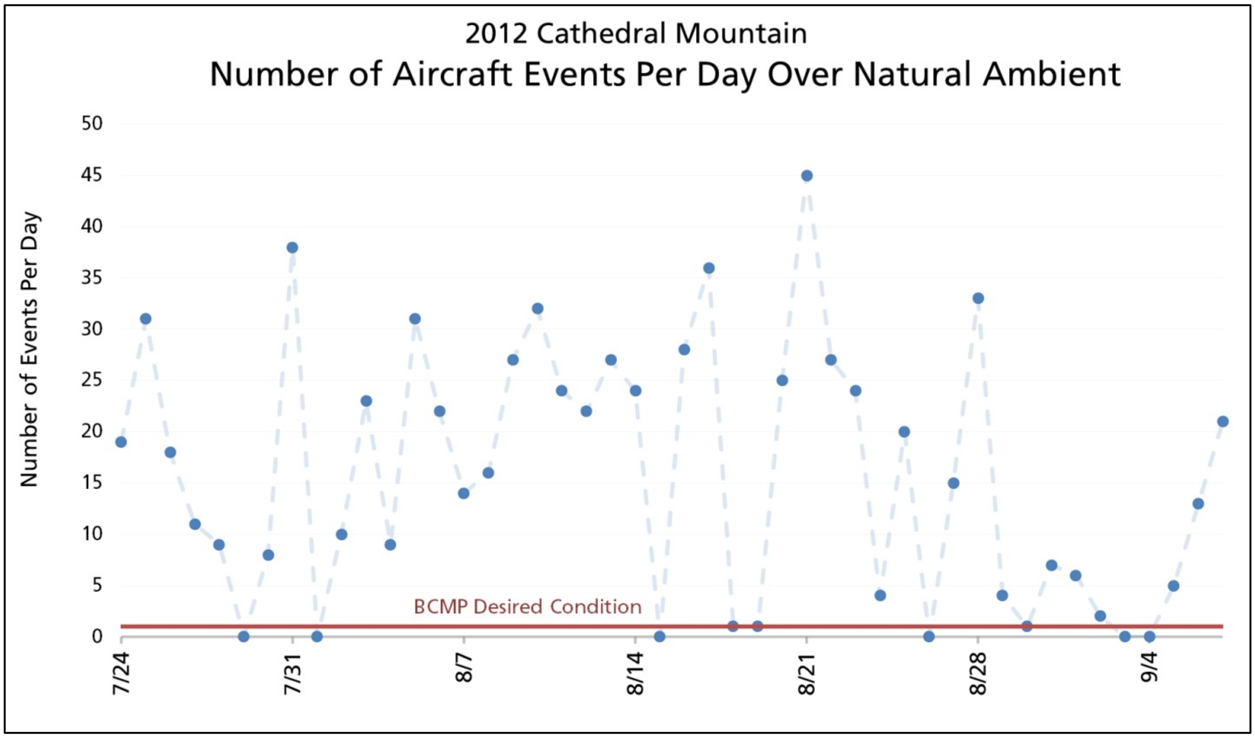


Figure 23. Number of aircraft noise events detected per day at Cathedral Mountain.

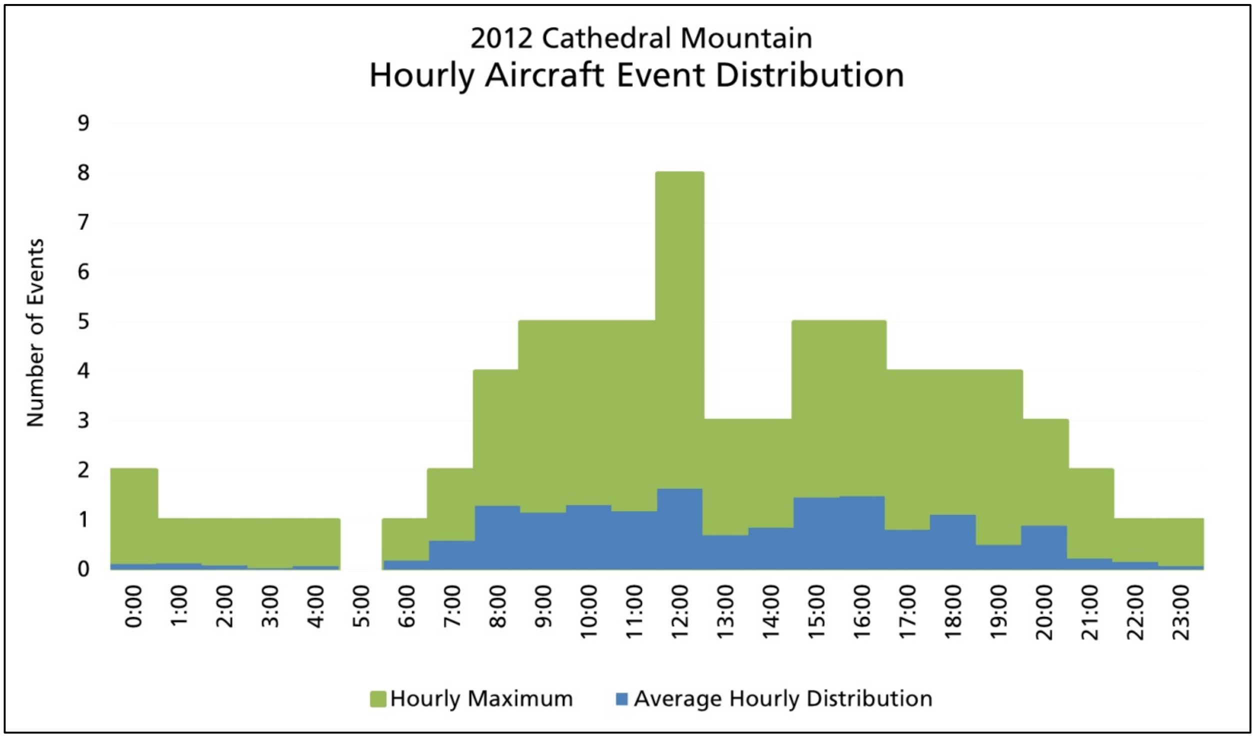


Figure 24. Hourly average and maximum rates of detection for aircraft noise events at Cathedral Mountain.

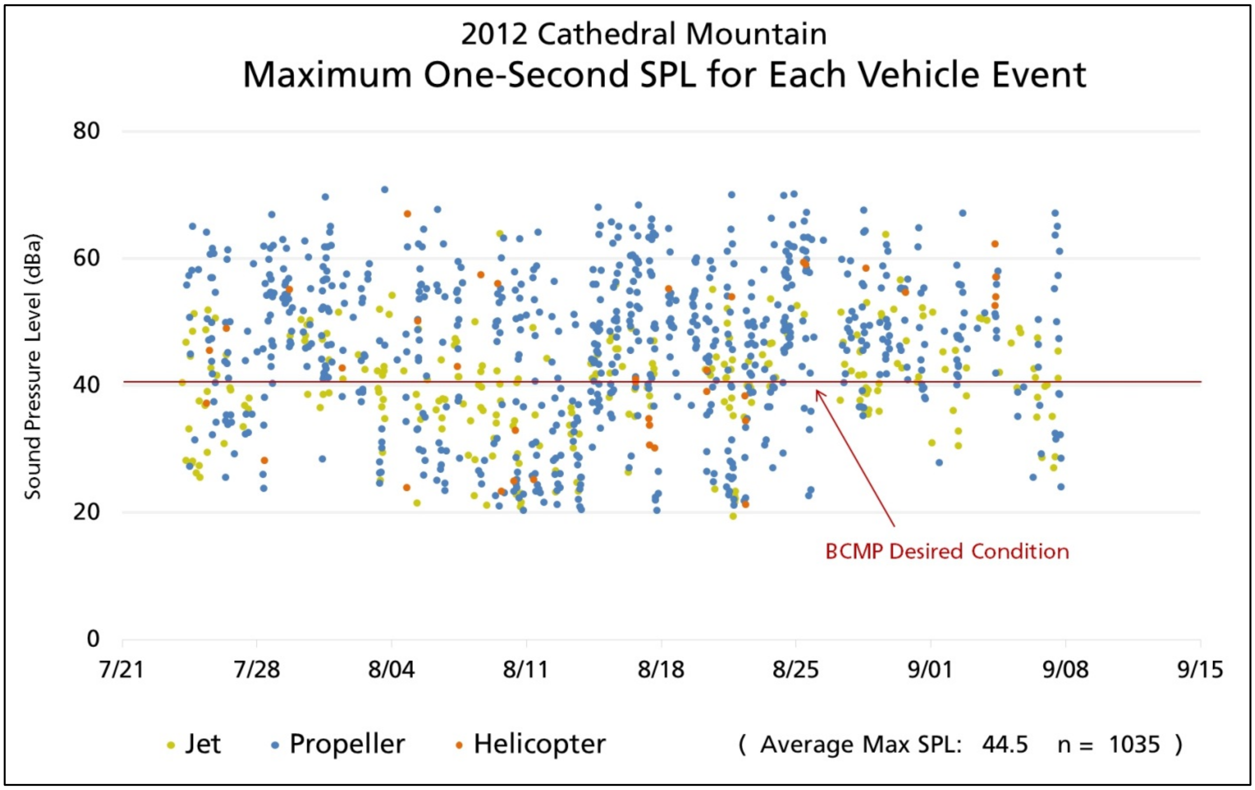


Figure 25. Maximum one-second sound pressure level for each aircraft event detected at Cathedral Mountain.

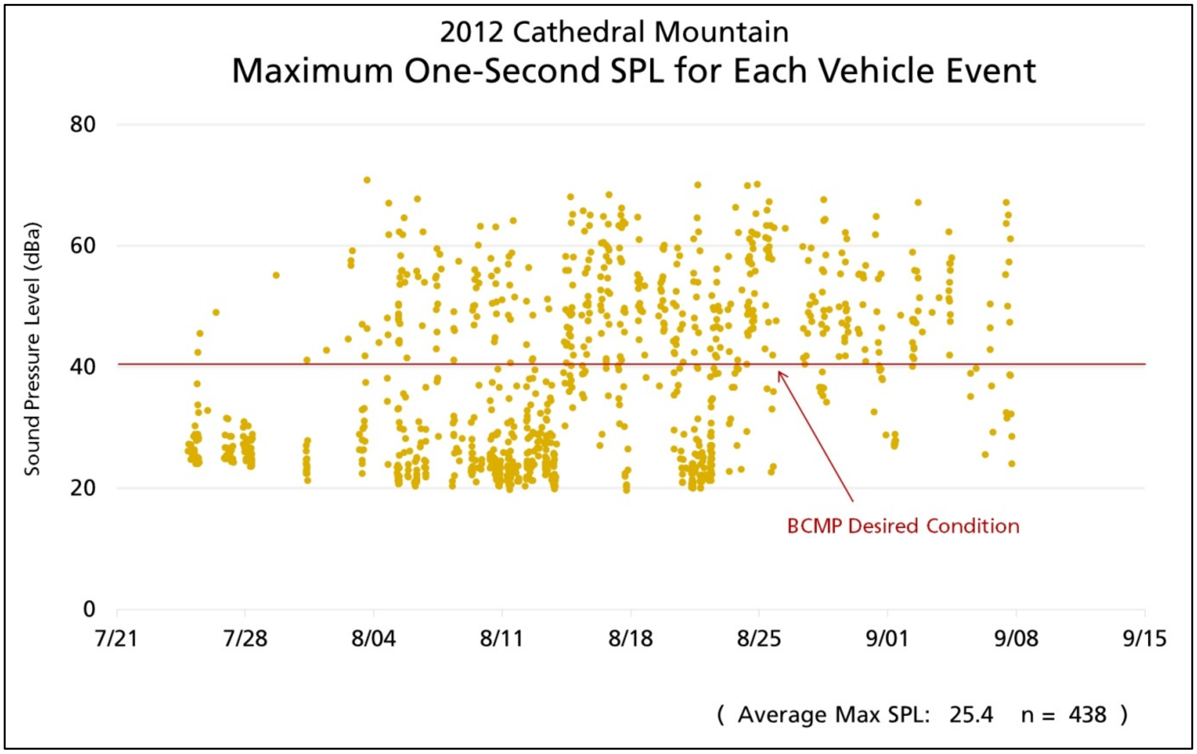


Figure 26. Maximum one-second sound pressure level for each vehicle event detected at Cathedral Mountain.

Dunkle Hills

Location Description: West of the Golden Zone Mine, inside the Park Boundary and approximately equidistant from the Dunkle Hills Climate Station and Snow Depth monitoring site.

Purpose/Project: Location chosen from winter-accessible LTEM grid points as part of the long-term Denali Soundscape inventorying and monitoring sampling plan.

Coordinates: 63.26703°, -149.54225° (WGS84)

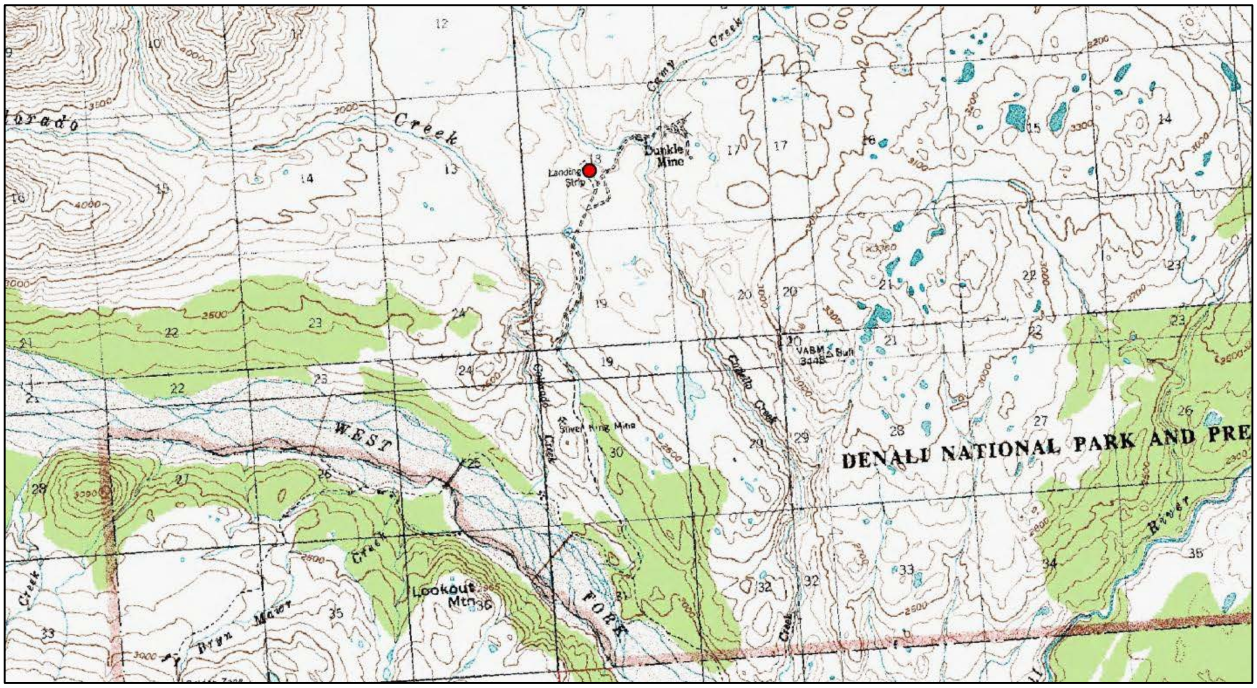
Elevation: 828 meters

Sampling Period: 02-February-2012 to 15-April-2012

BCMP Management Area: A (High Natural Sound Disturbance)

Park Ecoregion: Cook Inlet Glaciated Hills and Plains

Access: Dog Sled Installation / Snowmachine Maintenance and Removal



Summary: The purpose of the Dunkle Mine location was to collect data on snowmobile use patterns in a commonly used area of the New Park (that is, new areas of Denali designated as park land by the Alaska National Interest Lands Conservation Act of 1980.) This site was previously sampled in 2001 and 2009 – however, the latter sampling period failed to capture a useful record of sound pressure level information and only an audio analysis could be conducted. In 2012 a complete record of both audio and sound pressure level information was analyzed.

Natural winter soundscapes of Dunkle Hills are simple – with little more than the sound of wind or falling snow audible on any given day. (During the sampling period wind was audible 61% of the time and had a median speed of 1.3 meters per second and an interquartile range of 1.3 m/s.) During periods of still weather, silence prevailed. In fact, at 15.64 dBA, average conditions of natural ambient pressure energy at Dunkle Hills from mid-February through mid-April were the lowest recorded thus far in any area of Denali National Park and Preserve. (Compare to 16.52 dBA at Hines Creek [Figure 39], or the quietest summer sampling location— 17.15 dBA at Myrtle Creek in 2010.) The only animals heard during the analysis were Rock Ptarmigan (*Lagopus muta*) and Northern Ravens (*Corvus corax*). Both were isolated to a limited section of a single sampling day.

The most commonly heard sounds at this site were wind (audible 61.4% of the time), silence (27.9%), and snowfall (5.9%). Human made sound was audible a total of 14.8% of the time. Trains on the Alaska Railroad were audible 4.9% of the time. Snowmachines were audible 4.4% of the time. While cross-country transit was the most common form of motion, highmarking was also frequent throughout the sampling period. Snowmachining was primarily a weekend endeavor— 84% of all event detections occurred on Friday, Saturday or Sunday. Aircraft were audible 5.5% of the time. (This is equivalent to 79.2 minutes of aircraft sound each day, or about 23 overflights a day.)

Conditions exceeded the BCMP percent audible standard 5% of the time, number of events per day 27% of the time, and maximum SPL 0.8% of the time.

The Dunkle Hills location was previously sampled in 2009, but could not be quantified in terms of the Backcountry Management Plan standards because sound pressure level data were not successfully collected (for detailed information on the original dataset, see Withers 2011). Instead, audibility analysis will be used for a rough comparison – but note that the percent time audible figures for motorized traffic probably underrepresent the actual conditions in 2009.

Natural sounds were very similar across sampling periods. The most common sounds heard in 2009 were wind (audible 75.3% of the time) and silence (23.0%). Human made sound was audible 2.4% of the time, with aircraft being audible 1.9% of the time and snowmachines 0.4% of the time. Trains were not detected during the analysis. Table 5 compares acoustic metrics for the two sampling periods.

Table 5. Comparison of soundscape conditions at Dunkle Hills, 2009 and 2012. Shaded columns indicate Denali Backcountry Management Plan Standards.

Year	% Time Aircraft	% Time Snowmobiles	% Time Standard	Events Standard	SPL Standard	% Time Wind	% Time Silence	% Time Snowfall
2009	1.9%*	0.4%*	--	--	--	75.3%	23.0%	0.0%
2012	5.7%	2.0%	5%	27%	0.8%	61.4%	27.9%	5.9%

*Because SPL data were not collected in 2009, results of audibility analysis are summarized, instead.

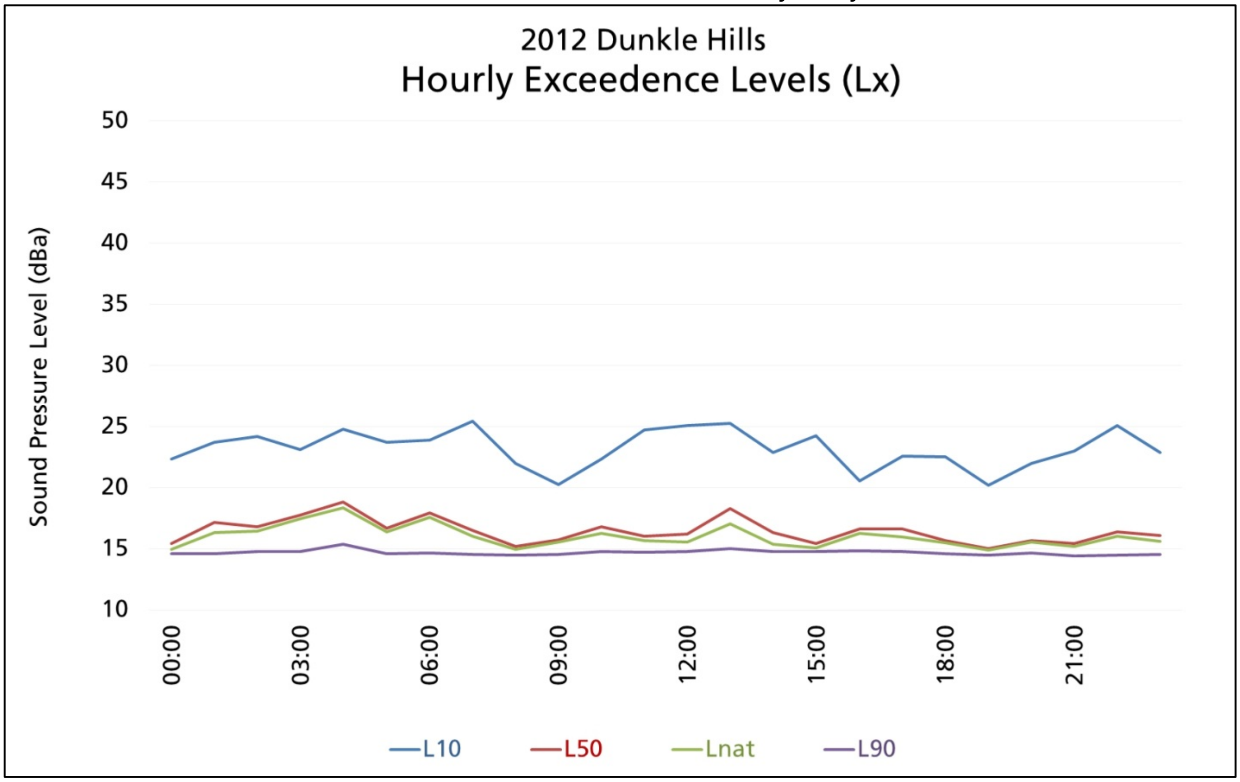


Figure 27. Exceedence levels for Dunkle Hills.

Figure 28. Temporal audibility of sound sources at Dunkle Hills, based on five seconds of audio every five minutes. The bar along the time axis indicates the average light conditions during the sampling period. The orange circles are sunrise/sunset, and the gray circles are the beginning and end of civil twilight.

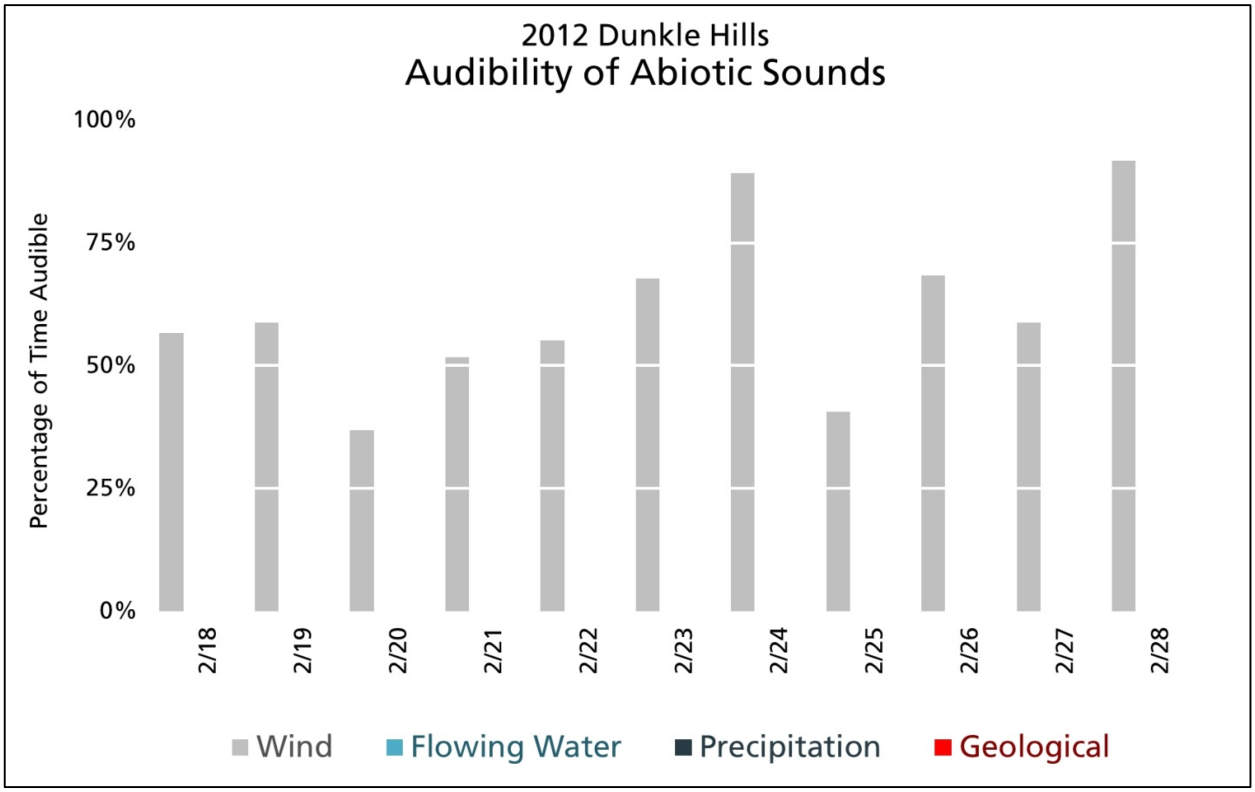


Figure 29. Audibility of abiotic sounds at Dunkle Hills.

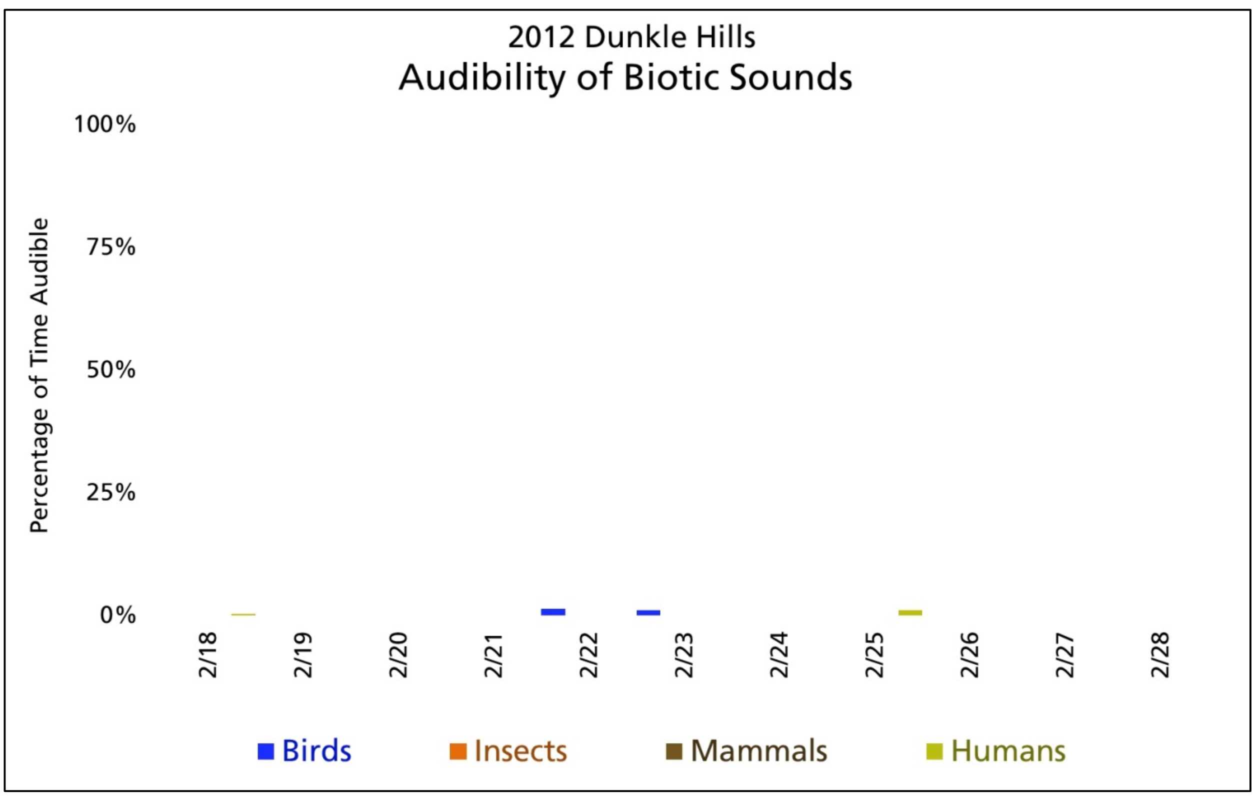


Figure 30. Audibility of biotic sounds at Dunkle Hills.

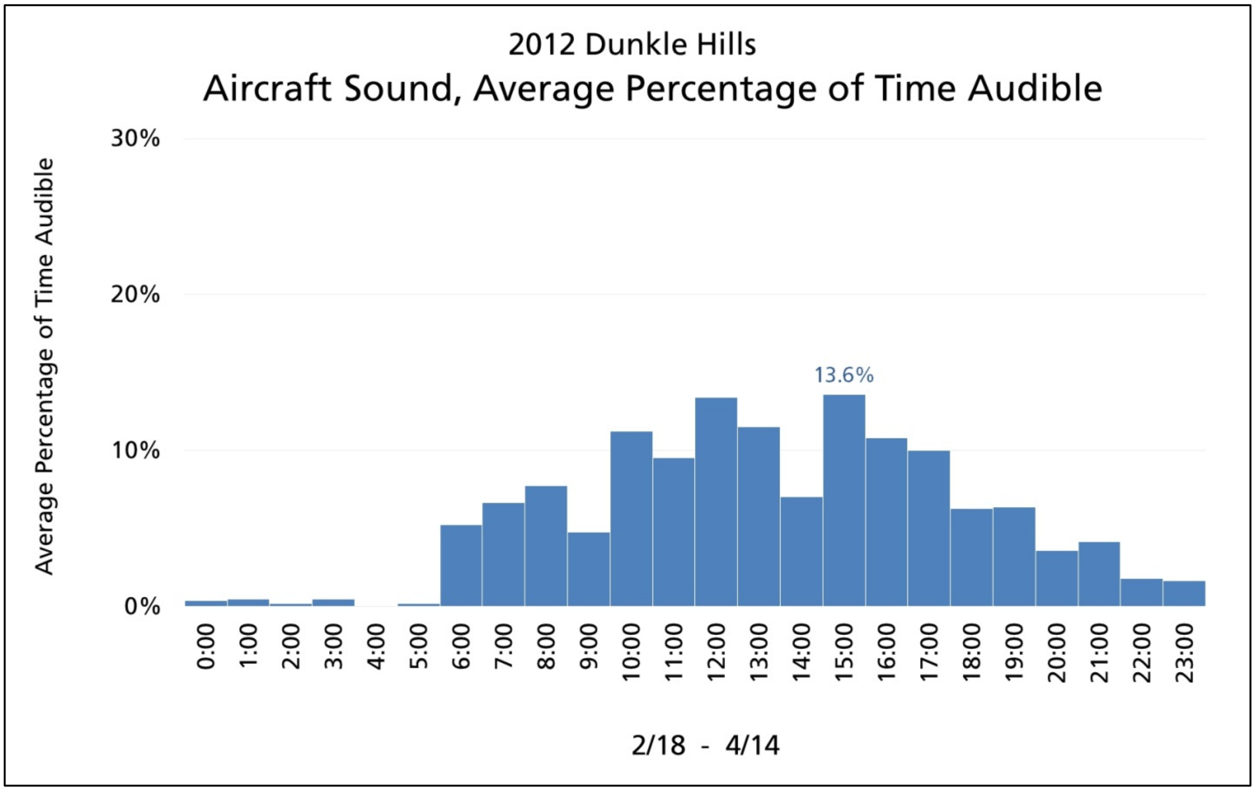


Figure 31. Audibility of aircraft noise for an average day, by hour, at Dunkle Hills.

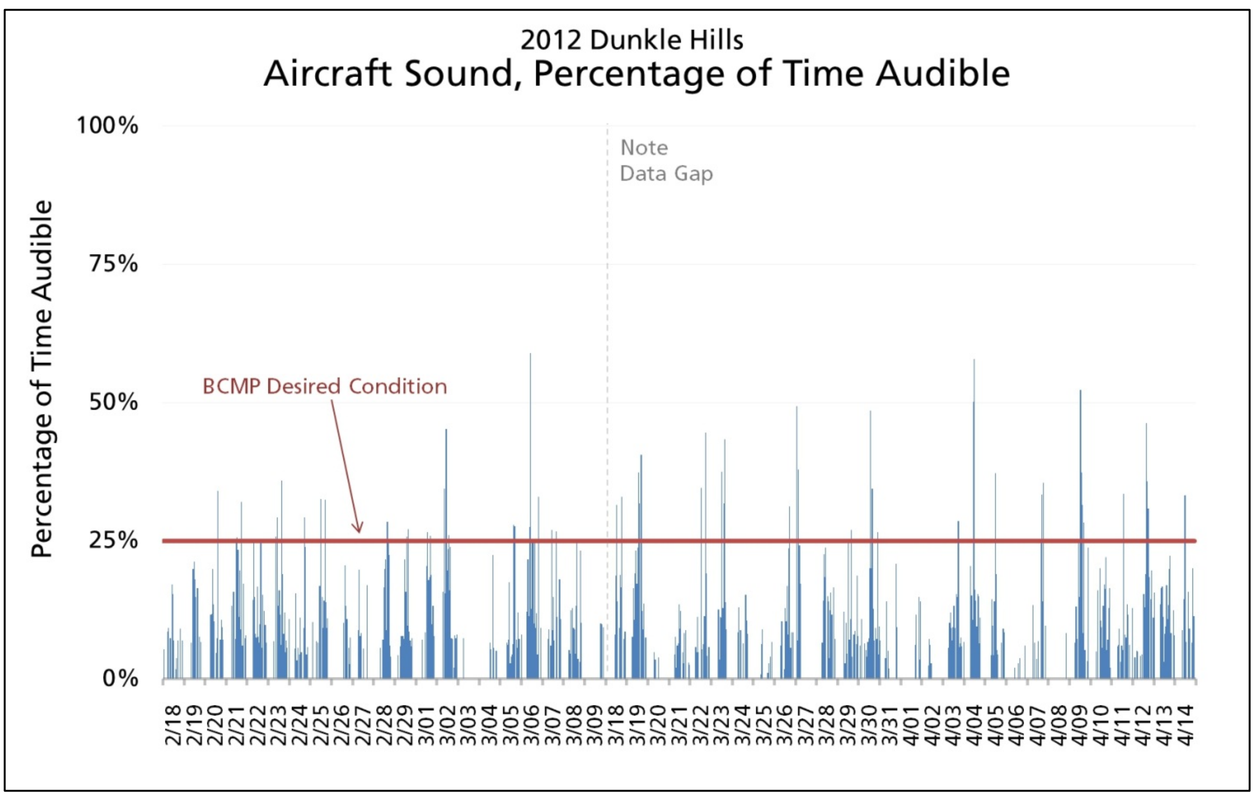


Figure 32. Audibility of aircraft noise at Dunkle Hills.

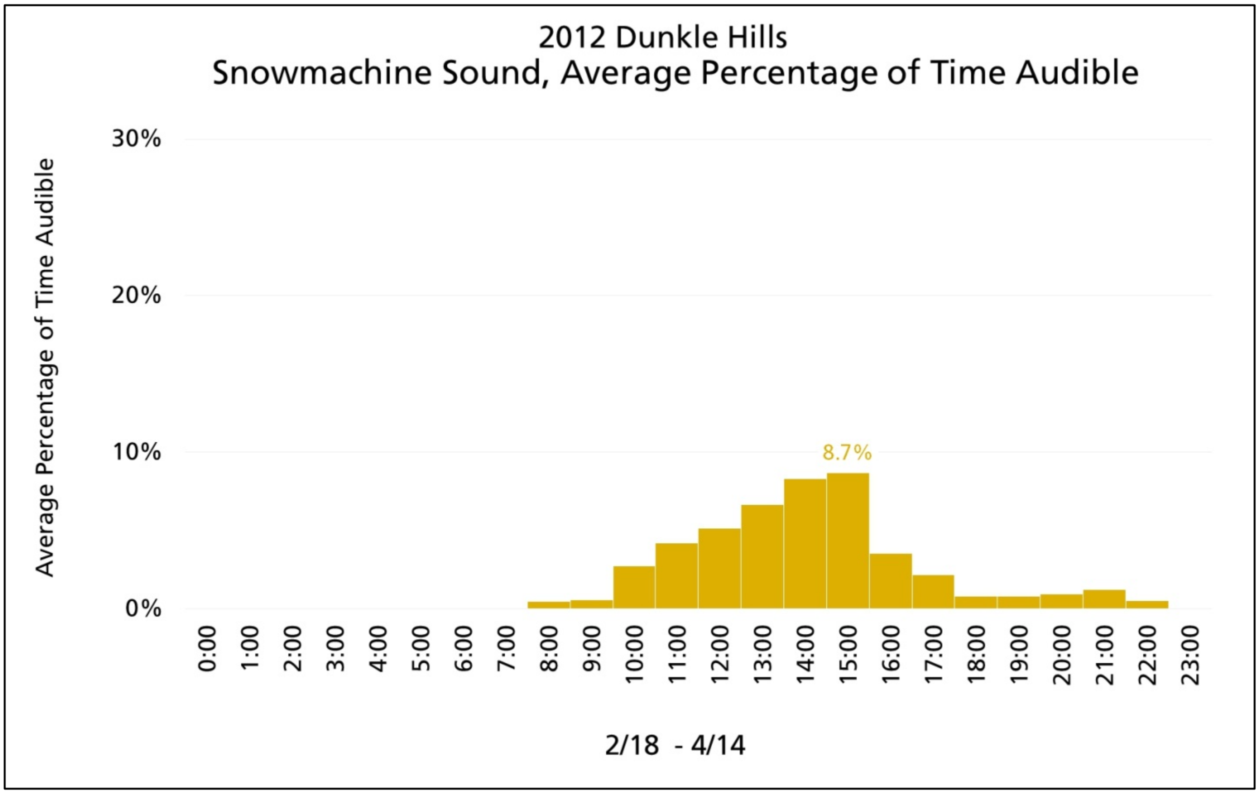


Figure 33. Audibility of snowmobile noise for an average day, by hour, at Dunkle Hills.

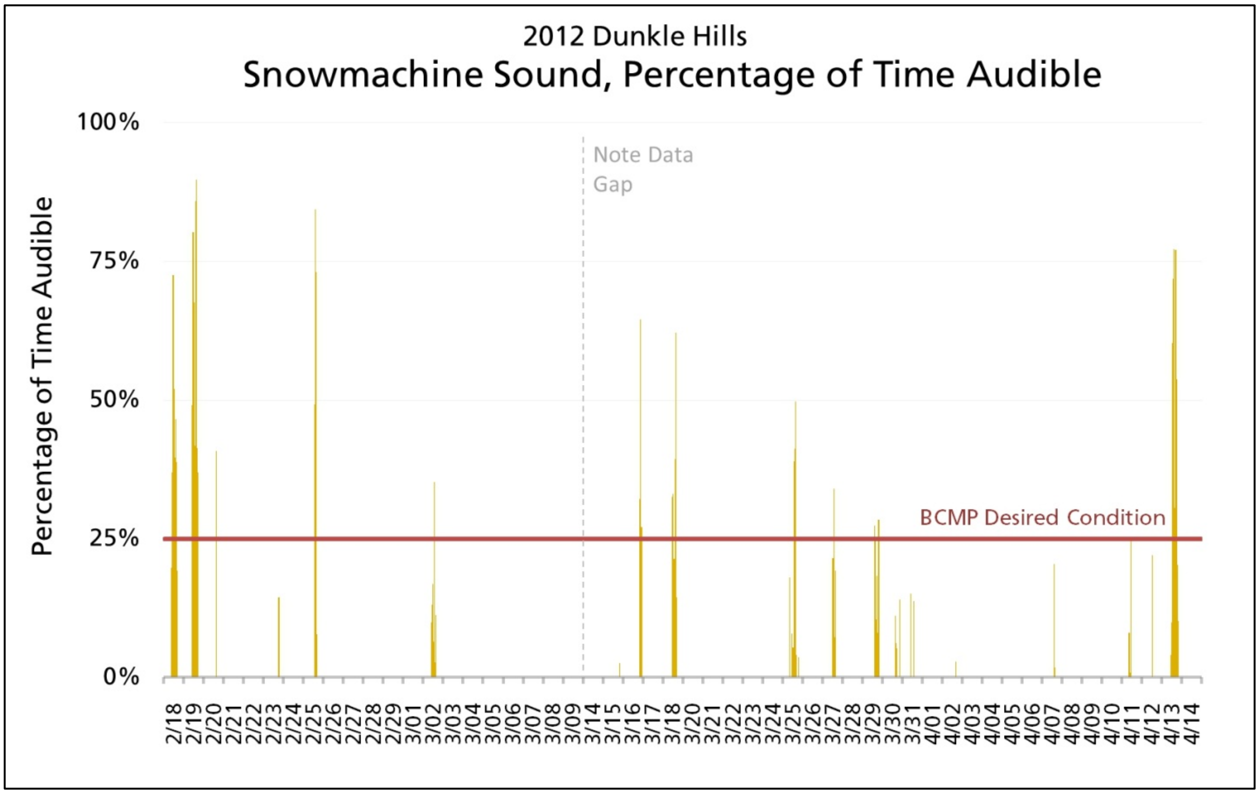


Figure 34. Audibility of snowmobile noise at Dunkle Hills.

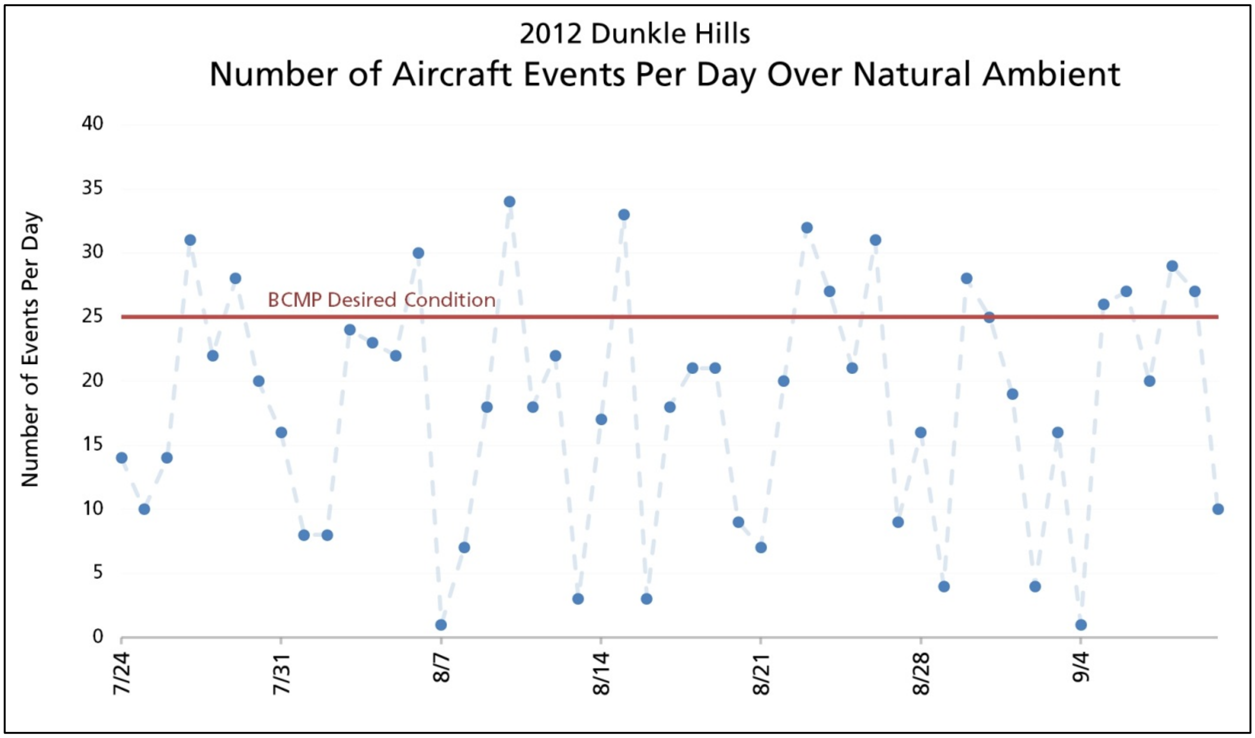


Figure 35. Number of aircraft noise events detected per day at Dunkle Hills.

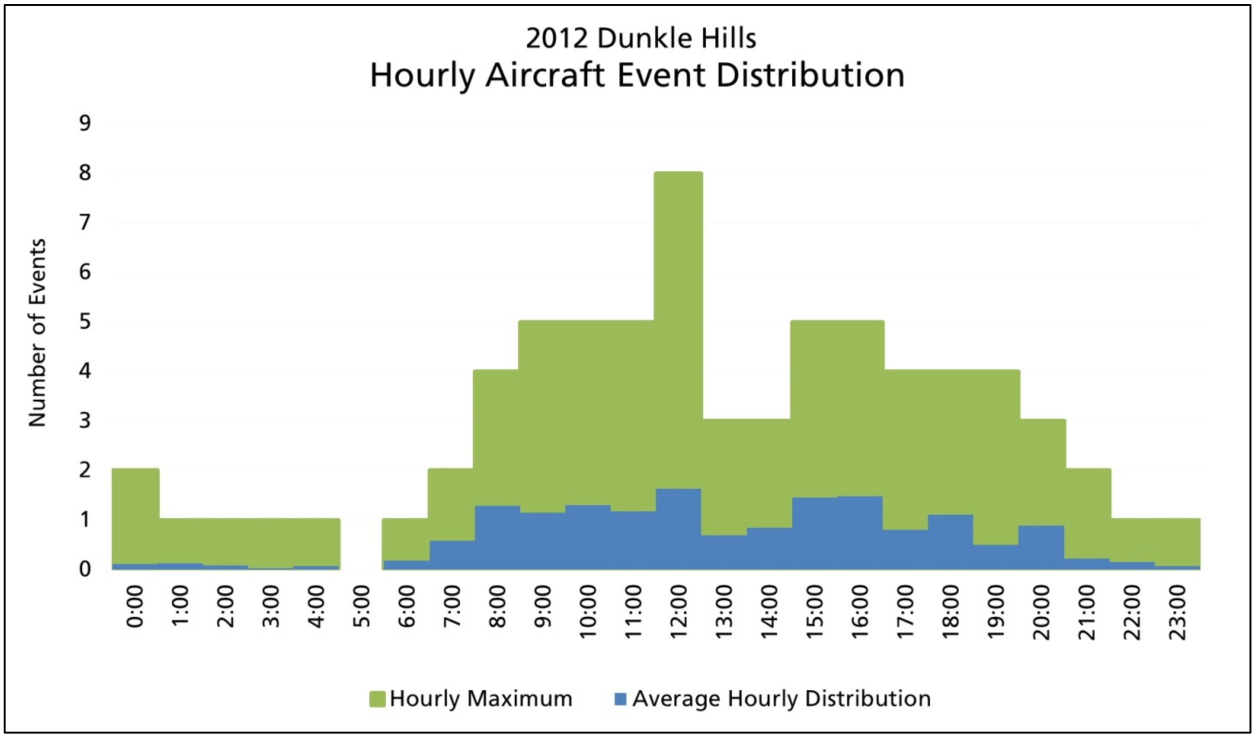


Figure 36. Hourly average and maximum rates of detection for aircraft noise events at Dunkle Hills.

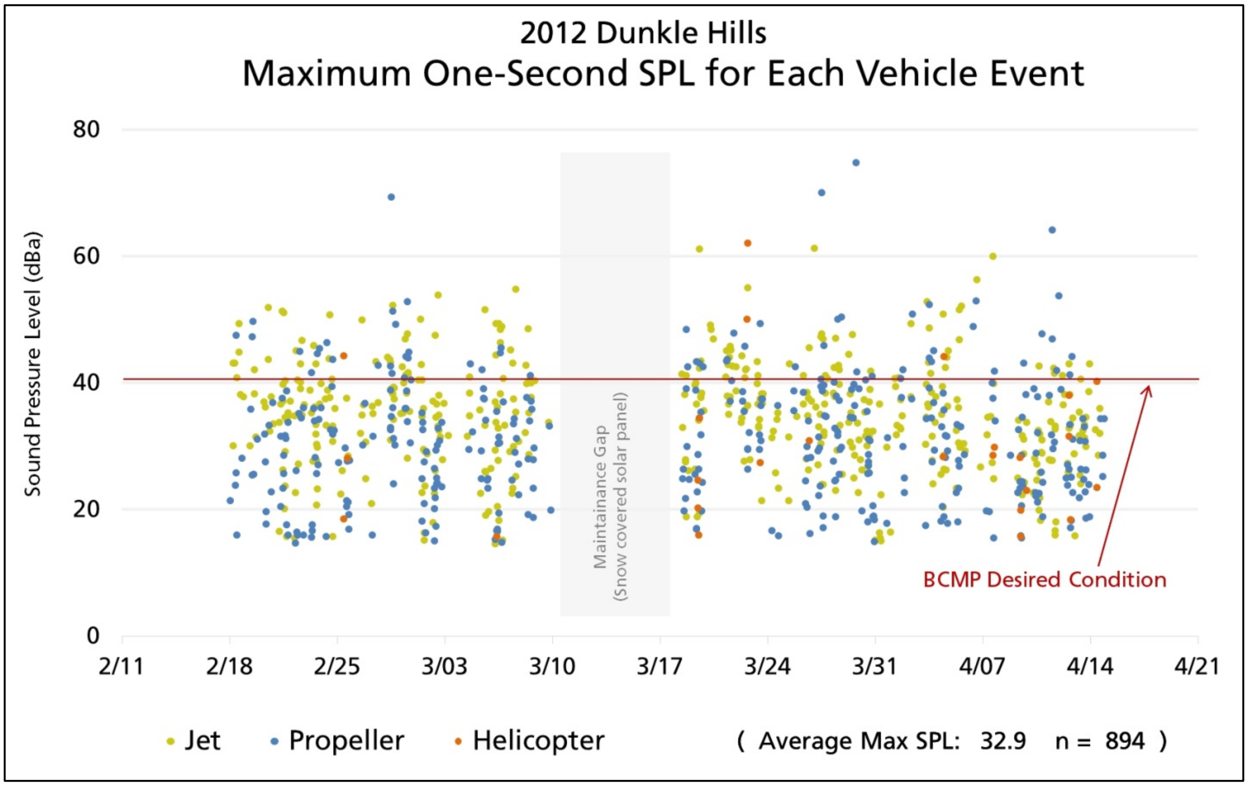


Figure 37. Maximum one-second sound pressure level for each aircraft event detected at Dunkle Hills.

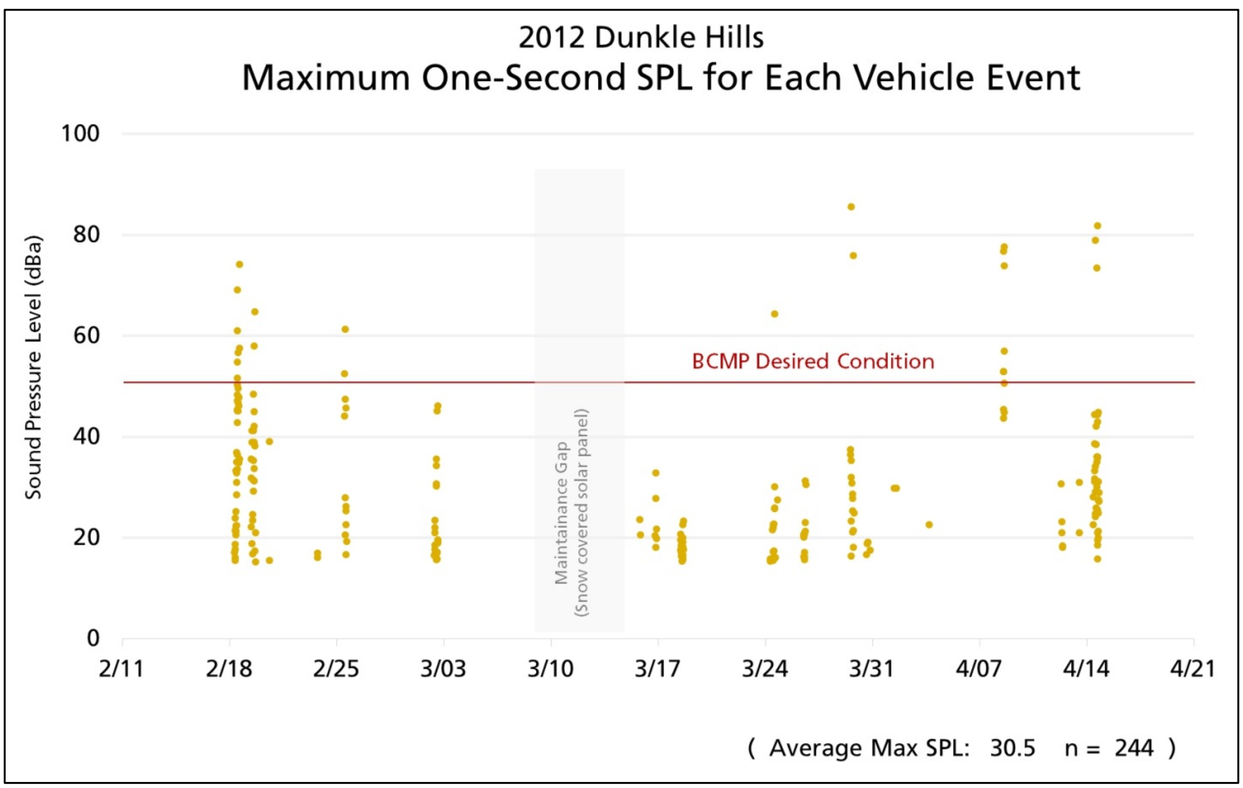


Figure 38. Maximum one-second sound pressure level for each snowmobile event detected at Dunkle Hills.

Hines Creek

Location Description: On a hillside 0.4 km south of the park road overlooking the 7-Mile gravel pit and the headwaters of Hines Creek.

Purpose/Project: Location chosen to document deep-winter acoustic conditions along the park road corridor. These data were used to supplement an environmental assessment concerning snowplowing on the road.

Coordinates: 63.71061°, -149.07915° (WGS84)

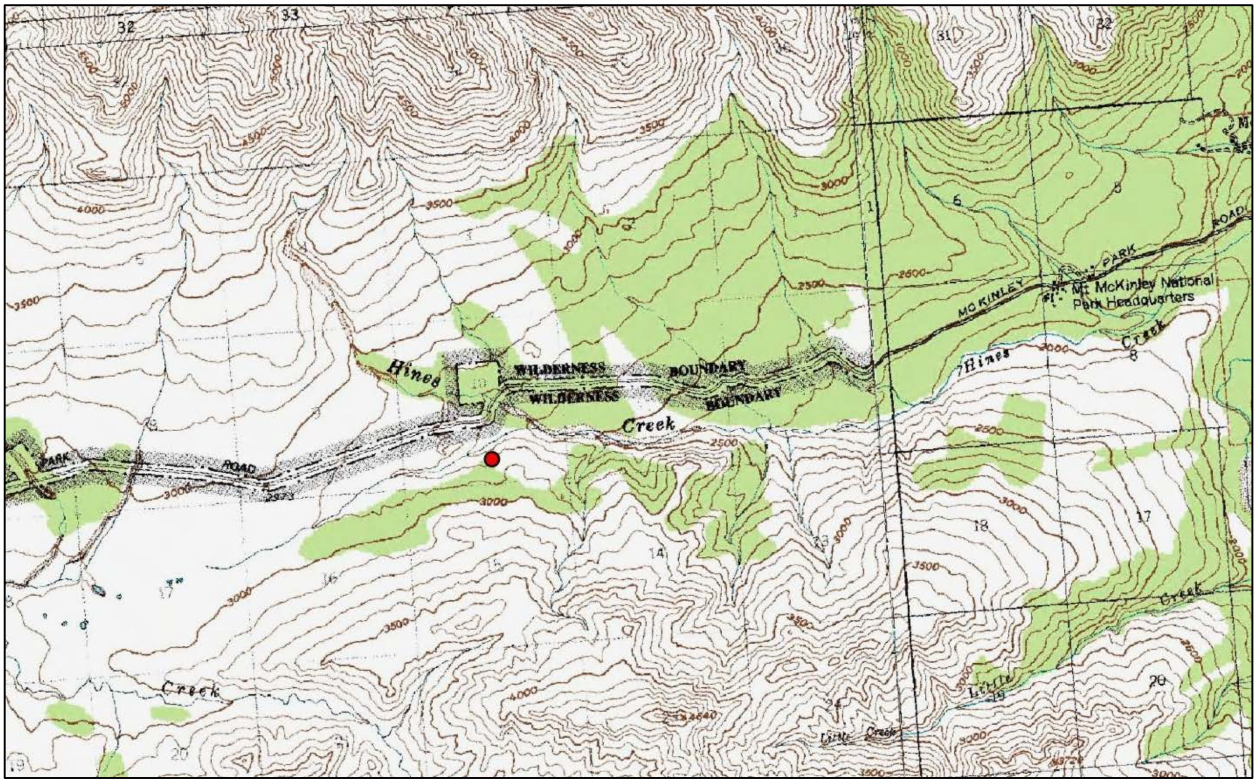
Elevation: 861 meters

Sampling Period: 28-November-2012 to 23-March-2012

BCMP Management Area: OP1 (Low Natural Sound Disturbance)

Park Ecoregion: Alaska Range Front Range

Access: Installed on Foot / Dog Sled and Ski Maintenance / Removal via Road Access



<u>Summary</u>: The purpose of the Hines Creek sampling location was to collect baseline data on wintertime noise in the vicinity of the park road corridor. Because winter conditions can be very still, a specialized preamplifier with low self-noise was selected for use. The site was selected from designated wilderness locations adjacent to the park road corridor.

Once flowing water is muted by ice and snow winter conditions in the vicinity of Hines Creek have the potential for very low ambient acoustic energy. Snow decreases the specific acoustic impedance of the ground surface, slowing the speed of sound waves, and maximizing sound attenuation. Average conditions during February 2012 were the second-lowest recorded thus far in any area of Denali National Park and Preserve. The time-weighted natural ambient level was 16.52 dBA. Only the 2012 Dunkle Hills sampling location had quieter average conditions, with an ambient level of 15.64 dBA (Figure 22). For comparison, consider the quietest summer sampling site - 17.15 dBA at Myrtle Creek in 2010, or the second quietest—18.16 dBA at West Buttress of Denali, also in 2010.

The majority of audible acoustic energy during the deep winter at this location is due to the motion of air through vegetation (especially spruce needles) and over snow. The energies of this motion are generally in the bands between 1000 and 10000 Hertz, and generally do not mask lower frequency energy, such as that produced by motor vehicles or aircraft.

Human made sound was audible 9.8% of the time. Vehicles, mainly road maintenance equipment and heavy trucks on the Parks Highway, were audible 2.9% of the time. Distant highway traffic is mostly heard in the middle of the night. This is probably partially due to the fact that more semi-trucks travel more during the late hours, but also to the refractive effects of temperature inversion on sound propagation. Aircraft were audible 6.9% of the time. (This is equivalent to 99.4 minutes of aircraft sound each day, or about 21 overflights a day.) Conditions exceeded the BCMP percent audible standard 15% of the time, number of events per day 100% of the time, and maximum SPL 37% of the time.

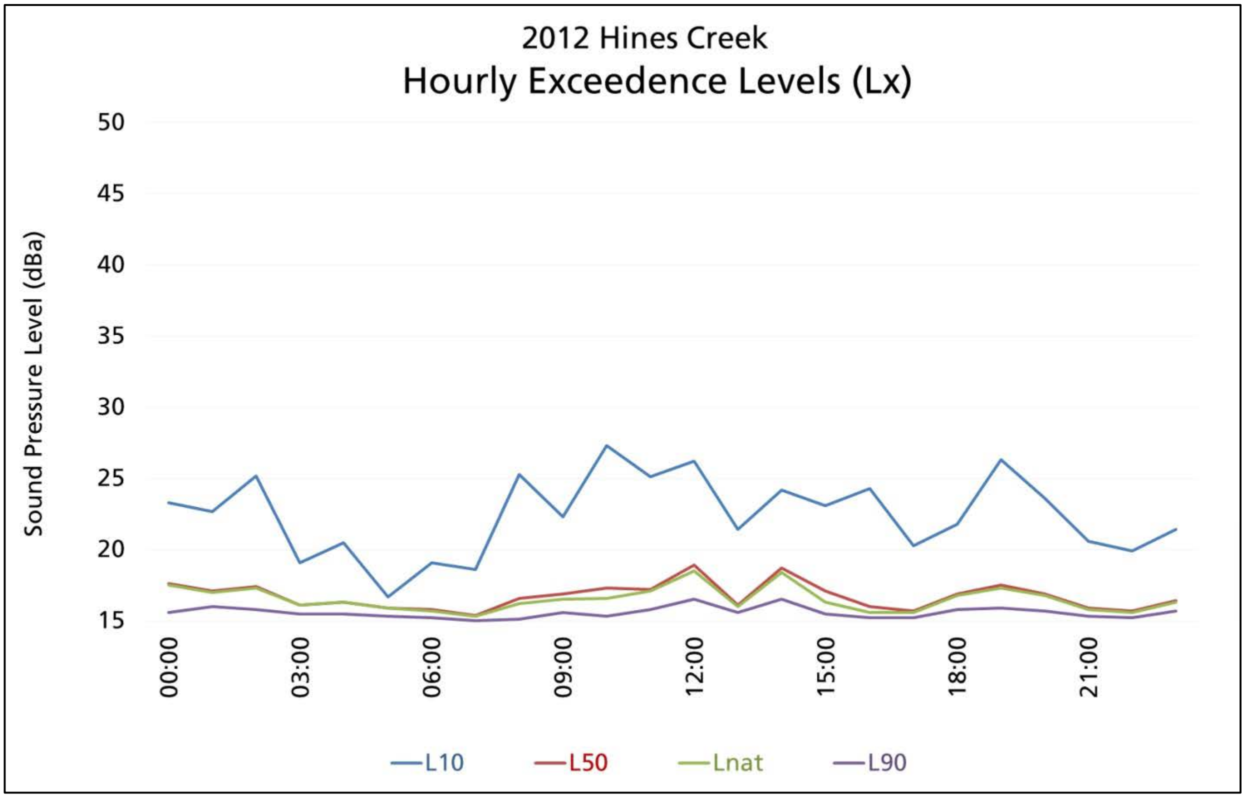


Figure 39. Exceedence levels for Hines Creek.

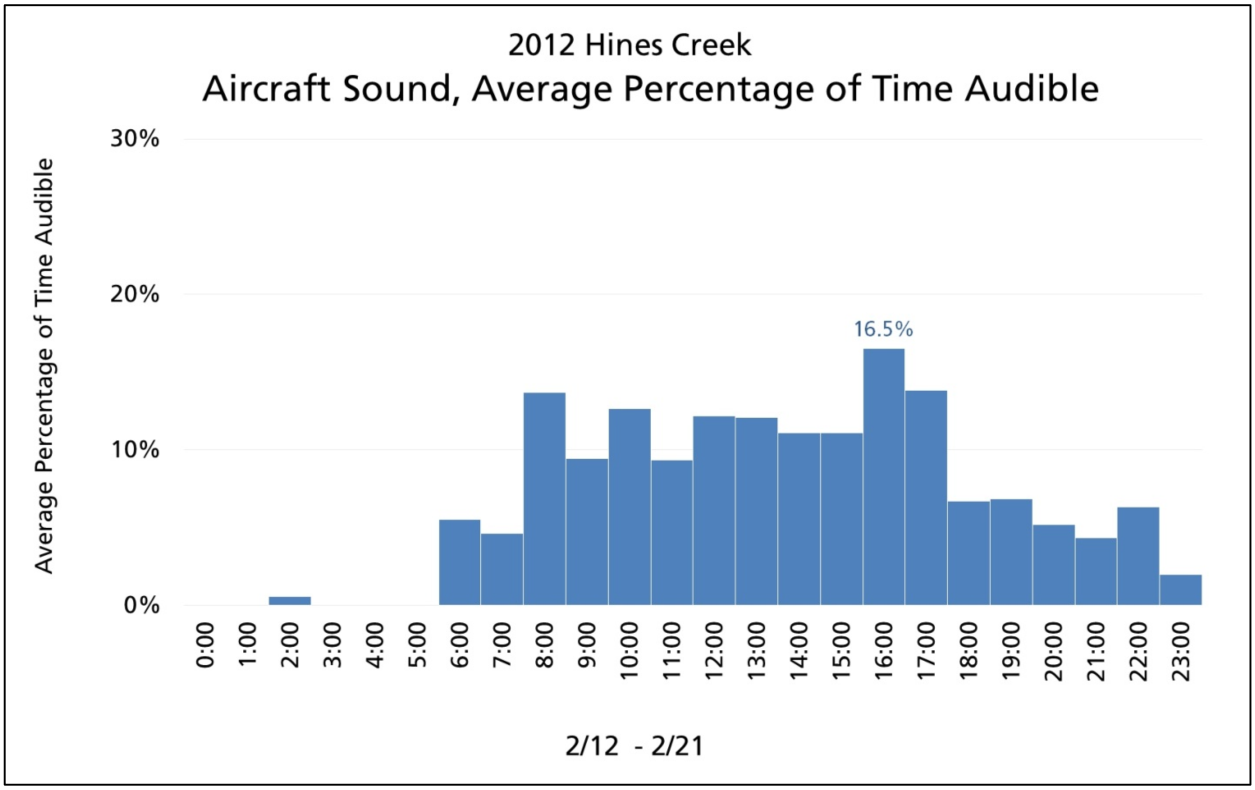


Figure 40. Audibility of aircraft noise for an average day, by hour, at Hines Creek.

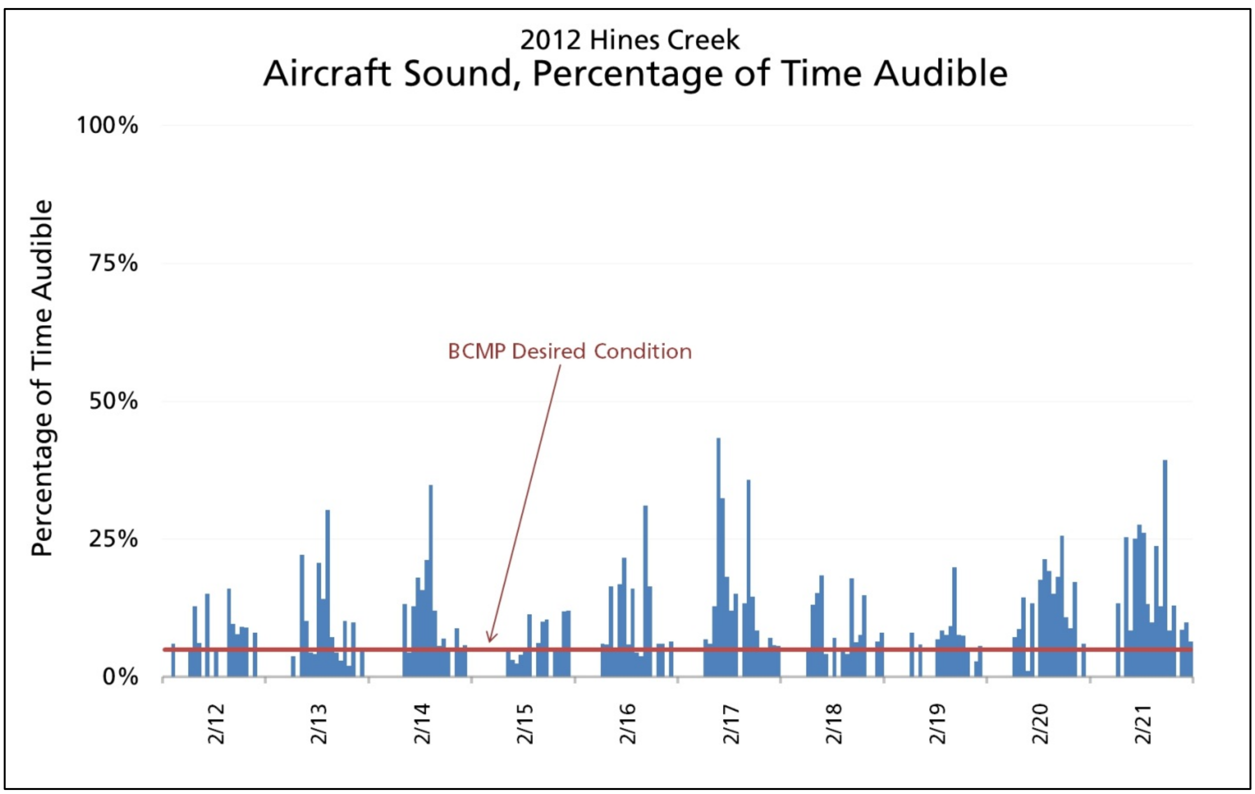


Figure 41. Audibility of aircraft noise at Hines Creek.

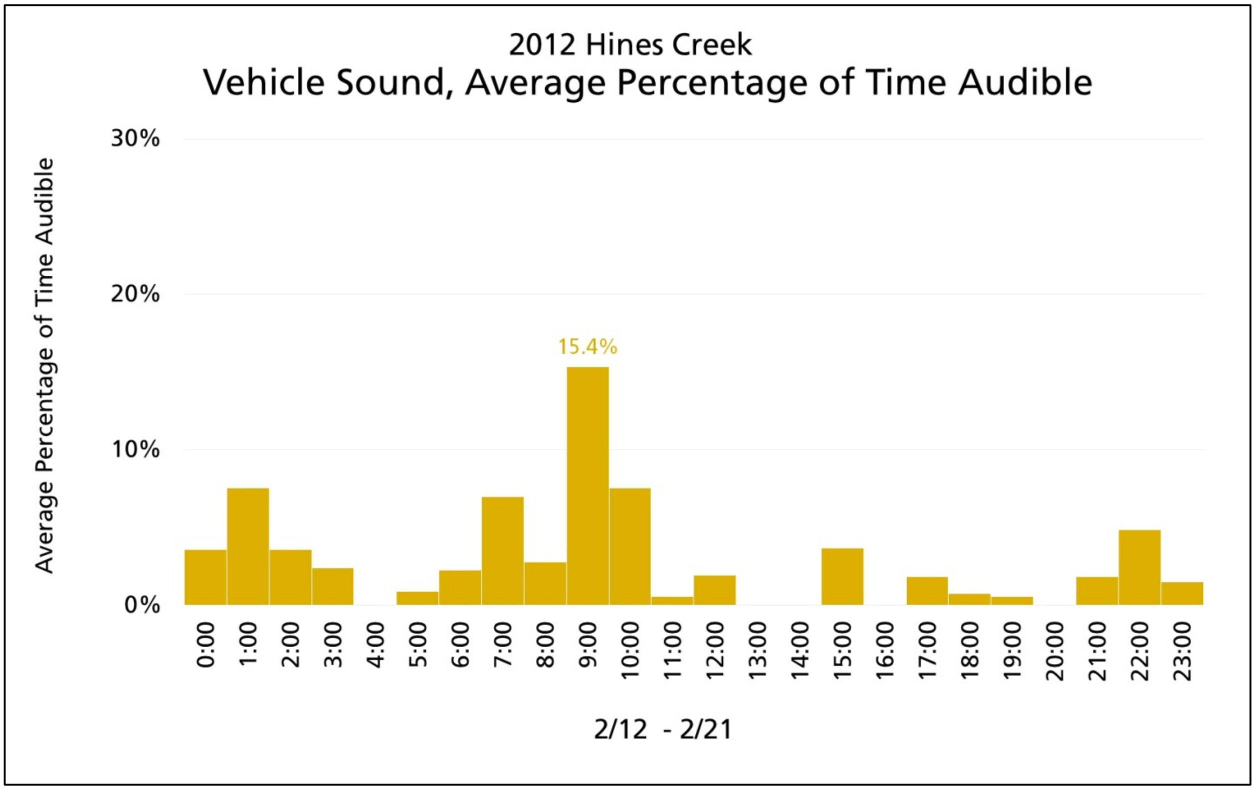


Figure 42. Audibility of road vehicle noise for an average day, by hour, at Hines Creek.

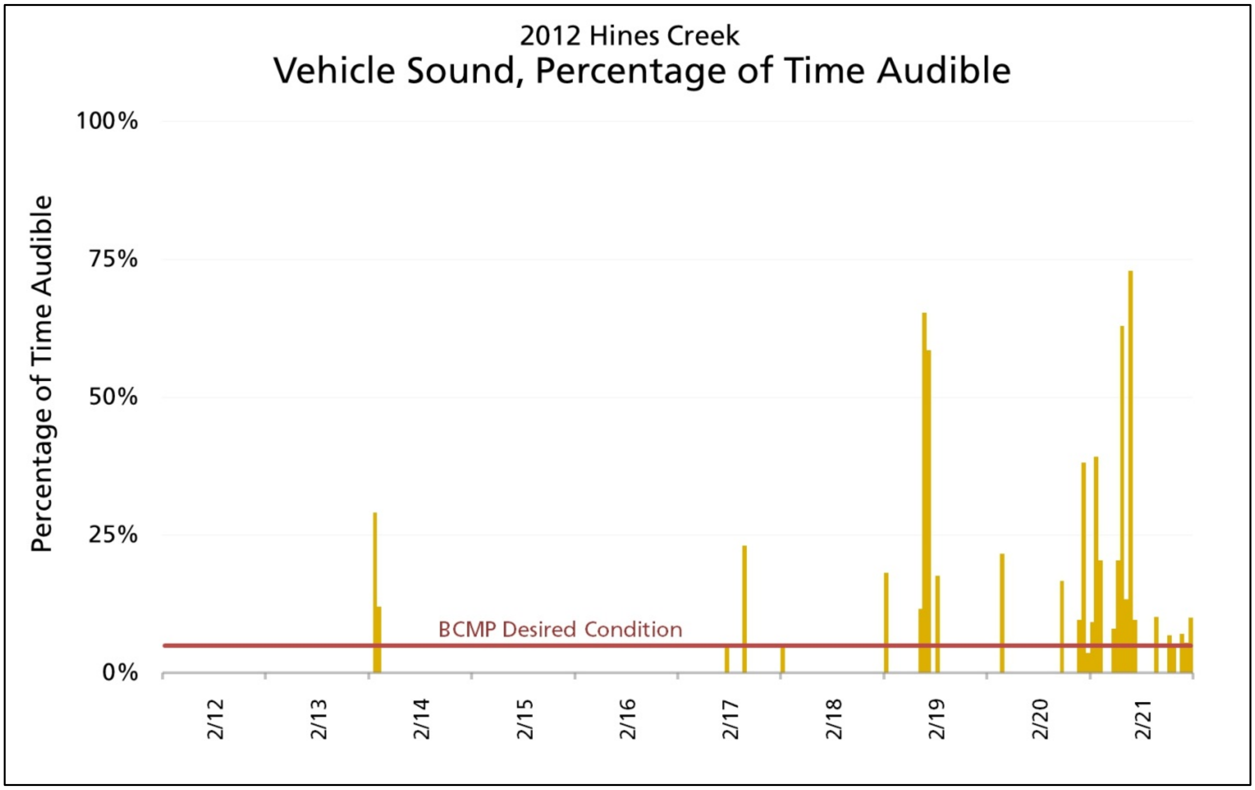


Figure 43. Audibility of road vehicle noise at Hines Creek.

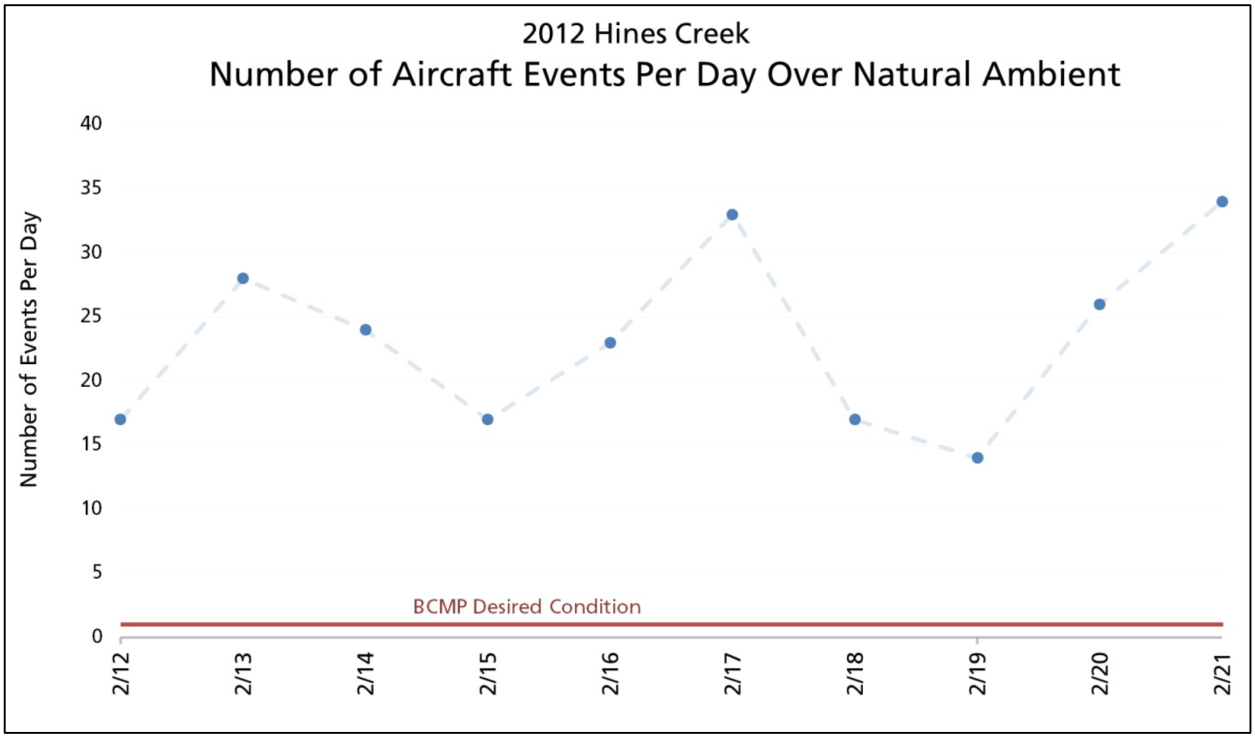


Figure 44. Number of aircraft noise events detected per day at Hines Creek.

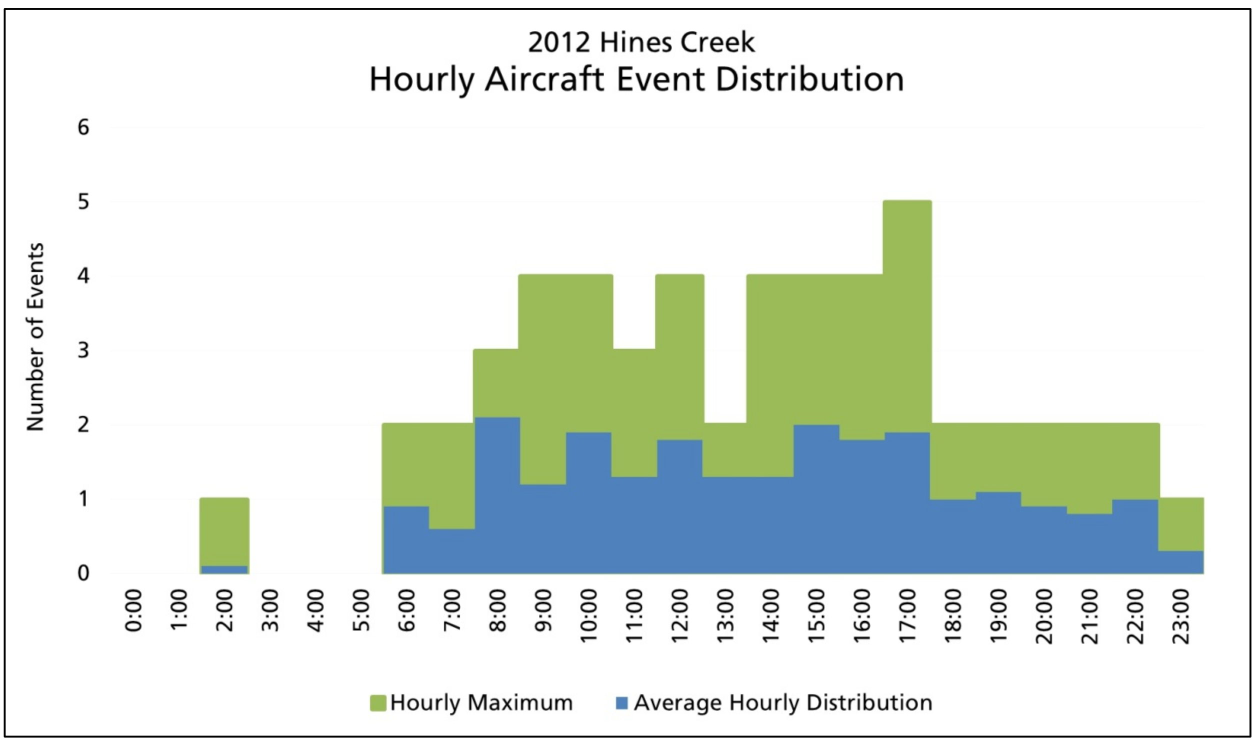


Figure 45. Hourly average and maximum rates of detection for aircraft noise events at Hines Creek.

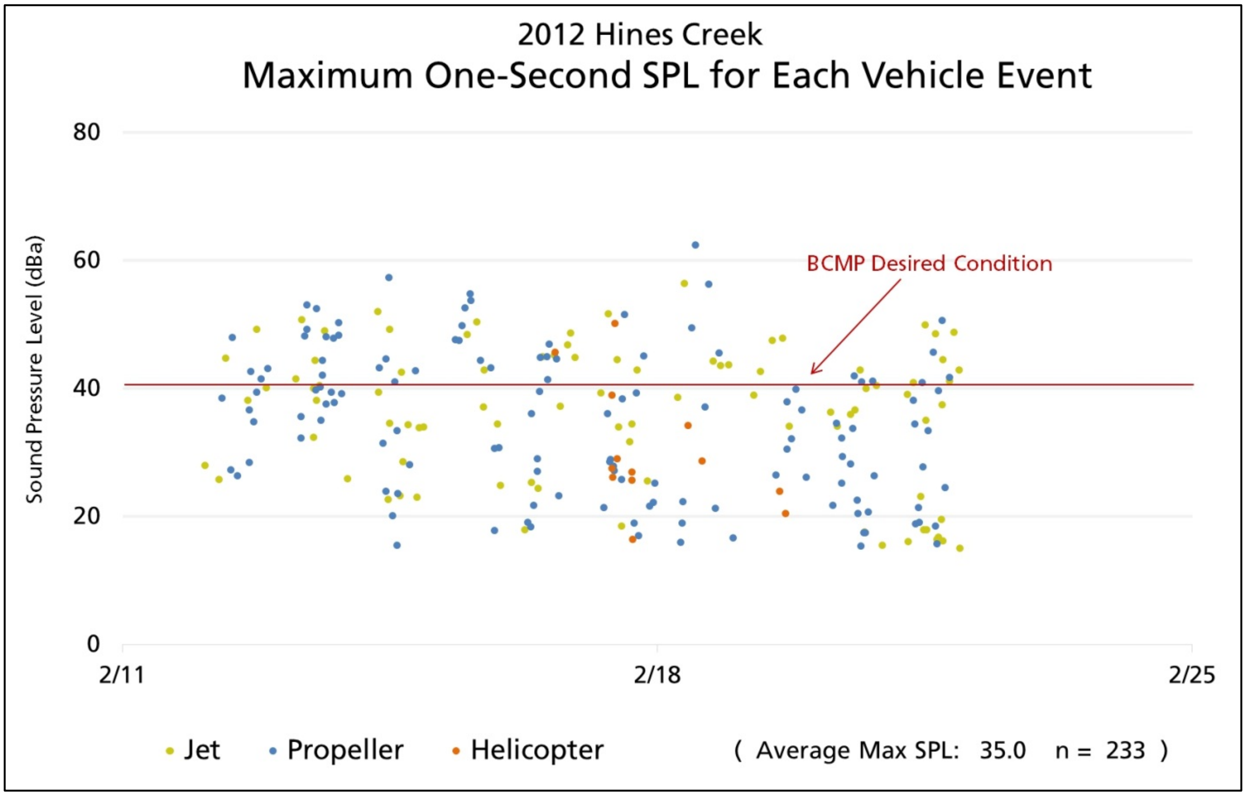


Figure 46. Maximum one-second sound pressure level for each aircraft event identified at Hines Creek.

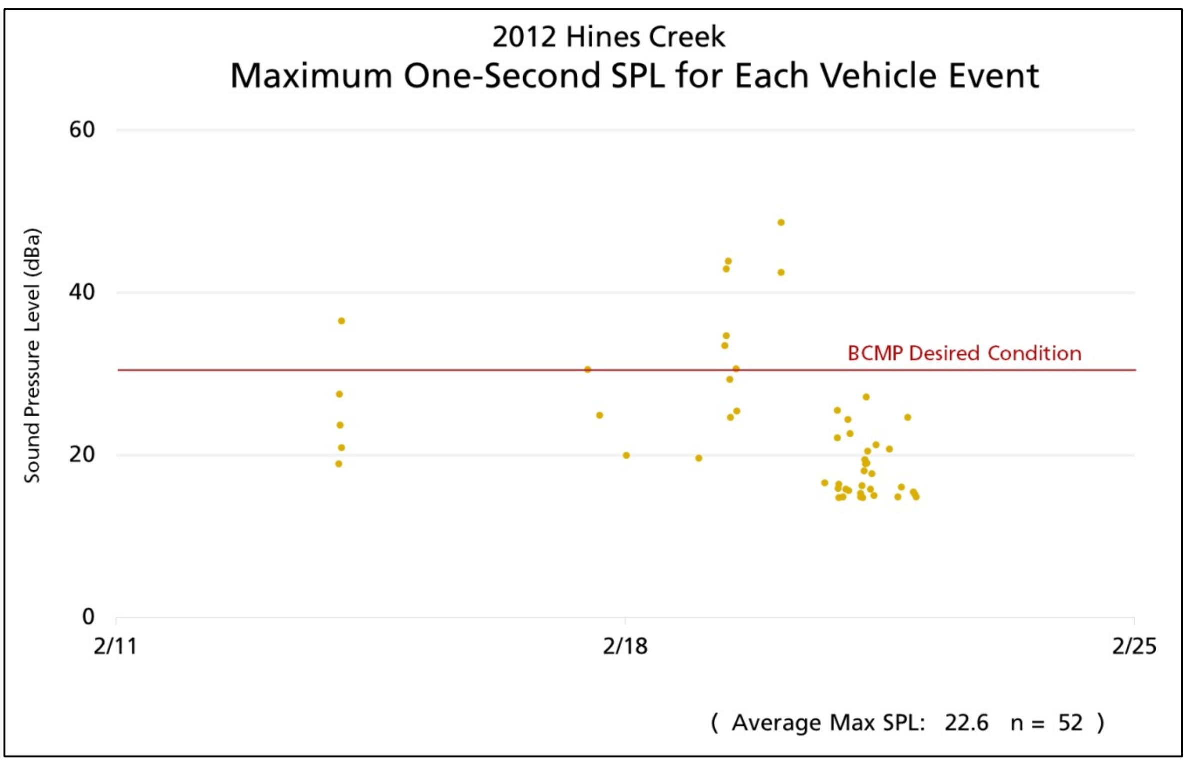


Figure 47. Maximum one-second sound pressure level for each road vehicle event identified at Hines Creek.

Kichatna Mountains

Location Description: A steep alpine alder slope above the headwaters of Fourth-of-July Creek in the Kichatna Mountains.

Purpose/Project: Location randomly chosen from the LTEM grid as part of the long-term Denali Soundscape inventorying and monitoring sampling plan.

Coordinates: 62.34868°, -152.44975° (WGS84)

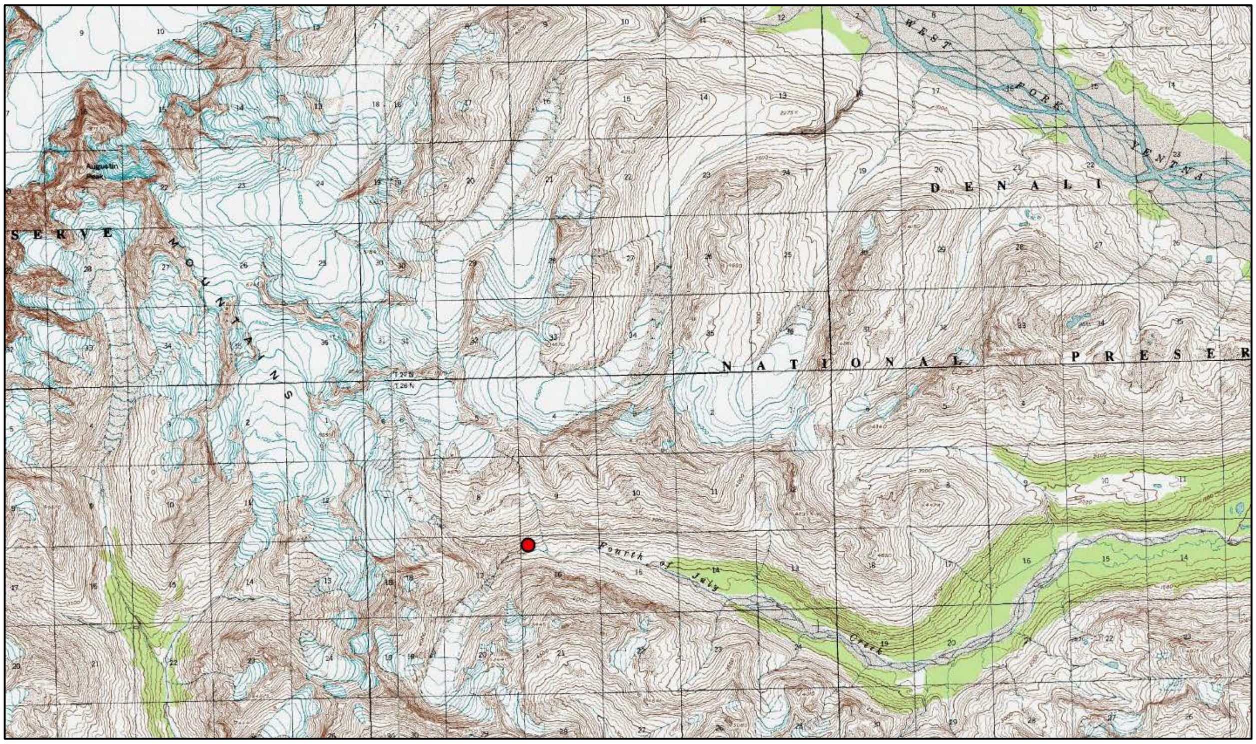
Elevation: 637 meters

BCMP Management Area: D (Low Natural Sound Disturbance)

Park Ecoregion: Alaska Range South Central Mountains and Valleys

Sampling Period: 19-May-2012 to 18-June-2012

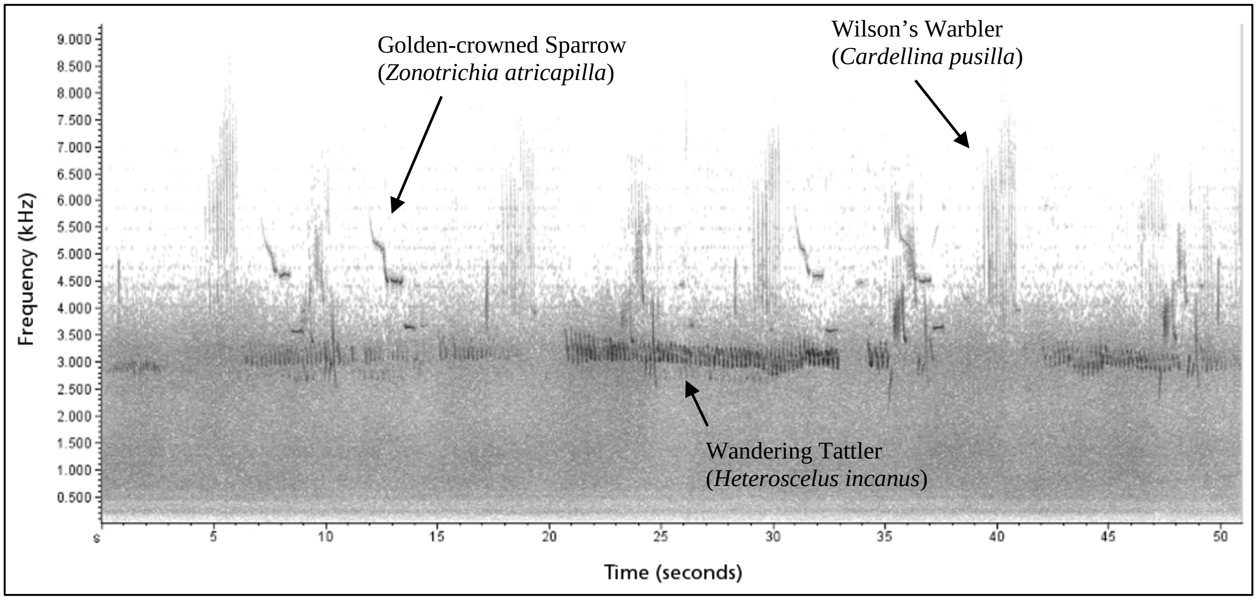
Access: Helicopter



Summary/Notes: The purpose of the Kichatna Mountains location was to collect data at one of the long-term ecological monitoring (LTEM) grid points, as outlined in the above sampling plan. LTEM grid point #8 was stratified as a New Park (ANILCA expansion) location and randomly selected from all locations requiring aircraft access.

The soundscape at the Kichatna Mountains sampling location was primarily characterized by the swift coursing water of Fourth-of-July Creek and it's nearby tributaries. With a time-averaged natural ambient level of 44.61 dBA, the natural soundscape of the area was the second loudest sampled in the park thus far (compared to 46.07 dBA at Upper West Fork Yentna River in 2010, and 44.14 dBA near at North Triple Lakes Trail on Riley Creek in 2011). Throughout the sampling period, water from melting snow and glacial ice steadily increased the discharge of the creek. This had a strong, direct effect on the natural ambient level. For instance, on May 20th the average sound pressure level for the day was about 35.7 dBA, but by June 17th the average level for the day had increased to 51.7 dBA— a change of about 16 decibels.

Avian sound was the second major natural component of the soundscape and also showed a seasonal progression throughout the sampling period. Golden-crowned Sparrow (*Zonotrichia atricapilla*), Fox Sparrow (*Passerella iliaca*), and Hermit Thrush (*Catharus guttatus*) were the main members of the dawn chorus at the beginning of the record, but Wilson's Warbler (*Cardellina pusilla*) - first detected on May 26th - quickly became the third most frequent singer at the site. White-tailed Ptarmigan (*Lagopus leucura*) and Redpoll (*Carduelis* sp.) were commonly heard calling throughout the record. Several other species were less-frequently heard, including: Ruby-crowned Kinglet (*Regulus calendula*), White-crowned Sparrow (*Zonotrichia leucophrys*), Black-capped Chickadee (*Poecile atricapillus*), and notably, Wandering Tattler (*Tringa incana*). Wandering Tattlers are a rarely recorded, high-interest species that rely on the gravel bars and stream-banks of Alaska and adjacent Canada for their breeding habitat. The first discovery of a Wandering Tattler nest was in Denali by Olaus and Adolph Murie at the Savage River, 07/01/1923 (Murie 1924).



Spectrogram 3. The trilling flight call of a Wandering Tattler (*Heteroscelus incanus*) as it passes the Kichatna Mountains sound station. The energy of the call is centered around 3 kHz. Songs of a Golden-crowned Sparrow (*Zonotrichia atricapilla*) and a Wilson's Warbler (Cardellina pusilla) are also apparent in the record. The spectrogram begins at 11:24:31 on 06/02/2012.

The most commonly heard sounds at this site were flowing water (audible 100.0% of the time), birds (67.6% of the time—55.5% of the time was song, 28.5% was calling), wind (37.5%), and rain (6.9%). Human made sound was audible 1.7% of the time on average; the source was always an aircraft. This is equivalent to 24.5 minutes each day, or approximately 7 overflights a day. Conditions exceeded the BCMP percent audible standard 13% of the time, number of events per day 100% of the time, and maximum SPL 100% of the time (this was due to a very energetic natural conditions). As evident in Figure 48, the natural ambient level was above 40 dBA during every hour of the day, and thus is was not possible to detect aircraft that were below the standard.)

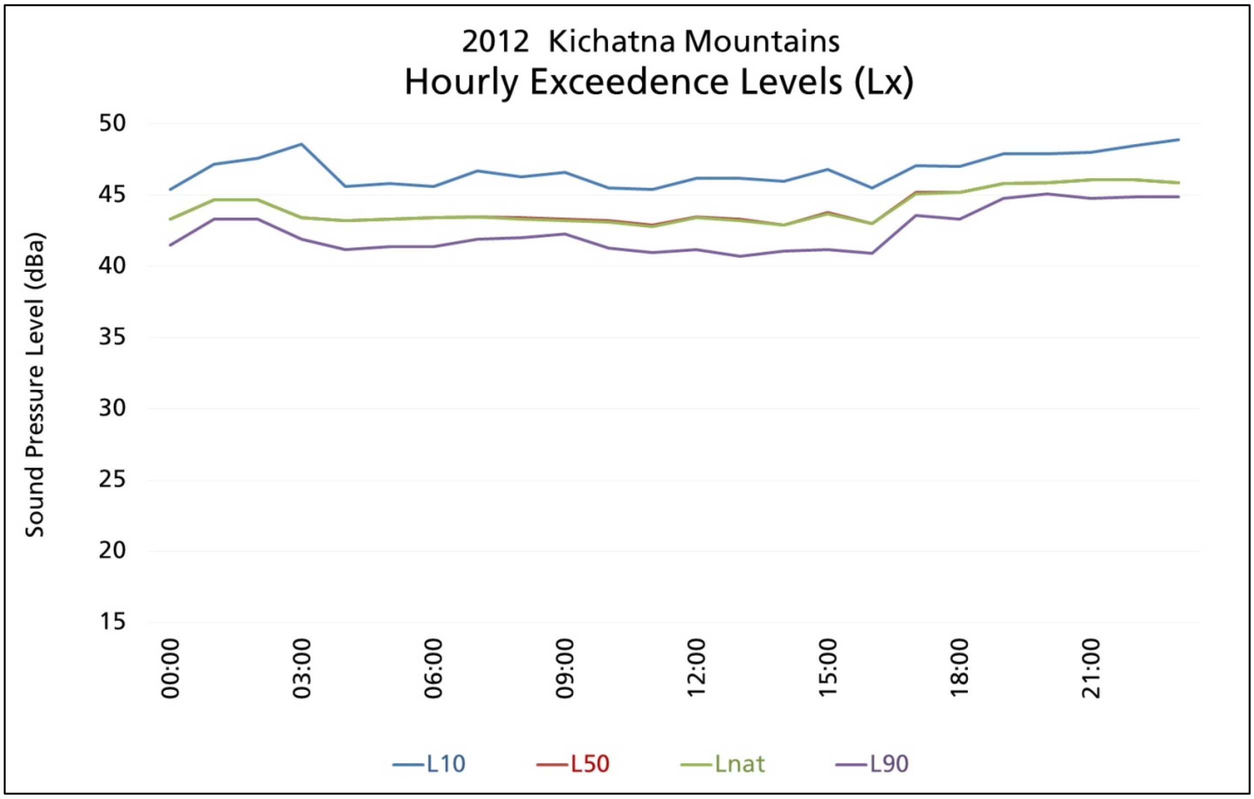


Figure 48. Exceedence levels for Kichatna Mountains.

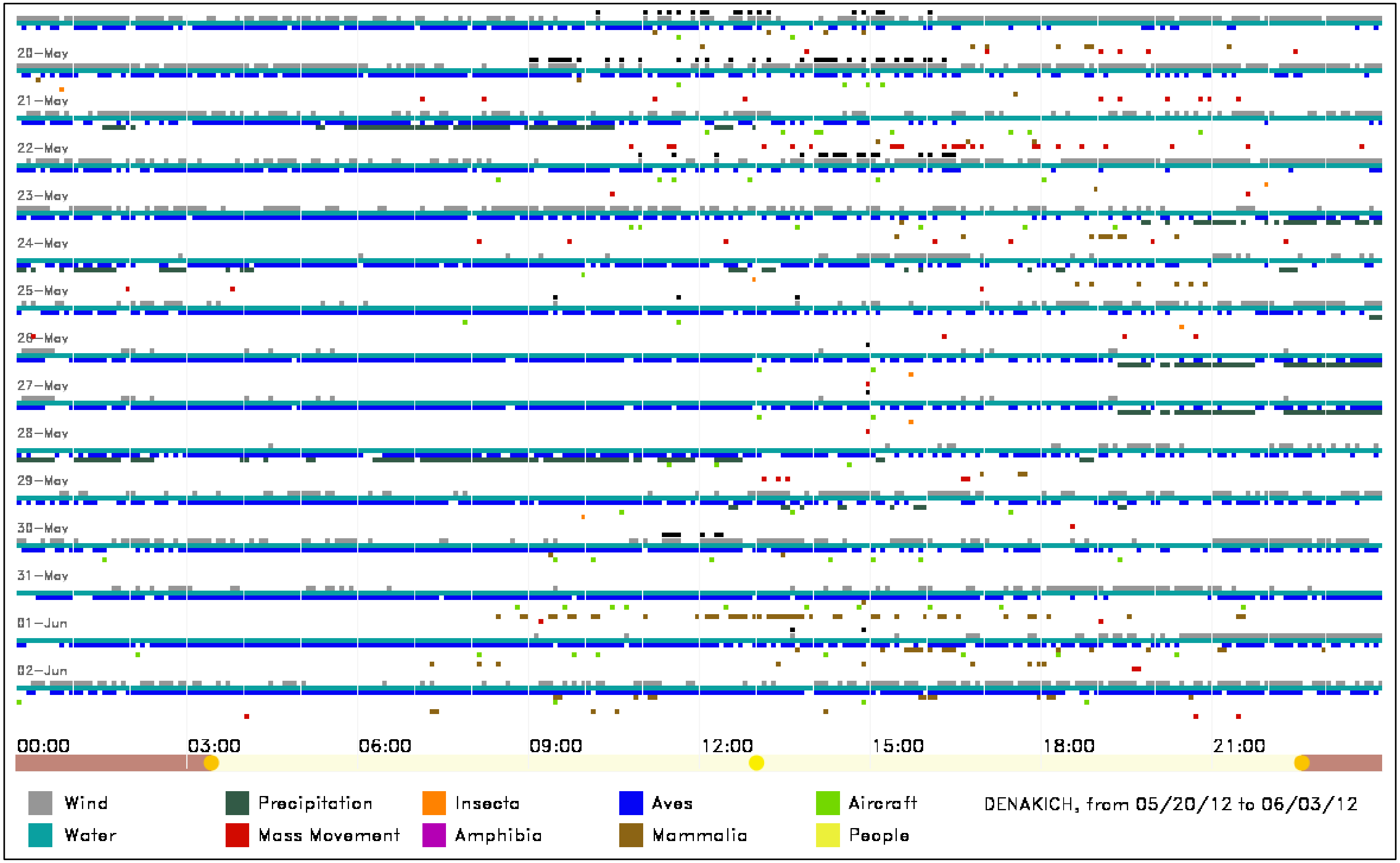


Figure 49. Temporal audibility of sound sources at Kichatna Mountains, based on five seconds of audio every five minutes. The bar along the horizontal axis indicates the average light conditions during the sampling period. The orange circles are sunrise/sunset. This site did have civil twilight or night-time conditions during the sampling period.

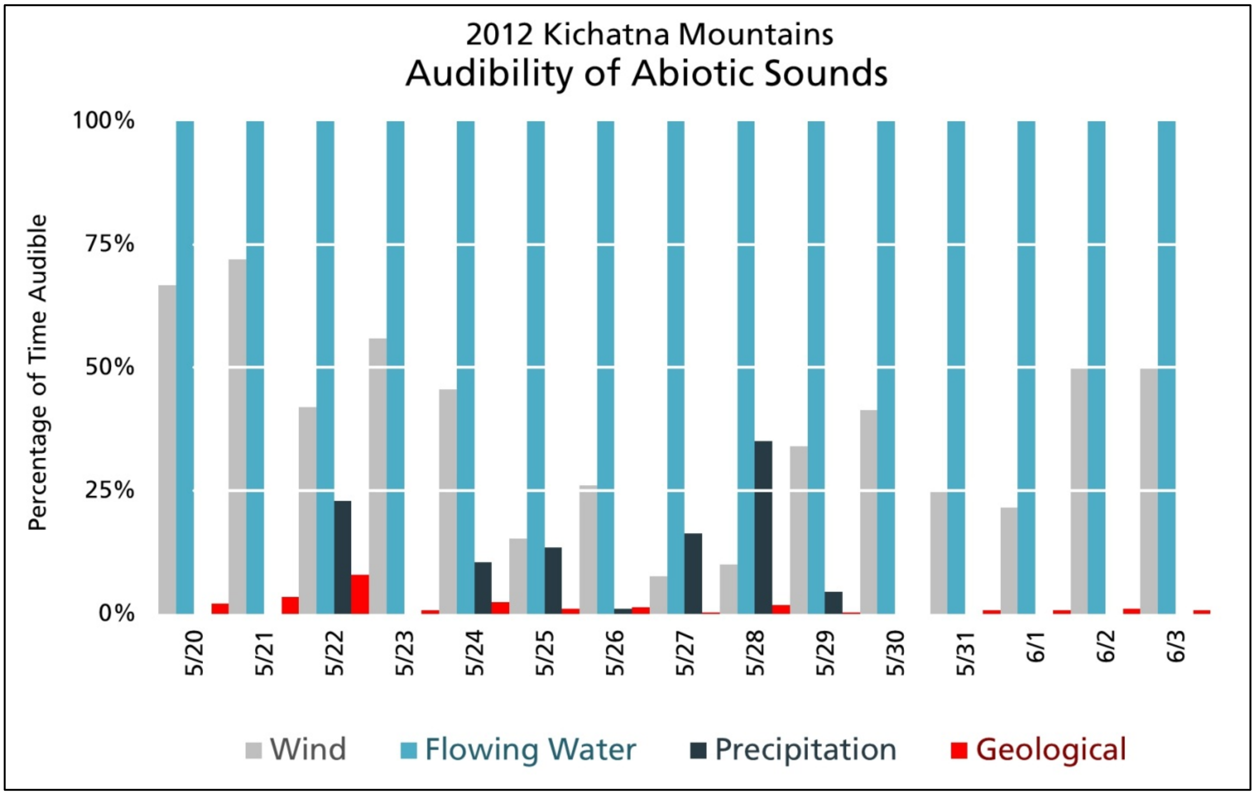


Figure 50. Audibility of abiotic sounds at Kichatna Mountains.

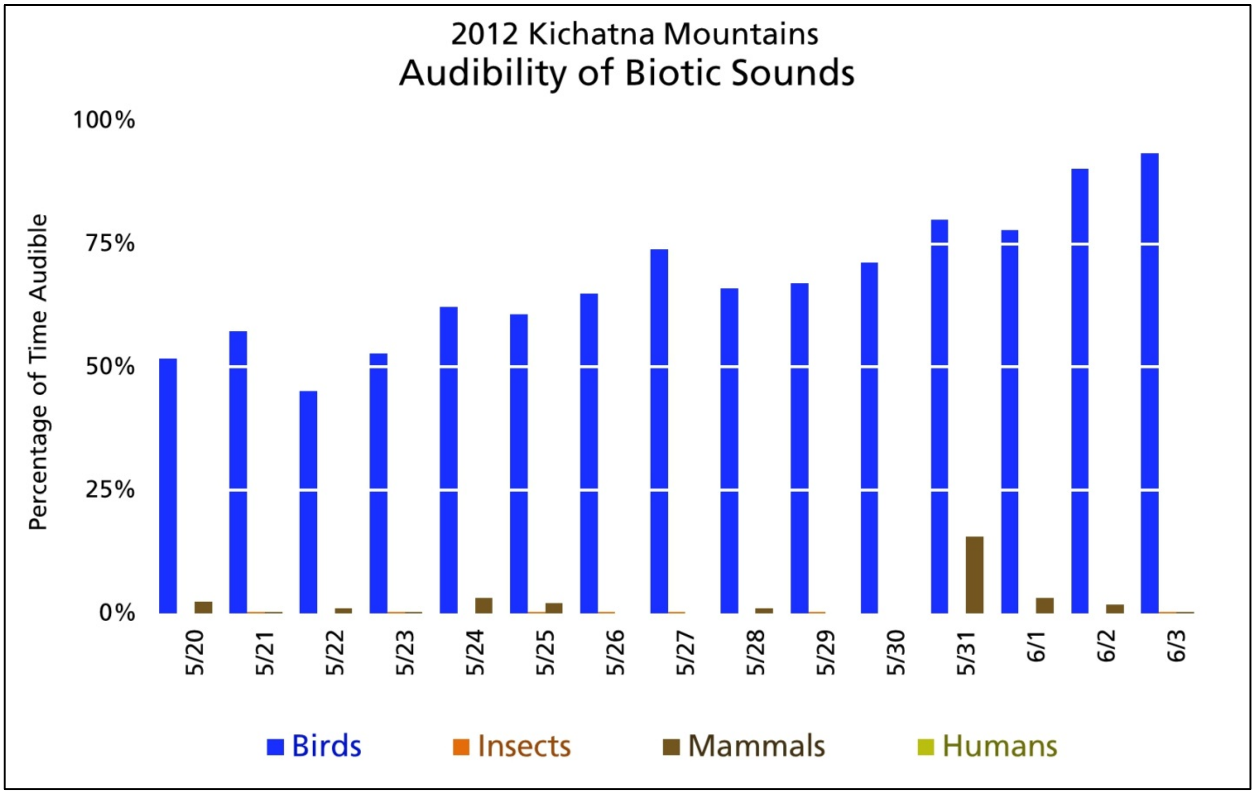


Figure 51. Audibility of biotic sounds at Kichatna Mountains.

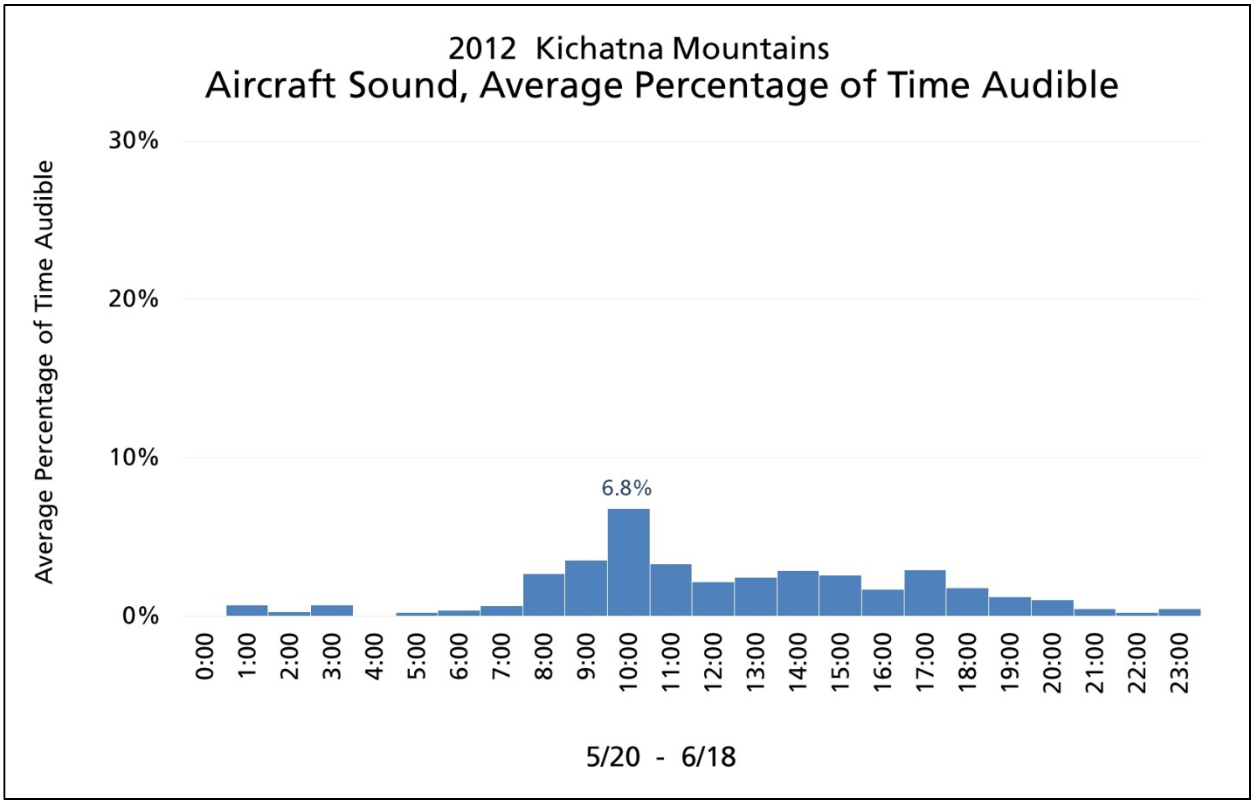


Figure 52. Audibility of aircraft noise for an average day, by hour, at Kichatna Mountains.

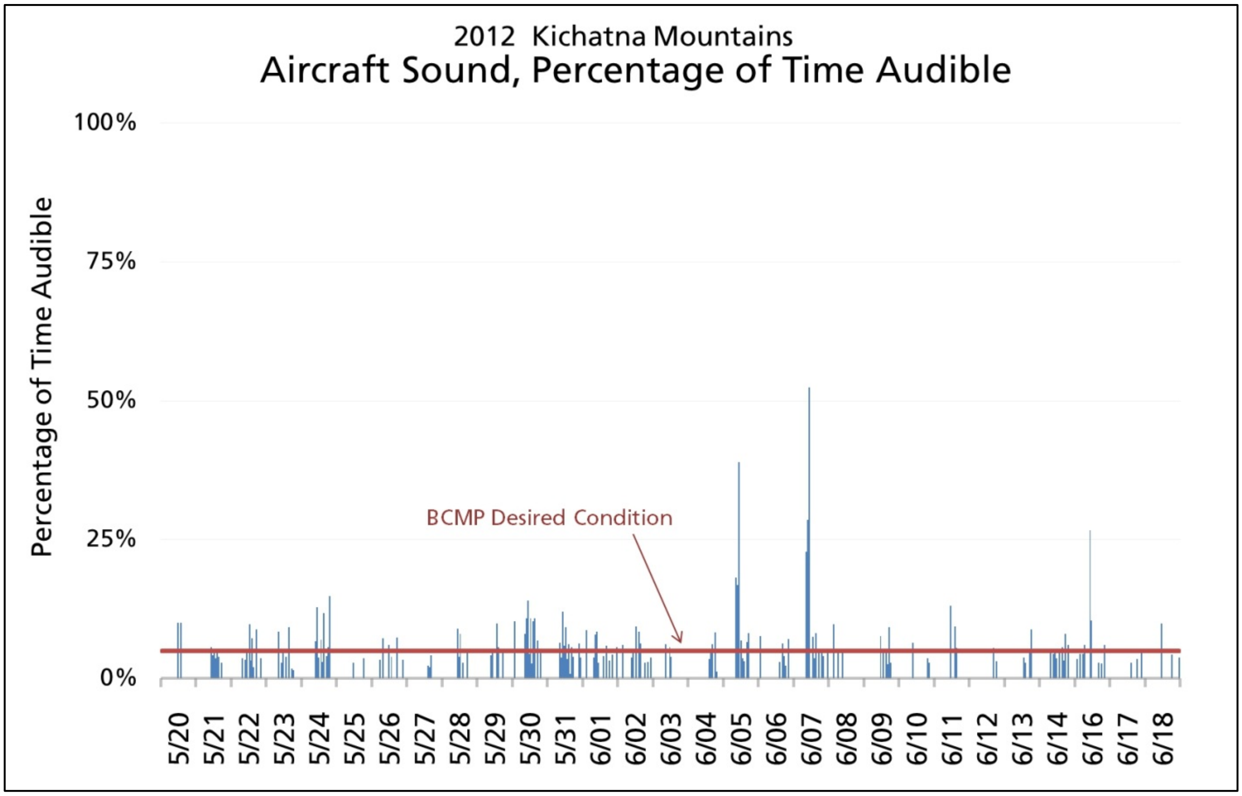


Figure 53. Audibility of aircraft noise at Kichatna Mountains.

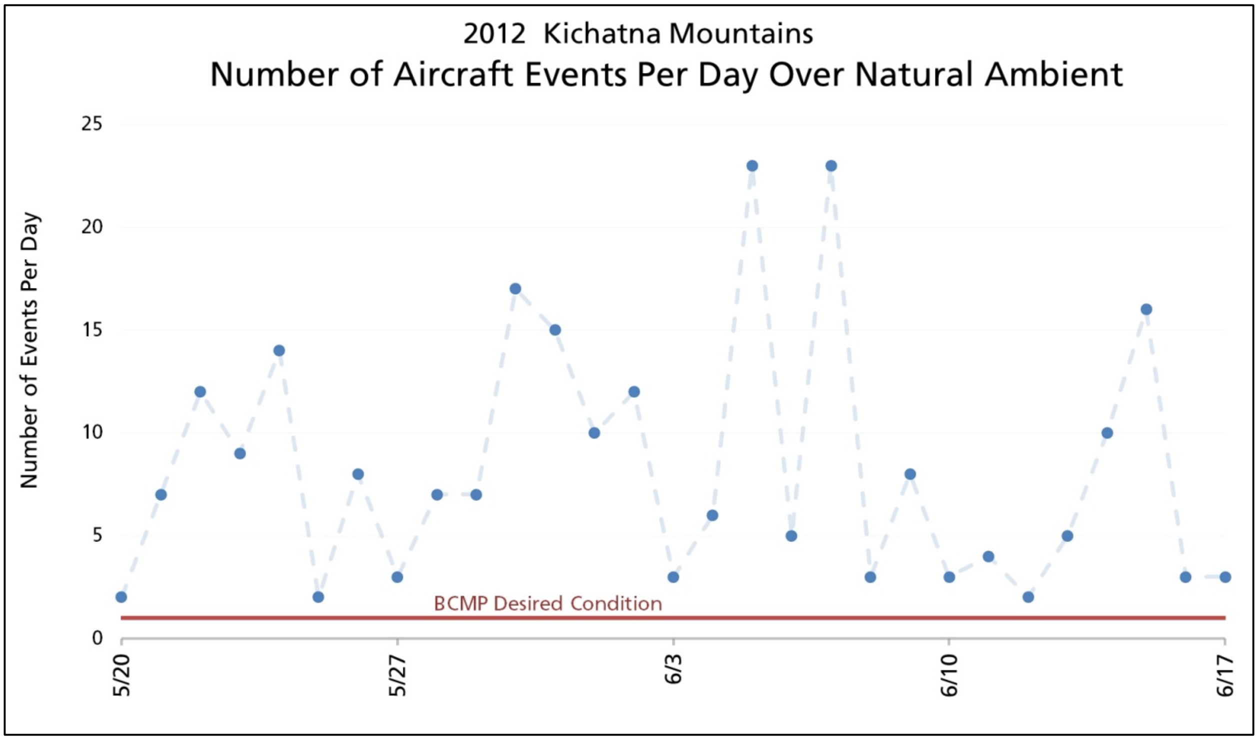


Figure 54. Number of aircraft noise events detected per day at Kichatna Mountains.

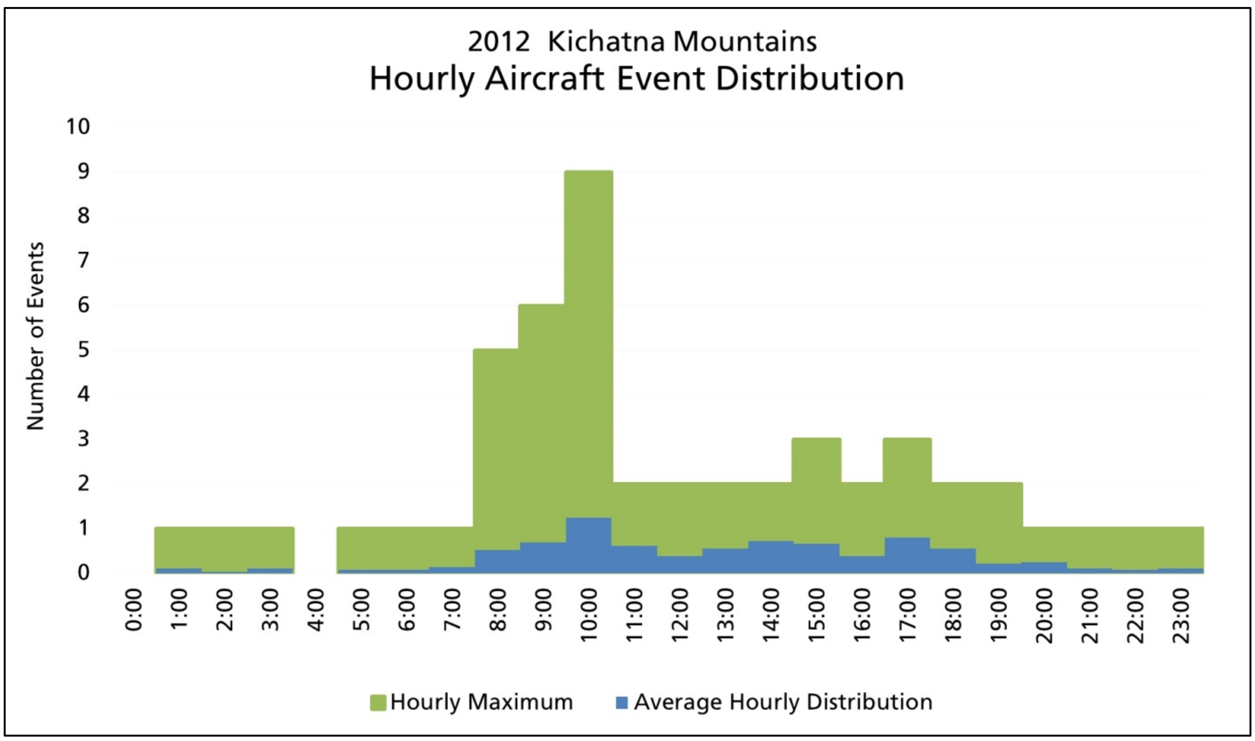


Figure 55. Hourly average and maximum rates of detection for aircraft noise events at Kichatna Mountains.

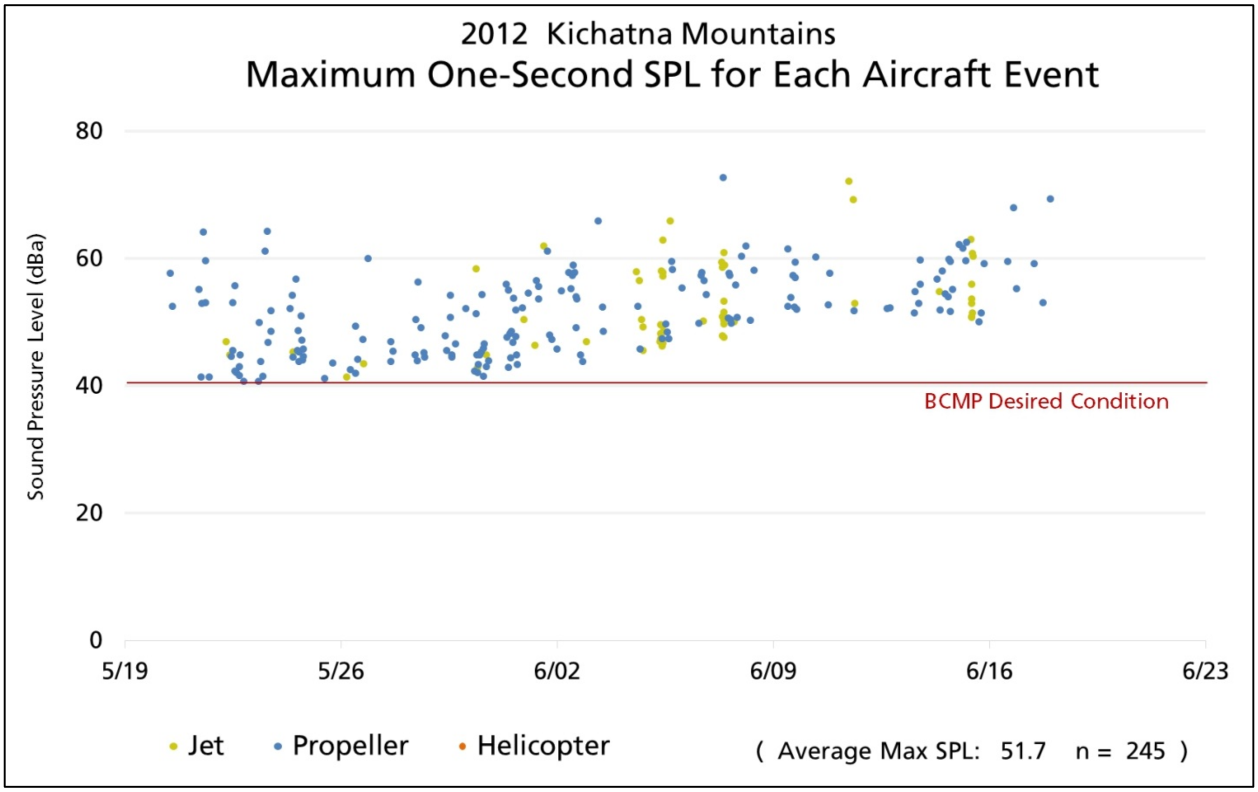


Figure 56. Maximum one-second sound pressure level for each aircraft event detected at Kichatna Mountains.

McKinley River

<u>Location Description</u>: About 5 km from the McKinley River, on a muskeg pond within the network of streams that feeds Slippery Creek.

<u>Purpose/Project</u>: Location randomly chosen from the LTEM grid as part of the long-term Denali Soundscape inventorying and monitoring sampling plan.

<u>Coordinates</u>: 63.61935°, -151.63177° (WGS84)

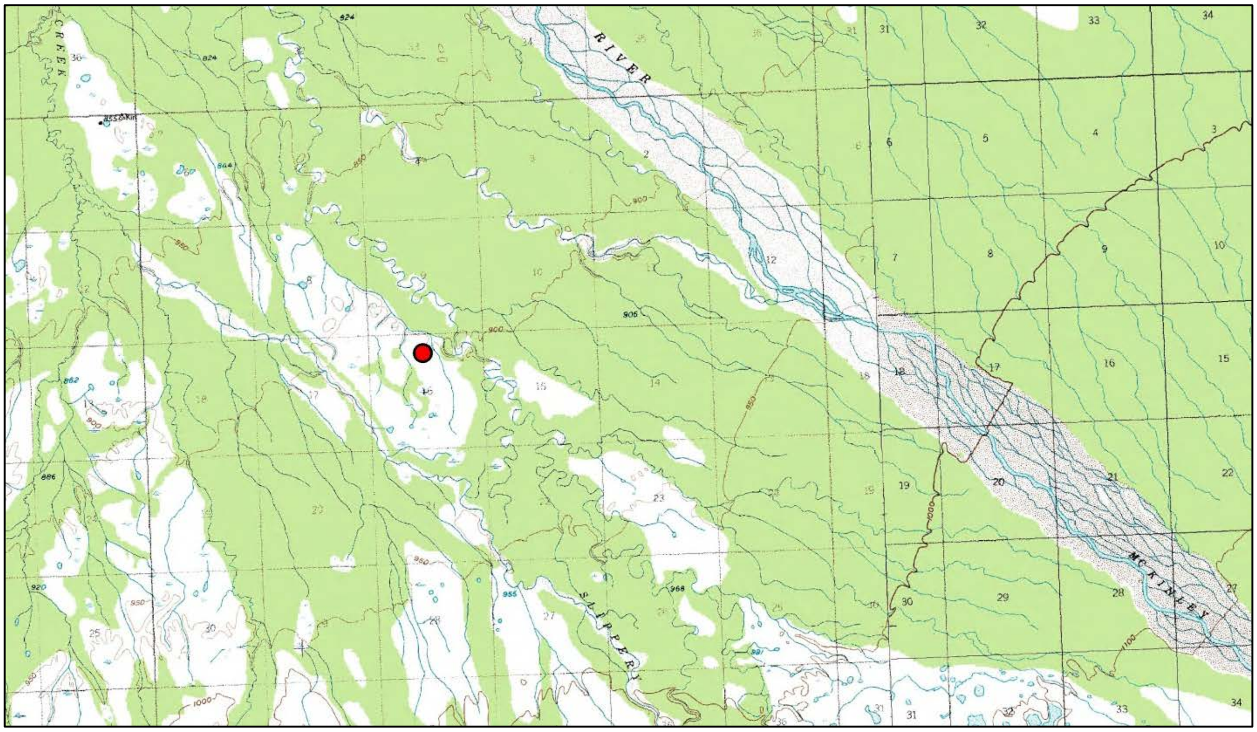
<u>Elevation</u>: 276 meters

<u>BCMP Management Area</u>: D (Low Natural Sound Disturbance)

<u>Park Ecoregion</u>: Kuskokwim Alluvial Fans and Floodplains

<u>Sampling Period</u>: 20-July-2012 to 11-September-2012

<u>Access:</u> Helicopter



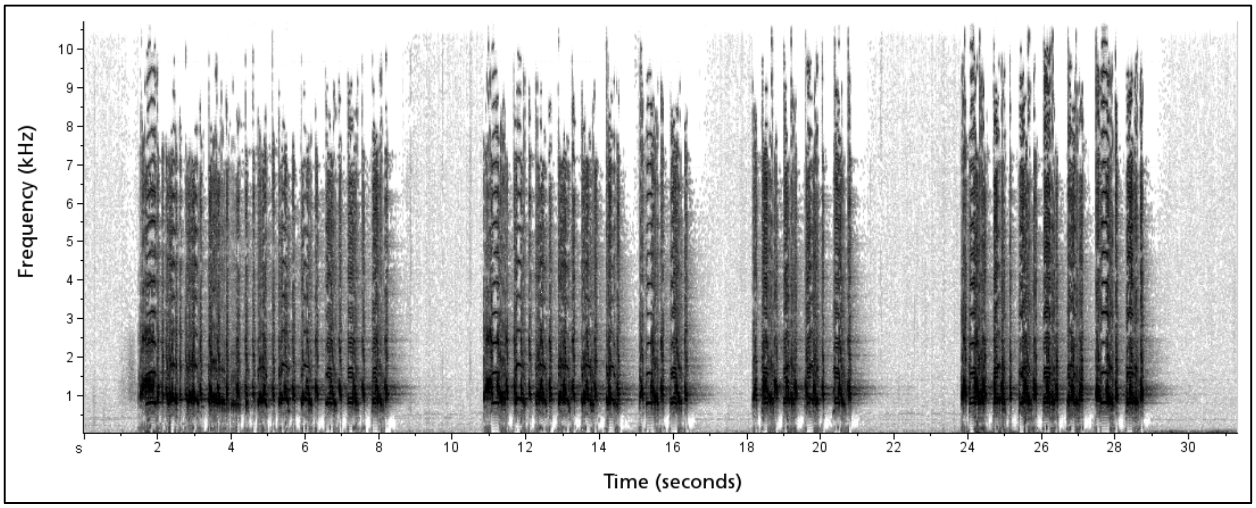
Summary/Notes: The purpose of the McKinley River location was to collect data at one of the long-term ecological monitoring (LTEM) grid points, as outlined in the above sampling plan. LTEM grid point #187 was stratified as a New Park (ANILCA expansion) location and randomly selected from all locations requiring aircraft access.

Natural sounds across the black spruce muskeg of the McKinley River area were primarily driven by heat fluxes through the air and ground. Diurnally, temperatures increased towards 16:00, bringing gentle afternoon winds (with a median speed of 0.03 meters per second,) that were primarily audible due to resistance from the surrounding boughs and stems. Flight of insects –and especially mosquitos – had a strong linear correlation to temperature as well (R = 0.91). These animals were audible in 49% of clips during the analysis, the highest detection rate anywhere in the park to date. Compare to 29% at Lower Kantishna River 2010, 21% at Highpower Creek 2008, or 19% at Castle Rocks 2009. Long-duration drizzling rain showers were also typical of the area during the diurnal hours.

Water carried by the McKinley River was audible in about 48% of clips – and always centered around the coolest times of day. During these times of day the boundary layer of the atmosphere is typically inverted, and sound is diffracted downwards. As the earth heats up, the air in the boundary layer is well mixed— and cools with altitude, causing sound to diffract upwards (Piercy et al. 1977). At distance, the sound of the river becomes inaudible under these conditions (see also West Kantishna Hills 2011, and McKinley Bar Trail 2011 for similar observations of this phenomenon in Denali).

Because of the time of year, no bird song was detectable during the analysis. Calls were intermittently heard, however. Gray Jay (*Perisoreus canadensis*), White-crowned Sparrow, and

Great-horned Owl (*Bubo virginianus*) were the main species detected. A very clear and close record of Sandhill Cranes (*Grus canadensis*) was also made. Several birds vocalized from ground level at distances as close as 10 - 20 meters from the station, but also antiphonally with individuals farther from the microphone. Observations of crane calls during migration tend to be centered on the diurnal hours, but these records were predominantly crepuscular - and would appear to be pre-migratory in nature. Despite this, both types of calls have a strong resonance near 1 kHz, a useful identifying quality on the spectrogram.



Spectrogram 4. A Sandhill Crane (*Grus canadensis*) calls in close proximity to the sound station at McKinley River. Spectrogram begins at 11:26:07 on 08/08/2012.

Human sounds in the area were primarily jet-propelled aircraft flying at high altitude - occurring at about twice the rate of low-level overflights (3.8 jets per day as compared to 2.0 propeller or helicopter aircraft per day).

The most commonly heard sounds at this site were insects (audible 49.0%), flowing water (47.8%), wind (18.0%), birds (13.3%), rain (9.4%), and silence (7.8%). Human made sound was audible 2.3% of the time on average; all of it was generated by aircraft. This is equivalent to 33.1 minutes each day, or approximately 6 overflights a day. Conditions exceeded the BCMP percent audible standard 19% of the time, number of events per day 96% of the time, and maximum SPL 18% of the time.

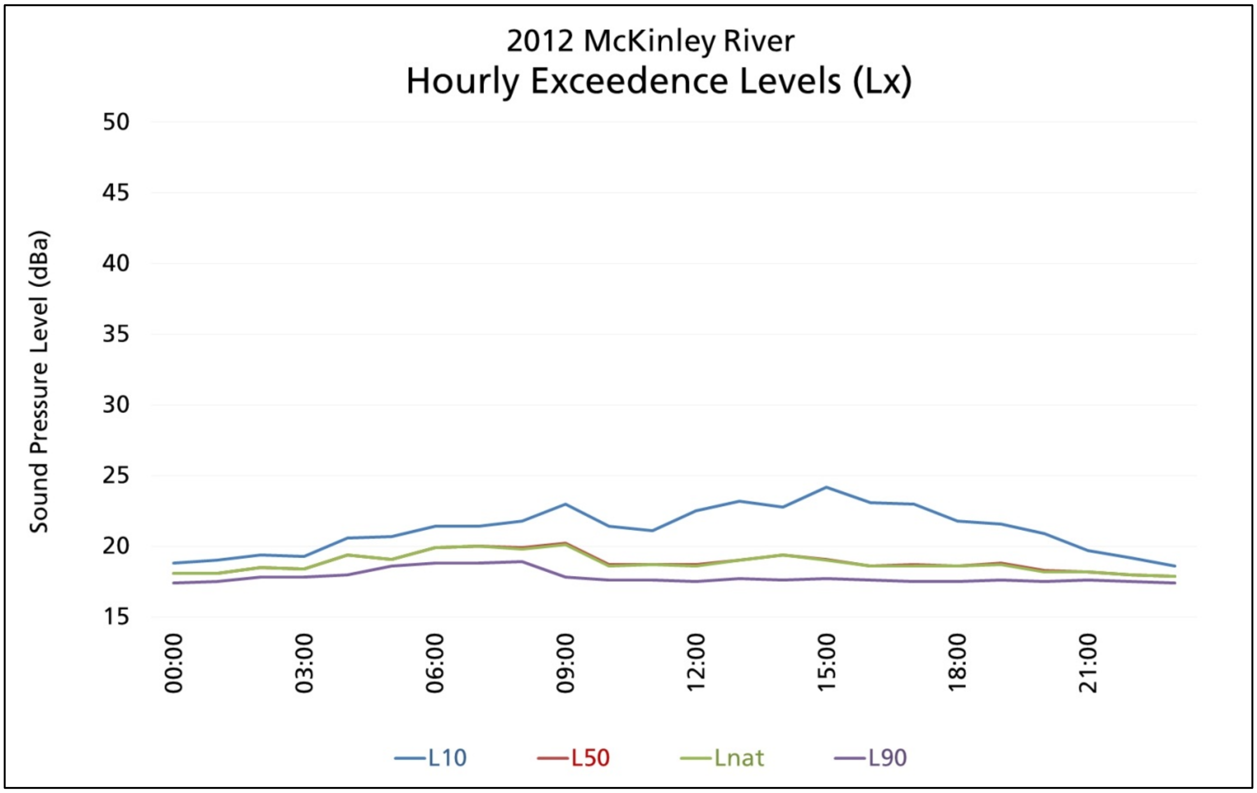


Figure 57. Exceedence levels for McKinley River.

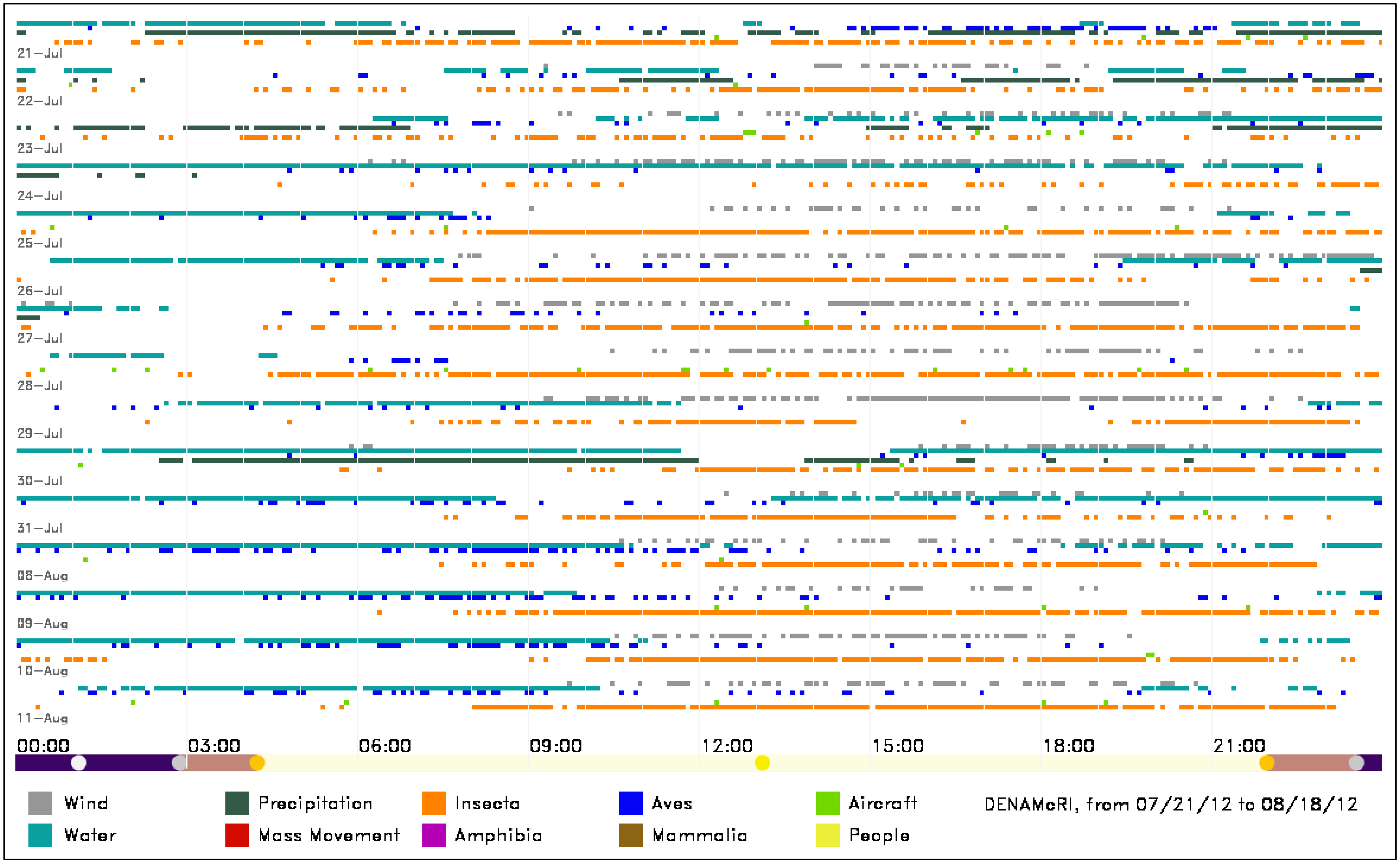


Figure 58. Temporal audibility of sound sources at McKinley River, based on five seconds of audio every five minutes. The bar along the time axis indicates the average light conditions during the sampling period. The orange circles are sunrise/sunset, and the gray circles are the beginning and end of civil twilight.

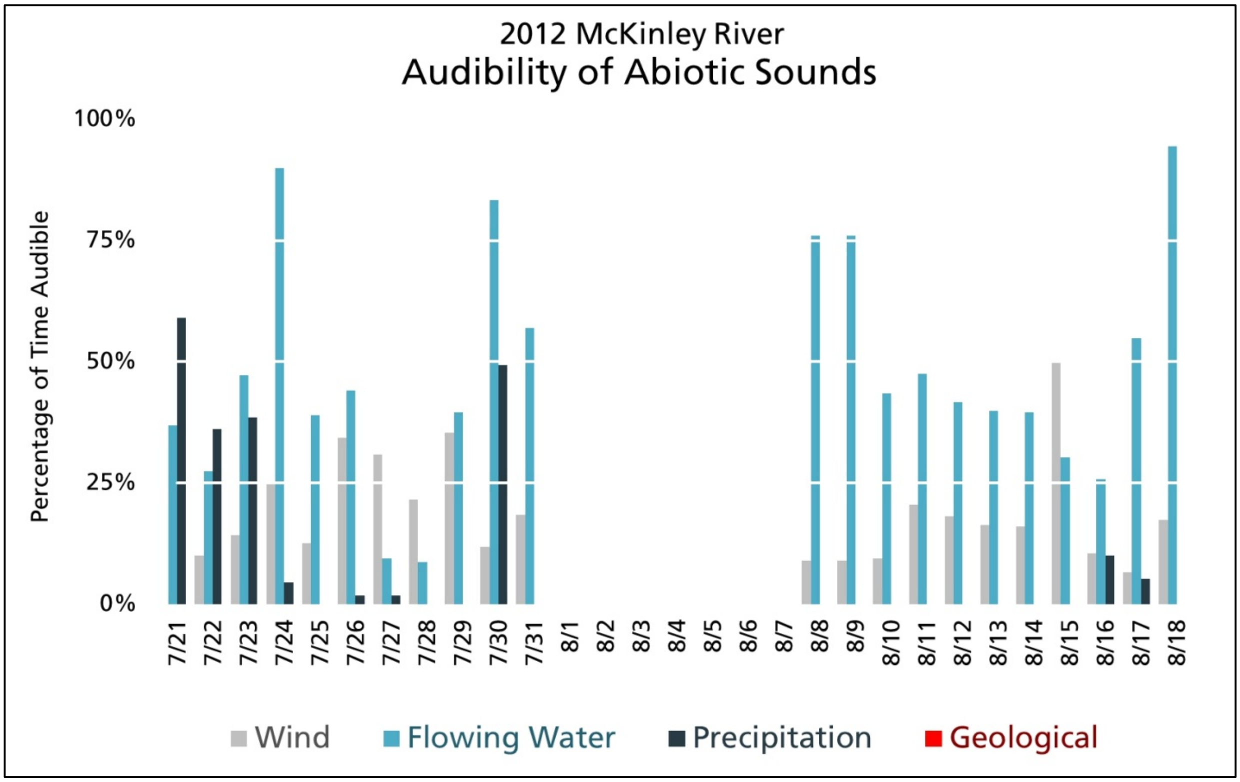


Figure 59. Audibility of abiotic sounds at McKinley River.

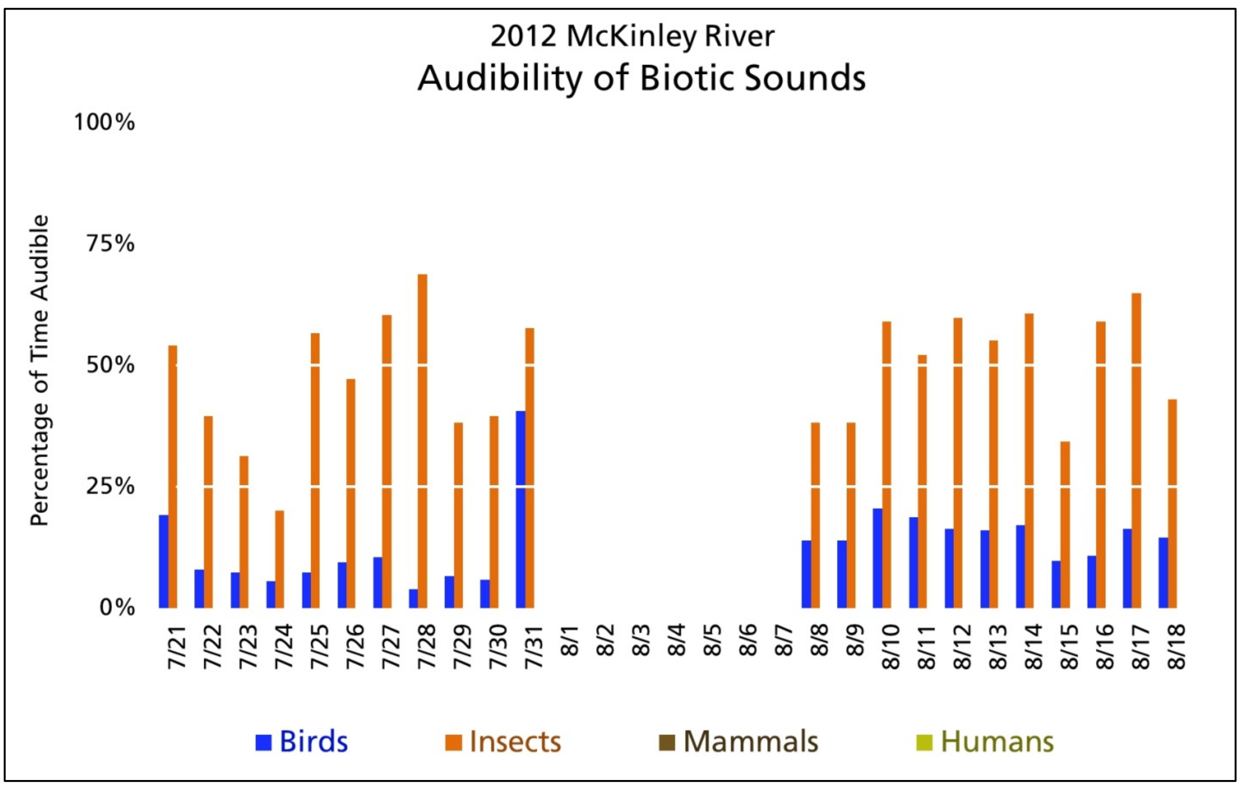


Figure 60. Audibility of biotic sounds at McKinley River.

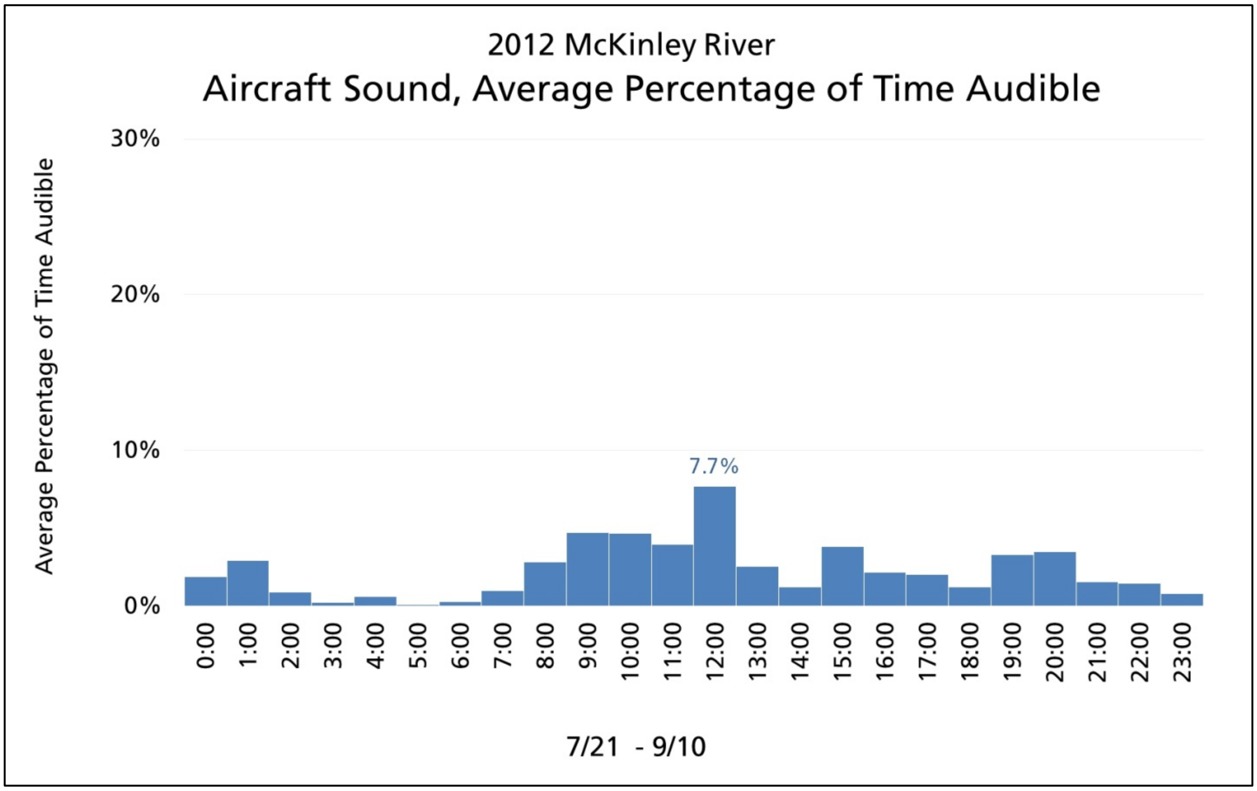


Figure 61. Audibility of aircraft noise for an average day, by hour, at McKinley River.

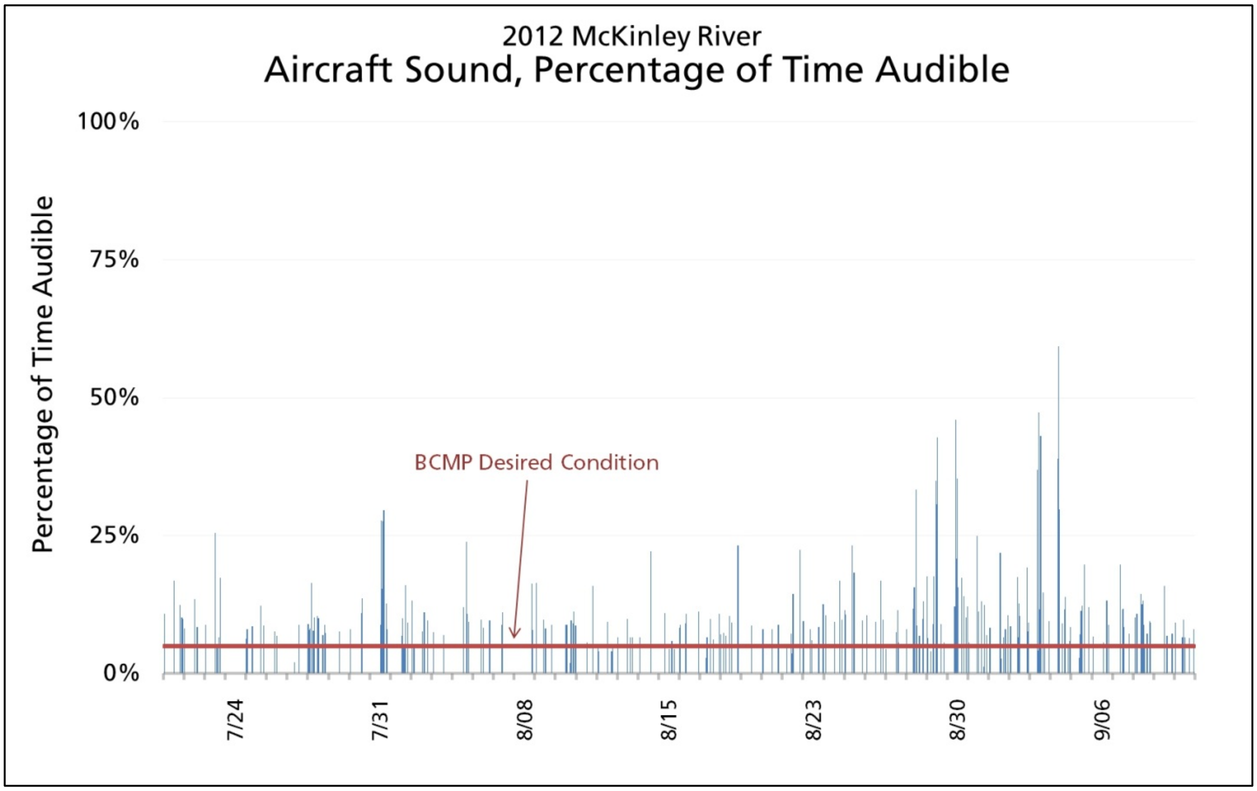


Figure 62. Audibility of aircraft noise at McKinley River.

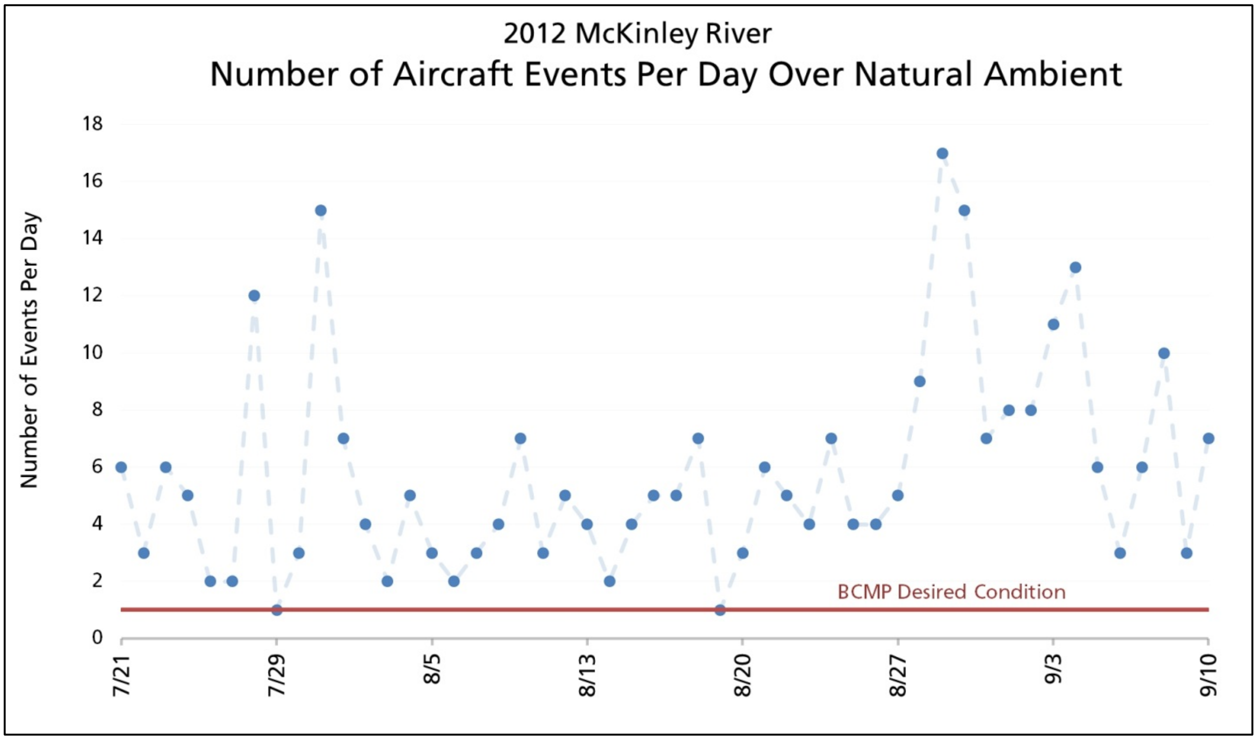


Figure 63. Number of aircraft noise events detected per day at McKinley River.

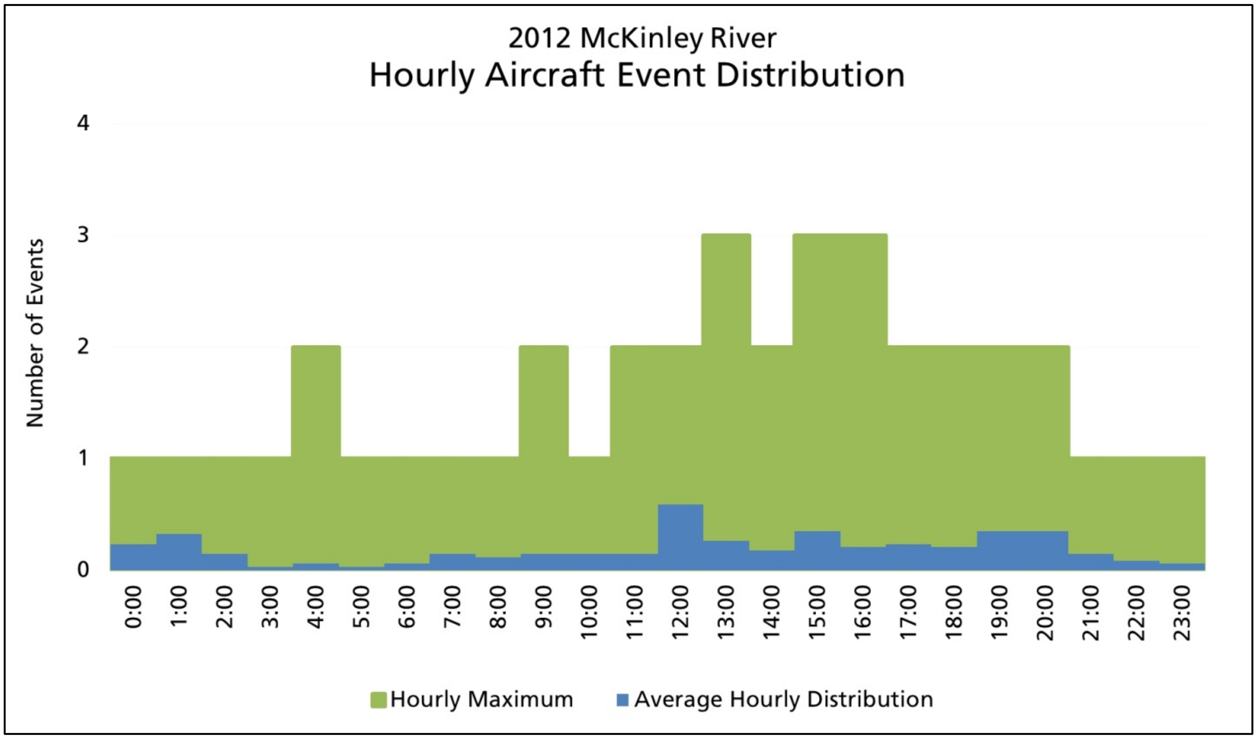


Figure 64. Hourly average and maximum rates of detection for aircraft noise events at McKinley River.

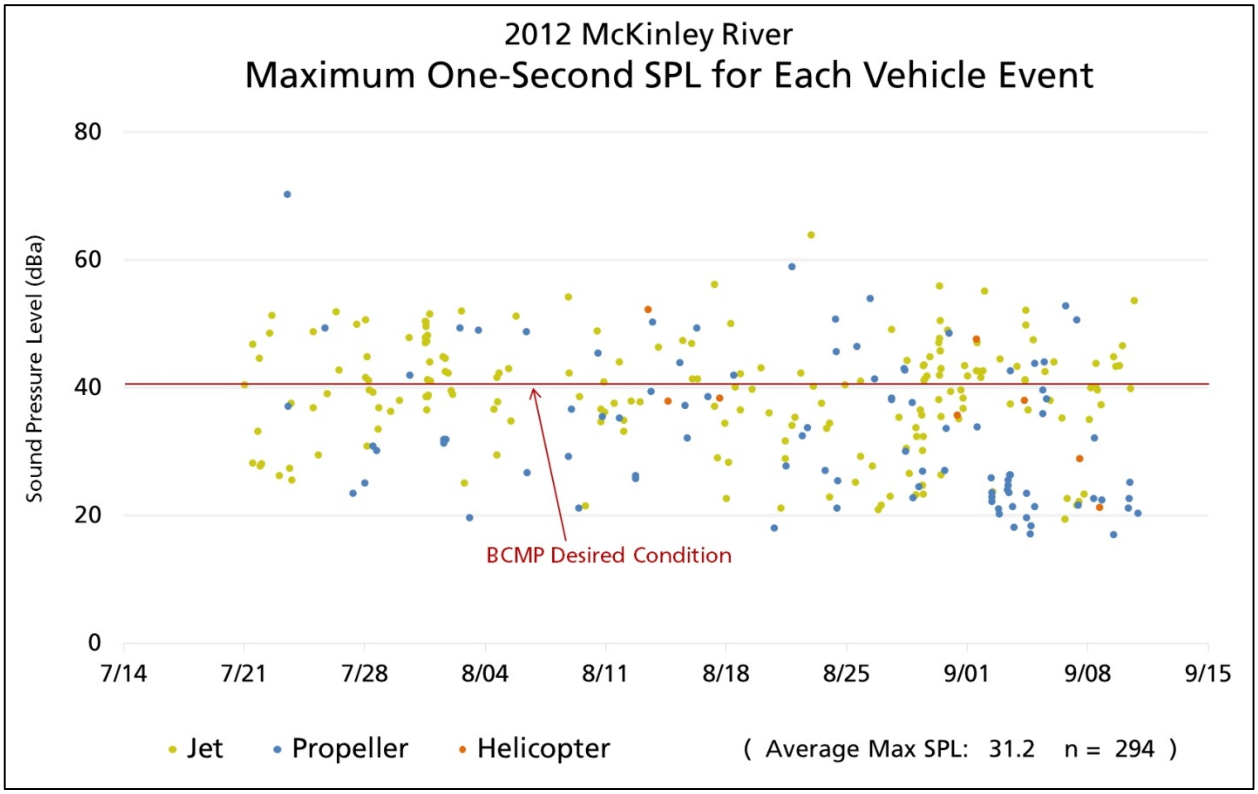


Figure 65. Maximum one-second sound pressure level for each aircraft event detected at McKinley River.

Sushana Ridge

Location Description: On the north side of the Sushana Ridge, adjacent to Mt. Wright and the Teklanika River.

Purpose/Project: Location randomly chosen from the LTEM grid as part of the long-term Denali Soundscape inventorying and monitoring sampling plan.

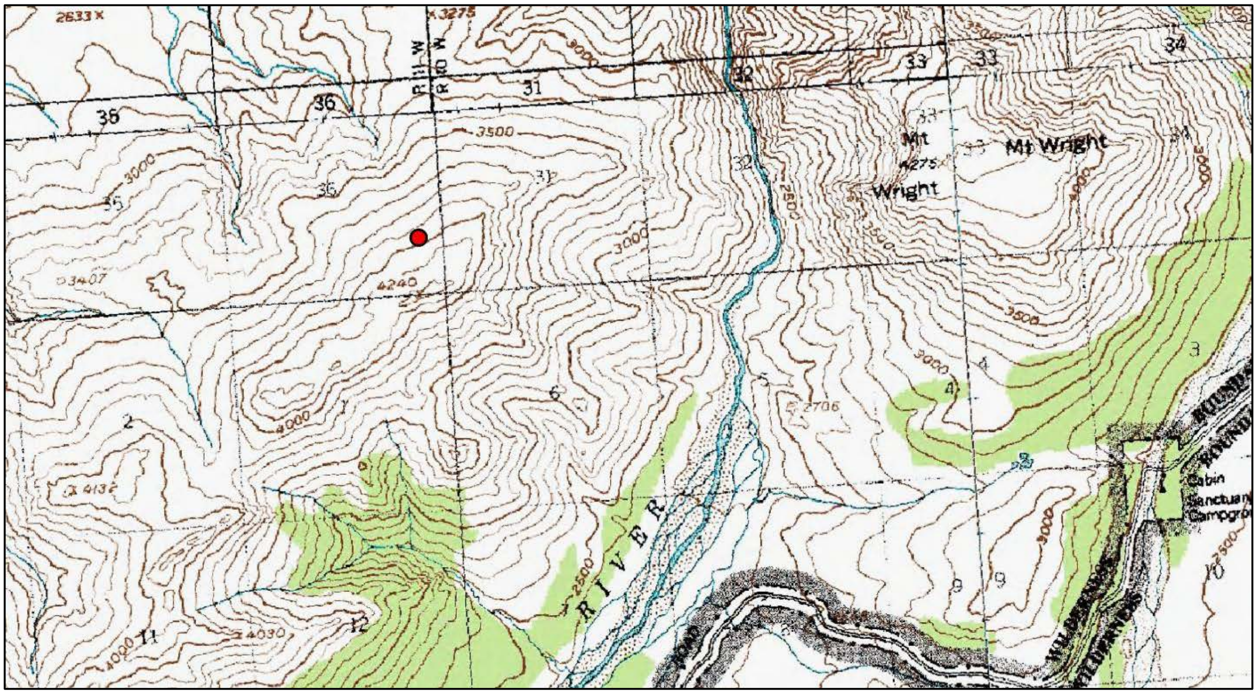
Coordinates: 63.74123°, -149.58362° (WGS84)

Elevation: 1211 meters

BCMP Management Area: OP1 (Low Natural Sound Disturbance)
Park Ecoregion: Alaska Range Front Range

Sampling Period: 14-May-2012 to 4-July-2012

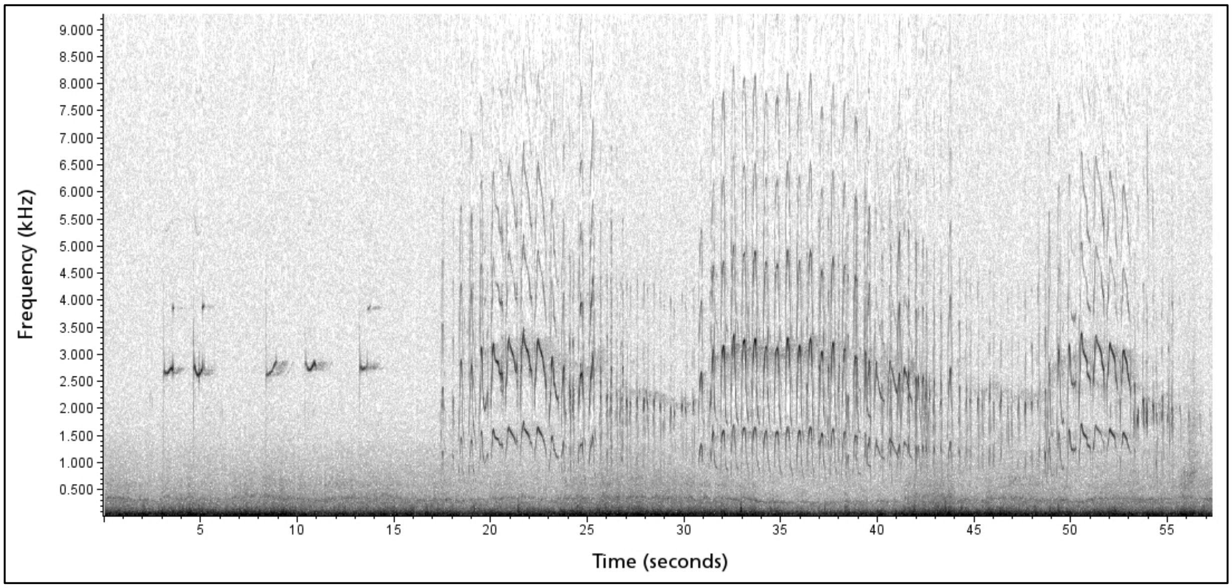
Access: Foot



Summary/Notes: The purpose of the Sushana Ridge location was to collect data at one of the long-term ecological monitoring (LTEM) grid points, as outlined in the above sampling plan. LTEM grid point #215 was stratified as a designated wilderness (former Mt. McKinley National Park) location and randomly selected from all locations requiring aircraft access.

Wind was the primary component of the soundscape at Sushana Ridge. Racing over the open landscape with little impediment, it travelled at a median speed of 3.2 meters per second (with an interquartile range of 2.5 m/s.) Because wind was consistently forceful, it was also detectable in a large percentage of clips – about 75% had some air motion audible.

Many avian species were detected across this area of open, dwarf-shrub habitat. In prevalent morning and evening choruses, their vocalizations aggregated to form a complex acoustic structure. White-crowned Sparrow (*Zonotrichia leucophrys*) and Savannah Sparrow (*Passerculus sandwichensis)* were the main members of the dawn chorus. Other calling birds such as American Golden Plover (*Pluvialis dominica*), Whimbrel (*Numenius phaeopus*), and Willow Ptarmigan were also frequently heard. Long-tailed Jaeger (*Stercorarius longicaudus),* an uncommon to rare circumarctic species, were often heard calling at the site, a good indication of nesting activity in the area (Sibley 2003). These birds are known to prefer territory on "exposed hummocks, mounds, or rocks, from which there were wide views." (Drury 1960). Included within such a set of geographic features are the exposed tors which typify the Sushana Ridge and the front range of which it is part (an example of a tor feature is included in the site photograph on the previous page).



Spectrogram 5. Two varieties of Long-tailed Jaeger (*Stercorarius longicaudus*) calls near the Sushana River sound station. The spectrogram begins at 20:00:08 on 06/11/2012.

The most commonly heard sounds at this site were wind (audible 75.4% of the time), birds (39.7%), precipitation (14.8% – with rain greatly predominating over hail), and silence (10.9%). Human made sound was audible 3.5% of the time on average; all of it was produced by aircraft. This is equivalent to 50.4 minutes each day, or approximately 14 overflights a day. Conditions exceeded the BCMP percent audible standard 26% of the time, number of events per day 81% of the time, and maximum SPL 77% of the time.

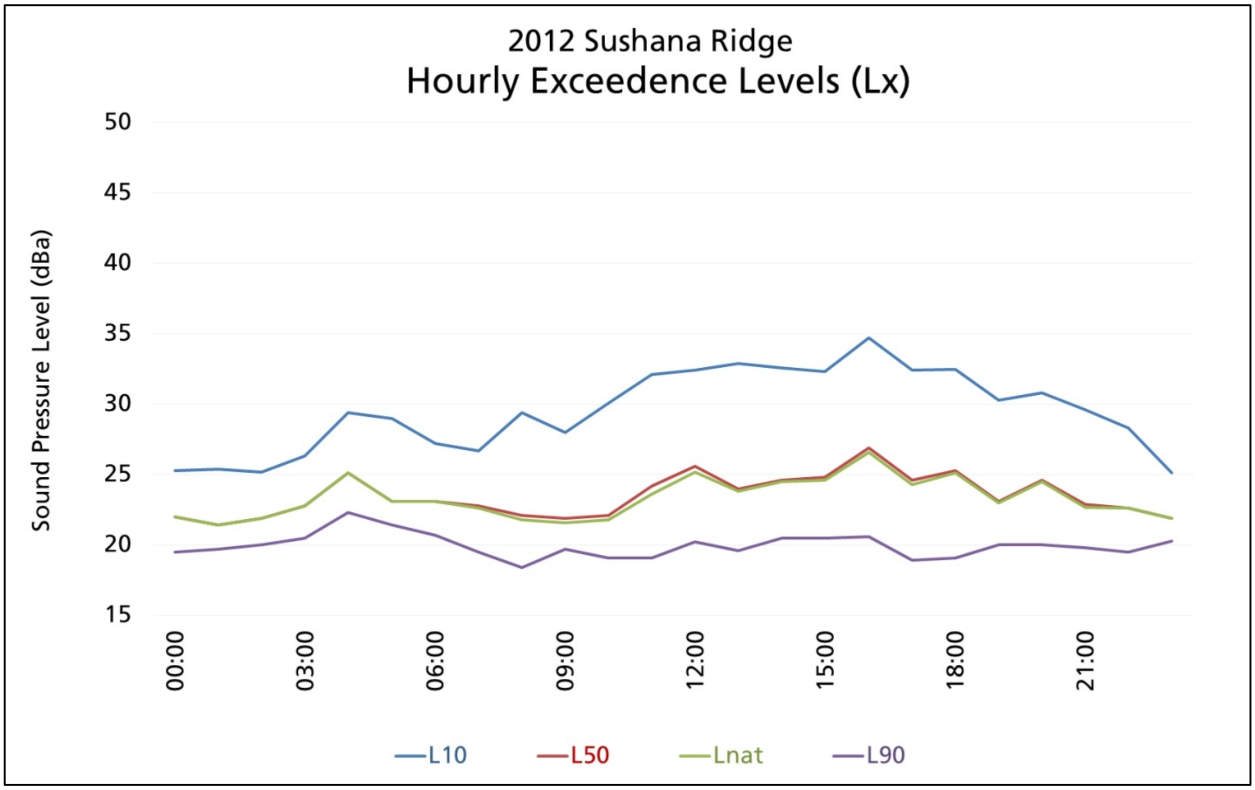


Figure 66. Exceedence levels for Sushana Ridge.

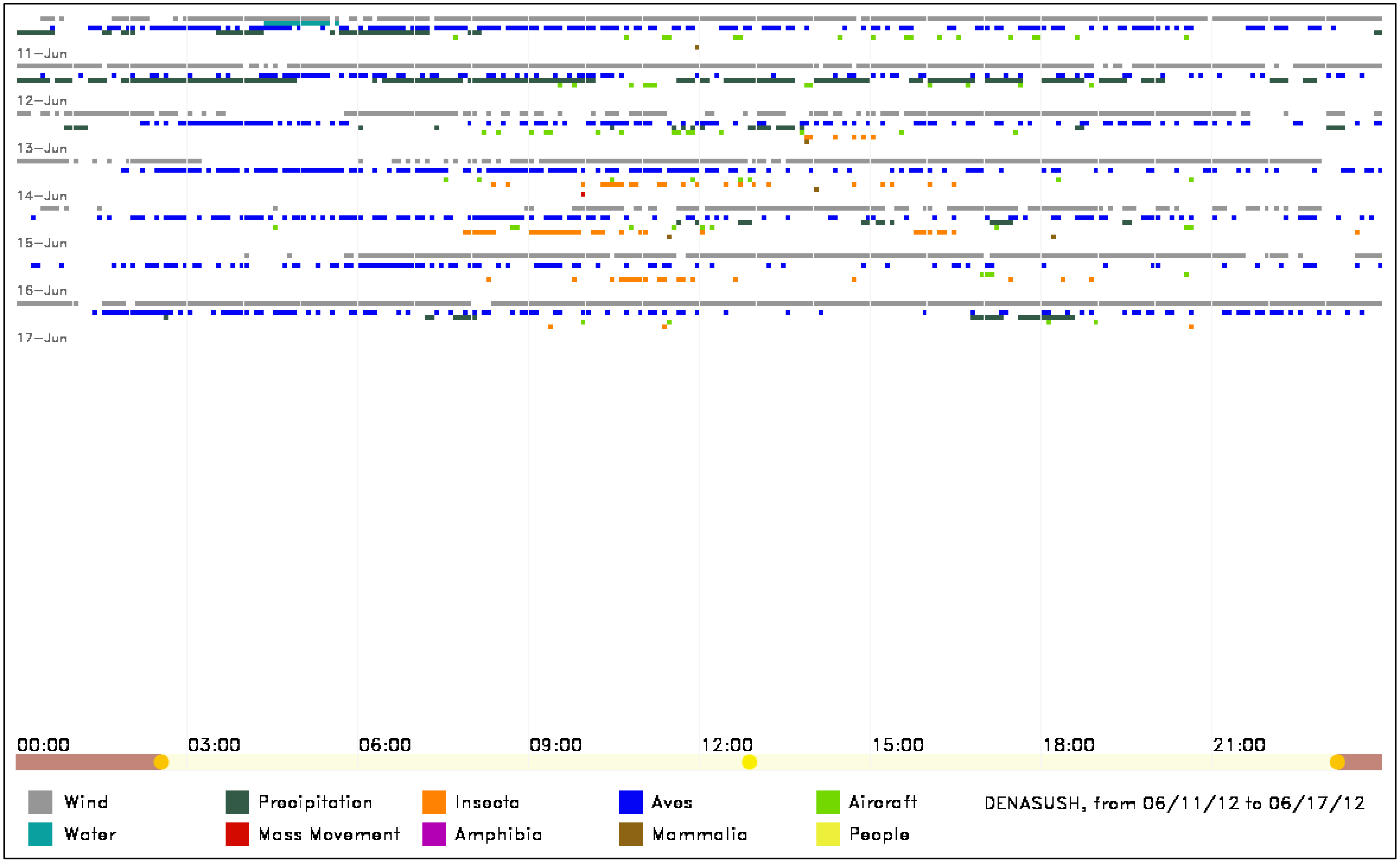


Figure 67. Temporal audibility of sound sources at Sushana Ridge, based on five seconds of audio every five minutes. The bar along the horizontal axis indicates the average light conditions during the sampling period. The orange circles are sunrise/sunset. This site did have civil twilight or night-time conditions during the sampling period.

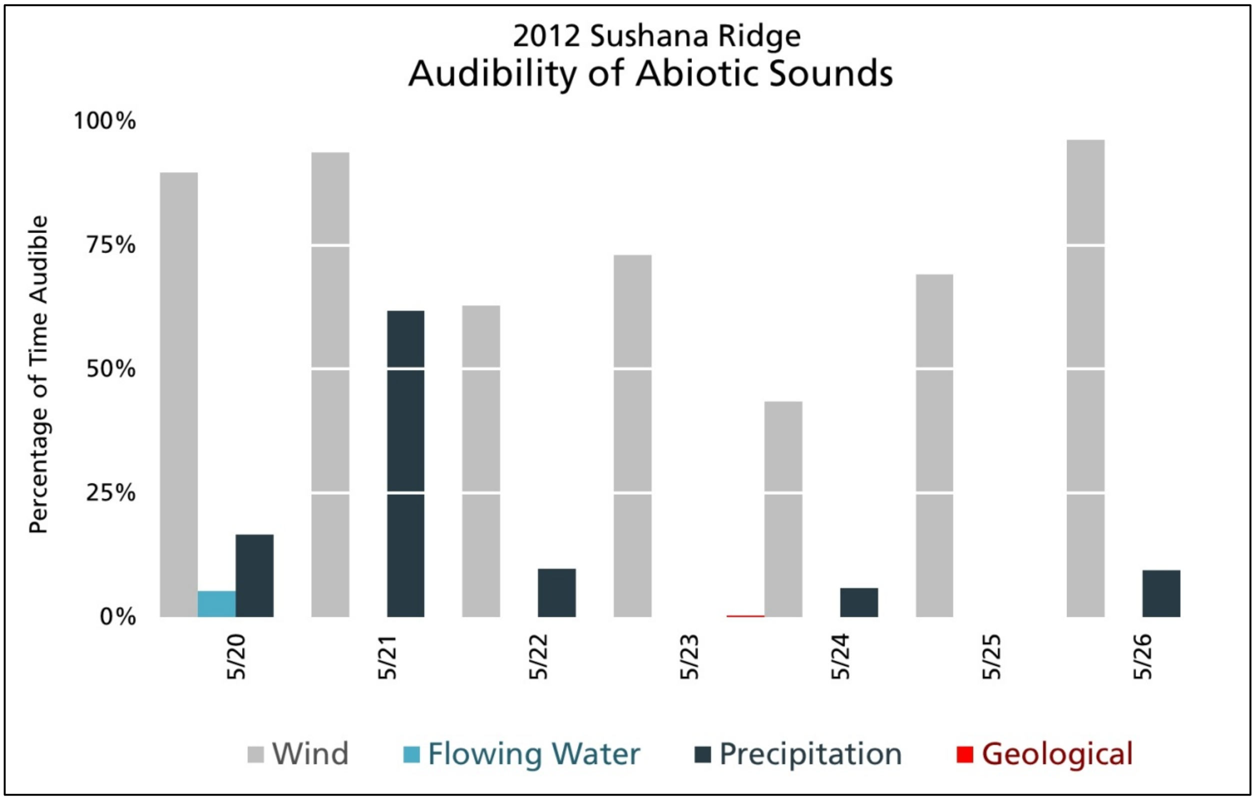


Figure 68. Audibility of abiotic sounds at Sushana Ridge.

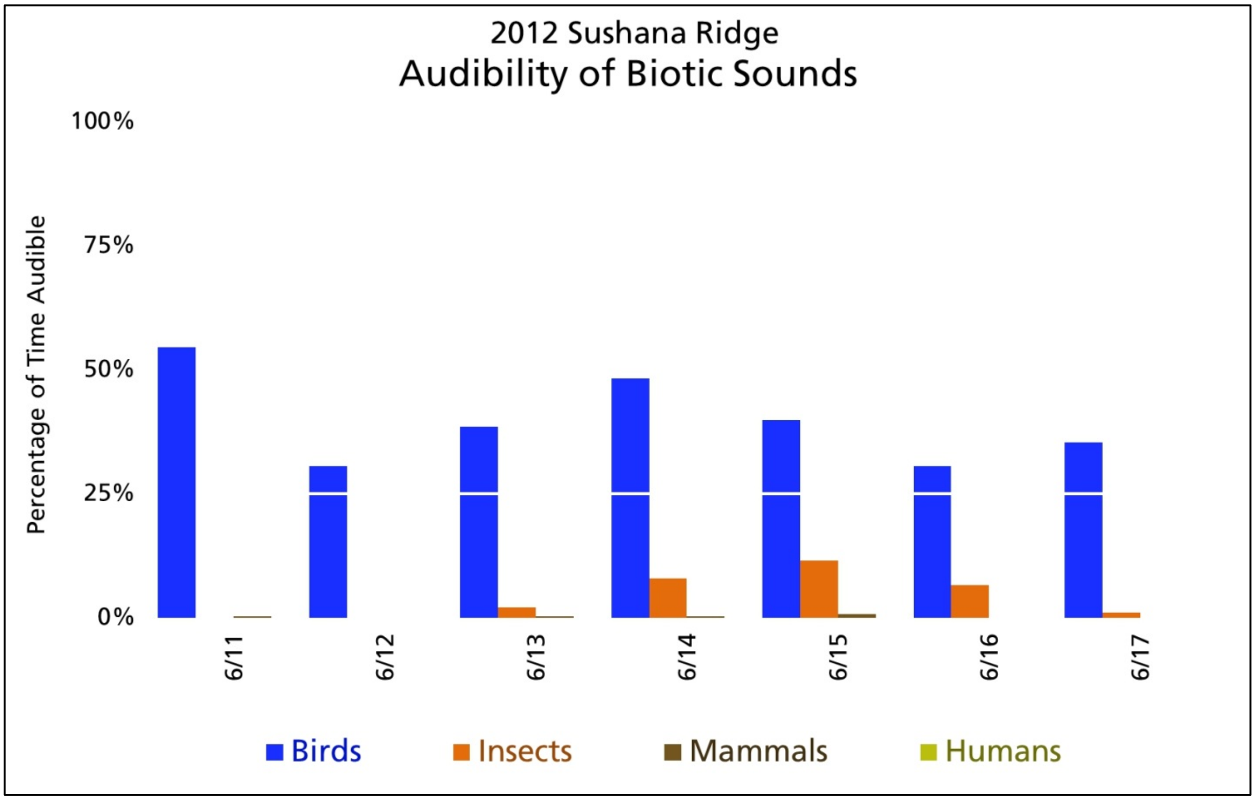


Figure 69. Audibility of biotic sounds at Sushana Ridge.

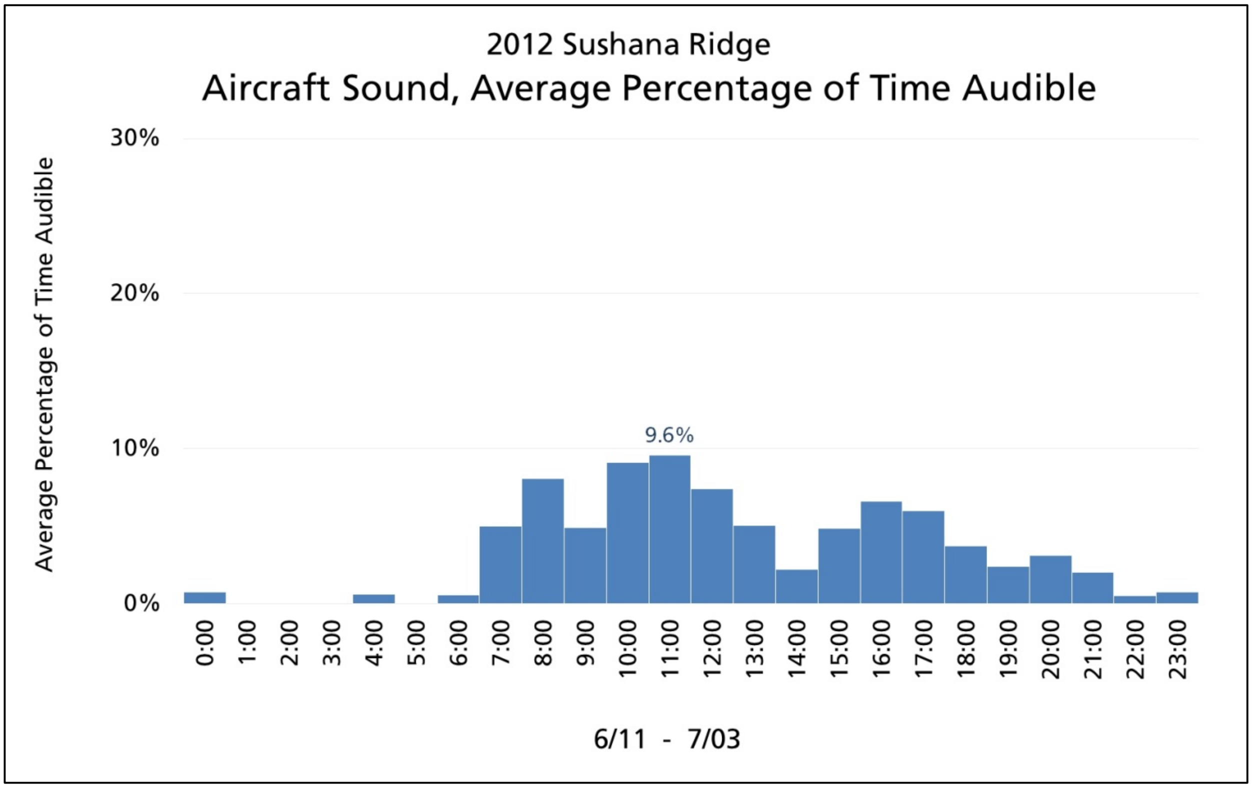


Figure 70. Audibility of aircraft noise for an average day, by hour, at Sushana Ridge.

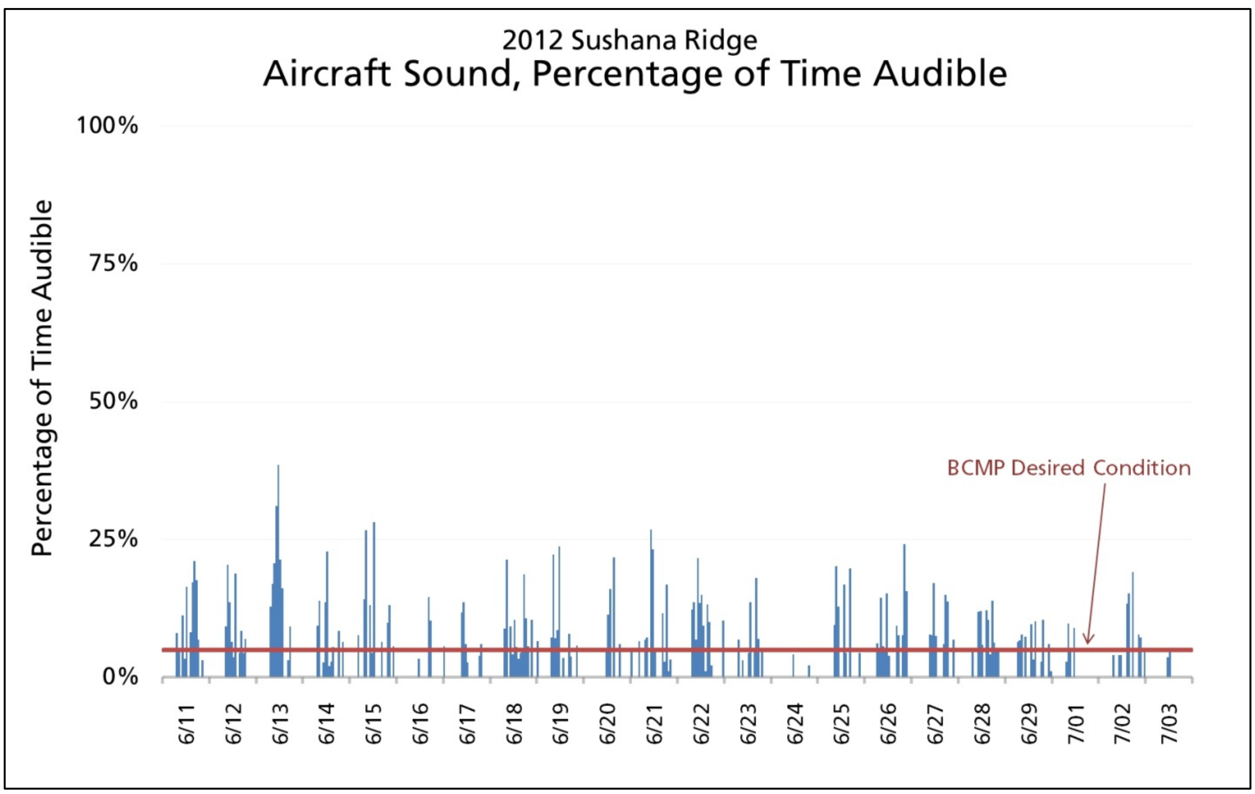


Figure 71. Audibility of aircraft noise at Sushana Ridge.

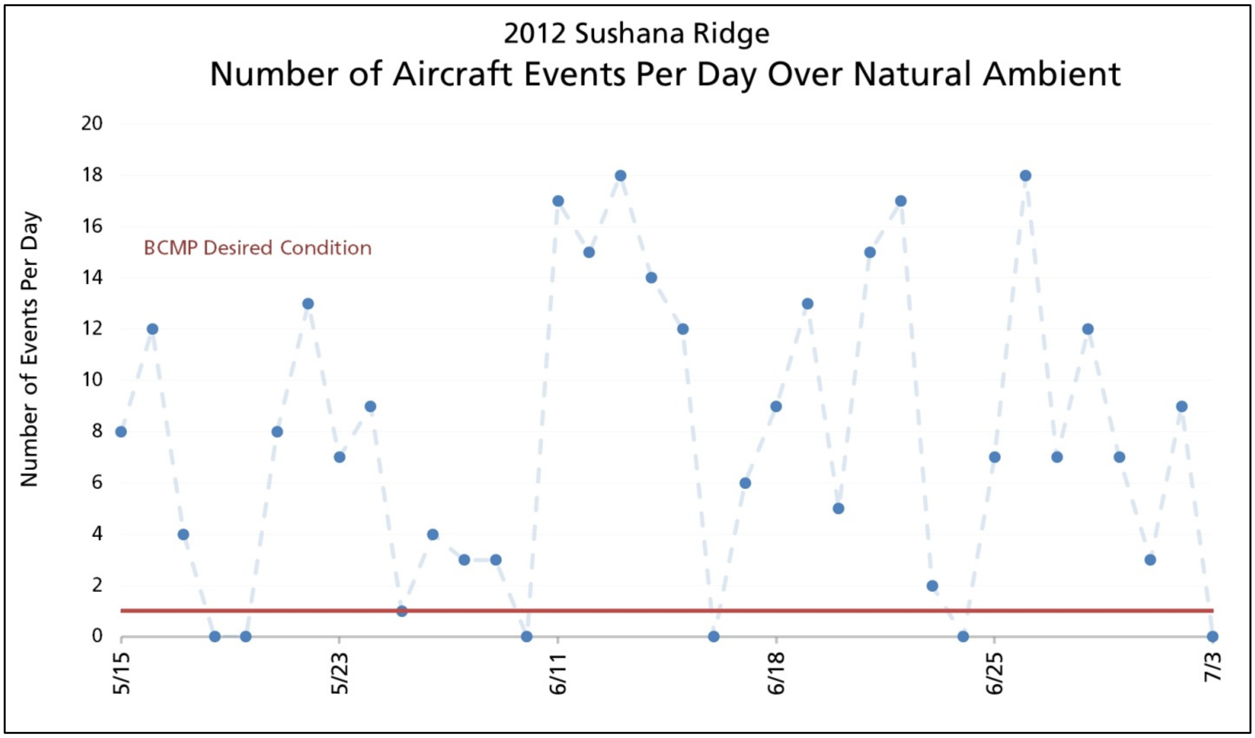


Figure 72. Number of aircraft noise events detected per day at Sushana Ridge.

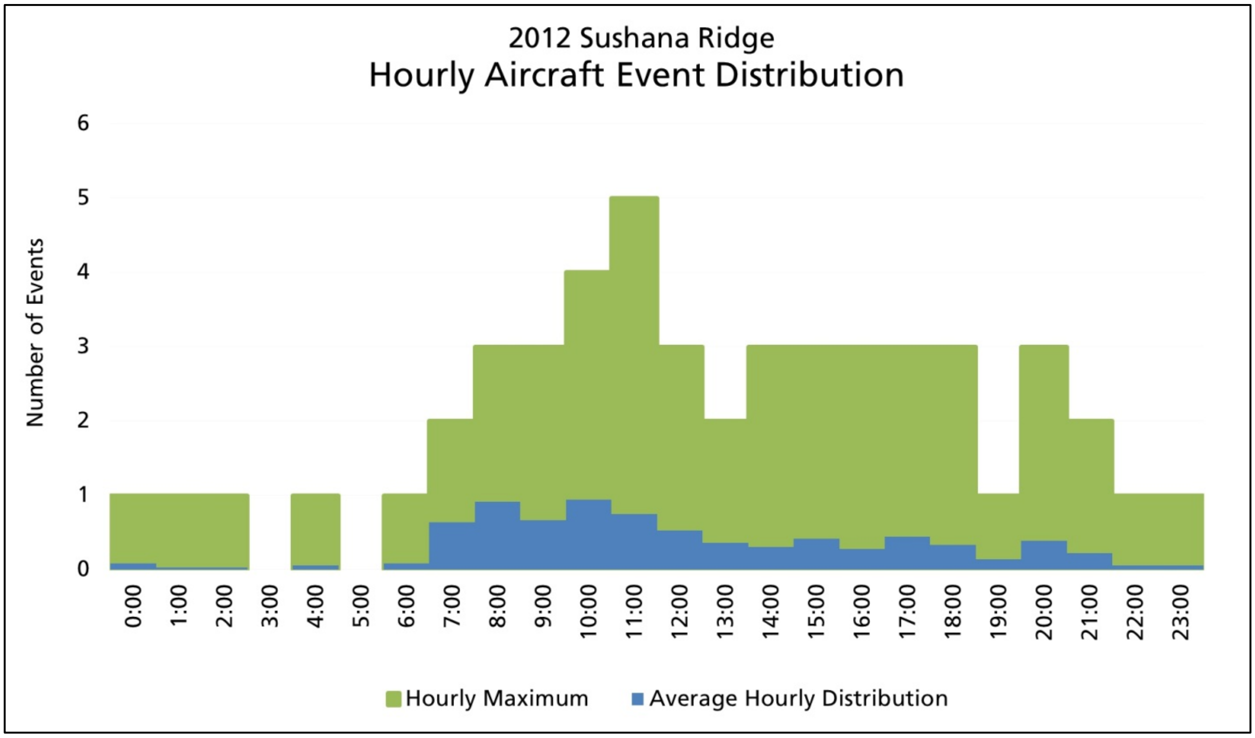


Figure 73. Hourly average and maximum rates of detection for aircraft noise events at Sushana Ridge.

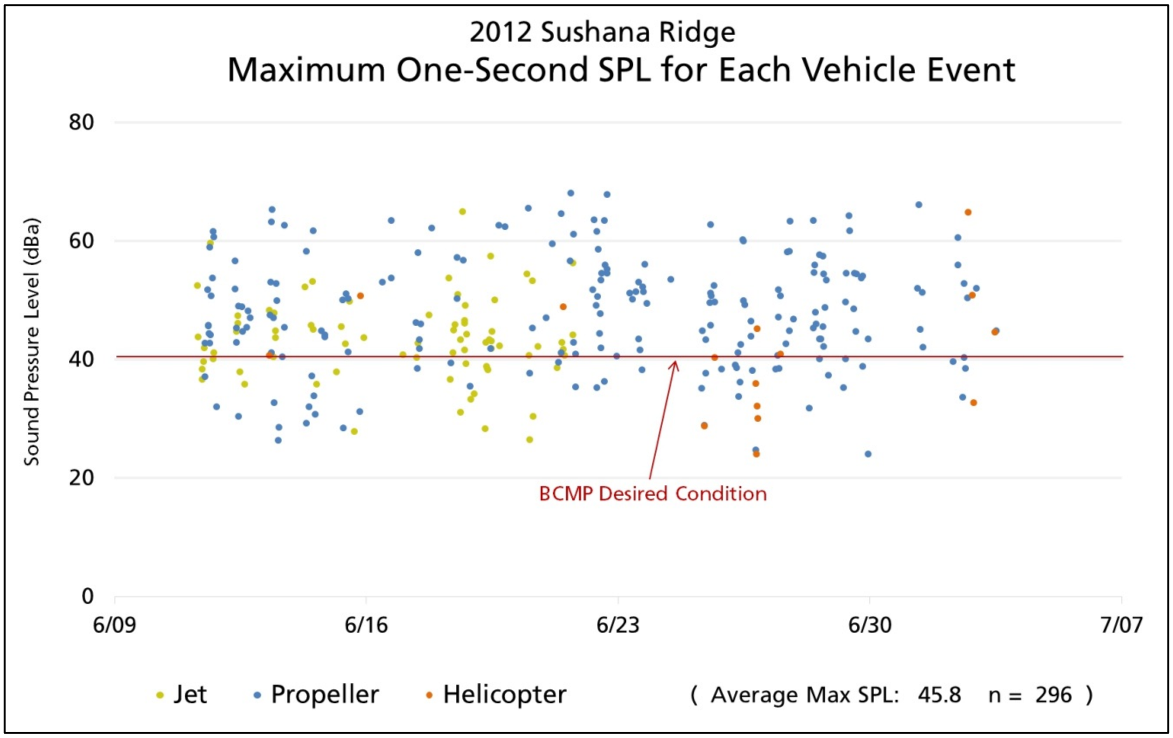


Figure 74. Maximum one-second sound pressure level for each aircraft event detected at Sushana Ridge.

Toe of the Kanikula Glacier

Location Description: The toe of the Kanikula Glacier, about 8 km north-west of the terminus of the Tokositna Glacier and 7 km north of the park boundary.

Purpose/Project: Location randomly chosen from the LTEM grid as part of the long-term Denali Soundscape inventorying and monitoring sampling plan.

Coordinates: 62.70562°, -150.91173° (WGS84)

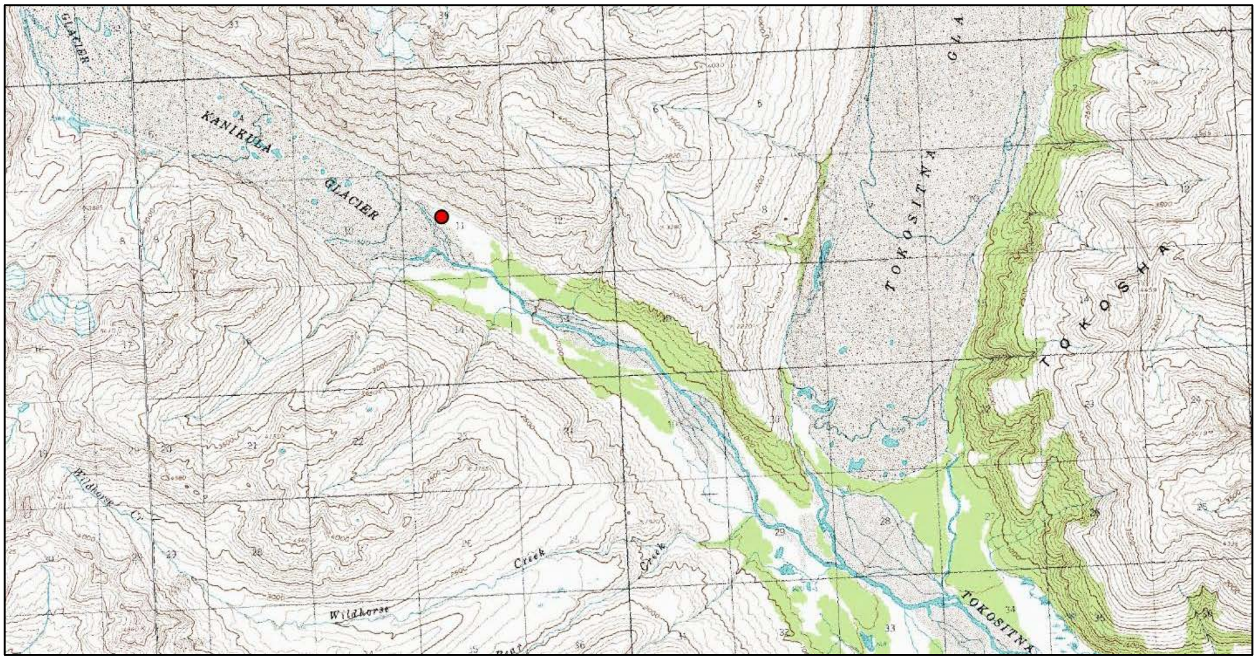
Elevation: 352 meters

BCMP Management Area: A (High Natural Sound Disturbance)

Park Ecoregion: Cook Inlet Braided Floodplains and Stream Terraces

Sampling Period: 19-May-2012 to 9-July-2012

Access: Helicopter



<u>Summary/Notes</u>: The purpose of the Toe of the Kanikula sampling location was to collect data at one of the long-term ecological monitoring (LTEM) grid points, as outlined in the above sampling plan. LTEM grid point #36 was stratified as a New Park (ANILCA expansion) location and randomly selected from all locations requiring aircraft access.

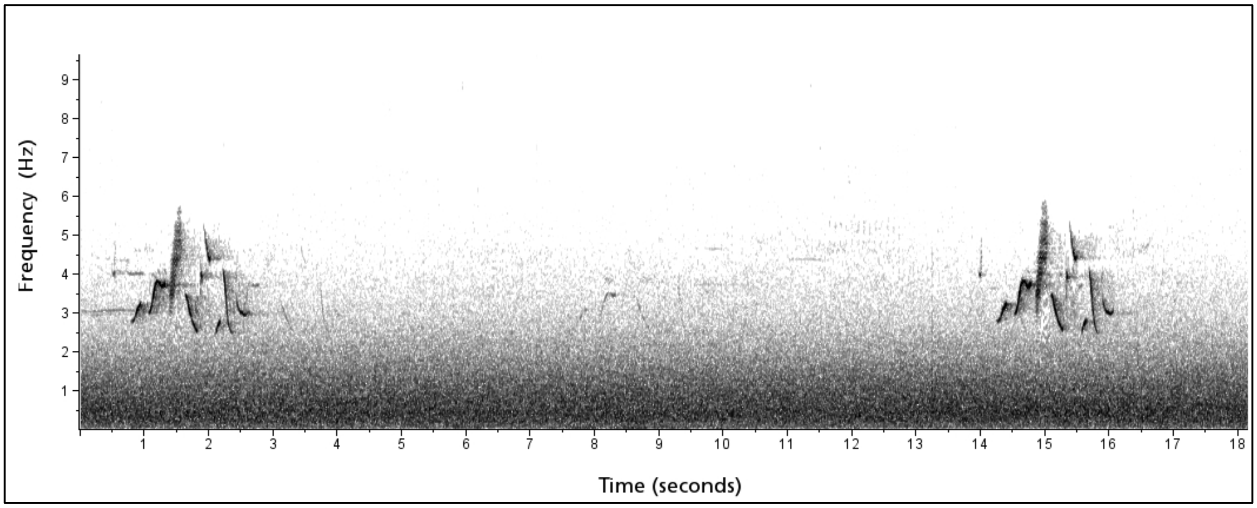
Of the 60 grid points in Denali's soundscape inventory, the Toe of the Kanikula site location is one of only two locations that fall within the Backcountry Management Plan high impact management zone (grid point #36, near Mt. Foraker, is the other - scheduled to be sampled in 2015, the last year of the inventory). As anticipated in the plan, sounds of aircraft were frequently audible in the area, yet often exceeded the Backcountry Management Plan standard of 25 events per day. Chains of two or three aircraft flying in queue were a common observation, and made for relatively long noise events. On average, events had a duration of 5.1 minutes, which placed the site in the 80th percentile parkwide.

All aircraft were detected despite the roaring output flow of water from the Kanikula. The torrent had clear effect on the soundscape, making the average natural ambient sound pressure level practically time invariant. This steady condition is apparent in Figure 75. Though relatively high when compared to other sites across Denali, it is nevertheless typical for areas within the immediate influence of rivers (for instance, compare to the North Triple Lakes Trail sampling location, Betchkal 2013).

Upon this energetic background was overlain a diverse variety of animal communications. Avian sounds were primarily song, with the total number of clips containing singing behavior steadily increasing as the sampling period progressed. Values ranged from about 50% of the day on 05/20 to nearly 85% of the day on 05/27 (Figure 78). A similar rate of singing was also observed at the

Kichatna Mountains site, sampled during approximately the same time period (see Figure 51 of this report.)

The most common members of the dawn chorus were Fox Sparrow, Dark-eyed Junco (*Junco hyemalis*), and White-crowned Sparrow. Hermit Thrush song was most frequent around midnight, but their calls were often heard during the diurnal hours. Gray Jay, Golden-crowned Sparrow, Redpoll (*Carduelis* sp.), and Boreal Chickadee (*Poecile hudsonicus*) were less-commonly heard, but still frequent.



Spectrogram 6. A Fox Sparrow (*Passerella iliaca*) sings over the sound of rushing water near the terminus of the Kanikula Glacier. The spectrogram begins at 05:53:42 on 05/22/2012.

Collared pika were heard during the 20:00 hour on 05/21. This solitary, talus-inhabiting mammal was also heard at three other sites during the 2012 season (Bull River, Cathedral Mountain, and Upper West Branch Toklat).

The most commonly heard sounds at this site were flowing water (audible 100.0% of the time), birds (73.6% - with song audible 65.5% of the time), wind (22.1%), and rain (5.3%). Human made sound was audible 9.3% of the time on average; all of it was generated by aircraft. This is equivalent to 133.9 minutes each day, or approximately 38 overflights a day. Conditions exceeded the BCMP percent audible standard 1% of the time, number of events per day 63% of the time, and maximum SPL 7% of the time.

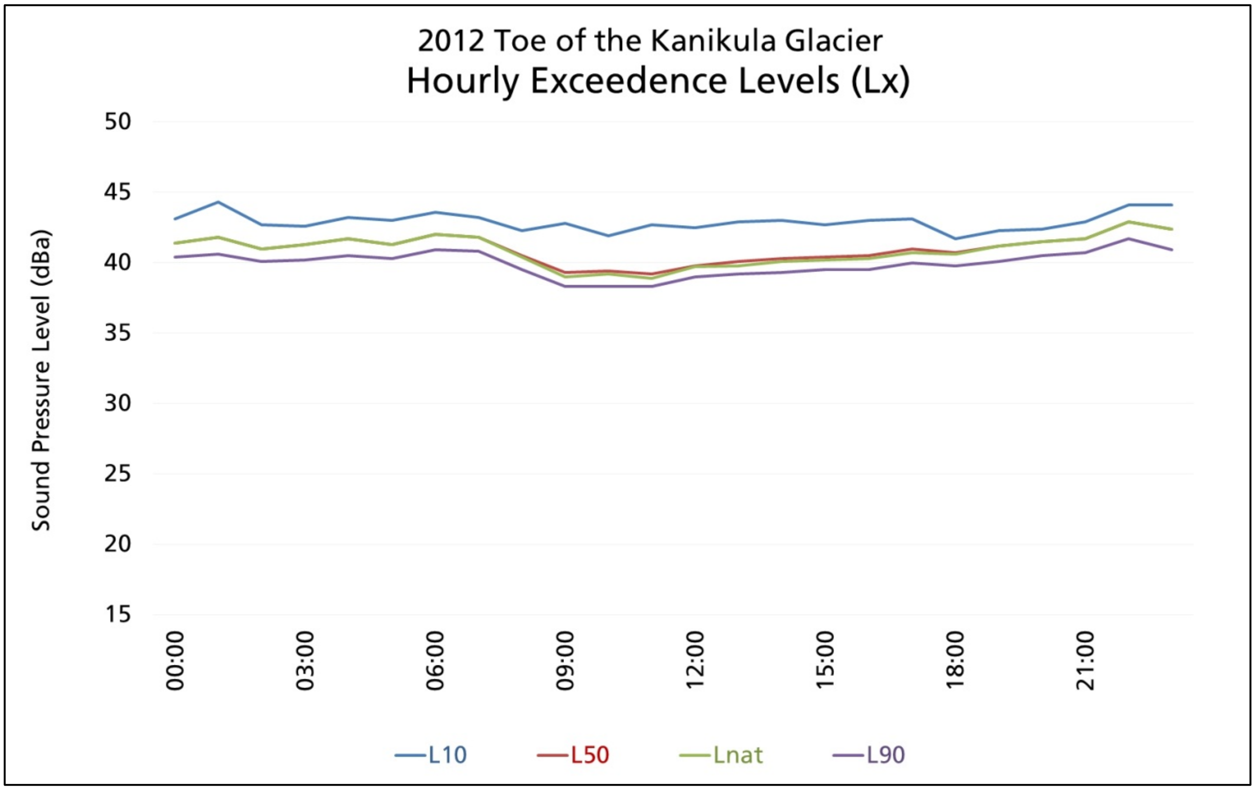


Figure 75. Exceedence levels for Toe of the Kanikula Glacier.

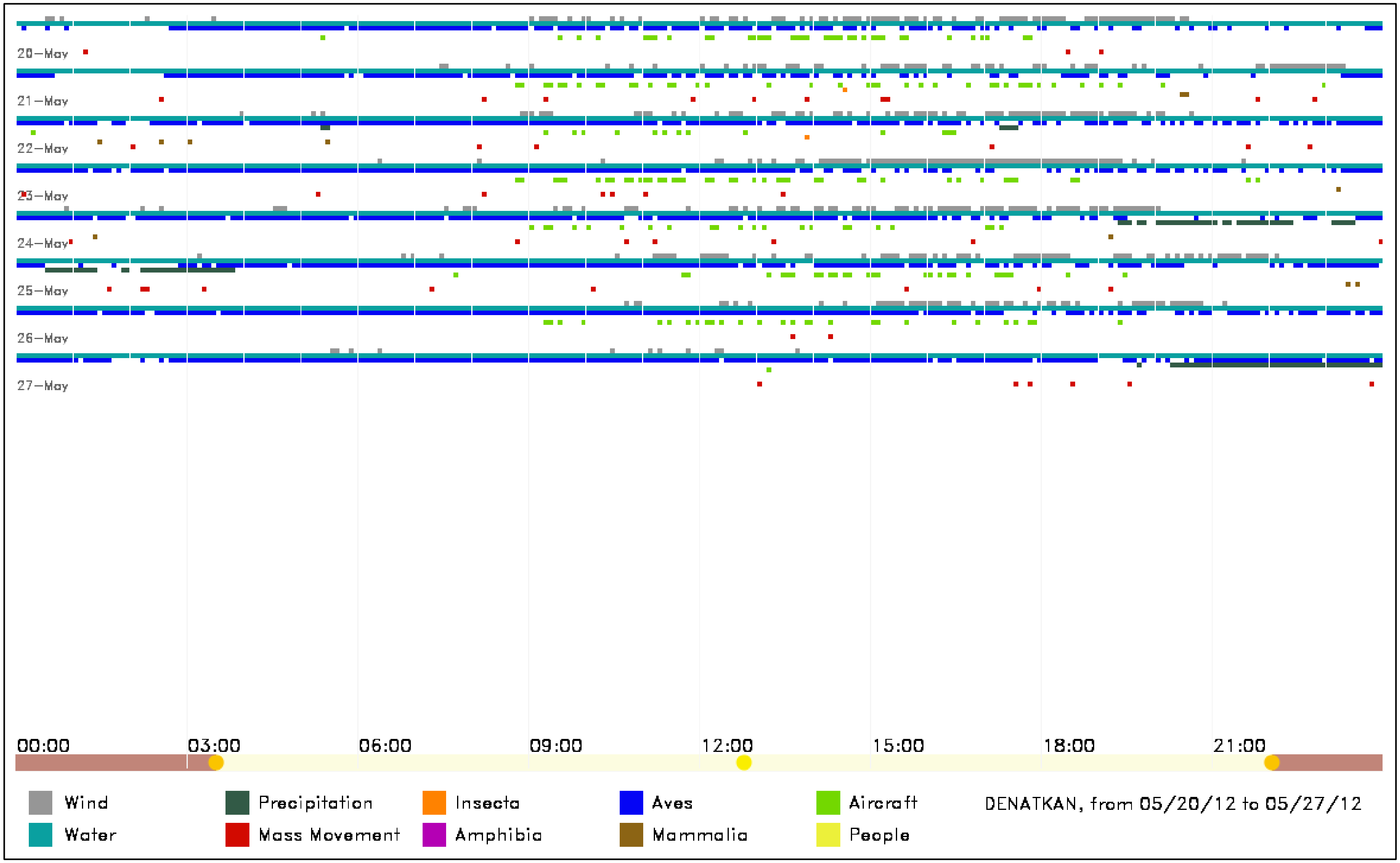


Figure 76. Temporal audibility of sound sources at Toe of the Kanikula Glacier, based on five seconds of audio every five minutes. The bar along the horizontal axis indicates the average light conditions during the sampling period. The orange circles are sunrise/sunset. This site did have civil twilight or night-time conditions during the sampling period.

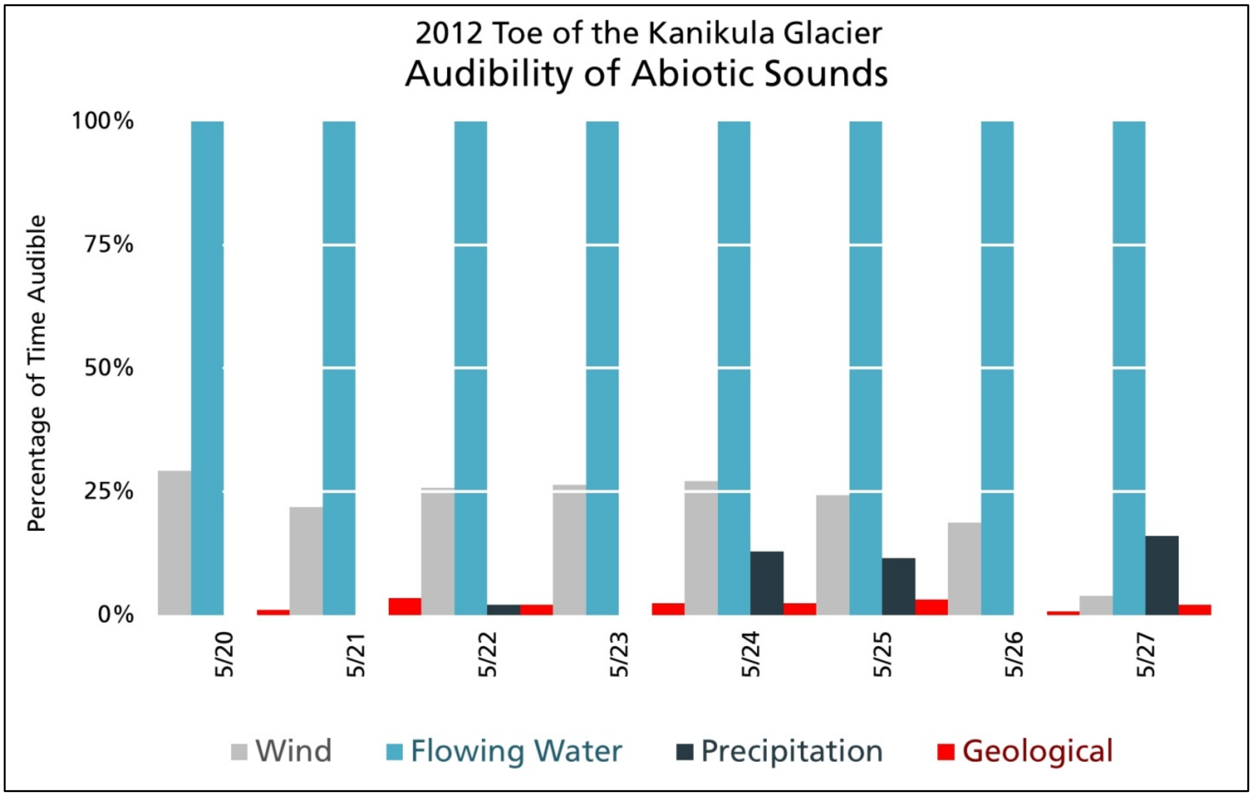


Figure 77. Audibility of abiotic sounds at Toe of the Kanikula Glacier.

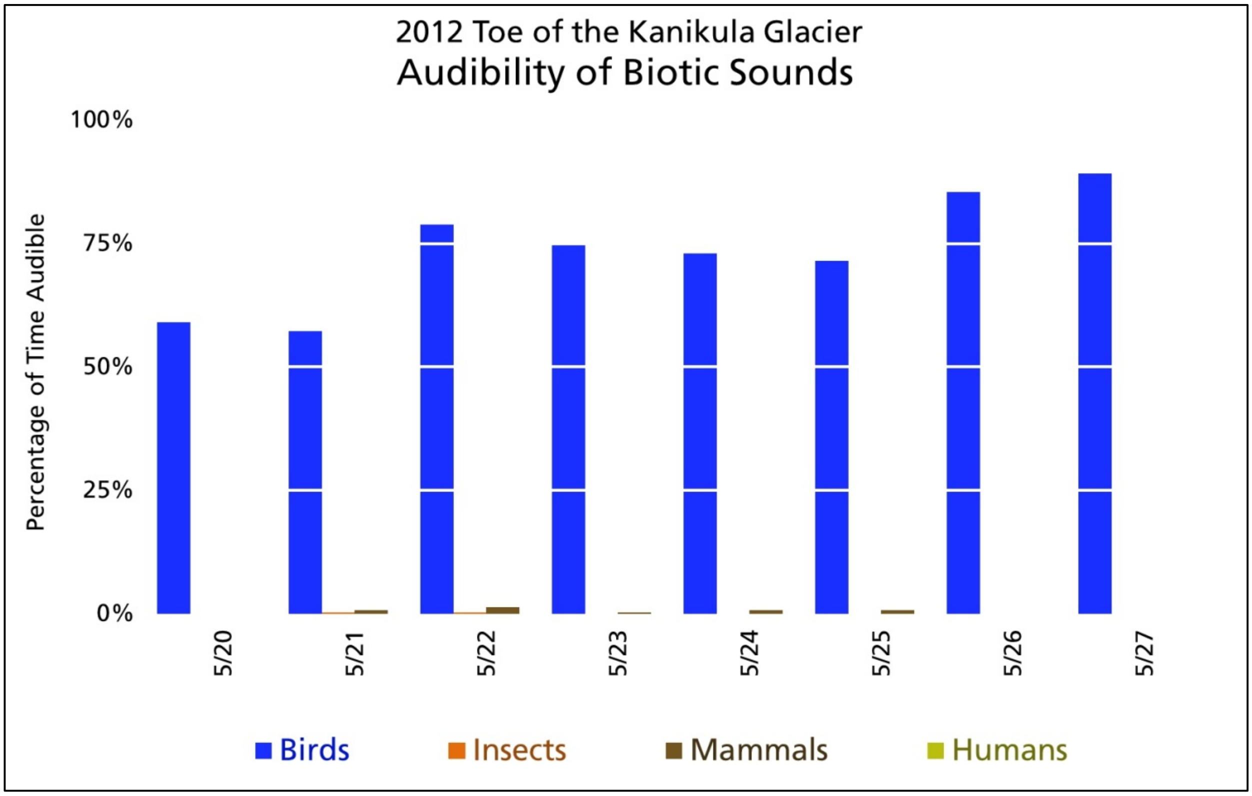


Figure 78. Audibility of biotic sounds at Toe of the Kanikula Glacier.

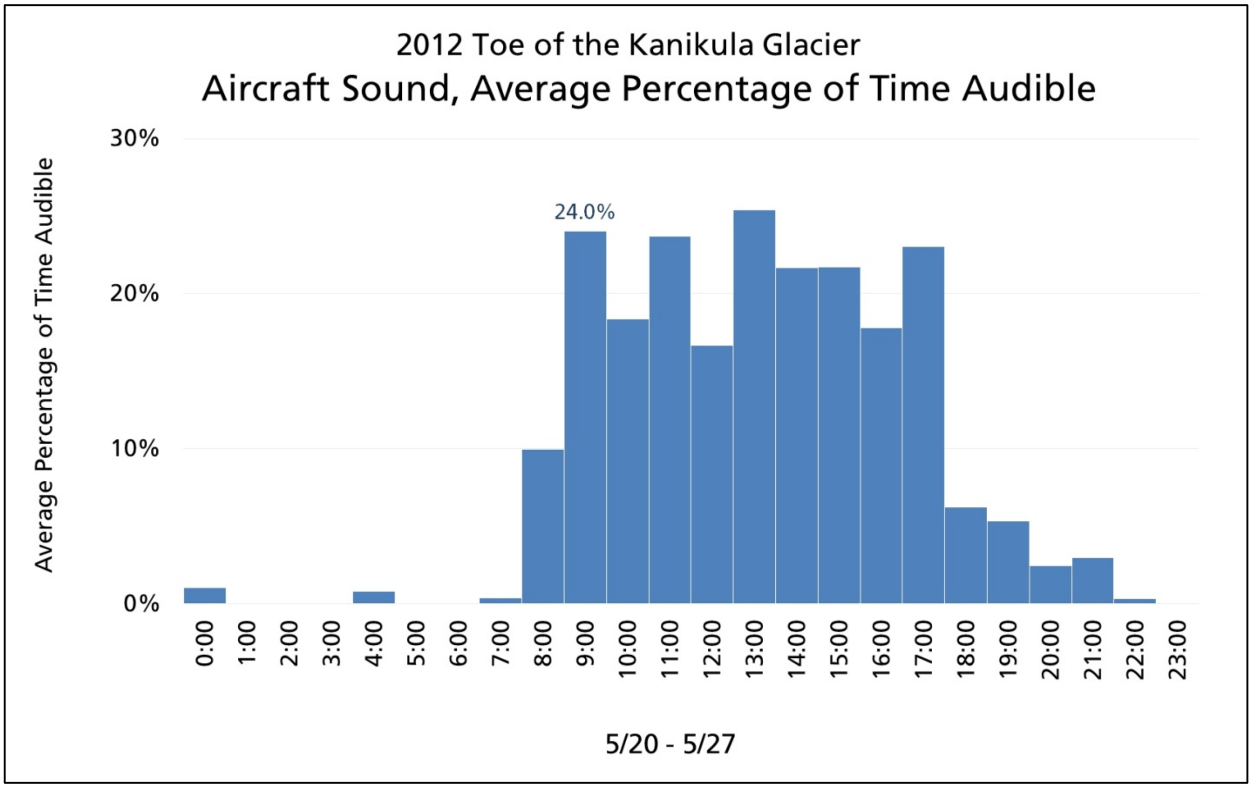


Figure 79. Audibility of aircraft noise for an average day, by hour, at Toe of the Kanikula Glacier.

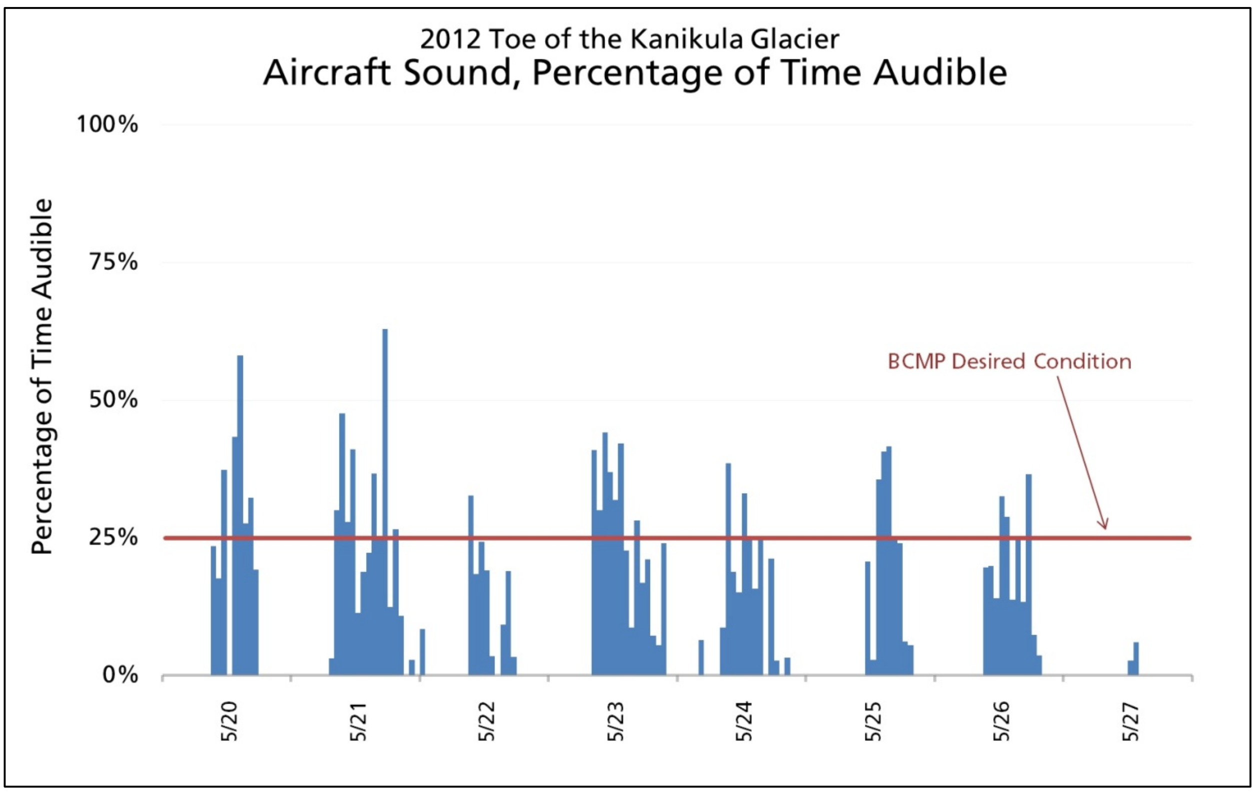


Figure 80. Audibility of aircraft noise at Toe of the Kanikula Glacier.

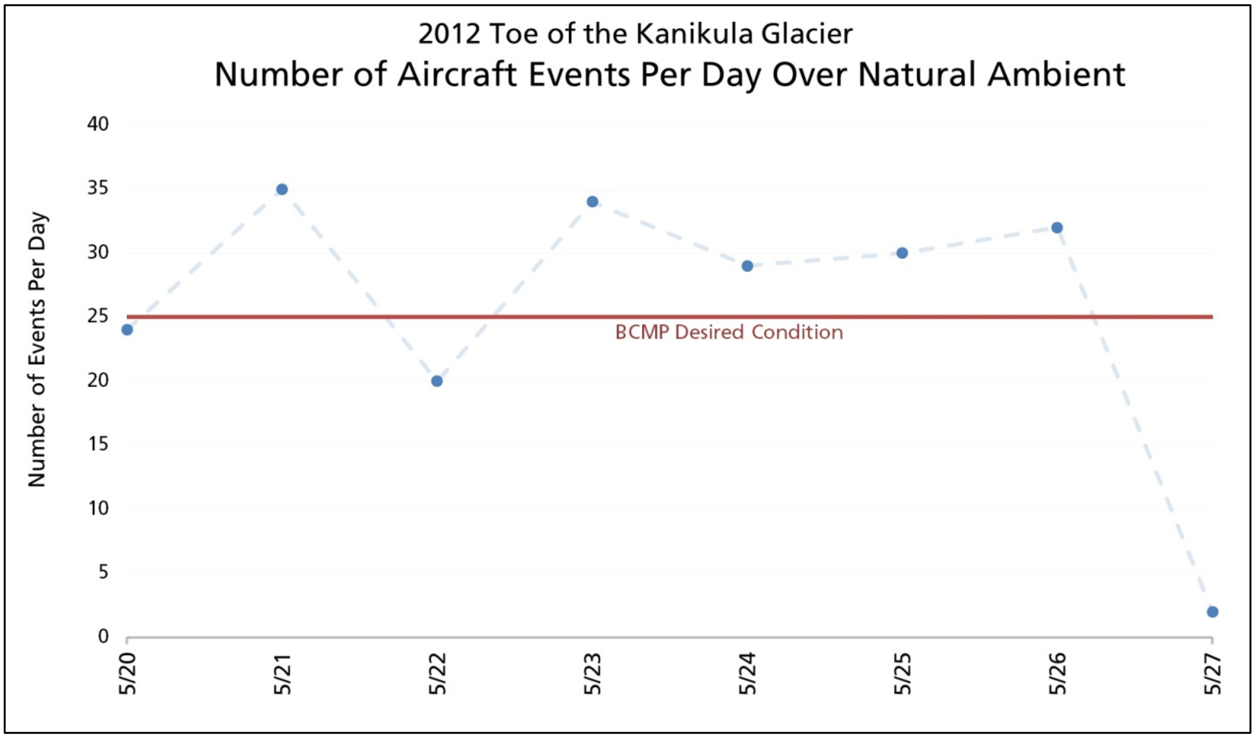


Figure 81. Number of aircraft noise events detected per day at Toe of the Kanikula Glacier.

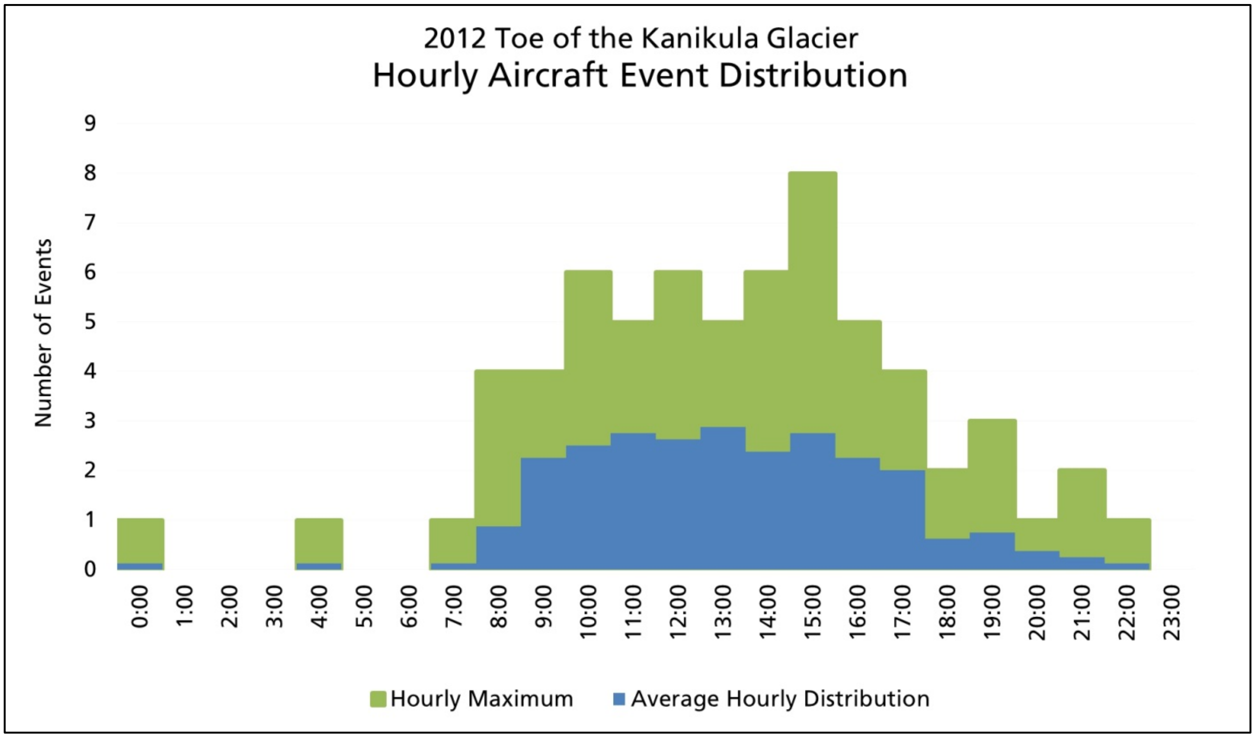


Figure 82. Hourly average and maximum rates of detection for aircraft noise events at Toe of the Kanikula Glacier.

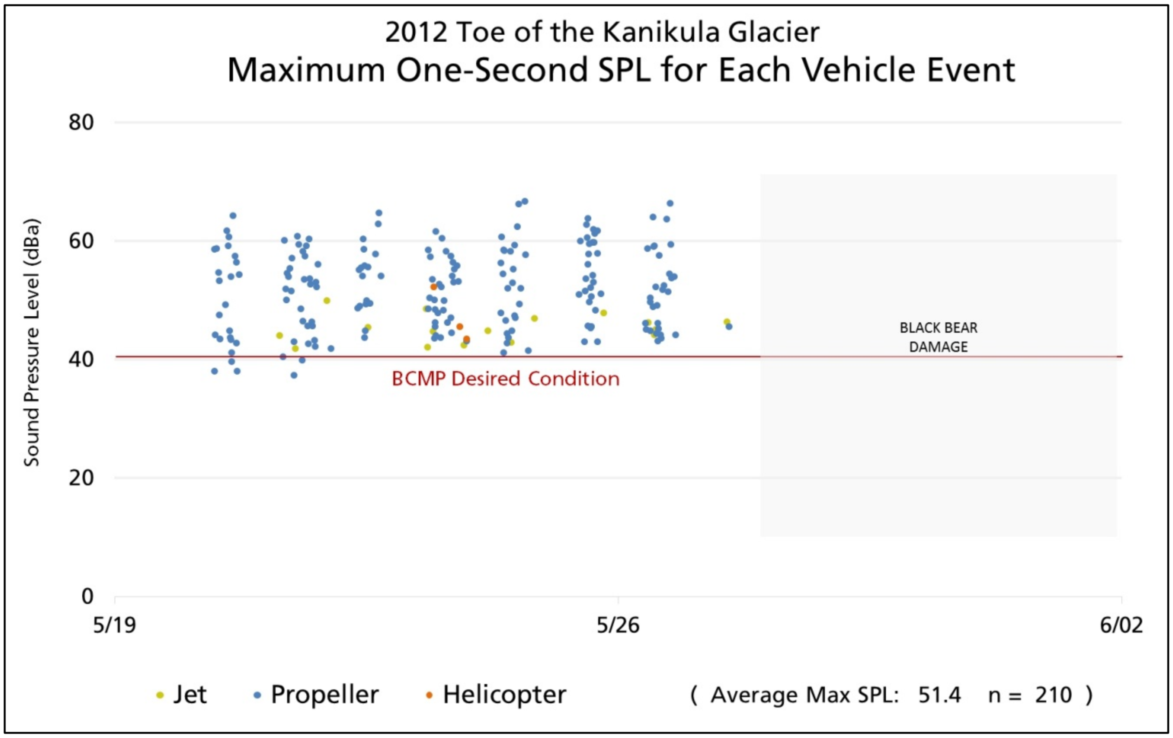
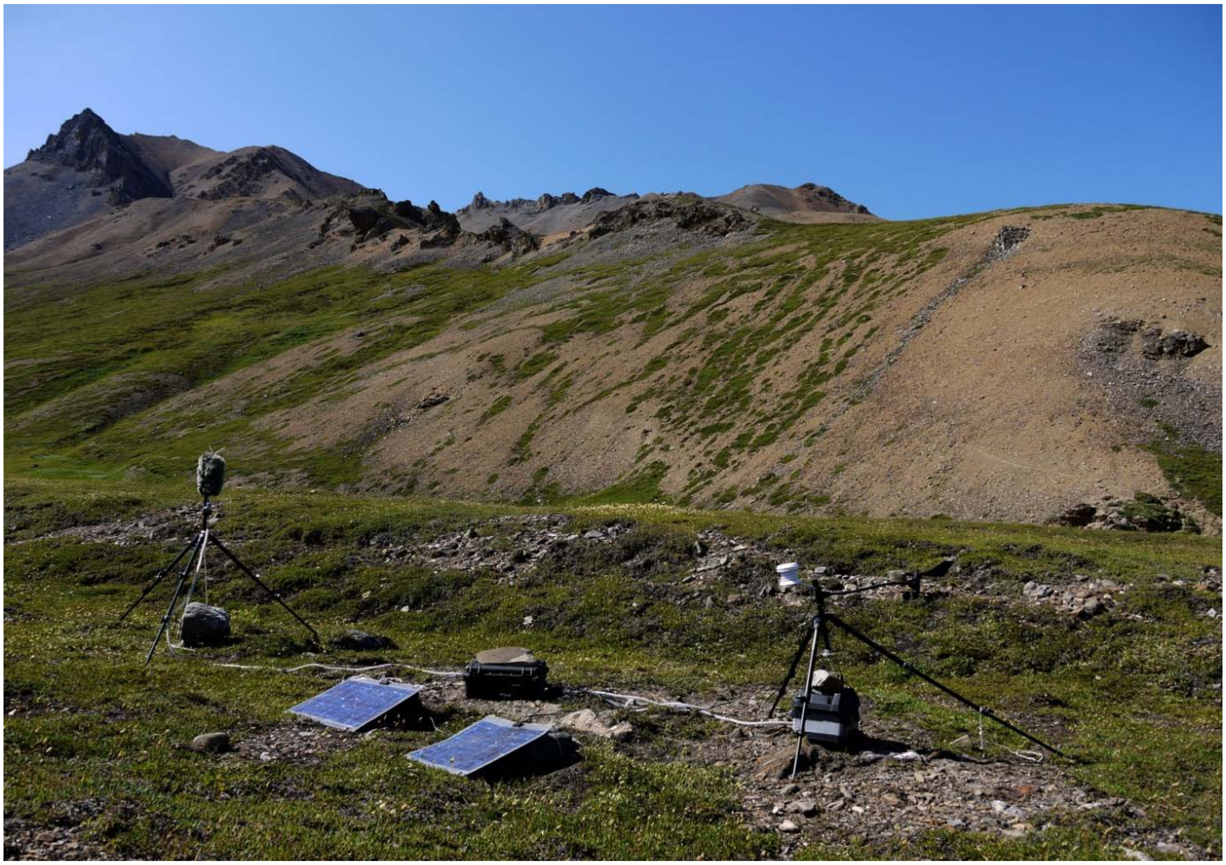


Figure 83. Maximum one-second sound pressure level for each aircraft event detected at Toe of the Kanikula Glacier.

Upper West Branch of the Toklat River



Location Description: Approximately 12km south of Toklat on the upper west branch of the Toklat River.

Purpose/Project: This location was chosen from the list of previously sampled locations within popular hiking regions of the park to assess whether management action had caused soundscape conditions to change along the spine of the Alaska Range south of the park road. The action involved asking aviators transiting this area to maintain an altitude of 8,000 feet MSL, and if not in a descending flight pattern to use minimum RPM settings. When weather and safety considerations allowed, they were to avoid the area entirely (Denali Aircraft Overflights Advisory Committee, 2012).

Coordinates: 63.40903°, -150.03513° (WGS84)

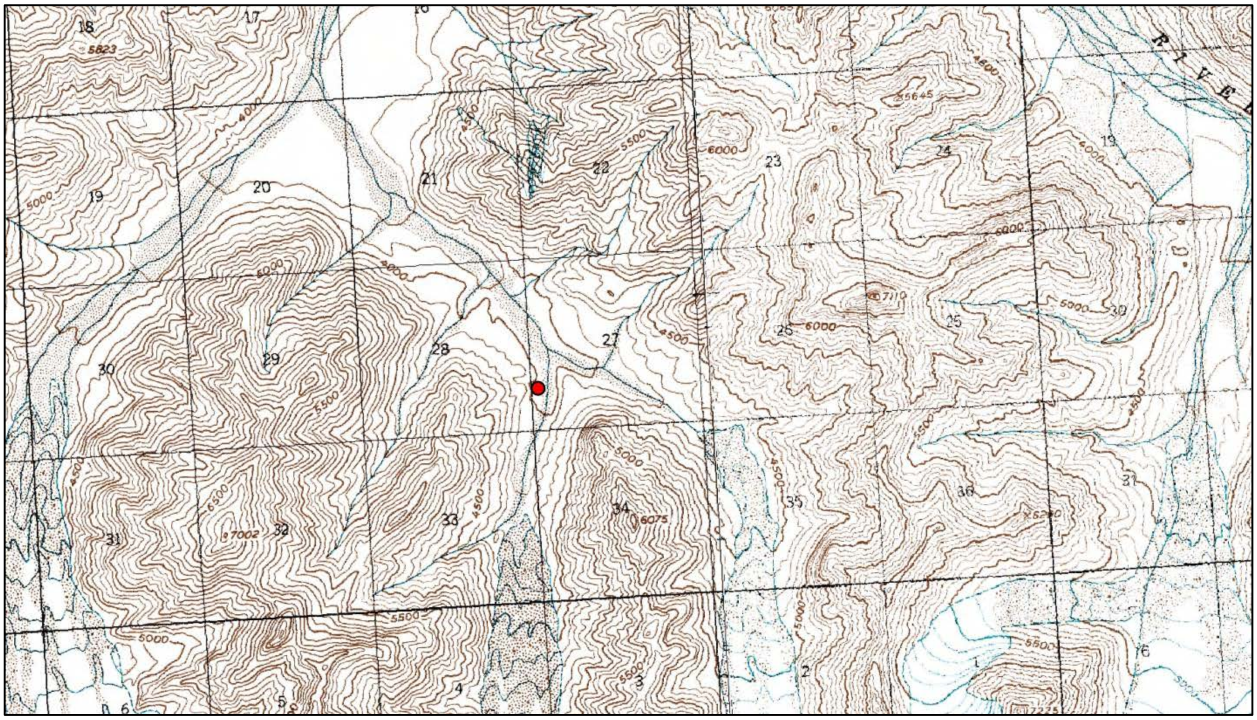
Elevation: 1215 meters

BCMP Management Area: OP1 (Low Natural Sound Disturbance)

Park Ecoregion: Alaska Range Interior Mountains and Valleys

Sampling Period: 28-July-2012 to 13-September-2012

Access: Foot



Summary: This location was chosen from the list of previously sampled locations within popular hiking regions of the park. Specifically, it was chosen to monitor backcountry soundscape conditions south of the road corridor in response to an aviation best practice enacted during the summer of 2012.

The time-averaged natural ambient level at this site was 38.09 dBA, and relatively invariant. Without wind, hourly sound pressure levels ranged between about 30 and 45 dBA – primarily due to the motion of water flowing from the eastern-most of the west-branch Toklat glaciers. Wind was also commonly heard at the sampling location (detected in 31.9% of audio clips,) moving at a median speed of 1.6 meters per second and interquartile range of 1.9 m/s. These abiotic sources of acoustic energy typify the open, dwarf shrub habitat of alpine floodplains throughout the Alaska Range.

Another typical sound of dwarf shrub habitat is the calling of Arctic Ground Squirrels and Collared Pika. Of these, the squirrels were particularly active at Upper West Branch Toklat, detected in 9.3% of audio clips (compare to the highest detection rate for mammals observed so far, 12.4% at Cathedral Mountain, 2012 [Figure 18]. Diurnal calling times are most common for these colonial animals – and consistent between sampling periods, as is shown in Figure 84.

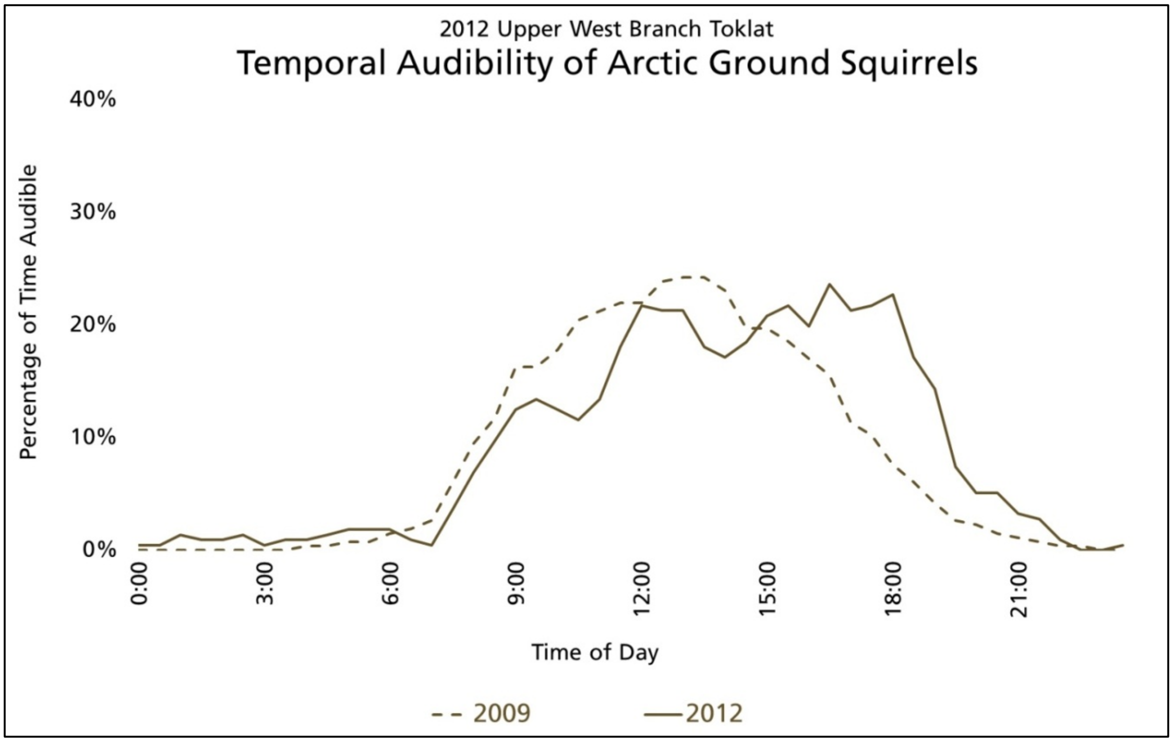


Figure 84. Comparison of the Temporal Audibility of Arctic Ground Squirrels at the Upper West Branch Toklat River, 2012 and 2009.

The most commonly heard sounds at this site were water (audible 100.0% of the time), wind (31.9%), arctic ground squirrels (9.3%), and rain (8.6%). Human made sound was produced entirely by aircraft, and audible 3.8% of the time. (This is equivalent to 54.7 minutes of aircraft sound each day, or about 16 overflights a day.) Conditions exceeded the BCMP percent audible standard 26% of the time, number of events per day 83% of the time, and maximum SPL 88% of the time.

This site was previously sampled in 2009. For comparison, the data collected from 08/12/2009 through 09/05/2009 – a similar sampling period to 2012 – showed the most commonly heard sounds at this site were wind (audible 43% of the time), rain (11%), arctic ground squirrels (11%), and birds (5%). An unexplained difference in natural sound involved the audibility of water, which was consistent in 2012, but not detected in 2009, despite proximity to the stream bed of the Toklat.

Human made sound was produced entirely by aircraft, and audible 3.7% of the time. In 2009, conditions exceeded the BCMP percent audible standard 28% of the time, number of events per day 100% of the time, and maximum SPL 89% of the time (for detailed information on the original dataset, see Withers 2012). Table 6 compares acoustic metrics for the two sampling periods.

Table 6. Comparison of soundscape conditions at Upper West Branch Toklat, 2009 and 2012. Shaded columns indicate Denali Backcountry Management Plan Standards.

Year	% Time Aircraft	% Time Standard	Events Standard	SPL Standard	% Time Water	% Time Wind	% Time Squirrels	% Time Rain
2009	3.7%	28% of all hours	100% of all days	89% of all events	0.0%	42.8%	8.5%	10.5%
2012	3.8%	26%	83%	88%	100.0%	31.9%	9.3%	8.6%

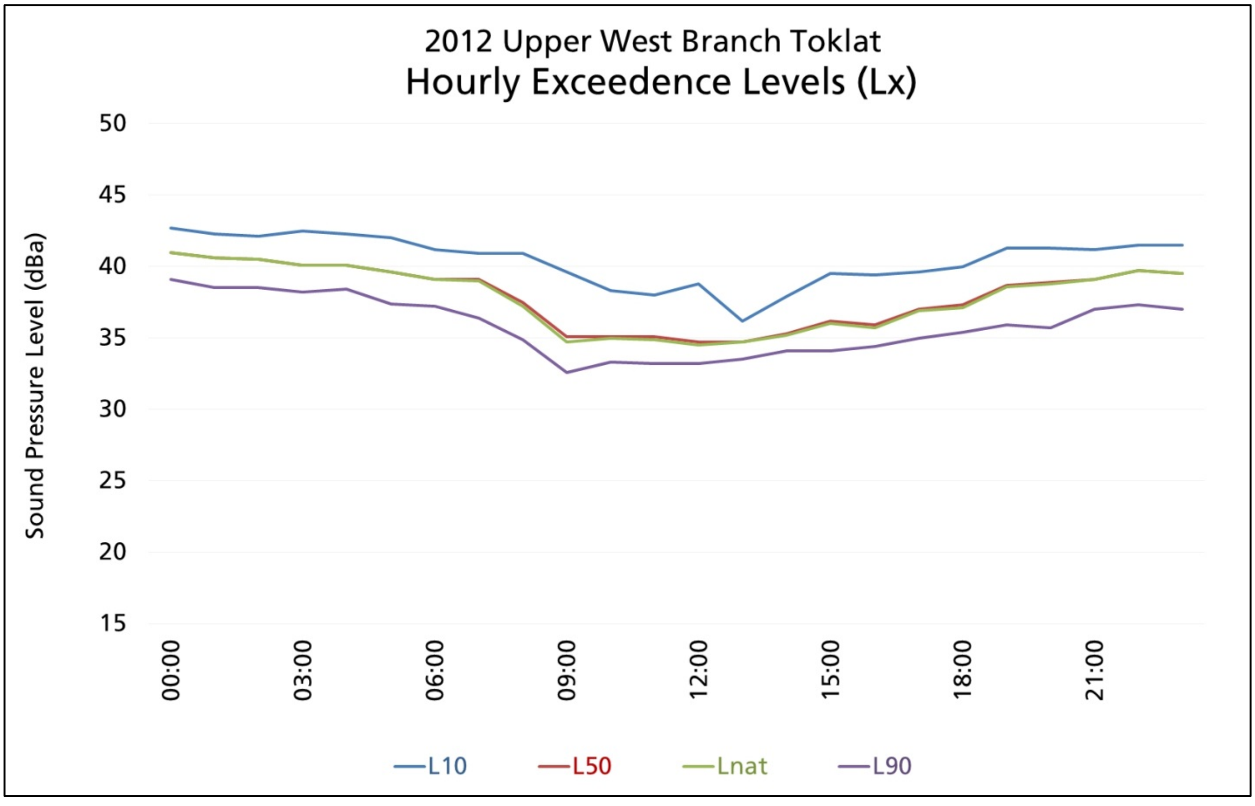


Figure 85. Exceedence levels for Upper West Branch Toklat.

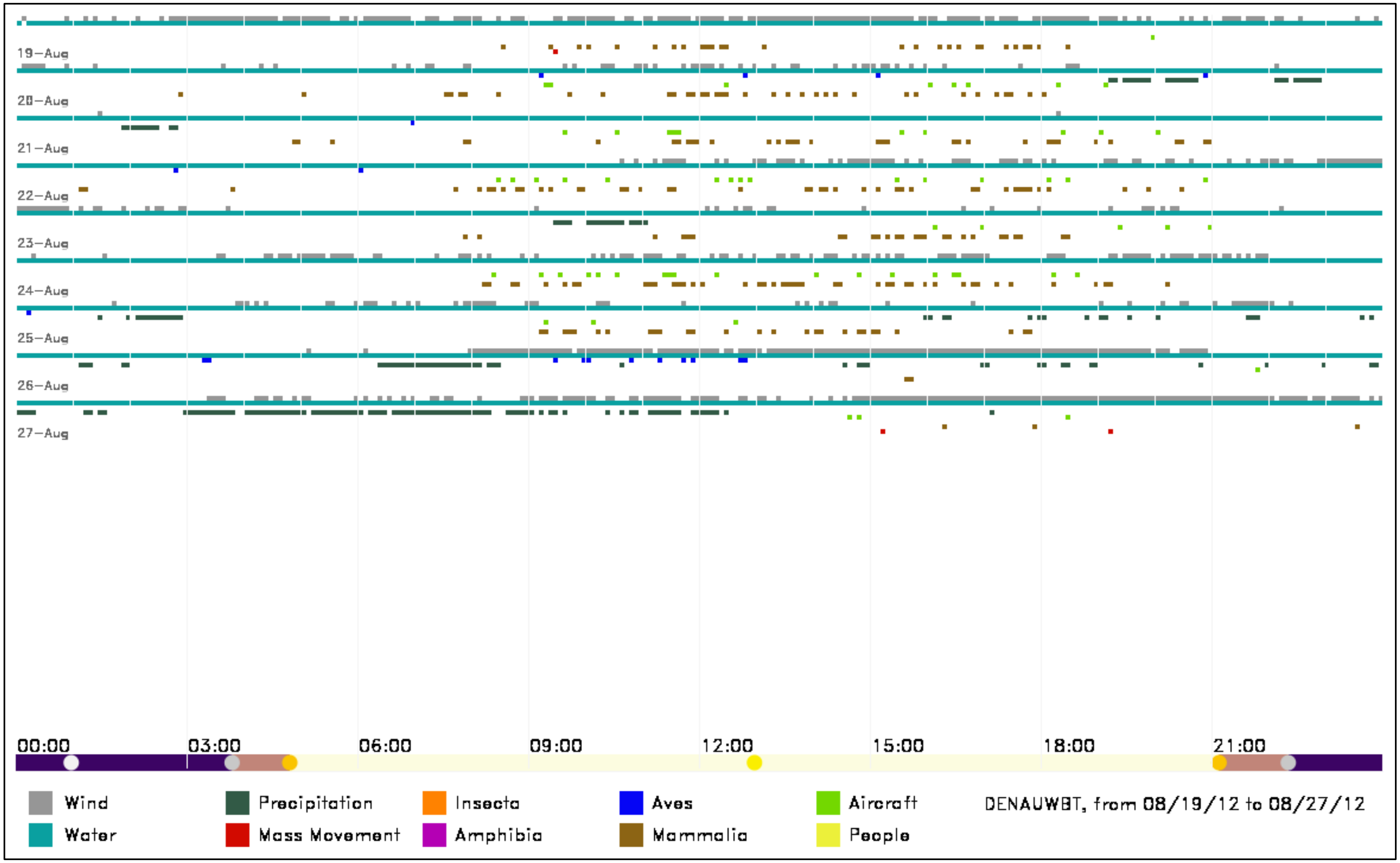


Figure 86. Temporal audibility of sound sources at Upper West Branch Toklat, based on five seconds of audio every five minutes. The bar along the time axis indicates the average light conditions during the sampling period. The orange circles are sunrise/sunset, and the gray circles are the beginning and end of civil twilight.

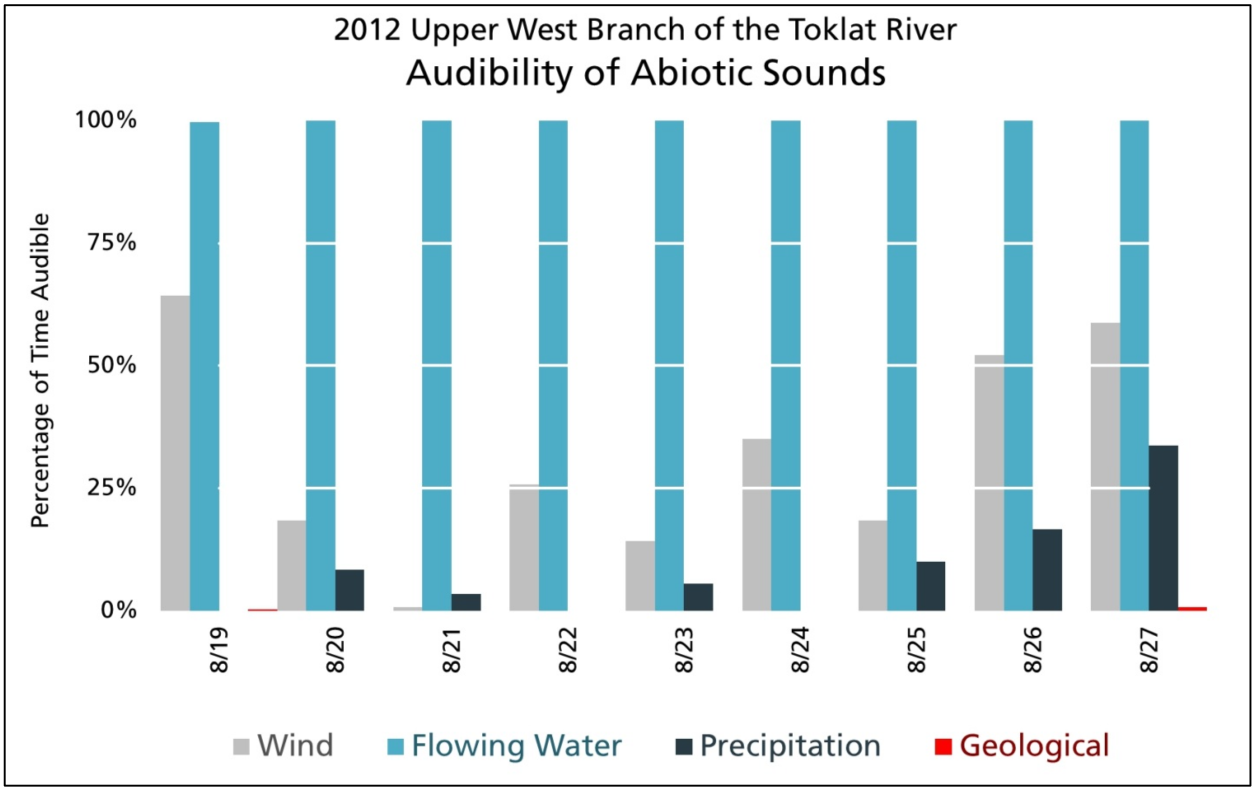


Figure 87. Audibility of abiotic sounds at Upper West Branch Toklat.

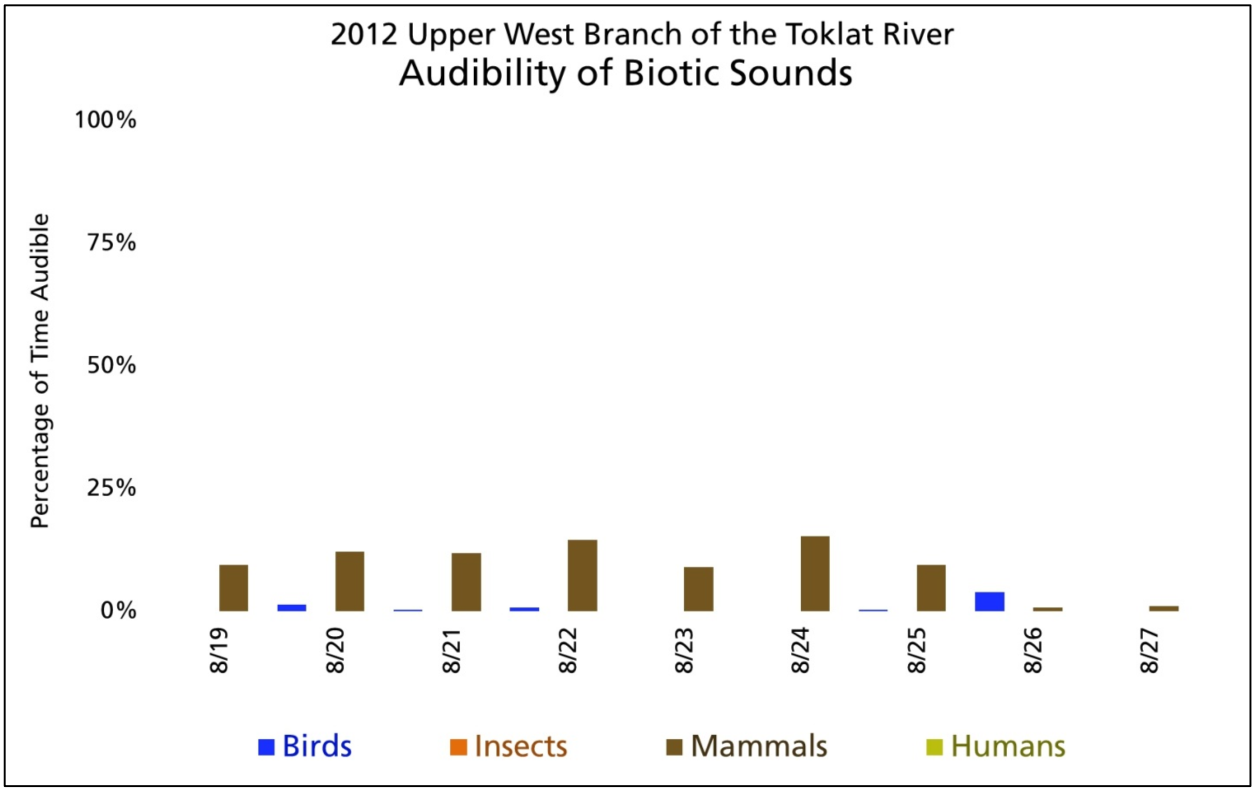


Figure 88. Audibility of biotic sounds at Upper West Branch Toklat.

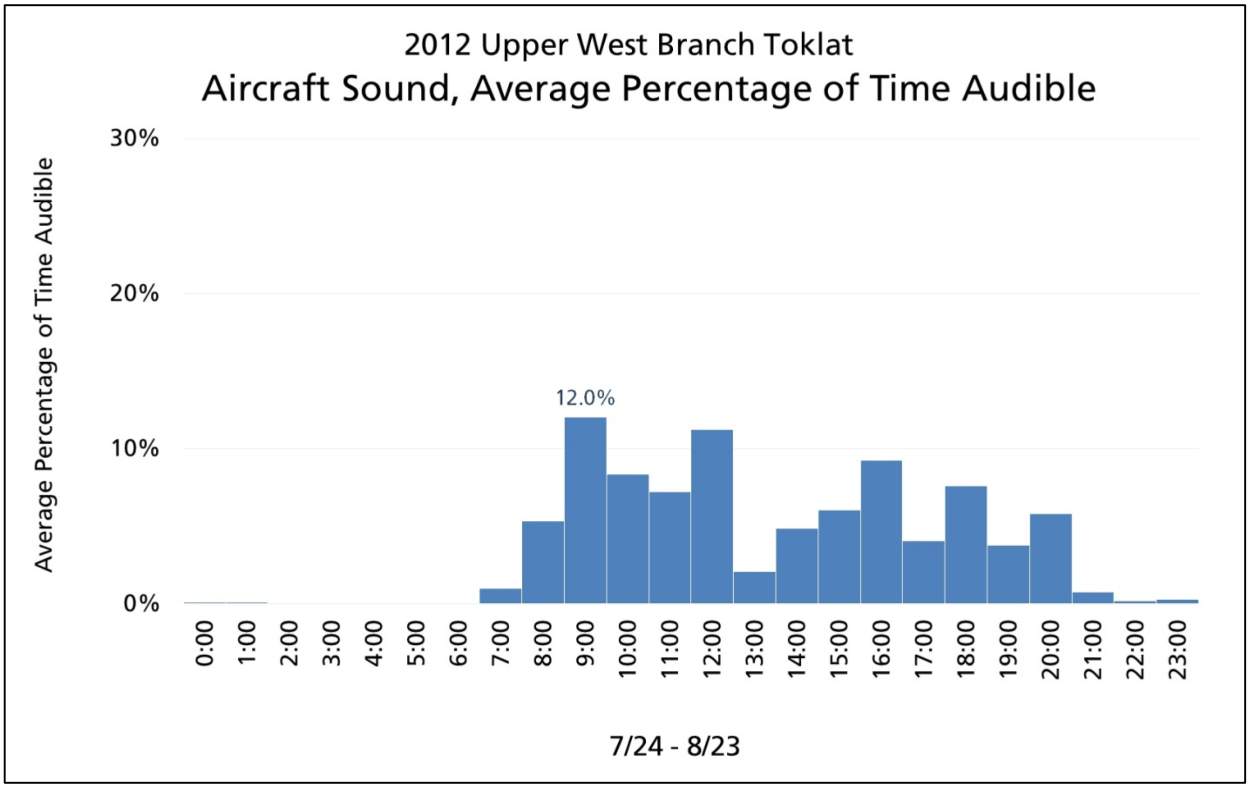


Figure 89. Audibility of aircraft noise for an average day, by hour, at Upper West Branch Toklat.

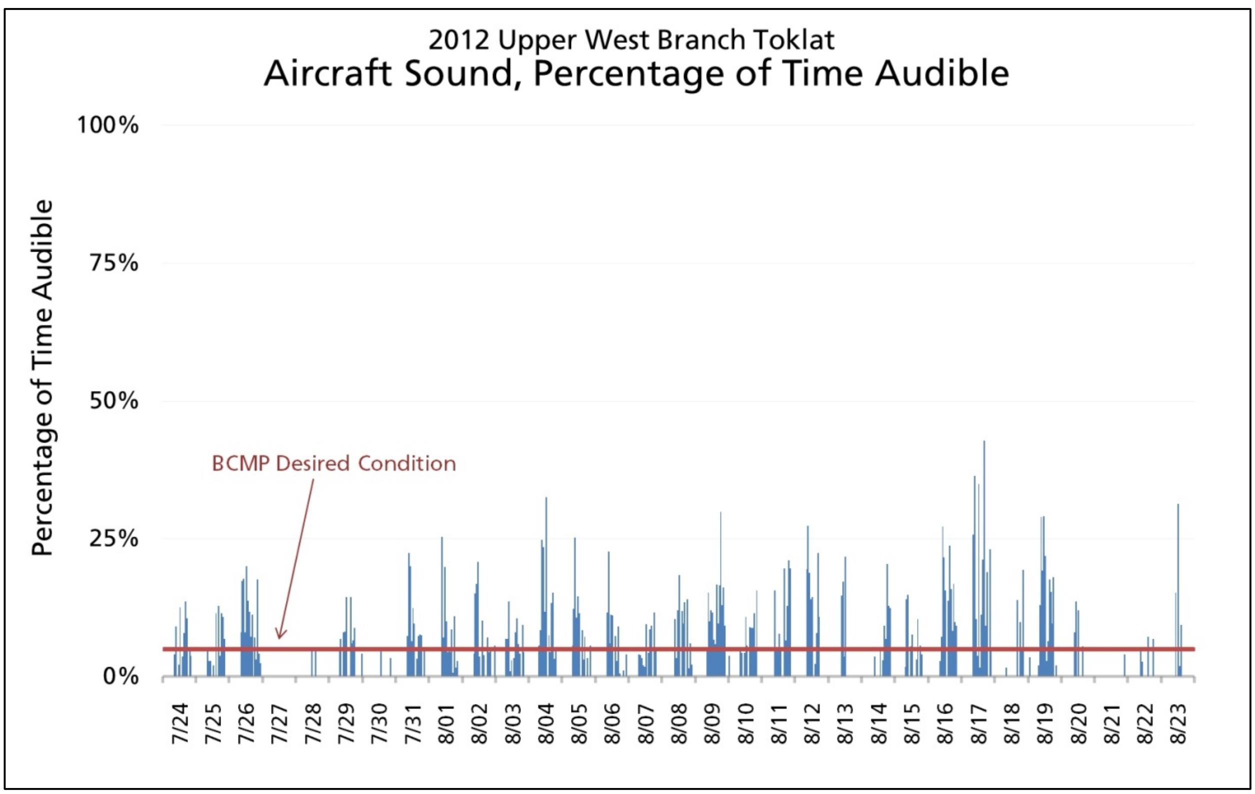


Figure 90. Audibility of aircraft noise at Upper West Branch Toklat.

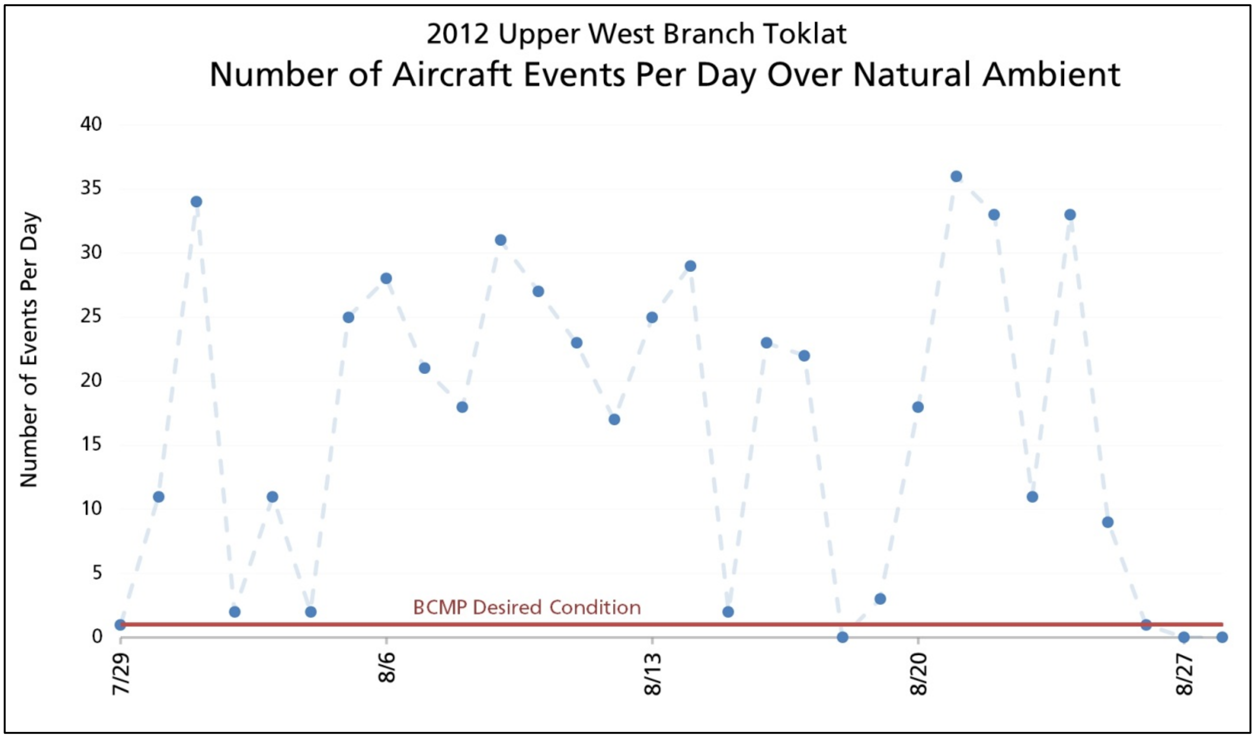


Figure 91. Number of aircraft noise events detected per day at Upper West Branch Toklat.

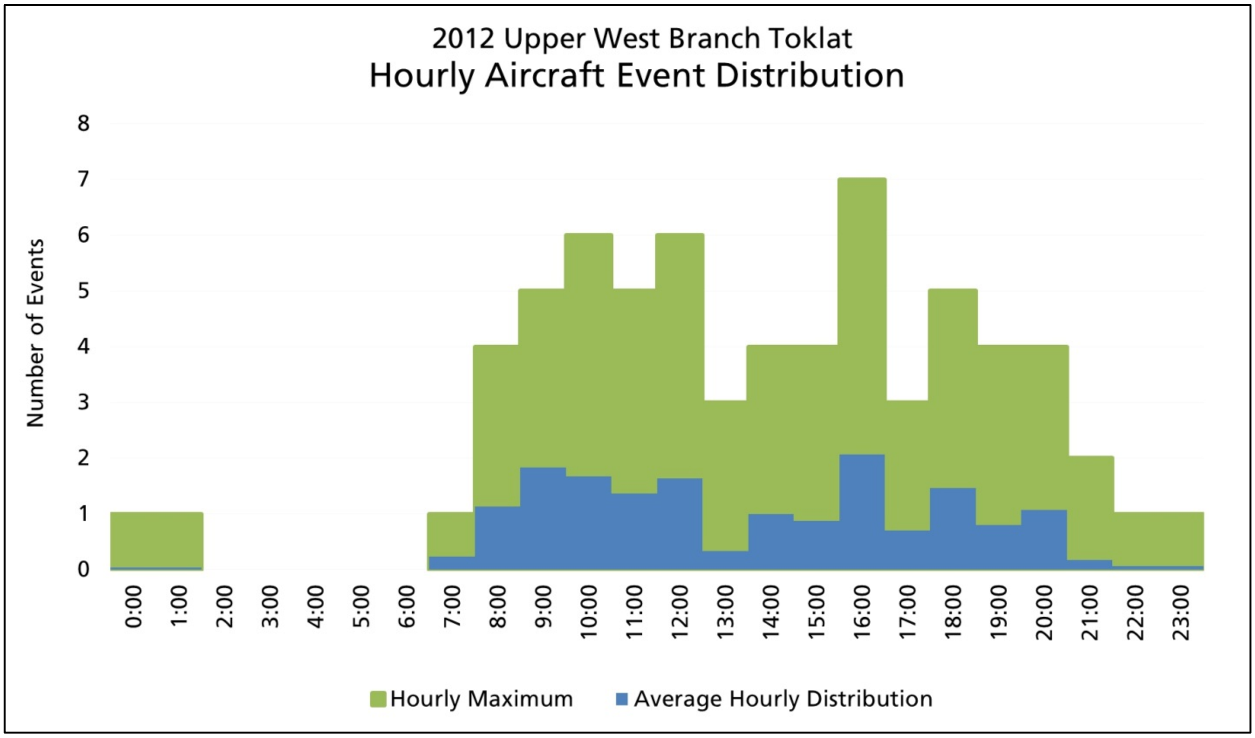


Figure 92. Hourly average and maximum rates of detection for aircraft noise events at Upper West Branch Toklat.

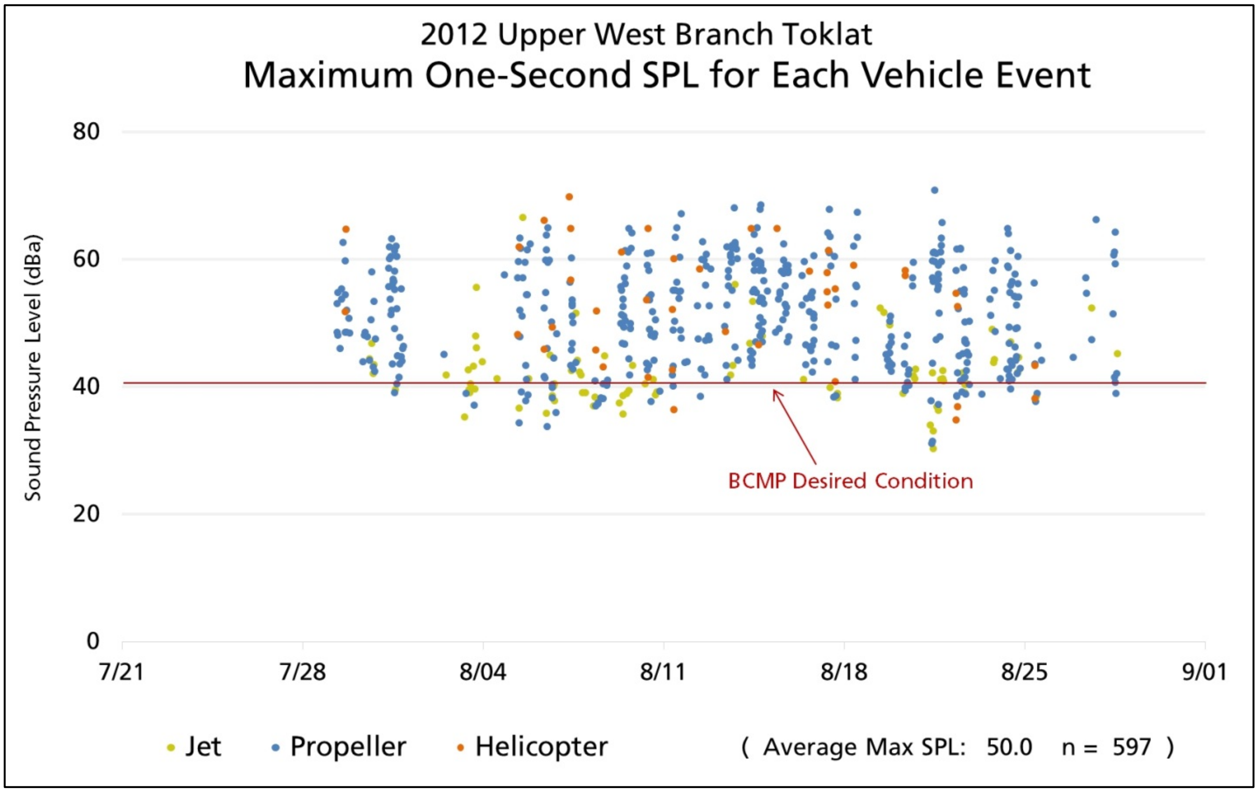


Figure 93. Maximum one-second sound pressure level for each aircraft event detected at Upper West Branch Toklat

Upper Yentna Glacier

Location Description: On the East Fork of the Yentna Glacier, approximately 15 km south-west of Mount Foraker and 6 km north of the wilderness boundary.

Purpose/Project: Location randomly chosen from the LTEM grid as part of the long-term Denali Soundscape inventorying and monitoring sampling plan.

Coordinates: 62.88545°, -151.64183° (WGS84)

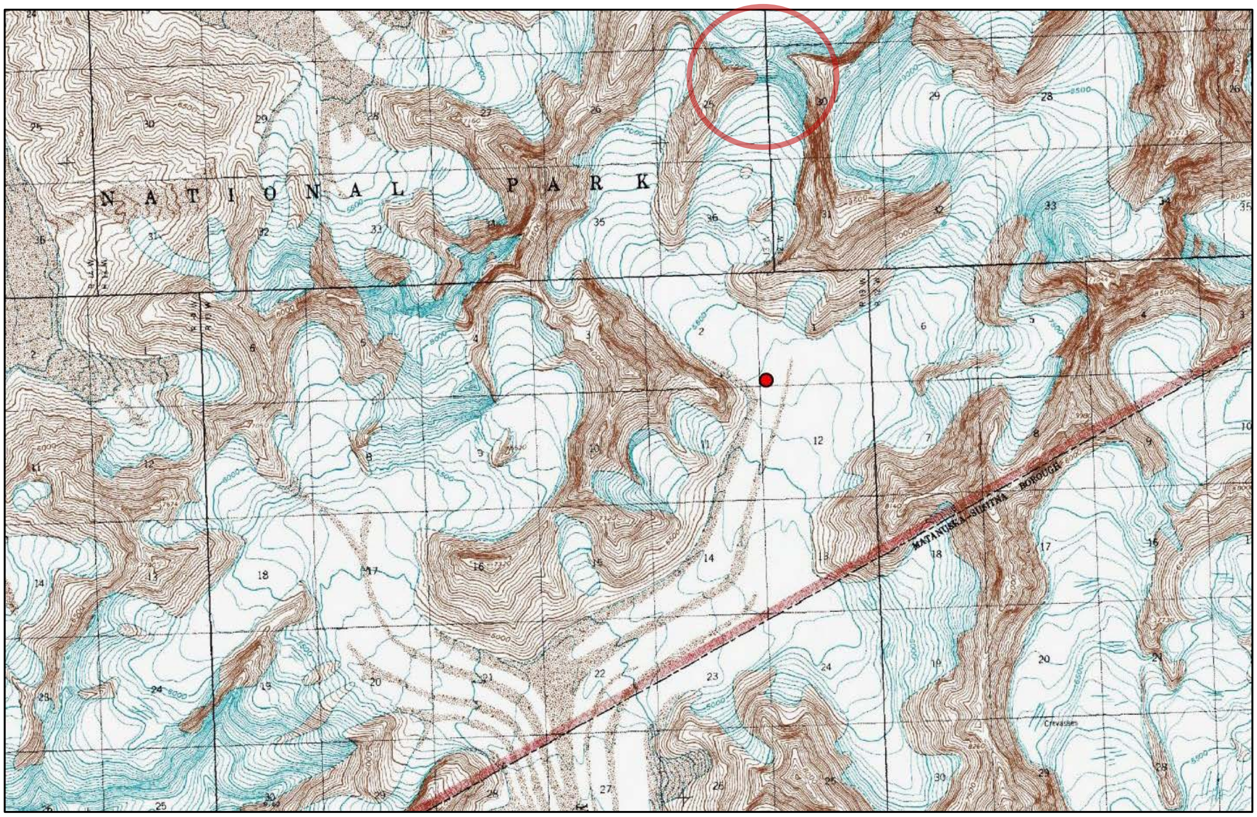
Elevation: 1575 meters

BCMP Management Area: OP2 (Low Natural Sound Disturbance)

Park Ecoregion: Alaska Range High Mountains

Sampling Period: 19-May-2012 to 18-June-2012

Access: Helicopter



Summary/Notes: The purpose of the Upper Yentna Glacier location was to collect data at one of the long-term ecological monitoring (LTEM) grid points, as outlined in the above sampling plan. LTEM grid point #61 was stratified as a designated wilderness location and randomly selected from all locations requiring aircraft access.

In this glacial environment, temperature and gravity joined in concert to generate motion – and subsequently, a variety of sounds. Melting snow mixed with rock to create powerful avalanches. Small tables and slabs of stone pivoted and toppled, ringing from the near-vertical walls of the glacial valley. Larger rock falls brought thunderous waves of granite crashing to the surface, with the finer particles trailing behind in a high-pitched waterfall of pebbles. Air bubbled and hissed from the glacier's surface under pressure.

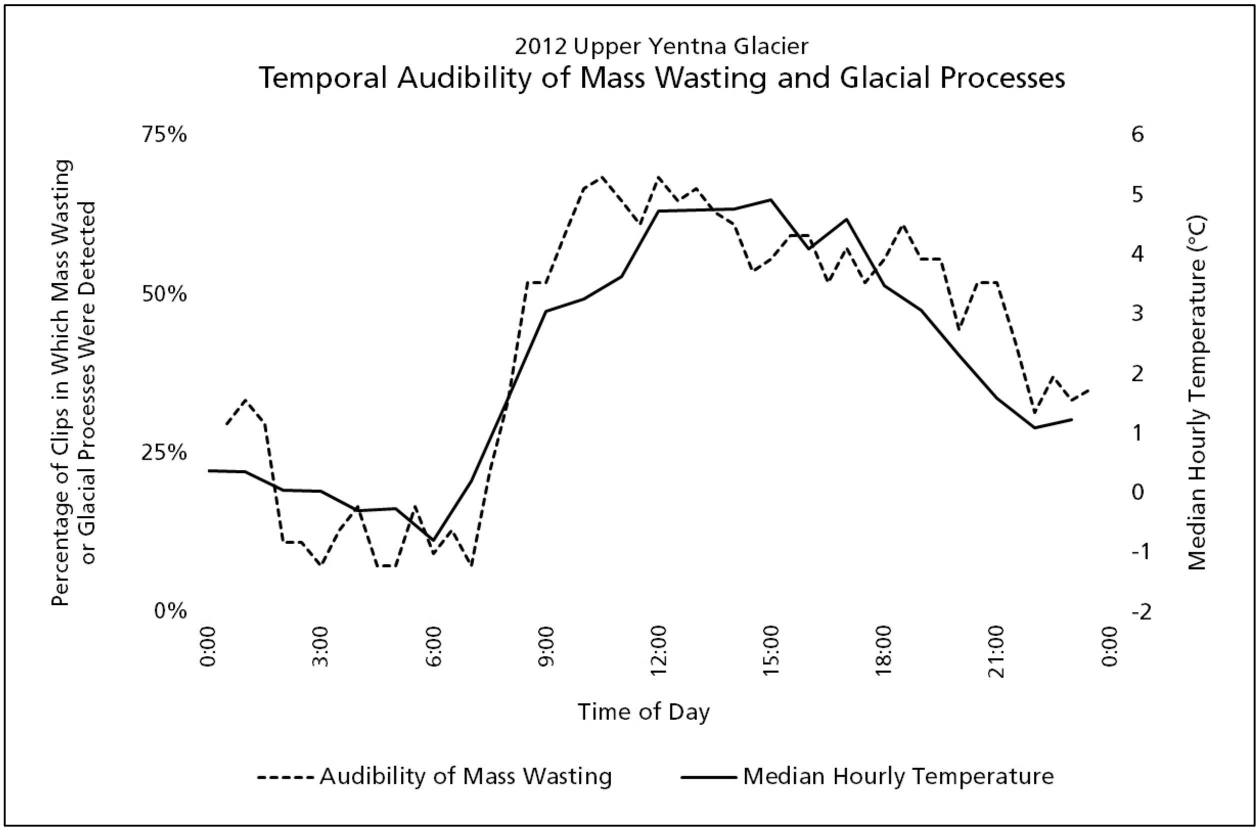
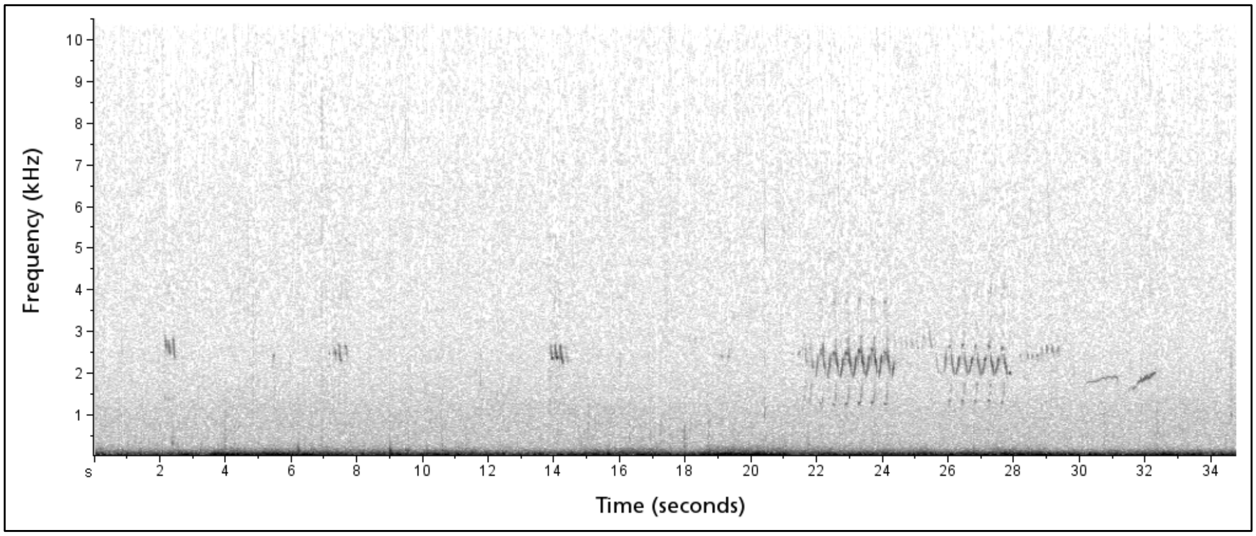


Figure 94. Temporal relationship between the median hourly temperature and audibility of mass wasting and glacial processes at Upper Yentna Glacier.

Aggregated as one large category, mass wasting and glacial processes were audible in 41.9% of audio clips, easily making Upper Yentna Glacier the most active location sampled to date for this class of sounds. Compare Muldrow Glacier (2006) at 8.6% of clips, and Upper Ohio Glacier (2010) at 6.2% of clips. The daily timing of geophonic sounds across the three sites share clear similarities: a sudden increase in motion around 08:00 or 09:00 tapers into the twilight hours - after which motion stops again.

Although the bare rock and snow of the high-alpine Alaska Range do not seem hospitable to life, birds were audible in 6.7% of audio clips at this site. The most common species detected during the sampling period were White-Tailed Ptarmigan and Fox Sparrow – fairly typical species at high elevation. However, early morning flight calls of Spotted Sandpiper (*Actitis macularius*), Greater Yellowlegs (*Tringa melanoleuca*), Whimbrel, and Trumpeter Swan (*Cygnus buccinator*) seem to indicate that the area is a migration route towards the Kusokwim / Lake Minchumina lowlands to the north. On the previous page, the red-circled area of the map indicates a possible migratory pass that birds may be using to traverse the range.



Spectrogram 7. Call of a migrating Greater Yellowlegs (*Tringa melanoleuca*) as it passes over the Upper Yentna Glacier site. The spectrogram begins at 00:18:22 on 05/27/2012.

The most commonly heard sounds at this site were wind (audible 56.6% of the time), mass wasting and glacial processes (41.9%), silence (12.7%), and birds (6.7%). Human made sound was audible 1.3% of the time on average; all of it was generated by aircraft. This is equivalent to 18.7 minutes each day, or approximately 5 overflights a day. Conditions exceeded the BCMP percent audible standard 8% of the time, number of events per day 66% of the time, and maximum SPL 19% of the time.

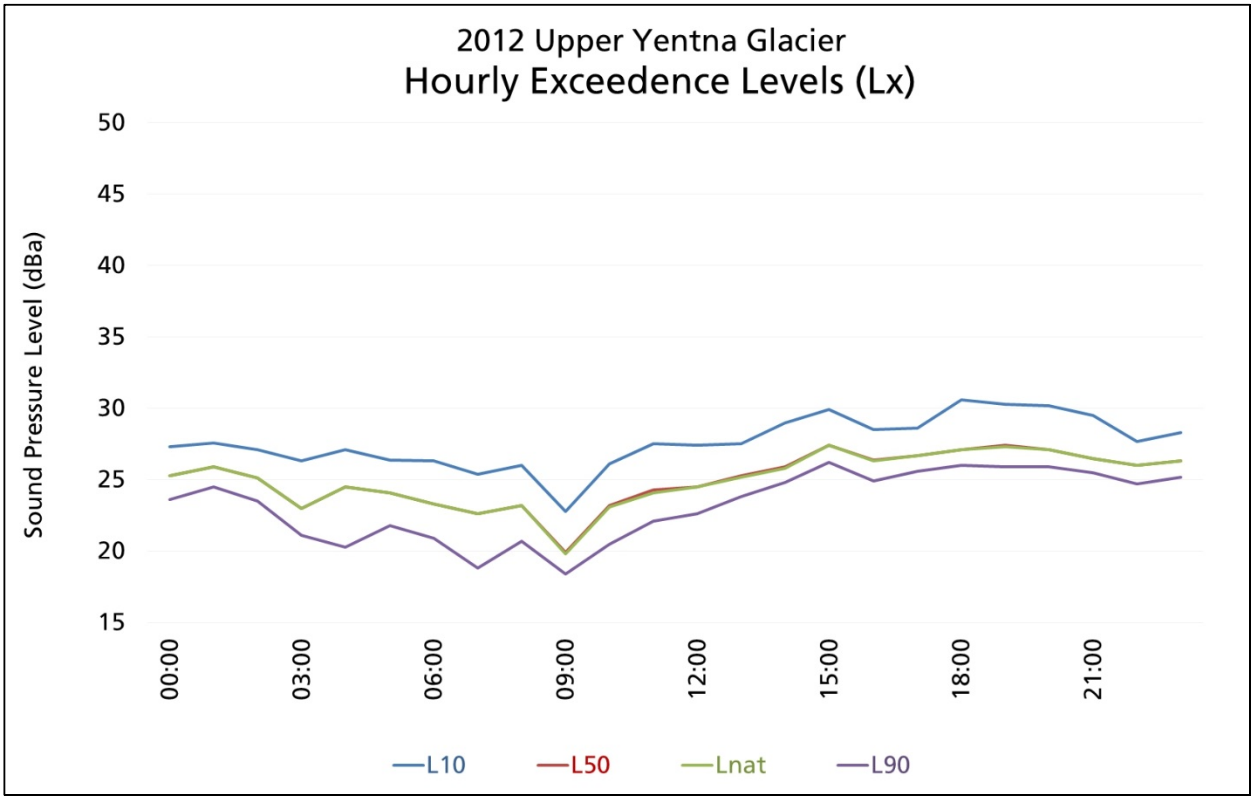


Figure 95. Exceedence levels for Upper Yentna Glacier.

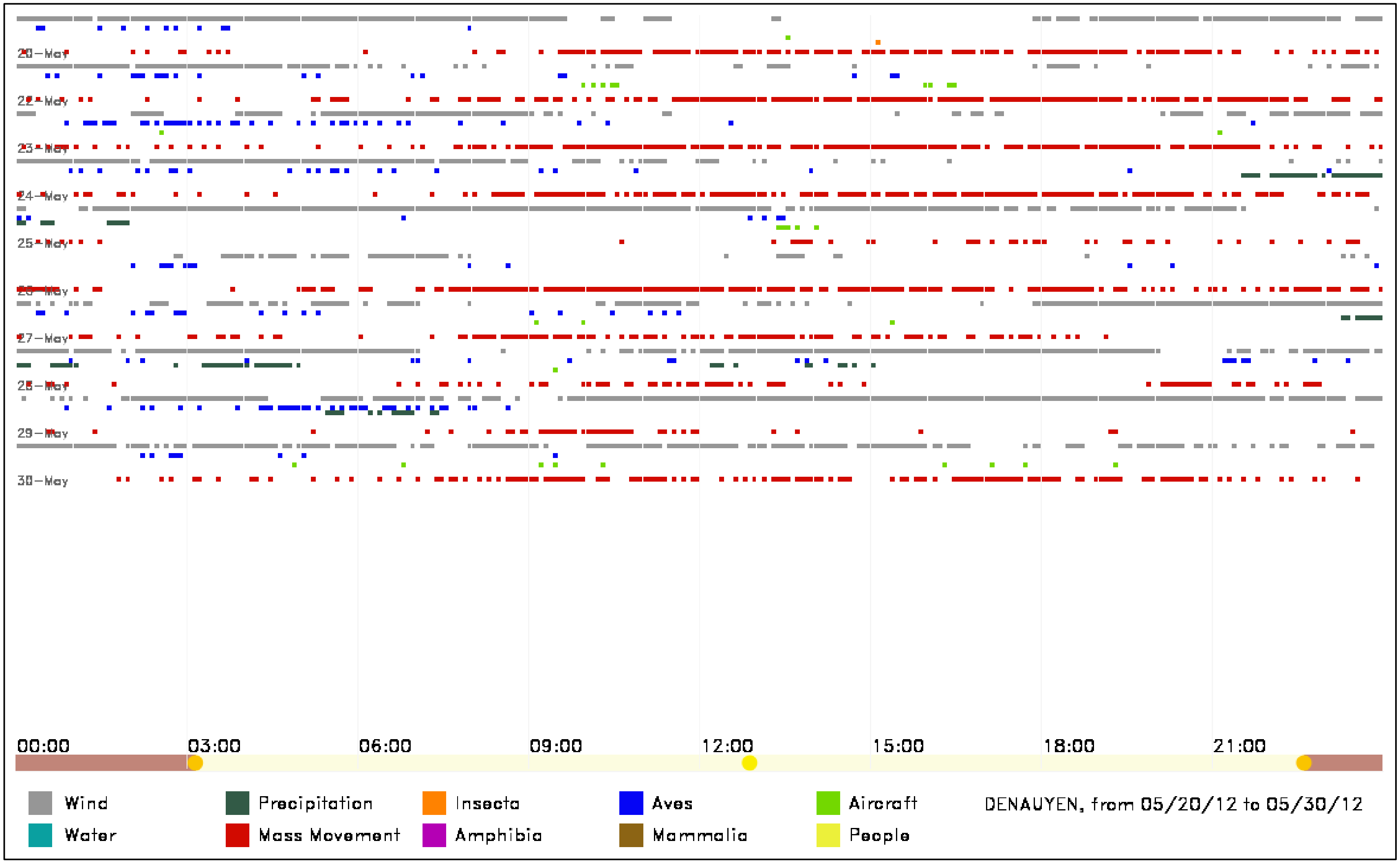


Figure 96. Temporal audibility of sound sources at Upper Yentna Glacier, based on five seconds of audio every five minutes. The bar along the horizontal axis indicates the average light conditions during the sampling period. The orange circles are sunrise/sunset. This site did have civil twilight or night-time conditions during the sampling period.

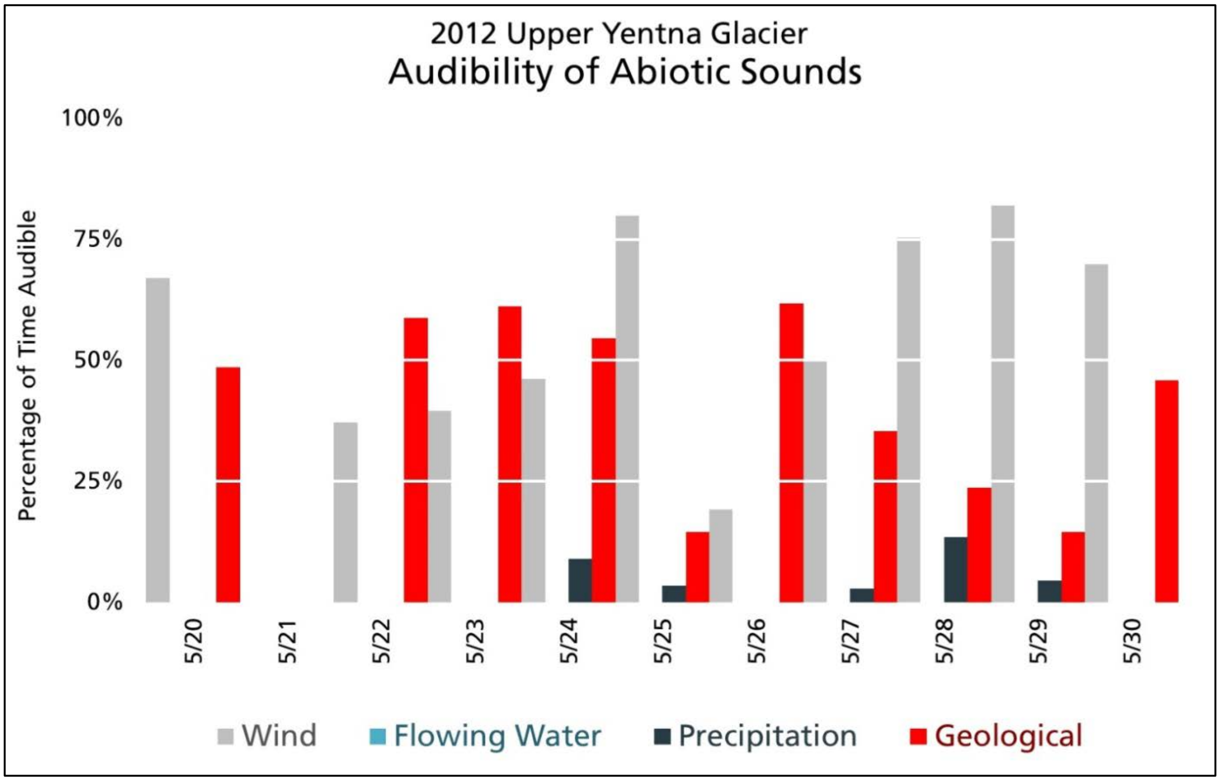


Figure 97. Audibility of abiotic sounds at Upper Yentna Glacier.

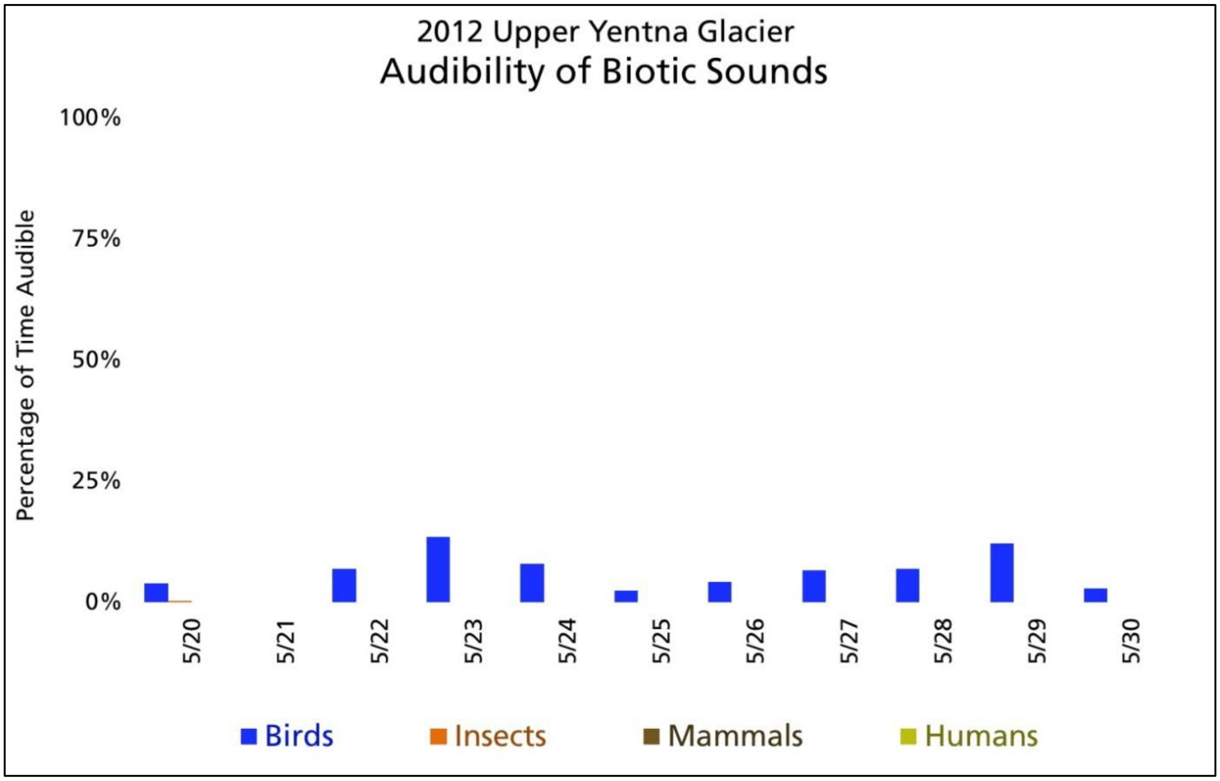


Figure 98. Audibility of biotic sounds at Upper Yentna Glacier.

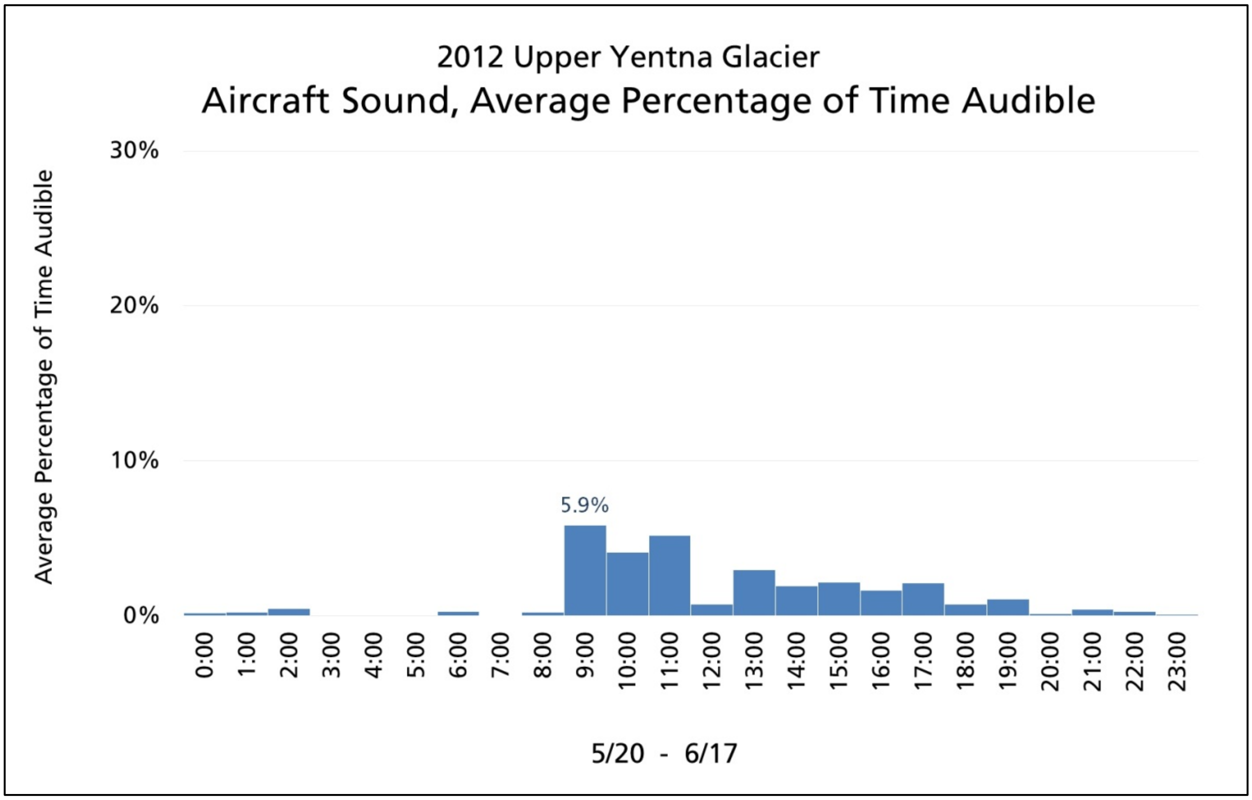


Figure 99. Audibility of aircraft noise for an average day, by hour, at Upper Yentna Glacier.

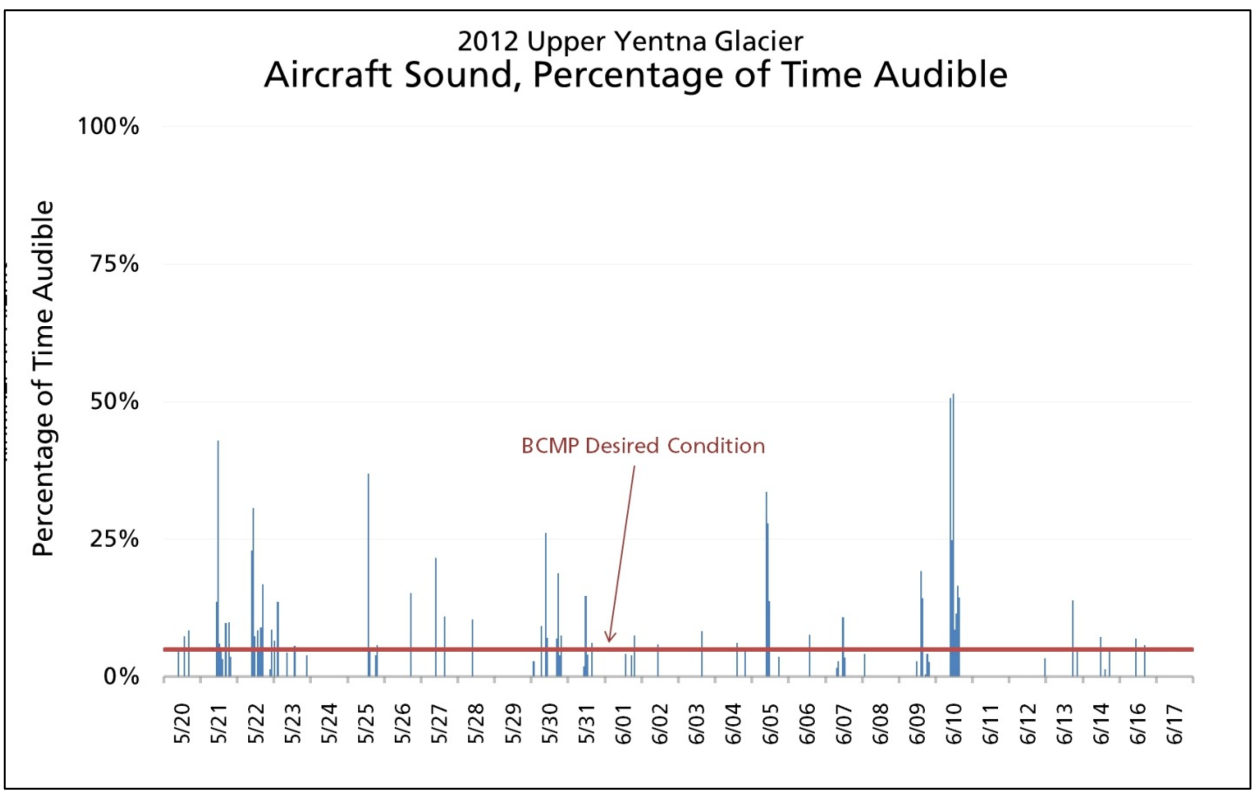


Figure 100. Audibility of aircraft noise at Upper Yentna Glacier.

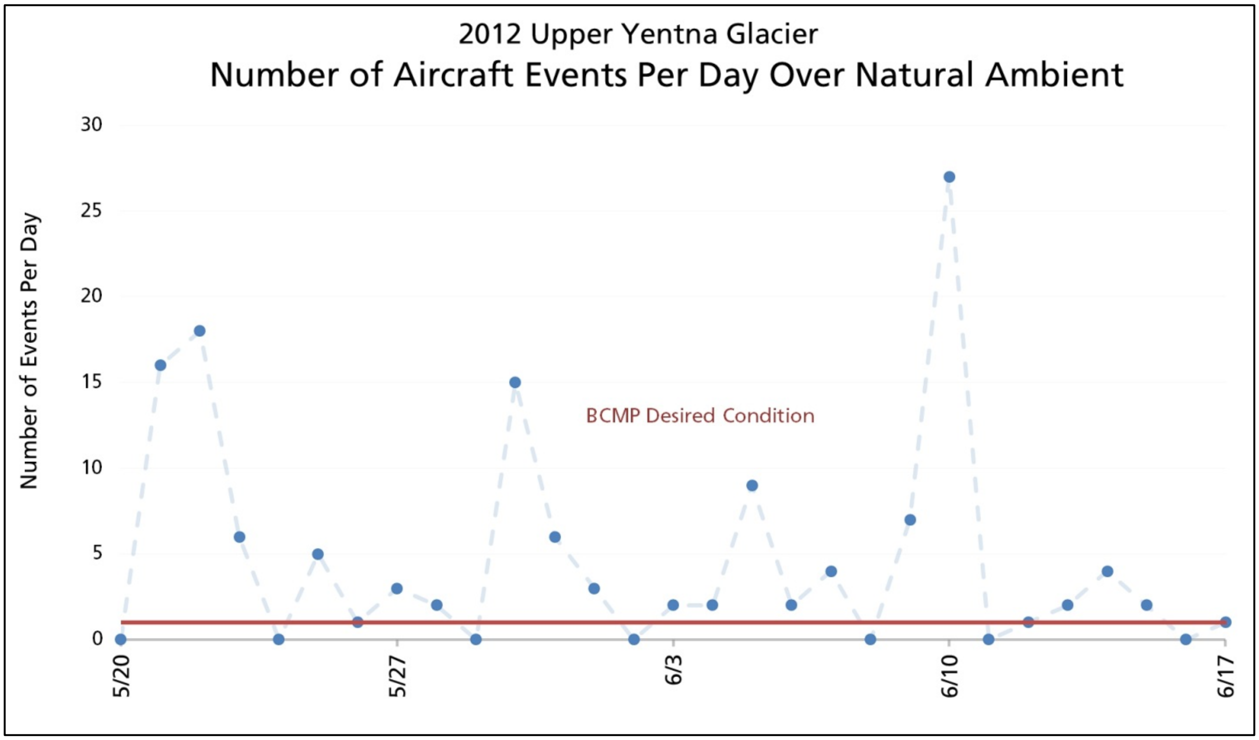


Figure 101. Number of aircraft noise events detected per day at Upper Yentna Glacier.

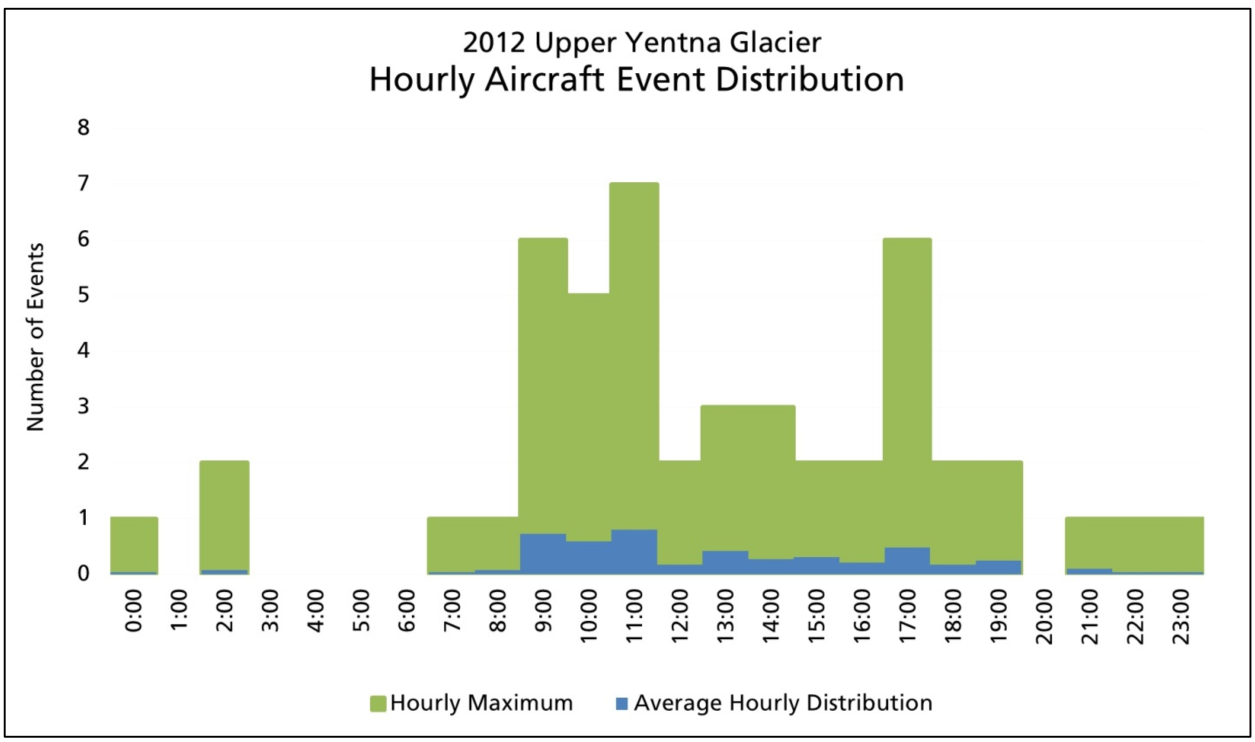


Figure 102. Hourly average and maximum rates of detection for aircraft noise events at Upper Yentna Glacier.

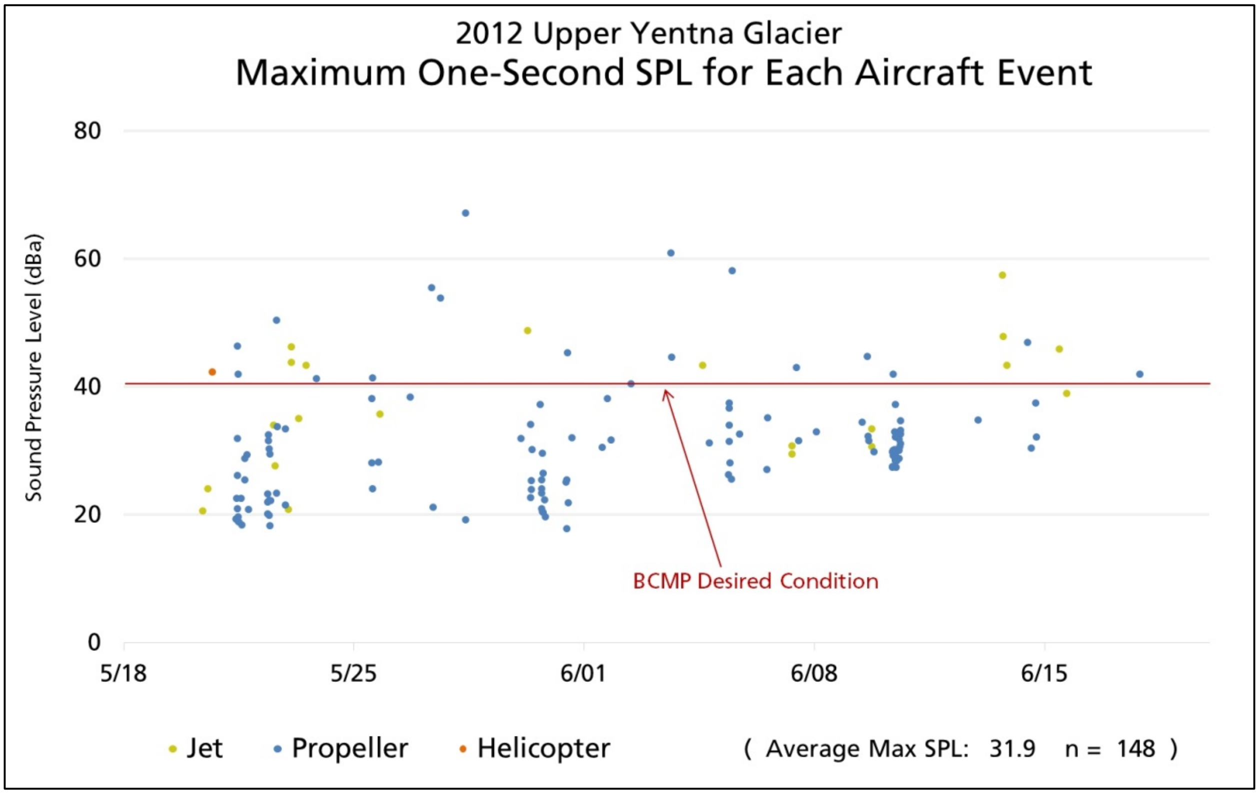


Figure 103. Maximum one-second sound pressure level for each aircraft event detected at Upper Yentna Glacier.

Conclusion

Natural sound is both a resource in its own right as well as an important aspect of Denali National Park and Preserve's wilderness resource values. The goal of the seventh year of the Denali Soundscape Inventory was to measure baseline natural sound conditions and current overflight data at an additional seven sites across the park. It built on previous work conducted in 2006–2011, which collected similar data at other locations. An additional goal was to resample two sites by which to monitor the effects of newly-enacted voluntary aviation best practice.

In 2012, automated acoustic monitoring systems collected varied records of ambient sound pressure level. Patterns of anthropogenic noise at each location became readily apparent upon analysis, with certain aspects typifying any particular soundscape. The highest rates of air traffic were measured at the Toe of the Kanikula. By contrast, the site at Upper Yentna Glaicer about 42 km north-west and away from flight paths between Mt. McKinley and Talkeetna, had an average rate of 5 events per day. This relatively-intact condition of solitude is shared by most nearby monitoring locations in the west-central portion of the park. (For detailed information on this especially intact soundscape, see Withers 2010, Withers 2012, Withers and Betchkal 2013, and Betchkal 2013. Of interest are the Highpower Creek, Herron Glacier, Herron River, North Vertical Access Benchmark, and Upper Dall Glacier, and Upper Yentna Glacier monitoring locations.)

Natural sound characteristics also typify a place. For instance, the quietest natural ambient conditions on record in 2012 were at in winter at Dunkle Hills – with a time-averaged level of 15.64 dBA. The quietest summer conditions were 18.70 dBA off the sloughs west of the McKinley River. In contrast, the loudest natural ambient level was documented at 44.61 dBA within the influence of snowmelt-charged Fourth-of-July creek in the Kichatna Mountains – a fourfold difference in acoustic energy.

Many species of animals were documented on record in 2012. Wandering Tattler were recorded at Kichantna Mountains, Long-tailed Jaeger at Sushana Ridge, and Golden Eagle at Cathedral Mountain. All are rarely-recorded species in North America, and notable additions to Denali's reference library.

White-tailed Ptarmigan, a high-alpine specialist species, were detected at three sampling locations – Bull River, Kichatna Mountains, and Upper Yentna Glaicer. Collared pika, another high-alpine specialist, were detected at four – Bull River, Cathedral Mountain, Toe of the Kanikula Glacier, and Upper West Branch Toklat. Still other recordings expanded Denali's documentation of calling behavior in Arctic ground squirrels and Sandhill Cranes.

Quality audio files of bird song and calls were contributed to the online project www.*xeno-canto.org* as part of a worldwide scientific reference library on avian bioacoustics. Subarctic records are sparse, and so documents from Denali add a large amount of information to the overall project.

All inventory sites exhibited some level of exceedence of the Denali Backcountry Management Plan standards as shown in Table 7. These findings have been added to the parkwide backcountry management plan compliance maps which can be found in Appendix B.

Table 7. Percentage of samples exceeding BCMP sound standards.

Site Name	Hourly Motorized Noise Audiblity	Motorized Noise Events/Day	Motorized Max SPL (dBA)	BCMP Area
Bull River	17% of all hours	82% of all days	100% of all events	OP1 (Low)
Cathedral Mountain	37%	80%	66%	OP1 (Low)
Dunkle Hills* [1]	5%	27%	0.8%	A (High)
Hines Creek [1]	15%	100%	37%	OP1 (Low)
Kichatna Mountains	13%	100%	100%	D (Low)
McKinley River	19%	96%	18%	D (Low)
Sushana Ridge	26%	81%	77%	OP1 (Low)
Toe of the Kanikula Glacier*	1%	63%	11%	A (High)
Upper West Branch Toklat	26%	83%	88%	OP1 (Low)
Upper Yentna Glacier	8%	66%	19%	OP2 (Low)

[1] : Winter season site.

*: Indicates that the site was an area managed for a high level of natural sound disturbance. All other sites were located in an area managed for low levels of natural sound disturbance.

As it stands today, Denali National Park and Preserve has the most extensive acoustical monitoring dataset in the National Park system. The data included in this report may be used to inform a Soundscape Management Plan, General Management Plan, Natural Resource Conditions Assessment, other park plans, or NEPA documents that consider impacts to the soundscape.

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Appendix A. Glossary of Acoustic Terms

Acoustical Environment
The actual physical sound resources, regardless of audibility, at a particular location.

Amplitude
The instantaneous magnitude of an oscillating quantity such as sound pressure. The peak amplitude is the maximum value.

Audibility
The ability of animals with normal hearing, including humans, to hear a given sound. Audibility is affected by the hearing ability of the animal, the masking effects of other sound sources, and by the frequency content and amplitude of the sound.

dBA
A-weighted decibel. A-weighted sum of sound energy across the range of human hearing. Humans do not hear well at very low or very high frequencies. Weighting adjusts for this.

Decibel (dB)
A logarithmic measure of acoustic or electrical signals. The formula for computing decibels is: 10(Log10(sound level/reference sound level)). 0 dB represents the lowest sound level that can be perceived by a human with healthy hearing. Conversational speech is about 65 dB.

Extrinsic Sound
Any sound not forming an essential part of the park purpose, or a sound originating from outside the park boundary.

Frequency
The number of times per second that the sine wave of sound repeats itself. It can be expressed in cycles per second, or Hertz (Hz). Frequency equals Speed of Sound/ Wavelength.

Hearing Range (frequency)
By convention, an average, healthy, young person is said to hear frequencies from approximately 20Hz to 20000 Hz.

Hertz (Hz)
A measure of frequency, or the number of pressure variations per second. A person with normal hearing can hear between 20 Hz and 20,000 Hz.

Human-Caused Sound
Any sound that is attributable to a human source.

Intrinsic sound
A sound which belongs to a park by its very nature, based on the park unit purposes, values, and establishing legislation. The term "intrinsic sounds" has replaced "natural sounds" in order to incorporate both cultural and historic sounds as part of the acoustic environment of a park.

Listening Horizon (sometimes synonymous with Active Space)
The range or limit of one's hearing capabilities. Just as smog limits the visual horizon, so noise limits the acoustic horizon.

L_{eq}
Energy Equivalent Sound Level. The level of a constant sound over a specific time period that has the same sound energy as the actual (unsteady) sound over the same period.

L_x
A metric used to describe acoustic data. It represents the level of sound exceeded x percent of the time during the given measurement period. Thus, L_{50} is the level exceeded 50% of the time (it is also referred to as existing ambient).

L_{nat}
An estimate of what the acoustical environment might sound like without the contribution of extrinsic (anthropogenic) sounds.

Masking
The process by which the threshold of audibility for a sound is raised by the presence of another sound.

Noise-Free Interval
The period of time between noise events (not silence).

Noise
Sound which is unwanted, either because of its effects on humans, its effect on fatigue or malfunction of physical equipment, or its interference with the perception or detection of other sounds (Source: McGraw Hill Dictionary of Scientific and Technical Terms).

Off-site Listening
The systematic identification of sound sources using digital recordings previously collected in the field.

Sound
Variations in local pressure that propagate through a medium (e.g. the atmosphere) in space and time.

Soundscape
Human perception of the acoustical environment.

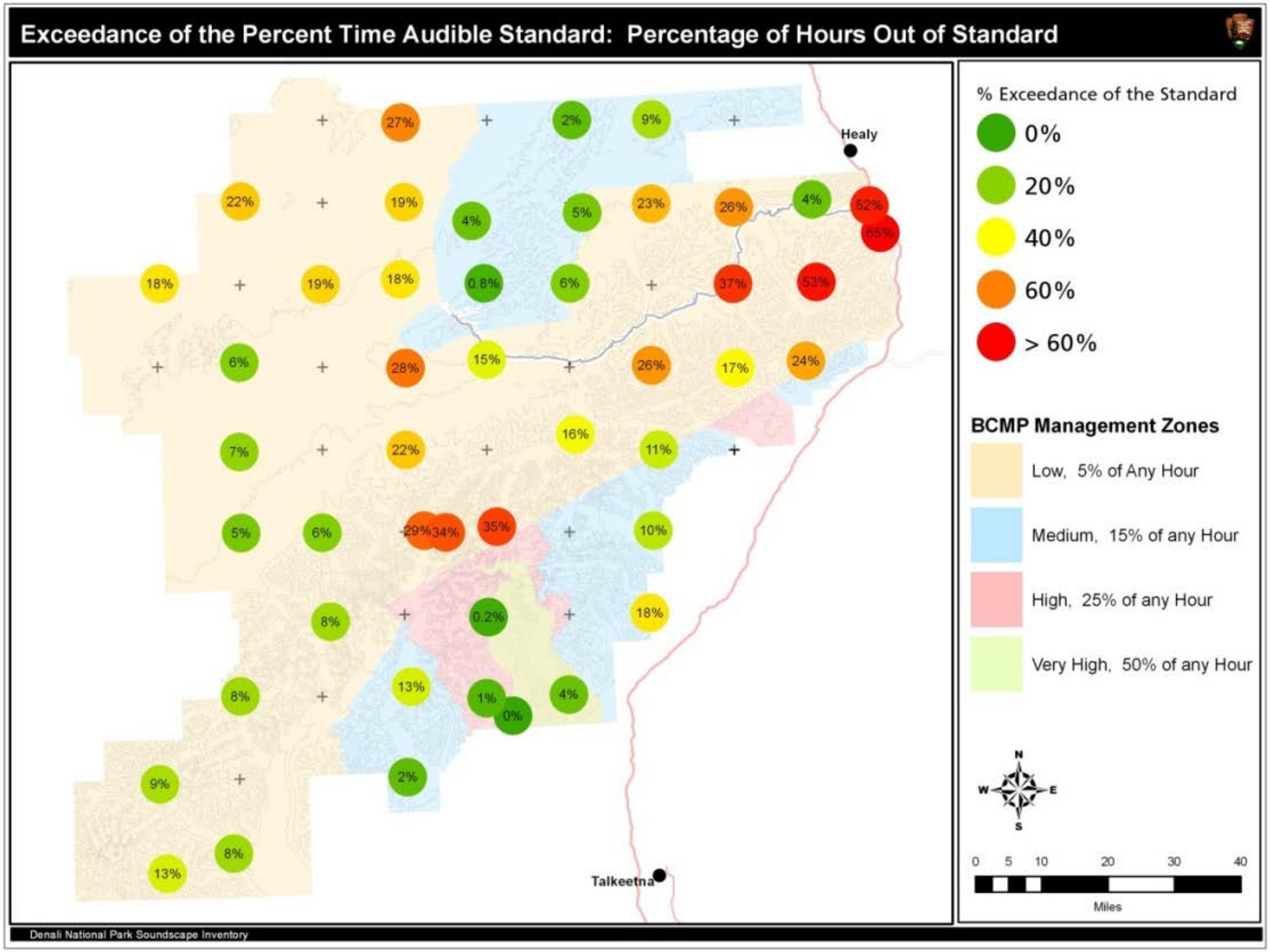
Sound Pressure
The difference between instantaneous pressure and local barometric pressure. Measured in Pascals (Pa), Newtons per square meter, which is the metric equivalent of pounds per square inch.

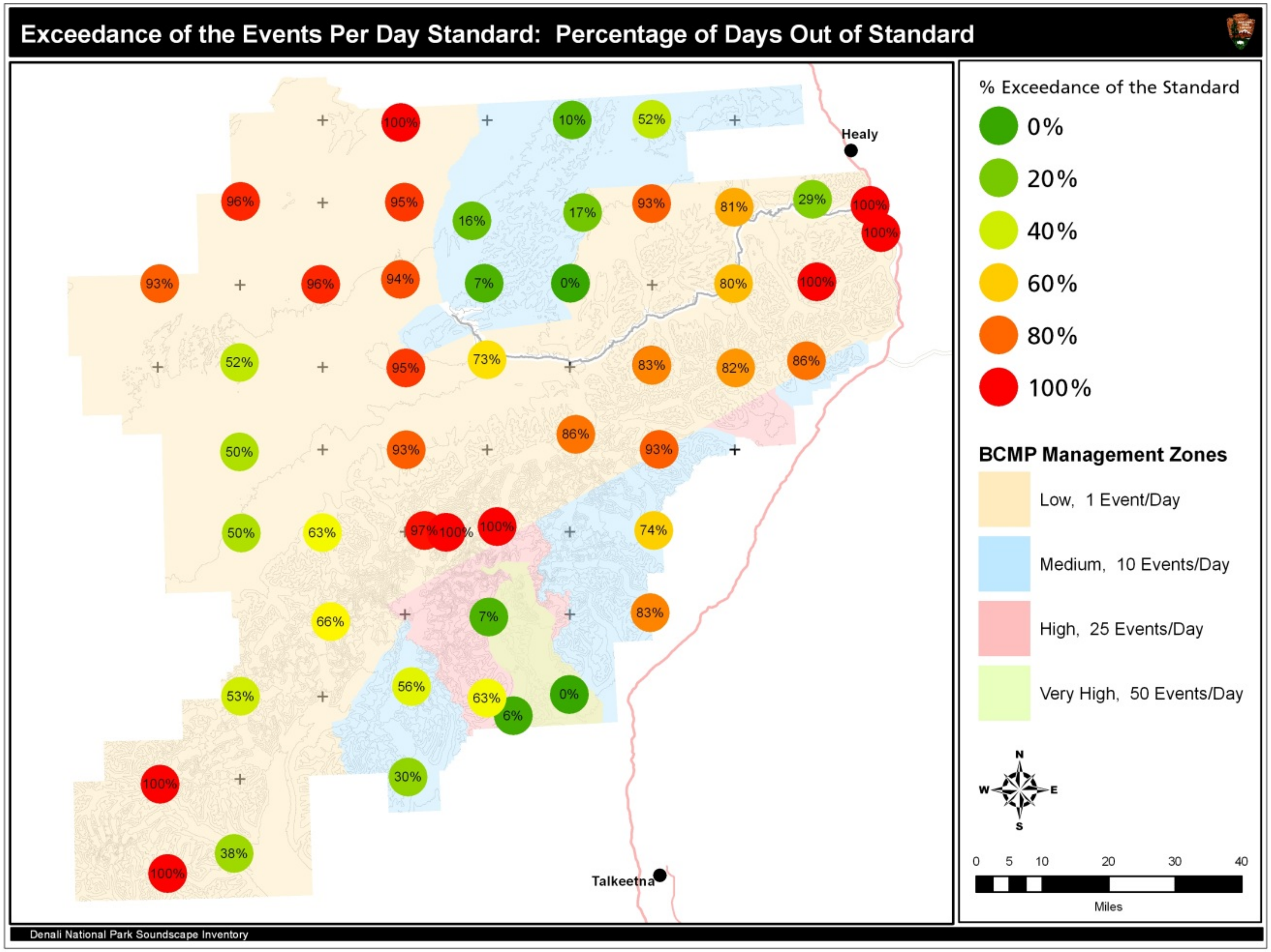
Sound Pressure Level (SPL)
A calibrated measure of sound level, expressed in decibels, and referred to an atmospheric standard of 20 micro Pascals.

Time Audible
The amount of time that a sound source is audible to a human with normal hearing.

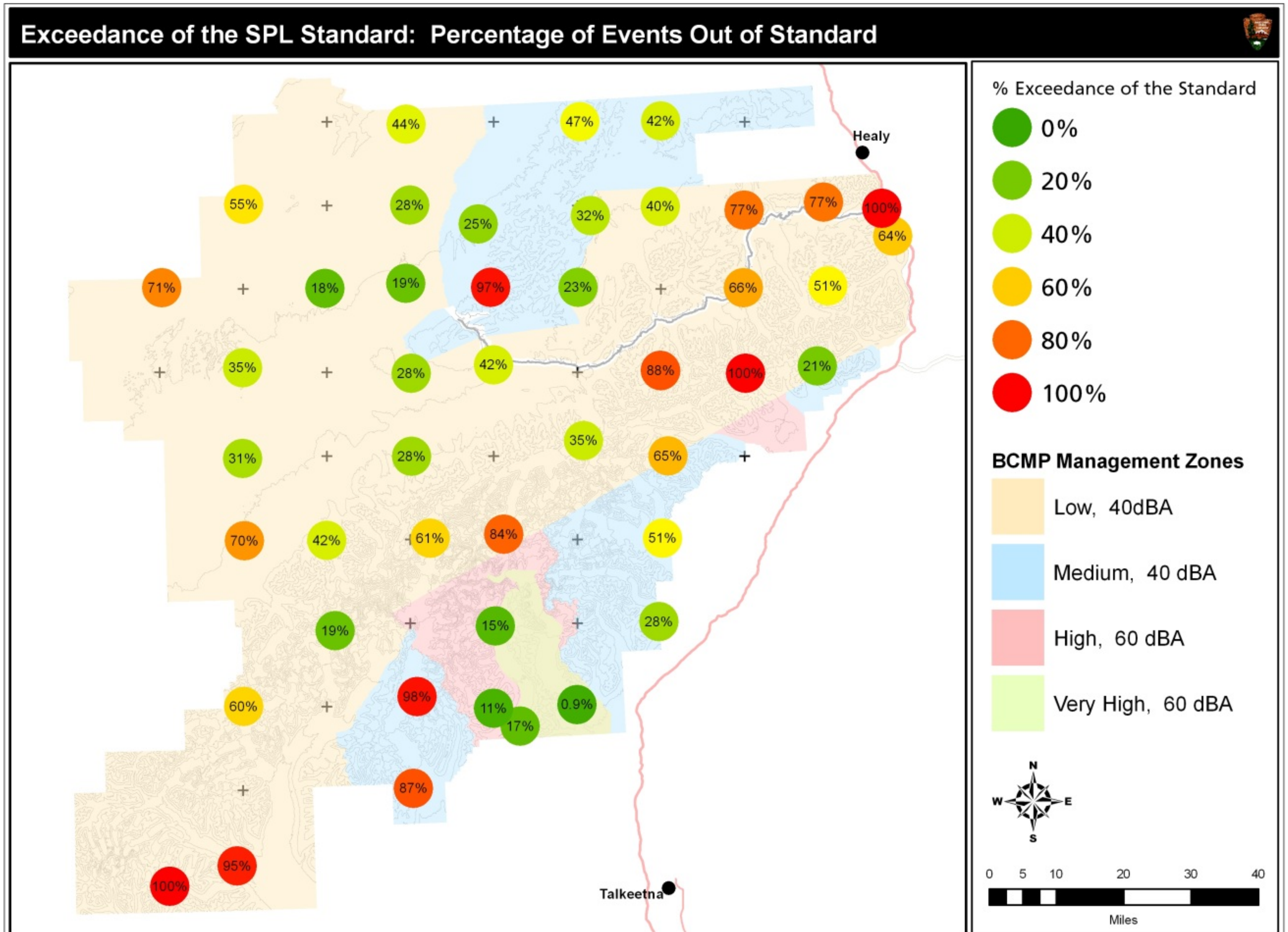
Appendix B. BCMP Exceedence Maps

The following three maps are compiled to provide a parkwide look at the acoustic measurements made to date, and indicate the current level compliance with BCMP acoustic standards. There is one map for each BCMP standard, and each sampling point is annotated with the percentage of time that standard was exceeded during the measurement period. Data from previous years is from Hults 2005, Withers and Hults 2006, Withers 2010, 2011, 2012, Withers and Betchkal 2013, and Betchkal 2013.


Exceedance of the Percent Time Audible Standard: Percentage of Hours Out of Standard
% Exceedance of the Standard
0%
20%
40%
60%
> 60%
BCMP Management Zones
Low, 5% of Any Hour
Medium, 15% of any Hour
High, 25% of any Hour
Very High, 50% of any Hour
Healy
Talkeetna
Miles
Denali National Park Soundscape Inventory



Exceedance of the Events Per Day Standard: Percentage of Days Out of Standard
Healy
Talkeetna
% Exceedance of the Standard
0%
20%
40%
60%
80%
100%
BCMP Management Zones
Low, 1 Event/Day
Medium, 10 Events/Day
High, 25 Events/Day
Very High, 50 Events/Day
N
W
E
S
0 5 10 20 30 40
Miles
Denali National Park Soundscape Inventory



Denali National Park Soundscape Inventory

Appendix C. Map of All Soundscape Sampling Locations

The following map (Figure APP C.1) shows the approximate location of every sound monitoring station deployed over the course of the study and during which year(s) data were collected. For a more detailed discussion of sampling design, see the Sampling Plan

section of this document. Summer-season sites are shown in green, while winter-season sites are shown in blue. Locations that have yet to be sampled on the 10x10 kilometer grid are indicated by black cross marks.

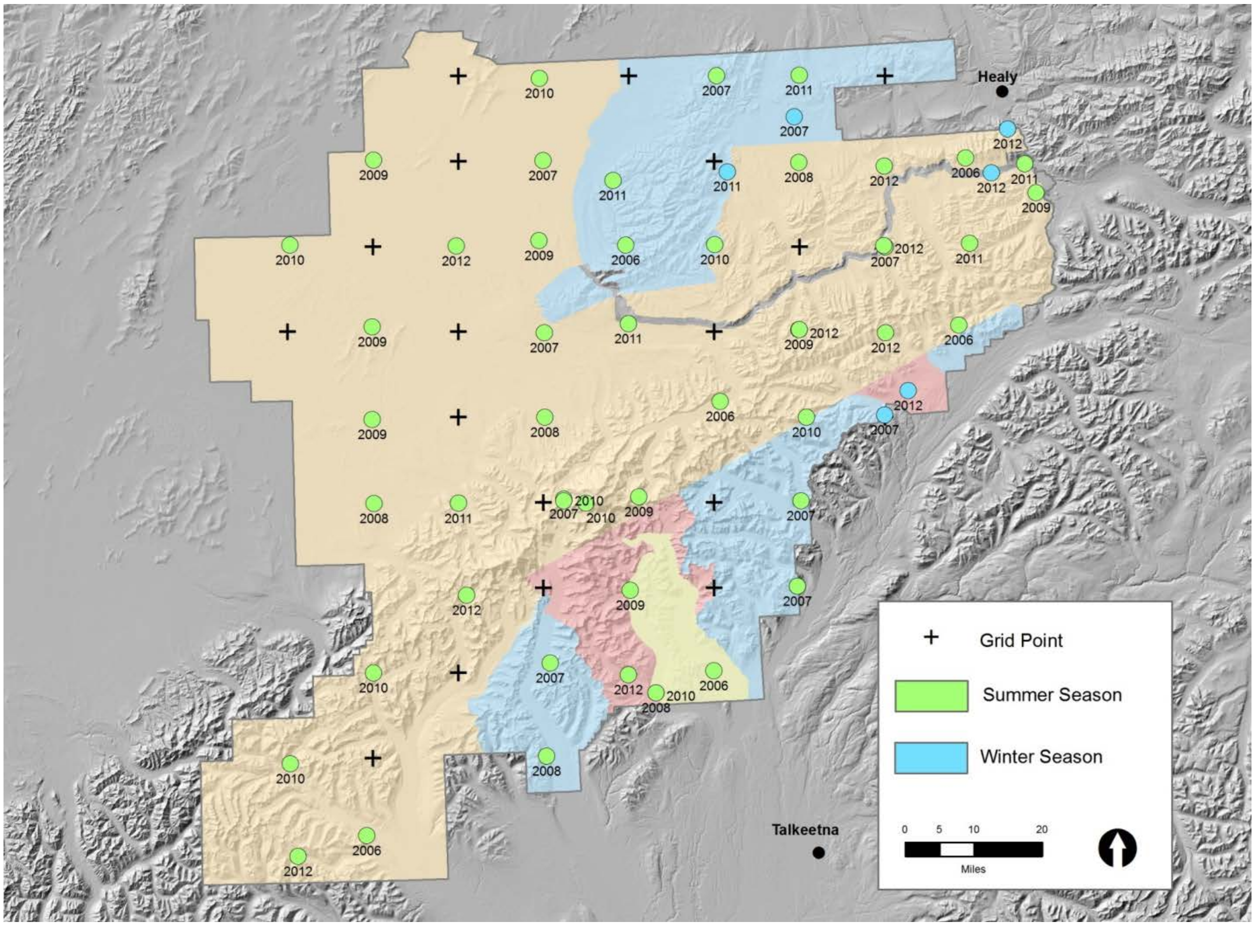
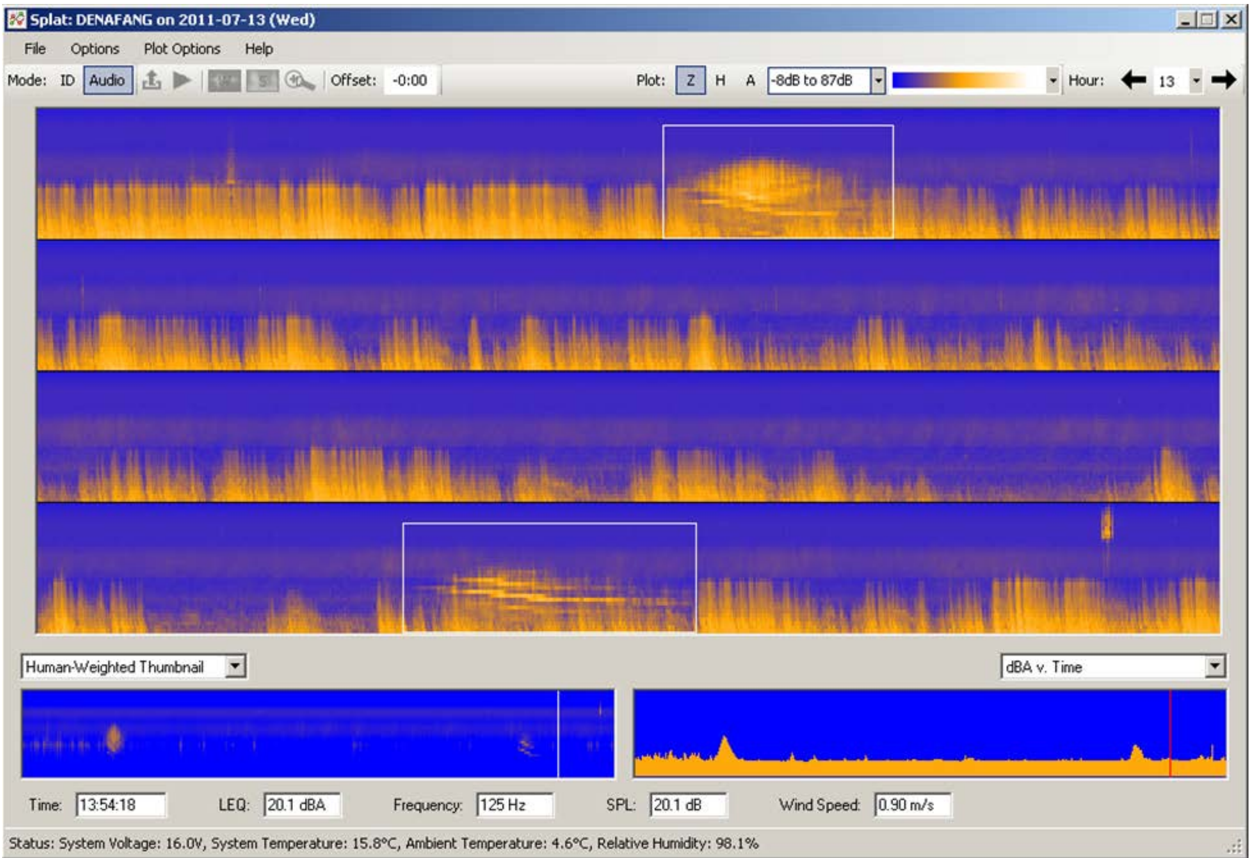


Figure APP C.1. Denali soundscape monitoring locations sampled from 2006 through 2012.

Appendix D. Analyzing Audio with Visual Tools

Sound pressure levels (SPL) from one hour at an acoustic monitoring site at Denali National Park and Preserve are shown below. One hour of SPL data is displayed over four rows. 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.



Acoustic events can be visually identified (by drawing a box around the event) and annotated. For each identified event, time, duration, maximum SPL, and spectral information are cataloged. For example, the white boxes above mark the occurrence of two propeller aircraft events.

Appendix E. Funding and Personnel

The 2012 soundscape program was funded from the Concessions Franchise Fee program. These funds were used to continue the soundscape inventory across the park. The following figures are approximate; please contact the author for comprehensive budget details.

Personnel

- *$34,500* Soundscape Technician: Davyd Betchkal GS-7 Term with 1 Month Furlough

Travel

- *$1,500* Denali Overflights Committee Meetings, Talkeetna Field Operations, Backcountry Per Diem, and Gov Trip Processing Fees

Aviation

- *$14,000* Helicopter

Equipment and Supplies

- $17,000

Appendix F. Project-Related Aircraft Use

Minimizing administrative aircraft use in the park is the first step in managing for quality solitude in Denali. Therefore, it is a priority of the soundscape program to conduct non-motorized research. Despite this, remote soundscape sampling locations often require helicopter access to install, maintain, and remove effectively.

Field operations during the 2012 season required six helicopter flights totaling 11.8 hours of flight time. For the use of the contracted Hughes 500-D, AStar B3, and R44 flight time, availability and OAS costs totaled $14,088.41. Details for each flight are summarized in the following table:

Table APP F.1. Flight details for fiscal year 2012:

Date	Aircraft	Sites Accessed	Flight Hours	Cost with OAS
05/19/2012	AStar B3	TKAN, KICH, UYEN	2.0	$2461.50
06/18/2012	AStar B3	TKAN, KICH, UYEN	2.0	$1979.50
07/09/2012	AStar B3	TKAN	Partial flight time shared with SAR, ~1.2	$630.00
07/20/2012	Hughes 500-D	McRI, CARL	2.2	$2376.86
08/08/2012	Hughes 500-D	McRI + stream ecology	2.7	$2788.11
09/11/2012	Robinson R44	McRI	1.7	$3852.44
TOTAL			11.8	$14,088.41

Table APP F.2. For comparison of use in 2012 with recent years:

Year	Total Number of Stations	Number of Stations Accessed By Air	Number of Flights	Total Flight Hours
2009	10	7 (70% by air)	9 (0.8 stations per flight)	19.1 (2.7 flight hours per station)
2010	9	8 (89% by air)	8 (1 station per flight)	17.2 (2.2 flight hours per station)
2011	8	4 (50% by air)	7 (0.57 stations per flight)	12.1 (3.0 flight hours per station)
2012	11	4 (36% by air)	6 (1.7 stations per flight)	11.8 (2.0 flight hours per station + shared work)