



Acoustic Monitoring Report, Denali National Park and Preserve – 2013

Natural Resource Report NPS/DENA/NRDS—2015/989



ON THE COVER

A soundscape monitoring system collects data on the west slope of Fang Mountain, in Denali National Park.
NPS Photo by Davyd Betchkal

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Natural Resource Data Series NPS/DENA/NRDS—2015/989

Davyd Betchkal

National Park Service
Denali National Park and Preserve
PO Box 9
Denali National Park, Alaska 99755

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Contents

	Page
Figures.....	v
Spectrograms.....	x
Tables.....	x
Appendixes	xi
Executive Summary	xii
Acknowledgments.....	xiv
Introduction.....	1
Soundscape Planning Authorities	1
Sampling Plan.....	2
Study Area	4
Methods.....	6
Automated Monitoring	6
Visual Analysis	6
Audibility Analysis	6
Calculation of Metrics	6
Results.....	8
Birch Creek	10
Cabin Peak	19
Carlson Creek	30
Fang Mountain.....	39
Flume Creek.....	49
Igloo Canyon	59
Lower McKinley River	69

NPS 184/130651, November 2015

Contents (continued)

	Page
Mount Lee.....	78
Upper Eldridge Glacier.....	87
Conclusion	95
Literature Cited	97

Figures

	Page
Figure 1. Denali National Park boundary map showing the Long Term Ecological Monitoring grid of 60 points to be sampled.....	3
Figure 2. Acoustic monitoring sites in Denali National Park, 2013.	5
Figure 3. Temporal Audibility of Great Grey Owls at Birch Creek.	12
Figure 4. Exceedence levels for Birch Creek.....	13
Figure 5. Temporal audibility of sound sources at Birch Creek, based on five seconds of audio every five minutes.....	14
Figure 6. Audibility of abiotic sounds at Birch Creek.	15
Figure 7. Audibility of biotic sounds at Birch Creek.	15
Figure 8. Audibility of aircraft noise for an average day, by hour, at Birch Creek.	16
Figure 9. Audibility of aircraft noise at Birch Creek.	16
Figure 10. Number of aircraft noise events detected per day at Birch Creek.	17
Figure 11. Hourly average and maximum rates of detection for aircraft noise events at Birch Creek.	17
Figure 12. Maximum one-second sound pressure level for each aircraft event identified at Birch Creek.	18
Figure 13. Histogram of Maximum Sound Pressure Levels for Propeller Aircraft Noise Events at Cabin Peak	21
Figure 14. Exceedence levels for Cabin Peak.....	24
Figure 15. Temporal audibility of sound sources at Cabin Peak, based on five seconds of audio every five minutes.	25
Figure 16. Audibility of abiotic sounds at Cabin Peak.	26
Figure 17. Audibility of biotic sounds at Cabin Peak.	26
Figure 18. Audibility of aircraft noise for an average day, by hour, at Cabin Peak.	27
Figure 19. Audibility of aircraft noise at Cabin Peak	27

Figures (continued)

	Page
Figure 20. Number of aircraft noise events detected per day at Cabin Peak	28
Figure 21. Hourly average and maximum rates of detection for aircraft noise events at Cabin Peak.	28
Figure 22. Maximum one-second sound pressure level for each aircraft event detected at Cabin Peak.	29
Figure 23. Exceedence levels for Carlson Creek.	33
Figure 24. Temporal audibility of sound sources at Carlson Creek, based on five seconds of audio every five minutes	34
Figure 25. Audibility of abiotic sounds at Carlson Creek.....	35
Figure 26. Audibility of biotic sounds at Carlson Creek.	35
Figure 27. Audibility of aircraft noise for an average day, by hour, at Carlson Creek.....	36
Figure 28. Audibility of aircraft noise at Carlson Creek.....	36
Figure 29. Number of aircraft noise events detected per day at Carlson Creek.	37
Figure 30. Hourly average and maximum rates of detection for aircraft noise events at Carlson Creek.....	37
Figure 31. Maximum one-second sound pressure level for each aircraft event detected at Carlson Creek.	38
Figure 32. Exceedence levels for Fang Mountain.....	43
Figure 33. Temporal audibility of sound sources at Fang Mountain, based on five seconds of audio every five minutes	44
Figure 34. Audibility of abiotic sounds at Fang Mountain.	45
Figure 35. Audibility of biotic sounds at Fang Mountain.....	45
Figure 36. Audibility of aircraft noise for an average day, by hour, at Fang Mountain.	46
Figure 37. Audibility of aircraft noise at Fang Mountain.	46
Figure 38. Number of aircraft noise events detected per day at Fang Mountain.	47

Figures (continued)

	Page
Figure 39. Hourly average and maximum rates of detection for aircraft noise events at Fang Mountain.	47
Figure 40. Maximum one-second sound pressure level for each aircraft event identified at Fang Mountain.	48
Figure 41. Exceedence levels for Flume Creek.	53
Figure 42. Temporal audibility of sound sources at Flume Creek, based on five seconds of audio every five minutes	54
Figure 43. Audibility of abiotic sounds at Flume Creek.	55
Figure 44. Audibility of biotic sounds at Flume Creek.	55
Figure 45. Audibility of aircraft noise for an average day, by hour, at Flume Creek.	56
Figure 46. Audibility of aircraft noise at Flume Creek.	56
Figure 47. Number of aircraft noise events detected per day at Flume Creek.	57
Figure 48. Hourly average and maximum rates of detection for aircraft noise events at Flume Creek.	57
Figure 49. Maximum one-second sound pressure level for each aircraft event detected at Flume Creek.	58
Figure 50. A relation showing the effect of bus engine size on observed maximum sound pressure levels at Igloo Canyon 2012 and 2013	61
Figure 51. Exceedence levels for Igloo Canyon.	64
Figure 52. Audibility of aircraft noise for an average day, by hour, at Igloo Canyon.	64
Figure 53. Audibility of road vehicle noise for an average day, by hour, at Igloo Canyon.	65
Figure 54. Audibility of aircraft noise at Igloo Canyon.	65
Figure 55. Audibility of road vehicle noise at Igloo Canyon.	66
Figure 56. Number of aircraft noise events detected per day at Igloo Canyon.	66
Figure 57. Hourly average and maximum rates of detection for aircraft noise events at Igloo Canyon.	67

Figures (continued)

	Page
Figure 58. Maximum one-second sound pressure level for each aircraft event detected at Igloo Canyon.	67
Figure 59. Maximum one-second sound pressure level for each vehicle event detected at Igloo Canyon.	68
Figure 60. Exceedence levels for Lower McKinley River.....	72
Figure 61. Temporal audibility of sound sources at Lower McKinley River, based on five seconds of audio every five minutes.....	73
Figure 62. Audibility of abiotic sounds at Lower McKinley River.	74
Figure 63. Audibility of biotic sounds at Lower McKinley River.....	74
Figure 64. Audibility of aircraft noise for an average day, by hour, at Lower McKinley River.	75
Figure 65. Audibility of aircraft noise at Lower McKinley River.	75
Figure 66. Number of aircraft noise events detected per day at Lower McKinley River.....	76
Figure 67. Hourly average and maximum rates of detection for aircraft noise events at Lower McKinley River.	76
Figure 68. Maximum one-second sound pressure level for each aircraft event detected at Lower McKinley River.....	77
Figure 69. Exceedence levels for Mount Lee.	81
Figure 70. Temporal audibility of sound sources at Mount Lee, based on five seconds of audio every five minutes.....	82
Figure 71. Audibility of abiotic sounds at Mount Lee.	83
Figure 72. Audibility of biotic sounds at Mount Lee.....	83
Figure 73. Audibility of aircraft noise for an average day, by hour, at Mount Lee.	84
Figure 74. Audibility of aircraft noise at Mount Lee.	84
Figure 75. Number of aircraft noise events detected per day at Mount Lee.....	85

Figures (continued)

	Page
Figure 76. Hourly average and maximum rates of detection for aircraft noise events at Mount Lee.	85
Figure 77. Maximum one-second sound pressure level for each aircraft event detected at Mount Lee. A time series of L50 is also included to demonstrate how an increase in natural ambience affects the measurement of noise.	86
Figure 78. Exceedence levels for Upper Eldridge Glacier.....	89
Figure 79. Temporal audibility of sound sources at Upper Eldridge Glacier, based on five seconds of audio every five minutes.....	90
Figure 80. Audibility of abiotic sounds at Upper Eldridge Glacier.	91
Figure 81. Audibility of biotic sounds at Upper Eldridge Glacier.	91
Figure 82. Audibility of aircraft noise for an average day, by hour, at Upper Eldridge Glacier.	92
Figure 83. Audibility of aircraft noise at Upper Eldridge Glacier.	92
Figure 84. Number of aircraft noise events detected per day at Upper Eldridge Glacier.....	93
Figure 85. Hourly average and maximum rates of detection for aircraft noise events at Upper Eldridge Glacier.	93
Figure 86. Maximum one-second sound pressure level for each aircraft event detected at Upper Eldridge Glacier.	94

Spectrograms

	Page
Spectrogram 1. The song of a Great Grey Owl (<i>Strix nebulosa</i>) in the vicinity of the Birch Creek sound station.....	12
Spectrogram 2. Buzzy stridulation of an unknown grasshopper species (Order: Orthoptera).....	23
Spectrogram 3. Recording of a Caribou (<i>Rangifer tarandus</i>) passing within close proximity of the Fang Mountain sound station.....	42
Spectrogram 4. A spectrogram showing two types of wind sound at Flume Creek.	51
Spectrogram 5. An example of dawn chorus in the vicinity of the Flume Creek sound station.....	51
Spectrogram 6. A spectrogram of a typical bus passby at Igloo Canyon.	62
Spectrogram 7. Greater Yellowlegs (<i>Tringa melanoleuca</i>) makes oscillating calls near the Lower McKinley River sound station.	71

Tables

	Page
Table 1. Sites sampled in 2013.....	4
Table 2. Median natural and existing ambient sound levels and mean aircraft statistics for all sites.	8
Table 3. Mean BCMP statistics* for vehicles at all sites.	8
Table 4. Comparison of soundscape conditions at Fang Mountain, 2011 and 2013.....	42
Table 5. Comparison of noise event rates at sites within the vicinity of Igloo Canyon.....	63
Table 6. Percentage of samples exceeding BCMP sound standards.	96

Appendixes

	Page
Appendix A. Glossary of Acoustic Terms	100
Appendix B. BCMP Exceedence Maps	103
Appendix C. Map of All Soundscape Sampling Locations	107
Appendix D. Analyzing Audio with Visual Tools.....	108
Appendix E. Funding and Personnel	109
Appendix F. Project-Related Aircraft Use.....	110
Appendix G. Bus Idle Tests / Wildlife Stop Simulation.....	111

Executive Summary

In 2013, park staff deployed acoustic monitoring systems to 9 locations in Denali National Park and Preserve. The purpose of this 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 sound pressure levels every second and continuous MP3 audio recordings throughout the sampling period. These data serve as a permanent record of existing acoustic conditions at these locations for the summer of 2013.

Table i shows summarized results of 2013 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 sound occurring in Denali's backcountry. (An extrinsic sound is defined as any sound not forming an essential part of the park purpose (see Glossary, Appendix A). 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 90th and 10th percentiles of sound pressure level, respectively.

When interpreting sound pressure level data, note that the decibel scale is logarithmic. Thus a six decibel increase in sound pressure level is a doubling of sound energy.

Table i. Ambient acoustic metrics and median aircraft statistics for 2013 sites*.

Site Name	L10	Lnat	L50	L90	% Time Audible, Aircraft	Average # Aircraft/Day	Max # Aircraft/Day	Aircraft Max SPL
Birch Creek	20.1	17.6	17.7	16.8	2.3	5.9	18	26.5
Cabin Peak	36.1	33.8	33.8	32.3	2.9	15.8	34	41.1
Carlson Creek	31.9	29.1	29.3	27.7	6.8	29.5	61	41.4
Fang Mountain	28.8	22.8	23.0	21.2	6.8	30.6	53	40.8
Flume Creek	32.2	23.8	24.0	19.7	1.4	6.3	22	38.5
Igloo Canyon	34.5	36.9	37.3	41.1	3.9	15.9	40	55.2
Lower McKinley River	29.0	22.5	22.6	19.9	1.9	7.0	15	36.8
Mount Lee	50.7	50.1	50.1	49.5	0.8	6.2	17	50.9
Upper Eldridge Glacier	22.5	17.9	17.9	16.7	3.4	16.6	38	39.0

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

Variation in anthropogenic noise were apparent upon analysis, typifying each location. The highest rates of air traffic were measured at Fang Mountain, where north-side flight routes culminate. It had an average of 31 aircraft noise events per day, and a maximum of 58 noise events per day. Similarly Carlson Creek (within the McGonagall Pass area) had an average of 29 events per day and a maximum of 61 noise events per day. In contrast, 6 events per day were detected at Birch Creek. This

relatively-intact condition of solitude is shared by most nearby monitoring locations in the west-central portion of the park.

The Fang Mountain location was originally sampled in 2011. Resampling sought to determine the effect of a Denali Aircraft Overflights Advisory Committee aviation best practice enacted during the spring of 2012. Table ii compares results from the two 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
Fang Mountain, 2011	21.94	9.5%	-	53%	100%	51%
Fang Mountain, 2013	22.80	6.8%	-	43%	100%	53%

*L_{nat} in A-weighted decibels.

Data from Igloo Canyon were used to quantify the effects of hybrid bus technology on the Denali Park Road corridor. The hybrid engines tested were louder than 60% of the conventional diesel fleet. The hybrid systems were also determined to be louder than the expected range of means for a conventional diesel engine of the same volume.

Acknowledgments

Many of the difficulties with soundscape fieldwork are related to moving heavy, awkward, or fragile components over the landscape. I'd like to thank all the people who helped move sound equipment on foot in 2013: Scot Sharp, Eric Walter, Doug Stringfellow, Dan Abbe, Sam Hooper, John Brueck, Jennifer Johnston, Kim Arthur, Aviva Hirsch, Chris Dunn, Kristin Pace, and participants of the 'Composing in the Wilderness' seminar. (That's a total of 23 individuals who assisted with non-motorized transport!)

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Introduction

Natural sound is both a resource in its own right and 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 (NPS 2006c). It also called for monitoring to evaluate whether the standards are being satisfied. Acoustic 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 manage the condition of the acoustic environment in these areas.

The initial push for Denali to begin soundscape inventories began with Director's Order 47 (DO-47; NPS 2000). National Park Service (NPS) Director 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, DO-47 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 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." (16 U.S.C. 1). 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." (16 U.S.C. 1a-1)

Direction for management of natural soundscapes¹ 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 (eight were available in 2013), 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.

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.

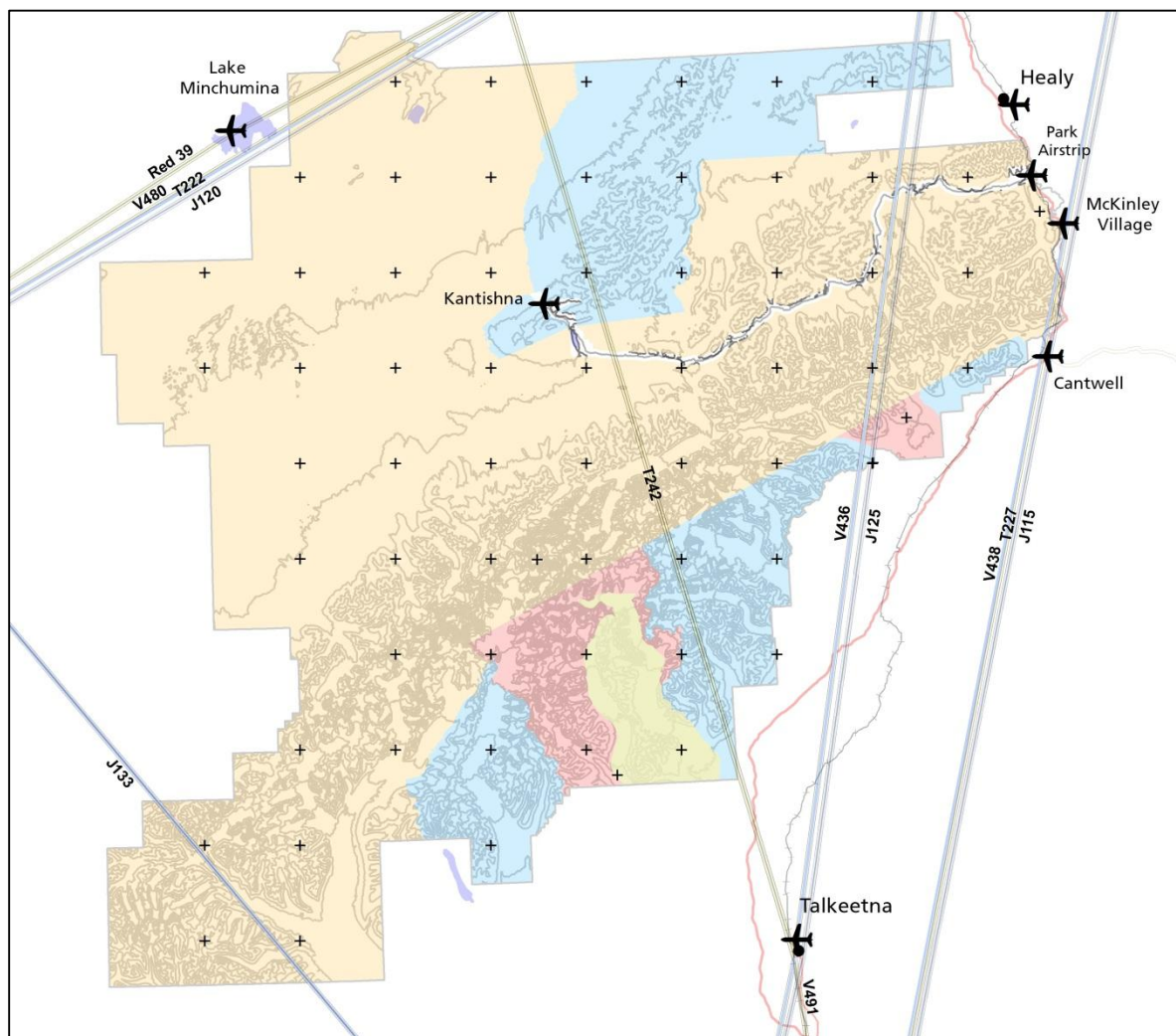


Figure 1. Denali National Park boundary map showing the Long Term Ecological Monitoring grid of 60 points to be sampled. As a frame of reference, major transportation features are indicated as well. FAA flight routes are indicated as blue and yellow lines, along with their alpha-numeric code. The main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

Study Area

Park staff deployed acoustic monitoring systems to nine locations in Denali National Park in 2013, as shown in Table 1 and Figure 2.

Table 1. Sites sampled in 2013.

Site Location	Elevation (meters)	Latitude	Longitude	Sampling Period*
Birch Creek	419	63.44044	-151.65901	Jul-04 to Aug-21
Cabin Peak	999	63.57665	-150.00888	Jun-05 to Aug-19
Carlson Creek	1325	63.24189	-150.83624	Aug-01 to Aug-28
Fang Mountain	1523	63.56617	-149.20564	Jun-29 to Aug-19
Flume Creek	161	63.96474	-150.81366	May-31 to Jul-03
Igloo Canyon	923	63.59588	-149.60712	Jul-04 to Sept-18
Lower McKinley River	223	63.78482	-151.61665	May-31 to Jul-03
Mount Lee	865	62.88357	-150.47589	May-09 to Jul-07
Upper Eldridge	2089	63.05705	-150.47620	May-09 to Jun-08

*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.

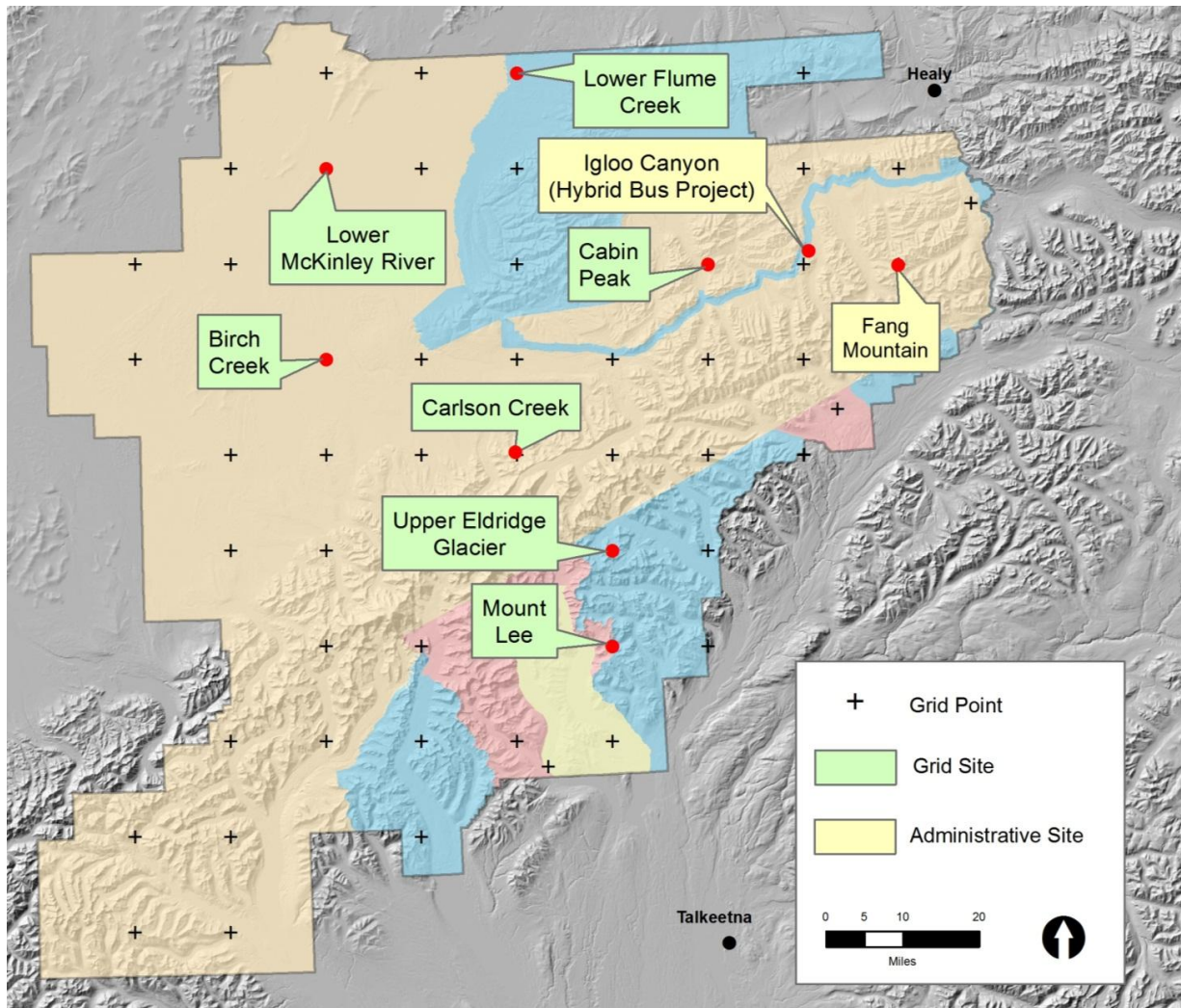


Figure 2. Acoustic monitoring sites in Denali National Park, 2013.

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 64 kilobit-per-second (kbps) 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 kbps digital audio recordings

Visual Analysis

For each monitoring site, staff visually analyzed collected SPL samples 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. If a month of audio was collected, every other day was listened to; if less than a month was collected, staff listened back to every day that was sampled. The purpose of the analyses was to identify natural and quiet sound sources which are difficult to reliably identify through 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 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 $100 \cdot x_H$ 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 2013 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 90th and 10th percentiles of sound pressure level, respectively. These metrics help to demonstrate the high and low bounds of the total acoustic environment as it changes throughout the sample period.

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	L_{10}^*	L_{nat}^*	L_{50}^*	L_{90}^*	Avg. Noise Free Interval*	% Time Audible, Aircraft	# Aircraft/Day	Median Aircraft Max SPL*
Birch Creek	20.1	17.7	17.7	16.8	4.36	2.3	5.9	26.5
Cabin Peak	36.1	33.8	33.8	32.3	2.67	2.9	15.8	41.1
Carlson Creek	31.9	29.1	29.3	27.7	0.76	6.8	29.5	41.4
Fang Mountain	28.8	22.8	23.0	21.2	0.75	6.8	30.6	40.8
Flume Creek	32.2	23.8	24.0	19.7	3.74	1.4	6.3	38.5
Igloo Canyon	34.5	36.9	37.3	41.1	0.17	3.9	15.9	55.2
Lower McKinley River	29.0	22.5	22.6	19.9	3.26	1.9	7.0	36.8
Mount Lee	50.7	50.1	50.1	49.5	3.86	0.8	6.2	50.9
Upper Eldridge Glacier	22.5	17.9	17.9	16.7	1.40	3.4	16.6	39.0

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

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

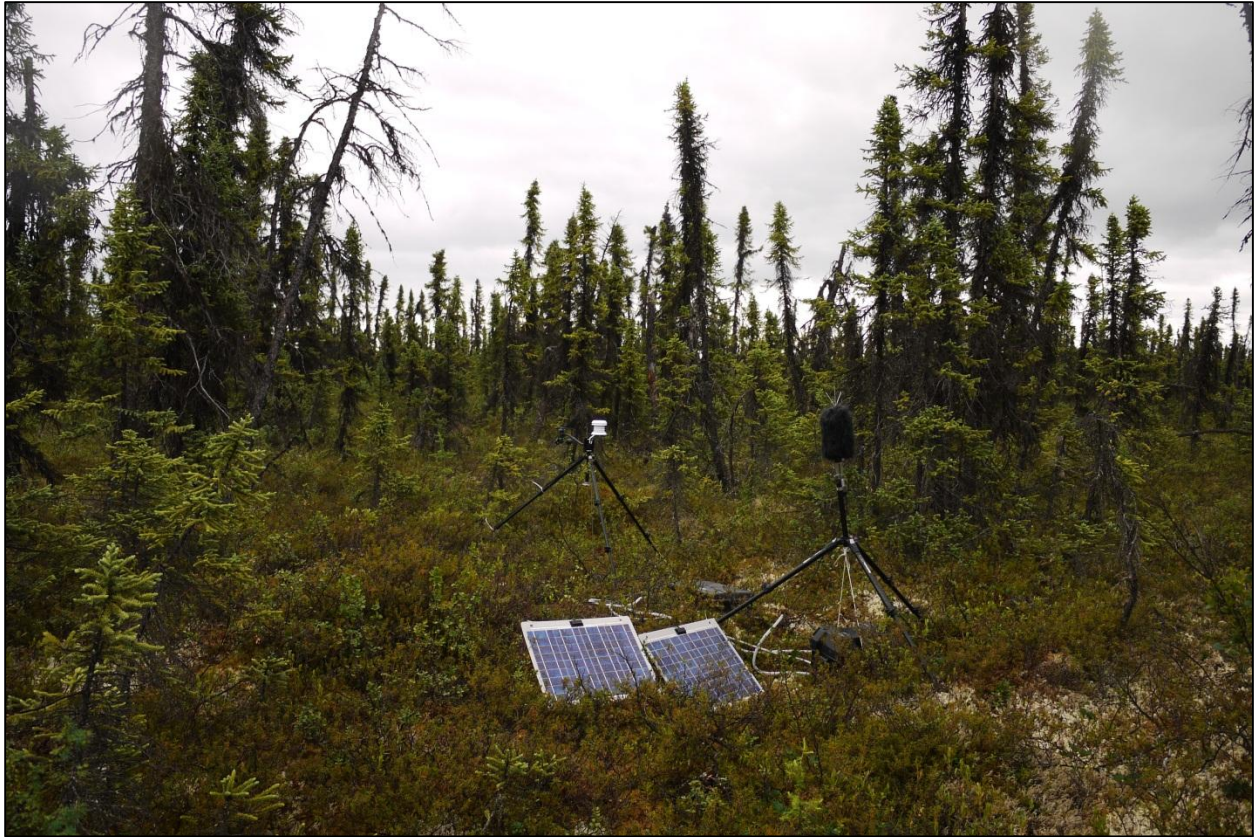
Site Name	Vehicle Type	% Time Audible, Vehicles	# Vehicle Events / Day	Median Vehicle Max SPL
Igloo Canyon	Buses, Maintenance Equipment, Trucks	12.4	114.3	55.4

*SPL in dBA. ¹ : Winter season site.

A tenth site was attempted near the toe of the Tokositna Glacier during the winter months. Due to power issues, the station failed shortly after being deployed. Several hours of data do not cover the range of variability in acoustic conditions influenced by wind, cloud cover, flight schedules, ambient temperature, etc. For that reason, the decision was made to drop this small dataset from subsequent analyses and redeploy at a future time with support from Talkeetna staff.

The following summaries and figures represent the reduced data for each of the 2013 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 by source type (NPS 2006c).

Birch Creek



Location Description: In open dwarf tree scrub (Viereck class II.A.2) surrounded by seasonal ponds with emergent sedges (Viereck class III.A.3, wet graminoid herbaceous). Approximately 2 km from Birch Creek and 6.5 km from Slippery Creek. The photo above faces roughly northwest.

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

Coordinates: 63.44044°, -151.65901° (WGS84)

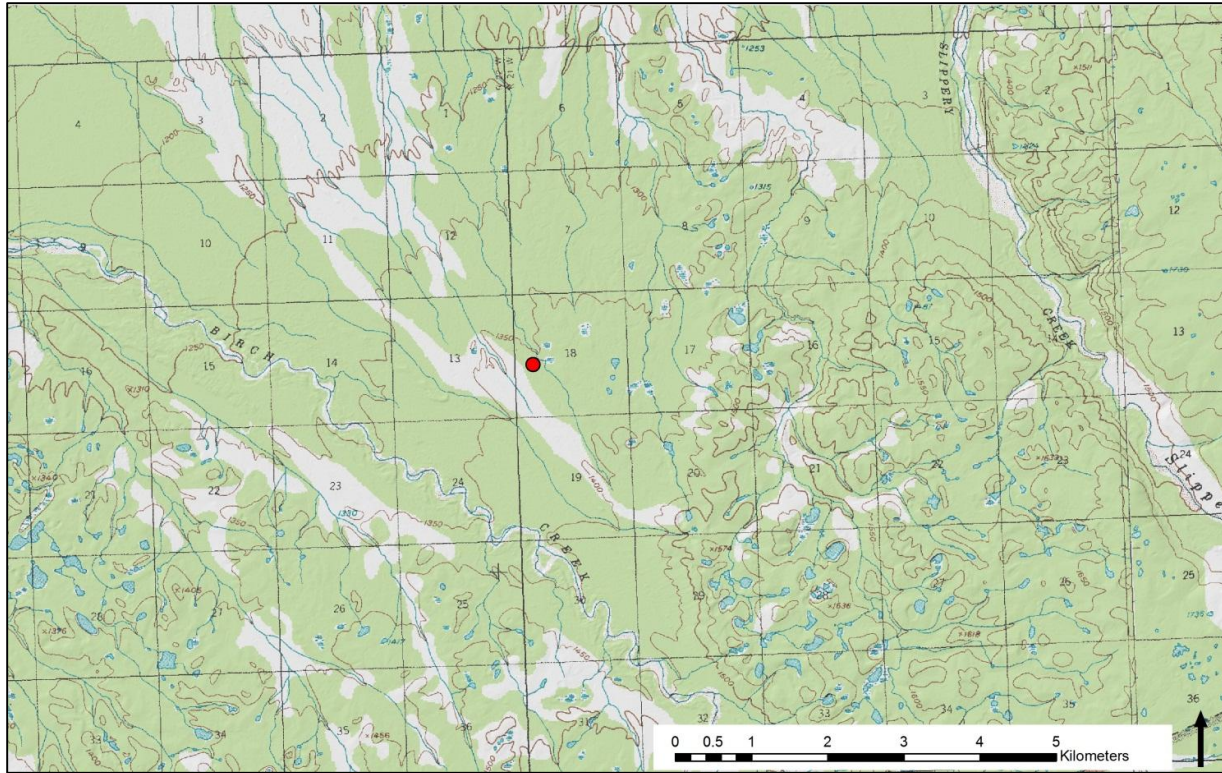
Elevation: 419 meters

Sampling Period: 4-July-2013 to 21-August-2013

BCMP Management Area: D (Low Natural Sound Disturbance)

Park Ecoregion: Kuskokwim Alluvial Fans and Floodplains

Access: Helicopter. Aerial photographs were taken for reference upon return.

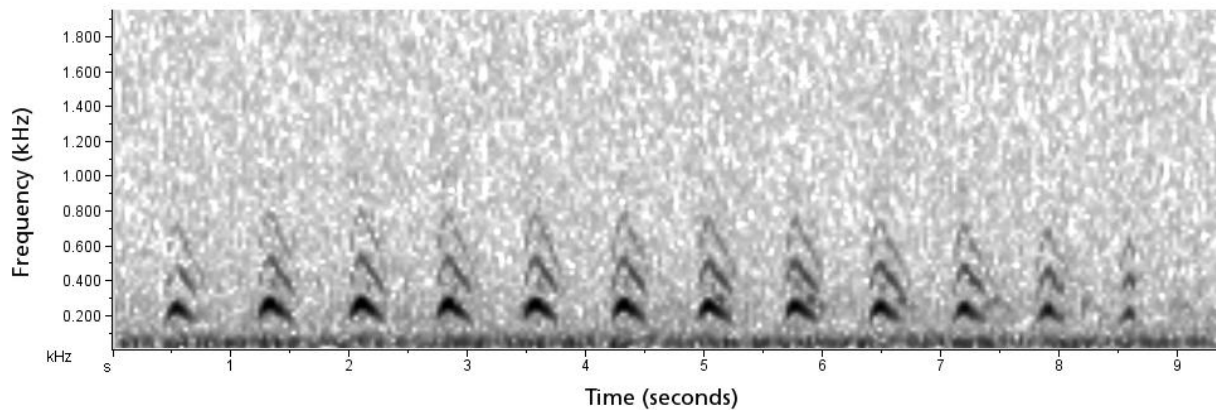


Summary: The purpose of the Birch Creek location was to collect data at one of the long-term ecological monitoring (LTEM) grid points, as outlined in the above sampling plan. LTEM grid point #146 was located in Denali National Preserve (ANILCA expansion).

At 17.7 dBA, Birch Creek had the 3rd lowest time-averaged natural ambient level of any summer site sampled in the park thus far (Figure 4; this places the area within the 3rd percentile of summer season sites parkwide). It is worth noting that Birch Creek shares similar levels of natural quietude with adjacent grid sites, including Lower Slippery Creek to the northwest (18.6 dBA, sampled 2009,) McKinley River to the north (18.8 dBA 2012,) and North Vertical Access Benchmark to the west (19.1 dBA, 2009).

It is also apparent from Figure 4. Exceedence levels for Birch Creek. that during the period from 03:00 through 09:00 the natural ambient level typically increases to a maximum. This time period corresponds with the timing of the dawn chorus phenomenon in the park. Though the site was deployed just outside of the main season for bird song (late May through late June,) there was still a substantial amount of singing and calling behavior from birds that was detected in the recordings. (Figure 5, Figure 7). Commonly heard species during analysis were Dark-eyed Junco (*Junco hyemalis*), White-crowned Sparrow (*Zonotrichia leucophrys*), Fox Sparrow (*Passerella iliaca*), Lincoln's Sparrow (*Melospiza lincolnii*), Grey Jay (*Perisoreus canadensis*), Wilson's Snipe (*Gallinago delicata*), Gray-cheeked Thrush (*Catharus minimus*), Great Grey Owl (*Strix nebulosa*), and Boreal Chickadee (*Poecile hudsonicus*).

Great Grey Owls are of particular interest as a rarely recorded species of the boreal forest. Twenty separate calling bouts were documented throughout the sampling period; enough that an hourly presence/absence count could be made. Totalling the count for each hour of the day results in a histogram showing typical singing times. This temporal audibility data is presented in **Figure 3**, and shows that Great Grey Owls were most frequently detected during the 01:00 hour. Also notable is that birds were not detected any time from 07:00 to 22:00. From the day length information, it is apparent that owls are generally calling during dusky hours, as expected. During the sampling period the deepest part of the night occurred at about 01:12 (Lammi 2008), which corresponds with when owls were most often heard in the backcountry.



Spectrogram 1. The song of a Great Grey Owl (*Strix nebulosa*) in the vicinity of the Birch Creek sound station. This spectrogram was taken from a longer clip of two owls singing antiphonally. It begins at 02:48:32 on 08/09/2013.

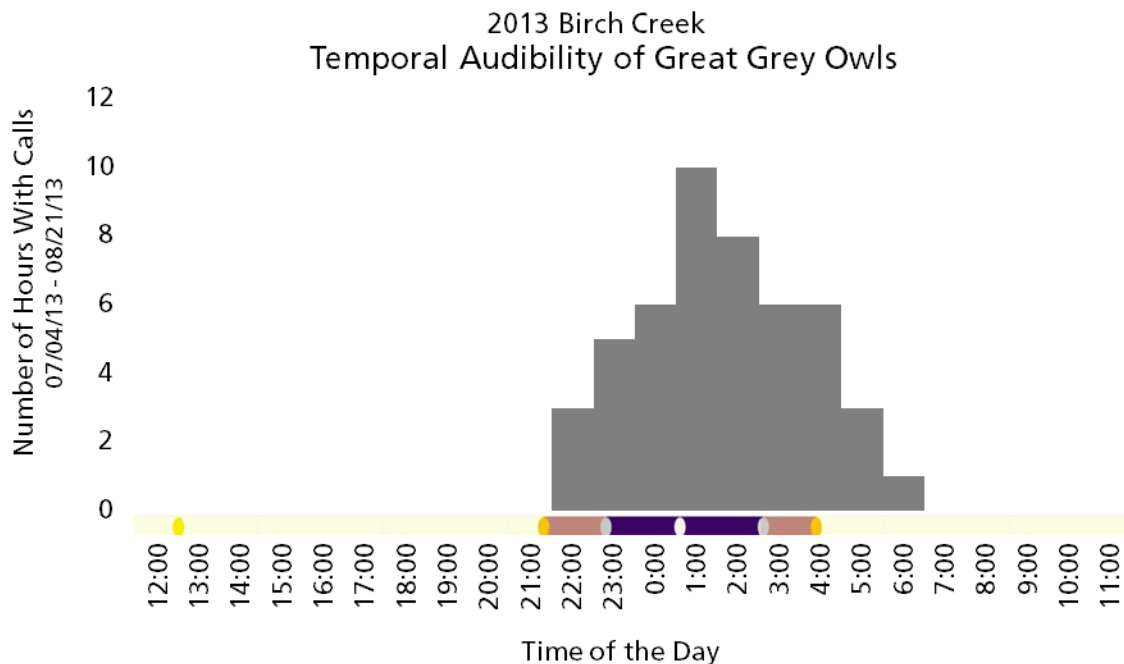


Figure 3. Temporal Audibility of Great Grey Owls at Birch Creek.

The most commonly heard sounds at this site were silence (audible 35.4% of the time), birds (29.9%), wind (21.7%), and insects (19.4%). Human made sound was audible 2.3% of the time on average. This is equivalent to 33.1 minutes each day, or approximately 6 overflights a day at the location. Conditions exceeded the BCMP percent audible standard 19% of the time, number of events per day 87% of the time, and maximum SPL 13% of the time.

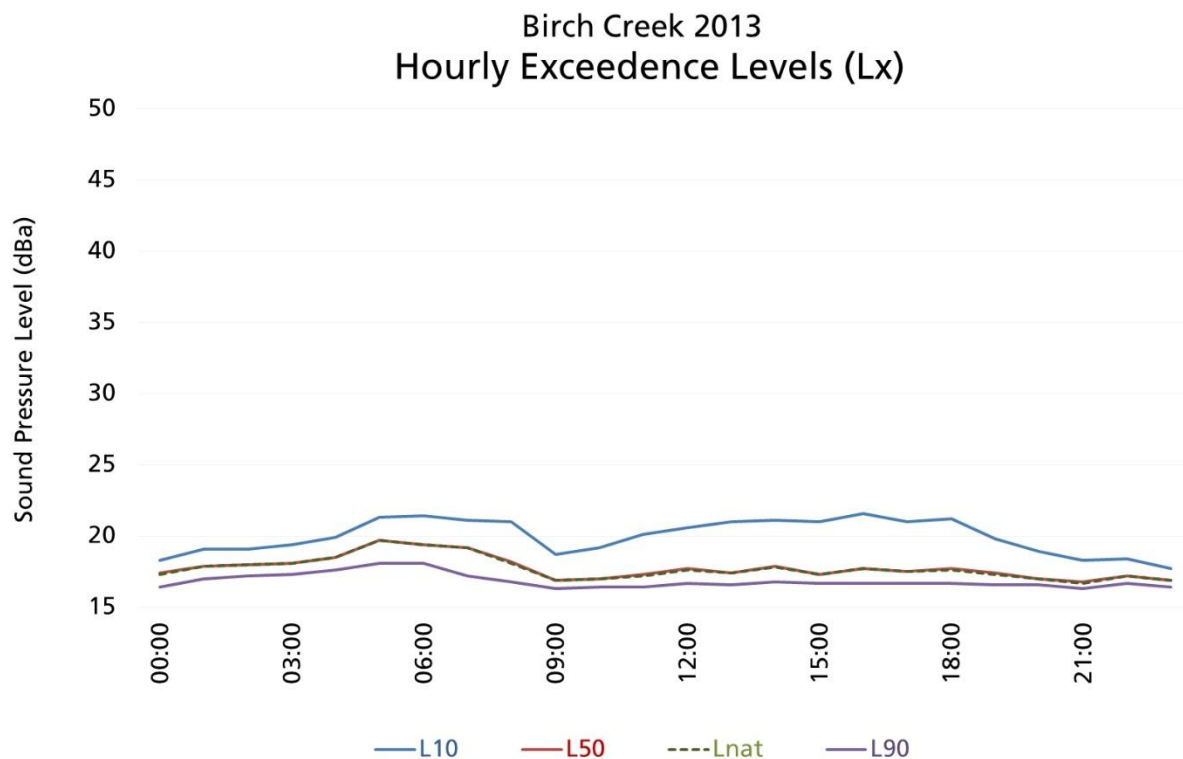


Figure 4. Exceedence levels for Birch Creek.



Figure 5. Temporal audibility of sound sources at Birch Creek, 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.

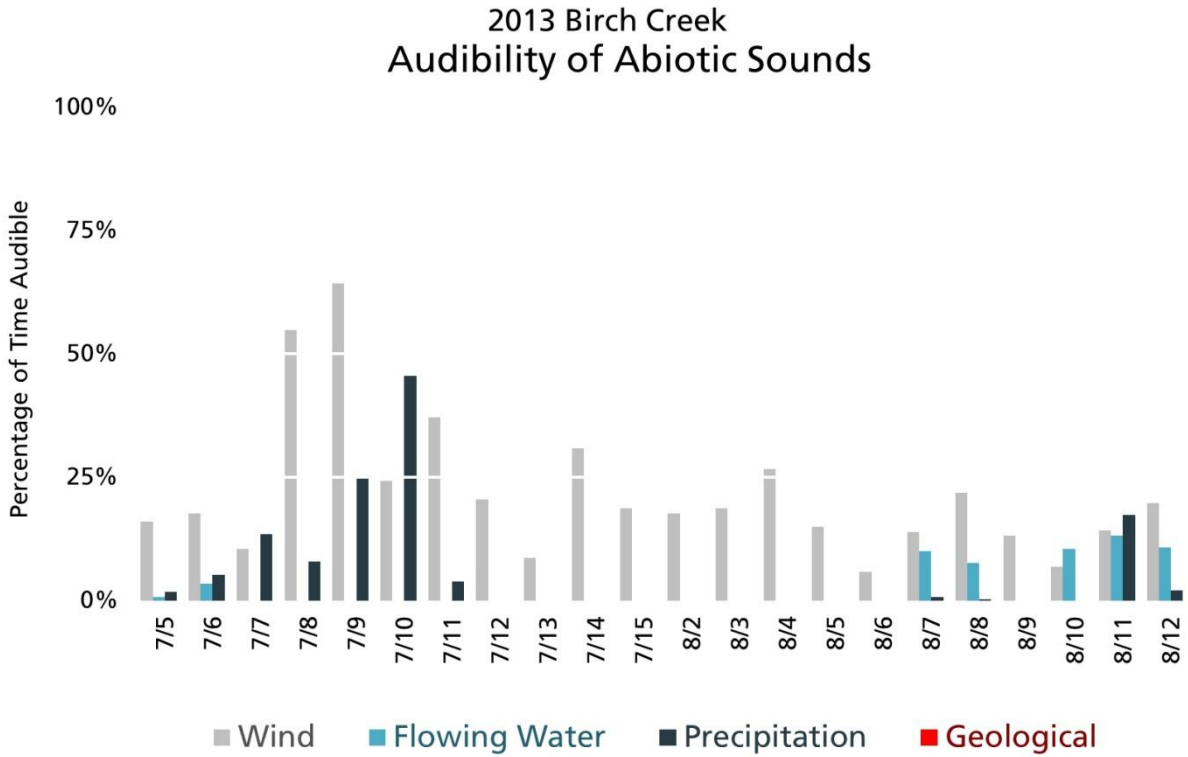


Figure 6. Audibility of abiotic sounds at Birch Creek.

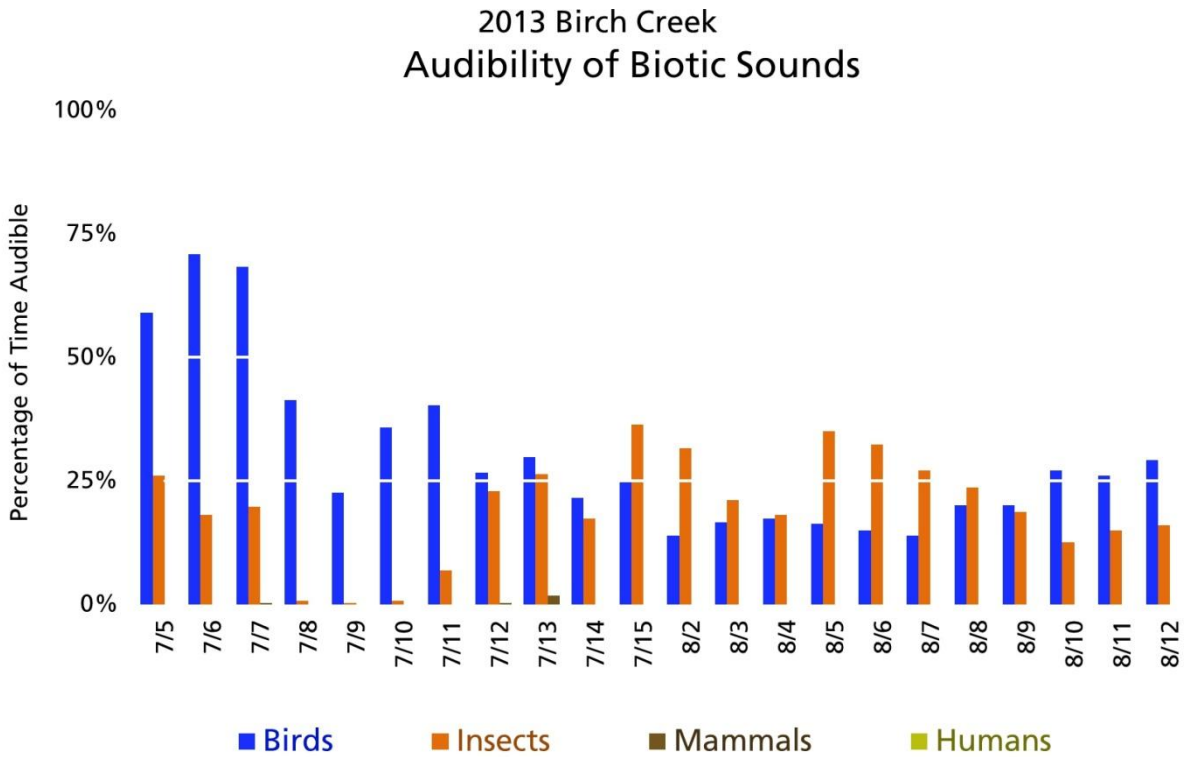


Figure 7. Audibility of biotic sounds at Birch Creek.

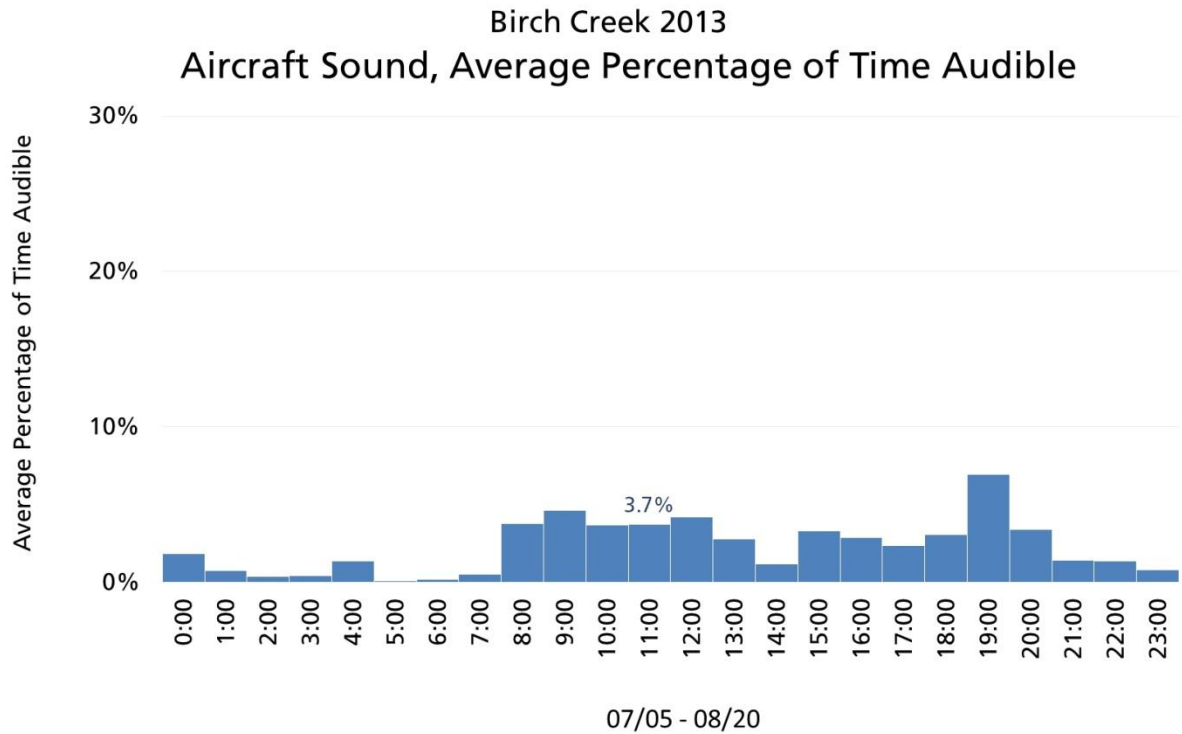


Figure 8. Audibility of aircraft noise for an average day, by hour, at Birch Creek.

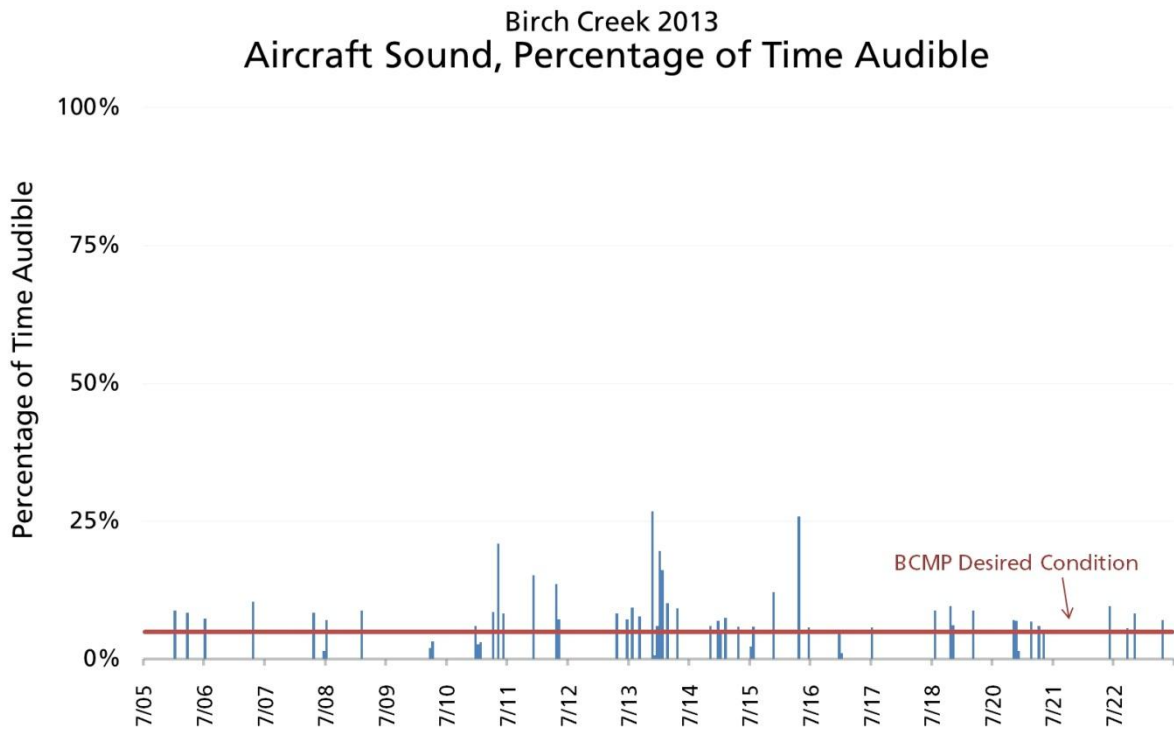


Figure 9. Audibility of aircraft noise at Birch Creek.

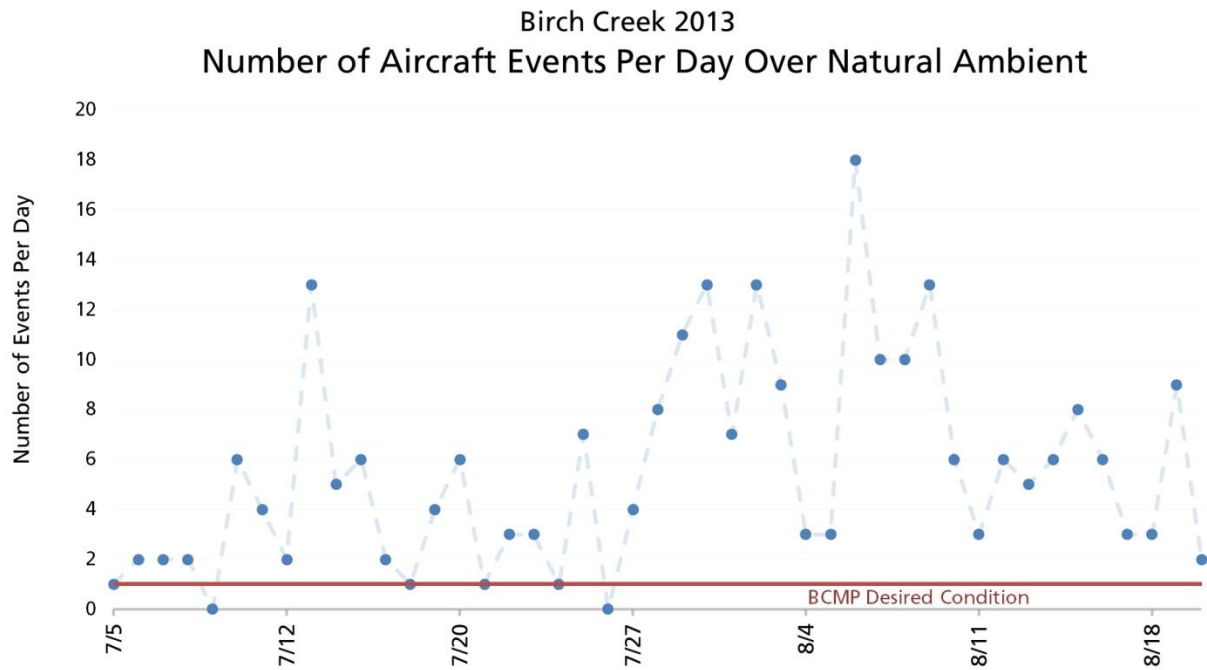


Figure 10. Number of aircraft noise events detected per day at Birch Creek.

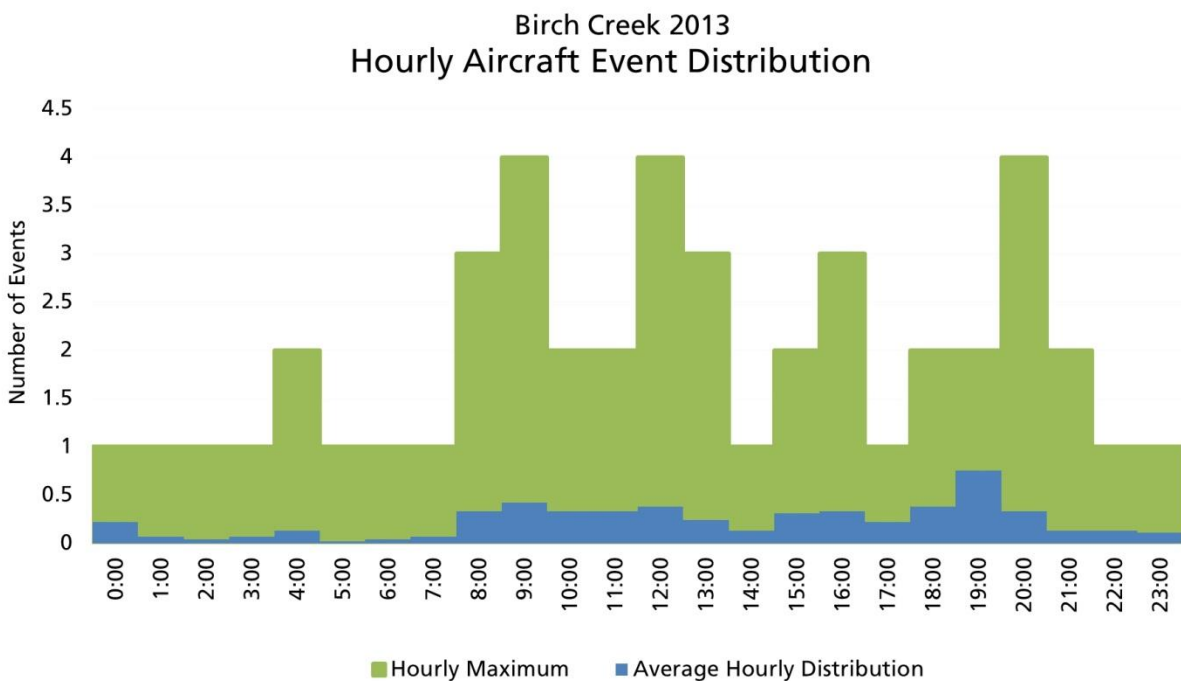


Figure 11. Hourly average and maximum rates of detection for aircraft noise events at Birch Creek.

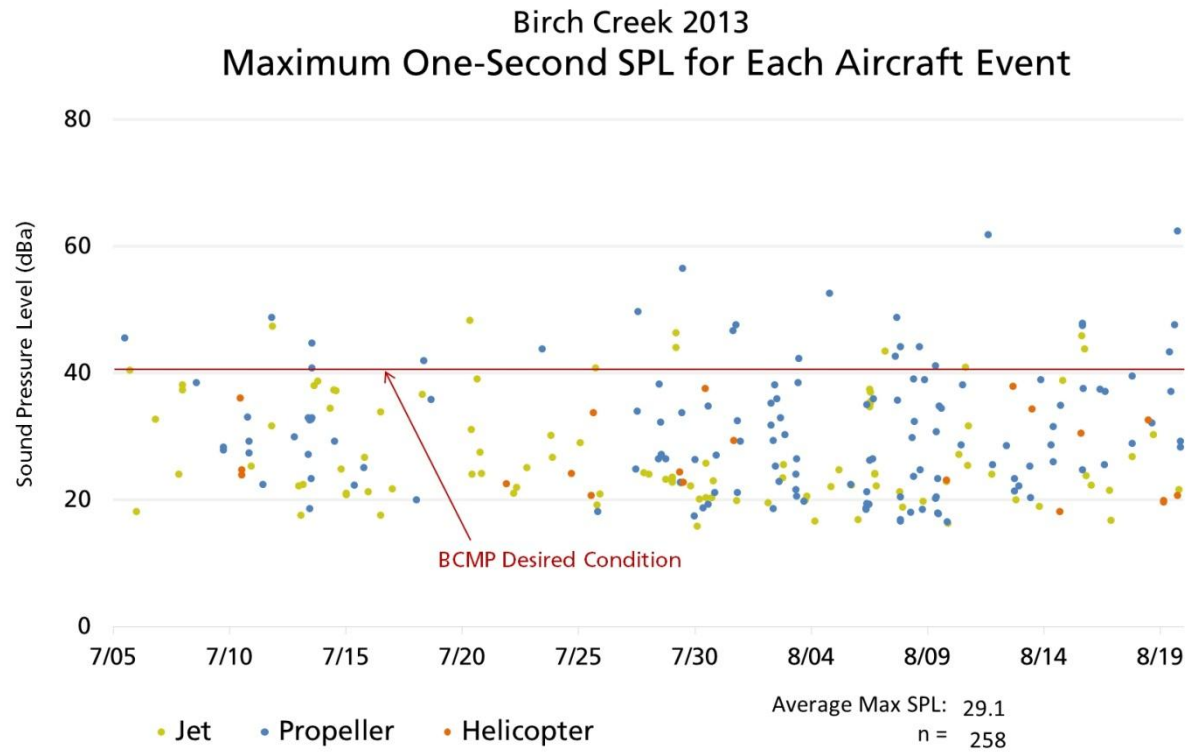


Figure 12. Maximum one-second sound pressure level for each aircraft event identified at Birch Creek.

Cabin Peak



Location Description: On the western slope of Cabin Peak in open low scrub (Viereck class II.C.2,) about 1.74 km east of the Toklat River and 1.70 km south of Cabin Creek as it flows from Cabin Divide. The photograph above faces roughly northwest towards Mt. Sheldon and the Wyoming Hills. Cabin Creek flows out of the cleft visible just above the wind vane. The shortest distance between the station and the band of white spruce (Viereck class 1.A.2, open needleleaf forest) visible in the center of the photograph was about 280 meters.

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

Coordinates: 63.57665°, -150.00888° (WGS84)

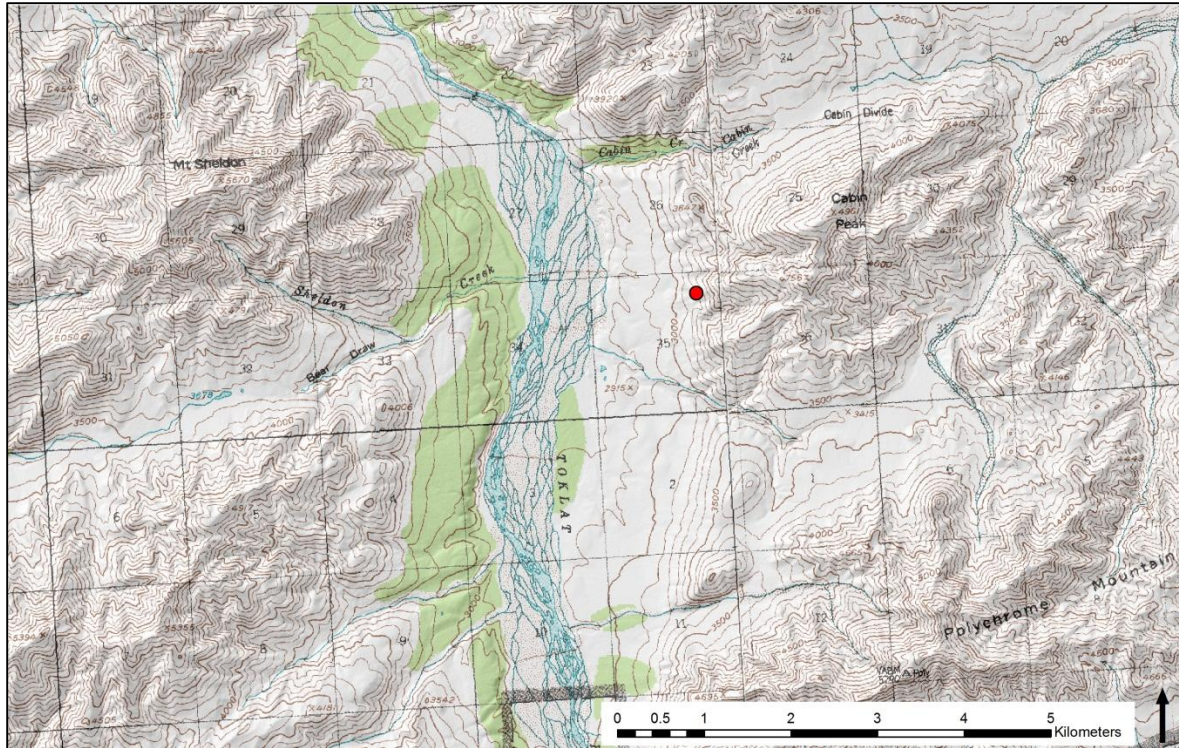
Elevation: 999 meters

Sampling Period: 5-June-2013 to 19-August-2013

BCMP Management Zone: OP1 (Low Natural Sound Disturbance)

Park Ecoregion: Alaska Range Interior Mountains and Valleys

Access: Foot



Summary: The purpose of the Cabin Peak 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 #179 was located in designated wilderness (former Mt. McKinley National Park). The site was easily accessible on foot from Toklat road camp.

With a time-averaged natural ambient level of 33.8 dBA, Cabin Peak is in the 68th percentile of summer-season sites parkwide. The sound pressure level that was exceeded 90% of the time, or L90, for the site was 32.3 dBA (see Table i), which suggests that the acoustic ambience was relatively stable. This is logical, considering most of this energy is contributed by the Toklat River. With no refractive propagation effects detected during the analysis, it was a fairly steady acoustic source. Furthermore, seasonal effects are also apparent in the sound pressure level record. Because of recurring electrical issues, the Cabin Peak station had to be restarted several times: once in June, once in July, and once in August. Considering L₉₀ for each of these sub-sampling periods separately, we find 32.6 dBA, 33.4 dBA, and 32.2 dBA which suggests July as a slightly louder month. Presumably meltwater and rain in the headwaters increases the discharge of the river and therefore changes the total acoustic power output of the river (Kolmogorov 1941, Lighthill 1952, Knighton 1998). However, in 2013 this effect was relatively small, changing L90 by less than a decibel.

When patrolling Cabin Peak to work on the equipment, several in-situ observations of aircraft traffic were helpful in interpreting the collected data. One observation in particular was consistent: Kantishna Air Taxi was observed flying east/west through Cabin Divide (~1700 meters distant horizontally) and just under the peak of Mt. Sheldon (at around 5600 feet, which equates to about 700 meters above the Cabin Peak sound station). The consistency of the flight path was helpful in a

very basic calculation of sound propagation, assuming the propeller aircraft radiates sound spherically. In such a simplified case, sound pressure level at distance is estimated by the equation:

$$L_p = L_w + 10 \log_{10} \left(\frac{1}{4\pi d^2} \right)$$

Where L_p is sound pressure level, L_w is sound power level, and d is the distance from the microphone (or ear) to the aircraft's power plant. From observed overflight behavior, $d = \sqrt{1700^2 + 700^2} \sim 1840$ meters. Given a typical cruising Cessna 206 has a sound power level in the 134 dB range (NPS unpublished data,) the expected sound pressure level at Cabin Peak is $L_p = 134 + 10 \log_{10} \left(\frac{1}{4\pi 1840^2} \right) = 57.7$ dBA. This figure is probably slightly higher than the actual observed value due to absorption of additional acoustic energy from the atmosphere. However, this additional attenuation is likely small (less than 1.0 dBA) due to the small slant distance between source and receiver.

When considering the distribution of maximum sound pressure levels, it is helpful to inspect a histogram that accumulates the number of times an event of a certain amplitude was observed at the site. Upon inspection of Figure 13, it appears the histogram is bimodal. Events greater than 46 dBA make up a louder subset of air traffic over Cabin Peak. In all, there were 202 events greater than 46 dBA over the 41 day sampling period. This equates to about 4.9 events per day, or, assuming a round trip and dividing by two, about 2.5 takeoffs/landings per day on average.

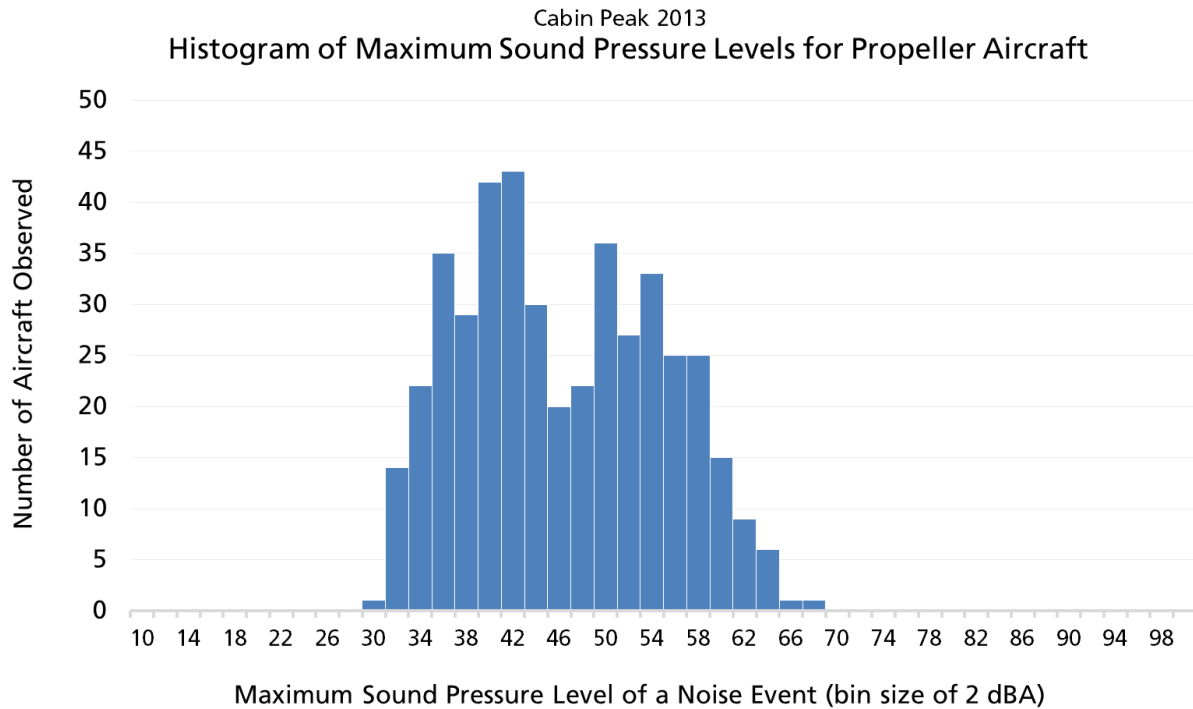


Figure 13. Histogram of Maximum Sound Pressure Levels for Propeller Aircraft Noise Events at Cabin Peak. Each bin is 2 decibels wide.

The lower subset of propeller events has a floor that is bounded by the natural ambience. For this reason, maximum levels below 29.2 were not observed during the sampling period. Events with maximum levels from 29 – 46 dBA are consistent with observed flightpaths over Toklat, Polychrome Mountain, and the park road beyond, greater than 6 km distant from the sampling location. At this distance the angle between the source and the ground surface is small enough that interactions with the surface may be an important factor in propagation and attenuation of sound. Similarly, surrounding terrain may have a large attenuating effect on the received signal (Piercy 1977, Gołębiewski 2002).

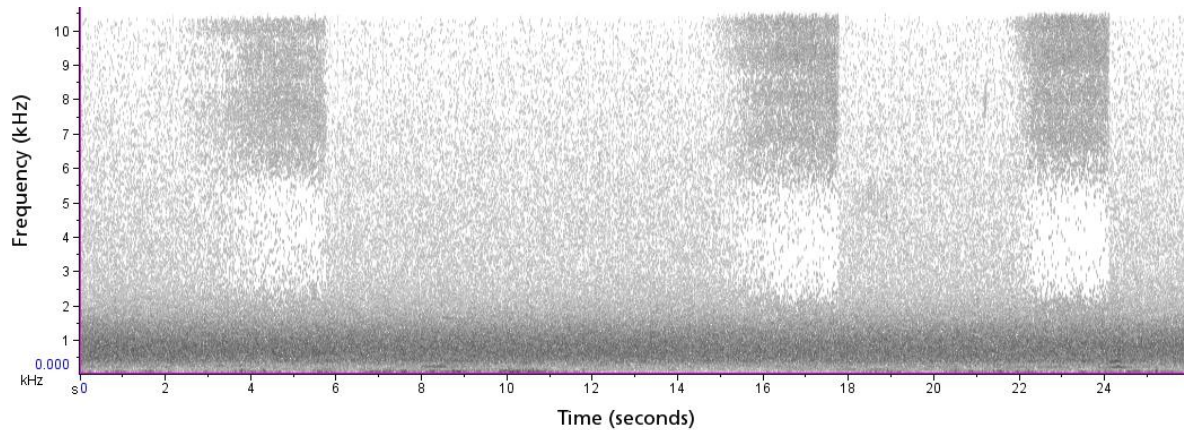
During the month of June and into early July, a vigorous dawn chorus was observed at Cabin Peak. The chorus was predominated by White-crowned Sparrow, but other birds were also common, especially Dark-eyed Junco, Orange-crowned Warbler (*Oreothlypis celata*), and Wilson's Warbler (*Cardellina pusilla*). The latter usually became more prominent in late morning and continued singing sparsely into the afternoon hours. Fox Sparrow was less predominant in the chorus, but still heard on most days. Hermit Thrush (*Catharus guttatus*) was sporadic and distant, but heard on many days. American Robin (*Turdus migratorius*) was late to begin singing and was infrequently heard as part of the chorus. Black-billed Magpie (*Pica hudsonia*) was heard calling on several days - usually in the afternoon and evening. Redpoll (*Acanthis* spp.) flight calls were also infrequently heard but were not associated with a particular time of day.

A variety of mammals were also audible at the site, detected in about 4.9% of clips. Arctic ground squirrel (*Spermophilus parryii*) and Collared Pika (*Ochotona collaris*) were detected most often. Grizzly bear (*Ursus arctos horribilis*) was also heard interacting with, but not destroying, the sound equipment.

Adult grasshoppers (order: Orthoptera) produce a buzzing sound called stridulation. This sound appears on a spectrogram as a rapidly repeated high-frequency broadband noise with very sudden onset and decay (see [Spectrogram 2](#)). Records of Orthopterans have been annotated throughout the course of the Denali soundscape inventory. Thus far, only four sites have had positive detections, including Cabin Peak. (The other sites were Estok 2011, West Kantishna Hills 2011, and McKinley River 2012). In previously published research in Alaska, *Melanoplus borealis* (Northern Spur-throat Grasshoppers) were found to be “generally sluggish under 20°C”, but were “increasingly active with spontaneous jumping and flying” from 23° - 35°C. In cold or rainy conditions, they sought shelter in dense vegetation (Kaufmann 1971). At Cabin Peak, grasshopper activity was also strongly related to air temperature (which drives ground temperature, the pertinent factor for basking animals). When only hours with average air temperatures over 20°C are considered, the conditional probability of observing stridulation is 34%. When all hours are considered, the conditional probability of observing stridulation is only 4%. In other words, given the correct habitat we should expect to hear orthopterans mostly during warmer periods.

In the previously mentioned study, *Melanoplus borealis* were observed to have started hatching in Fairbanks on 06/10/1967, with the population having entirely matured into adults by 07/25/1967. At Cabin Peak the earliest detections of stridulation were on 07/12/2013, which suggests that eggs in the area likely hatched in mid-June. This is consistent with the work in Fairbanks in the 1960s, but

inconsistent with the climatic differences between these two areas. Because they are closely related to temperature, changes in stridulation phenology may be a useful way to monitor the effects of climate change over long periods of time. The last stridulation event observed was on 08/03/13, about 14 days before the end of the record.



Spectrogram 2. Buzzy stridulation of an unknown grasshopper species (Order: Orthoptera). Note that most of the energy of the sound is above 6 kHz. The spectrogram begins at 11:26:33 on 07/14/2013. The most commonly heard sounds at this site were flowing water (audible 99.9% of the time), birds (40.3%), wind (34.4%), precipitation (12.6%), and insects (9.3%). Human made sound was audible 8.9% of the time. Aircraft were audible 2.9% of the time. (This is equivalent to 41.8 minutes of aircraft sound each day, or about 16 overflights a day.) Conditions exceeded the BCMP percent audible standard 22% of the time, number of events per day 98% of the time, and maximum SPL 55% of the time.

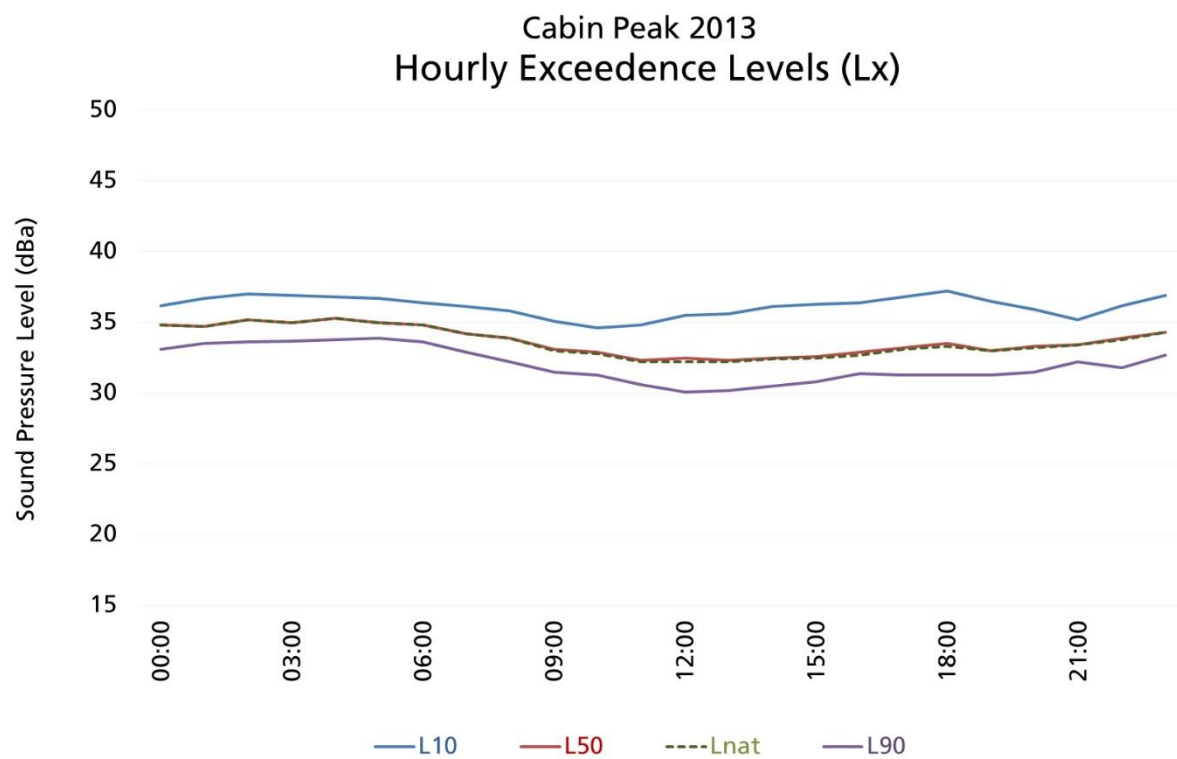


Figure 14. Exceedence levels for Cabin Peak.

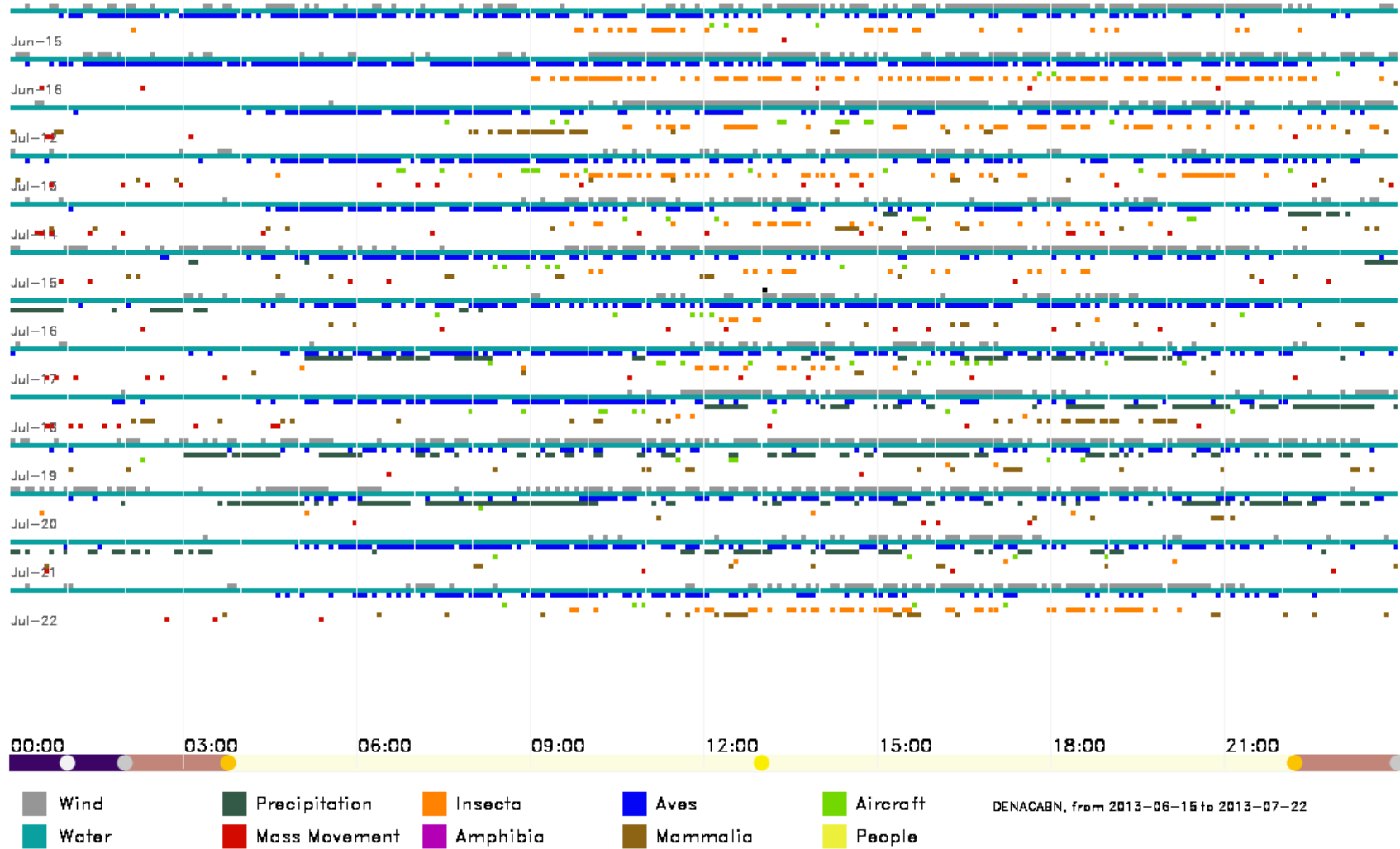


Figure 15. Temporal audibility of sound sources at Cabin Peak, based on five seconds of audio every five minutes. The bar along the time axis indicates the average light conditions during the sampling period. The orange circles are sunrise/sunset, and the gray circles are the beginning and end of civil twilight.

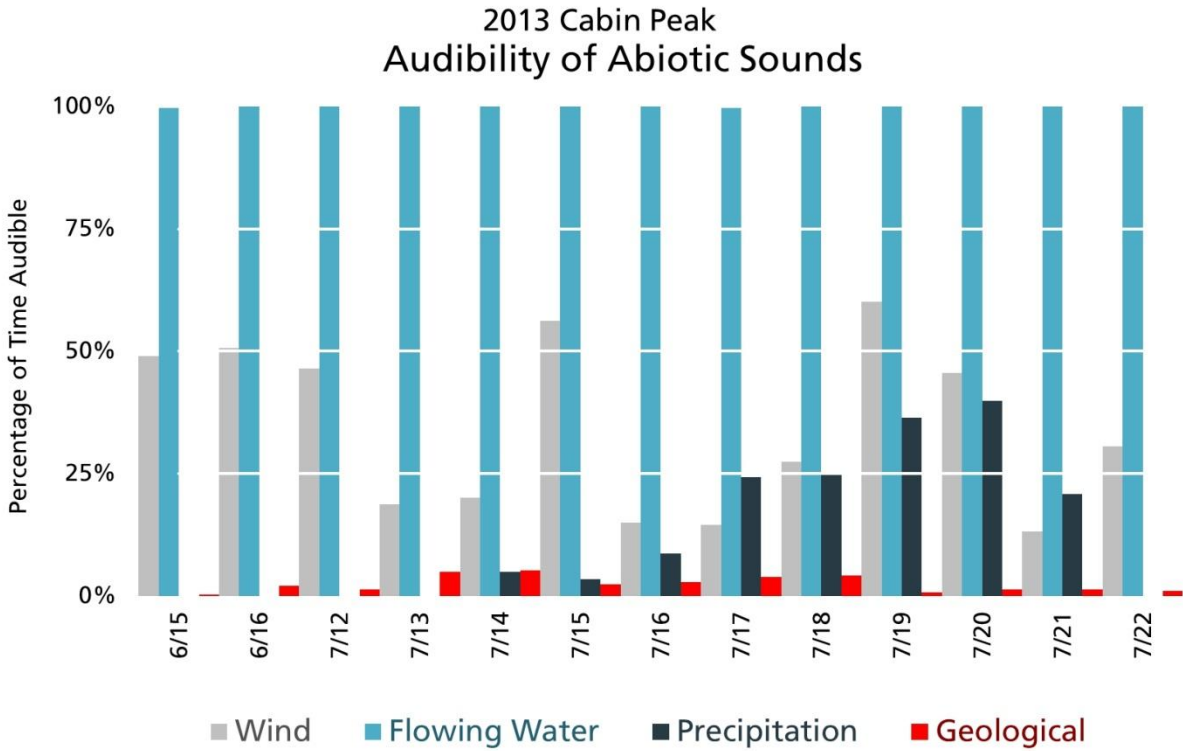


Figure 16. Audibility of abiotic sounds at Cabin Peak.

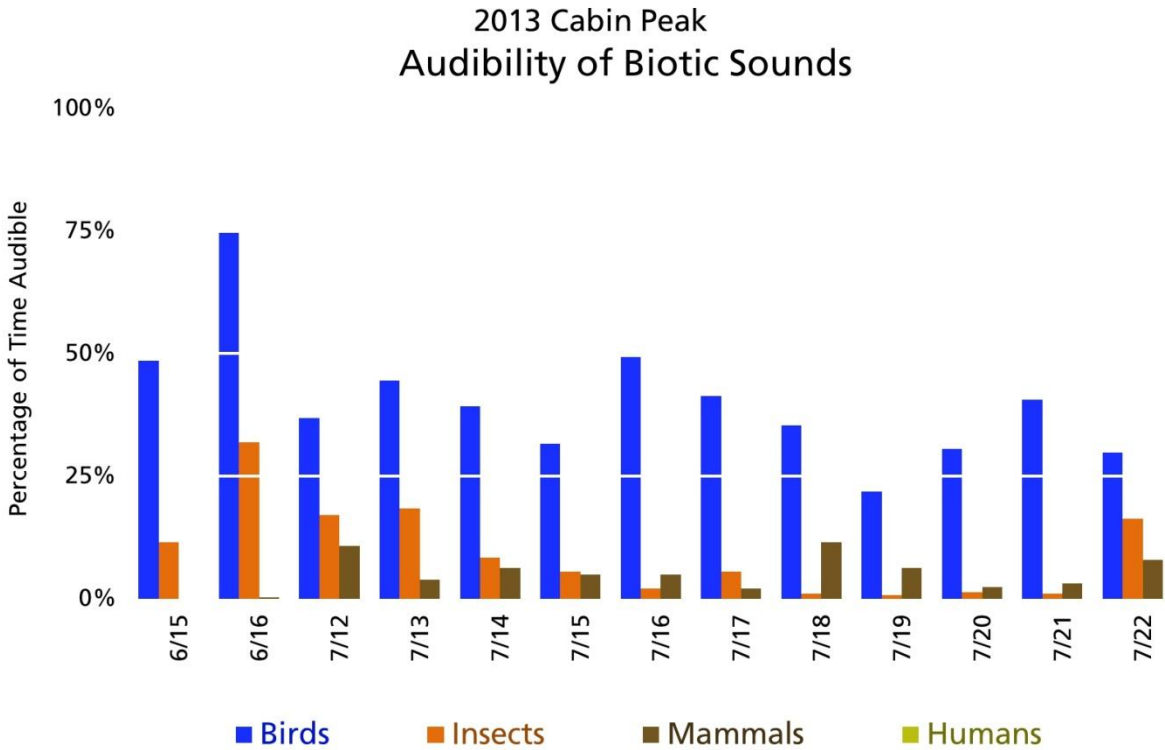


Figure 17. Audibility of biotic sounds at Cabin Peak.

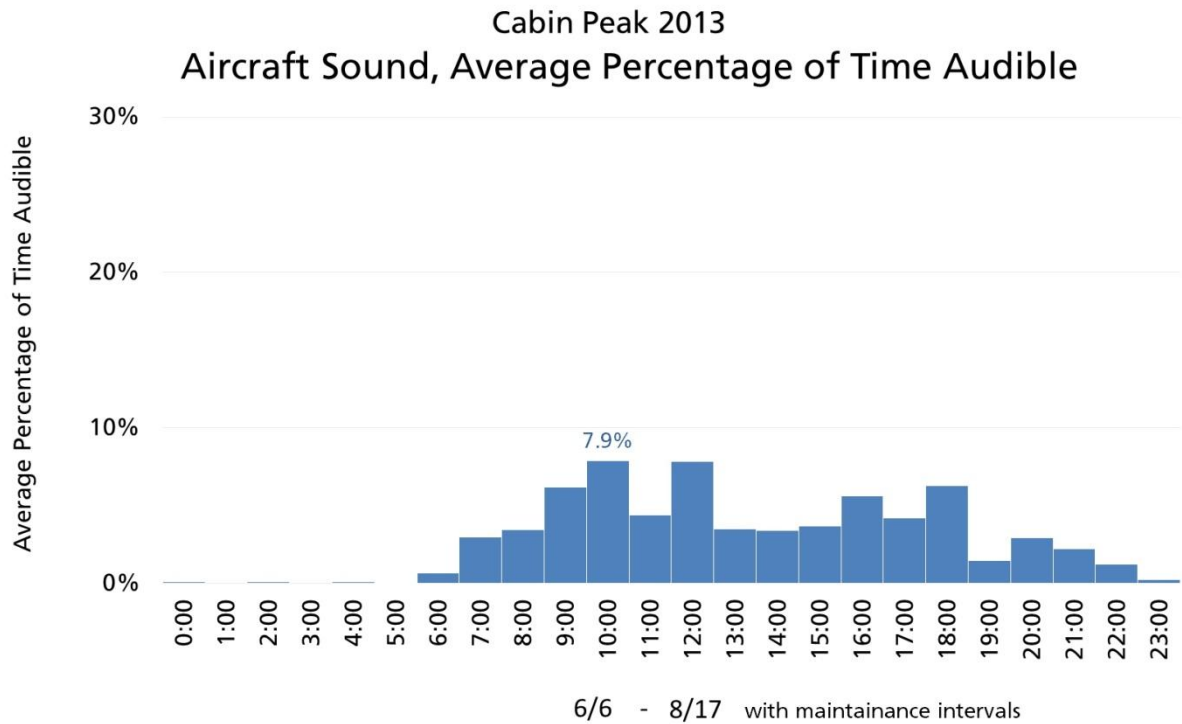


Figure 18. Audibility of aircraft noise for an average day, by hour, at Cabin Peak.

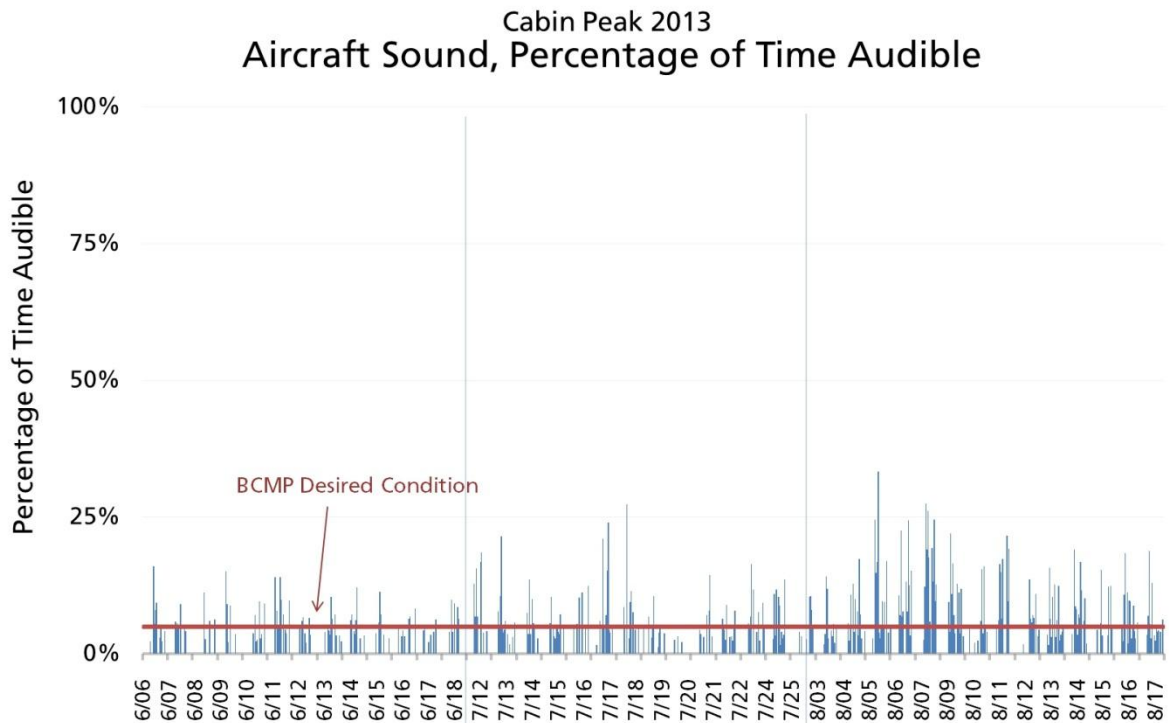


Figure 19. Audibility of aircraft noise at Cabin Peak. Vertical lines indicate gaps in data set.

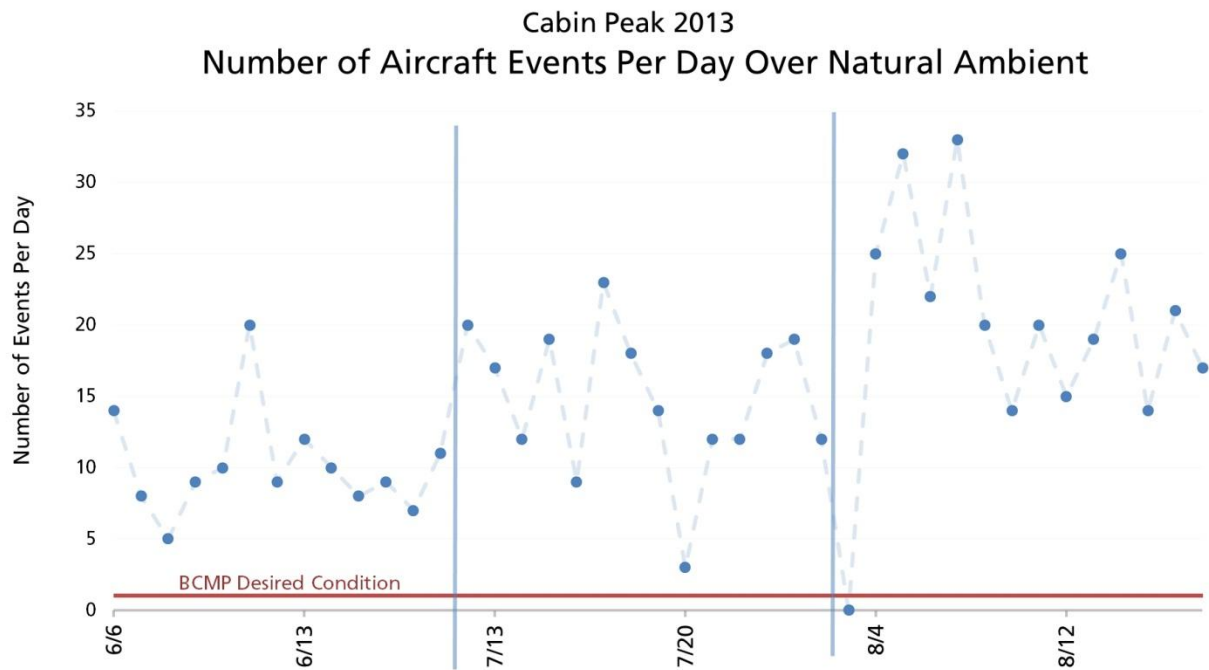


Figure 20. Number of aircraft noise events detected per day at Cabin Peak. Vertical lines indicate gaps in data set.

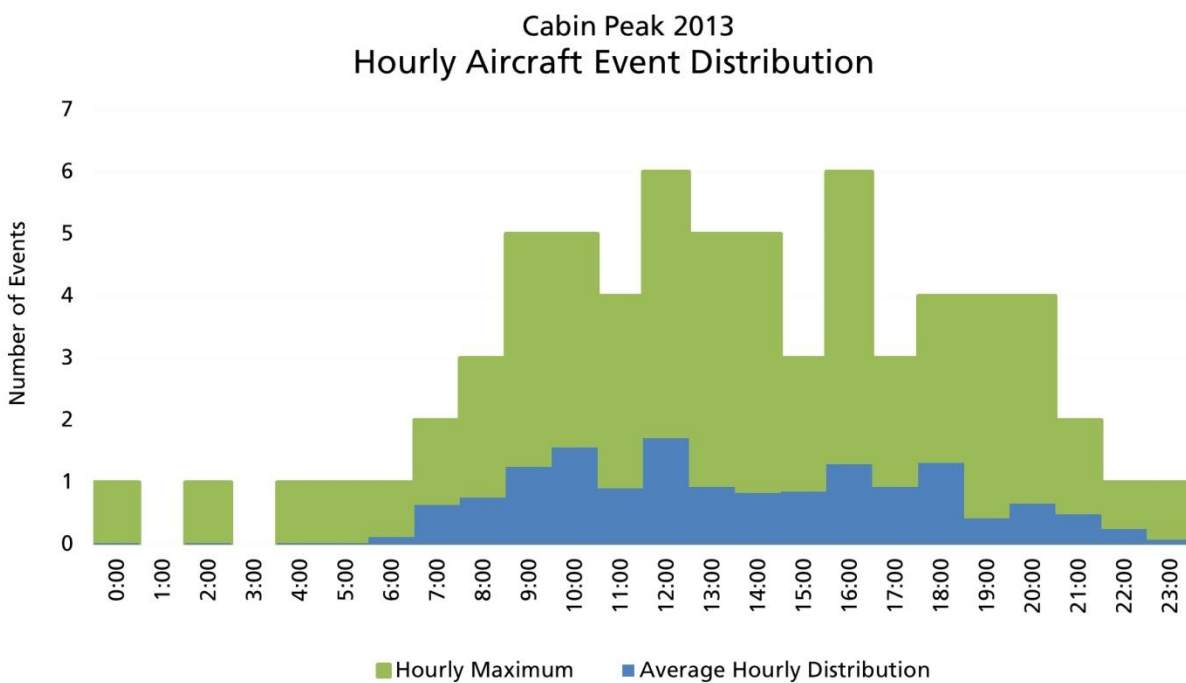


Figure 21. Hourly average and maximum rates of detection for aircraft noise events at Cabin Peak.

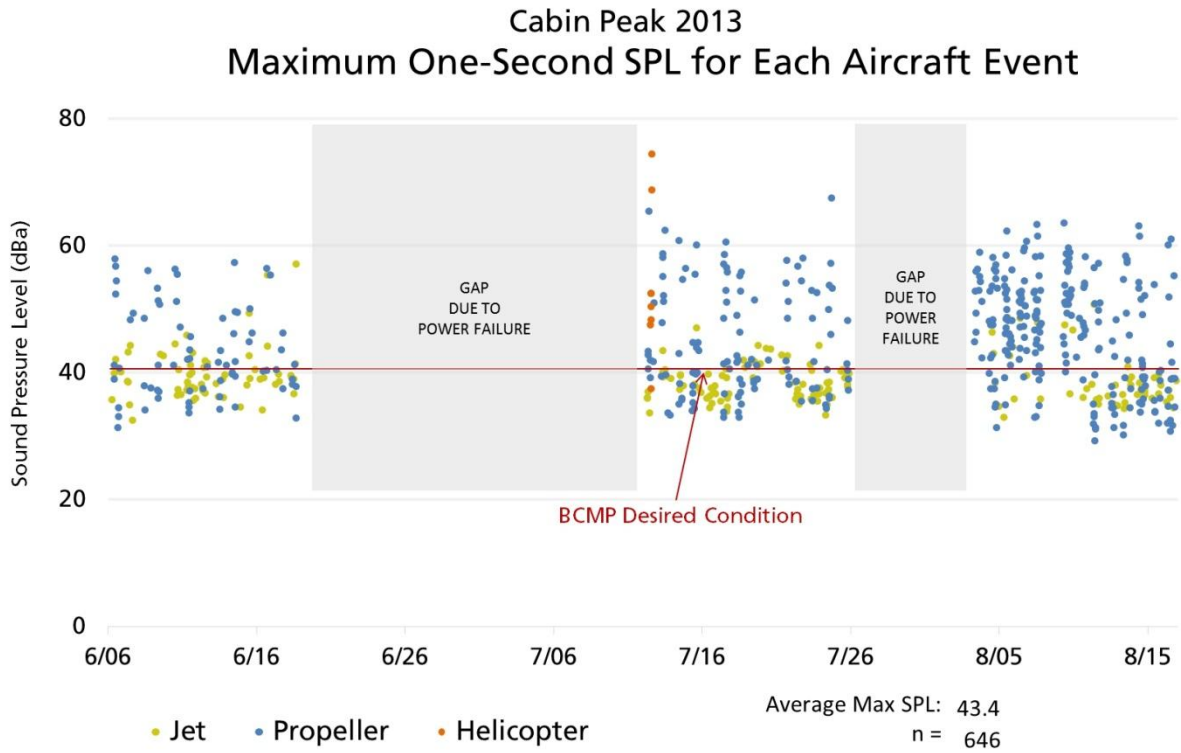


Figure 22. Maximum one-second sound pressure level for each aircraft event detected at Cabin Peak.

Carlson Creek



Location Description: In the headwaters of Carlson Creek in a dry forb herbaceous habitat (Vioreck class III.B.1) dominated by *Dryas*. As visible in the photograph the site is near the elevation where vegetation becomes sparse. The photograph above faces roughly west towards a pass to the Peters Glacier.

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

Coordinates: 63.24189°, -150.83624° (WGS84)

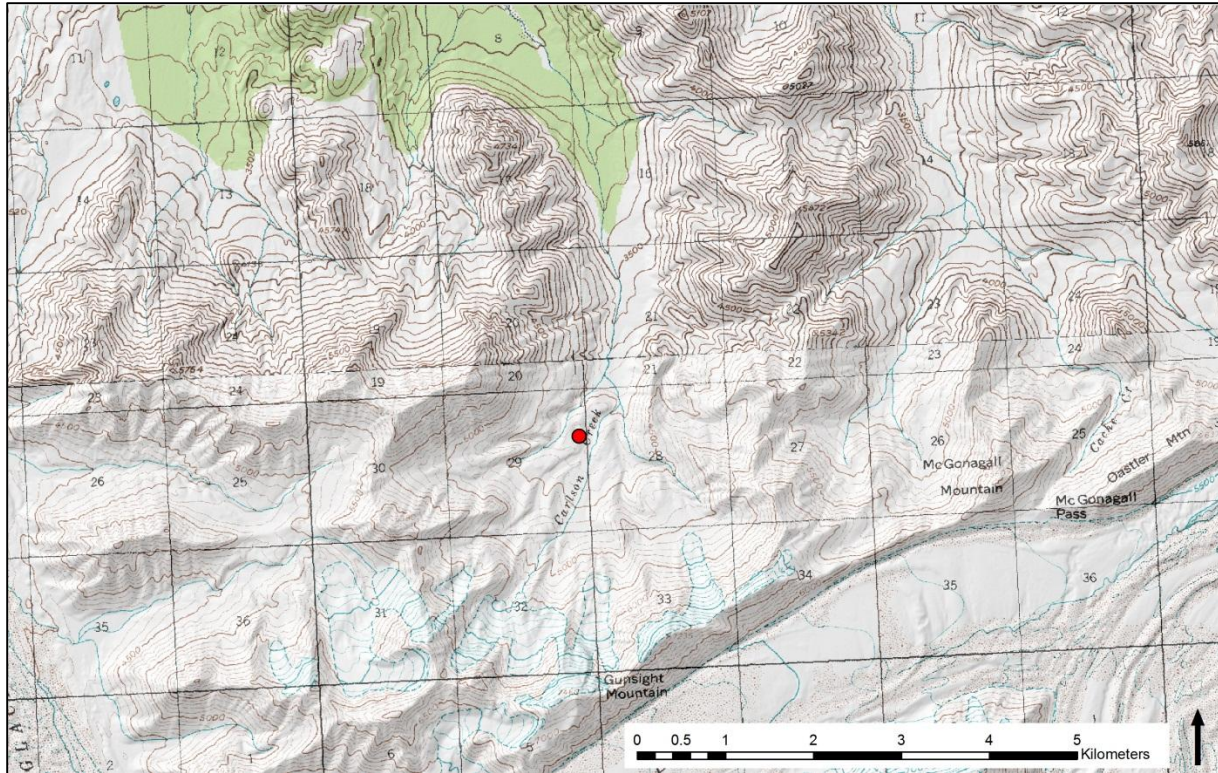
Elevation: 1325 meters

Sampling Period: 01-August-2013 to 28-August-2013

BCMP Management Area: OP1 (Low Natural Sound Disturbance)

Park Ecoregion: Alaska Range Interior Mountains and Valleys

Access: Helicopter install / Foot removal



Summary: The purpose of the Carlson Creek 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 #107 was located in designated wilderness (former Mt. McKinley National Park). Carlson Creek is proximal to Cache Creek, a popular backpacking area in the park that allows access to McGonagall Pass and Oastler Pass as well as the Muldrow Glacier. Carlson Creek flows from the base of Gunsight Mountain and Gunsight Pass, both of which are themselves situated at the base of the greater Denali massif.

With a time-averaged natural ambient level of 29.1 dBA, Carlson Creek is in the 55th percentile of sites parkwide. The station was about 415 meters from several adjoining forks of the creek's headwaters. This proximity to energetic water makes the ambience somewhat constant, as can be seen in Figure 23. There is, however, a noticeable decrease in levels starting around the 06:00 hour, making this the quietest time of a typical day. On average 06:00 was also the coolest hour, with an average temperature of 5.6°C (42.7°F). Contrast this with 15:00, the warmest hour on average, at 10.5°C (50.8°F). In fact, sound pressure level at the site was positively correlated with air temperature at one meter above ground level. ($R = 0.85$) The difference in sound pressure level between the coolest hour and the warmest hour is 4.3 dBA on average - a large difference equivalent to a 63% reduction in listening area. (The equation used to calculate listening area can be found in Barber 2010, pg 183).

Human-created sound was prevalent at Carlson Creek, detected over 6.8% of the sampling period. It was the fourth most commonly heard source after long-duration phenomena such as flowing water, wind, and precipitation. Human-caused noise was entirely contributed by aircraft overflights. This

impact is similar to many sites that have been inventoried on the Denali massif and along the spine of the Alaska Range stretching east. For example, [Fang Mountain](#) also had aircraft noise audible 6.8% percent of the sampling period in 2013. Kahiltna Pass (Withers and Betchkal 2013b), the grid point immediately south-west of Carlson Creek, also had aircraft noise audible 6.8% of the time in 2011. Upper West Branch Toklat (Betchkal 2013), along the spine of the Alaska Range and a popular backpacking area, had noise audible 7.8% of the sampling period in 2012. Scenic mountainous landscapes are an obvious attraction to commercial flightseeing operations, and during the summer months these areas are saturated with a high-volume pulse of air traffic. Carlson Creek's location beneath the north-eastern face of Denali makes it especially useful in understanding how traffic patterns of air tour operators based out of Healy, Canyon, McKinley National Park Airport, McKinley Village, and Kantishna (collectively "north side" operators) affect the soundscape of Denali's designated wilderness.

Naturally, Carlson Creek is at the periphery of the northwestern lowlands, the most bioacoustically diverse region of the park. At Carlson Creek, however, this diverse assemblage is tempered by the harsh glaciated environments directly south of the site. Despite this and the fact that the sample was entirely outside the main period of avian singing activity, birds were audible in 6.4% of audio clips. The bulk of these detections were the calls of White-tailed Ptarmigan (*Lagopus leucura*). These birds have been detected at nine other alpine sites, including [Fang Mountain](#). Mammals were also heard at Carlson Creek, audible in 2.0% of audio clips. Both Arctic Ground Squirrel and Collared Pika were detected during the analysis. Collared Pika is of particular interest as a species potentially affected by climate change. They have been detected at seven other sub-alpine and alpine sites including [Cabin Peak](#).

The most commonly heard sounds at this site were flowing water (audible 99.8% of the time), wind (11.4%), precipitation (9.2%), and aircraft (6.8%). Human made sound was audible 6.8% of the sampling period. This is equivalent to about 97.9 minutes of aircraft sound each day, or about 30 overflights a day. Conditions exceeded the BCMP percent audible standard 37% of the time, number of events per day 92% of the time, and maximum SPL 54% of the time.

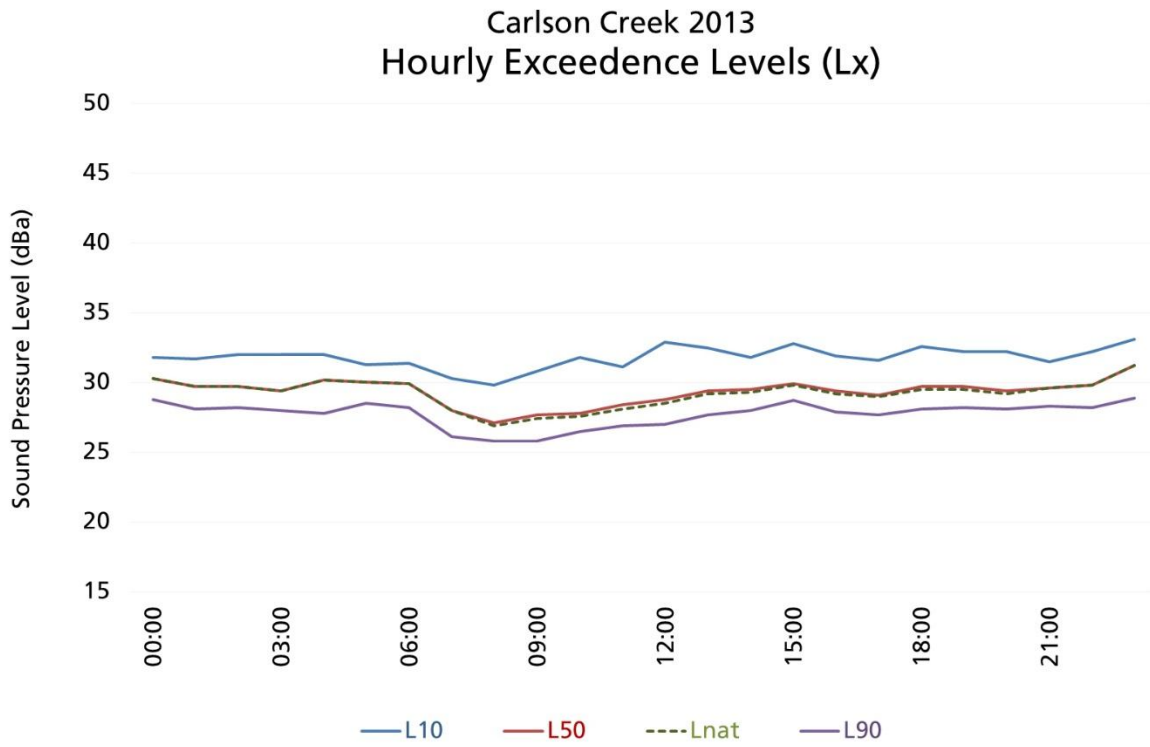


Figure 23. Exceedence levels for Carlson Creek.

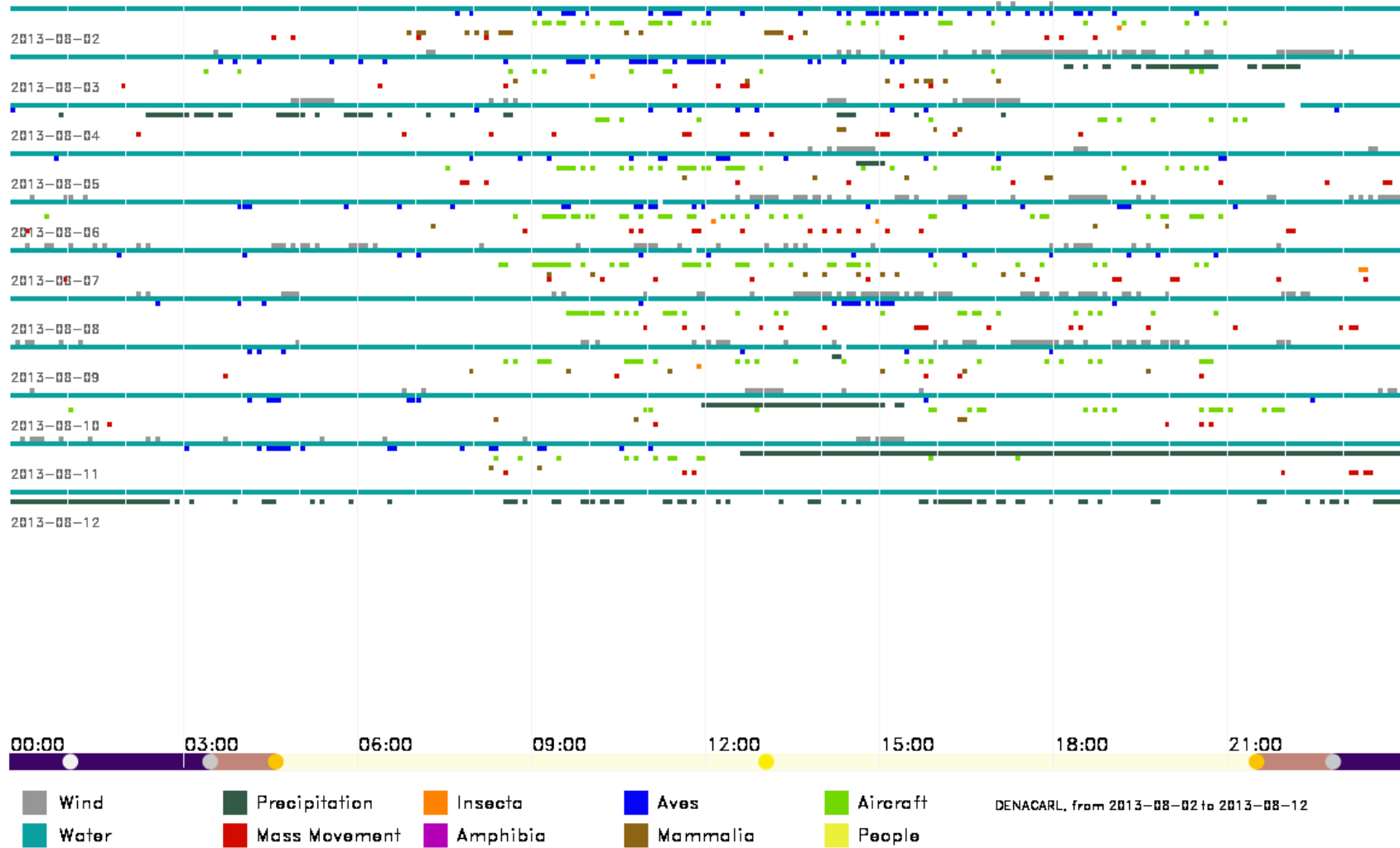


Figure 24. Temporal audibility of sound sources at Carlson Creek, based on five seconds of audio every five minutes. The bar along the time axis indicates the average light conditions during the sampling period. The orange circles are sunrise/sunset, and the gray circles are the beginning and end of civil twilight.

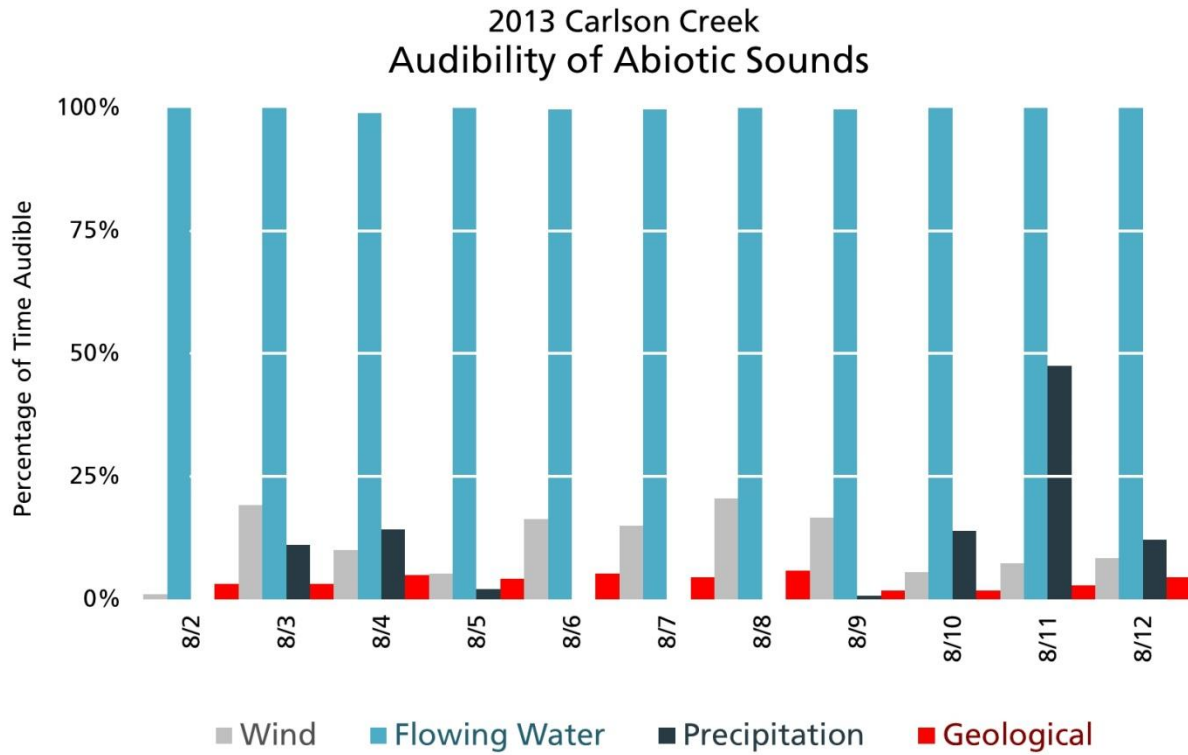


Figure 25. Audibility of abiotic sounds at Carlson Creek.

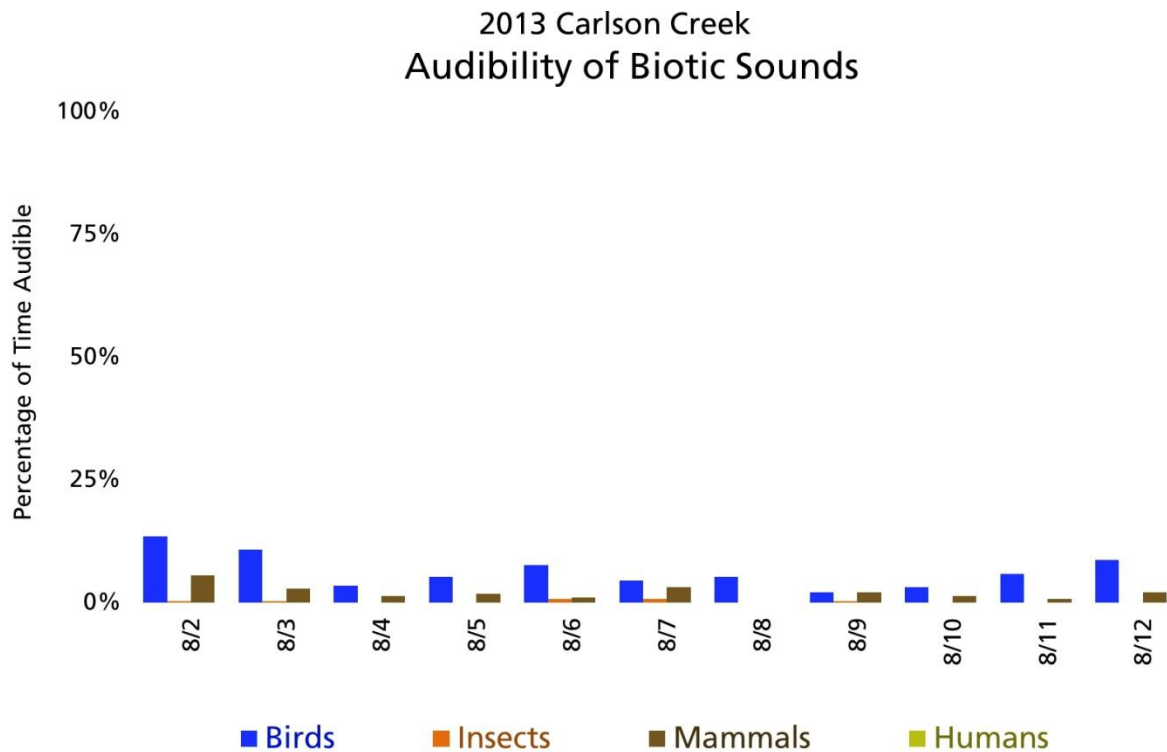


Figure 26. Audibility of biotic sounds at Carlson Creek.

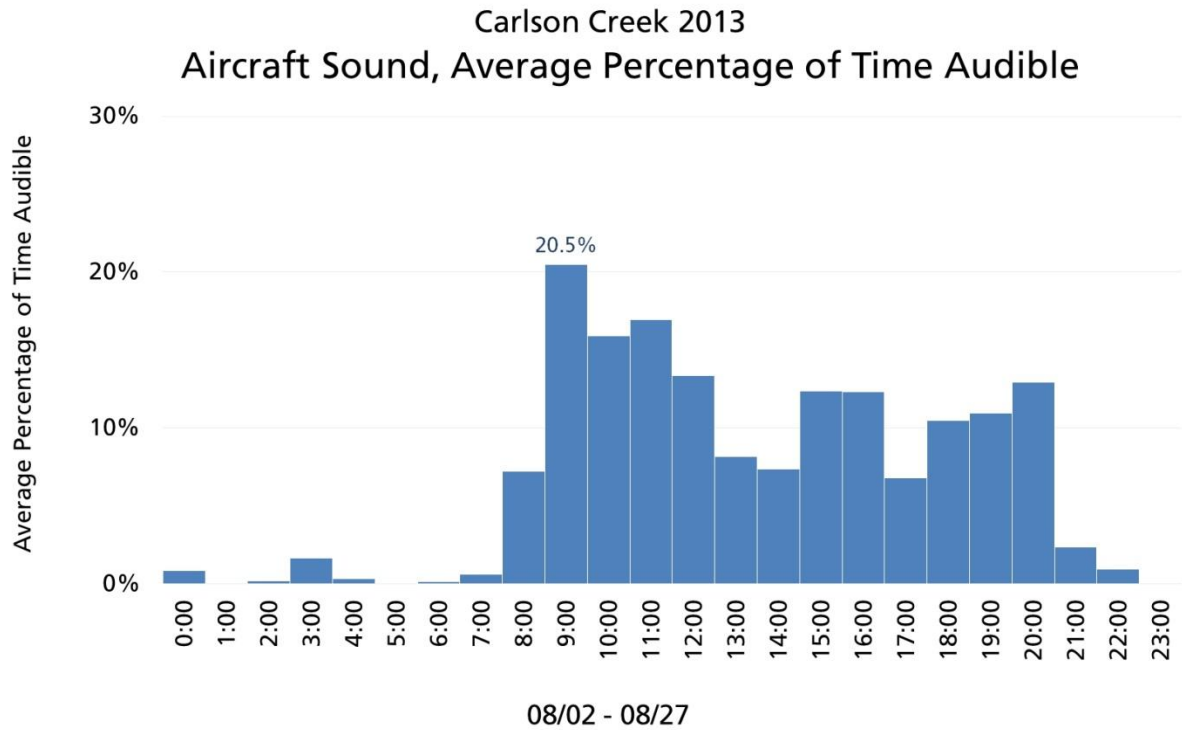


Figure 27. Audibility of aircraft noise for an average day, by hour, at Carlson Creek.

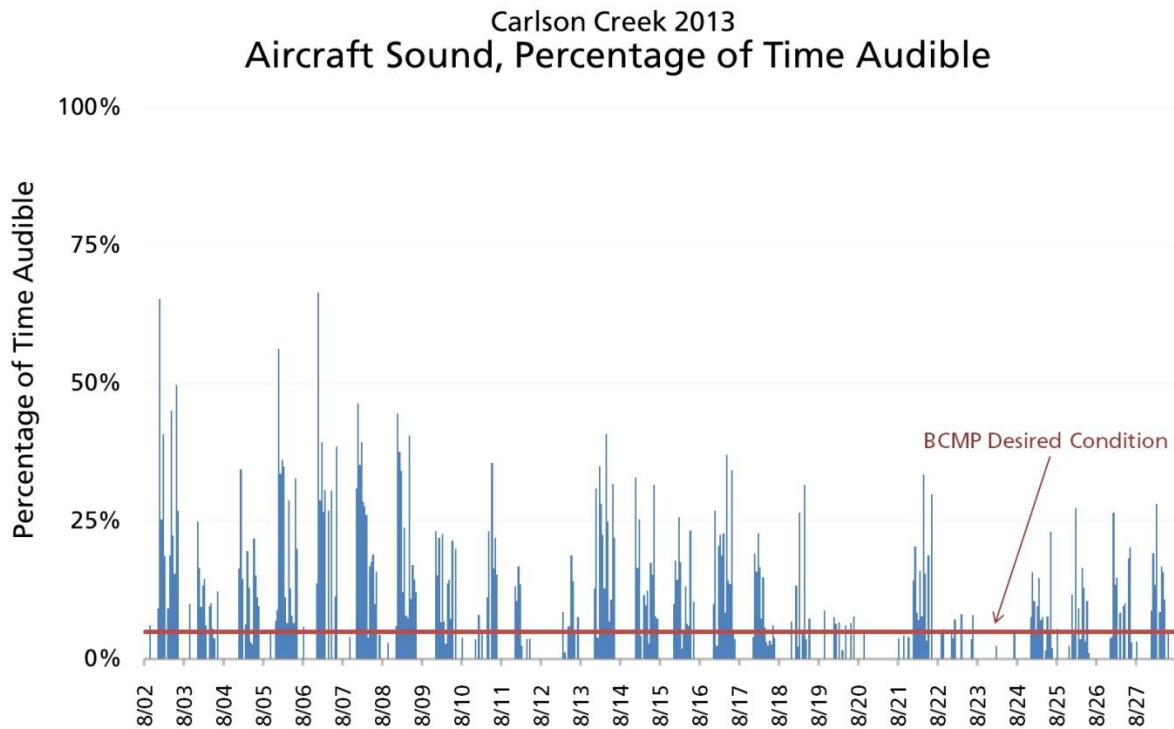


Figure 28. Audibility of aircraft noise at Carlson Creek.

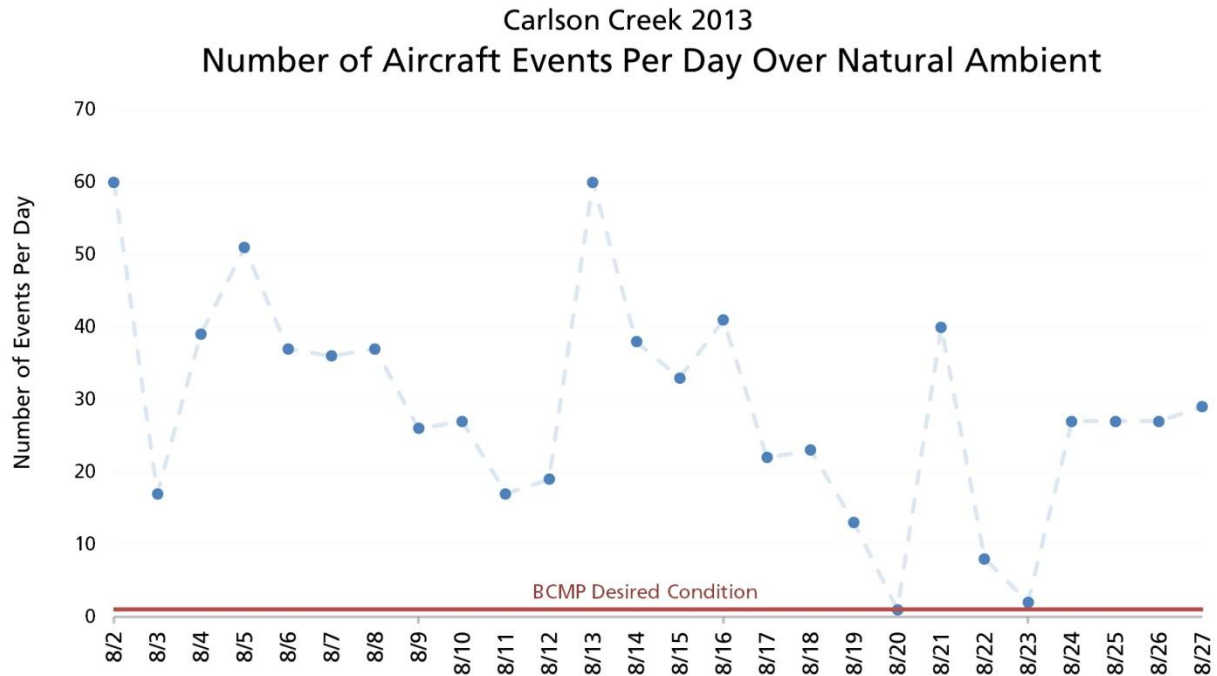


Figure 29. Number of aircraft noise events detected per day at Carlson Creek.

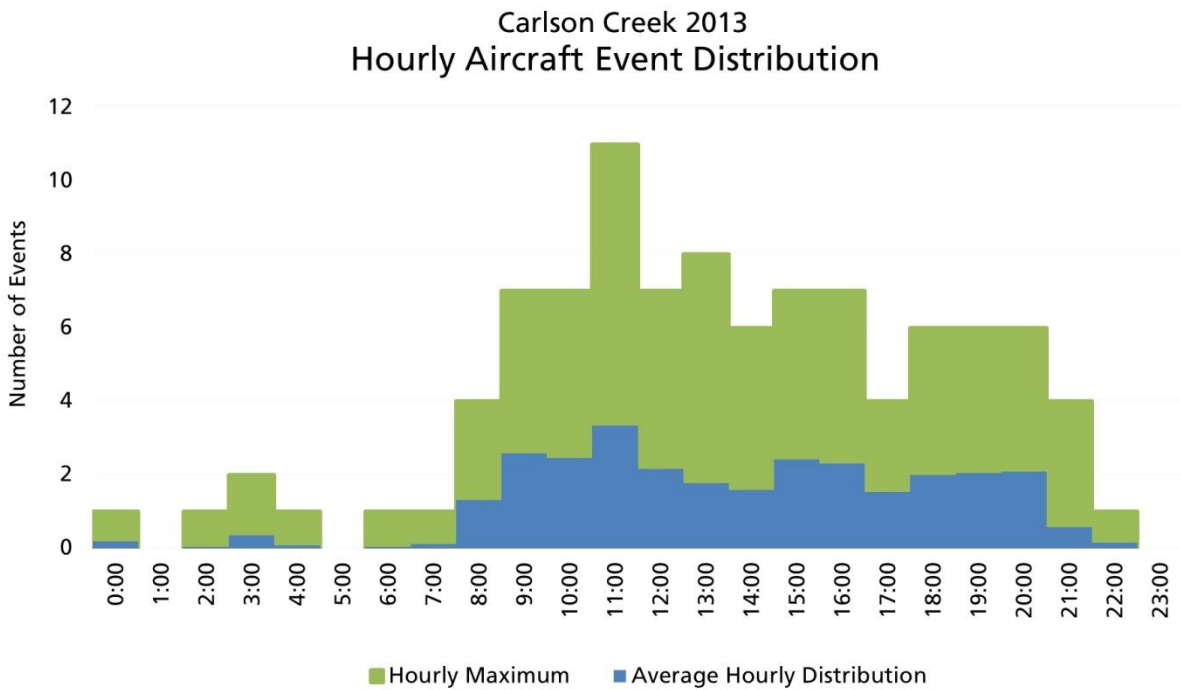


Figure 30. Hourly average and maximum rates of detection for aircraft noise events at Carlson Creek.

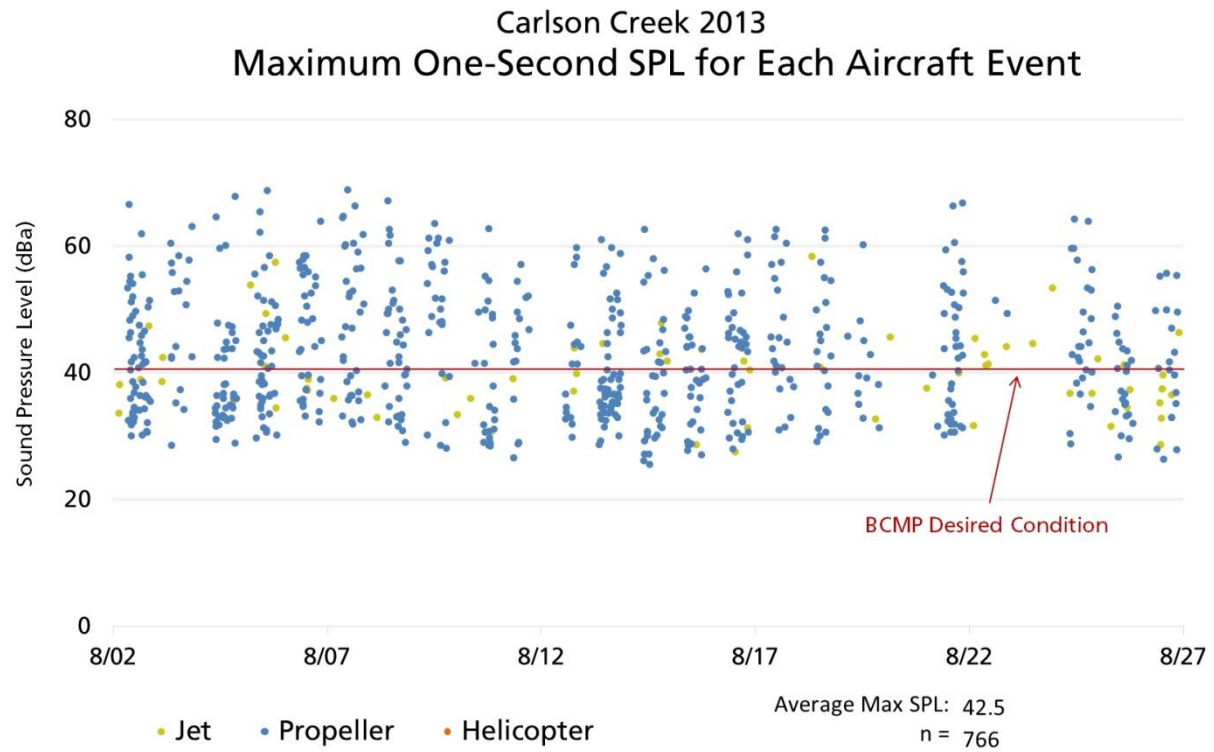


Figure 31. Maximum one-second sound pressure level for each aircraft event detected at Carlson Creek.

Fang Mountain



Location Description: The site was located on a rock glacier flowing from the west slope of Fang Mountain. The rock glacier is bounded to the south and west by a small inaudible tributary of the Sanctuary River. Vegetation was of the mesic graminoid herbaceous class (Vioreck III.A.2). The photograph above faces west towards the Sanctuary River.

Purpose/Project: To further assess the effects of the 2012 Denali Aircraft Overflights Advisory Committee best practice, as detailed below. (Other sites involved in this assessment were Upper West Branch Toklat 2012, and Cathedral Mountain 2012).

Coordinates: 63.56617°, -149.20564° (WGS84)

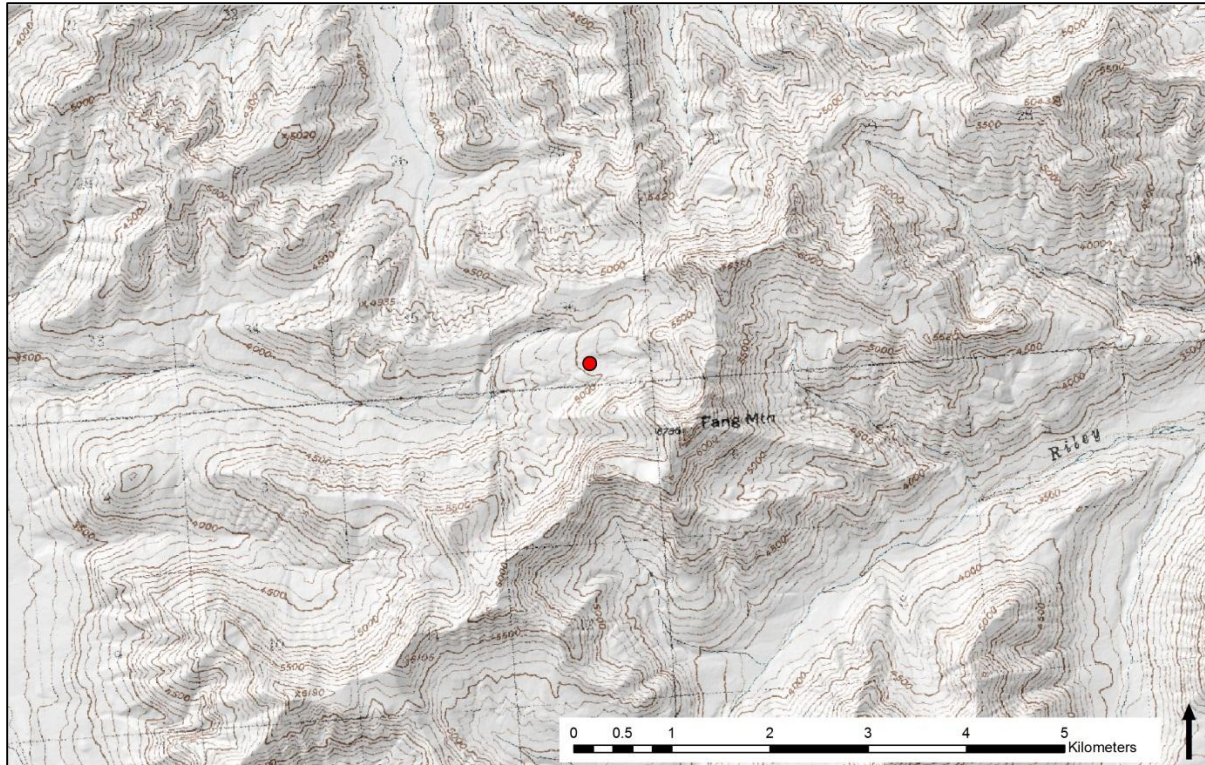
Elevation: 1523 meters

Sampling Period: 29-June-2013 to 19-August-2013

BCMP Management Area: OP1 (Low Natural Sound Disturbance)

Park Ecoregion: Alaska Range High Mountains

Access: Foot



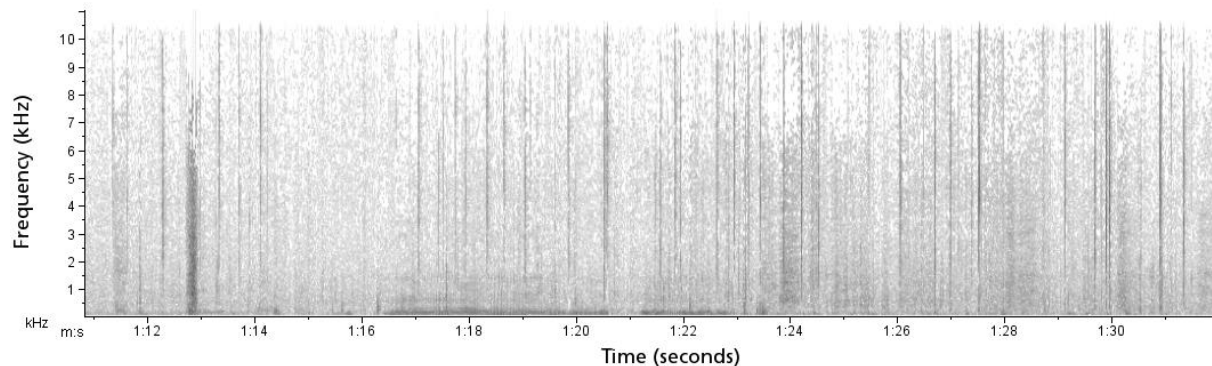
Summary: LTEM grid point #175 was chosen from the list of previously sampled locations within popular hiking regions of the park to assess whether management action had caused soundscape conditions to change along the spine of the Alaska Range south of the park road. The action asks aviators transiting the spine 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 spine entirely (Denali Aircraft Overflights Advisory Committee 2012). To be clear, the best practice area does not contain Fang Mountain nor the sound station, but the easternmost portion of the area does contain Refuge Valley, which is about 9 km distant from the site location. Ultimately, Fang Mountain represents a confluence of north-side air traffic, and likely describes a typical daily pulse of aviation noise in and around the spine of the Alaska Range. Understanding this pulse is essential to understanding if best practices are effective.

With a time-averaged natural ambient level of 22.8 dBA, Fang Mountain is in the 25th percentile of sites parkwide. Although flowing water was not distinctly audible, known sources of sound included a small cascade on the higher slopes of Fang and a tributary of the Sanctuary River that wraps around the site from the north-east to the west. There were likely numerous other small streams and seeps on the surrounding mountains that contributed to a diffuse acoustic ambience during windless-periods. Wind, however, was not a negligible factor in the natural ambience. Like many exposed alpine sites, wind was the most commonly heard sound at Fang Mountain (audible in 46.7% of audio clips). The median hourly wind speed was 1.3 m/s (2.8 mph). This is similar to the 2011 sampling period, which had a median hourly wind speed of 1.2 m/s. For comparison to other exposed sites, Bull River 2012 had a median hourly wind speed of 1.2 m/s, Upper West Branch of the Toklat River 2012 was 1.5 m/s, Cathedral Mountain 2012 was 2.4 m/s, and Sushana Ridge 2012 was 3.2 m/s.

Despite a sampling period on the border of breeding season, only a small number of avian species were detected at the site. One species of particular interest and vociferity was the Surf-bird (*Aphriza virgata*). During the sampling period males were frequently observed to produce their 'rhythmically-repeated' and 'laughing' calls as well as song. Song in the species is associated with aerial displays and courtship, a sign of breeding behavior in the area (Miller 1987). In fact, one of the earliest records of the bird's nesting habitat was given by Olaus Murie in a 1924 edition of *The Auk*. His observations in the park were made "*at the head of the Savage River on July 4th, 1923*", and his account of the habitat preferred for nesting was "*very different from that of the Wandering Tattler. The Surf-bird [sic] was found on a gentle slope of a high hill, a considerable distance above the timber, where the ground was covered with a lumpy growth of mosses, grass and other low vegetation.*" This description is very close to conditions found at the Fang Mountain site location, as can be seen in the site photograph, above. Vegetation at the site was keyed to the Viereck III.A.2. mesic graminoid herbaceous class (Viereck 1992).

White-tailed Ptarmigan were also prominent in the early hours of the morning. Their flight screams / ground challenge calls are quite powerful and have been observed to carry as far as 1.6 km (Schmidt 1969), though this is not necessarily the limit of their propagation, which is ultimately dependent on background ambience. Recent climate change modelling scenarios have suggested that the Rocky Mountain populations may be extirpated from their limited range by the latter half of this century, but that Alaskan populations will either be stable or show signs of range expansion. (Lawler 2009). The species' pervasiveness at treeless sites above 1000 meters and the ease of acoustic detection combine to make this a possibly useful indicator species. (See [Carlson Creek](#) or [Mount Lee](#) sections in this report for additional observations of White-tailed Ptarmigan in 2013).

Another interesting biological record at Fang Mountain was the sound of Caribou (*Rangifer tarandus*) passing the station. Though usually vocally silent, a characteristic sound of these animals is the clicking of a tendon over the sesamoid bone in their foot. This sound is clearly seen in Spectrogram 3 as narrow, vertical lines representing short-duration, broadband energy. Also heard occasionally were various snorts and grunts, some nasal, others low-pitched, guttural, and purring. The latter vocalizations were extended, but lasted no more than 8 to 10 seconds.



Spectrogram 3. Recording of a Caribou (*Rangifer tarandus*) passing within close proximity of the Fang Mountain sound station. The characteristic clicking of the sesamoid bone in the animal's ankle is visible as short-duration vertical lines. A nasal snort is visible at 1:13, and an extended low-pitched purring "growl" begins around 1:16 and extends to 1:24. The spectrogram begins at 13:20:18 on 07/29/2013.

The most commonly heard sounds at this site were wind (audible 46.7%), silence (36.6%), precipitation (7.4%), and aircraft (6.8%). Human made sound was audible 6.8% of the time on average; all of it was generated by aircraft. This is equivalent to 97.9 minutes each day, or approximately 31 overflights a day at this location. Conditions exceeded the BCMP percent audible standard 43% of the time, number of events per day 100% of the time, and maximum SPL 53% of the time.

This site was previously sampled in 2011. For comparison, the data collected from 07/01/2011 through 08/04/2011 – a similar sampling period to 2013 – showed the most commonly heard sounds at this site were water (audible 100% of the time), wind (49.3%), insects (15.8%), and precipitation (14.3%). An unexplained difference in natural sound involved the audibility of water, which was consistent in 2011, but not detected in 2013, despite proximity to the same cascade on the western slopes of Fang Mountain as in 2011. One possible explanation is that precipitation was audible almost twice as frequently in 2011 as in 2013, and may have resulted in more drainage from Fang and a higher sound power level of the cascade. (Note that the percentage of time rain was audible and the total volume of rainfall are not necessarily related, however).

In 2011, human made sound was also produced entirely by aircraft, and audible 9.7% of the time. Soundscape conditions exceeded the BCMP percent audible standard 53% of the time, number of events per day 100% of the time, and maximum SPL 51% of the time (for detailed information on the original dataset, see Betchkal 2013a). Table 4 compares acoustic metrics for the two sampling periods.

Table 4. Comparison of soundscape conditions at Fang Mountain, 2011 and 2013. Shaded columns indicate Denali Backcountry Management Plan Standards.

Year	% Time Aircraft	% Time Standard	Events Standard	SPL Standard	% Time Water	% Time Wind	% Time Rain	% Time Insects
2011	9.7%	53% of all hours	100% of all days	51% of all events	100.0%	46.7%	14.3%	15.8%
2013	6.8%	43%	100%	53%	0.0%	49.3%	7.3%	3.5%

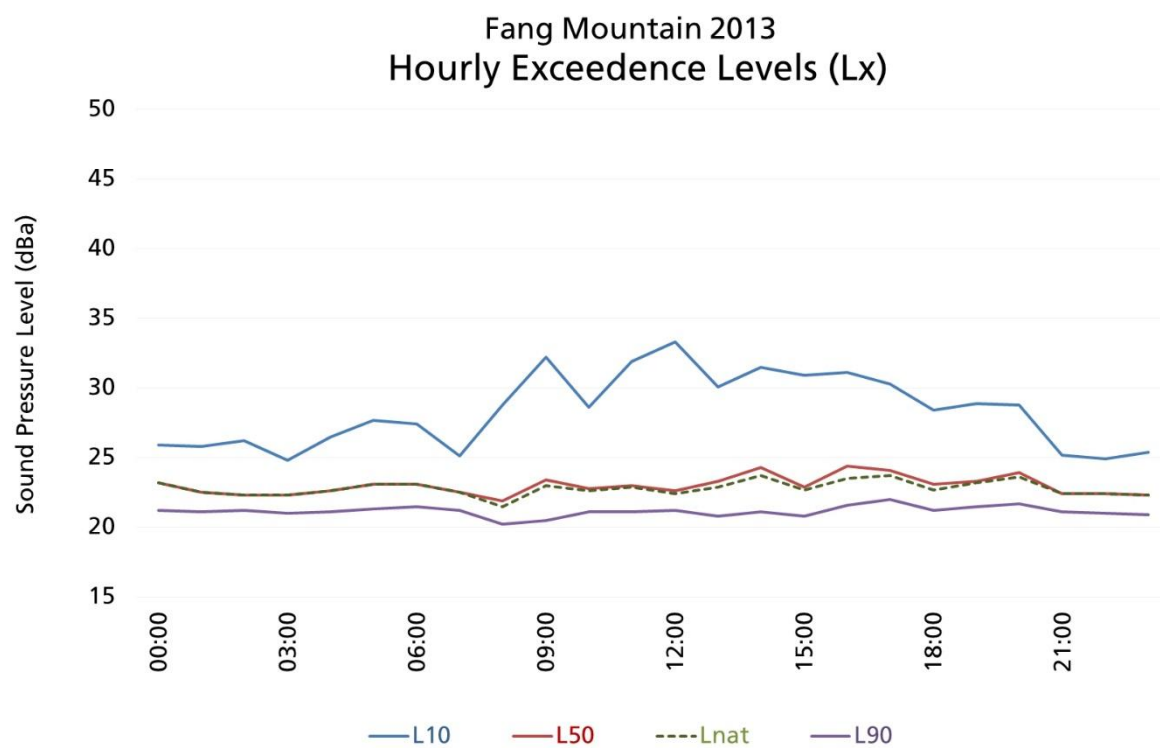


Figure 32. Exceedence levels for Fang Mountain.



Figure 33. Temporal audibility of sound sources at Fang Mountain, 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.

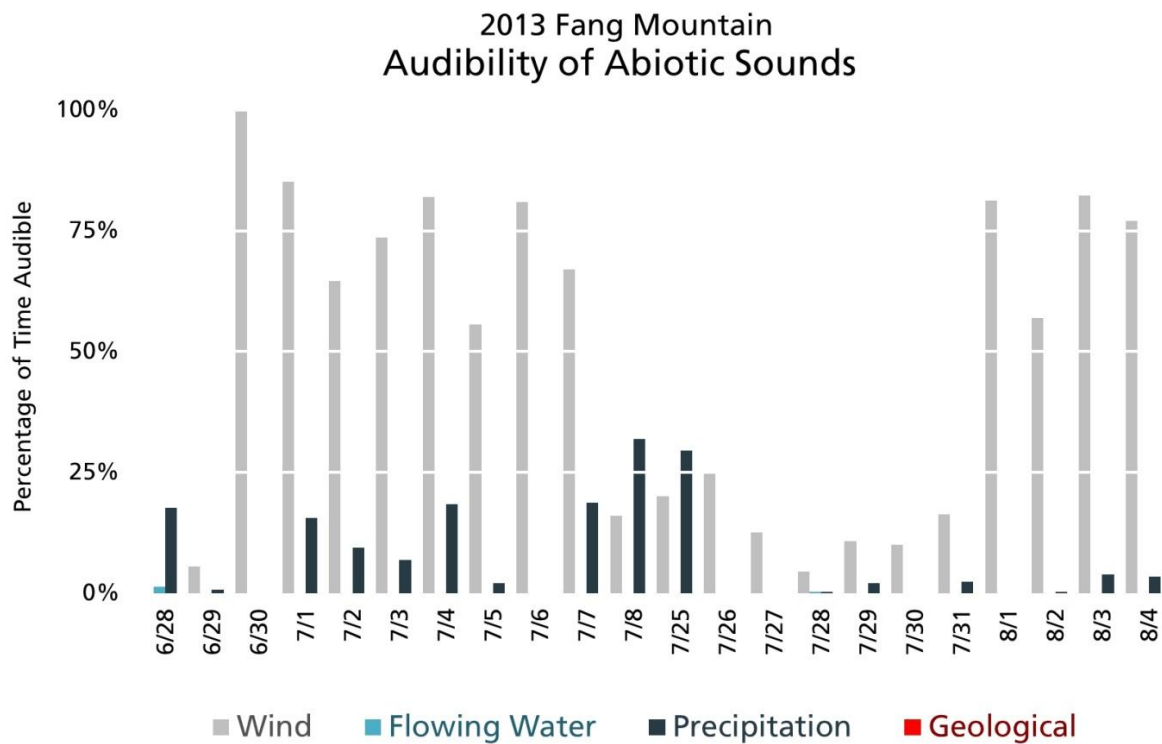


Figure 34. Audibility of abiotic sounds at Fang Mountain.

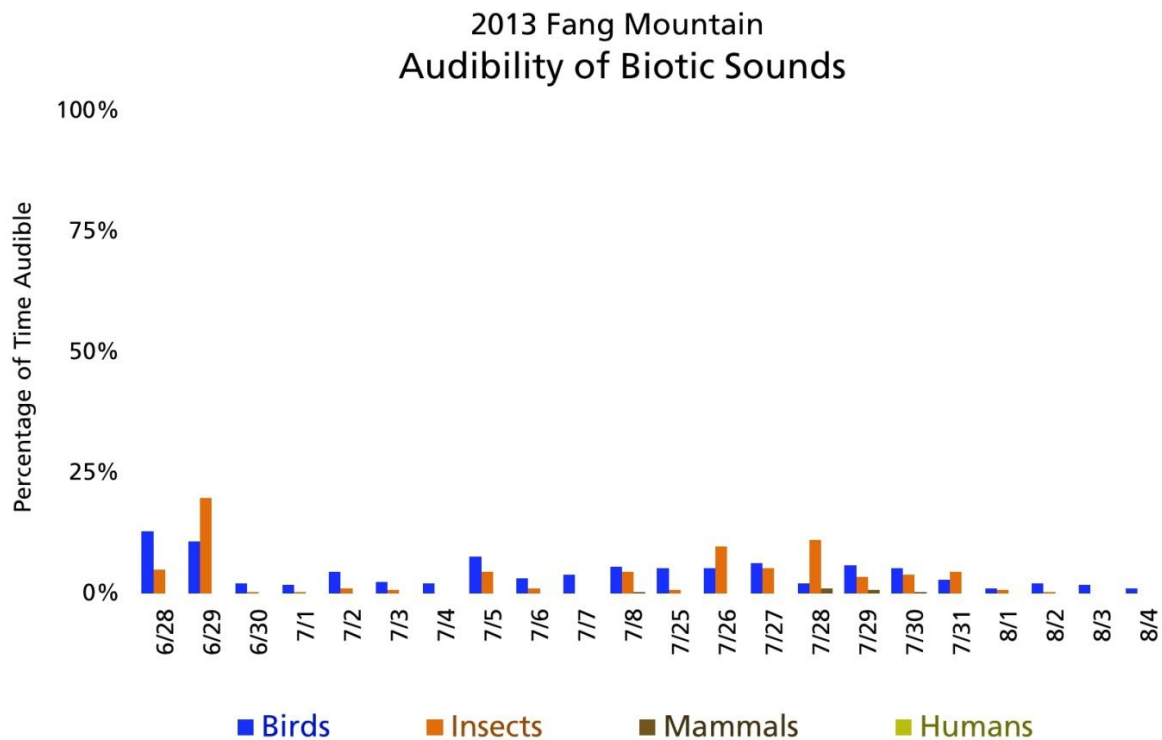


Figure 35. Audibility of biotic sounds at Fang Mountain.

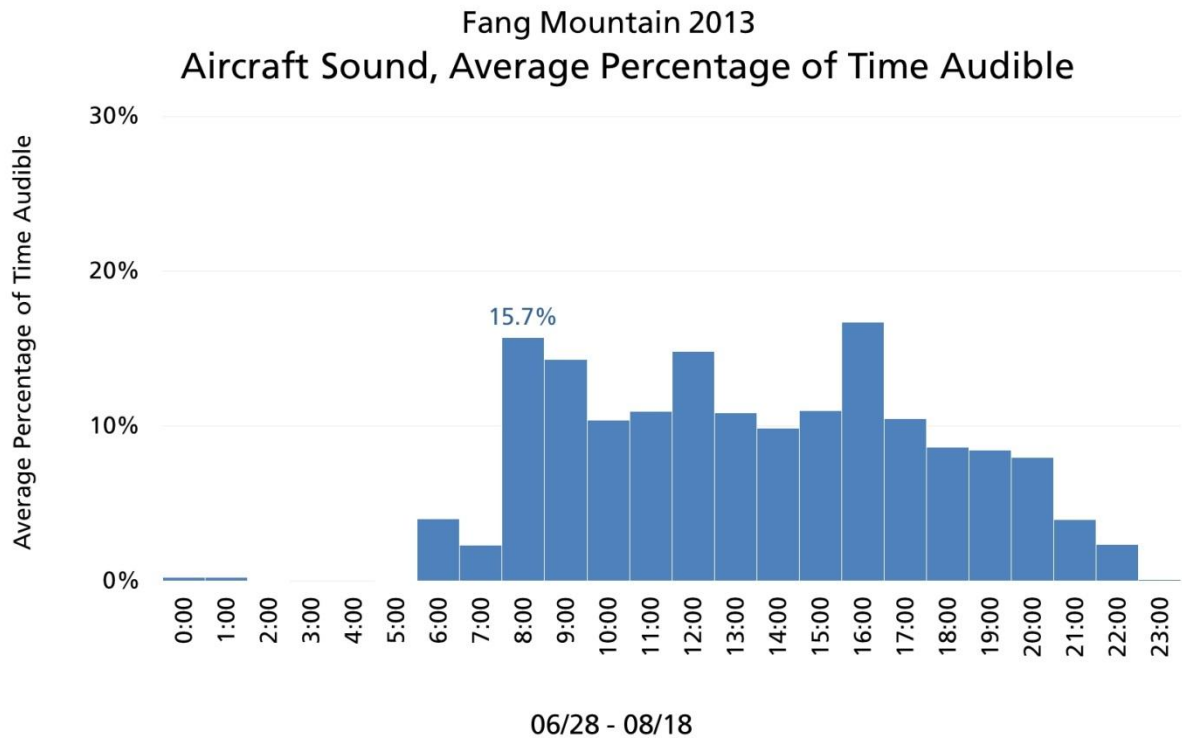


Figure 36. Audibility of aircraft noise for an average day, by hour, at Fang Mountain.

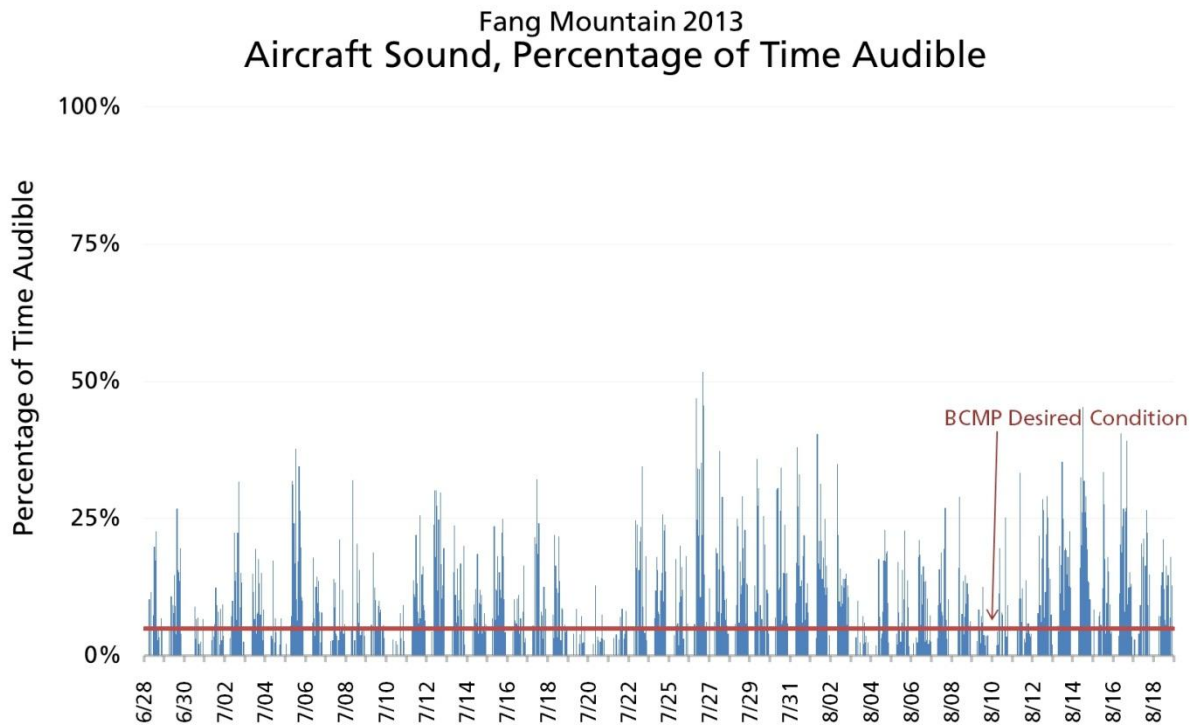


Figure 37. Audibility of aircraft noise at Fang Mountain.

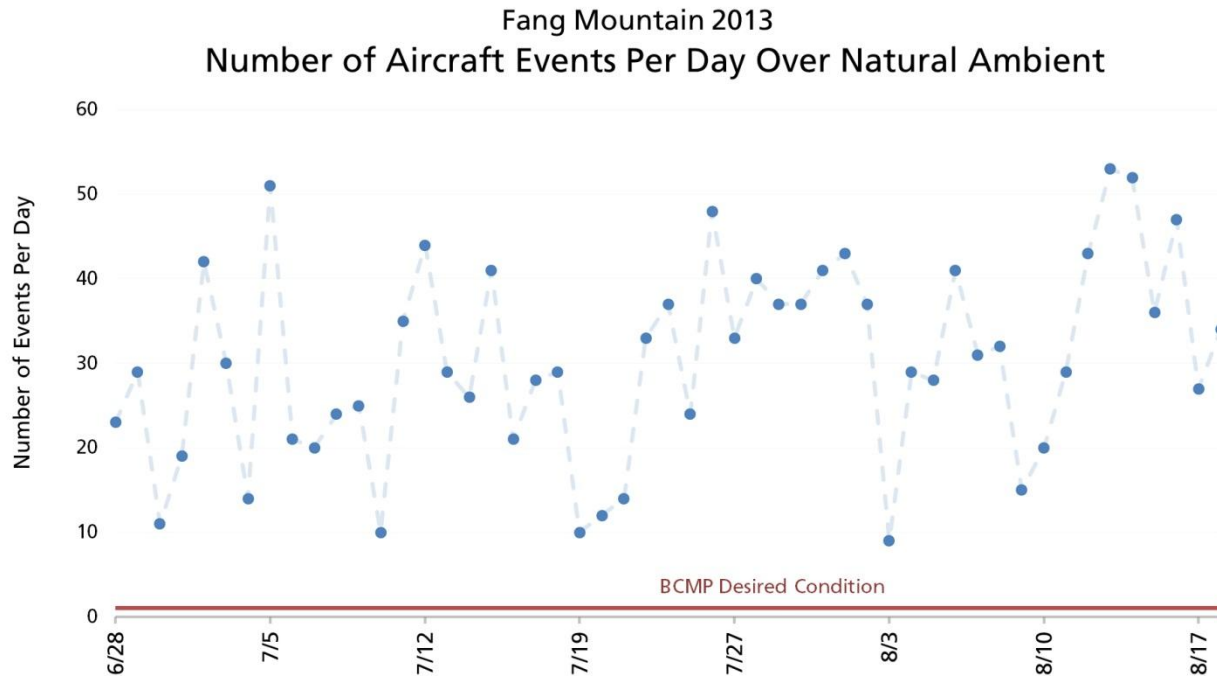


Figure 38. Number of aircraft noise events detected per day at Fang Mountain.

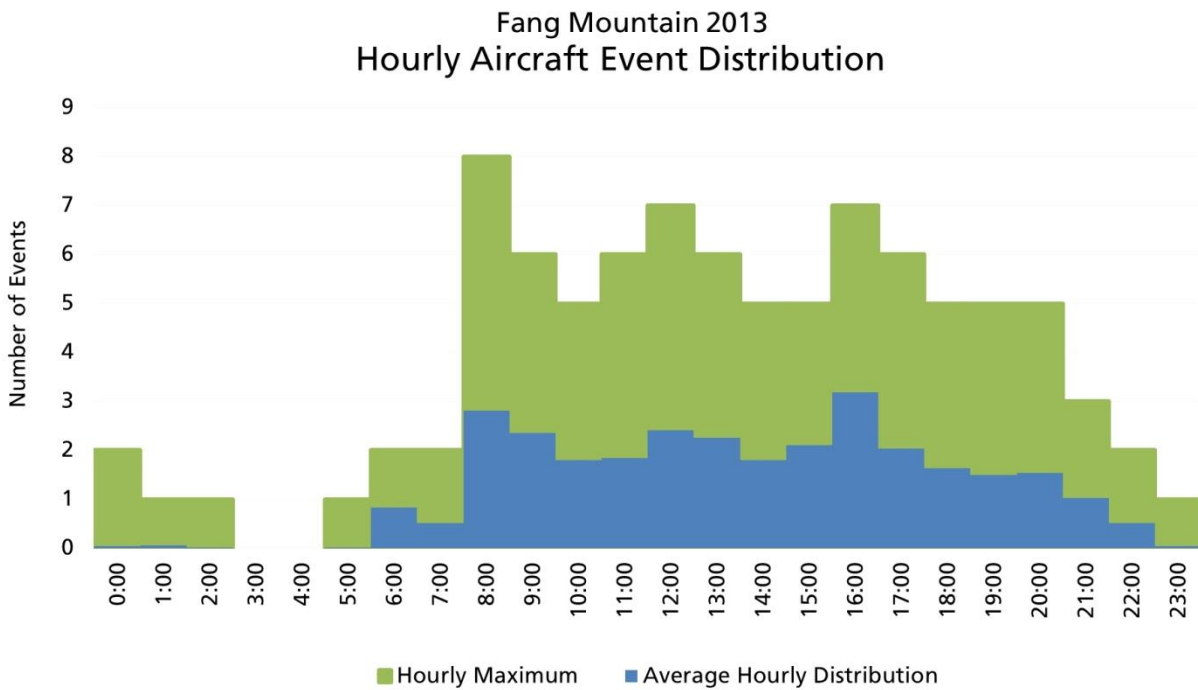


Figure 39. Hourly average and maximum rates of detection for aircraft noise events at Fang Mountain.

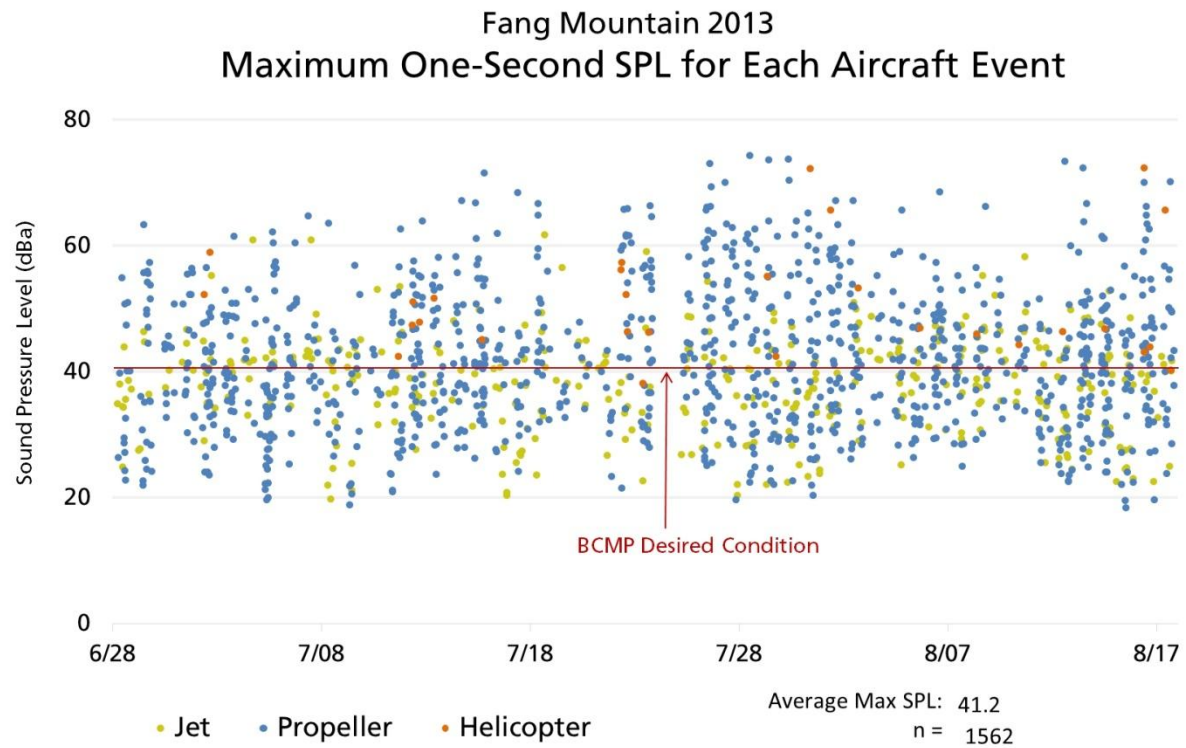


Figure 40. Maximum one-second sound pressure level for each aircraft event identified at Fang Mountain.

Flume Creek



Location Description: Located in open dwarf tree scrub (Viereck class II.A.2) bordered by a seasonal wetland ponds and closed mixed spruce/hardwood forest (Viereck class I.C.1). The lower Bearpaw River was almost visible from the station, about 125 meters distant. The photograph above faces roughly northwest.

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

Coordinates: 63.96474°, -150.81366° (WGS84)

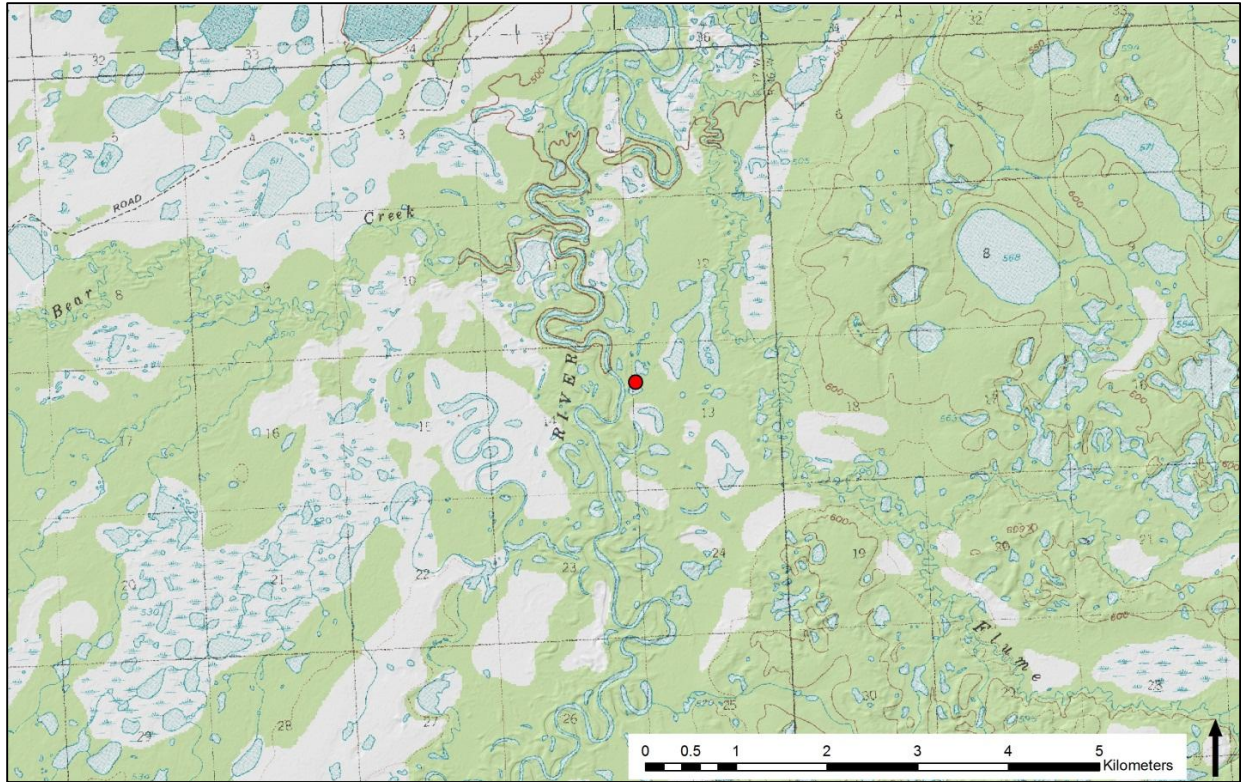
Elevation: 161 meters

BCMP Management Area: B (Medium Natural Sound Disturbance), the Bearpaw River forms the boundary with D (Low Natural Sound Disturbance)

Park Ecoregion: Kuskokwim Minchumina Basin

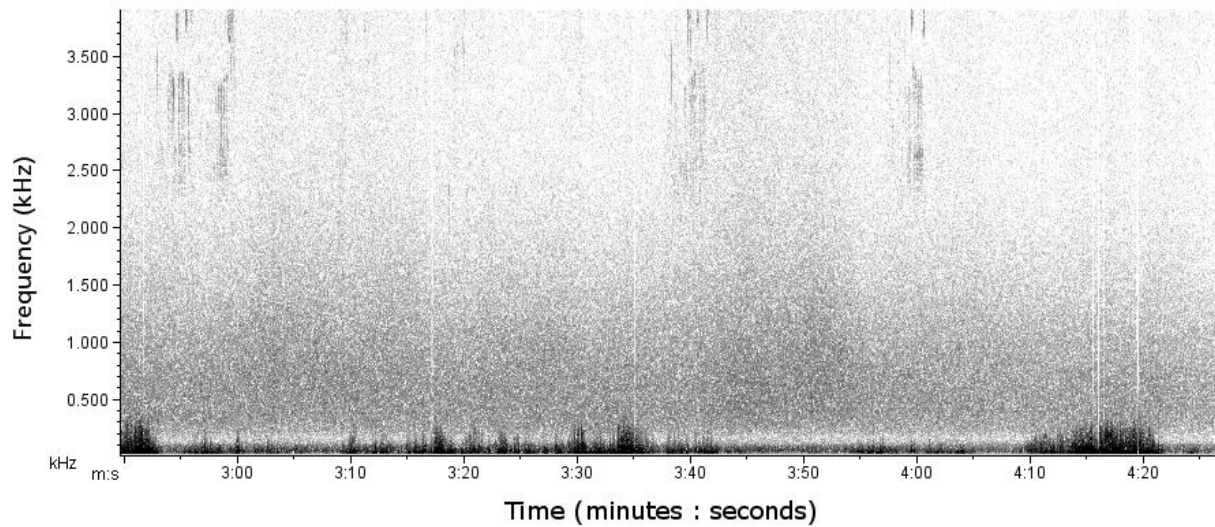
Sampling Period: 31-May-2013 to 03-July-2013

Access: Helicopter. Aerial photographs were taken for reference upon return.



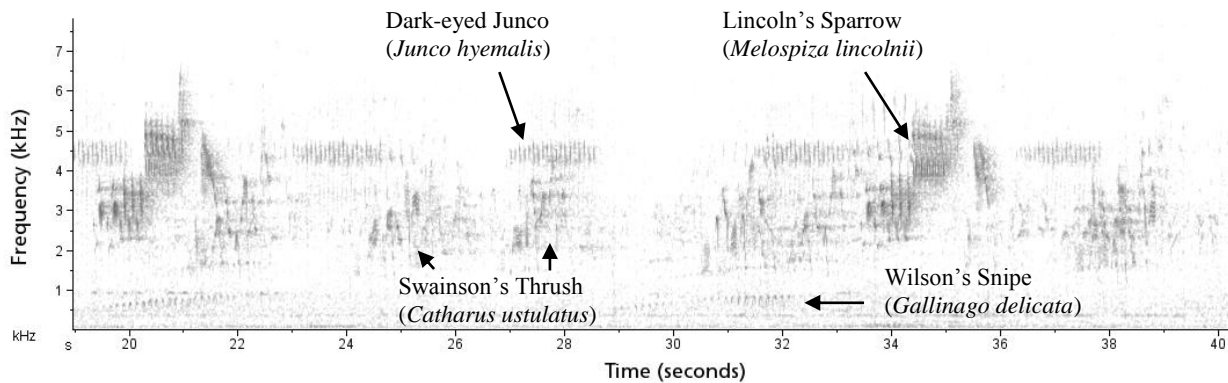
Summary/Notes: The purpose of the Flume Creek location was to collect data at one of the long-term ecological monitoring (LTEM) grid points, as outlined in the above sampling plan. LTEM grid point #247 was located in the New Park (ANILCA expansion).

With a time-averaged natural ambient level of 23.8 dBA, Flume Creek is in the 30th percentile of summer-season sites parkwide. The median hourly wind speed at the site was 0.2 m/s (0.4 mph) a relatively low value. The sampling location was in an open dwarf tree scrub wreathed by taller mixed spruce/birch forest to the south-east and west. Dissipation of wind energy by these relatively resistive forest patches may explain why natural ambient levels saw considerable afternoon increases (see Figure 41) despite relatively low wind speeds near the microphone. This hypothesis is further supported by evidence from the site's spectrograms. In NPS Sound Pressure Level Annotation Tool software (see [Appendix D](#)), in the unweighted mode, the direct interaction of wind energy with the microphone windscreen was visible as spiky, high-amplitude features with most energy occurring below the 315 Hz band. On the other hand, indirect wind was visible as a more diffuse broadband signal with energy spread out from the 160 to the 8000 Hz bands. This latter signal was often present even when direct interaction with the microphone was not.



Spectrogram 4. A spectrogram showing two types of wind sound at Flume Creek. The spectrogram begins at 14:04:44 on 06/02/2013. Wind energy interacting with the microphone screen is visible as dark patches below 0.3 kHz. Wind energy interacting with surrounding vegetation can be seen as a lighter gray broadband signal from 0.2 to 2.0 kHz. In SPLAT software in unweighted mode, energy from wind-vegetation interactions was clearly visible up to the 8000 Hz band.

Avian sound was the major natural component of the soundscape at Flume Creek. Swainson's Thrush (*Catharus ustulatus*), Wilson's Snipe, American Robin, Dark-eyed Junco, Ruby-crowned Kinglet (*Regulus calendula*), and Olive-sided Flycatcher (*Contopus cooperi*) were all commonly heard in the chorus, in descending order of vociferity.



Spectrogram 5. An example of dawn chorus in the vicinity of the Flume Creek sound station. The spectrogram begins at 03:23:51 on 06/01/2013. Songs of a Dark-eyed Junco (*Junco hyemalis*), a Lincoln's Sparrow (*Melospiza lincolnii*), and Swainson's Thrush (*Catharus ustulatus*) are apparent above 1.5 kHz. Winnowing sounds produced by the tail feathers of a male Wilson's Snipe (*Gallinago delicata*) are visible as a sequence of ascending tones below 2 kHz.

The most commonly heard sounds at this site were birds (audible 84.1%), wind (38.9%), rain (15.4%), and insects (3.7%). Note that despite the fact the Bearpaw River was only 125 meters distant, it was inaudible. The sinuous course of the river is indicative of a low slope and slow-moving water. (Knighton, 1998). Lighthill's equations on sound generated aerodynamically (Lighthill 1952) as well as Kolmogorov's energy microscale equations (Kolmogorov 1941) both suggest that slower moving fluids should radiate less acoustic energy. Therefore it is not surprising that Flume Creek (and other lowland sites) sometimes do not have audible flowing water despite close proximity.

Human made sound was audible 1.4% of the time on average; all of it was generated by aircraft. This is equivalent to 20.2 minutes each day, or approximately 6 overflights a day at this location. Conditions exceeded the BCMP percent audible standard 13% of the time, number of events per day 16% of the time, and maximum SPL 42% of the time.

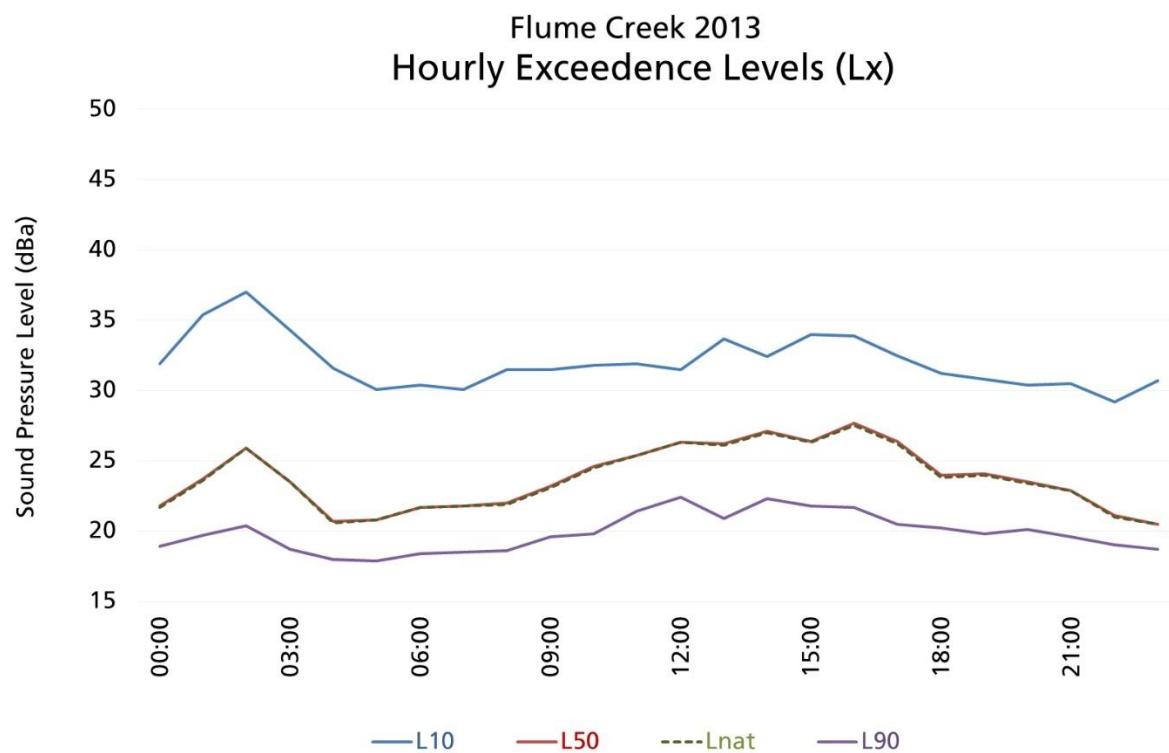


Figure 41. Exceedence levels for Flume Creek.

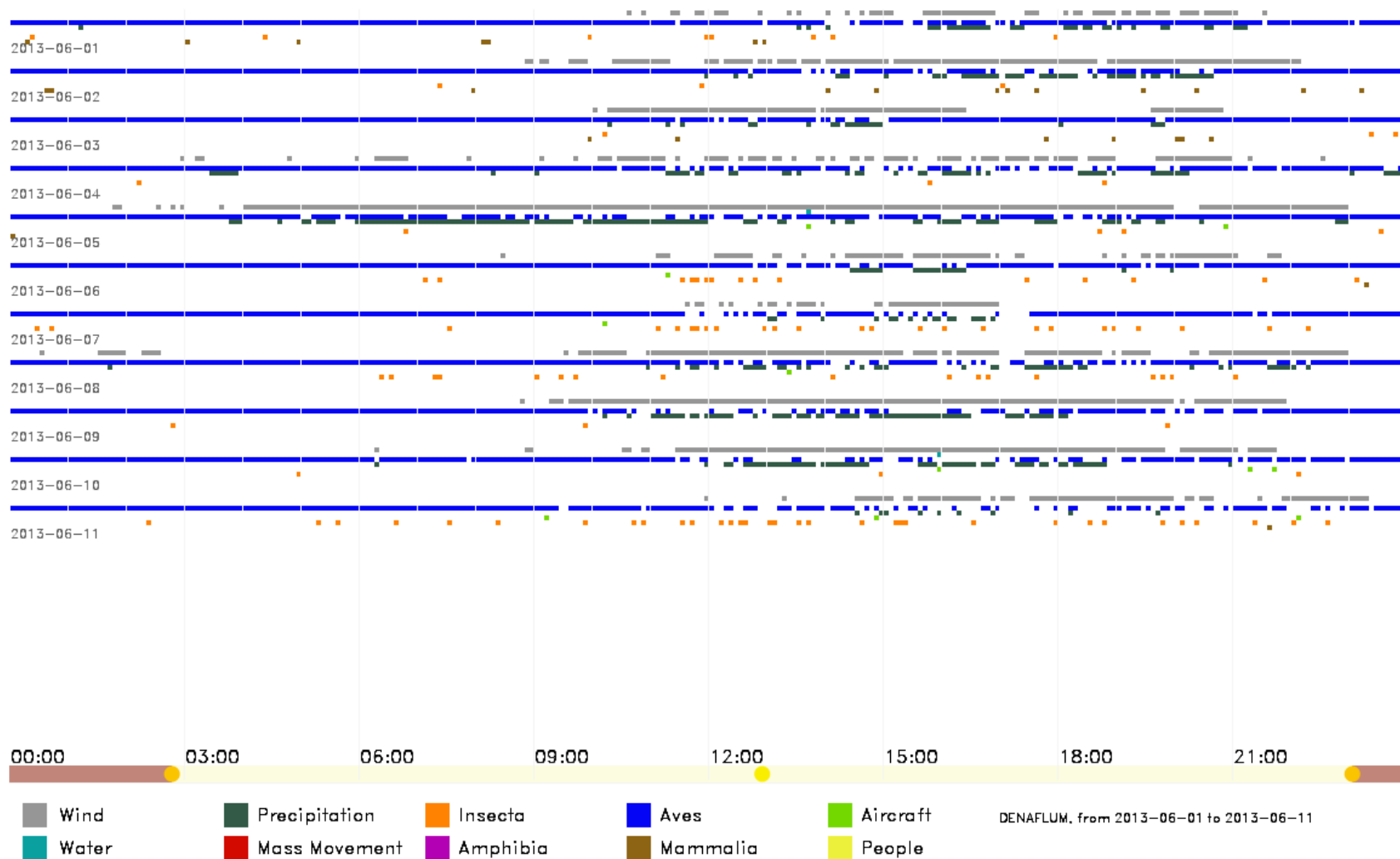


Figure 42. Temporal audibility of sound sources at Flume Creek, based on five seconds of audio every five minutes. The bar along the horizontal axis indicates the average light conditions during the sampling period. The orange circles are sunrise/sunset. This site did have civil twilight or night-time conditions during the sampling period.

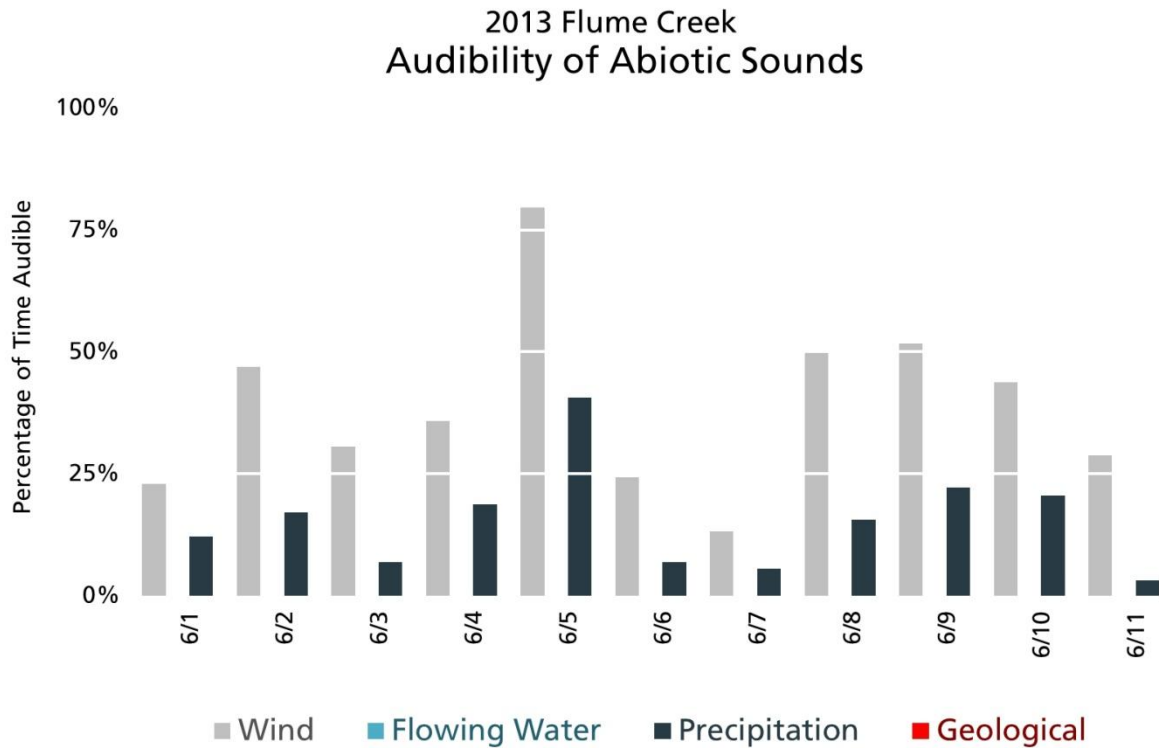


Figure 43. Audibility of abiotic sounds at Flume Creek.

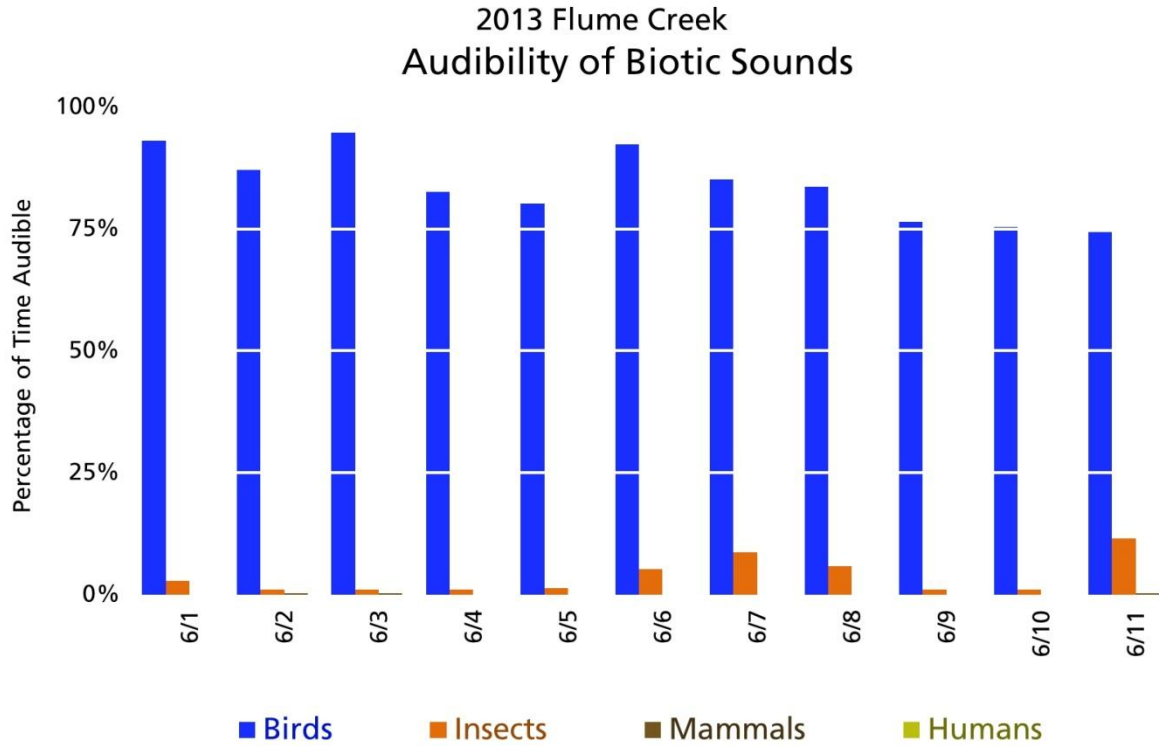


Figure 44. Audibility of biotic sounds at Flume Creek.

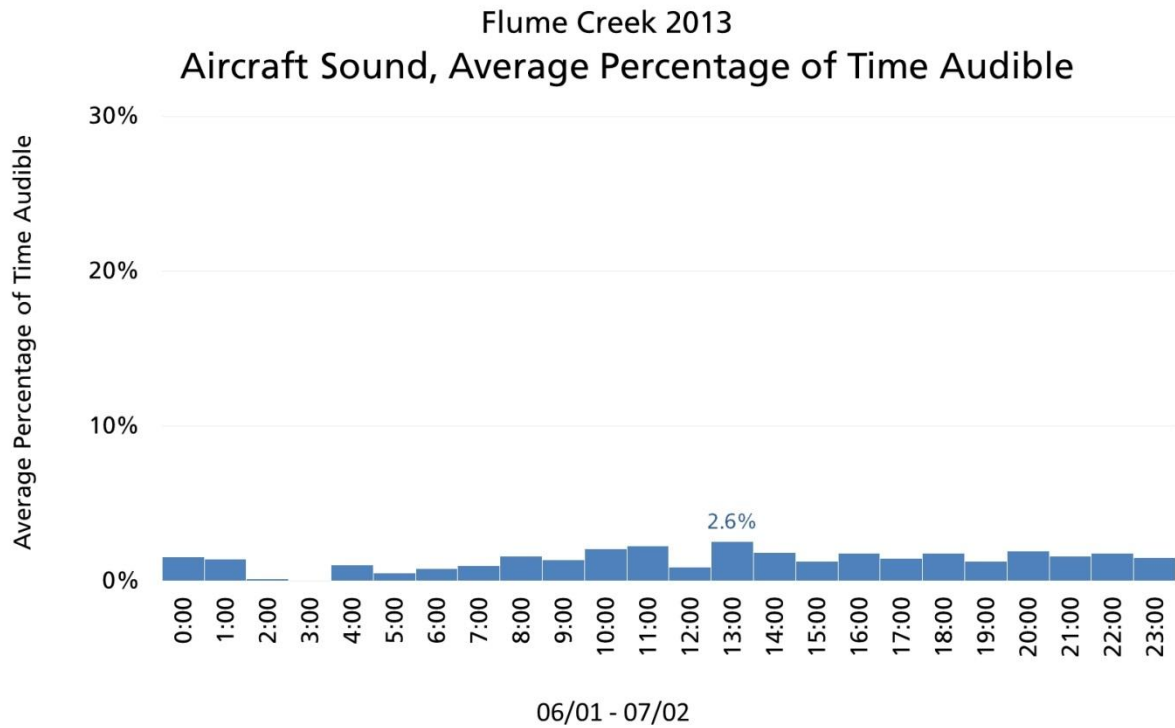


Figure 45. Audibility of aircraft noise for an average day, by hour, at Flume Creek.

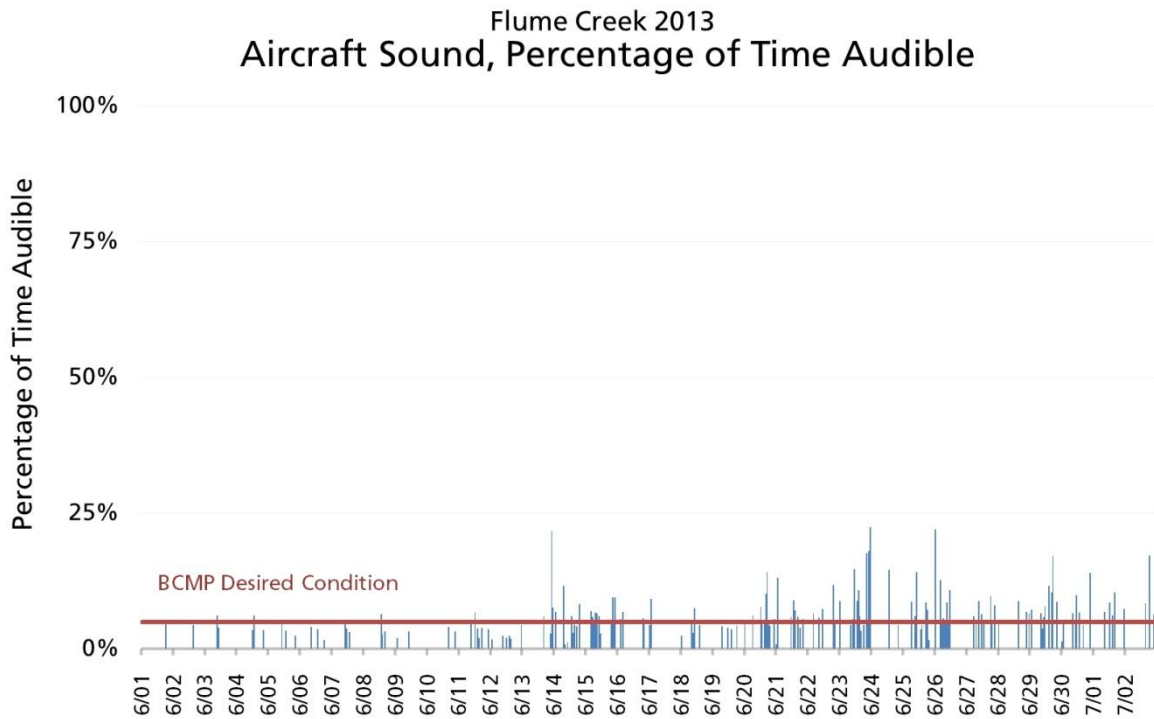


Figure 46. Audibility of aircraft noise at Flume Creek.

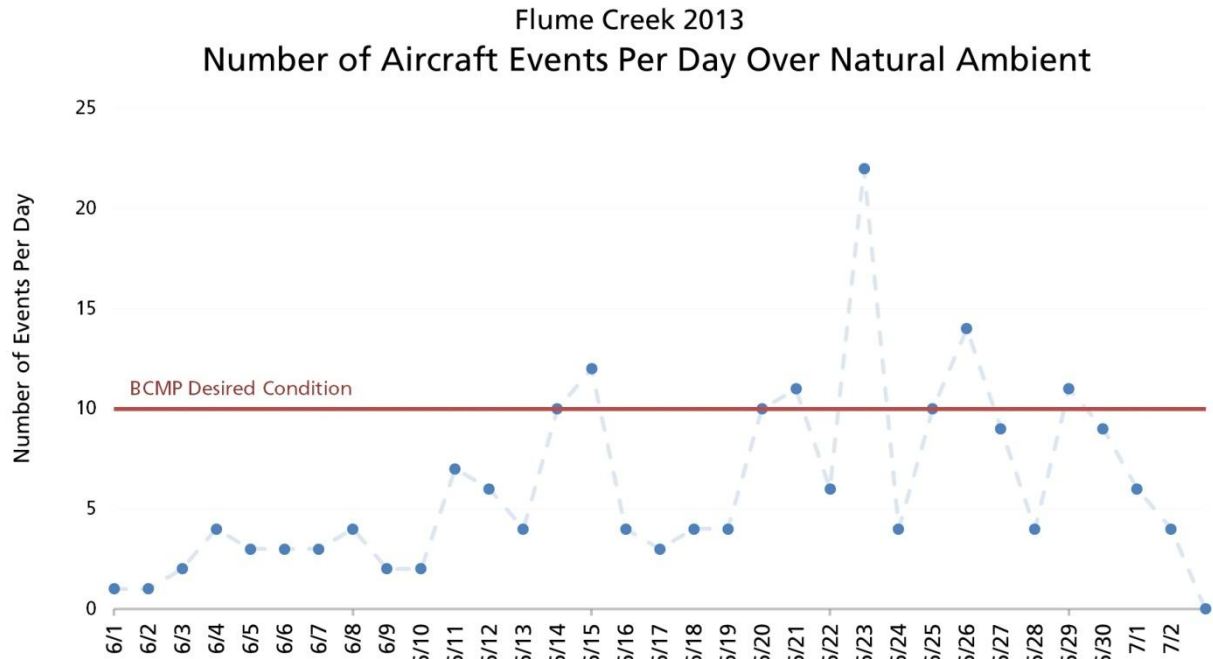


Figure 47. Number of aircraft noise events detected per day at Flume Creek.

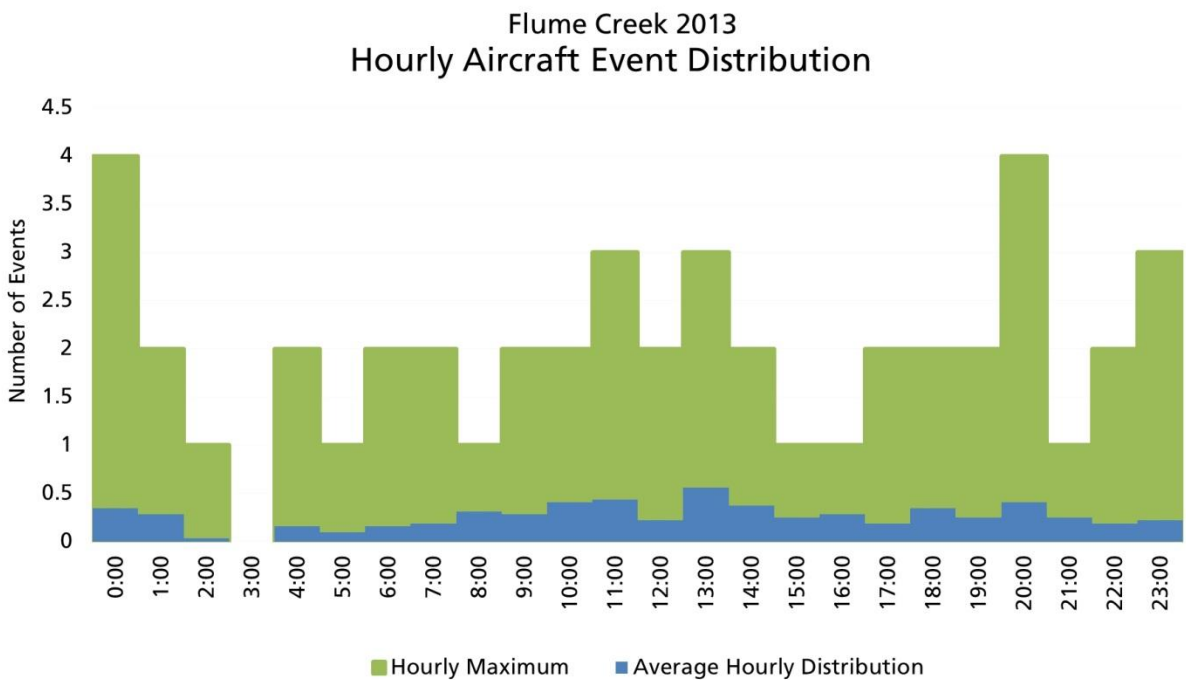


Figure 48. Hourly average and maximum rates of detection for aircraft noise events at Flume Creek.

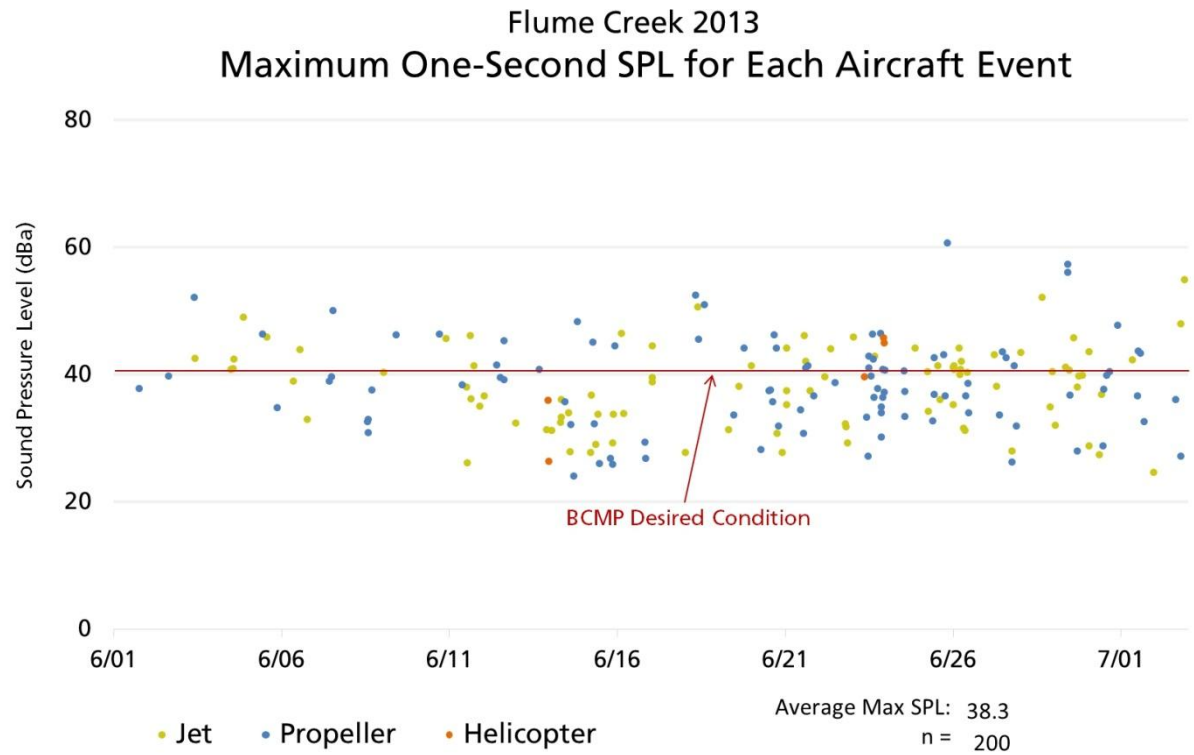


Figure 49. Maximum one-second sound pressure level for each aircraft event detected at Flume Creek.

Igloo Canyon



Location Description: This site was located 47 meters from the centerline of the Denali Park Road. Opposite the road from the station (but not completely visible in this west-facing photograph) flows Igloo Creek, which was approximately 195 meters from the microphone. The site itself was placed on the base of Cathedral Mountain in open low scrub (Vioreck class II.C.2).

Purpose/Project: To document baseline levels of noise impact due to road traffic, and to quantify the potential effects of hybrid technology on soundscapes of the Denali Park Road corridor.

Coordinates: 63.59588°, -149.60712° (WGS84)

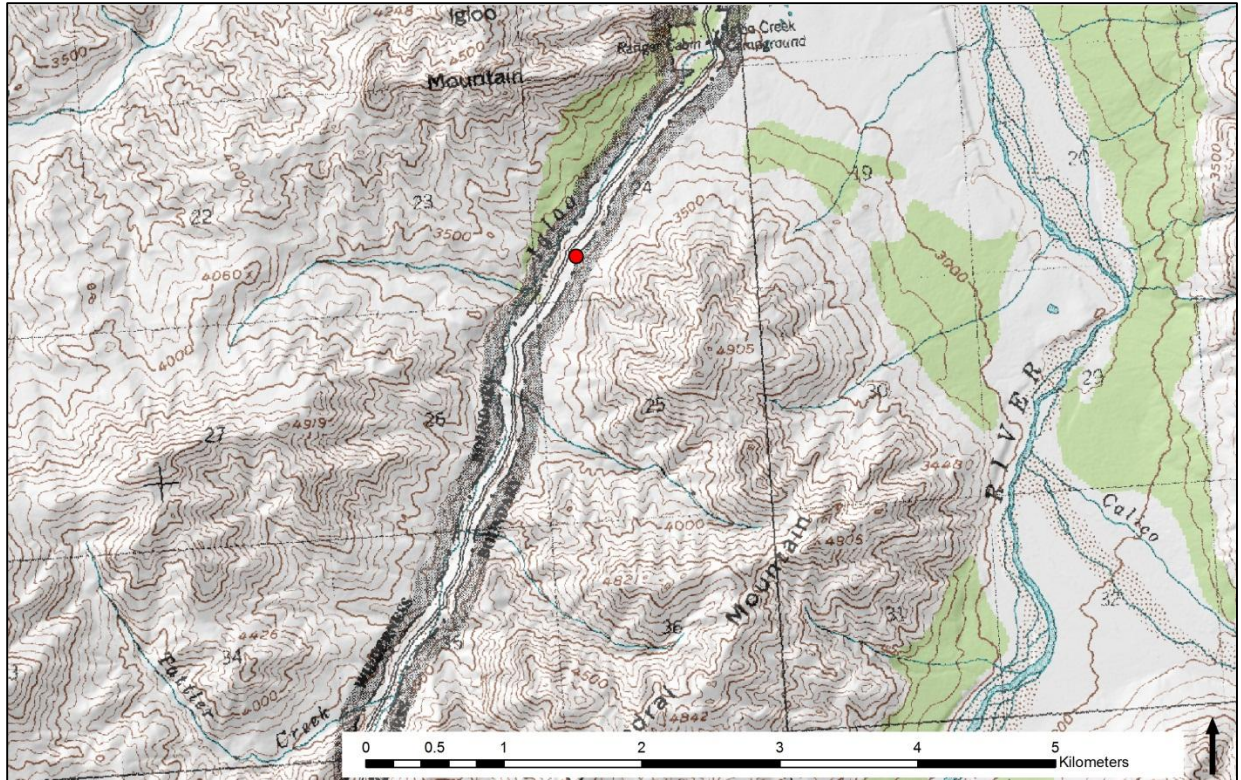
Elevation: 963 meters

BCMP Management Area: Non-backcountry adjacent to OP1 (Low Natural Sound Disturbance)

Park Ecoregion: Alaska Range Interior Mountains and Valleys

Sampling Period: 04-June-2013 to 18-September-2013

Access: via the Denali Park Road



Summary/Notes: Over the course of two operating seasons, 2012 and 2013, roadside sound monitoring stations were deployed to document sound pressure levels of the bus fleet along the Denali Park Road. These tests sought to document a baseline of the conventional fleet and then compare hybrid models. Near the wilderness boundary at Igloo Creek (150 feet from the road's center line), hybrids were found to have a median sound pressure level peak of 57.9 ± 1.9 dBA as they passed. This level was consistent between individual hybrid buses, and did not vary significantly across the season. When compared to the conventional fleet, hybrids were in the 60th percentile of passbys - in other words, they were louder than 60% of the conventional fleet.

In addition to this finding, the study also found clear evidence in support of the physical theory that buses with larger engine volume are quieter than buses with smaller engines on the same road grade (Priede 1971). Despite this, hybrids were observed to be much louder than predicted for diesel models with the same engine size, on the order of about 2-3 dBA; a difference clearly noticeable to the human ear (see Figure 50). This means that the hybrid technology tested was louder than conventional technology for the same losses in fuel efficiency that accompany a larger engine.

Igloo Canyon 2012 - 2013

Engine Volume vs. Average Sound Pressure Level at Maximum

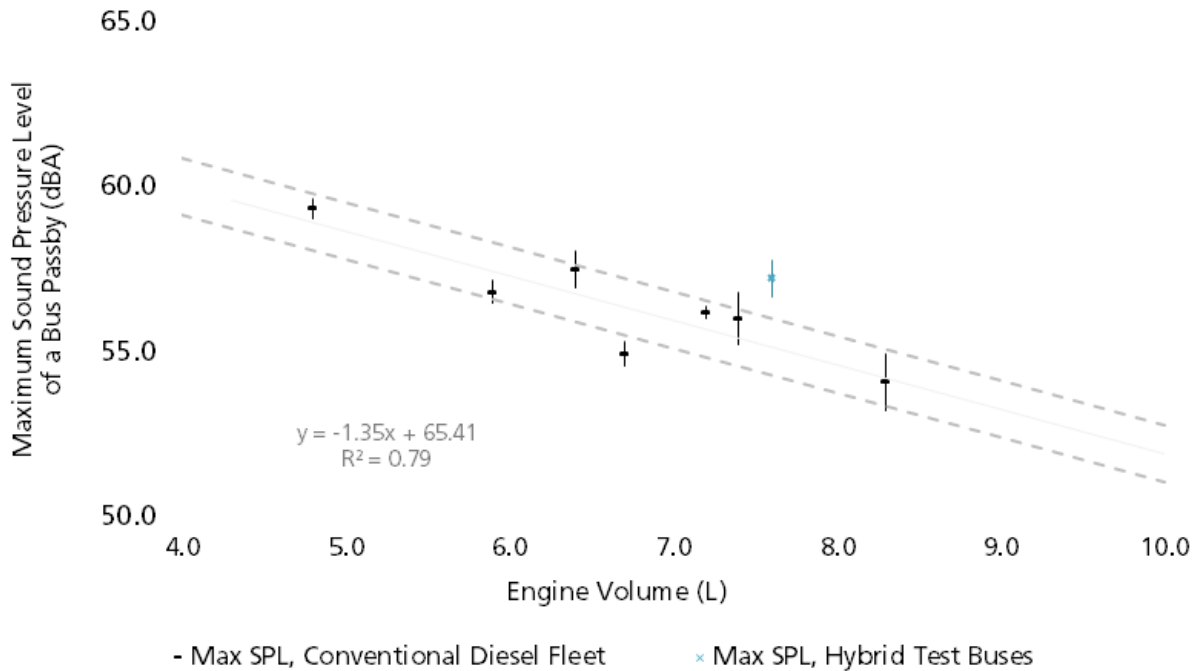
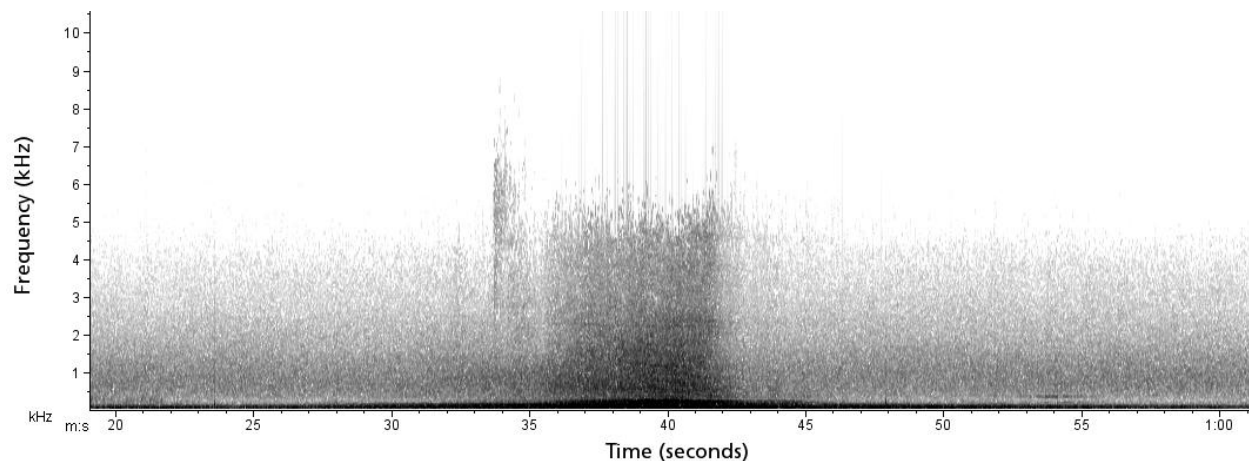


Figure 50. A relation showing the effect of bus engine size on observed maximum sound pressure levels at Igloo Canyon 2012 and 2013. Levels of the conventional diesel fleet (shown in black) were documented in 2012, and levels of two hybrid test buses (shown in blue) were documented in 2013. Because the measured noise levels were considerably higher than natural levels (>10 dBA) there should be no issue in comparison across years. The thin grey line indicates the linear regression of the diesel fleet; thicker barred lines indicate the 99% confidence interval. (In other words, the range expected to contain the mean response.) It should be apparent that the hybrid tests did not fall within the expected mean response range for a diesel engine of the same size, but were instead observed to be louder than the conventional technology, even when variation across passbys is accounted for.

A third component of the study compared bus noise during idling. These tests sought to simulate the soundscape of a wildlife stop along the road corridor. (Further detail on these wildlife stop simulations can be found in [Appendix G](#)). Ideally, quieter conditions would improve experiences for wildlife and visitor alike - by providing a reprieve for the first and a more intimate sensory experience for the latter. However, tests indicated that hybrids took about 5 minutes to switch off their diesel engine - about the same duration as a typical wildlife stop (H. Mc Kenny and W. Clark, personal communication). Idling levels varied greatly between the two individual hybrids, with 10-minute averages of 49.9 and 53.3 dBA Leq, respectively. (This 3 decibel range made them the third and eighth loudest buses of the eight tested.) Though these idle levels are a substantial 6 dBA lower than levels in transit, it is clear to see that continuing to target driver behavior in turning off the bus engine (i.e., not contributing any noise at all) would have a far greater quieting effect than any engine technology currently available.



Spectrogram 6. A spectrogram of a typical bus passby at Igloo Canyon. Note considerable energy at low-frequencies. (Darker shading on the spectrogram indicates greater energy carried by the wave at that frequency.) Prominent tones of this passby were 22, 46, 94, and 198 Hz - tones contributed by the mechanics of the engine. From 33.5 to 41.5 seconds, broadband energy is contributed by a variety of sources, including mechanical noise, exhaust noise, tire noise, and aerodynamic noise. At about 33.6 seconds the pneumatic air brakes on the bus release pressure, with most of the energy audible between 2.5 and 8 kHz. Spectrogram begins at 21:14:02 on 06/09/2013.

Because of the site's close proximity to the road, human activity was audible 15.4% of the time on average. Buses and other road vehicles were audible 12.4% of the time on average. This is a considerable amount of time – equivalent to about 178.6 minutes (2.98 hours) of the day. Aircraft were audible about 3.9% of the time on average. This percentage is equivalent to 56.2 minutes of the day, or about 16 events per day at this location. (Note that because sounds can overlap each other, 12.4% time road vehicles + 3.9% time aircraft \neq 15.4%, the total time motorized sound was audible.)

An interesting fact to consider is that in Igloo Canyon the duration of a typical vehicle noise event is much shorter (1.1 minutes) than an aircraft noise event (3.3 minutes). This discrepancy in durations is likely the case for many locations along the park road corridor. The importance of this fact becomes especially clear when the traffic rates for each source are compared: 114.3 vehicle noise events per day were detected on average and 15.9 aircraft noise events per day. So, although there are almost seven times as many buses as there are aircraft travelling through the area, they amount to only about 3 times ($= 178.6/56.2$ minutes per day) the amount of *temporal* impact to the soundscape. This is a salient fact when focusing the efforts of management action.

Another interesting comparison is to consider the similarities and differences of the Igloo Canyon site and another sound station that was located on the western slopes of Cathedral Mountain. (This site was previously sampled in 2007 and 2012.) While the two locations were about 2 – 2.5 km apart in three-dimensional space, Cathedral Mountain was about 1 km from the park road, while Igloo Canyon was five times closer, only 0.2 km away. It is not surprising, then, that the number of vehicles detected at the closer station was somewhere between 3.5 to 11 greater than at the distant station. (Construction traffic and changes in natural ambient level between sampling periods account for this large range.)

Table 5. Comparison of noise event rates at sites within the vicinity of Igloo Canyon.

Site	Year	% Time Road Vehicles	Avg. Vehicle Noise Events Per Day	% Time Aircraft	Avg. Air Noise Events Per Day
Igloo Canyon	2013	12.4% of record	114.3	3.9% of record	15.9
Cathedral Mountain	2012	3.7%	10.5	3.6%	22.5
Cathedral Mountain	2007	15.4% (construction)	32.4	5.2%	13.3

With a time-averaged natural ambient level measured to be 36.92 dBA, Igloo Canyon was in the 77th percentile of summer-season sites parkwide. This relatively loud natural level was underlain by Igloo Creek, the water source that flows through the canyon. At only 195 meters distance, it was a prominent source of acoustic energy between 50 and 2,700 Hz. The typical daily pattern of natural ambient level is strikingly similar to Carlson Creek (see [Carlson Creek](#) section for a written description, and compare Figure 23 to Figure 51), in that the proximity to energetic water makes the ambience relatively constant, yet the quietest time of day also tends to be the coolest time of day. For example, 06:00 was typically the coolest hour, with an average temperature of 8.5°C (47.4°F). Contrast this with 17:00, the warmest hour on average, at 16.3°C (61.3°F).

One other interesting note is that due to the occurrence of loud, short-duration sounds at the site - mainly road traffic and gusty winds - the difference between L10 and L90 is relatively large during the diurnal hours.

The most common avian species detected at the site, in descending order of vociferity, were White-crowned Sparrow, Orange-crowned Warbler, Hermit Thrush, and Arctic Warbler (*Phylloscopus borealis*). Compare this list to the similar species observed at [Cabin Peak](#) in 2013.

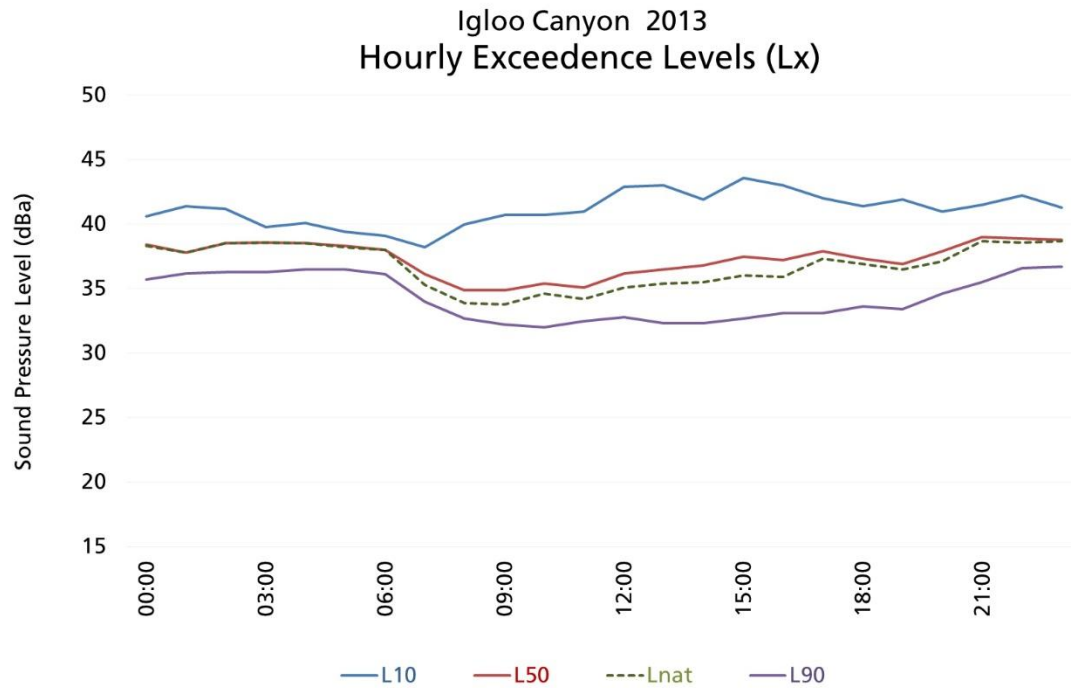


Figure 51. Exceedence levels for Igloo Canyon.

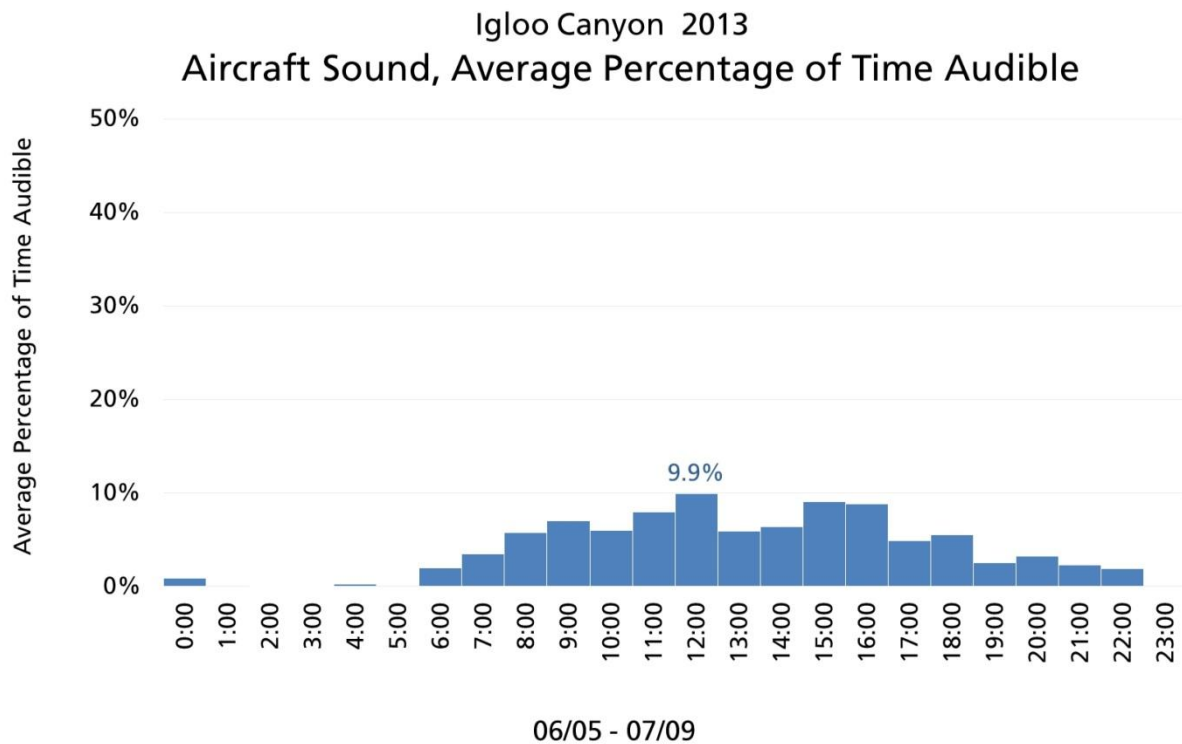


Figure 52. Audibility of aircraft noise for an average day, by hour, at Igloo Canyon.

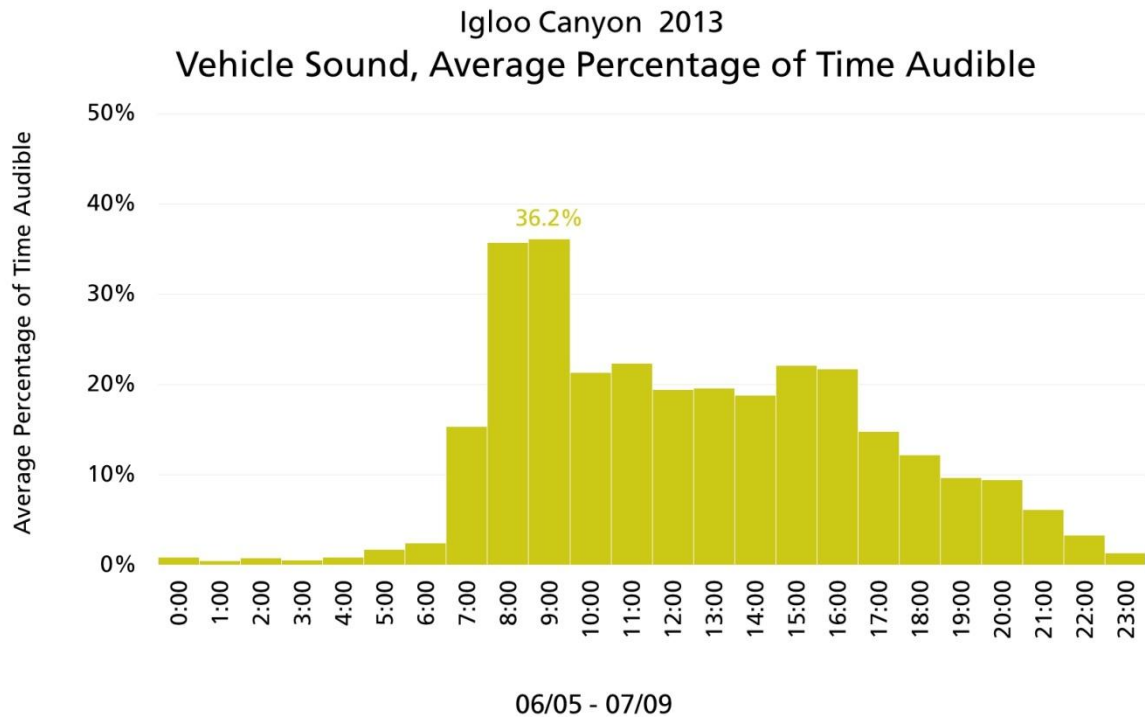


Figure 53. Audibility of road vehicle noise for an average day, by hour, at Igloo Canyon.

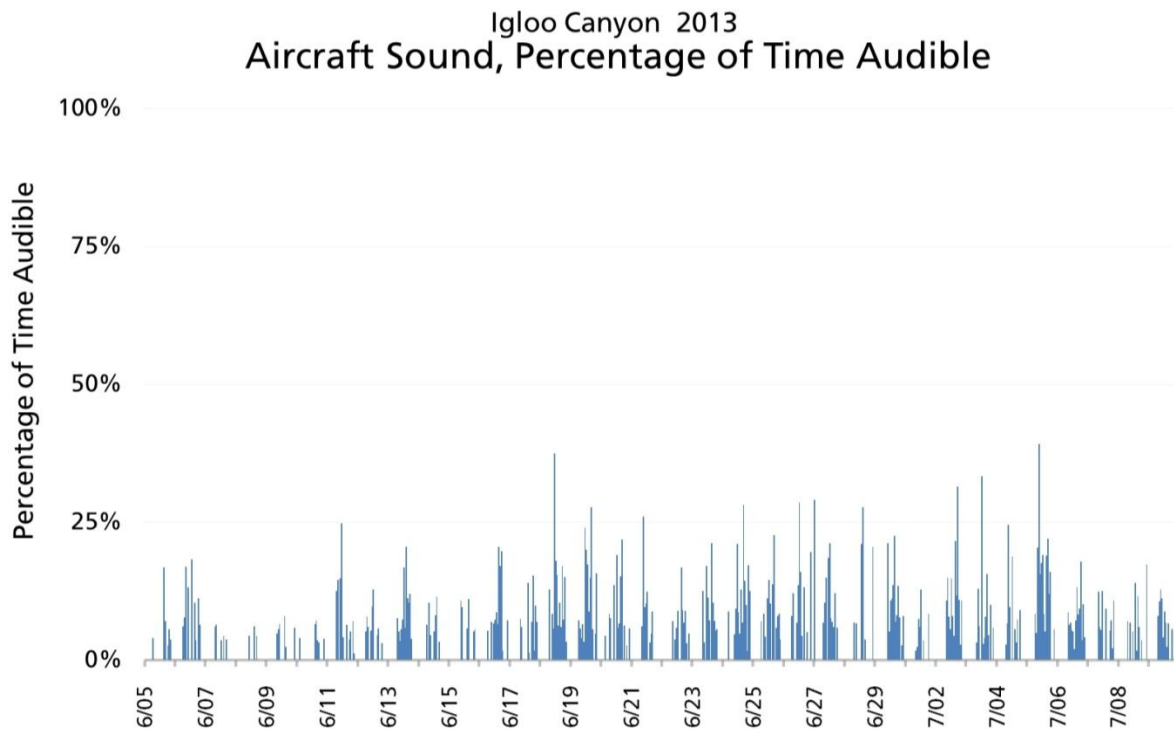


Figure 54. Audibility of aircraft noise at Igloo Canyon.

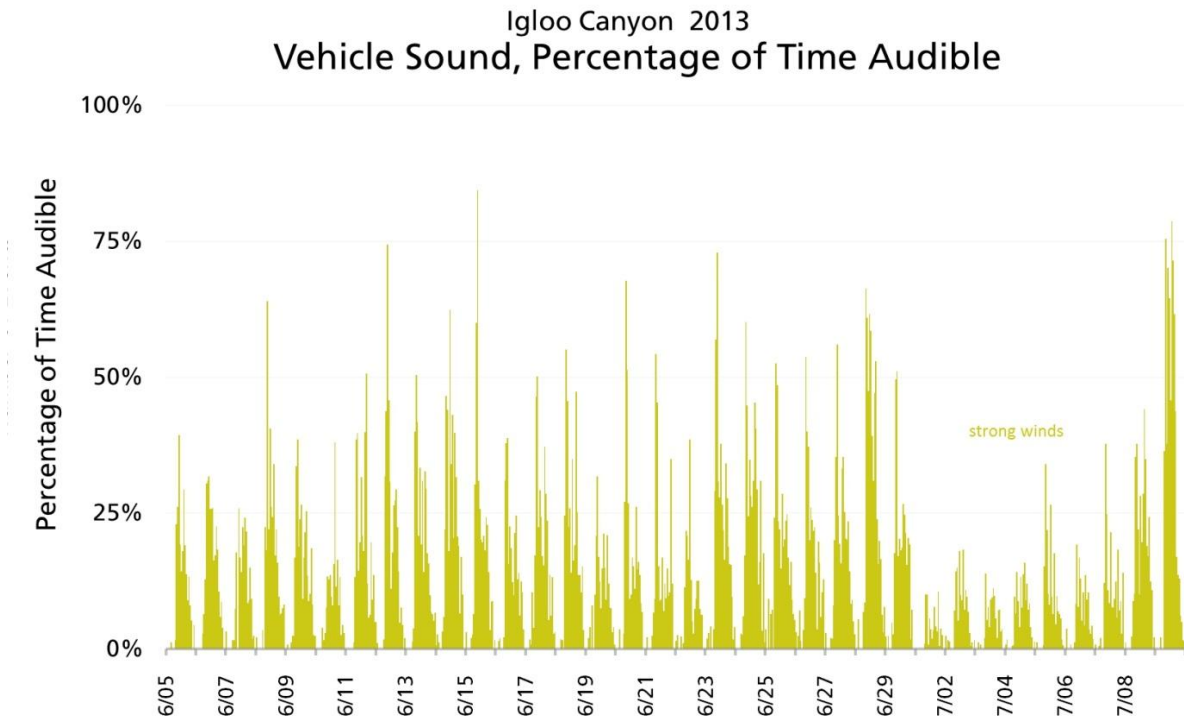


Figure 55. Audibility of road vehicle noise at Igloo Canyon.

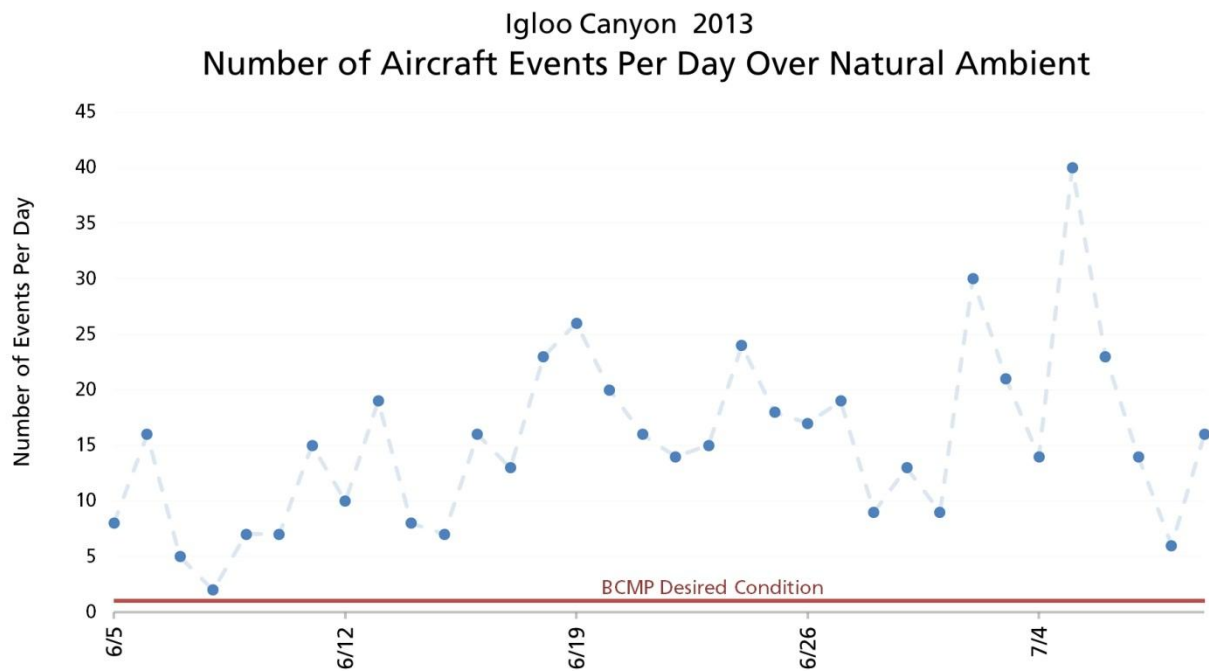


Figure 56. Number of aircraft noise events detected per day at Igloo Canyon.

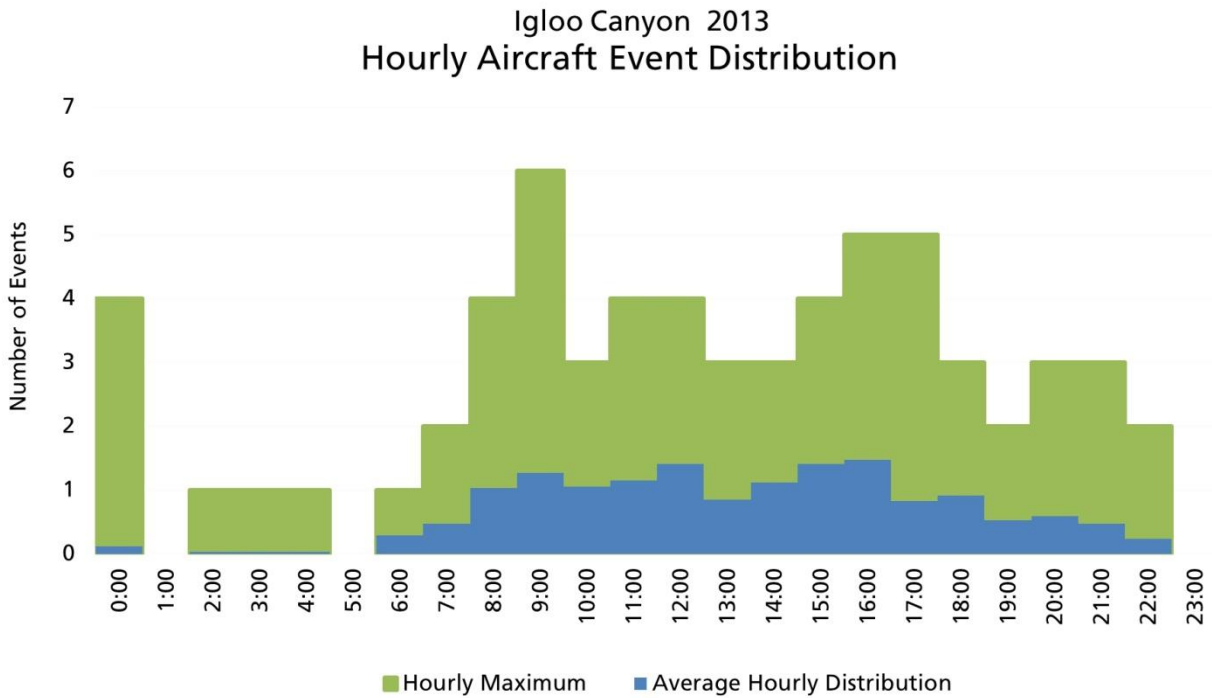


Figure 57. Hourly average and maximum rates of detection for aircraft noise events at Igloo Canyon.

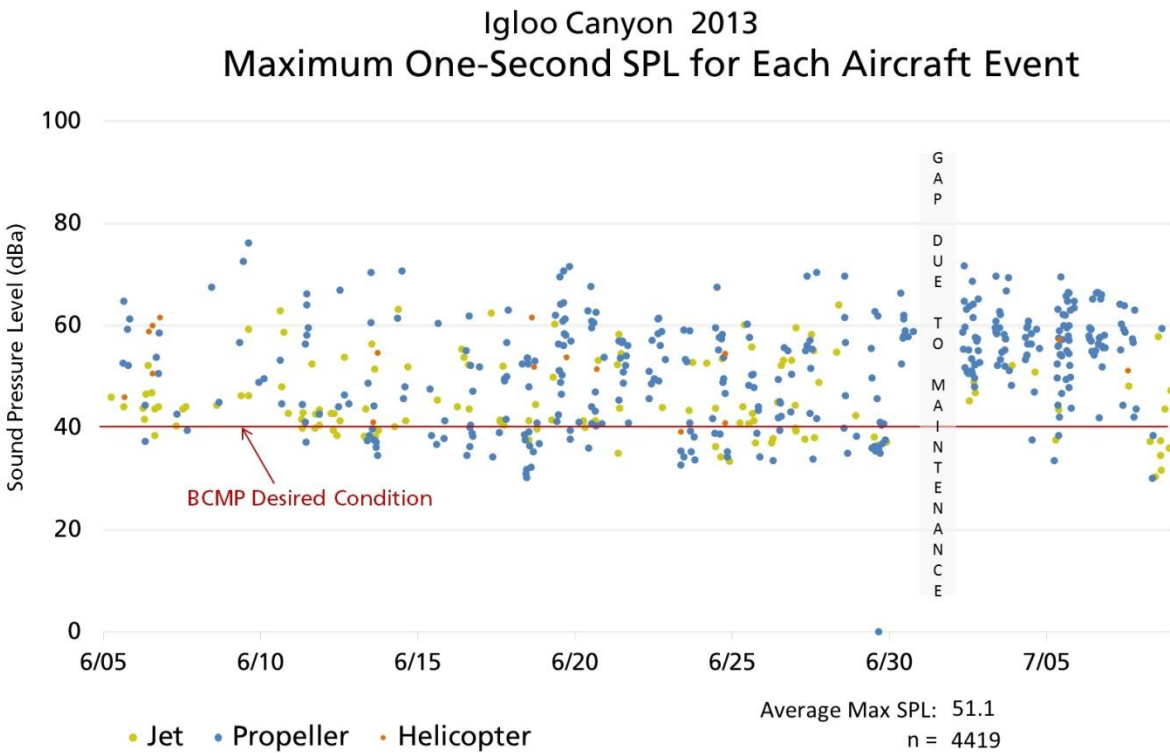


Figure 58. Maximum one-second sound pressure level for each aircraft event detected at Igloo Canyon.

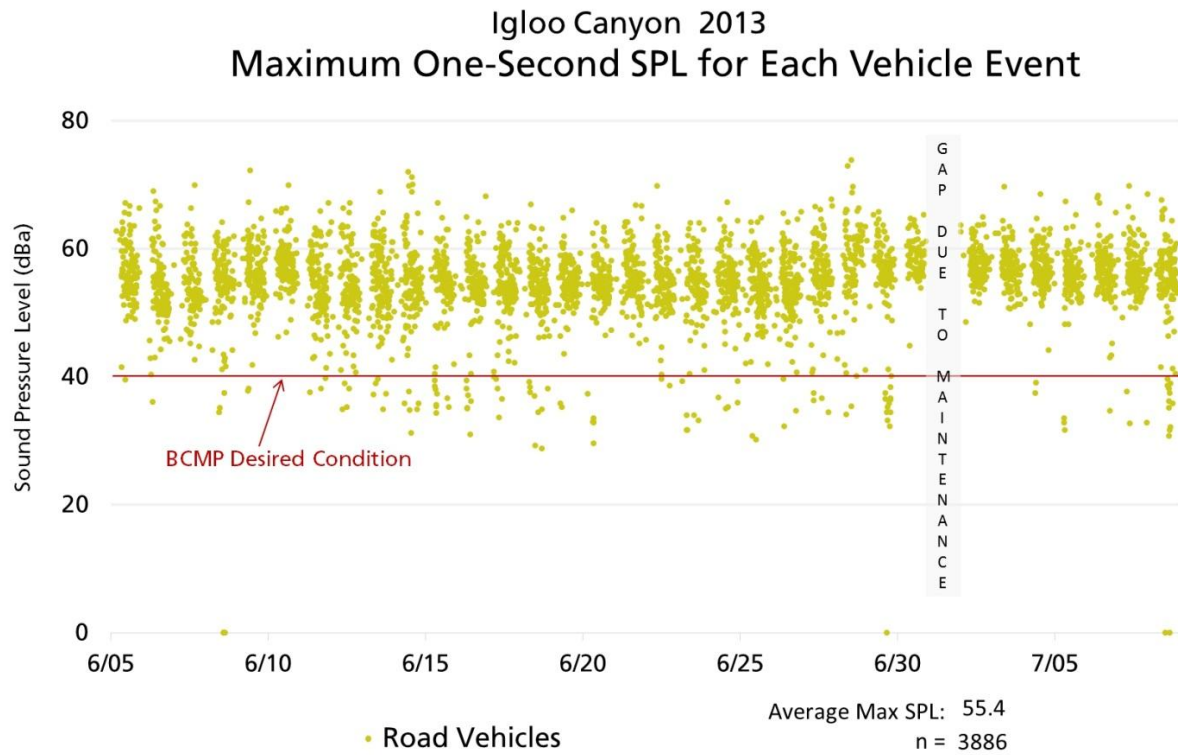


Figure 59. Maximum one-second sound pressure level for each vehicle event detected at Igloo Canyon.

Lower McKinley River



Location Description: Open needleleaf forest (Vioreck class I.A.2) of black spruce and tamarack. The site was located within a network of small tributaries that feed the McKinley River. The shortest distance to the river from the site was approximately 1.5 km west. The photo above faces roughly north.

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

Coordinates: 63.78482°, -151.61665° (WGS84)

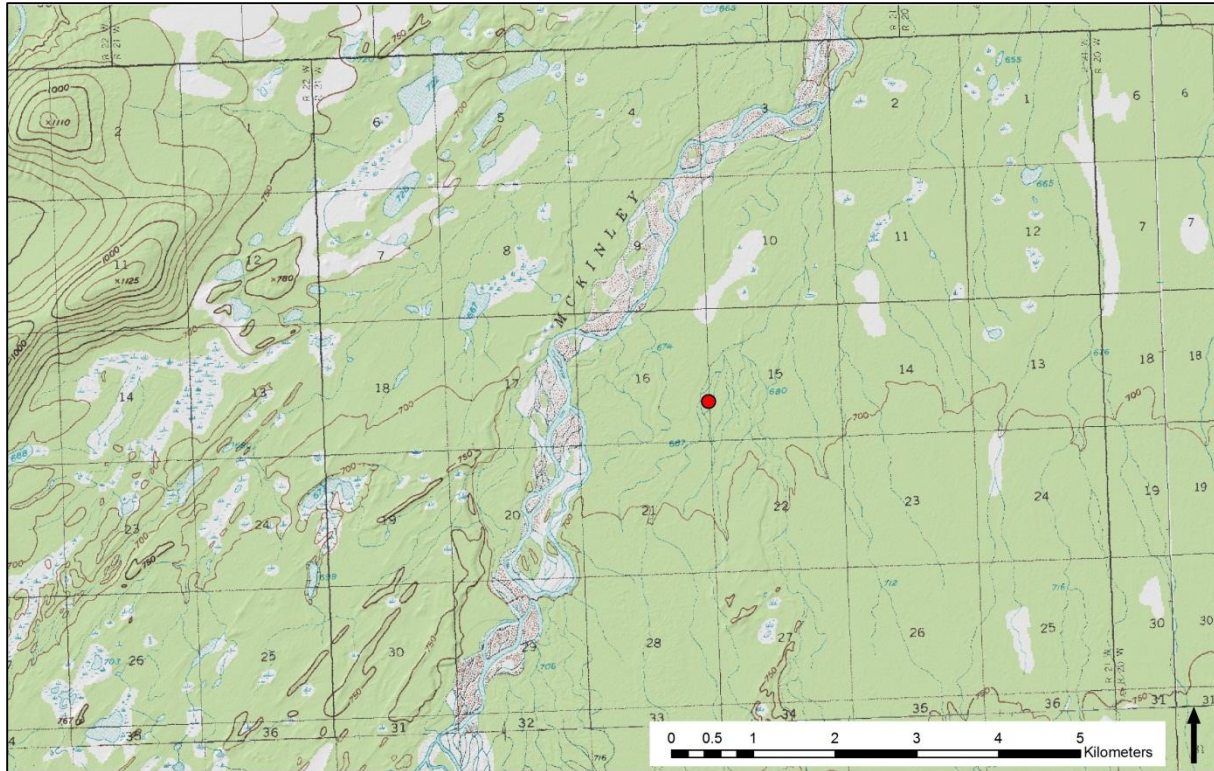
Elevation: 223 meters

BCMP Management Area: D (Low Natural Sound Disturbance)

Park Ecoregion: Kuskokwim Alluvial Fans and Floodplains

Sampling Period: 31-May-2013 to 03-July-2013

Access: Helicopter. Aerial photographs were taken for reference upon return.

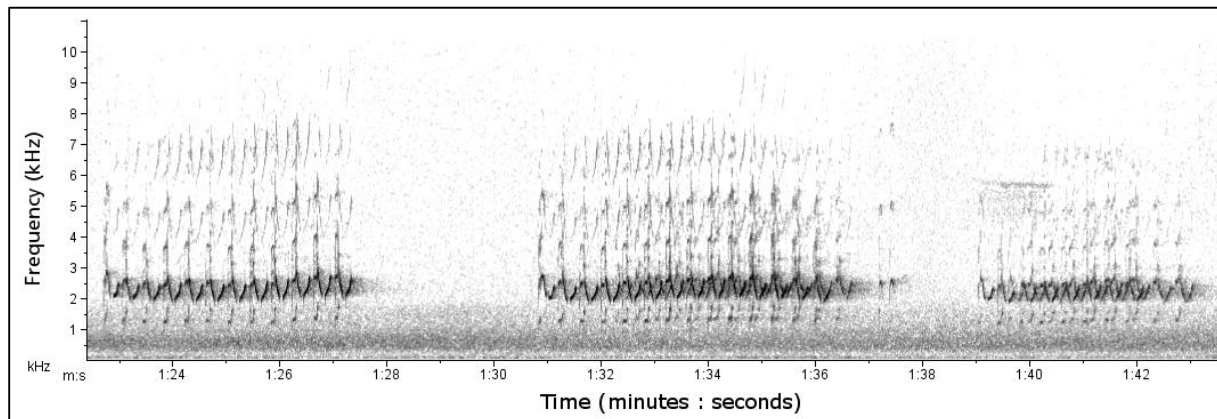


Summary/Notes: The purpose of the Lower McKinley River location was to collect data at one of the long-term ecological monitoring (LTEM) grid points, as outlined in the above sampling plan. LTEM grid point #225 was located in Denali National Preserve (ANILCA expansion).

With a time-averaged natural ambient level measured to be 22.5 dBA, Lower McKinley River was in the 23rd percentile of summer-season sites parkwide. The continuous broadband energy of the McKinley River was the keynote of the soundscape, and was not observed to be affected by atmospheric refraction. This is dissimilar to several other sites sampled along the McKinley (McKinley Bar Trail 2011 and McKinley River 2012), which showed strong refractive effects that caused the river to become inaudible during the daytime (Betchkal 2013b, pg. 60). Further understanding of the atmospheric boundary layer across the park is necessary to predict when and where such refractive media may form and how they may affect the propagation of anthropogenic noise.

Many avian species were detected in this area of open forest habitat bounded by wetlands. Lincoln's Sparrow, White-crowned Sparrow, Wilson's Snipe, and Greater Yellowlegs (*Tringa melanoleuca*) were the most vociferous species heard. Greater Yellowlegs were not only observed throughout the acoustic record (Spectrogram 7), but also during site installation on 05/31/2014. This is in keeping with a previous phenological record of the species, which was documented in migration by the Upper Yentna Glacier sound station on 05/27/2012 (Betchkal 2013b). Other commonly heard species included Grey Jay, Lesser Yellowlegs (*Tringa flavipes*), American Robin, Canada Goose (*Branta canadensis*), and Sandhill Crane (*Grus canadensis*). New records of Sandhill Cranes add to a series of observations of the species on the north side of the Alaska Range, including McKinley River 2012

(the next site to the south of Lower McKinley River), Myrtle Creek 2010, West Kantishna Hills 2011, and Estok 2011.



Spectrogram 7. Greater Yellowlegs (*Tringa melanoleuca*) makes oscillating calls near the Lower McKinley River sound station. The spectrogram begins at 04:42:50 on 06/10/2013. This species was also observed in the field during deployment of the sound equipment.

Also notable biologically was the amount of insect activity at the site. Lower McKinley River had the third highest number of samples with insects thus far in the inventory, with 26.2% of audio clips containing some insect sound. Compare this with McKinley River 2012 (the next grid point south, 48.9%), Lower Kantishna River (the grid point to the north-east, 29.2%) and Highpower Creek (21.4%). Acoustic detections of insects are generally due to the sound of wings in flight (and occasionally stridulation in Orthoptera, see [earlier description](#)). Because of this, possible groups detected by soundscape methods could include Diptera (flies), Hymenoptera (bees and wasps), Odonata (dragonflies and their kin), and Lepidoptera (butterflies and their kin). Coleoptera (beetles) might also be detected when in flight. At Lower McKinley River most detections were flies, likely mosquitos.

The most commonly heard sounds at this site were water (audible 100% of the time), birds (54.5%), insects (26.2%), and wind (20.0%). Human made sound was audible 1.9% of the time on average; all of it was produced by aircraft. This is equivalent to 27.4 minutes each day, or approximately 7 overflights a day at this location. Conditions exceeded the BCMP percent audible standard 19% of the time, number of events per day 96% of the time, and maximum SPL 36% of the time.

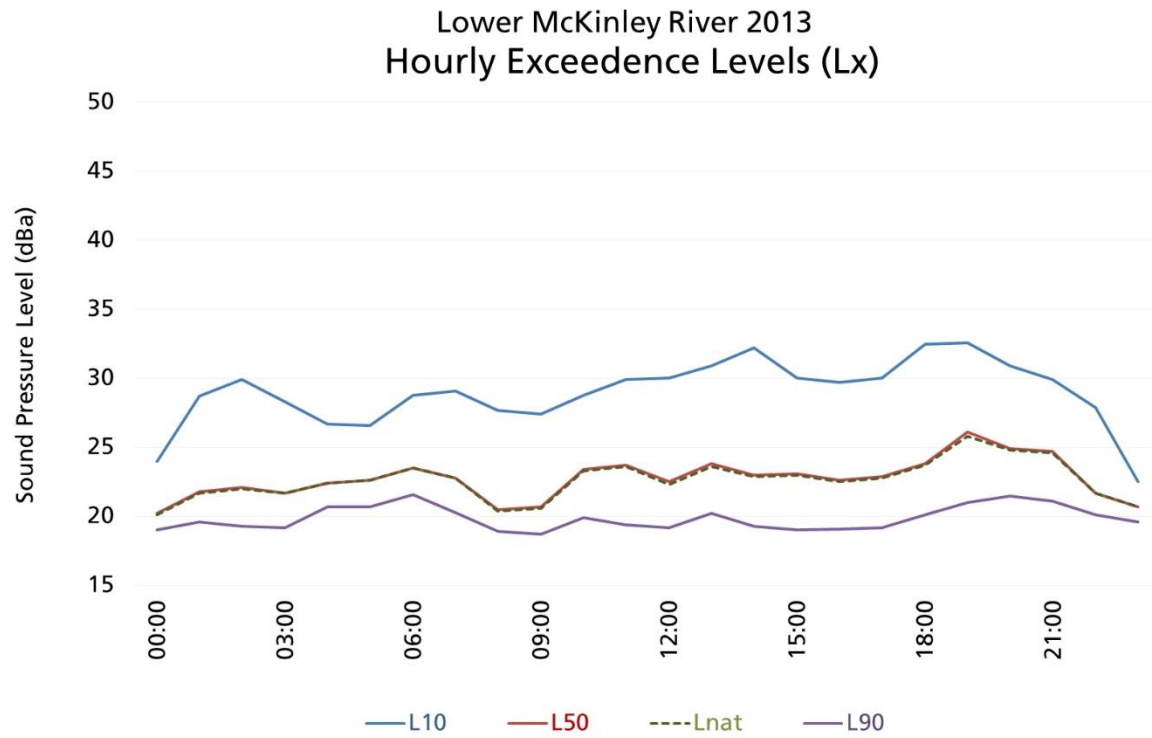


Figure 60. Exceedence levels for Lower McKinley River.

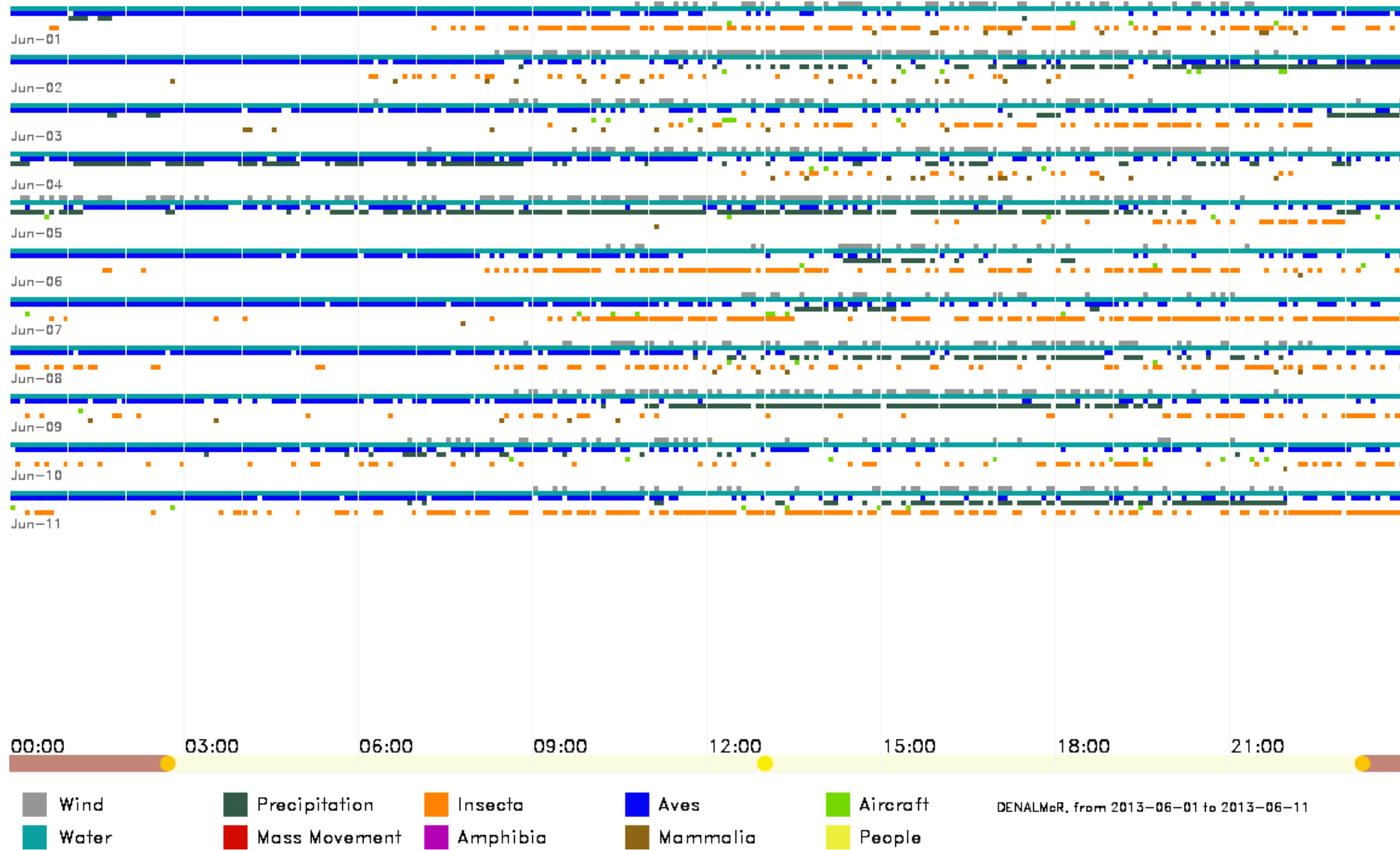


Figure 61. Temporal audibility of sound sources at Lower McKinley River, based on five seconds of audio every five minutes. The bar along the horizontal axis indicates the average light conditions during the sampling period. The orange circles are sunrise/sunset. This site did have civil twilight or night-time conditions during the sampling period.

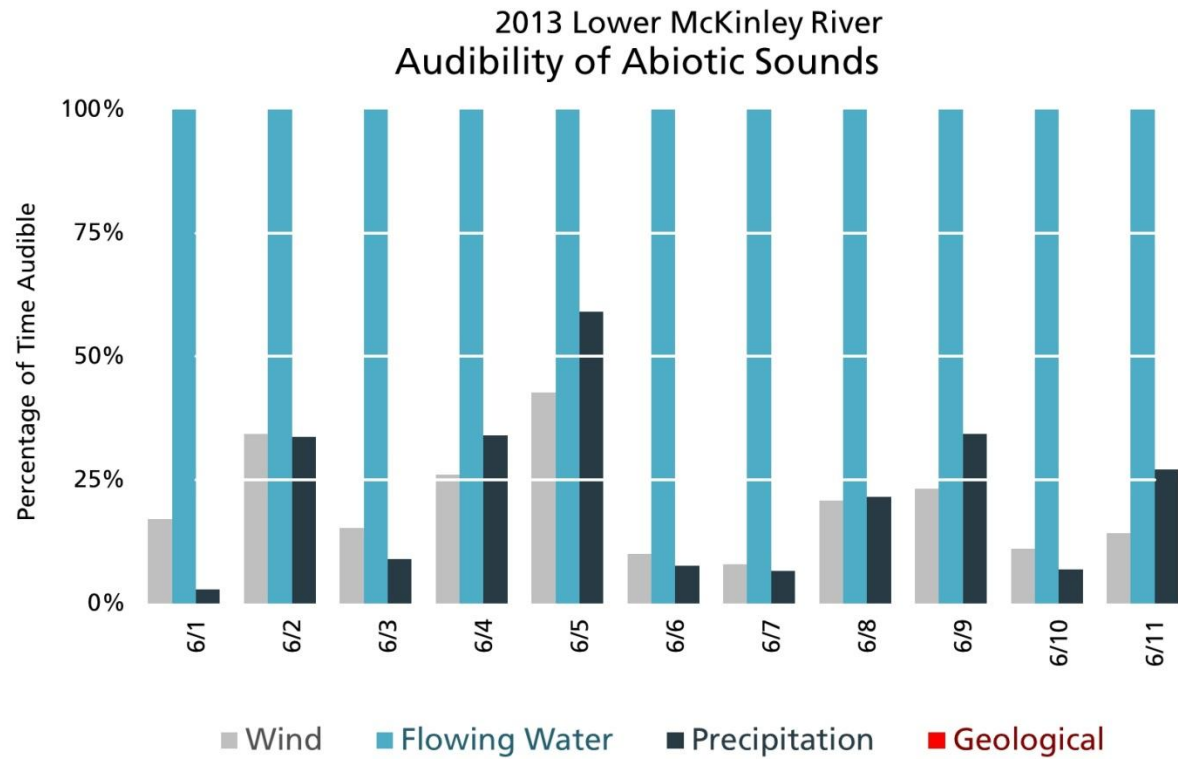


Figure 62. Audibility of abiotic sounds at Lower McKinley River.

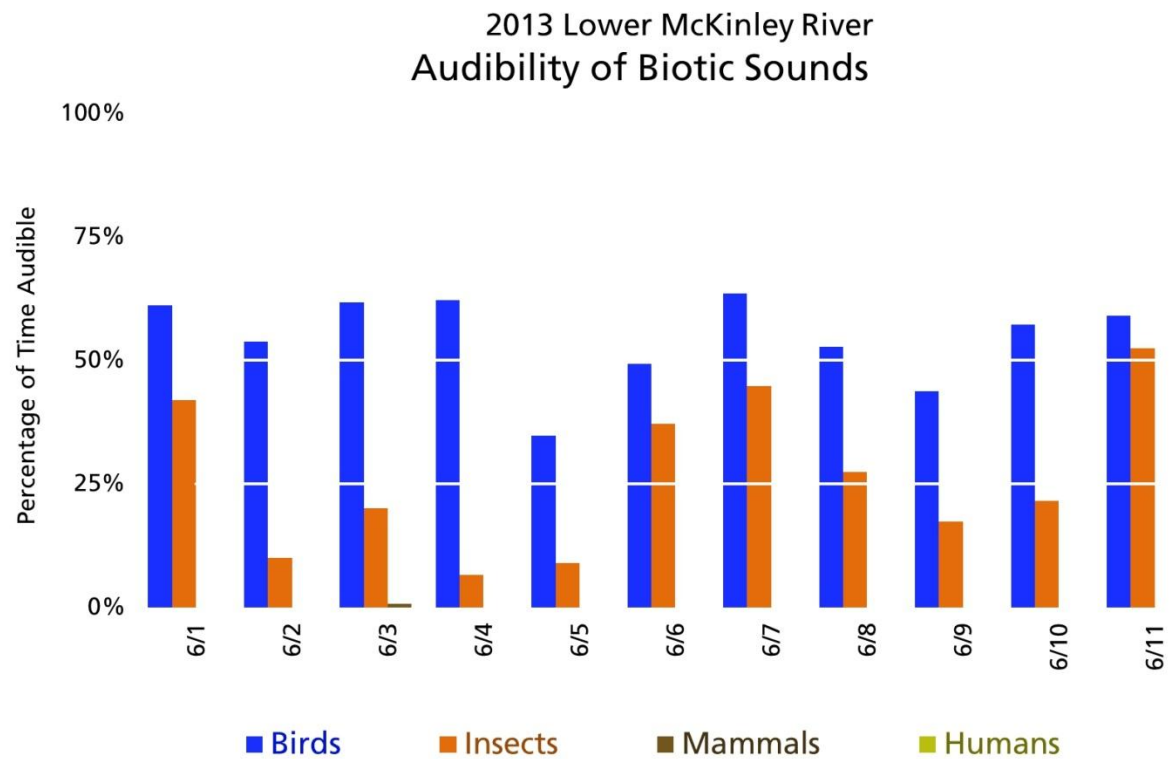


Figure 63. Audibility of biotic sounds at Lower McKinley River.

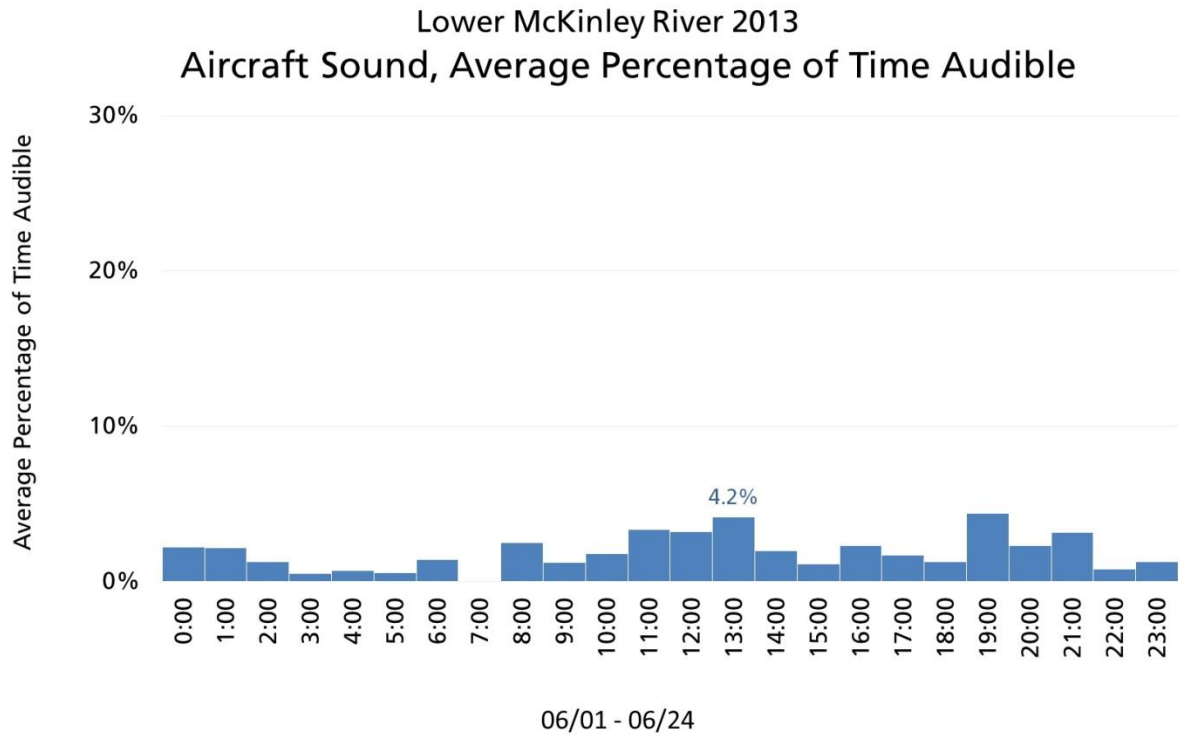


Figure 64. Audibility of aircraft noise for an average day, by hour, at Lower McKinley River.

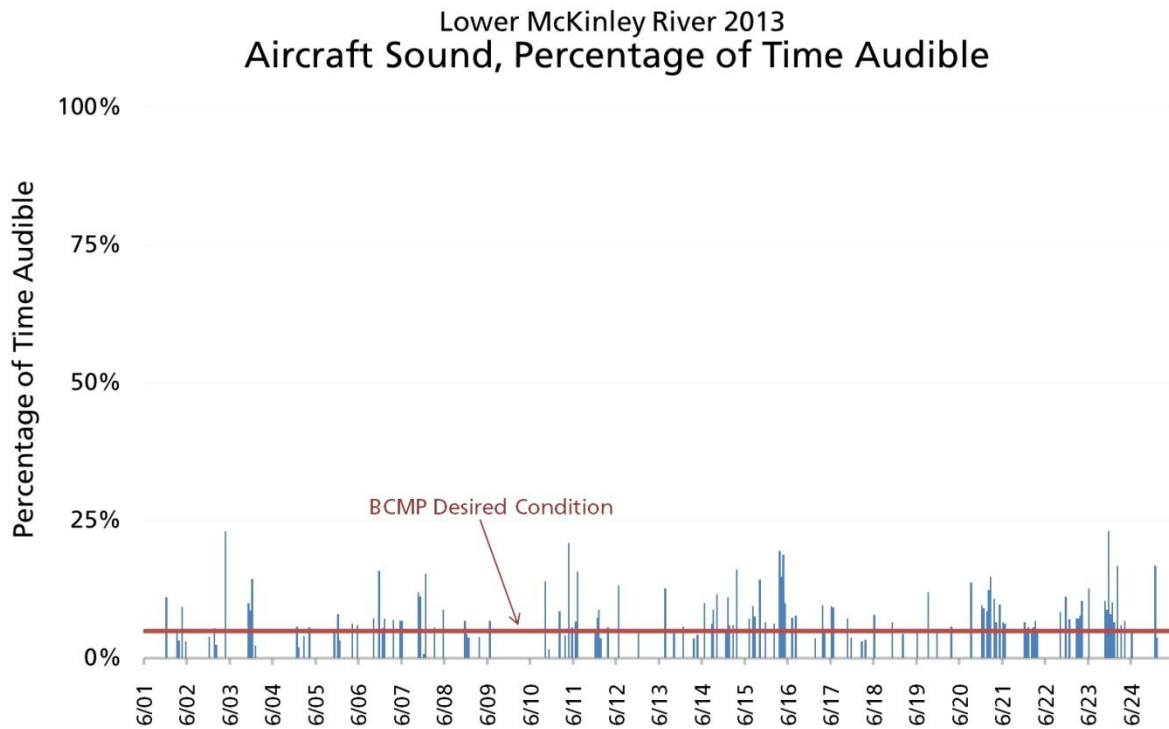


Figure 65. Audibility of aircraft noise at Lower McKinley River.

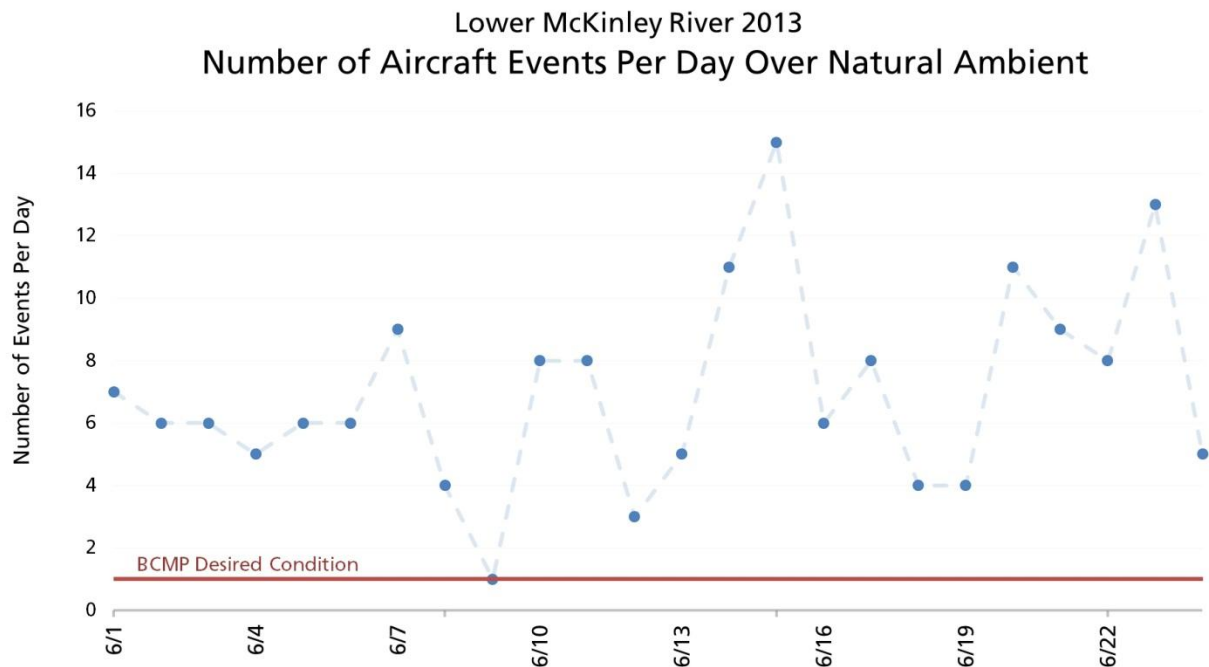


Figure 66. Number of aircraft noise events detected per day at Lower McKinley River.

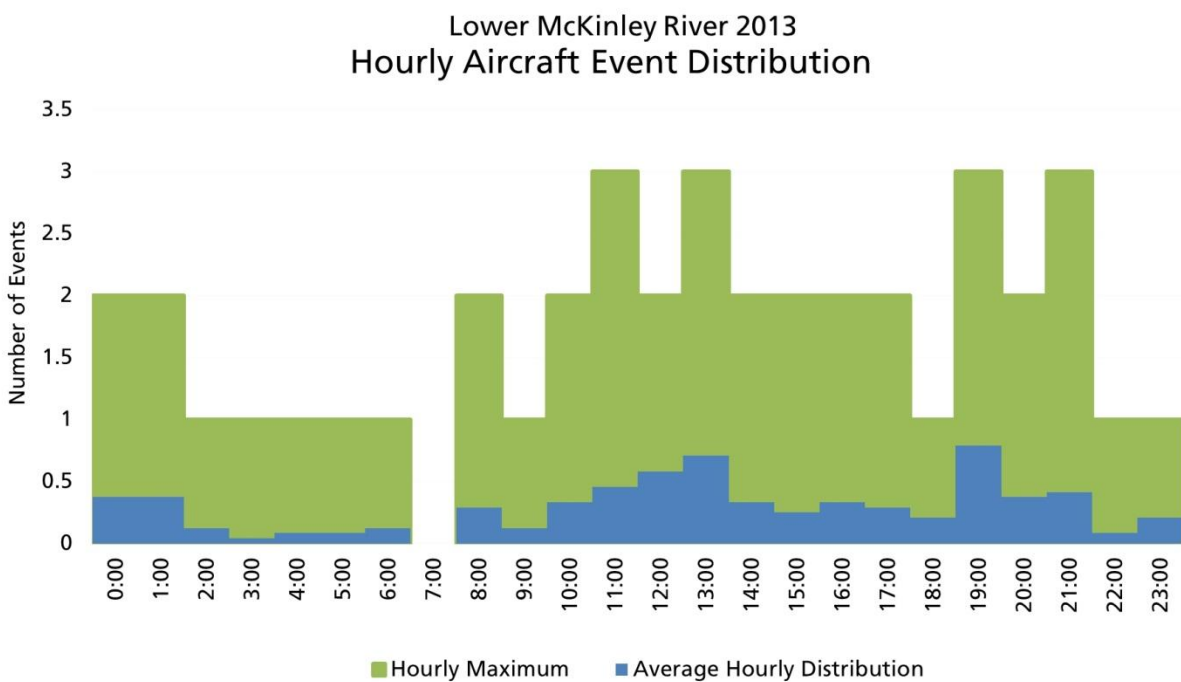


Figure 67. Hourly average and maximum rates of detection for aircraft noise events at Lower McKinley River.

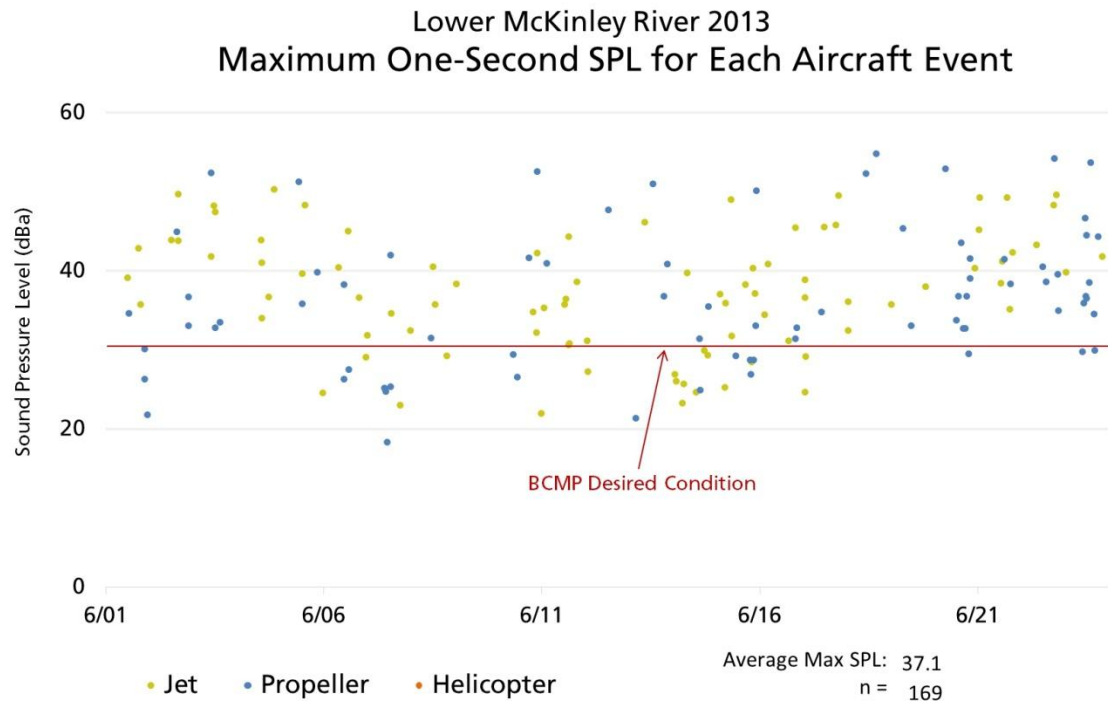


Figure 68. Maximum one-second sound pressure level for each aircraft event detected at Lower McKinley River.

Mount Lee



Location Description: Located at the base of Mount Lee near a small, but powerful tributary of the Coffee River. Vegetation at the site was in the dry forb herbaceous class (Vioreck III.B.1) dominated by *Cassiope*. Opposite the site and close to the creek was a narrow band of *Alnus*. The photograph is oriented roughly northwest, looking towards the tributary stream and beyond towards Mount Glisen and the Ruth Glacier. Another low pass to the Ruth connects just east of the site.

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

Coordinates: 62.88357 °, -150.47589 ° (WGS84)

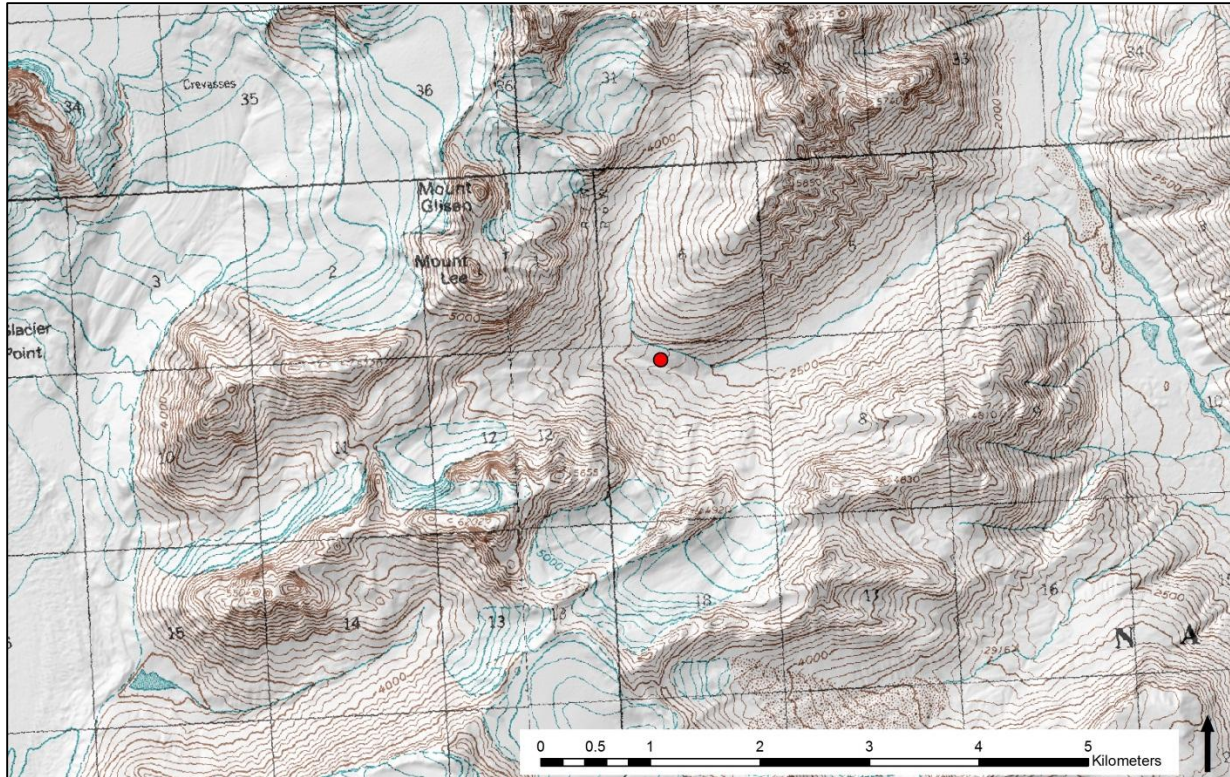
Elevation: 865 meters

BCMP Management Area: C (Medium Natural Sound Disturbance)

Park Ecoregion: Alaska Range South Central Mountains and Valleys

Sampling Period: 09-May-2013 to 07-July-2013

Access: Helicopter



Summary/Notes: The purpose of the Mount Lee 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 #55 was located in the New Park (ANILCA expansion).

With the onset of the spring freshet, the soundscape at the Mount Lee sampling location became overwhelmingly characterized by an adjacent tributary of the Coffee River. With a time-averaged natural ambient level of 50.1 dBA, the natural soundscape of the area was the single loudest site sampled in the park thus far (compared to 46.1 dBA at Upper West Fork Yentna River in 2010, 44.6 dBA at Kichatna Mountains in 2012, and 44.1 dBA near the North Triple Lakes Trail on Riley Creek in 2011). This time-averaged level is particularly striking when the difference between the minimum and maximum levels are compared. The minimum and maximum hourly L50 values observed were 21.5 dBA (on 5/10/2013 during the 02:00 hour), and 56.7 dBA (on 6/9/2013 during the 21:00 hour). This is an enormous difference of 35.2 dBA. An observer moved through time from the original environment to the later would experience a 99.97% reduction in their listening area. (The equation used to calculate listening area reduction can be found Barber 2010, p 183.) Another way of phrasing this is that the environment would sound anywhere from 3.5 to 6 times as loud to an observer.

The practical effects of a changing natural ambient level on detection can be most readily visualized by studying Figure 77, which shows the maximum sound pressure level for each motorized noise event over the entire sampling period. An hourly median sound pressure level is shown as a time series on the graph. It is immediately apparent that as the natural level of acoustic energy increases, listening area decreases and faint aircraft are more difficult to detect. Also, the instantaneous ambient sound pressure level sets a floor for measuring the maximum level of a noise event. This is apparent

on the graph as detections within a trough of the L50 time series – during quieter times (or places), it is possible to measure quieter maximum motorized levels. This is especially important when noise sources are strongly tonal: they may be audible, but in terms of broadband energy their maximum levels are below the instantaneous level.

As year-round residents, White-tailed Ptarmigan were active early in the sampling period and make up the vast majority of avian detections at Mount Lee. One interesting observation at this site was an apparent gap in ptarmigan activity from 01:00 to 03:00 on most days, which is readily visible in Figure 70. This interval of rest from vocalization did not appear to change duration as the season progressed, though the daily number of clips with vocalizations does wane. White-tailed Ptarmigan were also detected at [Carlson Creek](#) and [Fang Mountain](#) in 2013 (see those sections for more detail).

The most commonly heard sounds at this site were flowing water (audible 92.4% of the time), wind (22.5%), and birds (20.8%). Human made sound was audible 0.8% of the time on average. This was largely influenced by a high background ambient level. In terms of time, 0.8% of a day is equivalent to 11.5 minutes each day, or approximately 6 overflights per day at this location. Conditions did not exceed the BCMP percent audible standard at all, but exceeded the number of events per day standard 82% of the time, and maximum SPL standard 73% of the time. This high level of exceedence for the last standard was due to a very energetic natural conditions. As evident in Figure 70, the natural ambient level crept above the 40 dBA standard as time progressed, making it impossible to measure the maximum level of aircraft that were below the standard.

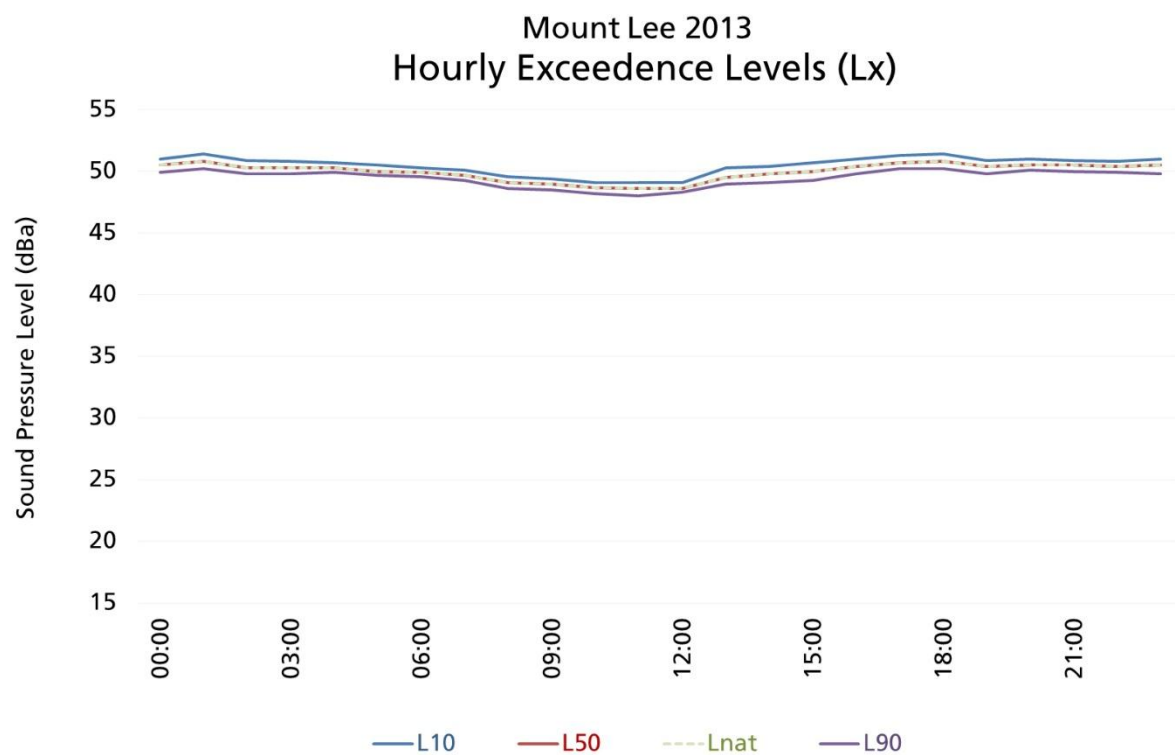


Figure 69. Exceedence levels for Mount Lee.

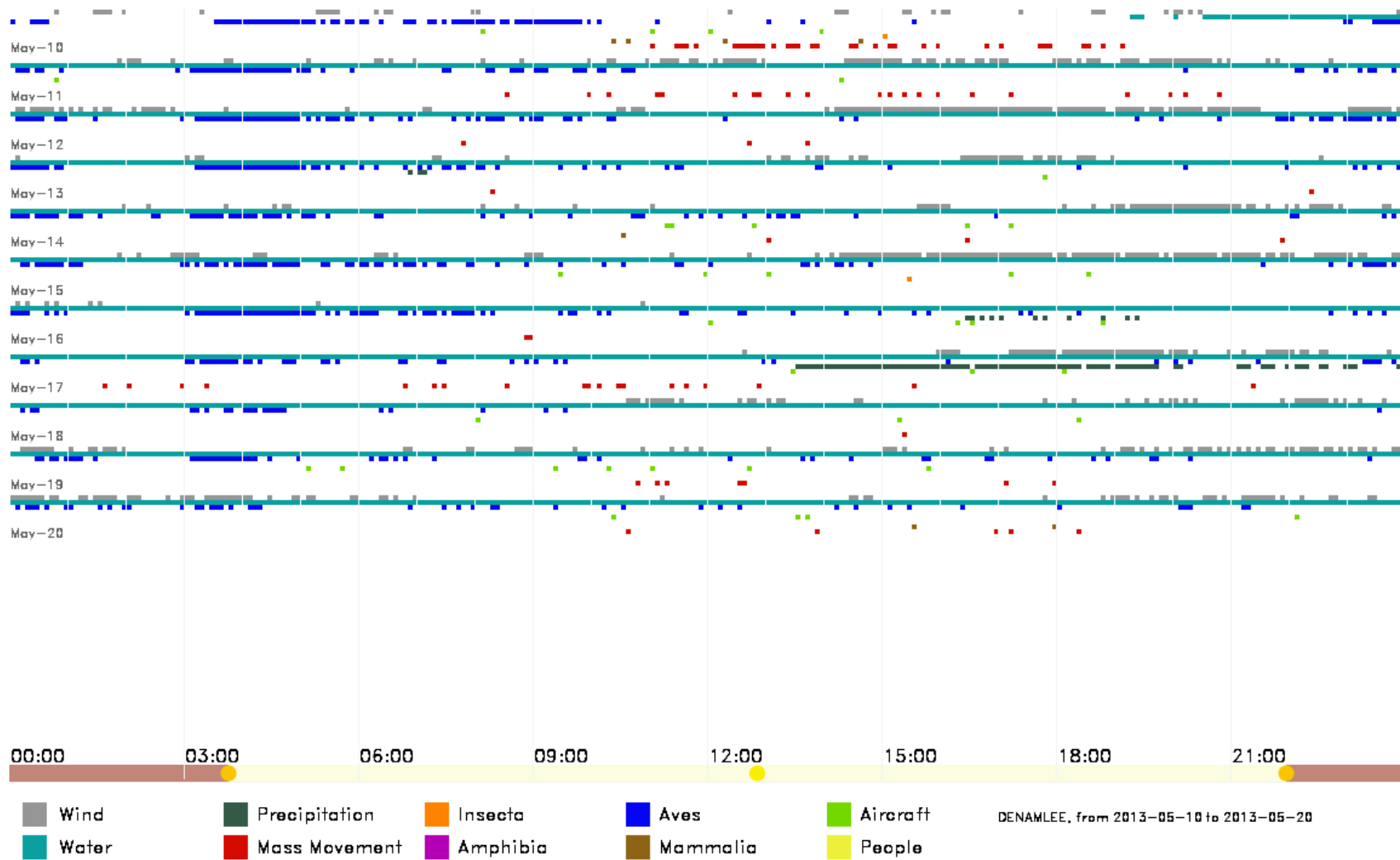


Figure 70. Temporal audibility of sound sources at Mount Lee, based on five seconds of audio every five minutes. The bar along the horizontal axis indicates the average light conditions during the sampling period. The orange circles are sunrise/sunset. This site did have civil twilight or night-time conditions during the sampling period.

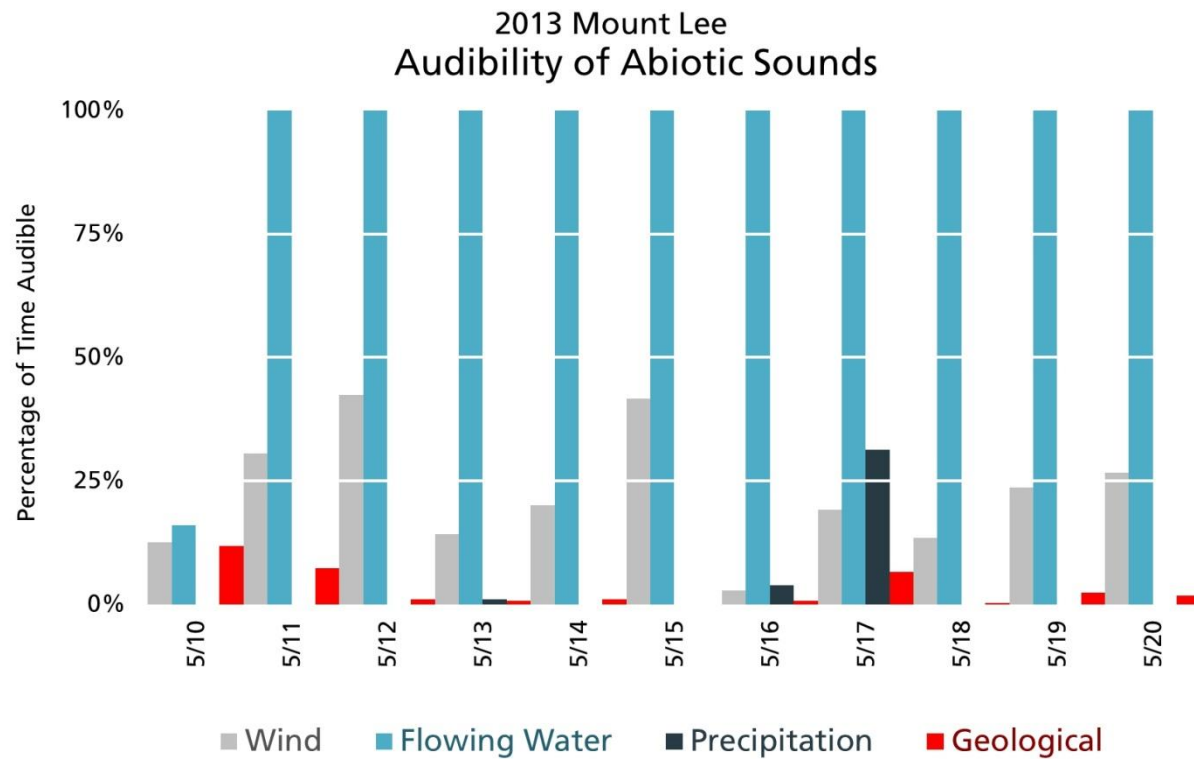


Figure 71. Audibility of abiotic sounds at Mount Lee.

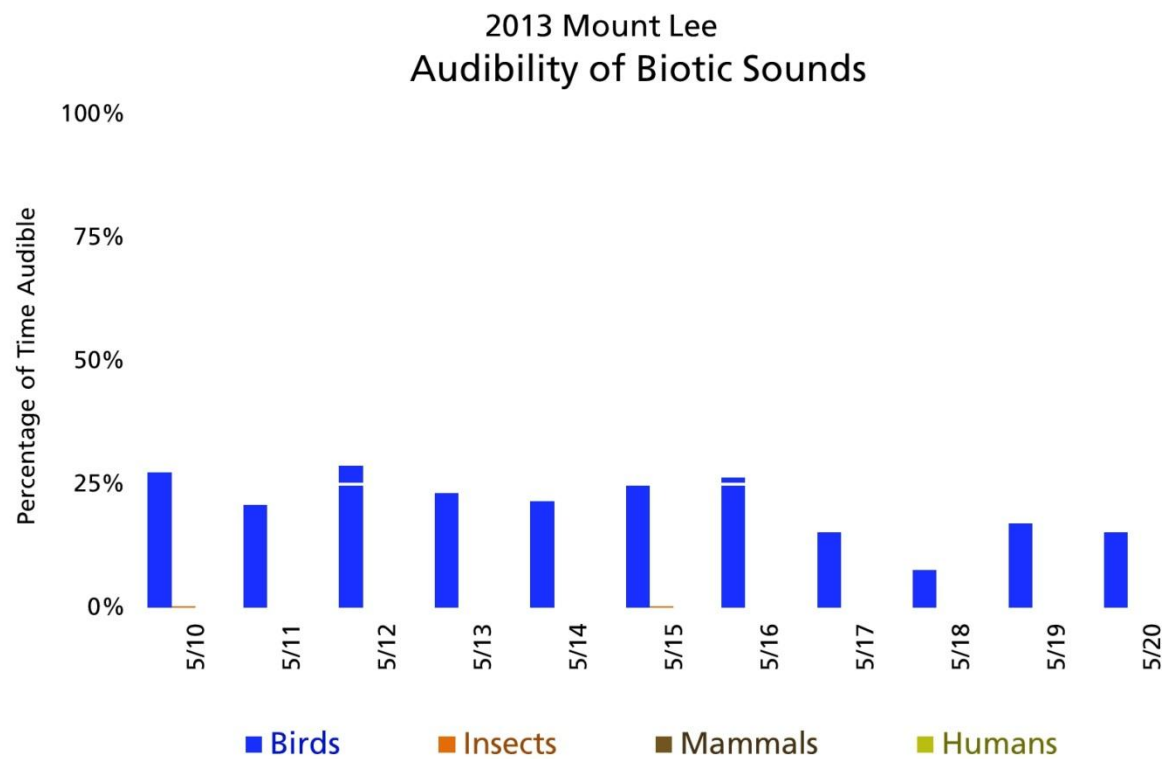


Figure 72. Audibility of biotic sounds at Mount Lee.

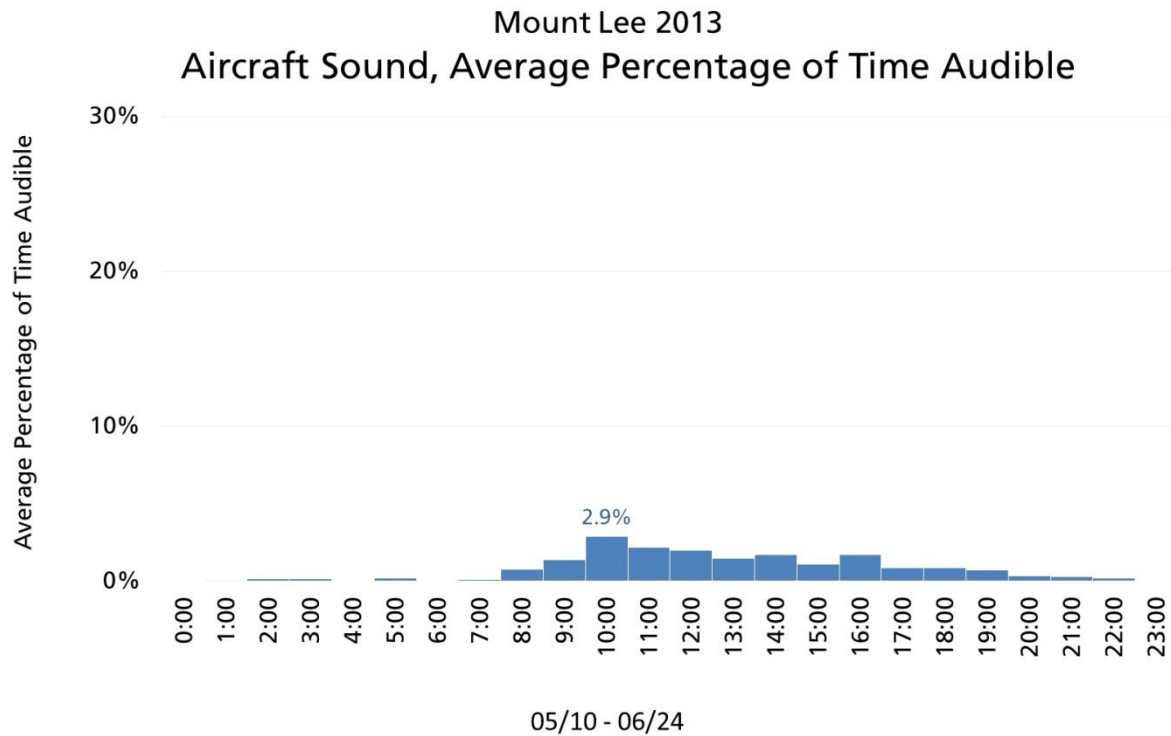


Figure 73. Audibility of aircraft noise for an average day, by hour, at Mount Lee.

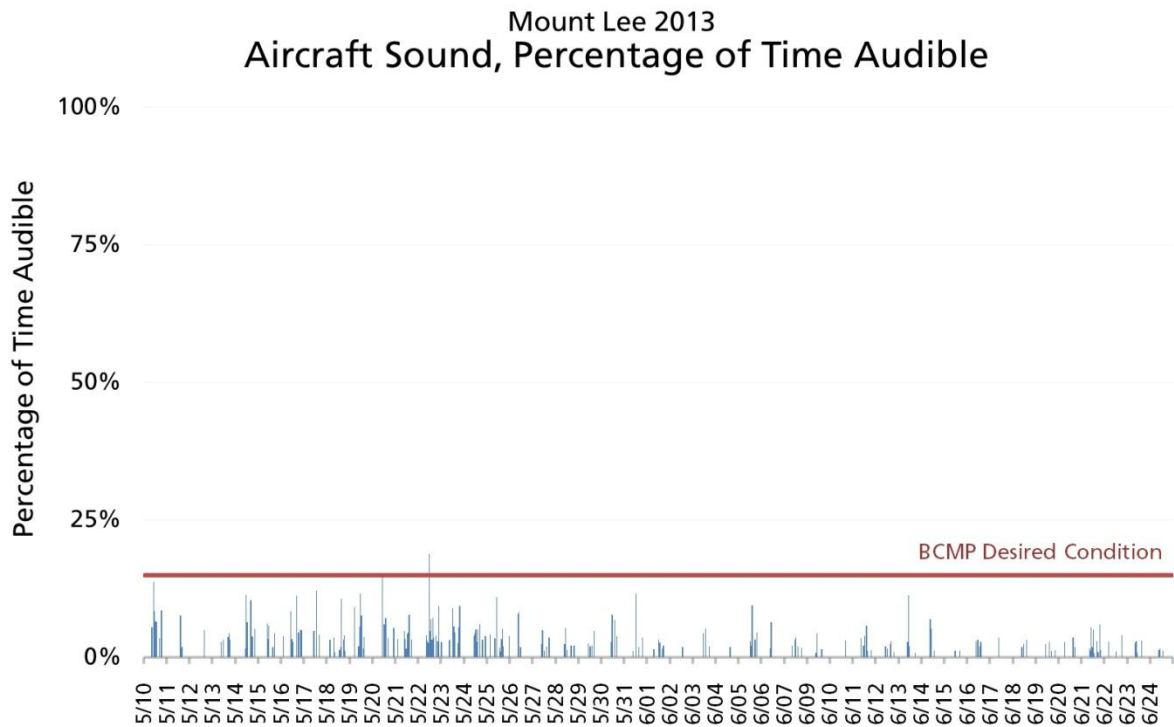


Figure 74. Audibility of aircraft noise at Mount Lee.

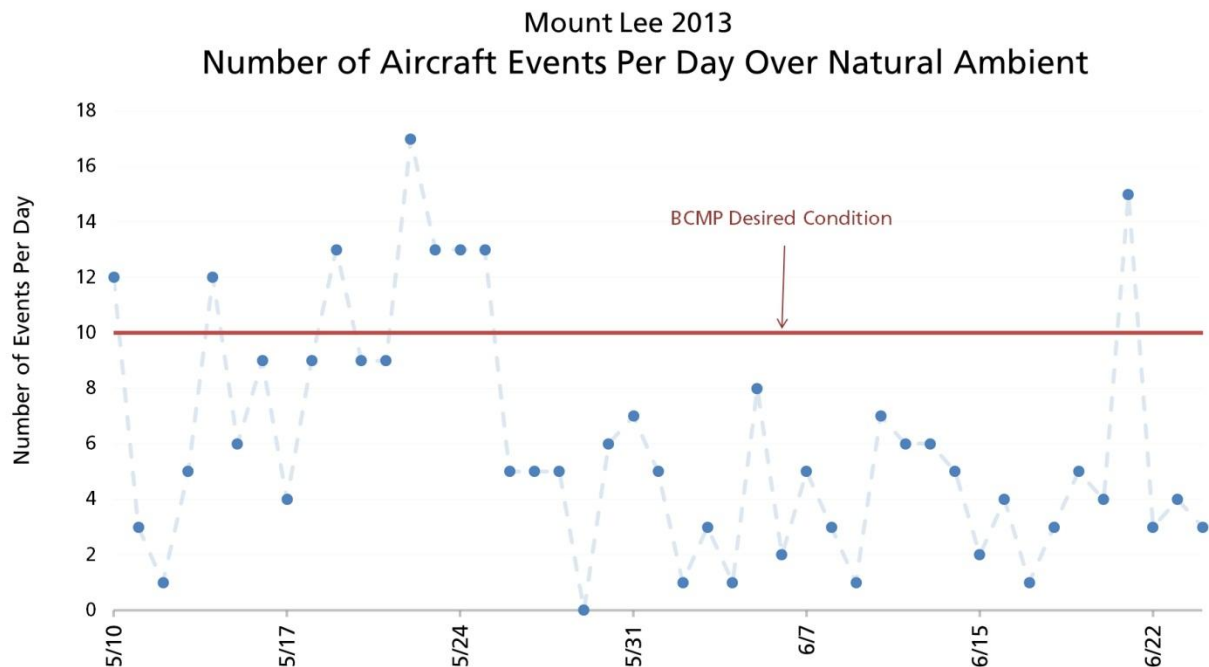


Figure 75. Number of aircraft noise events detected per day at Mount Lee.

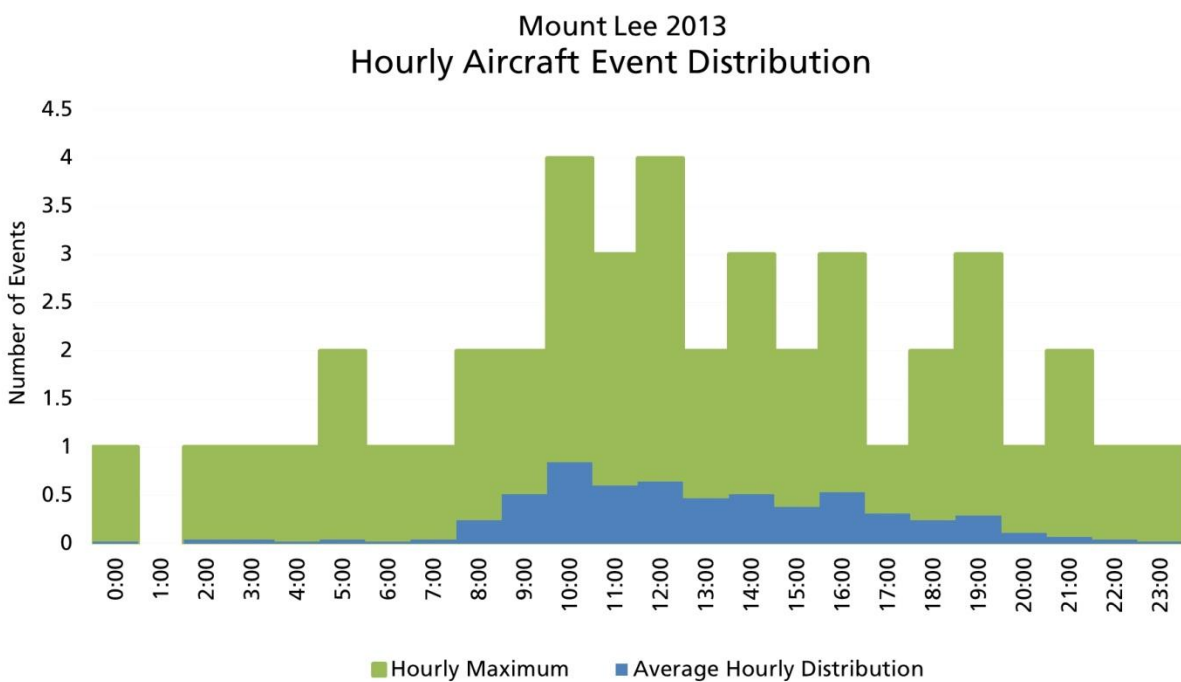


Figure 76. Hourly average and maximum rates of detection for aircraft noise events at Mount Lee.

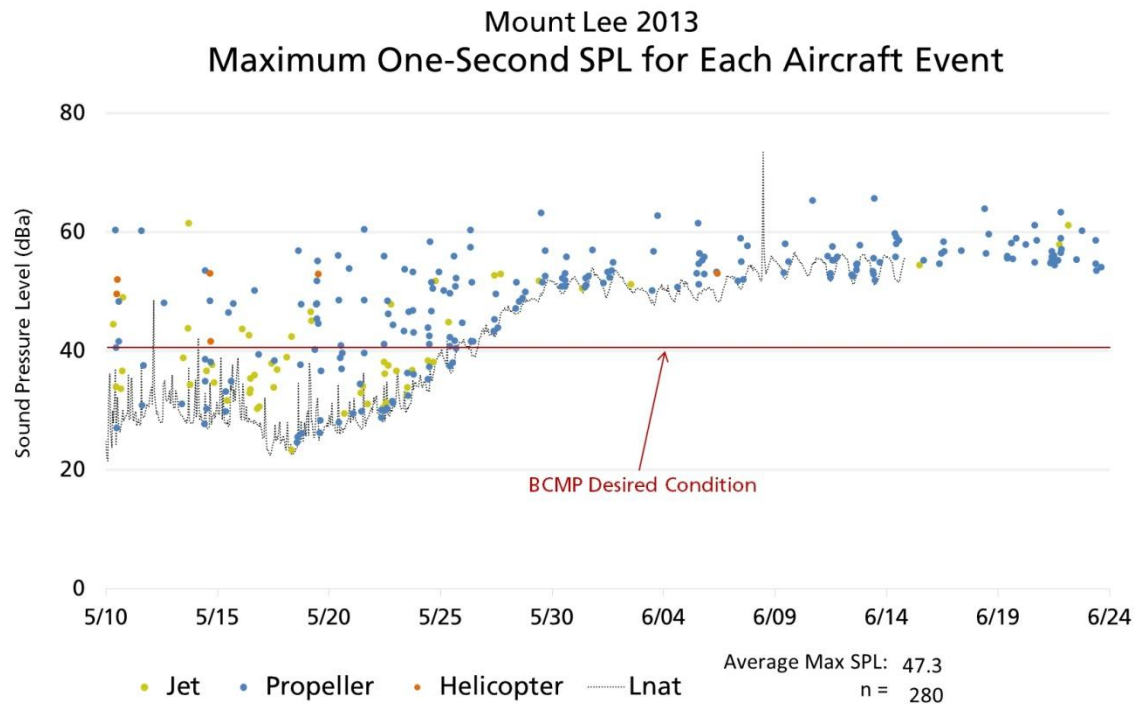


Figure 77. Maximum one-second sound pressure level for each aircraft event detected at Mount Lee. A time series of L50 is also included to demonstrate how an increase in natural ambience affects the measurement of noise.

Upper Eldridge Glacier



Location Description: On an unnamed western fork of the Eldridge Glacier, about 6.5 km from the main body of the Eldridge Glacier and 6 km from the eastern-most fork of the Don Sheldon Amphitheatre. The site was unvegetated. The photo above faces roughly south towards the head of the glacial fork.

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

Coordinates: 63.05705°, -150.47620° (WGS84)

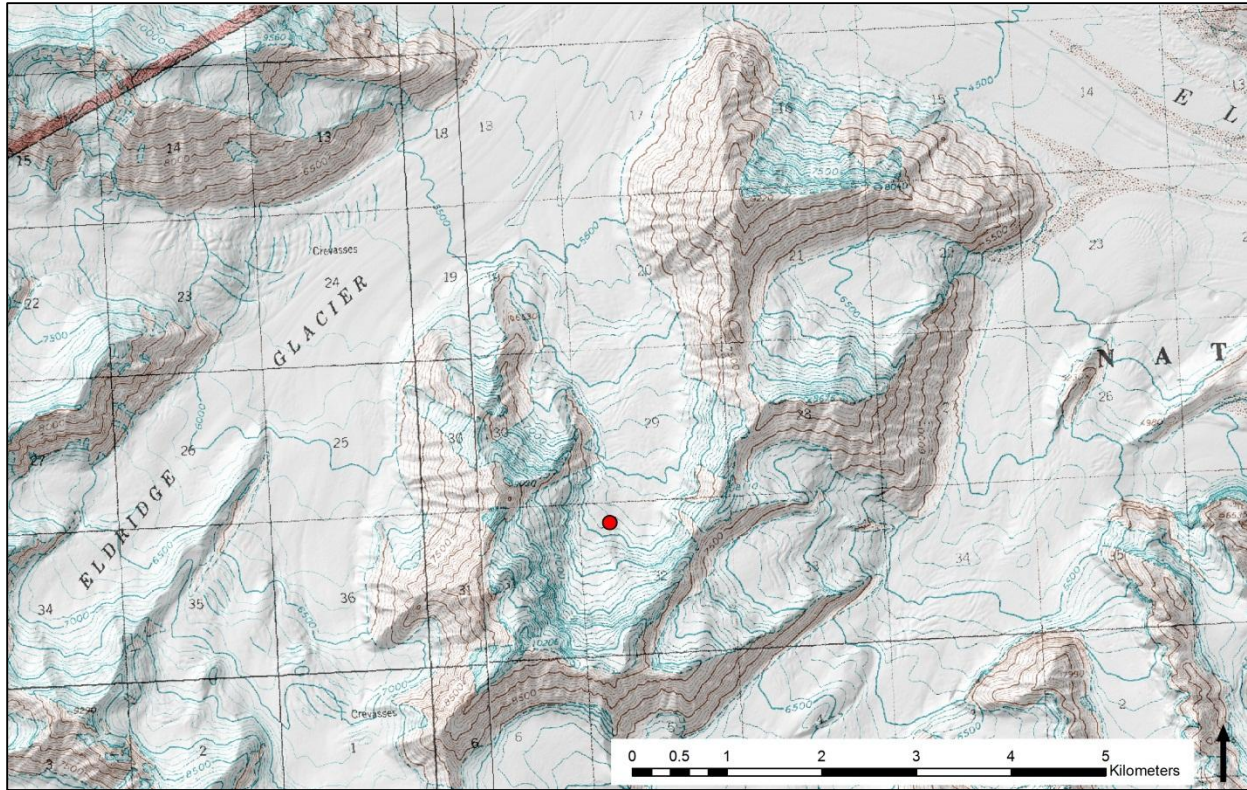
Elevation: 2089 meters

BCMP Management Area: C (Medium Natural Sound Disturbance)

Park Ecoregion: Alaska Range High Mountains

Sampling Period: 09-May-2013 to 08-June-2013

Access: Helicopter.



Summary: The purpose of the Upper Eldridge Glacier 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 #78 located in the New Park (ANILCA expansion).

The time-averaged natural ambient level at this site was 17.9 dBA, putting Upper Eldridge Glacier in the 7th percentile of summer-season sites parkwide. This value is close to the median Lnat for winter sites, at 17.1 dBA. (Other summer sites with natural ambient levels at or below 18.0 dBA include Myrtle Creek 2010 and Birch Creek 2013.) A pattern of nocturnal winds gives the natural ambient level a slight increase in the evening hours. Along with a counterpoint of silence, these winds were a predominant component of the soundscape (detected in 44.7% of audio clips). The median wind speed was 0.8 meters per second with an interquartile range of 0.7 m/s.

Mass movement - primarily rock and ice falling from the steep valley walls – was also commonly heard, audible in 24.7% of clips. Such abiotic sources of acoustic energy typify the unvegetated alpine mountains of the Alaska Range. Compare Upper Yentna Glacier 2012 at 41.9% of clips, 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 builds until about 12:00, then tapers into the twilight hours - after which motion stops again.

One interesting human phenomenon that elucidates the seasonality of aircraft noise in Denali is apparent in Figure 86, which shows the maximum sound pressure level of aircraft noise events through time. On May 17th and 18th the rate of propeller aircraft noise transitions from a low median

rate of 3 noise events per day to a much higher rate of 15 noise events per day. The middle of May is when high-volume tourism businesses open in the park area, which affects rates of commercial flightseeing and glacier landings (some of which land on the Eldridge Glacier). This influx of visitation immediately increases air traffic rates to over 10 events per day, putting the site out of standard with the Backcountry Management Plan. This can be clearly seen in Figure 84, which depicts the number of noise events per day greater than the natural ambient level.

Biotic sound was not detected frequently at the site. In the deeply crevassed and snowy glacial valley no insects, mammals, nor amphibians were detected. Only 0.2% of audio clips contained bird calls: a sequence of Redpoll flight calls confined to a single day, 05/13/13. See Figure 79 for timing.

The most commonly heard sounds at this site were wind (audible 44.7% of the time), silence (36.1%), mass movement (24.7%), and precipitation (7.9%). Human made sound was produced entirely by aircraft, and audible 3.4% of the time. (This is equivalent to 49.0 minutes of aircraft sound each day, or about 17 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.

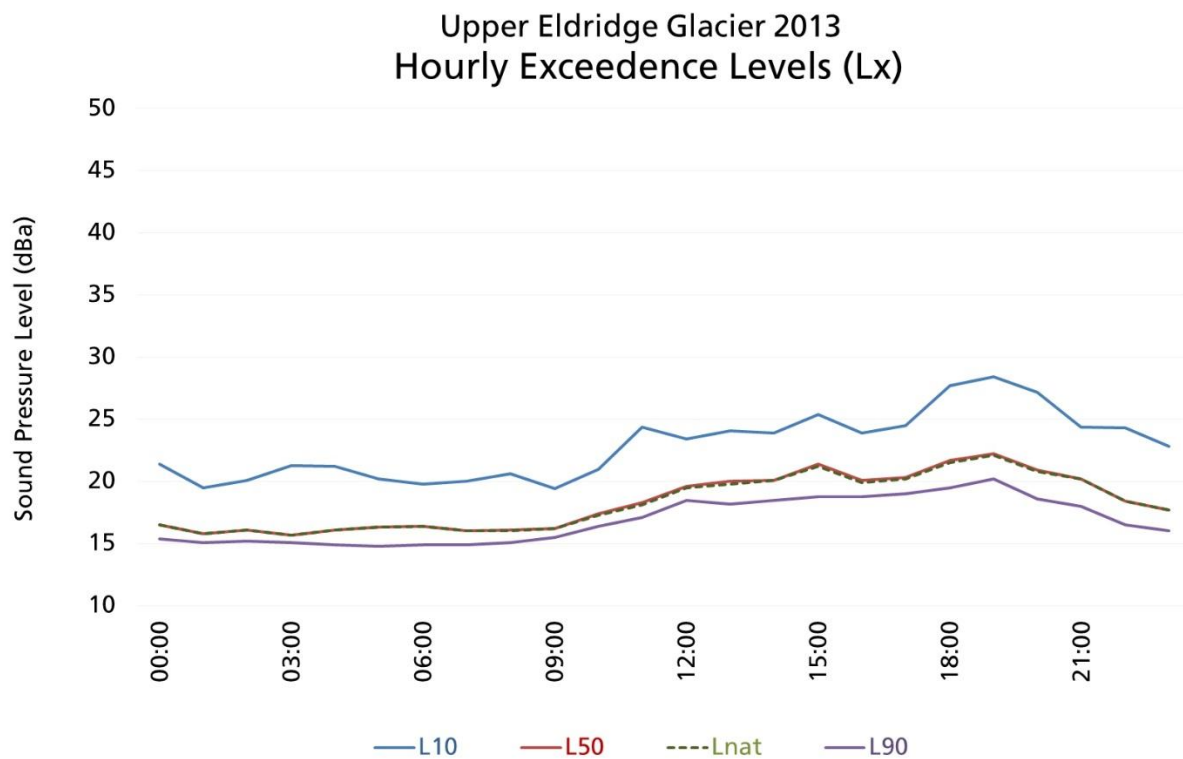


Figure 78. Exceedence levels for Upper Eldridge Glacier.

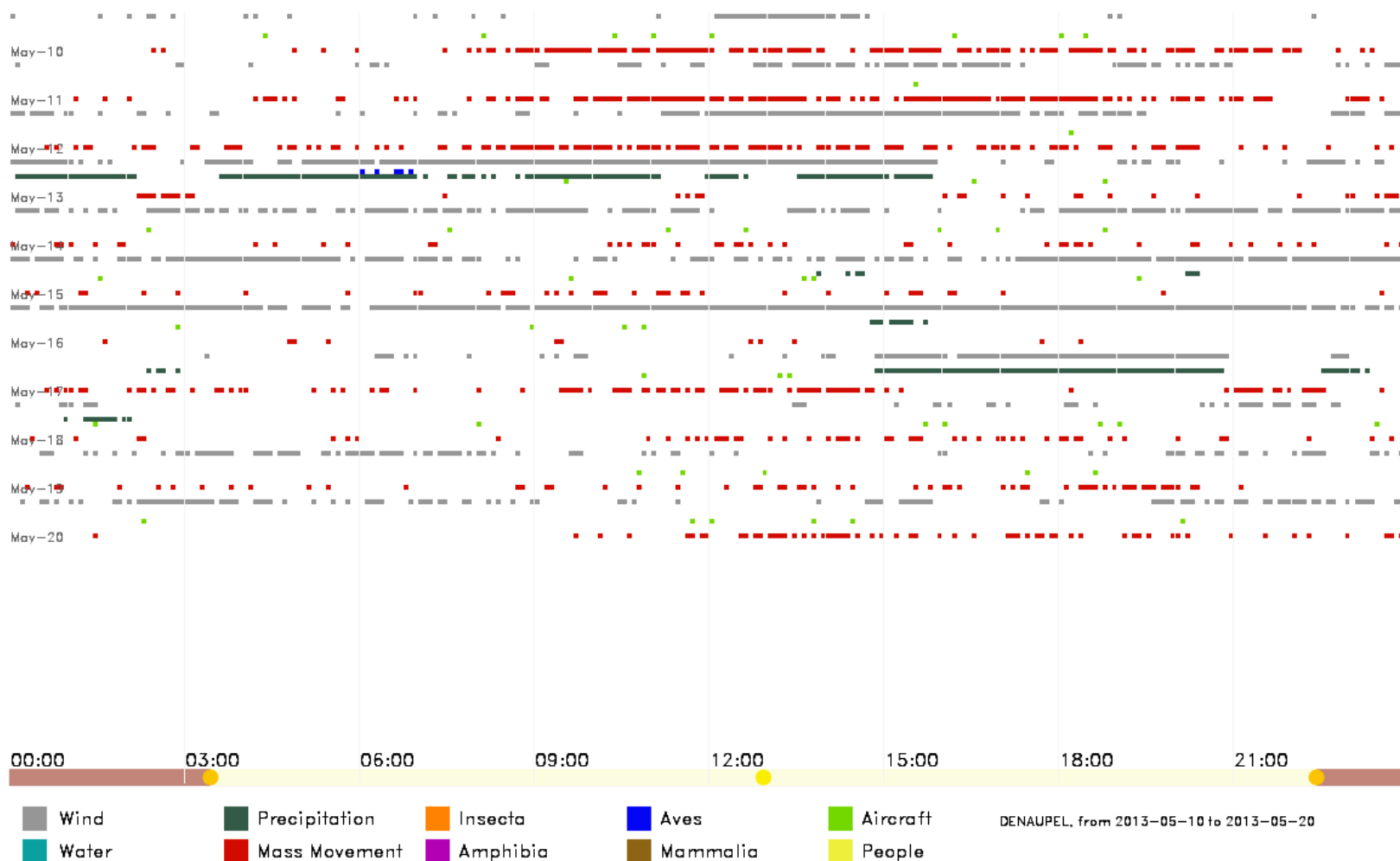


Figure 79. Temporal audibility of sound sources at Upper Eldridge Glacier, based on five seconds of audio every five minutes. The bar along the horizontal axis indicates the average light conditions during the sampling period. The orange circles are sunrise/sunset. This site did have civil twilight or night-time conditions during the sampling period.

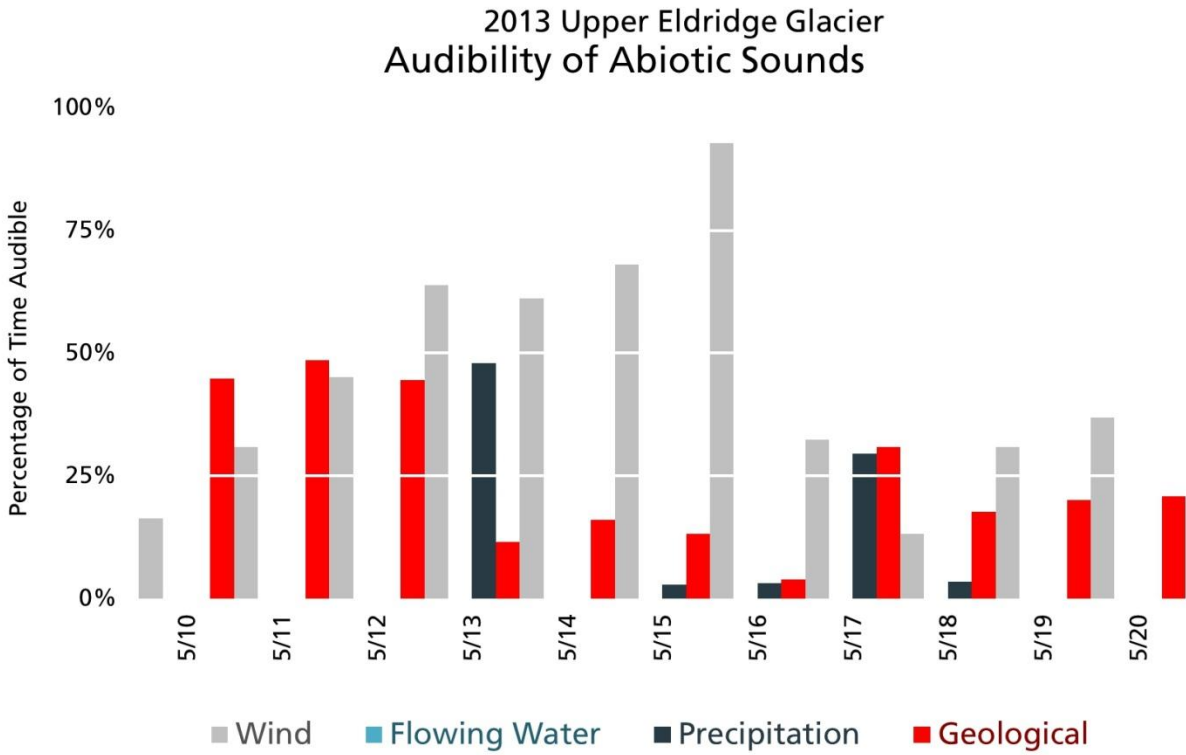


Figure 80. Audibility of abiotic sounds at Upper Eldridge Glacier.

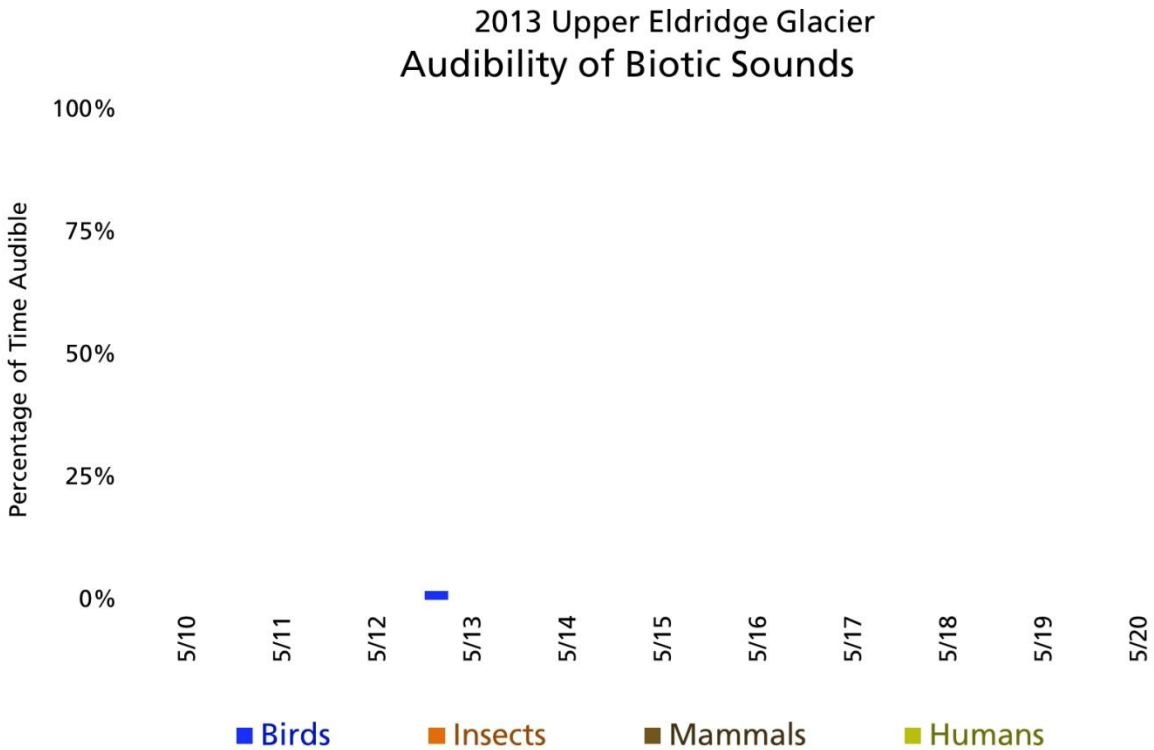


Figure 81. Audibility of biotic sounds at Upper Eldridge Glacier.

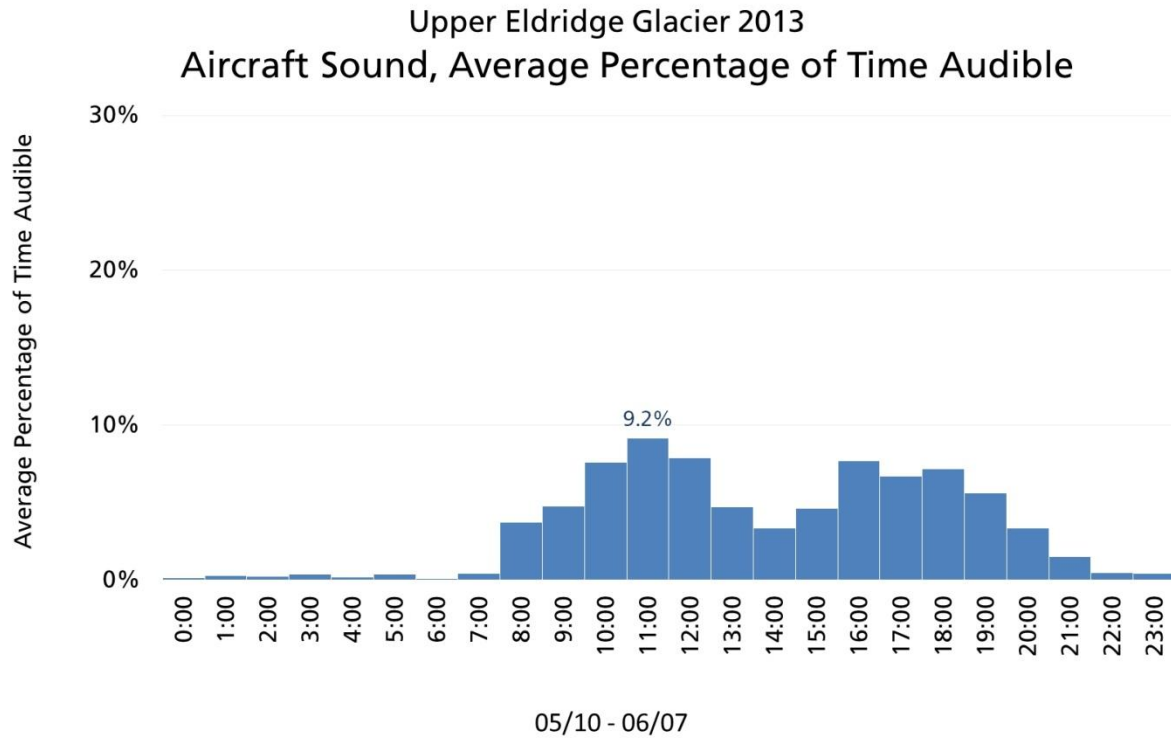


Figure 82. Audibility of aircraft noise for an average day, by hour, at Upper Eldridge Glacier.

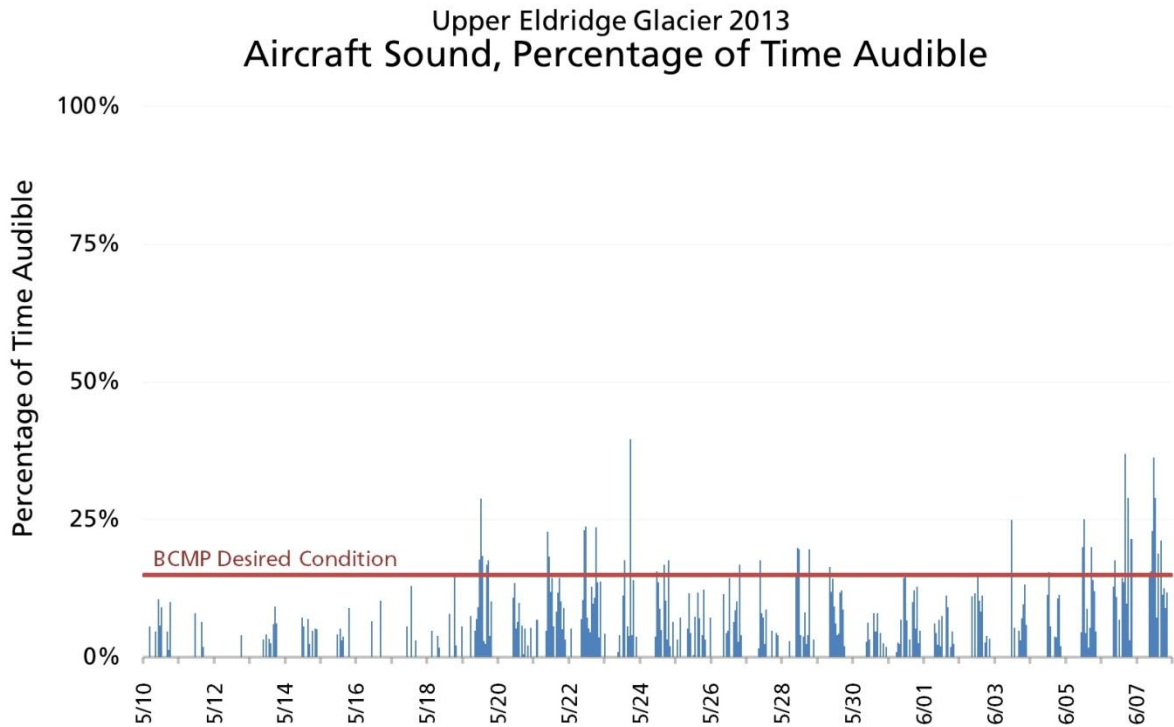


Figure 83. Audibility of aircraft noise at Upper Eldridge Glacier.

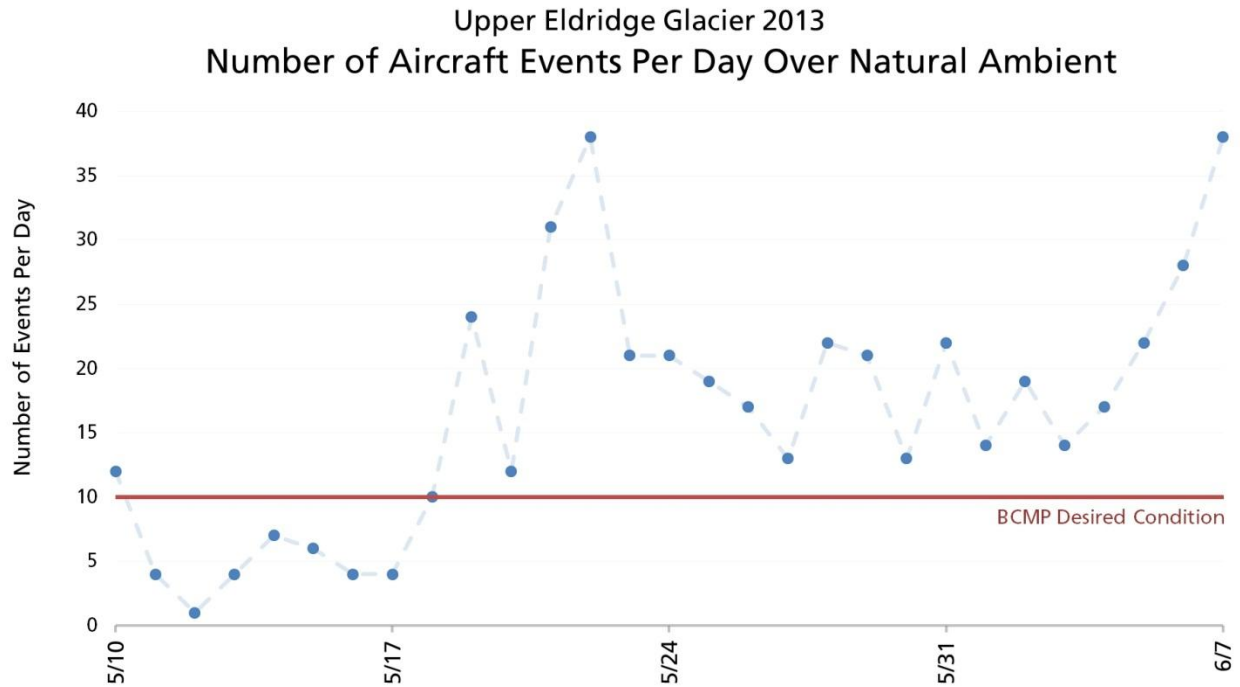


Figure 84. Number of aircraft noise events detected per day at Upper Eldridge Glacier.

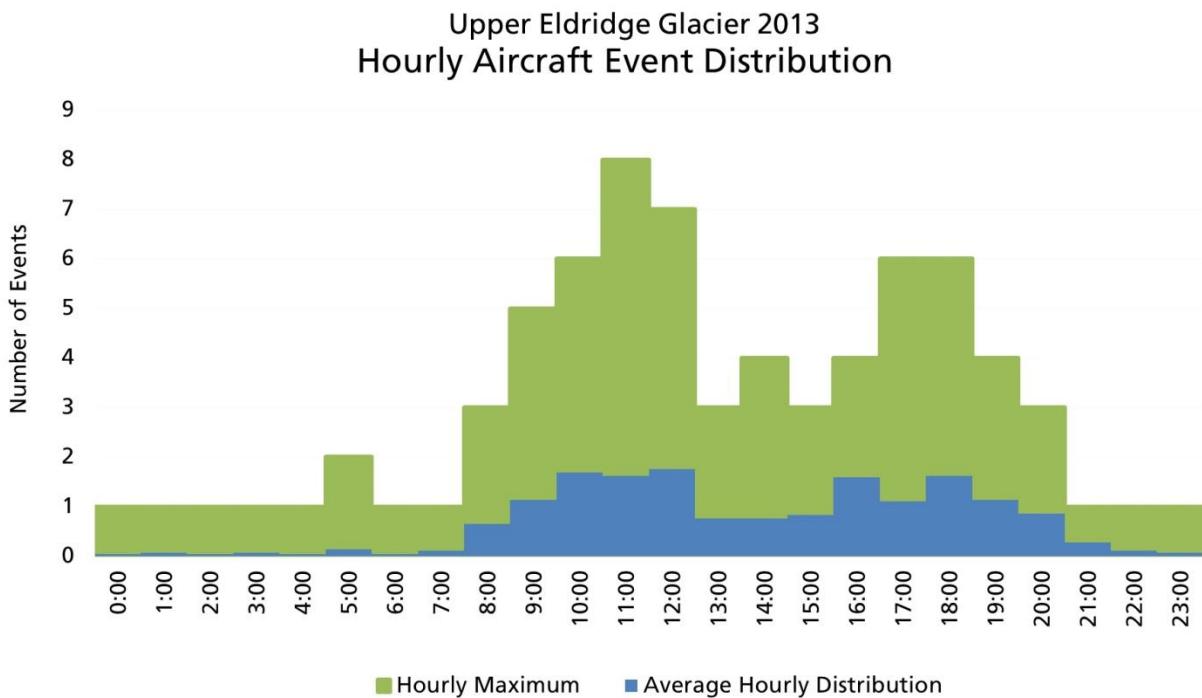


Figure 85. Hourly average and maximum rates of detection for aircraft noise events at Upper Eldridge Glacier.

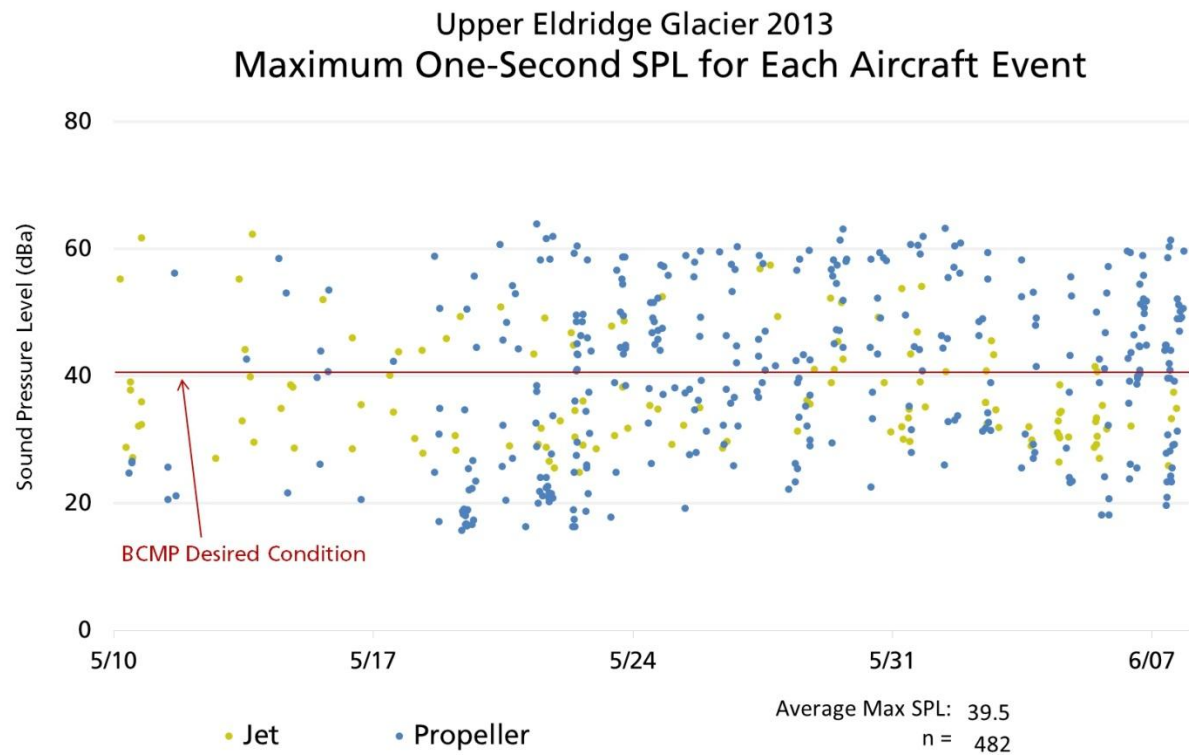


Figure 86. Maximum one-second sound pressure level for each aircraft event detected at Upper Eldridge Glacier.

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 eighth 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 2006–2012, which collected similar data at other locations. An additional goal was to resample two administrative sites: one to monitor the effects of a voluntary aviation best practice, and the other to measure the acoustic performance of hybrid buses as compared to the conventional diesel fleet.

In 2013, 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 Fang Mountain - a culmination of north-side flight routes – at which an average of 31 aircraft noise events were detected per day, with a maximum of 58 noise events per day. This was followed closely by Carlson Creek (within the McGonagall Pass area) with an average of 29 events per day and a maximum of 61 noise events per day.

Natural sound characteristics also typify a place. The loudest time-averaged natural ambient level in the park on record was documented in 2013 – 50.06 dBA at the Mount Lee sampling location. Proximity to a steep and rapidly-flowing stream caused this uncommonly high energy time average. Now compare the quietest natural ambient conditions on record in 2013 at Birch Creek, with a time-averaged natural ambient level of 17.65 dBA. Moving from the quieter site to the louder site would result in a listening environment with over five times more ambient acoustic energy and an incredible 99.94% reduction in listening area.

Many species of animals were documented on record in 2013. Great-Grey Owls were recorded at Birch Creek, Caribou and Surfbirds at Fang Mountain, and Arctic Warblers at Igloo Canyon. All are rarely-recorded species in North America, and notable additions to Denali's reference library. Running documentation of interesting phenological or climatological indicator species continued in 2013 as well. Sandhill Cranes and Greater Yellowlegs were detected at Lower McKinley River, White-tailed Ptarmigan were detected at Mount Lee and Carlson Creek, Collared Pika were detected at Cabin Peak and Carlson Creek, and grasshoppers were detected at Cabin Peak.

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 . These findings have been added to the parkwide backcountry management plan compliance maps which can be found in [Appendix B](#).

Table 6. Percentage of samples exceeding BCMP sound standards.

Site Name	Hourly Motorized Noise Audibility	Motorized Noise Events/Day	Motorized Max SPL (dBA)	BCMP Area
Birch Creek	19% of all hours	87% of all days	13% of all events	D (Low)
Cabin Peak	22%	98%	55%	OP1 (Low)
Carlson Creek	37%	92%	54%	OP1 (Low)
Fang Mountain	43%	100%	53%	OP1 (Low)
Flume Creek	13%	16%	42%	B (Med)
Igloo Canyon*	32%	100%	95%	OP1 (Low)
Lower McKinley River	19%	96%	36%	D (Low)
Mount Lee	0%	82%	73%	C (Med)
Upper Eldridge Glacier	1%	72%	47%	C (Med)

*: Technically the Igloo Canyon site was in the backcountry day-use area along the road corridor, but being within a few feet of BCMP zone OP1 and so the standards will be evaluated for the surrounding area.

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 an Acoustic Resource 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: $10(\text{Log}_{10}(\text{sound level}/\text{reference sound level}))$. 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)

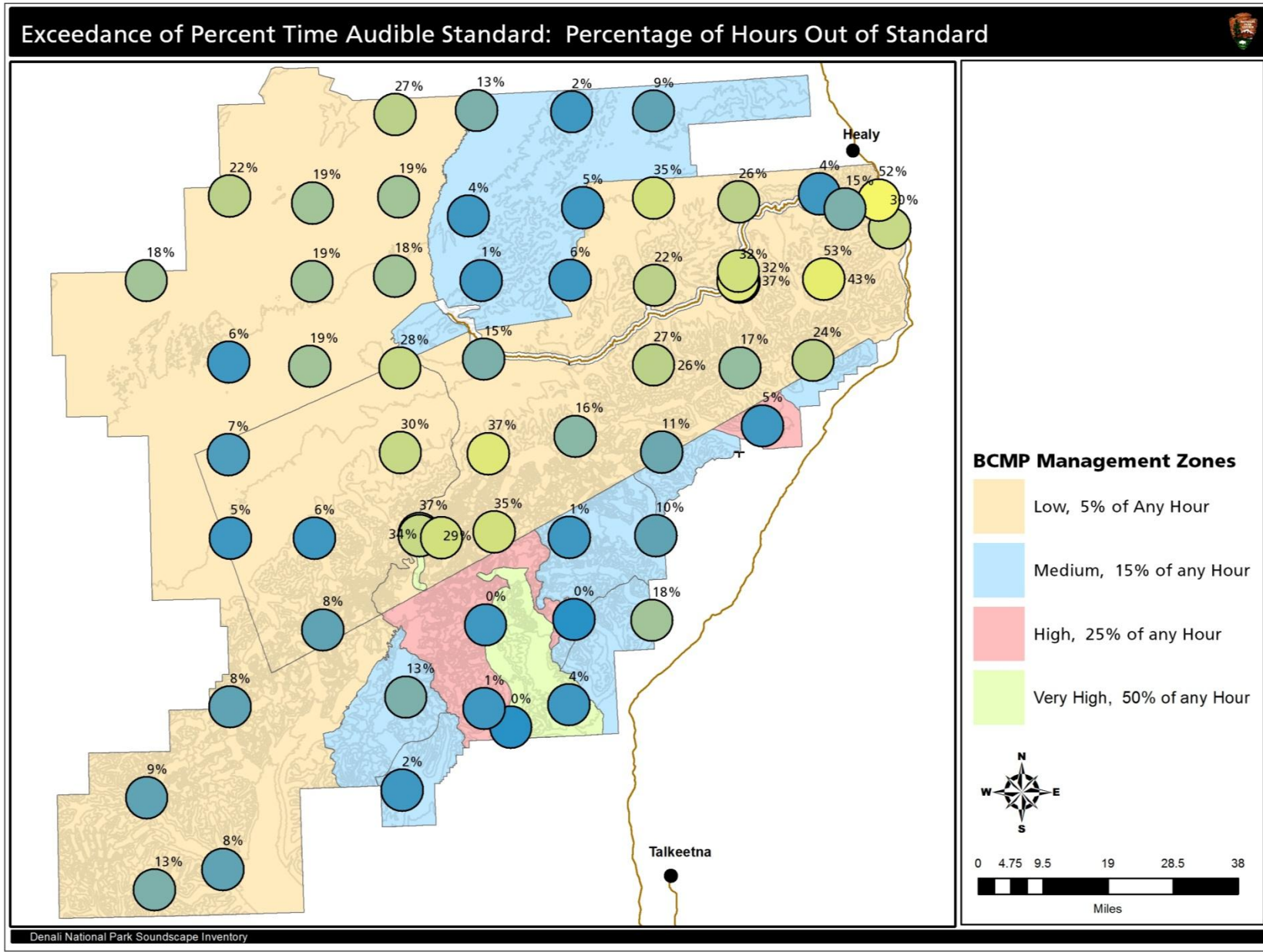
A calibrated measure of sound level, expressed in decibels, and referred to an atmospheric standard of 20 micro Pascals.

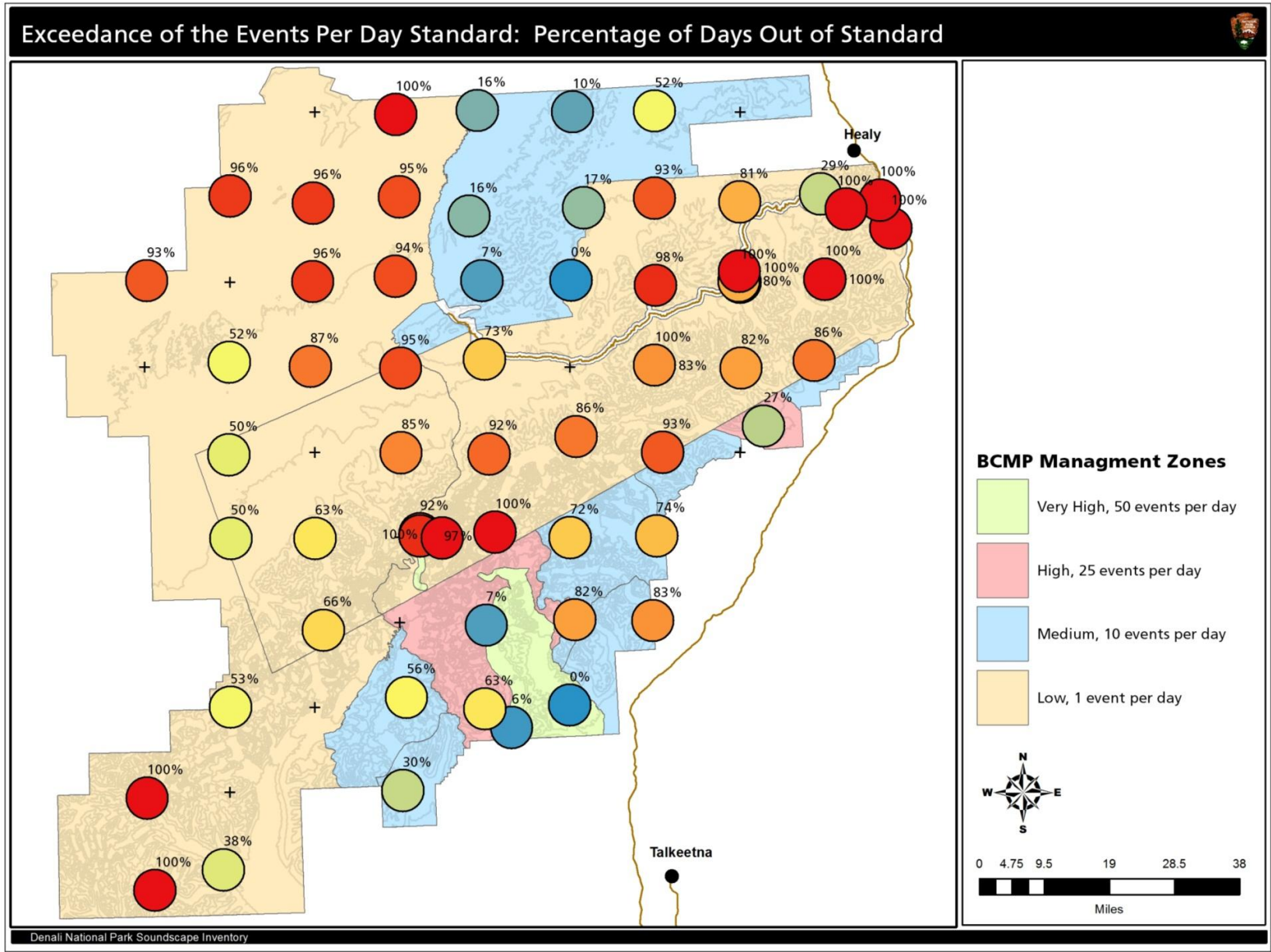
Time Audible

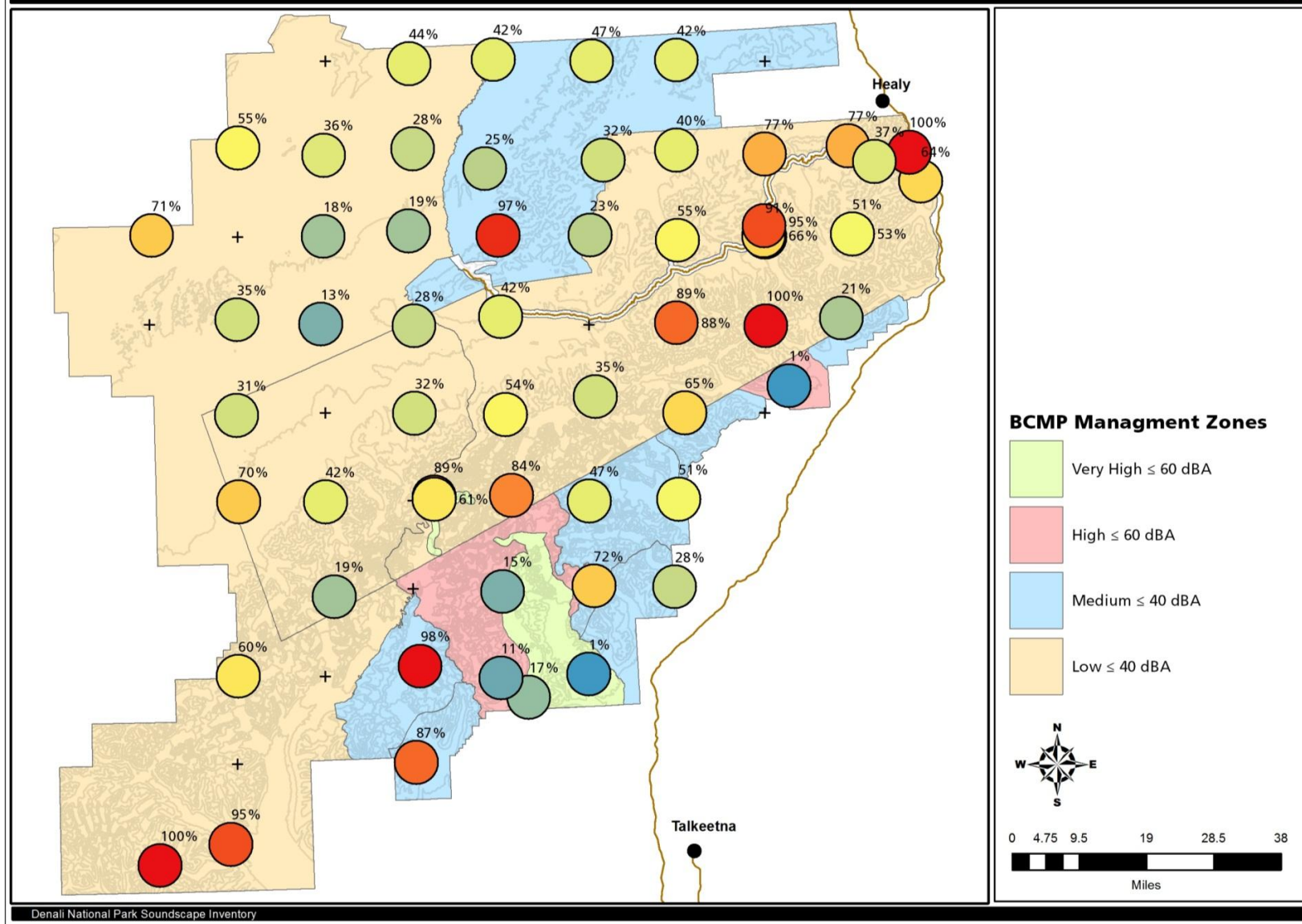
The amount of time that a sound source is audible to a human with normal hearing.

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 percent exceedence of the standard during the measurement period. Each map has the same color scale. Data from previous years is from Hults 2005, Withers and Hults 2006, Withers 2010, 2011, 2012, Withers and Betchkal 2013, Betchkal 2013a, and Betchkal 2013b.







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 as a blue snowflake. Sites sampled prior to the publishing date of the final Backcountry Management Plan EIS (2006) are shown in dark blue. Locations that have yet to be sampled on the 10x10 kilometer grid are indicated by black cross marks.

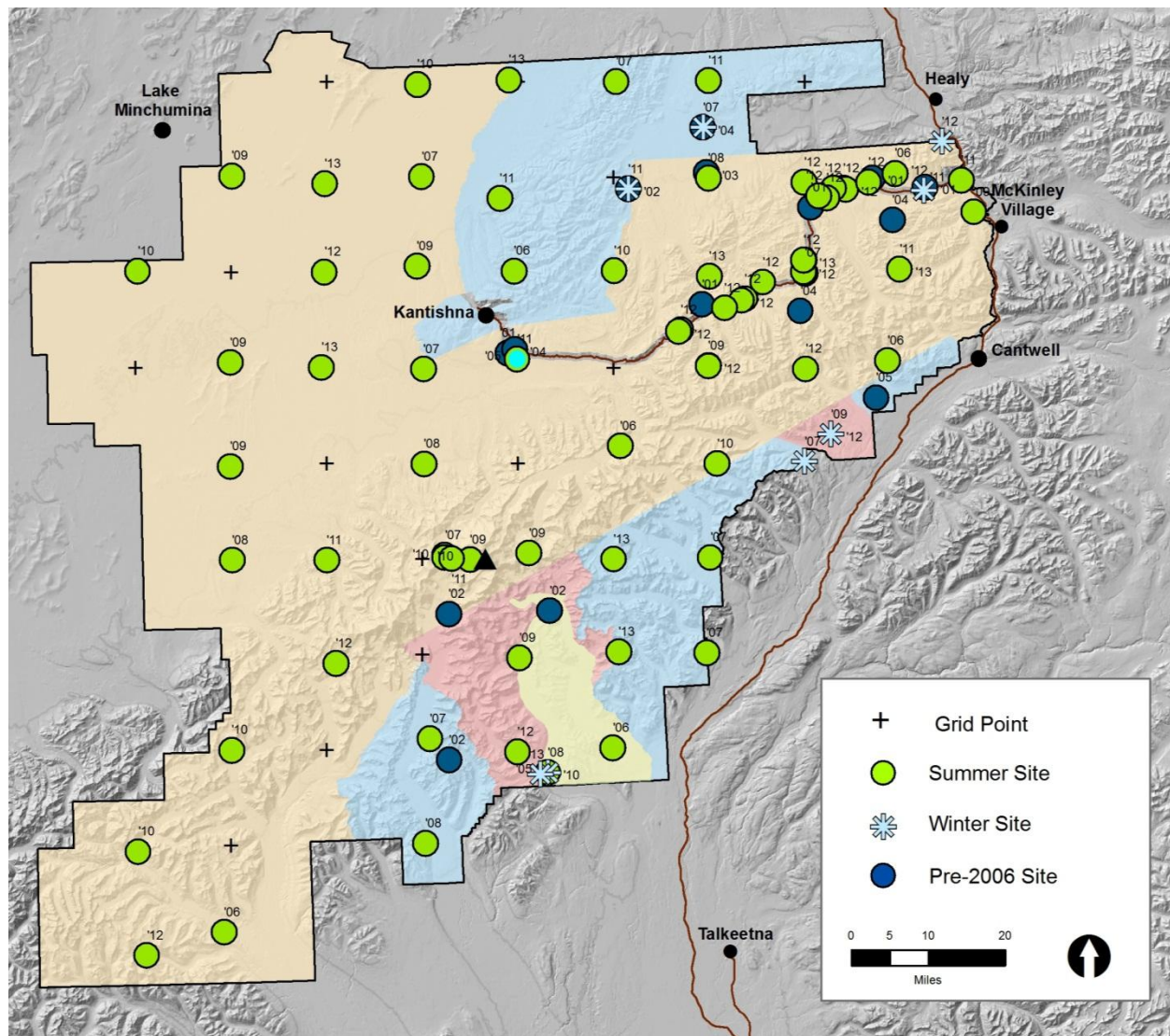
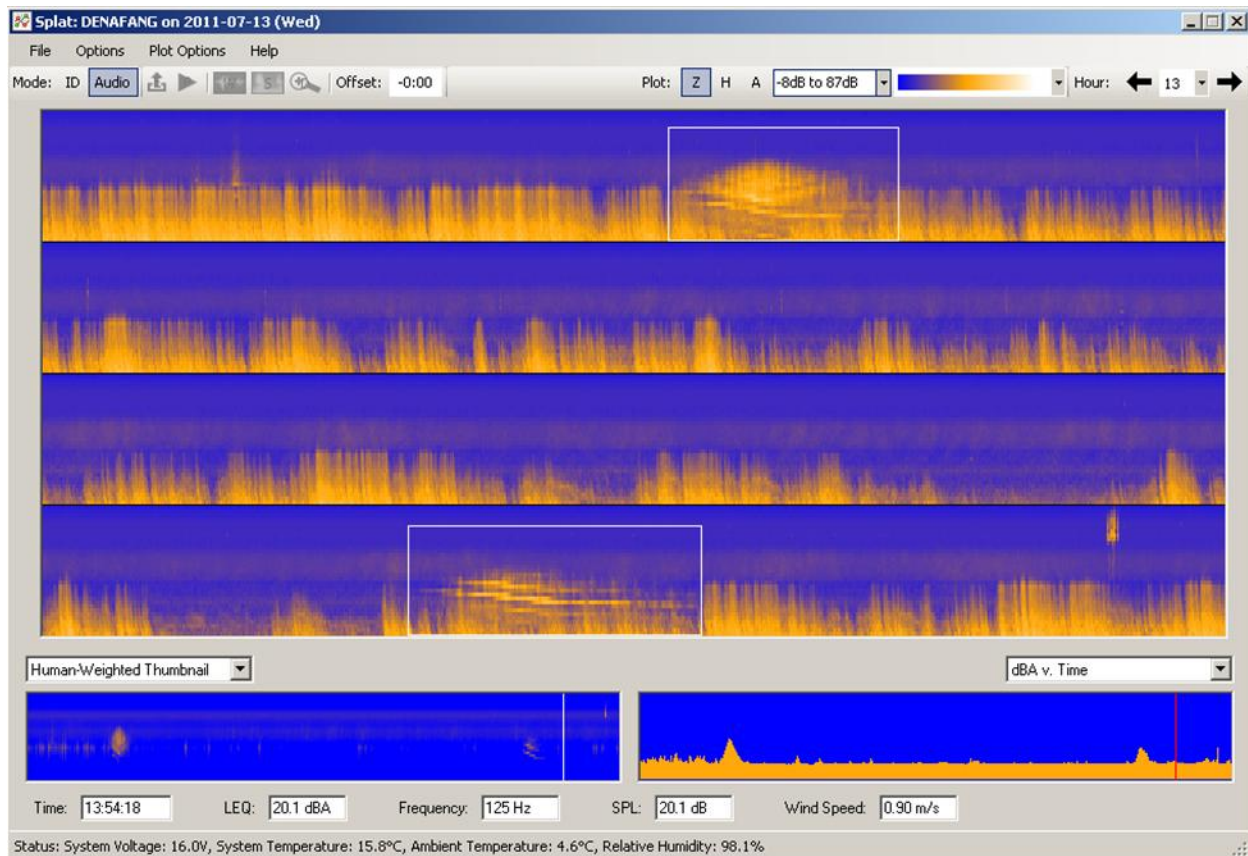


Figure APP C.1. Denali soundscape monitoring locations sampled from 2006 through 2013.

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 2013 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

- \$13,000 Helicopter

Equipment and Supplies

- \$21,000

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 2013 season required eight helicopter flights totaling 13.0 hours of flight time. For the use of the contracted Hughes 500-D, and AStar B3 flight time, availability and OAS costs totaled \$13,044.98. 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
05/09/2013	AStar B3	MLEE, UPEL, TOKO	1.4	\$2427.57
06/08/2013	AStar B3	MLEE, UPEL + glaciology	Partial flight time shared with SAR, 0.9	\$594.00
07/07/2013	AStar B3	MLEE		\$1052.50
05/31/2013	Hughes 500-D	FLUM, LMcR + archeology	2.4	\$2165.50
07/03/2013	Hughes 500-D	LMcR, FLUM + stream ecology	1.8	\$1770.00
07/04/2013	Hughes 500-D	BICR	1.9	\$1803.50
08/01/2013	Hughes 500-D	BICR, CARL	1.8	\$1817.24
08/23/2013	Hughes 500-D	BICR	1.7	\$1414.67
TOTAL			13.0	\$13,044.98

Table APP F.2. For comparison of use in 2013 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)
2013	9	7 (78% by air)	8 (0.88 stations per flight)	13.0 (1.9 flight hours per station + shared work)

Appendix G. Bus Idle Tests / Wildlife Stop Simulation

On September 18th 2013, stationary idling measurements were conducted on select models from the bus fleet. These tests sought to simulate soundscape conditions of a wildlife stop along the road corridor. Ideally, quieter conditions during wildlife stops should improve experiences for wildlife and visitor alike - by minimizing stress for the first and by providing a more intimate sensory experience for the latter.

Overall, eight buses were tested, two of which were equipped with hybrid technology. A commercial driver for Aramark/Doyon Joint Venture worked to position and operate buses for the measurements. Tests began at 07:30 and ended at 15:30.

Table APP G.1. Bus idle tests in sequential order.

Test #	Bus #	Make / Model	Engine Capacity (L)
1	888	International Max Force HC (hybrid)	7.6
2	559	Bluebird All American	6.7
3	886	International Max Force HC (hybrid)	7.6
4	299	International Max Force	10
5	296	Freightliner B2	7.4
6	294	Freightliner FS65	6.4
7	153	Thomas Saf-T-Liner HDX	4.8
8	557	Thomas Saf-T-Liner MVP EF	5.9

These eight buses (seven models) were tested using the following procedure:

1. Tests were conducted in the parking lot in front of the Denali Backcountry Information Center (BIC) after the lot was closed for the season. This gave a large, flat, open space to conduct measurements. The front of a specific parking space was marked with a traffic cone. Before each test began, the bus of interest was pulled into the space with its nose flush to the cone. *See Figure APP G.1 for a photograph of the test conditions.*
2. From the center-point of the parking space, a transect was run perpendicularly out from the bus. Along this transect two sound monitoring stations were deployed, at 23 and 41 m. The 41 m deployment approximates conditions of the road test. (At 134.5 feet, it is very close to the average distance stations were deployed from buses travelling the road – about 143 ± 10 feet.) The station at 23 meters is approximately half that distance, but still within the far field for frequencies greater than 30 Hz.
3. A weather monitoring site was included at the farther station (41 m), because propagation effects were more likely to affect measurements at distance. At the beginning of each test these data were field-proofed by recording temperature, wind speed and relative humidity from a handheld Kestrel 4000 weather meter.

4. During idling, a continuous record of sound pressure level in the cabin was also collected. Sound level meters were mounted to the luggage racks in both the front and rear of the bus. The microphone of these systems was pointed towards the seat. Though their position varied with the rack, most of the time the microphones were about a half a meter above ear height of a seated passenger. *See Figure APP G.2 for an example of positions for interior measurements.*
5. A continuous record of the entire eight-hour sampling period was collected by the exterior microphones and weather station. In order to delineate various test conditions for analysis, times were notated from a handheld GPS unit.
6. After installing and starting the interior meters, a ten-minute measurement of ambient was collected. If interruptions >3 dBA over the background occurred, their times were noted and these intervals were omitted from the analysis. This period serves as a control to the noise trial.
7. Immediately following the first ten minutes, the bus was started and another ten-minute measurement was conducted on the idling bus. Similar procedures for omitting interruptions were used for these measurements.
8. Photographs were taken of the setup, interior meters removed, and a new bus was moved into position.

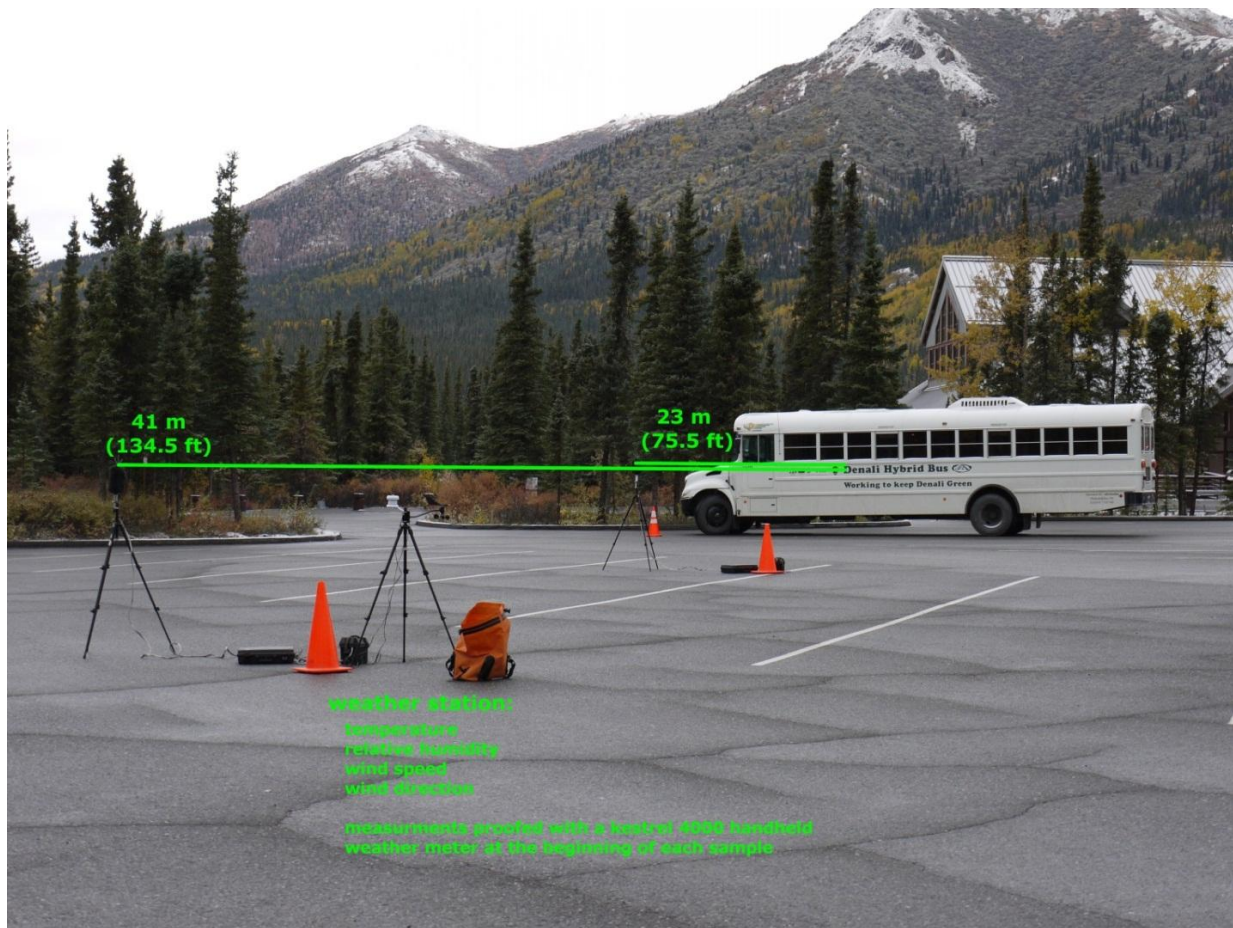


Figure APP G.1. Photograph showing orientation of bus and acoustic apparatus during idling tests in the BIC parking lot. One microphone was positioned 23 meters distant from the center of the bus body and a second microphone was positioned 41 meters distant. At the more distant location weather data (temperature, relative humidity, wind speed/direction), were also collected and proofed against measurements from a handheld weather unit.



Figure APP G.2. Photograph showing orientation of acoustic apparatus for interior measurements during bus idling. One sound level meter was positioned in the front of the bus, and another at the rear.

This experiment also served as an analytical tool to study how buses radiate energy into the environment. An often-employed assumption for the engines of individual road vehicles is spherical spreading in half-space. In other words, the scientist assumes that acoustical energy radiates from the engine equally in all directions above ground level. An equation for sound pressure level expected by spherical spreading at distance d_2 as deduced from the sound pressure level taken at distance d_1 is as follows:

$$L_1 - [10 \log_{10} (d_2/d_1)] = L_2$$

Setting d_1 to the distance of the first station (23 meters,) and d_2 to the distance of the second station (41 meters) it is possible to test this assumption. The root mean square error between the observed levels and those calculated is ± 1.8 dBA, which is greater than the range for which the instruments are certified (± 1.0 dBA). This suggests that spreading is may not be perfectly hemispherical, but the mathematical model is quite accurate nonetheless (see Figure APP G.3 for further confirmation of the equation's accuracy). Furthermore, the squared error for each individual test showed a generally decreasing pattern as the day progressed. This corresponded with an increase in temperature and wind speed and a decrease in relative humidity. One explanation for this observation is a transition from an inverted to a mixed atmosphere, which would minimize refractive effects within the direct locality of the bus (see Figure APP G.4 for a graphical depiction of this phenomenon).

Table APP G.2. Results from idle tests with expected levels assuming spherical spreading loss.

Test #	Bus #	LAeq at 23m	LAeq at 41m	Calculated LAeq at 41 m	Square Error	T (°C)	Wind Speed (m/s)	RH (%)
1	888	54.4	49.9	51.9	3.9	-0.9	0	97.0
2	559	56.7	51.4	54.2	7.7	-0.6	0	97.0
3	886	58.0	53.3	55.4	4.6	0.4	0	88.9
4	299	55.7	51.5	53.1	2.8	0.7	0	90.0
5	296	54.7	51.0	52.2	1.6	0.7	0.4	89.5
6	294	58.7	54.5	56.1	2.9	1.6	0.9	79.6
7	153	62.7	59.2	60.2	1.0	1.7	0.9	76.9
8	557	55.0	51.9	52.5	0.4	1.8	0.6	76.3

DENA Bus Idle Tests, 09/18/2013:

Observed SPL vs. Expected SPL at 41 meters

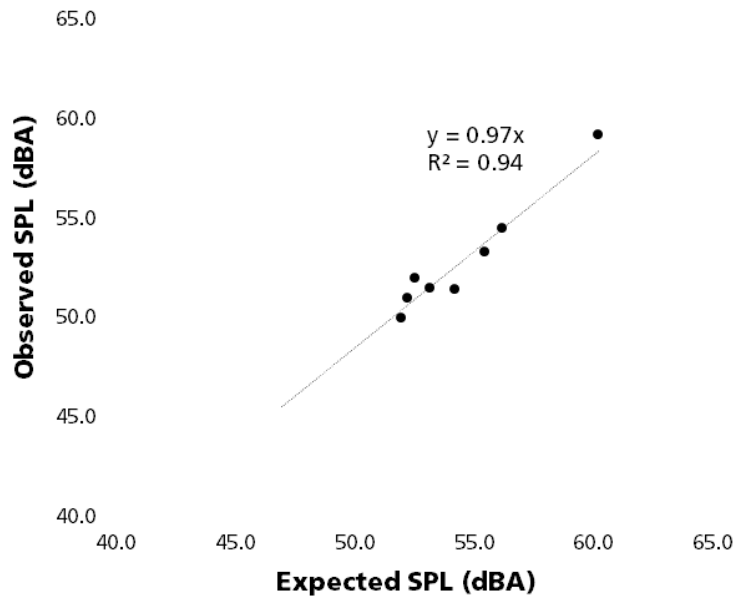


Figure APP G.3. Relation between sound pressure level measured at 41 meters and that expected due to hemispherical spreading. Note that the slope of a linear regression through this plot is very close to 1.0, as anticipated for an accurate theory.

DENA Bus Idle Tests, 09/18/2013:

Air Temperature vs. Deviation From Spherical Spreading

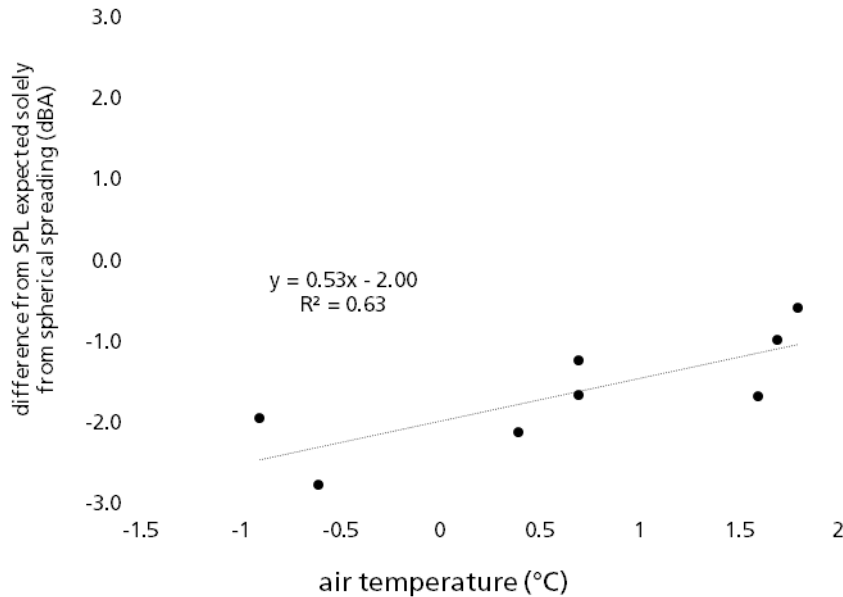


Figure APP G.4. Scatterplot showing relation between air temperature and the difference between measured and predicted sound pressure level at 41 meters from a bus. Note that as the day progressed air temperature increased while the difference between the measured and expected levels decreased.

Finally, it seems appropriate to put these measurements in context with the measurements of buses *in situ* along the road corridor in Igloo Canyon (see Figure APP G.5 for a graphical depiction). The clearest comparison, surprisingly, comes from using two different metrics. At the test sites on the road, buses were moving, and the maximum sound pressure level was measured to capture the greatest sound impact of the bus. Over many observations we expect to be measuring this maximum level at approximately the shortest distance – a perpendicular path from the microphone to the road. During the idle tests, buses were stationary. The distance between the engine and the microphone does not change, and so a more robust measure of how loud the vehicle is comes from taking an average over the entire period of steady idling. This average, called the equivalent sound pressure level (L_{eq}), should be more comparable to many passbys averaged together than a single momentary maximum during the idling period. In fact, this turns out to be true. A plot of engine volume vs. L_{eq} shows the same relation as engine volume vs. L_{max} – mainly that the larger bus engines produce less acoustic energy with the same workload. Because of a limited sample and the specific mechanics of each bus, the idling values are not nearly as correlated as passbys were ($R^2 = 0.40$ versus $R^2 = 0.79$ respectively), but the slope of the two relations is very similar (-1.21 dBA/L versus -1.35 dBA/L, respectively).

Engine Volume vs. Sound Pressure Level (Idling and Cruising)

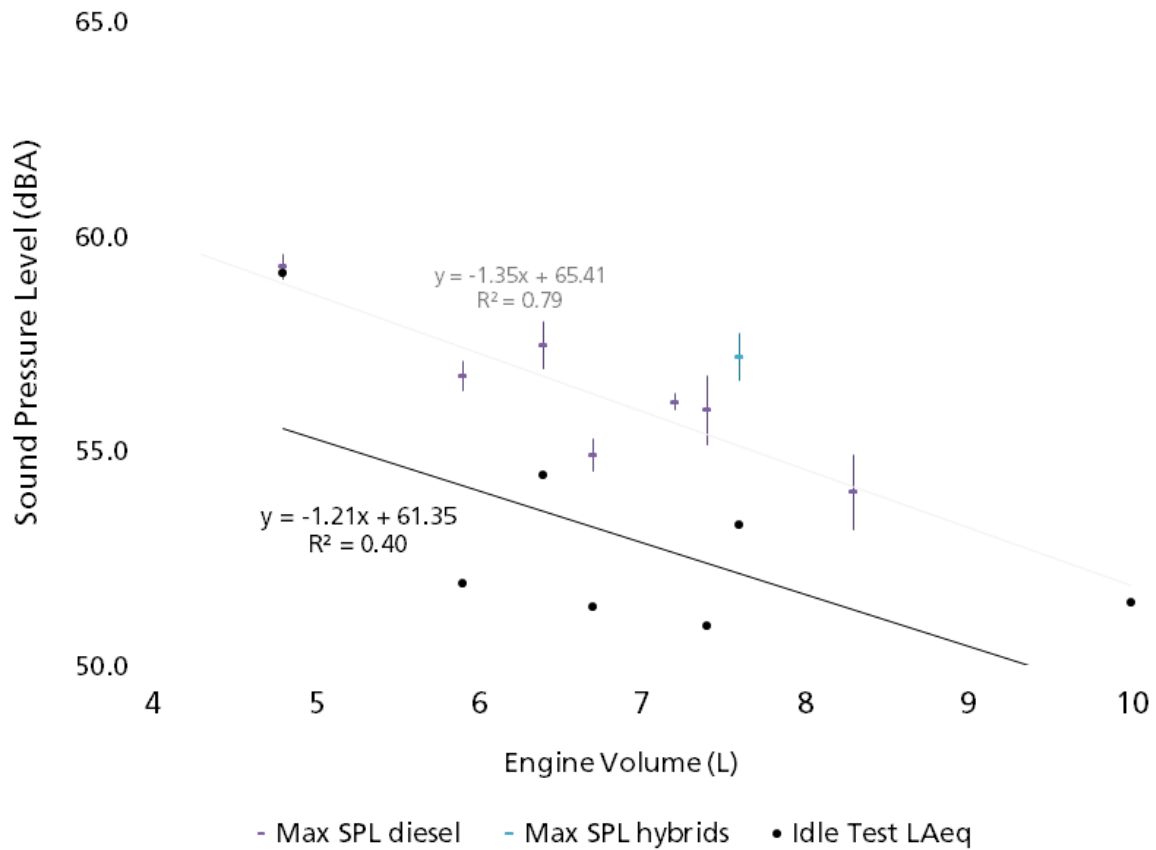


Figure APP G.5. A relation showing the effect of bus engine size on observed equivalent sound pressure levels during bus idle testing, 2013 (circles). For context, averaged maximum sound pressure levels observed for buses driving past the Igloo Canyon site in 2012 and 2013 are also shown (flat bars). Although idle levels were considerably lower than maximum levels *in situ*, they share the same slope when related to engine volume.

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

NPS 184/130651, November 2015

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