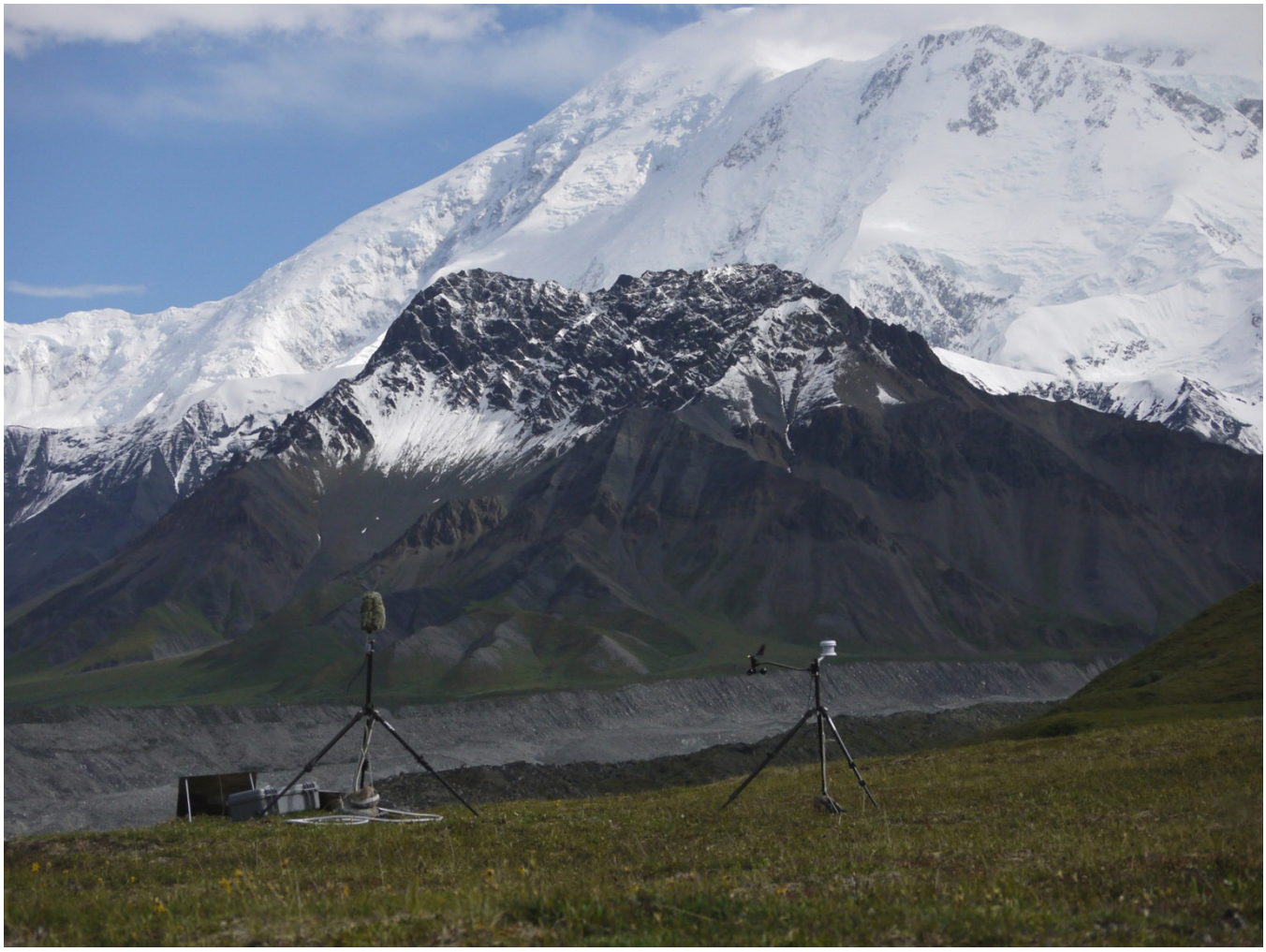
National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Acoustic Monitoring Report, Denali National Park and Preserve – 2011

Natural Resource Data Series NPS/DENA/NRDS—2013/474



ON THE COVER
A soundscape monitoring system collects data above the Herron Glacier, which flows off of the northwest face of Mount Foraker in Denali National Park.
NPS Photo by Davyd Betchkal

Acoustic Monitoring Report, Denali National Park and Preserve – 2011

Natural Resource Data Series NPS/DENA/NRDS—2013/474

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April 2013

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

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

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

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

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

Views, statements, findings, conclusions, recommendations, and data in this report are those of the author(s) and do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the National Park Service.

This report is available from the Denali website (http://www.nps.gov/dena/naturescience/index.htm), and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/).

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Contents

Page

Figures v

Tables ix

Executive Summary xi

Introduction 1

Soundscape Planning Authorities 1

Sampling Plan 2

Study Area 5

Methods 7

Automated Monitoring 7

Visual Analysis 7

Audibility Analysis 7

Calculation of Metrics 7

Results 9

Estok 11

Fang Mountain 20

Herron Glacier 29

McKinley Bar Trail 38

North Triple Lakes Trail 48

Stampede Airstrip 58

West Kantishna Hills 63

Conclusion 73

Acknowledgments 75

References 77

Contents (continued)

Page

Appendix A. Glossary of Acoustic Terms 79

Appendix B. BCMP Exceedence Maps 83

Appendix C. Map of All Soundscape Sampling Locations 87

Appendix D. Analyzing Audio with Visual Tools 89

Appendix E. Funding and Personnel 91

Appendix F. Project-Related Aircraft Use 93

Figures

Page

Figure 1. Map showing the coarse grid of sixty points to be sampled, marked by green squares..... 3

Figure 2. Acoustic monitoring sites in Denali National Park, 2011. 6

Figure 3. Exceedence levels for Estok. 14

Figure 4. Temporal audibility of sound sources at Estok, based on five seconds of audio every five minutes..... 15

Figure 5. Percentage of time audible for geophonic sounds at Estok. 16

Figure 6. Percentage of time audible for biophonic sounds at Estok. 16

Figure 7. Audibility of aircraft noise for an average day, by hour, at Estok. 17

Figure 8. Audibility of aircraft noise at Estok. 17

Figure 9. Number of aircraft noise events identified per day at Estok. 18

Figure 10. Hourly average and maximum aircraft event distribution at Estok. 18

Figure 11. Maximum one-second SPL for each aircraft event identified at Estok. 19

Figure 12. Exceedence levels for Fang Mountain..... 23

Figure 13. Temporal audibility of sound sources at Fang Mountain, based on five seconds of audio every five minutes..... 24

Figure 14. Percentage of time audible for geophonic sounds at Fang Mountain..... 25

Figure 15. Percentage of time audible for biophonic sounds at Fang Mountain 25

Figure 16. Audibility of aircraft noise for an average day, by hour, at Fang Mountain. 26

Figure 17. Audibility of aircraft noise at Fang Mountain. 26

Figure 18. Number of aircraft noise events identified per day at Fang Mountain. 27

Figure 19. Hourly average and maximum aircraft event distribution at Fang Mountain. 27

Figure 20. Maximum one-second SPL for each aircraft event identified at Fang Mountain. 28

Figures (continued)

Page

Figure 21. Exceedence levels for Herron Glacier. 32

Figure 22. Temporal audibility of sound sources at Herron Glacier, based on five seconds of audio every five minutes 33

Figure 23. Percentage of time audible for geophonic sounds at Herron Glacier. 34

Figure 24. Percentage of time audible for biophonic sounds at Herron Glacier. 34

Figure 25. Audibility of aircraft noise for an average day, by hour, at Herron Glacier. 35

Figure 26. Audibility of aircraft noise at Herron Glacier. 35

Figure 27. Number of aircraft noise events identified per day at Herron Glacier. 36

Figure 28. Hourly average and maximum aircraft event distribution at Herron Glacier. 36

Figure 29. Maximum one-second SPL for each aircraft event identified at Herron Glacier. 37

Figure 30. Exceedence levels for McKinley Bar Trail. 41

Figure 31. Temporal audibility of sound sources at McKinley Bar Trail, based on five seconds of audio every five minutes 42

Figure 32. Temporal audibility of sound sources at McKinley Bar Trail. 43

Figure 33. Percentage of time audible for biophonic sounds at McKinley Bar Trail. 43

Figure 34. Audibility of aircraft noise for an average day, by hour, at McKinley Bar Trail. 44

Figure 35. Audibility of vehicle noise for an average day, by hour, at McKinley Bar Trail. 44

Figure 36. Audibility of aircraft noise at McKinley Bar Trail. 45

Figure 37. Audibility of vehicle noise at McKinley Bar Trail. 45

Figure 38. Number of aircraft noise events identified per day at McKinley Bar Trail. 46

Figure 39. Hourly average and maximum aircraft event distribution at McKinley Bar Trail. 46

Figures (continued)

Page

Figure 40. Maximum one-second SPL for each aircraft event identified at McKinley Bar Trail. 47

Figure 41. Maximum one-second SPL for each vehicle event identified at McKinley Bar Trail. 47

Figure 42. Exceedence levels for North Triple Lakes Trail. 51

Figure 43. Temporal audibility of sound sources at North Triple Lakes Trail, based on five seconds of audio every five minutes 52

Figure 44. Percentage of time audible for geophonic sounds at North Triple Lakes Trail. 53

Figure 45. Percentage of time audible for biophonic sounds at North Triple Lakes Trail. 53

Figure 46. Audibility of aircraft noise for an average day, by hour, at North Triple Lakes Trail. 54

Figure 47. Audibility of aircraft noise at North Triple Lakes Trail. 54

Figure 48. Audibility of vehicle noise for an average day, by hour, at North Triple Lakes Trail. 55

Figure 49. Audibility of vehicle noise at North Triple Lakes Trail. 55

Figure 50. Number of aircraft noise events identified per day at North Triple Lakes Trail. 56

Figure 51. Hourly average and maximum aircraft event distribution at North Triple Lakes Trail. 56

Figure 52. Maximum one-second SPL for each aircraft event identified at North Triple Lakes Trail. 57

Figure 53. Maximum one-second SPL for each vehicle event identified at North Triple Lakes Trail. 57

Figure 54. Exceedence levels for Stampede Airstrip. 60

Figure 55. Audibility of aircraft noise for an average day, by hour, at Stampede Airstrip. 60

Figure 56. Audibility of aircraft noise at Stampede Airstrip. 61

Figures (continued)

Page

Figure 57. Number of aircraft noise events identified per day at Stampede Airstrip. 61

Figure 58. Hourly average and maximum aircraft event distribution at Stampede Airstrip. 62

Figure 59. Maximum one-second SPL for each aircraft event identified at Stampede Airstrip. 62

Figure 59. Maximum one-second SPL for each aircraft event identified at Stampede Airstrip. 63

Figure 60. Exceedence levels for West Kantishna Hills. 66

Figure 61. Temporal audibility of sound sources at West Kantishna Hills, based on five seconds of audio every five minutes. 67

Figure 62. Percentage of time audible for geophonic sounds at West Kantishna Hills. 68

Figure 63. Percentage of time audible for biophonic sounds at West Kantishna Hills. 68

Figure 64. Audibility of aircraft noise for an average day, by hour, at West Kantishna Hills. 69

Figure 65. Audibility of aircraft noise at West Kantishna Hills. 69

Figure 66. Number of aircraft noise events identified per day at West Kantishna Hills. 70

Figure 67. Hourly average and maximum for aircraft events at West Kantishna Hills. 70

Figure 68. Maximum one-second SPL for each aircraft event identified at West Kantishna Hills 71

Tables

Page

Table 1. Median natural sound, existing ambient sound, and mean aircraft statistics for all sites xi

Table 2. Sites sampled in 2011. 5

Table 3. Median natural and existing ambient sound levels and mean aircraft statistics for all sites. 9

Executive Summary

Park staff deployed acoustic monitoring systems to eight locations in Denali National Park and Preserve in 2011. The purpose of this monitoring effort was to inventory the ambient acoustic conditions and amount of non-natural sound in Denali National Park as called for in the 2006 Backcountry Management Plan. Data collected included existing ambient sound pressure levels, natural ambient sound pressure levels, percentage of time audible, and loud acoustic event statistics for intrinsic and extrinsic sound sources. Deployed systems were configured to log sound pressure levels every second and continuous mp3 audio recordings 24 hours per day. These data serve as a permanent record of existing acoustical conditions at these locations for the summer of 2011.

Table 1 shows summarized results of 2011 monitoring, including ambient and natural ambient sound statistics in dBA (A-weighted decibels) and average percentage of time audible, number of events per day, and the average maximum sound pressure level (SPL) for aircraft sound sources, which are the most prominent of extrinsic sounds occurring at these sites. Median ambient (L_{50}) describes the acoustical environment as is, including both natural and extrinsic sounds. Natural ambient (L_{nat}) estimates what the acoustical environment might sound like 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.

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

Table 1. Median natural sound, existing ambient sound, and mean aircraft statistics for all sites*.

Site Name	L_{nat}	L_{10}	L_{50}	L_{90}	% Time Aircraft	# Aircraft/Day	Aircraft Max SPL
Estok	24.55	28.01	24.65	22.82	4.0	12.0	38.9
Fang Mountain	21.94	30.57	22.36	19.54	10.4	34.1	40.6
Herron Glacier	33.75	35.25	33.76	32.31	0.7	3.3	40.9
McKinley Bar Trail	26.58	30.55	27.32	24.44	7.2	14.3	39.6
North Triple Lakes Trail	43.86	45.48	44.10	43.43	17.9	75.9	53.8
Stampede Airstrip[1]	**	20.88	20.42	19.77	2.7	6.6	35.1
West Kantishna Hills	19.26	24.59	19.36	17.36	2.4	7.5	32.6

*L_{nat}, L_{10}, L_{50}, L_{90}, and SPL in dBA. [1] : Winter season site.
** Due to software issues, L_{nat} was not calculable at this site.

An eighth site was attempted at 11,000' camp on Mt. McKinley's West Buttress climbing route. The equipment for this installation was packaged to be light weight and compact, powered by lithium ion batteries. Despite insulation from the cold, the batteries failed after three days of use. These three days of data do not cover the range of variability in acoustic conditions likely experienced at this location, which are influenced by wind, cloud cover, flight schedules, etc. For that reason, the decision was made to drop this small dataset from subsequent analyses.

Overall, the acoustic conditions measured in 2011 varied. The natural ambient level at North Triple Lakes Trail was relatively high due to the proximity of the equipment to the moving water

of Riley Creek. A high ambient level masks quieter overflights, and the average maximum sound pressure level for events in these locations is also higher for that reason. In addition, the North Triple Lakes Trail site had a tremendous amount of aircraft traffic – the highest rate measured at any place in the park so far. By contrast, the Herron Glacier site was among the most pristine soundscapes measured in the park so far – a quality shared by several other monitoring locations in the west-central portion of the Denali Wilderness. The quietest average natural ambient level on record in 2011 was at West Kantishna Hills.

Introduction

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

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

The primary purpose behind the Denali soundscape study has been to measure the level of influence overflight traffic and snowmachine traffic has on the Park's soundscape. An understanding of the natural soundscape is necessary to evaluate the level of impact human-generated sounds may have on this important resource. The natural soundscape is generally comprised of two main sound categories, physical and biological. Physical sounds are created by physical forces (wind, rock fall, rivers, etc.), whereas biological sounds are created by organisms (birds, frogs, plants, etc.). The presence and abundance of sounds from these two categories is used to characterize different habitats (Dunholter et al. 1989). Different habitats have specific soundscape characteristics that are an important attribute of the natural system, with distinct impacts on the human perception of the environment. Impacts on the natural soundscape and on visitor experiences come from extrinsic human-generated sounds.

Soundscape Planning Authorities

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

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

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

It should be noted that the Management Policy 8.2.3: Use of Motorized Equipment states "the natural ambient sound level—that is, the environment of sound that exists in the absence of human-caused noise—is the baseline condition, and the standard against which current conditions in a soundscape [acoustic resource] will be measured and evaluated" (NPS 2006b). However, the desired acoustic condition may also depend upon the resources and the values of the park. For instance, "culturally appropriate sounds are important elements of the national park experience in many parks" (NPS 2006b). In this case, "the Service will preserve soundscape resources and values of the parks to the greatest extent possible to protect opportunities for appropriate transmission of cultural and historic sounds that are fundamental components of the purposes and values for which the parks were established" (NPS 2006b).

Sampling Plan

Denali's soundscape sampling plan was designed using a coarse grid derived from the Long Term Ecological Monitoring (LTEM) grid (NPS 2006c). The number of points sampled in the coarse grid was driven by the number of acoustic monitoring stations available (five), 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). To maximize the spatial coverage with only five stations it was decided to sample two locations through the entire field season, while rotating three stations over two sites each – two months at each site. Six of the two month-long sites would be established on the LTEM sampling grid, with two free to allow park managers to collect data at sites of specific interest which may not fall on a grid point. As such, six LTEM grid locations will be sampled each year, with 60 grid points to be sampled overall (Figure 1). In addition, opportunistic sampling may be attempted during the winter months as permitted by funding, personnel, and ease of access to provide an

[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.

indication of acoustic conditions outside the field/tourist season and to determine winter use patterns.

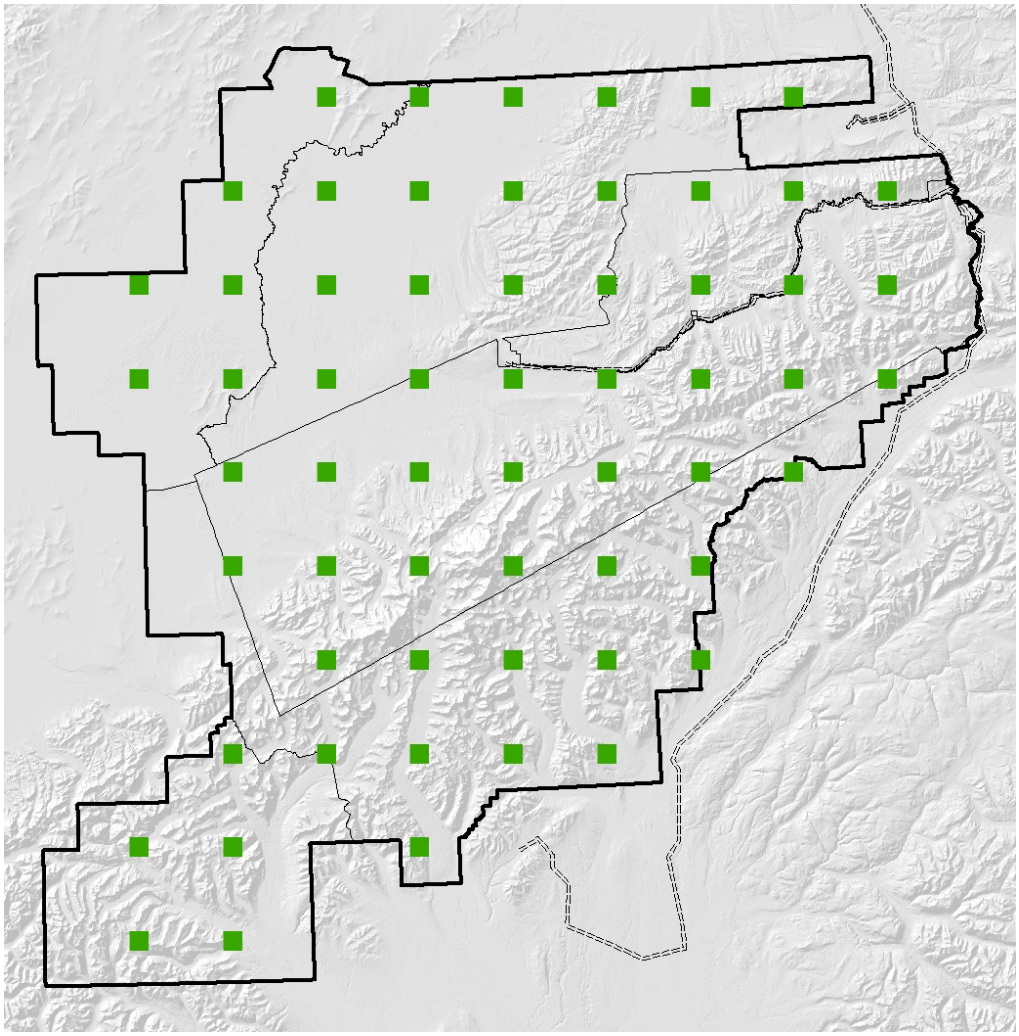


Figure 1. Map showing the coarse grid of sixty points to be sampled, marked by green squares.

Study Area

Park staff deployed acoustic monitoring systems to seven locations in Denali National Park in 2011, as shown in Table 3 and Figure 2.

Table 2. Sites sampled in 2011.

Site Location	Elevation (meters)	Latitude	Longitude	Sampling Period*	Analyzed Days
Estok	452	63.94298	-149.96233	Jul-31 to Sept-10	27
Fang Mountain	1534	63.56616	-149.2056	June-30 to Aug-20	33
Herron Glacier	1115	63.07925	-151.66535	Jun-18 to Aug-27	34
McKinley Bar Trail	611	63.4407	-150.83578	Jun-01 to July-20	29
North Triple Lakes Trail	516	63.72408	-148.91745	Jun-19 to Aug-22	8
Stampede Airstrip [1]	566	63.74886	-150.33001	Jan-27 to Jun-18	30
West Kantishna Hills	467	63.7433	-150.87653	Jul-20 to Sept-10	49

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

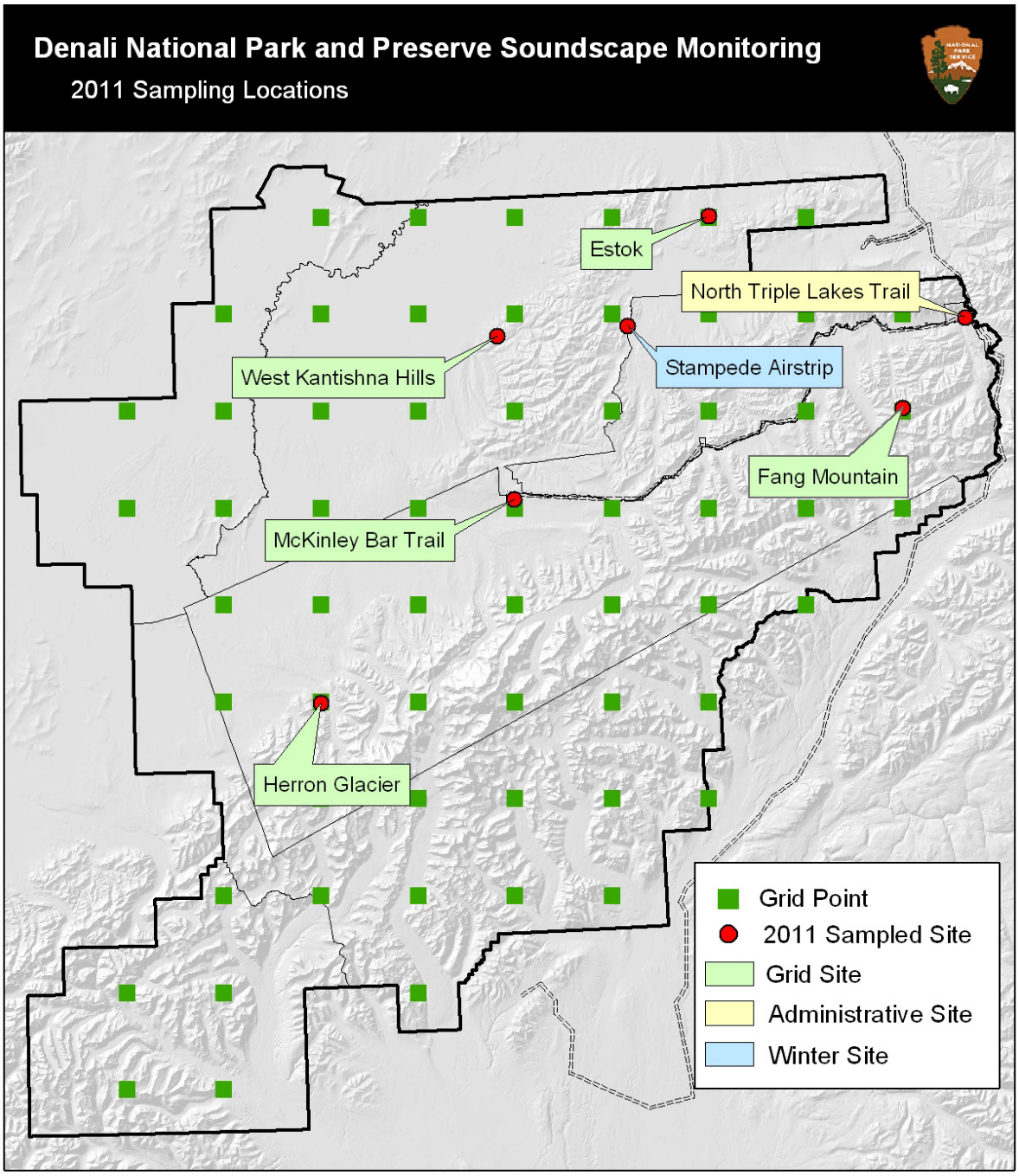


Figure 2. Acoustic monitoring sites in Denali National Park, 2011.

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 1992, 1968). To supplement the SPL data, Roland R-05 field recorders capture 64kpbs mp3 recordings via the Larson Davis 831 audio output.

Each Larson Davis sampling station consisted of:

- Microphone with environmental shroud and Rycote windscreen
- Preamplifier
- Roland R-05 mp3 recorder
- Solar panel and batteries
- Anemometer or Anemometer/Wind Vane/Temperature and Relative Humidity Probe

Each acoustic sampling station collected:

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

Visual Analysis

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

Audibility Analysis

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

Calculation of Metrics

Several metrics are calculated in order to provide some detail about the characteristics of the acoustical environment. The current status of the acoustical environment can be characterized by a number of measurements. These include sound pressure levels for each 1/3 octave band from 12.5 Hz to 20,000 Hz, overall broad-band sound pressure levels, and percent time audible durations for various sound sources. Two fundamental descriptors of the acoustic environment are existing ambient and natural ambient sound levels which are presented as exceedence levels (L_x). Equivalent to percentiles, exceedence levels represent the dBA exceeded x percent of the time during the given measurement period. For example, measured in dBA, the existing ambient

(L_{50}) is the sound level exceeded 50% of the time, or median sound level. It is the uncensored composite of all sounds at a site, both human caused and natural. The natural ambient (L_{nat}) estimates the acoustic environment without the contribution of anthropogenic sounds. L_{10} and L_{90} are also presented which describe the sound levels exceeded 10% and 90% of the time, respectively.

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

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

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

- NPS staff calculates the percentage, P_H, of all samples containing extrinsic sounds for each hour of the day both by listening to samples, or visually analyzing daily spectrograms.
- P_H is used to complete this formula for every hour in the dataset: $x = \frac{1 - P_H}{2} + P_H$
- Hourly x_H values are entered into a database of all octave band information.
- Example: if extrinsic sounds are audible 50% of the time (P_H =0.5), then x_H is 0.75.
- L_{nat} is computed as the sound level that is exceeded 100*x_H percent of the time. (In practice, Lnat is calculated by sorting the relevant sound level measurements and using xH 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. (NPS 2008)

Results

The following tables are summaries of the 2011 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 3) and other motorized sound sources (in Table 4). The 24-hour average noise-free interval describes the typical amount of time that can be expected between motorized events at any time of day. The median existing ambient level (L_{50}) describes the acoustical environment as it is directly observed, including both natural and extrinsic sounds. Natural ambient (L_{nat}) estimates what the magnitude of acoustical energy at the location might be 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.

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 3. Median natural and existing ambient sound levels and mean aircraft statistics for all sites.*

Site Name	L_{nat}	L_{10}	L_{50}	L_{90}	Avg. Noise Free Interval	% Time Audible, Aircraft	# Aircraft/Day	Aircraft Max SPL
Estok	24.55	28.01	24.65	22.82	1.96 hours	4.0	12.0	38.9
Fang Mountain	21.94	30.57	22.36	19.54	0.62	10.4	34.1	40.6
Herron Glacier	33.75	35.25	33.76	32.31	4.80	0.7	3.3	40.9
McKinley Bar Trail	26.58	30.55	27.32	24.44	1.75	7.2	14.3	39.6
North Triple Lakes Trail	43.86	45.48	44.10	43.43	0.29	17.9	75.9	53.8
Stampede Airstrip[1]	**	20.88	20.42	19.77	3.25	2.7	6.6	35.1
West Kantishna Hills	19.26	24.59	19.36	17.36	2.92	2.4	7.5	32.6

*L_{nat}, L_{10}, L_{50}, L_{90}, and SPL in dBA. Noise-Free Interval in hours.
** Due to software issues, L_{nat} was not calculable at this site.
[1] : Winter season site.

Table 4. Mean BCMP statistics* for vehicles at all sites.

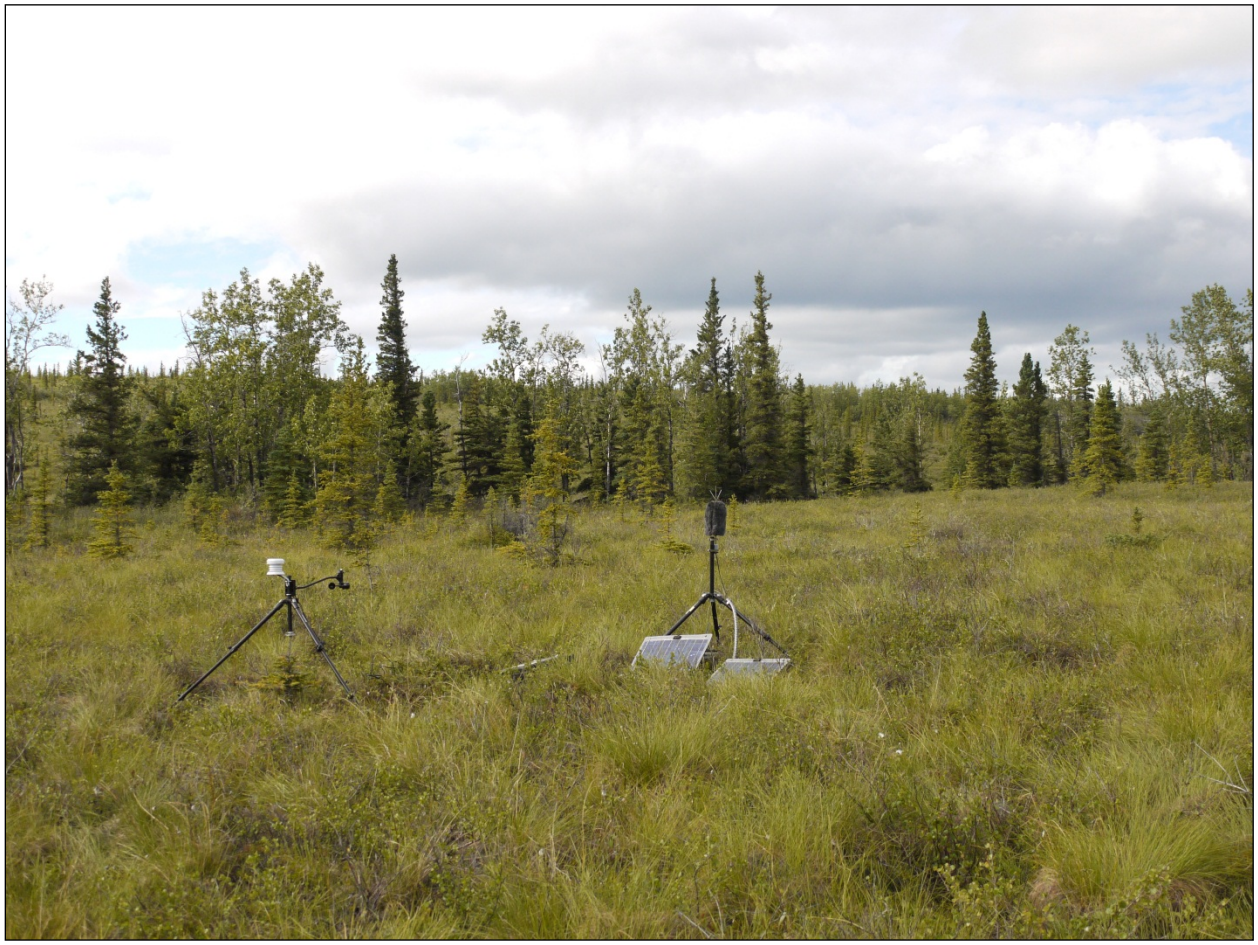
Site Name	% Time Vehicles	# Vehicles/ Day	Vehicle Max SPL
McKinley Bar Trail	26.58	30.55	27.32
North Triple Lakes Trail	43.86	45.48	44.10

*SPL in dBA.

An eighth site was attempted at 11,000' camp on Mt. McKinley's West Buttress climbing route. The equipment for this installation was packaged to be light weight and compact, powered by lithium polymer batteries. Despite insulation from the cold, the batteries failed after three days of use. These three days of data do not cover the range of variability in acoustic conditions likely experienced at this location, which are influenced by wind, cloud cover, flight schedules, etc. For that reason, the decision was made to drop this small dataset from subsequent analyses.

The following summaries and figures represent the reduced data for each of the 2011 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 levels. (NPS 2006c)

Estok



Location Description: A deeply-tussocked meadow approximately 7 km northeast of Estok mountain and 4 km west of the Sushana River. The meadow was bounded by a tributary of the Toklat River approximately 60 meters to the west and by a vegetated slope 200 meters to the east.

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

Coordinates: Lat. 63.94298, Long. -149.96233

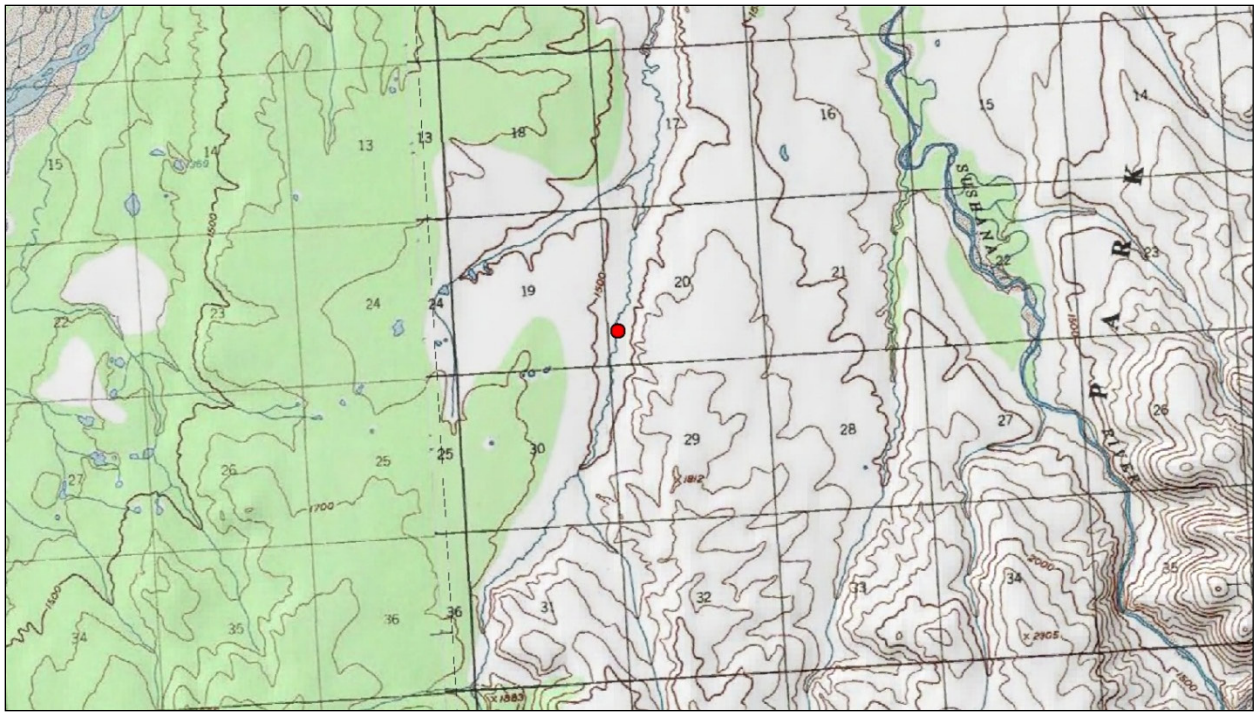
Elevation: 452 meters

BCMP Management Zone: Medium

Park Ecoregion: Lowland Floodplains & Terraces & Fans

Analysis Period: 01-August-2011 – 09-September-2011

Access: Helicopter

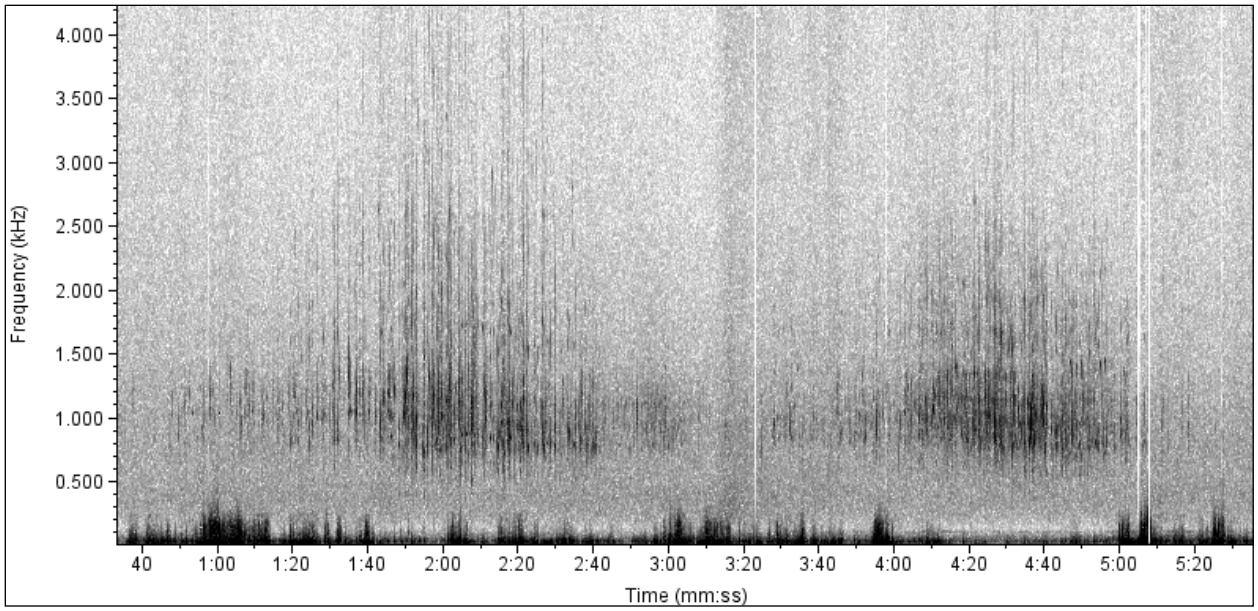


Summary/Notes: The purpose of the Estok location was to collect data at one of the long-term ecological monitoring (LTEM) grid points, as outlined in the above sampling plan. LTEM grid point #243 was stratified as a New Park location and randomly selected from all locations requiring aircraft access.

The unnamed tannic creek to the west of the station was continuously audible during the sampling period. Fringed with balsam poplar and spruce, it created a natural windbreak. This resistance made wind clearly audible on both site visits. Prior to reaching this break, wind was largely unobstructed as it moved across the Toklat Basin. For that reason it could be very forceful in the Estok area, and at times the sound of the creek was masked entirely by gusts. Most of the trees were balsam poplar, and so the platy rattling of their leaves was predominant over the wideband fizz of the spruce needles.

In contrast to the McKinley River, Herron River, Bearpaw River, or Riley Creek – all recorded in 2011 as well – the creek at Estok radiates a relatively small amount of acoustic energy. The speed, size, and proximity of the creek all combine on the record to create a crisp and detailed splash unlike any of the other recorded flows. Tannic lowland streams are less common than the larger, glacially fed streams in Denali and by their differences in genesis they seem to offer a different sonic texture as well.

Gray Jays (*Perisoreus canadensis*), Boreal Chickadees (*Poecile hudsonicus)*, and American Red Squirrels (*Tamiasciurus hudsonicus*) were all very vocal at this site. Later on in the sampling period Sandhill Cranes (*Grus canadensis*) were audible in migration. (The first acoustic detection of cranes was 09/02/2011.) Avian sounds were primarily calls, with the total number of clips containing calls being similar on most days.



Spectrogram 1. Two flocks of Sandhill Cranes (*Grus canadensis*) pass over the Estok area. The spectrogram begins at 17:20:26 on 09/02/2011.

The most commonly heard sounds at this site were flowing water (audible 98.6% of the time – it was masked by wind the remaining 1.4% of the time), wind (36.8%), birds (17.9% – but only 2% of these clips were song), and rain (4.9%). Human made sound was audible 4.0% of the time on average; all of it was generated by aircraft. This is equivalent to 58.2 minutes each day, or approximately 12 overflights a day. Conditions exceeded the BCMP percent audible standard 9% of the time, number of events per day 52% of the time, and maximum SPL 42% of the time.

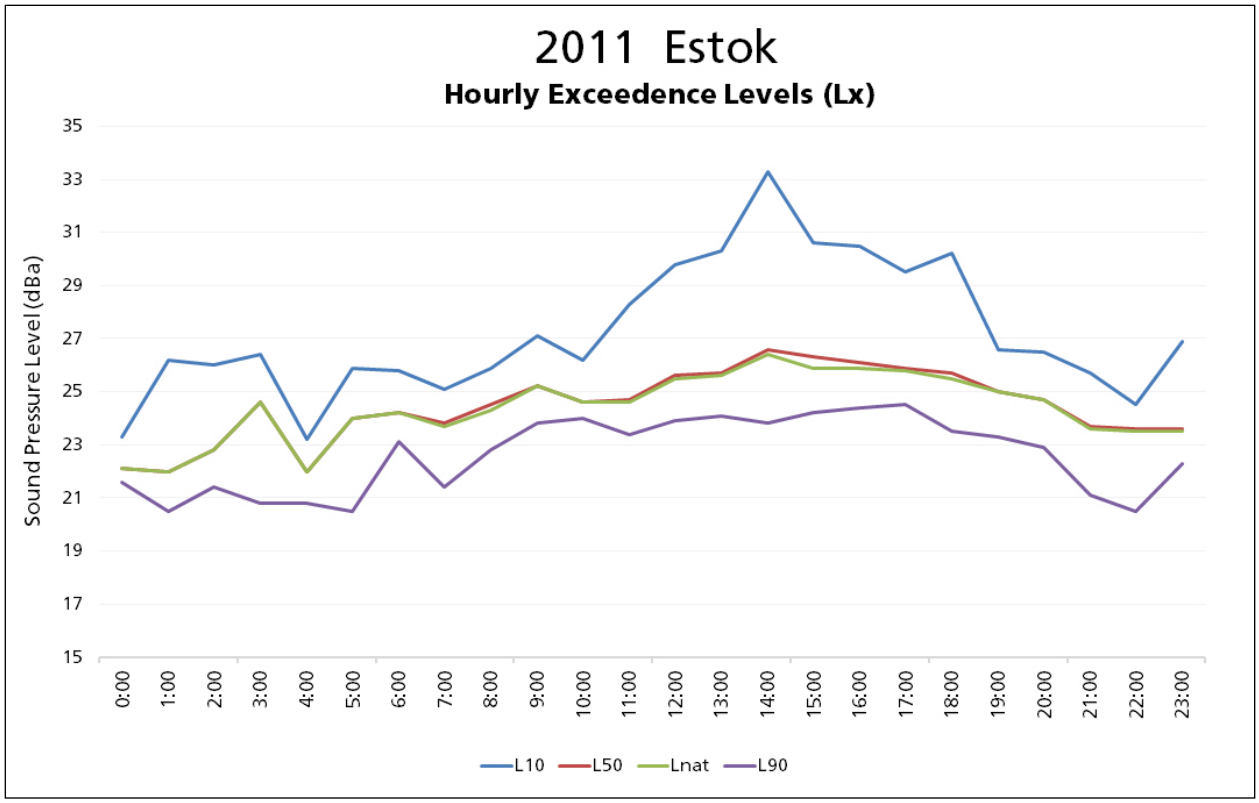


Figure 3. Exceedence levels for Estok.

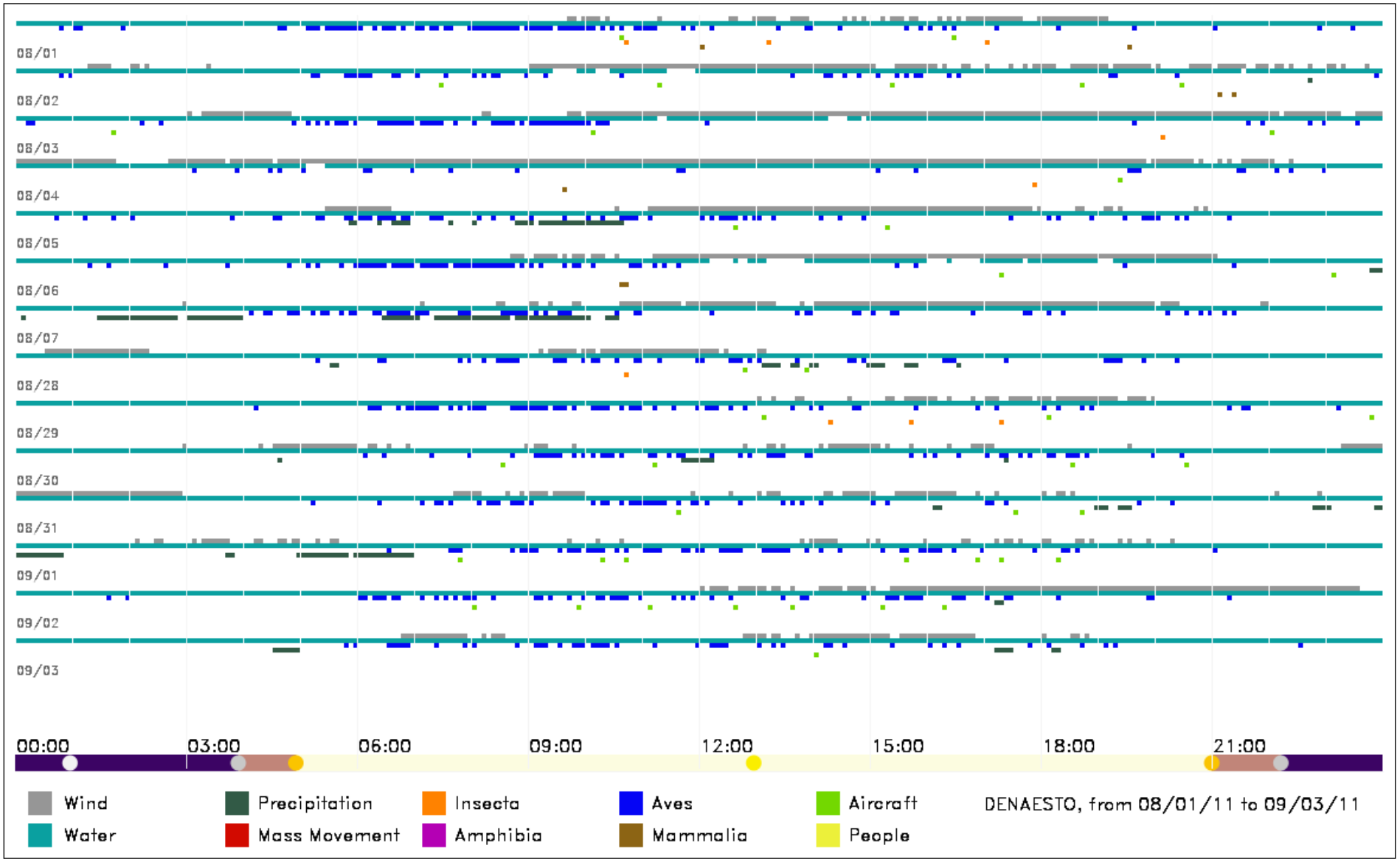


Figure 4. Temporal audibility of sound sources at Estok, based on five seconds of audio every five minutes. The bar along the time axis indicates the average light conditions during the sampling period. The orange circles are sunrise/sunset, and the gray circles are the beginning and end of civil twilight.

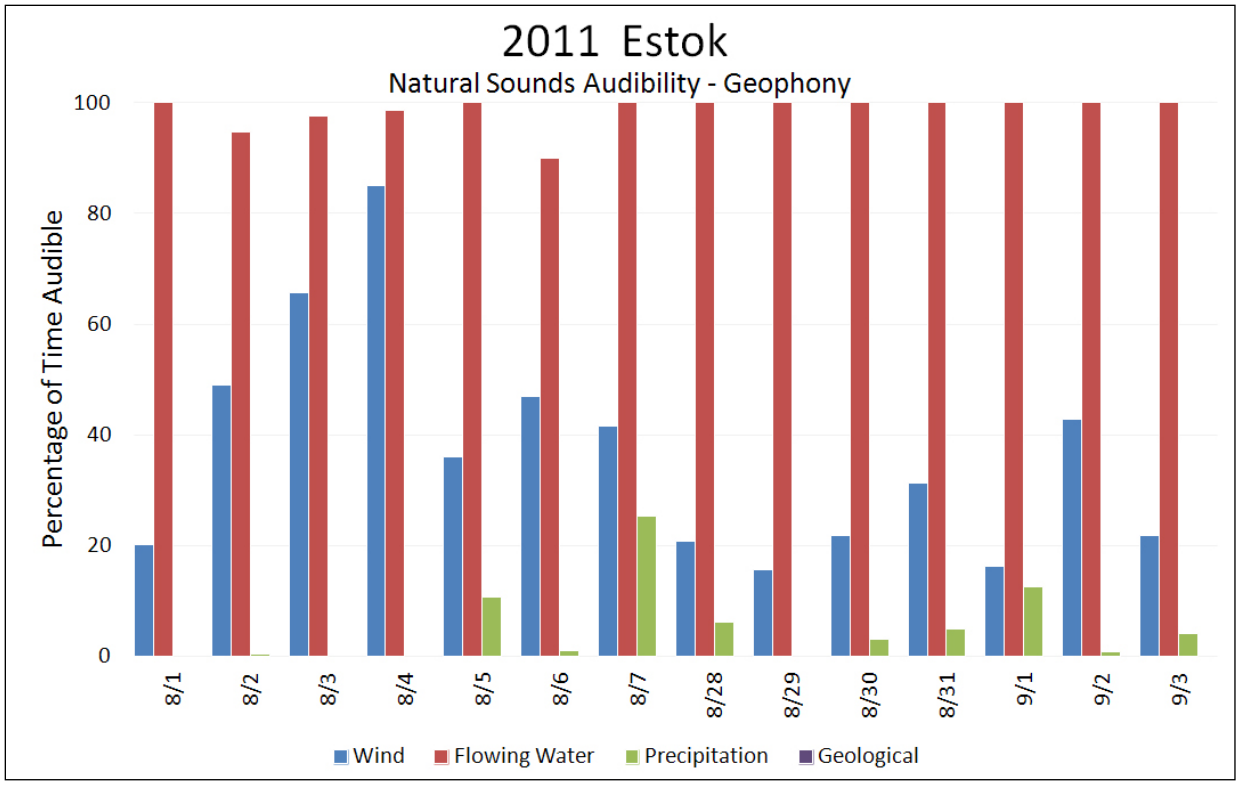


Figure 5. Percentage of time audible for geophonic sounds at Estok.

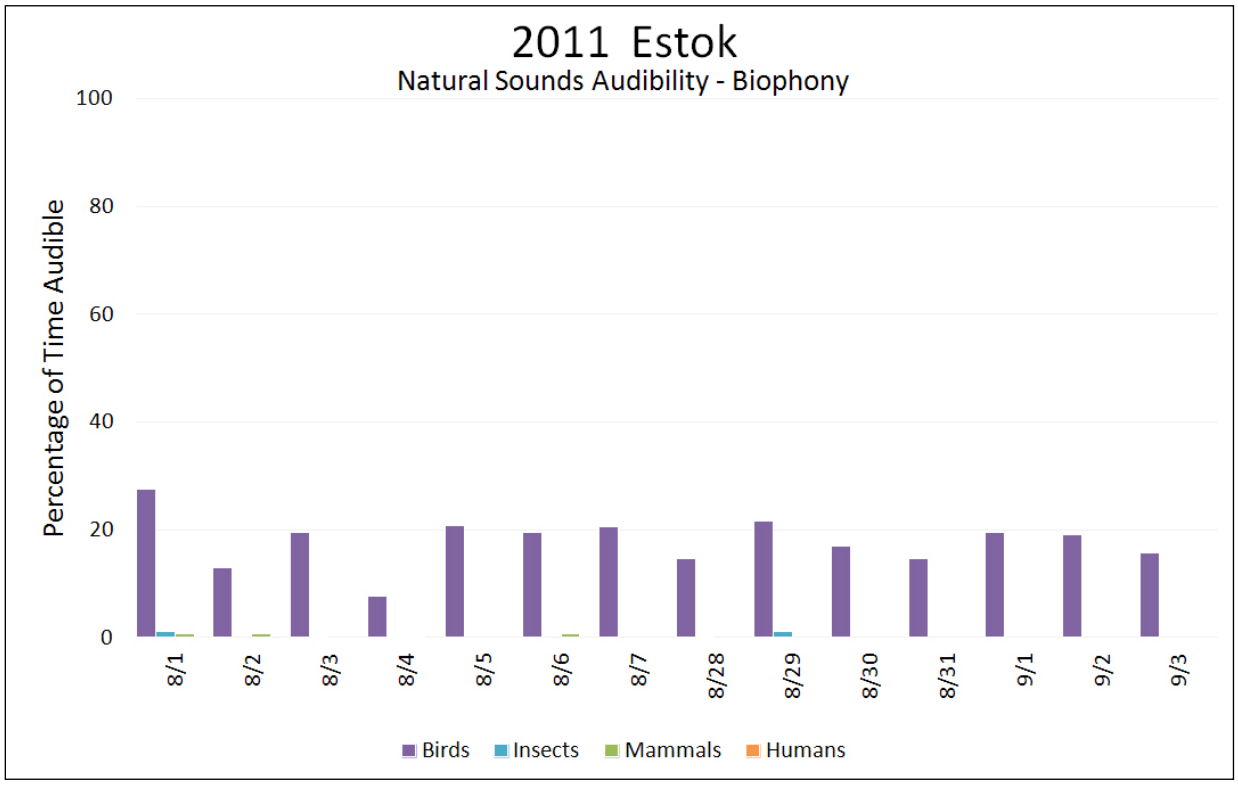


Figure 6. Percentage of time audible for biophonic sounds at Estok.

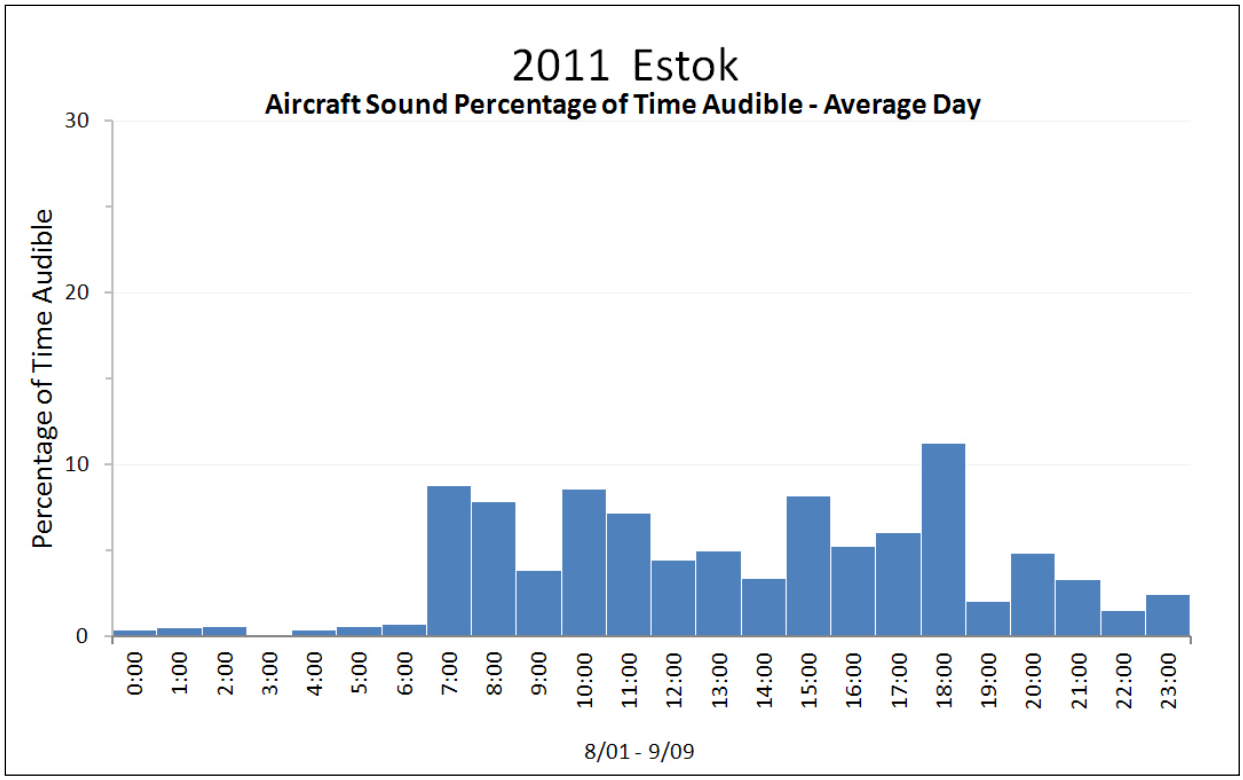


Figure 7. Audibility of aircraft noise for an average day, by hour, at Estok.

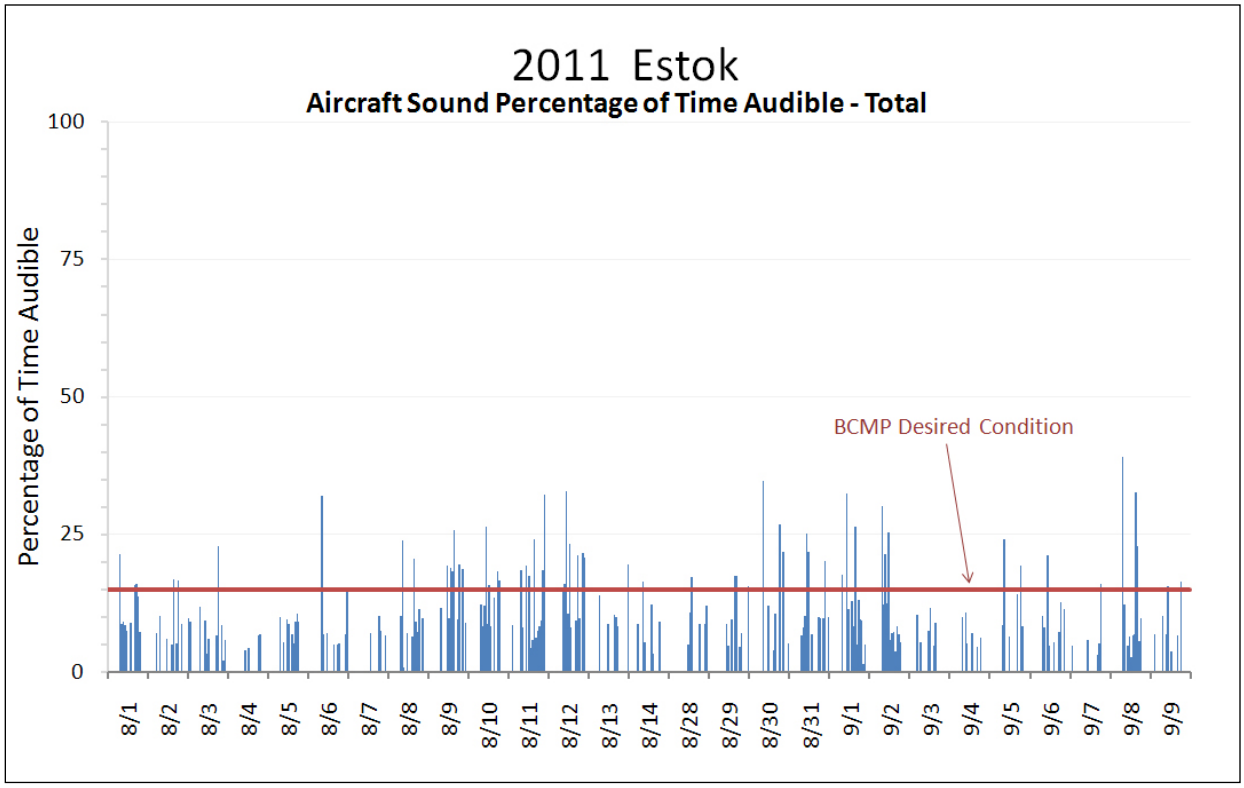


Figure 8. Audibility of aircraft noise at Estok.

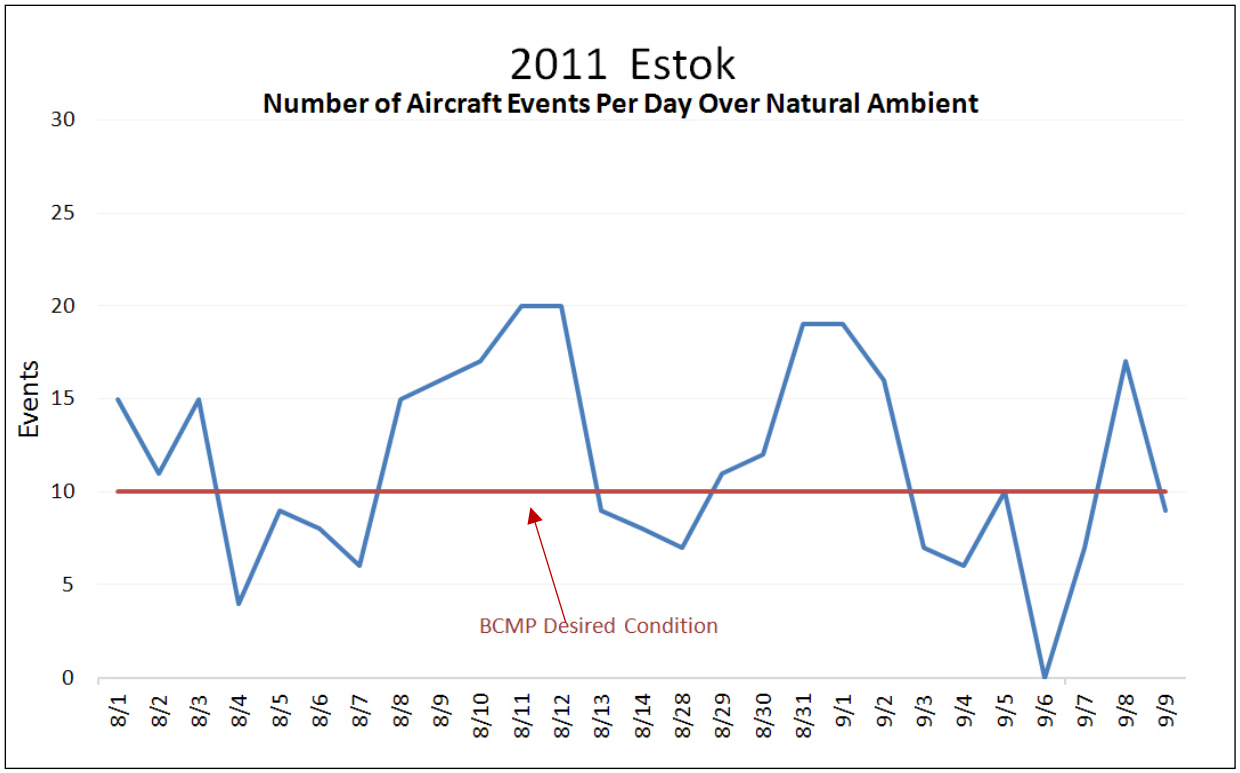


Figure 9. Number of aircraft noise events identified per day at Estok.

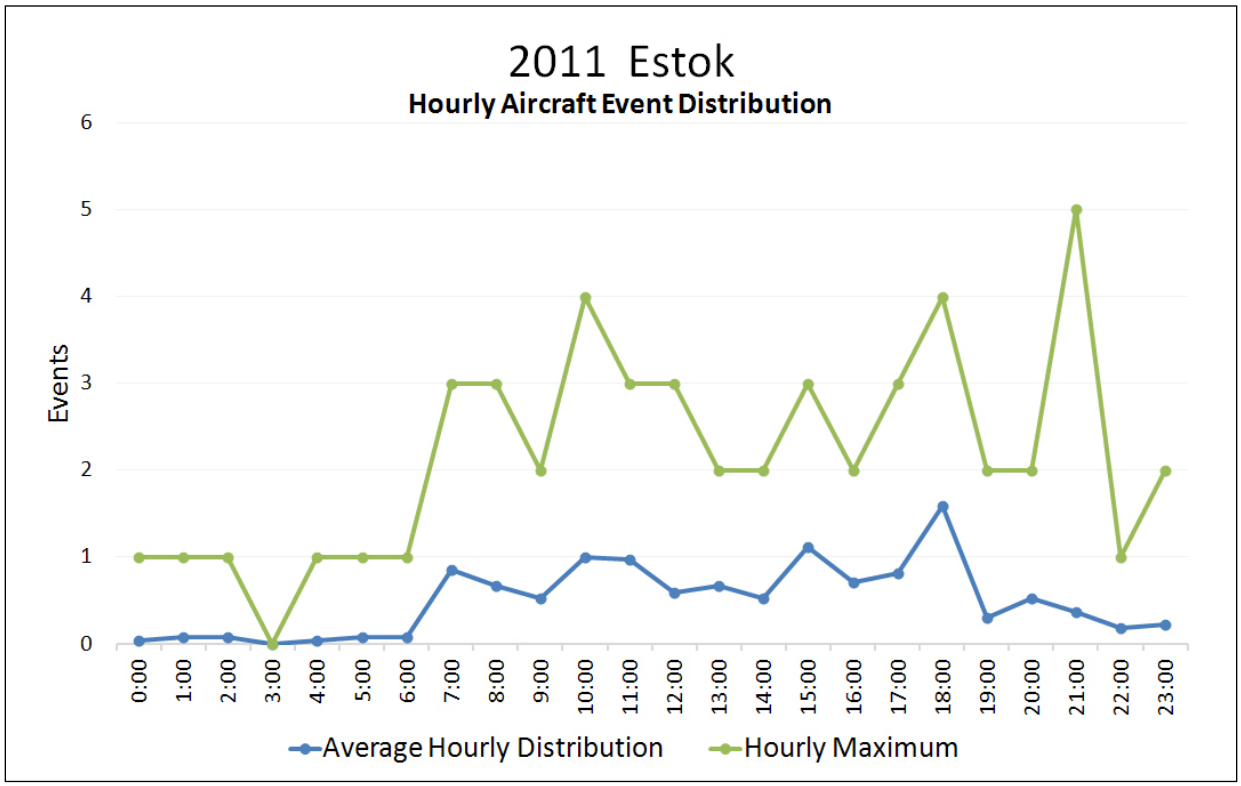


Figure 10. Hourly average and maximum aircraft event distribution at Estok.

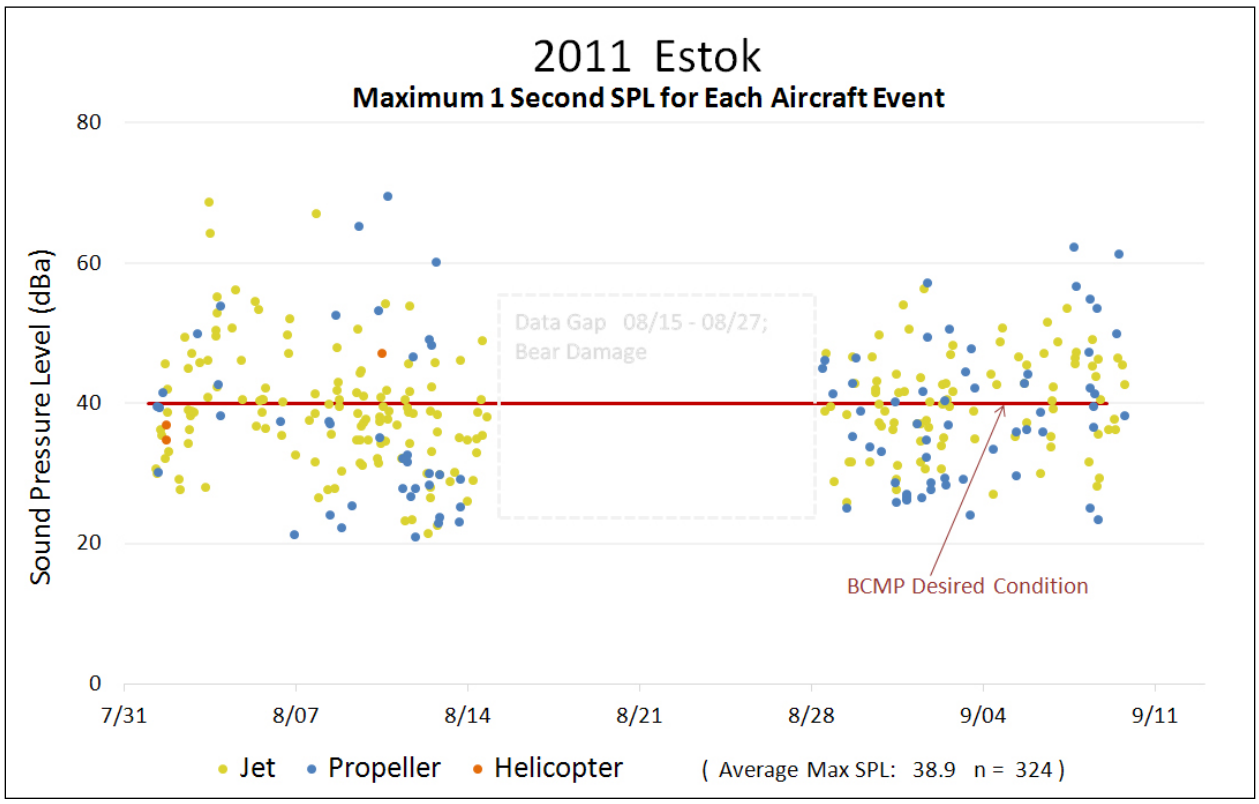


Figure 11. Maximum one-second SPL for each aircraft event identified at Estok.

Fang Mountain



Location Description: This site rested upon an old glacial moraine flowing from the west slope of Fang Mountain. The moraine was bounded to the south and west by a small (inaudible) creek, a tributary of the Sanctuary River.

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

Coordinates: Lat. 63.56617, Long. -149.2056

Elevation: 1533.61 Meters

Time at Location: 01-July-2011 – 04-August-2011

BCMP Management Zone: Low

Park Ecoregion: Alpine Mountains

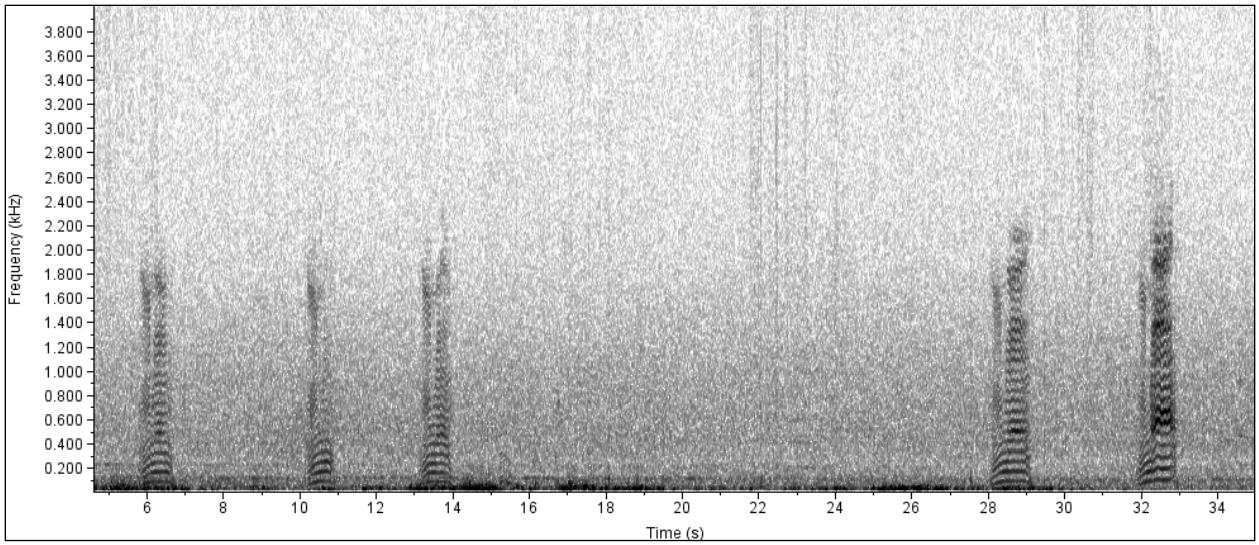
Access: Foot



Summary: The purpose of the Fang Mountain 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 #175 was stratified as an Old Park location and randomly selected from all locations requiring access on foot.

This site was visited early on by a small creature, probably an arctic ground squirrel (*Spermophilus parryii*), but possibly a red fox (*Vulpes vulpes*). (Both types of animal were seen within the immediate vicinity of the station during site visits.) There was considerable activity by this creature on 07/01/2011, leaving the left latch of the equipment enclosure slightly gnawed.

Biophony in general was prevalent. A group of Dall Sheep (*Ovis dalli*) visited the site during the week of 07/08/2011. Rams and ewes were both heard, as well as numerous hoof-steps. Over most of the sampling period, avian sound was sparsely but consistently heard in the morning hours. White-tailed Ptarmigan (*Lagopus leucura*) was the species primarily observed. Towards the end of the sampling period flying insects were heard in the majority of diurnal clips.



Spectrogram 2. The deep, guttural vocalizations of a male Dall Sheep (*Ovis dalli*). The spectrogram begins at 19:06:39 on 07/07/2011.

Over the entire sampling period the sound of a somewhat distant waterfall was faintly audible. The cascade was very splashy and aerated, with an energy density spectrum similar to pink noise. However, unlike true pink noise, the energy spectrum dropped off very quickly after about 13 kHz. The sound of the cascade was present as a keynote throughout the entire audio record and likely sets a floor for the natural ambient level on very still days.

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%). Human made sound was audible 10.4% of the time, all of which was generated by aircraft. This is equivalent to 149.8 minutes of aircraft sound each day, or about 49 overflights a day. 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.

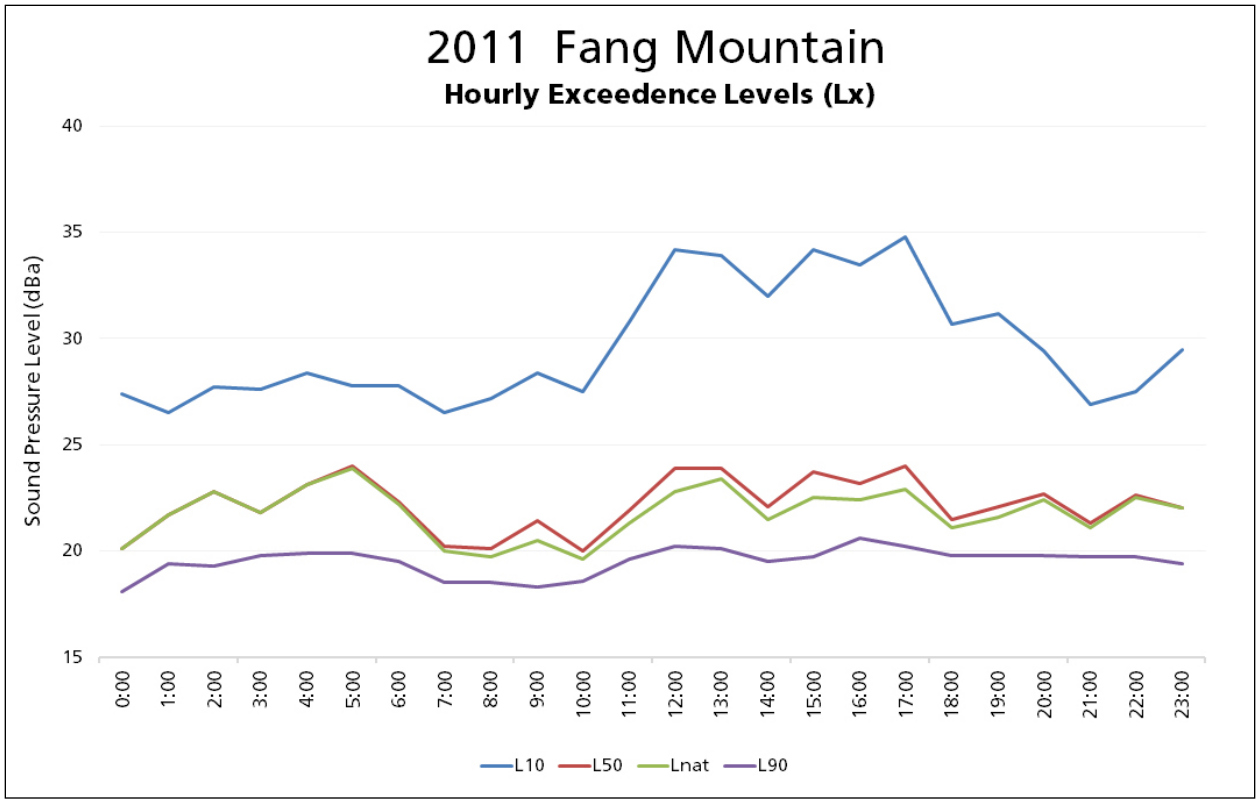


Figure 12. Exceedence levels for Fang Mountain.

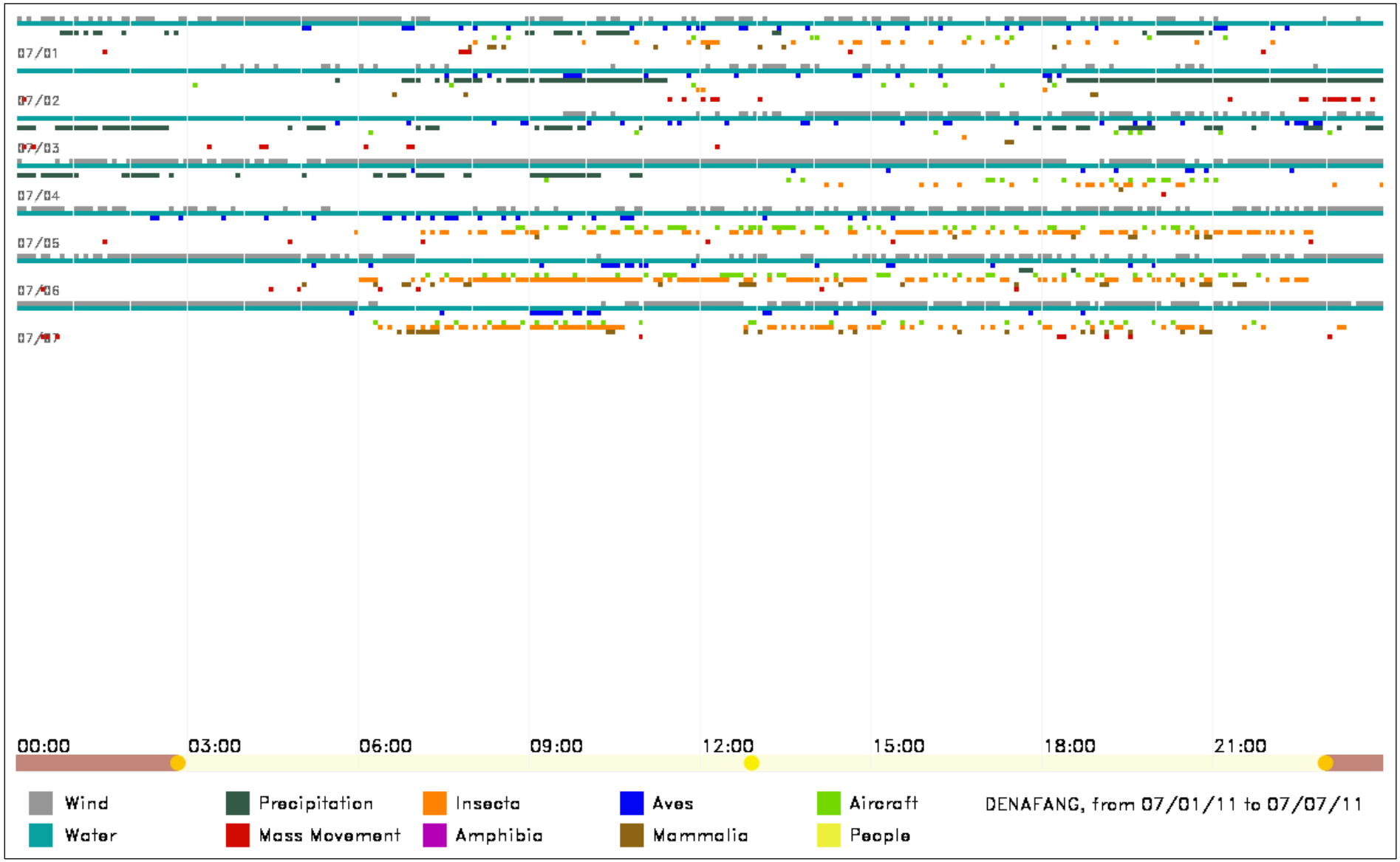


Figure 13. Temporal audibility of sound sources at Fang Mountain, based on five seconds of audio every five minutes. The bar along the horizontal axis indicates the average light conditions during the sampling period. The orange circles are sunrise/sunset. This site did have civil twilight or night-time conditions during the sampling period.

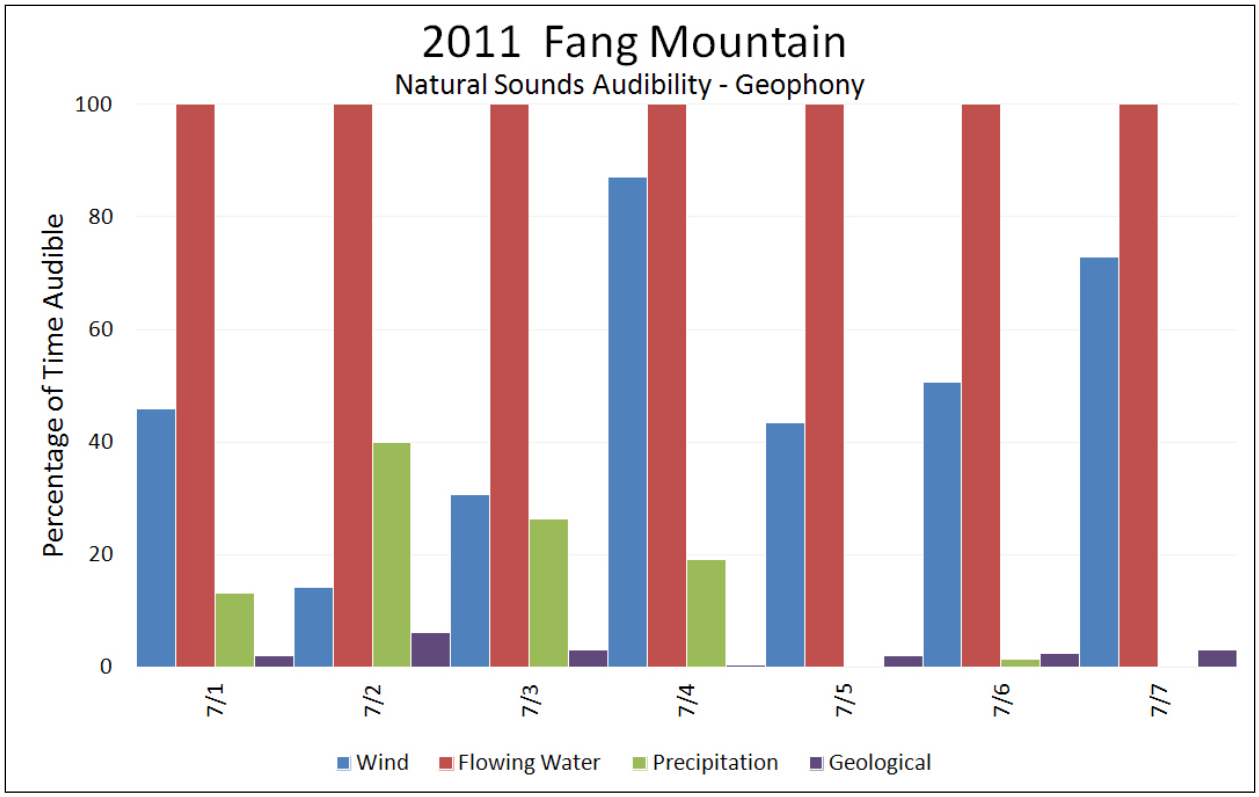


Figure 14. Percentage of time audible for geophonic sounds at Fang Mountain.

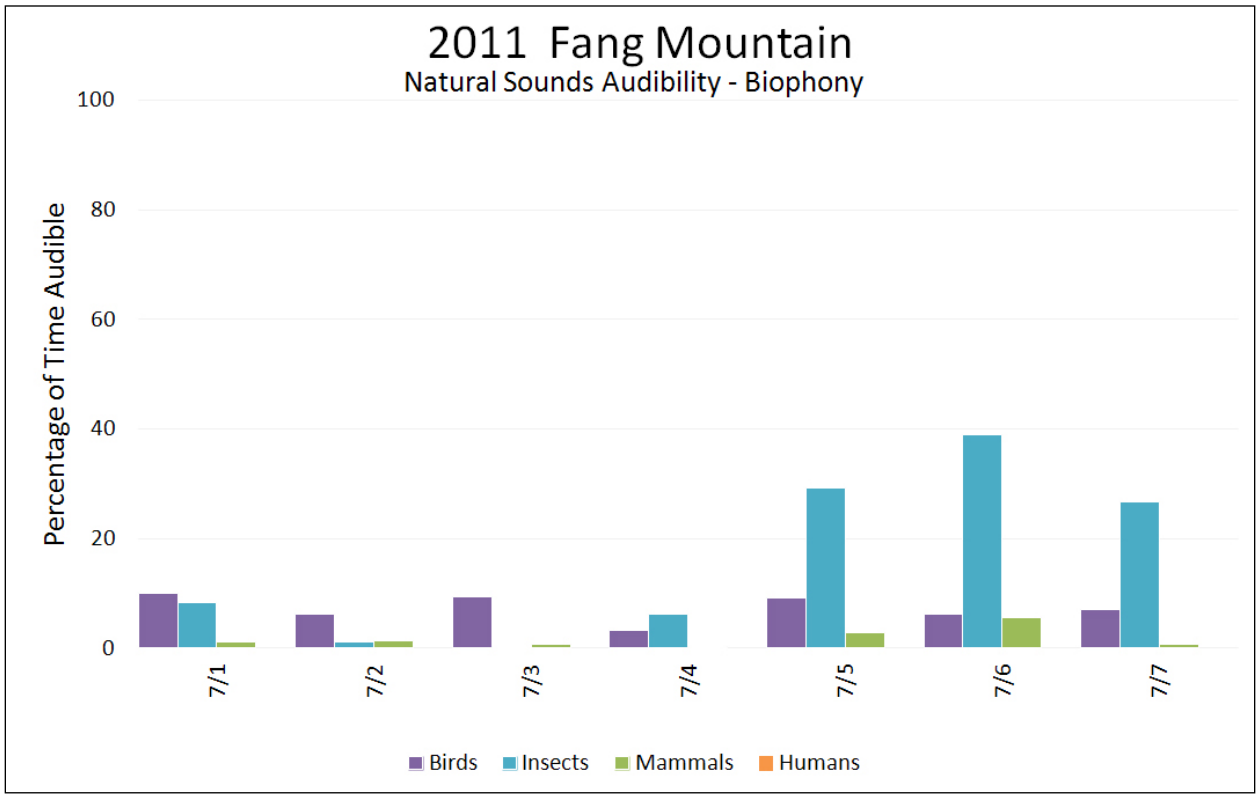


Figure 15. Percentage of time audible for biophonic sounds at Fang Mountain

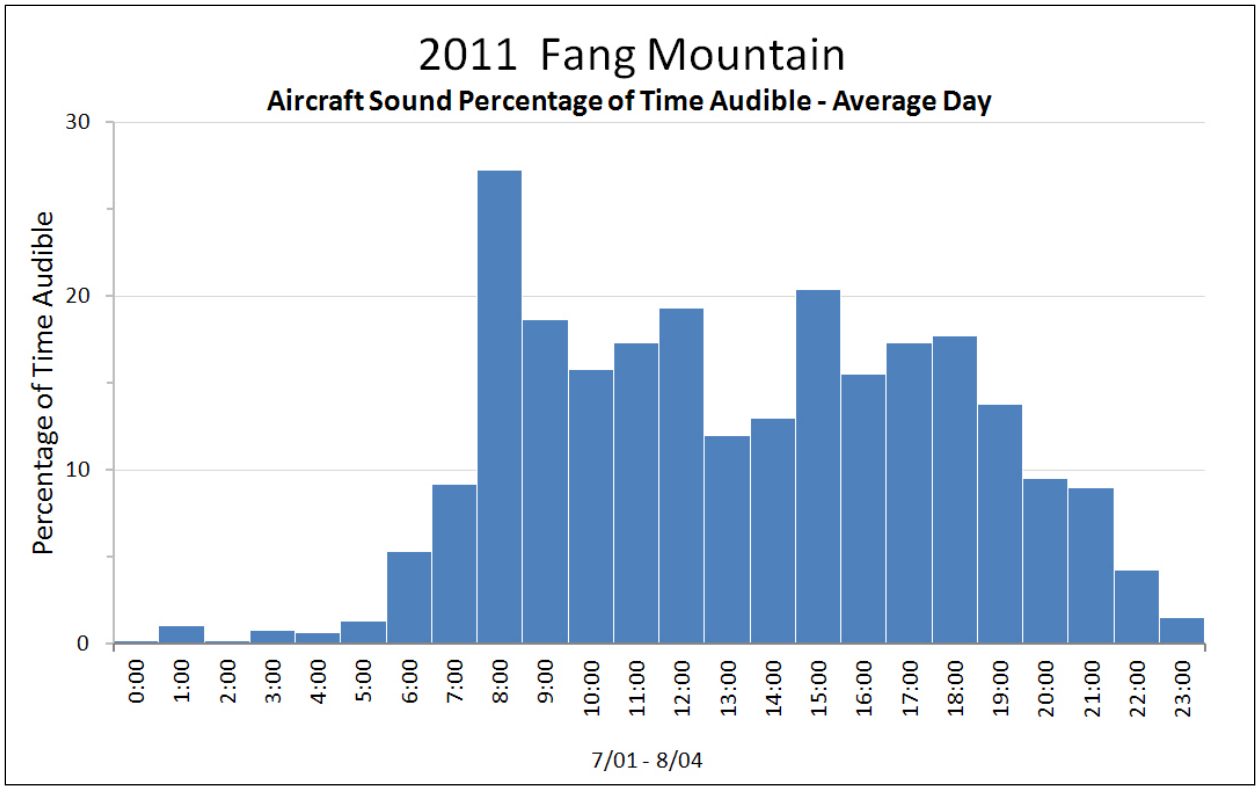


Figure 16. Audibility of aircraft noise for an average day, by hour, at Fang Mountain.

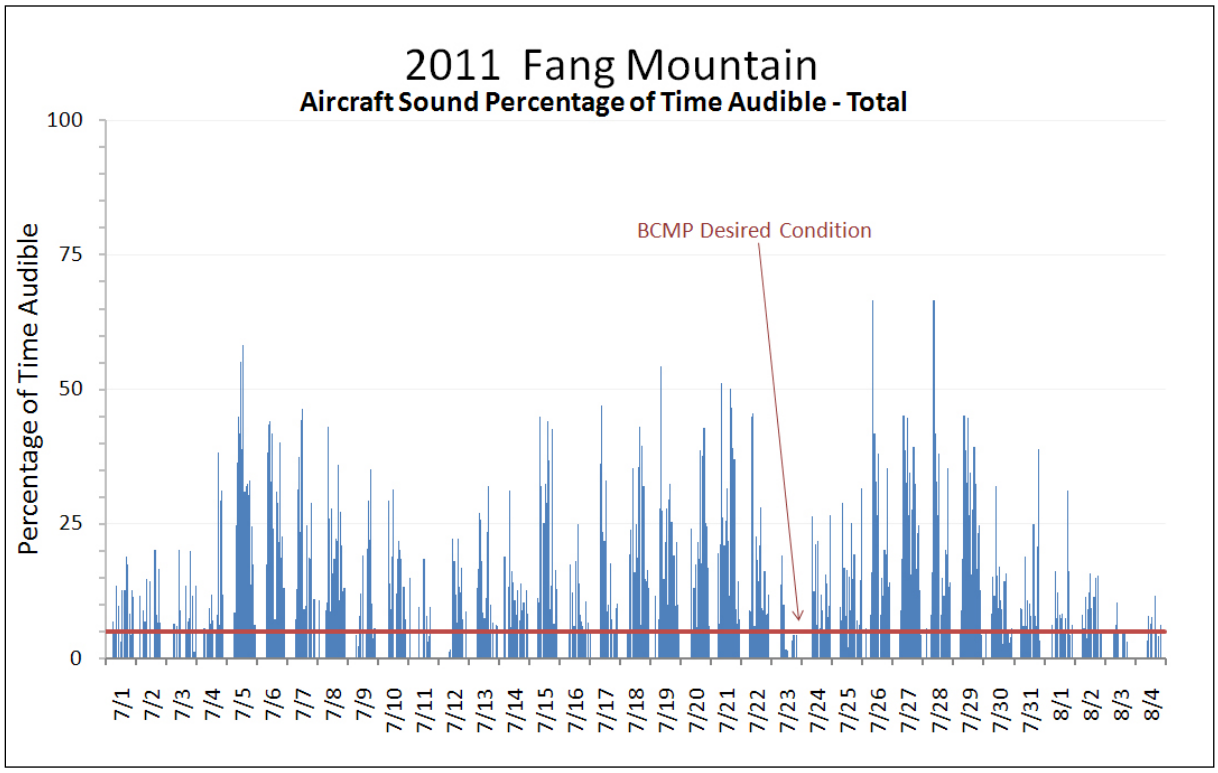


Figure 17. Audibility of aircraft noise at Fang Mountain.

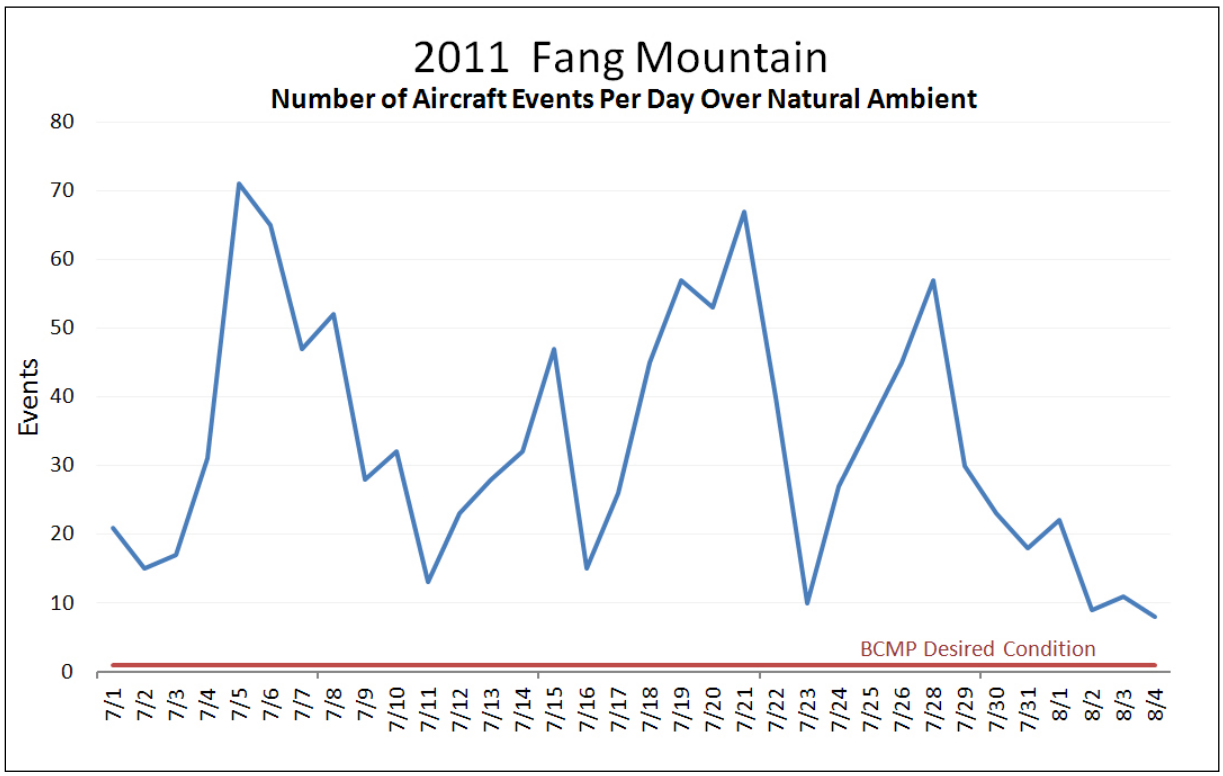


Figure 18. Number of aircraft noise events identified per day at Fang Mountain.

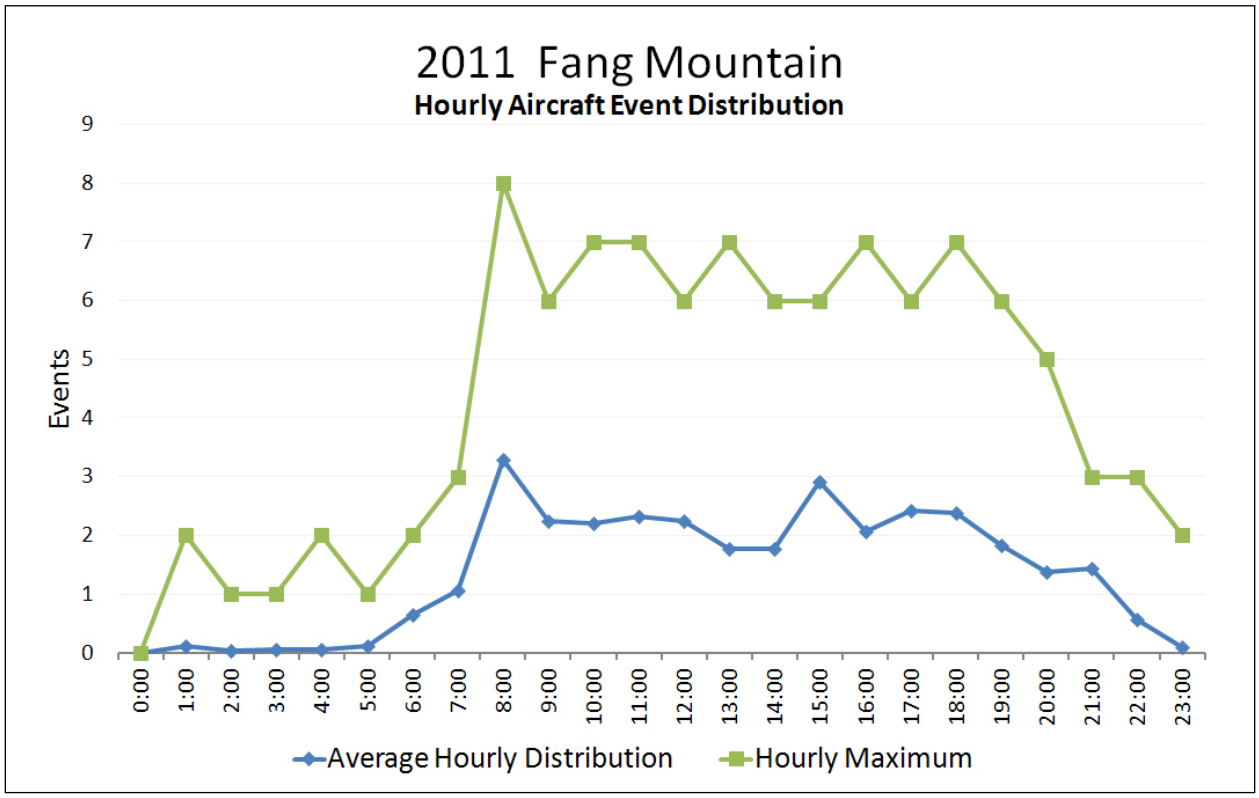


Figure 19. Hourly average and maximum aircraft event distribution at Fang Mountain.

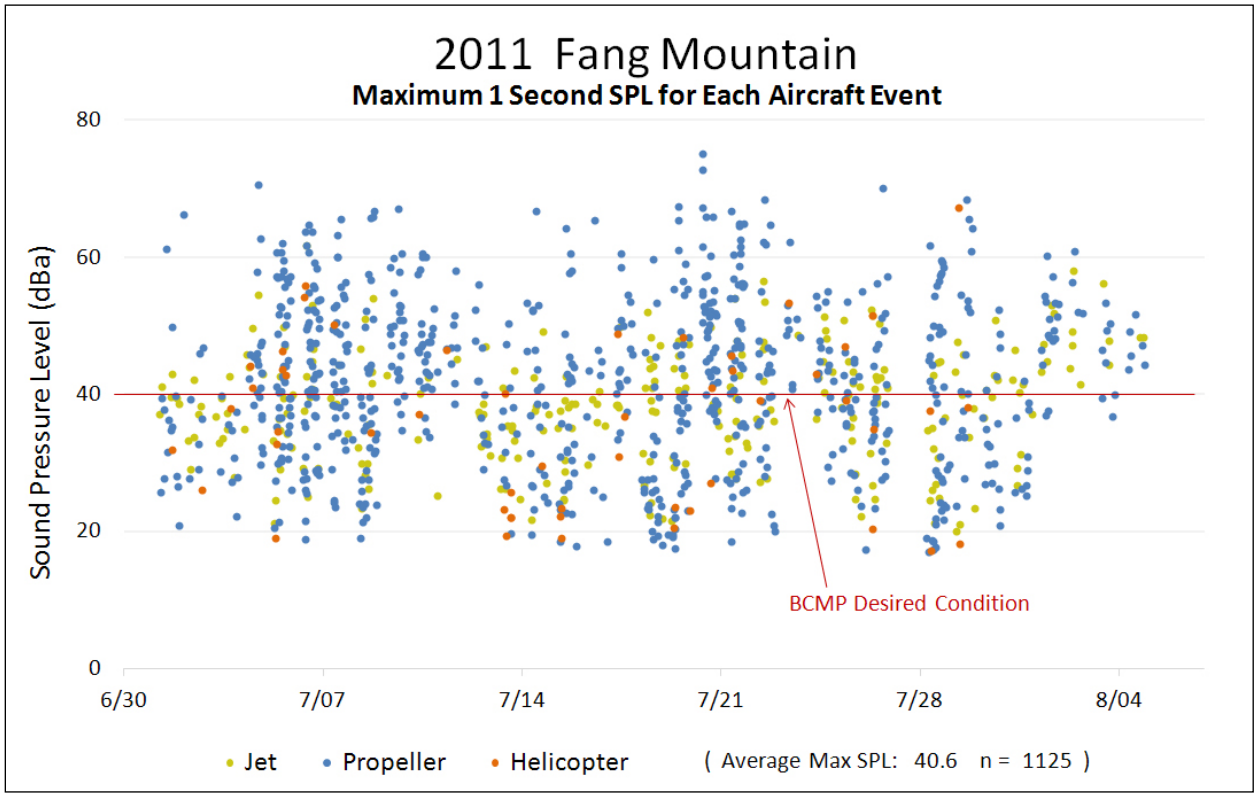
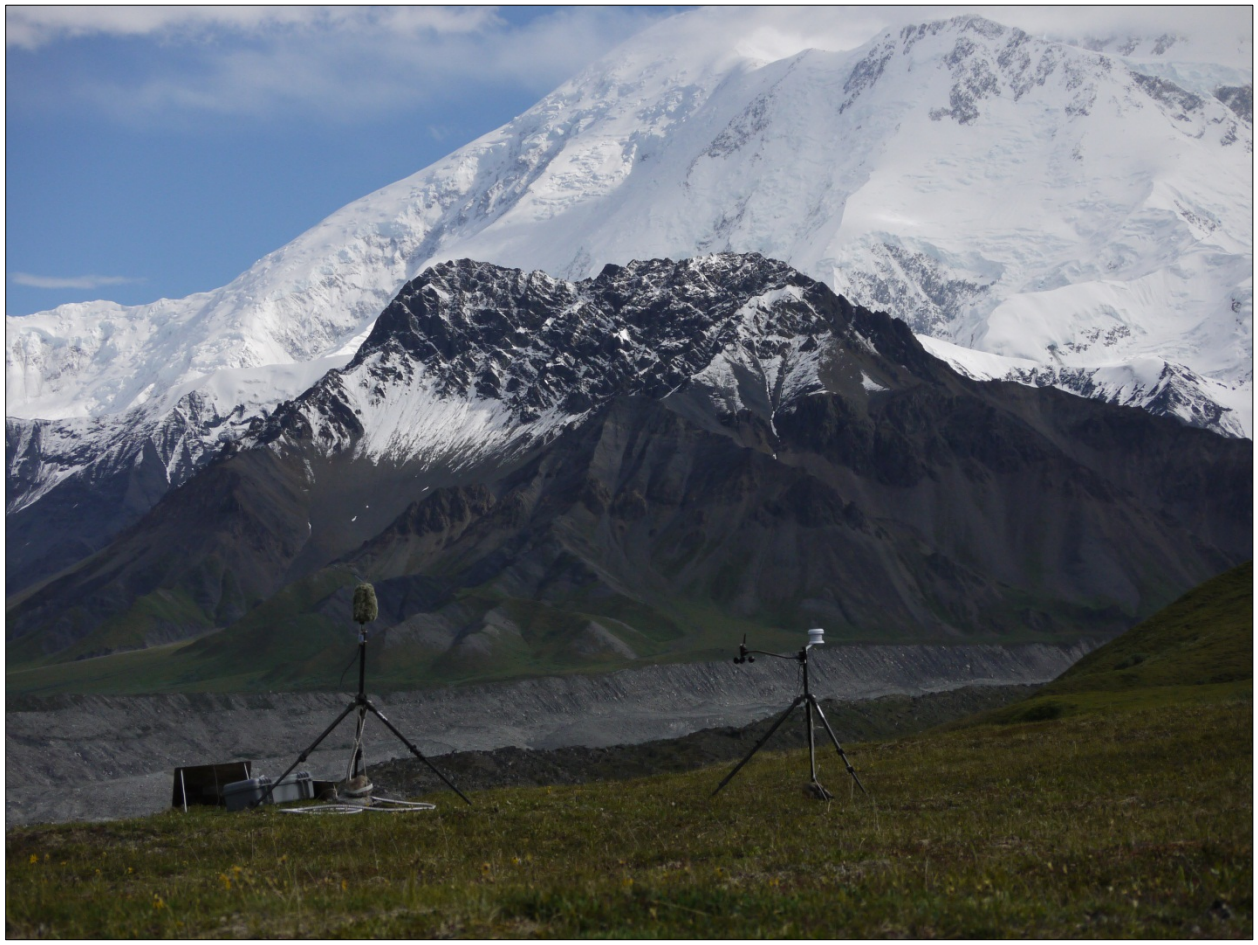


Figure 20. Maximum one-second SPL for each aircraft event identified at Fang Mountain.

Herron Glacier



Location Description: Just above the west lateral moraine of the Herron Glacier, approximately 3 Km from the toe. The equipment rested on a large, relatively flat bench of alpine tundra.

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

Coordinates: Lat. 63.07925, Long. -151.66535

Elevation: 1115.36 Meters

Time at Location: 21-July-2011 – 25-August-2011

BCMP Management Zone: Low

Park Ecoregion: Alpine Mountains

Access: Helicopter



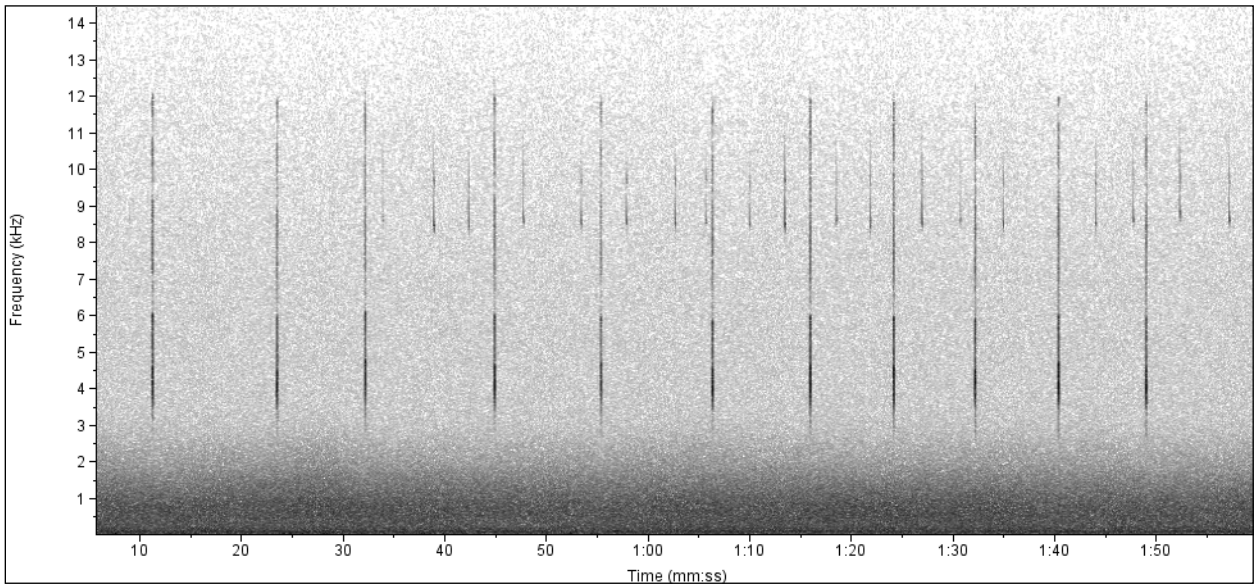
Summary: The purpose of the Herron Glacier location was to collect data at one of the long-term ecological monitoring (LTEM) grid points, as outlined in the above sampling plan. LTEM grid point #84 was stratified as a New Park location and randomly selected from all locations requiring aircraft access.

With little human impact in the area and some animal life to balance the abiotic sounds of the range, the Herron Glacier site was a quintessential record of Denali's monophonic subalpine soundscape. The overall audio impression was thin yet spacious, especially during the latter sampling period (07/21 - 07/26).

The sound of flowing water was the predominant keynote of the soundscape. Although the energy travelled more than a kilometer to reach the microphone, it was easily the main contributor to the natural ambient sound pressure level. This is apparent in the relative time-invariance of exceedence levels shown in Figure 20. On record, the approximate bandwidth of the river was about 1800 Hz, with bounds near 200 and 2000 Hz. This envelope is somewhat similar to the energy of the McKinley River as heard from the McKinley Bar Trail station and seems to be typical of large glacially fed rivers in general.

Animals, though more prominent in the early sampling period (06/19 - 06/25), were an essential but understated component of the Herron Glacier soundscape. Both the Willow Ptarmigan (*Lagopus lagopus*) and Rock Ptarmigan (*Lagopus muta*) were audible in the dusky hours. The prominent songbirds in the area were White-Crowned Sparrows (*Zonotrichia leucophrys*), Golden-Crowned Sparrows (*Zonotrichia atricapilla*), American Robins (*Turdus migratorius*), and Savannah Sparrows (*Passerculus sandwichensis*), though others were heard less frequently during the sampling period. Of interest is that no Boreal Chickadees (*Poecile hudsonicus*),

Common Ravens (*Corvus corax*), nor Gray Jays (*Perisoreus canadensis*) were heard, though they are common elsewhere in the park. Arctic ground squirrels (*Spermophilus parryii*) nested on the bench where the equipment was placed and they were heard frequently. They were primarily diurnal and presented a variety of calls during these hours. Some antiphonal communication behavior was observed between individuals.



Spectrogram 3. Two Arctic ground squirrels (*Spermophilus parryii*) communicate across the alpine tundra at Herron Glacier. The difference in offset from the microphone is apparent in the relative bandwidth of the calls. The spectrogram begins at 08:02:03 on 07/28/2011.

Despite a diversity of animals, the constant, smooth roaring of the Herron River was only occasionally punctuated by their sounds. In the majority of clips with biophony, there was usually only one species heard. However, during the 02:00 through 05:00 hours, it was possible for as many as three species to be heard in the same clip. For a dawn chorus in Denali, this is relatively thin.

The most commonly heard sounds at this site were water (audible 99.9% of the time – the sound was masked by wind the remaining 0.1% of the time), birds (17.5% of the time - 52% of these clips were song), wind (16.4%), and rain (9.2%). Human made sound was audible 0.7% of the time on average. This is equivalent to 10.1 minutes each day, or approximately 3 overflights a day. Conditions exceeded the BCMP percent audible standard 6% of the time, number of events per day 63% of the time, and maximum SPL 42% of the time.

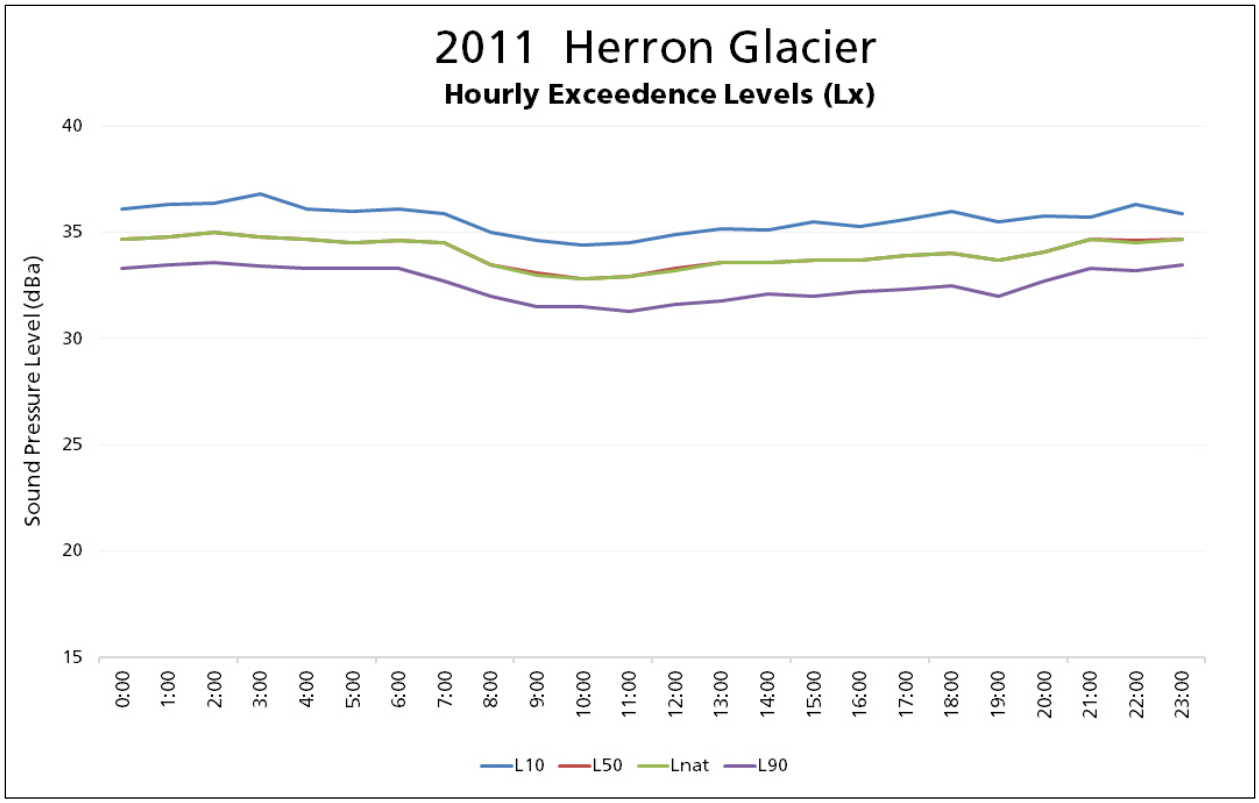


Figure 21. Exceedence levels for Herron Glacier.

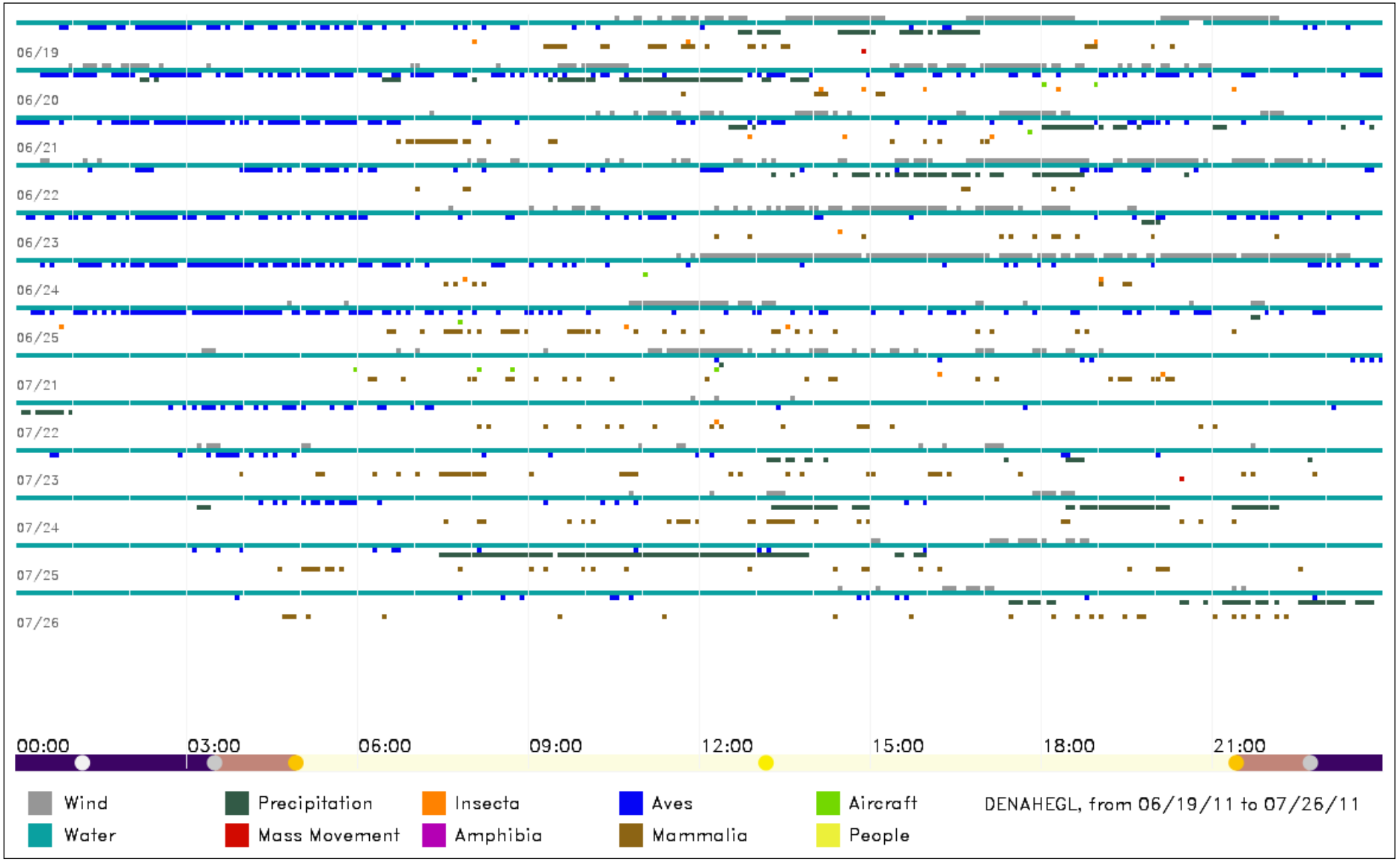


Figure 22. Temporal audibility of sound sources at Herron Glacier, based on five seconds of audio every five minutes. The bar along the horizontal axis indicates the average light conditions during the sampling period. The orange circles are sunrise/sunset, and the gray circles are the beginning and end of civil twilight.

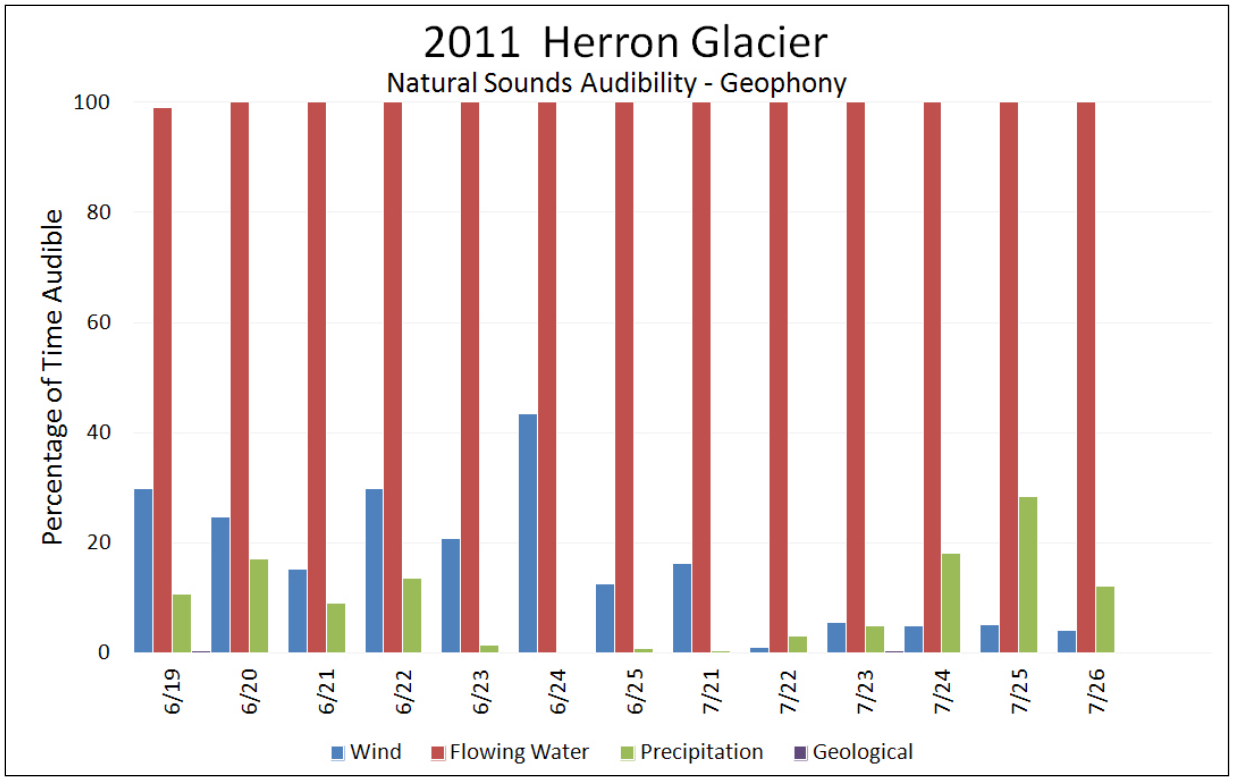


Figure 23. Percentage of time audible for geophonic sounds at Herron Glacier.

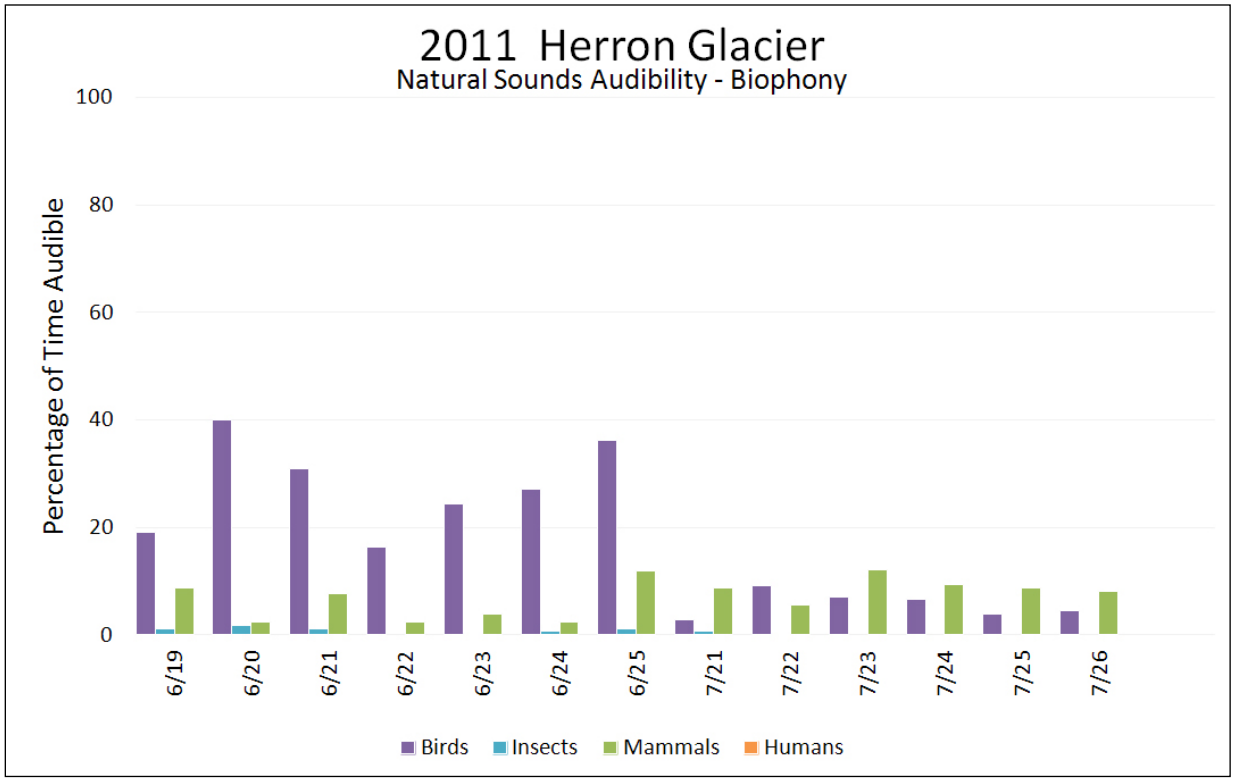


Figure 24. Percentage of time audible for biophonic sounds at Herron Glacier.

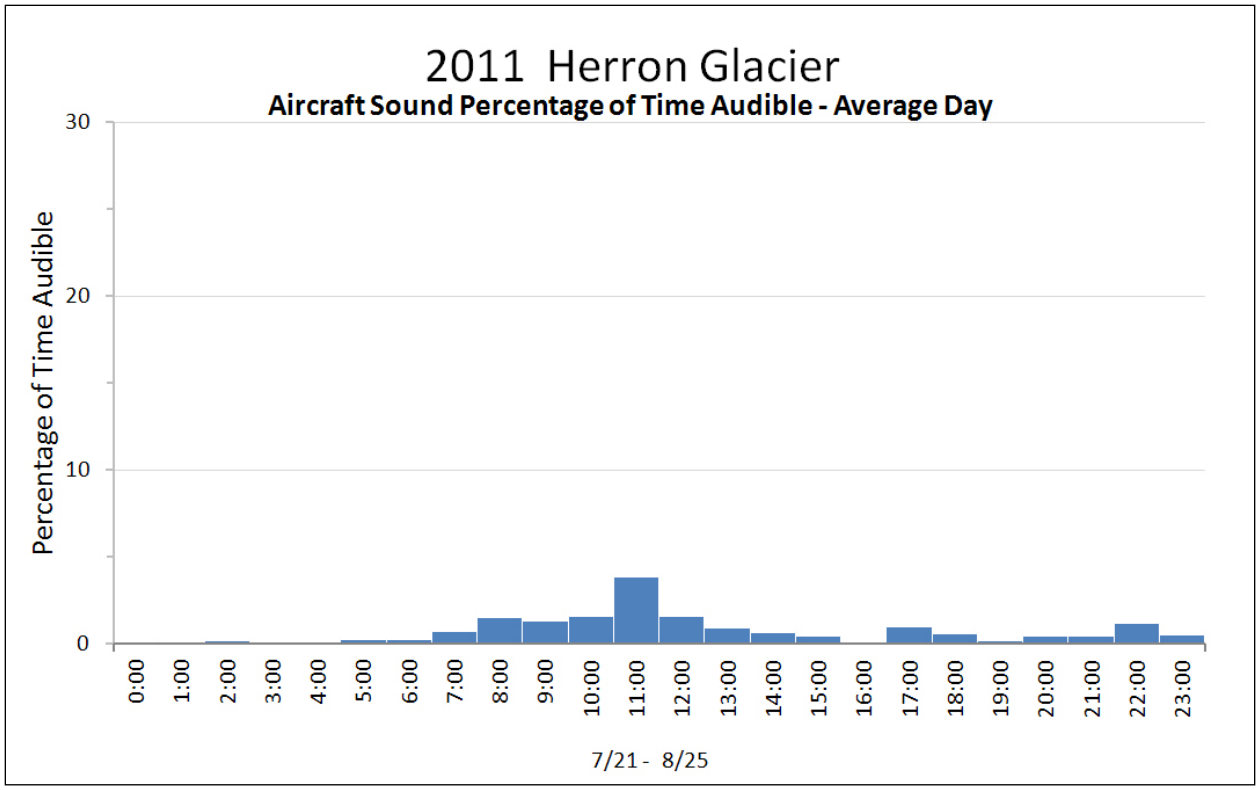


Figure 25. Audibility of aircraft noise for an average day, by hour, at Herron Glacier.

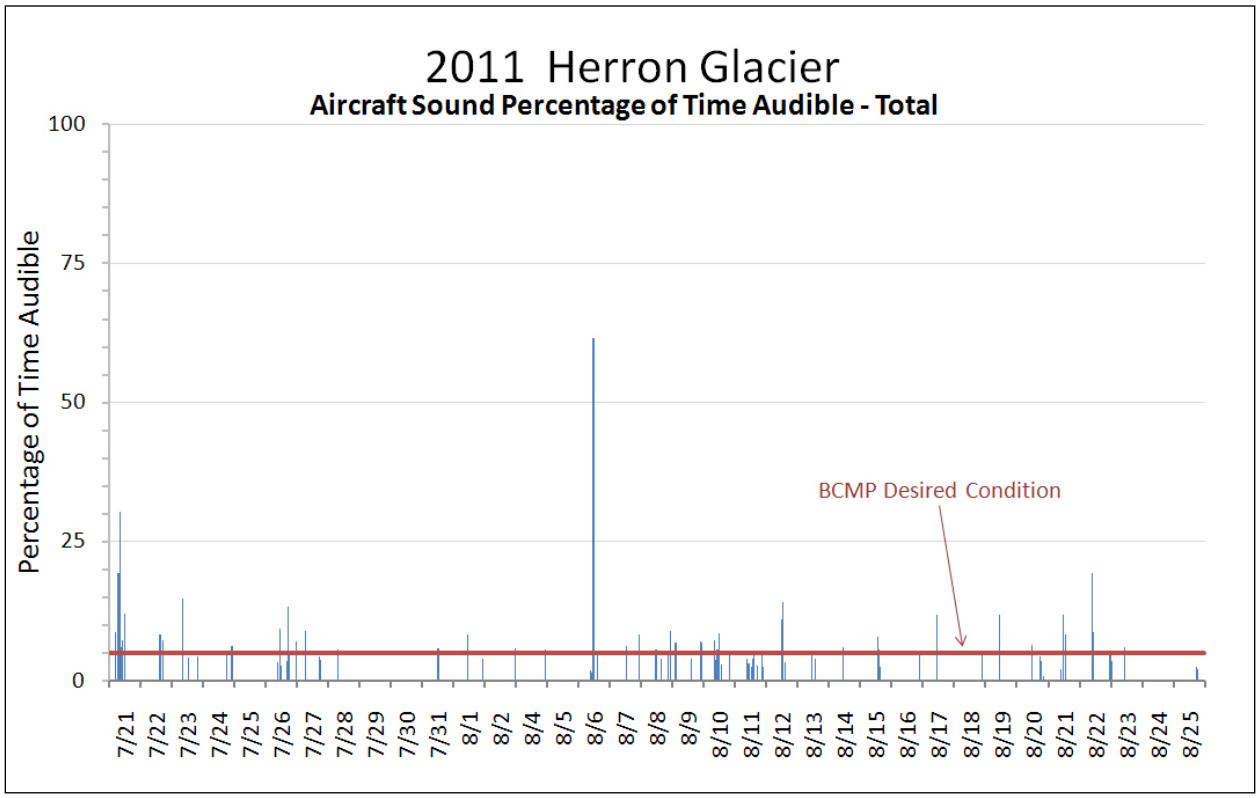


Figure 26. Audibility of aircraft noise at Herron Glacier.

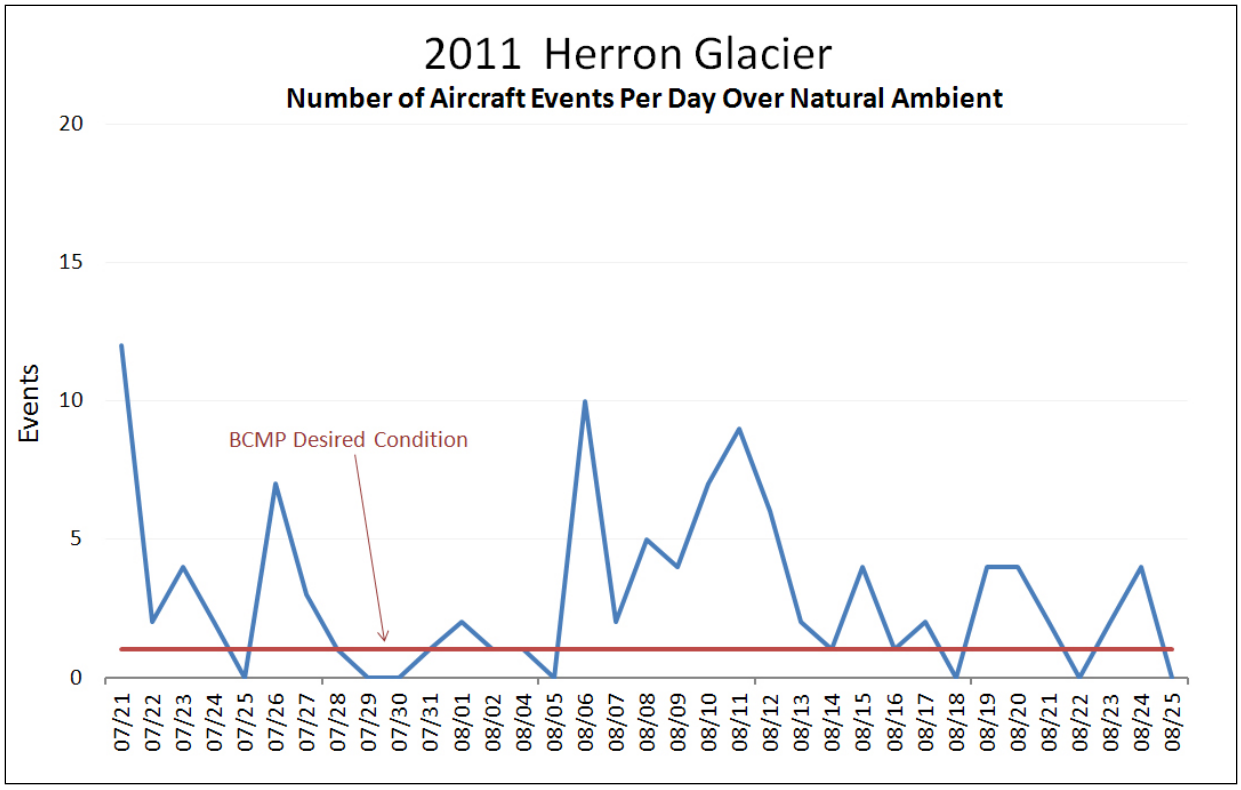


Figure 27. Number of aircraft noise events identified per day at Herron Glacier.

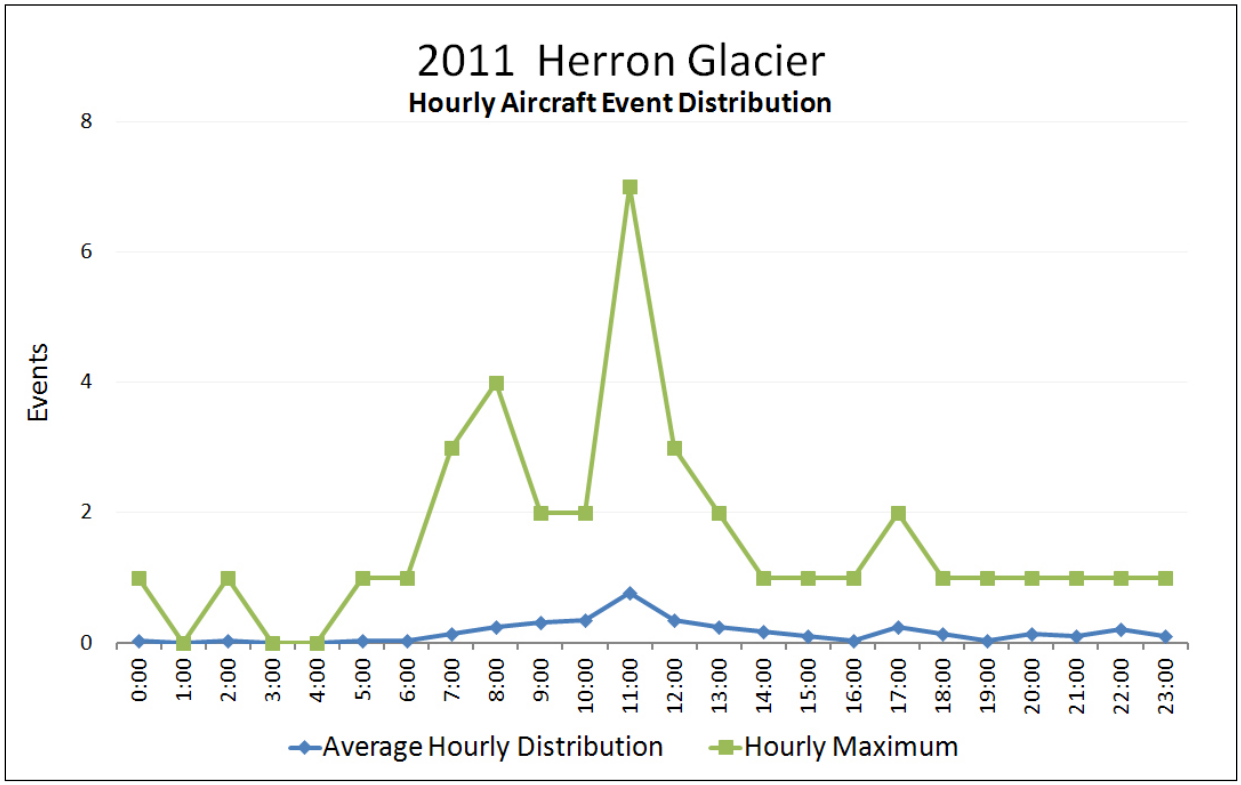


Figure 28. Hourly average and maximum aircraft event distribution at Herron Glacier.

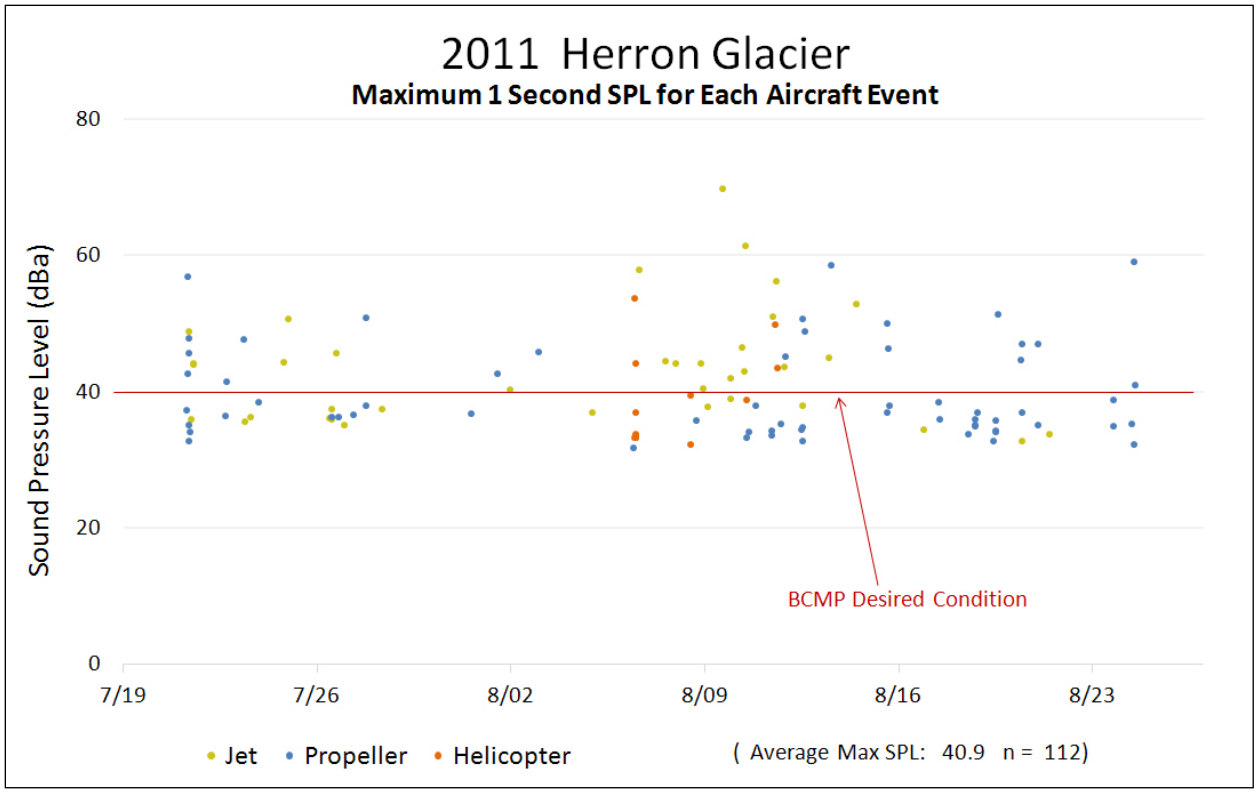


Figure 29. Maximum one-second SPL for each aircraft event identified at Herron Glacier.

McKinley Bar Trail



Location Description: Equidistant from the McKinley River Bar and the Park Road. The site is located approximately 1.3 Km from the head of the McKinley Bar Trail, offset about 100 meters west of the trail, itself.

Purpose/Project: Location randomly chosen from the LTEM grid as part of the long-term Denali Soundscape inventorying and monitoring plan. The location was slightly adjusted to resample a site previously monitored in 2005. During the latter half of the station's deployment researchers surveyed day-hikers about Soundscape conditions along the trail.

Coordinates: Lat. 63.44070, Long. -150.83578

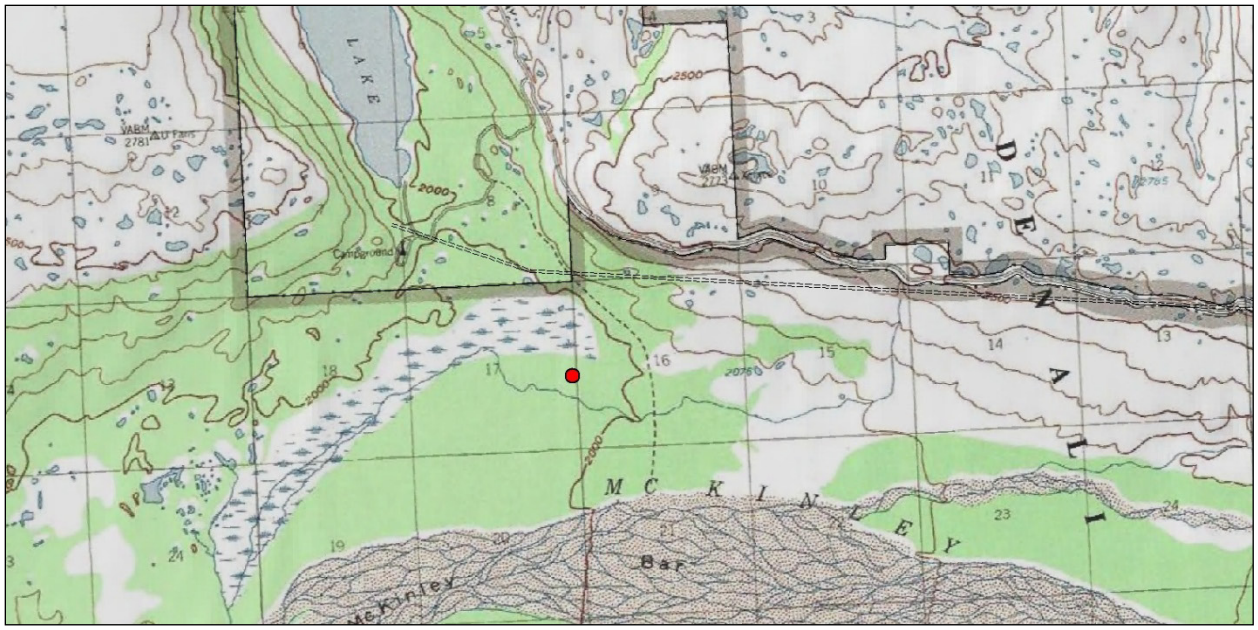
Elevation: 610.7 Meters

Time at Location: 02-June-2011 – 04-July-2011

BCMP Management Zone: Backcountry Hiker (equivalent to Medium)

Park Ecoregion: Lowland Floodplains and Terraces and Fans

Access: Foot



Summary: The purpose of the McKinley Bar Trail 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 #142 was stratified as an Old Park location and randomly selected from all locations requiring aircraft access. This location also collected physical data to supplement the 2011 Soundscape Social Survey, which occurred on the trail during the latter half of the sampling period.

The McKinley Bar Trail station was located in a widely spaced spruce forest. The sampling period spanned the summer solstice, documenting a wide variety of vigorous bird songs. Singing was most dense and overlapped during the early hours of the morning - about 02:00 through 04:00. Commonly heard birds included Swainson's Thrush (*Catharus ustulatus*), White-Crowned Sparrow (*Zonotrichia leucophrys*), Dark-eyed Junco (*Junco hyemalis*), Varied Thrush (*Ixoreus naevius*), Myrtle Warbler (*Dendroica coronata coronata*), Gray Jay (*Perisoreus canadensis*) and Lesser Yellowlegs (*Tringa flavipes*), though many species were audible during the sampling period, including large waterfowl. Some insect sound was heard - presumably mosquitos, flies, and/or bees - but they were only a minor component of the soundscape.

The McKinley River is faintly audible for about half of the recording. When audible, it occupied a bandwidth of about 1080 Hz, with bounds at 120 and 1200 Hz. An interesting component of this soundscape was the oscillating audibility of the river; during the nighttime it was clearly audible, but as the temperature warmed (usually about 07:00 or 08:00) the sound gradually diminished until it was no longer heard. This diurnal 'sound shadow' was likely due to temperature gradients in the atmosphere, and is readily observable in Figure 31.

Buses, construction equipment and maintenance graders on the park road were all audible from the site, and considered together were more prevalent than aircraft events. (Contract road construction surely aggravated this condition.) Though the buses were generally faint, wheels over the gravel of the road were sometimes surprisingly clear. For instance, rocks 'popping'

under the tires were clearly audible during many pass-by events. NPS grading work regularly began around 06:00 and lasted for long durations of time. Contract construction work was less regular and consisted of an ensemble of overlapping sounds. These were also audible for large intervals of time.

One undoubted source of error in this analysis was the inability of the hour-long spectrograms to show back-up beepers clearly. (Despite being a high-amplitude signal, it was transmitted over a very narrow bandwidth that was 'diluted' in the 1/3rd Octave average.) Attempts at documenting back-up beepers were made, but some were inevitably missed. For that reason, the total duration of vehicle noise may be underestimated.

Numerous aircraft were also heard at the site. Propeller aircraft were most common, but helicopters (presumably the park-operated Hughes 500-D and the A-Star, though possibly R-44s operated by Pollux Aviation as well) and high-altitude jets were also prevalent. The duration of aircraft events were surprisingly long. The median duration at this site was about 5:40, well above the median for most sites in Denali (~3:30 – 4:00.)

The most commonly heard sounds at this site were birds (audible 77.6% of the time – mostly song), water (55.4%), wind (21.8%), rain (10.4%), and insects (6.6%). Human made sound was audible 18.7% of the time. Vehicles – mainly buses, road construction equipment, and road maintenance equipment - were audible 11.48% of the time. Aircraft were audible 7.2% of the time. (This is equivalent to 103.7 minutes of aircraft sound each day, or about 18 overflights a day.) Conditions exceeded the BCMP percent audible standard 15% of the time, number of events per day 73% of the time, and maximum SPL 42% of the time.

This site was previously sampled in 2005. For comparison, the data collected from 06/11/2005 through 07/07/2005 – a similar sampling period to 2011 – showed the most commonly heard sounds at this site were wind (audible 75.4% of the time), birds (74.5%), insects (27.6%), and rain (9.5%). It is interesting that water was not audible during the analysis, but this may have been because of the poor signal quality in early clips, which would have made the sound of the McKinley difficult to differentiate from electrical noise. Human made sound was audible 13.0% of the time. Vehicles were audible 6.9% of the time. This is an interesting figure because it estimates that nearby road construction (and/or the addition of the Kantishna Experience tour) almost doubled the amount of time vehicles were audible in the area. On the other hand, Aircraft sound was audible 7.6% of the time on average, which was very similar to observations in 2011. In 2005, conditions exceeded the BCMP percent audible standard 20.7% of the time, number of events per day 100% of the time, and maximum SPL 17.3% of the time. (For detailed information on the original dataset, see Hults 2005.) Table 5 compares acoustic metrics for the two sampling periods.

Table 5. Comparison of soundscape conditions at McKinley Bar Trail, 2005 and 2011.

Year	% Time Aircraft	% Time Vehicles	% Time Standard	Events Standard	SPL Standard	% Time Avian	% Time Wind	% Time Insects	% Time Rain
2005	7.6%	6.9%	21% of all hours	100% of all days	17% of all events	74.5%	75.4%	27.6%	9.5%
2011	7.2%	11.5%	15%	73%	42%	77.6%	21.8%	6.6%	10.4%

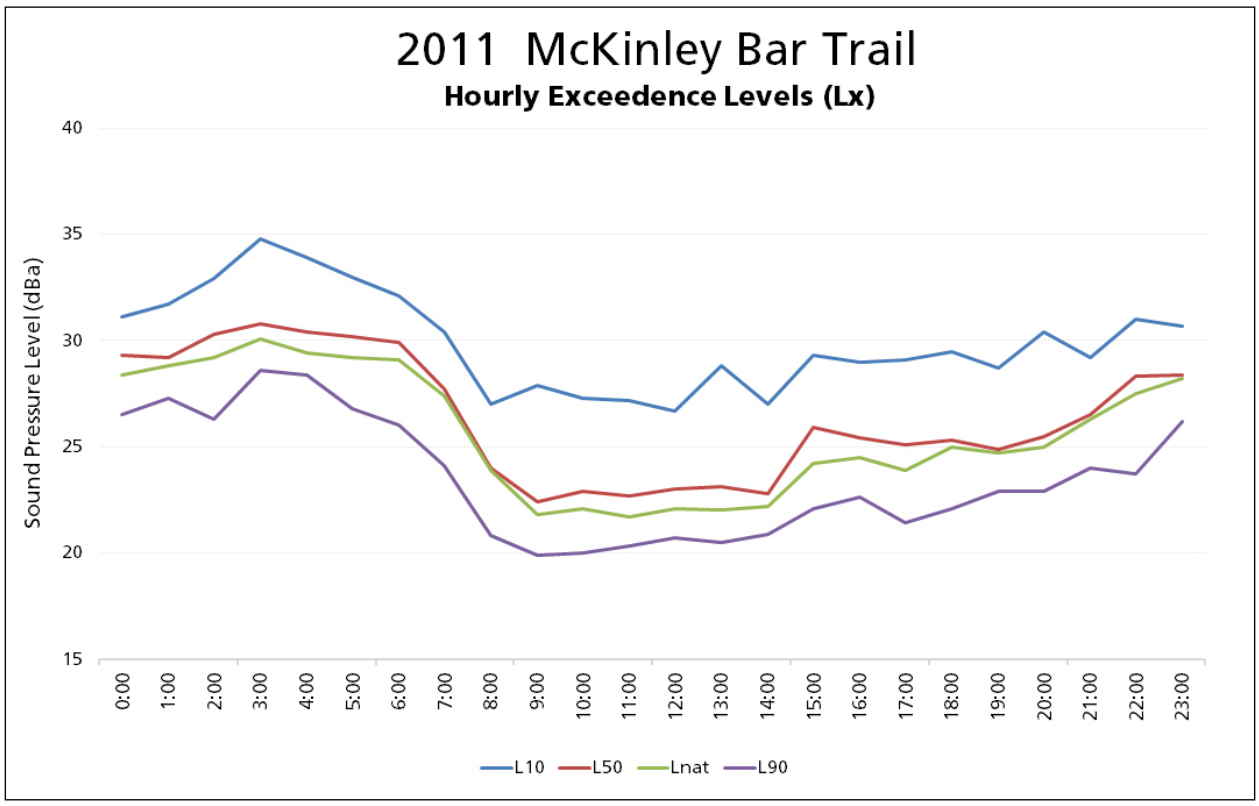


Figure 30. Exceedence levels for McKinley Bar Trail.

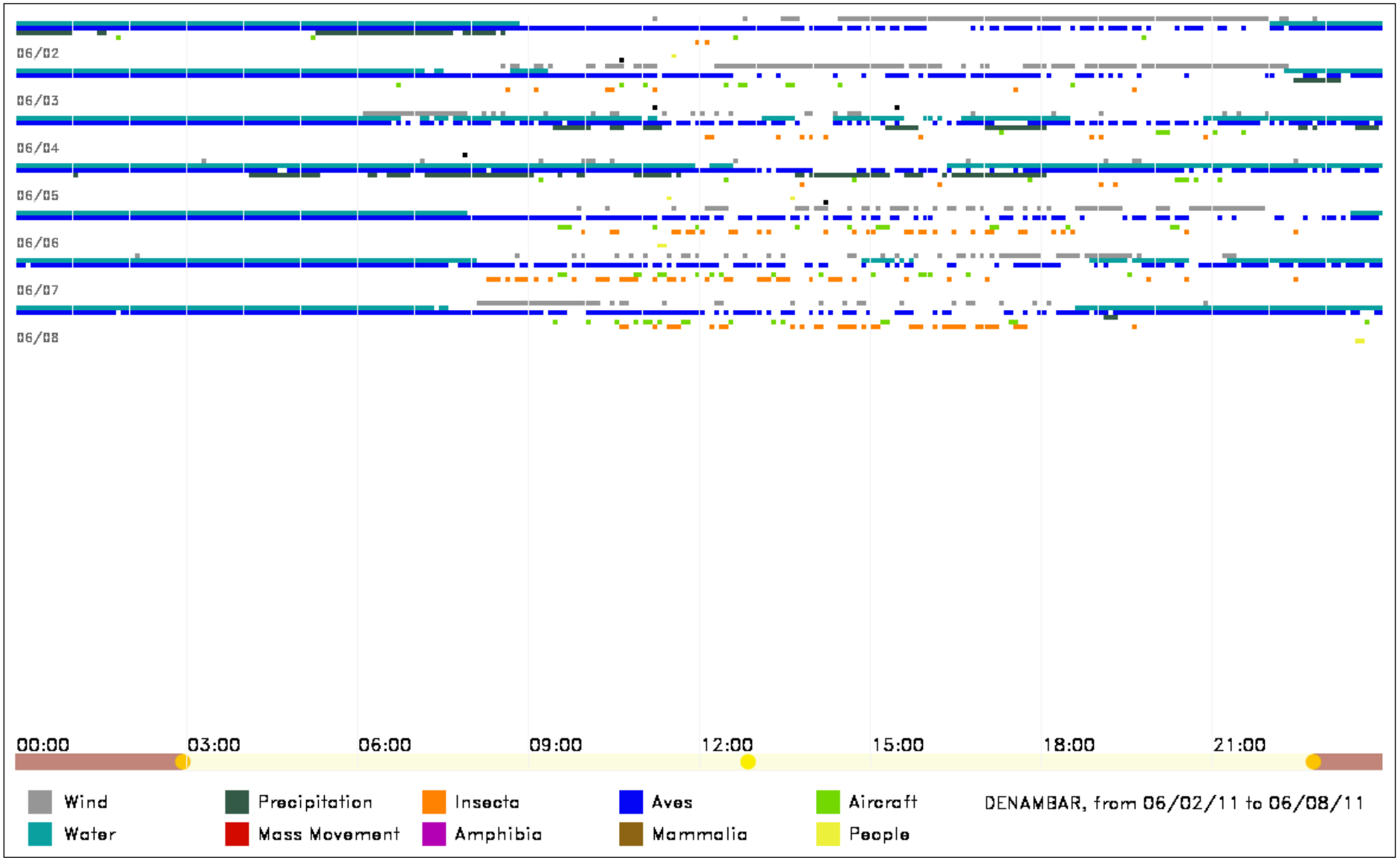


Figure 31. Temporal audibility of sound sources at McKinley Bar Trail, based on five seconds of audio every five minutes. The bar along the horizontal axis indicates the average light conditions during the sampling period. The orange circles are sunrise/sunset. This site did have civil twilight or night-time conditions during the sampling period.

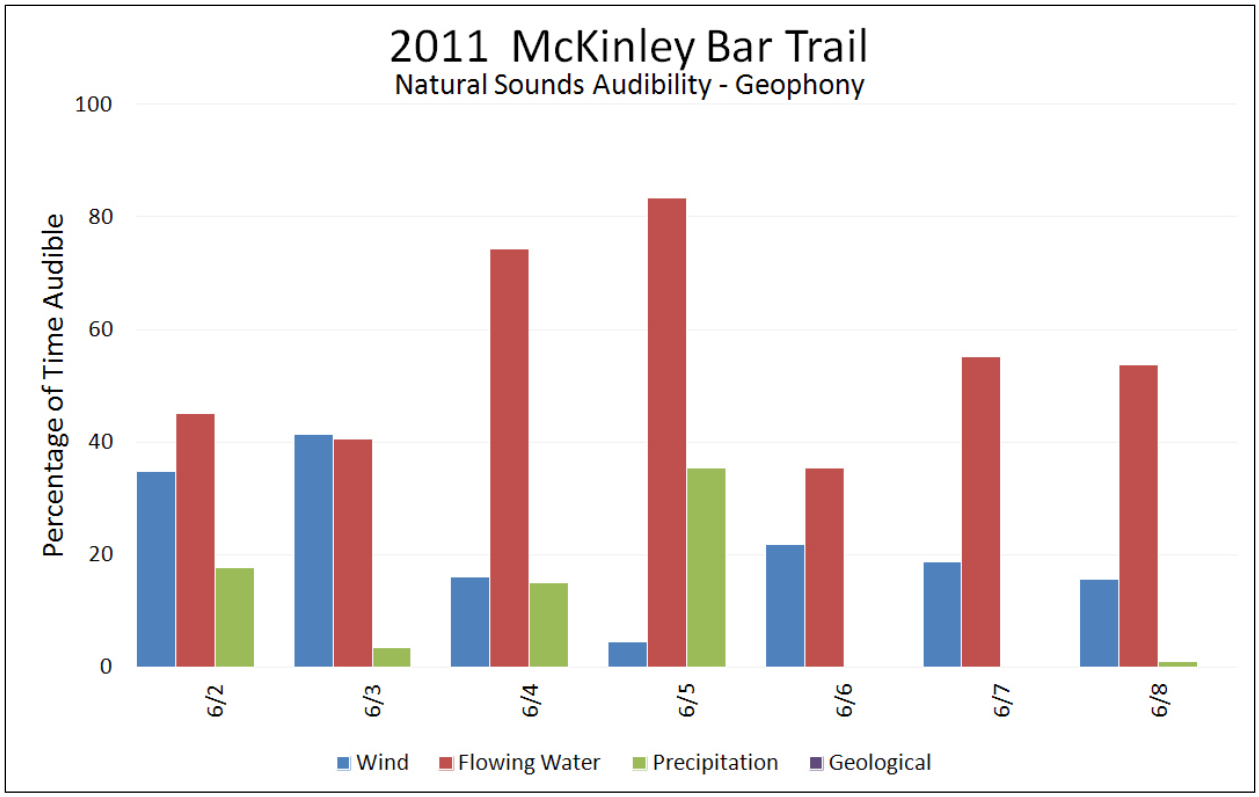


Figure 32. Temporal audibility of sound sources at McKinley Bar Trail.

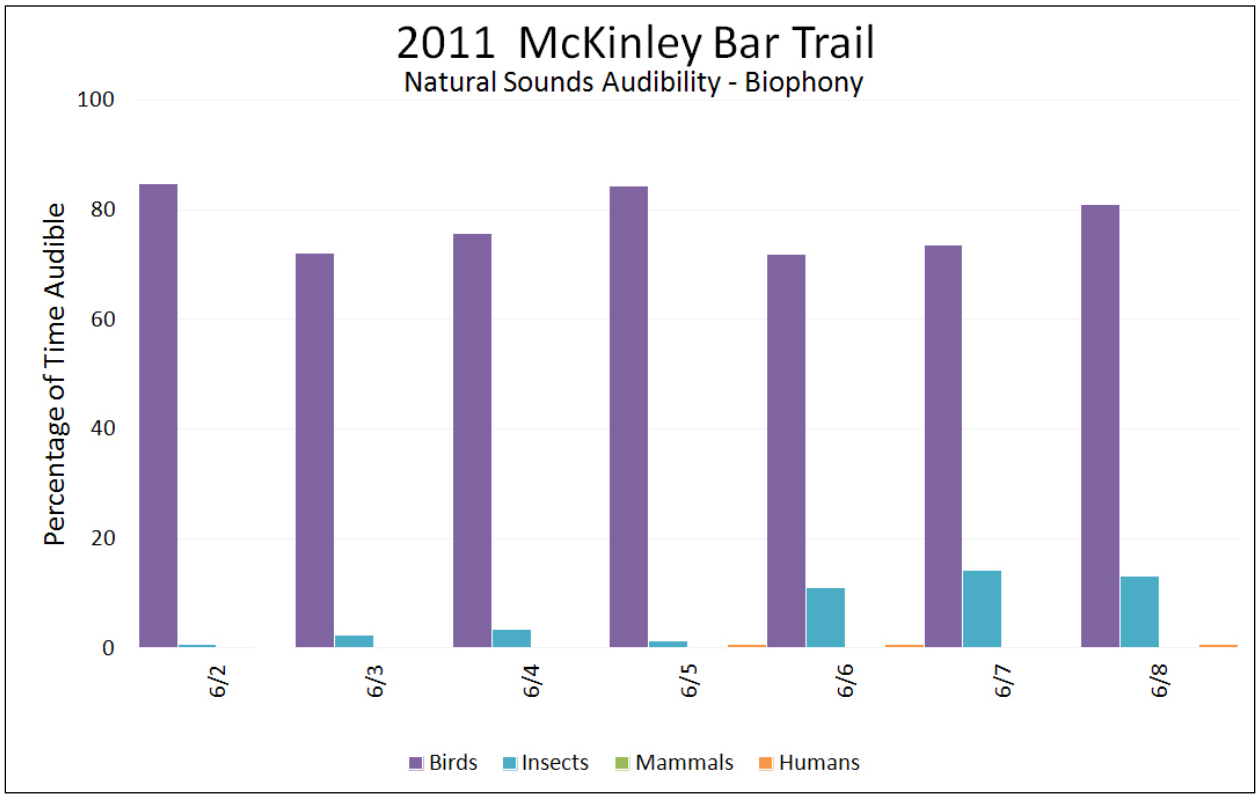


Figure 33. Percentage of time audible for biophonic sounds at McKinley Bar Trail.

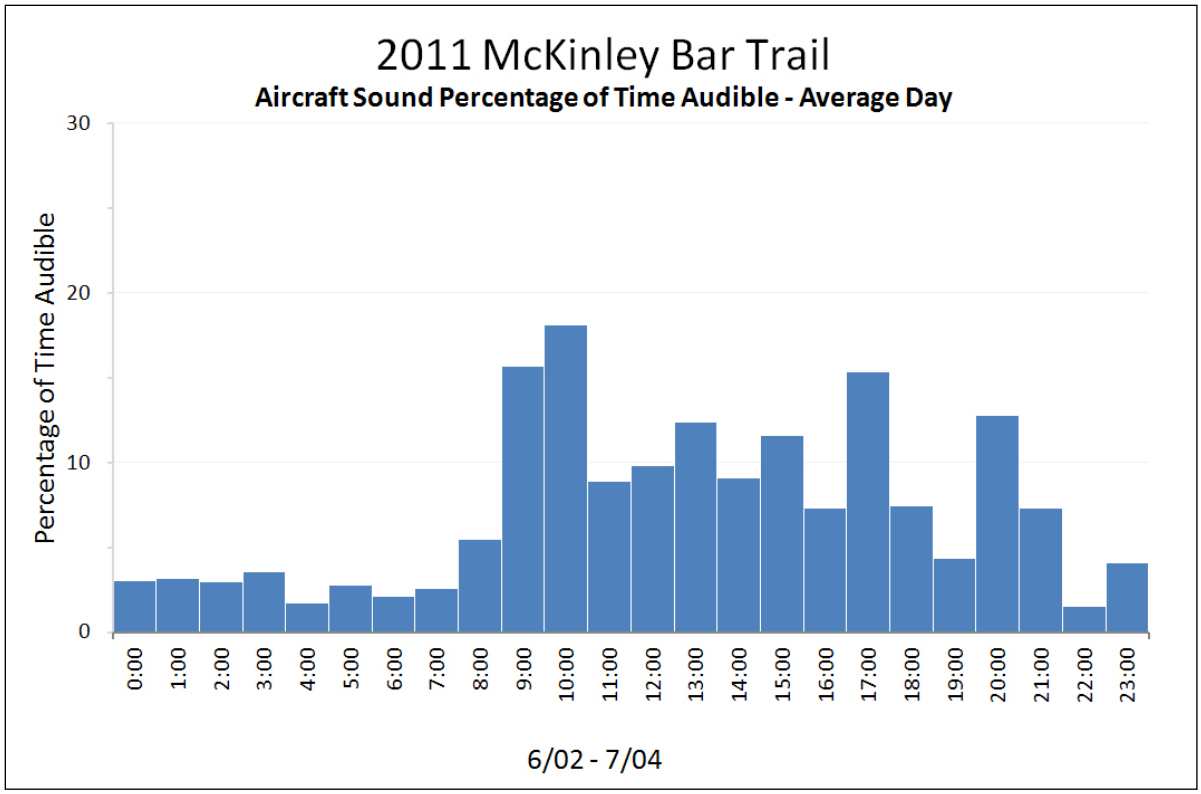


Figure 34. Audibility of aircraft noise for an average day, by hour, at McKinley Bar Trail.

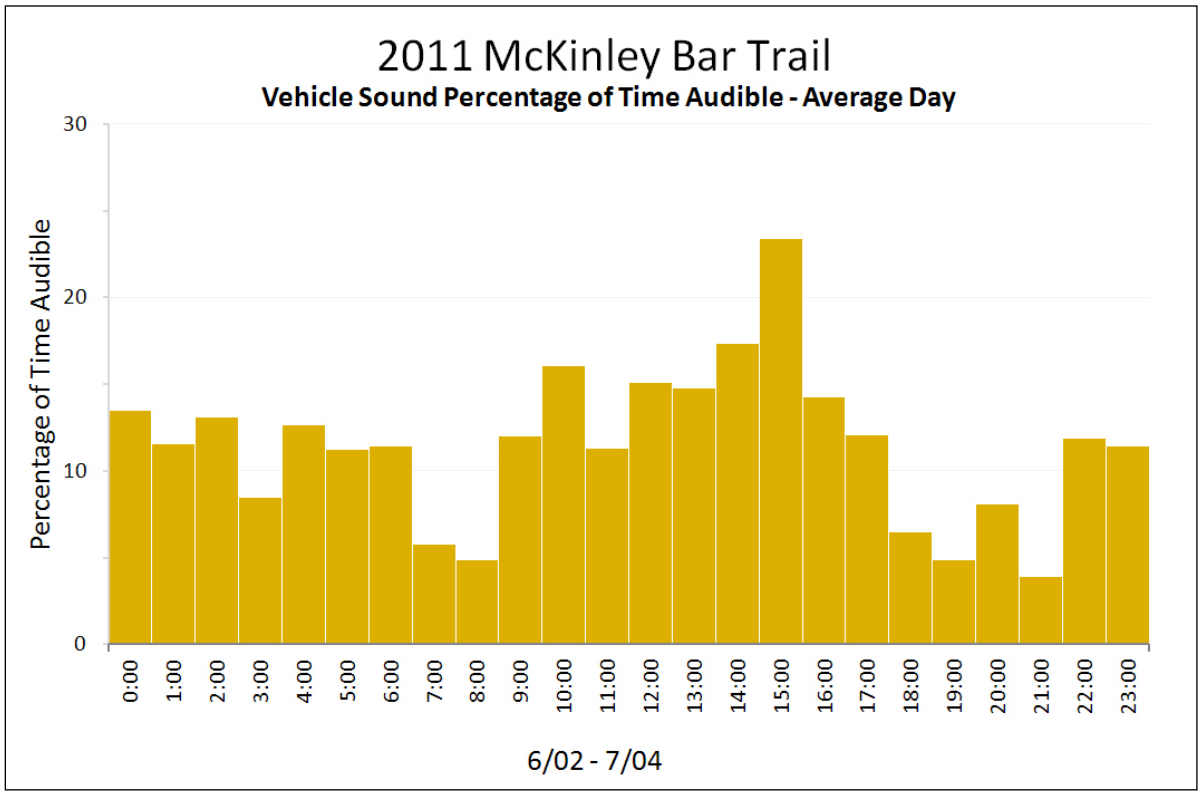


Figure 35. Audibility of vehicle noise for an average day, by hour, at McKinley Bar Trail.

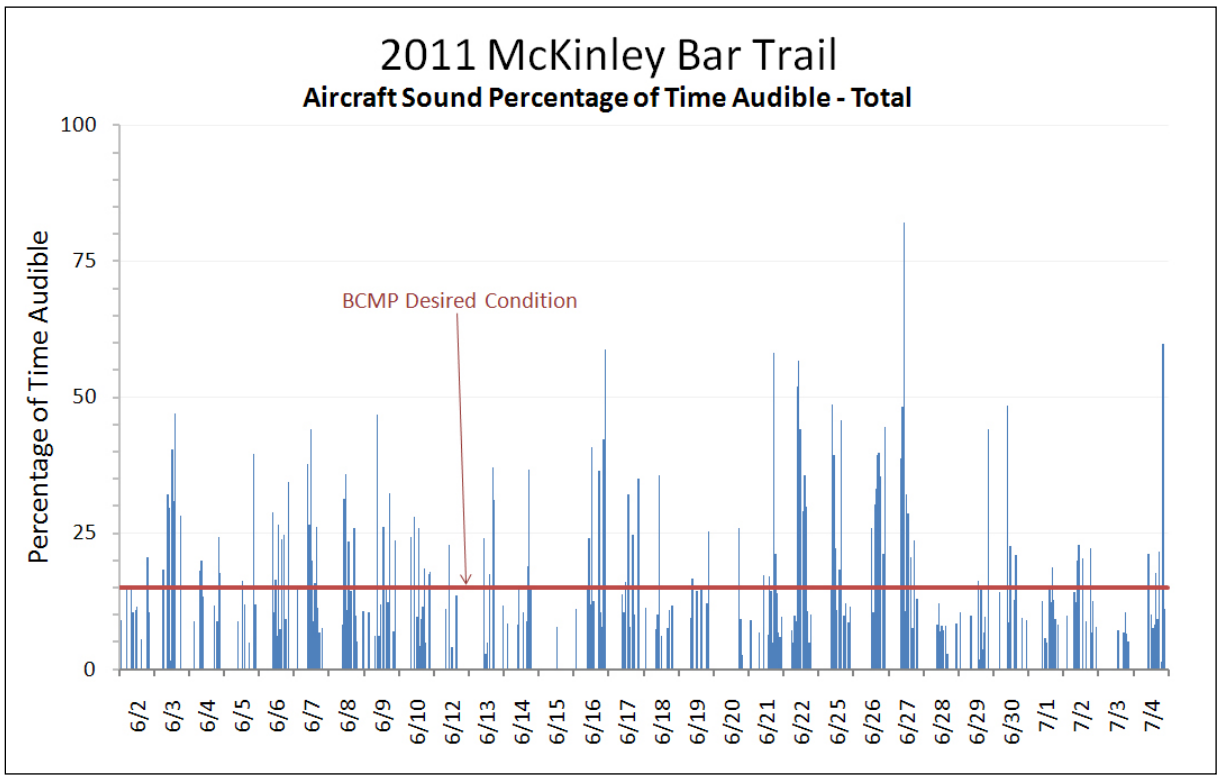


Figure 36. Audibility of aircraft noise at McKinley Bar Trail.

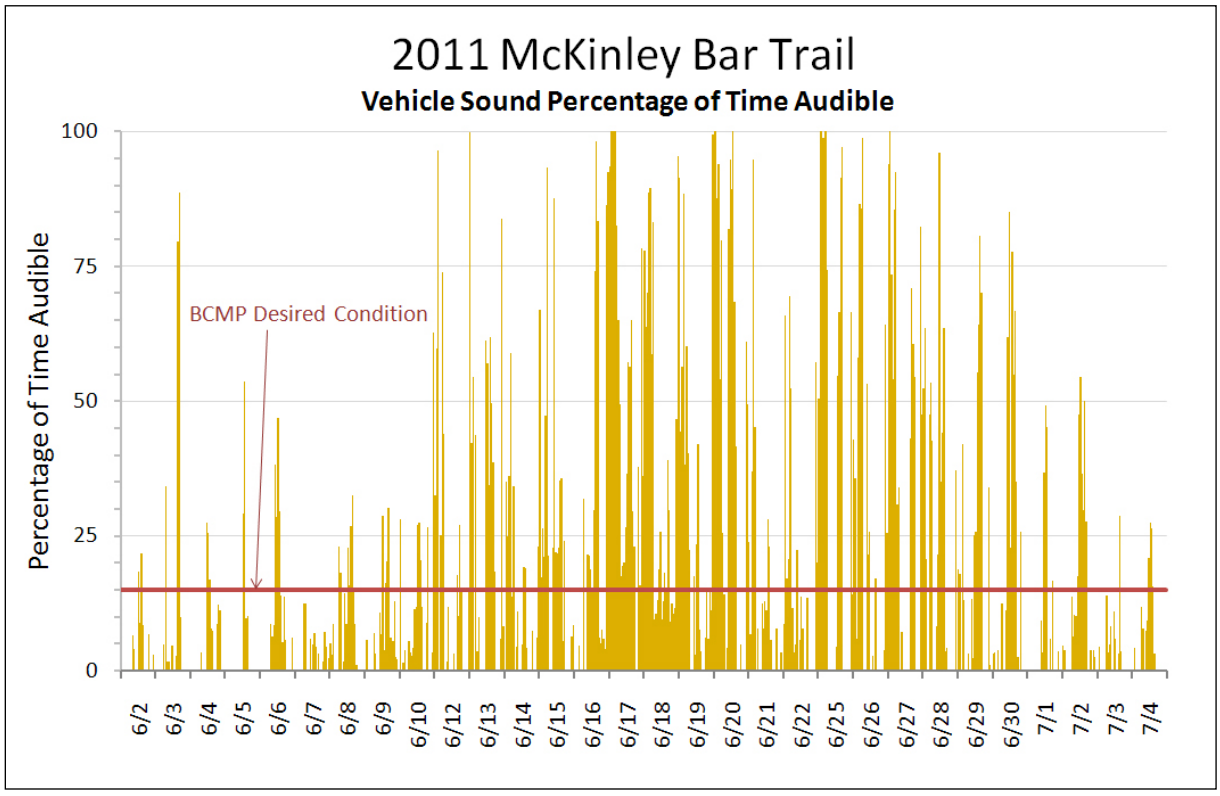


Figure 37. Audibility of vehicle noise at McKinley Bar Trail.

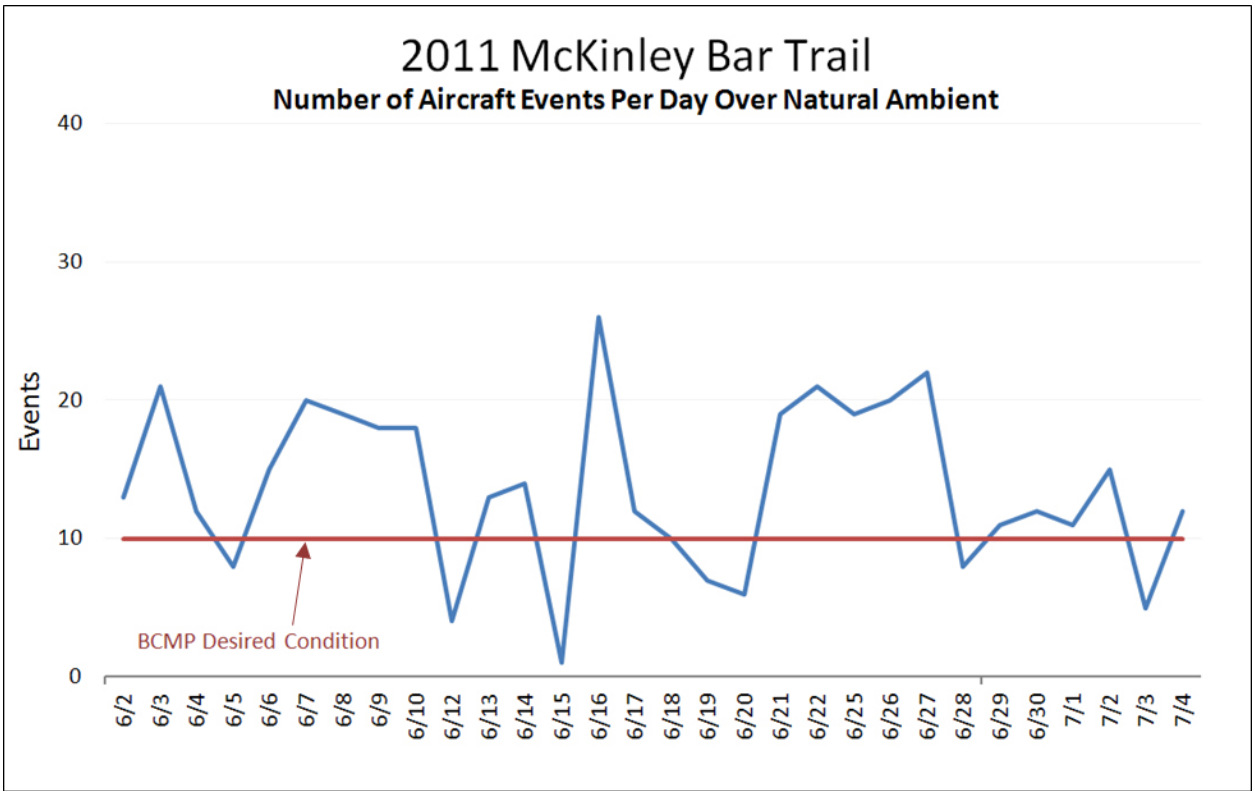


Figure 38. Number of aircraft noise events identified per day at McKinley Bar Trail.

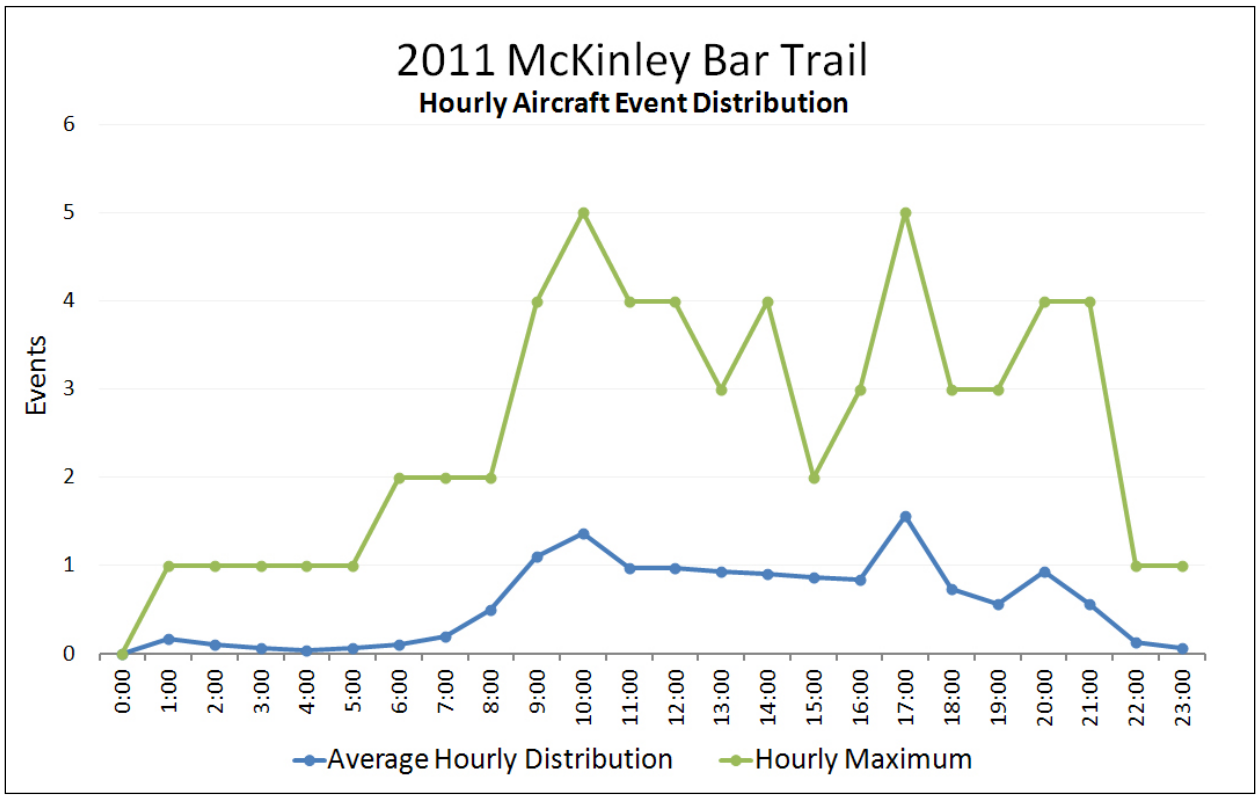


Figure 39. Hourly average and maximum aircraft event distribution at McKinley Bar Trail.

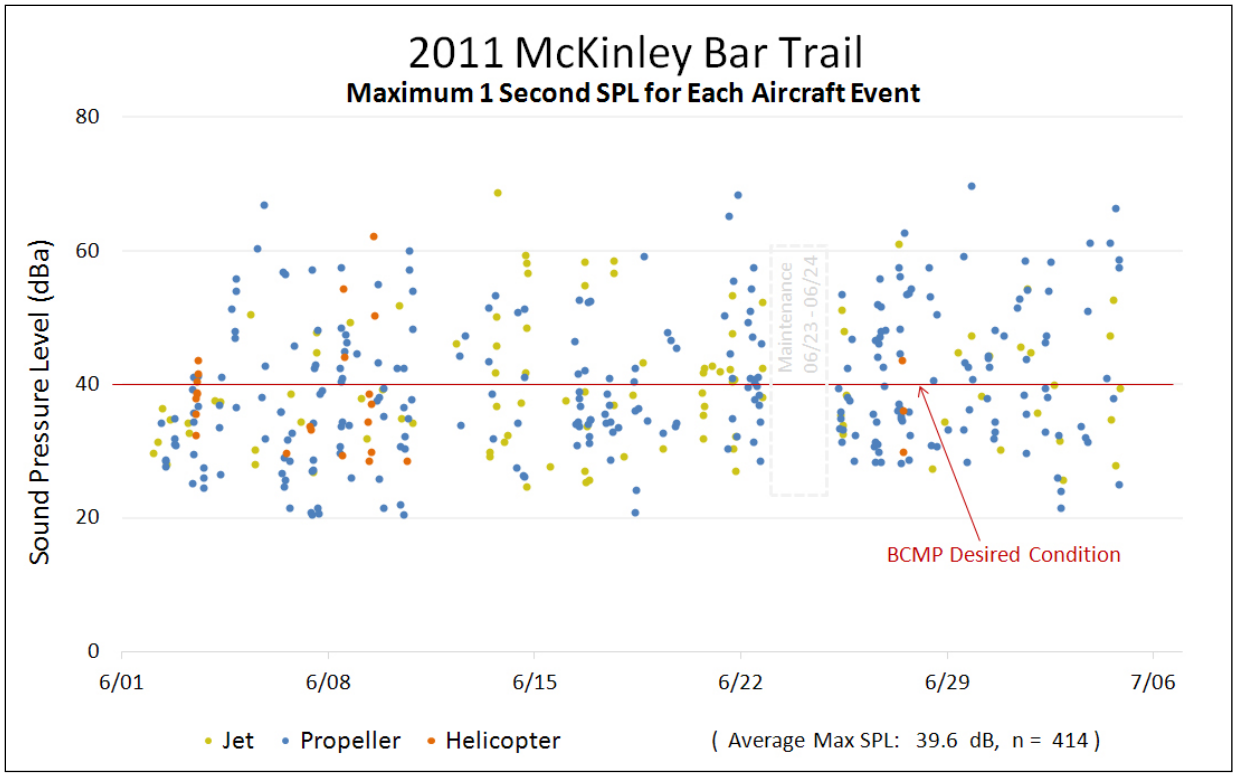


Figure 40. Maximum one-second SPL for each aircraft event identified at McKinley Bar Trail.

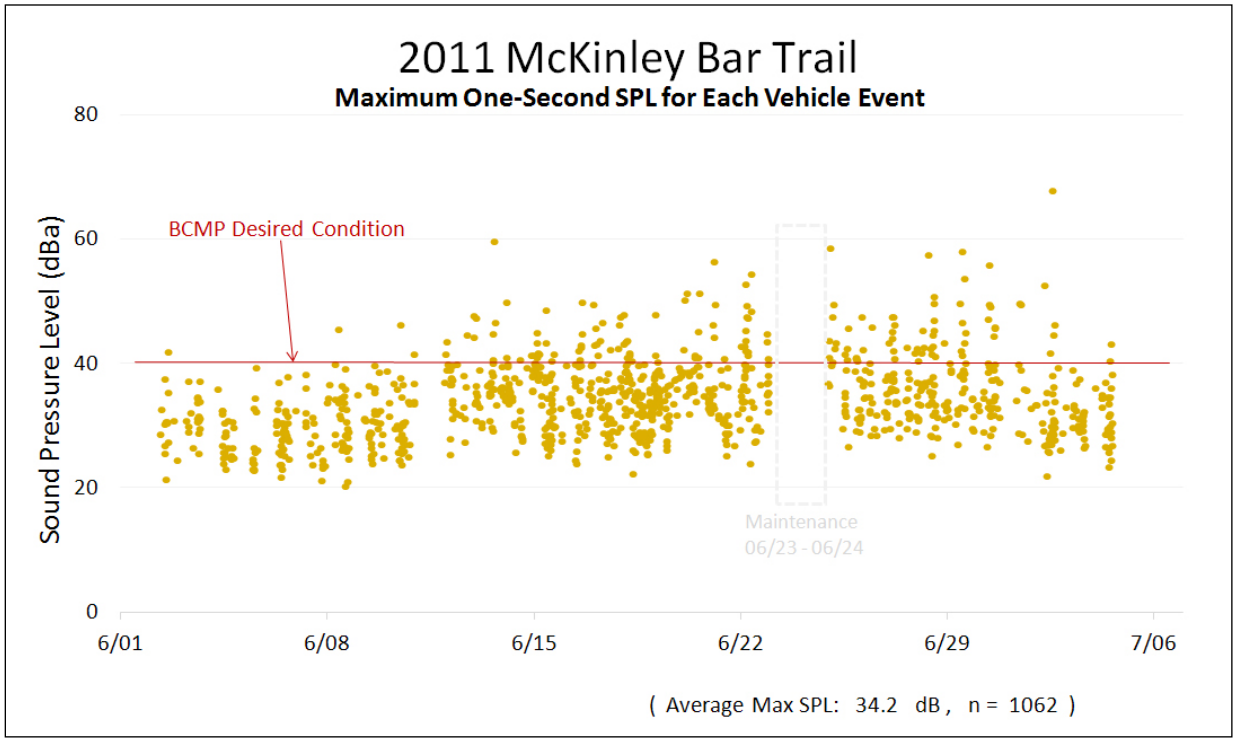
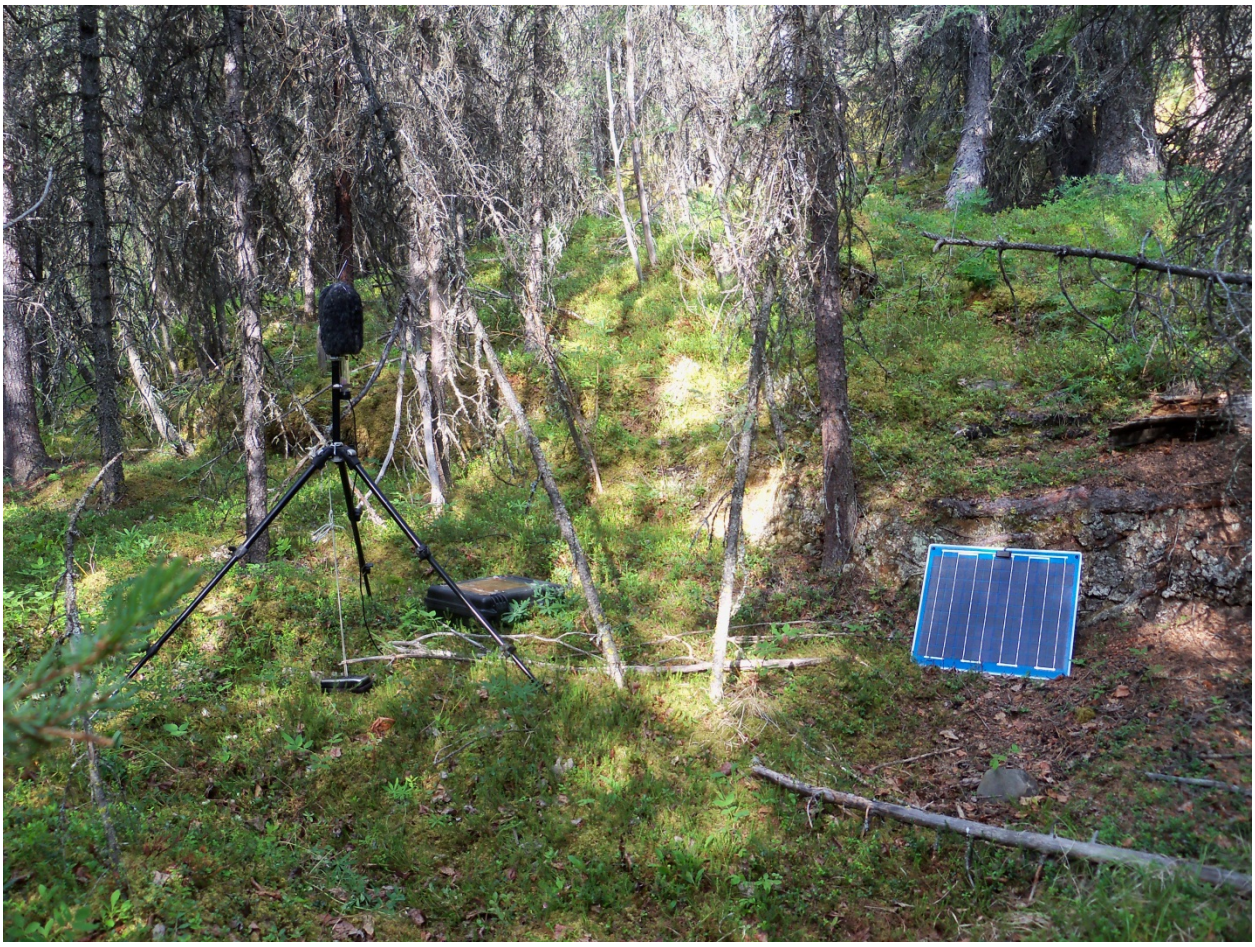


Figure 41. Maximum one-second SPL for each vehicle event identified at McKinley Bar Trail.

North Triple Lakes Trail



Location Description: Along the Triple Lakes Hiking trail, approximately equidistant from the Hines Creek and Riley Creek footbridges. The station was placed southwest of the trail by about 15 meters.

Purpose/Project: This location was administratively selected to provide physical information in support of the Soundscape Social Survey. During the station's deployment, researchers surveyed day-hikers about Soundscape conditions along the trail.

Coordinates: Lat. 63.72408, Long. -148.91745

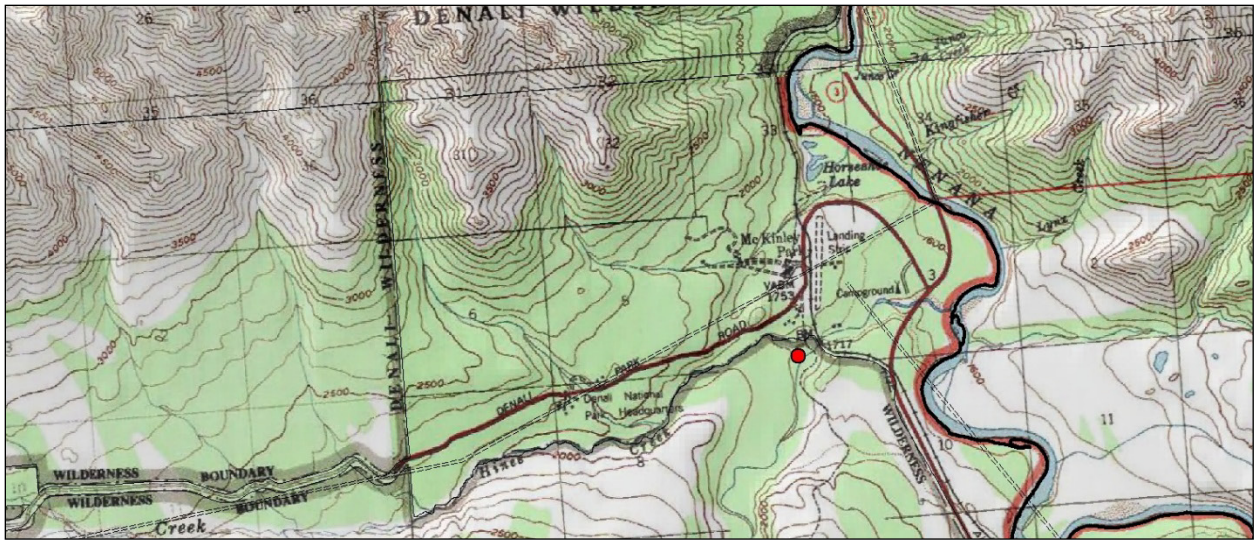
Elevation: 516.0 Meters

Time at Location: 20-June-2011 – 27-June-2011

BCMP Management Zone: Backcountry Hiker (equivalent to Medium)

Park Ecoregion: Lowland Floodplains & Terraces & Fans

Access: Foot



Summary: The purpose of this administratively chosen location was to collect data in support of the 2011 Soundscapes Social Survey. Hikers were surveyed concurrently with the collection of physical data in order to study the differences between what was reported to be heard in the field and what was heard during analysis.

This site was predominantly characterized by the sound of Riley Creek, a continuous rushing flow of water. The average natural ambient sound pressure level in the area - as apparent in Figure 42 - was around 45 dBA throughout the entire day. Though this level is relatively high when compared to other sites throughout Denali, it is nevertheless typical for areas within the immediate influence of rivers.

Because of its proximity to the water, this station did not experience any temperature-dependent sound shadows during the sampled period. (This is opposed to the stations at McKinley Bar Trail and West Kantishna Hills, at which this temporal variation was clearly observed.) Another effect of proximity to the creek was that the high-frequency energies of the water had less distance over which to be absorbed by the air before reaching the microphone. For that reason, the bandwidth occupied by the river was relatively large, 5000 Hz or more. Because of the masking power of the water, especially for the higher frequencies, listening area was greatly reduced. This tended to create a snug, localized acoustic perspective; most natural sounds were only audible within close proximity to the station. For instance, when birds and red squirrels were audible, they were probably no more than 50 meters distant.

The site was tucked beneath an old embankment of the creek in a relatively dense grove of spruce and aspen. The branches and foliage also contributed to the 'closeness' of the soundscape, primarily by slowing down the air enough that wind was not audible in the windscreen. Instead, the platy rattle of aspen leaves was usually the only audible indication of breezes. This sound was masked heavily in the lower frequencies, so it was usually identified by components of the sound greater than 5000 Hz.

Human impacts to the area were intense, but considering the site's proximity to transportation thoroughfares - the PAIN airstrip, ERA helibase, Riley Creek train bridge, and the Parks Highway, to name a few - they were not exactly unexpected. Still, it is noteworthy to mention that some propeller aircraft taking off from the PAIN strip were loud enough to cause prominent distortion in the recordings. Helicopters working with the Alaska Fire Service were likely stationed on the airstrip at this time as well. Their operations were often unusually timed (late evenings after fire activity had slowed) and may be responsible for some of the unusual signatures observed during visual analysis.

Factors in both the social dimension (source timing) and physical (temperature gradients) likely affected the audibility of traffic on the Parks Highway. Most vehicle sounds were centered on midnight (most likely semi or construction traffic), and during the 06:00 and 07:00 hours (most likely employees and visitors arriving to the park). Train pass-bys were prominently audible from the North Triple Lakes Trail station, and were the longest events observed at the site. An average train event was audible for about 12 minutes.

The most commonly heard sounds at this site were flowing water (audible 99% of the time), birds (50.5%), wind in the trees (14.5%), propeller aircraft (7.4%), and rain (7.4%). Human made sound was audible 33.0% of the time on average. Vehicles – mainly automobiles, semis, and buses – were audible 9.4% of the time. Trains on the railroad were audible 6.6% of the time. Aircraft were audible 17.2% of the time on average. This is equivalent to 247.7 minutes of aircraft sound each day, or about 71 overflights a day. Conditions exceeded the BCMP percent audible standard 52% of the time, number of events per day 100% of the time, and maximum SPL 100% of the time.

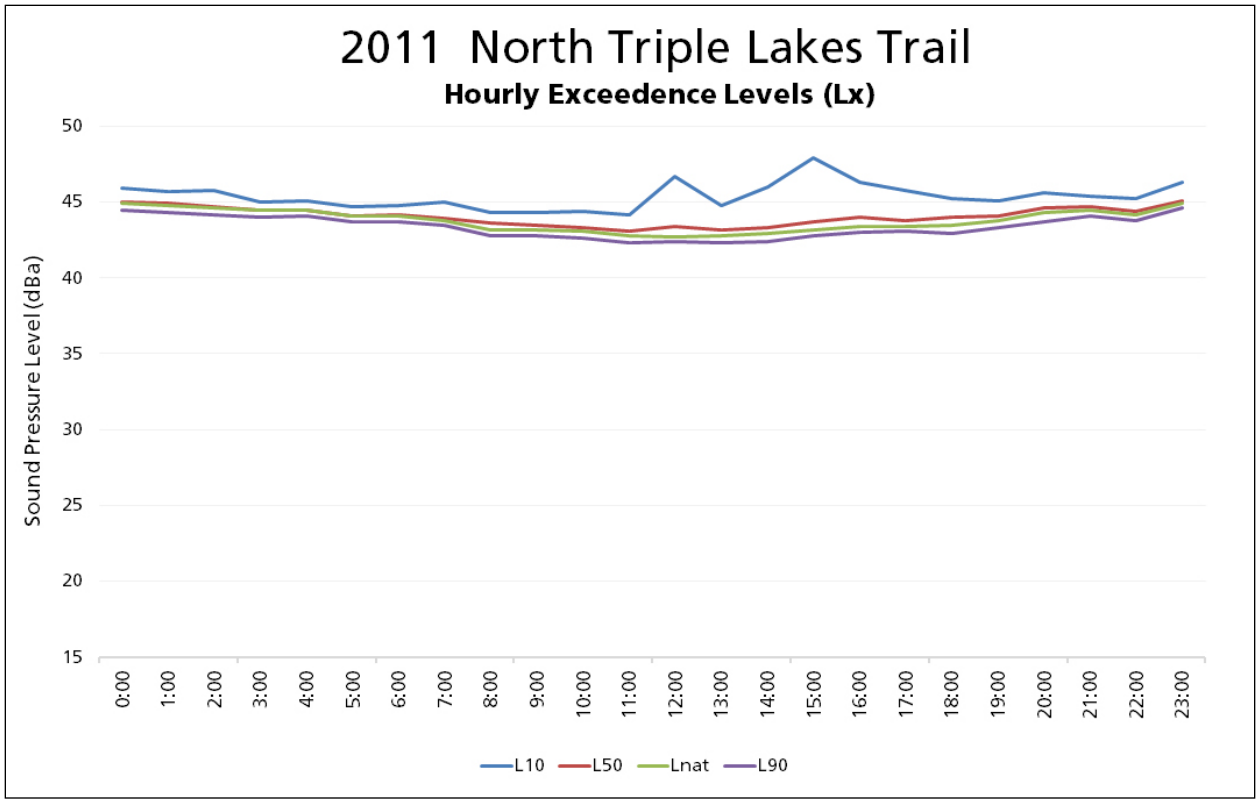


Figure 42. Exceedence levels for North Triple Lakes Trail.

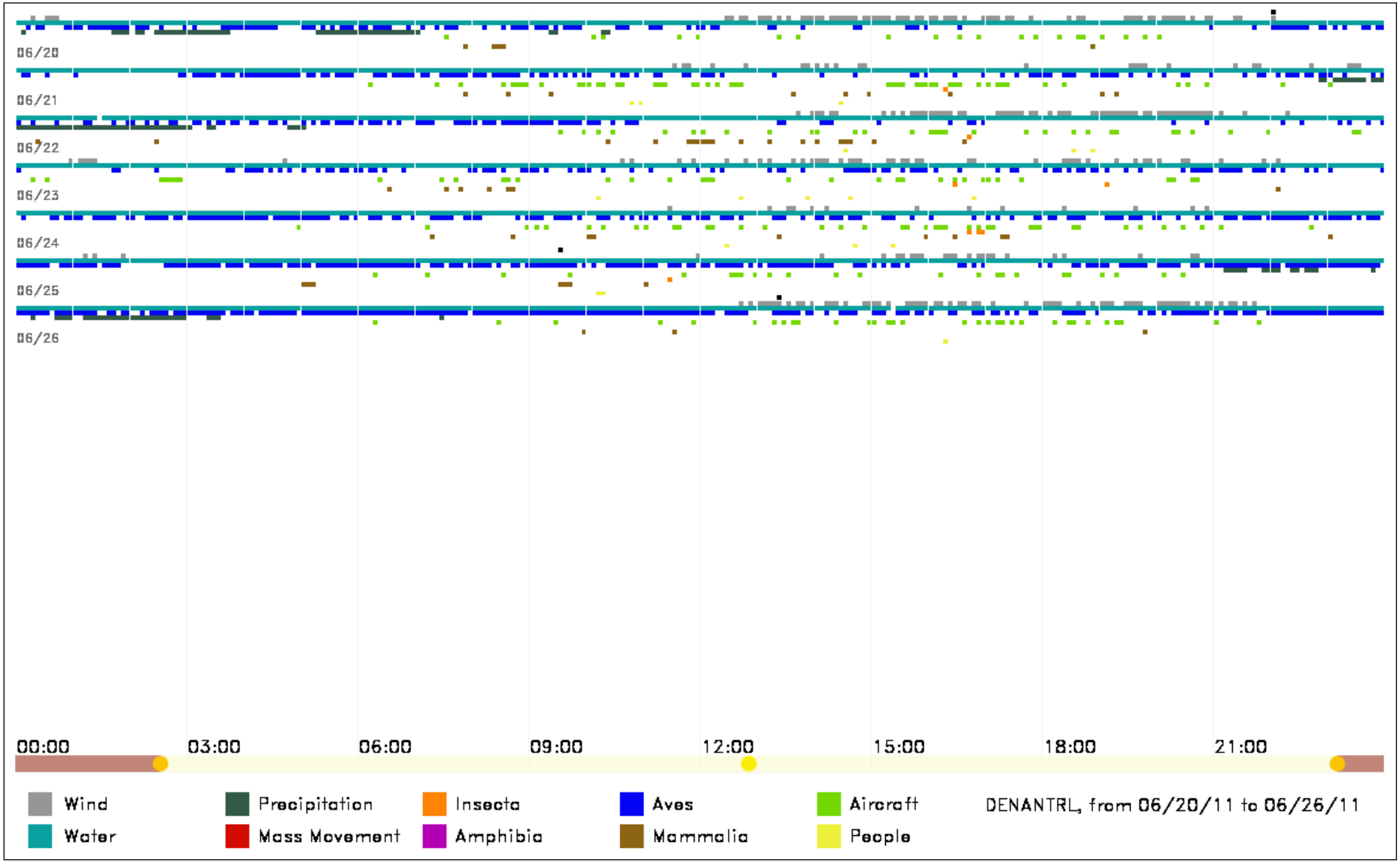


Figure 43. Temporal audibility of sound sources at North Triple Lakes Trail, based on five seconds of audio every five minutes. The bar along the horizontal axis indicates the average light conditions during the sampling period. The orange circles are sunrise/sunset. This site did have civil twilight or night-time conditions during the sampling period.

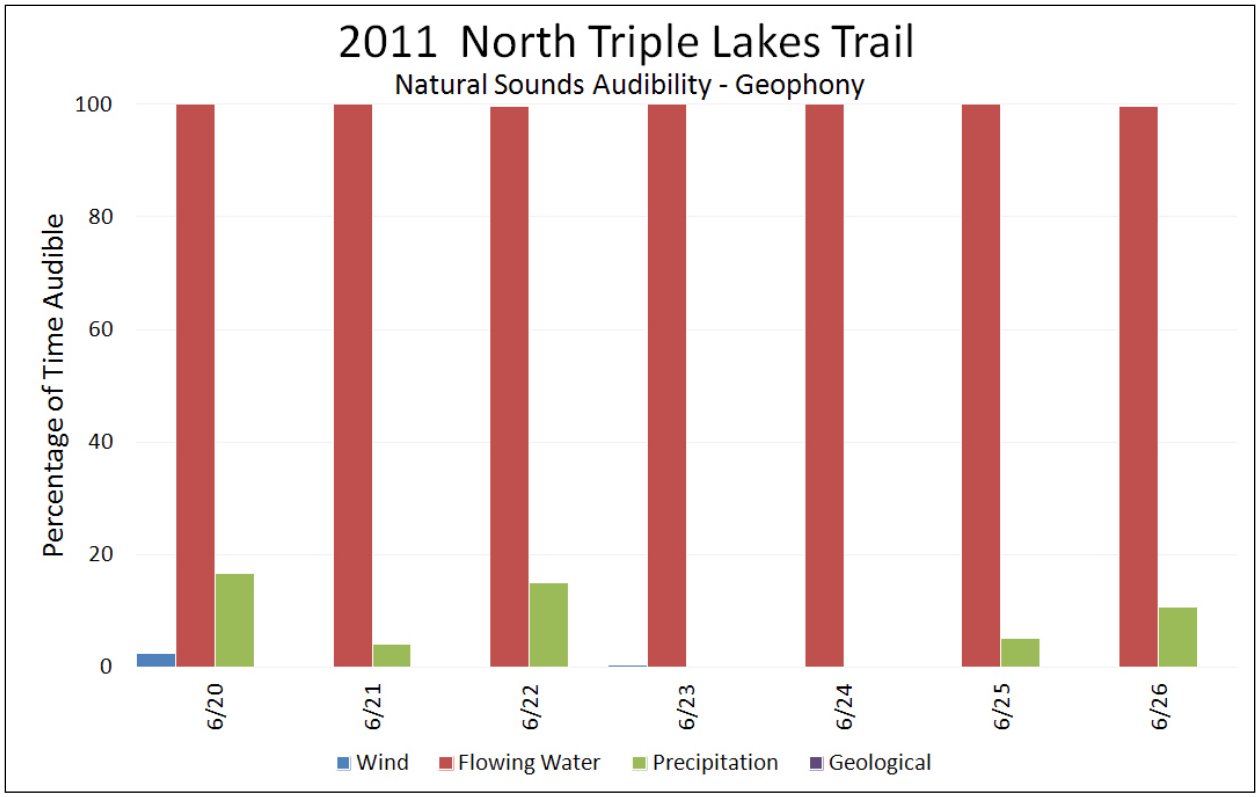


Figure 44. Percentage of time audible for geophonic sounds at North Triple Lakes Trail.

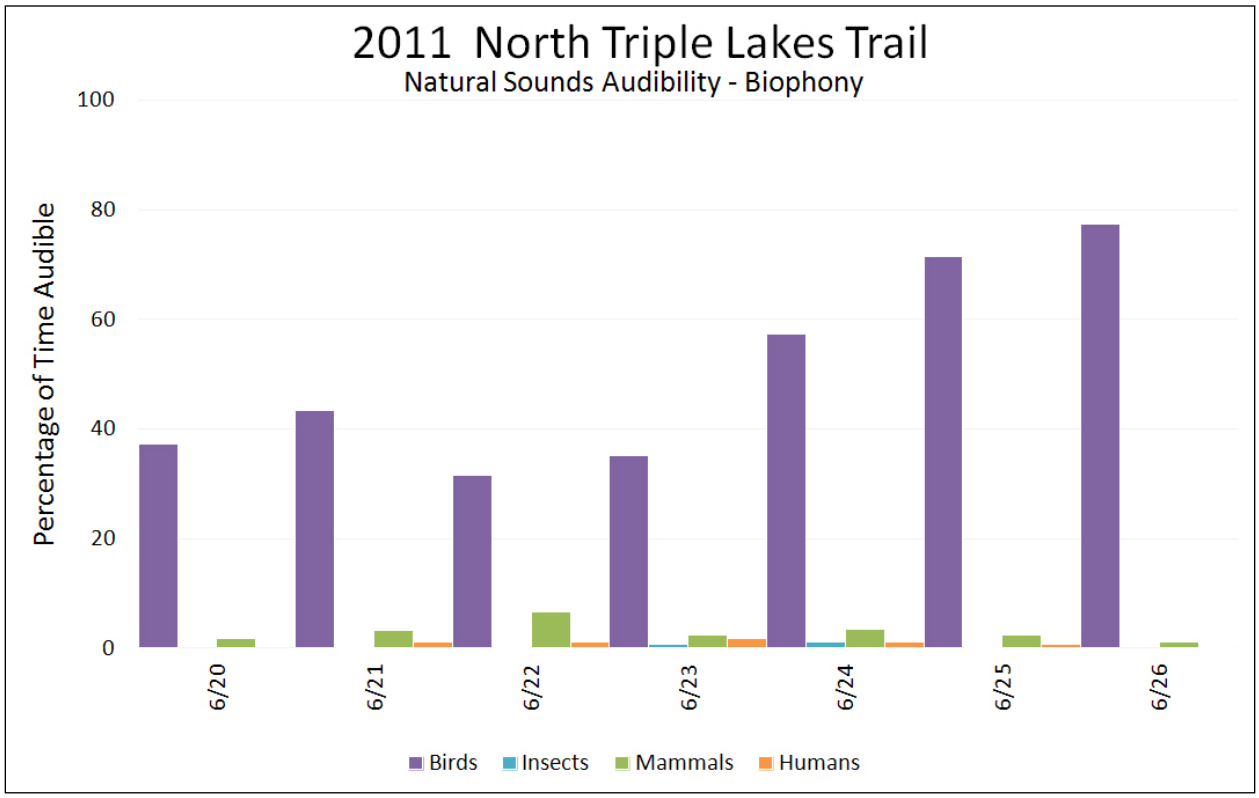


Figure 45. Percentage of time audible for biophonic sounds at North Triple Lakes Trail.

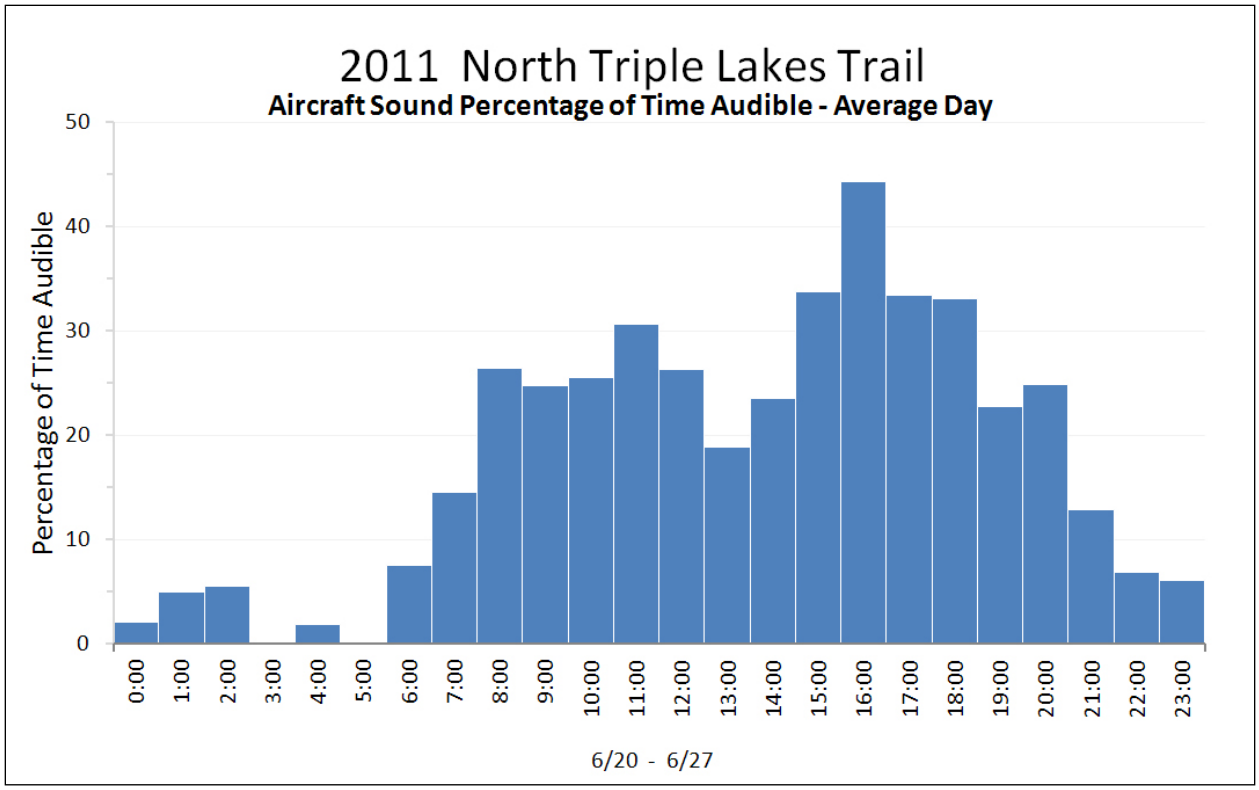


Figure 46. Audibility of aircraft noise for an average day, by hour, at North Triple Lakes Trail.

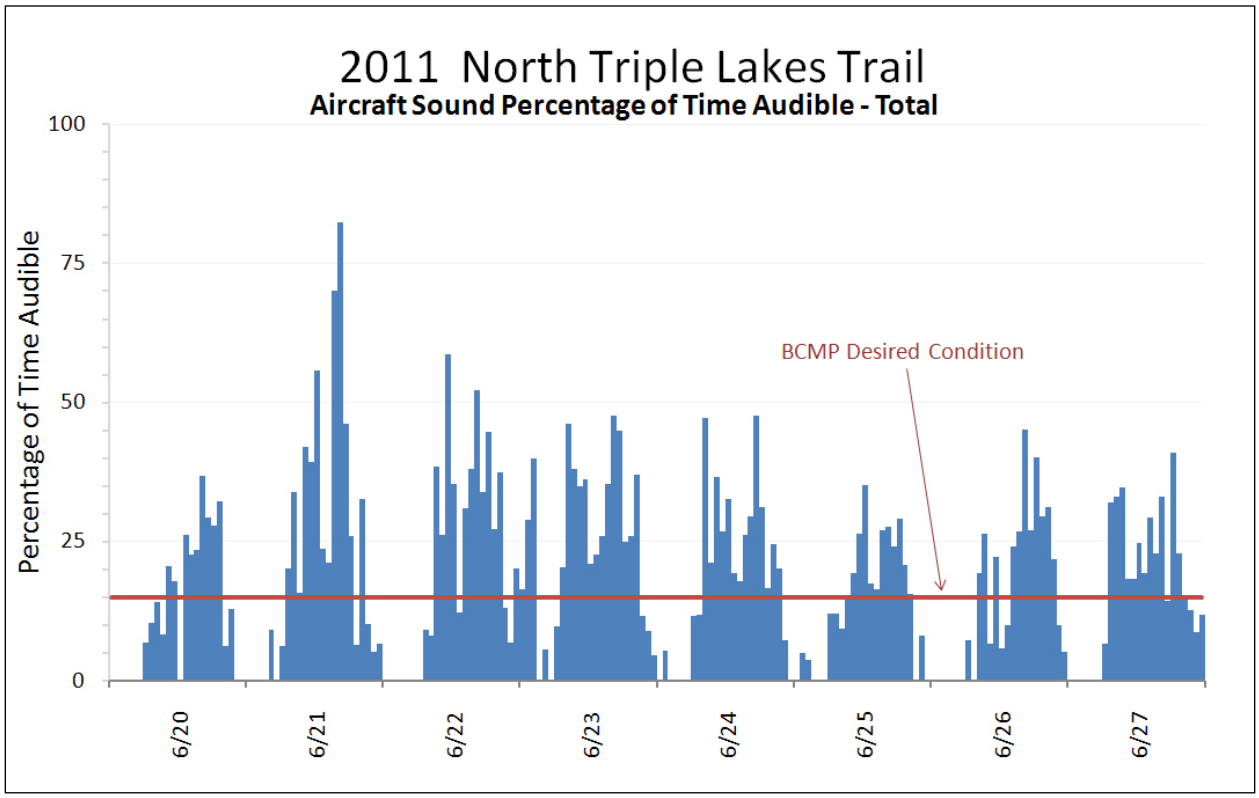


Figure 47. Audibility of aircraft noise at North Triple Lakes Trail.

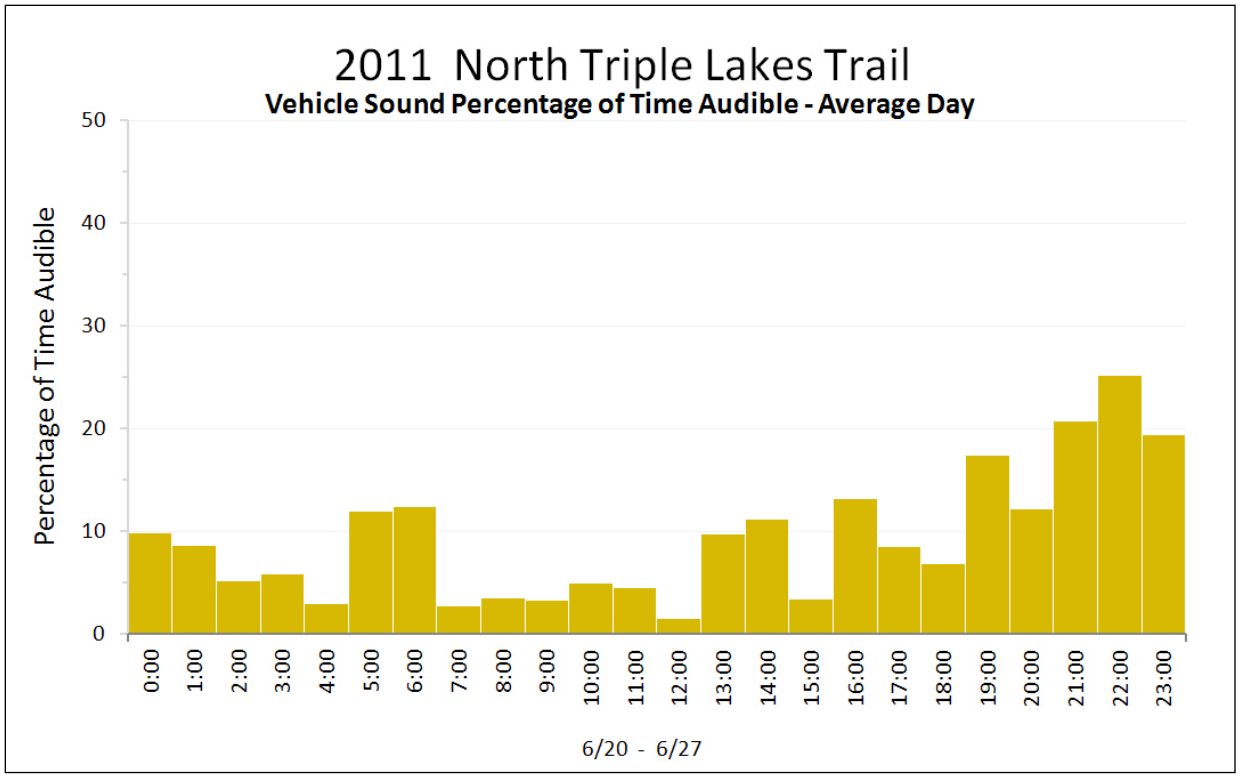


Figure 48. Audibility of vehicle noise for an average day, by hour, at North Triple Lakes Trail.

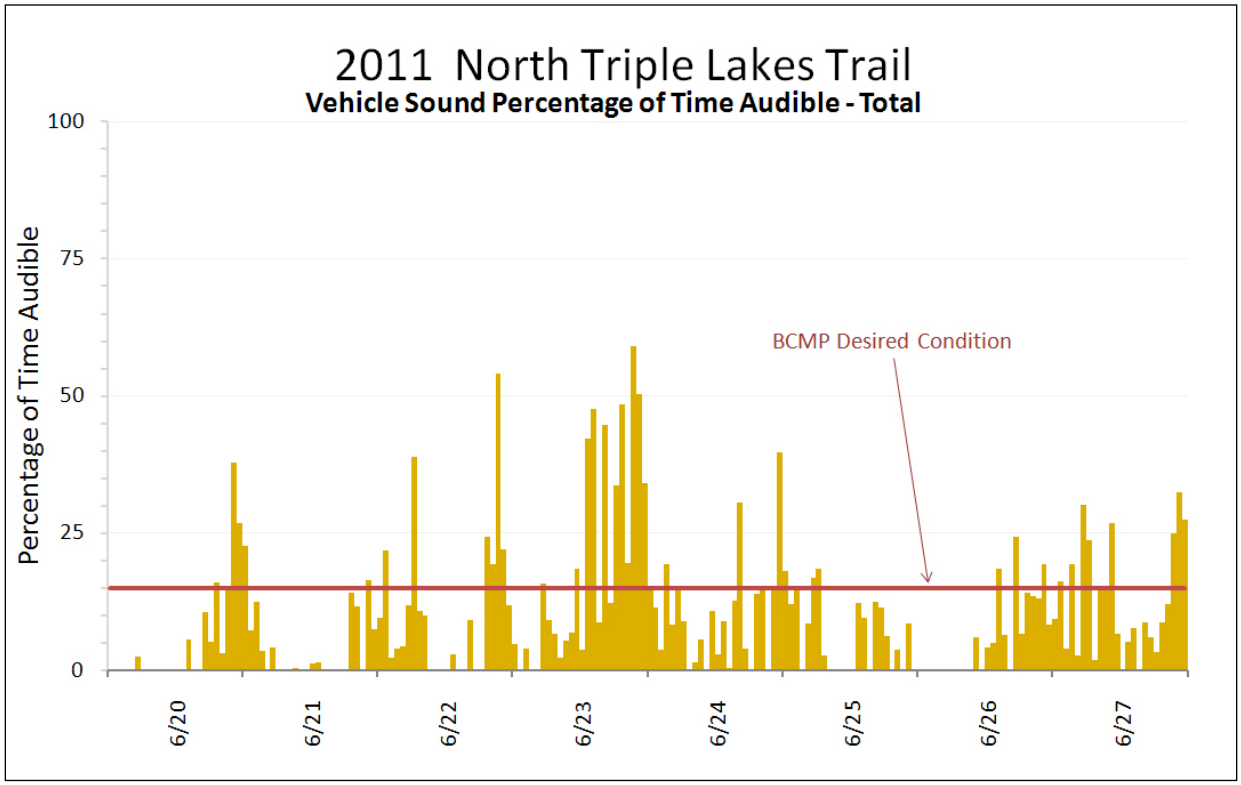


Figure 49. Audibility of vehicle noise at North Triple Lakes Trail.

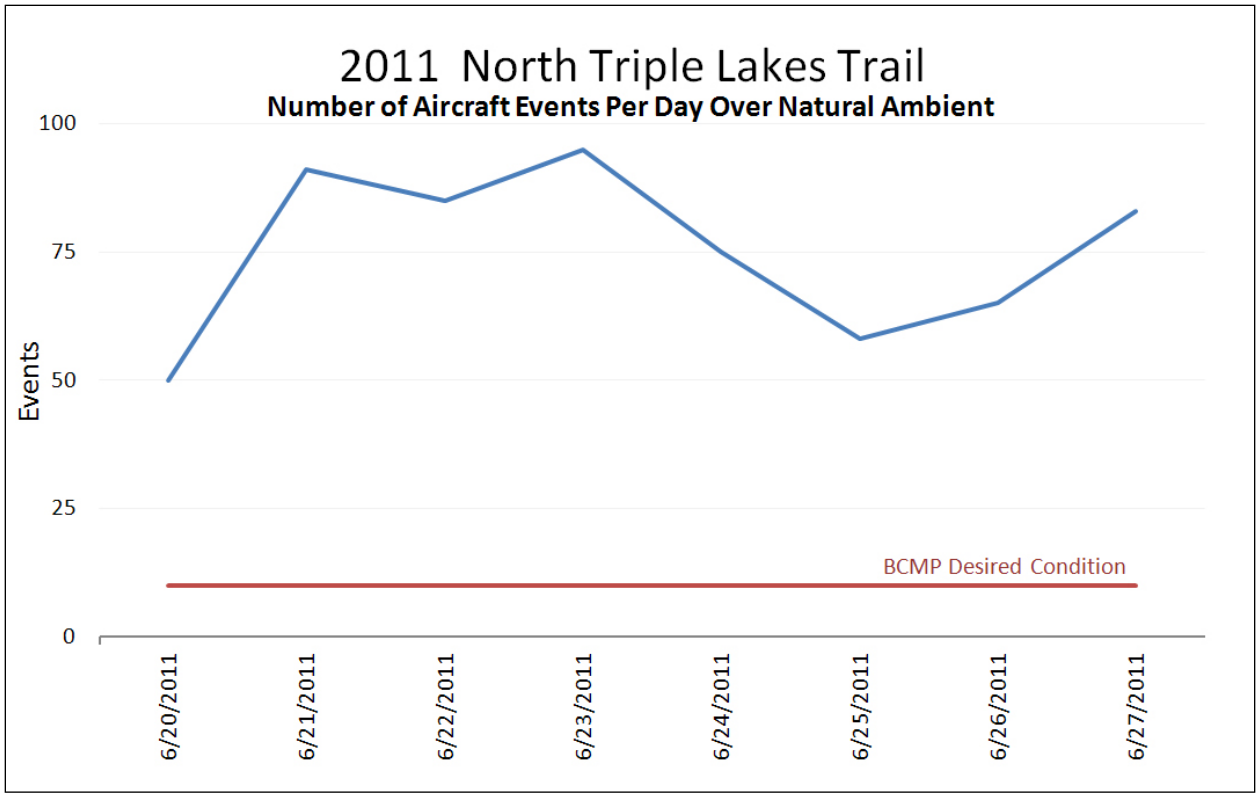


Figure 50. Number of aircraft noise events identified per day at North Triple Lakes Trail.

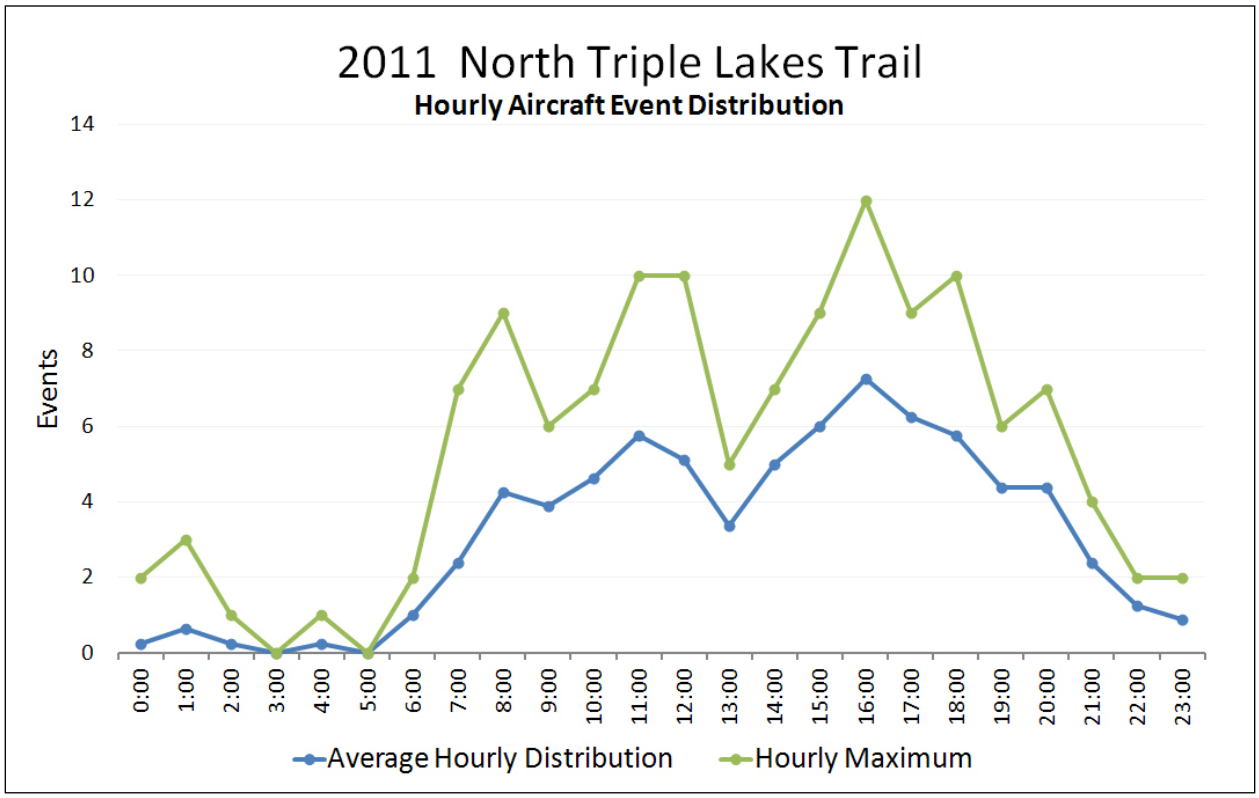


Figure 51. Hourly average and maximum aircraft event distribution at North Triple Lakes Trail.

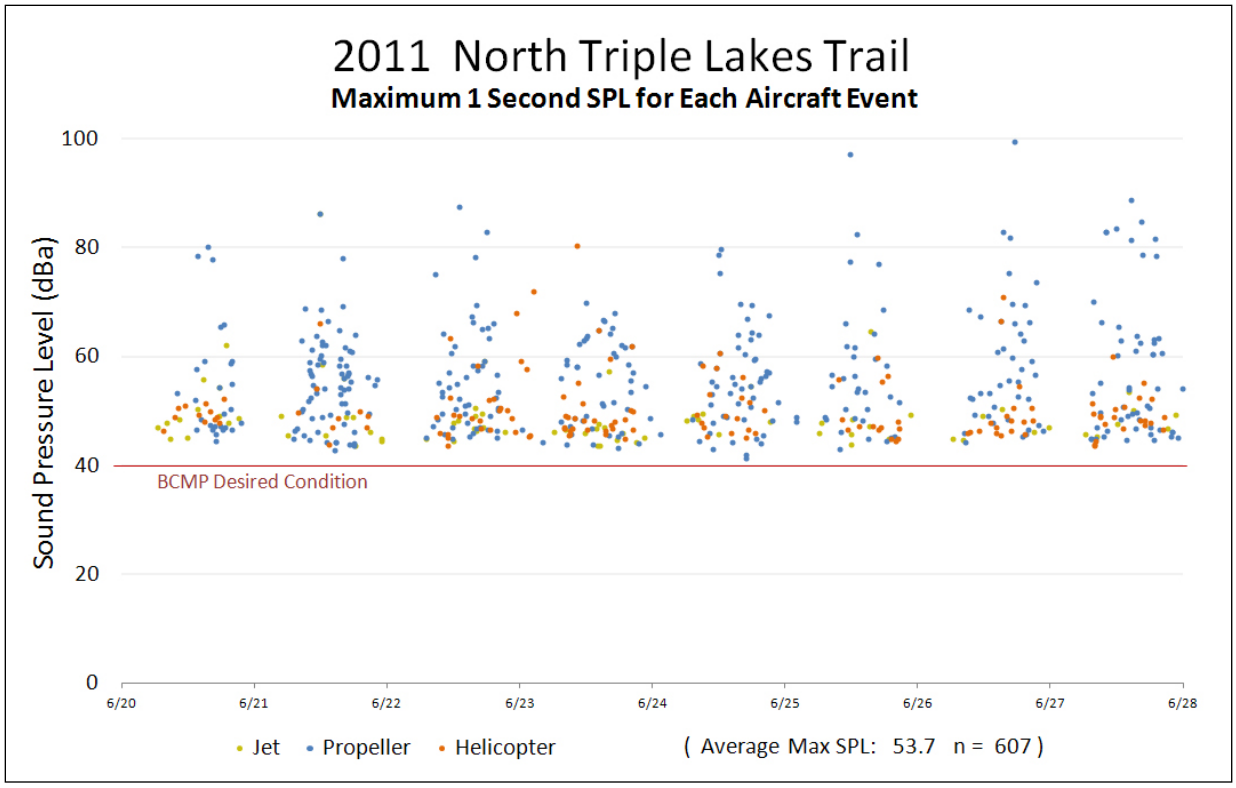


Figure 52. Maximum one-second SPL for each aircraft event identified at North Triple Lakes Trail.

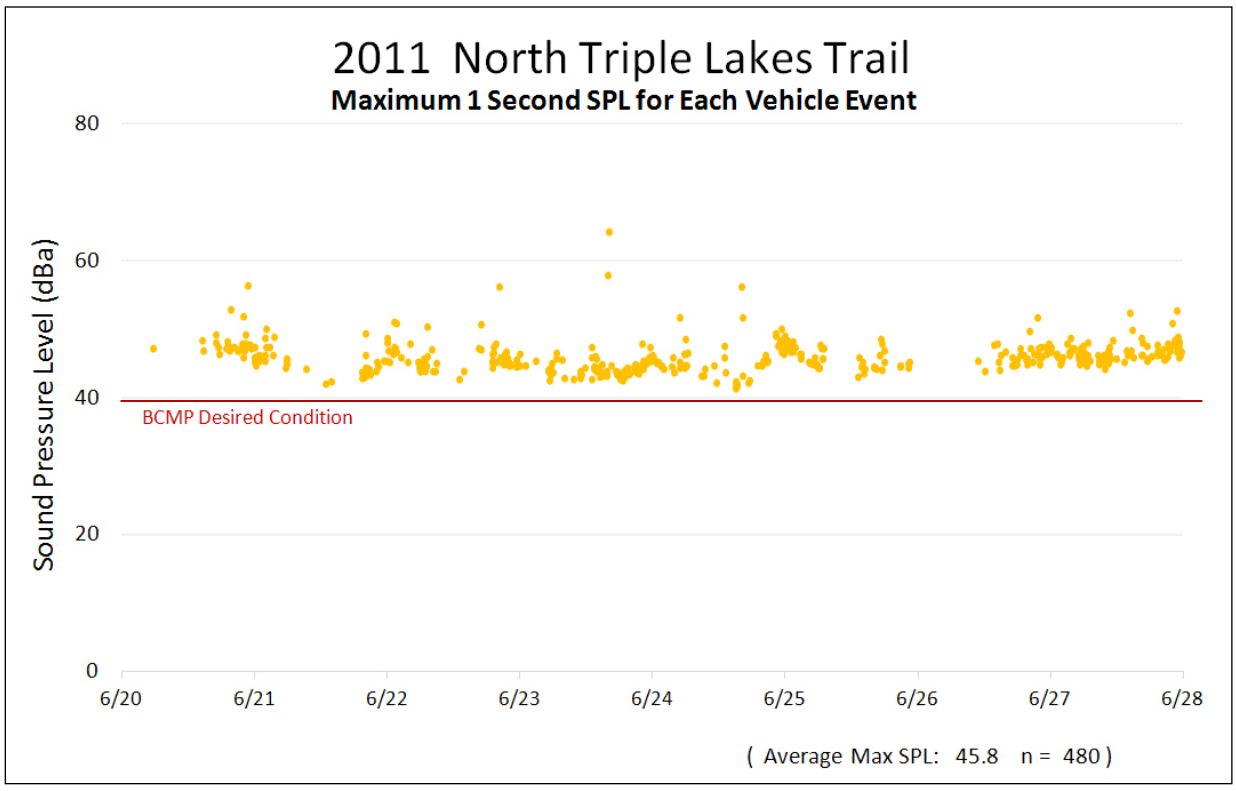


Figure 53. Maximum one-second SPL for each vehicle event identified at North Triple Lakes Trail.

Stampede Airstrip



Location Description: About 20 meters west of the southwest corner of Stampede Airstrip.

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

Coordinates: Lat. 63.74887, Long. -150.330017

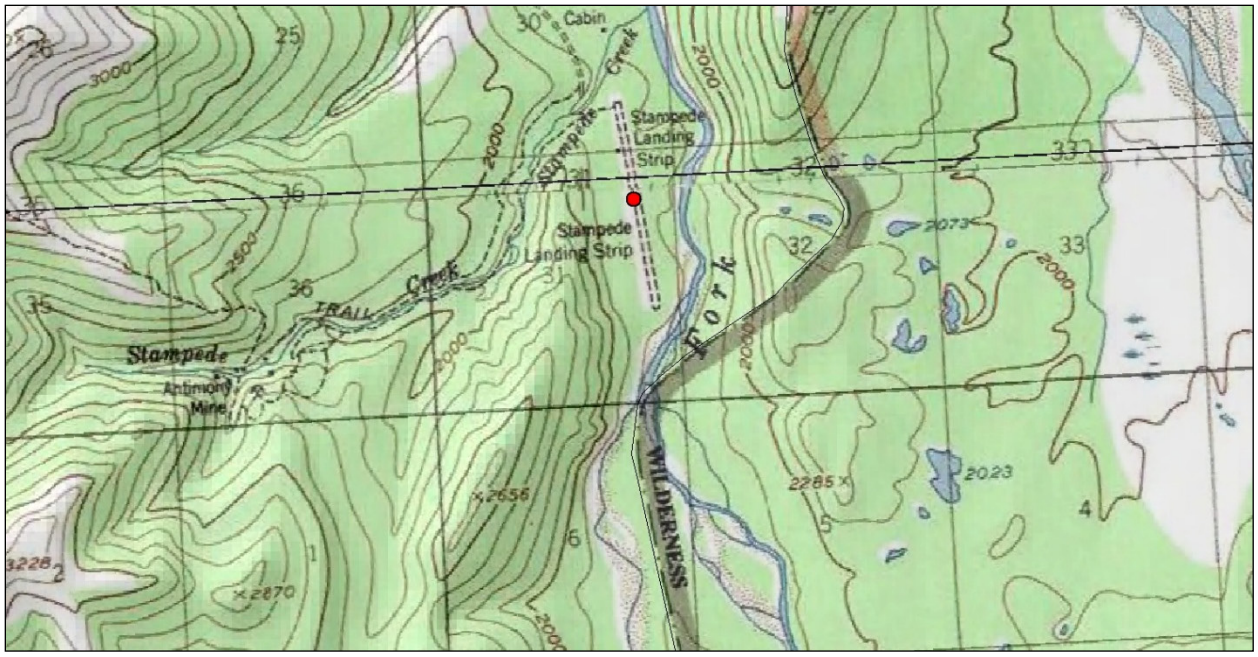
Elevation: 565.6 Meters

Time at Location: 27-January-2011 – 18-June-2011

BCMP Management Zone: Medium

Park Ecoregion: Alpine Outer Range & Kantishna Hills

Access: Dog Sled Installation and Maintenance / Helicopter Removal



<u>Summary</u>: The purpose of the Stampede Airstrip location was to collect data where snowmobiles are occasionally used along the wilderness boundary. A specialized low-noise preamplifier was used to provide an indication of the levels of associated noise with respect to the natural ambient sound pressure level. Because winter conditions can be very still, an instrument with a lower noise floor was selected for use. The site was a New Park location and selected from locations possible to access via dogsled.

Due to ground loop interference (an old trouble reborn into this new system) the collection of audibility data at this site was not successful, and no audibility analysis was possible. However, SPL data was collected, so a visual analysis of human-caused noise was still performed.

When the station was being set up, wolves (*Canis lupis*) were heard howling to the South of the airstrip, most likely from somewhere on Clearwater Creek. The dog teams remained completely quiet until the wolves were finished howling (about 30 seconds or so), and after a long, still pause of listening, they replied with a similar howl. After a similar duration of howling, the teams stopped, and the wolves began again. This alternate, antiphonal communication continued for about five minutes, but regrettably was not captured on record.

The Stampede Airstrip data, especially the first month, appear to be a good example of Denali's deep-winter soundscape. Conditions alternate clearly between spells of incredible calm and those of powerful all-day winds. Aircraft were the main punctuation of this otherwise extremely continuous, though polarized environment.

Human made sound was audible 2.7% of the time on average, all of which was created by aircraft (73% of all traffic was high-altitude jets). This is equivalent to 38.9 minutes of aircraft sound each day, or about 7 overflights a day. Conditions exceeded the BCMP percent audible standard 5% of the time, number of events per day 17% of the time, and maximum SPL 32% of the time.

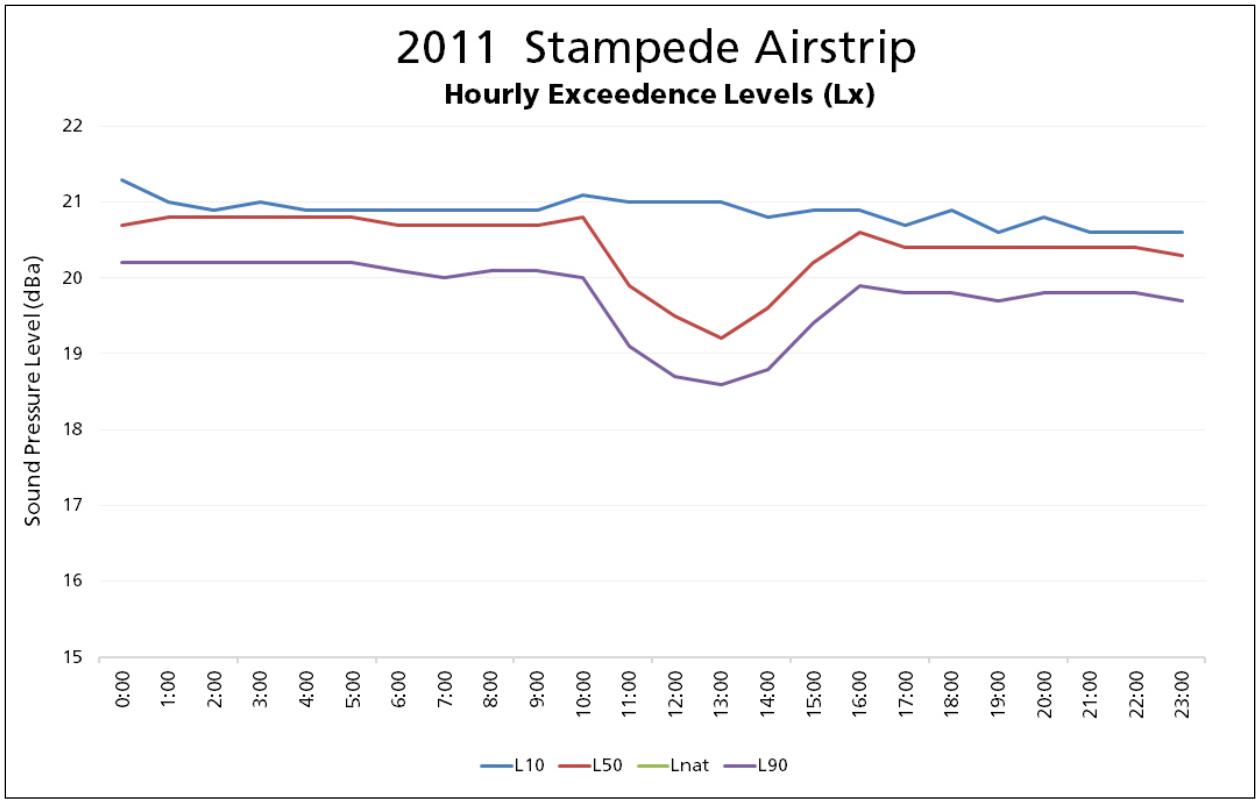


Figure 54. Exceedence levels for Stampede Airstrip.

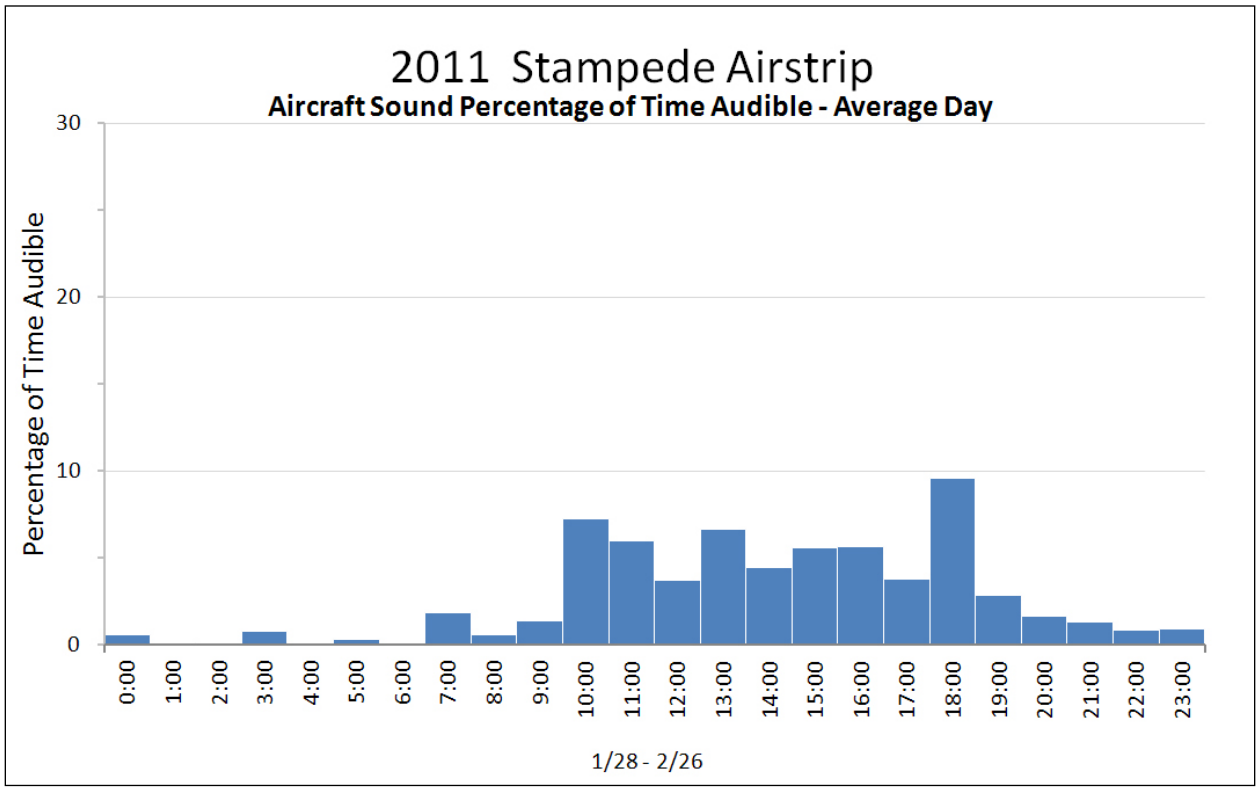


Figure 55. Audibility of aircraft noise for an average day, by hour, at Stampede Airstrip.

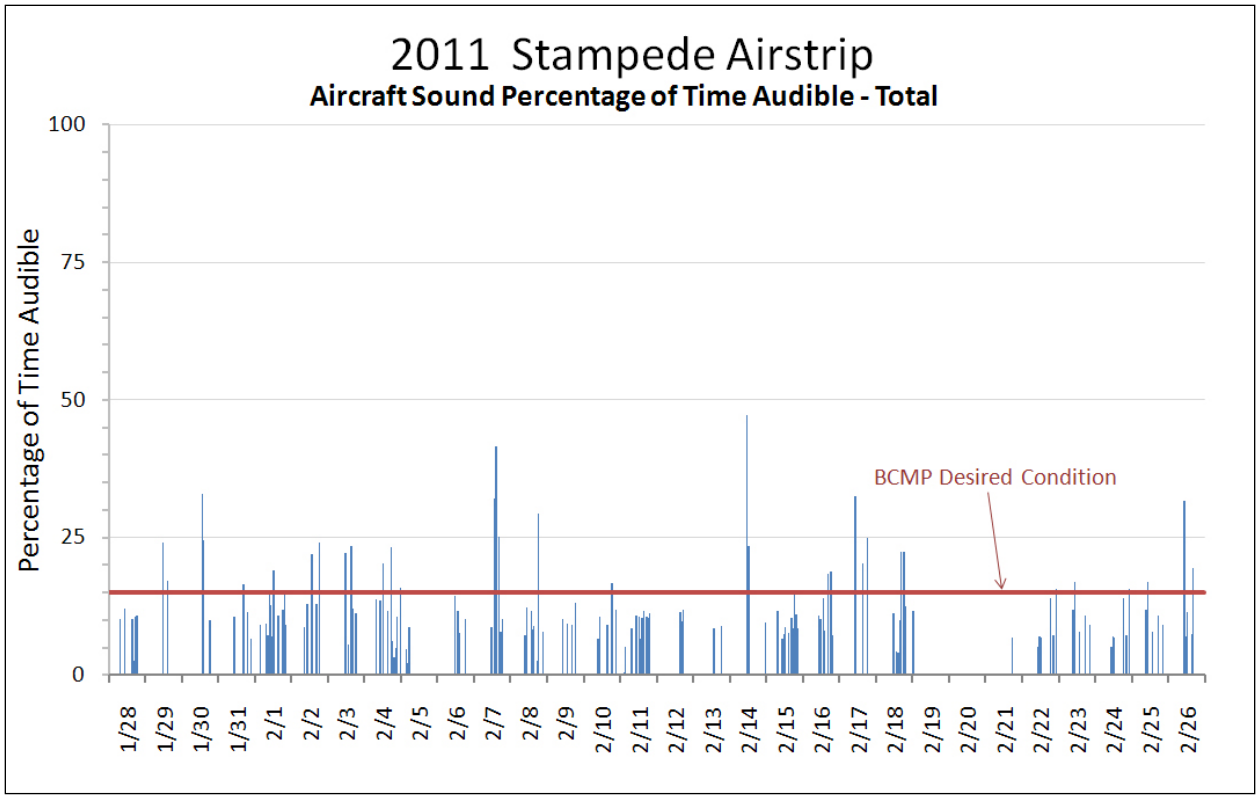


Figure 56. Audibility of aircraft noise at Stampede Airstrip.

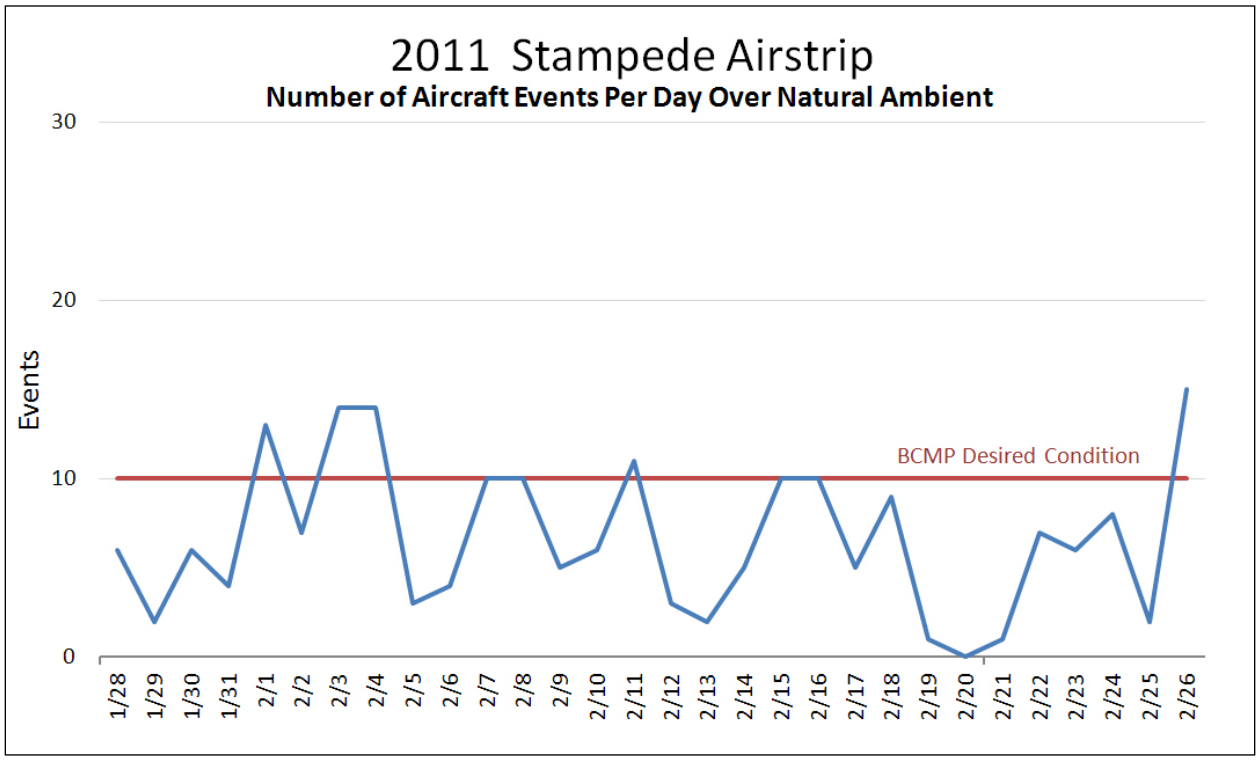


Figure 57. Number of aircraft noise events identified per day at Stampede Airstrip.

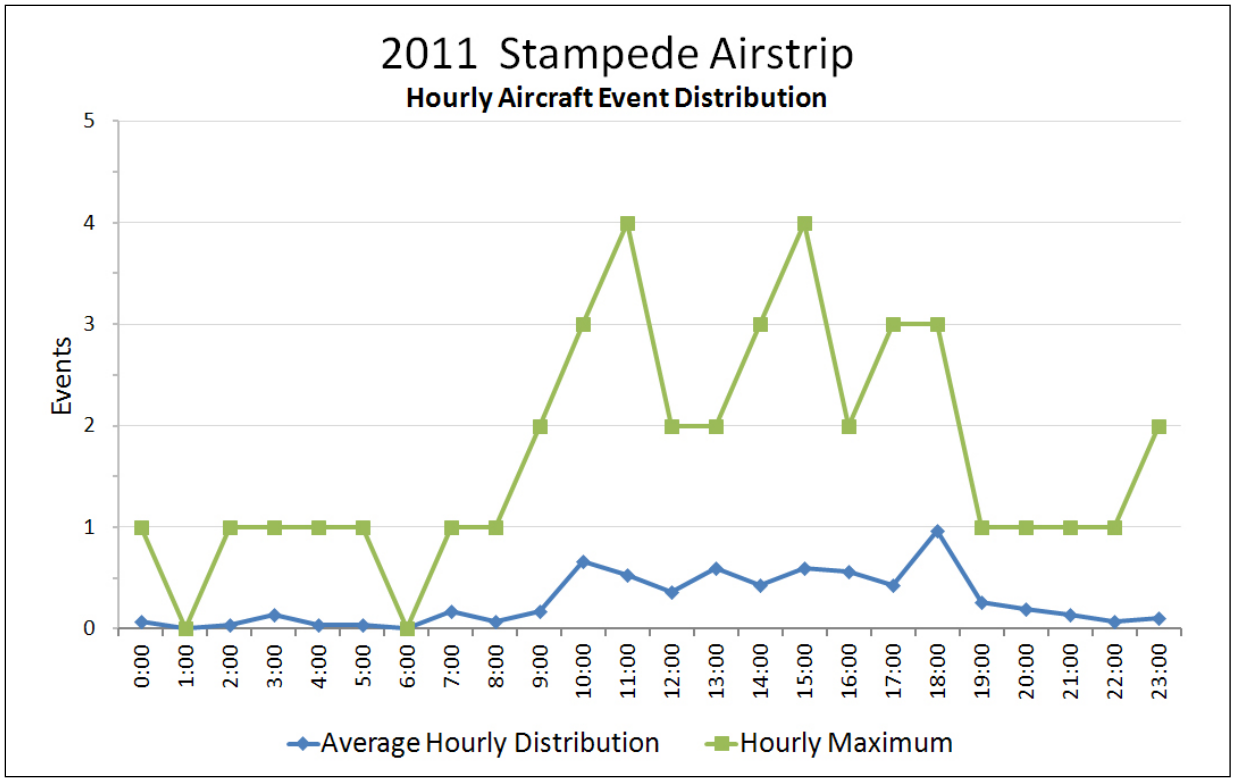


Figure 58. Hourly average and maximum aircraft event distribution at Stampede Airstrip.

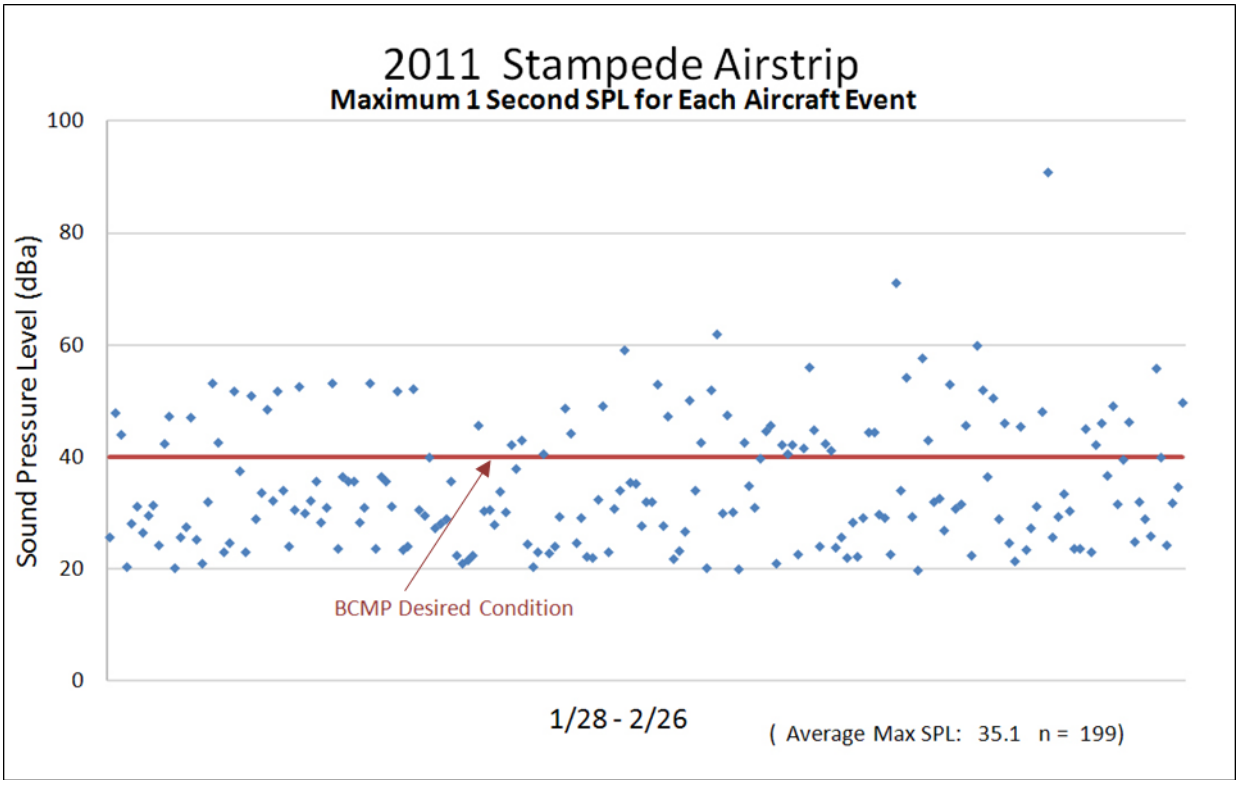
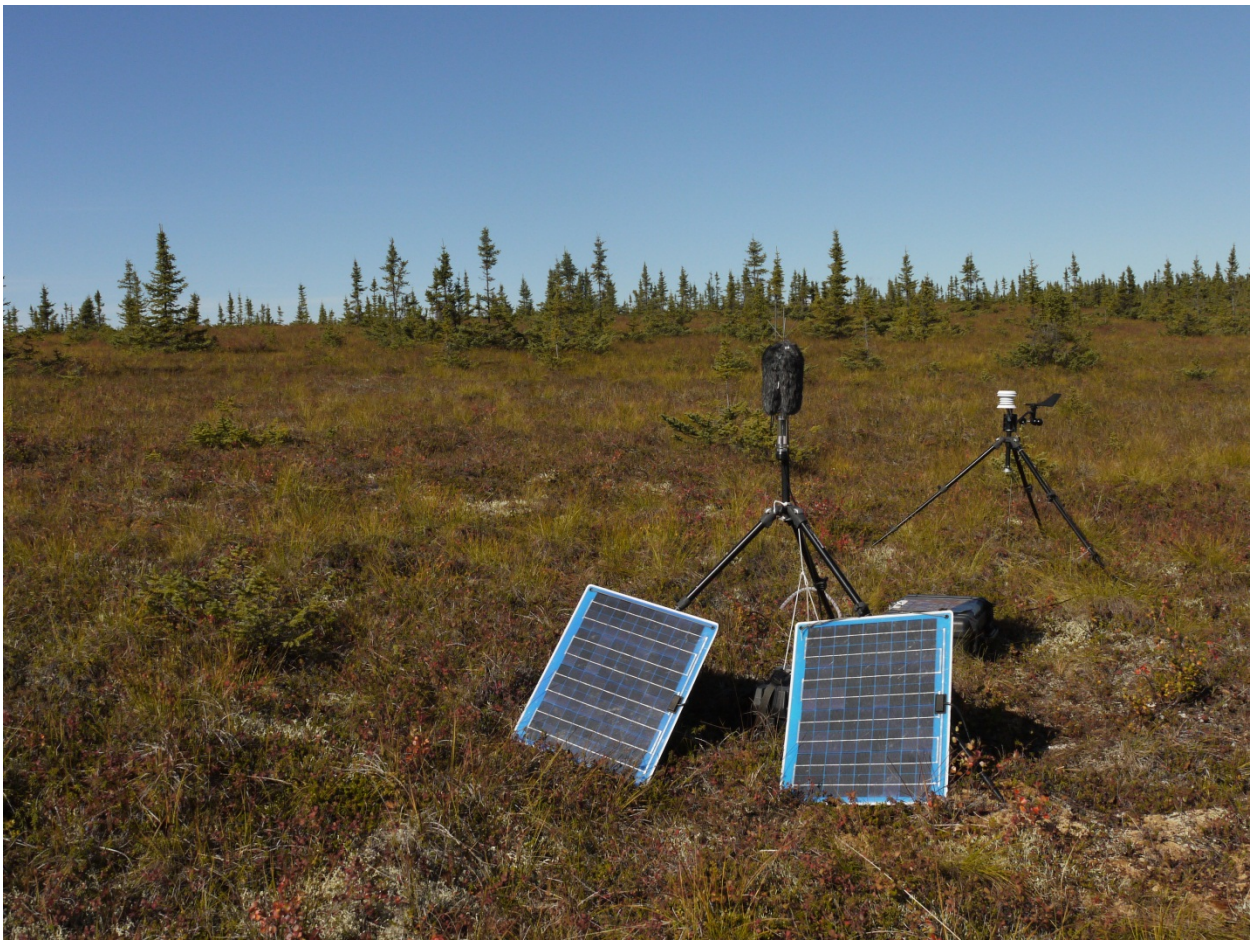


Figure 59. Maximum one-second SPL for each aircraft event identified at Stampede Airstrip.

West Kantishna Hills



Location Description: About three kilometers north of the confluence of Beauty Creek and the Bearpaw River, and about 5 kilometers northeast of the abandoned village of Glacier.

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

Coordinates: Lat. 63.74330, Long. -150.87653

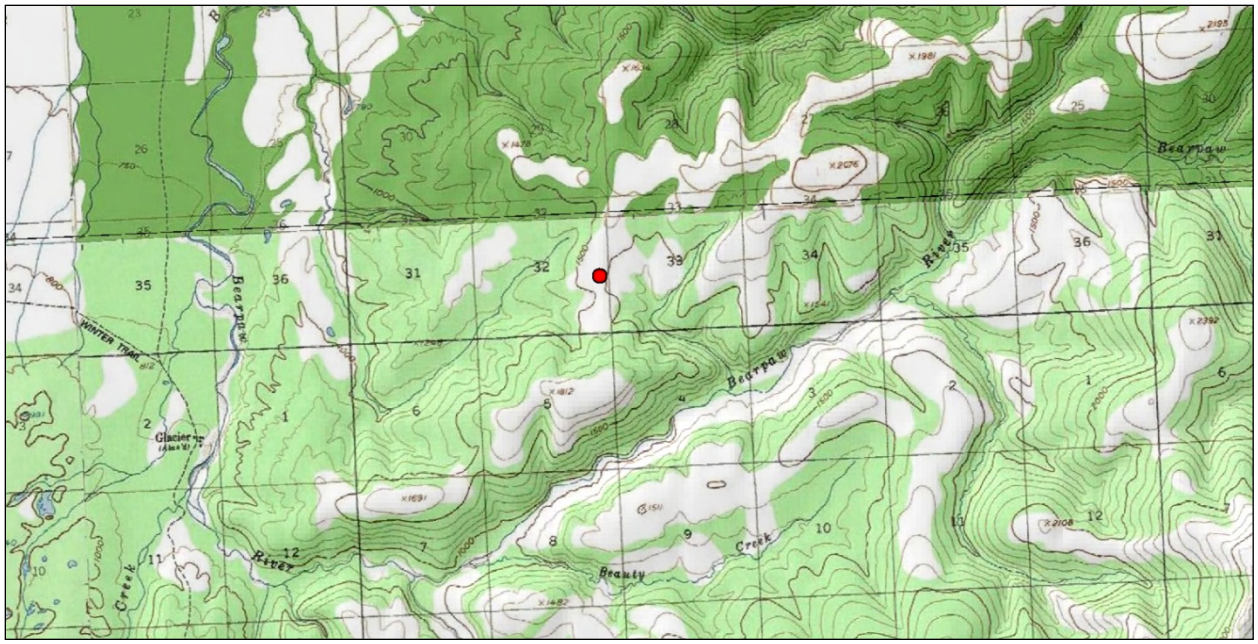
Elevation: 466.6 Meters

Time at Location: 20-July-2011 – 10-September-2011

BCMP Management Zone: Medium

Park Ecoregion: Alpine Outer Range & Kantishna Hills

Access: Helicopter

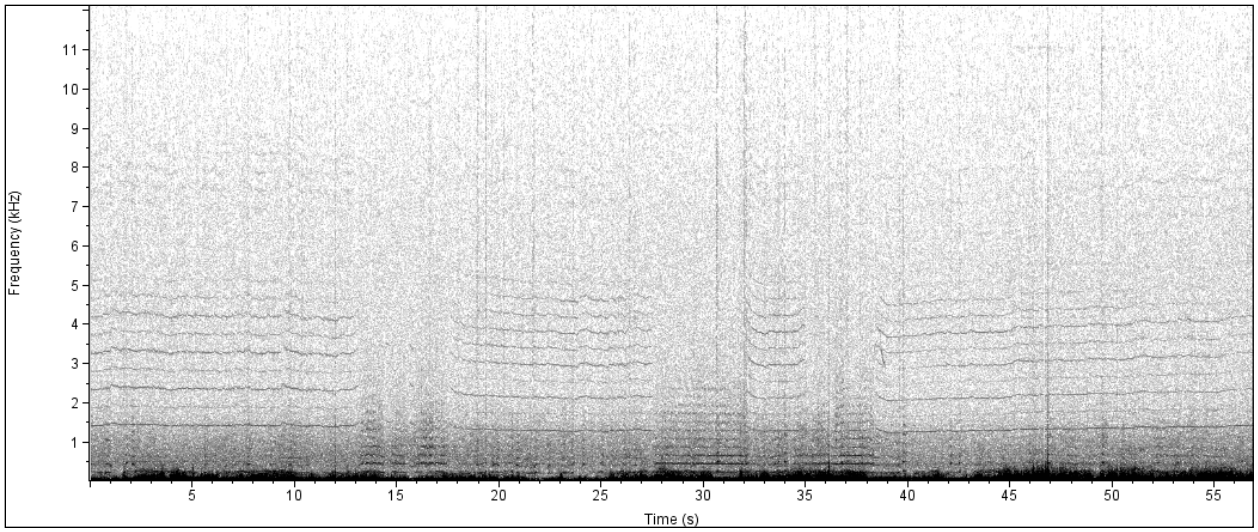


Summary: The purpose of the West Kantishna Hills location was to collect data at one of the long-term ecological monitoring (LTEM) grid points as outlined in the above sampling plan. LTEM grid point #221 was stratified as a New Park location and randomly selected from all locations requiring aircraft access.

West Kantishna Hills had the quietest natural ambient sound pressure level of any site sampled in 2011. 08/04/2011 was a particularly quiet day, with sections of the 21:00 hour reaching 14.8 dBA.

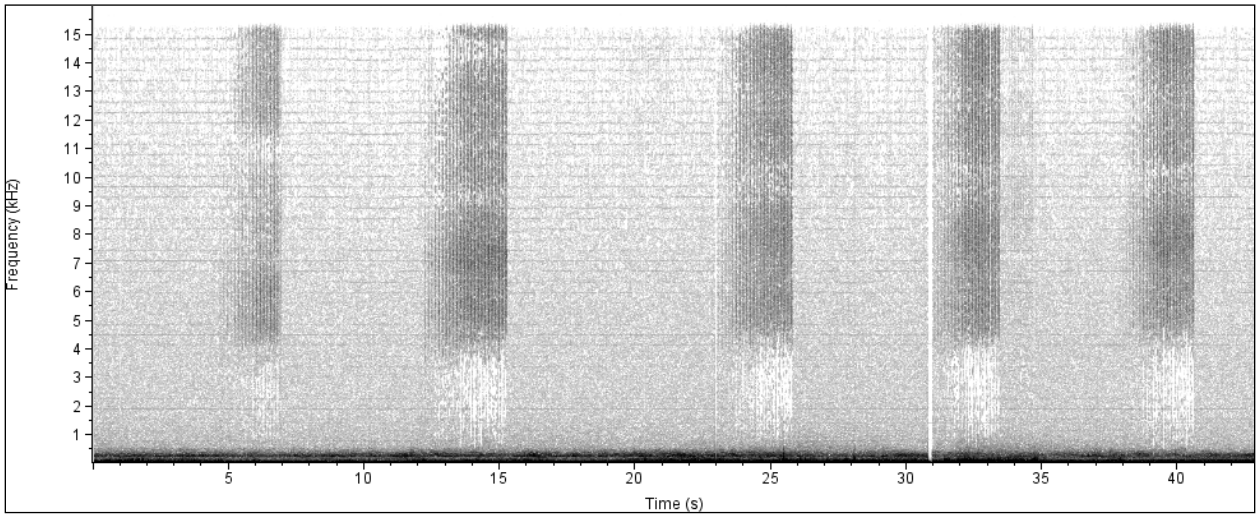
The Bearpaw River flows through the valley below this site. The sound of the water occupies the frequency band from about 160 to 1600 Hz. (A bandwidth of about 1440 Hz.) Similar to the McKinley River as audible from the McKinley Bar Trail station, the amplitude of the Bearpaw was observed to oscillate with the time of day. During the nighttime and early morning the river was audible, but as the day progressed, the sound gradually became inaudible. This diurnal 'sound shadow' was likely due to temperature gradients in the atmosphere, and is apparent in Figure 61.

Insect life was a prominent part of the soundscape at West Kantishna Hills, especially during the earlier portion of the sampling period. Many female mosquitos were heard, but the males were also heard occasionally. (The male mosquito has a thin, high-pitched whine easily distinguished from the female's lower-frequency wingbeats.)



Spectrogram 4. Wingbeats of male and female mosquitos. The male has a smaller body, and thus wingbeats of a higher frequency. The female is audible beginning 13 seconds into the clip. The spectrogram begins at 07:49:29 on 07/21/2011.

At times large moths or butterflies landed on the windscreen. The softness of their wingbeats distinguishes them from flies or bees, but the rapidity of the wingbeats distinguishes them from birds. Finally, an unidentified grasshopper, most likely in the genus *Melanoplus*, was heard diurnally over the majority of the sampling period. The calls of these animals were evenly clustered around 13:00.



Spectrogram 5. The buzzy, broadband call of an unidentified grasshopper, *Melanoplus spp*. The spectrogram begins at 13:52:24 on 08/28/2011.

Sandhill cranes (*Grus canadensis*) were also heard in migration during the latter half of the sampling period. (The first acoustic detection was 08/26/2011). The iconic squawking of the birds is focused narrowly on 1000 Hz, making it easy to identify on the spectrogram. The birds are generally audible for several minutes as they slowly pass overhead.

The most commonly heard sounds at this site were flowing water (audible 46.8% of the time), wind (43.2%), insects (20.4%), birds (14.9%), and silence (12.3%). Human made sound was audible 1.1% of the time on average; all of it was generated by aircraft. (This is equivalent to 15.8 minutes each day, or approximately 3 overflights per day.) Conditions exceeded the BCMP percent audible standard 4% of the time, number of events per day 16% of the time, and maximum SPL 25% of the time.

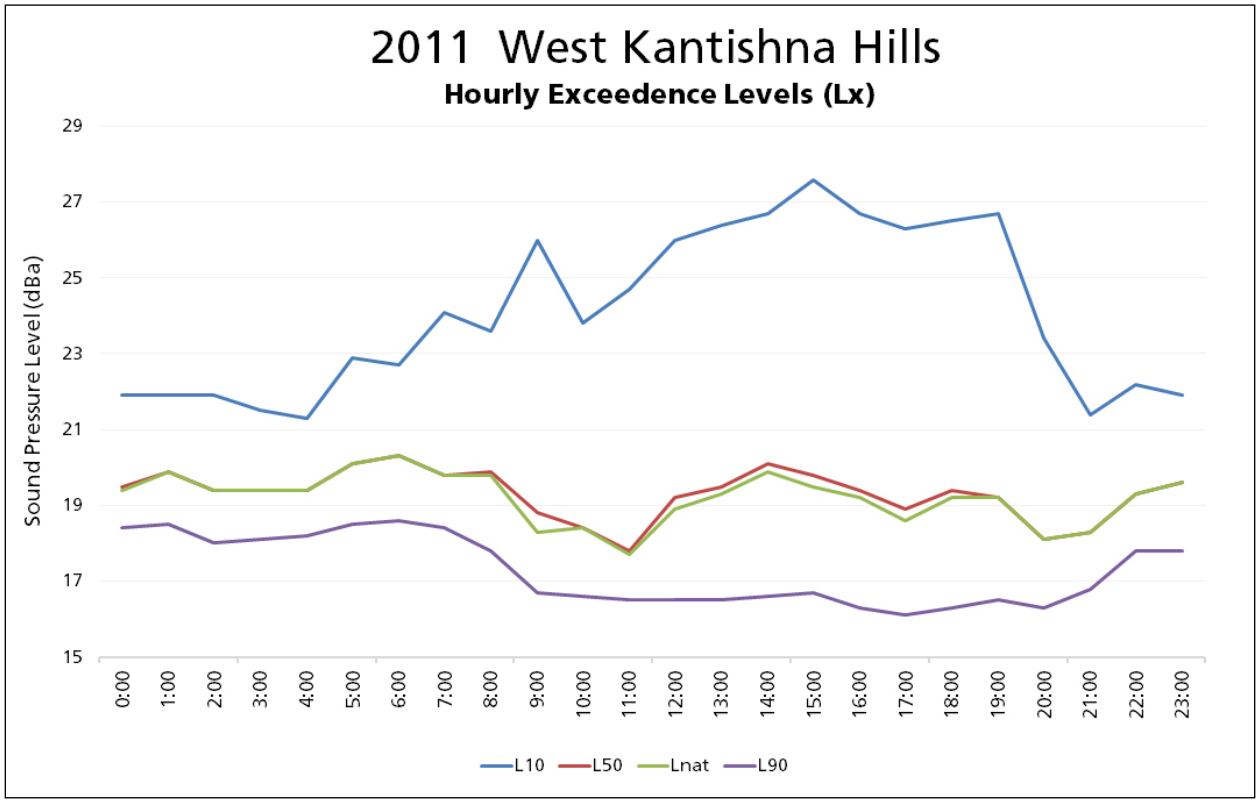


Figure 60. Exceedence levels for West Kantishna Hills.

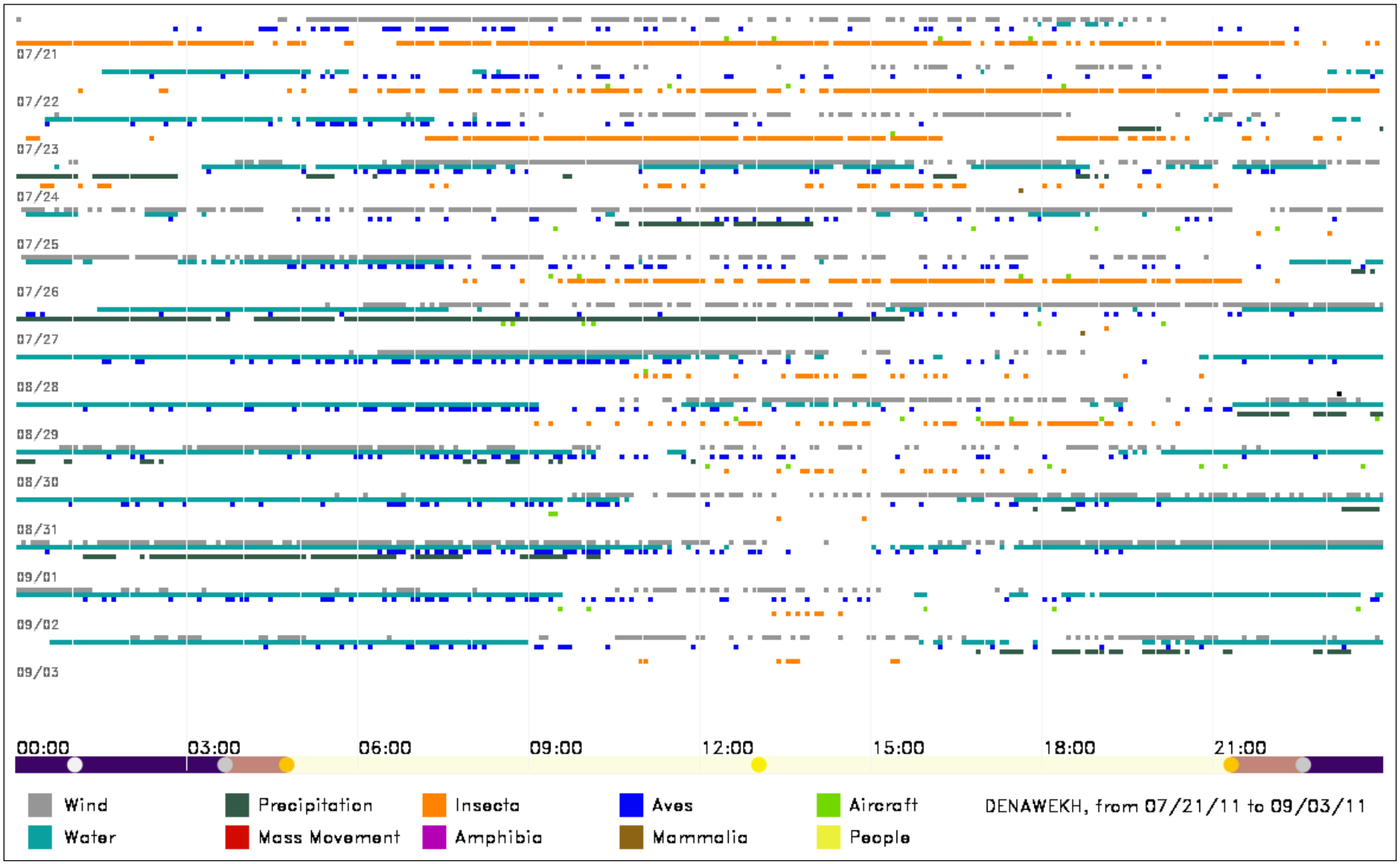


Figure 61. Temporal audibility of sound sources at West Kantishna Hills, based on five seconds of audio every five minutes. The bar along the time axis indicates the average light conditions during the sampling period. The orange circles are sunrise/sunset, and the gray circles are the beginning and end of civil twilight.

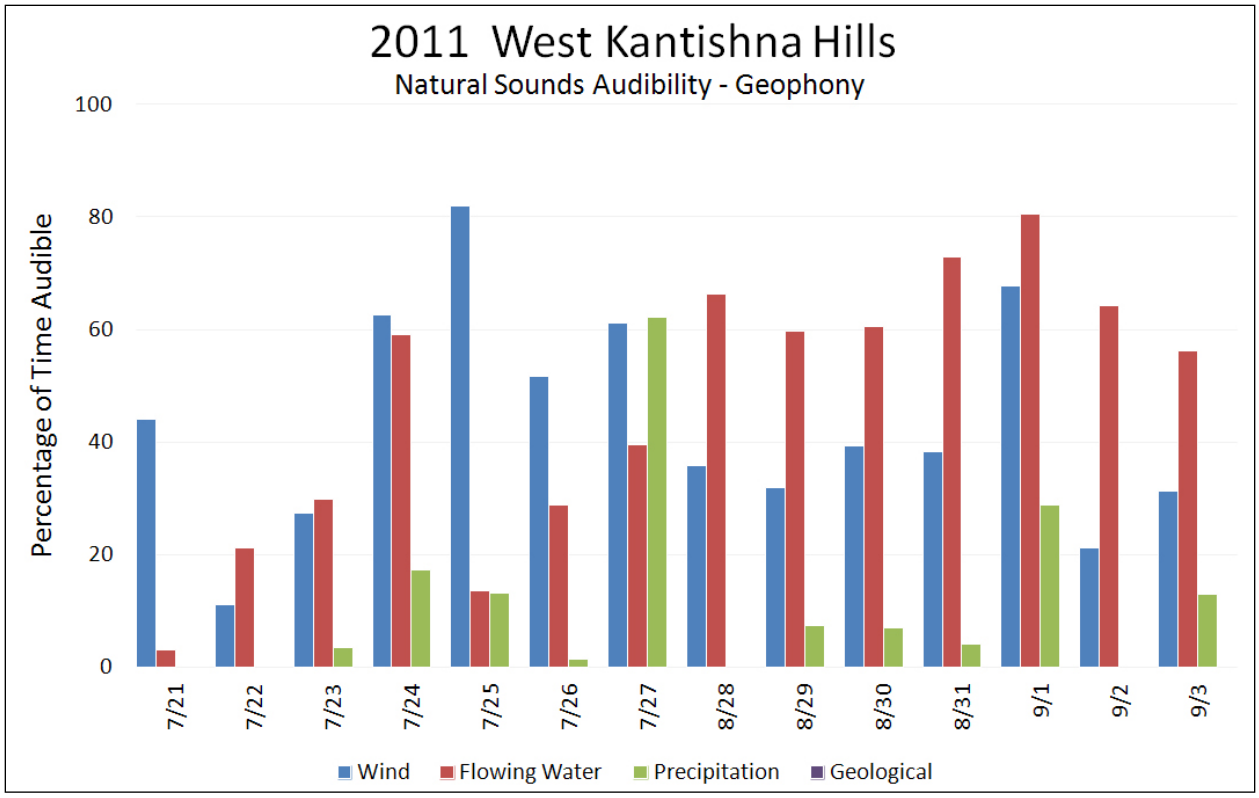


Figure 62. Percentage of time audible for geophonic sounds at West Kantishna Hills.

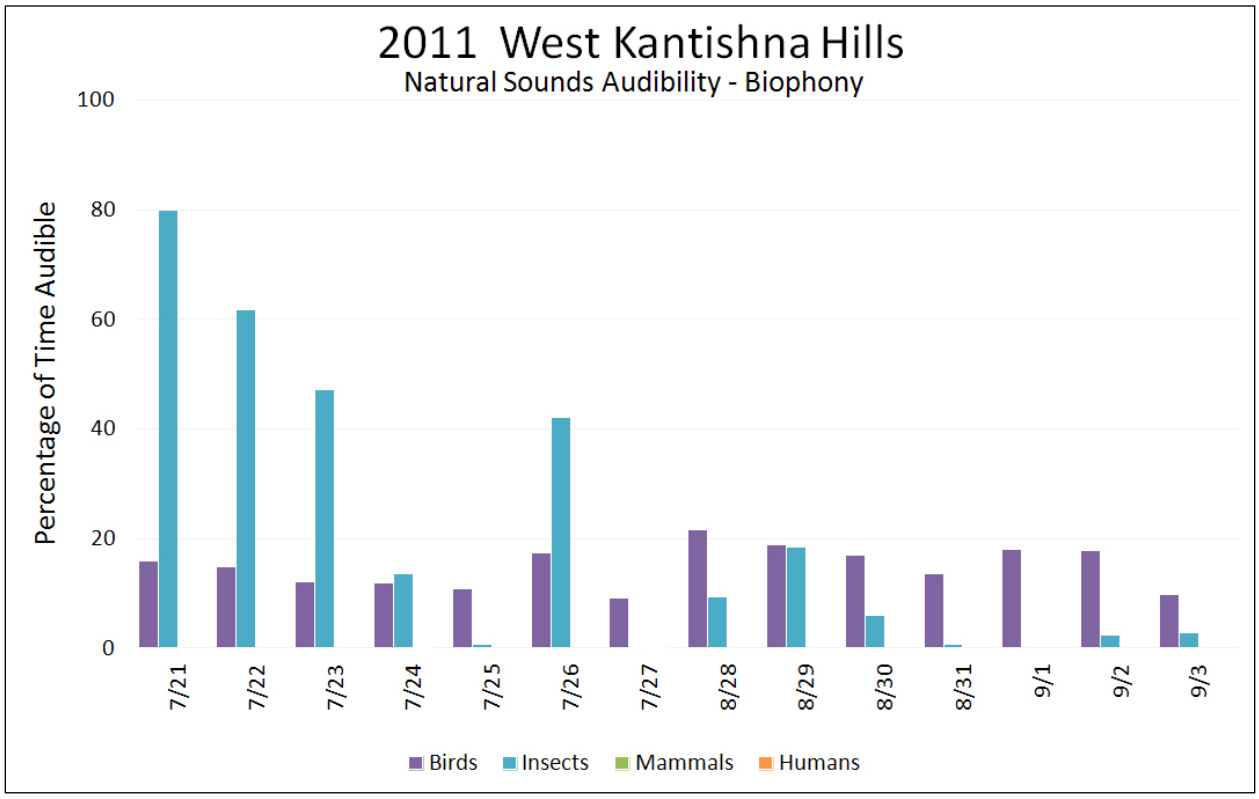


Figure 63. Percentage of time audible for biophonic sounds at West Kantishna Hills.

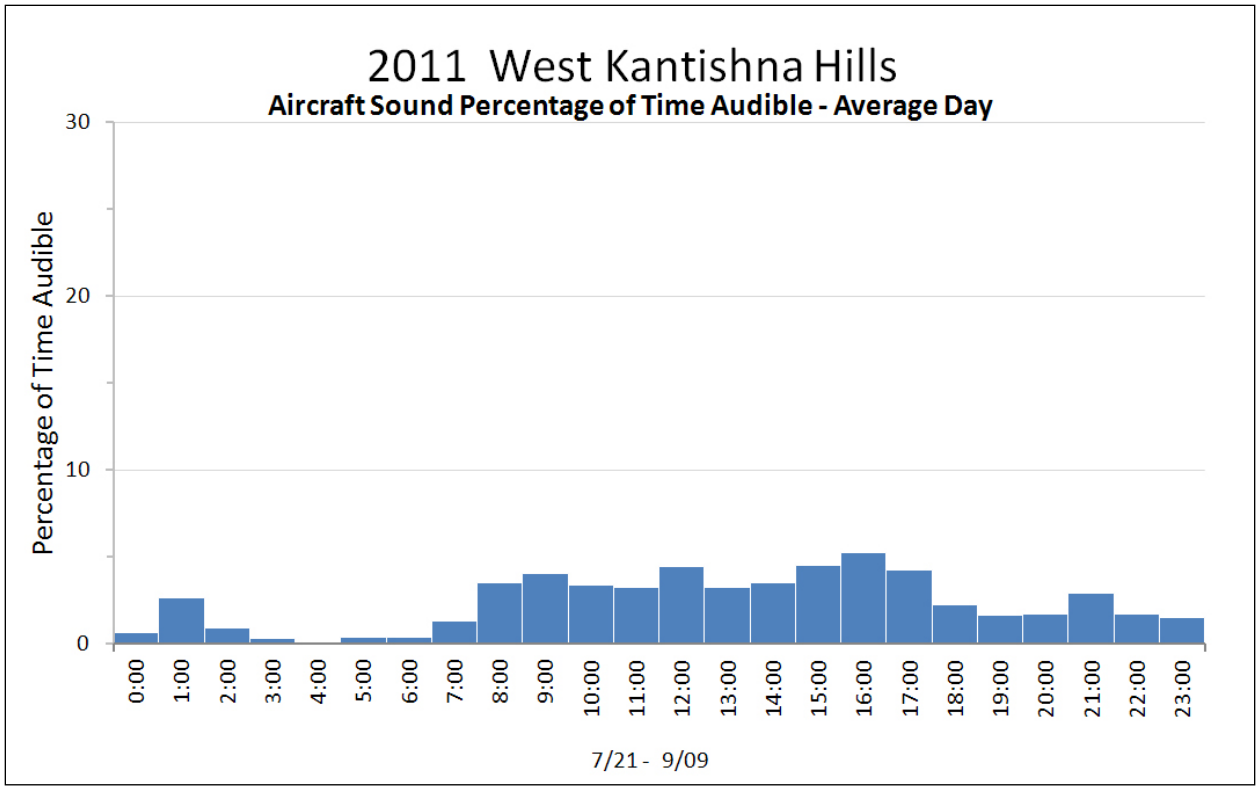


Figure 64. Audibility of aircraft noise for an average day, by hour, at West Kantishna Hills.

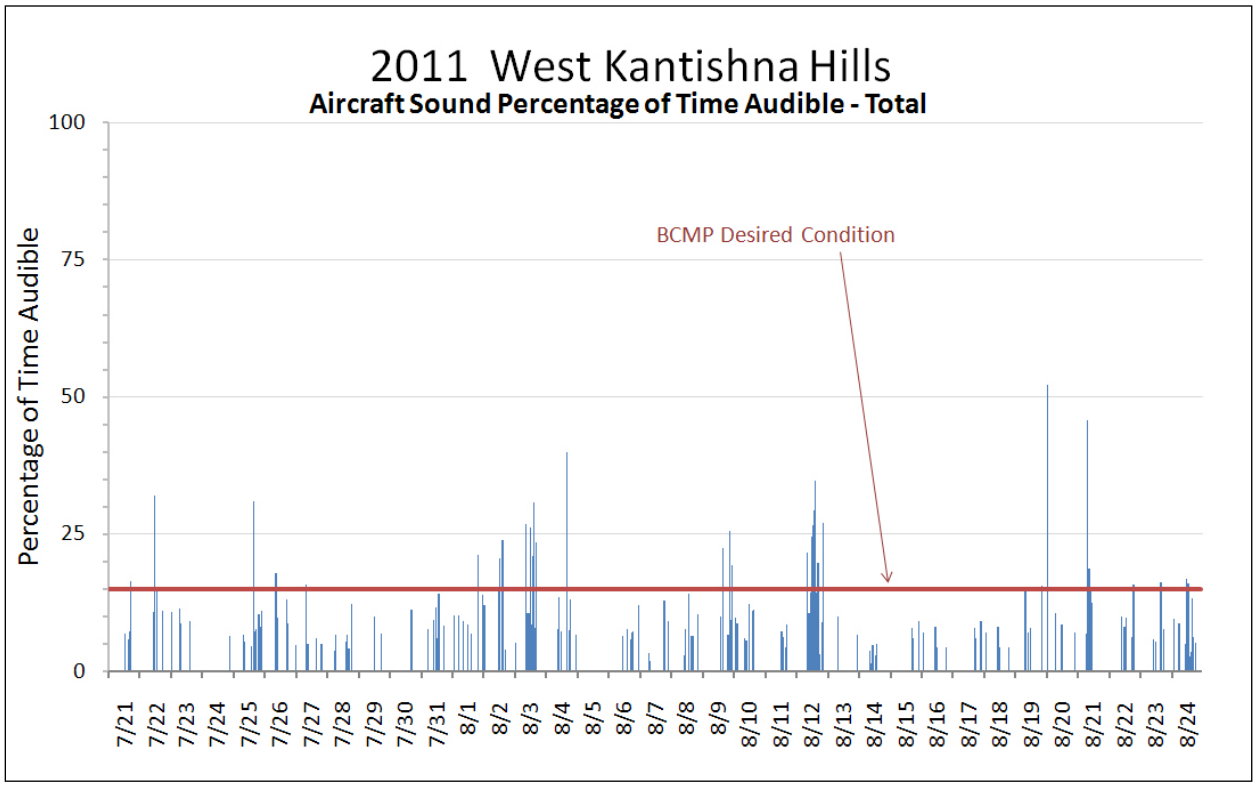


Figure 65. Audibility of aircraft noise at West Kantishna Hills.

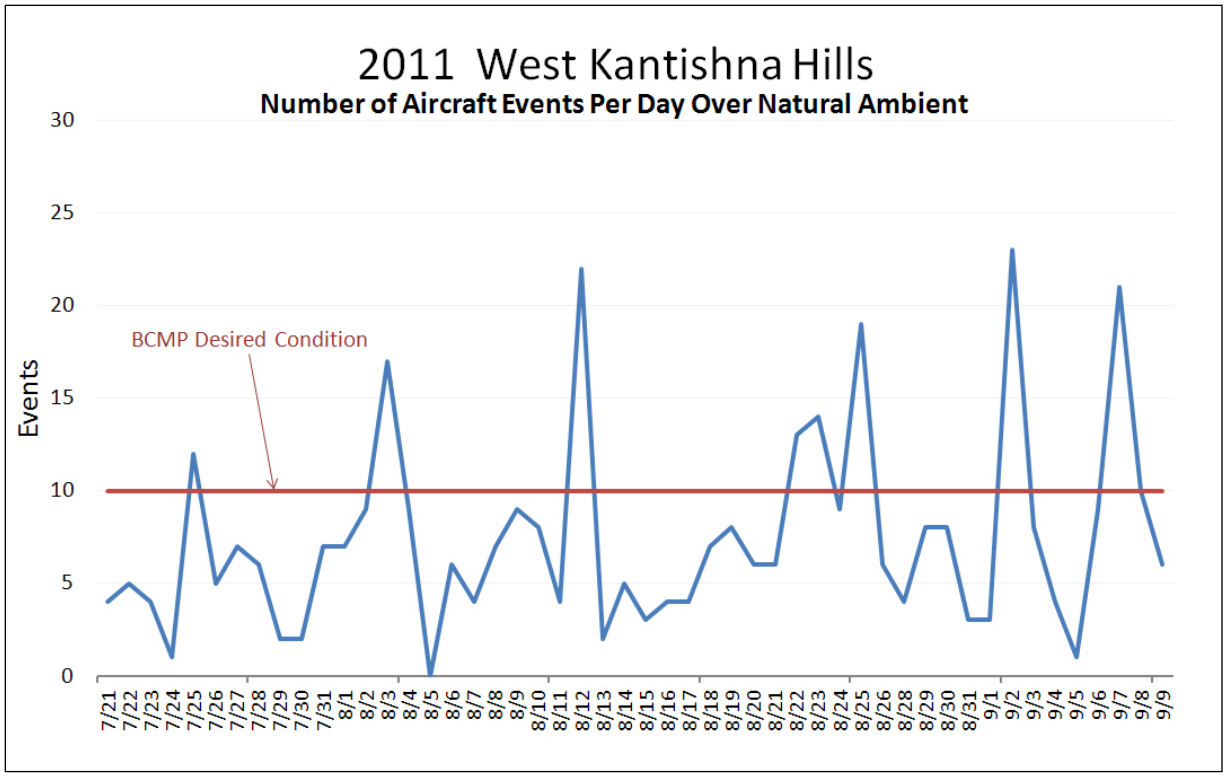


Figure 66. Number of aircraft noise events identified per day at West Kantishna Hills.

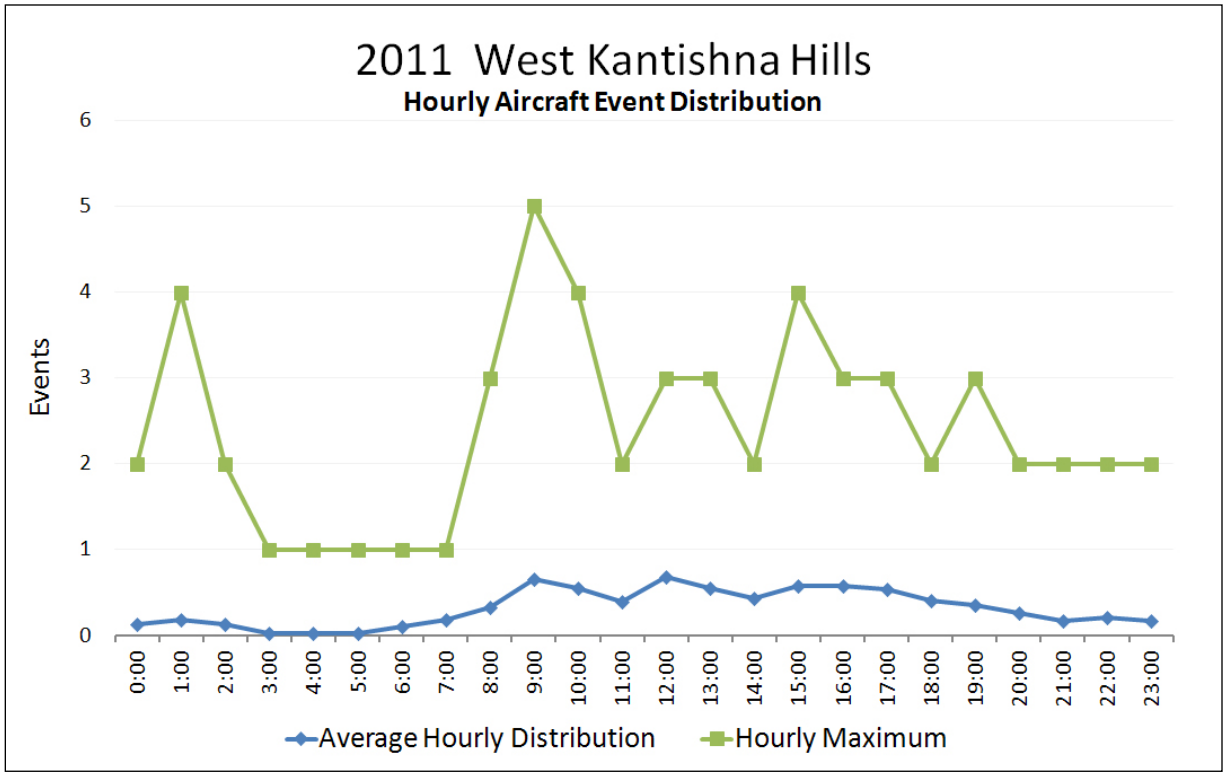


Figure 67. Hourly average and maximum for aircraft events at West Kantishna Hills.

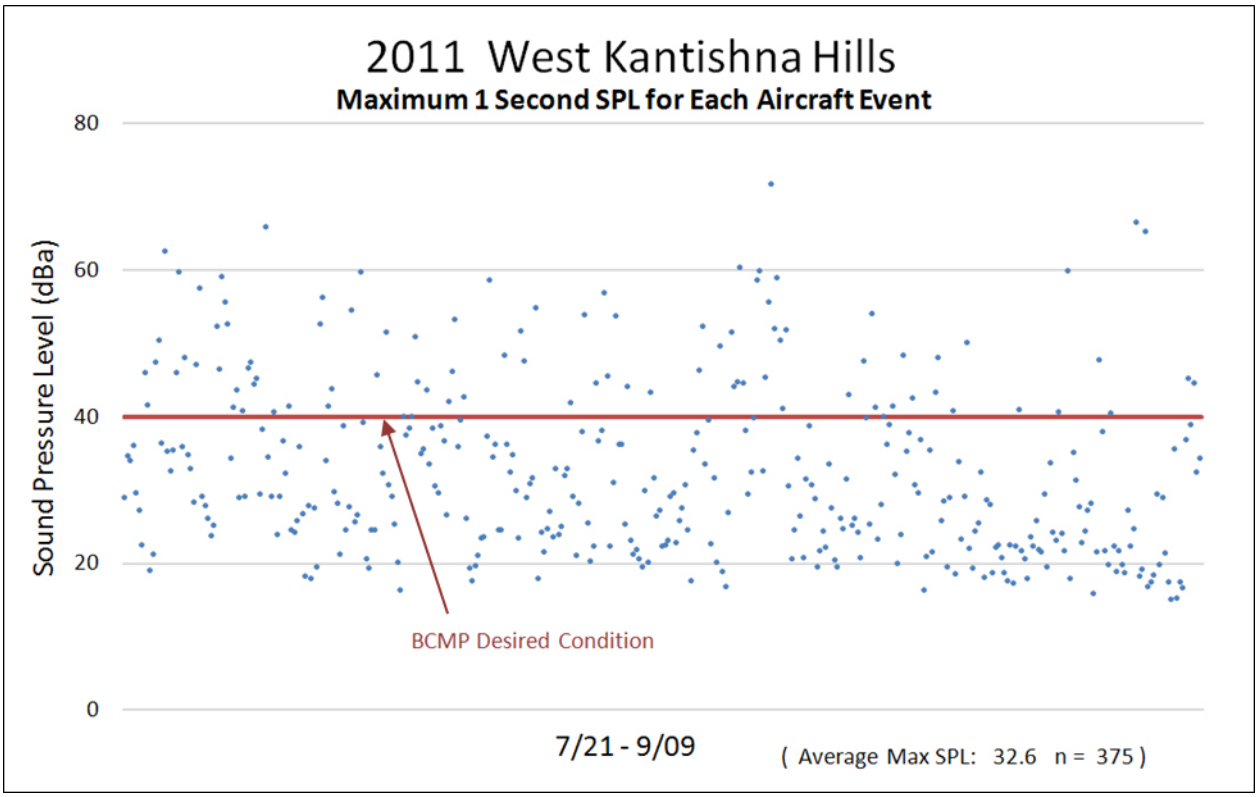


Figure 68. Maximum one-second SPL for each aircraft event identified at West Kantishna Hills.

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 sixth 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 - 2010, which collected similar data at other locations.

In 2011, automated acoustic monitoring systems collected varied records of ambient sound pressure level. Patterns in natural and anthropogenic sound at a location became readily apparent upon analysis, with certain aspects typifying any particular soundscape. For instance, the site at North Triple Lakes Trail had a tremendous amount of air traffic – 75 overflights a day on average. This rate represents the highest number of events per day measured at any place in the park so far. By contrast, the Herron Glacier site was among the most pristine examples of solitude measured in the park. Only 3 events per day occurred on average, a quality shared by several nearby monitoring locations in the west-central portion of the park. (For detailed information on this area see Withers 2009 and Withers 2010, especially the Highpower Creek, Herron River, North Vertical Access Benchmark, and Upper Dall Glacier locations.)

Natural sound characteristics, too, can typify a place. For instance, the quietest natural ambient conditions on record in 2011 were at West Kantishna Hills – an average of 19.3 dBA as compared to the next-quietest conditions, 21.9 dBA at Fang Mountain. The loudest natural ambient level was documented in the nearly-continuous acoustic footprint of Riley Creek on the Triple Lakes Trail, with the sound level meter logging an average sound pressure level of 43.9 dBA. In contrast to the steadiness of Riley, daily cycles of inaudibility were observed at two other rivers, the Bearpaw and the McKinley. This phenomenon appears to be dependent on both distance and air temperature.

Many species of animals were documented on record in 2011. Dall Sheep (*Ovis dalli*) were recorded at Fang Mountain, and were a notable addition to the reference library. Grizzly Bears *(Ursus arctos horribilis)* were heard at three locations – Estok, Herron Glacier, and West Kantishna Hills. The third of these encounters was especially informative in that it was the first documentation of a bear approaching the equipment without making contact.

Still other recordings expanded the documentation of calling behavior in Arctic ground squirrels (*Spermophilus parryii*), Red Squirrels (*Tamiasciurus hudsonicus*), and the avian family *Corvidae* (Ravens, Magpies, and Gray Jays). Two late-season stations – Estok and West Kantishna Hills - documented the migration phenology of Sandhill Cranes (*Grus canadensis*), a regular autumnal component of Denali's soundscape.

All sites exhibited some level of exceedence of the Denali Backcountry Management Plan standards as shown in Table 6. 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 Audiblity	Motorized Noise Events/Day	Motorized Max SPL (dBA)
Estok	9% of all hours	52% of all days	42% of all events
Fang Mountain	53%	100%	51%
Herron Glacier	6%	63%	42%
McKinley Bar Trail	15%	73%	42%
North Triple Lakes Trail	52%	100%	100%
Stampede Airstrip [1]	5%	17%	32%
West Kantishna Hills	4%	16%	25%

[1] : Winter season site.
*: Collection of SPL data was unsuccessful. This precludes calculation of BCMP Max SPL metrics.

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

Acknowledgments

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

In my first year as a program manager, I was fortunate to have the guidance of Melissa Snover, Guy Adema, Tom Meier, Dr. Lucy Tyrrell, Suanne Sauvey, and Stacie Oaks to smooth (the inevitable) administrative bumps along the way.

Many of the difficulties with soundscape fieldwork are related to moving heavy, awkward, or fragile components over the landscape. I'd like to thank Kristin Knight-Pace and her 2011 Backcountry Ranger staff - especially Michael Bardwell, Diana Liles, and Alonzo Mandana - as well as Ben Cosgrove, Andrew Ackerman, Dr. Adam Gibson, Dr. Derrick Taff, Melanie Reed, Rob Burrows, Kimber Burrows, and Hannah Davis for their help carrying equipment or coordinating field operations on foot. Gilbert Garcia, Forrest Ford, Joe Riechert, Jon Chabala, Andy Hermansky, Eric Eichner, and Russell Johnson were invaluable for their assistance in the air. A special thanks to Jennifer Raffaeli and her 2011 Denali Kennels staff - Jess Toubman, Jason Reppert, Michael Raffaeli, and Kristin Knight-Pace. I believe their energy and enthusiasm for non-motorized winter travel is unparalleled anywhere in the National Park Service.

I received technical assistance from the Natural Sounds and Night Skies Division office many times during the year, especially from Dr. Kurt Fristrup and Damon Joyce. I also received technical insights from Jon Paynter, who was always ready to drop everything and share GIS wizardry with me.

I received patient, insightful and thorough critiques on graphs and text throughout the season from Dave Schirokauer, Andrew Ackerman, Andrea Blakesley, Rob Burrows, and Kristin Knight-Pace. Sincere thanks for helping to improve the communication of soundscape information – with a new science, every adjustment is a real step forward.

Excellent thoughts and suggestions on sound and wilderness arose from conversations with many, including Joe Van Horn, Andrew Ackerman, Ben Cosgrove, Scott Burch, Miriam Valentine, Jon Morton (USFWS at Kenai Wildlife Refuge), Tom George (AOPA), and Joan Frankevich (NPCA). Special effort by Brian Napier to record overflight observations while on patrol deserves mention here, as his data found great use in facilitating discussion on future wilderness monitoring efforts.

Finally, I want to thank Superintendent Paul Anderson and Assistant Superintendent Philip Hooge for their continued vision and stewardship of Soundscape issues in Denali National Park and Preserve.

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Appendix A. Glossary of Acoustic Terms

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

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

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

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

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

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

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

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

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

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

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

Listening Horizon
The range or limit of one's hearing capabilities. Just as smog limits the visual horizon, so noise limits the acoustic horizon.

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

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

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

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

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

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

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

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

Soundscape
Human perception of the acoustical environment.

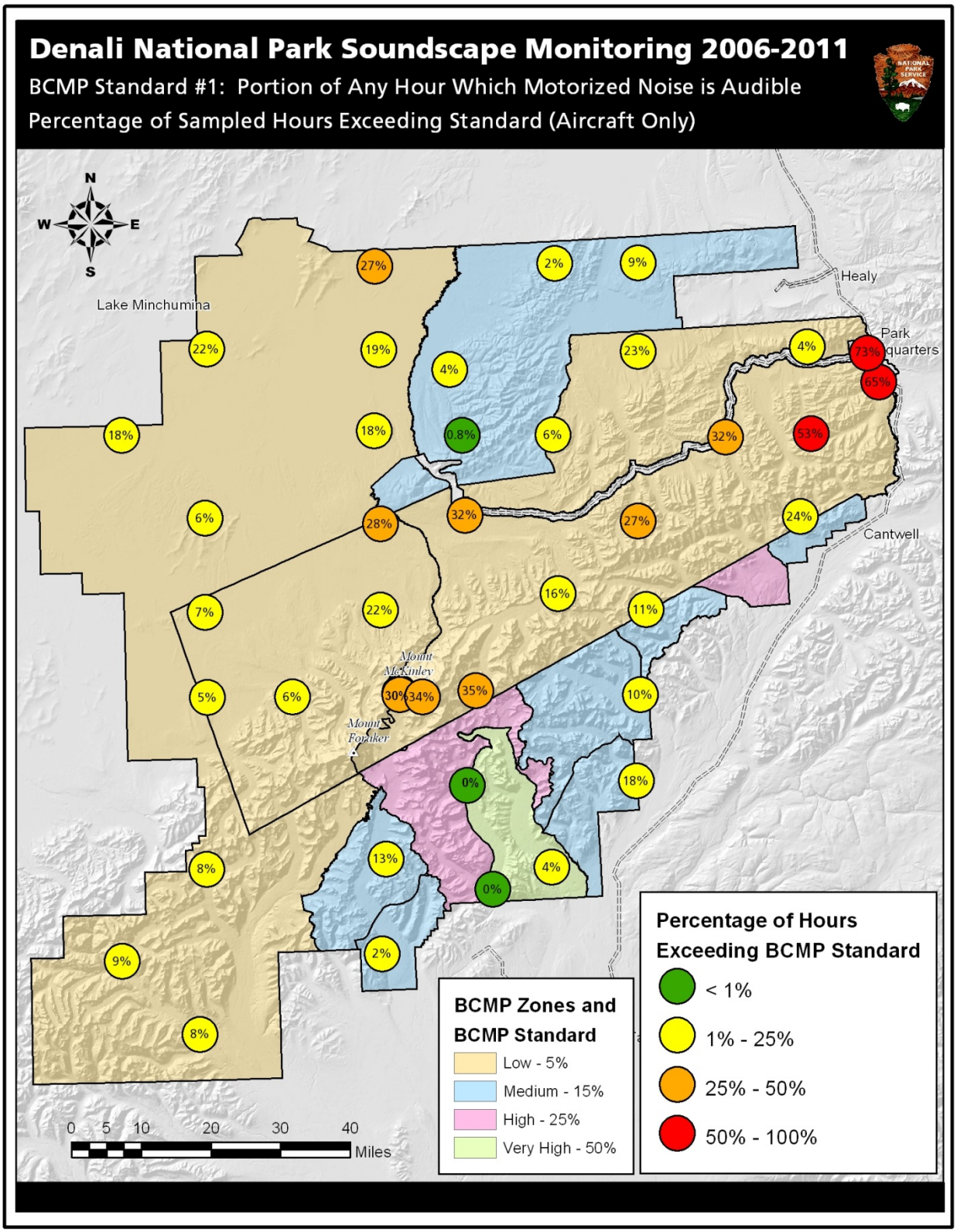
Sound Pressure
The difference between instantaneous pressure and local barometric pressure. Measured in Pascals (Pa), Newtons per square meter, which is the metric equivalent of pounds per square inch.

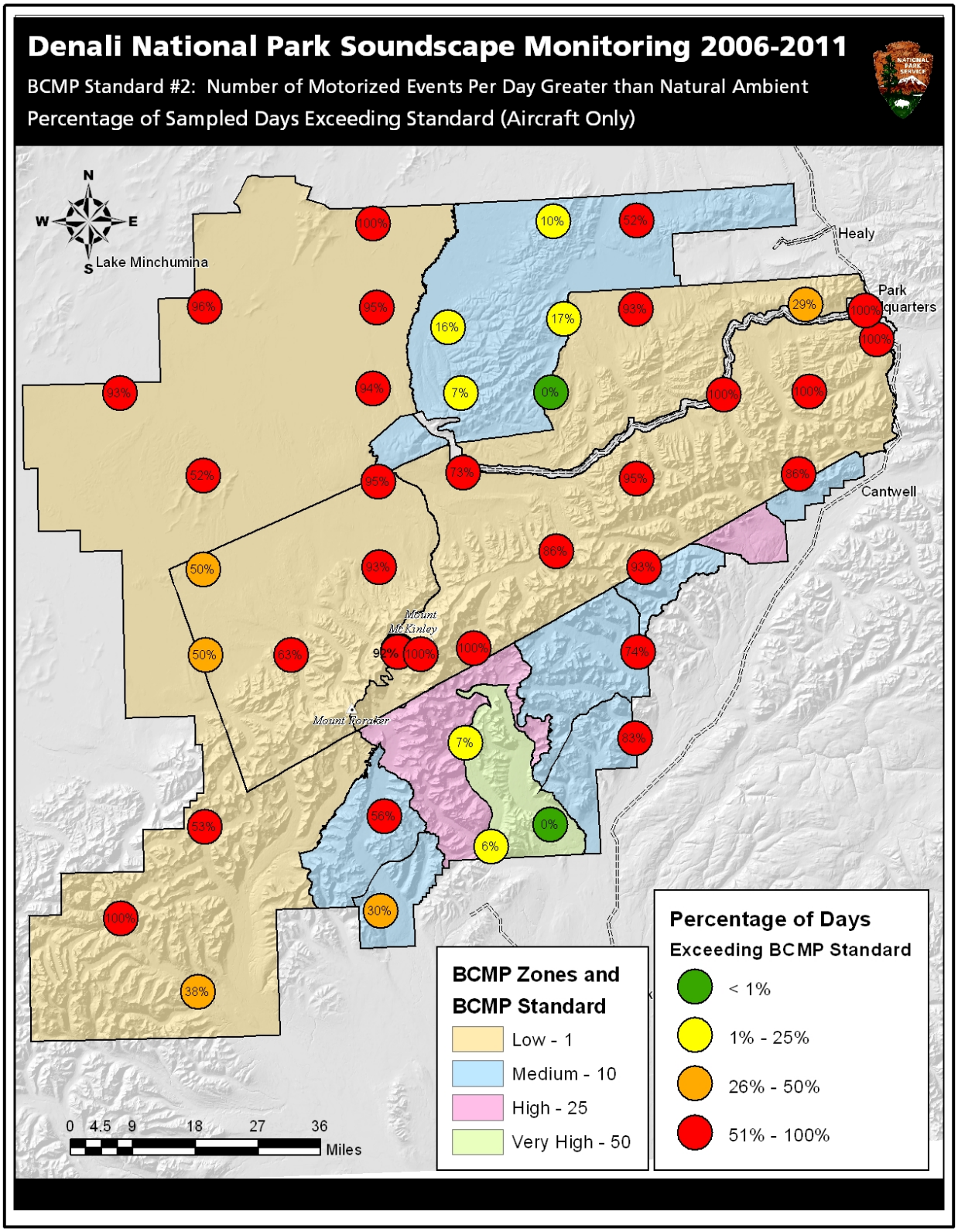
Sound Pressure Level (SPL)
A calibrated measure of sound level, expressed in decibels, and referred to an atmospheric standard of 20 micro Pascals.

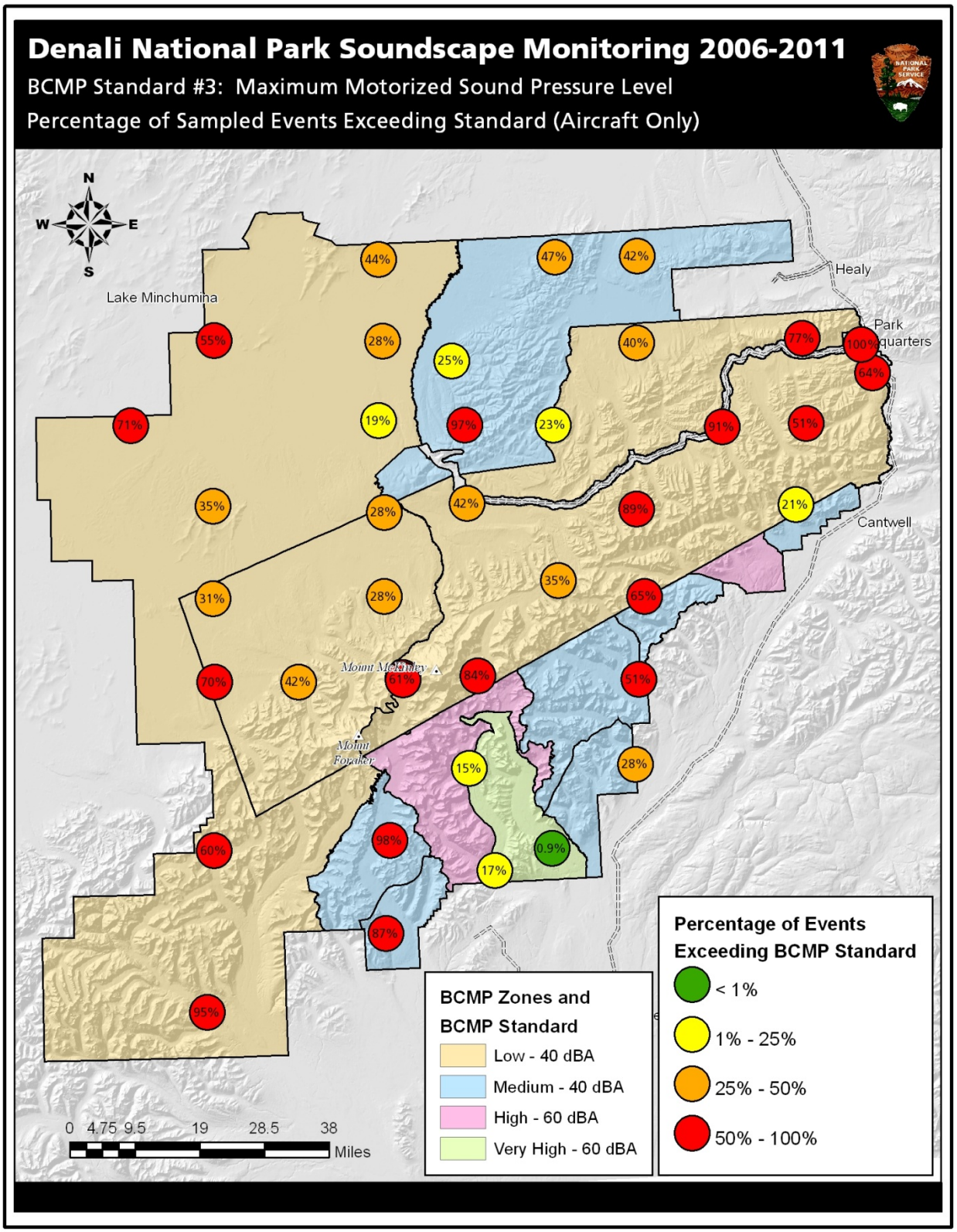
Time Audible
The amount of time that a sound source is audible to a human with normal hearing.

Appendix B. BCMP Exceedence Maps

The following three maps are compiled to provide a parkwide look at the acoustic measurements made to date, and indicate the current level compliance with BCMP acoustic standards. There is one map for each BCMP standard, and each sampling point is annotated with the percentage of time that standard was exceeded during the measurement period. Data from previous years is from Hults 2005, Withers and Hults 2006, Withers and Betchkal 2010, and Withers 2009.

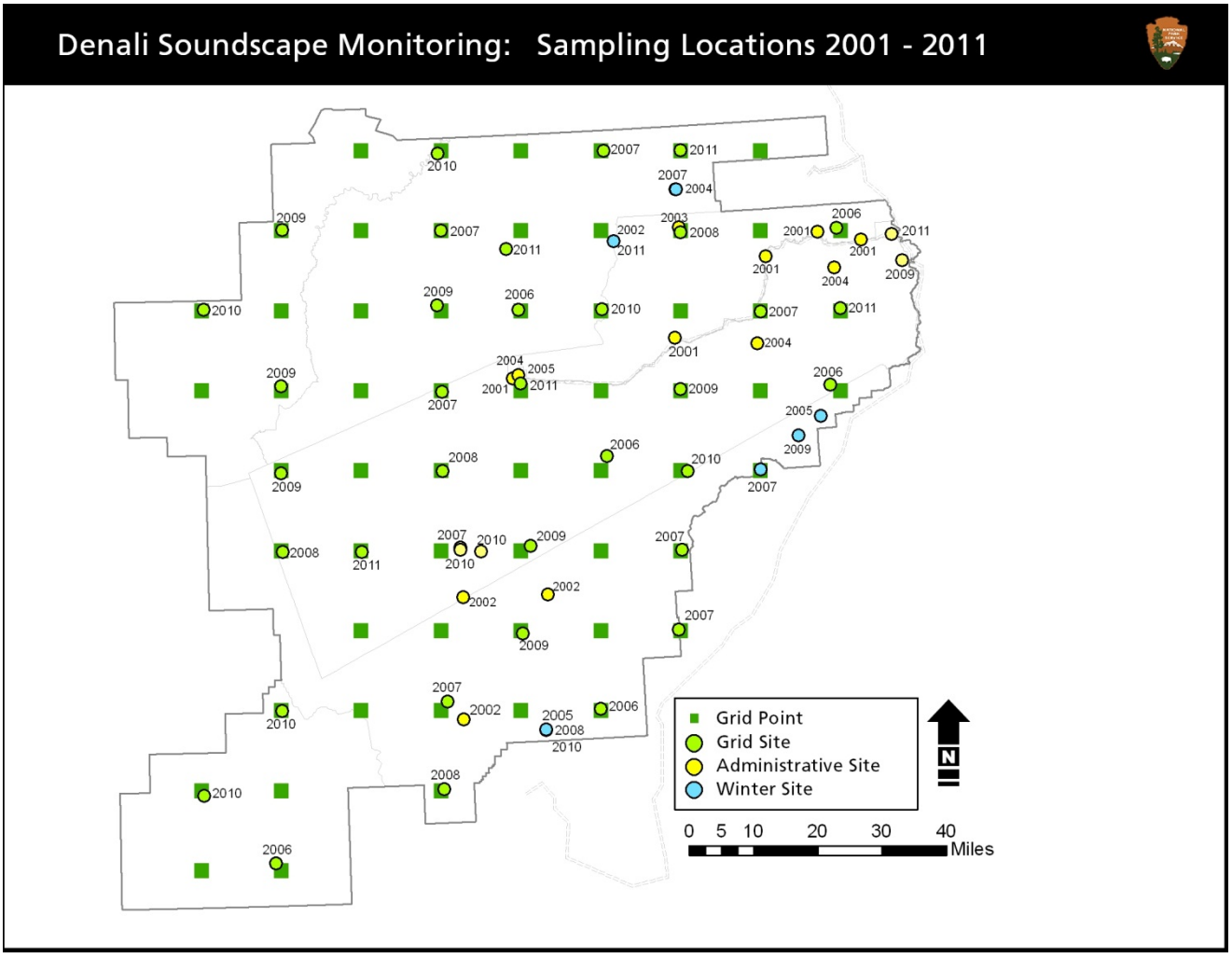

Denali National Park Soundscape Monitoring 2006-2011
BCMP Standard #1: Portion of Any Hour Which Motorized Noise is Audible
Percentage of Sampled Hours Exceeding Standard (Aircraft Only)
N
W
E
S
Lake Minchumina
Healy
Park Headquarters
Cantwell
Mount McKinley
Mount Foraker
27%
2%
9%
22%
19%
4%
23%
4%
73%
65%
18%
18%
0.8%
6%
32%
53%
6%
28%
32%
27%
24%
7%
22%
16%
11%
5%
6%
30%
34%
35%
10%
0%
18%
13%
4%
0%
8%
9%
2%
8%
0 5 10 20 30 40
Miles
BCMP Zones and BCMP Standard
Low - 5%
Medium - 15%
High - 25%
Very High - 50%
Percentage of Hours Exceeding BCMP Standard
< 1%
1% - 25%
25% - 50%
50% - 100%


Denali National Park Soundscape Monitoring 2006-2011
BCMP Standard #2: Number of Motorized Events Per Day Greater than Natural Ambient
Percentage of Sampled Days Exceeding Standard (Aircraft Only)
N
W
E
S
Lake Minchumina
Healy
Park
quarters
Cantwell
Mount McKinley
Mount Foraker
100%
10%
52%
96%
95%
16%
17%
93%
29%
100%
100%
93%
94%
7%
0%
100%
100%
52%
95%
73%
95%
86%
50%
93%
86%
93%
50%
63%
92%
100%
100%
74%
7%
83%
53%
56%
0%
6%
100%
30%
38%
0 4.5 9 18 27 36
Miles
BCMP Zones and
BCMP Standard
Low - 1
Medium - 10
High - 25
Very High - 50
Percentage of Days
Exceeding BCMP Standard
< 1%
1% - 25%
26% - 50%
51% - 100%


Denali National Park Soundscape Monitoring 2006-2011
BCMP Standard #3: Maximum Motorized Sound Pressure Level
Percentage of Sampled Events Exceeding Standard (Aircraft Only)
N
W
E
S
Lake Minchumina
Healy
Park Headquarters
Cantwell
Mount McKinley
Mount Foraker
44%
47%
42%
55%
28%
25%
40%
77%
100%
64%
71%
19%
97%
23%
91%
51%
35%
28%
42%
89%
21%
31%
28%
35%
65%
70%
42%
61%
84%
51%
15%
28%
60%
98%
0.9%
17%
87%
95%
0 4.75 9.5 19 28.5 38
Miles
BCMP Zones and BCMP Standard
Low - 40 dBA
Medium - 40 dBA
High - 60 dBA
Very High - 60 dBA
Percentage of Events Exceeding BCMP Standard
< 1%
1% - 25%
25% - 50%
50% - 100%

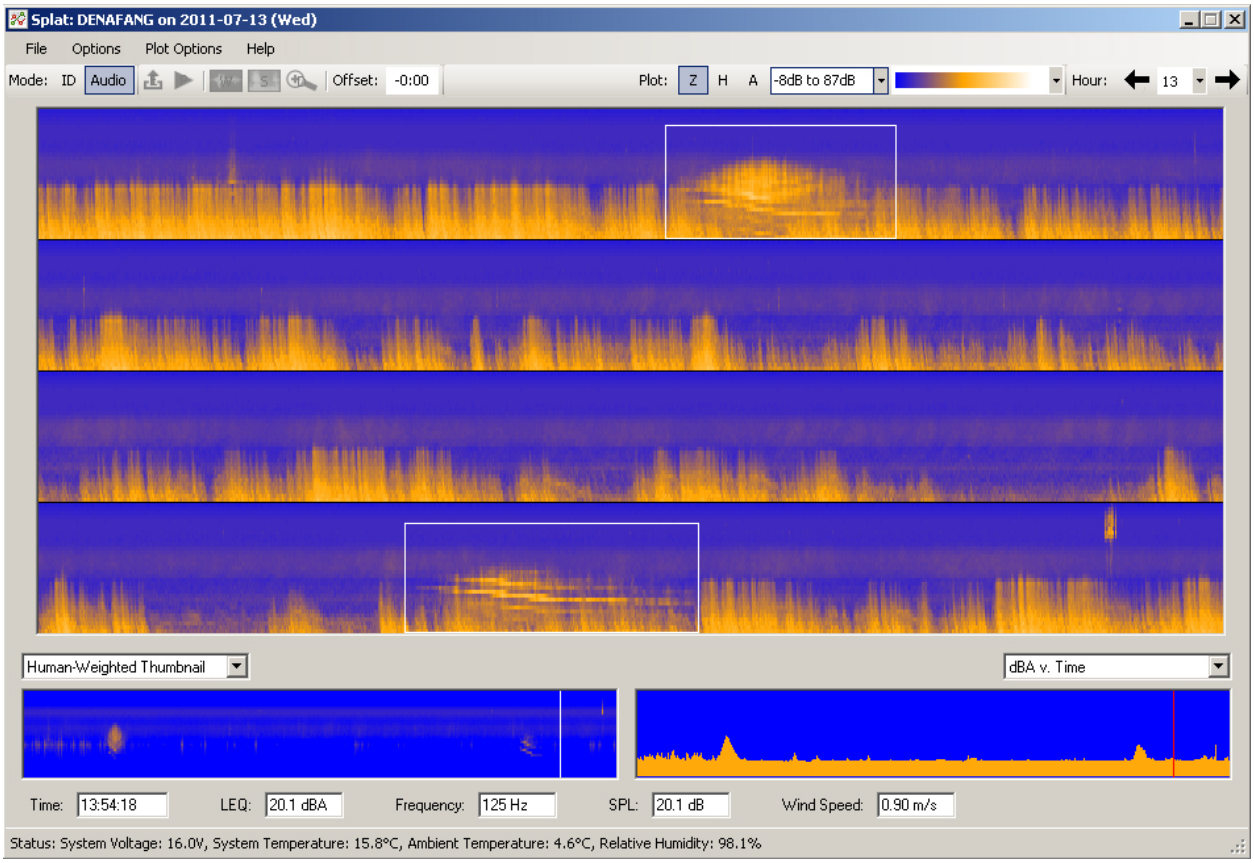
Appendix C. Map of All Soundscape Sampling Locations

The following map shows the approximate location of every sound monitoring station deployed over the course of the study and during which year(s) data were collected. Sites that represent locations on the coarse sampling grid are green, and are shown overlaying the grid, itself. (*For a more detailed discussion of sampling design, see page 2.)* Summer-season administrative sites are shown in yellow, while winter-season admin sites are shown in blue.



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 soundscape program was funded for 2011 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

- $26,253 Soundscape Program Manager: Davyd Betchkal GS-7 Term with 1 Month Furlough

Travel

- $3,755 George Wright Society Conference, Denali Overflights Committee Meetings, Talkeetna Field Ops.

Aviation

- $12779.91 Helicopter

Equipment and Supplies

- $20,460

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 2011 season required seven helicopter flights totaling 12.1 hours of flight time. 11 helicopter landings were made outside of accepted portal areas. (Of these, five were in the Wilderness.) For the use of the contracted Hughes 500-D and AStar B3, flight time, availability and OAS costs totaled $12779.91. Details for each flight are summarized in the following table:

Date	Aircraft	Sites Accessed	Flight Hours	Availability Cost	Flight Cost	OAS 17%
06/12/2011	AStar B3	Base Camp	1.4	Waived, SAR	$868	$147.56
06/16/2011	AStar B3	UKAH	0.4	Waived, SAR	$248	$42.16
06/18/2011	Hughes 500-D	HEGL	2.1	$1780	$693	$420.41
07/20/2011	Hughes 500-D	MBAR, HEGL, WEKH	3	$1602	$990	$440.64
07/31/2011	Hughes 500-D	ESTO	0.8	$534	$264	$135.66
08/27/2011	Hughes 500-D	HEGL, WEKH, ESTO	2.2	$1246	$726	$335.24
09/10/2011	Hughes 500-D	WEKH, ESTO	2.2	$1246	$726	$335.24
TOTAL			**12.1**	**$6408**	**$4515**	**$1856.91**
					$12779.91	

For comparison of use in 2011 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)

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

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National Park Service
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