

National Park Service
U.S. Department of the Interior



Sequoia & Kings Canyon National Park Acoustic Monitoring Report 2005 & 2006



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Executive Summary

Management of acoustic resources at Sequoia and Kings Canyon National Parks is mandated by the Organic Act, NPS policy and guidance, and park management plans. These two parks, managed as one unit, are affected by noise from a variety of sources. Growth in commercial air traffic and the expansion of Mammoth airport will increase anthropogenic noise over the Sierra parks and associated wilderness areas. These developments have focused attention on the importance of sounds for visitor experience and wildlife in the Sierra Network (SIEN) parks. As a result, the network (Sequoia and Kings Canyon National Parks, Yosemite National Park, and Devil's Postpile National Monument) submitted technical assistance requests for acoustic monitoring and noise impact assessment.

The objectives of this report are to quantify existing acoustic conditions in Sequoia and Kings Canyon, and provide results that can be used for park planning. Two years of monitoring data from six sites in Sequoia and Kings Canyon were analyzed. These data quantify current acoustic conditions for a variety of vegetation zones and seasons in backcountry locations.

As shown below, the percent time audible metrics indicate the amount of the 24 hour day that is affected by extrinsic and more specifically, aircraft sounds, while the loss of listening area metrics provide a measure of the severity of these impacts during the noisiest four hours of the day. Aircraft, especially jets, were by far the most frequently audible extrinsic sounds in Sequoia and Kings Canyon. Interestingly enough, although Crabtree Meadow was the most remote site in terms of location, it did not have the longest noise free interval or the smallest percent time extrinsic sounds audible. Rather, the Buckeye Flat summer site had the longest noise free interval due to the masking effect of the sound of the Kaweah River. Nevertheless, the mean percent time audible for extrinsic sounds at all sites was relatively low. As shown in the median A-weighted existing ambient levels column, the quietest site was Redwood Canyon while the loudest existing ambient levels were recorded at the Buckeye Flat winter site.

Summary statistics based on acoustic monitoring

Site Location	<u>UUUU</u> Mean % time <u>audible</u> ^a		<u>Median A-weighted Existing</u> <u>Ambient (L₅₀)</u> ^b		<u>Mean % Loss of</u> <u>Listening Area</u> ^c
	Extrinsic sounds	Aircraft sounds	Day (0800-1900)	Night (2000-0700)	4 Noisiest hours (0900, 1000, 1800, 1900)
Buckeye Flat Winter	10.6	10.5	54.7	54.3	
Cedar Grove	8.0	5.1	43.1	43.5	
Redwood Canyon	17.3	16.6	24.9	22.3	
Buckeye Flat Summer	5.8	4.9	47.8	48.8	
Crabtree Meadow	9.1	8.8	29.9	29.7	
Kaweah	10.1	9.8	30.3	30.5	

^a Over 24 hour period, based on off-site listening analysis.

^b For comparison, nighttime sound level in a typical residential area is about 40 dBA.

^c Represents the average percent loss of listening area for sounds between 200 and 800 Hz for the noisiest four hours of the day. There was some variation among sites. See pg. 25 for an explanation of this metric.

Introduction

A 1998 survey of the American public revealed that 72 percent of respondents thought that providing opportunities to experience natural quiet and the sounds of nature was a very important reason for having national parks, while another 23 percent thought that it was somewhat important (Haas & Wakefield, 1998). In another survey specific to park visitors, 91 percent of respondents considered enjoyment of natural quiet and the sounds of nature compelling reasons for visiting national parks (McDonald, Baumgartner, & Iachan, 1995). Acoustic monitoring provides a scientific basis for assessing the current status of acoustic resources, identifying trends in resource conditions, quantifying impacts from other actions, assessing consistency with park management objectives and standards, and informing management decisions regarding desired future conditions. Acoustic monitoring is timely for Sequoia & Kings Canyon and other parks in the Sierra Nevada network (SIEN)¹ due to continued growth in commercial air traffic. Aircraft overflights are the most ubiquitous noise source throughout the Sierra parks and associated wilderness areas. The SIEN parks also experience commercial air tour activity, and are required to develop an air tour management plan under the National Parks Air Tour Management Act of 2000.

As a result of an FY05 technical assistance request, the NPS Natural Sounds Program conducted an acoustic workshop hosted by SIEN in July, 2005. The workshop produced a plan for acoustic monitoring, and data has been collected at 20 sites over the ensuing two year period. The SIEN parks requested continued assistance to:

1. Analyze the 2005-2006 data and produce reports that document the results,
2. Support development of indicators and standards for acoustic resource² management in different SIEN areas,
3. Conduct a social science/visitor survey of backcountry users to better define the wilderness experience and expectations as related to extrinsic sounds³,
4. Support YOSE sound monitoring by providing consultation for equipment operation and/or providing a technician for the summer season,
5. Support DEPO in developing their acoustic resource management plan.

This report describes the acoustic monitoring effort for Sequoia and Kings Canyon National Parks and summarizes the results that emerged from analyzing the monitoring data.

¹Sequoia and Kings Canyon National Park (SEKI), Devil's Postpile National Monument (DEPO), and Yosemite National Park (YOSE)

²This report clarifies the differences in terminology between "soundscape" (the visitor perception of the acoustic environment), and "acoustic resources" (sound sources, factors that modify sound transmission, and the soundscape). Our revised use of "soundscape" conforms with the historical origins and general meaning of the term, in contrast to earlier NPS documents that used "soundscape" to refer to physical resources.

³ Any sound not forming an integral part of the park unit, or a sound originating from outside the park boundary.

National Park Service Natural Sounds Program

The NPS Natural Sounds Program (NSP) Office was established in 2000 to help parks manage sounds in a way that balances access to the park with the expectations of park visitors and the protection of park resources. The NSP addresses acoustical issues raised by Congress, NPS Management Policies, and NPS Directors Orders. An important element of this mission is working with the Federal Aviation Administration (FAA) to implement the National Parks Air Tour Management Act. Congress mandated that FAA and NPS jointly develop Air Tour Management Plans (ATMPs) for more than 106 parks where commercial air tours operate. The program also provides technical assistance to parks in the form of acoustic monitoring, data processing, park planning support, and comparative analyses of acoustic environments throughout the national park system.

Soundscape Planning Authorities

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

Direction for management of natural soundscapes⁴ 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 natural ambient sound level—that is, the environment of sound that exists in the absence of human-caused noise—is the baseline condition, and

⁴ 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.

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, 2006c). 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, 2006c).

Study Area



Sequoia and Kings Canyon National Parks are located in the southern Sierra Nevada. Managed as one unit, the two parks encompass a diverse variety of habitats, ranging from low elevation chaparral and oak woodlands, to mid elevation sequoia groves, and finally, high alpine wilderness. As a result of the large elevation gradient, these parks harbor an abundance of plant and animal species. Over 260 native vertebrate species (150 of which are rare or uncommon) and 1,200 plant species are found within park boundaries. Sequoia and Kings Canyon National Parks contain over 723,000 acres of designated wilderness, along with 850 miles of maintained wilderness trails. The parks are easily accessed from several metropolitan areas. They are located about 70 miles from Fresno, 235 miles from Los Angeles, and 250 miles from Oakland and Sacramento.

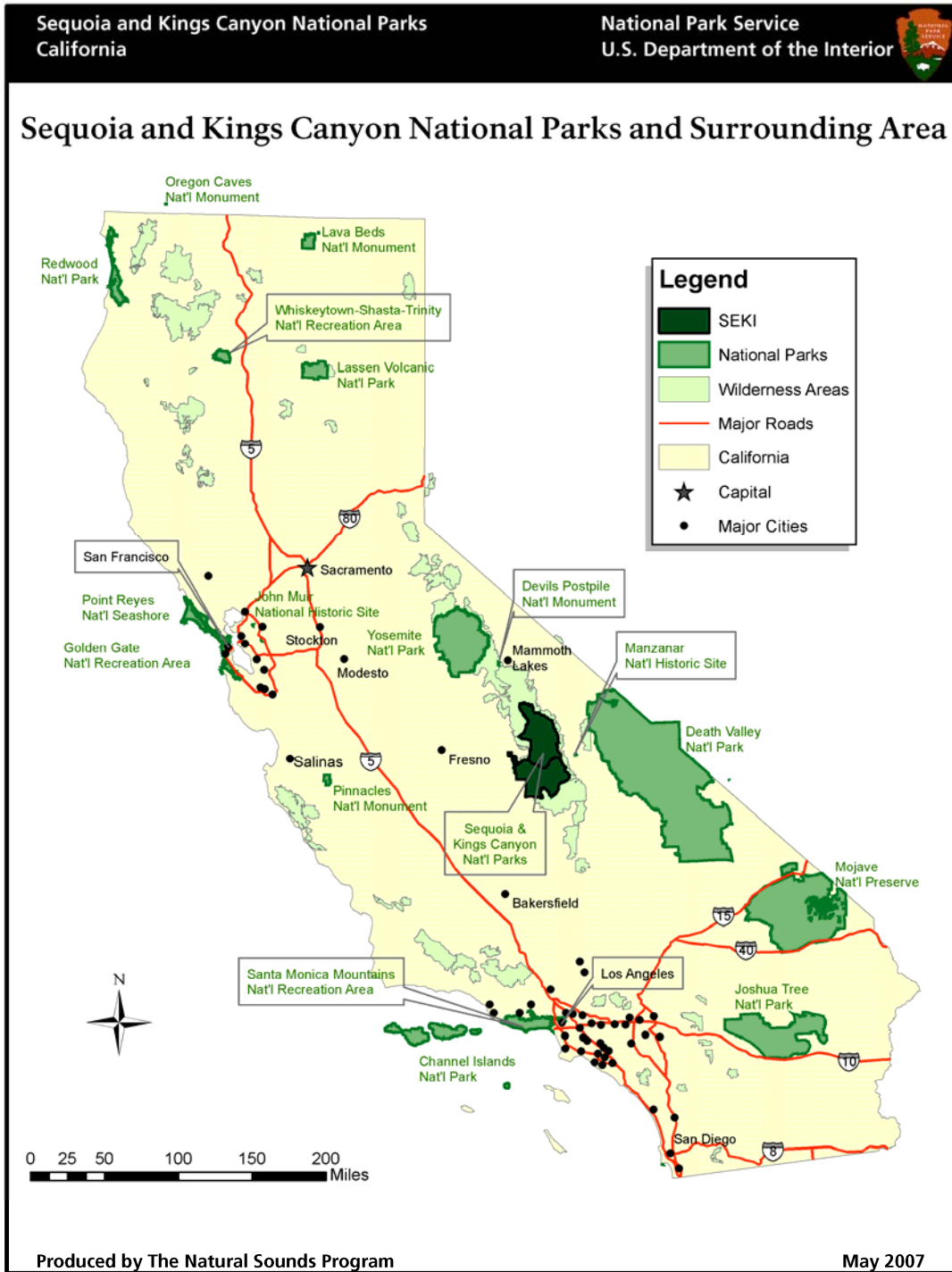
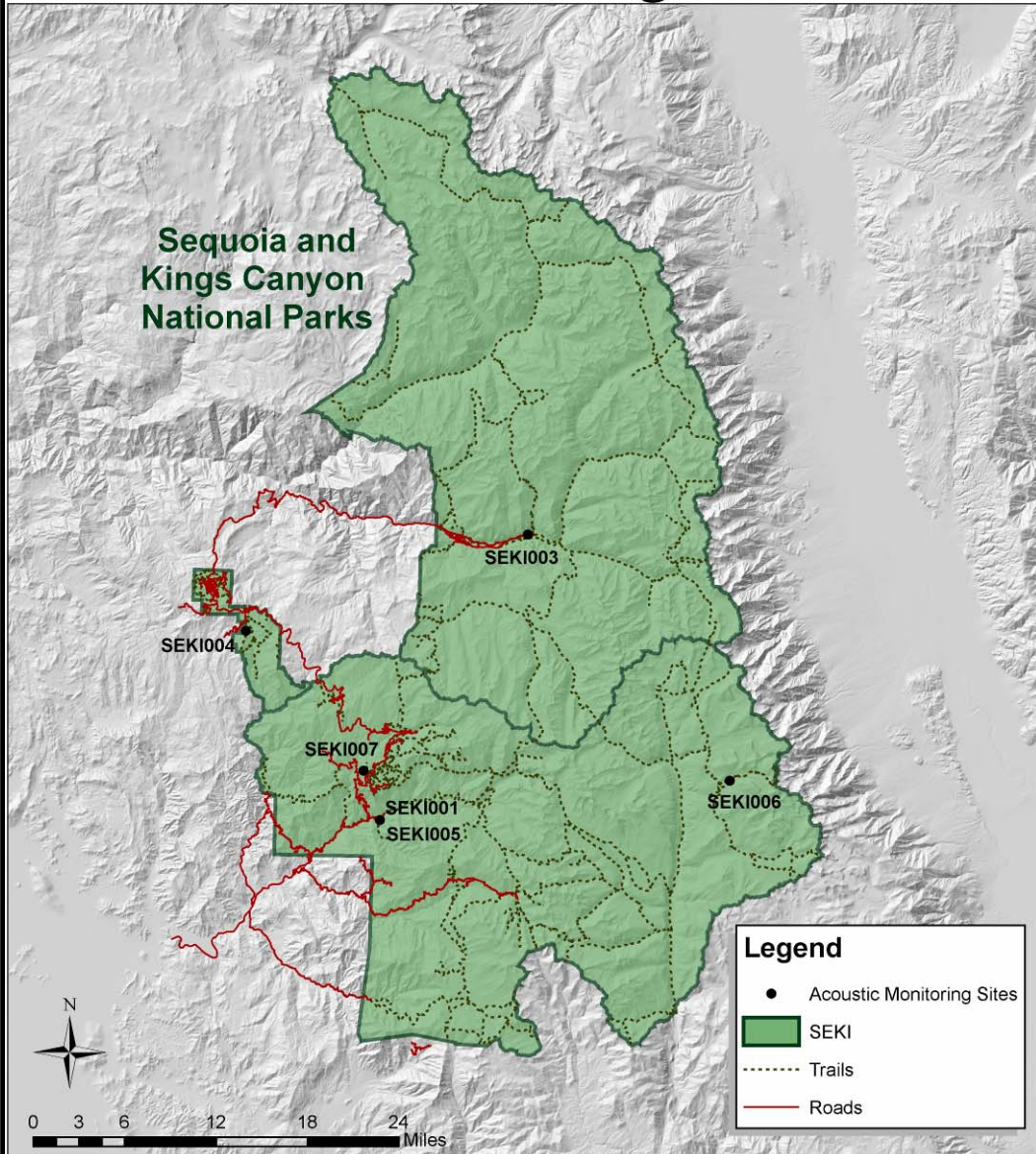


Figure 1. Map of California showing the location of Sequoia and Kings Canyon National Parks, surrounding parks, major cities, and interstate highways.



Acoustic Monitoring Sites



Produced by The Natural Sounds Program

June 2007

FILE: T:/Sounds File Structure/2. Acoustic Science/2.9 Project Specific Files/SEKI/GIS

Figure 2. Map of SEKI 2005 and 2006 acoustic monitoring sites. Site 2 was omitted because no data were collected from this site.

Description of Monitoring Areas

Seven acoustic monitoring sites were erected in Sequoia and Kings Canyon during 2005 and 2006. SEKI002 was dismantled soon after deployment due to equipment failure. SEKI007 experienced technical difficulties and produced a full monitoring period of sound pressure level (SPL) data, but no audio (.wav) recordings.

Table 1.

<i>SEKI acoustic monitoring sites, locations, and year when monitoring occurred.</i>					
<u>Site Location</u>	<u>Latitude</u>	<u>Longitude</u>	<u>Habitat Type</u>	<u>Elevation (meters)</u>	<u>Year</u>
SEKI001: Buckeye Flat winter	36.52080	-118.75762	Oak woodland	940	2005
SEKI003: Cedar Grove	36.79533	-118.58887	Vertical canyon/ Jeffrey pine	1527	2006
SEKI004: Redwood Canyon	36.69860	-118.92010	Sequoia grove	1997	2006
SEKI005: Buckeye Flat summer	36.52080	-118.75762	Oak woodland	940	2006
SEKI006: Crabtree Meadow	36.56369	-118.34556	Subalpine/ foxtail pine	3290	2006
SEKI007: Kaweah	36.56760	-118.77808	Open mixed conifer	1923	2006



Figure 3. Buckeye Flat Winter (SEKI001).

SEKI001 was located at 940 meters of elevation, just above the Buckeye Flat campground, off Generals Highway. Dominant vegetation included buckeye, blue oak and assorted grasses. This site was relatively loud because the Kaweah River in the valley below was almost constantly audible. Monitoring occurred from November through December of 2005, and was intended to characterize the oak woodland vegetation zone.



Figure 4. Cedar Grove (SEKI003).

SEKI003 was located on the site of a recent (2005) understory burn. The remaining vegetation consisted of Jeffrey pine, incense cedar, and burned manzanita. Rock cover was estimated to be about 40 percent. The site was situated about 150 m from Kings Canyon Scenic Byway, near the Road's End permit station, and 220 m from the Kings River. It sat about 20 m from the base of a vertical canyon at an elevation of about 1500m. It was deployed in June and dismantled in August of 2006. The vegetation zone was identified as vertical canyon and Jeffrey pine.



Figure 5. Redwood Canyon (SEKI004)

SEKI004 was located in the Redwood Canyon area, off the Sugar Bowl Grove trail. It was placed at an elevation of about 2000m. As demonstrated in Figure 5, the dominant vegetation at this monitoring site was giant sequoia with a mixture of mature and immature Jeffrey Pine.



Figure 6. Buckeye Flat Summer (SEKI005)

This site was the summer portion of a two-season (winter/summer) monitoring effort at Buckeye Flat. Thus, SEKI005 was assembled in the same place as SEKI001: at an elevation of 940 meters, just above the middle fork of the Kaweah River.



Figure 7. Crabtree Meadow (SEK1006)

The Crabtree Meadow site was the most remote of all Sequoia and Kings Canyon monitoring sites. It was located at 3290 m of elevation, about 20 miles into the backcountry on the western side of Mt. Whitney, in the subalpine vegetation zone. It was also located in proximity to Whitney Creek. The site was open, with about 30 percent tree cover (consisting of foxtail pine and lodgepole pine).



Figure 8. Kaweah (SEKI007)

This site was located at 1923m near the Kaweah air quality monitoring station. It was accessed via the Giant Forest museum overflow parking lot. The monitoring effort here was intended to characterize the acoustic qualities of the open mixed conifer vegetation zone. Dominant species included Jeffrey pine, sugar pine, oak, and incense cedar. This site was frequently disturbed by bears.

Equipment, Procedures, & Processing

Measurement Period

To produce existing and natural ambient data with a margin of error less than 3dB at backcountry sampling sites, the National Park Service Natural Sounds Program (NSP) has determined that sound monitors should remain at sampling sites for a minimum of 25 days (NPS, 2005a). Thus, in order to guarantee 25 days of acceptable data, the acoustic sampling stations were left in place for at least 30 days. NSP suggests a 10 day minimum sample size for frontcountry sampling sites, where a full range of natural variability is not expressed. Sound monitors remained at frontcountry locations for 12-15 days.

Automatic Monitoring

Larson Davis sound level meters (SLM) were employed over the two-year monitoring period at SEKI. The Larson Davis SLM is a hardware-based real-time analyzer which constantly records one second SPL and 1/3 octave band data, and exports these data to an external storage device (laptop or PDA). Larson Davis-based sites met American National Standards Institute (ANSI) Type 1 standards. (See Appendix II: Recording equipment specs for more detailed information).

Each Larson Davis sampling station consisted of:

- Toughbook PC
- Microphone with environmental shroud
- Preamp
- Between three and five 12V gel cell sealed lead acid batteries
- Anemometer
- Meteorological data logger
- Two photovoltaic panels

Each acoustic sampling station collected:

- SPL data in the form of A-weighted decibel readings (dBA) every second.
- Ten second digital audio clips every two minutes.
- One third octave band data every second. (The one third octave band data ranged from 12.5 Hz – 20,000 Hz with the Larson Davis system).

Off-Site Listening

For each day of monitoring, a total of 7,200 seconds of digital .wav recordings (sampled at ten seconds every two minutes) were collected. NSP staff then listened to a subset of these samples (eight days or 57,600 seconds per site) and identified sound sources by entering corresponding source codes into a Microsoft Excel spreadsheet. The total percent time extrinsic sounds were audible was then used to calculate the natural ambient sound level. See “Calculation of Metrics.” Bose Quiet Comfort Noise Canceling headphones were used for off-site listening playback to minimize limitations imposed by the office acoustic environment.

On-Site Listening

On-site listening takes full advantage of human binaural hearing capabilities, and most closely matches the experience of park visitors. Logistic constraints prevent comprehensive sampling by this technique, but selective samples of on-site listening provide a basis for relating the results of off-site listening to the probable auditory perception of events by park visitors and wildlife. On-site listening sessions are also an excellent screening tool for parks initiating acoustic environment studies. They produce an extensive inventory of sound sources, require little equipment or training, and can help educate park staff and volunteers.

Thus, periods of on-site listening were conducted in order to discern the type, timing, and duration during sound-level data collection at SEKI. As recommended by NSP protocol (NPS, 2005a), these sessions generally began at the top of an hour and lasted for one hour. Staff recorded the beginning and ending times of all audible sound sources using custom-designed Personal Digital Assistant (PDA) software. These on-site listening sessions provided the basis for the calculation of metrics including the period of time between noise events (average noise free interval [NFI]), percent time each sound source was audible, and maximum, minimum, and mean length (in seconds) of sound source events.

Calculation of Metrics

The current status of the acoustic environment can be characterized by spectral measurements, durations, and overall sound levels (intensities). The NSP uses descriptive figures and metrics to interpret these characteristics. Two fundamental descriptors are existing and natural ambient sound levels. Existing ambient (L_{50}) is characterized by spectra (in dB) drawn from uncensored data, and encompasses all sound sources. Natural ambient (L_{nat}) is an estimate that attempts to remove sound energy from all extrinsic or anthropogenic noises from the existing ambient. The differences between these two values allow the NSP 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 noise?

To calculate L_{nat} , the NSP does the following:

- Listen to ten second audio samples from eight days of monitoring (about 25% of total monitoring period).
- Identify all extrinsic sounds in each 10 second sample.
- Calculate the percentage of all samples containing extrinsic sounds for each hour of the day (P_H).
- Use P_H to complete this formula for every hour: $x = \frac{1 - P_H}{2} + P_H$
- Example: if extrinsic sounds are audible 50% of the time ($P_H = 0.5$), then x_H is 0.75.
- Enter hourly x_H values into a database of all octave band information.
- Compute L_{nat} (the sound level that is exceeded $100 \cdot x_H$ percent of the time).

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 level, and the results of this calculation have produced consistent results at most sites.

Percent Listening Area Reduction

The indirect costs of noise resemble air quality issues in that noise limits the auditory horizon just as smog limits the expanse of visibility. A bird misses the sound of a worm, a mouse misses the footfall of a coyote, a visitor misses the babble of a nearby brook: percent listening area reduction quantifies the extent of noise impacts to wildlife resources and visitor experiences.

The maximum distance that a particular sound can be heard depends on its amplitude. But the primary mechanism accounting for the reduction of sound energy as it propagates away from the source is spherical spreading. This assumption is reasonable for most natural sounds that carry a few hundred meters or less when noise is absent.

The general formula for the residual listening area at a monitoring site given a specified increase in ambient sound level (Z in dB) is:

$$\text{Percent Residual Area} = 100(10^{-Z/10}).$$

The following table illustrates the relationship between increased ambient and listening area reduction with some commonly referenced decibel values.

dB ambient increase	3	6	10	20	30	40
Percent Residual Area	50.12%	25.12%	10.00%	1.00%	0.10%	0.01%

This simple formula will overestimate the reduction in listening area for loud sounds that can ordinarily be heard at great distances (several hundred meters or more). This is because other factors reduce the transmission of sound energy: atmospheric absorption of sound energy, interactions of the propagating sound with the ground, the scattering of sound by vegetation, and obstruction of the sound path due to topography. When more accurate assessments are needed for specific classes of sounds, the formula can be amended to incorporate corrections for these effects. However, the more complicated formula is not easily applied to a wide range of sounds, or easily interpreted. Though it is mentioned in the executive summary, this metric had not been fully developed when analysis took place. However, NSP plans to use this metric in future acoustic reports.

Limitations

Audibility

In terms of total percent time extrinsic sounds audible, on-site audibility listening sessions produced slightly different results than off-site sessions. It should be noted that the on-site listening process sampled a smaller number of seconds of the day than off-site listening (approximately 18,000 seconds versus 57,600 seconds). Furthermore, the on-site listening sessions were generally performed during daylight hours when it was easiest for field personnel to visit the sites, while off-site listening sessions sampled all hours of the day. Thus, with respect to percent time audible, more weight should be given to off-site listening results.

The park has voiced an interest in knowing the degree to which military overflights affect the acoustic environment at Sequoia and Kings Canyon, especially in the Crabtree Meadow area. This question can be answered to some degree by using the on-site attended logging data. During these sessions, listeners were able to positively identify military jets both aurally and visually. About 8 percent of the 15.6 percent total aircraft audibility was attributed to military jets during 21 on-site listening sessions at Crabtree Meadow. However, it is impossible to extract the same sort of data (with the same degree of certainty) from off-site sessions, where the listener has only audio cues.

Equipment Failure and Visual Analysis

SEKI007 experienced equipment failure during the monitoring period, resulting in blank audio recording files. Without audio files, the Natural Sounds Program can still analyze the existing sound pressure levels. However, it is not possible to determine the percent time extrinsic sounds were audible and therefore, natural ambient levels, with traditional audio-based methods. Instead, we used visual analysis to determine the percent time aircraft and other extrinsic noises were audible. In the visual analysis process, eight days of continuous sound pressure level data are examined. All aircraft and obvious extrinsic sound events are noted and amassed into a table. From this table, it is possible to extract an approximate percent time audible for each hour. In comparisons between the traditional method of analysis and the visual analysis, we found that the two methods returned similar results. See Appendix X for further explanation.

Results and Discussion

Acoustic monitoring systems were erected at seven sites. Due to equipment failure, the Kaweah monitoring site (SEKI007) did not collect audio samples, and thus can not be analyzed in the same manner as the other sites. The remaining sampling areas spanned various vegetation types and seasons; they are representative of acoustic conditions in a large portion of the park. On-site and off-site listening results are presented separately.

On-Site Listening

Table 2.

On-Site Listening: Summary of Results

Site Location	Sessions (n hours)	% Time extrinsic sources audible	% Time aircraft audible	Mean noise free interval (min:sec)
SEKI001: Buckeye Flat Winter	9	23.5	22.2	4:48
SEKI003: Cedar Grove	10	11.6	4.6	3:14
SEKI004: Redwood Canyon	7	26.1	19.6	3:08
SEKI005: Buckeye Flat Summer	8	10.4	9.7	8:36
SEKI006: Crabtree Meadow	21	16.6	15.7	4:51
SEKI007: Kaweah	7	39.0	19.0	1:35

See Appendix IV: On-site Listening Reports for a detailed list of on-site listening results.

Table 2 presents the results for on-site listening sessions at each monitoring station. The longest noise free interval (or period of time during which no extrinsic sounds were audible) was eight minutes and thirty-six seconds, and was measured at the Buckeye Flat summer site. This remarkably long NFI is most likely a product of the site's proximity to flowing water: the sound of the water masked distant or faint extrinsic sounds.

By comparison, the shortest NFI was measured at the Kaweah site, and was only one minute and thirty-five seconds. This relatively short NFI seems reasonable because extrinsic sound sources were audible almost 40 percent of the time during the measurement period. It is interesting to note that the most remote site, Crabtree Meadow, did not have the longest NFI. It seems that aircraft audibility was the primary determinant for NFI length at this site, because of the 16.6 percent extrinsic sources audible, 15.7 percent were aircraft. In fact, based on these on-site listening results, aircraft appears to be a prominent (if not dominant) extrinsic sound source at all of the Sequoia and Kings Canyon monitoring sites.

Off-Site Listening

See Appendix V: Off-site Listening Reports for a detailed list of sounds audible at each study site during off-site listening sessions.

SEKI001-Audibility

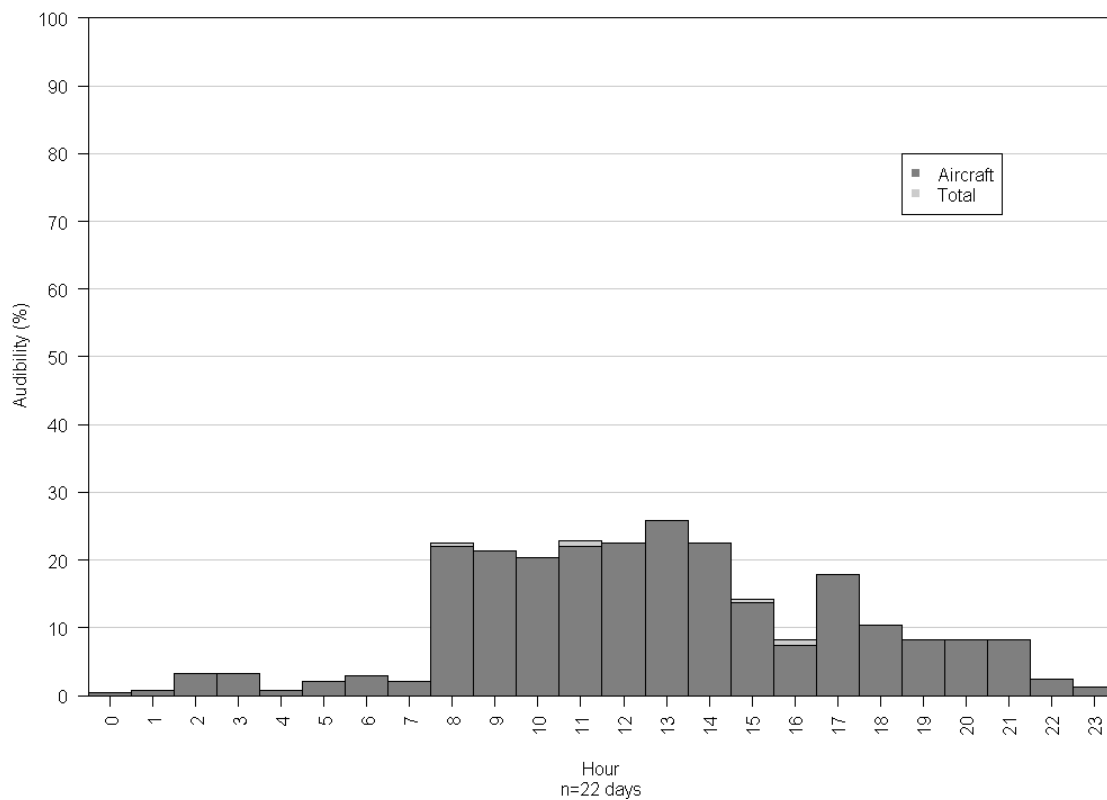


Figure 9. Audibility of extrinsic and aircraft sounds at SEKI001 (Buckeye Flat 2005).

Figure 9 shows the total percent time that extrinsic sounds (light gray) were audible in off-site listening sessions and the percent time that aircraft (dark gray) were audible. As demonstrated in this figure, the dominant audible sound source at Buckeye Flat was aircraft. With the exception of a few hours in the middle of the day, aircraft were the only audible extrinsic noise (people and vehicles contributed the rest). However, it should be noted that the constant sound of the Kaweah River might have limited the audibility of sound sources at this site. This site demonstrates a common aircraft overflight pattern: frequent flights in the mid morning hours (8, 9, and 10), frequent flights in the mid afternoon hours (13, 14, and 15), and almost no flights in the very early morning hours (0, 1, 2, and 3).

SEKI001- Natural Ambient

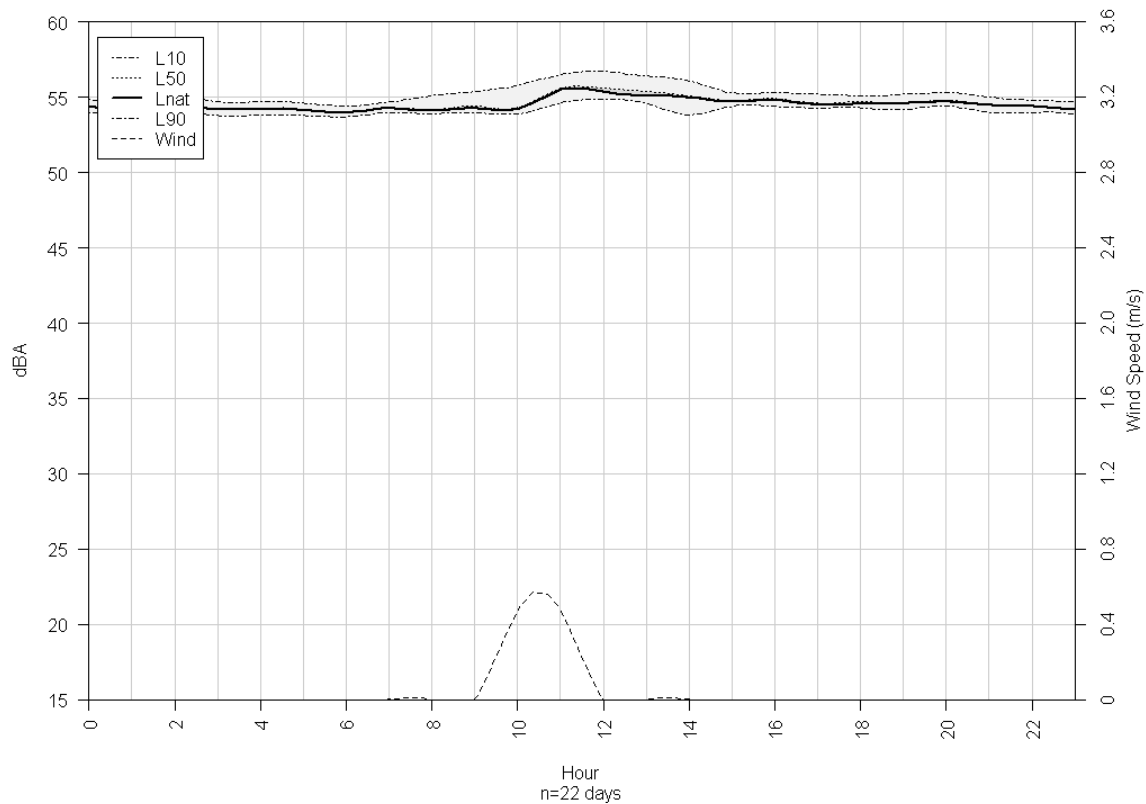


Figure 10. Exceedence values and median wind speed by hour at SEKI001 (Buckeye Flat 2005).

In the above figure, A-weighted dB metrics are shown as a function of time. A-weighted dB values provide an index of overall sound levels, a weighted sum of sound energy across the audible spectrum. The bold black line is the median L_{nat} , or the median natural ambient. L_{nat} is an estimation of what SEKI001 would sound like without the contribution of extrinsic sound. The line above L_{nat} is L_{50} , or the median existing ambient. Existing ambient includes both intrinsic and extrinsic sounds. L_{nat} and L_{50} are bordered above by L_{10} and below by L_{90} . Median L_{90} is the median dBA value exceeded 90 percent of the time during the sample period. Essentially, it represents the quietest sound levels that occur each hour. Median L_{10} is the dBA value exceeded 10 percent of the time. It represents the median loudest conditions each hour. The existing ambient at SEKI001 was very loud. Although wind speed tended to increase in the afternoon, the masking effect of the river kept the existing ambient at a relatively constant level, hovering around 55 dBA. In addition, there is very little difference between the L_{50} and L_{nat} at this site because extrinsic noise was heard so infrequently. This means that extrinsic noise contributed little to the overall sound level at this site.

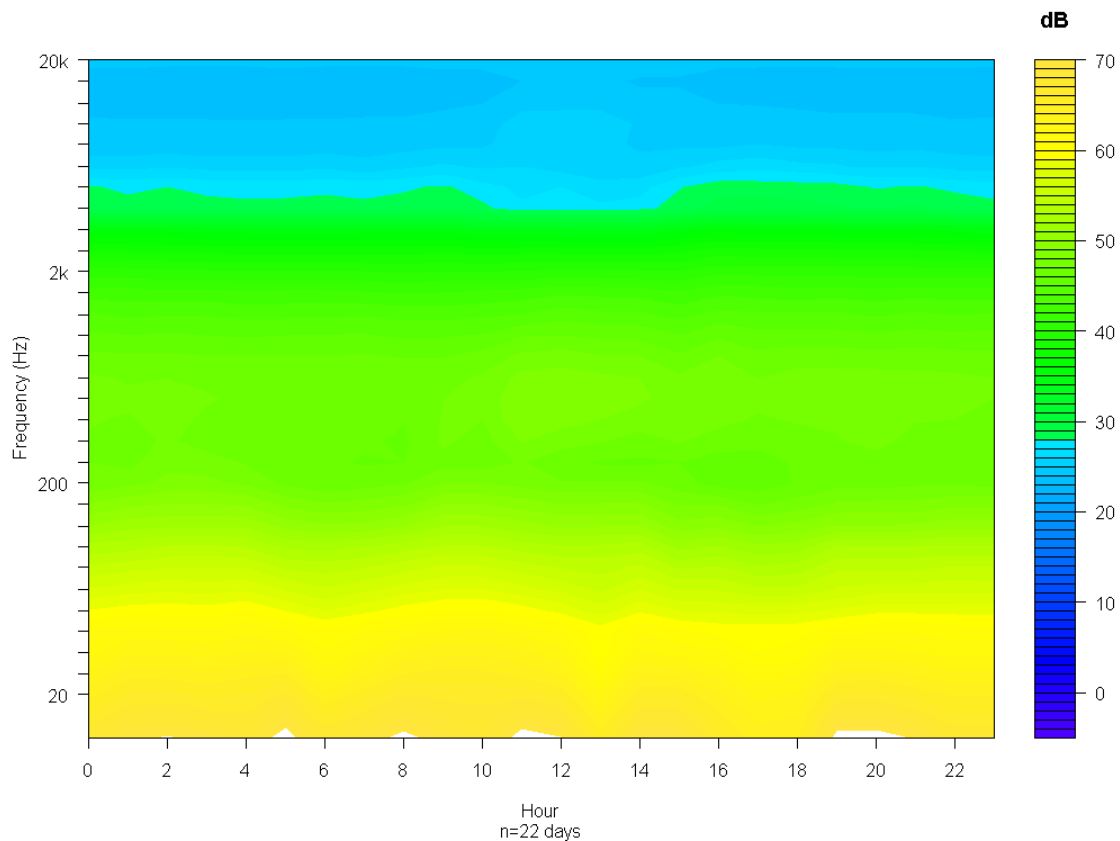


Figure 11. Flat-weighted contour plot of median existing ambient decibel and frequency levels at SEKI001 (Buckeye Flat 2005) across all hours.

This figure illustrates the variation in existing ambient dB across all frequencies by hour. Darker shades denote lower dB values while lighter shades denote higher dB values. In Figure 11, the existing ambient is consistently very high across all hours and frequencies. This uniformity can probably be attributed to the constant sound of the Kaweah River.

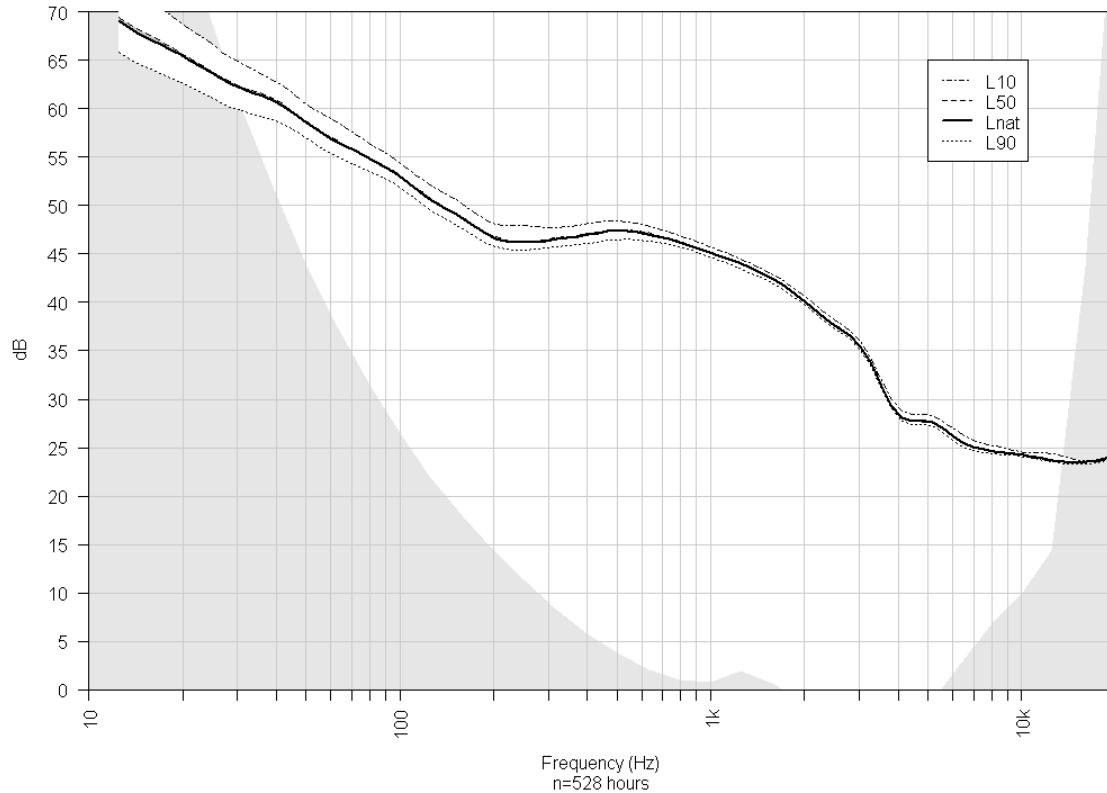


Figure 12. Human threshold of hearing and exceedence values by frequency at SEKI001 (Buckeye Flat 2005).

This figure plots sound pressure levels on the y axis and frequency (on a logarithmic scale) on the x axis. The threshold of human hearing is represented by the light gray shading in the background. Humans do not hear sounds in the light gray areas. This graph demonstrates the fact that SEKI001 was a very loud site. Both very low frequency sounds (30 Hz-100 Hz) and very high frequency sounds (4 kHz-10 kHz) were clearly audible. In other words, a large portion of the data lies within the human threshold of hearing.

SEKI003- Audibility

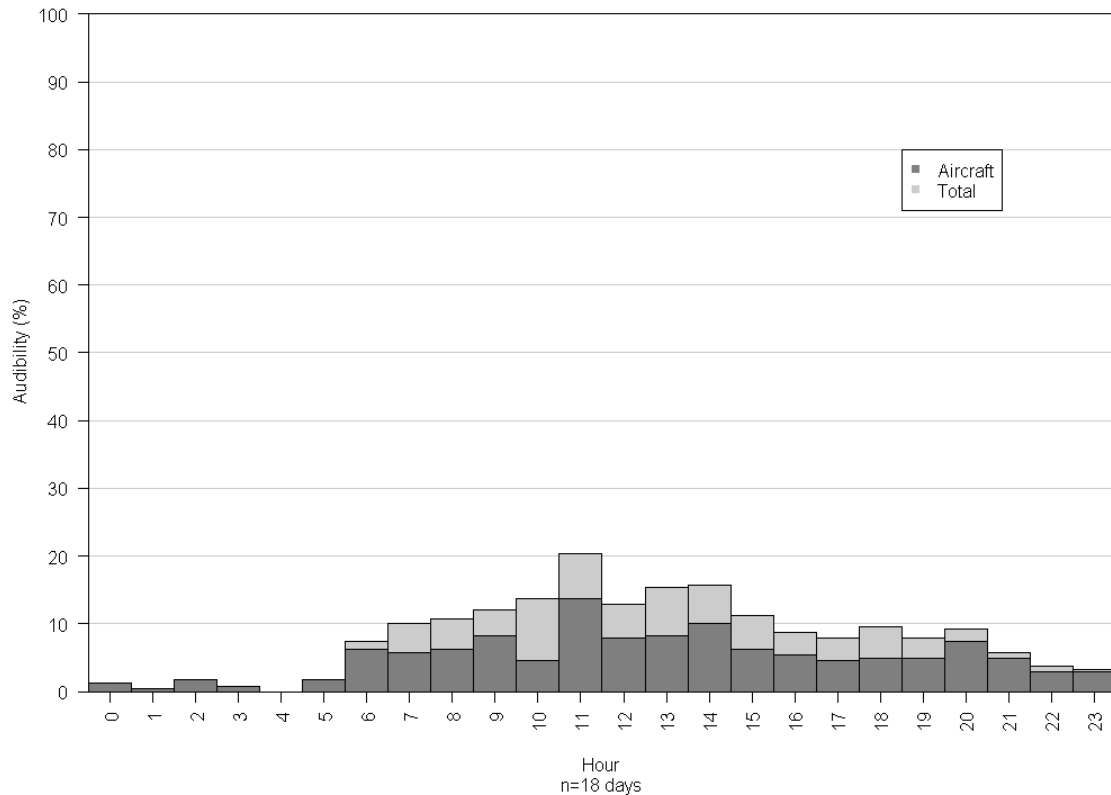


Figure 13. Audibility of extrinsic and aircraft sounds at SEKI003 (Cedar Grove). This site was located very close to the Kings River and thus, extrinsic sounds were not often audible. In fact, during the hour with the largest percentage of extrinsic sounds audible, 11h00, extrinsic sounds were only audible 20 percent of the time. Aircraft contributed a great deal to the total percent time audible, but vehicles were also audible due to the proximity of the road and the reflective quality of the vertical canyon wall.

SEKI003- Natural Ambient

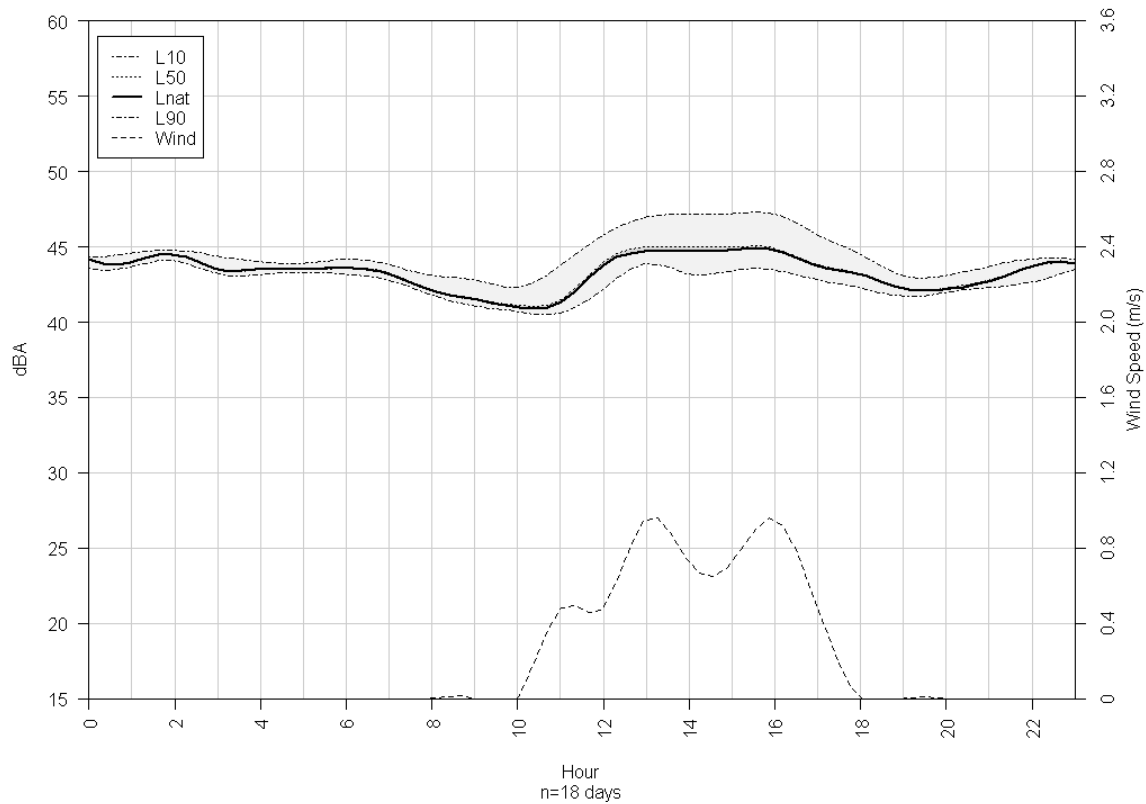


Figure 14. Exceedance values and median wind speed by hour at SEKI003 (Cedar Grove).

The existing ambient remains relatively constant in this figure. Both natural and existing ambient rise slightly from 11h00 to 18h00, but this can probably be attributed to the simultaneous increase in wind speed. There is very little difference between L_{50} and L_{nat} , which suggests that extrinsic sounds do not significantly raise the natural ambient at SEKI003. This is because the natural ambient is already elevated due to the sound of the Kings River.

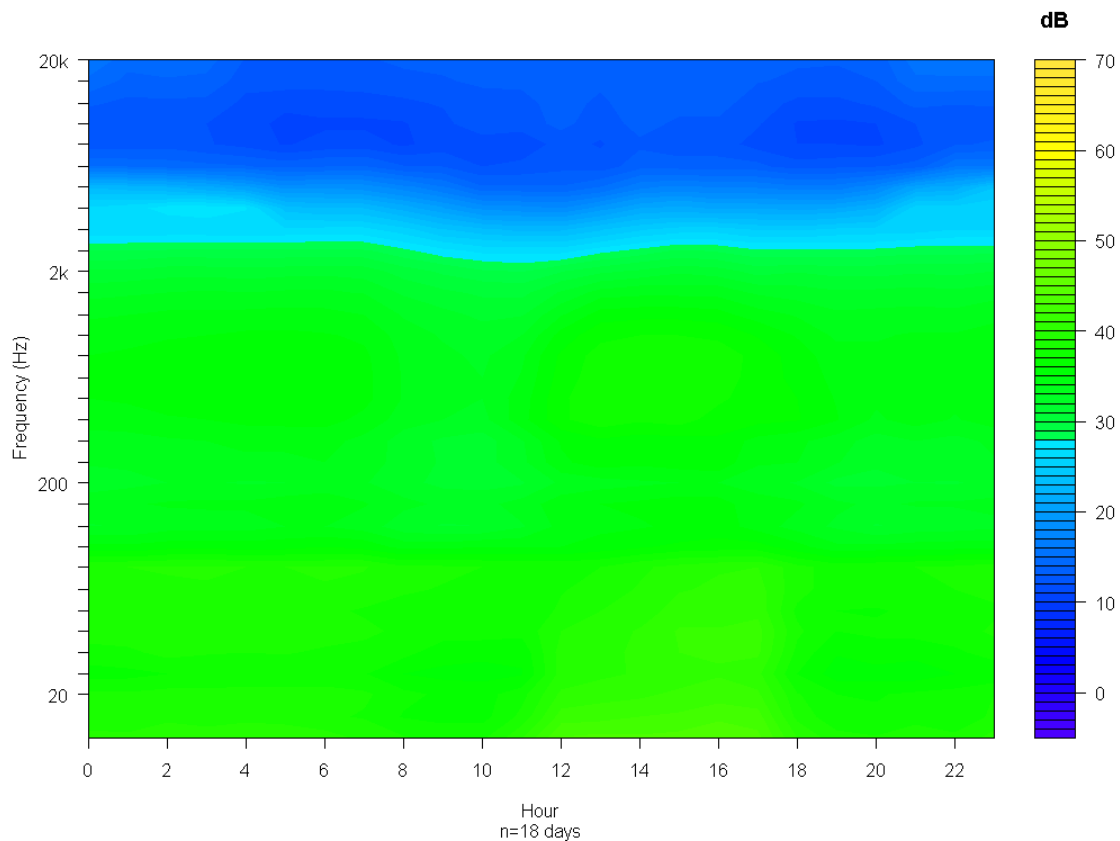


Figure 15. Flat-weighted contour plot of median existing ambient decibel and frequency levels at SEKI003 (Cedar Grove) as a function of time. This contour plot is typical of a site located near flowing water. There is very little hourly variation in existing ambient because of the persistent sound of the Kings River.

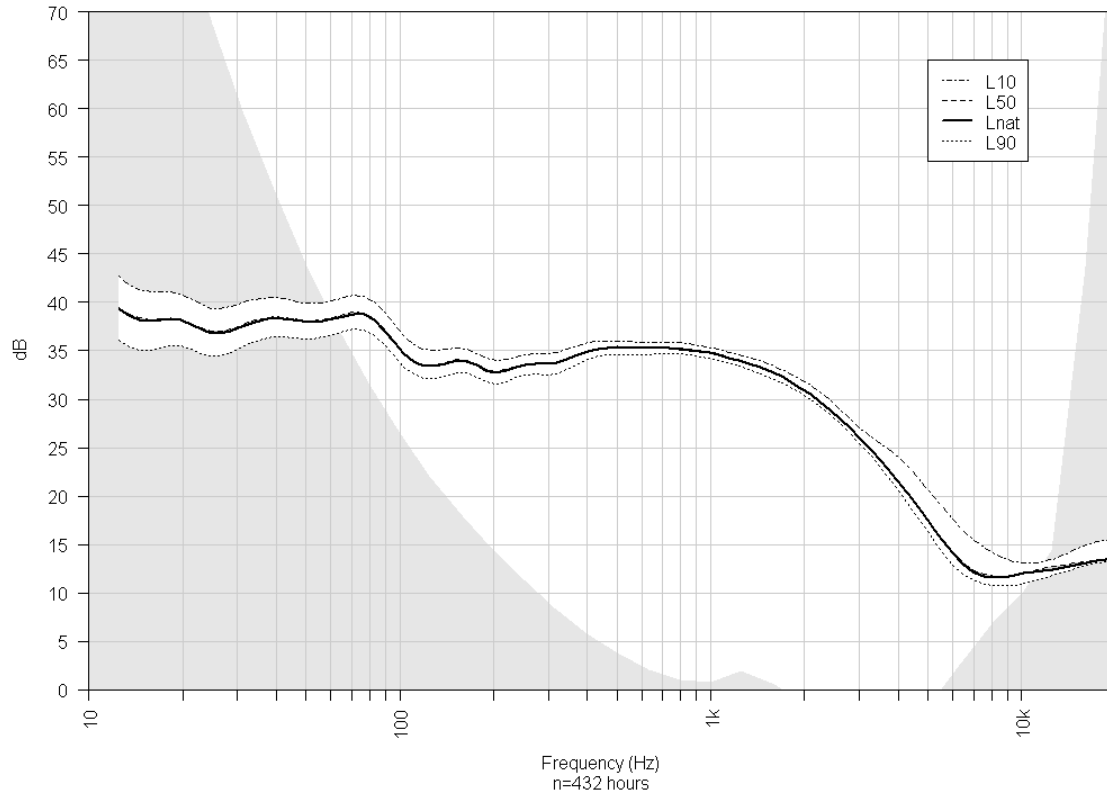


Figure 16. Human threshold of hearing and exceedence values by frequency at SEKI003 (Cedar Grove).

Even though both sites were near rivers, this site was significantly quieter than SEKI001, particularly in the lower frequencies (see Figure 12 for comparison). There is little variation in L_{50} and L_{nat} , indicating that extrinsic sounds did not significantly raise the median existing ambient. The dB levels shown in this figure above 10 kHz reflect the minimum measurement levels of the microphones. It is believed that the actual sound levels were below this portion of the curve.

SEKI004- Audibility

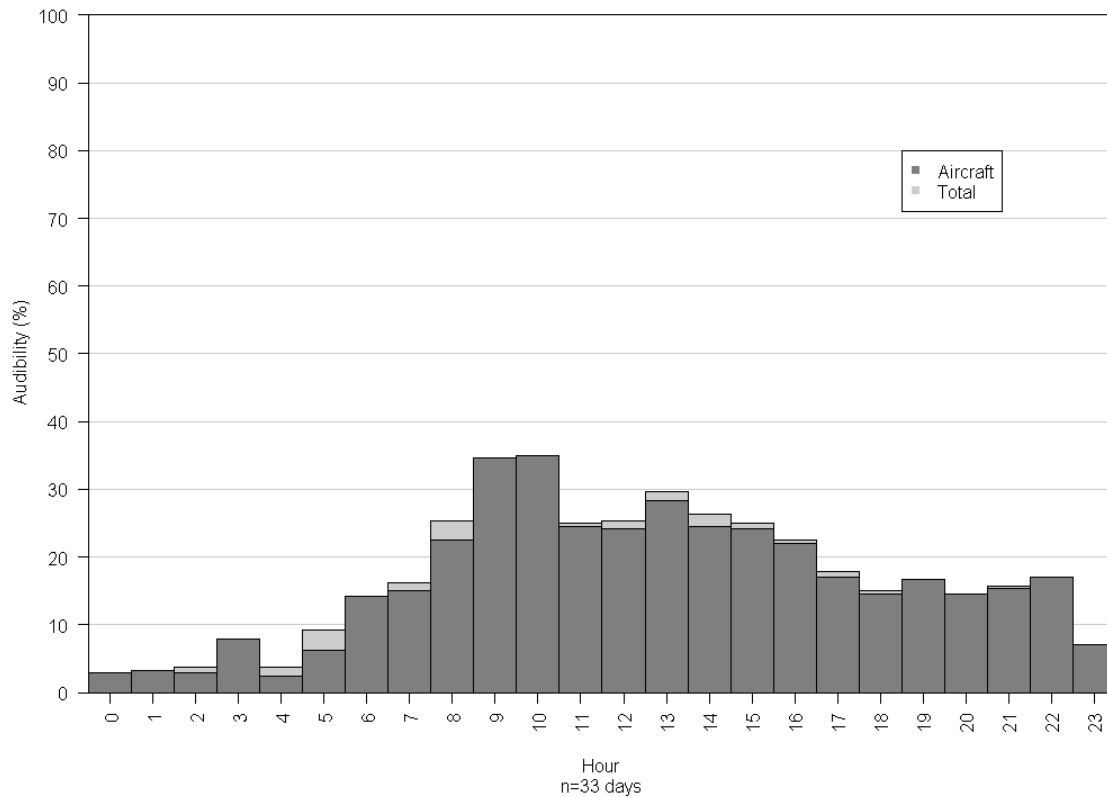


Figure 17. Audibility of extrinsic and aircraft sounds at SEKI004 (Redwood Canyon).

Of all monitoring sites in SEKI, the Redwood Canyon site had the greatest overall extrinsic audibility. Situated amongst large redwoods, the site was well protected from wind, and there were no constant masking sounds (such as the Kaweah or Kings river) to limit the audibility of extrinsic sounds. The dominant extrinsic sound at SEKI004 was aircraft, but people hiking on the Sugar Bowl Grove trail and distant vehicles were also audible. The aircraft overflight “rush hour” pattern shown in Figure 9 is also demonstrated here. It is particularly notable in the morning hours (8, 9, and 10).

SEKI004- Natural Ambient

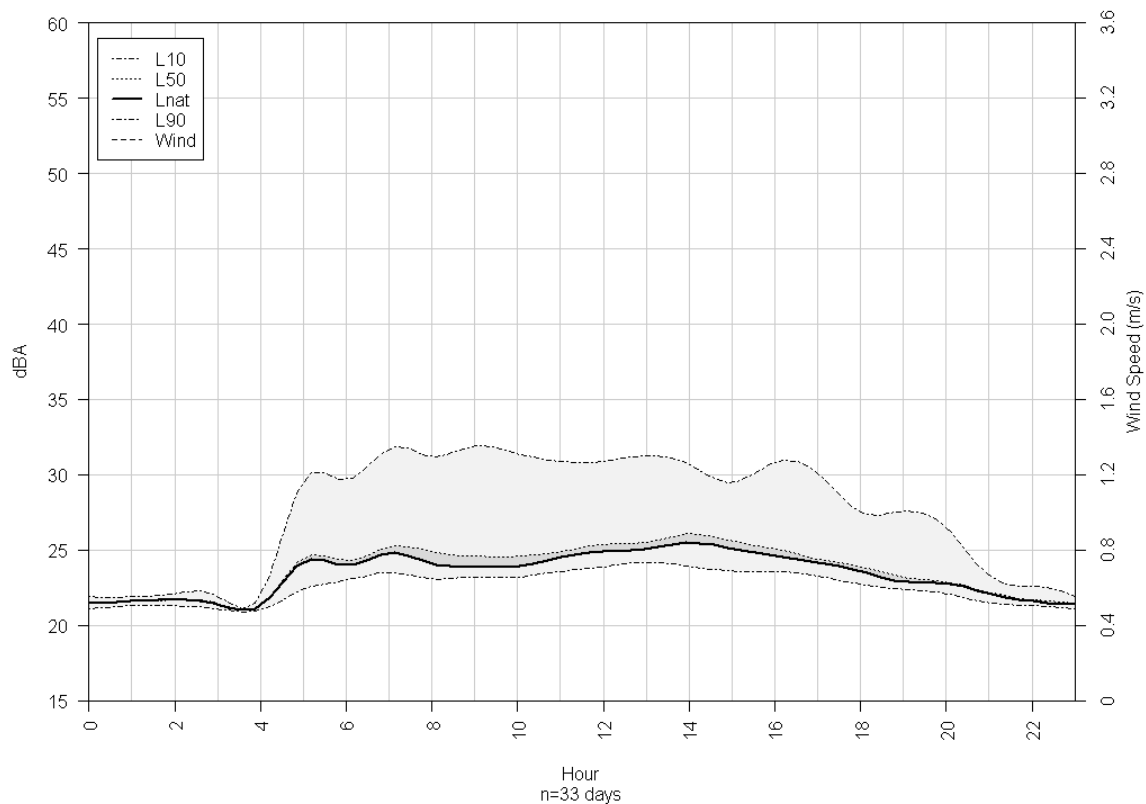


Figure 18. Exceedence values and median wind speed by hour at SEKI004 (Redwood Canyon).

Though SEKI004 had the highest percent time audible of all monitoring sites, it had the lowest natural and existing ambient sound levels. In fact, because this monitoring location was so well protected, during the quietest night time hours (00h00-04h00), the natural ambient was estimated to be only 5 dB above the noise floor (i.e. the absolute sensitivity of the electronic components in the system). The attenuating characteristics of the soft ground cover (duff) and large redwood trunks also served to quiet this site. The spike at 04h00 can probably be attributed to the morning bird chorus. The median wind speed at SEKI004 was not great enough to appear on the graph.

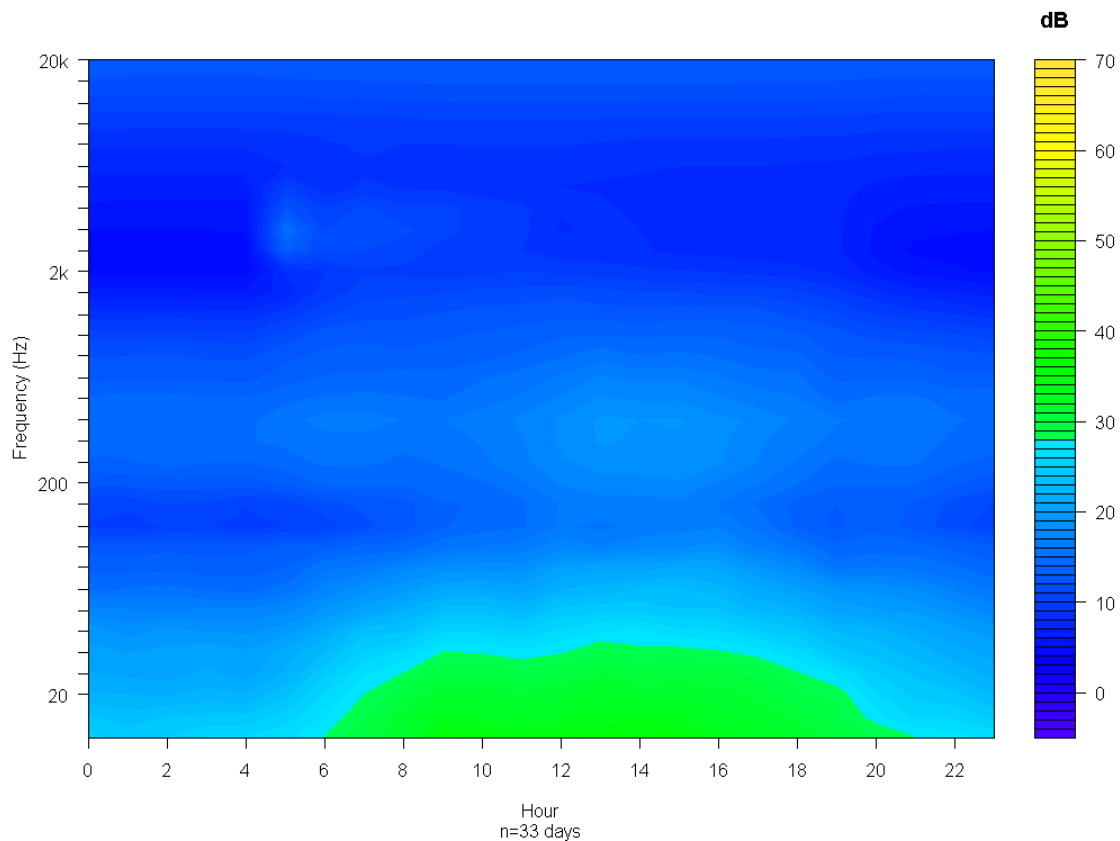


Figure 19. Flat-weighted contour plot of median existing ambient decibel and frequency levels at SEKI004 (Redwood Canyon) as a function of time. In contrast to the previous contour plots, this graph displays very low median existing ambient levels. The brighter bloom in the low frequencies (0-80 Hz) is probably due to the slight movement of wind across the microphone. The morning bird chorus is clearly visible as a bright spot at about 05h00 and 6 kHz.

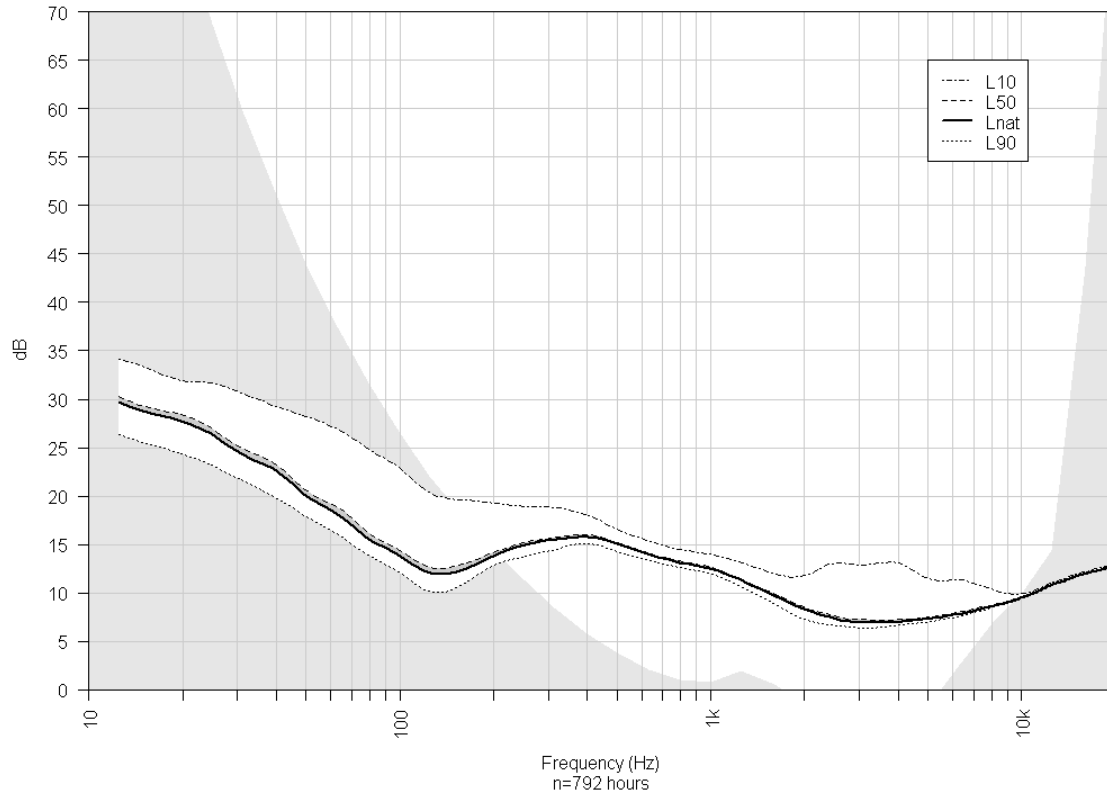


Figure 20. Human threshold of hearing and exceedence values by frequency at SEKI004 (Redwood Canyon).

This graph confirms what the previous two figures suggest: SEKI004 was the quietest of all monitoring sites in terms of natural and existing ambient sound levels. There is little difference between natural and existing levels in this figure, which suggests that even though extrinsic sound sources are audible at SEKI004, they did not significantly raise the median existing ambient level. However, the L_{10} is notably higher than both L_{50} and L_{nat} in two places: at about 125 Hz and at 3 kHz. Both aircraft and thunder emit sound around 125 Hz, and both were audible in SEKI004 off-site listening sessions (aircraft 16.6%, thunder 1.2%). The rise in L_{10} at 3 kHz probably reflects the contribution of bird song to the acoustic environment during certain hours of the day.

SEKI005- Audibility

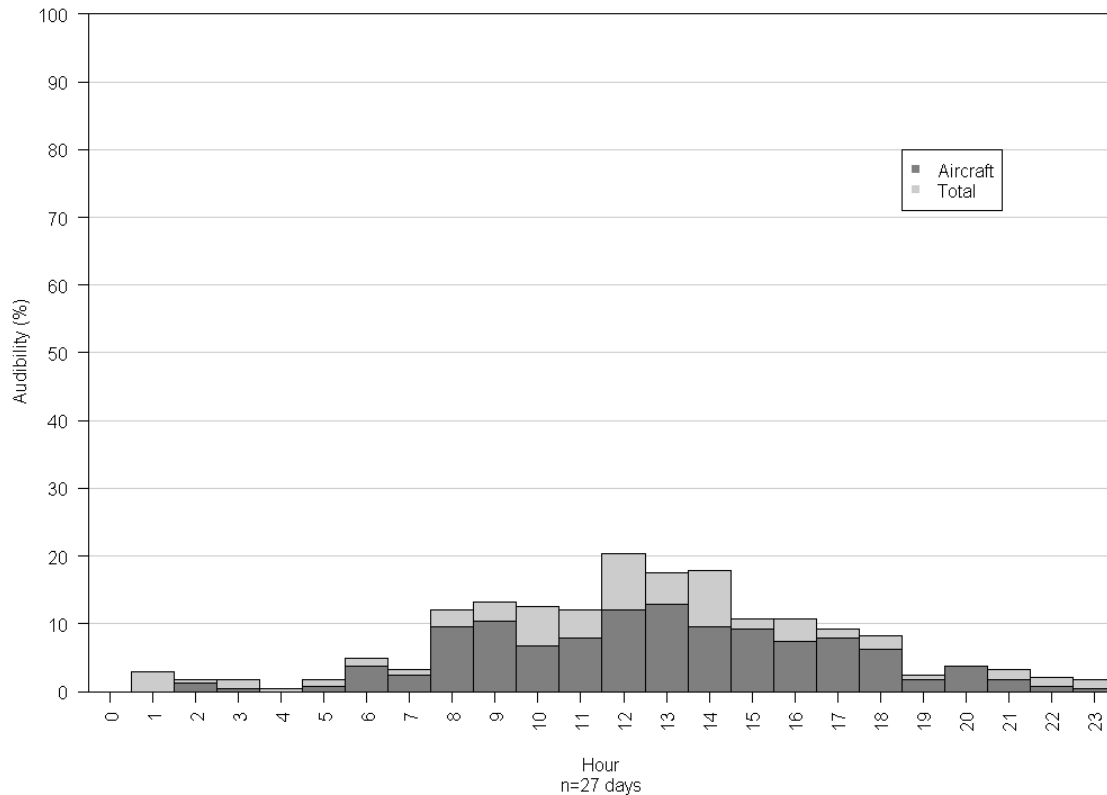


Figure 21. Audibility of extrinsic and aircraft sounds at SEKI005 (Buckeye Flat 2006).

SEKI001 and SEKI005 were located in the same place, but were deployed in different seasons. The summer site, SEKI005, actually appears to have a slightly smaller percent time extrinsic sounds audible than the winter site. One possible explanation for this variance is that the sound of the Kaweah River was louder in the summer due to snowmelt in the high country. However, the median existing ambient in the summer was consistently about 5 dB less than it was in the winter (compare Figure 10 and Figure 22). Therefore, one would assume one of two possibilities: either extrinsic activity was greater in the winter and therefore more audible, or extrinsic sound sources were less audible in the summer because the atmospheric conditions limited sound propagation.

SEKI005- Natural Ambient

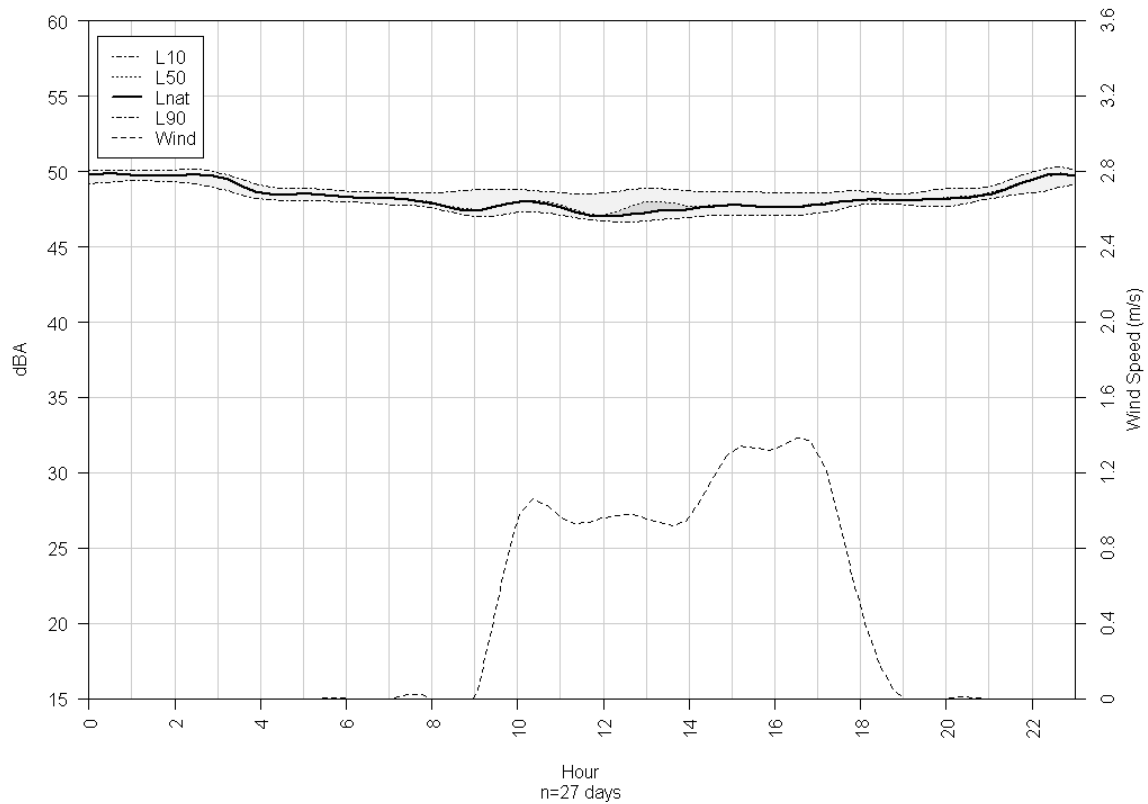


Figure 22. Exceedence values by hour at SEKI005 (Buckeye Flat 2006).

The natural and existing ambient remained relatively constant (between 45 dBA and 50 dBA) at this site due to the influence of the sound of the Kaweah River. Though wind speed increased during the middle of the day, its effects on the acoustic environment are not evident because the ambient sound level was already very high.

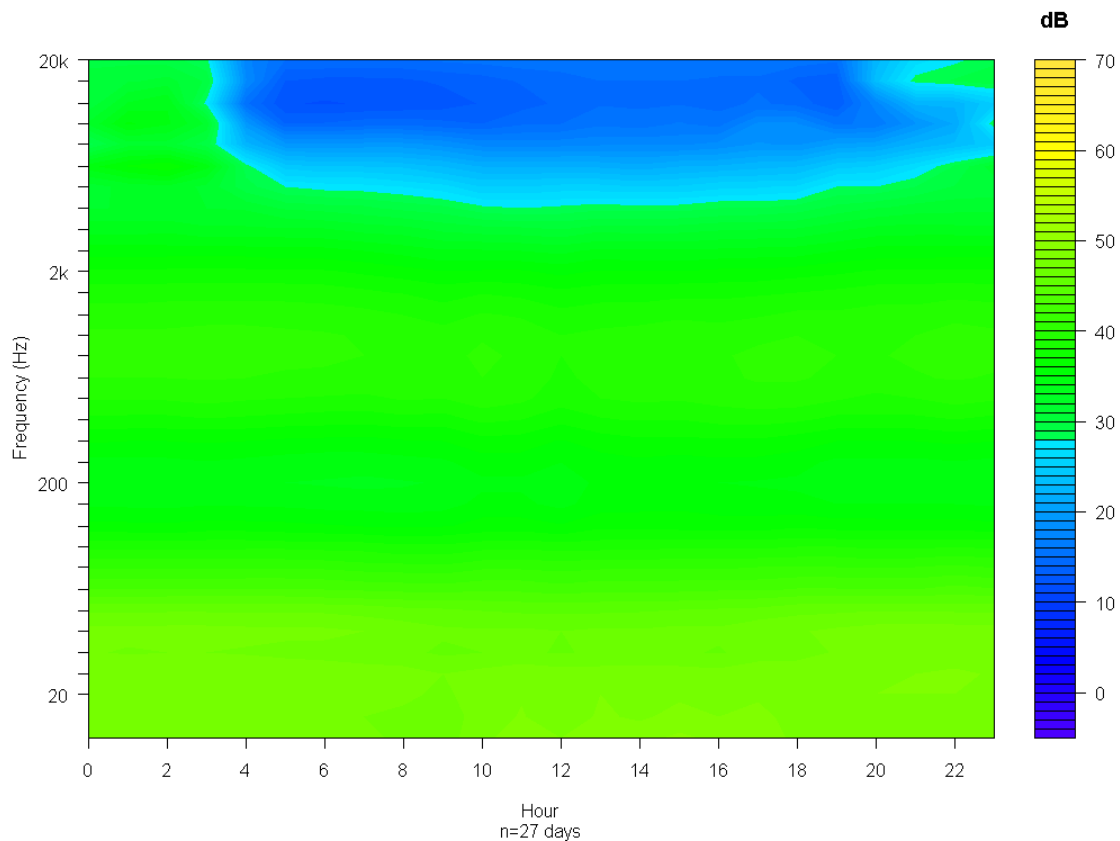


Figure 23. Flat-weighted contour plot of median existing ambient decibel and frequency levels at SEKI005 (Buckeye Flat 2006) as a function of time. This plot displays a great deal of sound energy. The median existing ambient is above 30 dB for most frequencies during most of the day. However, the most interesting feature of this graph appears at the highest frequencies in the late hours of the night and early hours of the morning. This sound energy most likely originated from insects which are more active at night than they are during the day.

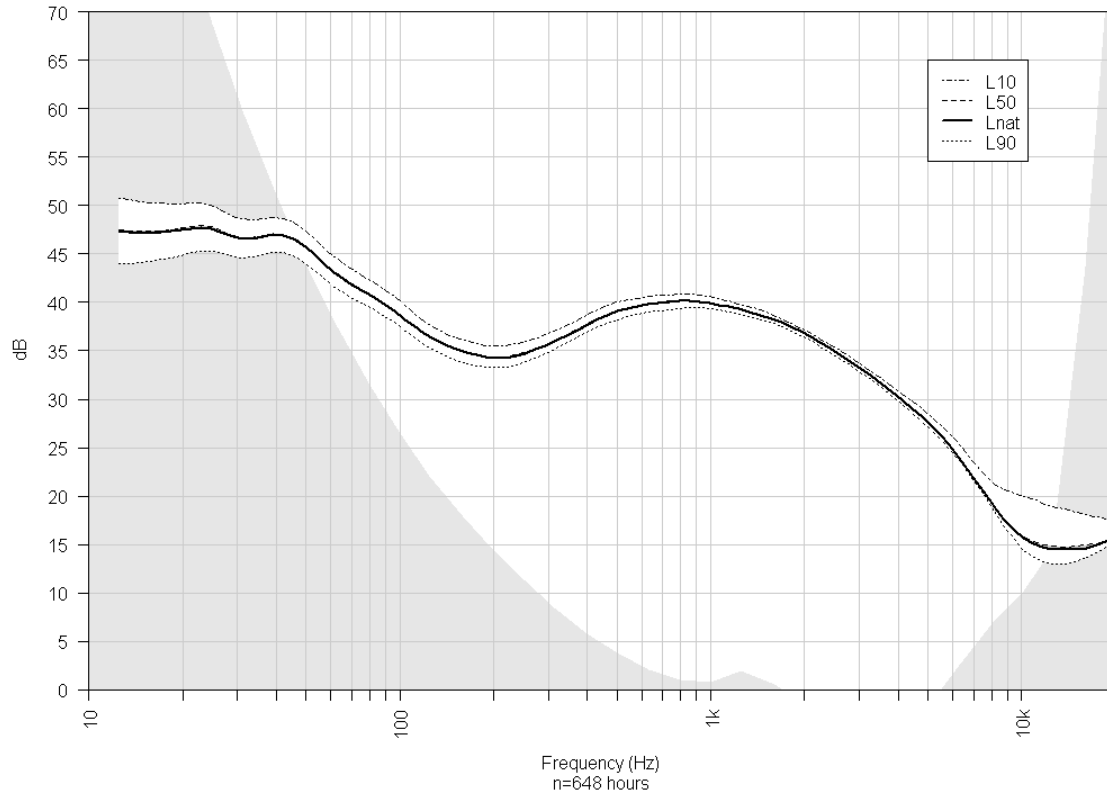


Figure 24. Human threshold of hearing and exceedence values by frequency at SEKI005 (Buckeye Flat 2006).

The contribution of insect sound to the acoustic environment at this site is visible in the high frequencies (8 kHz- 10 kHz) where L_{10} differs greatly from L_{nat} and L_{50} . This means that there were certain times (i.e. night time insect chorus) when the ambient sound level at these frequencies was considerably higher than the median existing and natural ambient. When this plot is compared to Figure 10 from SEKI001, it becomes apparent that there were much higher levels of low frequency sound in the winter. It is possible that the low frequency sounds traveled further in the winter because there was less scattering due to leaves.

SEKI006- Audibility

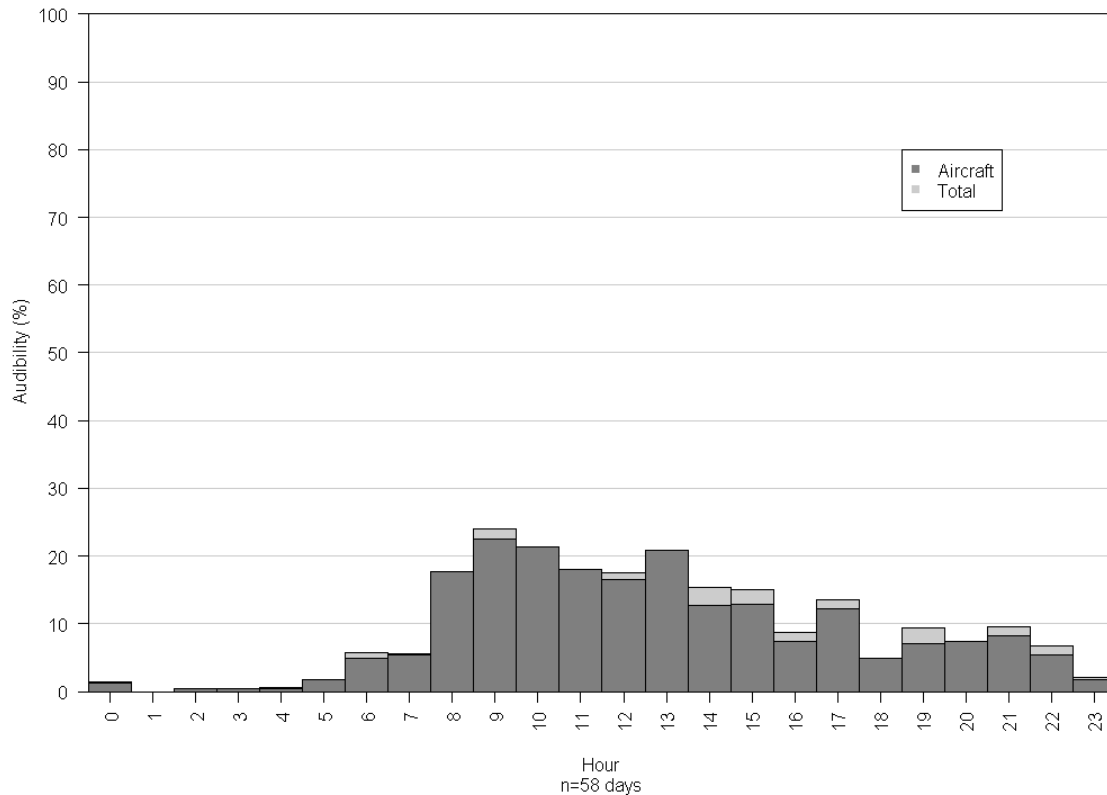


Figure 25. Audibility of extrinsic and aircraft sounds at SEKI006 (Crabtree Meadow).

The dominant extrinsic sound at SEKI006 was aircraft, but people hiking on the nearby trails were also audible and contributed to the total percent of extrinsic sounds audible. During 21 on-site listening sessions where visual (as well as audio) identification was possible, military jets were audible 8% of the time while commercial high-flying jets were audible 6% of the time. See Appendix IV: On-site Listening Reports for detailed on-site listening reports. As demonstrated at several other monitoring locations, aircraft overflight pattern increases in the morning hours (8, 9) and then decreases throughout the day. Very little aircraft was audible from 23h00 to 05h00.

SEKI006- Natural Ambient

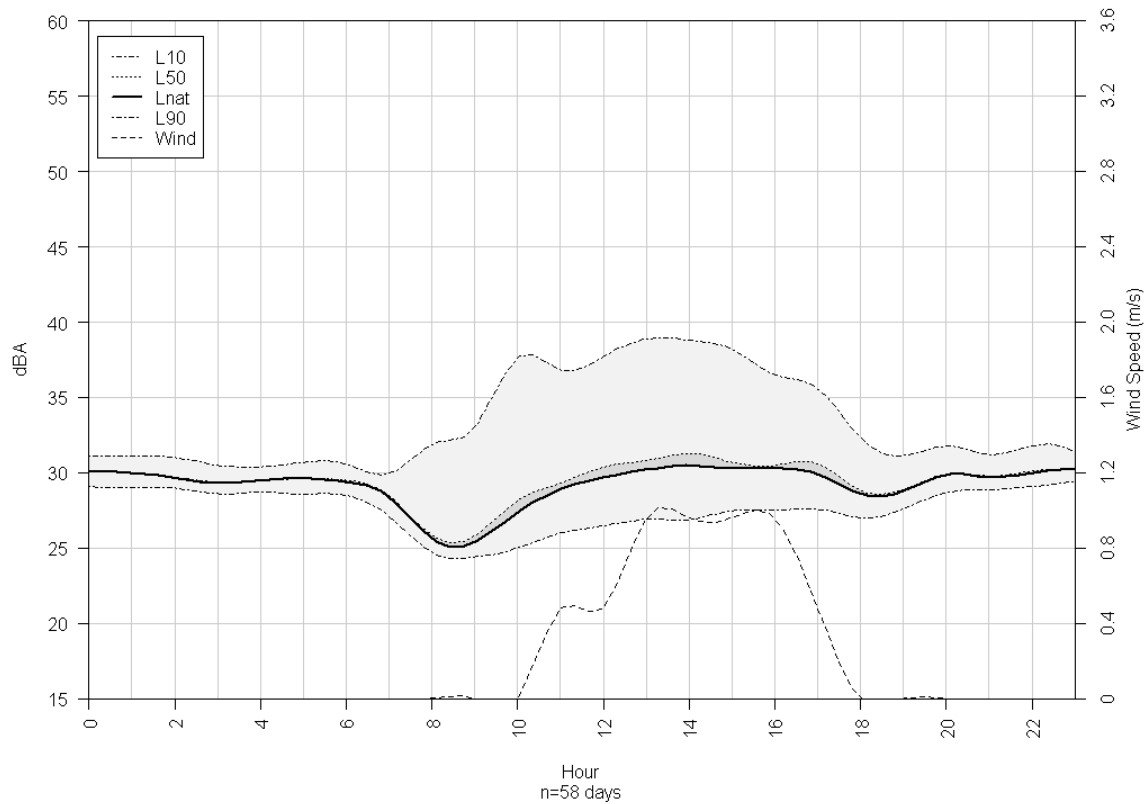


Figure 26. Exceedence values and median wind speed by hour at SEKI006 (Crabtree Meadow).

The existing ambient dBA remains relatively constant in this figure, except for the decrease in dBA between 07h00 and 09h00. This drop in dBA is probably due to diel cycles in atmospheric temperature profiles. In other words, cool air at night allows sound to propagate a certain distance. When the sun rises, the atmosphere heats up, and sound does not propagate as far. This daily variation in air temperature has a quieting effect on the existing and natural ambient sound levels before the mid day wind picks up. The L_{10} rises between the 09h00 and 18h00, which can likely be attributed to the simultaneous increase in wind speed. There is very little difference between L_{50} and L_{nat} across all hours of the day, which suggests that extrinsic sounds only slightly raised the existing ambient at SEKI006.

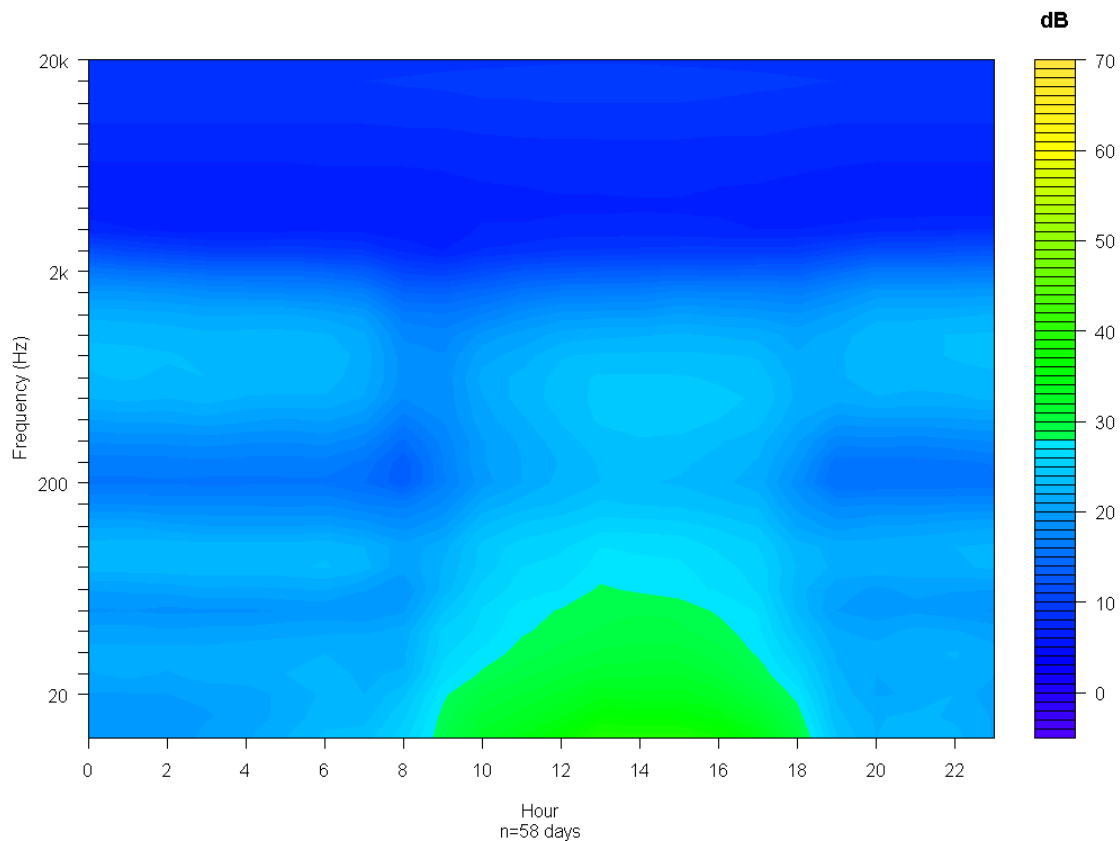


Figure 27. Flat-weighted contour plot of median existing ambient decibel and frequency levels at SEKI006 (Crabtree Meadow) as a function of time.

The most prominent feature in Figure 25 is the plume of sound energy that occurs between 09h00 and 18h00. This increase in sound pressure is directly related to an increase in wind at this location. A lighter, corresponding band appears between 200 Hz and 2000 Hz. This upper band of sound energy probably represents the sound of wind in vegetation while the lower bloom represents the movement of wind across the microphone.

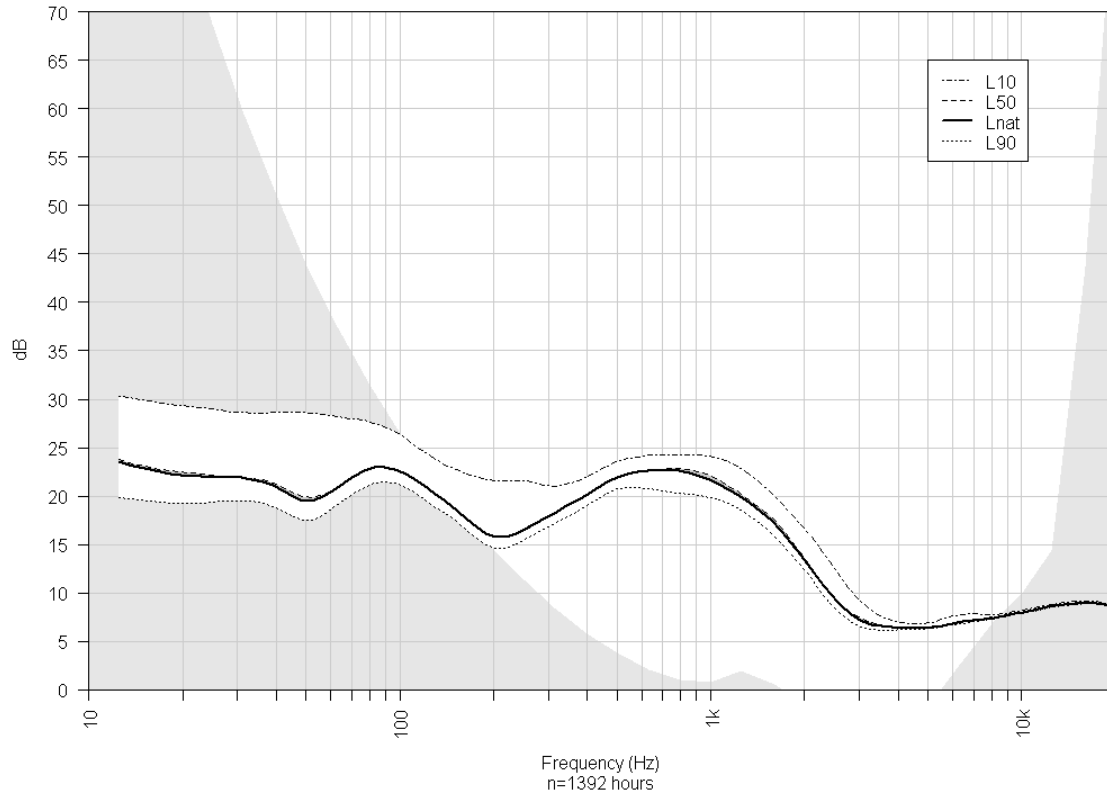


Figure 28. Human threshold of hearing and exceedence values by frequency at SEKI006 (Crabtree Meadow).

In general, Figure 26 demonstrates higher sound pressure levels in the lower and mid frequencies, and lower sound pressure levels in the higher frequencies. However, this is a relatively quiet site. There is little difference between natural and existing ambient sound pressure levels across all frequencies. Within the threshold of human hearing there is an increase in sound pressure level from 200Hz to 700Hz that could be attributed to nearby flowing water.

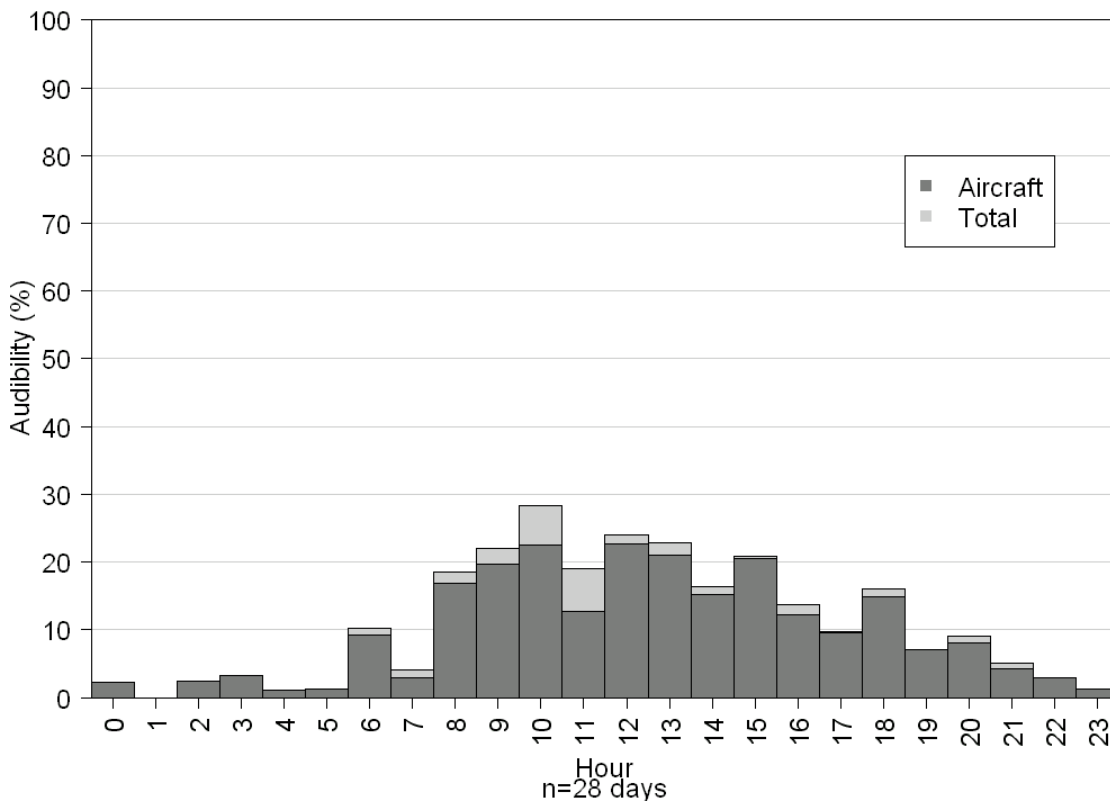


Figure 29. Audibility of extrinsic and aircraft sounds at SEKI007 (Kaweah).

Because no audio files were collected at this site, percent time audible per hour was determined by means of visual analysis for this site. Therefore, the above percentages are estimates of audibility. Aircraft were the most frequently audible extrinsic sound, but other extrinsic sounds did occur. Based on visual analysis, we can speculate that the other extrinsic sounds which contributed to the overall percent audibility of extrinsic sounds were likely vehicles. However, because no audio files exist to confirm or refute that speculation, the sounds were characterized as “human-caused, unknown.” During seven on-site listening sessions, extrinsic sources were audible 39 percent of the time while aircraft were audible 19 percent of the time. Road vehicles were heard about 20 percent of the time. As is the case with many sites in SEKI, the early morning hours contained very few extrinsic events.

SEKI007- Natural Ambient

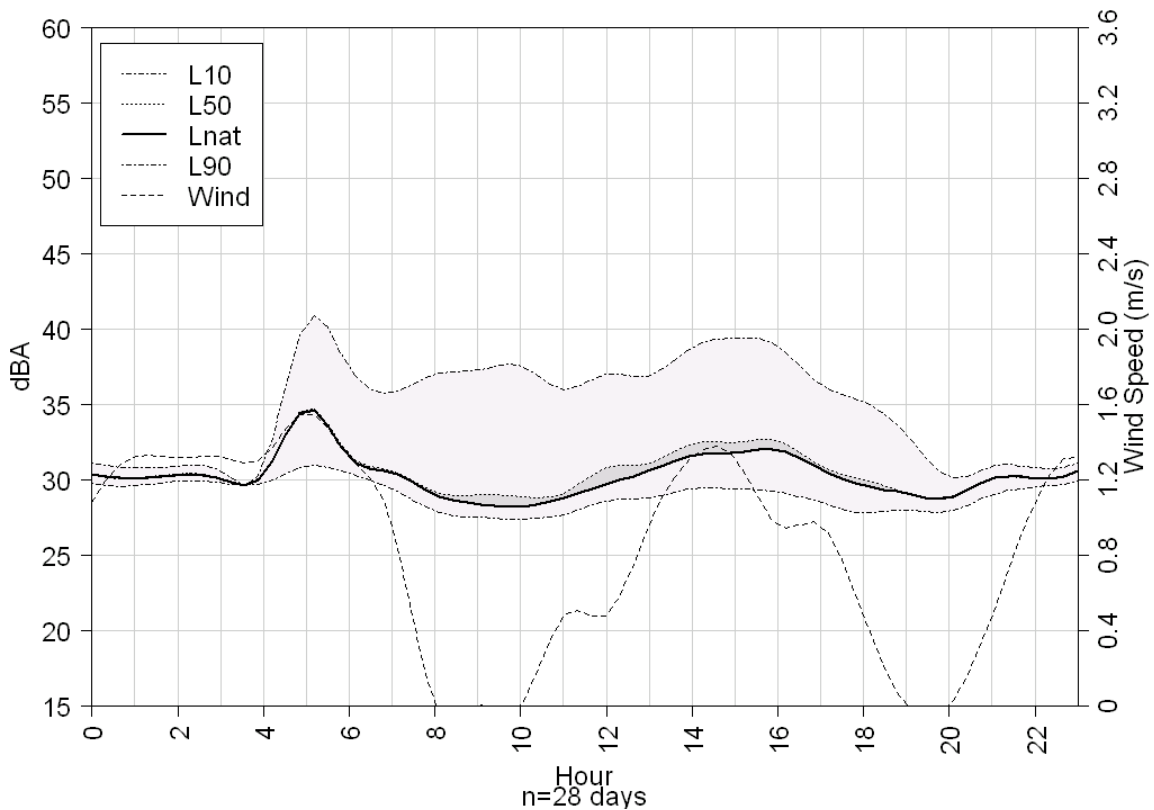


Figure 30. Exceedence values and median wind speed by hour at SEKI007(Kaweah).

The natural and existing ambient levels remain relatively stable at this site, except for in the early morning hours. Because birds were audible so often during these hours, it seems likely that this 5 dBA rise in natural and existing ambient can be attributed to the morning bird chorus. The natural and existing ambient differ from each other only slightly during the middle of the day when extrinsic activity increases.

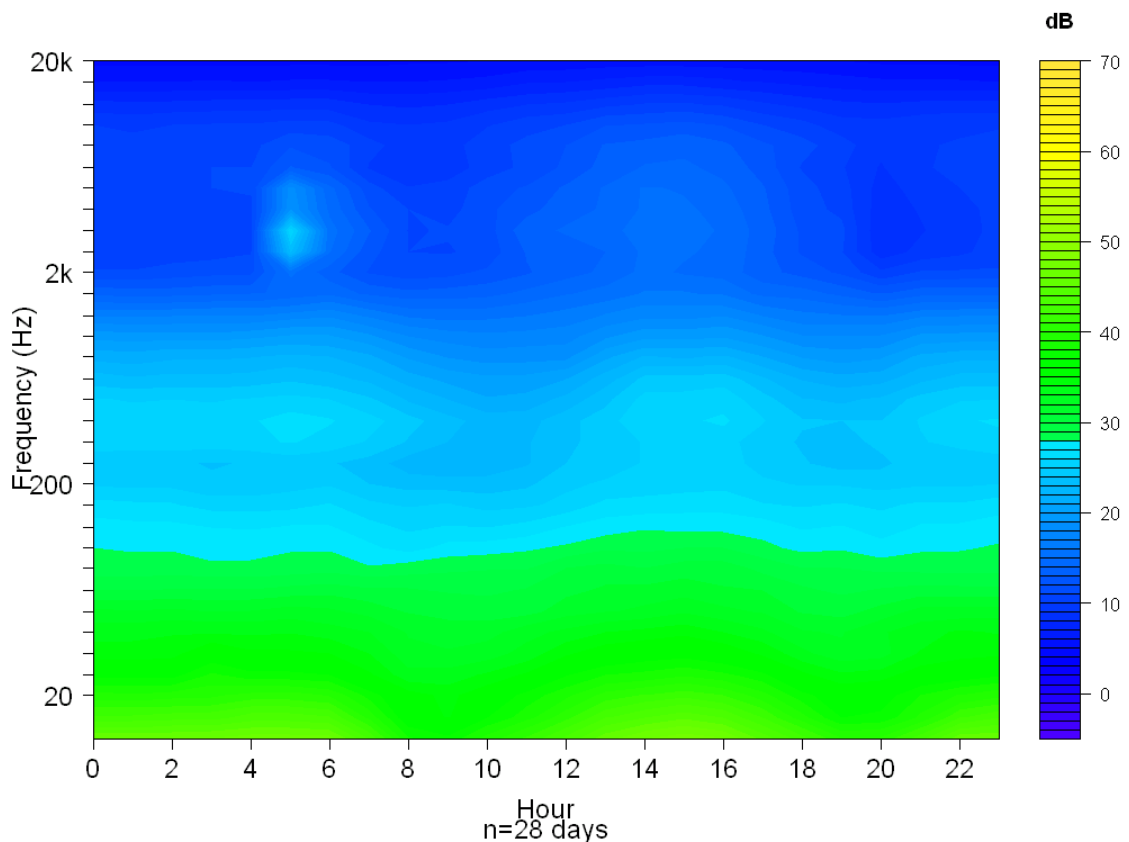


Figure 31. Flat-weighted contour plot of median existing ambient decibel and frequency levels at SEKI007 (Kaweah) as a function of time.

The morning bird chorus is plainly evident in this plot as a bright start between 2 kHz and 10 kHz at about 05h00. The rest of the contour plot is relatively quiet. The green band across all hours is probably a result of a constant background sound such as distant wind rustling the vegetation.

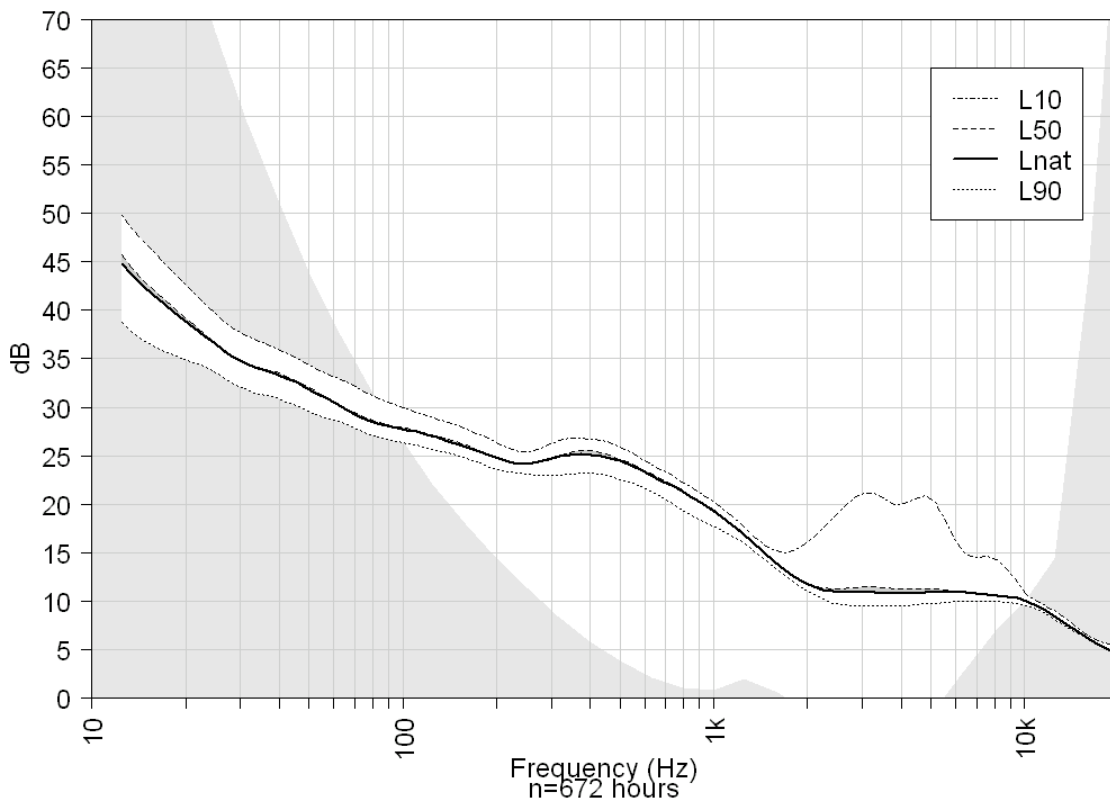


Figure 32. Human threshold of hearing and exceedence values by frequency at SEKI007 (Kaweah).

This graph confirms what the previous three have already suggested: this site is relatively quiet. Furthermore, natural ambient sound levels and existing sound levels are very similar, suggesting that extrinsic sounds have only a slight effect on the existing sound levels. The spike in L_{10} from 2 kHz to 10 kHz is probably a result of the morning bird chorus which produces sound in these frequencies.

Conclusion

Ambient Metrics

The existing ambient levels at all sites were highest during the day when both extrinsic and intrinsic sounds were most prevalent. The notable exceptions to this pattern were the Buckeye Flat winter and summer sites. The sound of the river was so loud at these sites that daytime activity had little effect on existing ambient sound levels. The ambient levels at the winter and summer Buckeye Flat sites remained consistently very high over the course of the day, hovering around 55 dBA and 50 dBA, respectively. (For comparison, conversation at 5 m is estimated to be about 60 dB). It might seem unusual that the winter site would be consistently louder than the summer site when both intrinsic and extrinsic activity are presumably greater in the summer. The likely explanation is that sound traveled further in the winter when there was less scattering due to leaves.

Although the Redwood Canyon site had the highest percent time extrinsic sounds audible (in off-site listening analysis) of all monitoring sites, it was the quietest in terms of natural and existing ambient sound levels. Situated in a densely-forested section of Redwood Canyon, this monitoring station was well-protected from wind, allowing the natural and existing ambient to remain low. The attenuating characteristics of the soft ground cover (duff) and large redwood trunks also served to quiet this site. However, because the existing ambient was so low, extrinsic sounds were audible more frequently and for longer durations.

When L_{nat} levels were analyzed by frequency, a trend emerged among sites near flowing water. In each of these plots, a bulge appeared, centered around the 1 kHz mark. This suggests that the sound of flowing water elevates the natural ambient level around 1 kHz, and may mask other sound sources (such as?) that emit sound at this frequency.

Acoustic Monitoring Zones

Strictly in terms of natural ambient levels, the acoustic monitoring zone with the lowest ambient levels in Sequoia and Kings Canyon was sequoia grove, represented by the Redwood Canyon site. The subalpine and foxtail pine zones had slightly higher natural ambient levels. Despite their differences in plant and animal species, the three sites near rivers (Buckeye Flat winter, Buckeye Flat summer, and Cedar Grove) all displayed very similar natural ambient profiles. Additional monitoring would have to be performed in order to determine if the similitude is based on proximity to flowing water, or actual acoustic similarities.

Noise Free Interval

By far, the longest mean noise free interval (NFI) recorded was 8 min. 36 sec. at the Buckeye Flat summer site. The site was close enough to the river that extrinsic sounds were masked by the natural sound of flowing water. By comparison, the shortest mean NFI was 1 min. 35 sec. It was recorded at the Kaweah site where vehicles on Generals Highway, hikers, and aircraft were audible. Although Crabtree Meadow was the most remote site in terms of location, it did not have the longest NFI or the smallest percent time extrinsic sounds audible. Aircraft were audible at Crabtree an average of 15.7% of the time in on-site listening sessions and 8.8 % of the time in off-site listening sessions.

Audibility

At each site, the mean extrinsic percent time audible generally ranged from about 5 percent to 10 percent, which is quite low. Extrinsic sounds were audible more frequently at the Redwood Canyon site (17.3%), where the natural ambient was already very low.

For all backcountry sites monitored in Sequoia and Kings Canyon, aircraft overflight noise was a pervasive and dominant sound source. Aircraft activity peaked during daylight hours, but from dusk to dawn, audibility dropped to almost zero at all backcountry sites. With the exception of sites near flowing water (such as Buckeye Flat and Cedar Grove), aircraft overflights slightly increased the average existing sound levels of backcountry sites, but they had a more dramatic effect on L₁₀ (a metric which documents the loudest average conditions). With respect to military aircraft audibility, about 8 percent of the 15.6 percent total aircraft audibility was attributed to military jets during 21 on-site listening sessions at Crabtree Meadow.

Chronically-elevated sound levels due to aircraft noise mean that visitors and wildlife experience smaller effective listening areas than they would experience under natural conditions. The full effects of this chronic loss of listening opportunity on wildlife are not known, but two presumed consequences are increased search times and increased anti-predator vigilance. Loss of listening opportunity also has the potential to endanger park visitors: avalanches, flash floods, and landslides will all have acoustic signatures similar to distant jets.

Future Monitoring and Adaptive Management

Monitoring existing conditions and trends allows managers to take action to move towards desired future conditions. The acoustic data in this report provide the necessary information for the application of acoustical indicators and standards, or the development of an Air Tour Management Plan. Additional guidance for planning efforts can be provided by the NSP office. The Natural Sounds Program intends to evaluate both on-site and off-site audibility and natural ambient data on a regional scale when acoustic analysis is complete for all Sierra Network parks.

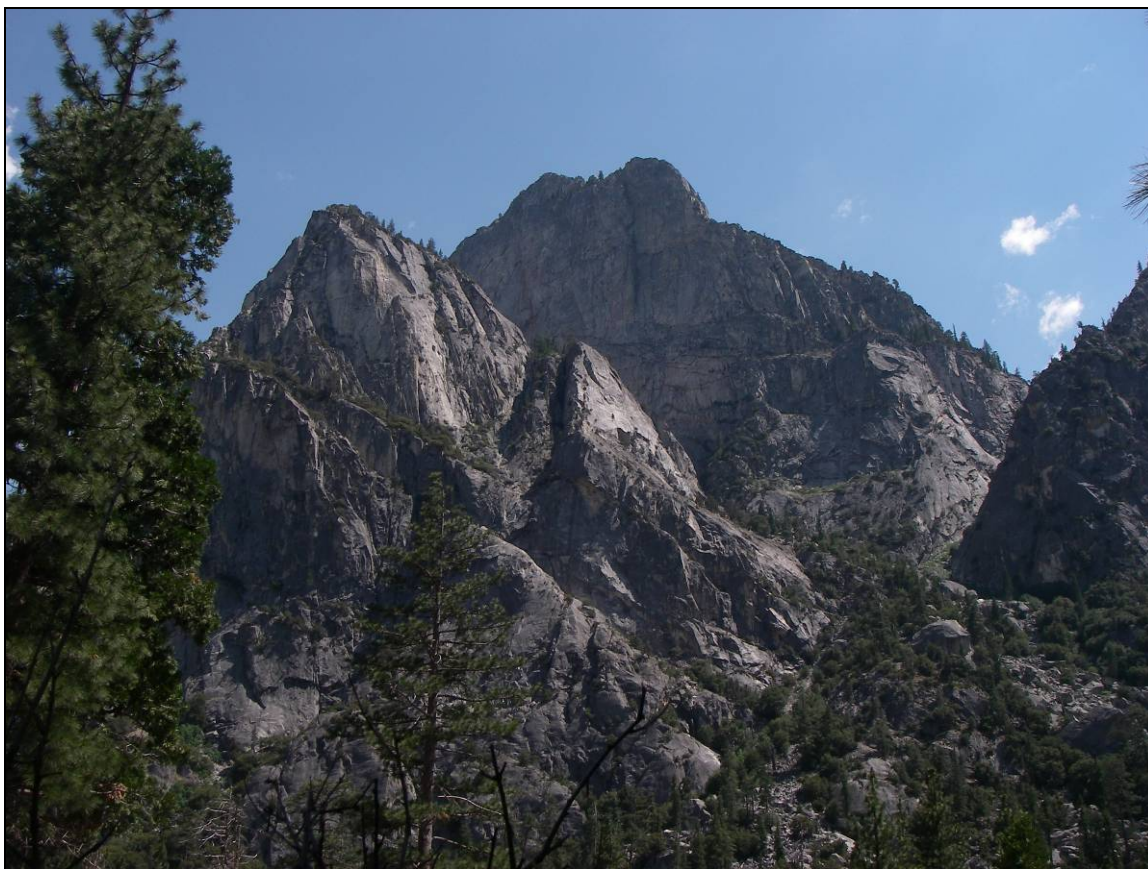
One of the most valuable features of this report is that it includes data from the same site during different seasons and different years. Two sites were erected at Buckeye Flat, one in the winter of 2005 and one in the summer of 2006. The winter site was consistently 5 dB louder than the summer site over the 30 day monitoring period, and aircraft were audible twice as often. If additional monitoring is conducted, it would be interesting to re-deploy an acoustic monitor at Buckeye Flat as well as at the location of SEKI002 (where data were not collected due to equipment failure).

Sequoia and Kings Canyon National Parks recently launched a shuttle system which offers visitors an alternative way to view some of the most popular features of the parks. Currently, there are buses servicing the Giant Forest area as well as the Moro Rock and Crescent Meadow areas. Of all monitoring sites, the Kaweah site was the most affected by vehicle noise. In fact, during seven on-site logging sessions, road vehicles were audible 20.6 percent of the time. The site with the next highest percent time audible for road vehicles was Cedar Grove with 7.1 percent during ten on-site listening sessions. Now that pre-shuttle data exists, it would be very interesting to monitor the acoustic conditions in these high-use areas again, to see how the introduction of a shuttle system affects the acoustic environment in these parks.

Acoustic monitoring efforts in Sequoia and Kings Canyon National Parks yielded valuable results that allow park managers to better understand the existing acoustic environment of the park. For instance, in addition to the percent time audible metrics, off-site analysis of acoustic (.wav) samples unearthed a number of interesting wildlife and natural sound recordings. In the process of listening to eight randomly-selected days for each site, NSP staff located recordings of spotted owls (Redwood Canyon), barn owls (Buckeye Flat summer), thunderstorms (Cedar Grove), and coyotes (Crabtree Meadow). In addition, NSP staff was surprised to hear a chainsaw in operation near Crabtree meadow.

Presumably, if continuous recordings had been collected instead of ten second samples every two minutes, or if a larger subset of samples had been analyzed, these unique sounds might have been discovered more frequently. Biological monitoring with the use of continuous recording acoustic equipment offers many opportunities to extend surveys to places and intervals when it is inconvenient or impossible for observers to be present. Acoustic monitoring and data storage technology is constantly evolving, and it is not unreasonable to expect that future monitoring efforts at Sequoia and Kings Canyon National Parks will incorporate continuous recording units in addition to sound level meters.

Acknowledgements



The NSP wishes to recognize the following individuals for their contributions to this report. Annie Esperanza, Heather Dumais, and Chris Miles assisted with site selection, site deployment, site maintenance, and data collection. Special thanks to Rob Pilewski, who monitored the station at Crabtree Meadow Ranger Station. Thanks also to Skip Ambrose for technical recommendations, Dave Schirokauer for field support and planning, and Ric Hupalo for both field support and technical assistance.

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Appendix I: Glossary of Acoustic Terms

Acoustic Environment

The composite of all sounds, regardless of audibility, at a particular location.

Acoustic Resources

Sound sources (wildlife, waterfalls, wind, precipitation, historic and cultural sounds), factors that modify sound transmission (vegetation, topography, and atmospheric conditions), and the soundscape perceived by park visitors.

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

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

Diel

A 24-hour period usually consisting of a day and the adjoining night.

Extrinsic Sound

Any sound not forming an essential part of the park unit, 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

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.

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.

On-site Listening

The systematic identification of sound sources at a specific monitoring site using a personal digital assistant (PDA). Custom PDA software records begin and end times of audible sound sources. These sessions often last for one hour.

Sound

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

Soundscape

The acoustic environment at a specific locale, as perceived by park visitors.

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.

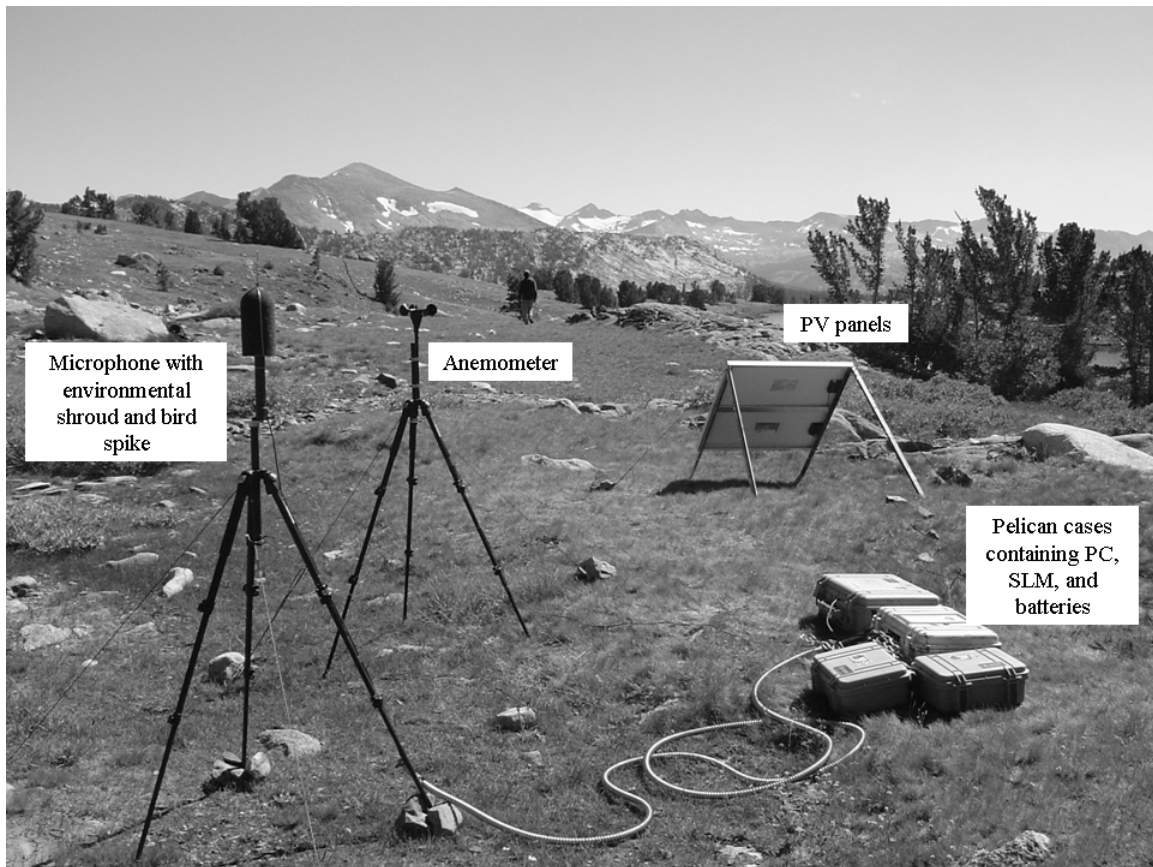
Time Audible

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

Appendix II: Recording equipment specs

Larson-Davis (All SEKI sites)

1. Panasonic Toughbook CF-18 computer.
2. Sound level meter. Larson Davis 824, ANSI/IEC type 1.
3. Microphone. GRAS 40 AE, GRAS 40AQ, PCB 377B02, or LD 2560 with preamp.
4. Power source. Three 12 V gel cell sealed lead acid batteries with Xantrex C-12 charge controller.
5. Photovoltaic panels. Two Kyocera model # LA321K455.
6. Weather data logger. Onset Computer Corporation Hobo micro logger with USB serial adapter. Onset Anemometer part # S-WSA-M003.
7. Weather-proof containers (Pelican cases) for batteries, LD, and computer.
8. Performance-verified calibrator. A calibrator by Bruel & Kjaer which meets accuracy requirements for Class 1 ANSI S1.4-1984, IEC 942-1988 and ISO 9001: 2000 sound calibrators. Calibrator is assessed and approved once a year.
9. Tripods (2)



An example of a Larson-Davis site setup.

Appendix III: Natural Sounds Program Sound Code List

Code	version: 2006-01-13				
0	No Sound Audible	0 No Sound Audible			
41	Artifacts	41 Artifact 41.1 Wind distortion 41.2 Static interference- quiet 41.3 Static interference- loud 41.4 Precipitation 41.5 Field Personnel			
99	Unknown	(Cannot determine if Non-Natural or Natural)			
Code	Non-Natural Sounds Codes (1-20)		Code	Natural Sounds Codes (21-40)	
1	Aircraft	1 Aircraft 1.1 Jet 1.11 Jet, Air Tour 1.12 Jet, Commercial 1.13 Jet, G/A 1.14 Jet, Military 1.2 Prop 1.21 Prop, Air Tour 1.22 Prop, Commercial 1.23 Prop, G/A 1.24 Prop, Military 1.25 Prop, Ultralight 1.3 Helicopter 1.31 Helicopter, Air Tour 1.32 Helicopter, Commercial 1.33 Helicopter, G/A 1.34 Helicopter, Military	21	Wind	21 Wind 21.1 Wind, Light (not mask most other sounds) 21.2 Wind, Strong (masks most other sounds)
2	Vehicles	2 Vehicle 2.1 Automobile (car, van, light truck) 2.2 Motorcycle 2.3 Bus (vehicle with capacity > 9 people) 2.4 Truck (6+ tires) 2.41 Truck Medium (2 ax 6 tire, 10K-26K lbs) 2.42 Truck Heavy (3+ ax 6+ tire, >26K lbs) 2.5 Heavy Equipment 2.6 Rotary Snow Plow 2.7 Other Snow Plow 2.8 RV 2.81 RV < 20 ft 2.82 RV >20 ft 2.9 ATV 2.11 Farm Equipment 2.12 Alarm, Horn 2.13 Door 2.14 Brakes 2.15 Rumble Strip	22	Water	22 Water 22.1 Rain, Fog Drip 22.2 Flowing Water 22.21 Flowing Water, Rapids 22.22 Flowing Water, Riffles 22.3 Snowfall 22.4 Waterfall 22.5 Waves (natural)
3	Watercraft	3 Watercraft 3.1 Outboard 3.11 Outboard 2-stroke 3.12 Outboard 4-stroke 3.13 Outboard Jet Drive 3.2 Inboard 3.21 Inboard 2-stroke 3.22 Inboard 4-stroke 3.23 Inboard Jet Drive 3.3 Jet Ski (PWC) 3.31 Jet Ski 2-stroke 3.32 Jet Ski 4-stroke 3.4 Pontoon Boat/Houseboat 3.41 Pontoon Boat/Houseboat 2-stroke 3.42 Pontoon Boat/Houseboat 4-stroke 3.5 Motorized Raft 3.51 Motorized Raft 2-stroke 3.52 Motorized Raft 4-stroke 3.6 Non-motorized Craft 3.7 Sail Boat 3.8 Boat Wake (on shore) 3.9 Air Boat	23	Thunder	23 Thunder
4	Over-snow Vehicles	4 Oversnow 4.1 Snowmobile 4.11 Snowmobile 2-stroke 4.12 Snowmobile 4-stroke 4.2 Snowcoach 4.3 Snowmobile or Snowcoach 4.4 Snow Groomer 4.5 Snowplane	24	Mammals	24 Mammal 24.1 Squirrel 24.2 Chipmunk 24.3 Coyote 24.4 Wolf 24.5 Elk (pending further revision)
5	Trains	5 Train 5.1 Train Rumble 5.2 Train Whistle	25	Birds	25 Bird 25.1 Raven 25.2 Canada Goose 25.3 Duck 25.4 Gray Jay 25.5 Magpie 25.6 Chickadee (pending further revision)
6	Motors	6 Motor 6.1 Generator 6.2 Pump 6.3 Ice Auger	26	Reptiles	26 Reptile
7	Grounds Care	7 Grounds Care 7.1 Lawnmower 7.2 Leaf Blower 7.3 Sprinkler 7.4 Dumpster / Trashcan	27	Amphibians	27 Amphibian
8	People	8 People 8.1 Voices 8.2 Walking 8.3 Skiing 8.4 Portable Audio Devices 8.5 Gunshot 8.6 Using Boardwalk 8.7 Bicycling 8.8 Segway	28	Insects	28 Insect
9	Domestic animals	9 Domestic animal 9.1 Dog 9.2 Cow 9.3 Horse	29	Animals	29 Animal (Unknown non-human sound from any species in the animal kingdom)
10	Buildings	10 Building Sounds 10.1 Utilities (HVAC, Alarm, etc.) 10.2 Door	30	Geothermal / Mass Movement	30 Geothermal / Mass Movement 30.1 Aval, Rockslide 30.2 Geyser/thermal Activity
11	Construction	11 Construction			
19	Non-natural Other	19 Non-natural Other 19.1 Wind-induced Non-natural	39	Natural Other	39 Natural Other 39.1 Wind-induced Natural
20	Non-natural Unknown	20 Non-natural Unknown	40	Natural Unknown	40 Natural Unknown

Appendix IV: On-site Listening Reports

On-Site Listening Results for SEKI001: Buckeye Flat Winter. n=9 sessions.

Sound Source	% Time Audible	Max event length*	Mean event length*	Min event length*	SD event*	Count
Flowing Water	100	59:59	48:59	19:27	15:50	11
Bird	43	09:13	00:13	00:00	00:34	1086
Jet	18	07:06	01:55	00:04	01:39	52
Insect	16	07:10	00:08	00:00	00:32	667
Wind, Light	14	59:54	01:32	00:00	08:21	51
Natural Other	7	02:18	00:05	00:00	00:12	508
Aircraft	3	04:39	01:17	00:01	01:26	11
Aircraft, Propeller	1	03:02	01:29	00:05	01:18	4
Non-natural Unknown	1	01:22	00:32	00:00	00:32	11
Wind	1	00:42	00:09	00:01	00:09	29
Raven	1	00:46	00:08	00:01	00:10	35
Vehicle	0	01:22	00:24	00:01	00:34	5
Heavy Equipment	0	00:10	00:10	00:10	00:00	1
Rain/Fog Drip	0	00:02	00:01	00:01	00:00	8
Thunder	0	00:03	00:01	00:01	00:01	9
Mammal	0	00:02	00:02	00:02	00:00	1
Squirrel	0	00:01	00:01	00:01	00:00	1
People	0	00:03	00:02	00:01	00:01	5
All Aircraft	22.2					
All Road Vehicles	0.4					
All Non-natural Sources	23.5					
All Natural Sources	99.9					
Noise Free Interval		24:47	04:48	00:01	06:29	01:26

**Sound events reported as minutes: seconds.*

On-Site Listening Results for SEKI003: Cedar Grove. n=10 sessions.

Sound Source	% Time Audible	Max event length*	Mean event length*	Min event length*	SD event*	Count
Bird	63	30:00	02:06	00:01	06:21	179
Water	50	30:00	42:48	05:43	23:20	7
Flowing Water	50	29:57	42:47	06:13	24:40	7
Insect	43	29:57	01:33	00:00	05:30	169
Wind	17	28:37	01:54	00:09	02:09	53
Vehicle	7	03:42	00:18	00:00	00:16	133
Mammal	7	24:13	01:06	00:00	02:09	37
Jet	4	06:35	01:09	00:21	00:39	19
Helicopter	1	04:23	01:40	01:34	00:08	2
Aircraft	0	04:32	01:49	01:49	00:00	1
Aircraft, Propeller	0	01:10	00:28	00:28	00:00	1
Vehicle Door	0	00:08	00:03	00:03	00:00	1
Motorcycle	0	02:05	00:36	00:17	00:14	4
Non-natural Unknown	0	00:28	00:11	00:11	00:00	1
Reptile	0	00:10	00:03	00:02	00:01	3
Natural Unknown	0	00:17	00:03	00:00	00:02	25
All Aircraft	4.6					
All Road Vehicles	7.1					
All Non-natural Sources	11.6					
All Natural Sources	99.9					
Noise Free Interval		58:17	03:14	00:02	03:56	164

**Sound events reported as minutes: seconds.*

On-Site Listening Results for SEKI004: Redwood Canyon. n=7 sessions.

Sound Source	% Time Audible	Max event length*	Mean event length*	Min event length*	SD event*	Count
Bird	99	1:00:00**	20:52	00:04	25:05	20
Insect	37	57:08	00:51	00:01	04:24	185
Wind	14	04:41	00:59	00:02	00:57	61
Jet	12	03:41	02:06	00:16	00:52	24
Helicopter	6	07:25	03:26	00:39	02:44	7
Vehicle	6	01:44	00:27	00:03	00:22	57
Thunder	5	01:27	00:12	00:01	00:13	105
Aircraft, Propeller	2	02:57	01:27	00:21	01:00	5
Rain/Fog Drip	2	05:55	01:39	00:02	02:30	5
Alarm, Horn	1	01:53	01:18	00:43	00:49	2
Aircraft	0	01:13	01:13	01:13	00:00	1
Non-natural Unknown	0	00:07	00:03	00:01	00:03	3
Mammal	0	00:26	00:09	00:02	00:08	8
Squirrel	0	00:18	00:12	00:07	00:08	2
Chipmunk	0	00:07	00:07	00:07	00:00	1
Natural Other	0	00:01	00:01	00:00	00:01	4
Natural Unknown	0	00:16	00:03	00:01	00:03	36
People, Voices	0	00:11	00:08	00:04	00:03	5
All Aircraft	19.59					
All Road Vehicles	6.75					
All Non-natural Sources	26.14					
All Natural Sources	99.79					
Noise Free Interval		11:20	03:06	00:01	03:04	100

**Sound events reported as minutes: seconds.*

***Sound events reported as hours: minutes: seconds.*

On-Site Listening Results for SEKI005: Buckeye Flat Summer. n=8 sessions.

Sound Source	% Time Audible	Max event length*	Mean event length*	Min event length*	SD event*	Count
Insect	82	59:54	04:32	00:00	08:12	87
Bird	66	42:17	03:25	00:01	07:45	93
Water	50	1:00:00**	59:59	59:58	00:01	4
Flowing Water	50	1:00:00**	59:58	59:57	00:01	4
Wind	11	06:18	01:00	00:03	01:04	55
Jet	7	03:50	01:30	00:22	00:55	23
Amphibian	3	02:05	00:47	00:09	00:30	16
Jet, Military	2	07:49	07:49	07:49	00:00	1
Aircraft, Propeller	1	02:25	01:12	00:26	01:04	3
Vehicle	1	00:31	00:12	00:04	00:08	13
Thunder	1	00:36	00:17	00:02	00:11	24
Aircraft	0	01:14	01:14	01:14	00:00	1
Non-natural Unknown	0	00:07	00:07	00:07	00:00	1
Mammal	0	00:04	00:04	00:04	00:00	1
Reptile	0	00:05	00:03	00:00	00:02	5
Natural Unknown	0	00:08	00:02	00:00	00:02	23
People, Voices	0	00:26	00:16	00:05	00:15	2
All Aircraft	9.74					
All Road Vehicles	0.53					
All Non-natural Sources	10.41					
All Natural Sources	99.95					
Noise Free Interval		25:26	08:36	00:01	07:39	50

**Sound events reported as minutes: seconds.*

***Sound events reported as hours: minutes: seconds.*

On-Site Listening Results for SEKI006: Crabtree Meadow. n=21 sessions.

<i>Sound Source</i>	<i>% Time Audible</i>	<i>Max event length*</i>	<i>Mean event length*</i>	<i>Min event length*</i>	<i>SD event*</i>	<i>Count</i>
Bird	66	00:00	01:14	00:00	04:57	674
Water	46	59:59	08:08	00:03	15:57	72
Wind	38	00:00	02:37	00:00	08:10	183
Flowing Water	26	59:58	11:21	00:09	18:14	29
Insect	11	11:37	00:13	00:00	00:38	647
Jet, Military	8	07:13	02:06	00:17	01:17	50
Jet	6	04:51	01:28	00:03	01:08	50
Aircraft	1	03:18	01:08	00:09	01:03	11
People, Voices	1	00:54	00:08	00:01	00:09	52
Jet, Commercial	0	01:36	01:36	01:36	00:00	1
Aircraft, Propeller	0	02:16	01:34	00:17	01:07	3
Wind-induced Non-natural	0	00:00	00:00	00:00	00:00	1
Non-natural Unknown	0	00:06	00:03	00:01	00:02	16
Rain/Fog Drip	0	00:05	00:02	00:00	00:03	3
Mammal	0	00:27	00:06	00:01	00:07	23
Chipmunk	0	00:06	00:04	00:03	00:01	7
Animal (Natural)	0	00:04	00:04	00:04	00:00	1
Avalanche / Rockslide	0	00:05	00:05	00:05	00:00	1
Natural Other	0	01:20	00:12	00:02	00:18	17
Natural Unknown	0	00:11	00:03	00:01	00:04	5
People	0	00:54	00:09	00:01	00:11	31
All Aircraft	15.66					
All Non-natural Sources	16.57					
All Natural Sources	99.32					
Noise Free Interval		37:33	04:51	00:01	07:22	217

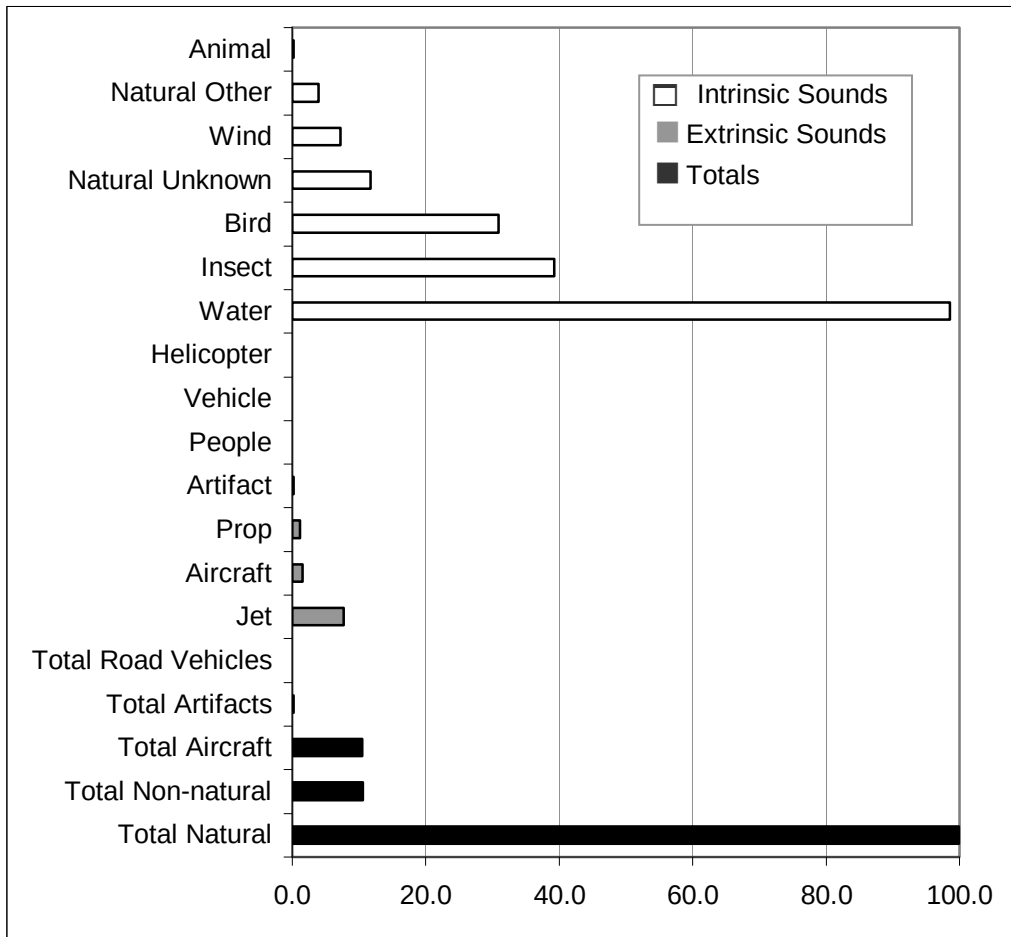
**Sound events reported as minutes: seconds.*

On-Site Listening Results for SEKI007: Kaweah. n=7 sessions.

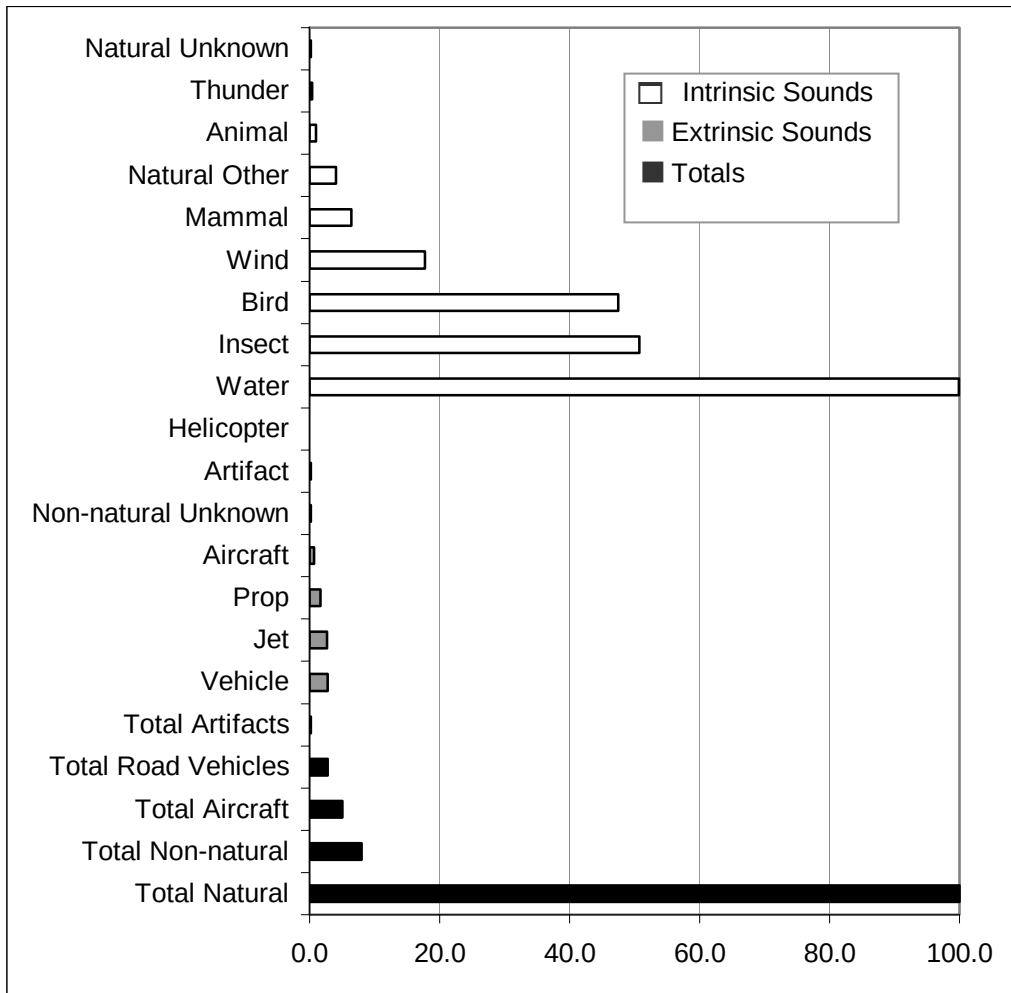
Sound Source	% Time Audible	Max event length*	Mean event length*	Min event length*	SD event*	Count
Bird	96	00:00	13:26	00:00	20:06	30
Wind	30	13:40	02:00	00:04	02:17	63
Insect	25	07:01	00:32	00:00	00:57	195
Vehicle	18	03:24	00:40	00:01	00:38	113
Jet	15	04:28	02:05	00:10	01:04	30
Aircraft, Propeller	3	03:18	02:21	01:16	00:56	5
Motorcycle	2	01:14	00:28	00:05	00:23	16
Helicopter	1	03:41	01:53	00:25	01:39	3
Alarm, Horn	1	01:24	00:21	00:01	00:28	10
Rain/Fog Drip	1	03:58	03:58	03:58	00:00	1
Natural Unknown	1	00:44	00:06	00:01	00:09	22
Non-natural Unknown	0	00:09	00:02	00:00	00:03	10
Thunder	0	00:06	00:06	00:06	00:00	1
Mammal	0	00:10	00:06	00:02	00:06	2
Squirrel	0	00:06	00:06	00:06	00:00	1
Chipmunk	0	00:03	00:02	00:02	00:01	2
Reptile	0	00:08	00:03	00:01	00:02	7
Natural Other	0	00:04	00:03	00:02	00:01	3
People, Voices	0	00:03	00:02	00:02	00:01	2
All Aircraft	18.96					
All Road Vehicles	20.59					
All Non-natural Sources	39.03					
All Natural Sources	99.88					
Noise Free Interval		16:37	01:35	00:01	02:07	161

**Sound events reported as minutes: seconds.*

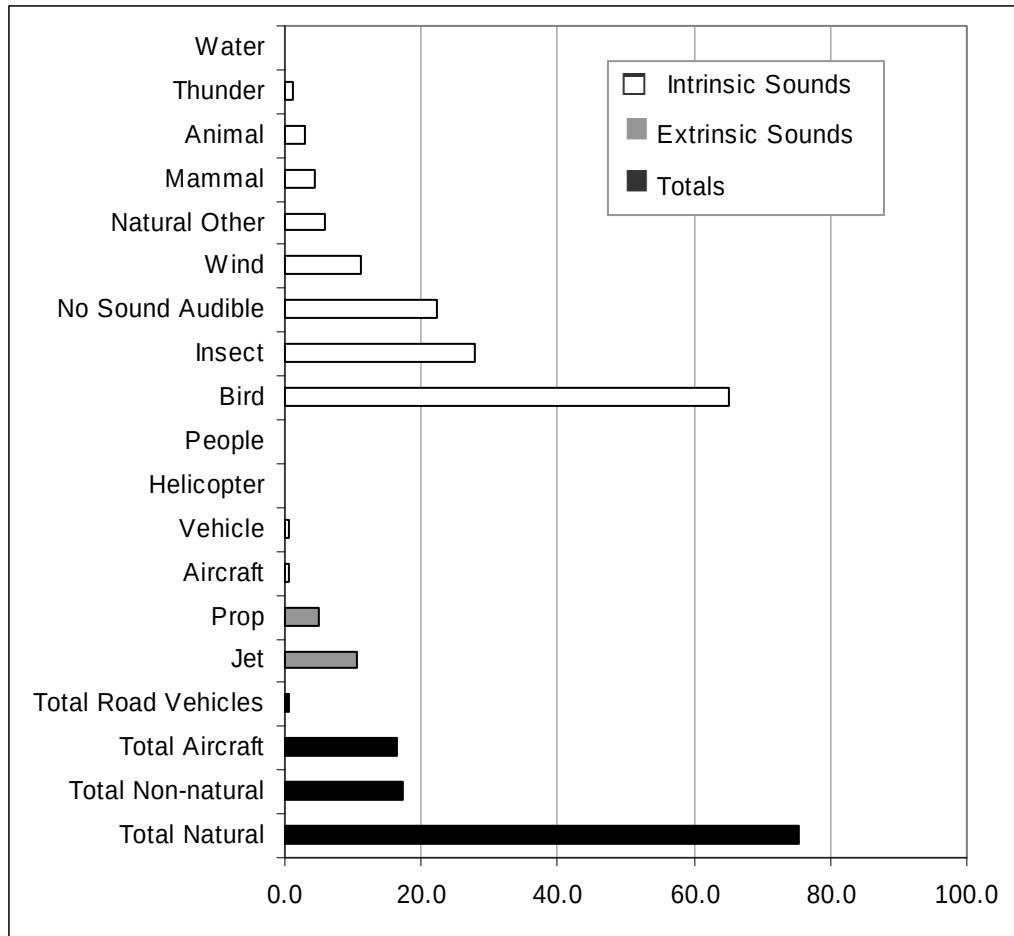
Appendix V: Off-site Listening Reports



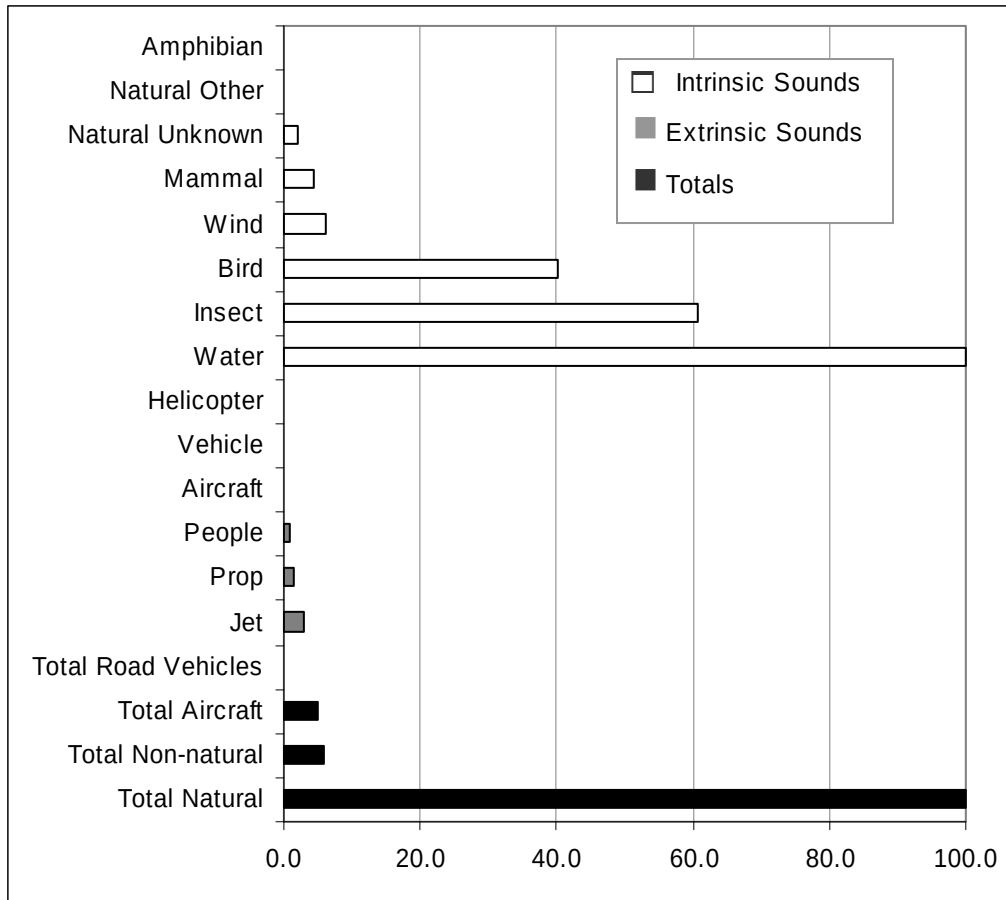
Percent time sound present during sampling period at SEKI001 (Buckeye Flat 2005).



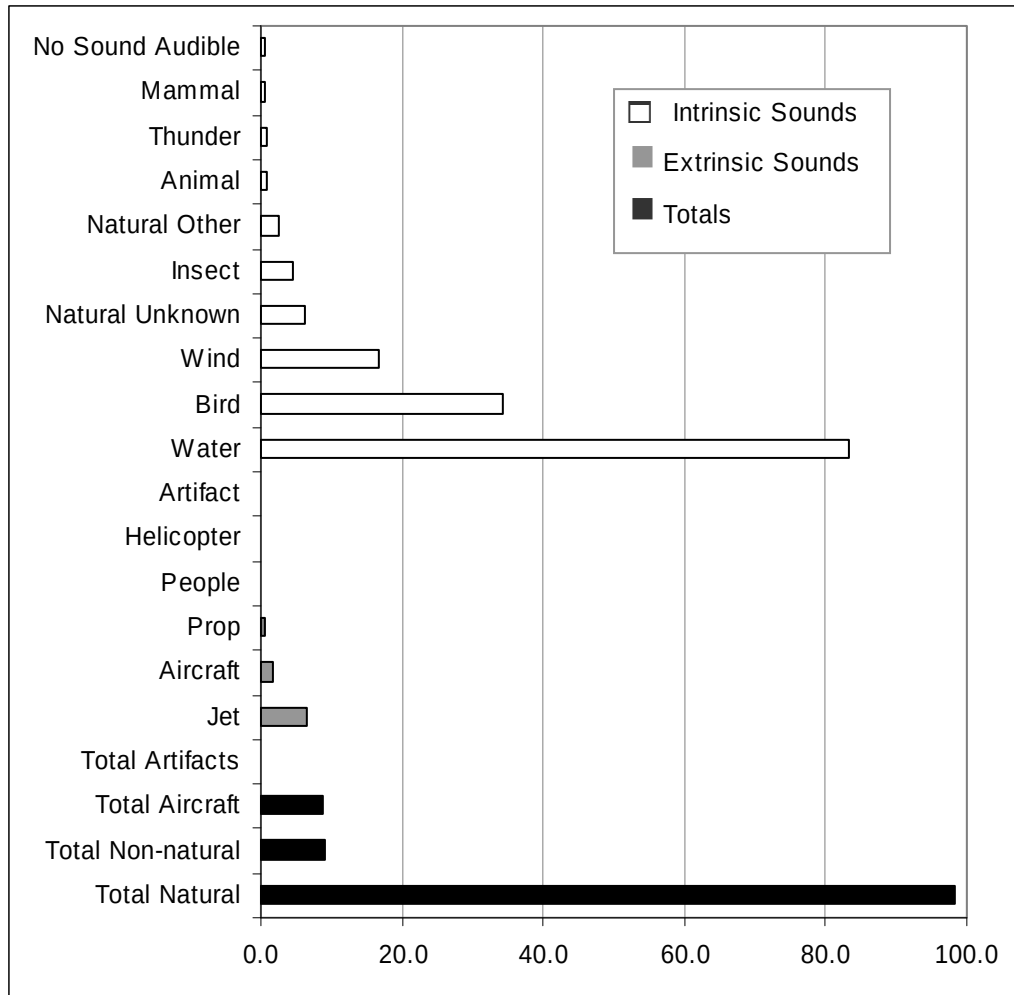
Percent time sound present during sampling period at SEKI003 (Cedar Grove).



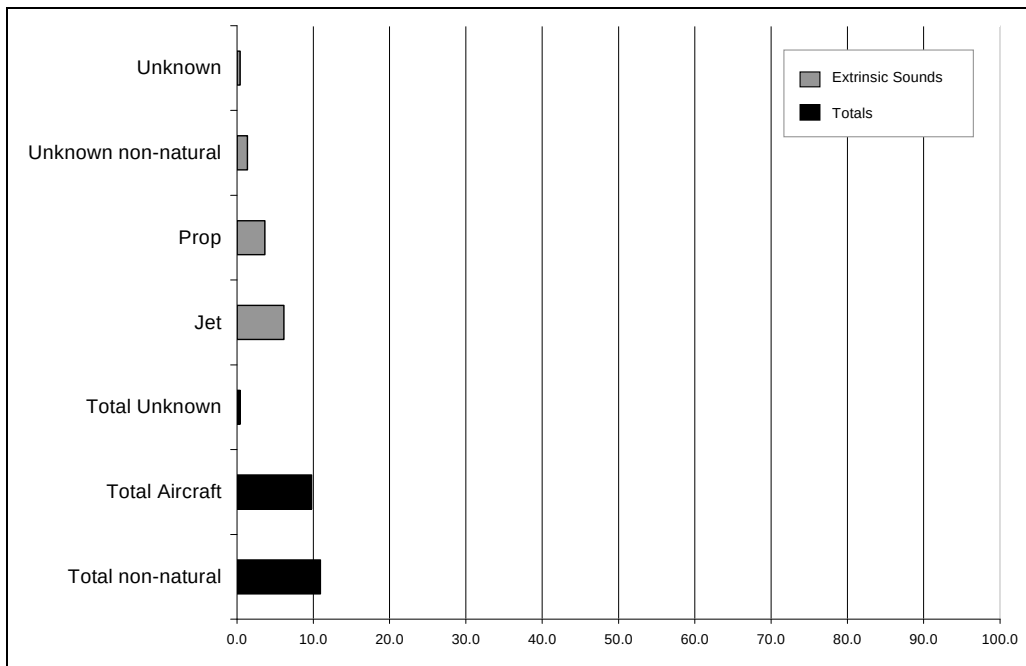
Percent time sound present during sampling period at SEKI004 (Redwood Canyon).



Percent time sound present during sampling period at SEKI005 (Buckeye Flat 2006).

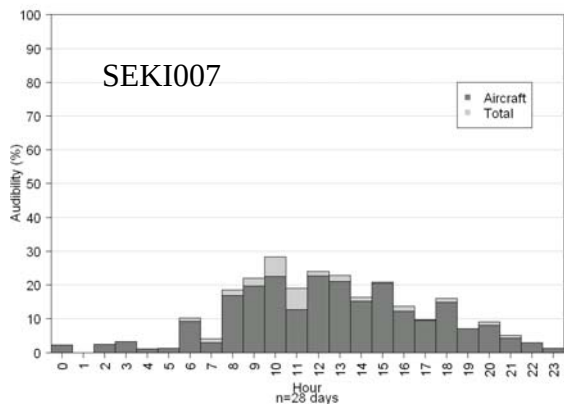
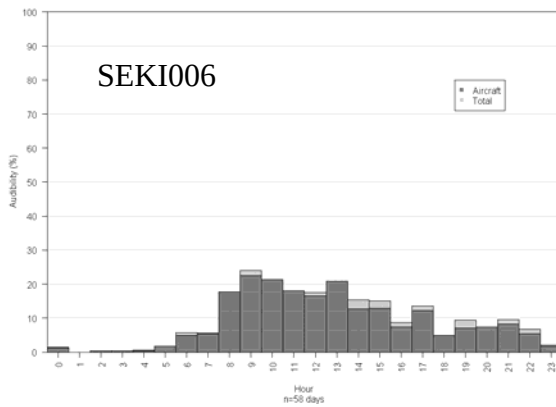
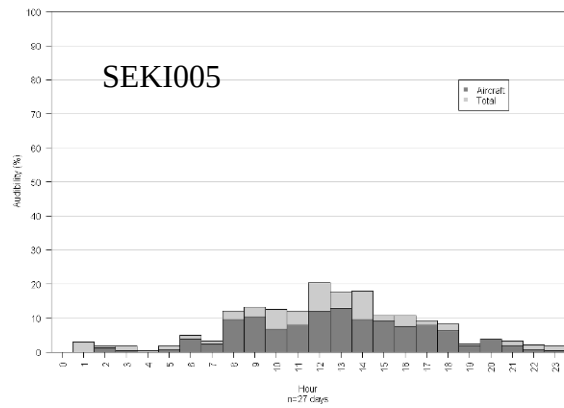
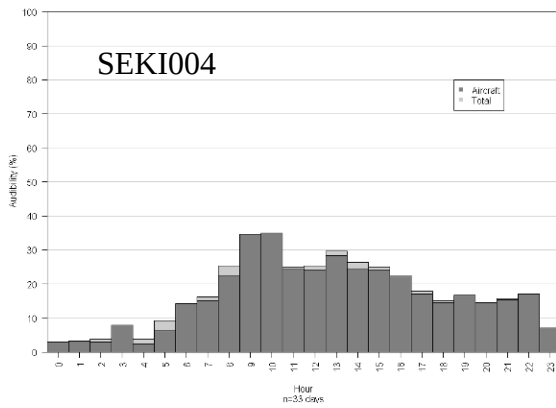
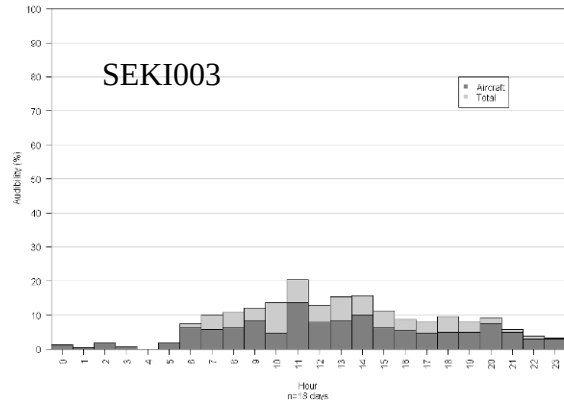
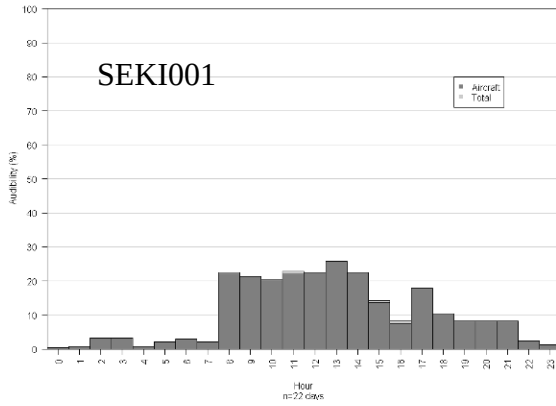


Percent time sound present during sampling period at SEKI006 (Crabtree Meadow).

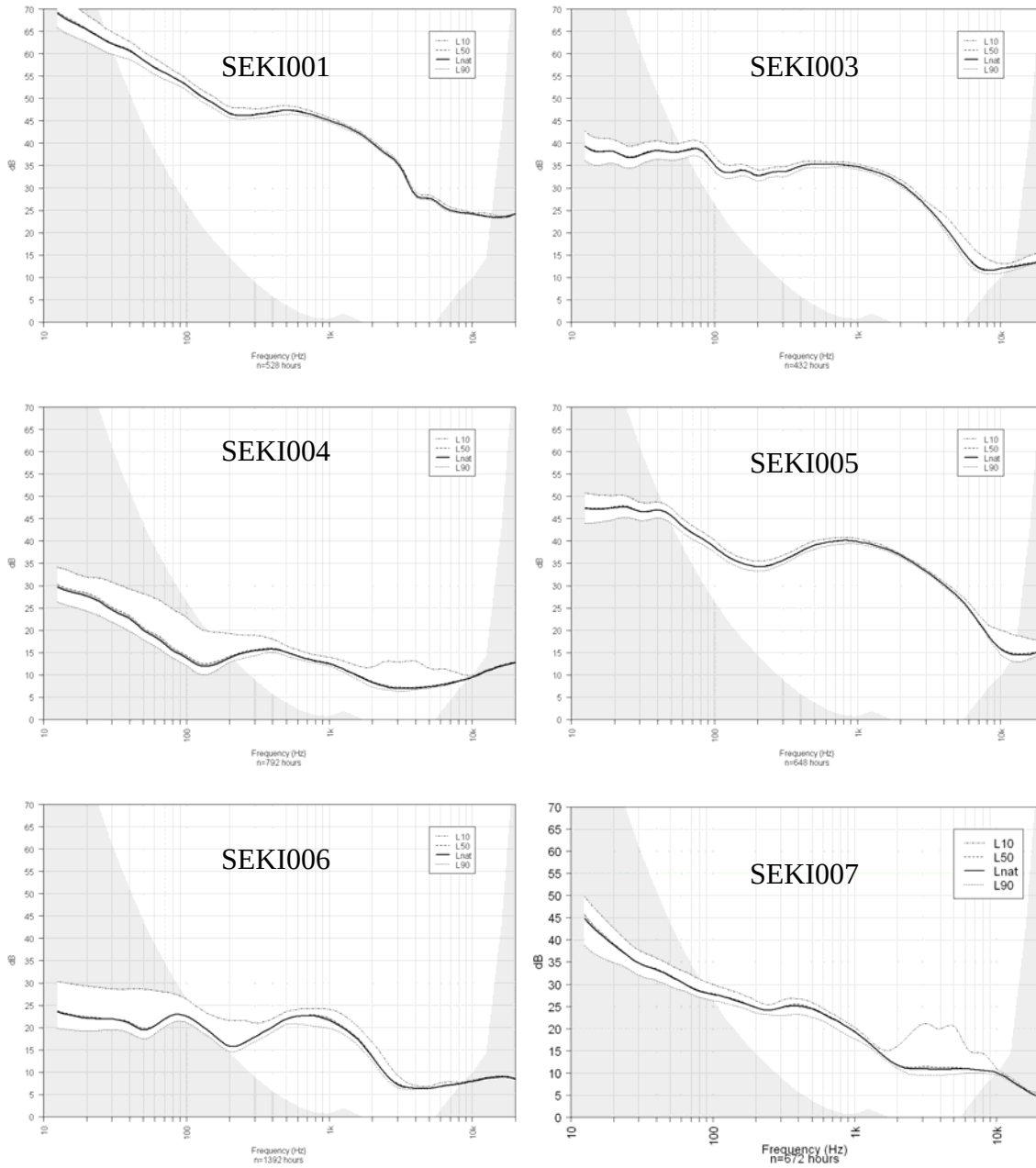


Percent time sound present during visual analysis of sampling period at SEKI007 (Kaweah).

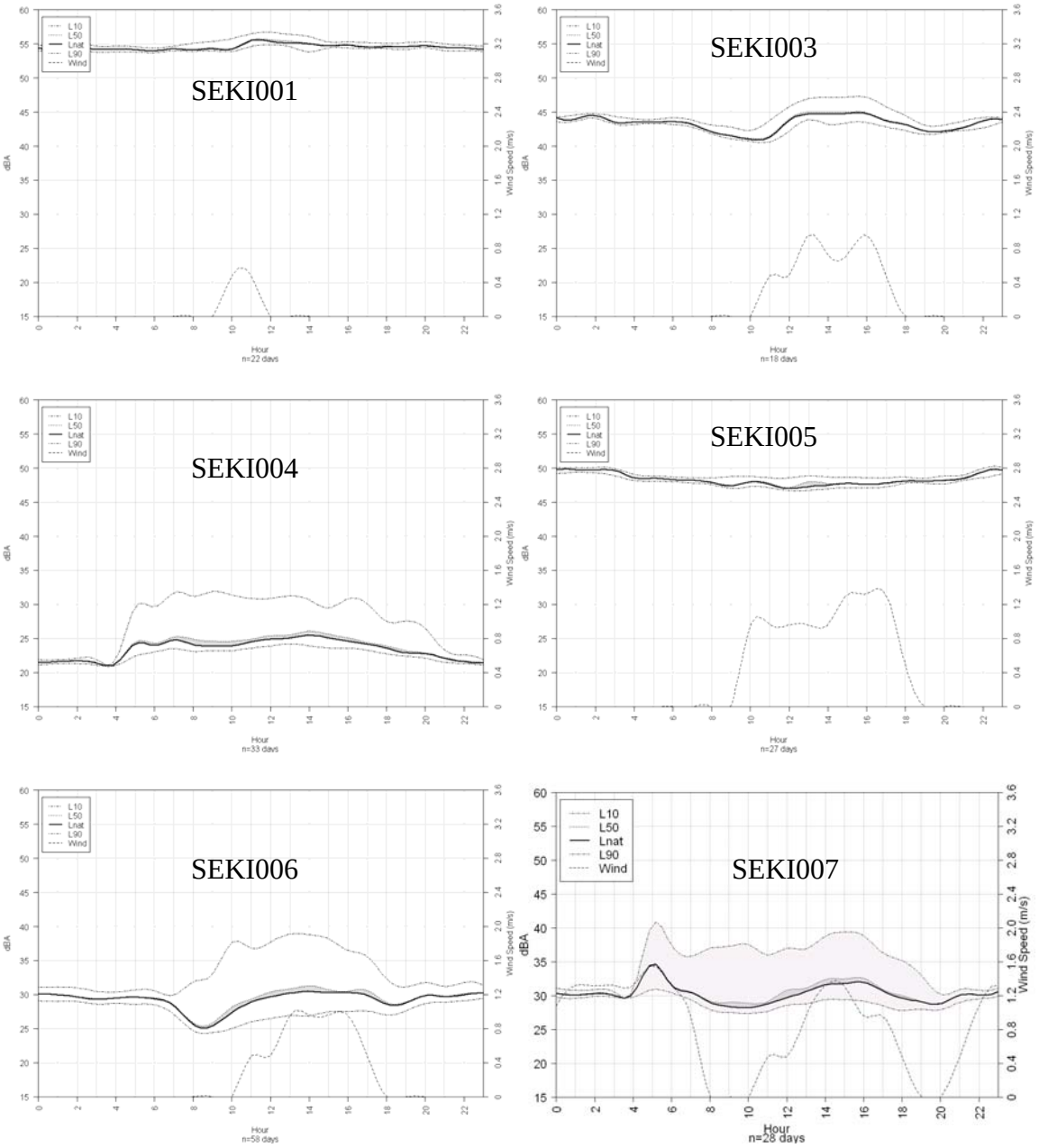
Appendix VI: Audibility of extrinsic and aircraft sounds by hour at all sites



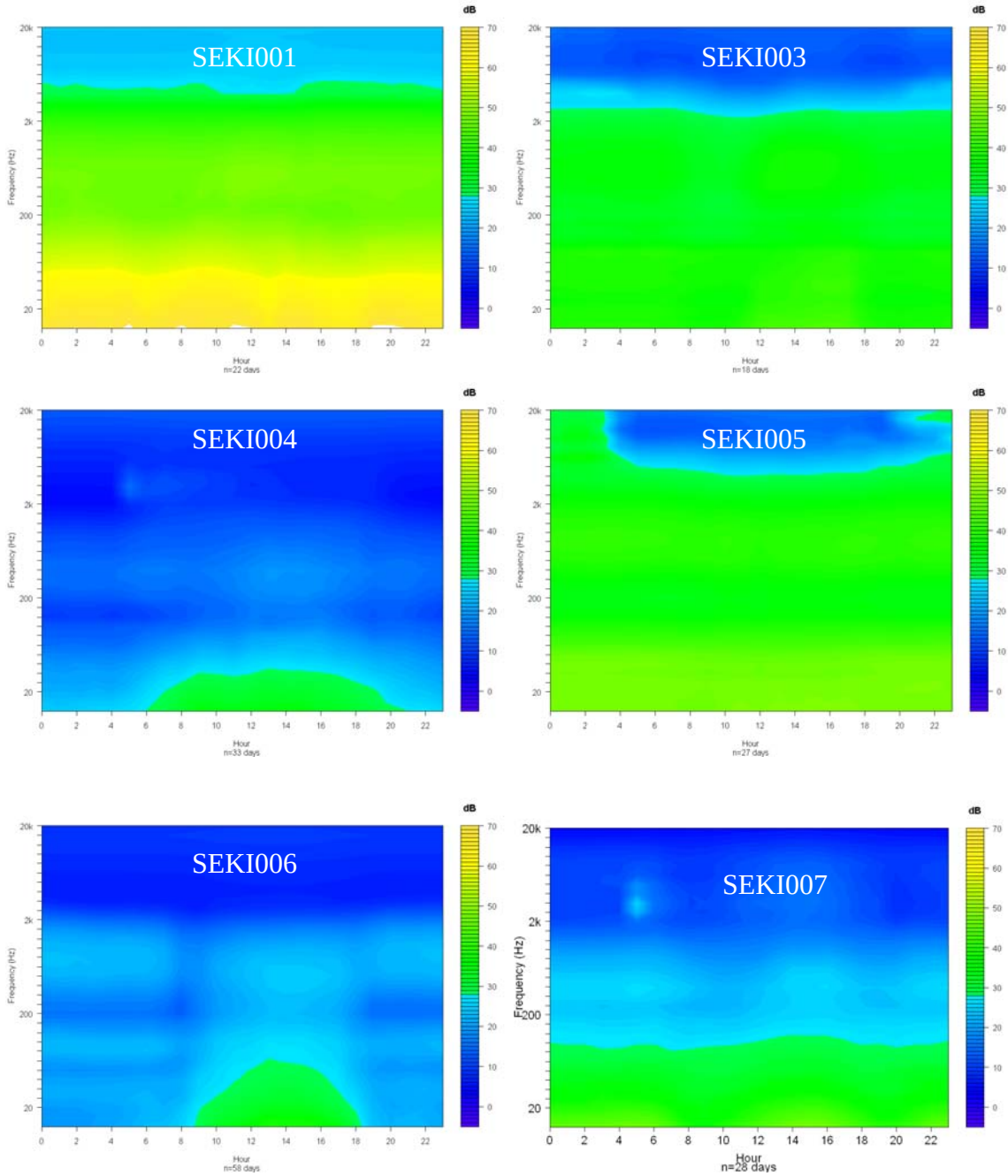
Appendix VII: Exceedence values by frequency at all sites. (Human threshold of hearing is shaded gray)



Appendix VIII: Exceedence values and wind speed by hour at all sites



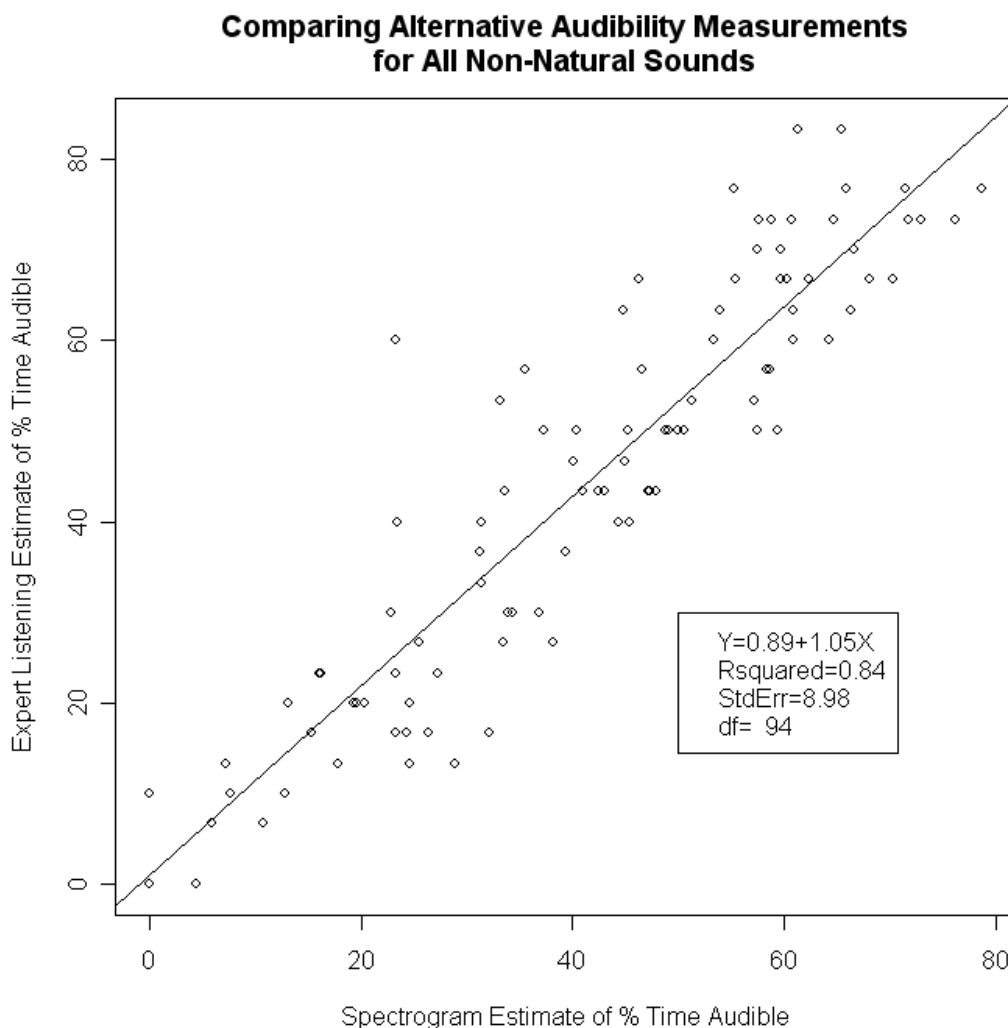
Appendix IX: Flat-weighted contour plots of median existing ambient decibel and frequency levels at all sites



Appendix X: Comparison of audio analysis and visual analysis for determining percent time extrinsic sounds audible.

The following graphs describe the percent time audible (PA) results acquired through traditional audio-based listening and newer spectrogram-based visual analysis. To determine the listening PA estimate, eight days of sound clips (10 seconds every 2 minutes) were analyzed. The visual analysis analyzed eight days of continuous spectrogram data.

When the results were compared, the standard error was moderately high (8.98 for all non-natural sounds and 10.05 for all aircraft sounds) because it was significantly affected by the outlying points. However, though the standard deviation might have been high, more than 50% of the data points actually lie within 6 PA of the mean, which is an acceptable margin of error.



Comparing Alternative Audibility Measurements for All Aircraft Sounds

