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North Cascades National Park Complex

Acoustic Monitoring 2009 – 2011

Natural Resource Technical Report NPS/NOCA/NRTR—2013/767

ON THE COVER
View of Fisher Creek Basin from Easy Pass, North Cascades National Park
Photograph by: Cathi Winings

North Cascades National Park Complex

Acoustic Monitoring 2009 – 2011

Natural Resource Technical Report NPS/NOCA/NRTR—2013/767

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Abstract

From 2009 through 2011, acoustic monitoring systems were deployed at 14 locations throughout North Cascades National Park Complex (NOCA). The purpose of this monitoring effort was to complete a baseline inventory of the acoustical environment of NOCA. The inventory was initiated in 2006 and in 2009 NOCA received funding to acquire equipment, employ one to two technicians, and analyze the data. This report summarizes the findings of the inventory efforts that took place from 2009 through 2011.

The monitoring sites included a mix of backcountry and front country locations that varied in elevation and forest type. Systems were deployed for approximately 30 days at each location, where automatic monitoring was supplemented by on-site listening sessions. A variety of metrics were calculated at each site, including existing and natural ambient sound levels, percent time audible of extrinsic (human-caused) sounds, percent time above four key thresholds, hourly exceedence metrics, and dB levels for one-third octave bands. Results show that NOCA has concentrated areas of noise intrusions surrounded by large expanses with very low levels of human-caused sound. The most prevalent sources of human-caused sound include vehicles and aircraft. Although human-caused sounds occur infrequently in many areas, natural ambient sound levels are often relatively high due to the prevalence of cascading water. This finding is especially appropriate given that the term “Cascades” is NOCA’s namesake. Other prevalent natural sounds include birdsong and insects, and on occasion, animal vocalizations from species of management concern, such as grey wolves and spotted owls, have been recorded. These findings are important attributes for NOCA as a large wilderness park that can be used to monitor wilderness character. The baseline data collected during this period will help park managers determine if desired conditions for natural acoustical environments (often referred to as soundscapes) are being met in the future.

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List of 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
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 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 20 Hz to 20,000 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
Noise. 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.

Leq
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.

Sound Level Floor (Noise Floor)
The lowest amplitude measurable by sound monitoring equipment.

Introduction

An acoustical environment can be defined as the aggregate of all the sounds in an area, including sounds inaudible to the human ear. Acoustical environments are typically composed of a variety of both natural ambient sounds and human-caused sounds. The NPS is required to preserve acoustical resources, which are those sounds that belong to a park by their very nature, based on the park unit purposes, values, and establishing legislation. Acoustical resources, therefore, can include human-caused sounds such as cultural and/or historic sounds, when they are appropriate for the area. Examples of natural sounds commonly heard in North Cascades National Park Complex (NOCA) include flowing water, bird songs, and insects. Examples of human-caused sounds commonly heard in some areas of NOCA include human voices and sounds produced by vehicles and aircraft. Human-caused sounds and sound levels (or loudness) may be appropriate or inappropriate depending on the management zone of an area.

The NPS recognizes natural sounds as inherent components of the resources it is required to protect under the 1916 Organic Act. Natural sounds are vital to the natural functioning of ecosystems; birds, insects, mammals, and amphibians rely on complex communication networks to live and reproduce. In habitats where wildlife vocalizations signify mating calls, danger from predators, or territorial claims, hearing these sounds is important to animal reproduction and survival. The natural acoustical environment is also a key element of the visitor experience in national parks. As was reported to the U.S. Congress in the "Report on the Effects of Aircraft Overflights on the National Park System (NPS 1994)," a system-wide survey of park visitors revealed that nearly as many visitors come to national parks to enjoy the natural acoustical environment (91%) as those who come to view the scenery (93%).

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. In an effort to characterize the acoustical environment of NOCA, park resource managers requested technical assistance from the National Park Service Natural Sounds and Night Skies Division (NSNSD) to begin acoustic monitoring within NOCA. From 2006 through 2008, the NSNSD assisted in the deployment and data analysis of seven sites located throughout NOCA. In 2009 funding was obtained to purchase two acoustic monitoring stations and to hire seasonal help to continue the program more independently at the park level. Beginning in 2009 park personnel worked to complete a full acoustical environment inventory of NOCA, which was completed in 2011. This report summarizes the results of this inventory project. Results of inventory work prior to 2009 are documented in two other reports produced by the NSNSD: Acoustic Monitoring Report, 2006-2008 (NPS 2008a), and Acoustic Monitoring in Wilderness, 2008 (NPS 2008b).

National Park Service Natural Sounds and Night Skies Division

The NSNSD helps 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 NSNSD addresses acoustical issues raised by Congress, NPS Management Policies, and NPS Director’s Orders. The NSNSD works to protect, maintain, or restore acoustical environments throughout the National Park System. Its goal is to provide coordination, guidance, and a consistent approach to acoustical environment protection with respect to park resources and visitor use. The program

also provides technical assistance to parks in the form of acoustical monitoring, data processing, park planning support, and comparative analyses of acoustical environments.

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 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." 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 soundscapes[1] is represented in NPS Management Policy 4.9 (2006):

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

It should be noted that “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 2006). However, the desired acoustical 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 2006). 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 2006).

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

Study Area

North Cascades National Park (501,458 acres), Ross Lake National Recreation Area (116,798 acres), and Lake Chelan National Recreation Area (62,902 acres) are collectively known as the North Cascades National Park Complex. NOCA contains over 680,000 acres of the heart of the North Cascades ecosystem, 94% of which is designated as the Stephen Mather Wilderness. The ecosystem is host to wide ranges in rainfall, temperature regimes, and elevation, which together result in a great diversity of habitat types. Four broadly defined vegetation zones are found within the North Cascades: lowland forest, montane forest, subalpine parkland, and the alpine zone. Overlaying these are three biogeographic zones caused by two orographic barriers within NOCA: the Boston-Picket-Spickard Divide and the Cascade Crest. Temperate marine conditions are found west of the Boston-Picket-Spickard Divide, while areas east of the Cascade Crest lie in the semi-arid continental zone. The region between the Boston-Picket-Spickard Divide and the Cascade Crest, essentially the Ross Lake drainage, comprises a transitional zone where vegetal and climatic characteristics are intermediate between the mild, wet conditions typical of the west side and the semi-arid conditions typical east of the Cascade Crest. The vegetation and biogeographic zones of NOCA were used to broadly identify acoustic zones in this study. An acoustic zone is an area that contains similar vegetation, land cover, topography, elevation, and climate, and it typically contains similar animals, physical processes, and other sources of natural sounds. Areas with similar attributes have similar natural sound sources, sound levels, propagation and attenuation properties, and other acoustic qualities.

The primary sources of human-caused sounds that influence acoustic zones at NOCA include vehicles, aircraft, power generation equipment, and motorboats. All of these activities occur extremely close to, or in the case of aircraft use, over, designated wilderness. NOCA is bisected by the North Cascades Scenic Highway, otherwise known as State Route 20. The highway draws large volumes of traffic during the summer months. Recreationists, truck drivers, and other users alike travel the highway to cross the Cascades, driving cars, RVs, motorcycles, and tractor-trailers. Other roads within NOCA experience considerably less vehicle traffic, including the Stehekin Valley Road and a number of single lane unpaved roads that provide trailhead access to the backcountry.

Air tours operate within NOCA, and float planes land on Lake Chelan and Ross Lake. The flight path into Lake Chelan is within a narrow mountain valley that is bounded by low-elevation designated wilderness. The Stehekin Airstrip is a turf airstrip that receives approximately 300 takeoffs and landings annually. The airstrip is operated by the Washington State Department of Transportation Aviation Division under a special use permit from the NPS. The permit does not allow commercial use of the airstrip; it is primarily used by Stehekin residents, visitors, and the NPS.

Seattle City Light (SCL) is a municipal electric utility for the City of Seattle that owns approximately 1,129 acres of land and has limited rights on approximately 19,300 acres of federal land under the terms of two Federal Energy Regulatory Commission (FERC) licenses, one for the Skagit River Hydroelectric Project (FERC Number 553), and a second license for the substantially smaller Newhalem Creek Hydroelectric Project (FERC Number 2705). The Skagit River Hydroelectric Project includes three dams and their associated facilities: Ross Dam, Diablo Dam, and Gorge Dam. Seattle City Light is authorized to utilize federal lands within the

hydroelectric project boundary for various purposes related to hydroelectric power generation, including operation of dams, powerhouses, transmission lines, substations, and other works necessary for hydropower production.

The largest of NOCA's three reservoirs, Ross Lake covers over 12,300 acres and stretches over 135 miles of shoreline. Although Ross Lake has limited access, it is popular among both motorized and non-motorized boat operators. Motorized boating also occurs on Lake Chelan near Stehekin. A passenger ferry service operates daily during most of the year, transporting passengers to and from Chelan and Stehekin.

Methods

Field Methods

Fourteen monitoring sites (Table 1, Figure 1) were purposefully selected within NOCA based on their geographical location, elevation and vegetation zone, and accessibility. To be accessible, selected sites were close to roads, along trails and within five miles of trailheads, or accessible by boat. For a select few sites (Park Creek Pass and Beaver Pass), stock support was used, which increased the distance into the backcountry that monitoring stations were deployed. Each site is considered a representative sample of an acoustic zone within NOCA. However, the alpine zone was not sampled because of the microphone distortion that is caused by prevalent winds on mountaintops.

Table 1. Acoustical environment monitoring sites surveyed from 2009-2011.

Site ID	Site Name	Location	Deployment Dates	Vegetation Zone*	Elevation (m)	Coordinates (Lat. /Long.)
NOCA008	Newhalem	Front country	07/07 - 08/05/2009	Lowland forest, TMZ	213	48.677114 -121.240368
NOCA009	Rainbow Loop	Backcountry	07/08 - 08/06/2009	Lowland forest, SCZ	628	48.347117 -120.698593
NOCA010	Easy Pass	Backcountry	08/10 - 09/09/2009	Subalpine parkland, SCZ	2,055	48.571843 -120.841577
NOCA011	Colonial Campground	Front country	08/11 - 09/11/2009	Lowland forest, TMZ	370	48.684388 -121.094286
NOCA012	Ross Dam Trailhead (winter)	Front country	01/27 - 03/10/2010	Lowland forest, TZ	707	48.731624 -121.058243
NOCA013	Thunder Knob	Front country	05/25 - 06/28/2010	Lowland forest, TMZ	525	48.700613 -121.105343
NOCA014	Big Beaver Valley	Backcountry	06/21 - 07/23/2010	Lowland forest, TZ	524	48.798918 -121.102065
NOCA015	Sourdough Mountain	Backcountry	07/08 – 08/05/2010	Montane forest, TMZ	1,597	48.743278 -121.122840
NOCA016	Park Creek Pass	Backcountry	08/08 – 09/09/2010	Subalpine parkland, SCZ	1,848	48.496378 -120.963382
NOCA017	Dagger Lake	Backcountry	08/17 - 09/15/2010	Montane forest, SCZ	1,655	48.467260 -120.664122
NOCA018	Sulphide Creek	Backcountry	06/15 - 07/18/2011	Lowland forest, TMZ	277	48.777061 -121.540783
NOCA019	Beaver Pass	Backcountry	07/07 - 08/08/2011	Montane forest, TZ	1,067	48.869272 -121.244899
NOCA020	Stehekin Airstrip	Front country	07/27 - 08/24/2011	Lowland forest, SCZ	398	48.347768 -120.720572
NOCA021	Thornton Lakes Trail	Backcountry	08/15 - 09/14/2011	Montane forest, TMZ	954	48.662878 -121.319592

* TMZ = Temperate Marine Zone; SCZ = Semi-arid Continental Zone; TZ = Transitional Zone

Monitoring stations were deployed at these sites primarily during the summer months, with Newhalem, Colonial Creek Campground, Thunder Knob, and Stehekin Airstrip serving as front country sites (less than two miles to nearest road), and Easy Pass, Rainbow Loop Trail, Big Beaver Valley, Sourdough Mountain, Park Creek Pass, Dagger Lake, Sulphide Creek, Beaver Pass, and Thornton Lakes Trail serving as backcountry sites (greater than or equal to two miles from nearest road). One winter front country site was deployed near the Ross Dam Trailhead.

Acoustic monitoring stations were deployed at each site for a minimum of 30 days. During the 30-day period, sites were visited four times to check on the systems and to conduct on-site listening sessions. Automatic monitoring took place throughout the deployment, and provided the data that was used in off-site listening analysis.

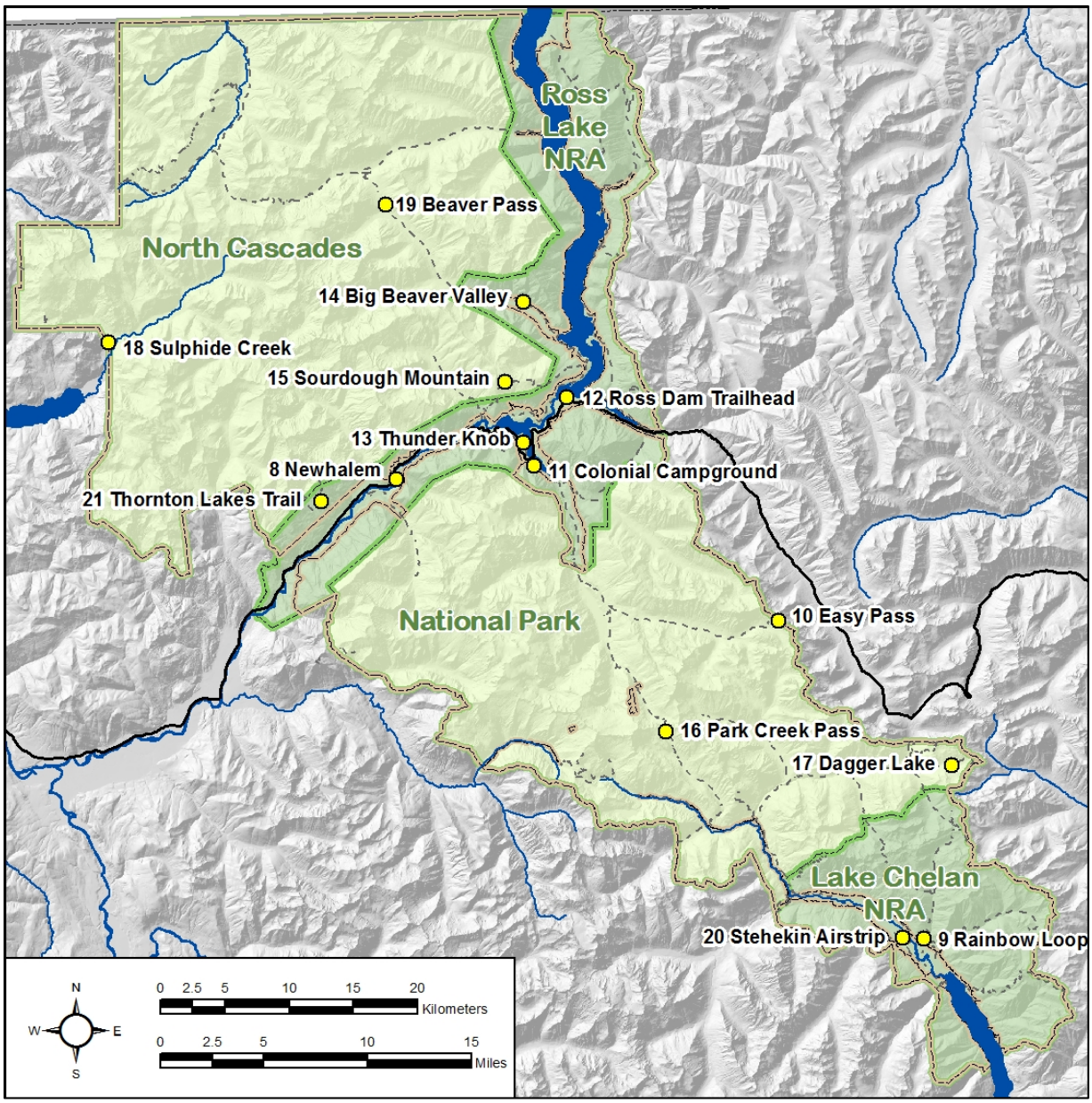

Figure 1. NOCA acoustic monitoring site locations.

Acoustic Monitoring Sites

Because sound travels differently over different surfaces, site descriptions are a useful tool to better understand the acoustics at each site. While sound is greatly affected by the microtopography of any location, a site description lends knowledge to the overall topography and habitat of each acoustic monitoring site.

Figure 2. Acoustic monitoring equipment at the Newhalem site (NOCA008).

The Newhalem site (NOCA008) was east of the Seattle City Light company town of Newhalem (Figure 2). Situated on a bedrock bench behind the Gorge Powerhouse, the site is 213 m above sea level (the lowest monitoring site), 60 m from the transmission lines, and 50 m above the Skagit River. Due to the topography of the valley, sounds from the valley floor are amplified as they resonate off the steep valley walls. In combination with the proximity of power lines, rushing water, and power generation equipment, the topography of the valley causes the site to have an overall higher ambient sound level than other survey locations.

Figure 3. Acoustic monitoring equipment at the Rainbow Loop Trail site (NOCA009).

The Rainbow Loop Trail (NOCA009) is a popular hike in the Stehekin Valley. A 5 mile loop, it provides a day hike just off the valley floor or a junction with trails that lead deeper into the backcountry. During deployment at this location (Figure 3), a curious bear visited the site and knocked over the equipment, resulting in fewer than 30 days of recording time.

Figure 4. Acoustic monitoring equipment at the Easy Pass site (NOCA010).

Easy Pass (NOCA010) is located 3.7 miles from the trailhead at State Route (SR) 20. The monitoring site (Figure 4) is located along a trail used as either a steep day trip to alpine meadows or a route to Fisher Basin. It is the highest monitoring site, at 2,055 m. Despite the backcountry location, vehicles were still infrequently audible at this site on clear nights.

Figure 5. Acoustic monitoring equipment at the Colonial Creek Campground site (NOCA011).

Colonial Creek Campground (NOCA011) is a busy campground throughout the summer months. The campground is located directly off of SR 20, on the southwest side of Thunder Arm. The site was situated just beyond the south unit of the campground (Figure 5). Despite the busy highway and campground, distant spotted owl calls were heard.

Figure 6. Acoustic monitoring equipment at the Ross Dam Trailhead site (NOCA012).

Positioned northeast of the SR 20 winter road closure gate, the Ross Dam Trailhead site (NOCA012) was positioned to capture snowmobile noise during the winter (Figure 6). No snowmobiles were present during the site deployment due to above average temperatures and below normal snowfall. Located on a high knob above the highway and Ross Dam, a distant hum from the dam was audible nearly 100 percent of the time at this site.

Figure 7. Acoustic monitoring equipment at the Thunder Knob site (NOCA013).

Thunder Knob (NOCA013) is located north of Colonial Creek Campground. A 1.9-mile trail leads to an exposed knob with views of Diablo Lake, surrounding mountains, and the highway corridor. The monitoring site was located near a pond, approximately 1.5 miles up the trail (Figure 7). While sounds from the nearby trail were hardly audible, the steep terrain amplified vehicle noise from SR 20 below. Interesting sounds of amphibians and a nighthawk making his courting dive were audible here.

Home to some of the largest remaining old growth cedar, the Big Beaver Valley (NOCA014) contains a system of expansive wetlands and towering forests. The monitoring site was located approximately three miles up the valley, in the lush forest on the north side of the trail.

Figure 8. Acoustic monitoring equipment at the Sourdough Mountain site (NOCA015).

Sourdough Mountain (NOCA015) is a popular North Cascades hiking destination. Soaring views of the valley reward visitors who climb the steep switchbacks. The site was located approximately 4.5 miles up the trail, and less than a mile below the historic Sourdough Lookout (Figure 8).

Figure 9. Acoustic monitoring equipment at the Park Creek Pass site (NOCA016).

The most remote site was Park Creek Pass (NOCA 016). Situated on the south side of the pass, the site was approximately 20 miles into the backcountry (Figure 9). It was located on a ridge, nestled in a clump of trees to protect it from wind. A nearby search and rescue operation (SAR) on Storm King Mountain resulted in increased air traffic. The days during the SAR were not included in the eight days chosen for analysis, but were instead analyzed separately for air traffic sound sources.

Figure 10. Acoustic monitoring equipment at the Dagger Lake site (NOCA017).

Dagger Lake (NOCA017) is located to the west of Twisp Pass. The lake is surrounded by a cirque, so the selected monitoring site was located at the edge of a nearby wetland downstream from the lake to avoid any echo or amplification of sounds that may have occurred near the lake (Figure 10).

Figure 11. Acoustic monitoring equipment at the Sulphide Creek site (NOCA018).

Sulphide Creek (NOCA018) is located in the northwest section of NOCA, south of Mount Shuksan. The site was situated about 2.5 miles up a busy trail (Figure 11). Positioned far off the trail, thick surrounding vegetation softened the sounds of hikers and trail maintenance.

Figure 12. Acoustic monitoring equipment at the Beaver Pass site (NOCA019).

The Beaver Pass (NOCA019) site was situated on the south side of the pass between the Big Beaver and Little Beaver drainages (Figure 12). One of the lower passes in the park, the elevation here is only 1,067 m. The pass itself is a flat, wet forest, covered by towering Douglas fir and cedar trees. The monitoring site was situated far back into the forest away from the trail.

Figure 13. Acoustic monitoring equipment at the Stehekin Airstrip site (NOCA020).

The Stehekin Airstrip (NOCA020) site was chosen to capture baseline acoustic data in support of planning efforts for a proposed housing area near the airstrip (Figure 13). This site was located next to the airstrip, with frequent sounds of small planes taking off and landing. Vehicle traffic was often audible here as well, along with heavy equipment sounds from the nearby NPS maintenance yard. These sounds mingled with the crows of roosters and howls of dogs at nearby houses along the Company Creek Road. At night, however; this site became very quiet, with very few extrinsic sounds that were audible. Due to technical difficulties, only 14 days of audio data were collected at this site; eight days were chosen out of those 14 days for analysis. During the period when the site was recording sound pressure levels but not audio, an animal (most likely a bear) shredded the microphone windscreen but did not otherwise damage the equipment.

Figure 14. Acoustic monitoring equipment at the Thornton Lakes Trail site (NOCA021).

The Thornton Lakes Trail (NOCA021) is a busy, often hiked trail in the North Cascades backcountry. The monitoring site was situated along an old roadbed, beyond the point at which the trail departs from the roadbed and heads to higher elevations (Figure 14). Hikers are heard infrequently at this site, although the trail is heavily used. Vehicle traffic from SR 20 far below is audible, as well as air traffic.

Automatic Monitoring

Each monitoring station consisted of three main components: a sound level meter (SLM), a digital audio recorder, and a meteorological data logger. The Larson Davis 831 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 portable storage device (thumb drive). Data collected using the Larson Davis SLM meets American National Standards Institute (ANSI) Type 1 standards. The acoustic sampling station consisted of the following equipment:

- Larson Davis 831 SLM
- MP3 recorder
- Microphone with environmental shroud
- Preamplifier
- Anemometer
- Meteorological data logger
- 8 LiFePO4 (rechargeable) batteries

The acoustic sampling station collected:

- SPL data in the form of A-weighted decibel readings (dBA) every second
- Continuous digital audio recordings
- One third octave band data every second ranging from 12.5 Hz – 20,000 Hz
- Continuous meteorological data, including wind speed and direction, temperature, and relative humidity

On-site Listening

While the SLM provides information about how loud or quiet the acoustical environment is at a given time, MP3 audio recordings or on-site listening sessions are needed to determine what or who is making the sound. On-site listening is the practice of placing an observer near the acoustical monitoring station with a handheld personal digital assistant (PDA). The observer listens for a designated period of time and identifies all sound sources and their durations. On-

site listening takes full advantage of human binaural hearing capabilities, and 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 was performed during four sessions at each site in order to discern the type, timing, and duration of sounds during the 30-day monitoring period. As recommended by NSNSD protocol (NPS 2005) these sessions began at the top of the hour and lasted for one hour. The beginning and ending times of all audible sound sources were recorded using custom-designed PDA software. These on-site listening sessions provided the basis for the calculation of some of the metrics, including the maximum amount of time between noise events (maximum noise free interval [NFI]) and the percent of time that extrinsic sounds were audible.

Data Analysis

Off-site Analysis

Acoustic data was analyzed differently depending on the site location in relation to human caused sound. Since backcountry sites have fewer audible sound sources on average, they were visually analyzed. Front country sites, on the other hand, were much more complex, requiring analysis by listening to the sound data.

Visual analysis of backcountry sites consisted of examining the spectrograms of a subset (eight days) of SPL samples in order to identify the source and duration of sounds. Audio samples were employed to confirm identification of sound sources. The total percent time extrinsic sounds were audible was used to calculate the natural ambient sound level for each hour.

Analysis of front country sites consisted of using 10 second sound clips every two minutes for an eight-day subset of audio data in order to identify sound sources. The sound clips were analyzed using Adobe Audition to isolate sound sources by listening to them when necessary, and cross referenced with visual analysis. Events that were not captured in the ten second sound clips (i.e., military jets) are noted. The total percent time extrinsic sounds were audible was used to calculate the natural ambient sound level.

Bose Quiet Comfort Noise Canceling headphones were used for audio playback to minimize limitations imposed by the office acoustic environment.

Calculation of Metrics

The status of the acoustic environment can be characterized by spectral measurements, durations, and overall sound levels (intensities). Both descriptive figures and metrics are used to interpret these characteristics. Two fundamental descriptors are existing ambient (L_{50}) and natural ambient (L_{nat}) sound levels. These are both examples of exceedence levels, where each L_x value refers to the sound pressure level that is exceeded x% of the time. The L_{50} represents the median sound pressure level, and is composed of spectra (in dB) drawn from a full dataset (removing data with wind speed > 5m/s to eliminate error from microphone distortion). The natural ambient (L_{nat}) is an estimate of what the ambient level for a site would be if all extrinsic or anthropogenic sources were removed. Unlike the existing ambient, the natural ambient is composed of spectra drawn from a subset of the original data.

For a given hour (or other specified time period), L_{nat} is calculated to be the decibel level exceeded x percent of the time, where x is defined by the equation (1):

$$x = \frac{100 - P_H}{2} + P_H \tag{1}$$

and P_H is the percentage of samples containing extrinsic or anthropogenic sounds for the hour. For example, if human caused sounds are present 30% of the hour, x = 65, and the L_{nat} is equal to the L_{65}, or the level exceeded 65% of the time.

Median A-weighted existing and natural ambient sound levels (expressed as dBA) at each monitoring location are reported in the Results section. Since humans do not hear well at very low or very high frequencies, A-weighting adjusts regular decibel readings to the sum of sound energy across the range of human hearing. Following reporting of the ambient sound level values, a spectral view is provided for each site. Spectral views are charts that plot frequencies and decibel levels by the hour. Sound levels are then further described using hourly exceedence metrics, which are displayed using box plots. These diagrams help to illustrate the contribution of human-caused noise to existing ambient sound levels.

To begin to understand sound sources, day and night decibel levels for 33 one-third octave bands were calculated for each site. By splitting the frequency spectrum into 33 smaller ranges, each encompassing one-third of an octave, high frequency and low frequency sounds could be quantified. For each one-third octave band, decibel level was recorded once per second for the duration of the monitoring period. Since high frequency sounds (e.g., birdsong) and low frequency sounds (e.g., transportation noise) often occur simultaneously, recording the sound intensity of each one-third octave band (combined with digital audio recordings) allowed technicians to determine what types of sounds contributed to the overall sound pressure level of a site.

The percent time audible is another metric that was used to further understand sound sources. First, the percent of time that sound sources were audible during eight continuous days of sound source analysis was calculated by identifying each audible sound source and compiling statistics (mean percent time audible). Results are presented for all extrinsic sounds, as well as sound sources of interest, including vehicle and aircraft noise. Additionally percent time audible was calculated for all sound sources, both extrinsic and intrinsic. Charts were then used to examine total extrinsic sounds, aircraft noise, and vehicle noise by hour.

Finally, decibel level thresholds were used to quantify some potential impacts of noise. Percent time above metrics were calculated for four key thresholds. The first, 35 dBA, was designed to address the health effects of sleep interruption. Recent studies suggest that sound events as low as 35 dB can have adverse effects on blood pressure while sleeping (Haralabidis 2008). The second threshold addresses the World Health Organization's recommendations that noise levels inside bedrooms remain below 45 dBA (Berglund et al. 1999). The third threshold, 52 dBA, is based on the Environmental Protection Agency's speech interference threshold for speaking in a raised voice to an audience at 10 meters (EPA 1982). This threshold addresses the effects of

sound on interpretive presentations. The final threshold, 60 dBA, provides a basis for estimating impacts on normal voice communications at one meter. Hikers, kayakers and canoeists, and visitors viewing scenic vistas in NOCA would likely be conducting such conversations.

The open source statistical program R2.11.0 was used in the creation of diagrams and figures. R is free software and a collaborative project with several contributors created by the R Foundation for Statistical Computing.

Results

This section reports the results of each 30-day monitoring session that took place at each of the 14 sampling locations. Results of the four on-site listening sessions conducted at each location are reported first, followed by the more in-depth off-site analysis.

On-site Listening Results

In Table 2 below, the results of the four one-hour, on-site listening sessions are displayed. The first column in the table, Percent Time Audible Extrinsic Sounds, is a measure of the percent of time during the four listening sessions that human-caused sounds were audible. The second column, Maximum Noise Free Interval (NFI), is the maximum length of time a site did not have extrinsic noise during the four listening sessions, reported in minutes and seconds (mm:ss).

Table 2. Percent time audible and noise free interval.

Site Location	Percent Time Audible Extrinsic Sounds (%)	Maximum Noise Free Interval (mm:ss)
NOCA008-Newhalem	98.7	00:51
NOCA009-Rainbow Loop	20.9	52:37
NOCA010-Easy Pass	28.4	16:05
NOCA011-Colonial Campground	97.4	01:22
NOCA012-Ross Dam Trailhead	77.8	14:44
NOCA013-Thunder Knob	70.9	18:38
NOCA014-Big Beaver Valley	4.9	60:00
NOCA015-Sourdough Mountain	43.9	10:33
NOCA016-Park Creek Pass	6.8	46:18
NOCA017-Dagger Lake	5.8	60:00
NOCA018-Sulphide Creek	18.0	38:42
NOCA019-Beaver Pass	9.0	32:13
NOCA020-Stehekin Airstrip	N/A	N/A
NOCA021-Thornton Lakes Trail	N/A	N/A

N/A = Not Available due to technical difficulties at the site.

Extrinsic sounds were heard most frequently at the Newhalem site (98.7% of the time), followed by Colonial Campground (97.4% of the time). Sites that had the lowest percentages include Big Beaver Valley (4.9%), Dagger Lake (5.8%), Park Creek Pass (6.8%), and Beaver Pass (9.0%). Both Dagger Lake and Big Beaver Valley had maximum NFI rates of 60 minutes, indicating that for the entire one hour listening session, the only sounds that a human could hear were natural. The shortest maximum NFI occurred at Newhalem (51 seconds). Due to technical issues with the equipment, on-site listening results were not calculated for the Stehekin Airstrip and the Thornton Lakes Trail sites.

It is important to note that the majority of the listening sessions took place during daytime hours on weekdays. These selective samples of on-site listening are intended to provide a basis for relating the results of the off-site analysis to the probable auditory perception of events. Results should be considered a snapshot of conditions at the site on weekdays during daytime hours, and not necessarily representative of the site at other times of the day or other days of the week.

Off-site Analysis Results

Presented in this section are the results from in-depth off-site analysis. Sound levels are described and quantified using a number of measures, including ambient sound levels, spectral views of each site, and hourly exceedence metrics. Day and night decibel levels for 33 one-third octave bands are used to better understand sound sources. Sound sources are then further examined and identified using percent time audible metrics. The percent of time that extrinsic sounds were heard at each site is calculated, along with a more detailed breakdown of all sound sources. Charts are used to examine total extrinsic sounds, aircraft noise, and vehicle noise by hour. Finally, percent time above metrics are used to quantify the impacts of noise.

Ambient Sound Levels

In Table 3, median A-weighted ambient sound levels are reported for each of the sites. The loudest existing ambient sound levels (46 dBA) were recorded at the Newhalem site during the day. This site also had the loudest nighttime existing ambient sound levels (43 dBA), and the loudest daytime natural ambient sound levels (43 dBA). The site tied with the Stehekin Airstrip for the loudest nighttime natural ambient sound levels (42 dBA). The quietest existing ambient sound levels (22 dBA) were recorded at the Dagger Lake site at night. Dagger Lake also had the quietest daytime existing ambient sound levels at 25 dBA. The site tied with Colonial Creek Campground for the quietest nighttime natural ambient sound levels (21 dBA), while the quietest daytime natural ambient sound levels (25 dBA) occurred at several sites: Colonial Creek Campground, Ross Dam Trailhead, Sourdough Mountain, and Dagger Lake.

It is generally expected that daytime existing ambient sound levels would be the highest of the four values in Table 3 since they include human-caused sounds, which are more likely to occur during the day. Thus, nighttime existing ambient sound levels would be expected to be less than daytime sound levels. Natural ambient sound levels would be expected to be lower than existing ambient, with a similar patterning of daytime sound levels being higher than nighttime sound levels. Areas where this expected pattern does not occur are identified below. Subsequent sections use additional metrics to help explain why results might not follow what was expected.

There are several sites where nighttime sound levels are higher than daytime sound levels, including Rainbow Loop (existing and natural ambient), Thunder Knob (natural ambient), Sourdough Mountain (natural ambient), Park Creek Pass (existing and natural ambient), Sulphide Creek (existing and natural ambient), and Stehekin Airstrip (natural ambient). In most cases the difference is only 1 dB, and the most plausible explanation is the increased runoff that peaks during the night for major drainages. There are also several sites that have the same daytime and nighttime sound levels, including Ross Dam Trailhead (existing and natural ambient), Big Beaver Valley (existing and natural ambient), Sourdough Mountain (existing ambient), Beaver Pass (existing and natural ambient), Stehekin Airstrip (existing ambient), and Thornton Lakes Trail (natural ambient). This means that sound levels remain constant regardless of the time of day.

Table 3. Ambient sound levels.

Site	Median A-Weighted Existing Ambient (in dBA)		Median A-Weighted Natural Ambient (in dBA)	
	Day (7am – 6:59 pm)	*Night (7pm – 6:59 am)*	*Day (7am – 6:59 pm)*	*Night (7pm – 6:59 am)*
NOCA008-Newhalem	46	43	43	42
NOCA009-Rainbow Loop	33	34	33	34
NOCA010-Easy Pass	30	27	29	26
NOCA011-Colonial Creek Campground	32	23	25	21
NOCA012-Ross Dam Trailhead	27	27	25	25
NOCA013-Thunder Knob	29	28	27	28
NOCA014-Big Beaver Valley	27	27	27	27
NOCA015-Sourdough Mountain	27	27	25	27
NOCA016-Park Creek Pass	32	34	32	34
NOCA016-Park Creek Pass SAR	32	34	31	34
NOCA017-Dagger Lake	25	22	25	21
NOCA018-Sulphide Creek	38	39	38	39
NOCA019-Beaver Pass	34	34	34	34
NOCA020-Stehekin Airstrip	42	42	41	42
NOCA021-Thornton Lakes Trail	29	28	28	28

Spectral Views

The diversity of ambient sound levels throughout NOCA is further emphasized in the spectral view of each site (Figures 15 through 28). Each spectral view averages the data from the site to create a picture of decibel and frequency levels by hour. Brighter levels of orange indicate higher decibel levels; while blue signifies quiet or very low decibel levels. By examining the frequencies at which ambient sound levels occur, we begin to understand more about the types of sounds that occur at a site.

Figure 15 demonstrates that Newhalem was a site with a high ambient sound level. The orange lines across the lower third of the graphic represent noise from power generation and transmission, running water, and highway traffic. The high sound level of this site is especially evident when compared to a backcountry site such as Rainbow Loop, shown in Figure 16.

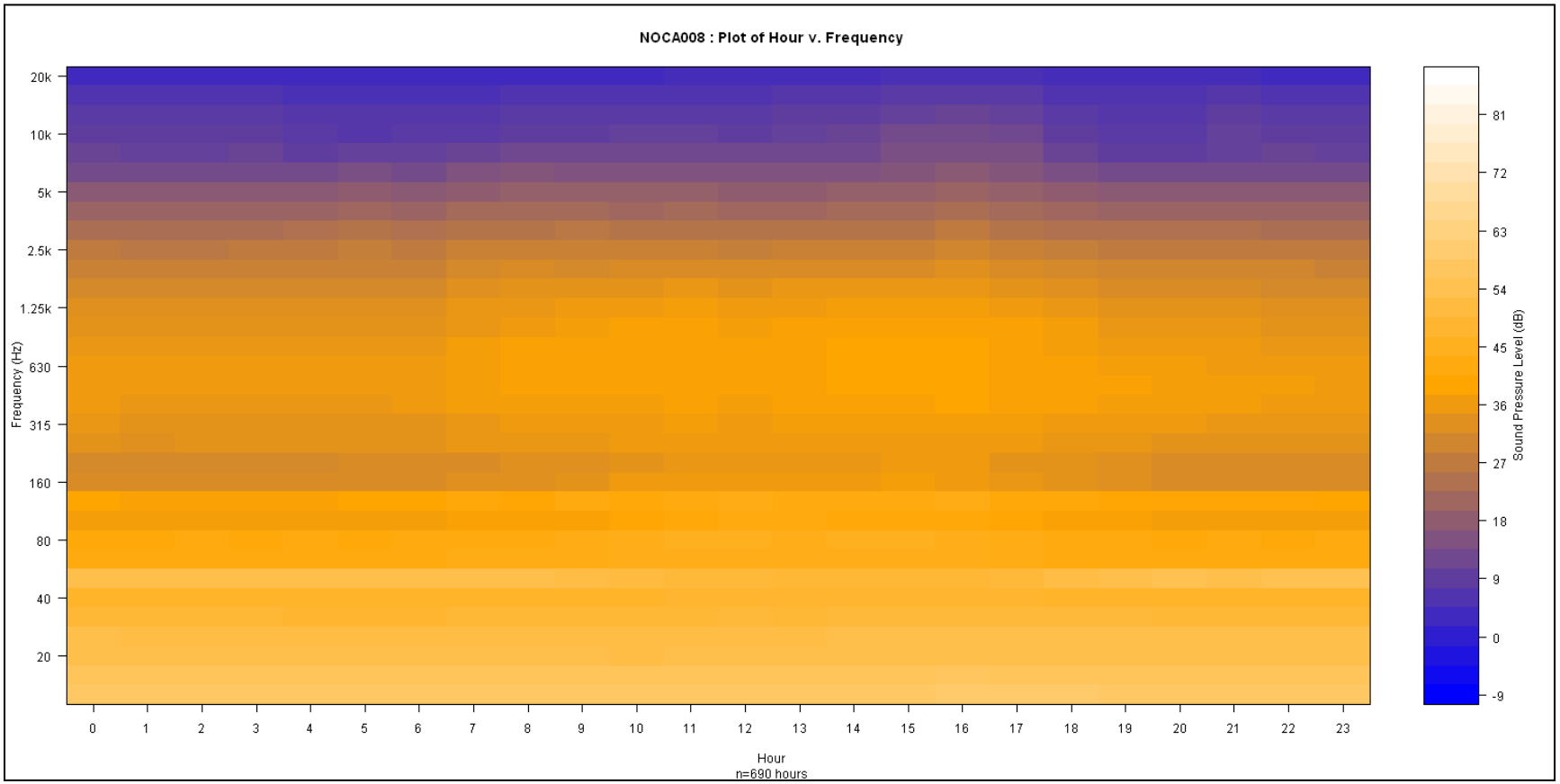

Figure 15. Newhalem spectral view.

In contrast to the Newhalem site (Figure 15), the Rainbow Loop site (Figure 16) was relatively quiet. The orange band at 0-40 Hz most likely represents low frequency sounds from a nearby stream. The band of orange from 160 to 5000 Hz is mostly composed of wind and air traffic.

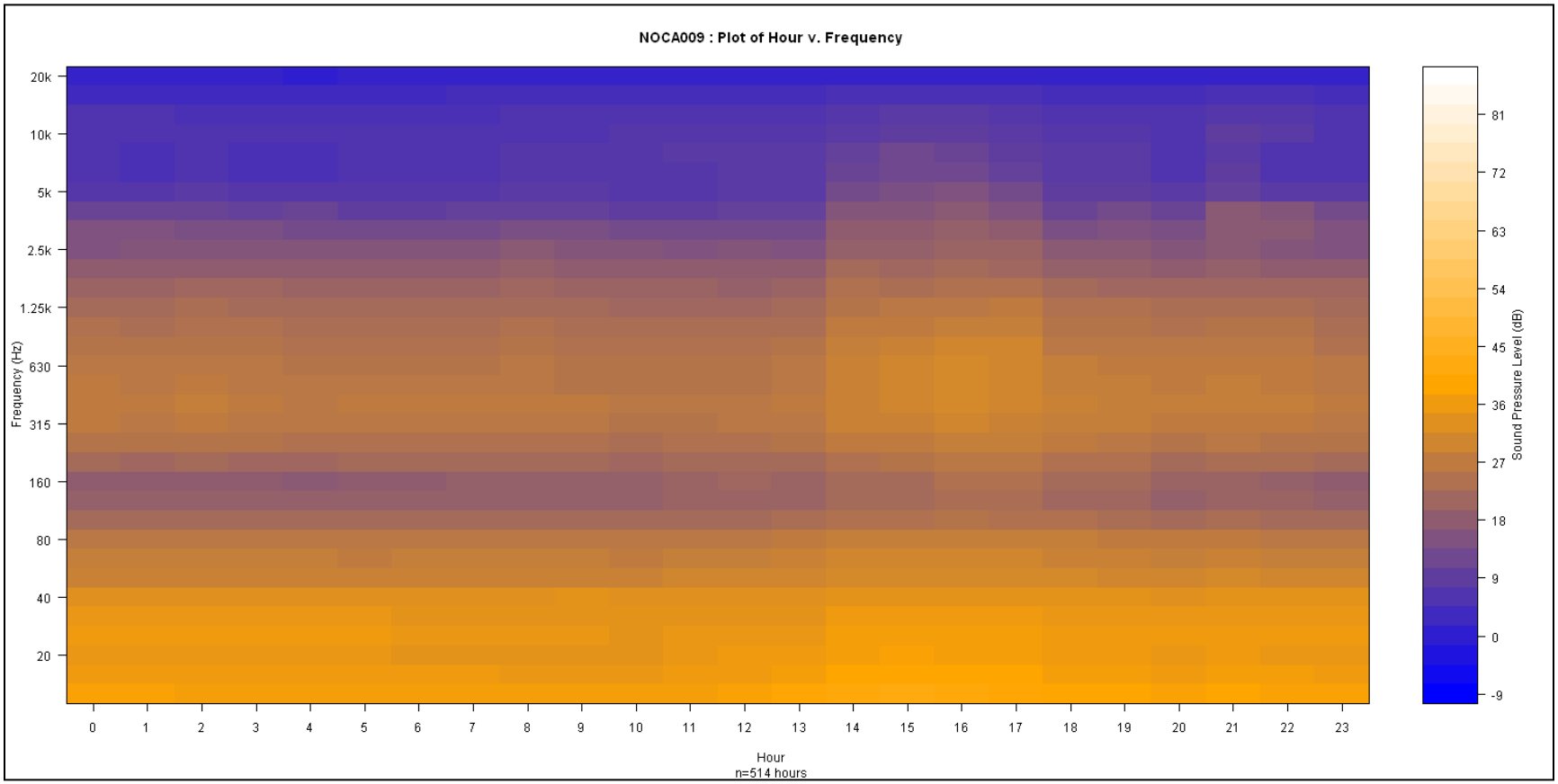

Figure 16. Rainbow loop spectral view.

Easy Pass was a quiet backcountry site (Figure 17). The high frequency sounds in the evening hours are insects. Midday sounds are due to wind and air traffic.

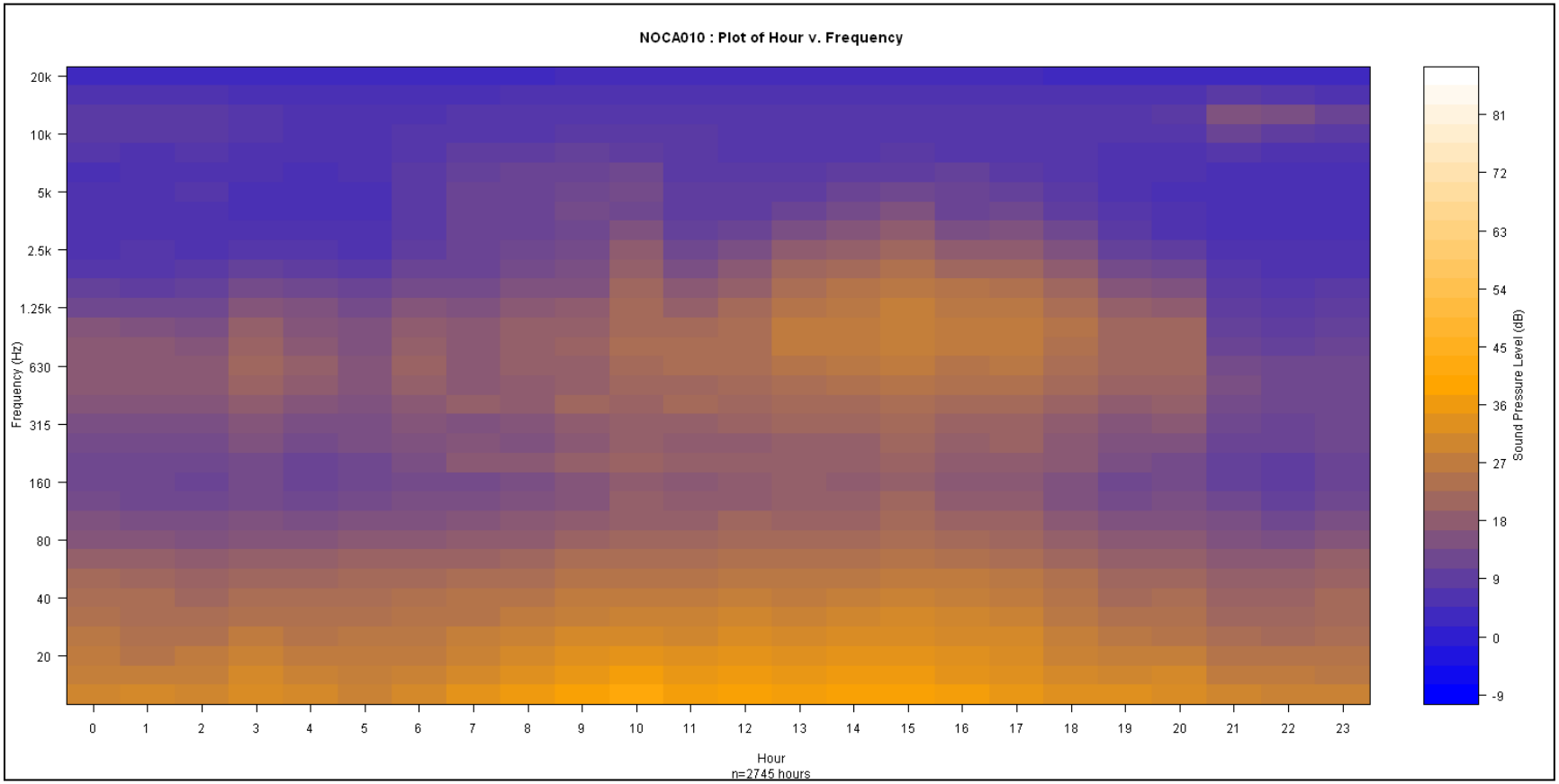

Figure 17. Easy Pass spectral view.

Although Colonial Creek Campground was a relatively loud site during the day, nighttime sound levels were some of the lowest recorded of the monitoring sites. In this spectrogram (Figure 18), highway traffic and campground noise become visible around 6 am, and begin to dissipate after 8 pm.

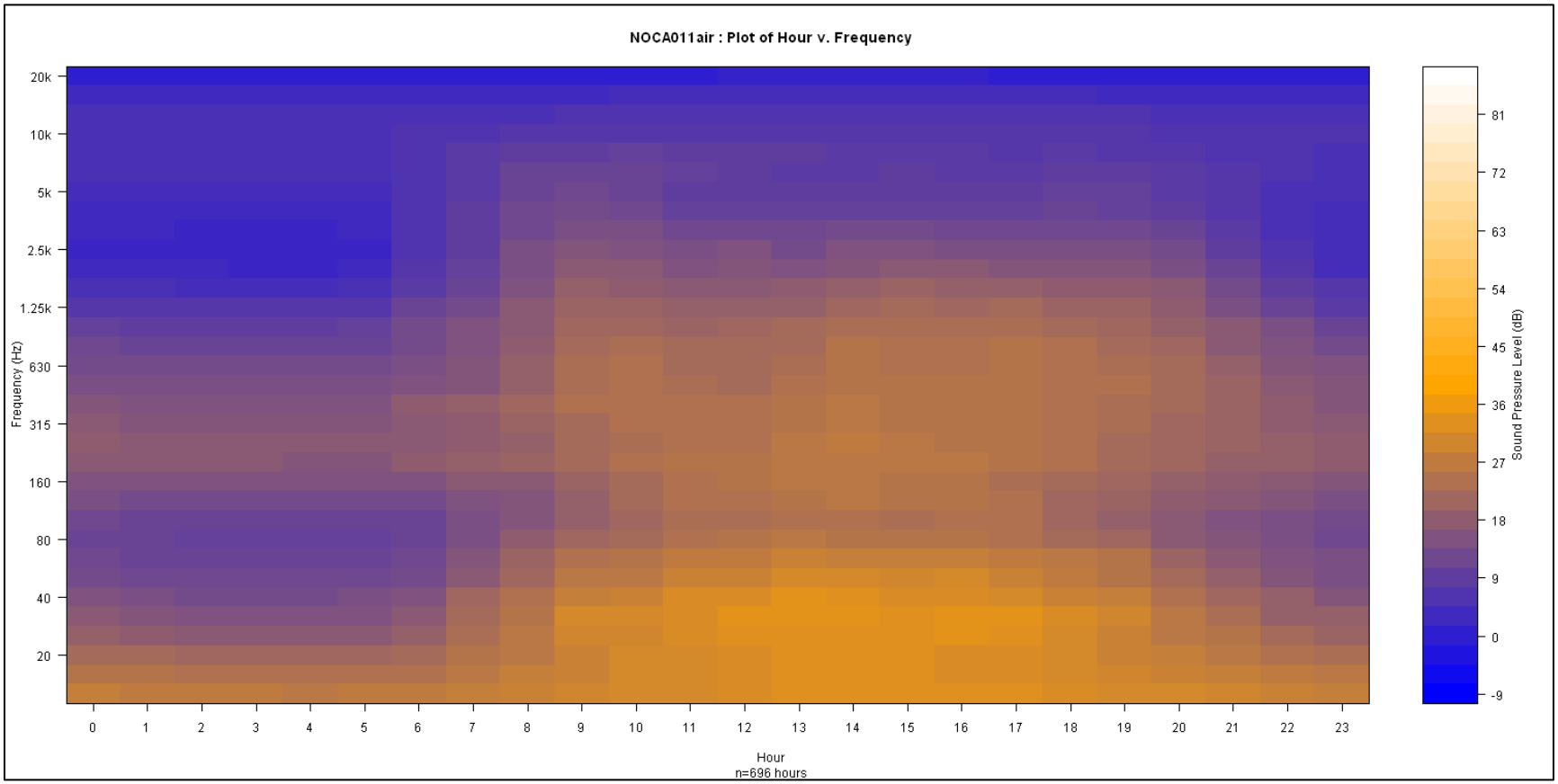

Figure 18. Colonial Creek Campground spectral view.

The Ross Dam Trailhead site (Figure 19) was deployed in the winter, and thus lacks any insect noise present in many of the other sites. The bright orange band represents power generation equipment at the Ross Dam.

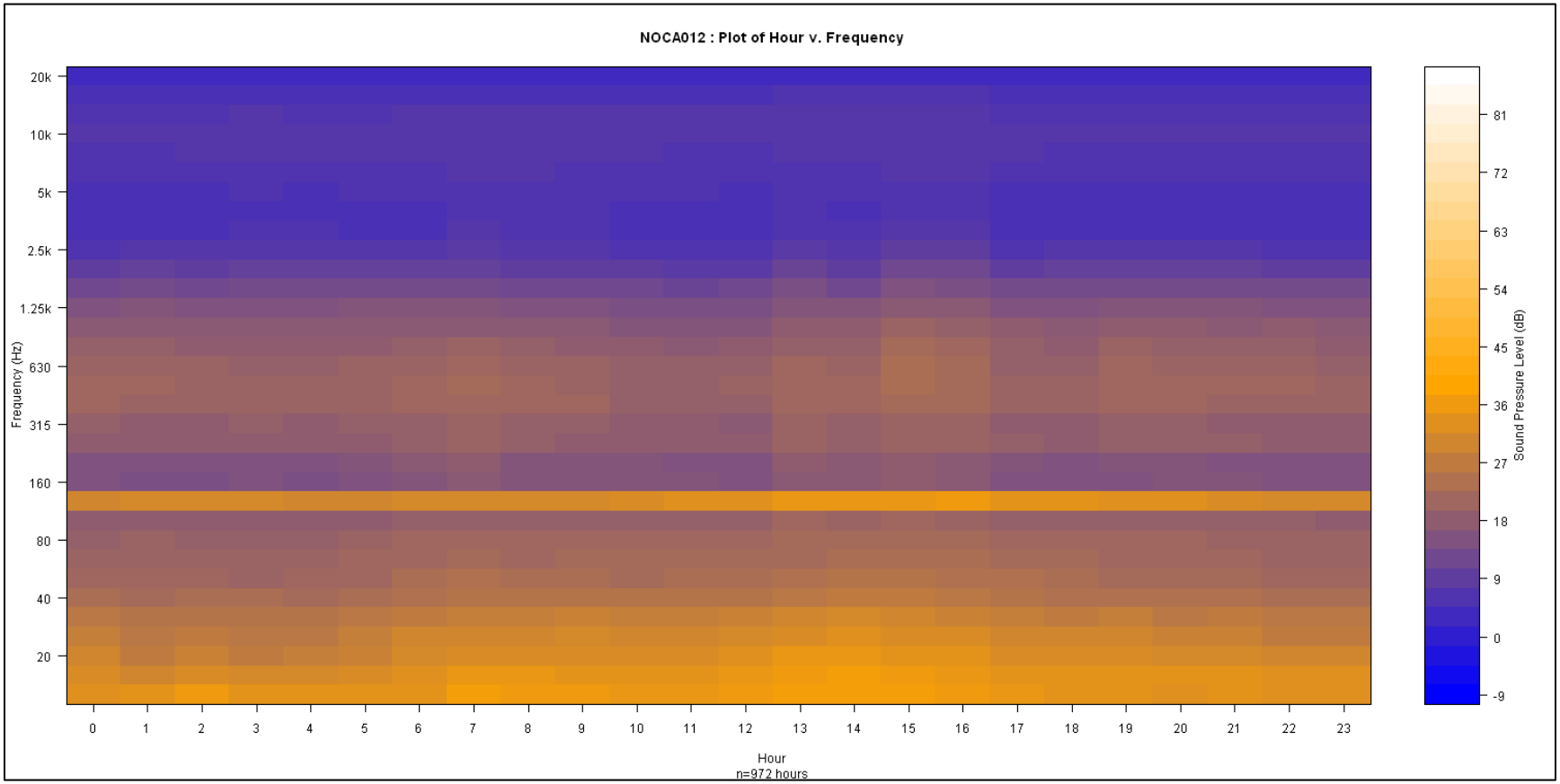

Figure 19. Ross Dam Trailhead spectral view.

Thunder Knob was a relatively quiet site (Figure 20), but traffic noise is evident between the hours of 8 am and 10 pm. The high frequency sounds in the early morning and late evening hours are due to insects and birds.

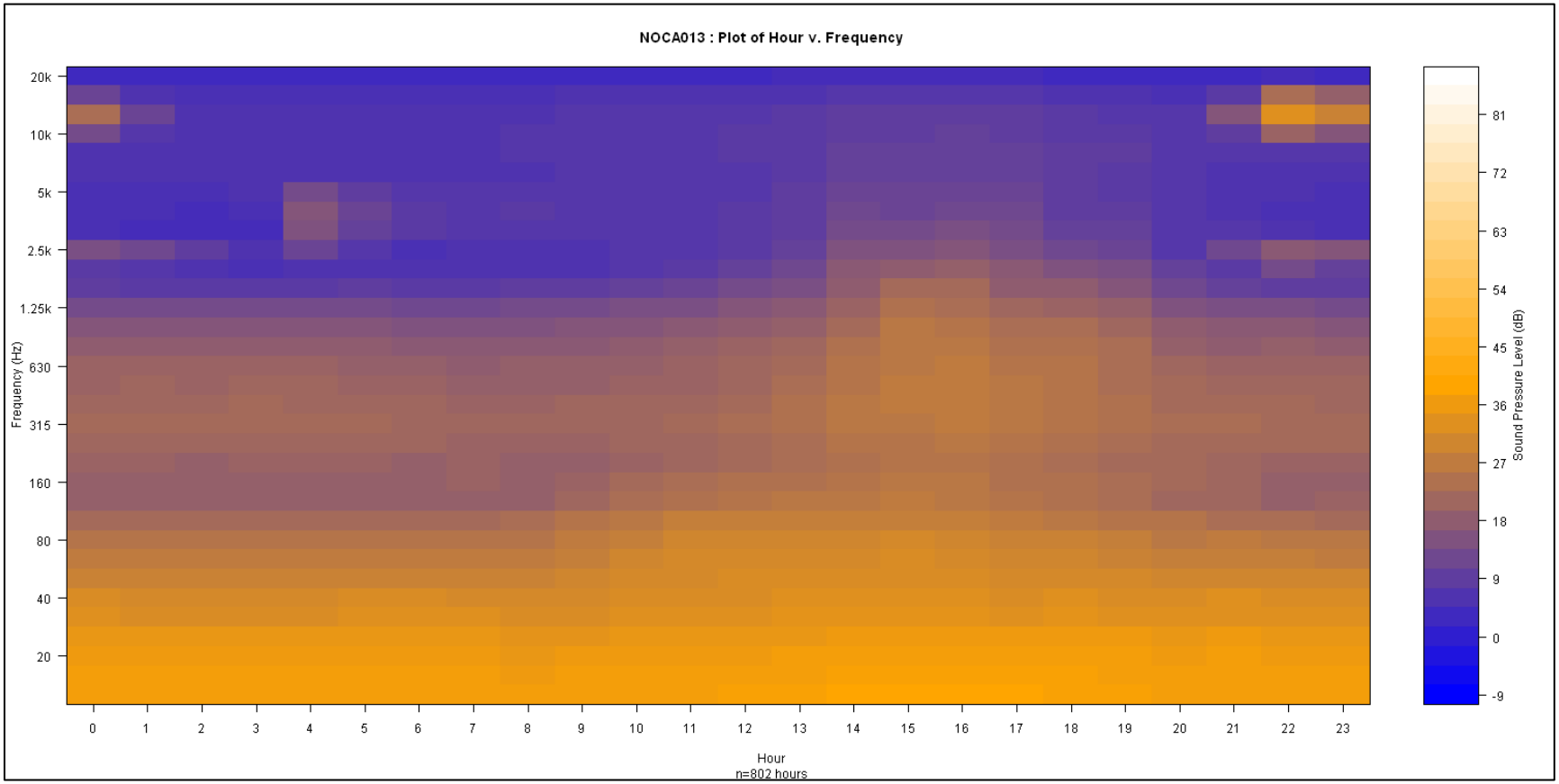

Figure 20. Thunder Knob spectral view.

Located in the Big Beaver Valley, this was a very quiet site (Figure 21). There was less commercial jet traffic here than at other sites. The high frequency sounds from 3 am to 5 am are the dawn chorus of birds.

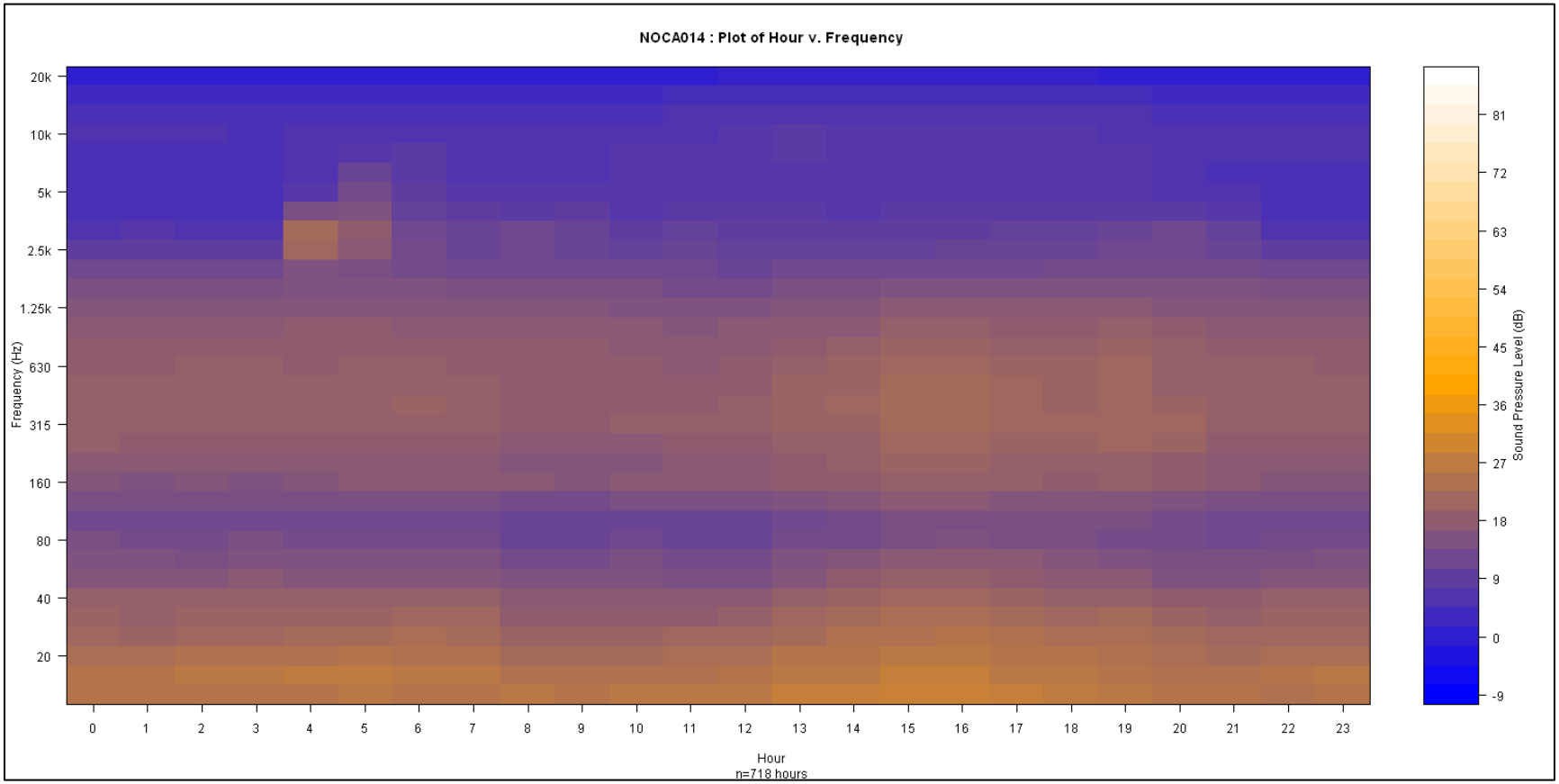

Figure 21. Big Beaver Valley spectral view.

Although it was a quiet site, vehicle traffic was still audible at Sourdough Mountain (Figure 22). This peak is shown in a slightly brighter orange color from 9 am to 6 pm. The high frequency sounds in the early morning and late evening hours are insects.

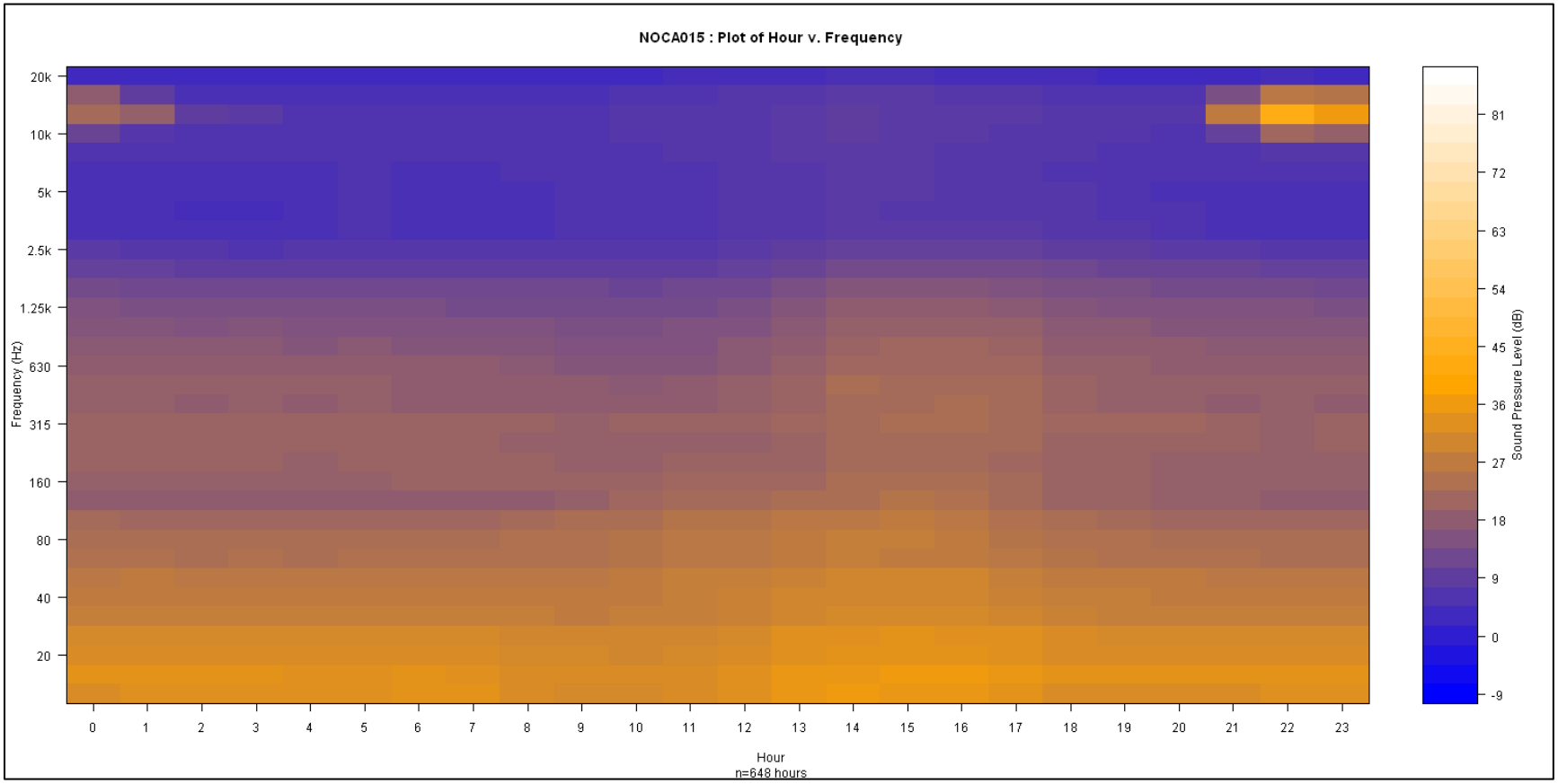

Figure 22. Sourdough Mountain spectral view.

While Park Creek Pass was the most remote site, it was not the quietest. The lower frequency band is due to aircraft, the mid frequency is due to wind. Like other high elevation backcountry sites, the high frequency sounds in the morning and evening are insects (Figure 23).

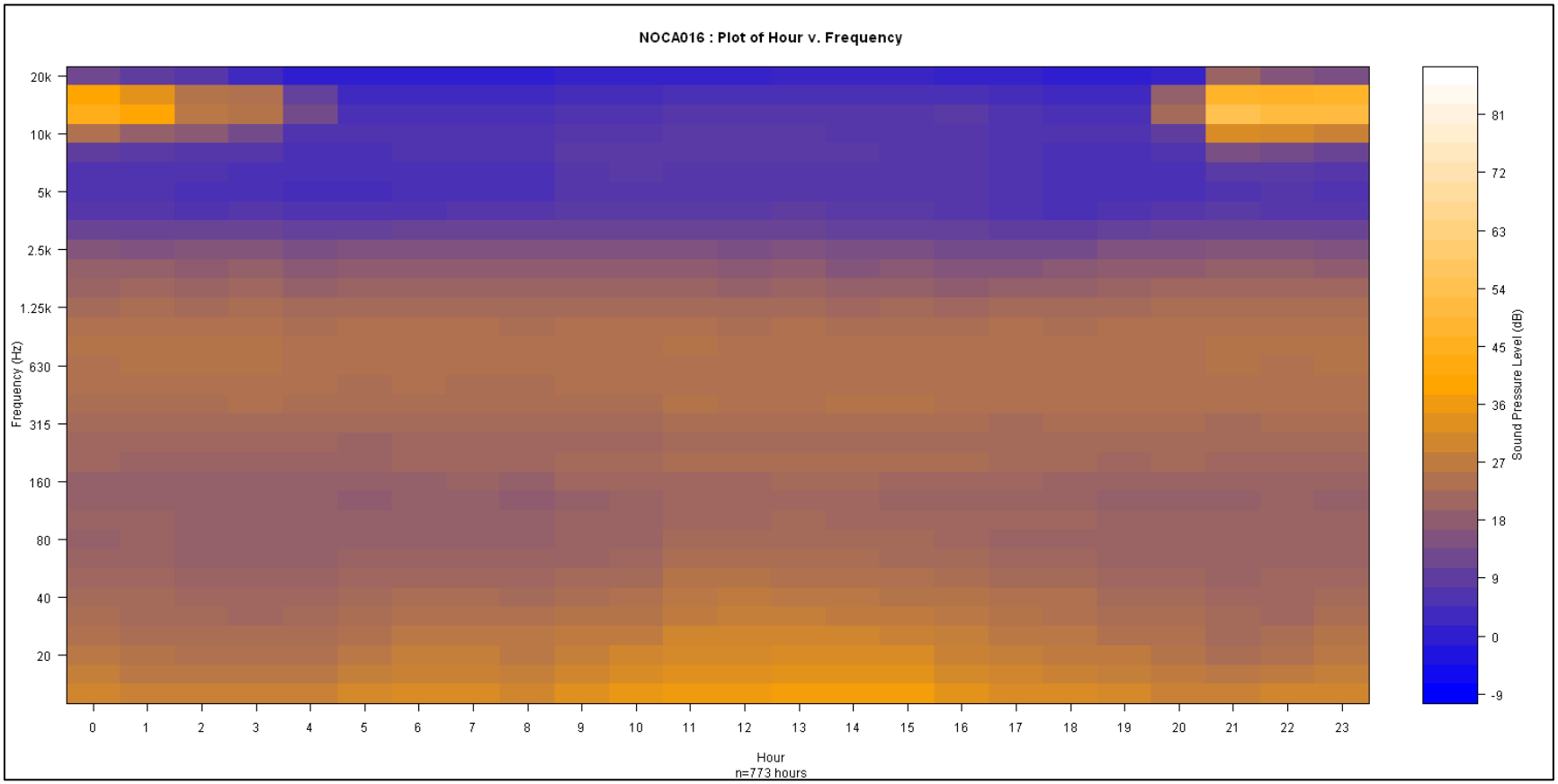

Figure 23. Park Creek Pass spectral view.

Dagger Lake is a very quiet backcountry site (Figure 24). Some aircraft noise was present during the late afternoon. The absence of insect activity may be due to the timing of site deployment in late August and September.

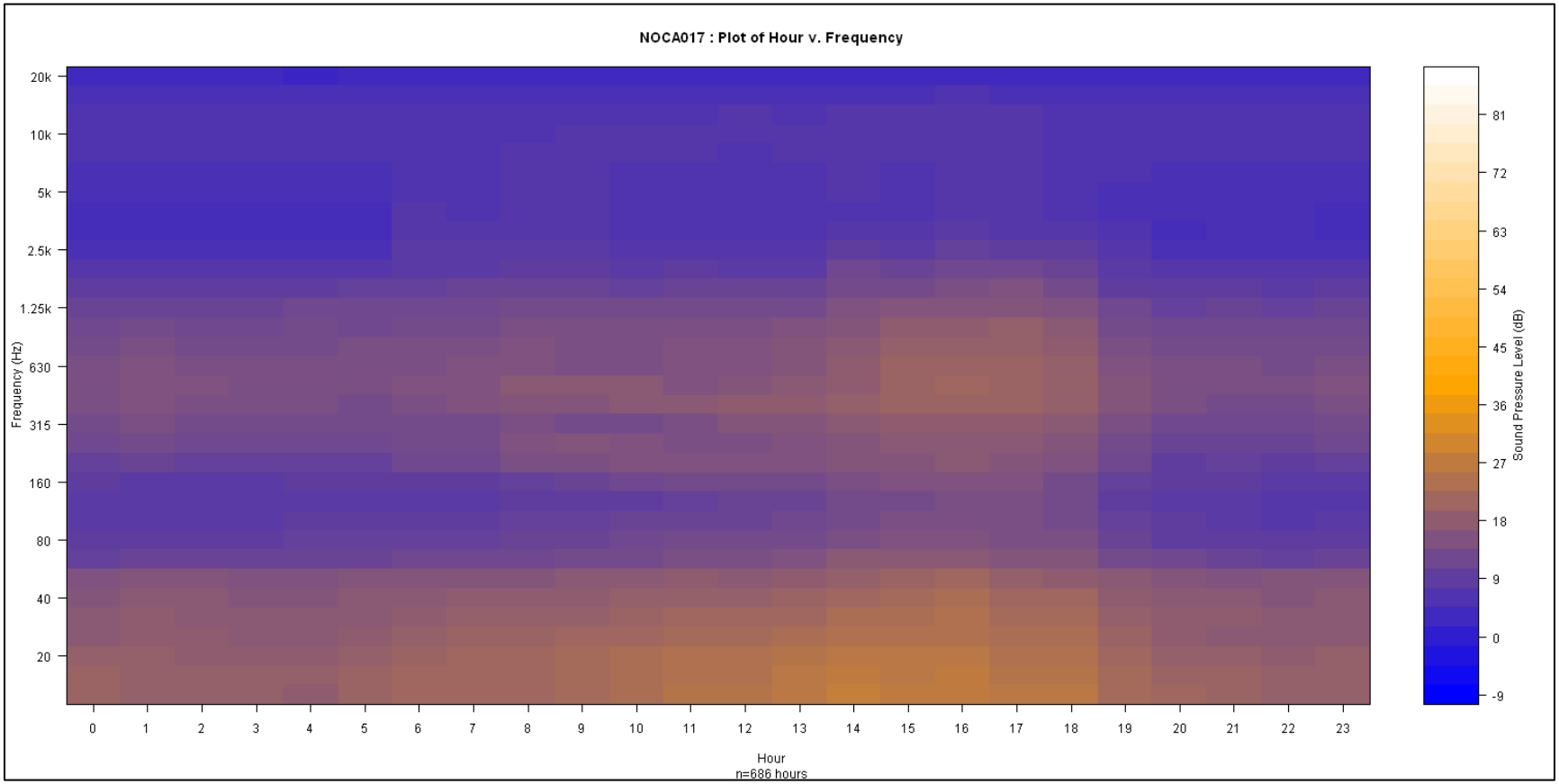

Figure 24. Dagger Lake spectral view.

The spectrogram of Sulphide Creek (Figure 25) shows high frequency sounds from dawn birdsong, along with large amounts of interference from water and wind.

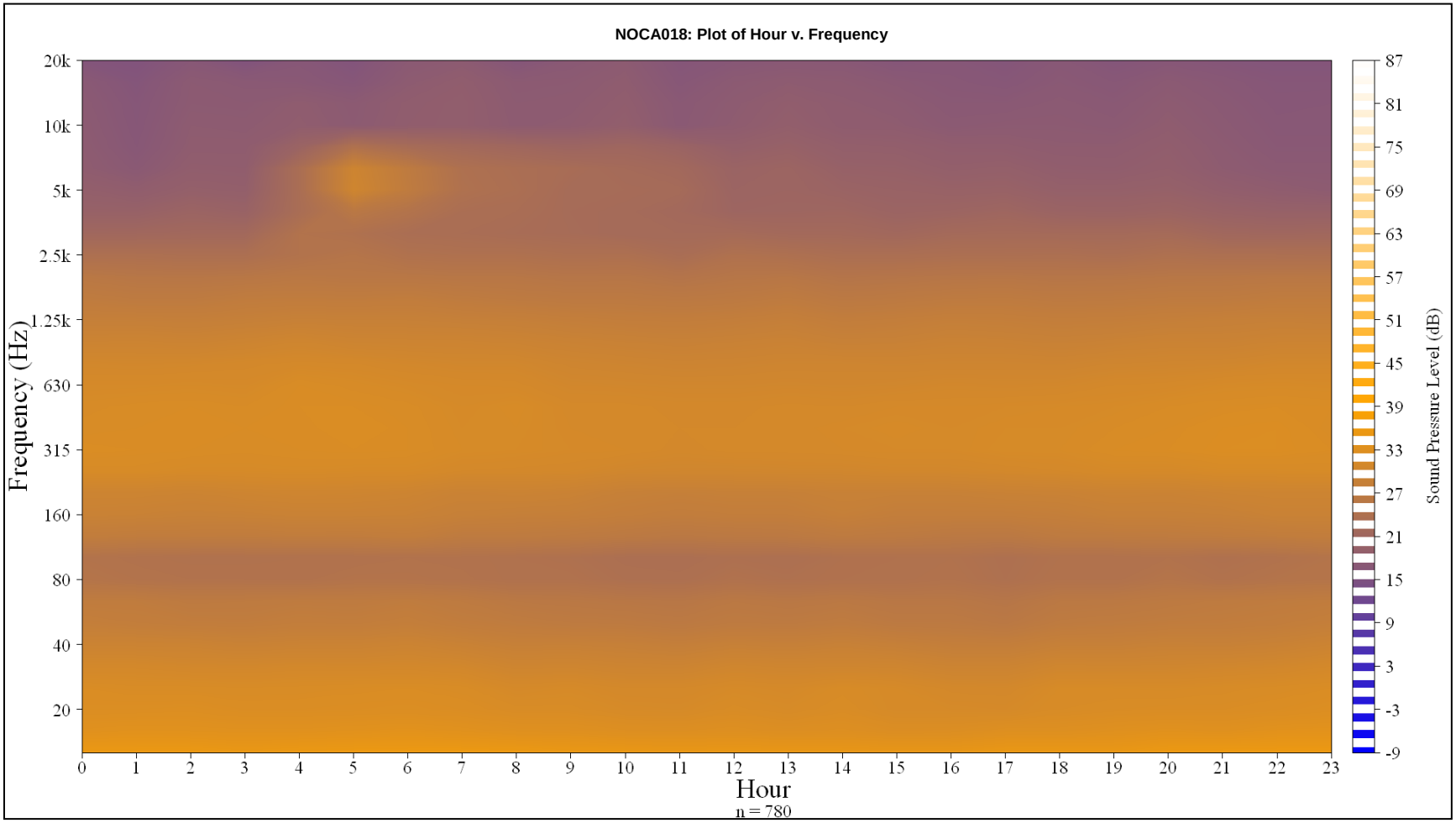

Figure 25. Sulphide Creek spectral view.

Beaver Pass was a quiet site (Figure 26). The low frequency sound is generated by flowing water, the mid-frequency by wind.

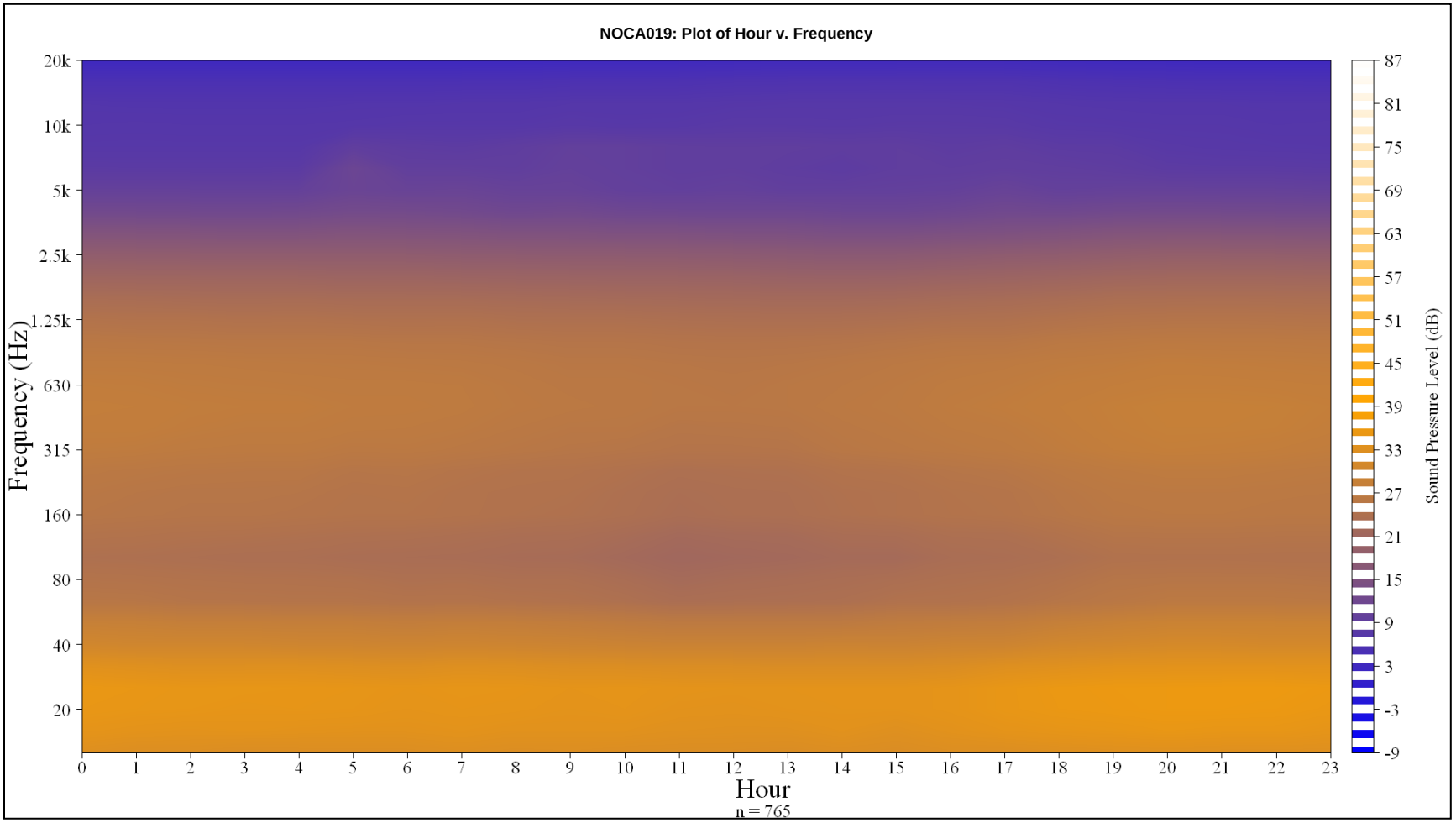

Figure 26. Beaver Pass spectral view.

The Stehekin Airstrip site (Figure 27) shows high sound levels in the low frequency range, due to both vehicle traffic and flowing water. Air traffic peaks slightly in midafternoon.

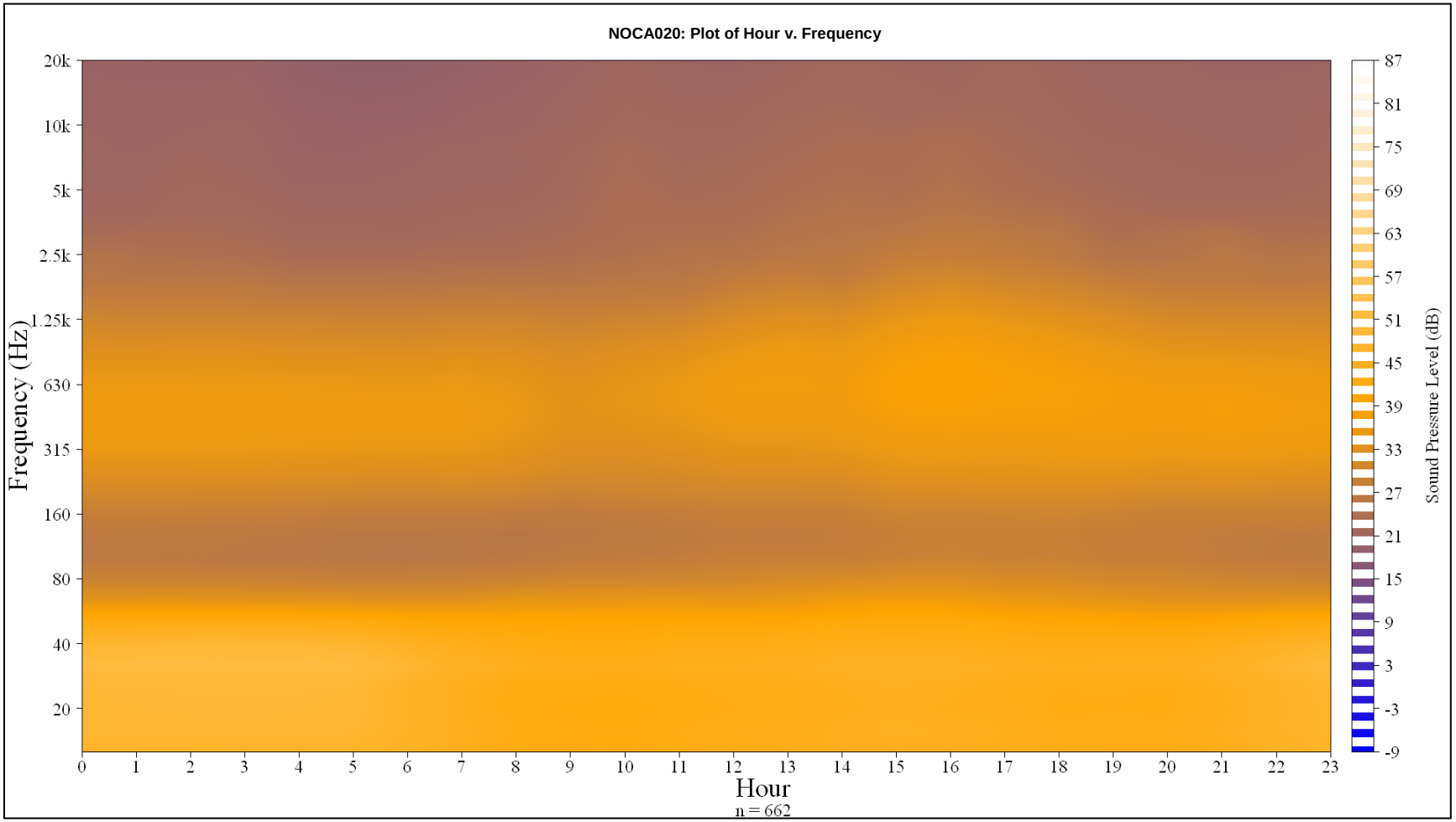

Figure 27. Stehekin Airstrip spectral view.

This spectrogram shows a fairly quiet site along the Thornton Lakes Trail (Figure 28), with some increased air traffic in the afternoon.

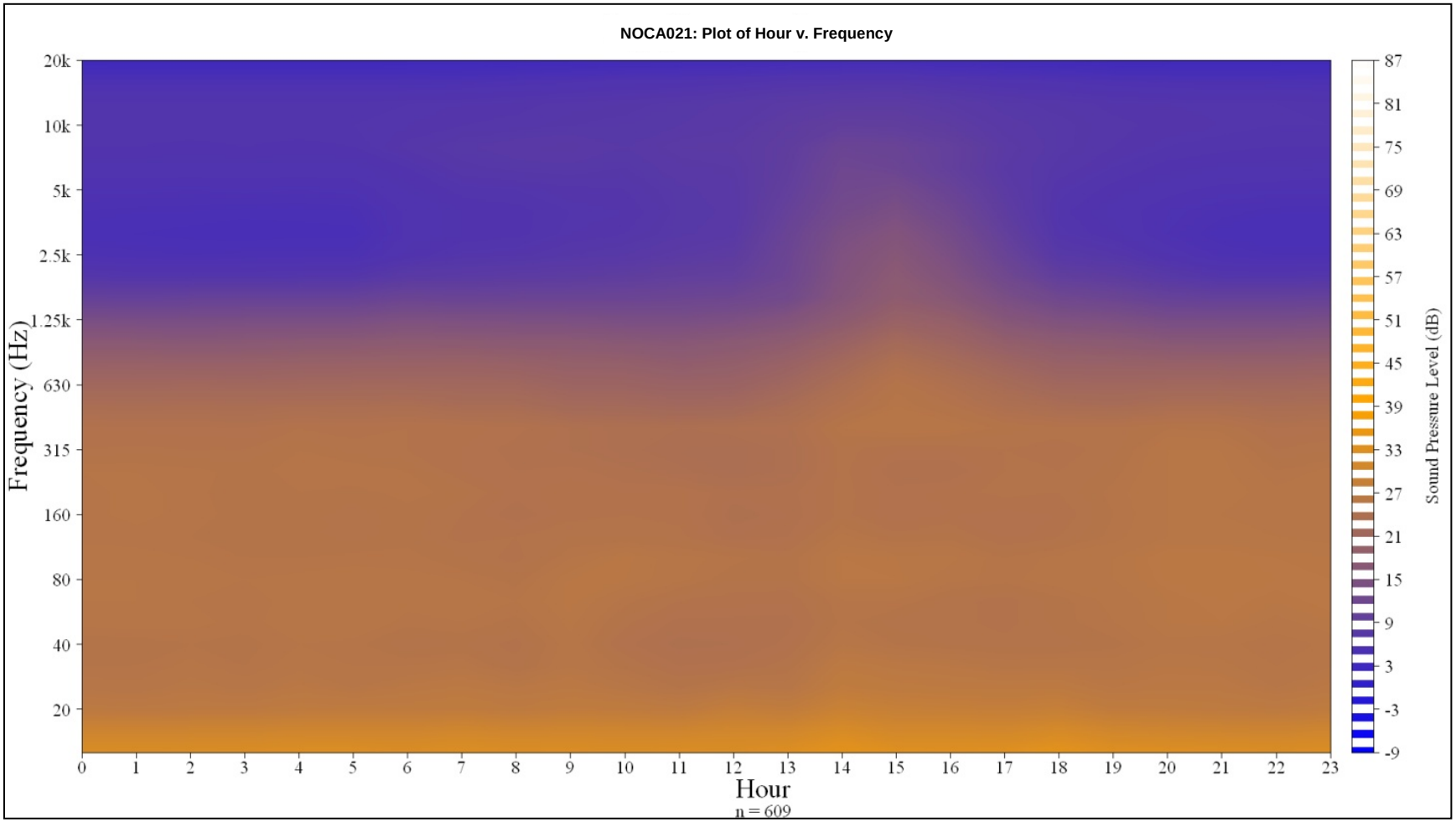

Figure 28. Thornton Lakes Trail spectral view.

Hourly Exceedence Metrics

Hourly exceedence metrics help to quantify the amount of extrinsic noise occurring at a site at different times of the day. Figures 29 through 42 are box plot diagrams that graphically depict the distribution of sound levels at each site. The sample minimum, or L_{90}, is the average minimum sound level for the monitoring period, and the sample maximum, or L_{10}, is the average maximum sound level for the monitoring period. These exceedence metrics are displayed as the whiskers at the bottom (L_{90}) and at the top (L_{10}) of the boxes. The existing ambient (or median) level for each hour is marked by the upper limit of the boxes while natural ambient levels (L_{nat}) are marked by the lower limit of the boxes. The height of the box is a measure of the contribution of human caused noise to the existing ambient sound levels per hour. Thus, the size of each box is directly related to the percent of time that human caused sounds are audible. When boxes do not appear, the natural and existing ambient levels were either very close to each other, or equal for that hour. It is important to note that the decibel level scale on the y-axis varies between charts.

At Newhalem, the peaks in L_{10} values correspond to high amounts of vehicle traffic mid-day (Figure 29). The absence of an L_{90} value indicates that L_{90} is equal to the natural ambient level.

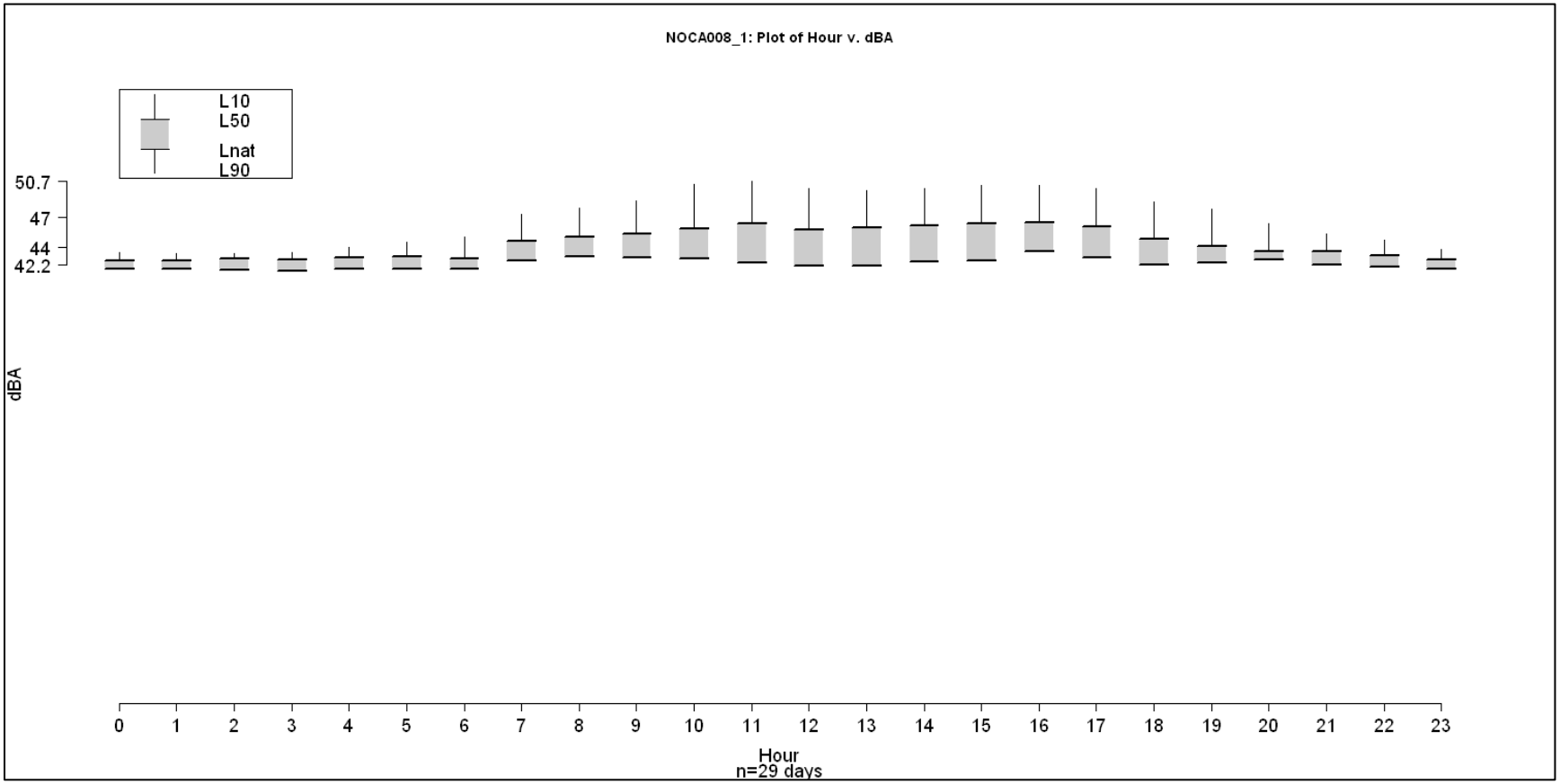

Figure 29. Newhalem median hourly exceedence levels.

For most hours at Rainbow Loop, median natural sound levels were very close to natural sound levels (Figure 30). The highest exceedence of natural sound levels occurred at 1:00 pm, which corresponds to aircraft overflights.

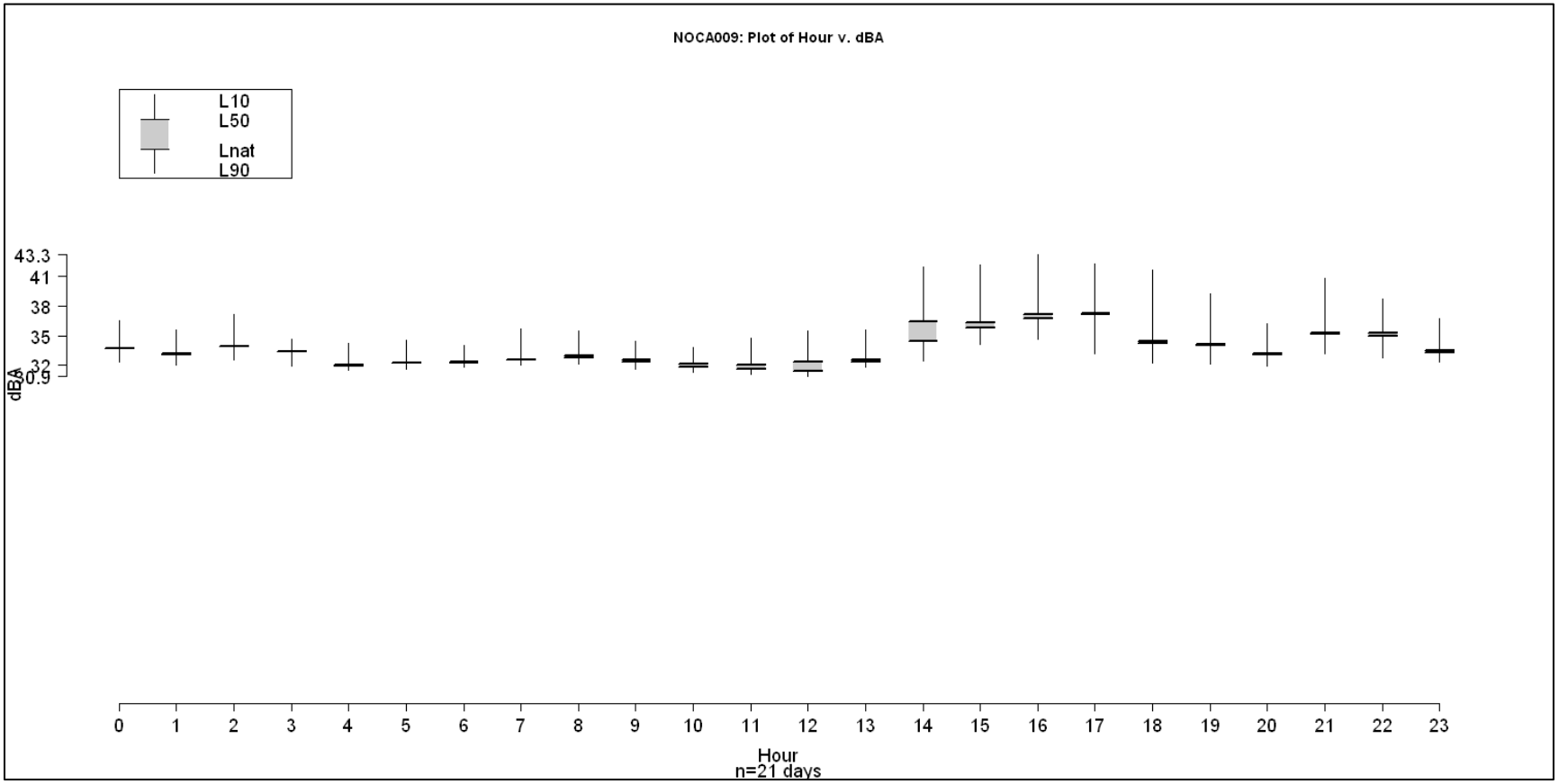

Figure 30. Rainbow Loop median hourly exceedence levels.

As expected in a backcountry site, the exceedence levels peak at Easy Pass in the midafternoon hours due to overflights (Figure 31).

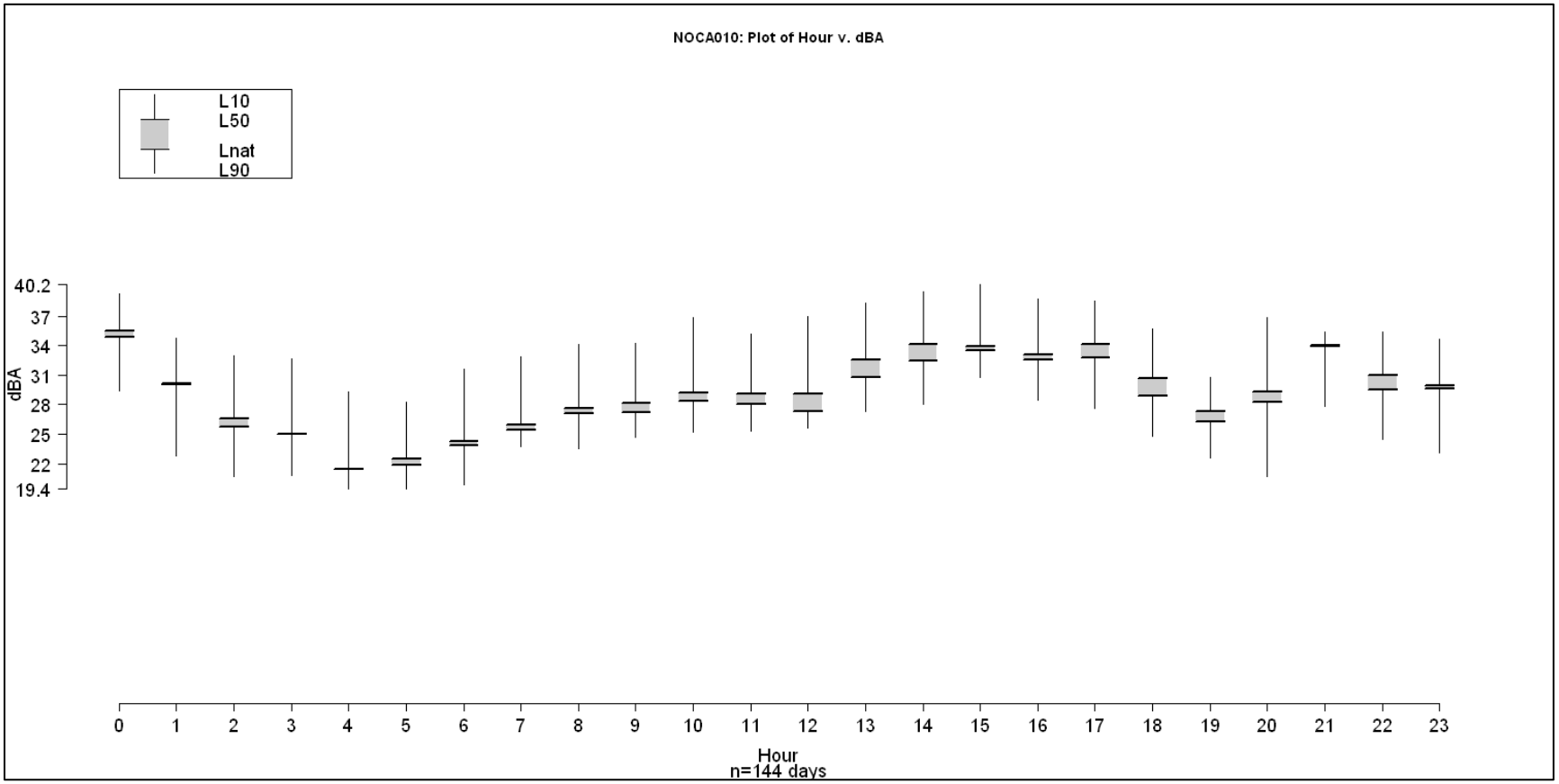

Figure 31. Easy Pass median hourly exceedence levels.

Colonial Creek Campground is a busy area during the day. The peaks in L_{50} and L_{10} values show the rise in non-natural sounds during daytime hours (Figure 32). L_{90} values are absent during the midday hours, showing that non-natural sounds were apparent 100 percent of the time during these hours.

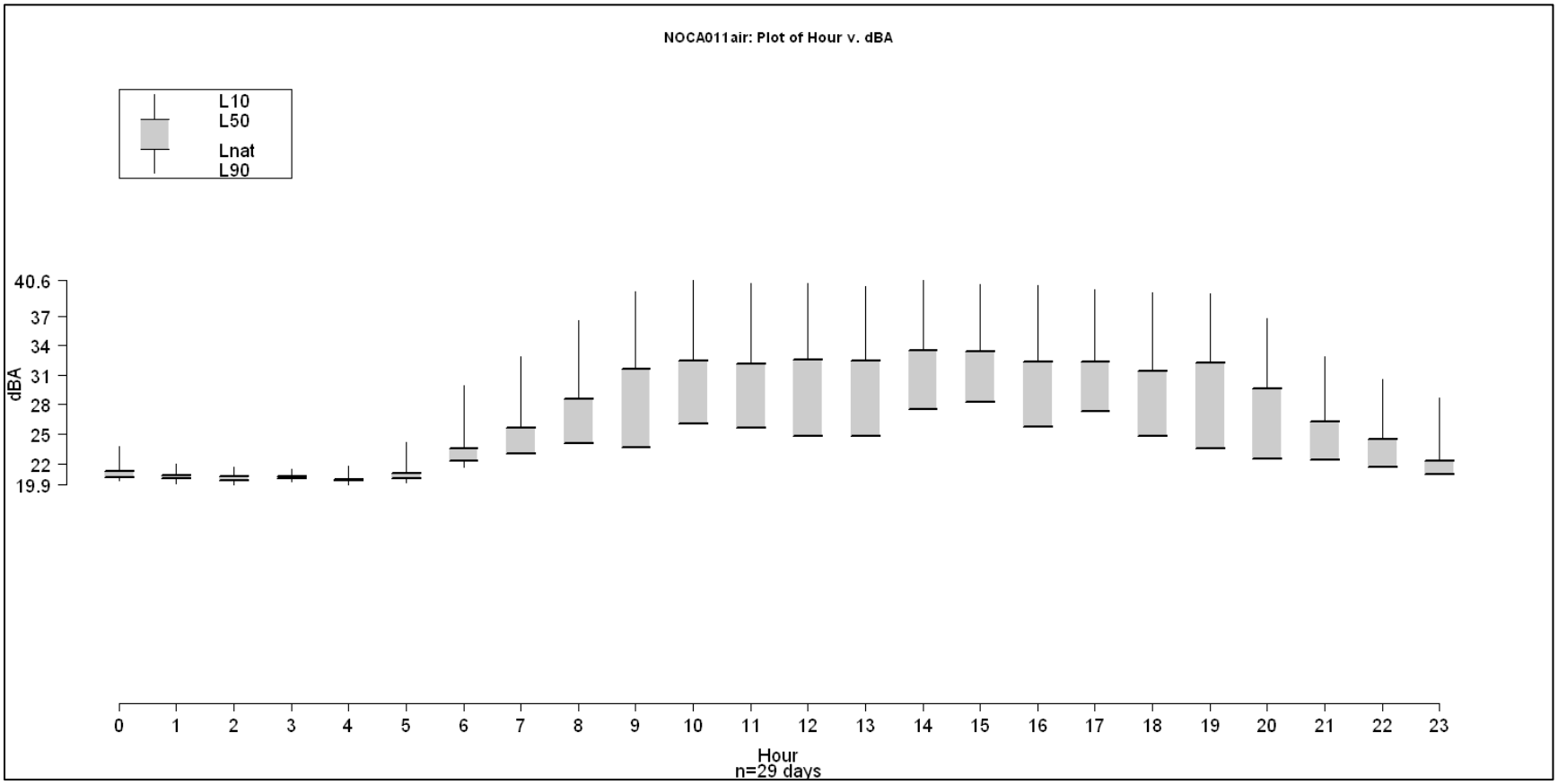

Figure 32. Colonial Creek Campground hourly exceedences.

While the Ross Dam Trailhead site shows a peak in L_{10} values during the midafternoon, corresponding to aircraft overflights, L_{90} values are not present, due to the constant noise from the dam (Figure 33).

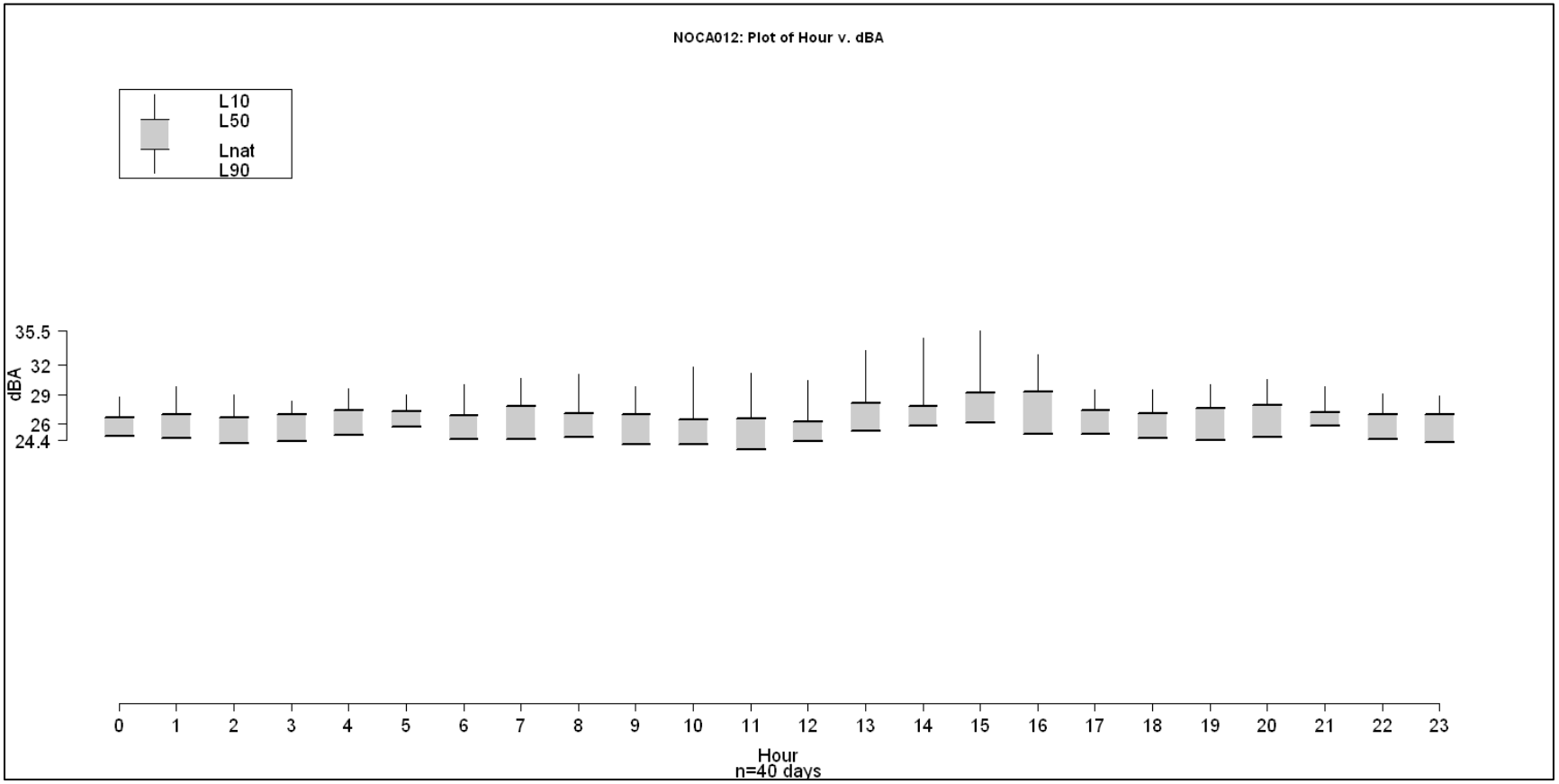

Figure 33. Ross Dam Trailhead median hourly exceedence levels.

At the Thunder Knob site a gradual increase of L_{50} values in the midafternoon corresponds to traffic on SR 20 (Figure 34). The late night peak corresponds to insect sounds.

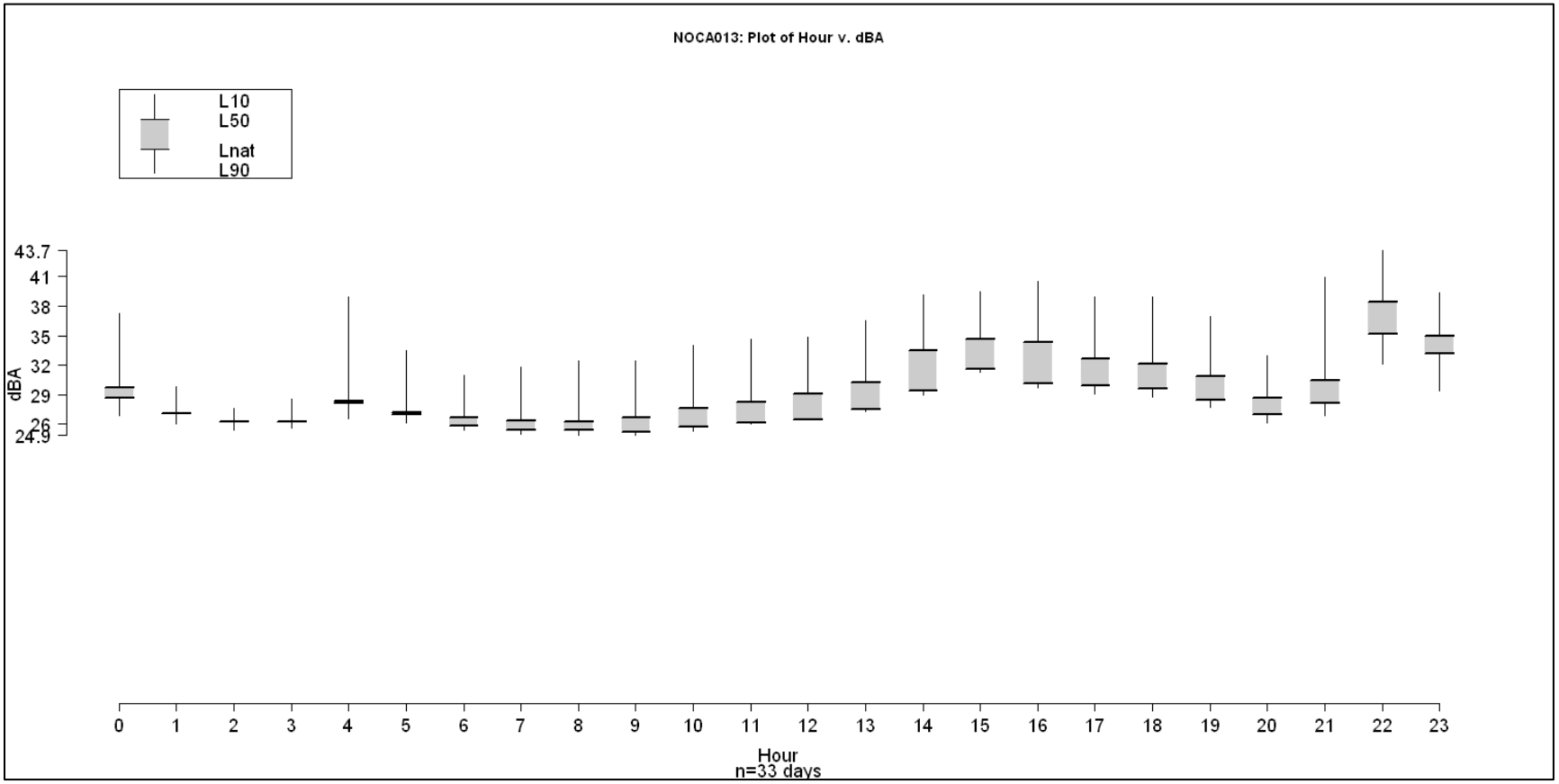

Figure 34. Thunder Knob median hourly exceedence levels.

The Big Beaver Valley site located in the backcountry shows little influence from aircraft overflights, and is a very quiet site overall (Figure 35). Birdsong is evident starting at 4 a.m.

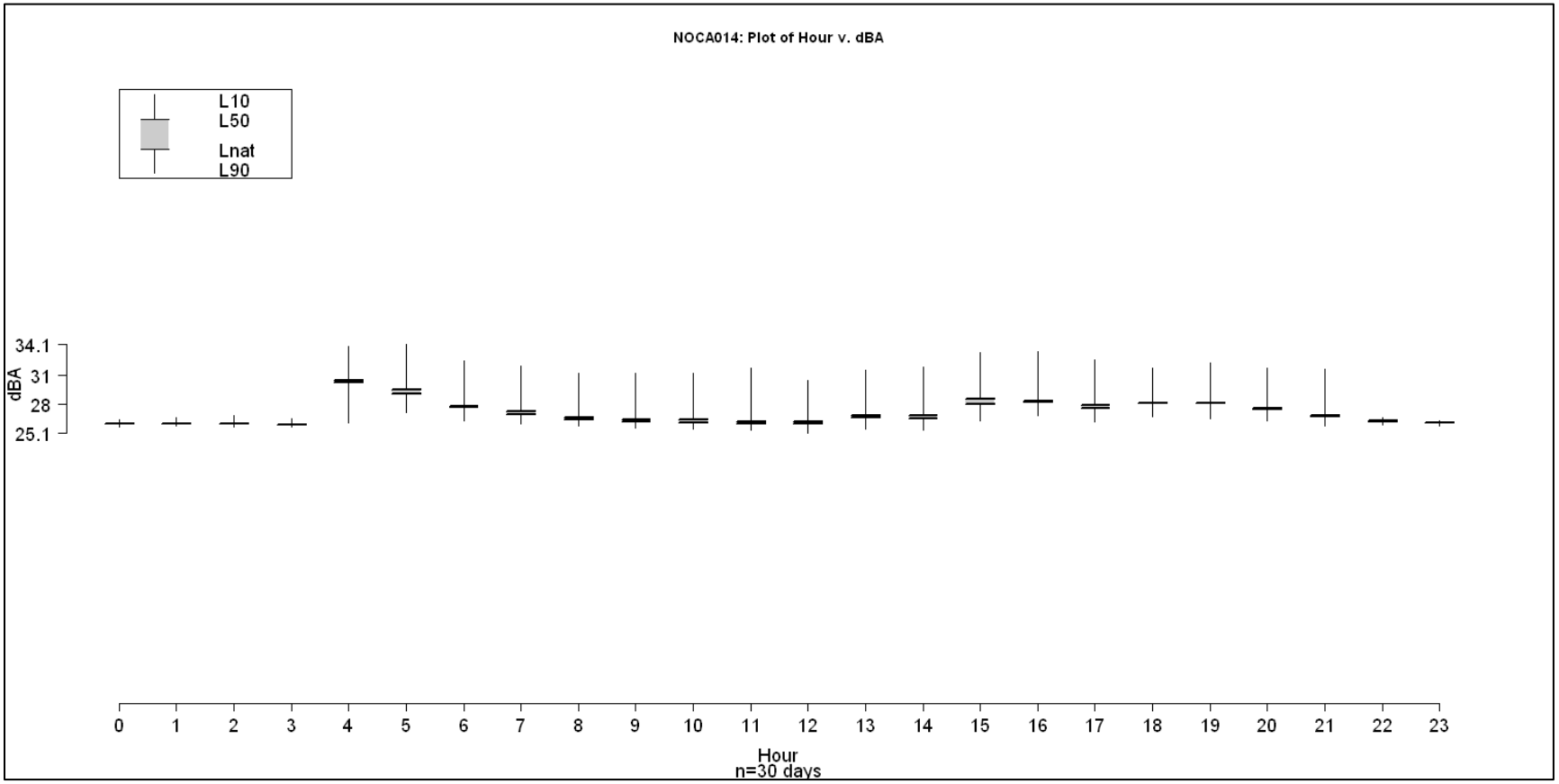

Figure 35. Big Beaver Valley median hourly exceedence levels.

A rise in L_{50} and L_{10} values in the midafternoon hours at Sourdough Mountain corresponds to vehicles and air traffic (Figure 36). The late evening spike corresponds to insect sounds.

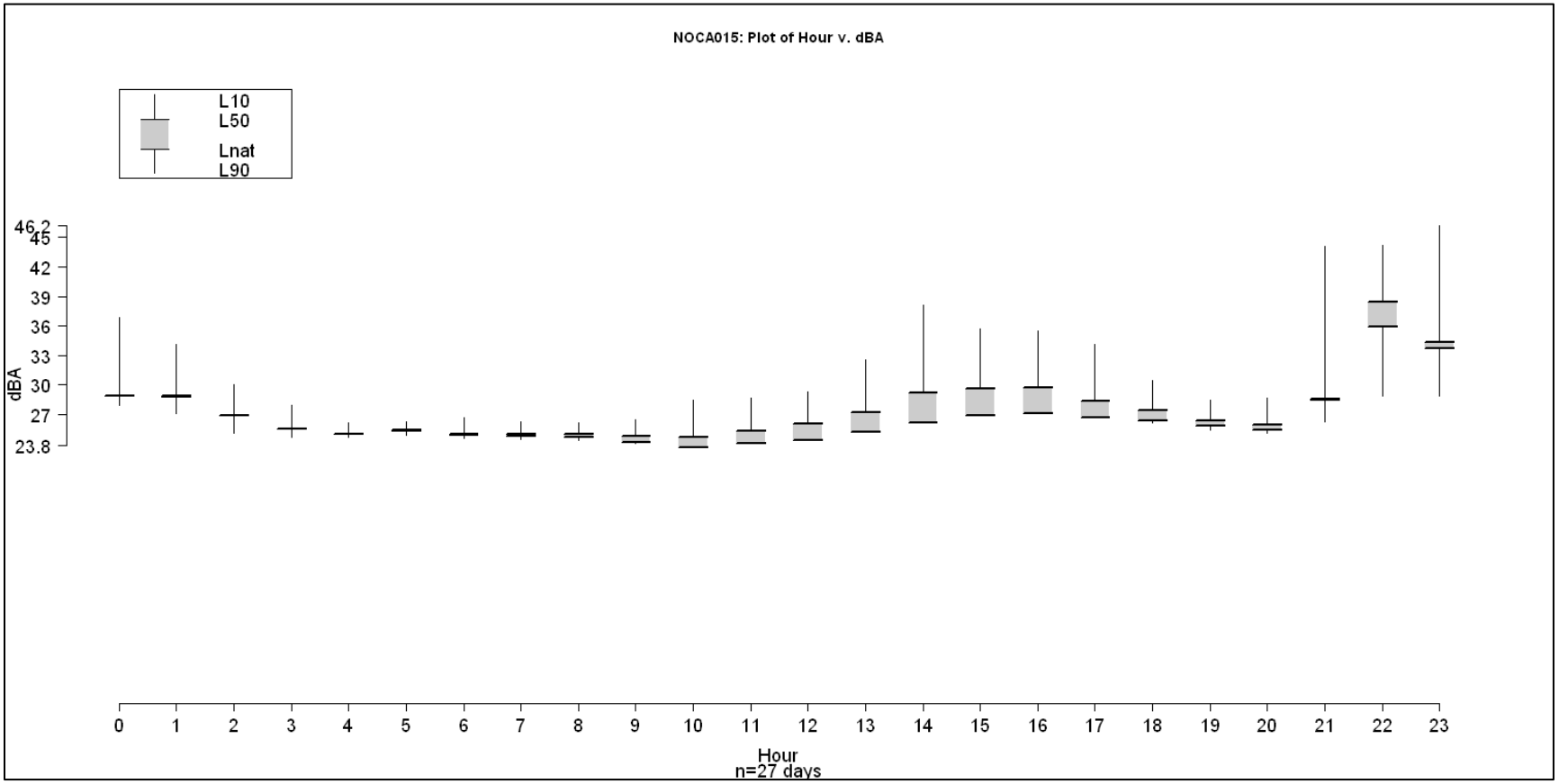

Figure 36. Sourdough Mountain median hourly exceedence levels.

The Park Creek Pass site is mostly unaffected by non-natural sounds (Figure 37). The late night peak corresponds to insect sounds.

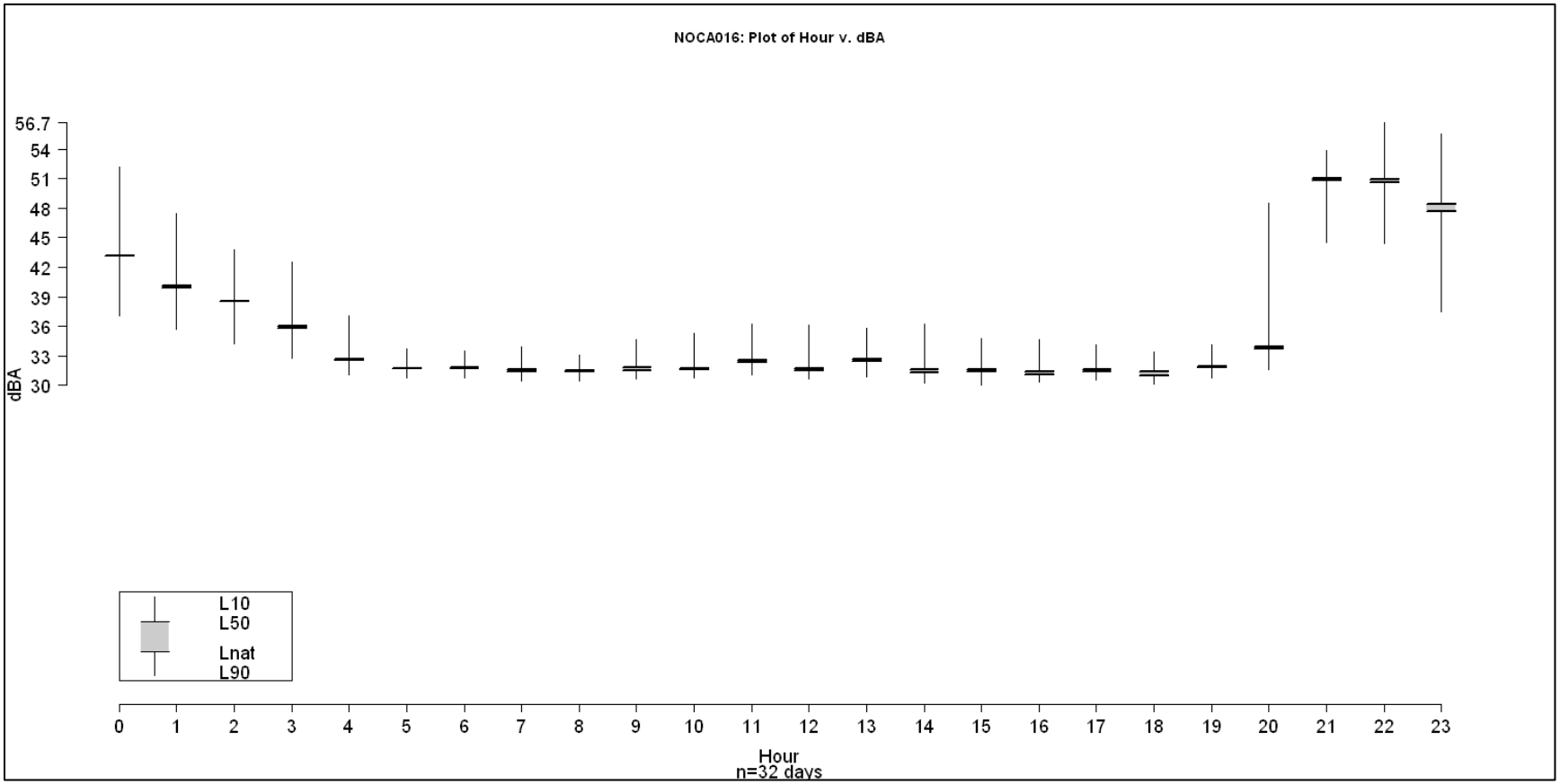

Figure 37. Park Creek Pass median hourly exceedence levels.

The Dagger Lake site has some increase in exceedence levels in the midafternoon hours due to aircraft overflights (Figure 38).

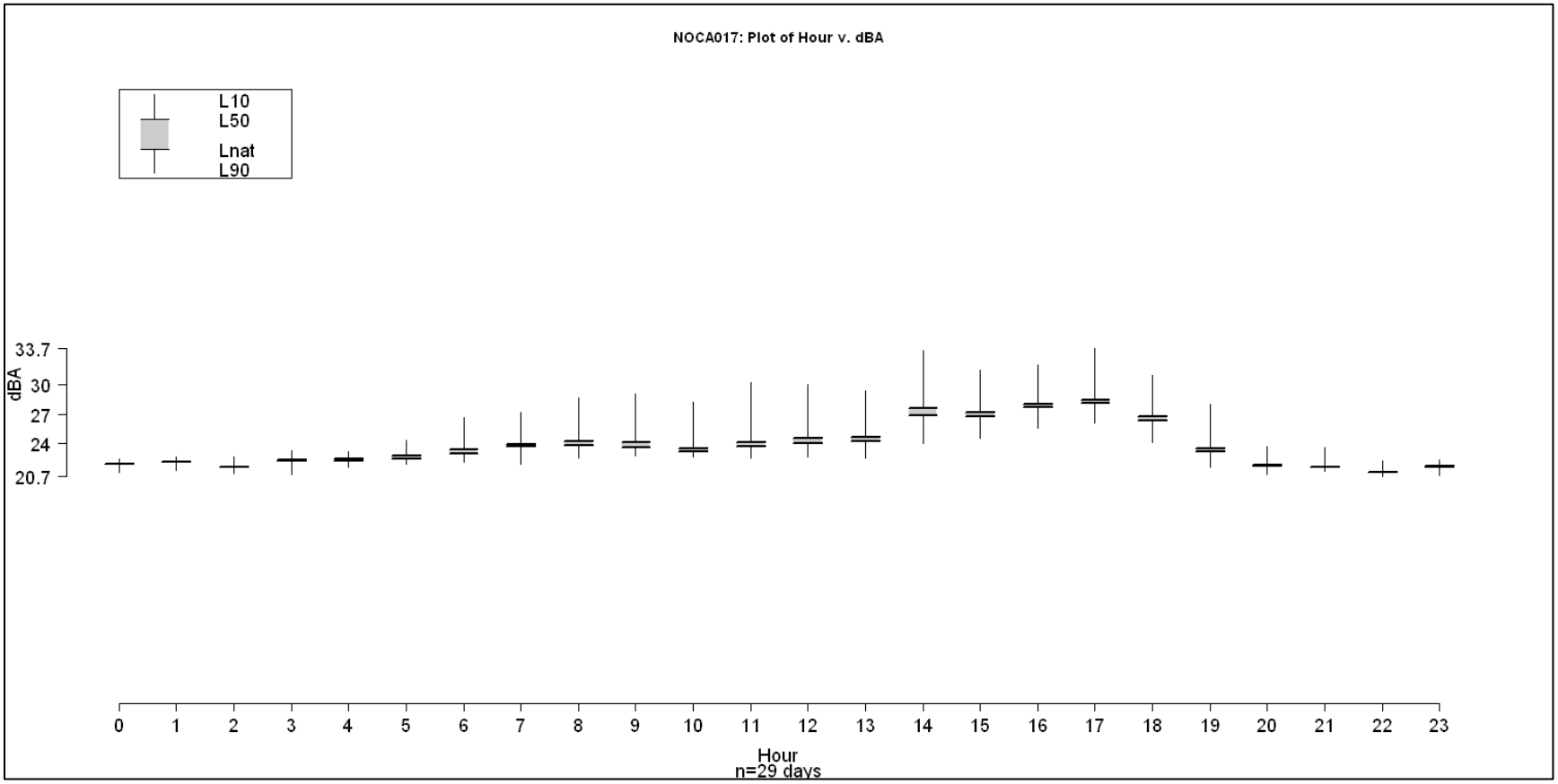

Figure 38. Dagger Lake hourly median hourly exceedence levels.

The Sulphide Creek site has a minimal increase in exceedence levels in the midafternoon hours, due to aircraft overflights (Figure 39). Birdsong is evident at 4 a.m.

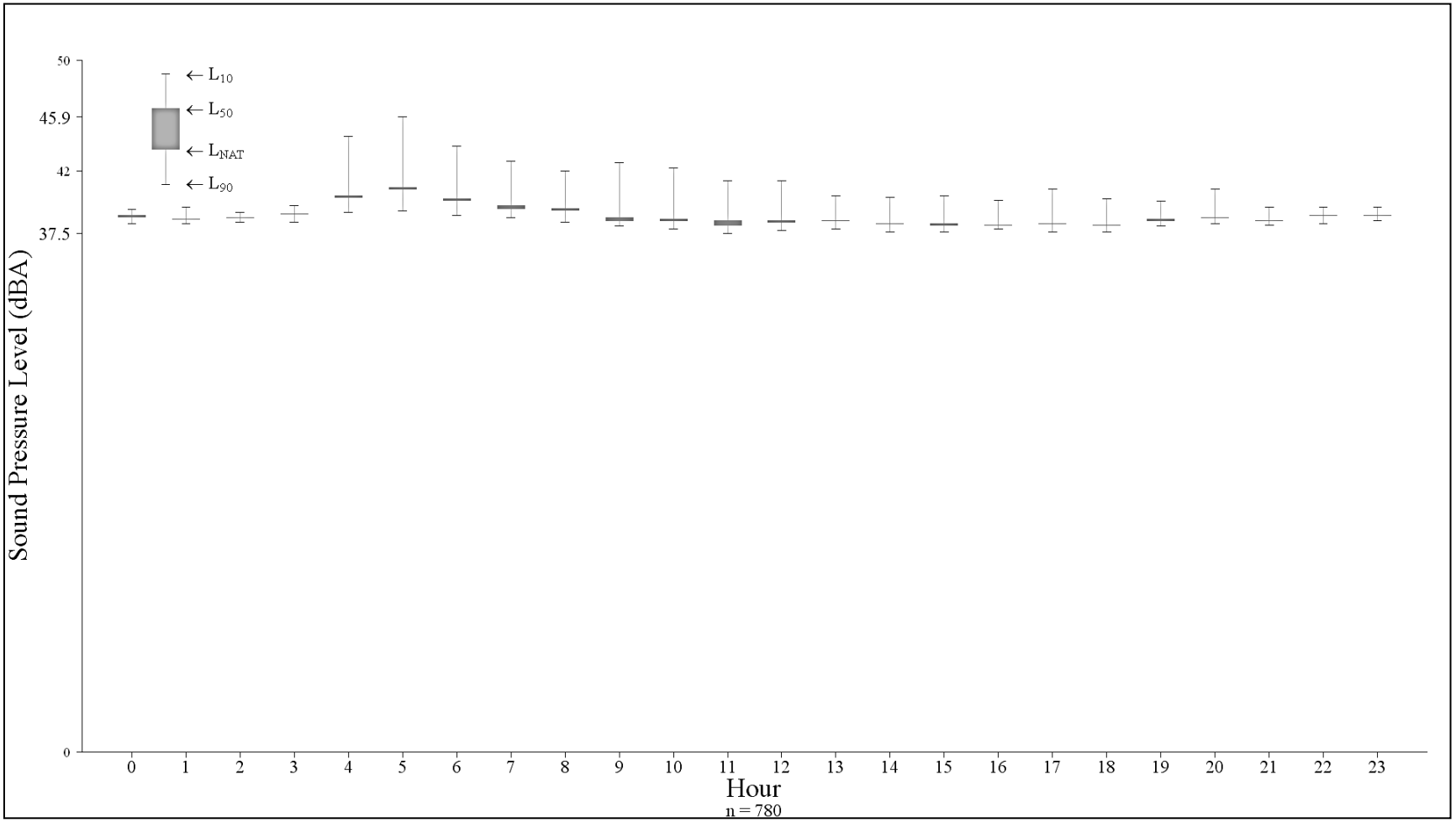

Figure 39. Sulphide Creek median hourly exceedence levels.

The Beaver Pass site was essentially unaffected by extrinsic sounds (Figure 40). Sound levels also remained fairly consistent throughout the day.

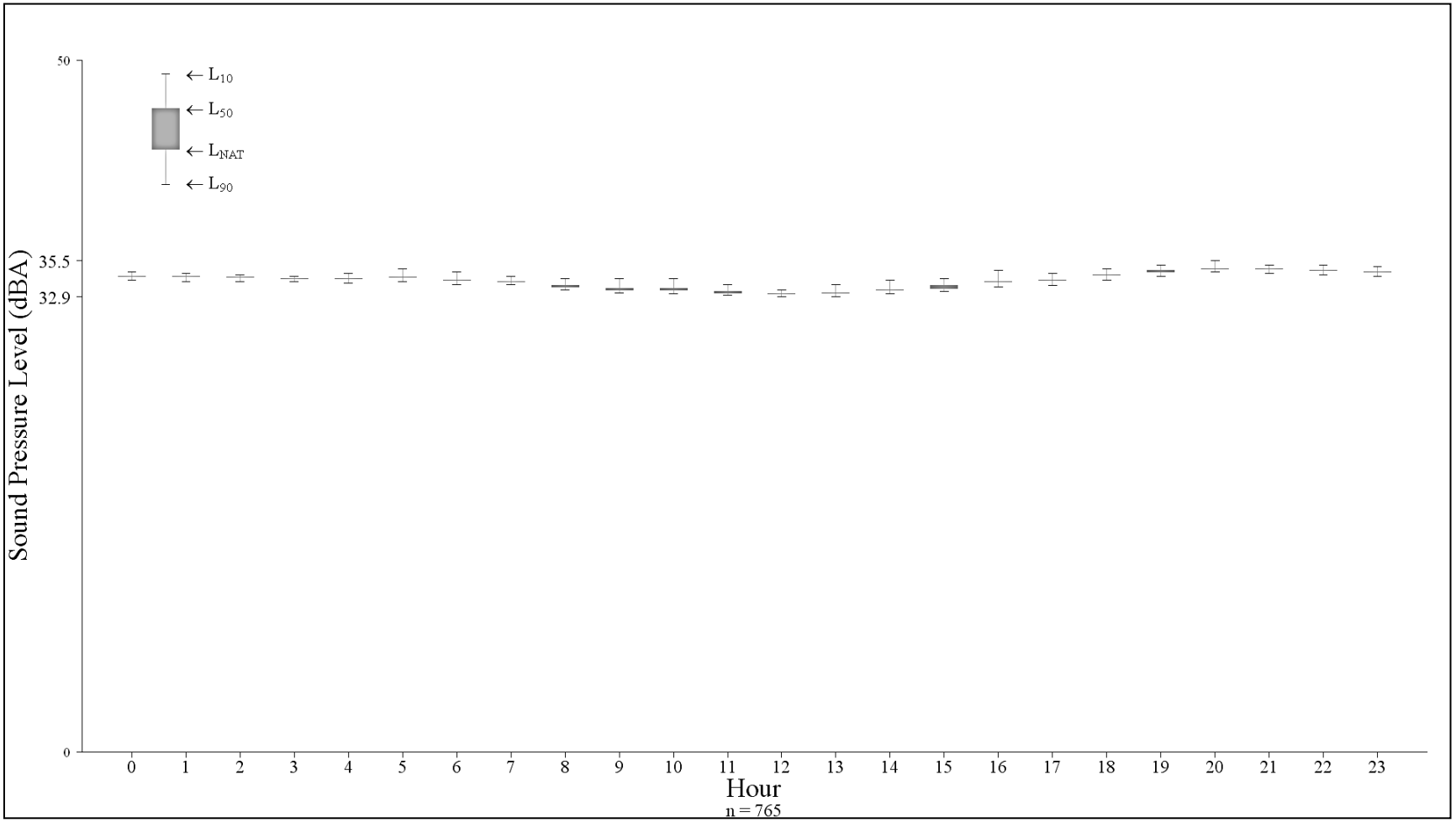

Figure 40. Beaver Pass median hourly exceedence levels.

The Stehekin Airstrip shows a marked increase in exceedence levels in the daytime due to vehicles and air traffic (Figure 41).

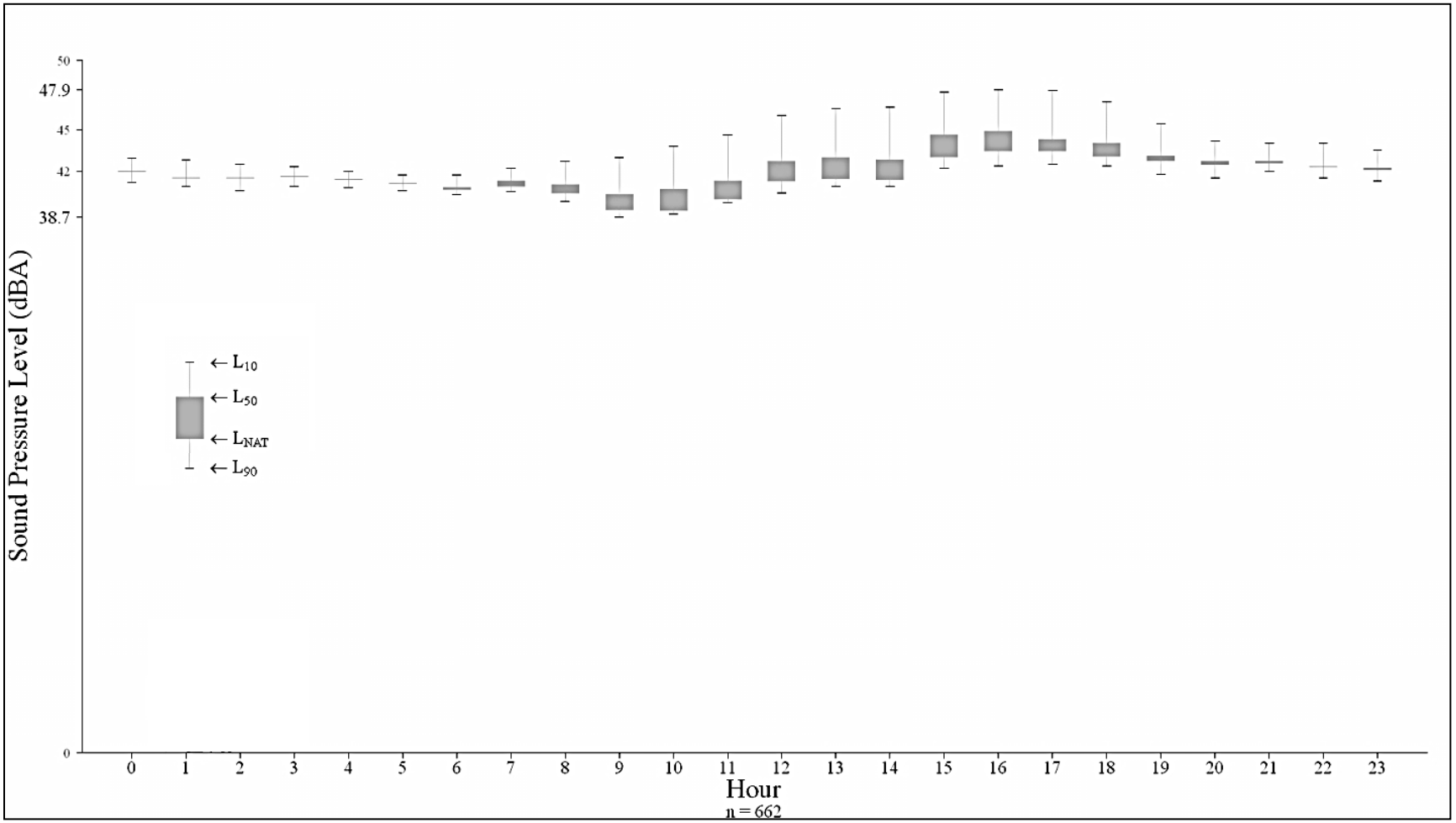

Figure 41. Stehekin Airstrip median hourly exceedence levels.

At the Thornton Lakes Trail site, higher exceedence values are seen mid-afternoon, due to vehicles and air traffic (Figure 42).

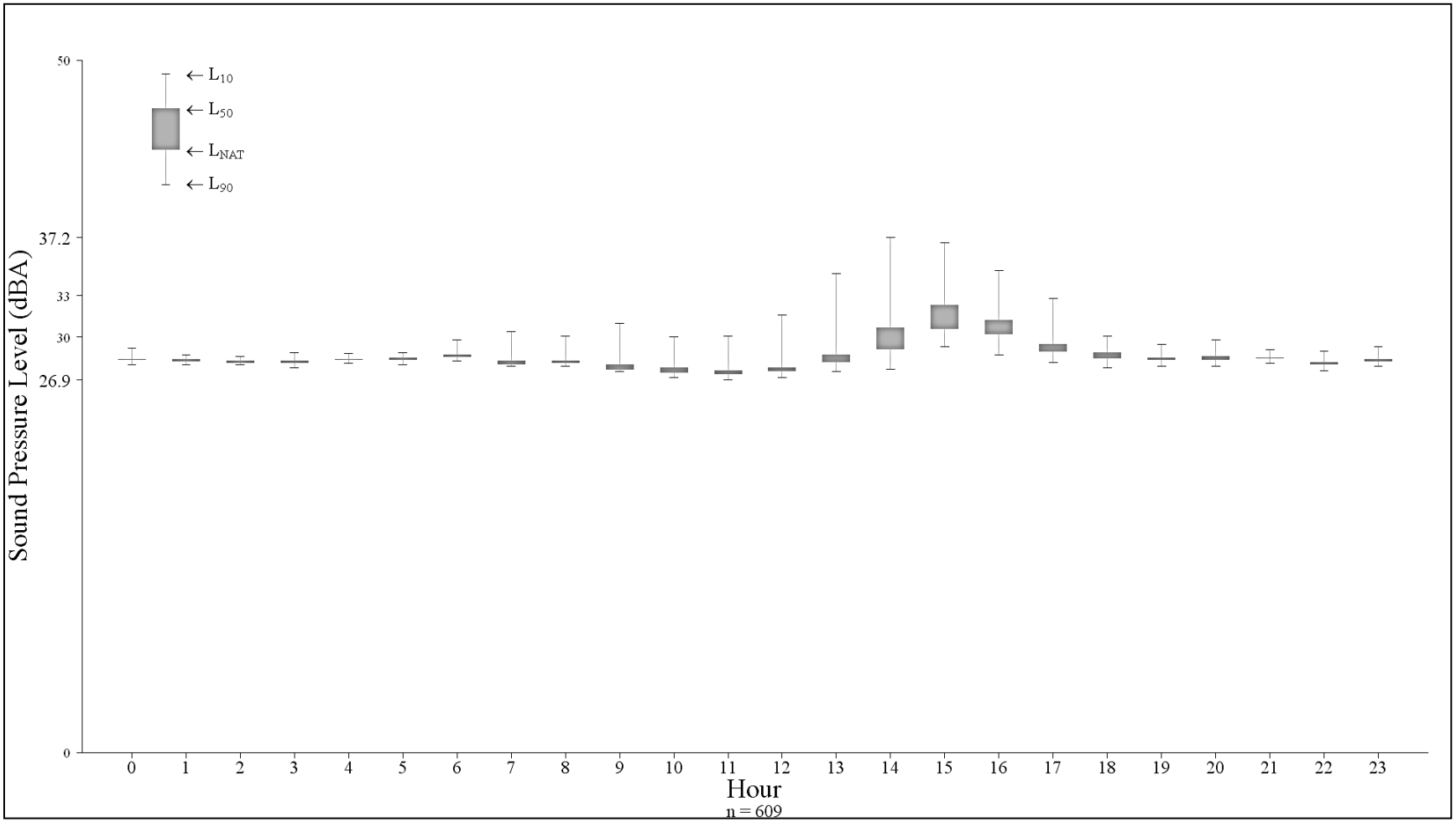

Figure 42. Thornton Lakes Trail median hourly exceedence levels.

Day and Night Decibel Levels for 33 One-third Octave Bands

Figures 43 through 56 help to distinguish between higher and lower frequency sounds by dividing the full frequency spectrum into 33 smaller frequency bands (each encompassing a one-third octave range), and by plotting the daytime and nighttime sound pressure level range for each band. The gray area in the background of each graph represents sound pressure levels outside the typical range of human hearing. The exceedence levels (L_x) are also shown for each one-third octave band. Similar to the previous section, they represent the decibel level exceeded x percent of the time. For example, L_{90} is the decibel level that has been exceeded 90% of the time, and only the quietest 10% of the samples can be found below this point. On the other hand, the L_{10} is the decibel level that has been exceeded 10% of the time, and 90% of the measurements are quieter than the L_{10}. The L_{10} and L_{90} essentially mark the maximum and minimum sound pressure levels, respectively, over the 30-day monitoring period.

The bold portion of each column represents the difference between L_{50} (existing ambient) and L_{nat} (natural ambient). The height of this bold portion is a measure of the contribution of anthropogenic noise to the existing ambient sound level at each site. The size of this portion of the column is directly related to the percent of time that human caused sounds were audible. When bold portions of the column are absent, the natural and existing ambient levels were either very close to each other, or were equal.

The typical frequency ranges for transportation, conversation, and songbirds are presented on each figure as examples for interpretation of the data. These ranges are estimates and are not vehicle, species, or habitat specific. However, the high levels at the lowest octave ranges are most likely due to the presence of human caused sounds. While these sounds are inaudible to the human ear, they would be audible to some wildlife species. Contributions of songbirds were often prominent in daytime hours, and nighttime sound levels in the same frequencies were often much quieter. There were, however, some sites that higher nighttime sound levels in the very high (mostly inaudible) frequencies, which can be attributed to insects. Other sites also had higher nighttime sound levels in the lower frequencies, which can be attributed to nighttime peak flows in nearby streams.

It can be useful to review each one-third octave band to predict the audibility of one sound or the masking of another. For example, notice that songbirds and transportation noise are audible at different frequency spectrums. There may be times when transportation sounds are louder than the songbirds. In this case, bird sounds would not be masked because their song is audible at a different frequency. However, when there are sounds that are within similar or overlapping frequency ranges, with one sound louder than the other, the quieter sound could be masked.

It is important to note that the decibel level scale on the y-axis varies between charts.

At the Newhalem site, the peak in decibel levels at the lowest end of the audible spectrum is due to the constant hum from power generation and transmission at the site (Figure 43). At this frequency (50 Hz), nighttime sound levels are higher than daytime sound levels, with natural ambient (L_{nat}) sound levels considerably higher at night. This chart also illustrates the fact that L_{90} values are absent, meaning that the L_{nat} is equal to the minimum sound pressure level at the site, i.e., the decibel level that is exceeded 90% of the time.

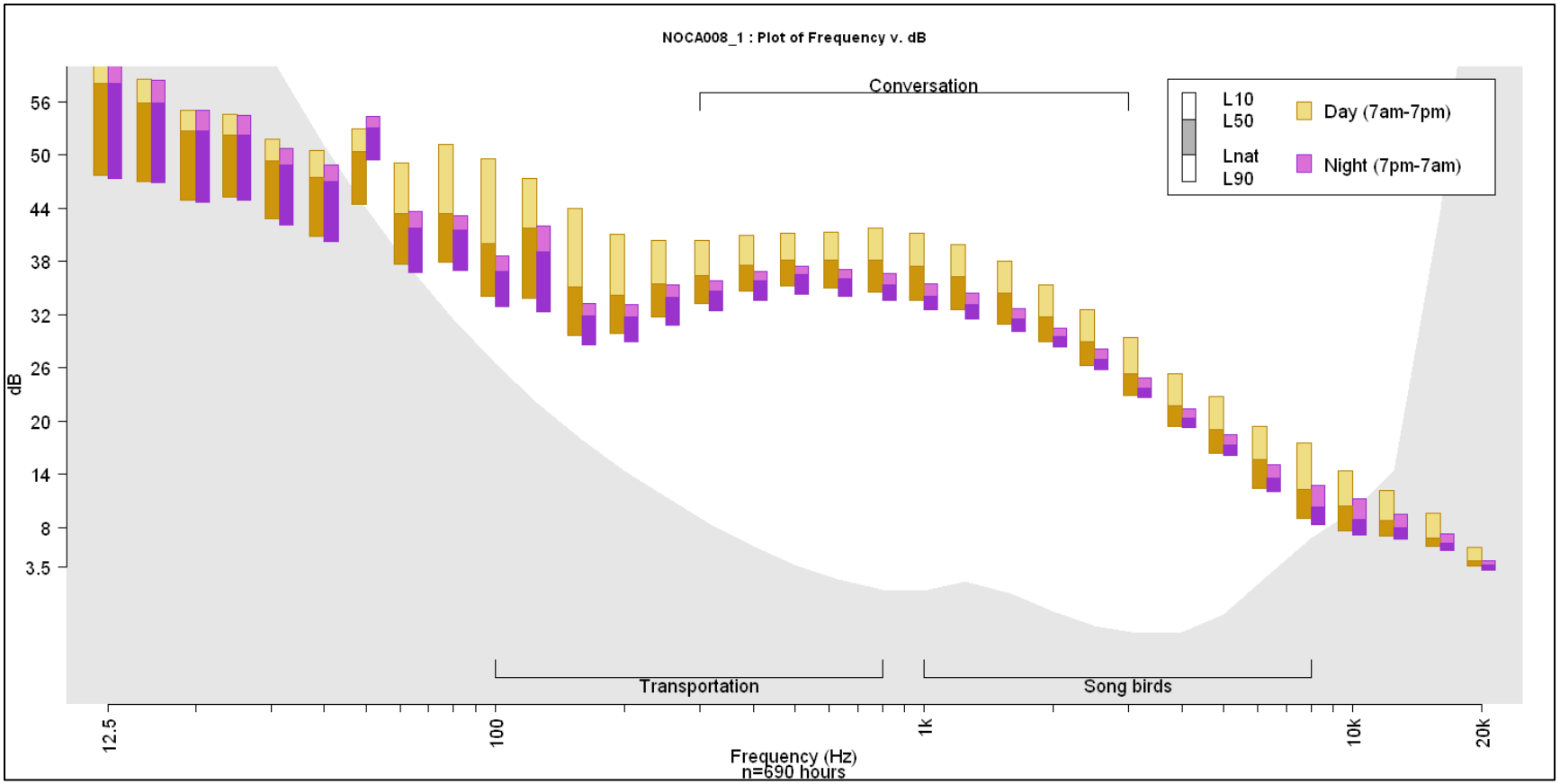

Figure 43. Day and night dB levels for 33 one-third octave bands at Newhalem.

At the Rainbow Loop site, the bold portion of each box is very small, indicating very little difference between natural and existing ambient sound levels (Figure 44). Daytime sound levels in the 100 to 200 Hz frequency range are likely due to air traffic noise, while sound levels in the 3,000 to 8,000 Hz are due to song birds. Higher nighttime sound levels in the high frequency range are likely due to insects.

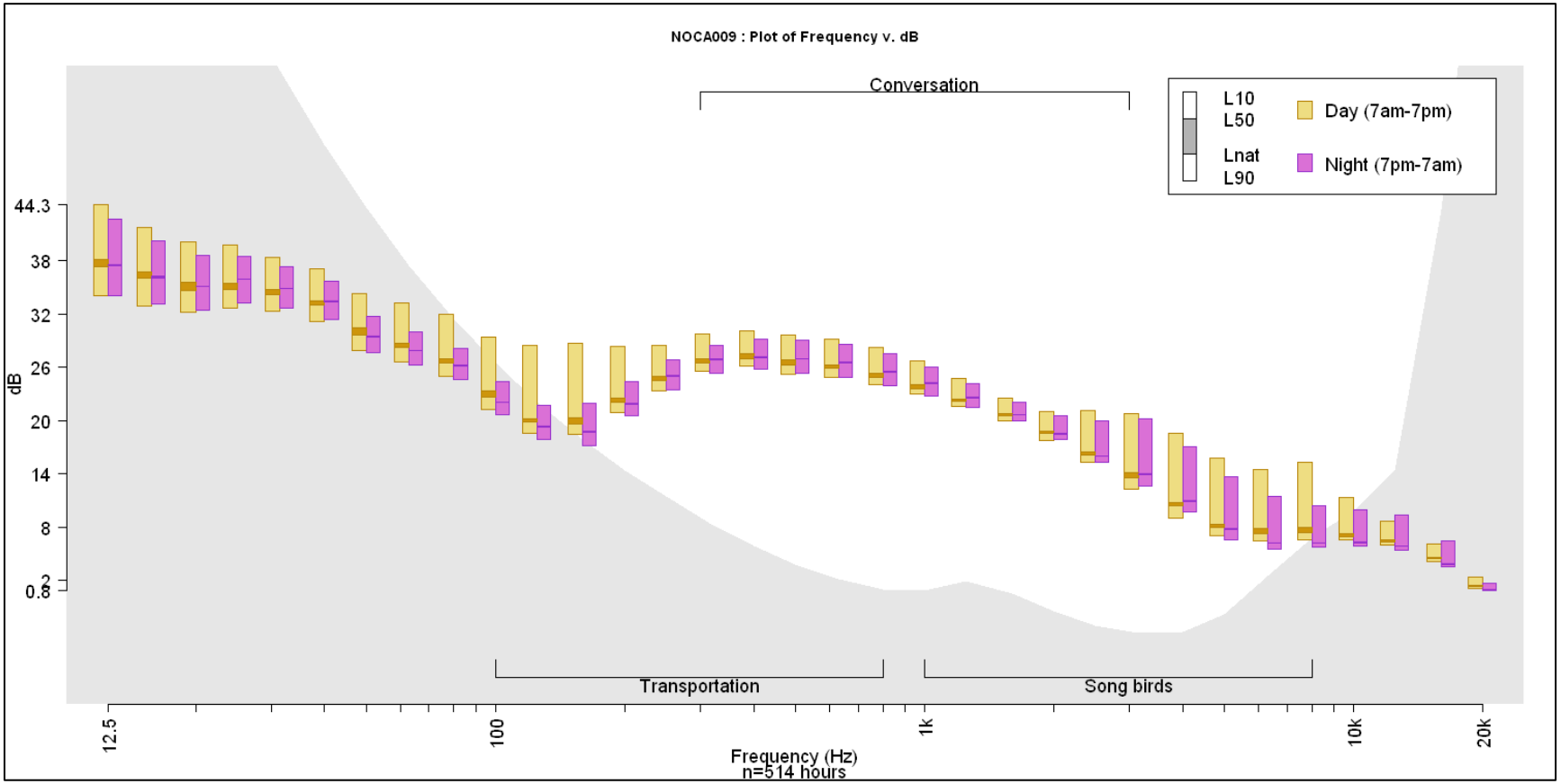

Figure 44. Day and night dB levels for 33 one-third octave bands at Rainbow Loop.

The Easy Pass site has a marked difference between daytime and nighttime sound levels at all of the audible frequencies (Figure 45). Higher nighttime sound levels in the high frequency range are due to insects.

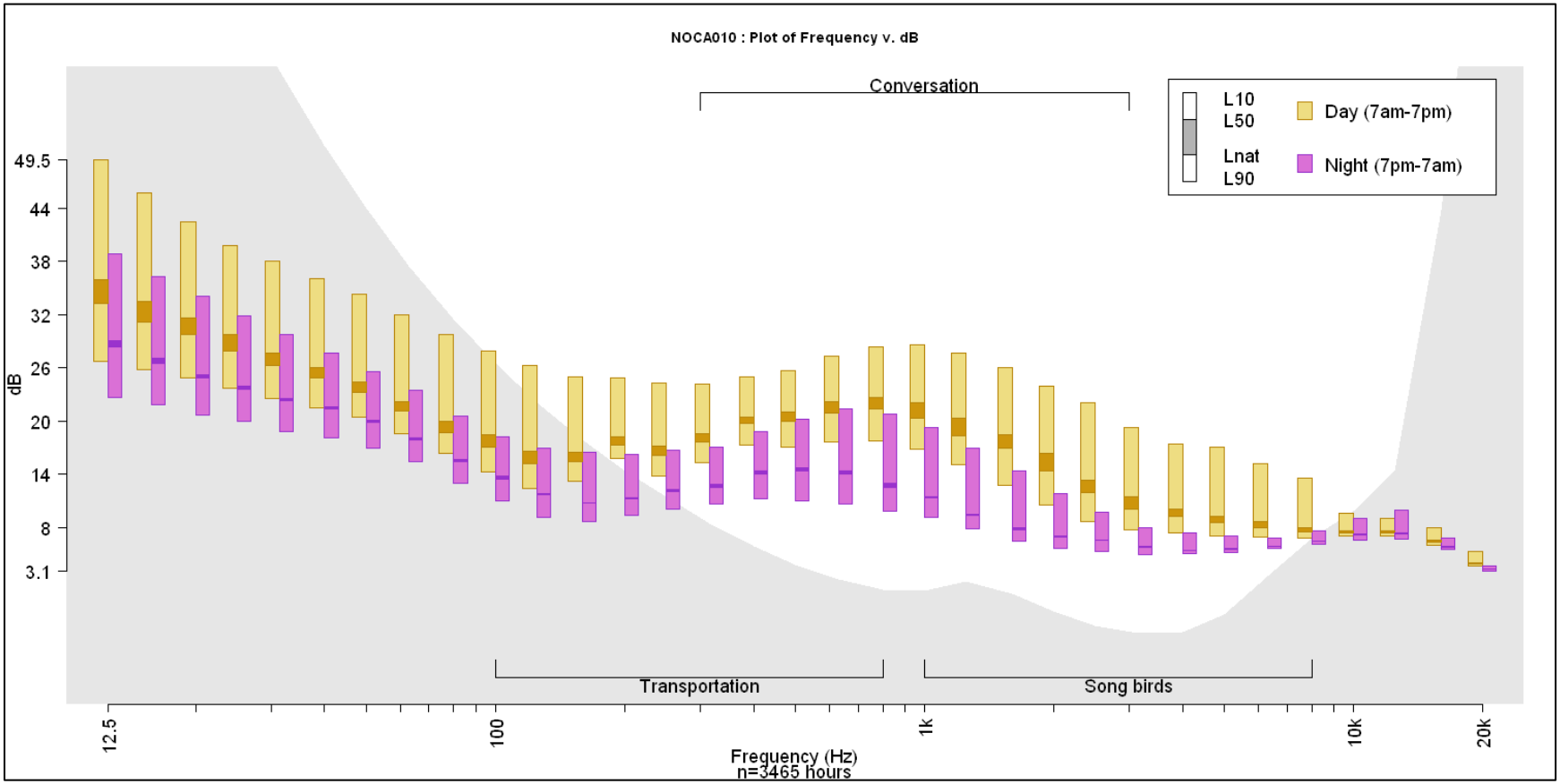

Figure 45. Day and night dB levels for 33 one-third octave bands at Easy Pass.

At the Colonial Creek Campground site, differences between daytime and nighttime sound levels are large, but when examined between frequencies, daytime sound levels have a small amount of variation compared to other sites (Figure 46). In most cases, L_{90} values are equal to L_{nat} values, except for some nighttime values in the lower and middle frequency ranges. The high daytime sound levels in the lower frequencies correspond to vehicle traffic.

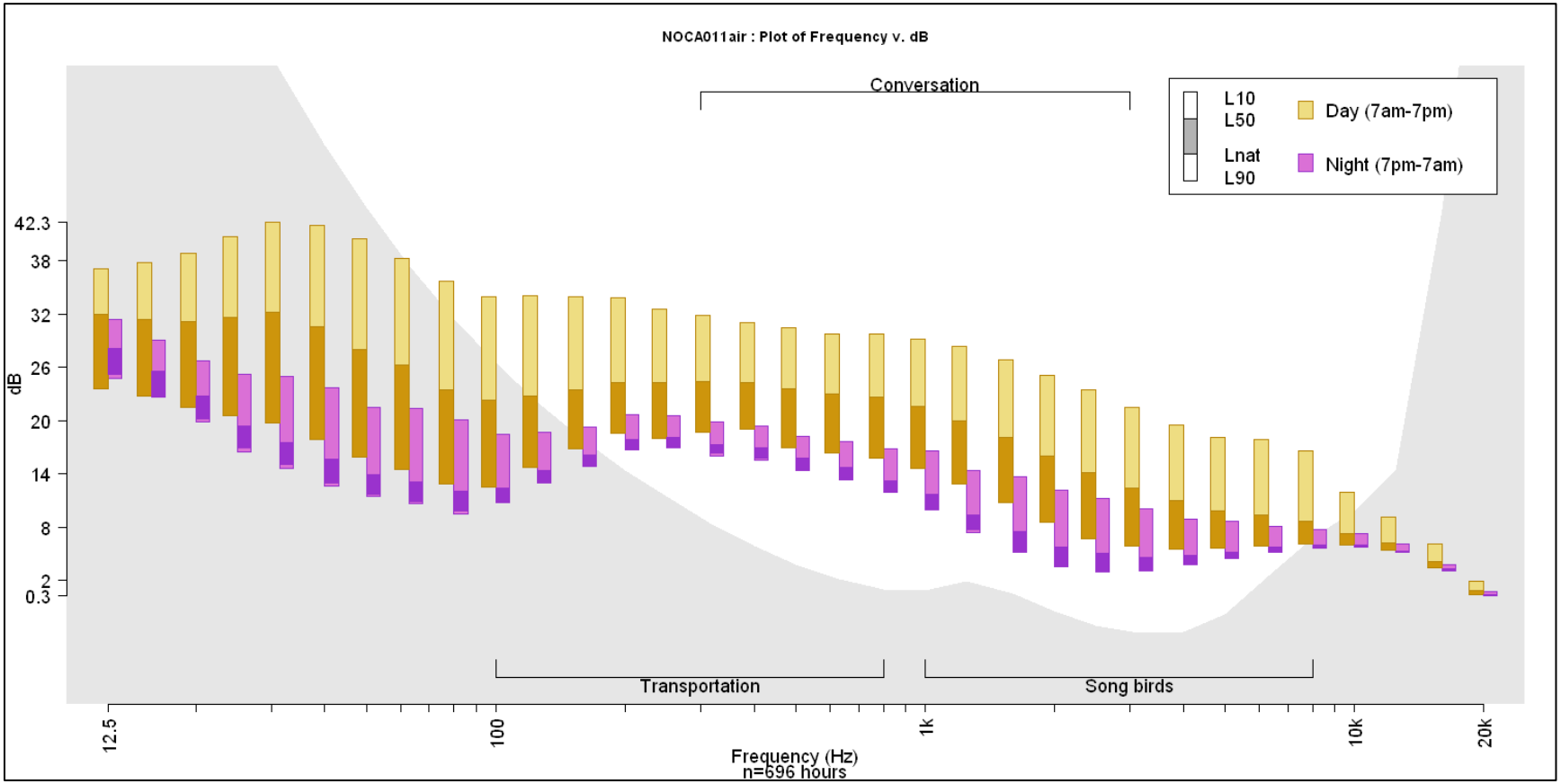

Figure 46. Day and night dB levels for 33 one-third octave bands at Colonial Creek Campground.

Similar to the Newhalem site, the Ross Dam Trailhead site has a sharp peak in the audible low frequency range of 120 to 150 Hz, which corresponds to noise generated at Ross Dam (Figure 47).

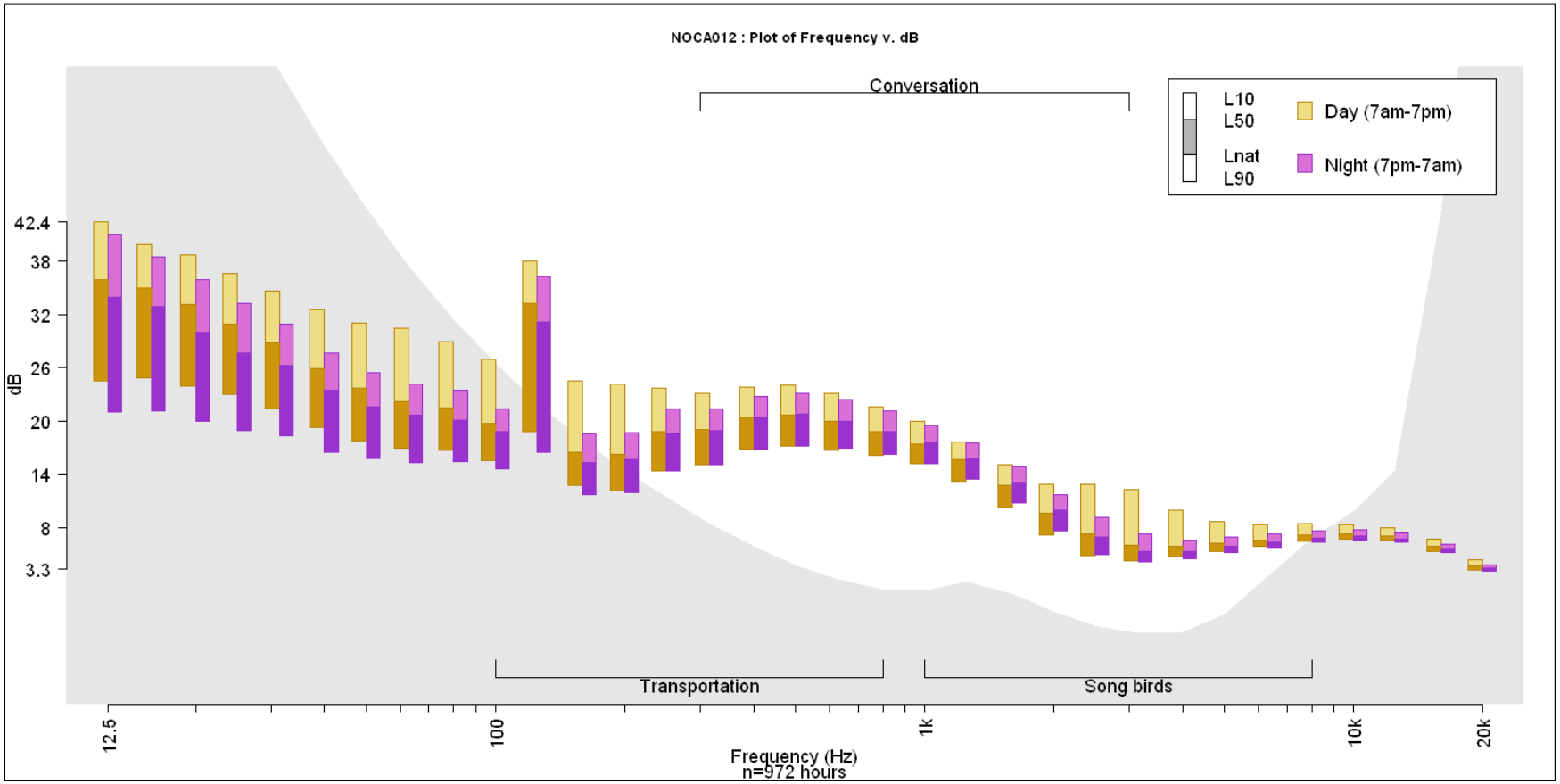

Figure 47. Day and night dB levels for 33 one-third octave bands at Ross Dam Trailhead.

The Thunder Knob site has an increase in low frequency daytime sound levels, which corresponds to vehicle traffic (Figure 48). Higher sound levels in the higher frequency ranges correspond to songbirds in the daytime and insects in the nighttime.

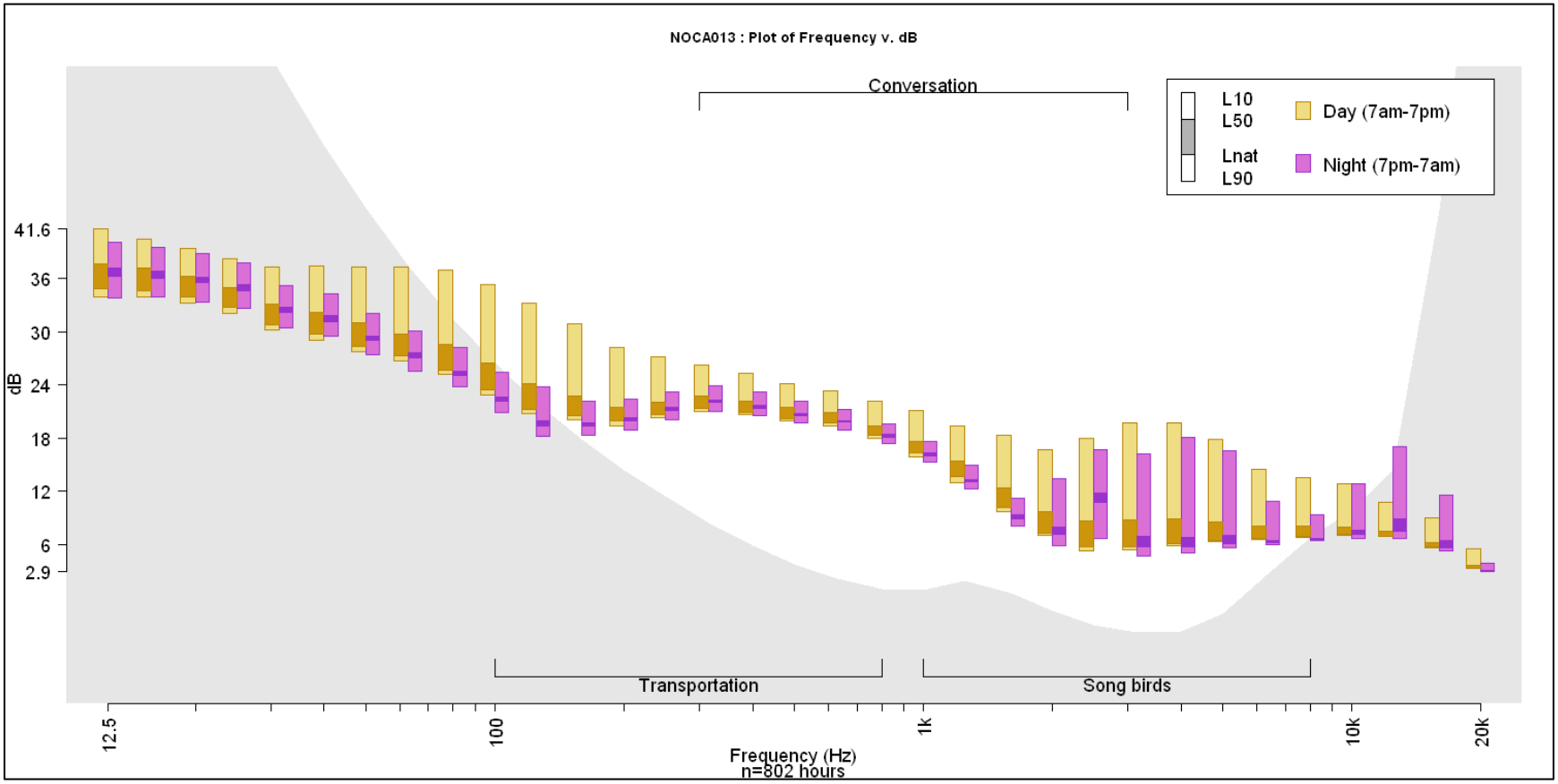

Figure 48. Day and night dB levels for 33 one-third octave bands at Thunder Knob.

The Big Beaver Valley was a very quiet site, with little difference between natural and existing ambient sound levels at all frequencies (Figure 49). Higher sound levels in the higher frequency ranges correspond to songbirds in the daytime and insects in the nighttime.

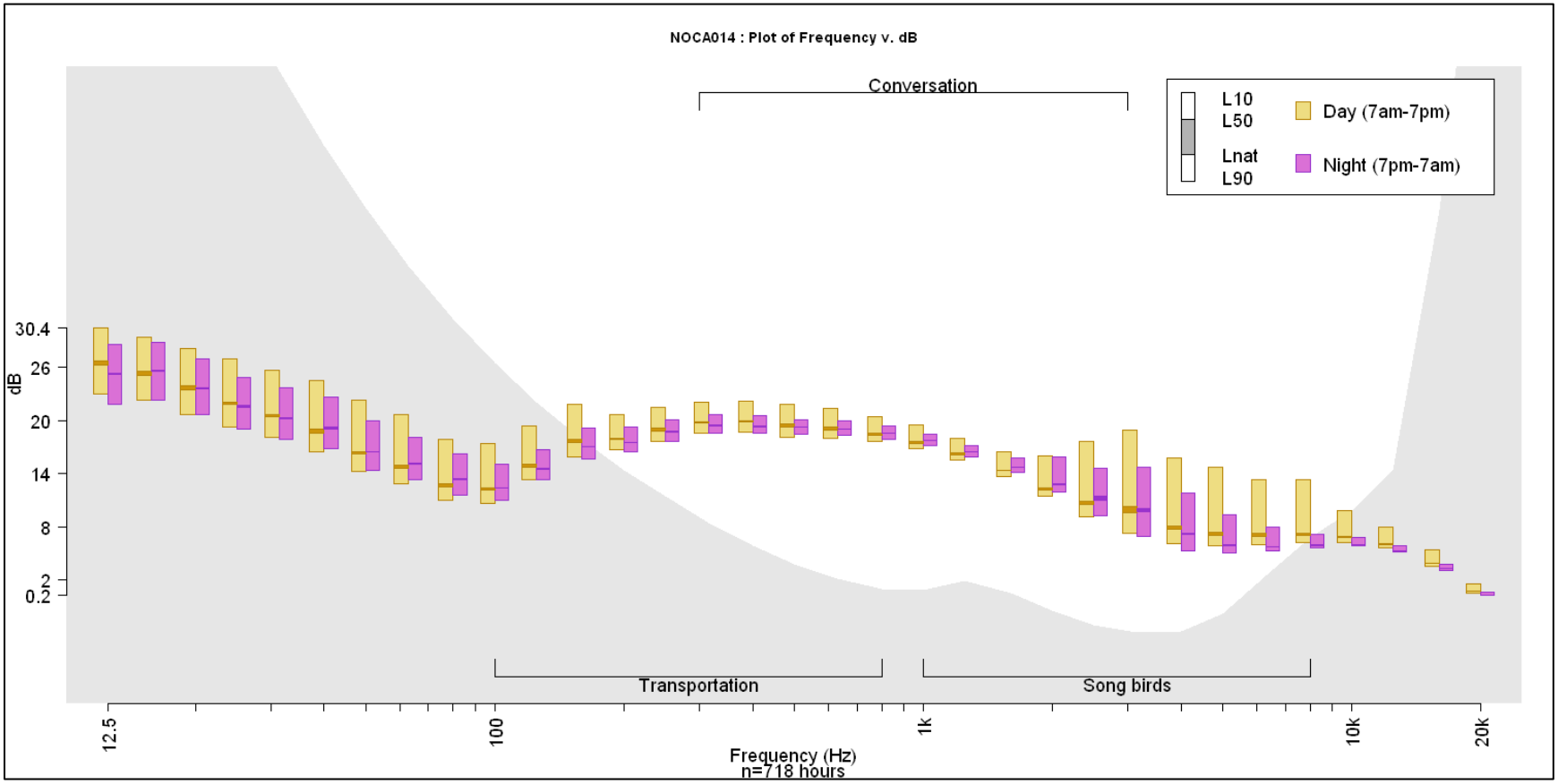

Figure 49. Day and night dB levels for 33 one-third octave bands at Big Beaver Valley.

At the Sourdough Mountain site, daytime vehicle noise is visible in the lower frequencies (Figure 50). The contribution of human-caused sounds is much more pronounced during the daytime, as illustrated by the longer bold bar that denotes the difference between natural and existing ambient sound levels. The same bar is much shorter for the nighttime sound levels. High nighttime sound levels in the high frequency range can be attributed to insects.

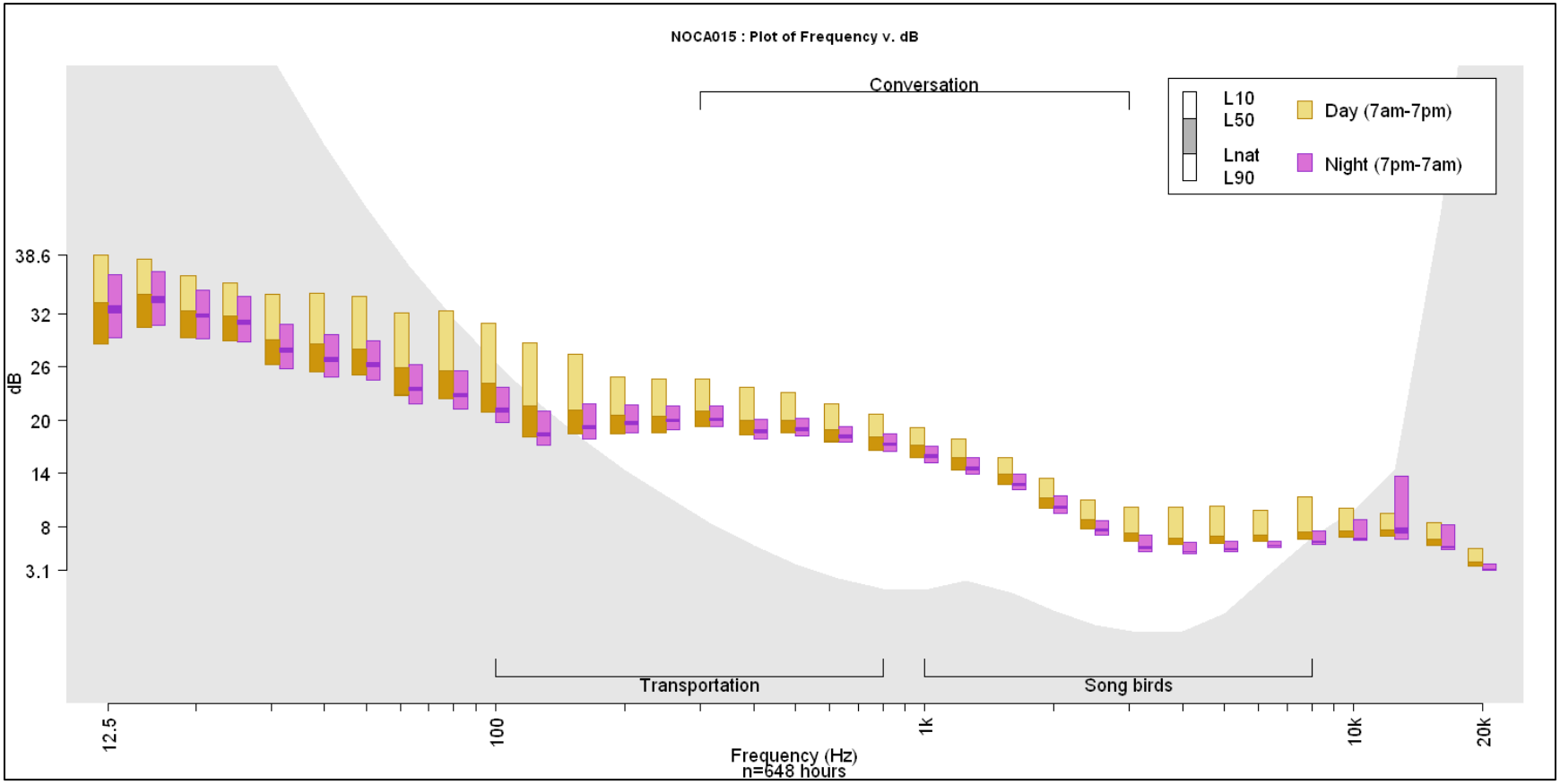

Figure 50. Day and night dB levels for 33 one-third octave bands at Sourdough Mountain.

The Park Creek Pass site has a dramatic increase in sound levels of high frequency sounds at night, caused by insects (Figure 51). High sound levels in the lowest, inaudible frequencies occur during both daytime and nighttime.

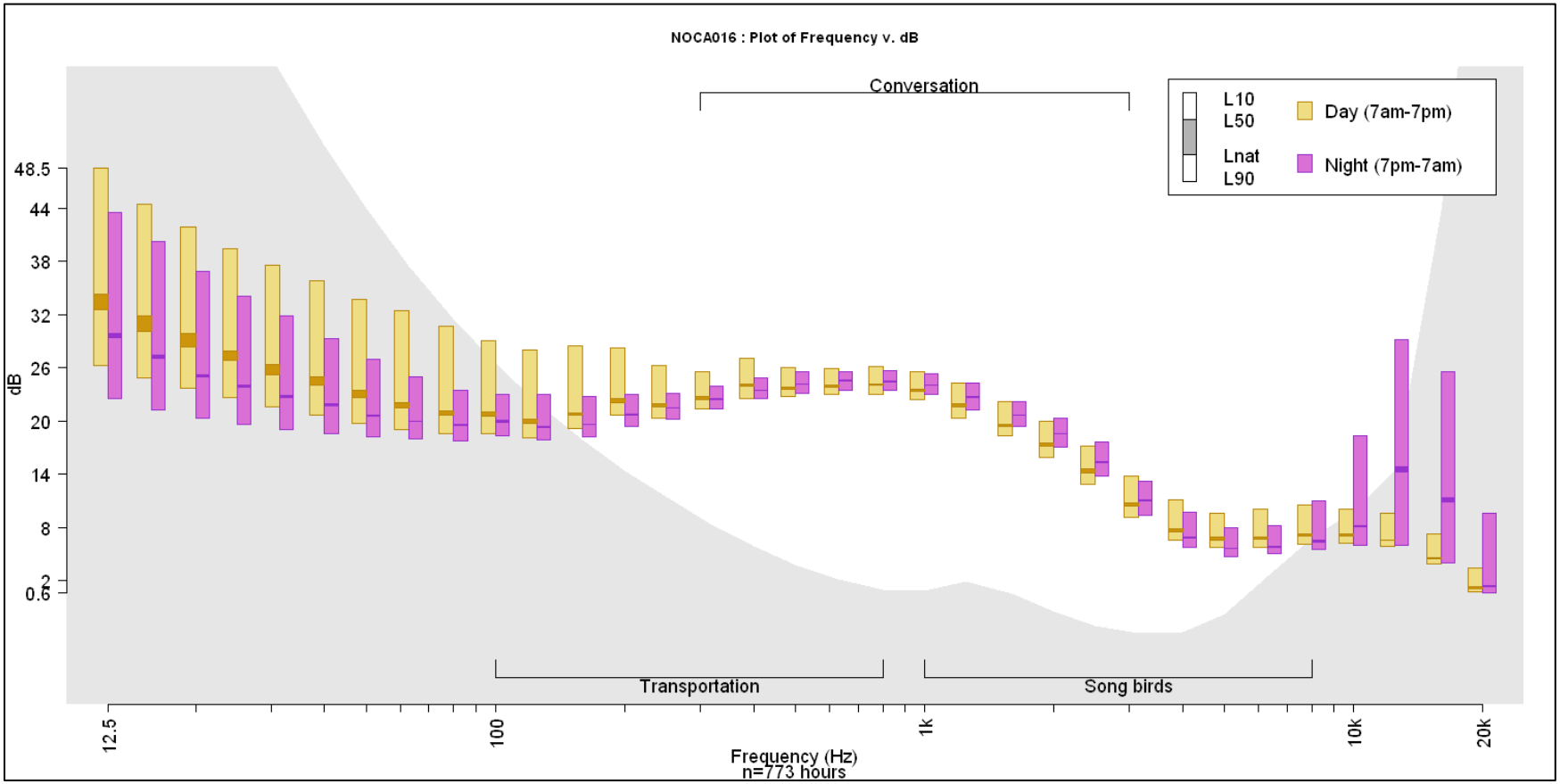

Figure 51. Day and night dB levels for 33 one-third octave bands at Park Creek Pass.

At the Dagger Lake site, nighttime sound levels were considerably lower than daytime sound levels at all frequencies (Figure 52). The difference between natural and existing ambient sound levels was small across all frequencies.

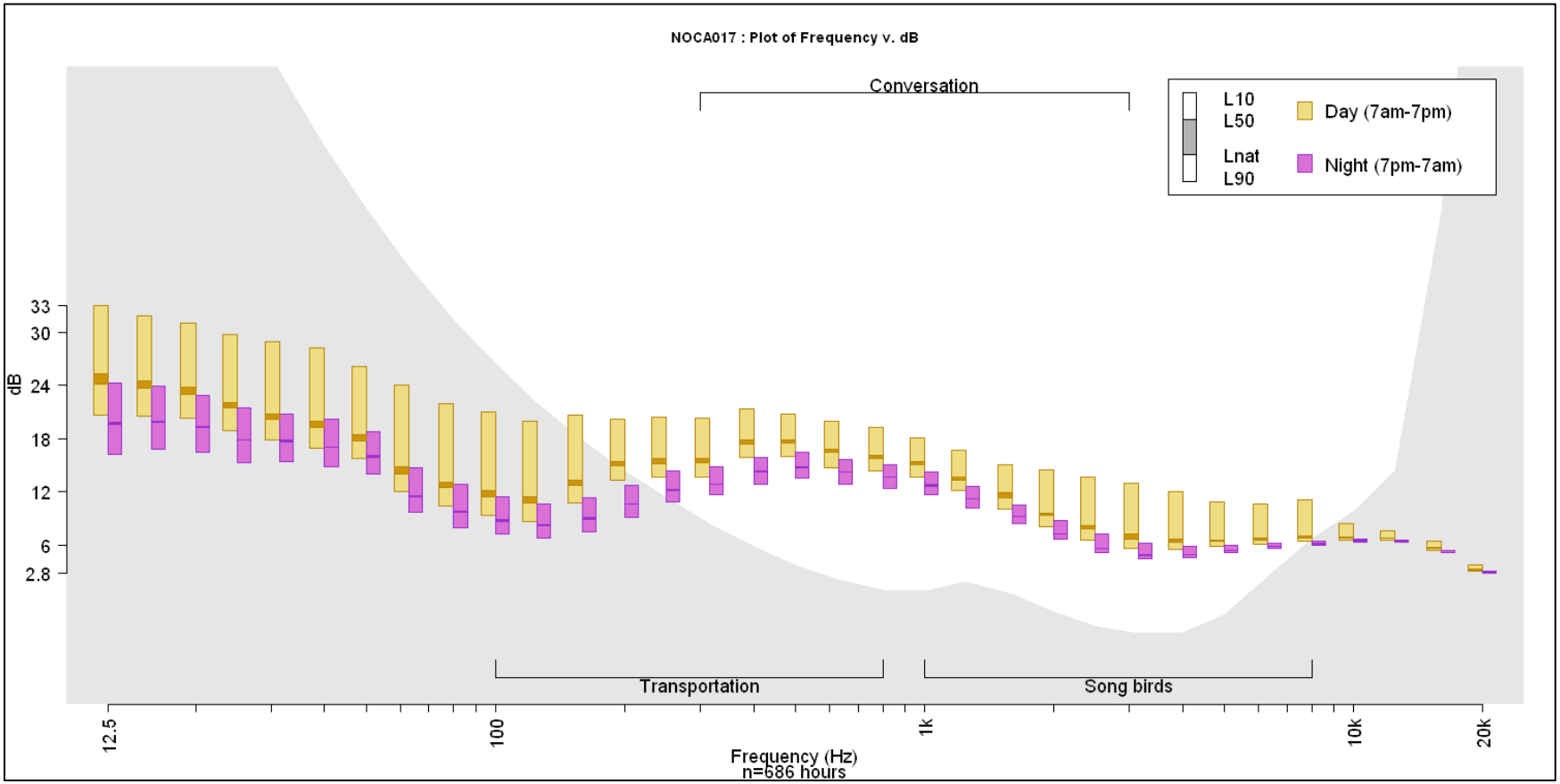

Figure 52. Day and night dB levels for 33 one-third octave bands at Dagger Lake.

At the Sulphide Creek site, daytime sound levels are lower than nighttime sound levels at all frequencies up to 3,150 Hz (Figure 53). This is likely due to the site's proximity to Sulphide Creek and the Baker River, which drain numerous glaciers and a large expanse of land. Peak flows occur at night, explaining why sound levels in the lower frequencies (representing flowing water) are higher at night than during the day. Higher sound levels in the higher frequency ranges correspond to songbirds in the daytime and insects in the nighttime.

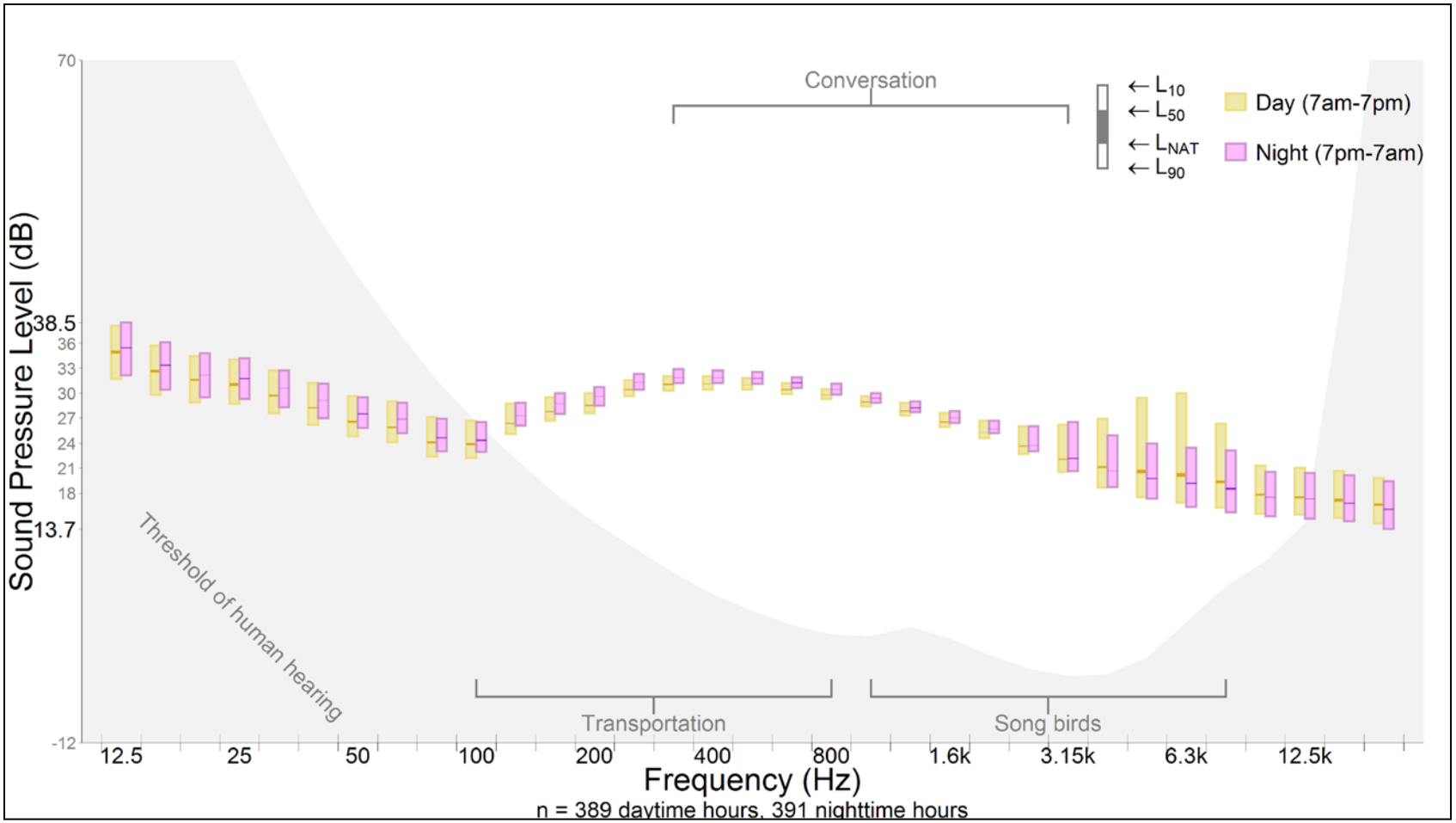

Figure 53. Day and night dB levels for 33 one-third octave bands at Sulphide Creek.

At Beaver Pass, nighttime sound levels in the lower frequencies (up to 6,300 Hz) are higher than daytime sound levels (Figure 54). This can be attributed to peak flows of nearby drainages occurring at night. The daytime chorus of songbirds becomes louder than nighttime sound levels at the higher frequencies.

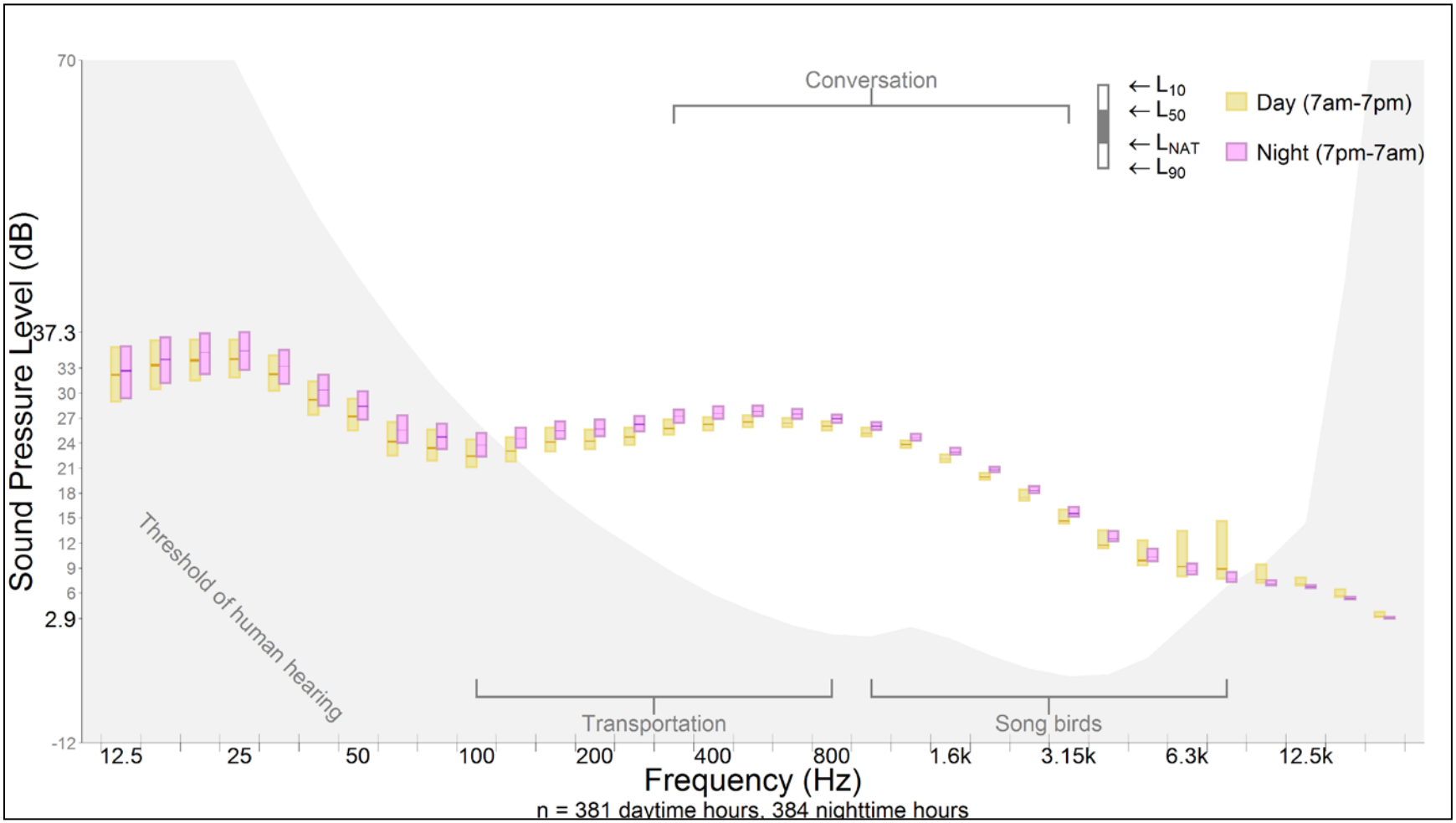

Figure 54. Day and night dB levels for 33 one-third octave bands at Beaver Pass.

At the Stehekin Airstrip, nighttime sound levels in the low frequency ranges were louder than daytime sound levels, which can be attributed to peak nighttime flows of the Stehekin River, Company Creek, and other drainages throughout the valley (Figure 55). The difference between natural and existing ambient sound levels is more pronounced during the day than at night throughout all frequencies.

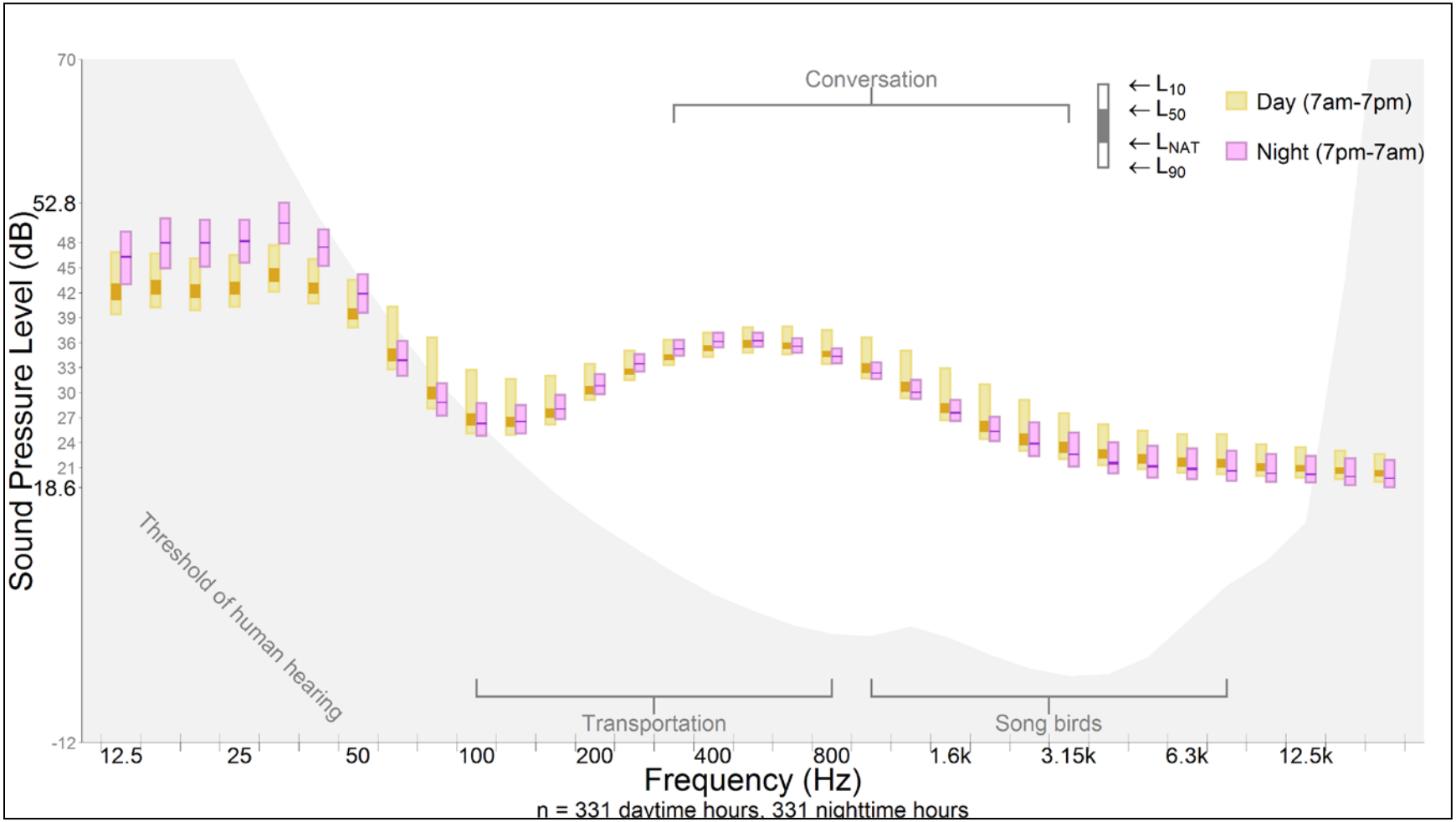

Figure 55. Day and night dB levels for 33 one-third octave bands at the Stehekin Airstrip.

At the Thornton Lakes Trail site, nighttime sound levels are slightly higher than daytime sound levels in the lower frequency ranges, which can be attributed to peak nighttime flows of many drainages that flow into the Skagit River, as well as the Skagit River itself (Figure 56). Daytime sound levels in the higher frequency ranges can be attributed to songbirds.

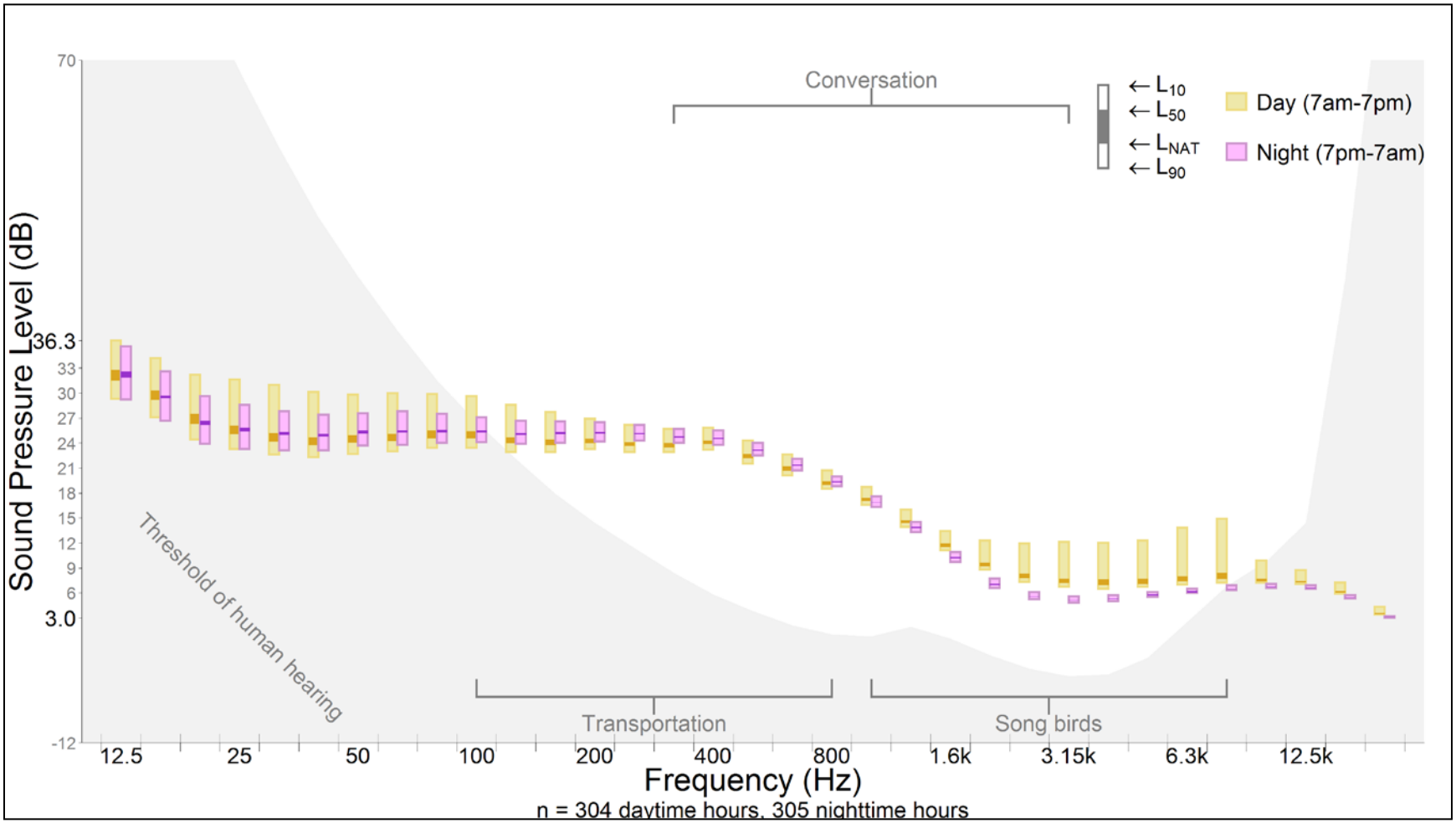

Figure 56. Day and night dB levels for 33 one-third octave bands at Thornton Lakes Trail.

Percent Time Audible

Table 4 reports the percent of time that all extrinsic sounds, as well as specific sound sources of interest (aircraft and vehicles) were audible during eight continuous days of sound source analysis. Results indicate that human-caused sounds are audible 100 percent of the time at the Newhalem site and 96.8 percent of the time at the Ross Dam Trailhead site. Inherently, this makes it impossible to accurately determine the natural ambient sound level at these sites, since the program used for analysis does not allow for the omission of a specific frequency. This explains the proximity in dBA values of existing and natural ambient sound levels at these sites as reported in Table 3, even though the percent time audible levels for aircraft and vehicle noise are much lower than 100 percent at these sites. The human caused sound that was audible in nearly all of the samples for both of these sites was a distant hum produced by the adjacent power lines and/or power generation equipment. In addition, natural ambient levels at Newhalem were intrinsically high due to rushing water from the Skagit River and Ladder Creek Falls. The rushing water may have added to the overall high ambient sound level at Newhalem.

Table 4. Mean percent time audible.

Site	**Mean Percent Time Audible (%)**		
	All Extrinsic Sounds	Aircraft Sounds	Vehicle Sounds
NOCA008-Newhalem	100.0	3.0	36.0
NOCA009-Rainbow Loop	13.2	12.4	0.0
NOCA010-Easy Pass	15.1	10.7	1.0
NOCA011-Colonial Creek Campground	79.1	3.7	51.5
NOCA012-Ross Dam Trailhead	96.8	9.0	1.1
NOCA013-Thunder Knob	46.1	8.5	37.9
NOCA014-Big Beaver Valley	9.6	8.8	0.0
NOCA015-Sourdough Mountain	50.1	8.4	42.0
NOCA016-Park Creek Pass	10.6	10.6	0.0
NOCA016-Park Creek Pass SAR	14.0	14.0	0.0
NOCA017-Dagger Lake	12.5	12.5	0.0
NOCA018-Sulphide Creek	5.6	4.9	0.0
NOCA019-Beaver Pass	6.4	6.4	0.0
NOCA020-Stehekin Airstrip	30.4	9.1	19.9
NOCA021-Thornton Lakes Trail	26.8	13.8	13.1

After Newhalem and Ross Dam Trailhead, the sites with the largest percentage of human caused sounds include Colonial Creek Campground (79.1%) and Sourdough Mountain (50.1%). Both sites had high amounts of vehicle noise contributing to existing ambient sound levels (51.5% of the time at Colonial, and 42.0% of the time at Sourdough). The site with the highest percentage of aircraft sounds (excluding the Park Creek Pass SAR event) was Thornton Lakes Trail. Aircraft was audible 13.8% of the time, accounting for roughly half of the total extrinsic sounds audible at the site.

The sites with the smallest percentage of human caused sounds include Sulphide Creek (audible 5.6% of the time) and Beaver Pass (audible 6.4% of the time). At Beaver Pass, extrinsic sounds were entirely attributed to aircraft, whereas aircraft sounds were audible at Sulphide Creek 4.9% of the time. Aircraft sounds were least audible at Newhalem (3.0% of the time) and Colonial Creek Campground (3.7% of the time); however, they were likely masked by the other prominent human-caused sounds occurring at these sites. Vehicle sounds were absent at Rainbow Loop, Big Beaver Valley, Park Creek Pass, Dagger Lake, Sulphide Creek, and Beaver Pass.

Table 5 reports the percent time audible of all sound sources at each monitoring site. In addition to aircraft and vehicle noise, other frequent human-caused sounds include grounds care (at Newhalem, Colonial Creek Campground, Sulphide Creek [trail maintenance], and the Stehekin Airstrip), people and/or voices (at Newhalem, Rainbow Loop, Easy Pass, Colonial Creek Campground, Big Beaver Valley, Stehekin Airstrip, and Thornton Lakes Trail), and dogs (at Newhalem, Colonial Creek Campground, and the Stehekin Airstrip).

Frequent natural sounds include those produced by mammals, especially squirrels, marmots, and pikas (at all sites except for Rainbow Loop, Thunder Knob, and Park Creek Pass), birds, and insects. Birds were audible at all sites, with percent time audible ranging from 12.5% of the time at the Stehekin Airstrip to 60.4% of the time at Big Beaver Valley. Insects were heard at all sites except for Ross Dam Trailhead, a winter monitoring site, and the Stehekin Airstrip. Insects were audible from 0.2% of the time at Sulphide Creek to 57.0% of the time at Park Creek Pass. Avalanches and/or rockslides were heard at several sites, including Newhalem, Easy Pass, Ross Dam Trailhead, Dagger Lake, Sulphide Creek, and Beaver Pass.

Note: some values for aircraft and vehicle noise in Table 5 may differ slightly from those reported previously in Table 4 due to rounding.

Table 5. Percent time audible by sound source.

Sound Source	Newhalem	Rainbow Loop	Easy Pass	Colonial Campground	Ross Dam Trailhead	Thunder Knob	Big Beaver	Sourdough Mountain	Park Creek	Park Creek SAR	Dagger Lake	Sulphide Creek	Beaver Pass	Stehekin Airstrip	Thornton Lakes Trail
Total Aircraft	2.8	12.4	11.0	3.7	9.0	8.5	8.8	8.4	10.6	14.0	12.5	4.9	6.4	9.1	13.8
Jet	1.7	6.7	6.0	2.7	3.8	3.0	7.0		6.5	5.3	9.1	3.9	4.3	4.2	7.6
Jet, Commercial					2.9									0.1	
Prop	0.5	1.4	1.7	0.7	1.9	1.5	1.6		1.6	0.9	1.2	0.7	1.9	4.6	4.2
Helicopter	0.5	4.1	2.9	0.4	0.3		0.2	0.1	2.7	7.9	2.2	0.4	0.4	0.1	2.2
Vehicle	31.0		1.0	42.9	0.1	37.6		42.0						19.6	13.1
Automobile	0.1			0.7											
Motorcycle	3.7			0.6		0.2									
Truck	1.0			0.9										0.2	
Truck Medium				0.1											
Truck Heavy	0.6														
Watercraft							0.6								
Alarm, Horn	0.7			0.5										1.1	
Door				11.4											
Heavy Equipment	0.1				1.0										
Train Rumble	0.4														
Train Whistle	0.6														
Motor	91.4			0.7										0.2	
Generator				4.3	94.6										
Pump				1.1											
Grounds Care	1.8			0.1								0.7		0.4	
People	0.1	0.1	2.3	54.1											
Voices	0.1	0.2	0.1	6.2			0.2							0.2	0.1
Walking			0.1	0.8											
Portable Audio Devices				0.6											

Table 5. Percent time audible by sound source (continued).

Sound Source	Newhalem	Rainbow Loop	Easy Pass	Colonial Campground	Ross Dam Trailhead	Thunder Knob	Big Beaver	Sourdough Mountain	Park Creek	Park Creek SAR	Dagger Lake	Sulphide Creek	Beaver Pass	Stehekin Airstrip	Thornton Lakes Trail
Gunshot	0.1														
Domestic animal				0.1										2.1	
Dog	0.2			3.4										0.2	
Building Sounds				0.4											
Utilities	0.1				0.5										
Door				0.2											
Construction	0.4			0.6										0.1	
Non-natural other				11.0											
Non-natural unknown	0.7	0.5	1.9	0.7	0.2										
Water						0.6									
Wind	0.6			0.3											
Wind, Light (not masking)	0.8														
Rain, fog drip	30.3			0.7	0.3	8.9						5.1			
Thunder	4.0	5.2	1.3				0.1								
Mammal	0.5		0.4	1.3	0.4			1.1	3.9		0.4	0.1	0.4	0.3	0.2
Squirrel	6.4			5.7			2.6						0.1	0.6	0.1
Chipmunk				0.1											
Bird	26.1	24.7	35.6	23.9	12.8	44.7	60.4	40.6	30.8		41.4	56.8	51.4	12.5	32.8
Raven				0.6											
Duck				0.5											
Reptile				0.1											
Amphibian	1.3			0.4		19.0	0.1	3.1				0.4			0.2
Insect	4.7	14.2	43.2	3.0		1.1	3.8	23.5	57.0		16.2	0.2	1.0		4.4
Animal		0.1	0.1	0.2			0.1		0.1		0.4				0.1
Avalanche/ Rockslide	0.1		0.1		0.1						0.1	0.1	0.1		

Table 5. Percent time audible by sound source (continued).

Sound Source	Newhalem	Rainbow Loop	Easy Pass	Colonial Campground	Ross Dam Trailhead	Thunder Knob	Big Beaver	Sourdough Mountain	Park Creek	Park Creek SAR	Dagger Lake	Sulphide Creek	Beaver Pass	Stehekin Airstrip	Thornton Lakes Trail
Natural Other	0.1			1.1											
Wind induced natural	4.3	0.9									0.8				
Natural Unknown				0.5											
Artifact[1]	0.3								15.5						
Wind distortion	0.5			0.1											
Static/interference- quiet	0.3			0.6											
Unknown	0.3		0.1												
No Sound Audible	0.1			14.8											

[1] Artifacts are sounds that we create at the logging site that would not otherwise happen if we weren't there. This includes sounds like sneezing, or raindrops / snowflakes falling on a raincoat.

Percent Time Above

Table 6 reports the percent of time that sound levels were above four key thresholds described in the Methods section. Results show that a number of sites exceeded the 35 dBA threshold (for sleep interruption) for all or a portion of the time. Sound levels at Newhalem, Sulphide Creek, and the Stehekin Airstrip exceeded this threshold 100 percent of the time during both day and night. The second highest percent of time above 35 dBA occurred at Easy Pass during the day (56% of the time), and Park Creek Pass at night (58% of the time). Except for Newhalem, the rest of the sites have naturally high ambient sound levels, in some cases due to running water, and in other cases due to insects and/or wind (especially for high nighttime values). Even at Newhalem, the sounds of rushing water contribute to the high sound levels. The sites that exceeded the 35 dBA threshold the least often were Dagger Lake (5% of the daytime and less than 1% of the nighttime), and Thornton Lakes Trail at night (less than 1% of the nighttime).

Table 6. Percent time above metrics.

Site Name	**% Daytime Exceedence (7am-6:59 pm)**				**% Nighttime Exceedence (7pm-6:59 am)**			
	35 dBA	45 dBA	52 dBA	60 dBA	35 dBA	45 dBA	52 dBA	60 dBA
NOCA008-Newhalem	100	63	6	<1	100	11	<1	<1
NOCA009-Rainbow Loop	36	5	<1	<1	23	1	<1	0
NOCA010-Easy Pass	56	15	1	<1	42	5	<1	0
NOCA011-Colonial Campground	30	4	1	<1	10	1	<1	0
NOCA012-Ross Dam Trailhead	7	1	<1	<1	4	<1	<1	0
NOCA013-Thunder Knob	22	2	<1	0	24	3	<1	0
NOCA014-Big Beaver Valley	6	1	<1	0	3	<1	<1	0
NOCA015-Sourdough Mountain	6	1	<1	0	20	11	<1	0
NOCA016-Park Creek Pass	13	1	<1	<1	58	27	16	3
NOCA017-Dagger Lake	5	1	<1	0	<1	<1	<1	0
NOCA018-Sulphide Creek	100	4	<1	<1	100	3	<1	<1
NOCA019-Beaver Pass	7	<1	0	0	38	<1	0	0
NOCA020-Stehekin Airstrip	100	25	1	<1	100	2	<1	0
NOCA021-Thornton Lakes Trail	8	<1	<1	0	<1	<1	<1	0

All of the sites exceeded the second threshold for noise levels in bedrooms (below 45 dBA), but much less frequently than the first threshold. Sound levels at Newhalem exceeded this threshold 63% of the time during the day and 11% of the time during the night. The second highest percent of time above 45 dBA during the day occurred at the Stehekin Airstrip (25% of the time). The

highest percent of time above 45 dBA during the night occurred at Park Creek Pass (27% of the time), which was primarily due to wind and insect sounds. A number of sites only exceeded this threshold 1% or less of the time during the day, including Ross Dam Trailhead, Big Beaver Valley, Sourdough Mountain, Park Creek Pass, Dagger Lake, Beaver Pass, and Thornton Lakes Trail. The same sites (except for Sourdough Mountain and Park Creek Pass) had low nighttime exceedences, along with Rainbow Loop and Colonial Creek Campground.

The third threshold for speech interference at 10 meters (below 52 dBA) was exceeded much less frequently at all sites. The highest daytime exceedence of 6% occurred at Newhalem, and the highest nighttime exceedence of 16% occurred at Park Creek Pass, which again was primarily due to wind and insect sounds. The remaining sites exceeded this level 1% or less of the time.

The final threshold for normal voice communication at one meter (below 60 dBA) was exceeded less than 1 percent of the time during the day for all of the sites. At night, most of the sites never exceeded this level; however at Park Creek Pass it was exceeded 3% of the time due to wind, and less than 1% of the time at Newhalem and Sulphide Creek.

Discussion

The purpose of this study was to complete a baseline inventory of the acoustical environment of North Cascades National Park Complex. The inventory was initiated in 2006, and results through 2008 were summarized in two reports that were completed by the NSNSD. This report summarizes the results from inventory efforts that began in 2009 and lasted through 2011, which was the end of the inventory period. For a full understanding of the complete NOCA acoustical environment, all reports should be considered together.

Results demonstrate that most noise intrusions occur from vehicles, aircraft, and power generation and transmission equipment. It is important to note that previous inventories revealed noise intrusions from watercraft as well; however, none of the sampling locations in this study were located near navigable water. Topography plays a significant role in the overall high ambient sound levels of several monitoring sites, where sounds from valley floors are amplified as they reverberate against valley walls and/or steep cliffs. This is especially true at Newhalem, Thunder Knob, and the Stehekin Airstrip.

Vehicle noise is most prevalent along SR 20 and this noise can be traced as far away as the ridgelines that overlook the highway. At the Sourdough Mountain site, located 1,597 m above sea level, nearly 1,300 m above SR 20, and 4.5 miles from the trailhead in Diablo, vehicle noise was audible 42% of the time. That said, vehicle noise is relatively concentrated within the valleys in which it is generated. Conversely, aircraft noise was audible at all locations, and was more prevalent in some the of the backcountry sites. Park Creek Pass, which was over 20 miles into the backcountry, experienced aircraft noise over 10% of the time. Other backcountry sites had similar audibility rates, such as Dagger Lake (12.5%), Easy Pass (10.7%), and Thornton Lakes Trail (13.8%). Power generation and transmission noise occurring at Newhalem and Ross Dam Trailhead is constant and it prevents natural ambient sound levels to be calculated in those areas. High ambient sound levels recorded at Newhalem are also attributed to the site's close proximity to SR 20. The exceedence of the 52 dBA and 60 dBA threshold levels at Newhalem was caused by highway noise, in particular heavy trucks and motorcycles.

Although noise intrusions occur at all sites because of aircraft noise, there are also areas that have high ambient sound levels because of natural sound sources. Most interesting are those sites with nighttime sound levels that were higher than daytime sound levels. Where this occurred in the high frequency ranges, insect sounds were the cause. Sites with higher nighttime natural ambient sound levels in the high frequency ranges include Rainbow Loop, Easy Pass, Thunder Knob, Sourdough Mountain, and Park Creek Pass. Sites where nighttime sound levels were higher than daytime sound levels in the lower frequency ranges indicated flowing water. These sites include Sulphide Creek, Beaver Pass, the Stehekin Airstrip, and Thornton Lakes Trail.

There were also a number of sites with low ambient sound levels. The quietest daytime and nighttime existing ambient sound levels were recorded at Dagger Lake. The site also tied with Colonial Creek Campground unexpectedly for the quietest nighttime natural ambient sound levels, and tied with Colonial Creek Campground, Ross Dam Trailhead, and Sourdough Mountain to have the quietest daytime natural ambient sound levels. Natural ambient levels are so low at these sites largely because they are located farther away from flowing water and/or the nighttime sites lack insect activity.

Finally, a few of the stations recorded animal vocalizations of species of management concern, including wolves and spotted owls. Although these species are known to occur within NOCA, they can be elusive. Sound recordings can be a less disruptive means to confirm their presence in different locations, some of which were unanticipated. The documentation of species of management concern will be helpful for project planning and is an important attribute that can be used to monitor wilderness character.

The results of this research can be applied to other areas within NOCA as long as similar acoustic conditions exist between the sampled location and the new location. Since all vegetation zones were sampled except for the alpine zone, it should be a matter of selecting the appropriate sample to apply to a new area. It would not be appropriate to apply existing ambient sound level results of an already sampled location to a new location if a new sound source is developed; however, natural ambient sound levels could be used as a baseline measure. New sound sources should be measured and monitored as funding allows.

Conclusions

The acoustic conditions of NOCA were inventoried using 14 acoustic monitoring sample sites. A combination of automatic monitoring and on-site listening was used to derive a variety of metrics that helped to understand and characterize the acoustical environment of NOCA. The results of the inventory will be used in future park planning activities as well as in the current management of park acoustical environments. Baseline data gathered through this inventory effort can be used to identify unacceptable levels and sources of noise in park management zones. Copies of all raw data will be stored at both North Cascades National Park Complex and in the NSNSD archives for future monitoring or comparison. If individual zones are degraded by extrinsic sounds, baseline data can be used to guide restoration activities. More in-depth analyses of the influence of noise on both visitors and wildlife will increase our understanding of the impact of noise and improve the park's ability to protect wilderness character, visitor experiences, and ecological processes.

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