



Zion National Park

Acoustical Monitoring Summary Report

Natural Resource Technical Report NPS/NRPC/NRTR—2011/420



ON THE COVER

“Canyon Overlook” by Tom Putnak

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Natural Resource Technical Report NPS/NRPC/NRTR—2011/420

Katy Warner
National Park Service
Natural Sounds Program
1201 Oakridge Drive, Suite 100
Fort Collins, CO 80525

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Contents

	Page
Tables	iv
List of Figures	v
Appendices.....	vi
Executive Summary	ix
Introduction.....	1
National Park Service Natural Sounds Program.....	1
Soundscape Monitoring and Planning Authorities	1
Study Area	3
Methods.....	5
Automatic Monitoring	5
Off-Site Listening/ Visual Analysis.....	7
Calculation of Metrics	8
Results.....	11
Data Analysis.....	11
Discussion	21
Literature Cited	23

Tables

	Page
Table 1. Explanation of sound level values.....	ix
Table 2. Acoustical terms and definitions.....	x
Table 3. Site descriptions and locations.....	3
Table 4. Summary of data collected at ZION from 2000 – 2008.....	6
Table 5. Key sound level values.....	11
Table 6. Mean percent time audible – 2008 sites.....	14
Table 7. Mean percent time audible – Wyle Laboratory sites 2000-2001.....	14

List of Figures

	Page
Figure 1. Map of acoustical monitoring sites at Zion from 2000 – 2008.	xi
Figure 2. Percent time above given decibel levels for daytime (0700-1900) and night-time (1900-0700) hours at ZION, by site.	xii
Figure 3. Daytime and nighttime existing and natural ambient levels.....	xiii
Figure 4. Percent of time aircraft and all extrinsic sources were identified, based on visual analysis and off-site listening covering 8 days of data for each site.....	xiv
Figure 5. Soundscape monitoring sites from 2000 — 2008.	4
Figure 6. Visual identification of aircraft and other non-natural sources using spectrograms.	8
Figure 7. Percent time above given decibel levels for daytime (0700-1900) and night-time (1900-0700) hours at ZION, by site.	12
Figure 8. Average percent time audible for 2008 sites.	13
Figure 9. Average audibility of vehicle noise for each hour of the day at 2008 sites.....	14
Figure 10. Visual example of exceedence levels, as used in subsequent figures.	15
Figure 11. L_{10} , L_{nat} , L_{50} and L_{90} levels for daytime (0700 – 1900).	16
Figure 12. L_{10} , L_{nat} , L_{50} and L_{90} levels for night (1900 – 0700).....	17
Figure 13. Day and night dB levels for 33 one-third octave bands at ZION site GWT.	18
Figure 14. Day and night dB levels for 33 one-third octave bands at ZION site PNCK.....	19

Appendices

	Page
Appendix A. Frequency plots for Wyle sites.....	25
Figure 15. Day and night dB levels for 33 one-third octave bands at CHINLE.....	25
Figure 16. Day and night dB levels for 33 one-third octave bands at CRZQLT.....	26
Figure 17. Day and night dB levels for 33 one-third octave bands at EASTRM ¹	27
Figure 18. Day and night dB levels for 33 one-third octave bands at HOPVAL.....	28
Figure 19. Day and night dB levels for 33 one-third octave bands at KOLOBC.....	29
Figure 20. Day and night dB levels for 33 one-third octave bands at LCREEK.....	30
Figure 21. Day and night dB levels for 33 one-third octave bands at LFRKTD.....	31
Figure 22. Day and night dB levels for 33 one-third octave bands at NCREEK.....	32
Figure 23. Day and night dB levels for 33 one-third octave bands at SCOUTS.....	33
Figure 24. Day and night dB levels for 33 one-third octave bands at WILDCT.....	34
Figure 25. Day and night dB levels for 33 one-third octave bands at PRWEAP ¹	35
Appendix B. Data tables for ZION sites.....	37
Table 8. Percent time above metrics for Wyle sites monitored in 2000-2001.....	37
Table 9. Percent time above metrics for summer 2008 sites.....	37
Table 10. Median Day and Night L ₅₀ and L _{nat} for Wyle sites.....	37
Table 11. Median Day and Night L ₅₀ and L _{nat} for 2008 sites.....	37
Table 12. Time above metrics by frequency range for Wyle sites.....	38
Table 13. Time above metrics by frequency range for 2008 ZION sites.....	38
Table 14. Exceedence levels for existing conditions at 2008 ZION sites.....	38
Table 15. Exceedence levels for 2000-2001 conditions at Wyle Laboratory sites.....	39
Appendix C. Site Photos for 2008 Sites.....	41
Figure 26. Great White Throne Site (GWT).....	41
Figure 27. Pine Creek Site (PNCK).....	42

Appendices (continued)

	Page
Appendix D. Spectrogram examples.	43
Figure 28. Some natural sounds, like this thunderstorm, can be identified using spectrograms.	43
Figure 29. Example of vehicle pass-bys in a , and a jet in b	44
Figure 30. Some extrinsic sources have distinct visual signatures - other sources are more ambiguous.	45
Appendix E. 2008 Acoustic Monitoring Summary Posters.	47
Appendix F. Hourly percent time audible tables for all 2000-2001 and 2008 sites.	51
Table 16. Average percent of time that extrinsic sounds were audible by hour of the day for front country sites from summer 2008 data.	51
Table 17. Average percent of time that extrinsic sounds were audible by hour of the day for backcountry sites from 2000 – 2001 data.	51
Appendix G. Glossary of Acoustical Terms.	53

Executive Summary

This report presents acoustical data that were collected at Zion National Park (ZION) between 2000 and 2008. Data were collected to provide park managers with information about the acoustical environment, noise sources, and to provide an estimate of natural ambient sound levels throughout the park. This report synthesizes the results from several data collection efforts by presenting figures, tables, and descriptions of the data; it does not attempt to make recommendations or draw management conclusions.

Over the past decade, several soundscape monitoring efforts have taken place at ZION. In 2000 and 2001, Wyle Laboratories established 12 monitoring sites within the park, and produced a report that summarizes their findings (Hobbs & Downing 2003). During the summer of 2008, the National Park Service Natural Sounds Program (NSP) established two additional monitoring sites (Figure 1). After working with the NSP, ZION acquired several monitoring systems, and monitoring efforts are continuing at the sites established in 2008, at some of the Wyle sites and at new sites throughout the park.

Several types of data were collected in 2000-2001, as described in the Wyle report (Hobbs & Downing 2003). At 11 of the 12 Wyle sites, 1 second L_{eq} data were collected for thirty-three 1/3-octave bands. The analysis of this type of data has evolved rapidly over the past decade, and this report includes updated analysis and graphical presentations from the 11 sites where 1/3-octave data were available. Figure 1 shows the locations of these 11 sites.

Starting in 2008, data were collected in accordance with the NSP internal protocols for acoustical monitoring. ZION staff received training on these protocols, and they are analyzing data collected after the summer of 2008. The 2008 sites each ran for more than three weeks in July and August, and the results from these sites are presented in this report. These results, in combination with more recent monitoring at ZION, provide a quantitative description of the acoustical environment at ZION.

In determining the current conditions of an acoustical environment, it is important to be familiar with the acoustical terms used in this report, and to examine how often sound levels exceed certain values. Table 1 summarizes sound level values that relate to human health and speech, as documented in the scientific literature. These values are relevant to various aspects of the park experience including: camping in front-country and back-country sites, communication between park staff and visitors, and informal communication. Human responses can serve as a proxy for potential impacts to other vertebrates because humans have more sensitive hearing at low frequencies than most species (Dooling and Popper, 2007, p. 5). Table 2 lists several key acoustical terms and their definitions. Appendix G contains additional acoustical terms.

Table 1. Explanation of sound level values.

Sound Levels (dBA)	Relevance
35	Blood pressure and heart rate increase in sleeping humans (Haralabidis et al., 2008)
45	World Health Organization's recommendation for maximum noise levels inside bedrooms (Berglund, Lindvall, and Schwela, 1999)
52	Speech interference for interpretive programs (U.S. Environmental Protection Agency, 1974)
60	Speech interruption for normal conversation (U.S. Environmental Protection Agency, 1974)

Figure 2 reports the percent of time that levels were above the four key values at sites within ZION. Exceedence values and percent time above values were calculated from continuous one-second L_{eq} data over the full duration of data collection, and include intrinsic and extrinsic sound sources.

Table 2. Acoustical terms and definitions¹.

Term	Definition
Acoustical Environment	The actual physical sound resources, regardless of audibility, at a particular location.
A-weighted sound pressure level in decibels (dB(A) or dBA)	A frequency-based methodology used to account for changes in human hearing sensitivity as a function of frequency. The A-weighting network de-emphasizes the high (6.3 kHz and above) and low (below 1 kHz) frequencies, and emphasizes the frequencies between 1 and 6.3 kHz, in an effort to simulate the relative response of the human ear. A-weighted decibels are defined as ten times the logarithm to the base ten of the ratio of A-weighted squared sound pressure to the squared reference sound pressure of 20 μ Pa, the squared sound pressure being obtained with fast (F) (125-ms) exponentially weighted time averaging. Alternatively, slow (S) (1000-ms) exponentially weighted time averaging may be specified.
Decibel	Decibel is abbreviated dB, and is a logarithmic unit of sound-pressure-squared level; it is common practice, however, to shorten this to sound pressure level, when no ambiguity results from so doing. 0 dB represents the lowest sound level that can be perceived by a human with healthy hearing. The formula for computing decibels is: $L_{db} = 10\log_{10}(P_1/P_0)$
Existing ambient	The composite, all-inclusive sound associated with a given environment, excluding only the analysis system's electrical noise (i.e., both extrinsic and intrinsic sounds are included).
Extrinsic Sound	Any sound not forming an essential part of the park unit, or a sound originating from outside the park boundary (also see Intrinsic Sound).
Frequency	Frequency equals the speed of sound divided by wavelength, and can be expressed in cycles per second, or Hertz (Hz). For a function periodic in time, the frequency is the reciprocal of the period, where the period is the smallest increment of an independent variable for which a function repeats itself (also see Hertz).
Hertz (Hz)	A measure of frequency, or the number of pressure variations per second. A person with normal hearing can hear between 20 Hz and 20,000 Hz. Kilohertz (kHz) equals 1000 Hz.
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 (also see Extrinsic Sound).
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 (exceedence level)	The A-weighted sound level equal to or exceeded by a fluctuating sound level x percent of a stated time period. For example, the symbol L10 represents that sound level which is exceeded 10 percent of the stated time period. ²
Natural ambient	The natural sound conditions found in a study area, including all sounds of nature (i.e., wind, streams, wildlife, etc.), and excluding all human and mechanical sounds.
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. ³
Percent Time Audible (PA)	The percent of time that a time-varying sound level may be detected in the presence of ambient sound as audible by the human ear.
Spectrum -- 1/3 octave	Acoustic intensity measurements in a sequence of spectral bands that span 1/3 octave. The International Standards Organization defines 1/3rd octave bands used by most sound level meters (ISO 266, 1975). 1/3rd octave frequency bands approximate the auditory filter widths of the human peripheral auditory system.
Sound pressure level	Ten times the logarithm to the base ten of the ratio of the time-mean-square pressure of a sound, in a stated frequency band, to the square of the reference sound pressure in gases of 20 μ Pa, the threshold of human hearing. $SPL = 10\log_{10}(p^2/p_{ref}^2)$, where p^2 = time-mean-square sound pressure and p_{ref}^2 = squared reference sound pressure of 20 μ Pa.

¹ Additional terms and definitions can be found in Appendix G² Hobbs & Downing, 2003. Wyle Report WR 03-08.³ McGraw Hill Dictionary of Scientific and Technical Terms, online
<http://www.accessscience.com/index.aspx>

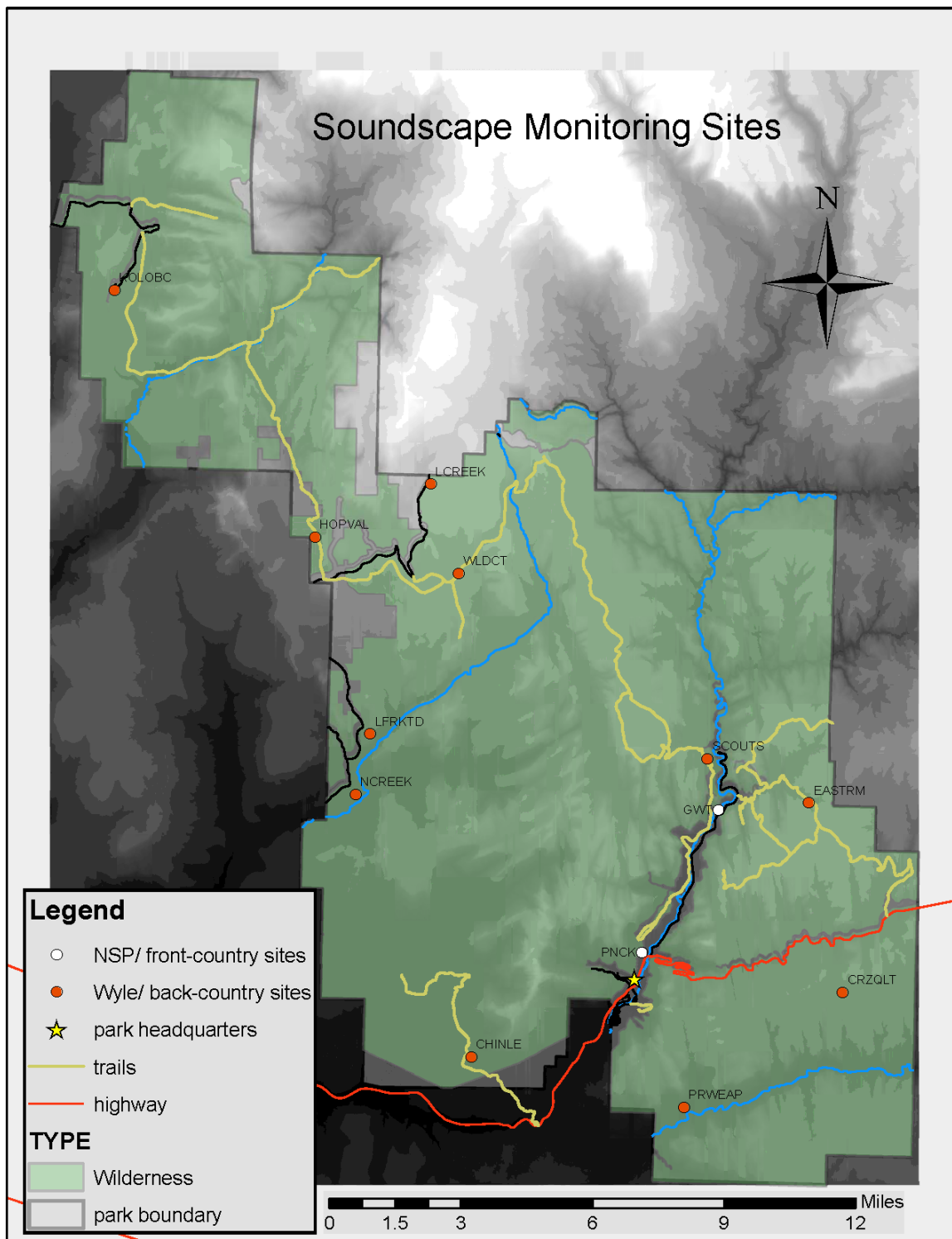


Figure 1. Map of acoustical monitoring sites at Zion from 2000 – 2008.

When comparing existing and natural ambient sound levels between sites, it is important to consider the proximity of each site to rivers, roads, and other features. Sites in or near riparian areas often have higher natural ambient sound levels due to the sound of flowing water, and sounds associated with increased biological activity (e.g., birds, insects, and other wildlife) near water sources.

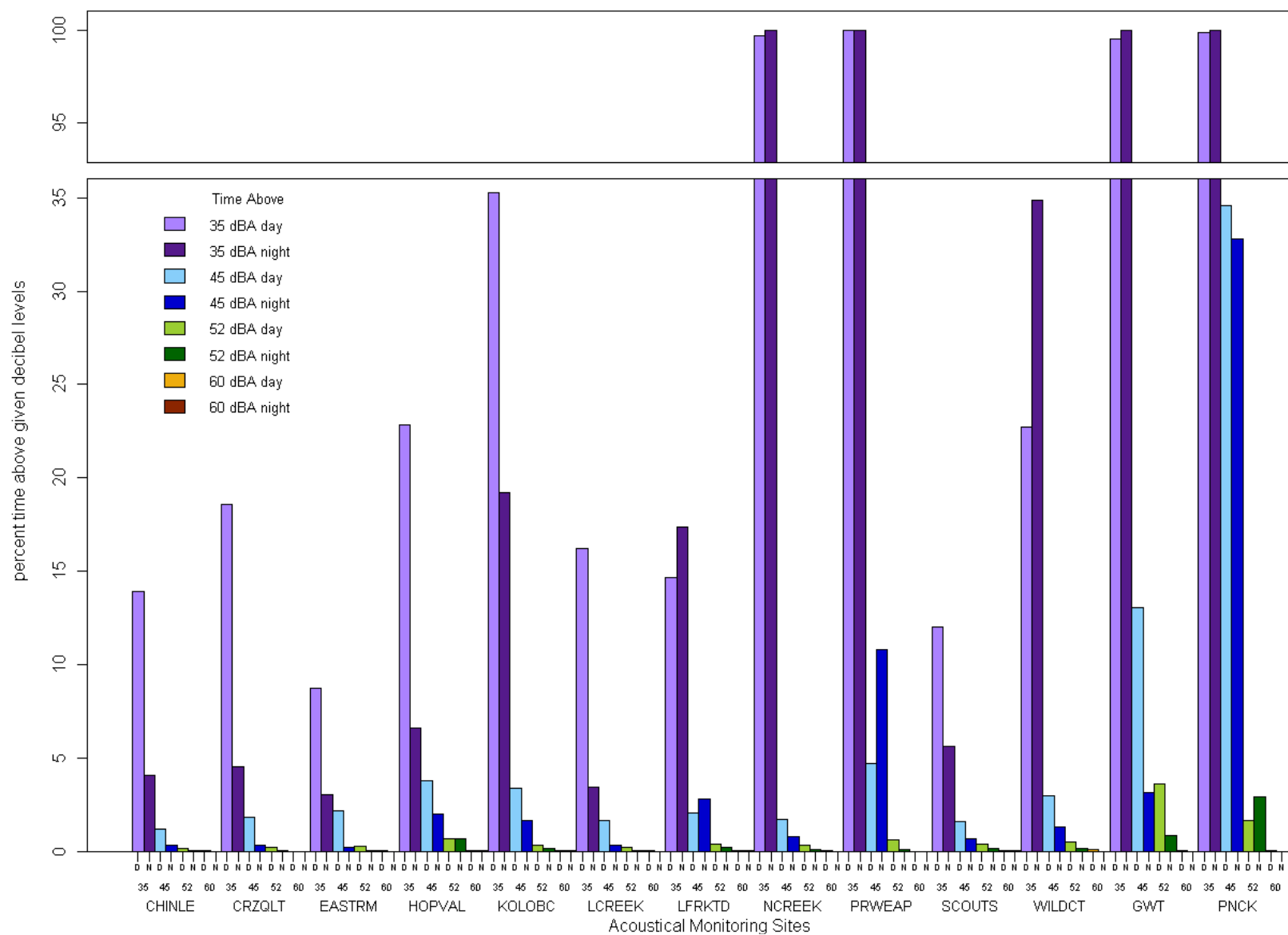


Figure 2. Percent time above given decibel levels for daytime (0700-1900) and night-time (1900-0700) hours at ZION, by site⁴.

⁴ Note the break in the y-axis. This gap was inserted to better display the wide range of values.

The median existing ambient sound pressure level (L_{50}) and the median natural ambient sound pressure levels (L_{nat}) can be seen in Figure 3. L_{nat} values are based on eight days of sound source identification (with the exception of EASTRM, where only two full days were available for analysis). The median L_{50} values were calculated using all of the available 1 second L_{eq} 1/3 octave data for the sites. Sound source identification was not done for the PRWEAP site, due to windy conditions. Aircraft overflights were identified visually using spectrograms created from the 1-second L_{eq} data. The NSP does not have an archive of audio data for the Wyle sites, so the identification of extrinsic sources with less-distinct sound signatures was not possible. However, at four of the Wyle sites (EASTRM, KOLOBC, SCOUTS and WILDCT), additional human-caused sounds were visually apparent on the spectrograms (see example in Appendix D). Without audio recordings, the sources of the “non-natural” sounds could not be confirmed. For the remainder of the Wyle sites, the percent time audible should be interpreted as the percent of time that *aircraft* were audible, and may be considered an under-estimate of the true percent time audible. Calculated from visual analysis or in-lab listening, Figure 4 shows the percent of time that aircraft were audible and the total percent of time that all extrinsic sources were audible.

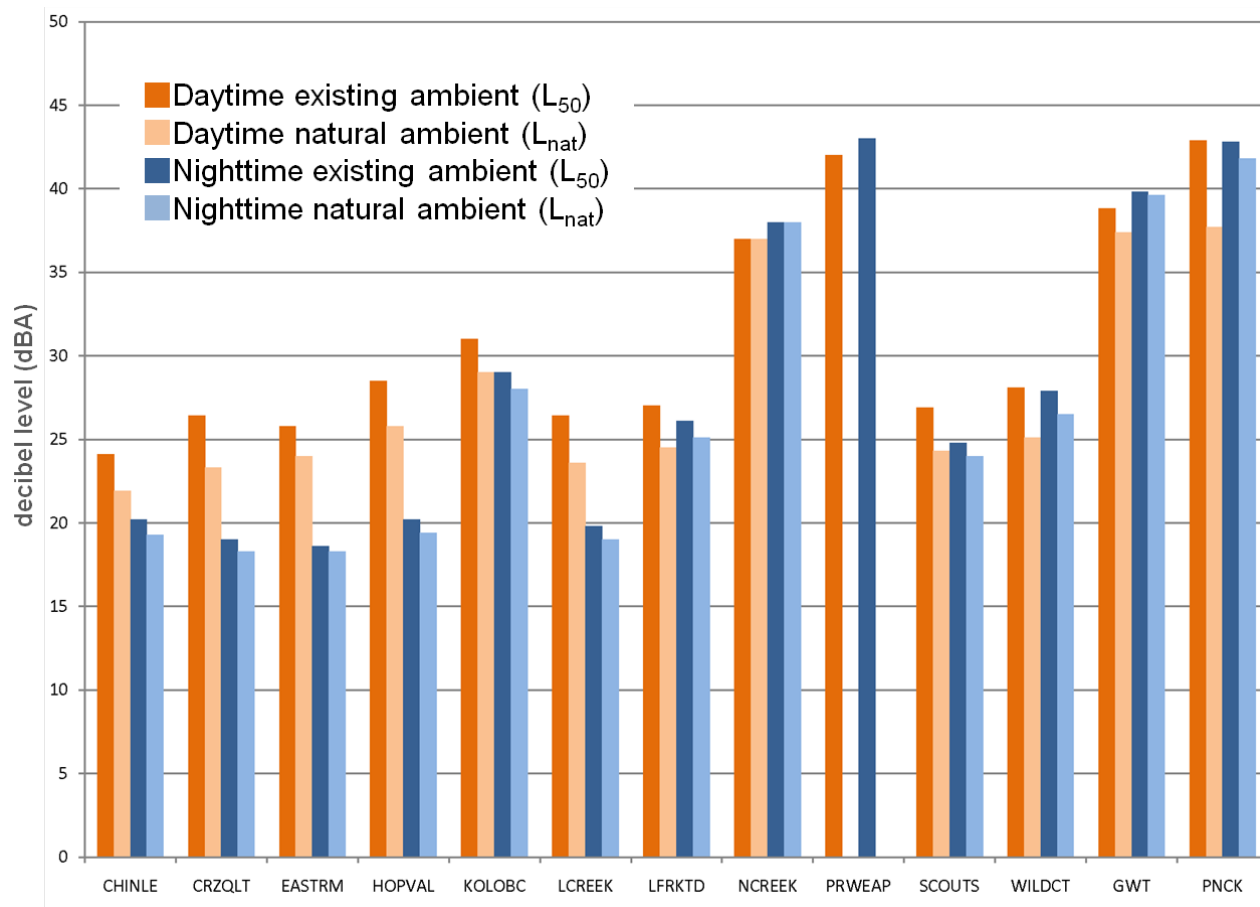


Figure 3. Daytime and nighttime existing and natural⁵ ambient levels.

⁵ Note: It was not possible to calculate L_{nat} for PRWEAP due to windy conditions at the site; only the existing conditions are reported.

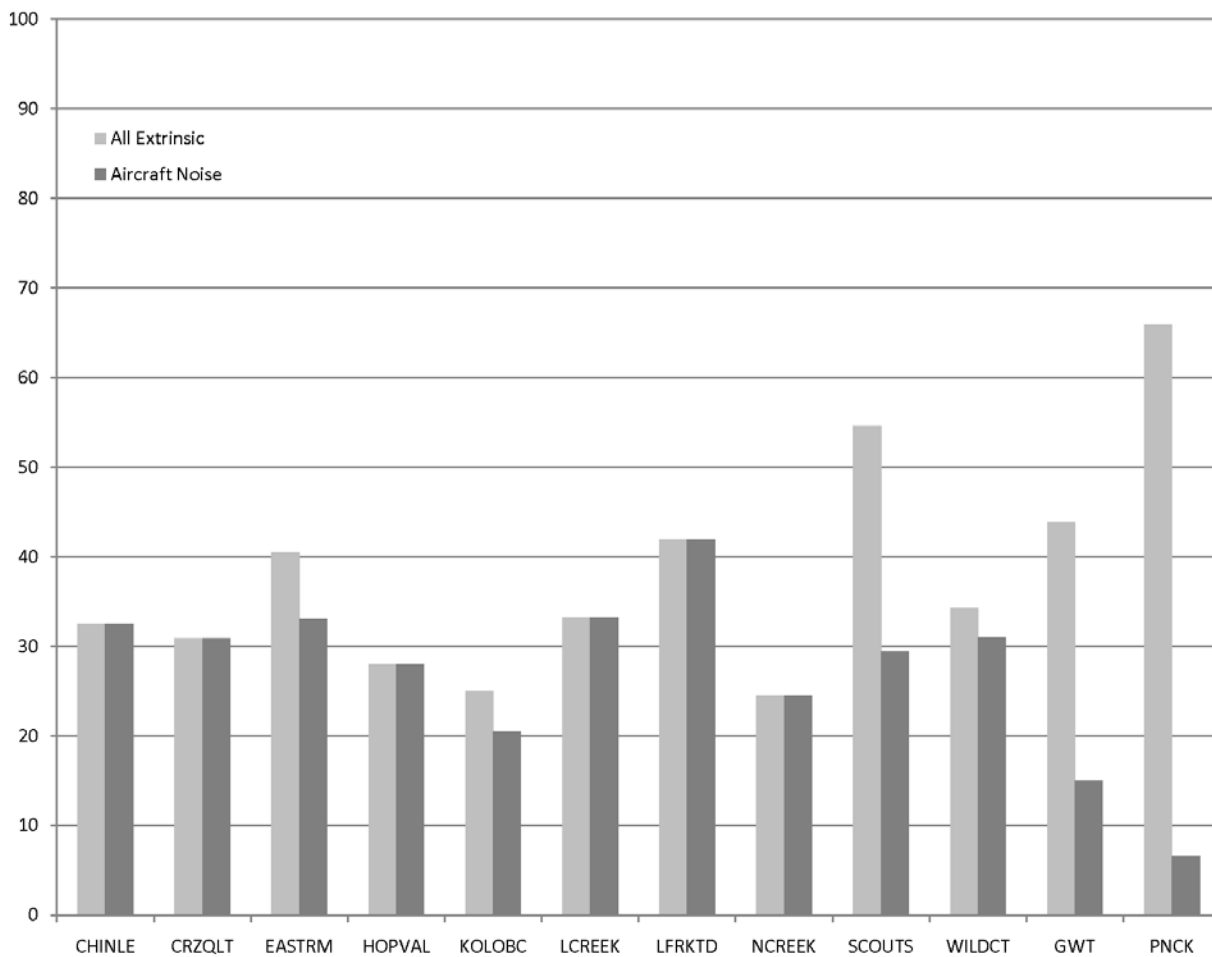


Figure 4. Percent of time aircraft and all extrinsic sources were identified, based on visual analysis and off-site listening covering 8 days of data for each site⁶.

Overall, natural ambient sound levels ranged from 21.9 – 37.7 dBA for daytime hours and from 19.3 – 41.8 dBA for nighttime hours. Natural sound sources including wind, water, wildlife, insects, etc. all contribute to the L_{nat} at each site. For backcountry sites (all of the Wyle sites), aircraft were the most prevalent source of human-caused sound. For the two frontcountry sites (GWT and PNCK), vehicle noise was the most common noise source. NCREEK and KOLOBC had the lowest percent time audible, but even at those sites, human-caused sounds were identifiable 24.5% and 25% of the time, respectively (Figure 4).

⁶ For EASTRM, only 2 days of suitable data were available for this analysis. The PRWEAP site was too windy for accurate source identification; PRWEAP results are not included.

Introduction

The purpose of this report is to present acoustical data that were collected at Zion National Park (ZION) between 2000 and 2008. These data were collected to quantify various aspects of the acoustical environment thereby providing information that can be applied to park management decisions and planning efforts. This report synthesizes the results from several data collection efforts by presenting figures, tables, and descriptions of the data; it does not attempt to make recommendations or draw management conclusions.

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 as compelling reasons for visiting national parks (McDonald et al. 1995). In response to the value placed on experiencing the sounds of nature by visitors and the importance of the acoustic environment in park ecosystems, NPS policy states that park managers will protect, preserve, and restore park soundscapes in a manner that will leave them unimpaired for future generations. Acoustical 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.

National Park Service Natural Sounds Program

The NPS Natural Sounds Program (NSP) was established in 2000 to help parks manage sounds in a way that protects park resources and is consistent with the expectations of park visitors. In 2010, the NSP became part of the new Natural Sounds and Night Skies Division of the National Park Service. The NSP works to protect, maintain, or restore acoustical environments throughout the National Park System. Program staff work in partnership with parks and others to increase scientific understanding and inspire public appreciation of the value and character of soundscapes. NSP measures the acoustic environment in parks by conducting acoustic monitoring, data collection in parks; analyses acoustic data to characterize and describe acoustic conditions; assists parks in identifying, assessing, and addressing noise intrusions; and provides technical, planning, and policy guidance to ensure that the acoustic environment is protected for future generations.

Soundscape Monitoring and 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 soundscapes⁷ 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

⁷ 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.

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 NPS Management Policies state “the natural ambient sound level—that is, the environment of sound that exists in the absence of human-caused noise—is the baseline condition, and the standard against which current conditions in a soundscape [acoustic resource] will be measured and evaluated” (NPS 2006b). However, the appropriate acoustic baseline and acceptable impacts may also depend upon the resources and the values of the park. For instance, “culturally appropriate sounds are important elements of the national park experience in many parks” (NPS 2006b). In this case, “the Service will preserve soundscape resources and values of the parks to the greatest extent possible to protect opportunities for appropriate transmission of cultural and historic sounds that are fundamental components of the purposes and values for which the parks were established” (NPS 2006b). A glossary of acoustical terms can be found in Appendix G.

According to NPS policy, best available scientific data must serve as the foundation of park management, decision making, and planning. NPS Management Policies states “Decision-makers and planners will use the best available scientific and technical information and scholarly analysis to identify appropriate management actions for protection and use of park resources...Decisions about the extent and degree of management actions taken to protect or restore park ecosystems or their components will be based on clearly articulated, well-supported management objectives and the best scientific information available.” The Management Policies further state that collection of relevant data is necessary for science-based decision making: “The collection and analysis of information about park resources will be a continuous process that will help ensure that decisions are consistent with park purposes.” This report summarizes acoustic data collected in ZION in order to inform park decision making, management and planning,

Study Area

In 2000-2001, Wyle Laboratories established 12 monitoring sites in backcountry areas in Zion National Park. One-third octave data were collected at 11 of these sites, which are addressed throughout this report as the Wyle sites. Additional data have been collected at several of the Wyle sites by Sandhill Company, and by ZION staff. Two front-country sites were established in the summer of 2008 by ZION staff and the Natural Sounds Program (NSP). Figure 5 illustrates the locations of these sites, and indicates which sites have had multiple rounds of monitoring. Additional details about each site are located in Table 3. Photos of the 2008 sites are located in Appendix C.

Table 3. Site descriptions and locations.

Site ID	Site Name	Designation	Days of data	Vegetation	Elevation (in meters)	Latitude	Longitude
CHINLE	Chinle Trail Mesa	Back country	58.6	Desert scrub	1281	37.181459	-113.046664
CRZQLT	Crazy Quilt Mesa	Back country	46.6	Slick rock	1748	37.20528	-112.893821
EASTRM	East Rim Mesa	Back country	3.7	Mountain brush	1949	37.267543	-112.909386
HOPVAL	Hop Valley Trail	Back country	17.5	Desert scrub	1930	37.351735	-113.116114
KOLOBC	Kolob Canyon	Back country	23.5	Pinyon/ juniper	1874	37.431788	-113.20153
LCREEK	Upper Kolob Terr.	Back country	50.6	Pinyon/ juniper	2365	37.370122	-113.06864
LFRKTD	Left Fork/ N Creek	Back country	21.1	Mountain brush	1563	37.287239	-113.091476
NCREEK	R Fork/ Kolob Terr.	Back country	19.2	Riparian	1273	37.267188	-113.096999
PRWEAP	Parunuweap Canyon	Back country	9.0	Riparian	1227	37.166277	-112.958414
SCOUTS	Scout's Lookout	Back country	19.4	Slick rock	1769	37.281346	-112.951614
WILDCT	Wildcat Trail	Back country	20.9	Conifer forest	2127	37.340927	-113.056483
GWT/01	Great White Throne	Front country	23.5	Near riparian area	1328	37.26470	-112.94664
PNCK/02	Pine Creek	Front country	21.1	Riparian	1240	37.21713	-112.97708

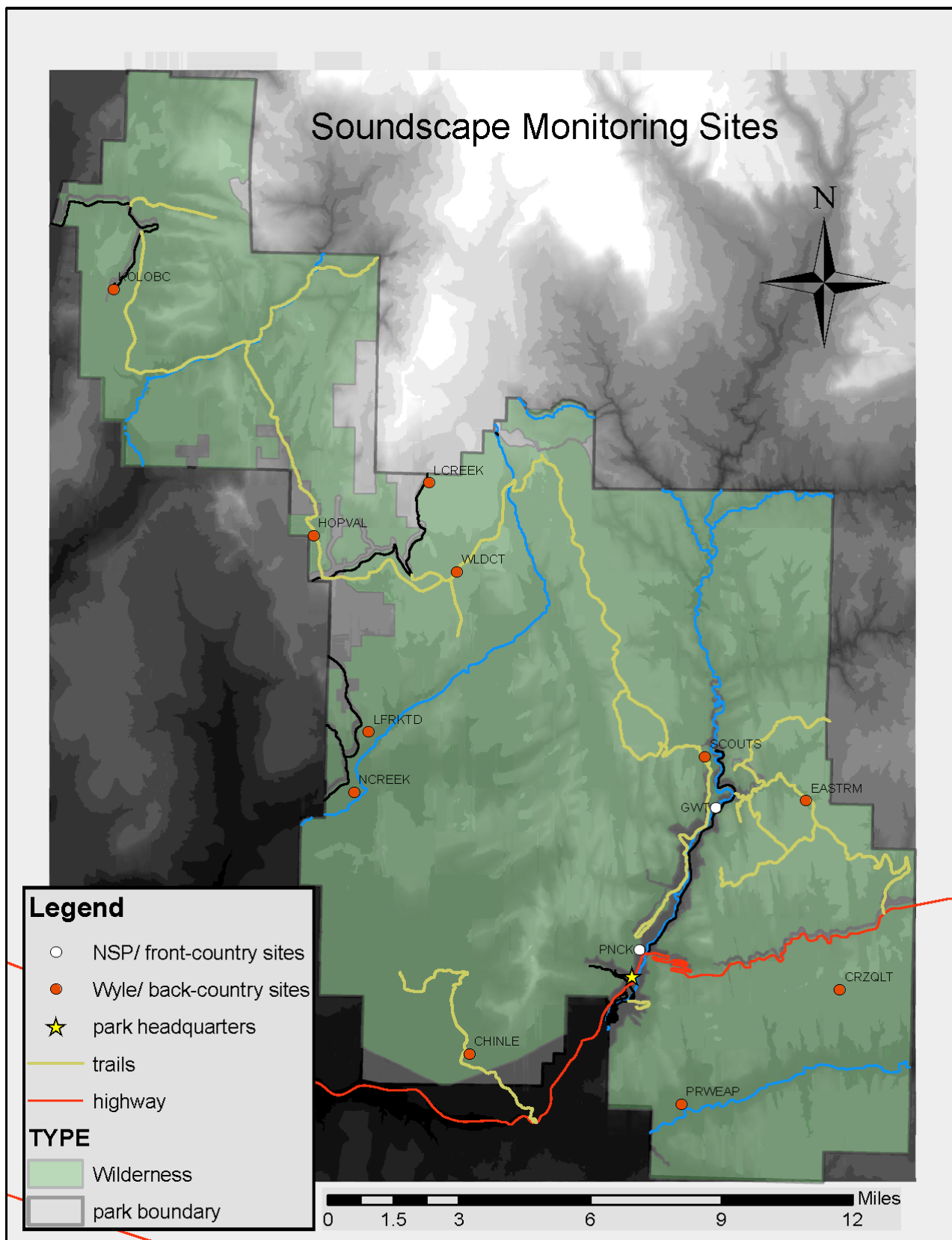


Figure 5. Soundscape monitoring sites from 2000 — 2008.

Methods

Automatic Monitoring

For both the Wyle sites and the NPS sites, Table 4 displays a summary of the data collected from 2000 – 2008.

NPS/NSP Systems

In 2008, the NSP used Larson Davis 824 sound level meters (SLM) for all monitoring conducted at ZION. The Larson Davis SLM is a hardware-based, real-time analyzer which records 1-second L_{eq} and 1/3 octave band data, and can export data to a laptop computer. These SLMs met American National Standards Institute (ANSI) Type 1 standards.

Each Larson Davis sampling station in 2008 consisted of:

- LD 824 SLM
- Microphone with environmental shroud
- Preamplifier
- Multiple NiMH rechargeable battery packs
- Anemometer
- Meteorological data logger
- Photo voltaic panels
- Data logging device (laptop)

Each acoustic sampling station collected:

- SPL data in the form of A-weighted decibel readings (dBA) every second
- One third octave band data every second ranging from 12.5 Hz – 20,000 Hz
- Meteorological data (wind speed)

Wyle Laboratory Sites

In 2000-2001, Wyle used several SLM models. Larson Davis 824 SLMs and Norsonic 121 Environmental Noise Analyzers (SLMs) were used to collect 1/3 octave data. The LD-824 and Norsonic 121 systems used by Wyle met ANSI Type I standards and produced comparable data to the LD-824 systems used by the NPS in 2008.

Each sampling station in 2000 – 2001 collected:

- SPL data in the form of A-weighted decibel readings (dBA) every second
- One third octave band data every second ranging from 12.5 Hz – 20,000 Hz

Additionally, the Norsonic 121 system collected C-weighted data. For full details on site set up, dates deployed, and for digital data files from the 2000 – 2001 deployments, please refer to the 2003 Wyle report (Hobbs & Downing 2003).

Table 4. Summary of data collected at ZION from 2000 – 2008.

site	data collector	days of data	SPL meter	frequency range collected	continuous audio	noise floor ⁸	dates of data collection	front-/back-country	visual analysis	in-lab listening	primary noise source
CHINLE	Wyle	58.6	LD-824	12.5-20000 Hz	no	16.5 dB	2/20/2001 - 5/4/2001	backcountry	8	0	aircraft
CRZQLT	Wyle	46.6	LD-824	12.5-20000 Hz	no	16.5 dB	10/20/2000 - 11/16/2000, 2/20/2001 - 5/17/2001	backcountry	8	0	aircraft
EASTRM	Wyle	3.7	LD-824	12.5-20000 Hz	no	16.5 dB	4/24/2001 - 4/28/2001	backcountry	2	0	aircraft
HOPVAL	Wyle	17.5	LD-824	12.5-20000 Hz	no	16.5 dB	4/24/2001 - 5/14/2001	backcountry	8	0	aircraft
KOLOBC	Wyle	23.5	LD-824	12.5-20000 Hz	no	16.5 dB	10/20/2000 - 11/15/2000	backcountry	8	0	aircraft
LCREEK	Wyle	50.6	NOR-121	12.5-20000 Hz	no	16.5 dB	10/26/2000 - 11/14/2000, 4/24/2001 - 5/16/2001, 7/31/2001 - 8/18/2001	backcountry	8	0	aircraft
LFRKTD	Wyle	21.1	LD-824	12.5-20000 Hz	no	16.5 dB	7/26/2001 - 8/16/2001	backcountry	8	0	aircraft
NCREEK	Wyle	19.2	LD-824	12.5-20000 Hz	no	16.5 dB	10/20/2000 - 11/16/2000	backcountry	8	0	aircraft
PRWEAP	Wyle	9.0	LD-824	12.5-20000 Hz	no	16.5 dB	10/20/2000 - 11/10/2000	backcountry	0	0	--
SCOUTS	Wyle	19.4	LD-824	12.5-20000 Hz	no	16.5 dB	7/30/2001 - 8/19/2001	backcountry	8	0	aircraft
WILDCT	Wyle	20.9	LD-824	12.5-20000 Hz	no	16.5 dB	7/26/2001 - 8/16/2001	backcountry	8	0	aircraft
GWT	NPS	23.5	LD-824	12.5-20000 Hz	yes	20.2 dB	7/29/2008 - 8/21/2008	frontcountry	0	8	vehicles
PNCK	NPS	21.1	LD-824	12.5-20000 Hz	yes	19.0 dB	7/28/2008 - 8/18/2008	frontcountry	0	8	Vehicles

⁸ Interpretation of the noise floor is discussed in detail in the 2003 Wyle report. The 16.5 dB noise floor for Wyle sites is an estimate of the system noise floor. For GWT and PNCK, the reported noise floor values were measured in the field using a dummy microphone, and represent the electronic noise floor.

Off-Site Listening/ Visual Analysis

In addition to the metrics reported by Wyle (Hobbs & Downing 2003), the Natural Sounds Program (NSP) staff visually analyzed a subset of 1/3 octave L_{eq} samples from the Wyle sites in order to identify aircraft overflights and estimate aircraft audibility. Audio was not available from the Wyle sites, so identification of noise sources with less distinctive sound signatures was not possible. At four of the Wyle sites (EASTRM, KOLOBC, SCOUTS and WILDCT), additional human-caused sounds were visually apparent on the spectrograms, but the source of the sounds could not be confirmed. For these four sites, noises other than aircraft were identified only as "non-natural unknown" and were included in the total PA. Figure 6 gives a visual example of aircraft and other non-natural sound signatures. For the remainder of the Wyle sites, the percent time audible should be interpreted as the percent of time that *aircraft* were audible, and may be considered an under-estimate of the true PA. Visual analysis was also used for the 2008 GWT site. For GWT in 2008, audio samples were used to confirm identification of noise sources. The total percent time extrinsic sounds were audible was then used to calculate the natural ambient sound level for each hour.

For the 2008 PNCK site, sound sources were identified through off-site listening. This technique is often employed for sites that have many competing noise sources, which makes visual detection of sound signatures difficult. For each day of monitoring, continuous MP3 (MPEG Audio Layer 3 Format) audio files were recorded. NSP staff listened to samples (10 seconds every two minutes) from eight days of the audio recordings. For each 10-second sample, sound sources were identified, and entered into a spreadsheet.

In 2005, the NPS drafted protocols for acoustic studies in National Parks, in cooperation with staff from the Volpe National Transportation Systems Center⁹. When these acoustic monitoring protocols were developed, the amount of power it took to run recording devices, and storage limitations of these devices, were such that continuous recordings could not be made. As an alternative, recordings were made every 2 minutes for 10 seconds. This sampling scheme was designed to ensure that events of interest (namely aircraft and vehicles) would be recorded. Since that time, audio recorders have become much smaller and require less power. In addition, storage devices with larger capacities have become readily available. Therefore, continuous audio recordings were collected during the 2008 monitoring effort at ZION.

Per the 2005 protocol, a 25 day monitoring period is recommended for each site. During the monitoring period, investigators are instructed to conduct several hours of observer logging or recording playback (typically 16 hours per site) to determine the audible sources of noise. Continuous recording has allowed us the convenience of conducting these listening sessions in the office instead of in the field. Natural Sounds Program staff still listen to a subset of the audio data, using the 10 seconds per 2 minutes sampling scheme. When placed end-to-end, these 10 second samples constitute 2 hours of audio recordings. To reach an equivalent 16 hours of observer logging, we listen to 8 days of sub-sampled audio. These listening sessions provide the basis for the calculation of metrics such as natural ambient, as explained in detail in the section on "Calculation of Metrics" below. Noise canceling headphones were used for off-site listening playback to minimize limitations imposed by the office acoustic environment.

⁹ National Park Service. 2005. Acoustic and Soundscape Studies in National Parks DRAFT.

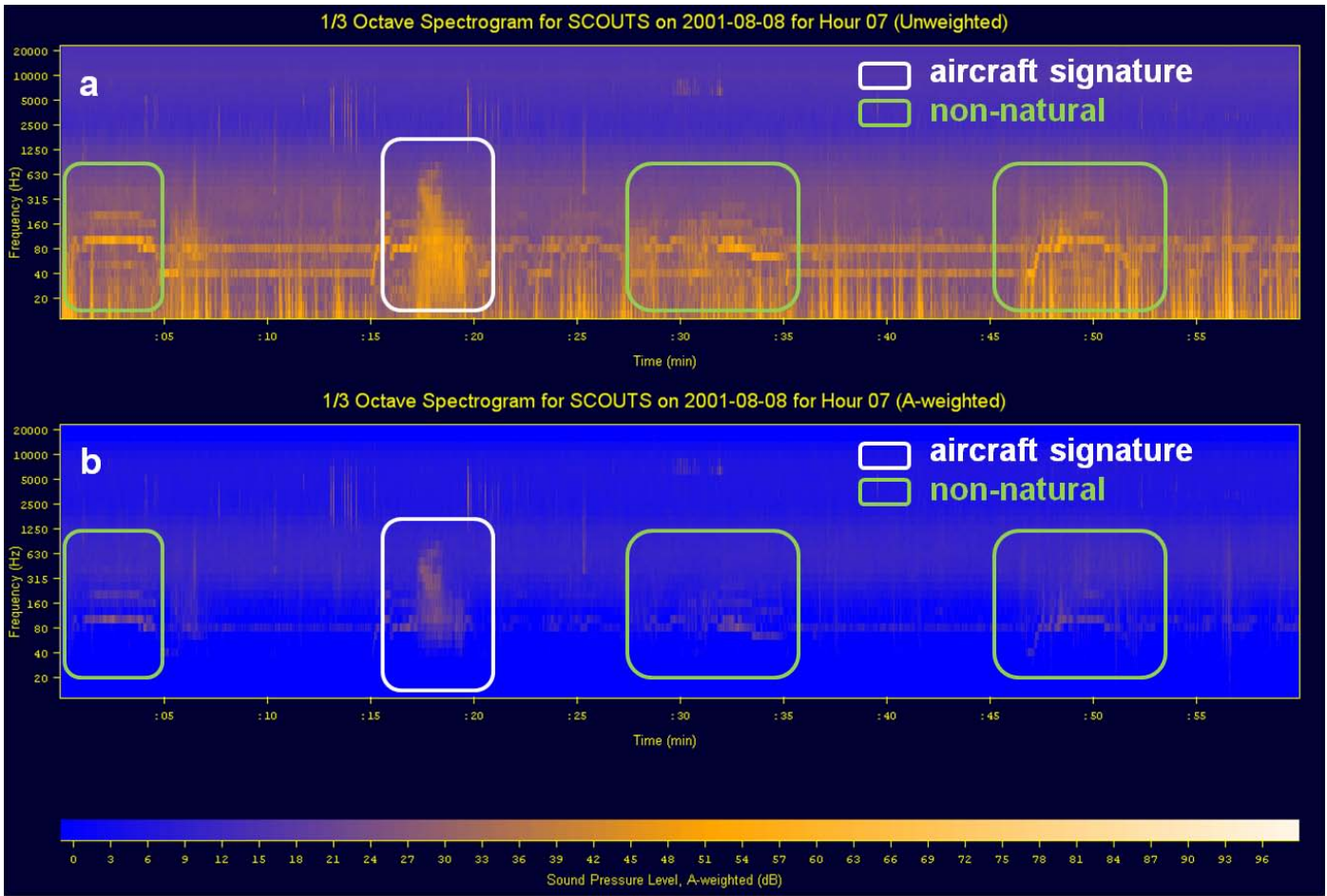


Figure 6. Visual identification of aircraft and other non-natural sources using spectrograms. Part **a** shows an unweighted spectrogram, and part **b** shows the A-weighted version. In both **a** and **b**, the aircraft sound signature is very apparent, and other non-natural sounds are also visible. These spectrograms display data from SCOUTS, where traffic noise or other human activities in the valley below the site are often audible.

Calculation of Metrics

The current status of the acoustical 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 ambient (L_{50}) and natural ambient (L_{nat}) sound levels. These are both examples of exceedence levels (L_x), where each L_x value refers to the sound pressure levels that is exceeded $x\%$ of the time. The L_{50} represents the median sound pressure level, and is comprised of spectra (in dB) drawn from a full dataset (removing data with wind speed $> 5\text{m/s}$ 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 comprised 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 equation 1:

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

and P_H is the percentage of samples containing extrinsic or anthropogenic sounds in a given 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.

Calculation of diel L_x values

The Natural Sounds Program uses a custom program called “Hourly Metrics” to generate L_x values from long term acoustical monitoring data. All of the values reported are medians. The software aggregates L_x values (L_{50} , L_{nat} , L_{90}) for each hour monitored, based on one-second L_{eq} data. Then, hourly percentile values (L_{50} , L_{nat} , L_{90} etc) are grouped by time category (daytime or nighttime), and the median of each time category is reported. For instance, for daytime L_{90} , all L_{90} values between 0700h and 1900h are calculated, the median of this set is reported.

Results

Data Analysis

In determining the current conditions of an acoustical environment, it is important to examine how often sound pressure levels exceed certain values. The four values we reference in this document are listed in Table 5. Figure 7 displays the percent of time that measured decibel levels were above four key values. Sound pressure levels above 35 dBA can negatively affect sleep, levels above 52 dBA can interfere with communication at a distance of 10 meters, and levels exceeding 60 dBA can cause speech interference at 1 meter. Exceeding these sound levels can negatively affect the visitor experience, and the ability of park staff to communicate with visitors.

Table 5. Key sound level values.

Sound Levels (dBA)	Relevance
35	Blood pressure and heart rate increase in sleeping humans (Haralabidis et al., 2008)
45	World Health Organization's recommendation for maximum noise levels inside bedrooms (Berglund, Lindvall, and Schwela, 1999)
52	Speech interference for interpretive programs (U.S. Environmental Protection Agency, 1974)
60	Speech interruption for normal conversation (U.S. Environmental Protection Agency, 1974)

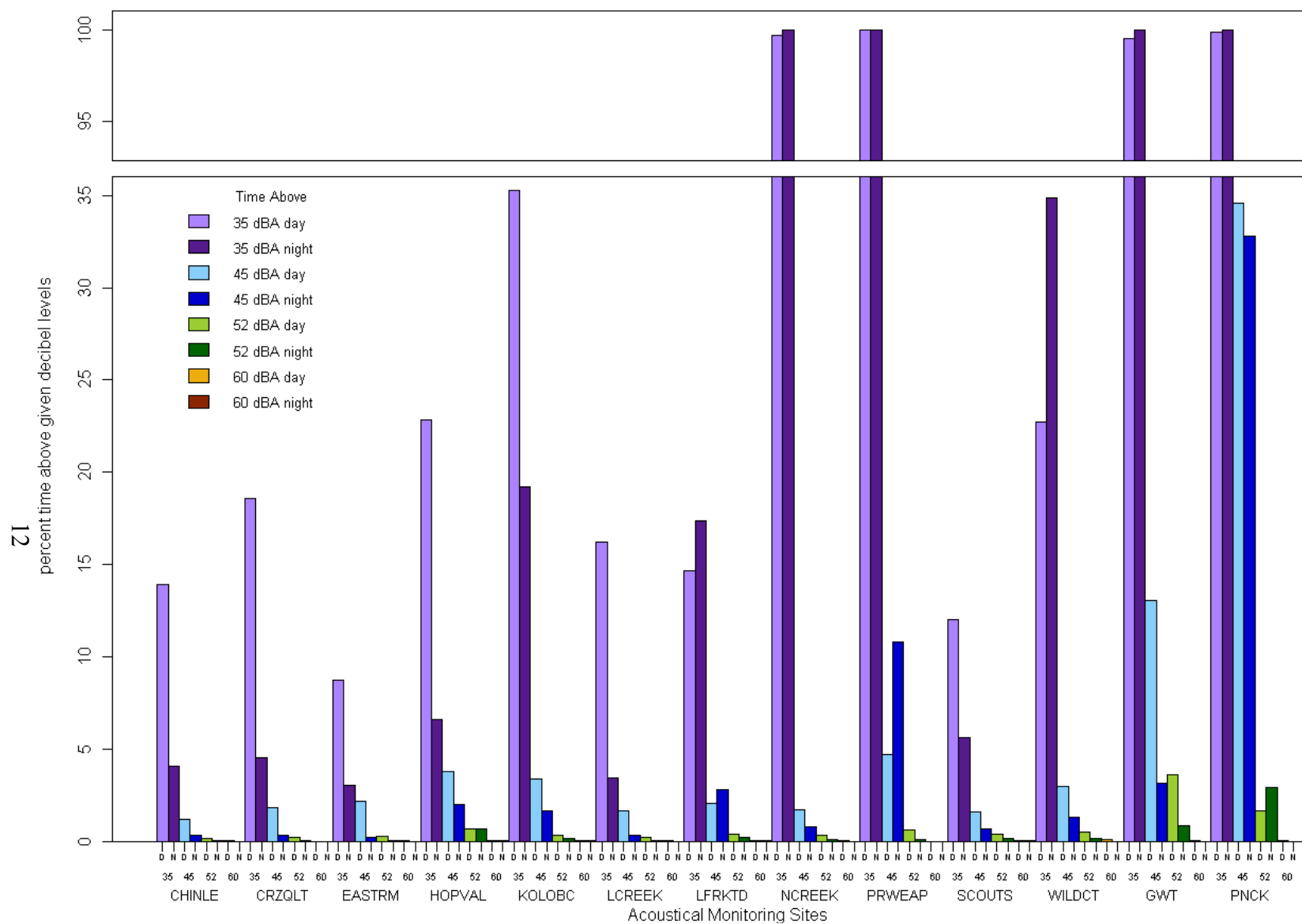


Figure 7. Percent time above given decibel levels for daytime (0700-1900) and night-time (1900-0700) hours at ZION, by site¹⁰.

¹⁰ Note the break in the y-axis. This gap was inserted to better display the wide range of values.

Audibility

For both of the 2008 sites, Figure 8 shows the mean percentage of time that vehicles, aircraft and all non-natural sound sources were audible based on either eight days of off-site listening or eight days of visual analysis.

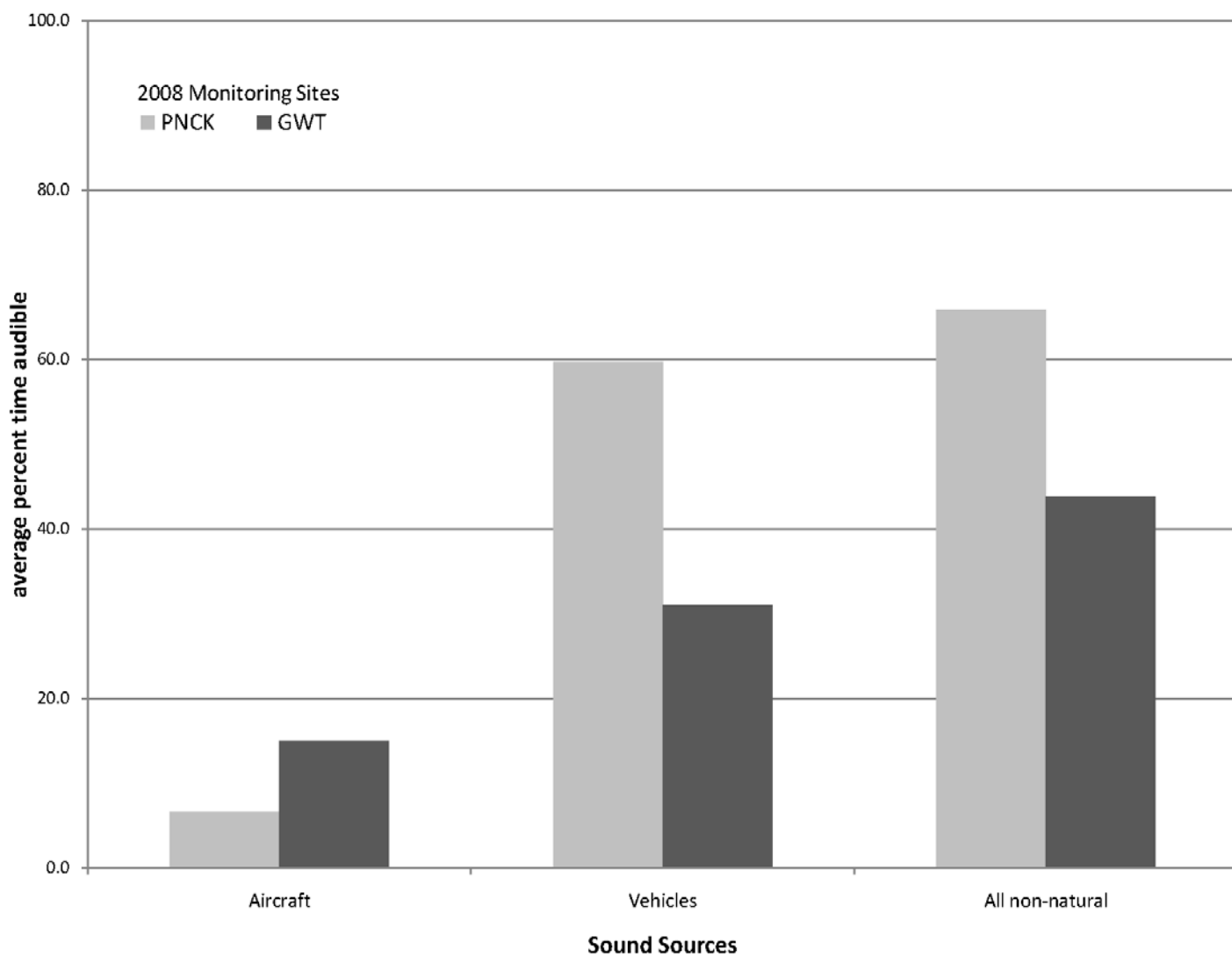


Figure 8. Average percent time audible for 2008 sites.

Figure 9 looks at vehicle noise for the 2008 sites, broken down by hour of the day. At both of the 2008 sites, vehicle noise was the most pervasive non-natural sound source.

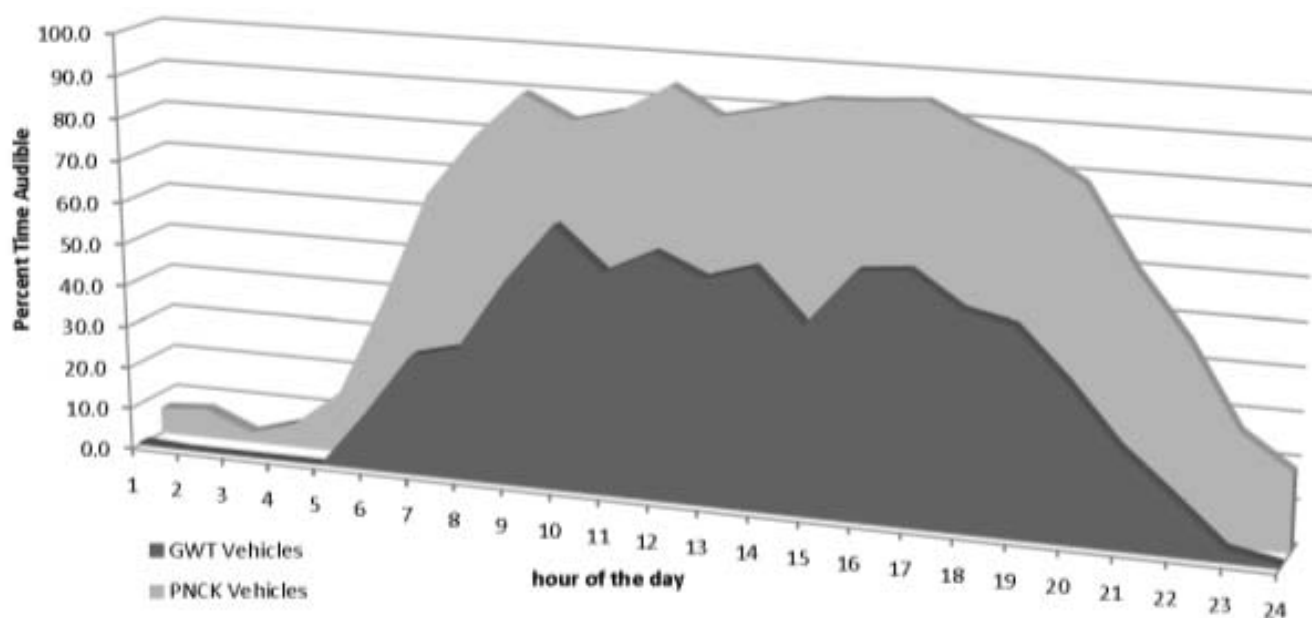


Figure 9. Average audibility of vehicle noise for each hour of the day at 2008 sites.

Table 6 displays the 2008 aircraft and total non-natural sound source results, and Table 7 shows the percent of time that aircraft and other extrinsic noise sources were easily identified on the spectrograms of the Wyle sites.

Table 6. Mean percent time audible – 2008 sites.

Site ID	Days analyzed	Mean % time audible	
		All Extrinsic	Aircraft Noise
GWT/01	8	43.9	15.0
PNCK/02	8	65.9	6.6

Table 7. Mean percent time audible – Wyle Laboratory sites 2000-2001.

Site ID	Days Analyzed	Mean % time audible	
		All Extrinsic	Aircraft Noise
CHINLE	8	32.5	32.5
CRZQLT	8	30.9	30.9
EASTRM	2	40.5	33.1
HOPVAL	8	28.0	28.0
KOLOBC	8	25.0	20.5
LCREEK	8	33.2	33.2
LFRKTD	8	41.9	41.9
NCREEK	8	24.5	24.5
PRWEAP	8	--	--
SCOUTS	8	54.6	29.4
WILDCT	8	34.3	31.0

Metrics

In order to determine the effects of extrinsic noise on the acoustical environment, it is useful to examine the median hourly exceedence metrics. In Figure 13 and Figure 14 the dB levels for 33 one-third octave band frequencies over the day and night periods are shown for the 2008 sites. All figures for the 11 Wyle sites are located in Appendix A. The grayed area represents sound levels outside of the typical range of human hearing. The exceedence levels (L_x) are also shown for each one-third octave band. They represent the dB exceeded x percent of the time. For example, L_{90} is the dB that has been exceeded 90% of the time, and only the quietest 10% of the sample can be found below this point. On the other hand, the L_{10} is the dB that has been exceeded 10% of the time, and 90% of the measurements are quieter than the L_{10} . The bold portion of the 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 levels at this site (Figure 10). The size of this portion of the column is directly related to the percent time that human caused sounds are audible. For the Wyle sites, only aircraft and other visually apparent non-natural sounds were included in the estimates of audibility (due to lack of audio for these sites). It is possible that there were other noise sources that were not visually distinct in the spectrograms, however, only the visually distinct sources were taken into account when estimating the L_{nat} . When bold portions of the column do not appear the natural and existing ambient levels were either very close to each other or were equal.

L_{nat} and L_{50} are bordered above by L_{10} and below by L_{90} , which essentially mark the median, maximum, and minimum sounds pressure levels over the 30 day monitoring period. In Figure 14, during the daytime hours the bold portion extends to the bottom of each column, indicating that the L_{nat} value was less than or equal to the L_{90} . The typical frequency levels for transportation, conversation and songbirds are presented on the figure as examples for interpretation of the data. These ranges are estimates and are not vehicle-, species, or habitat-specific. It can be useful to review each one third octave band on these figures to adequately predict the audibility of one sound or the masking of another. For example, you will notice bird sounds and transportation noise are audible at different frequency spectrums. There may be times when transportation sounds were louder than the bird sounds; however the bird sounds would not be masked because their song is audible at a different frequency. However, if two sounds are within similar or overlapping frequency ranges and one sound is louder than the other, you can begin to predict when sounds are going to be masked. As an example, vehicle noise, wind, and running water can mask distant aircraft, in some cases.

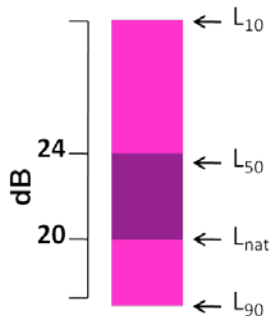


Figure 10. Visual example of exceedence levels, as used in subsequent figures.

The 4 dB bold portion of the column in Figure 10 shows the difference between the L_{nat} and L_{50} . The bold portions of the columns shown in the day and night decibel levels figures represent the decibel increase caused by extrinsic noise. See Figure 13, Figure 14, and figures in Appendix A.

Figure 11 reports the daytime L_{90} , L_{nat} , L_{50} , and L_{10} values for the sites at ZION, where daytime was calculated for the hours 0700 - 1900.

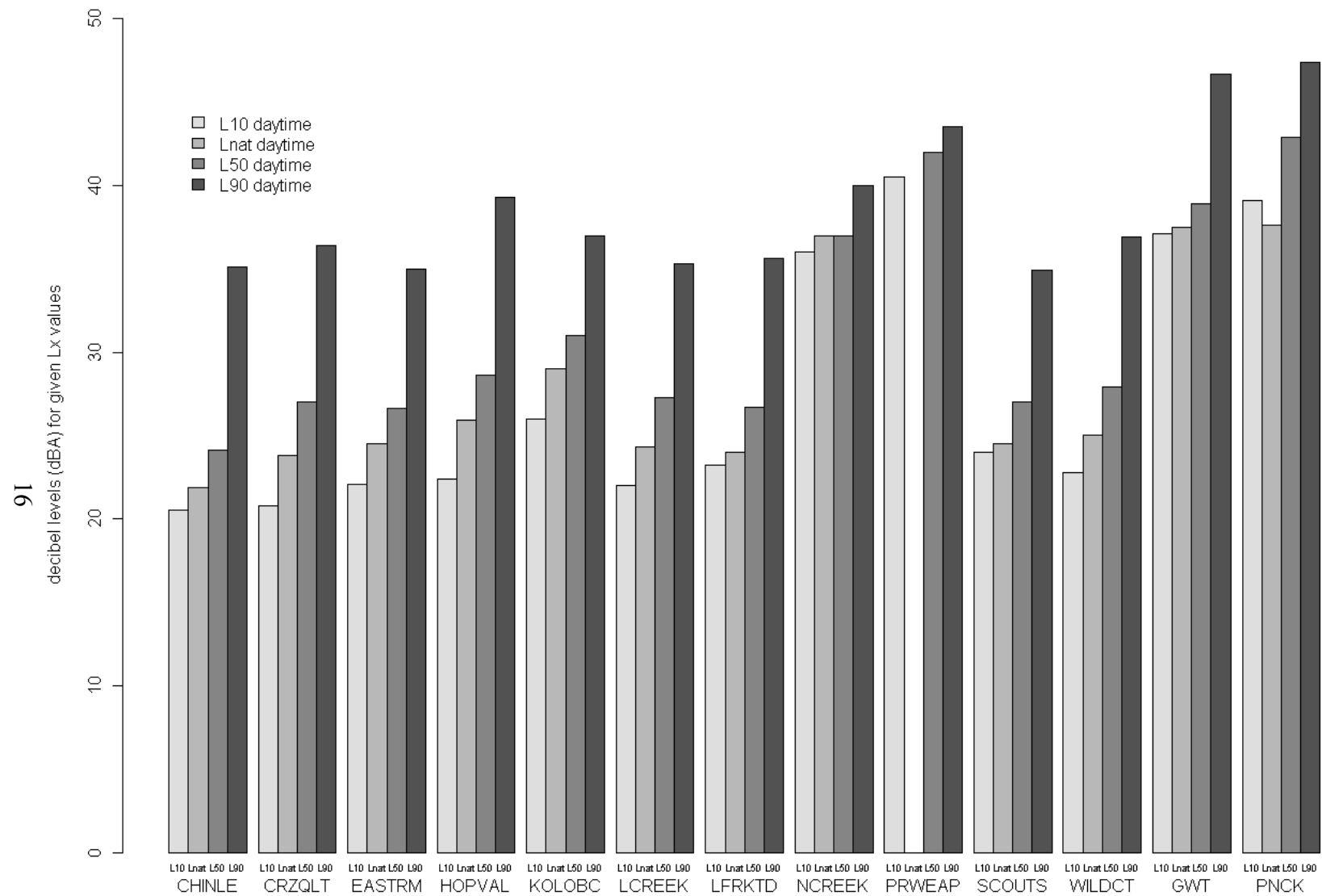


Figure 11. L_{10} , L_{nat} , L_{50} and L_{90} levels for daytime (0700 – 1900).

Figure 12 reports the nighttime L_{90} , L_{nat} , L_{50} , and L_{10} values for the sites at ZION, where nighttime was calculated for the hours 1900 - 0700.

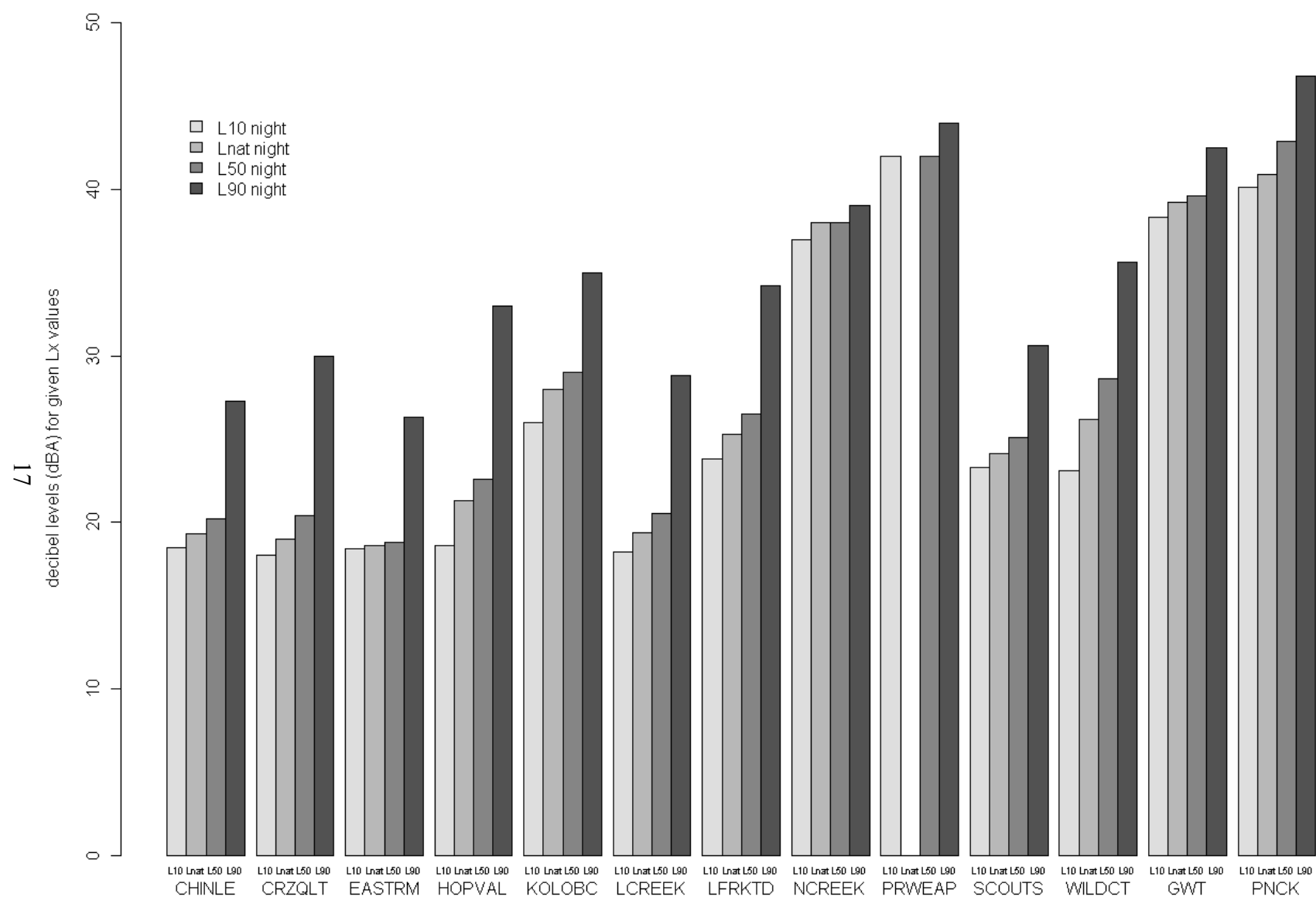


Figure 12. L_{10} , L_{nat} , L_{50} and L_{90} levels for night (1900 – 0700).

Figure 13 and Figure 14 display the L_{10} , L_{nat} , L_{50} and L_{90} levels for each site, separating the data into 33 one-third octave bands. Additional figures from Wyle sites are in Appendix A.

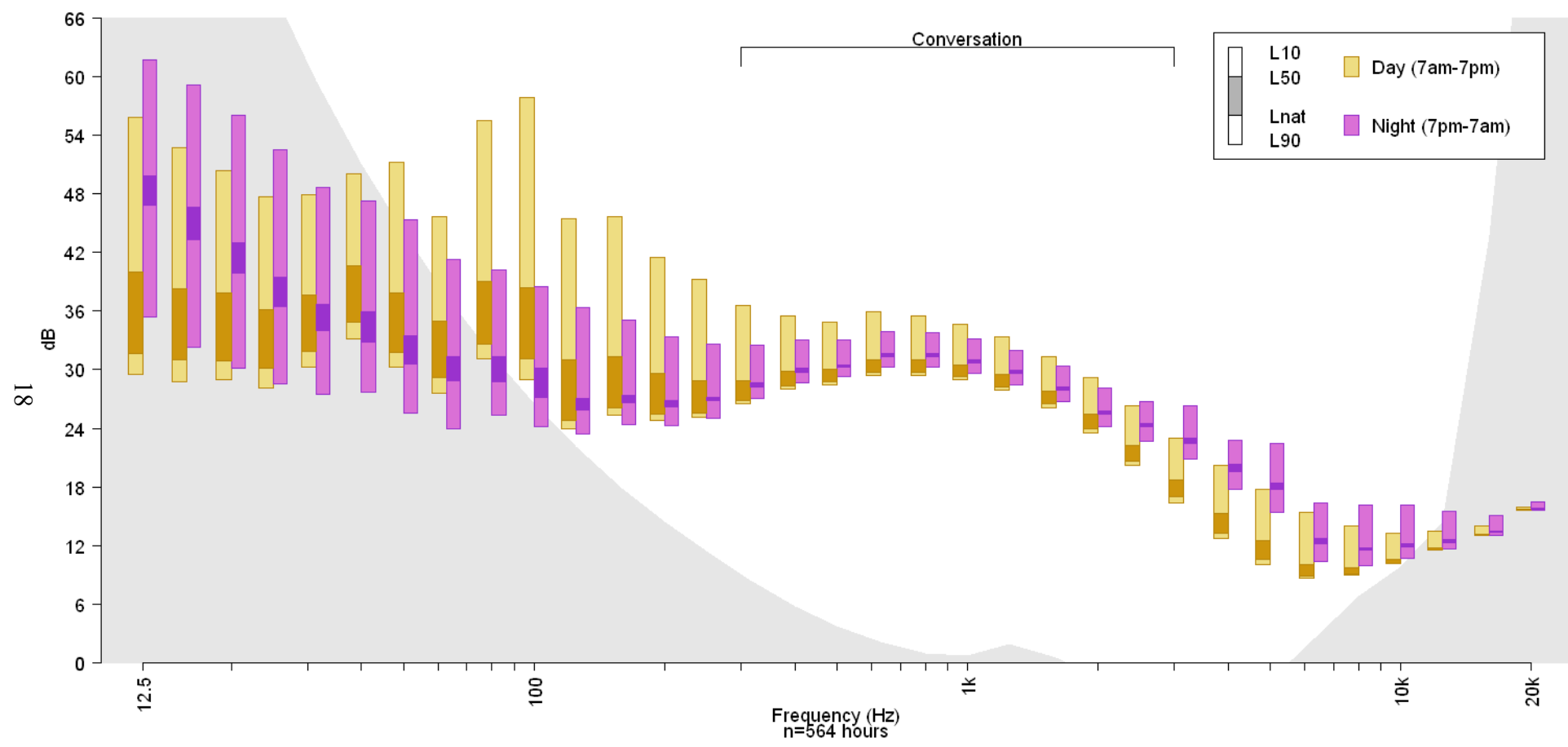


Figure 13. Day and night dB levels for 33 one-third octave bands at ZION site GWT.

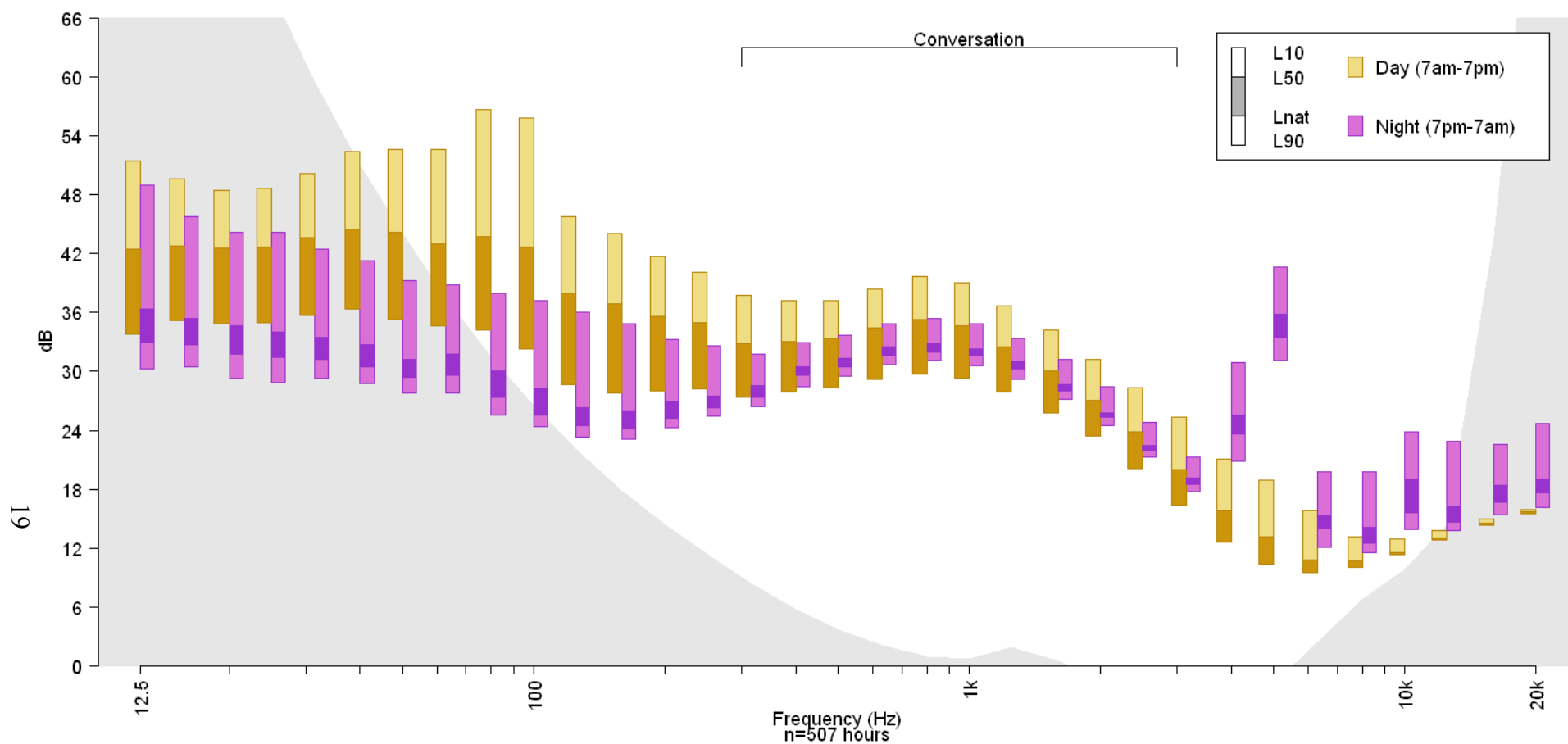


Figure 14. Day and night dB levels for 33 one-third octave bands at ZION site PNCK¹¹.

¹¹ ¹The L_{nat} value for the daytime is less than the L_{90} value due to almost constant human-caused sounds

Discussion

This summary report was designed to bring data together from several previous monitoring efforts, and to update graphics and metrics for the 2000-2001 Wyle data. Monitoring results are intended to give the park baseline information as well as inform management decisions.

The Wyle sites were established in 2000-2001 at the request of ZION. The 2003 Wyle report (Hobbes & Downing) summarizes their findings, and gives detailed information about the sites and equipment used. For 11 of their 12 sites, Wyle collected 1/3 octave data. The analysis of this type of data has evolved rapidly over the past few years. Using the Wyle data, we were able to create updated figures and metrics for the sites where 1/3 octave data were available. See Appendix A, Appendix E and Appendix F.

There were, however, some limitations to the Wyle data. Continuous audio is not available from the Wyle sites, and current analysis techniques use audio files, in combination with SPL data, to identify and verify sound sources. Using only 1/3 octave L_{eq} data, it was possible (for all sites except PRWEAP) to identify aircraft overflights, and estimate the percent time that aircraft were audible. The sound signature of an aircraft overflight is very distinct, and can be identified using one-second L_{eq} data. Examples of spectrograms are located in. Other human-caused sounds are more difficult to identify without audio verification. Due to these limitations, the PA for the Wyle sites may be an underestimate of the total PA, since noise sources that were not visually apparent in the spectrograms were not included in the calculation of PA. This affects the estimate of L_{nat} for the Wyle sites. Since the PA for the Wyle sites may be underestimated, the L_{nat} for these sites might be an overestimate (the L_{nat} could appear louder than it likely was, since some noise sources were not removed). Additionally, many of the back-country sites monitored in 2000 – 2001 were very quiet, and the equipment noise floor was limiting in some cases. This is discussed at length in the Wyle report. Overall sound levels at the front-country sites (GWT and PNCK) were consistently higher than the noise floor levels, indicating that the noise floor did not affect the data collected in 2008.

Data from the GWT and PNCK sites were collected in July – August 2008. Many of the same natural sounds could be heard at both sites including birds, insects, wind and rain. For the duration of the 2008 monitoring, the GWT site was accessible only by bus, not by personal vehicle. The PNCK site was accessible to all vehicles during the monitoring period. The difference in vehicle mix was one of the primary factors for choosing these sites. Figure 9 shows the average audibility of vehicles at both sites, broken down by hour of the day. At PNCK, for several hours in the middle of the day, vehicles are audible over 90% of the time, on average. The highest hourly average PA for vehicles at PNCK occurred in the 1700 hour, when vehicles were audible 94.2% of the time (56.5 minutes of the hour). Peak audibility at GWT occurred in the 10am hour, when vehicles were audible 62.3% of the time (37.3 minutes of the hour), on average. From midnight to 1am, the average PA at GWT was only 1%, compared to 18.3% at PNCK. Figure 9 illustrates the difference in vehicle audibility in an area where cars are allowed (PNCK) and an area where personal vehicles are prohibited and the shuttle system is in place (GWT) and can be used to estimate the reduction in audible noise attributed to implementation of the shuttle system.

Figure 8 shows the total PA, the PA for aircraft, and the PA for vehicles for both sites. Overall, human-caused sounds were audible 65.9% of the time at PNCK, and 43.9% at GWT. Although human-caused sounds were more prevalent at PNCK, aircraft audibility was lower. This may seem odd, but it is important to consider that vehicle noise and other human-caused sounds at PNCK may have been masking aircraft sounds. At quieter sites where fewer extrinsic noise sources are present, it is easier to hear a distant plane.

The figures in Appendix D are spectrograms of several natural and human-caused noise sources. These spectrograms represent time on the horizontal axis, and frequency on the vertical axis. The brighter the image, the louder the event.

Acoustical monitoring allows us to estimate natural ambient sound levels, determine the prevalence of extrinsic noise, and consider how it may affect the visitor experience and wildlife activity within the park. Median daytime L_{nat} values ranged from 21.9 dB at Wyle's CHINLE site, to 37.7 at PNCK in 2008. For the Wyle sites and the 2008 sites, the estimated L_{nat} for sites near riparian areas (GWT, PNCK and NCREEK) were very similar. Sites near riparian areas typically have higher L_{nat} values due to natural sounds such as running water, and increased activity of birds, insects, and other wildlife. For these three sites, and for several other sites, the median nighttime L_{nat} values were higher than the daytime L_{nat} values, likely as a result of persistent insect sounds during the nighttime hours.

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Appendix A. Frequency plots for Wyle sites.

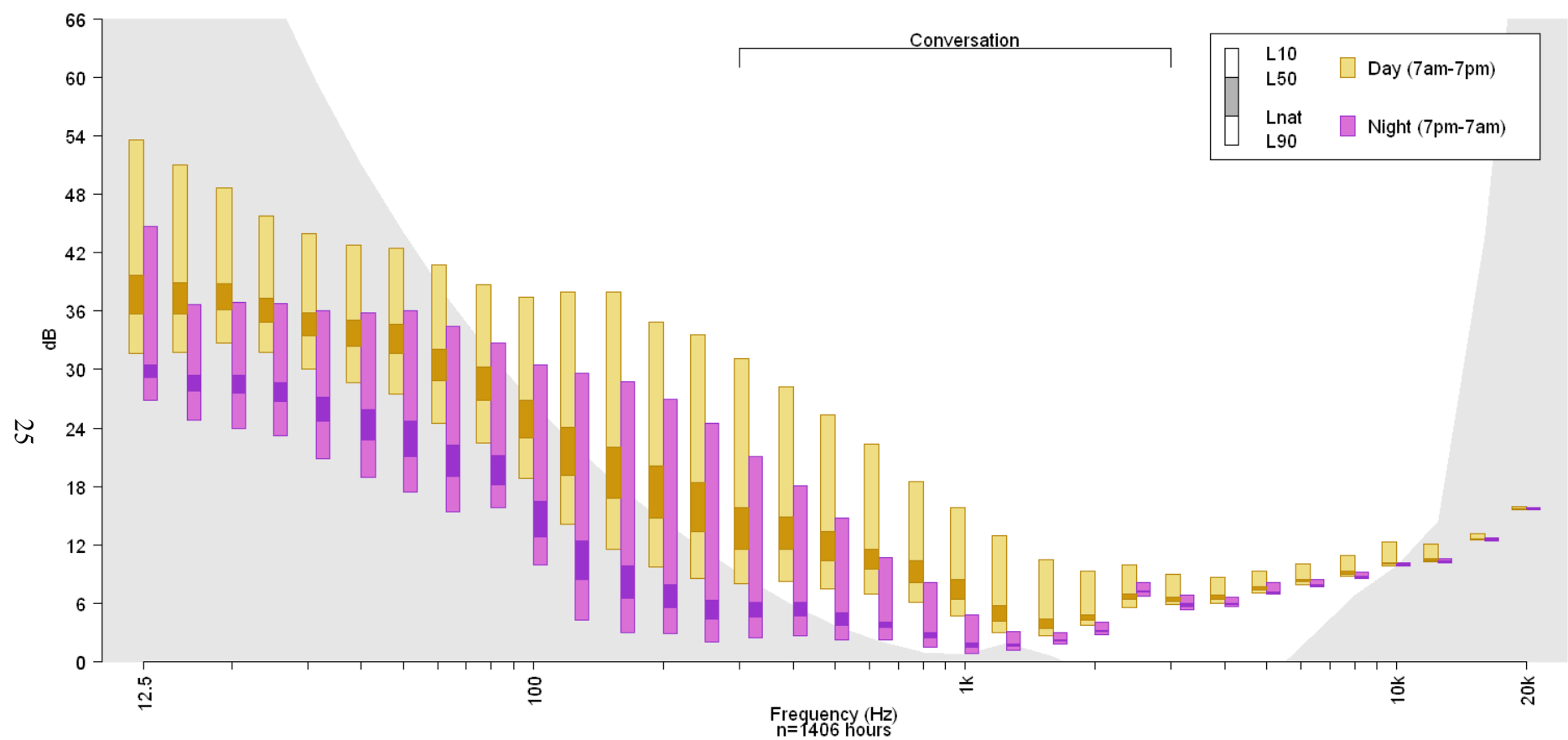


Figure 15. Day and night dB levels for 33 one-third octave bands at CHINLE.

Appendix A. Frequency plots for Wyle sites (continued)

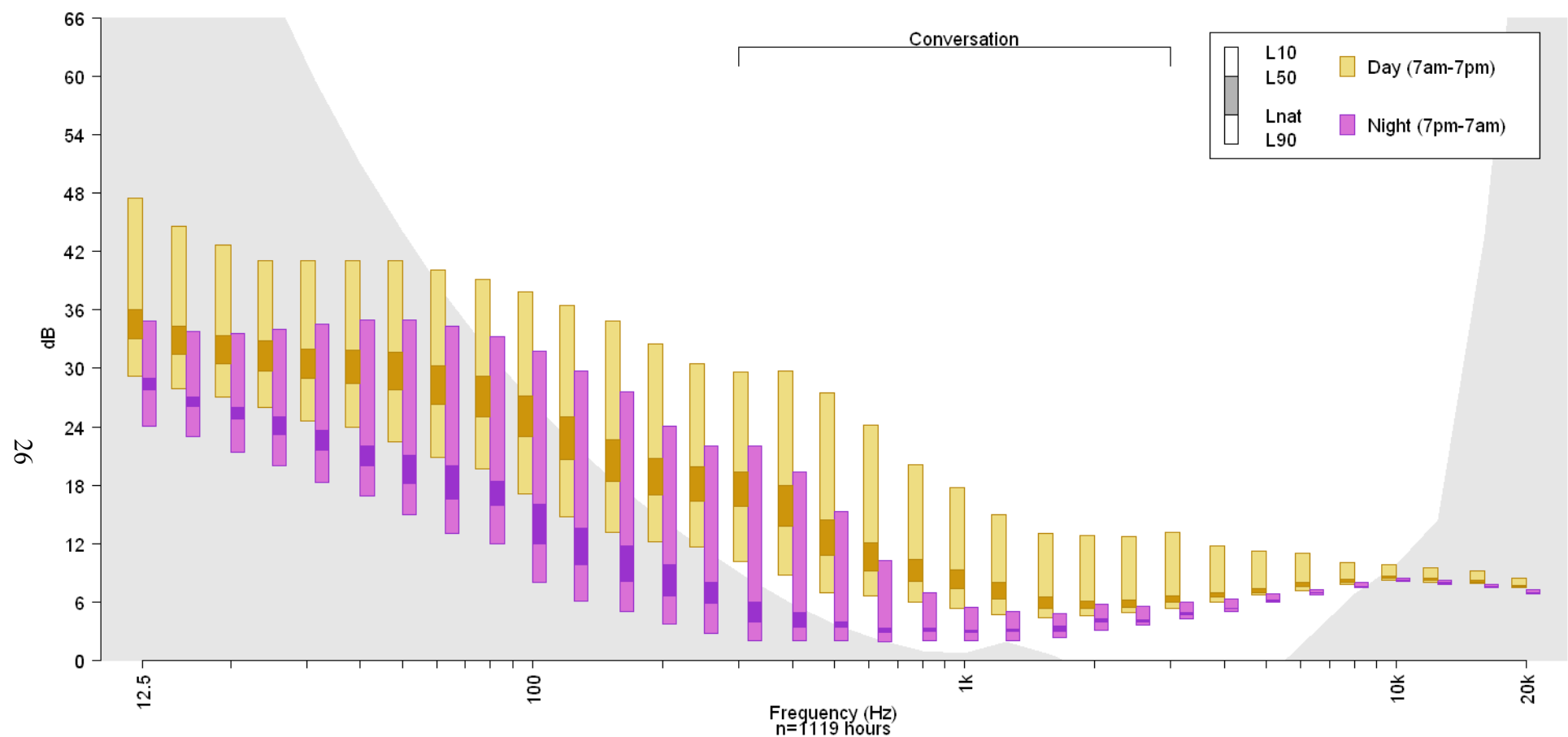


Figure 16. Day and night dB levels for 33 one-third octave bands at CRZQLT.

Appendix A. Frequency plots for Wyle sites (continued)

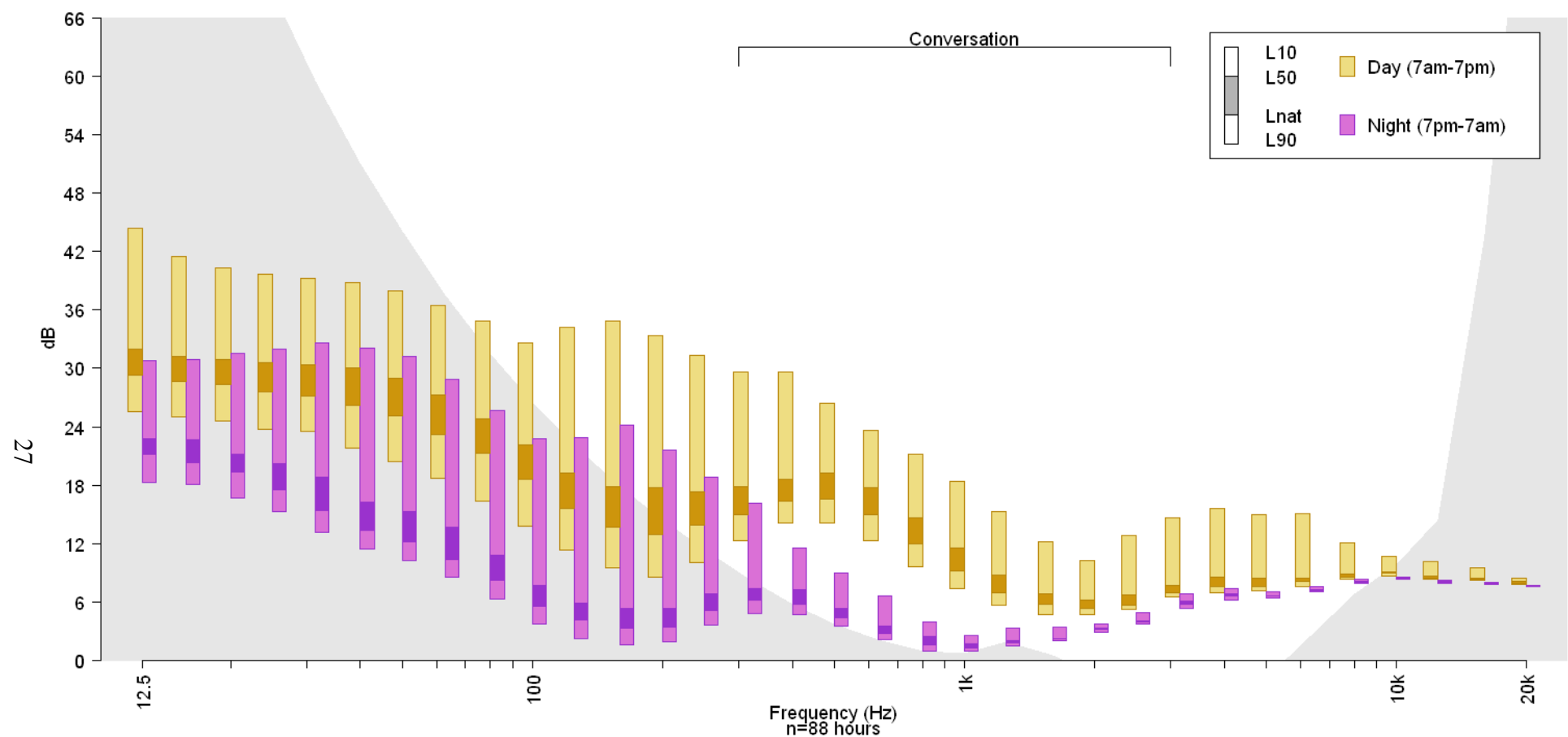


Figure 17. Day and night dB levels for 33 one-third octave bands at EASTRM¹.

¹Lnat estimates for EASTRM are based on 2 days of visual analysis, not the standard 8 days

Appendix A. Frequency plots for Wyle sites (continued)

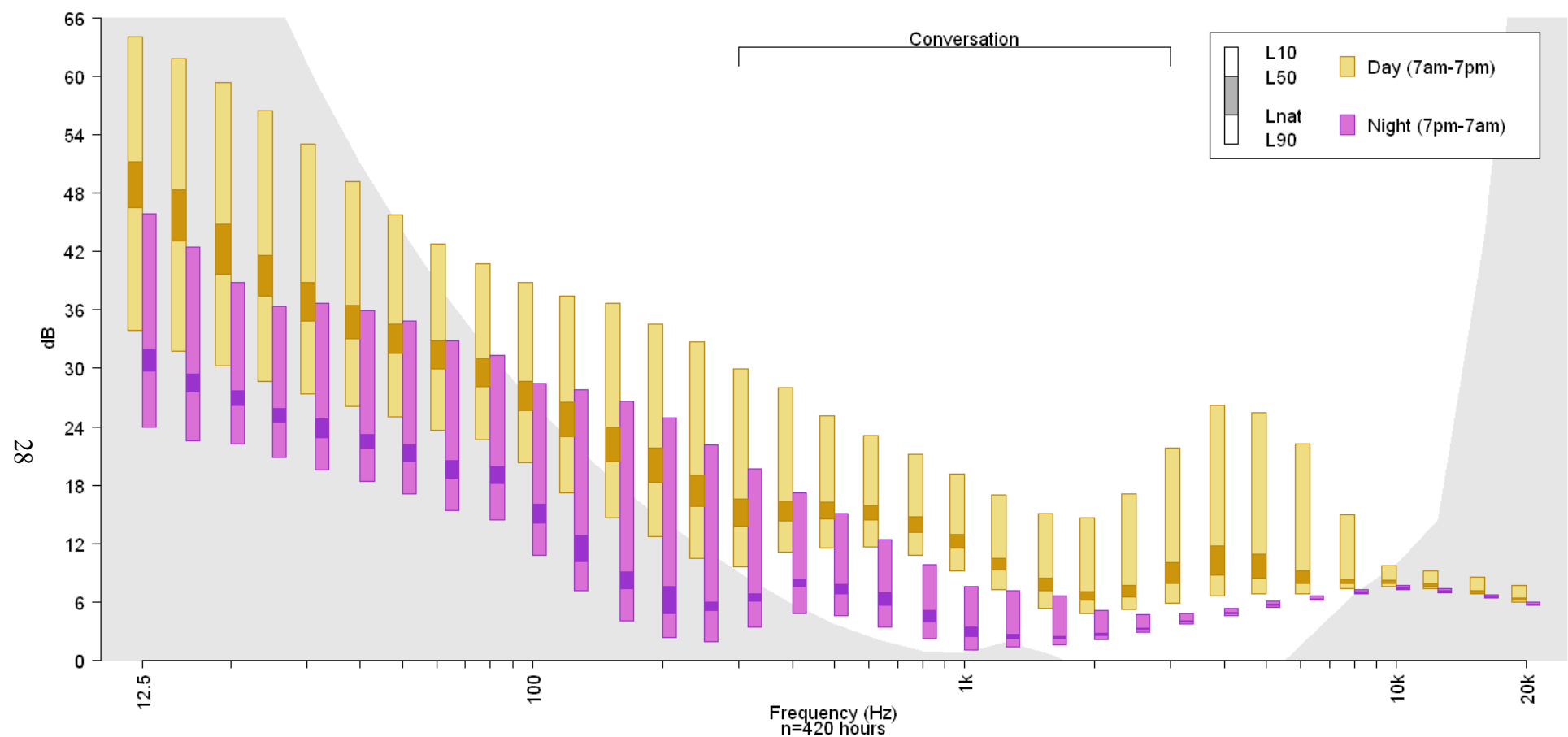


Figure 18. Day and night dB levels for 33 one-third octave bands at HOPVAL.

Appendix A. Frequency plots for Wyle sites (continued)

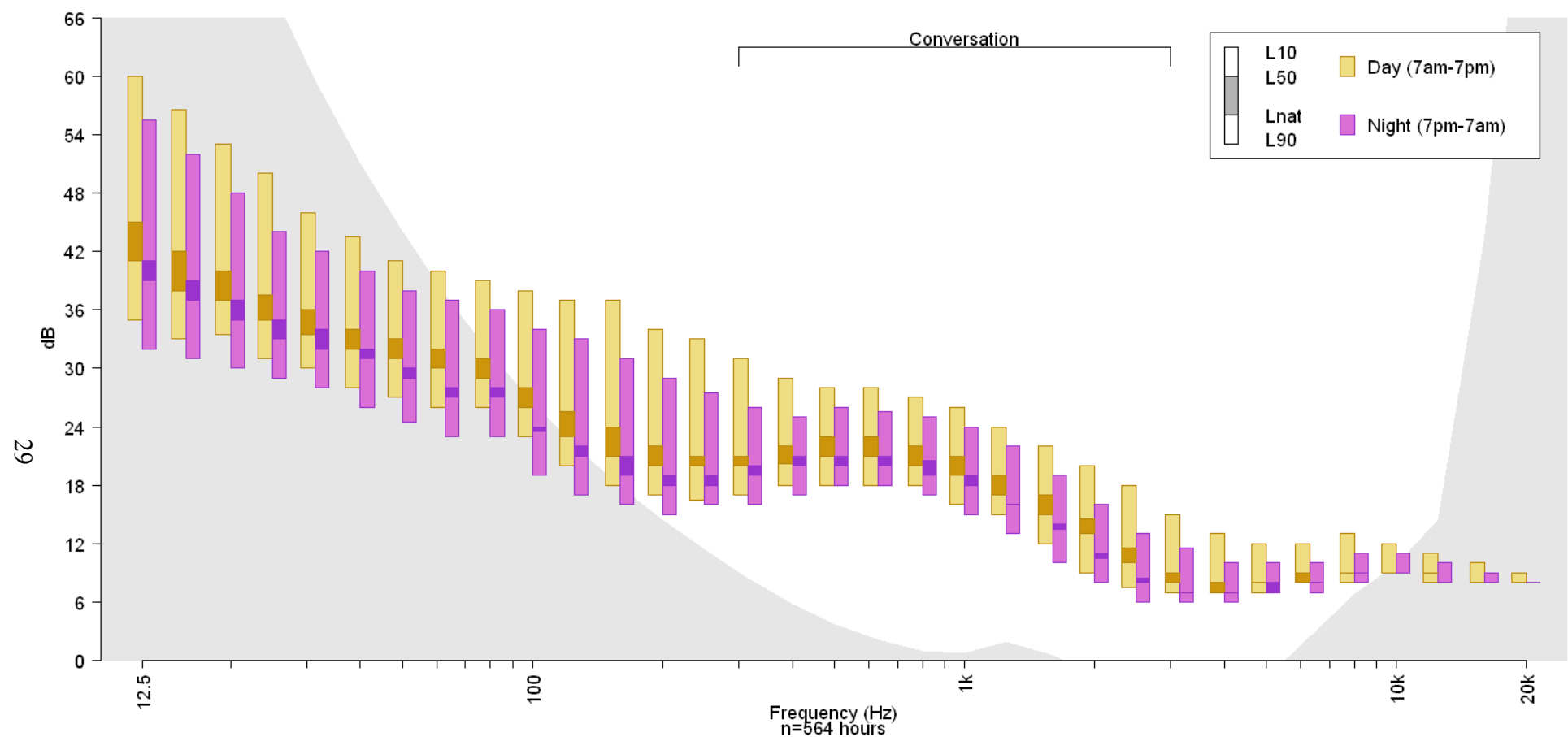


Figure 19. Day and night dB levels for 33 one-third octave bands at KOLOBC.

Appendix A. Frequency plots for Wyle sites (continued)

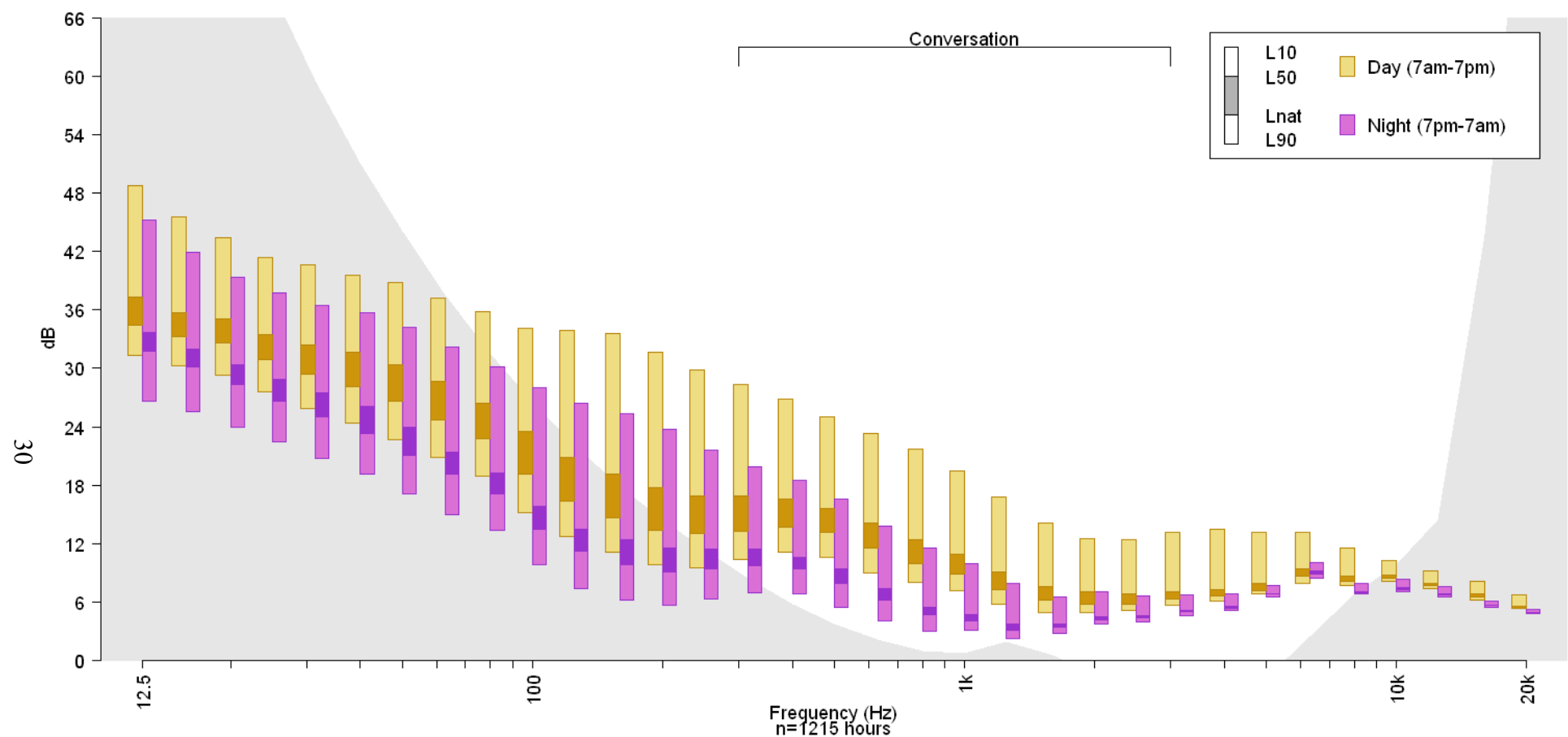


Figure 20. Day and night dB levels for 33 one-third octave bands at LCREEK.

Appendix A. Frequency plots for Wyle sites (continued)

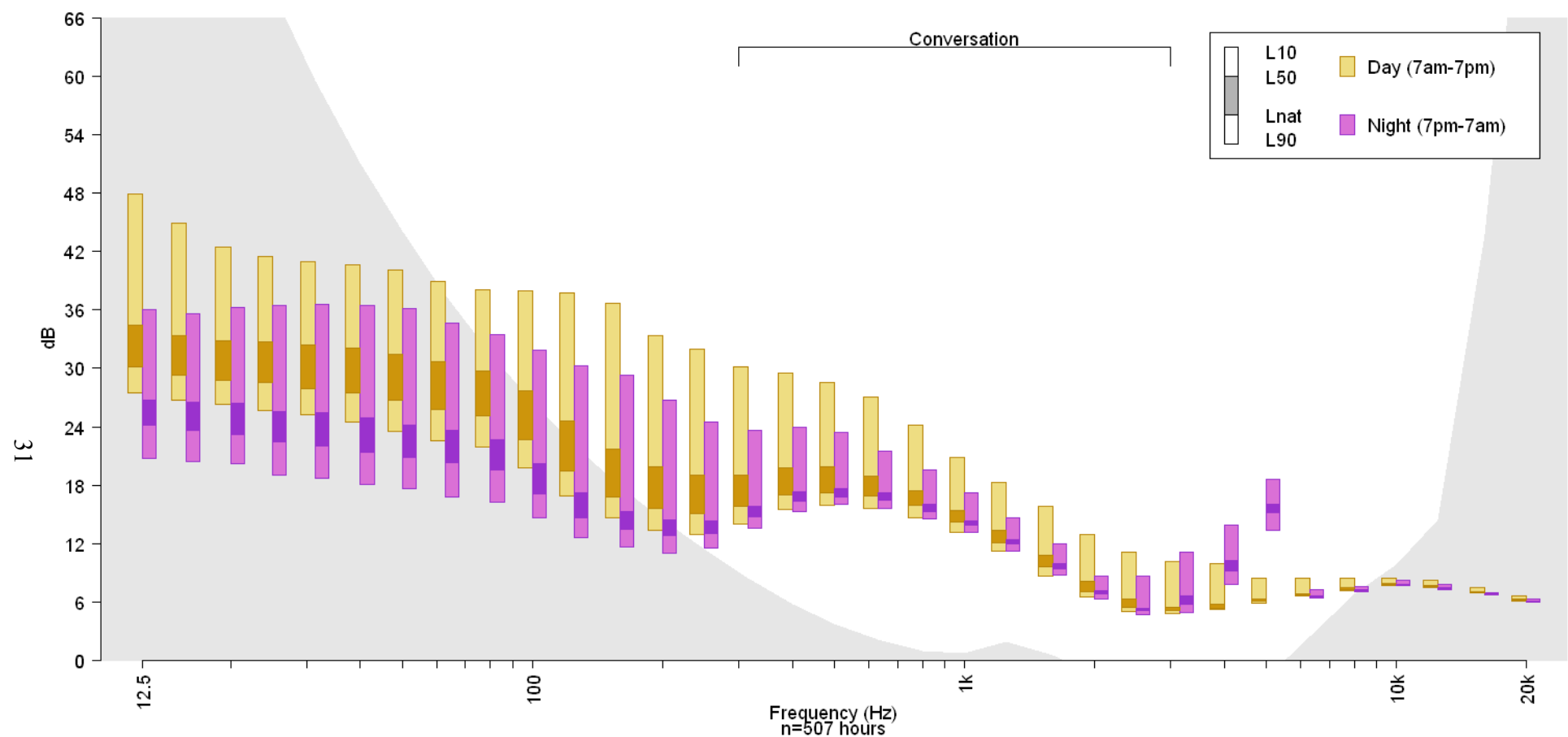


Figure 21. Day and night dB levels for 33 one-third octave bands at LFRKTD.

Appendix A. Frequency plots for Wyle sites (continued)

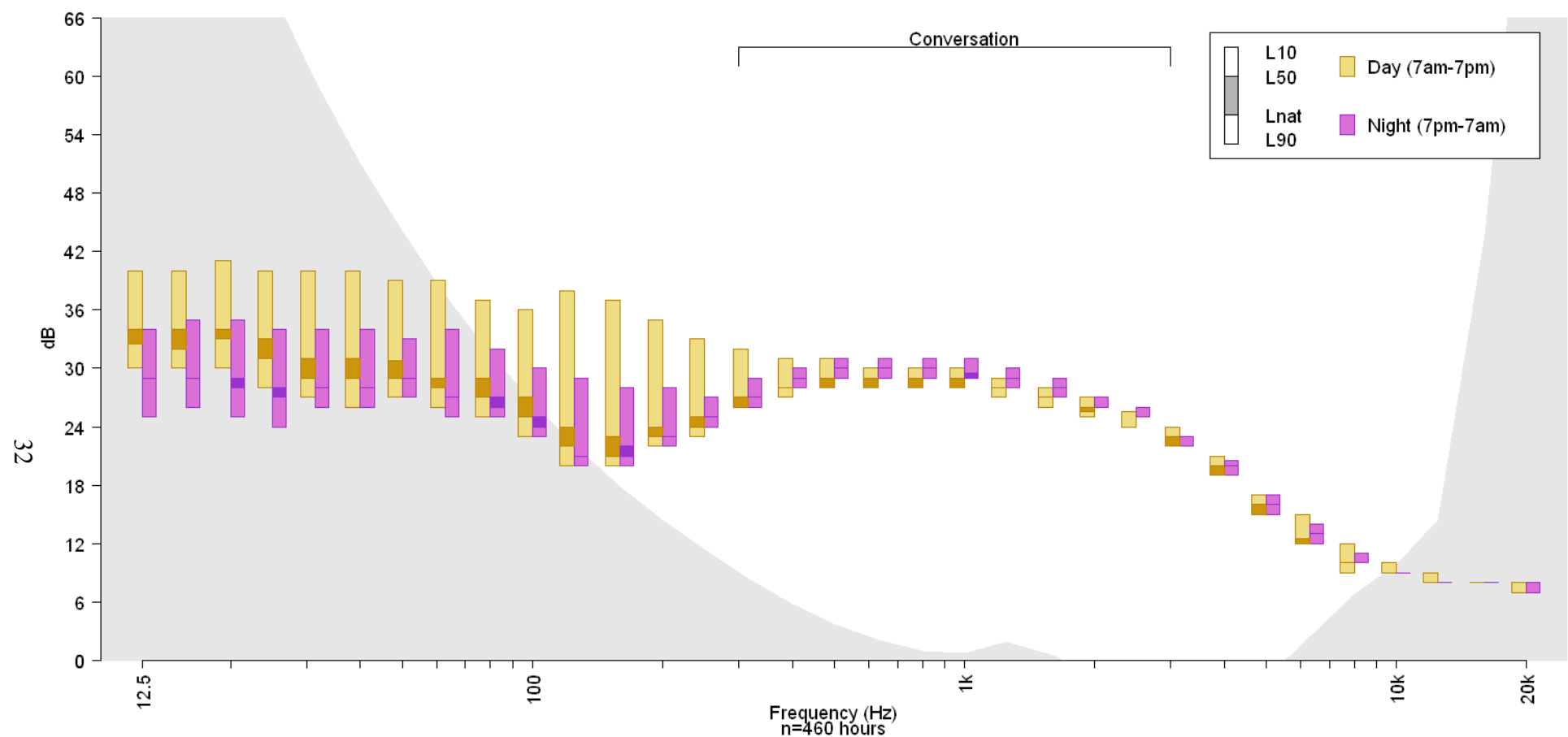


Figure 22. Day and night dB levels for 33 one-third octave bands at NCREEK.

Appendix A. Frequency plots for Wyle sites (continued)

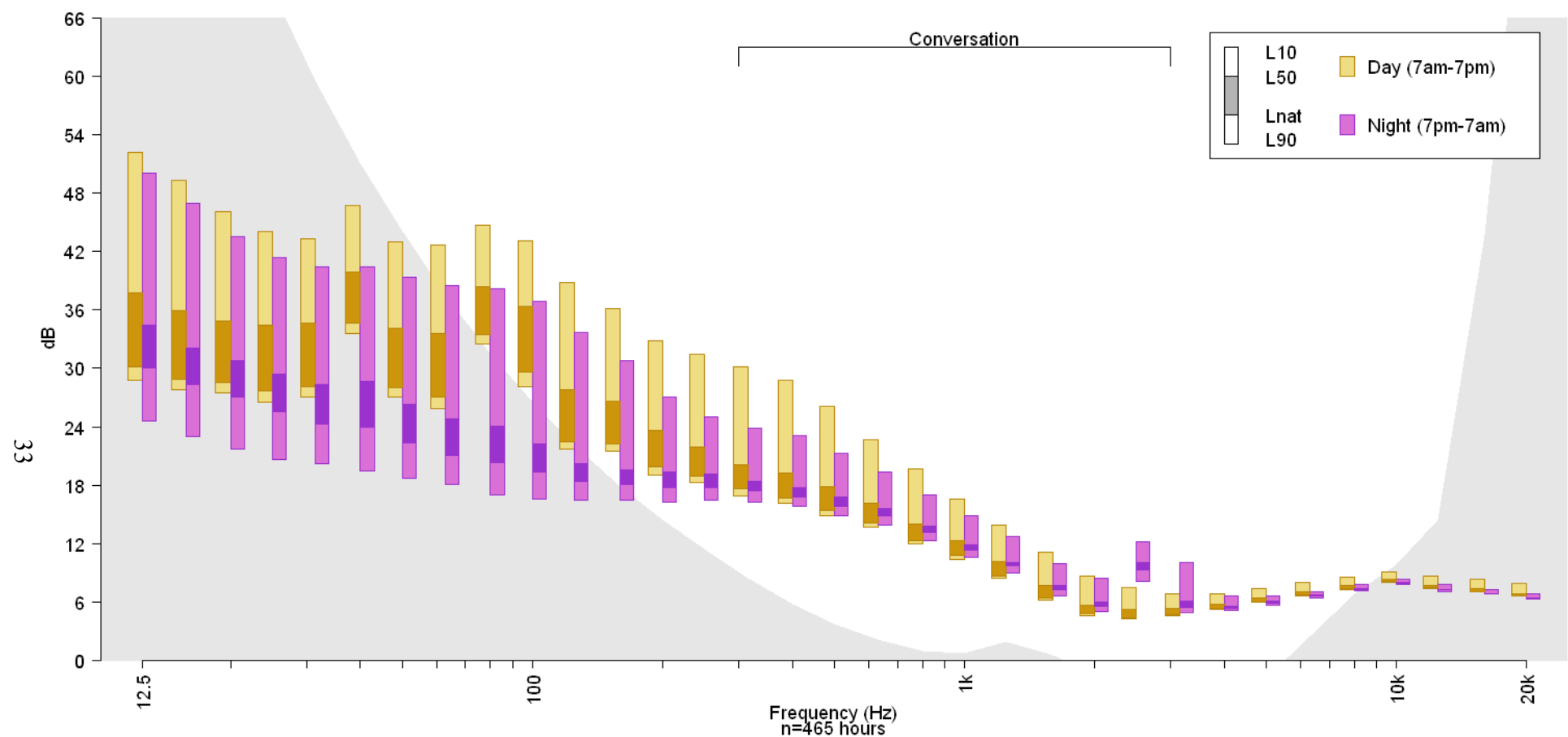


Figure 23. Day and night dB levels for 33 one-third octave bands at SCOUTS.

Appendix A. Frequency plots for Wyle sites (continued)

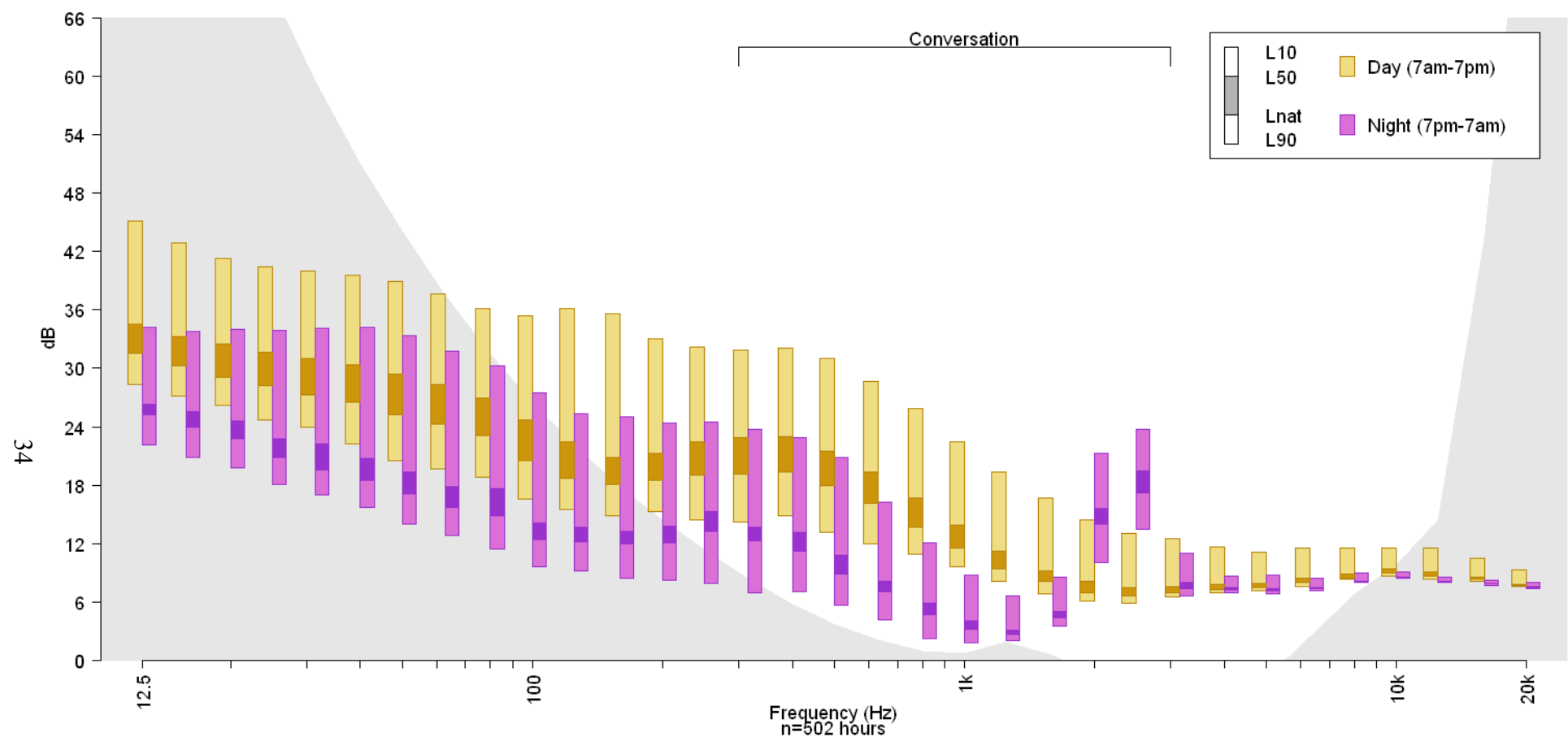


Figure 24. Day and night dB levels for 33 one-third octave bands at WILDCT.

Appendix A. Frequency plots for Wyle sites (continued)

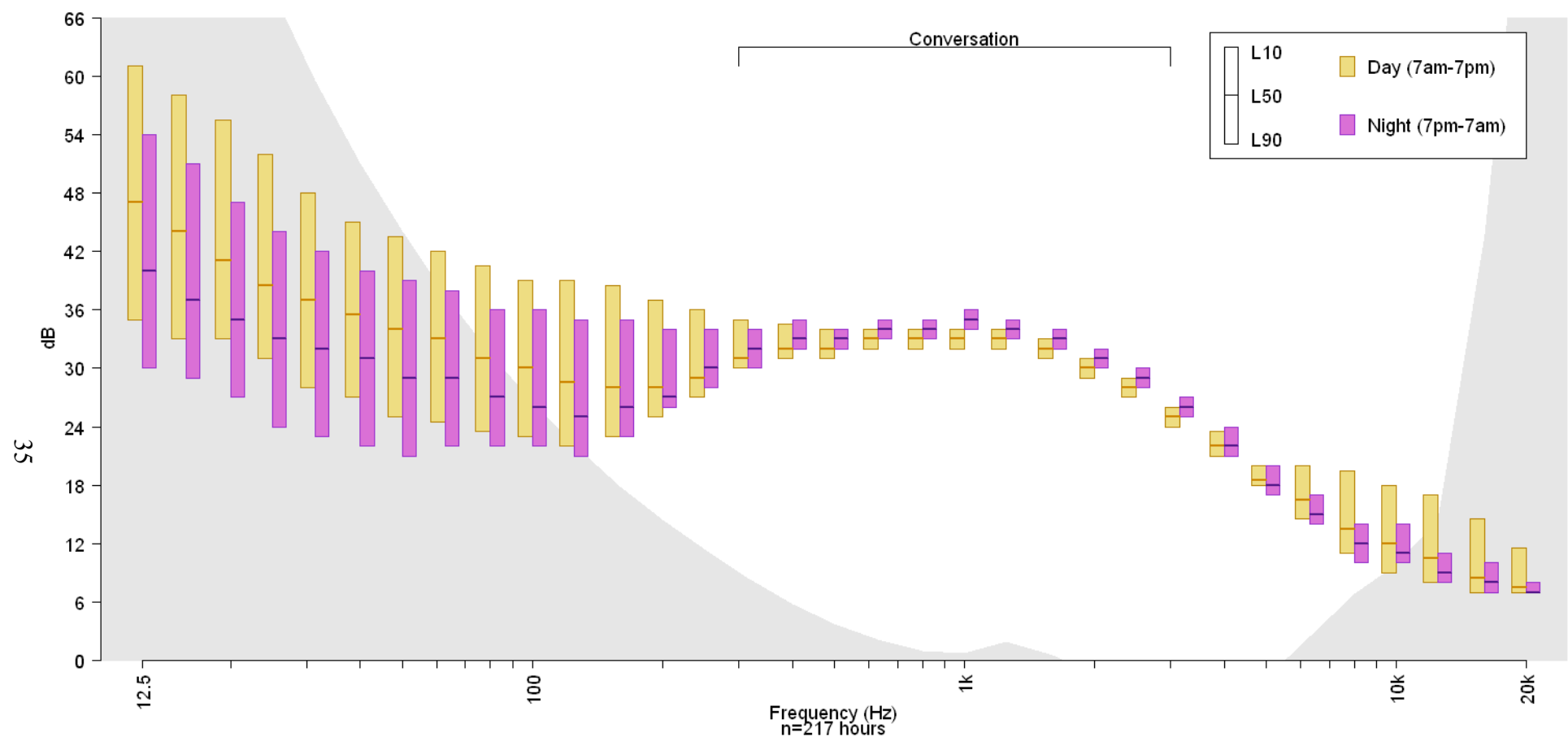


Figure 25. Day and night dB levels for 33 one-third octave bands at PRWEAP¹.

¹PRWEAP does not include Lnat values, because site was too windy to use visual analysis

Appendix B. Data tables for ZION sites.

Table 8. Percent time above metrics for Wyle sites monitored in 2000-2001.

Site ID	Days of data	% Time above sound level: 0700 to 1900				% Time above sound level: 1900 to 0700			
		35 dBA	45 dBA	52 dBA	60 dBA	35 dBA	45 dBA	52 dBA	60 dBA
CHINLE	58.6	13.92	1.18	0.15	0.01	4.09	0.33	0.03	0.00
CRZQLT	46.6	18.58	1.83	0.20	0.00	4.52	0.33	0.04	0.00
EASTRM	3.7	8.71	2.17	0.28	0.05	3.03	0.21	0.01	0.00
HOPVAL	17.5	22.82	3.79	0.64	0.03	6.60	1.99	0.64	0.01
KOLOBC	23.5	35.26	3.40	0.34	0.04	19.24	1.65	0.13	0.01
LCREEK	50.6	16.23	1.66	0.18	0.02	3.46	0.30	0.03	0.00
LFRKTD	21.1	14.68	2.04	0.37	0.02	17.39	2.79	0.18	0.01
NCREEK	19.2	99.69	1.71	0.32	0.02	100.00	0.79	0.11	0.00
PRWEAP	9.0	100.00	4.71	0.61	0.00	100.00	10.81	0.10	0.00
SCOUTS	19.4	11.99	1.57	0.38	0.02	5.62	0.65	0.14	0.01
WILDCT	20.9	22.70	2.95	0.47	0.07	34.89	1.28	0.14	0.00

Table 9. Percent time above metrics for summer 2008 sites.

Site ID	Days of data	% Time above sound level: 0700 to 1900				% Time above sound level: 1900 to 0700			
		35 dBA	45 dBA	52 dBA	60 dBA	35 dBA	45 dBA	52 dBA	60 dBA
GWT/01	23.5	99.53	13.07	3.58	0.02	100.00	3.12	0.83	0.00
PNCK/02	21.1	99.84	34.57	1.67	0.04	100.00	32.80	2.92	0.00

Table 10. Median Day and Night L_{50} and L_{nat} for Wyle sites.

Site ID	Days of data	Median Existing Ambient (L_{50}) in dBA		Median Natural Ambient (L_{nat}) in dBA	
		Day	Night	Day	Night
CHINLE	58.6	24.1	20.2	21.9	19.3
CRZQLT	46.6	26.4	19.0	23.3	18.3
EASTRM	3.7	25.8	18.6	24.0	18.3
HOPVAL	17.5	28.5	20.2	25.8	19.4
KOLOBC	23.5	31.0	29.0	29.0	28.0
LCREEK	50.6	26.4	19.8	23.6	19.0
LFRKTD	21.1	27.0	26.1	24.5	25.1
NCREEK	19.2	37.0	38.0	37.0	38.0
PRWEAP	9.0	42.0	43.0	--	--
SCOUTS	19.4	26.9	24.8	24.3	24.0
WILDCT	20.9	28.1	27.9	25.1	26.5

Table 11. Median Day and Night L_{50} and L_{nat} for 2008 sites.

Site ID	Days of data	Median Existing Ambient (L_{50}) in dBA		Median Natural Ambient (L_{nat}) in dBA	
		Day	Night	Day	Night
GWT/01	23.5	38.8	39.8	37.4	39.6
PNCK/02	21.1	42.9	42.8	37.7	41.8

Appendix B. Data tables for ZION sites (continued)

Table 12. Time above metrics by frequency range for Wyle sites.

Site ID	Days of available data	Frequency (Hz)	% Time above sound level: 0700 to 1900				% Time above sound level: 1900 to 0700			
			35 dBA	45 dBA	52 dBA	60 dBA	35 dBA	45 dBA	52 dBA	60 dBA
CHINLE	58.6	20-800 ¹	11.97	0.98	0.15	0.01	3.17	0.27	0.01	0.00
		12.5-20,000 ²	13.92	1.18	0.15	0.01	4.09	0.33	0.03	0.00
CRZQLT	46.6	20-800 ¹	10.88	0.82	0.11	0.00	3.18	0.19	0.03	0.00
		12.5-20,000 ²	18.58	1.83	0.20	0.00	4.52	0.33	0.04	0.00
EASTRM	3.7	20-800 ¹	7.07	1.04	0.17	0.05	2.99	0.21	0.01	0.00
		12.5-20,000 ²	8.71	2.17	0.28	0.05	3.03	0.21	0.01	0.00
HOPVAL	17.5	20-800 ¹	10.92	1.28	0.15	0.01	1.63	0.14	0.02	0.00
		12.5-20,000 ²	22.82	3.79	0.64	0.03	6.60	1.99	0.64	0.01
KOLOBC	23.5	20-800 ¹	10.02	1.65	0.25	0.02	11.01	0.76	0.09	0.00
		12.5-20,000 ²	35.26	3.40	0.34	0.04	19.24	1.65	0.13	0.01
LCREEK	50.6	20-800 ¹	6.97	0.63	0.12	0.02	2.57	0.21	0.03	0.00
		12.5-20,000 ²	16.23	1.66	0.18	0.02	3.46	0.30	0.03	0.00
LFRKTD	21.1	20-800 ¹	13.36	1.66	0.21	0.01	6.29	0.72	0.18	0.01
		12.5-20,000 ²	14.68	2.04	0.37	0.02	17.39	2.79	0.18	0.01
NCREEK	19.2	20-800 ¹	16.53	1.14	0.21	0.02	25.95	0.59	0.09	0.00
		12.5-20,000 ²	99.69	1.71	0.32	0.02	100.00	0.79	0.11	0.00
PRWEAP	9.0	20-800 ¹	99.07	1.23	0.10	0.00	100.00	1.41	0.07	0.00
		12.5-20,000 ²	100.00	4.71	0.61	0.00	100.00	10.81	0.10	0.00
SCOUTS	19.4	20-800 ¹	10.84	1.41	0.31	0.03	5.11	0.54	0.14	0.01
		12.5-20,000 ²	11.99	1.57	0.38	0.02	5.62	0.65	0.14	0.01
WILDCT	20.9	20-800 ¹	18.65	1.67	0.23	0.02	8.03	0.92	0.13	0.00
		12.5-20,000 ²	22.70	2.95	0.47	0.07	34.89	1.28	0.14	0.00

¹The top value in each split-cell focuses on frequencies affected by transportation. This range does not correspond to a specific vehicle or type of transportation.

²The bottom value in each split-cell uses the full frequency spectrum, from 12.5-20,000 hertz.

Table 13. Time above metrics by frequency range for 2008 ZION sites.

Site ID	Days of available data	Frequency (Hz)	% Time above sound level: 0700 to 1900				% Time above sound level: 1900 to 0700			
			35 dBA	45 dBA	52 dBA	60 dBA	35 dBA	45 dBA	52 dBA	60 dBA
GWT/01	23.5	20-800 ¹	61.03	10.75	2.92	0.01	62.16	2.25	0.63	0.00
		12.5-20,000 ²	99.53	13.07	3.58	0.02	100.00	3.12	0.83	0.00
PNCK/02	21.1	20-800 ¹	93.21	11.18	0.79	0.02	65.30	1.69	0.07	0.00
		12.5-20,000 ²	99.84	34.57	1.67	0.04	100.00	32.80	2.92	0.00

¹The top value in each split-cell focuses on frequencies affected by transportation. This range does not correspond to a specific vehicle or type of transportation.

²The bottom value in each split-cell uses the full frequency spectrum, from 12.5-20,000 hertz.

Table 14. Exceedence levels for existing conditions at 2008 ZION sites.

Site	Frequency (Hz)	Exceedence levels (dBA): 0700 to 1900				Exceedence levels (dBA): 1900 to 0700			
		L ₉₀	L _{nat}	L ₅₀	L ₁₀	L ₉₀	L _{nat}	L ₅₀	L ₁₀
GWT/01	20-800 ¹	33.5	33.8	35.5	45.7	34.1	35.0	35.3	38.4
	12.5-20,000 ²	37.1	37.4	38.8	46.7	38.5	39.6	39.8	42.0
PNCK/02	20-800 ¹	35.9	34.2	40.1	45.2	34.6	35.4	36.2	39.2
	12.5-20,000 ²	39.1	37.7	42.9	47.5	40.6	41.8	42.8	46.5

¹The top value in each split-cell focuses on frequencies affected by transportation. This range does not correspond to a specific vehicle or type of transportation.

²The bottom value in each split-cell uses the full frequency spectrum, from 12.5-20,000 hertz.

Appendix B. Data tables for ZION sites (continued)

Table 15. Exceedence levels for 2000-2001 conditions at Wyle Laboratory sites.

Site ID	Days of available data	Frequency (Hz)	Exceedence levels (dBA): 0700 to 1900				Exceedence levels (dBA): 1900 to 0700			
			L ₉₀	L _{nat}	L ₅₀	L ₁₀	L ₉₀	L _{nat}	L ₅₀	L ₁₀
CHINLE	58.6	20-800 ¹	14.4	17.9	21.6	34.2	8.0	10.0	11.9	26.1
		12.5-20,000 ²	20.5	21.9	24.1	35.1	18.5	19.3	20.2	27.3
CRZQLT	46.6	20-800 ¹	14.7	19.7	23.4	33.9	7.7	9.4	11.9	25.4
		12.5-20,000 ²	20.4	23.3	26.4	36.0	17.8	18.3	19.0	28.0
EASTRM	3.7	20-800 ¹	17.9	20.9	23.7	33.3	7.9	8.7	10.5	19.2
		12.5-20,000 ²	21.7	24.0	25.8	34.4	18.2	18.3	18.6	22.7
HOPVAL	17.5	20-800 ¹	17.4	21.2	23.7	24.3	9.4	11.5	12.6	24.3
		12.5-20,000 ²	22.4	25.8	28.5	28.9	17.8	19.4	20.2	28.9
KOLOBC	23.5	20-800 ¹	23.0	26.2	28.0	34.9	22.0	25.0	25.9	31.7
		12.5-20,000 ²	26.0	29.0	31.0	37.0	25.0	28.0	29.0	34.0
LCREEK	50.6	20-800 ¹	15.5	18.3	21.6	32.3	10.7	13.4	15.0	24.9
		12.5-20,000 ²	21.1	23.6	26.4	34.8	17.9	19.0	19.8	27.2
LFRKTD	21.1	20-800 ¹	20.4	22.0	24.9	34.8	19.6	20.8	21.7	29.3
		12.5-20,000 ²	23.3	24.5	27.0	35.9	23.9	25.1	26.1	33.5
NCREEK	19.2	20-800 ¹	31.9	32.6	32.9	36.2	32.9	33.7	33.9	35.2
		12.5-20,000 ²	36.0	37.0	37.0	39.0	37.0	38.0	38.0	39.0
PRWEAP ¹²	9.0	20-800 ¹	36.0	*---	37.0	39.5	37.0	*---	37.8	39.3
		12.5-20,000 ²	41.0	*---	42.0	43.0	42.0	*---	43.0	44.0
SCOUTS	19.4	20-800 ¹	22.1	22.7	26.0	34.2	19.6	20.7	22.2	28.2
		12.5-20,000 ²	23.8	24.3	26.9	34.6	23.2	24.0	24.8	29.8
WILDCT	20.9	20-800 ¹	18.8	22.7	26.4	36.0	11.2	14.4	16.6	26.4
		12.5-20,000 ²	22.6	25.1	28.1	37.1	24.1	26.5	27.9	34.4

Note: L_{nat} estimates for Wyle sites only take visually distinct noise sources into account

¹The top value in each split-cell focuses on frequencies affected by transportation. This range does not correspond to a specific vehicle or type of transportation.

²The bottom value in each split-cell uses the full frequency spectrum, from 12.5-20,000 hertz.

¹² L_{nat} not calculated at PRWEAP. Sounds sources could not be identified due to windy conditions

Appendix C. Site Photos for 2008 Sites.



Figure 26. Great White Throne Site (GWT).



Figure 27. Pine Creek Site (PNCK).

Appendix D. Spectrogram examples.

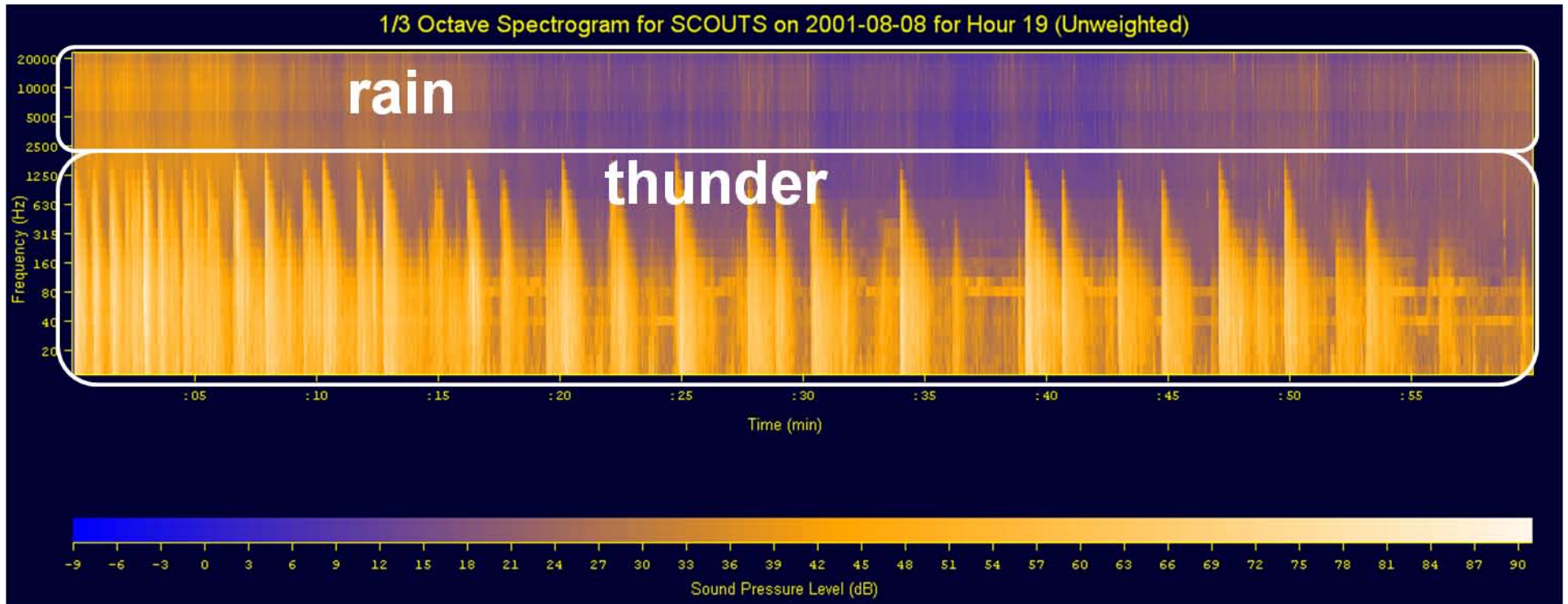


Figure 28. Some natural sounds, like this thunderstorm, can be identified using spectrograms.

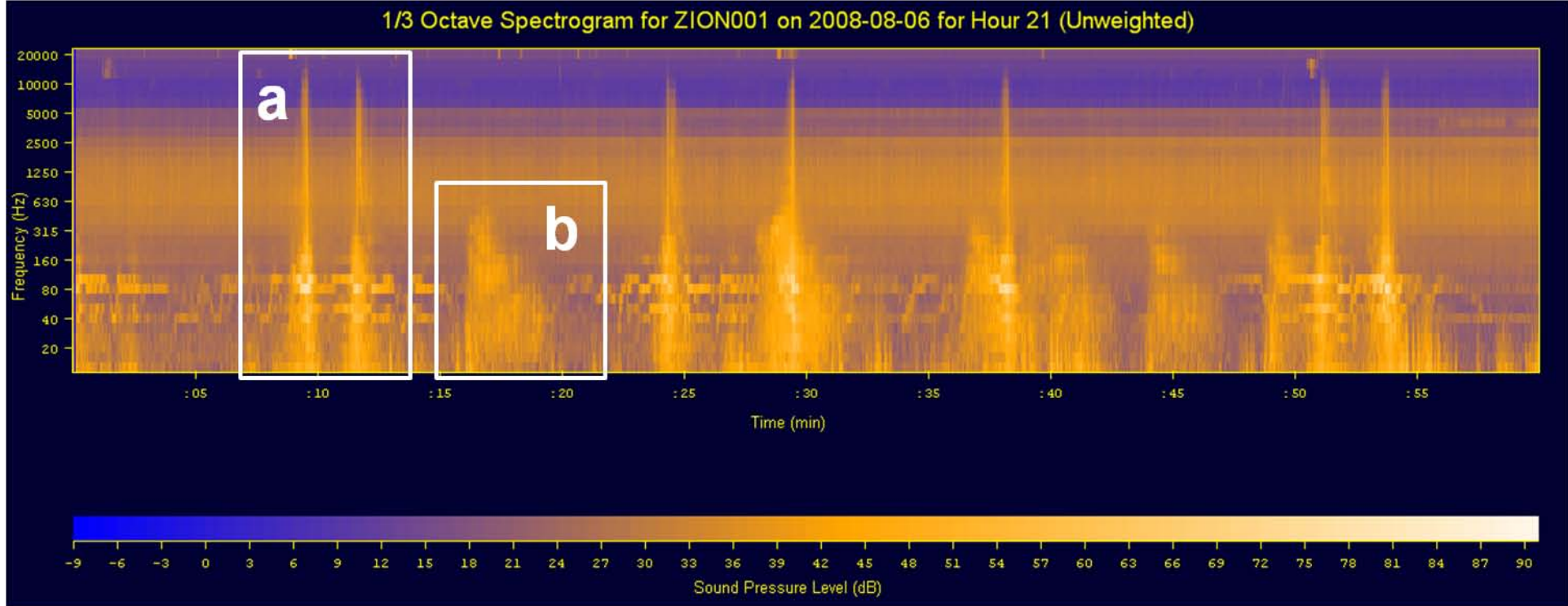


Figure 29. Example of vehicle pass-bys in **a**, and a jet in **b**.

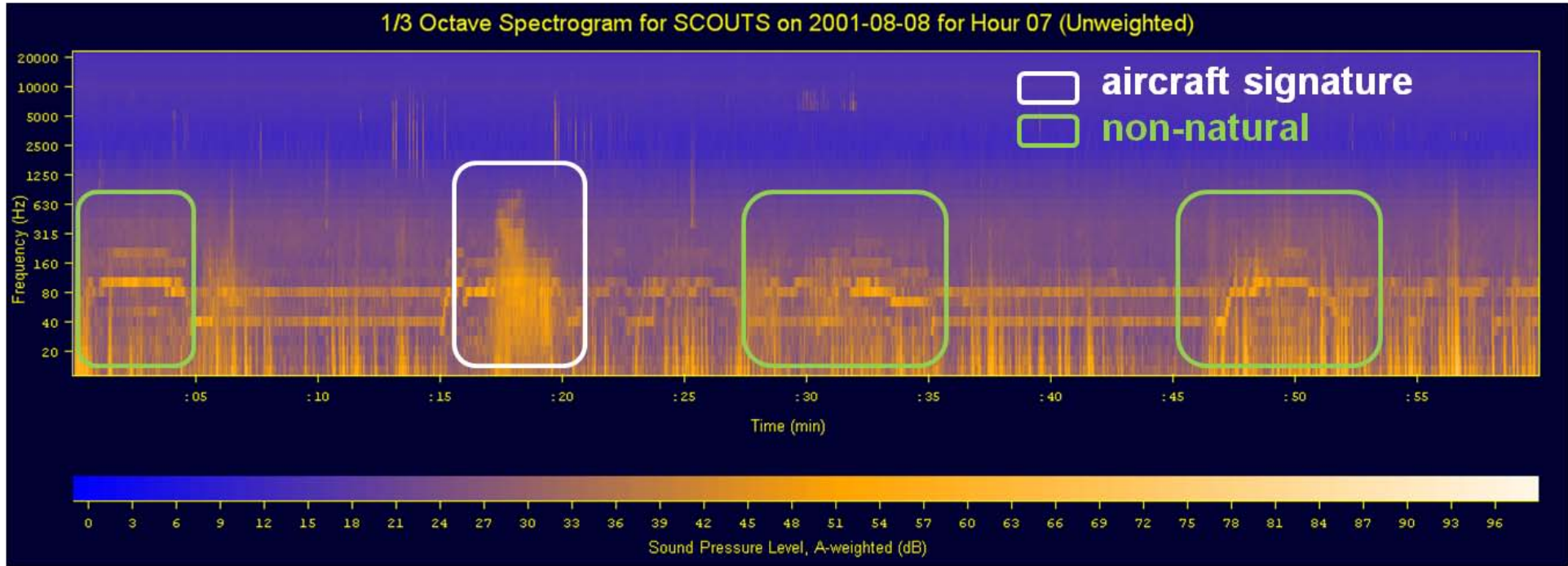


Figure 30. Some extrinsic sources have distinct visual signatures - other sources are more ambiguous.

Appendix E. 2008 Acoustic Monitoring Summary Posters.

Original document names:

AppendixE_ZionPoster1.pdf

AppendixE_ZionPoster2.pdf

AppendixE_ZionPoster3.pdf

These posters were displayed at public meetings in 2008, and have been included in this document on the following poster-sized pages.

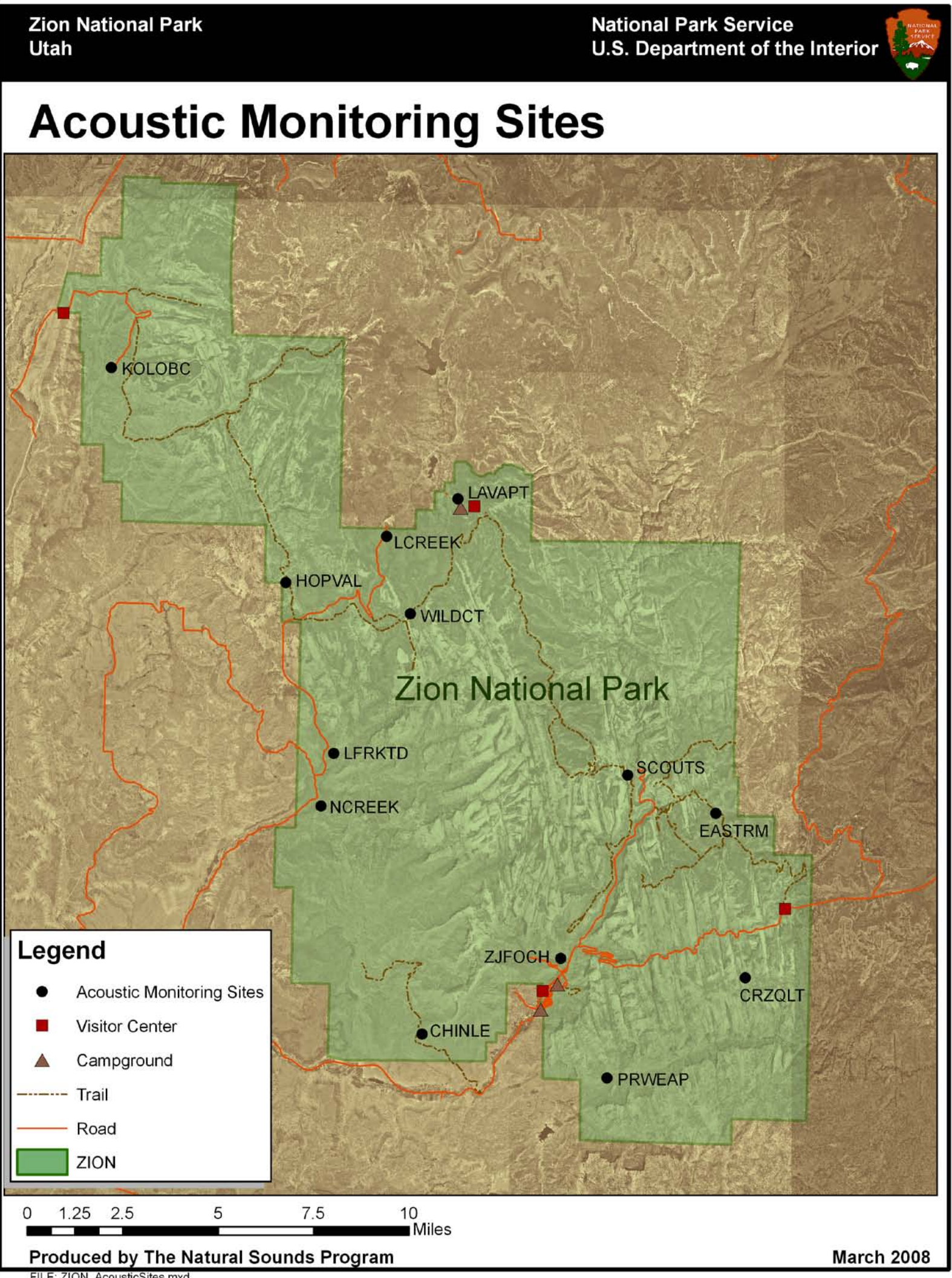
Acoustic Monitoring in Zion National Park

Charlotte Formichella, Kurt Frstrup, Damon Joyce, Emma Lynch, and Ericka Pilcher

National Park Service
Natural Sounds Program
Fort Collins, Colorado



Background:



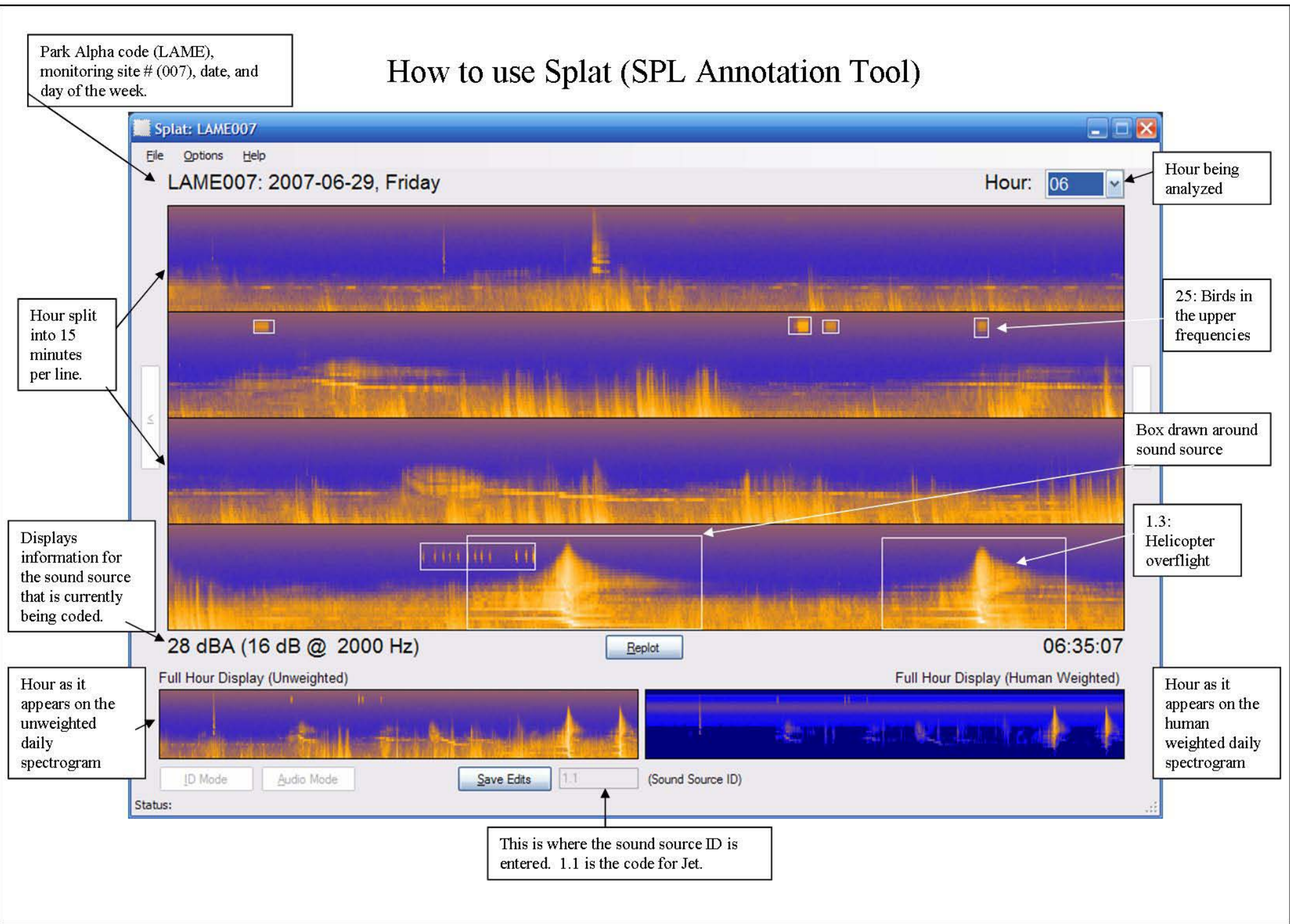
Acoustic Monitoring at Zion:

13 acoustic monitoring sites were set up in Zion during 2000 and 2001 by Wyle Laboratories. Sound pressure level (SPL) data were collected at each site, but audio was not recorded. No useful data were recovered from LAVAPT, PRWEAP, or ZJFOCH.

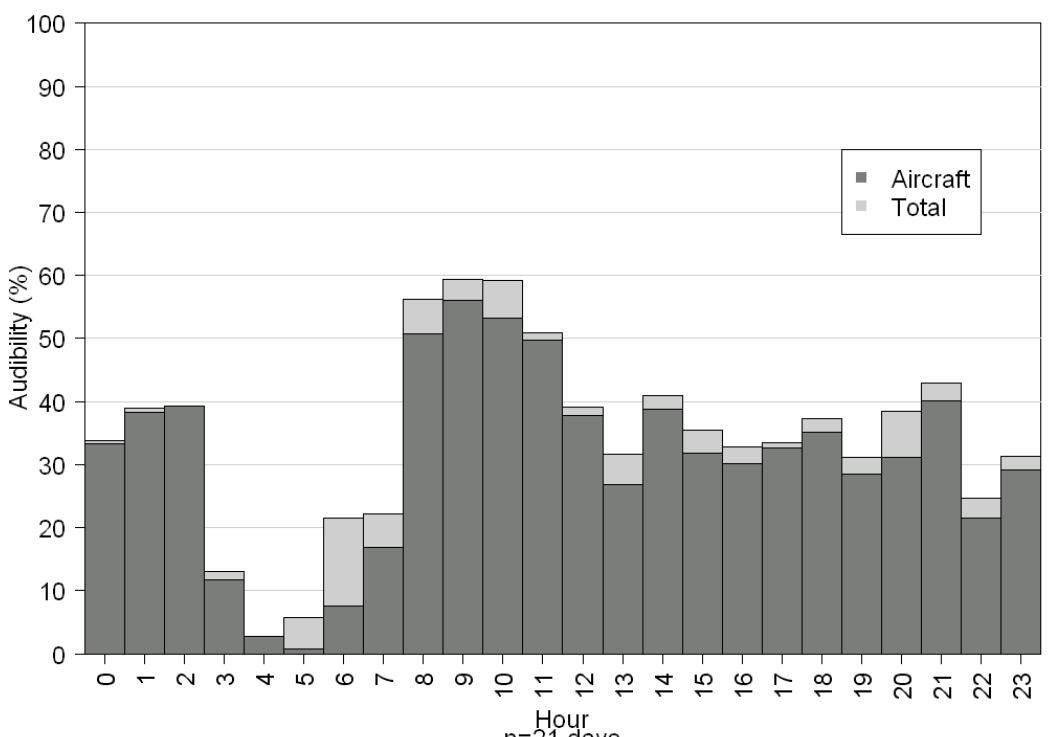
The 10 sites that produced useful data were analyzed visually using a program (“Splat” SPL annotation tool) which is created and maintained by the NPS Natural Sounds Program. This program was created so that SPL data could be analyzed when there is no associated audio data.

How to use Splat:

We calculate the SPL data by hour. For each sound source we draw a box around the sound signature and enter the number code for the sound. This records the sound code, overall dBA, the dB per frequency, and the time and duration of the sound source. We then use this information to calculate overall metrics.



How to interpret the figures:



Audibility of extrinsic and aircraft sounds:

This figure shows the total percent time that extrinsic sounds (light gray) were audible and the percent time that aircraft (dark gray) were audible per hour.

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

Exceedence values by hour:

In this figure dBA metrics are shown as a function of time. dBA provides 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 the site would sound like without the contribution of extrinsic sound. 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. It represents a chronic sound level, or the best listening conditions that occur each hour. Median L_{10} is the dBA value exceeded 10 percent of the time. It represents acute conditions when listening opportunities are least favorable.

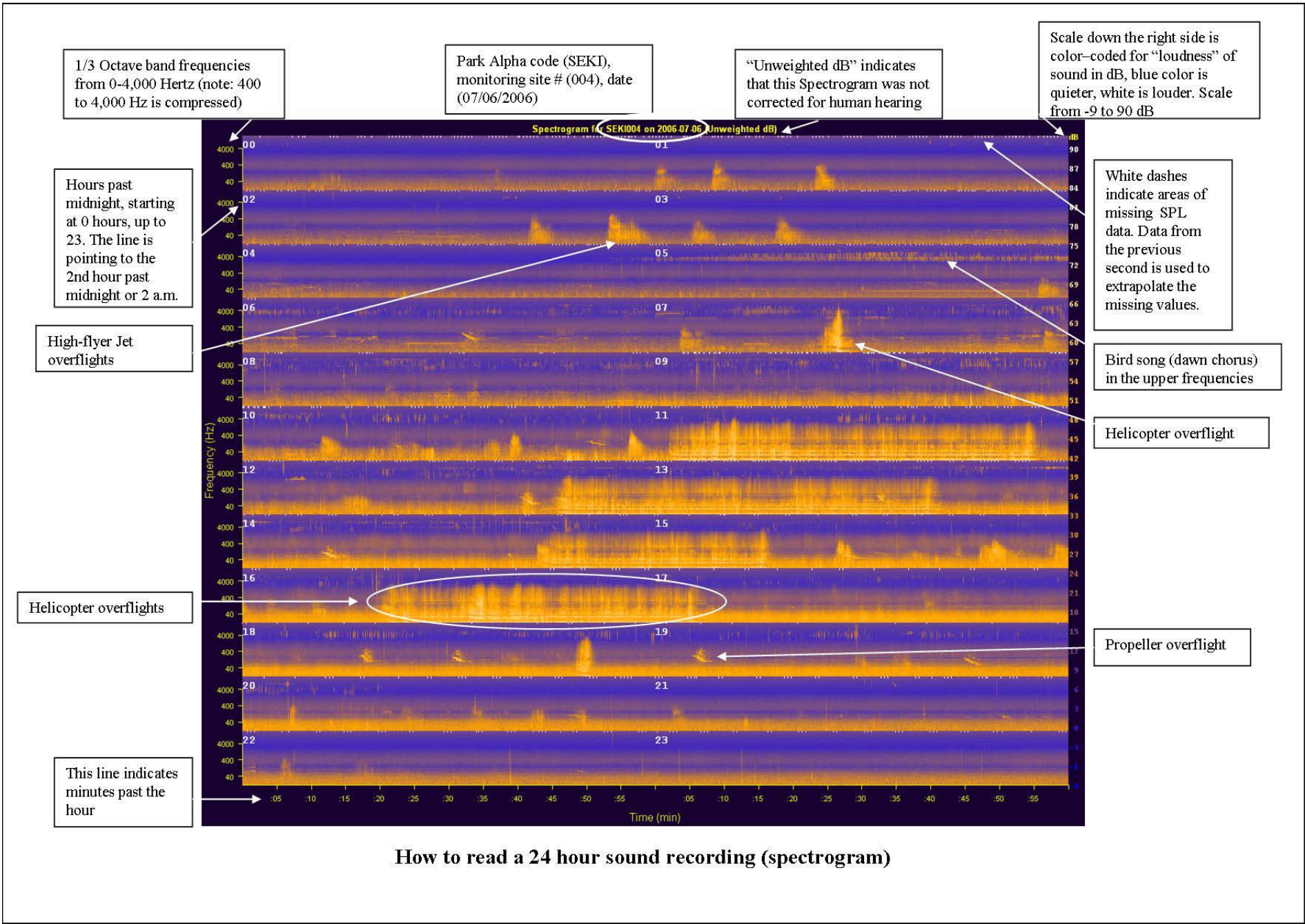
Spectrogram:

A visualization of an entire days worth of Sound pressure level data.

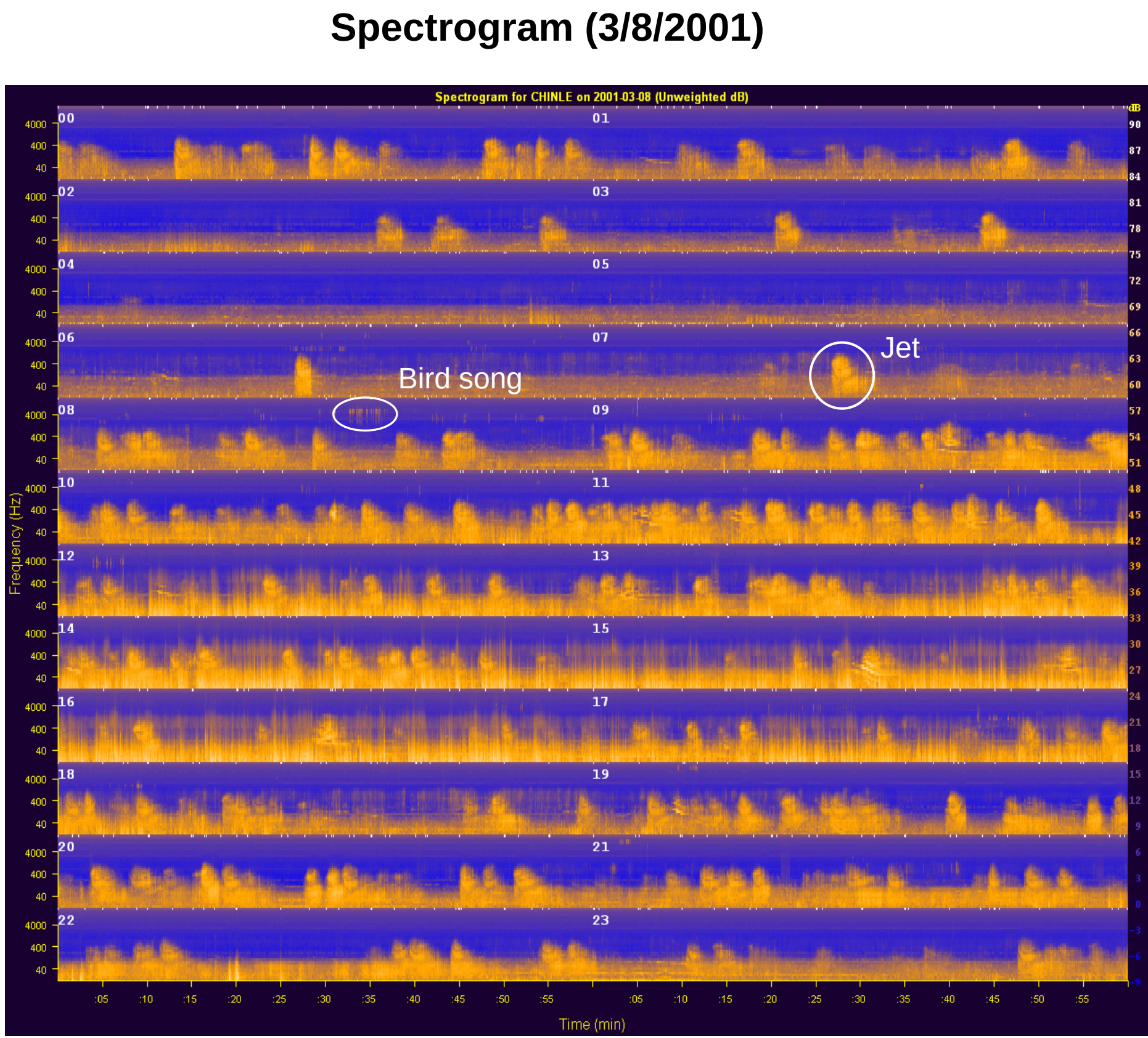
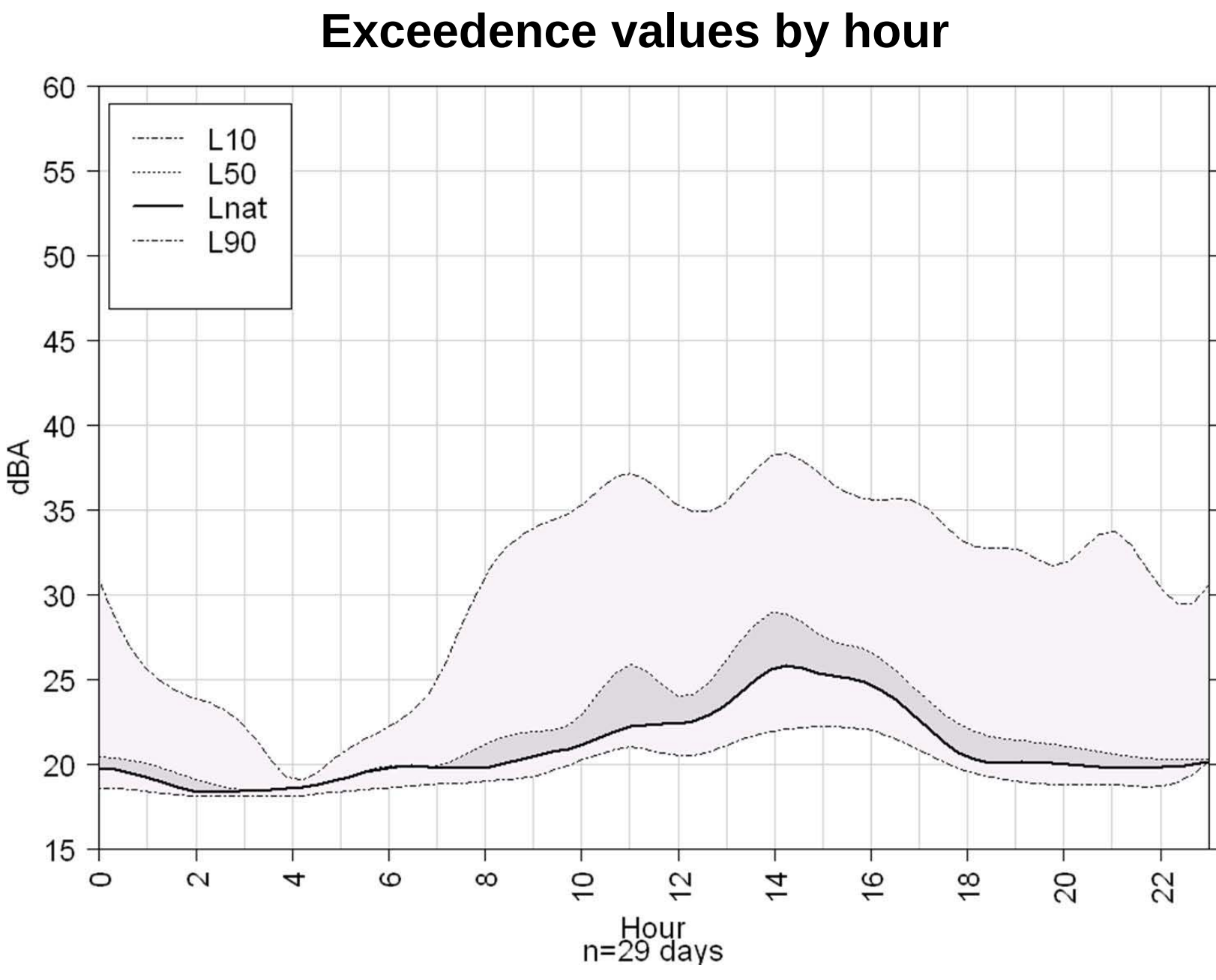
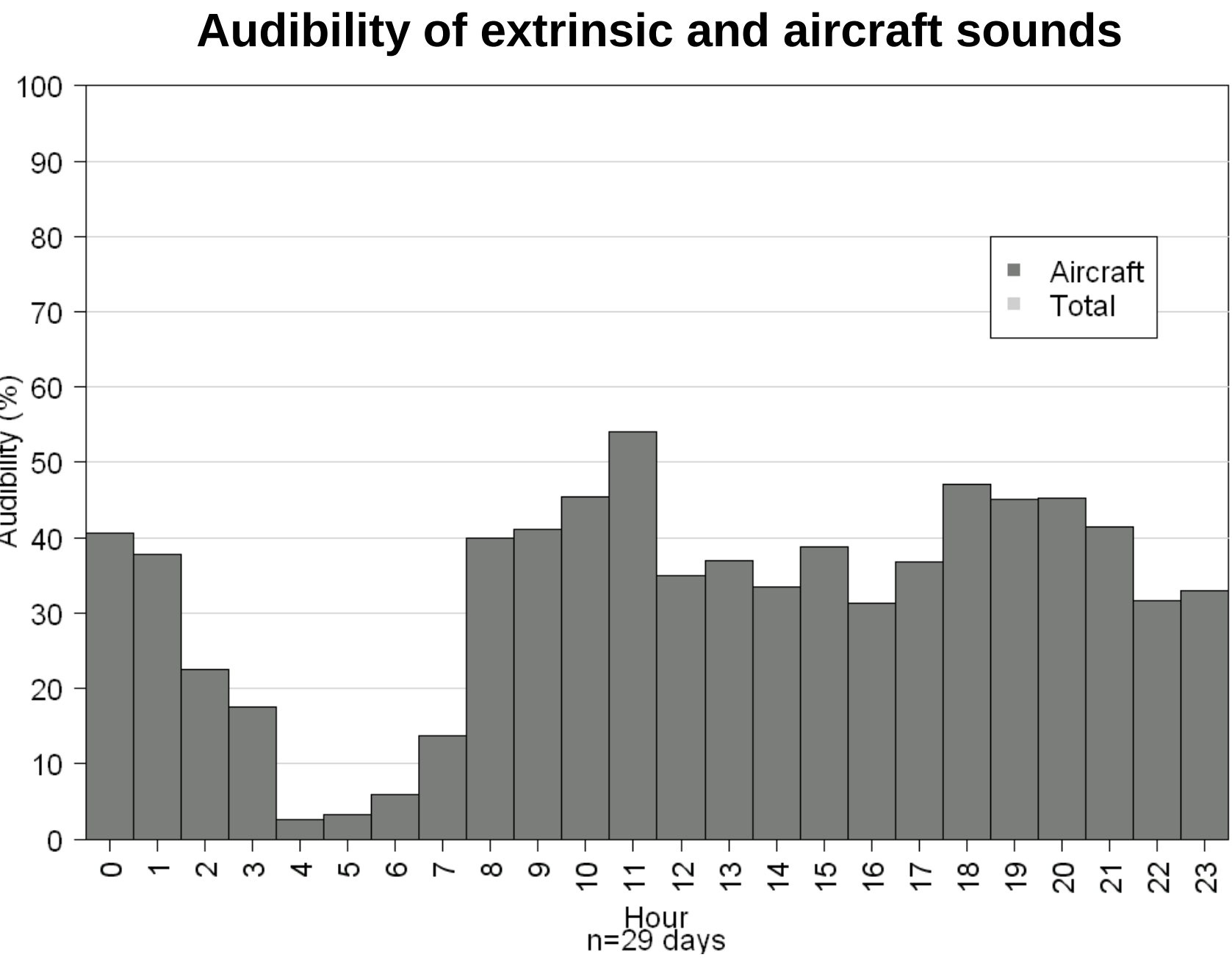
-X axis represents Time

-Y axis represents frequency on a log scale, to emphasize low frequency sounds.

-Z axis (the color map) represents the dB level for that particular octave band. The scale goes from blue (quieter) to white (louder).



Results for CHINLE:



Metrics:

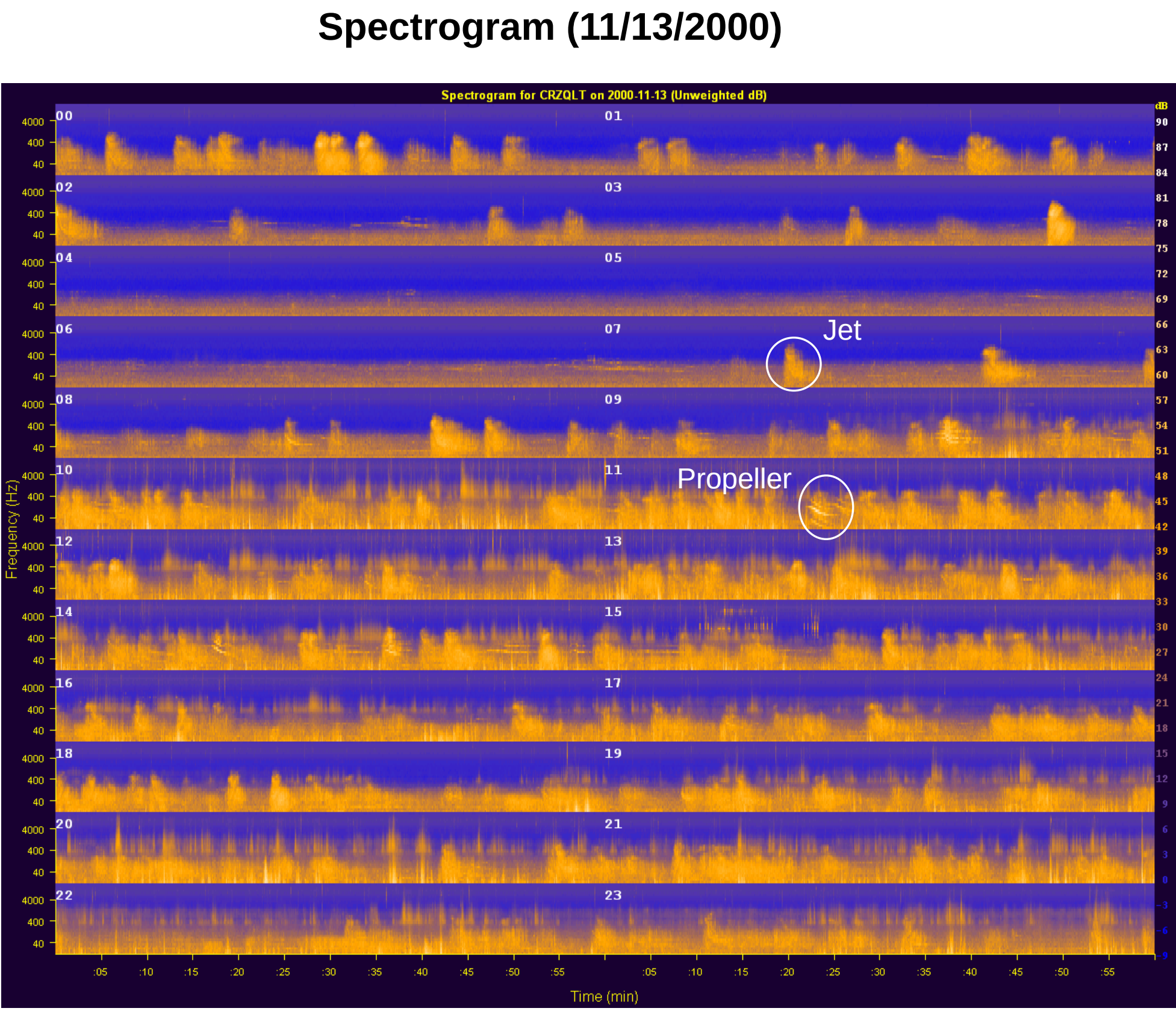
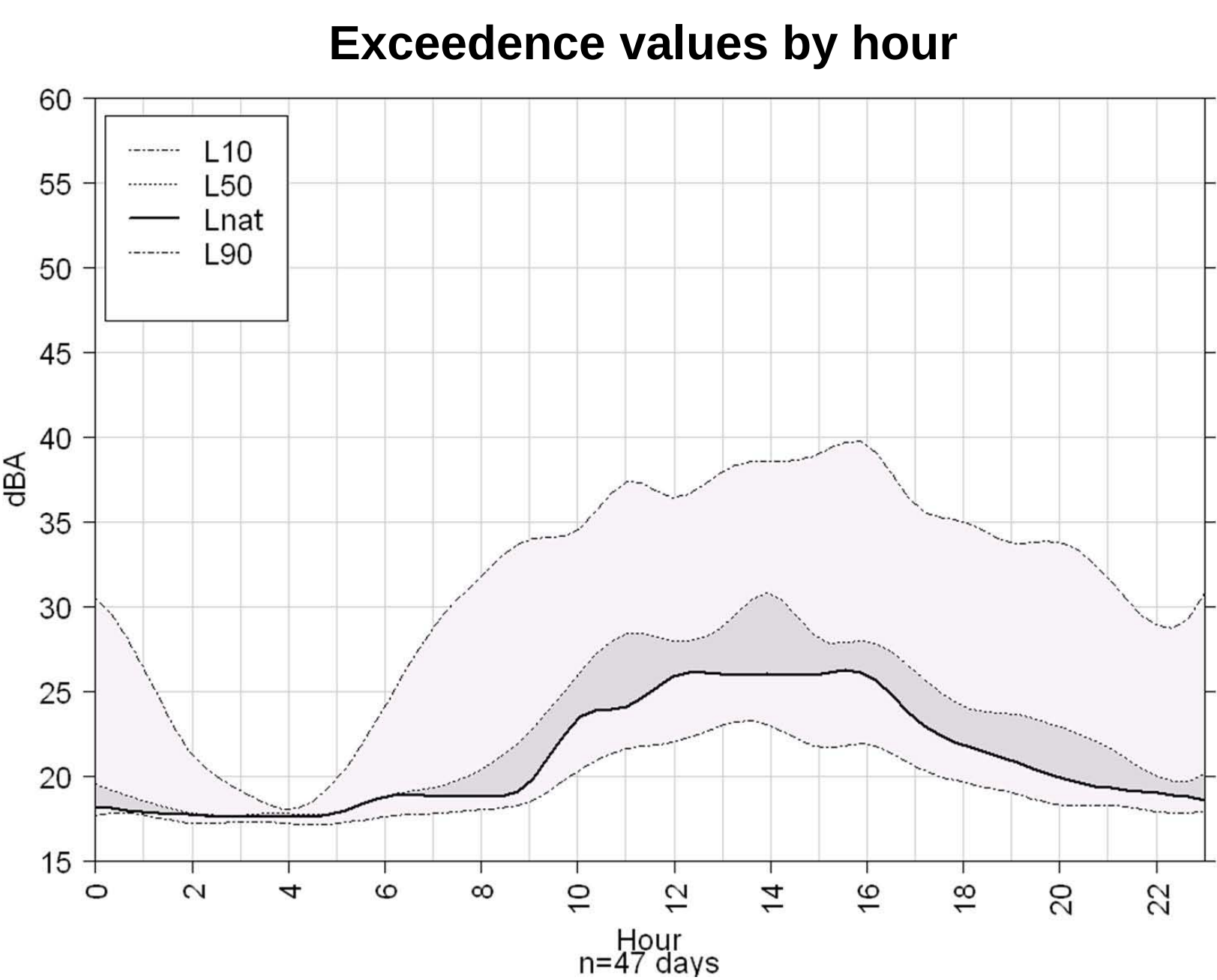
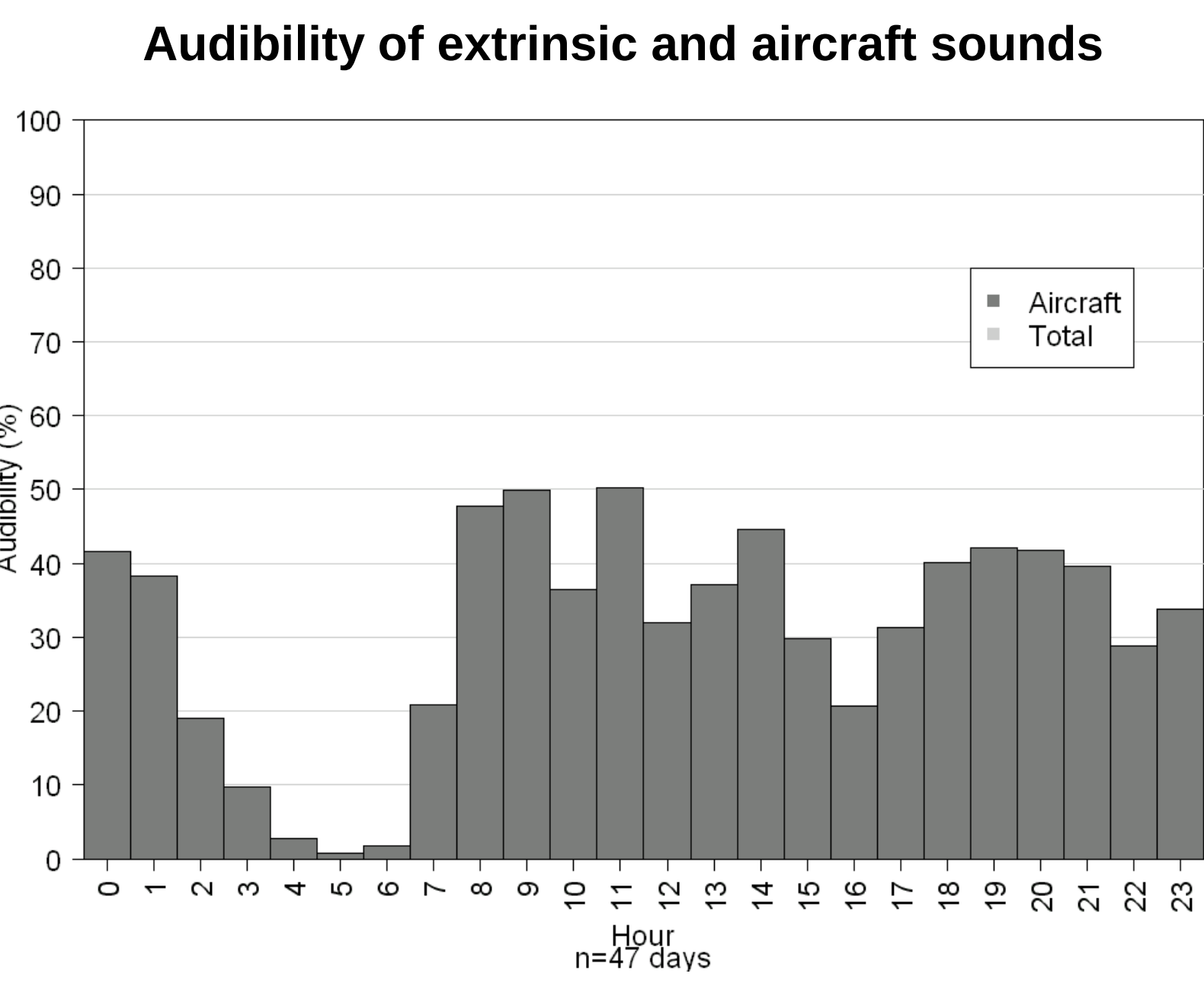
Noise Free Interval¹:

- Median = 2 minutes 36 seconds
- Mean = 6 minutes 26 seconds
- Max = 3 hours 31 minutes 48 seconds

Percent time above:

- Day (6 am to 6 pm)
 - 38dBA is exceeded 6% of the time
 - 44dBA is exceeded 2% of the time
 - 52dBA is exceeded 1% of the time
 - 65dBA is exceeded 0% of the time
 - 75dBA is exceeded 0% of the time
- Night (6 pm to 6 am)
 - 32dBA is exceeded 4% of the time
 - 38dBA is exceeded 1% of the time
 - 44dBA is exceeded 1% of the time
 - 50dBA is exceeded 1% of the time
 - 65dBA is exceeded 0% of the time

Results for CRZQLT:



Metrics:

Noise Free Interval:

- Median = 3 minutes 26 seconds
- Mean = 7 minutes 49 seconds
- Max = 4 hours 24 minutes 0 seconds

Percent time above:

- Day (6 am to 6 pm)
 - 38dBA² is exceeded 6% of the time
 - 44dBA is exceeded 2% of the time
 - 52dBA is exceeded 1% of the time
 - 65dBA is exceeded 0% of the time
 - 75dBA is exceeded 0% of the time
- Night (6 pm to 6 am)
 - 32dBA is exceeded 4% of the time
 - 38dBA is exceeded 1% of the time
 - 44dBA is exceeded 1% of the time
 - 50dBA is exceeded 1% of the time
 - 65dBA is exceeded 0% of the time

1. Noise Free Interval – The period of time between noise events. This is not to be confused with silence. It is the time between extrinsic sounds.

2. 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.

Acoustic Monitoring in Zion National Park

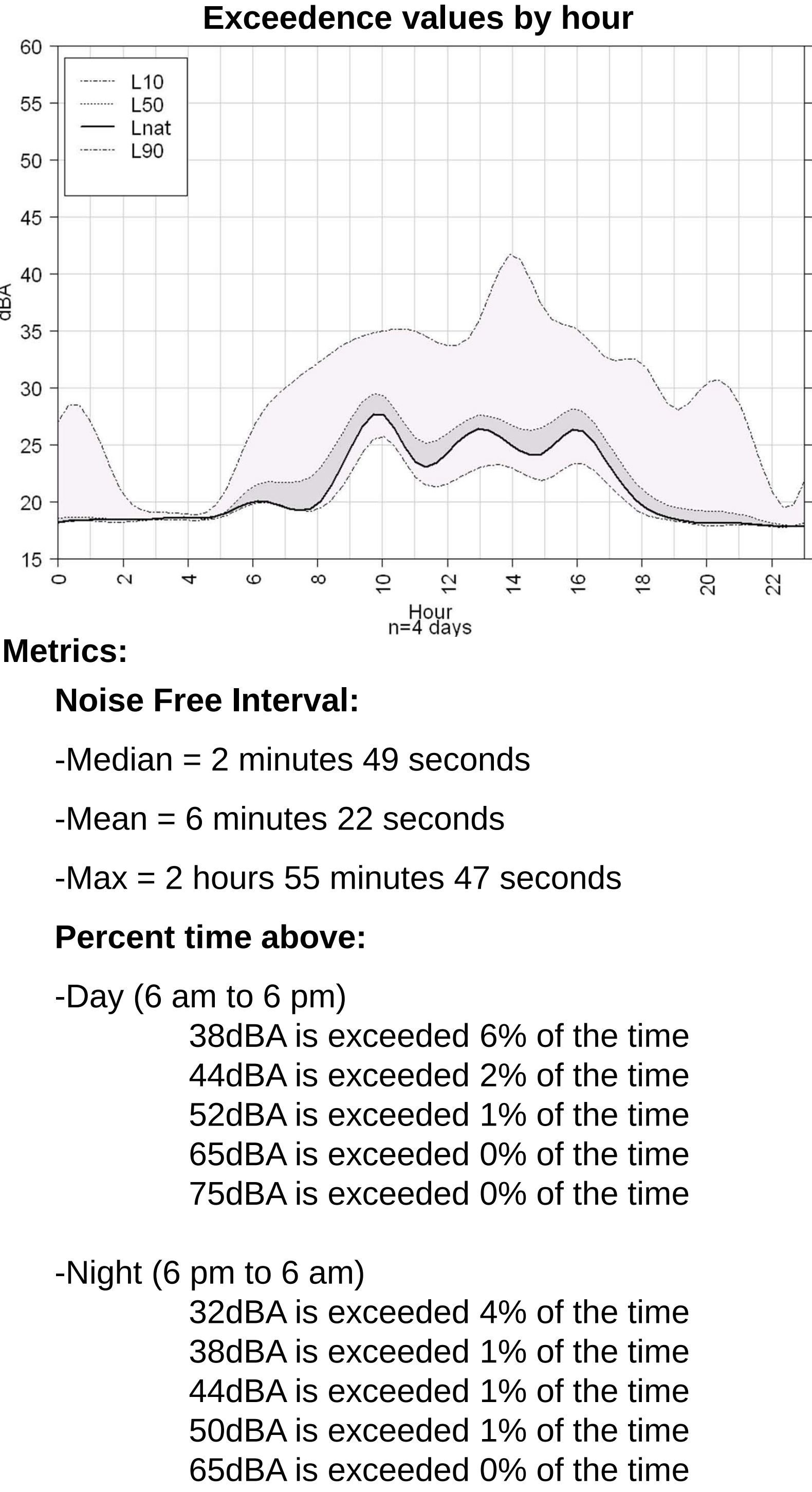
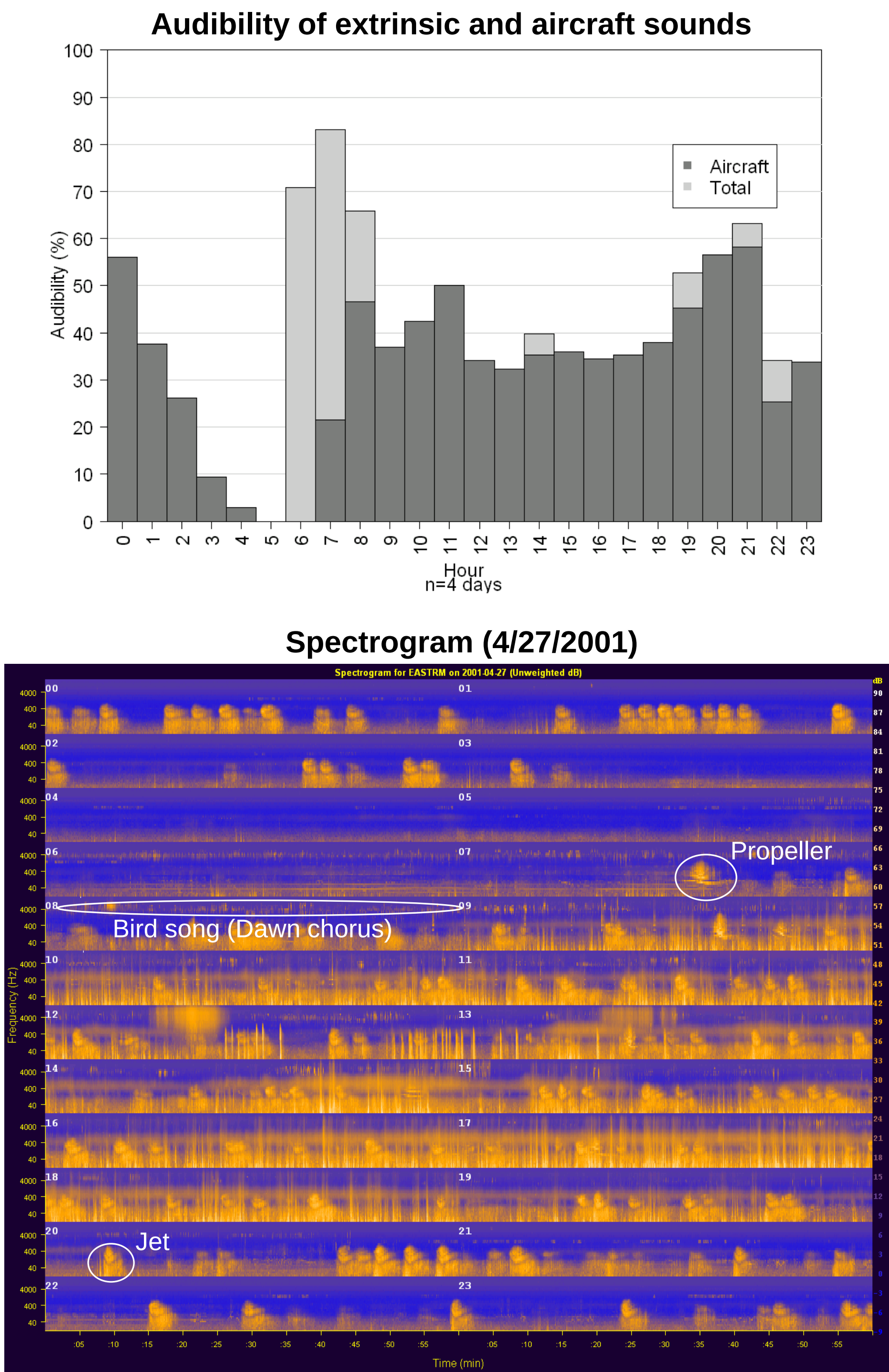
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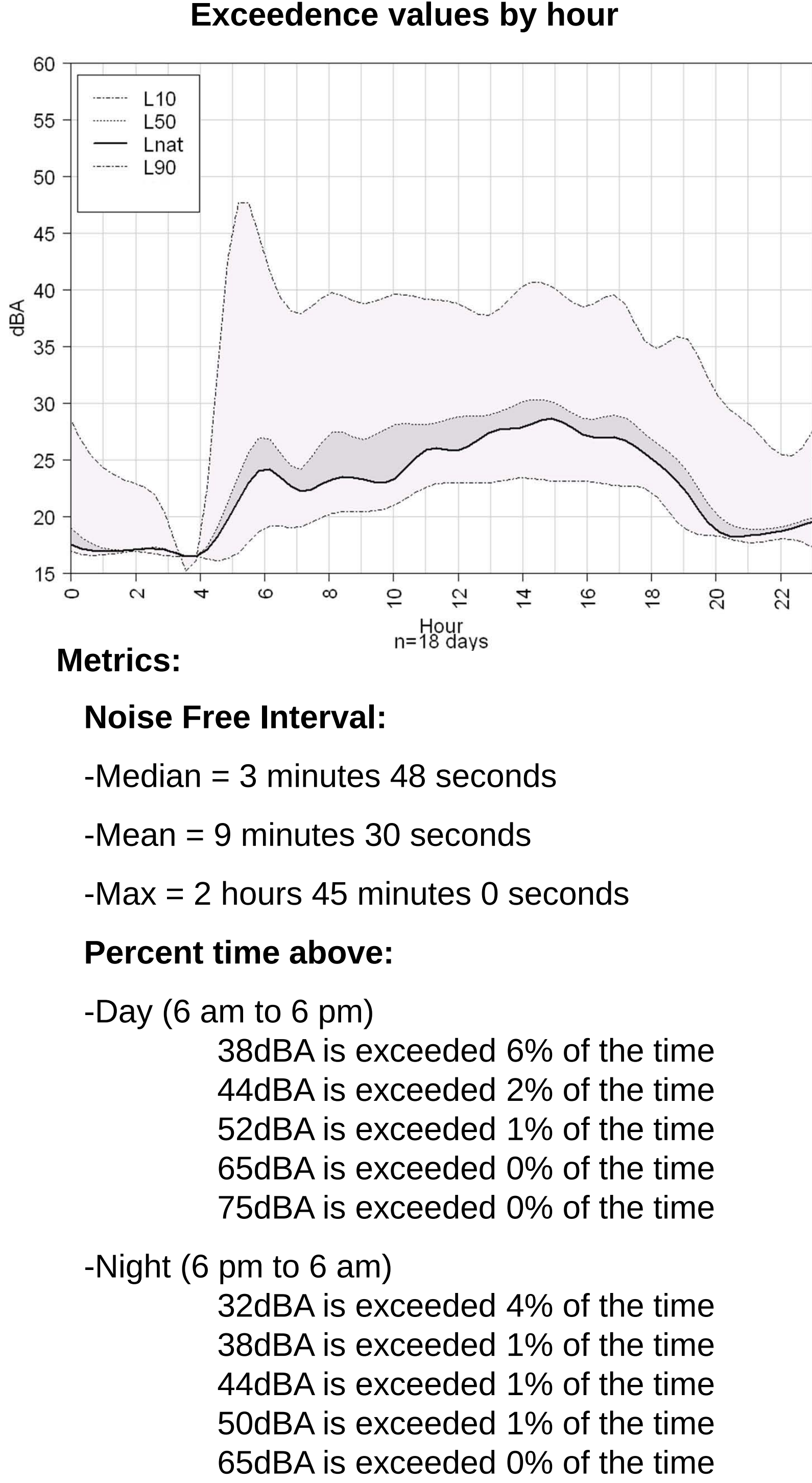
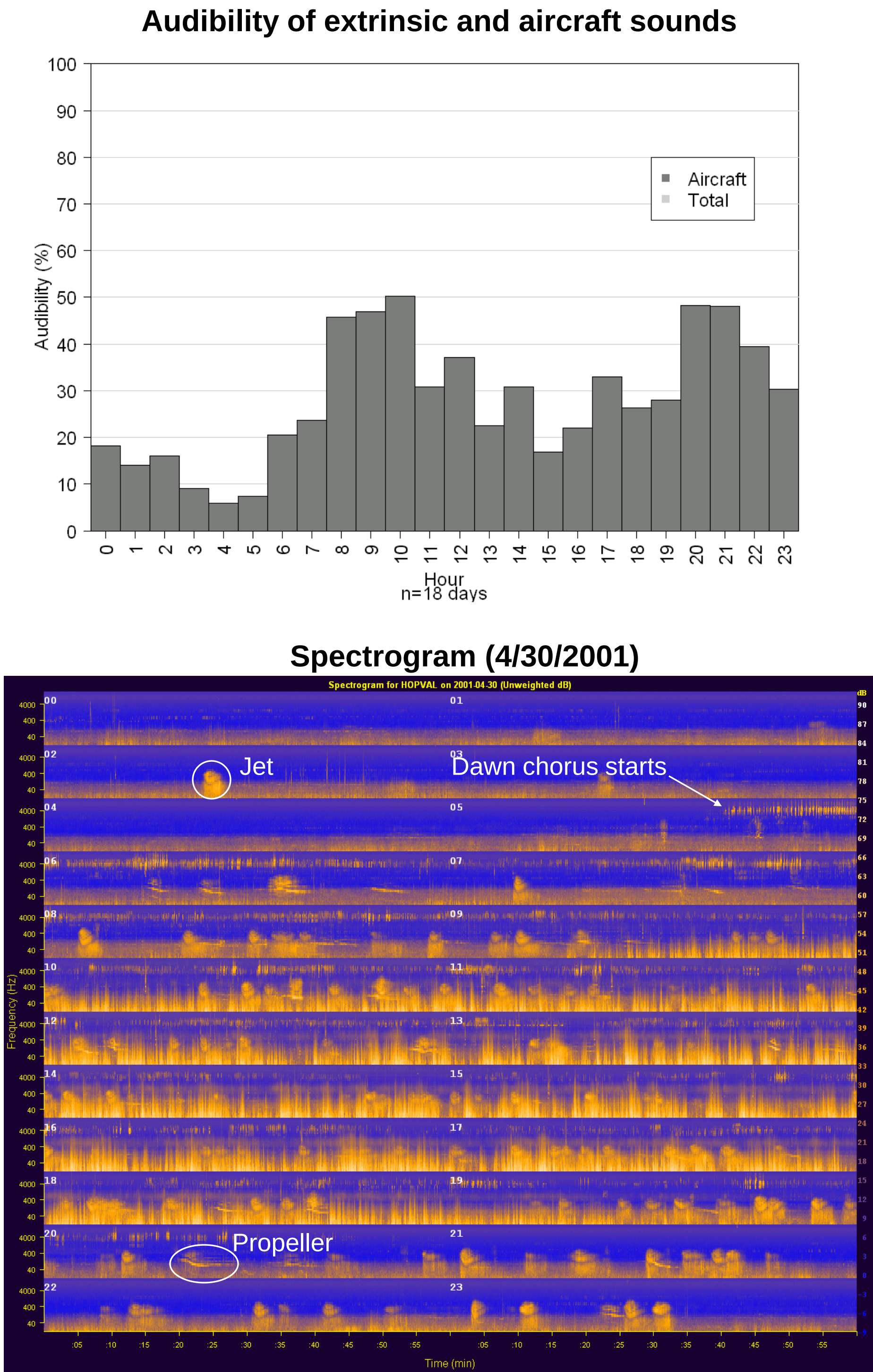
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Results for EASTRM:

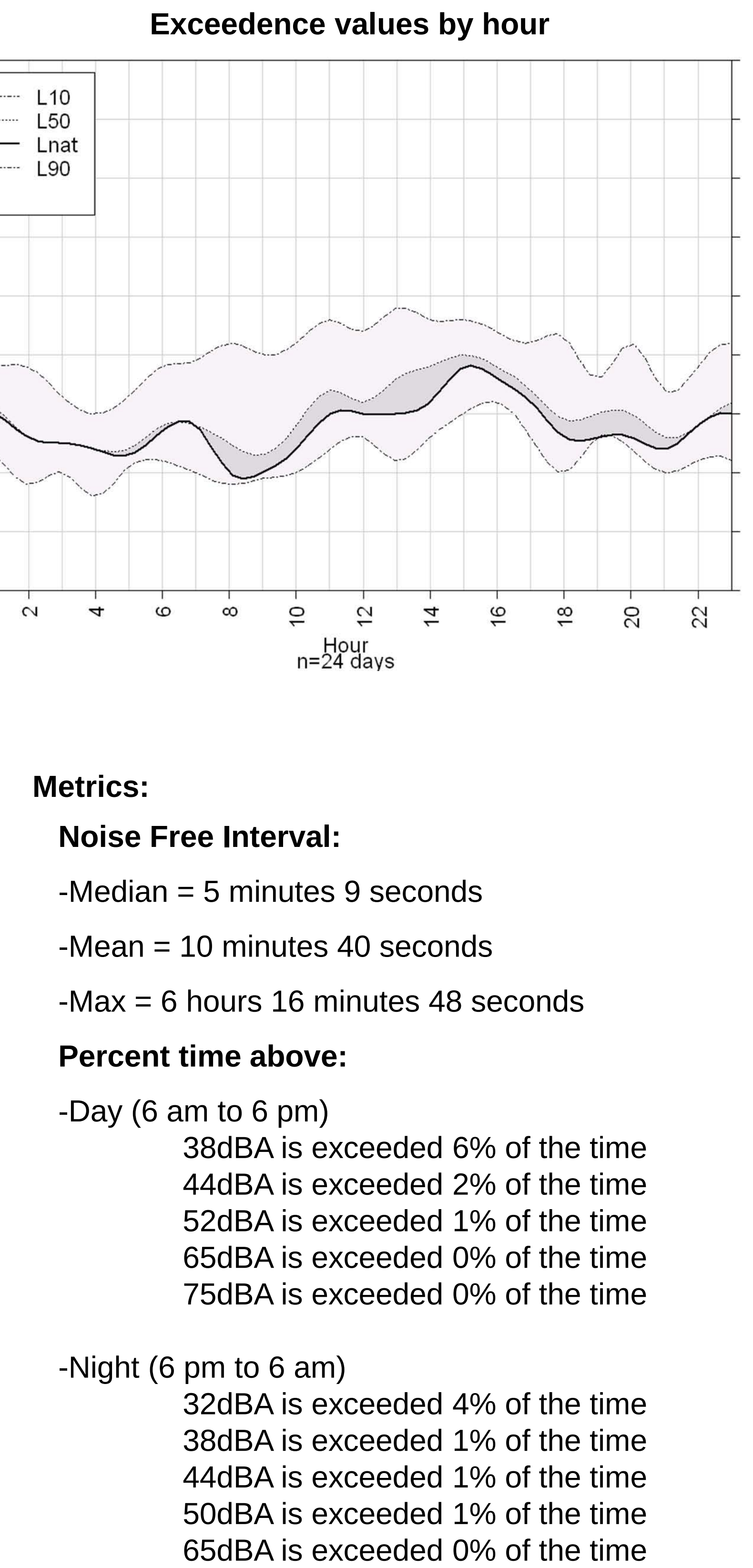
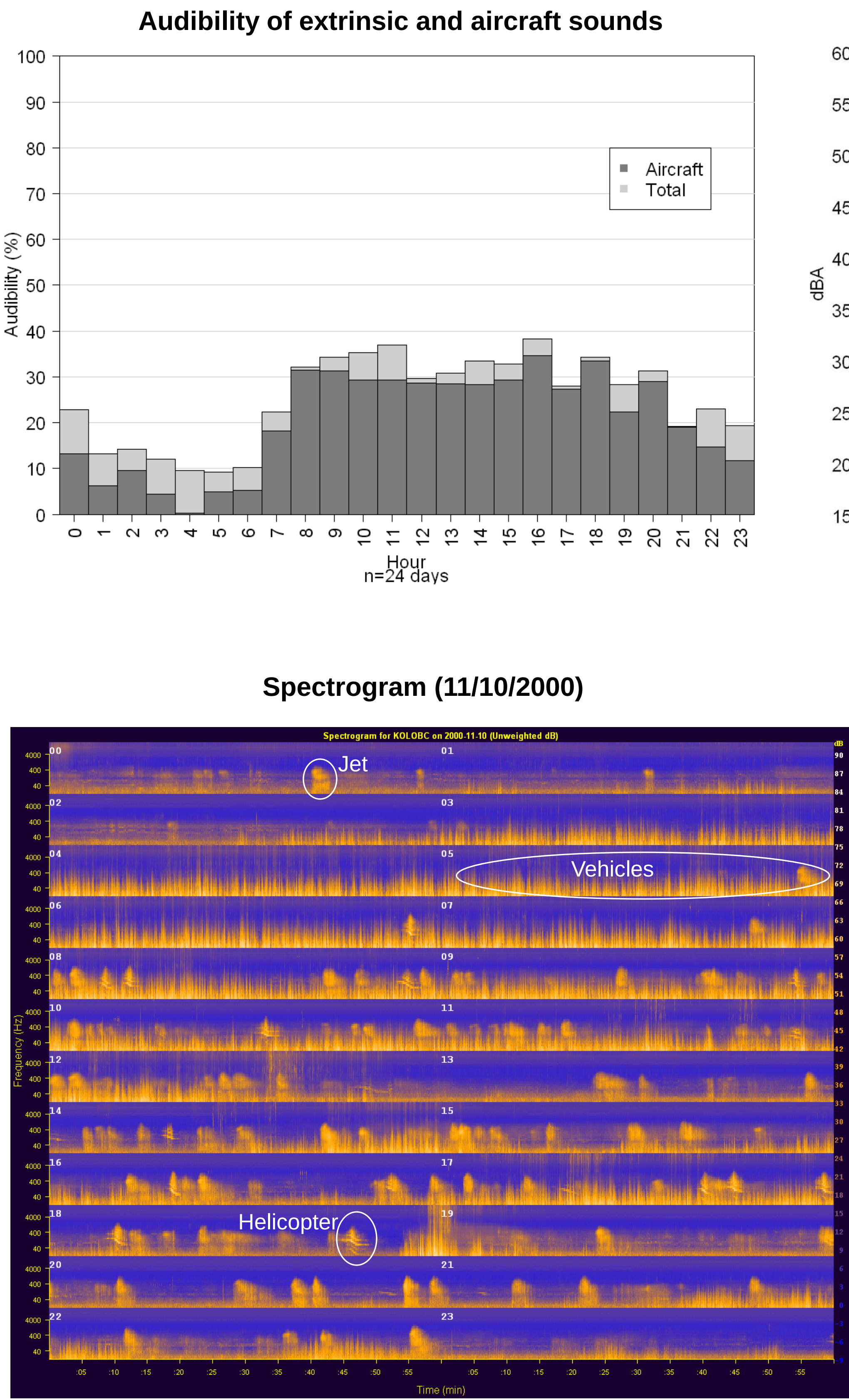
Notice that we were only able to analyze 4 days worth of data for this site and that these data are not statistically significant.



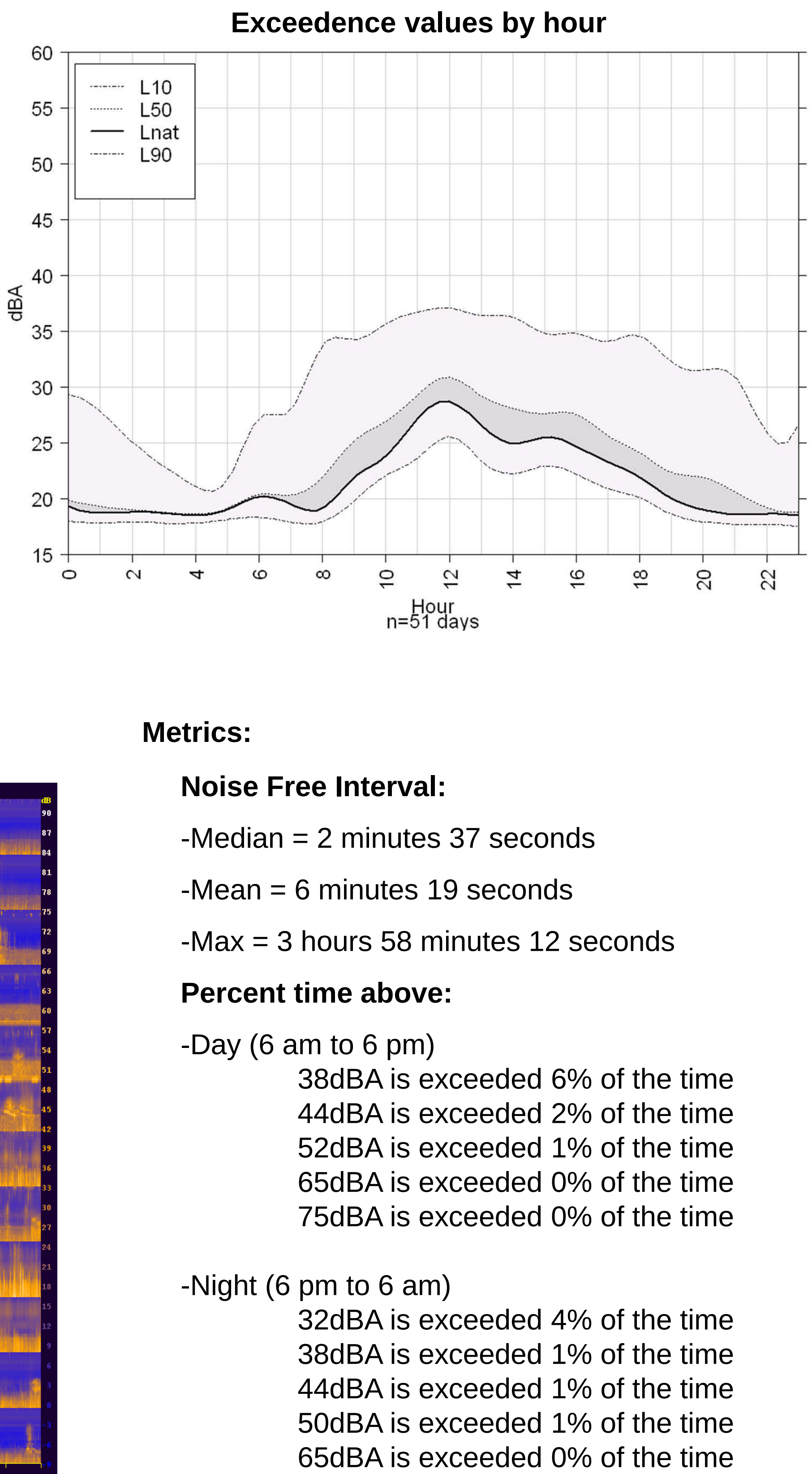
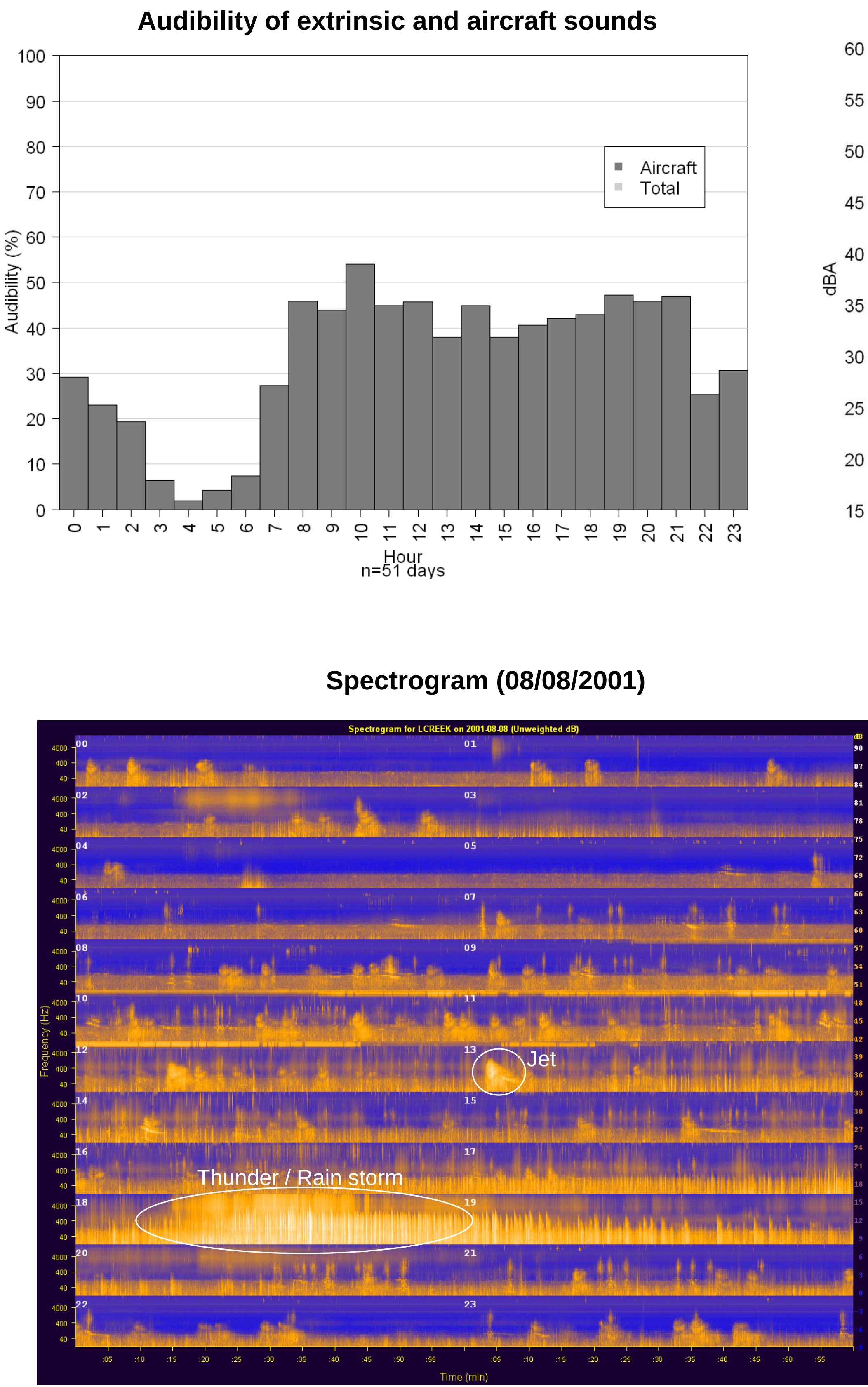
Results for HOPVAL:



Results for KOLOBC:



Results for LCREEK:



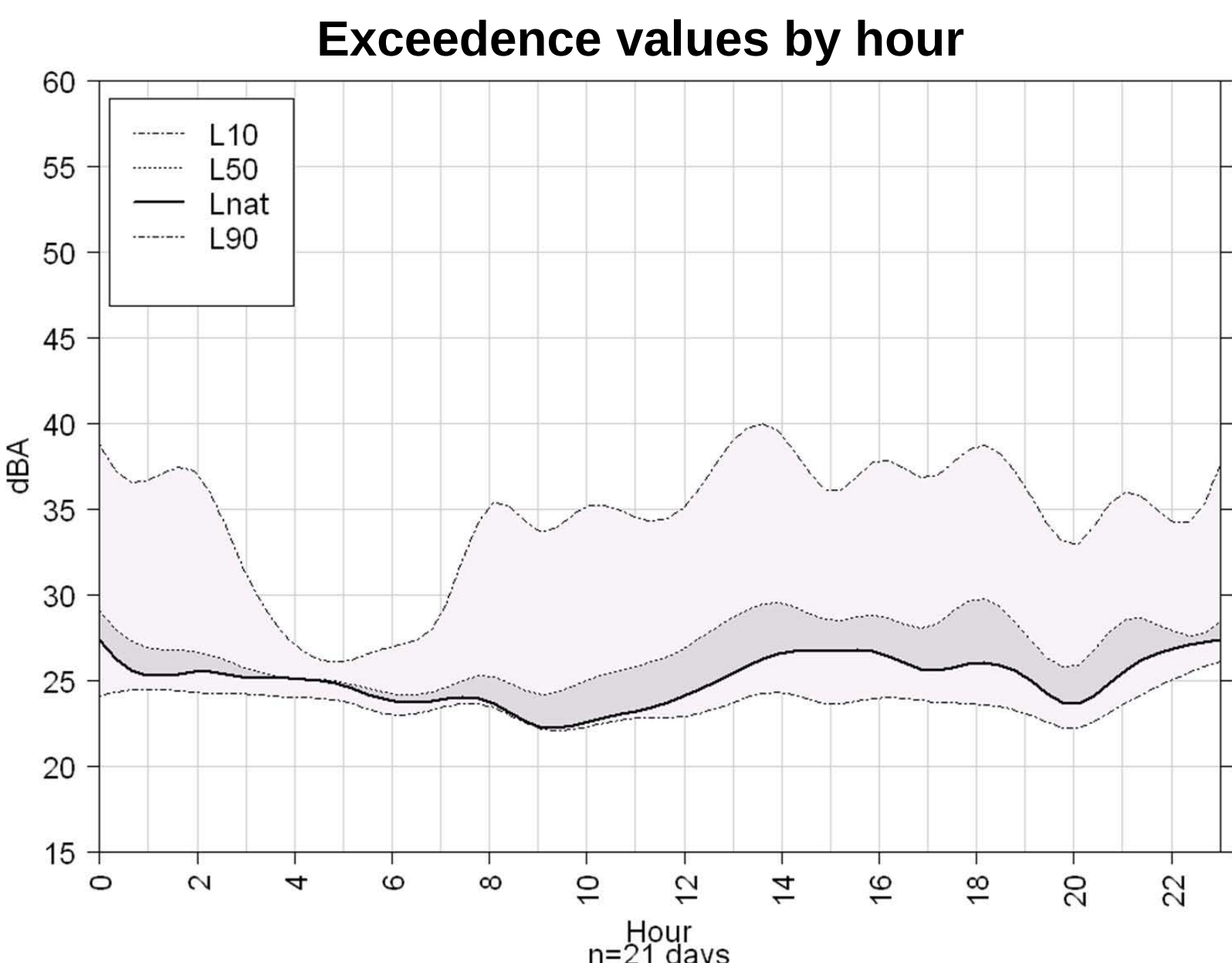
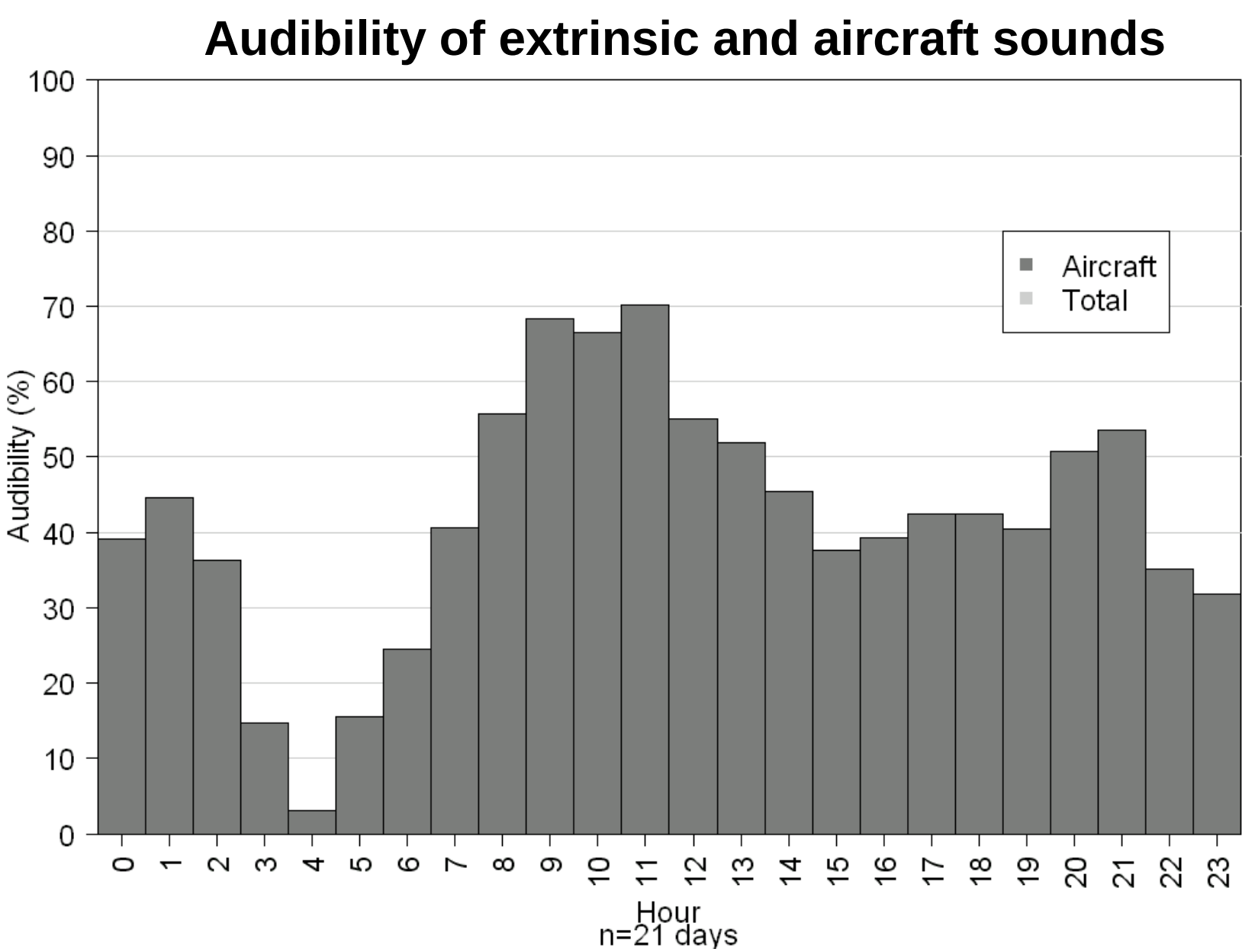
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Natural Sounds Program
Fort Collins, Colorado



Charlotte Formichella, Kurt Frstrup, Damon Joyce, Emma Lynch, and Ericka Pilcher

Results for LFRKTD:



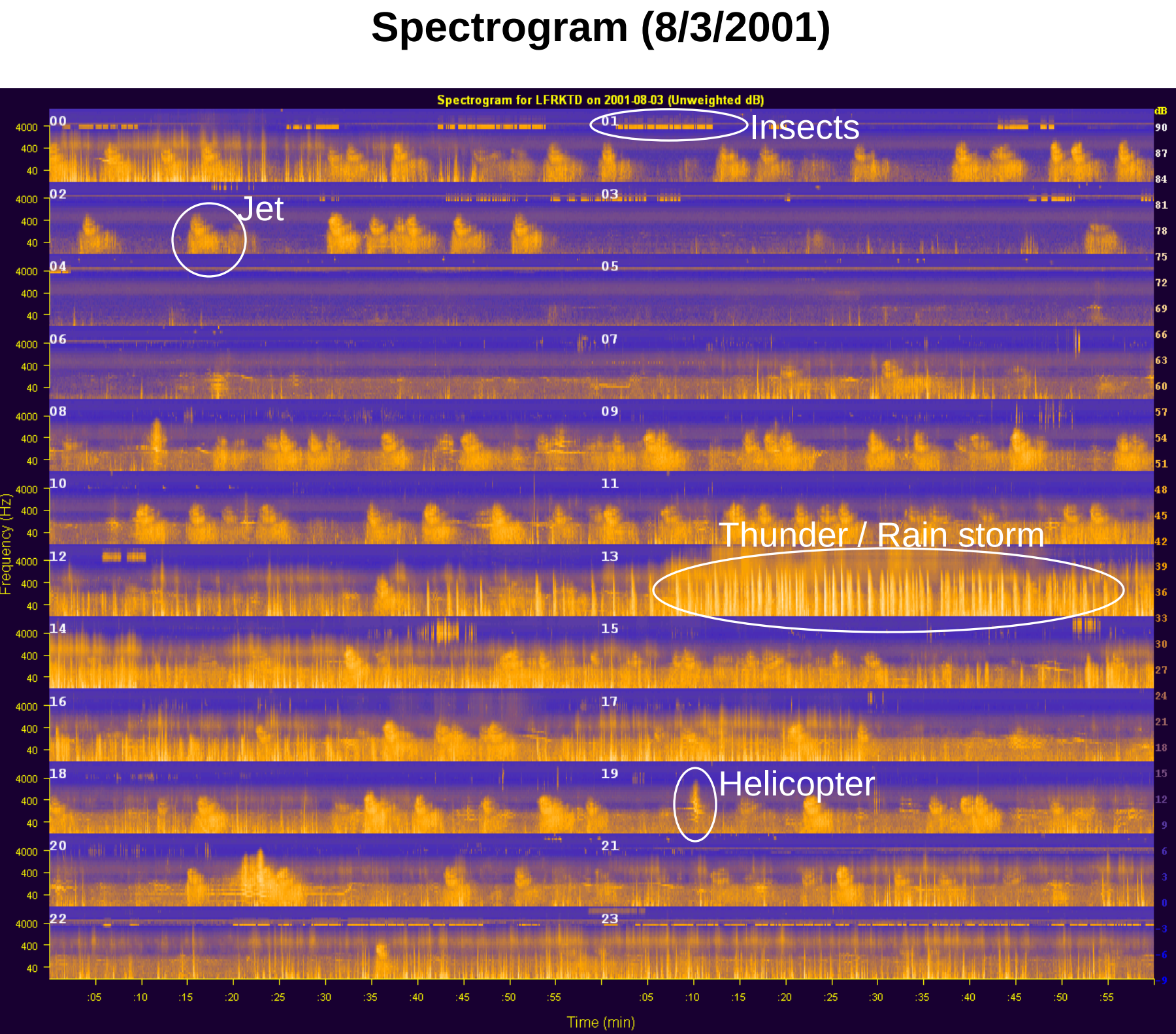
Metrics:

Noise Free Interval:

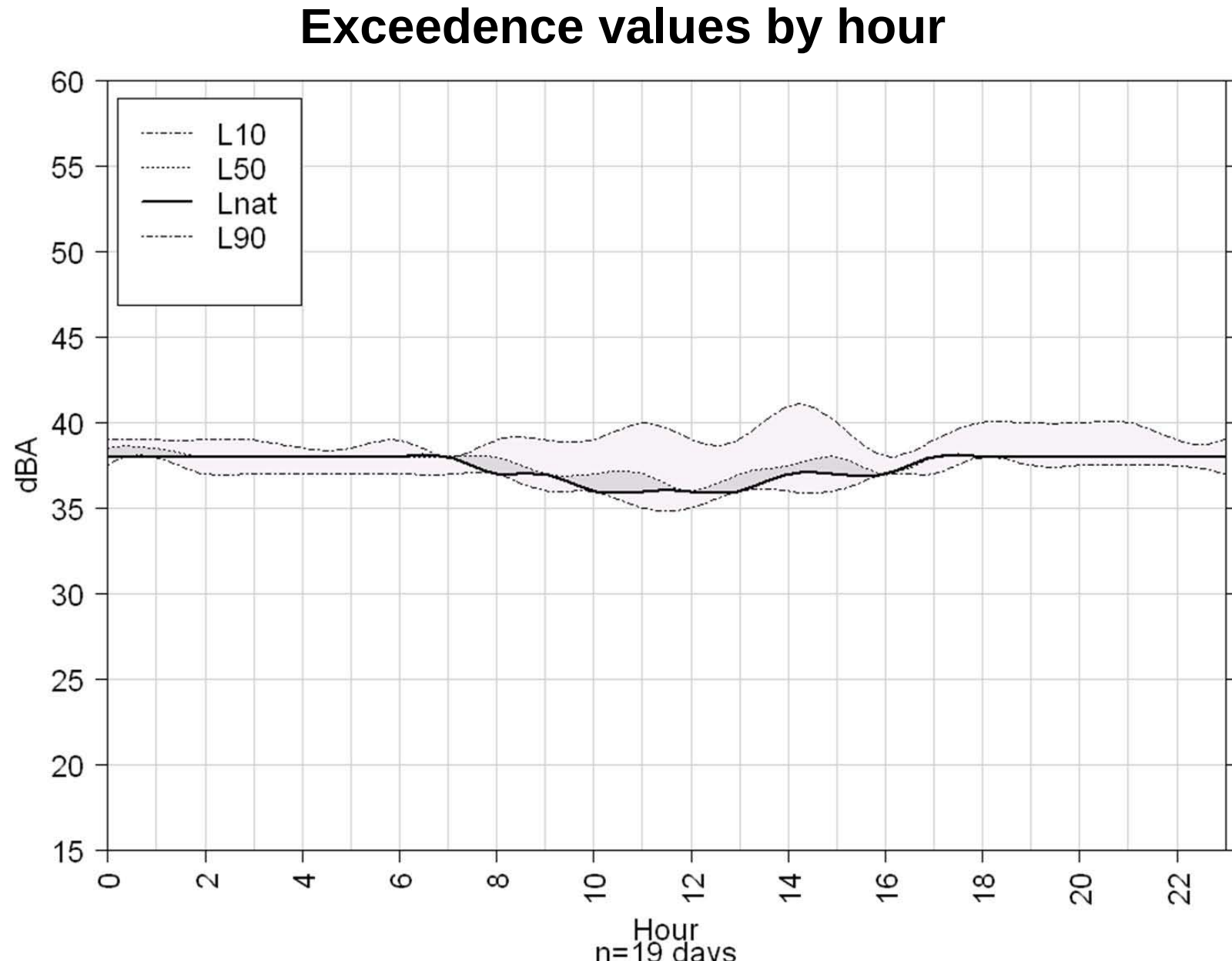
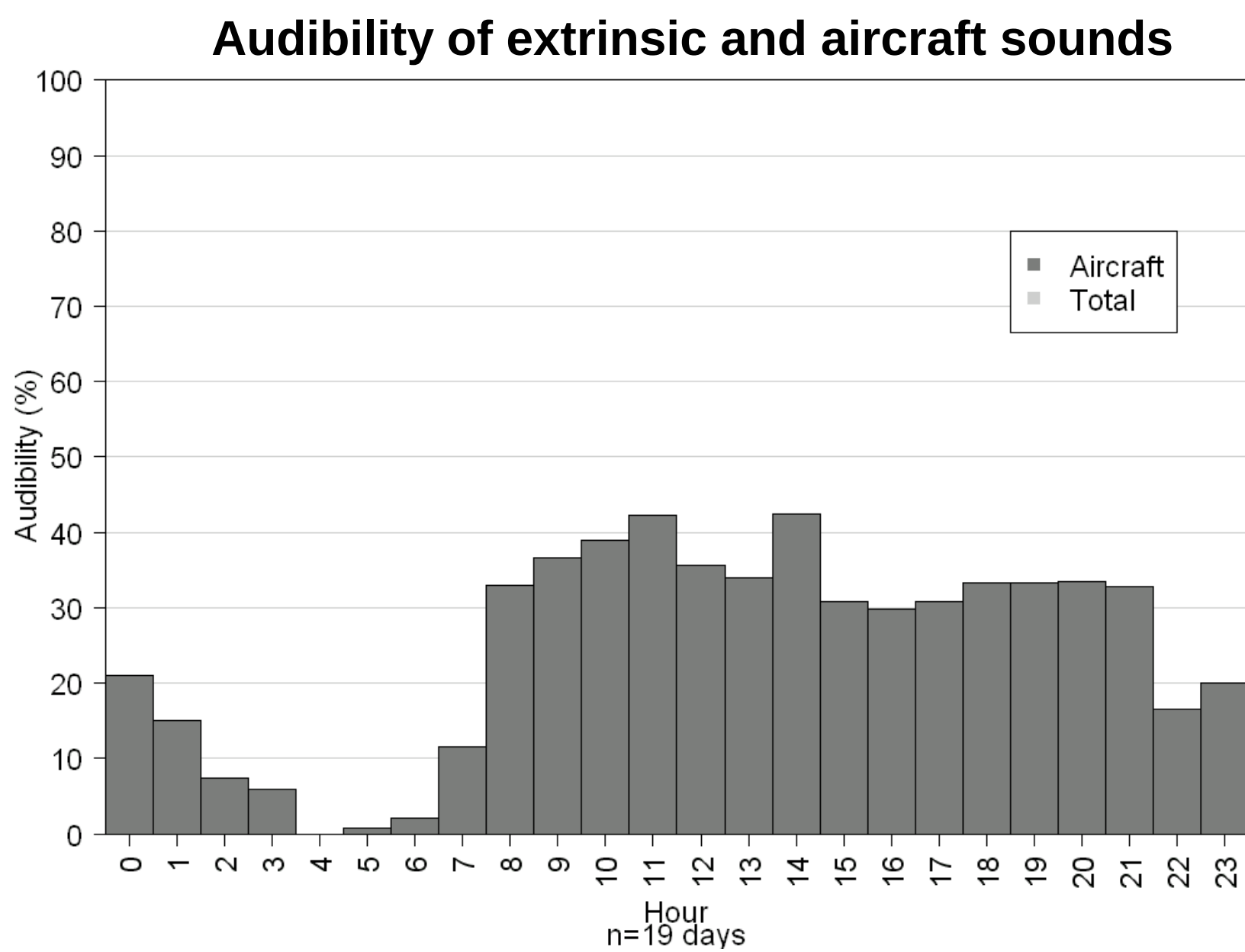
- Median = 1 minute 28 seconds
- Mean = 4 minutes 58 seconds
- Max = 2 hours 54 minutes 0 seconds

Percent time above:

- Day (6 am to 6 pm)
 - 38dBA is exceeded 6% of the time
 - 44dBA is exceeded 2% of the time
 - 52dBA is exceeded 1% of the time
 - 65dBA is exceeded 0% of the time
 - 75dBA is exceeded 0% of the time
- Night (6 pm to 6 am)
 - 32dBA is exceeded 4% of the time
 - 38dBA is exceeded 1% of the time
 - 44dBA is exceeded 1% of the time
 - 50dBA is exceeded 1% of the time
 - 65dBA is exceeded 0% of the time



Results for NCREEK:



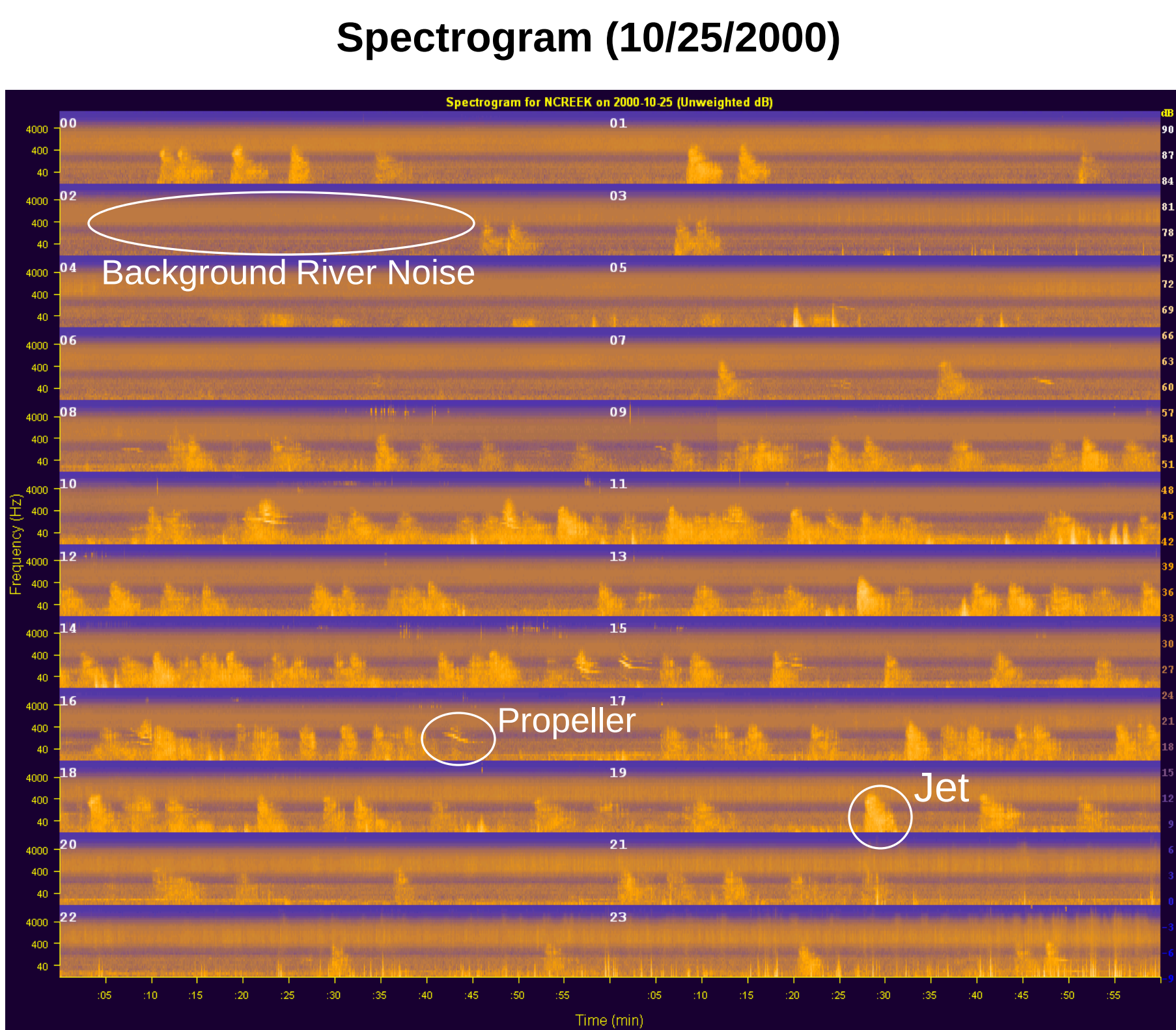
Metrics:

Noise Free Interval:

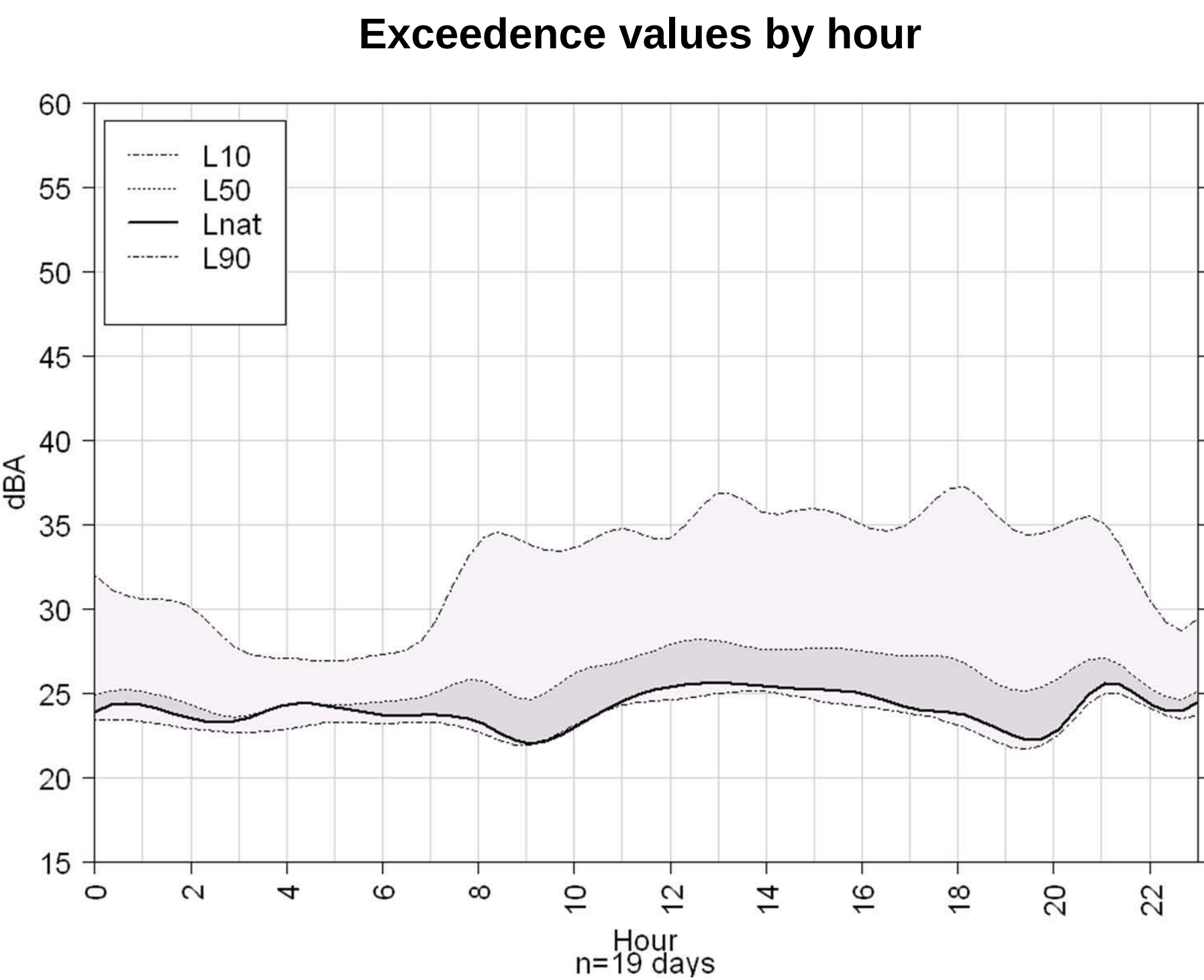
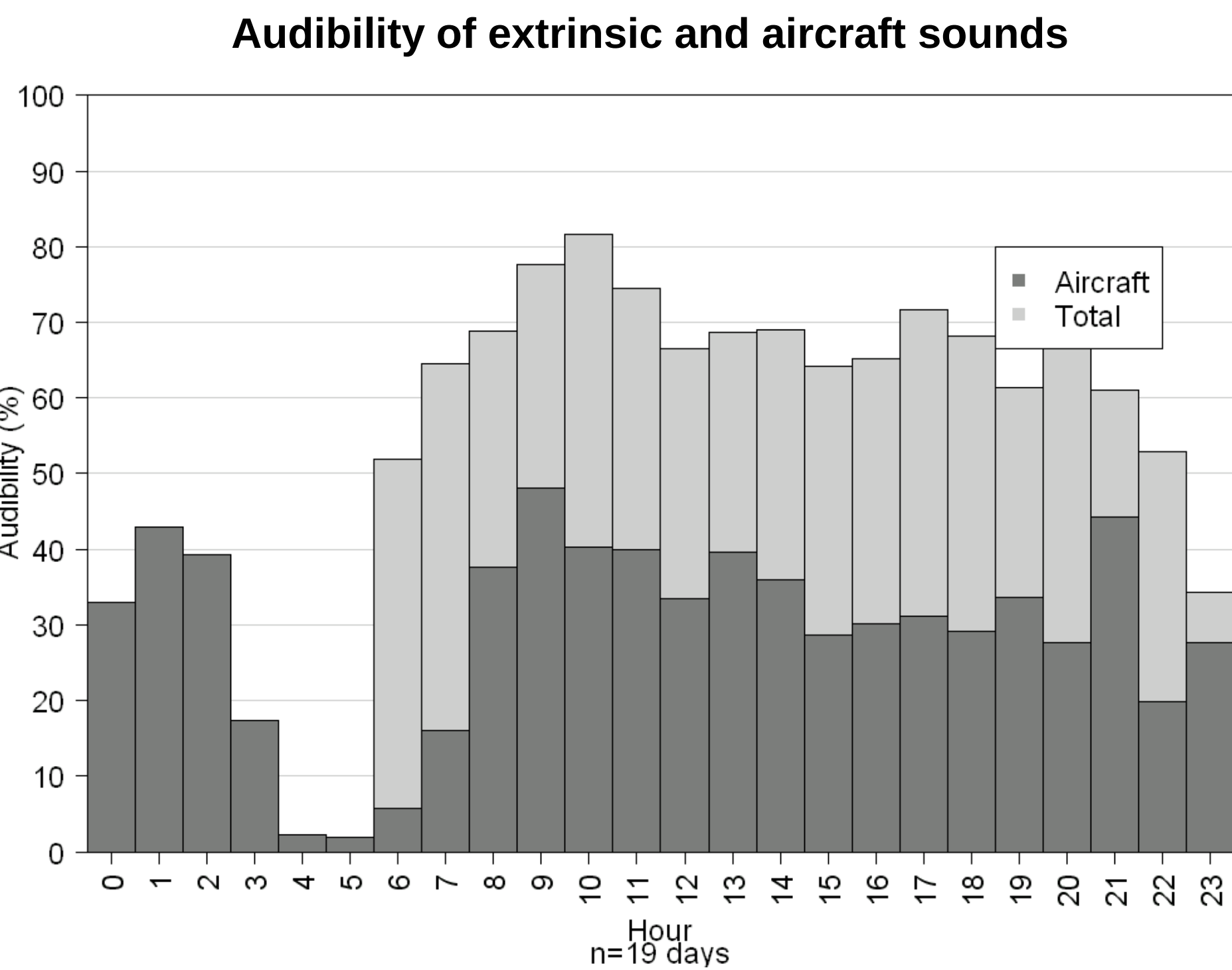
- Median = 4 minutes 0 seconds
- Mean = 9 minutes 10 seconds
- Max = 5 hours 45 minutes 0 seconds

Percent time above:

- Day (6 am to 6 pm)
 - 38dBA is exceeded 6% of the time
 - 44dBA is exceeded 2% of the time
 - 52dBA is exceeded 1% of the time
 - 65dBA is exceeded 0% of the time
 - 75dBA is exceeded 0% of the time
- Night (6 pm to 6 am)
 - 32dBA is exceeded 4% of the time
 - 38dBA is exceeded 1% of the time
 - 44dBA is exceeded 1% of the time
 - 50dBA is exceeded 1% of the time
 - 65dBA is exceeded 0% of the time



Results for SCOUTS:



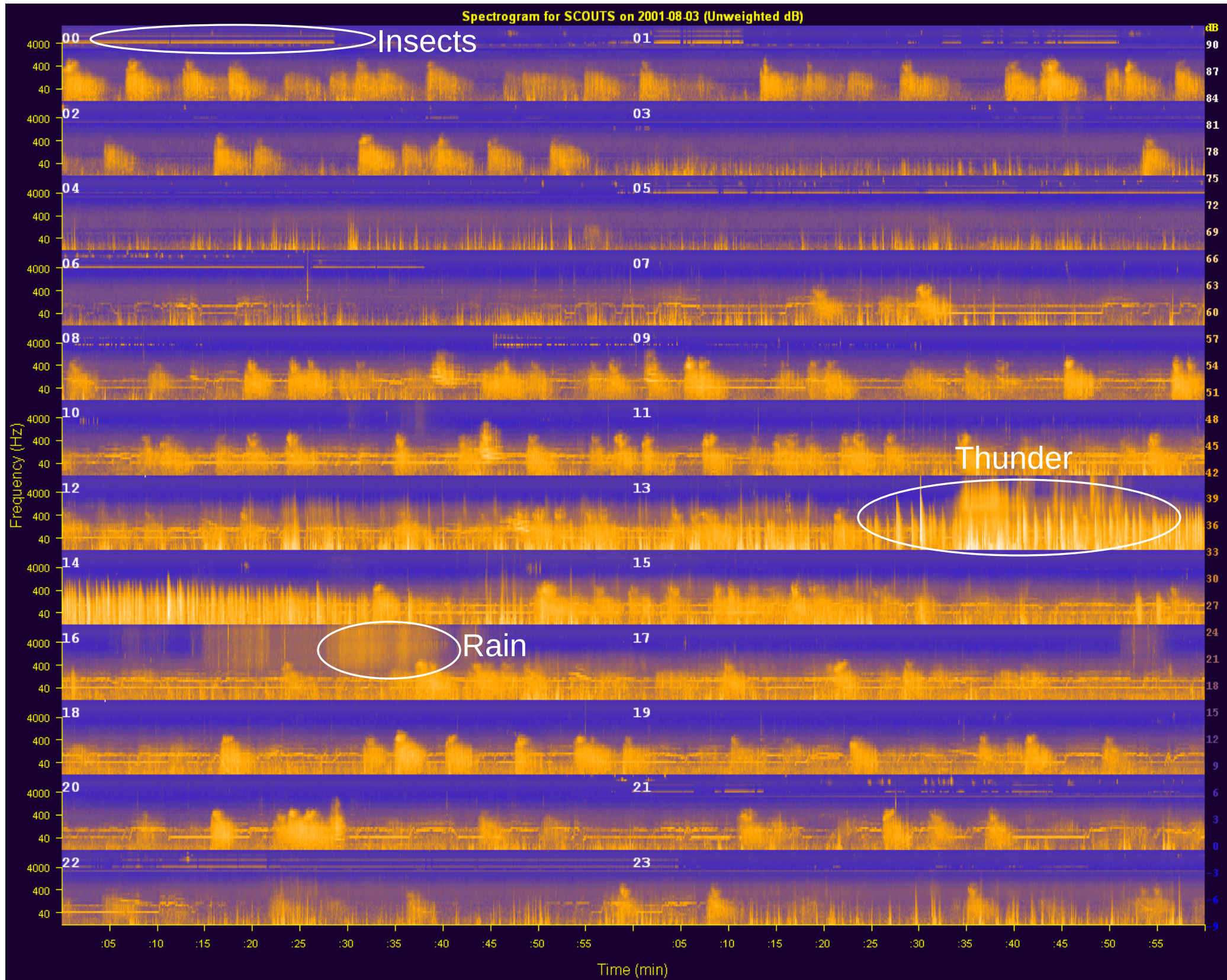
Metrics:

Noise Free Interval:

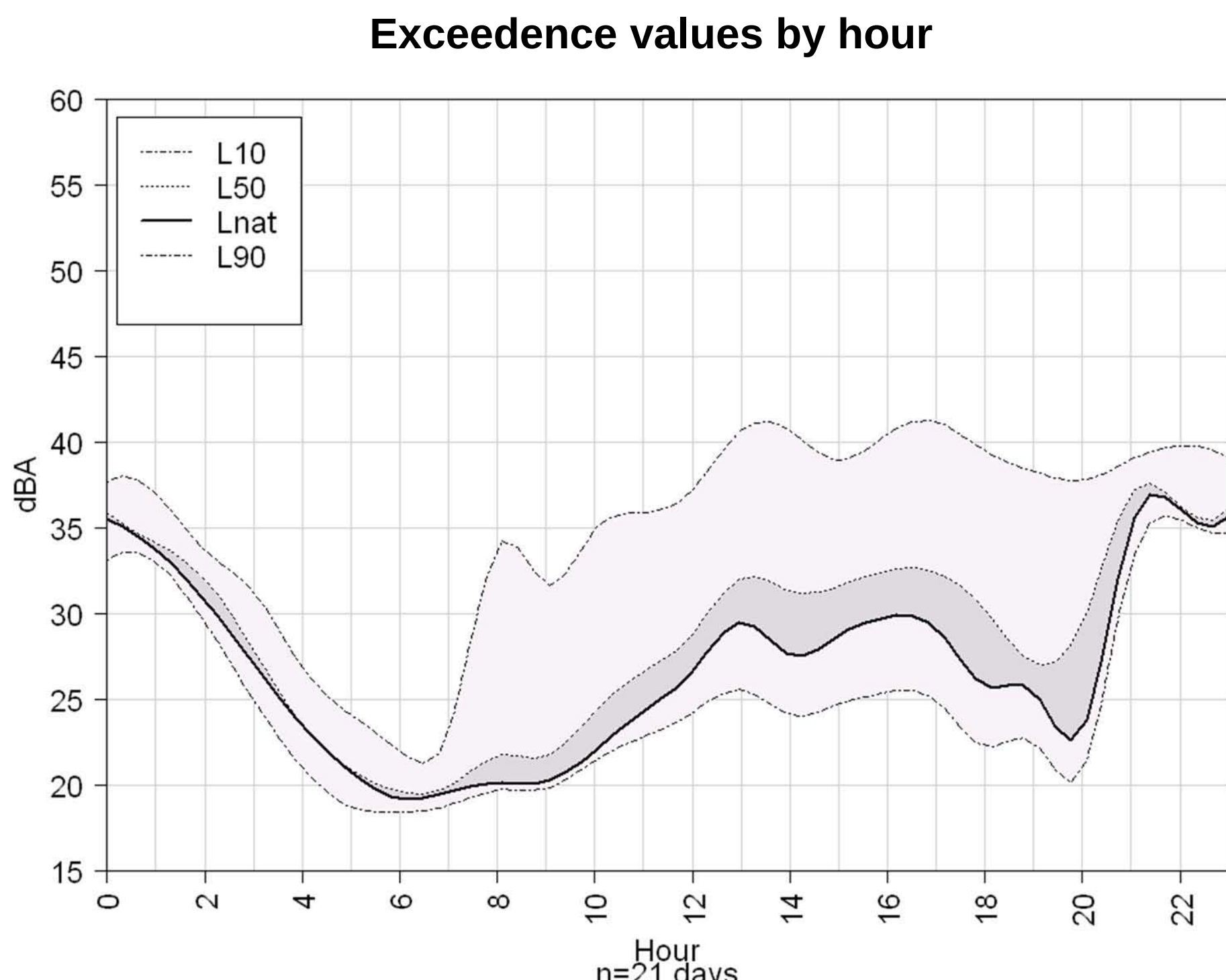
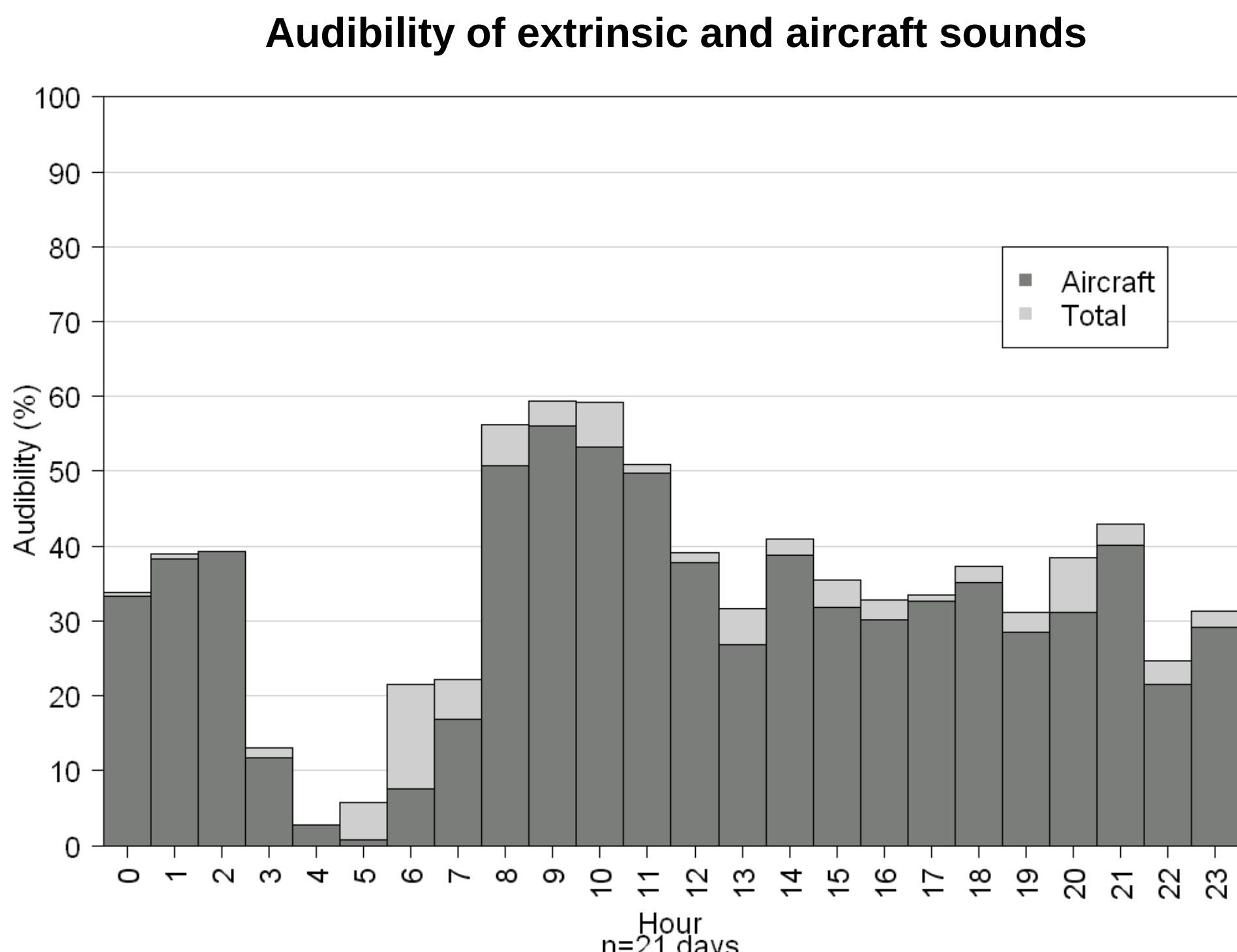
- Median = 46 seconds
- Mean = 3 minutes 38 seconds
- Max = 3 hours 14 minutes 24 seconds

Percent time above:

- Day (6 am to 6 pm)
 - 38dBA is exceeded 6% of the time
 - 44dBA is exceeded 2% of the time
 - 52dBA is exceeded 1% of the time
 - 65dBA is exceeded 0% of the time
 - 75dBA is exceeded 0% of the time
- Night (6 pm to 6 am)
 - 32dBA is exceeded 4% of the time
 - 38dBA is exceeded 1% of the time
 - 44dBA is exceeded 1% of the time
 - 50dBA is exceeded 1% of the time
 - 65dBA is exceeded 0% of the time



Results for WILDCT:



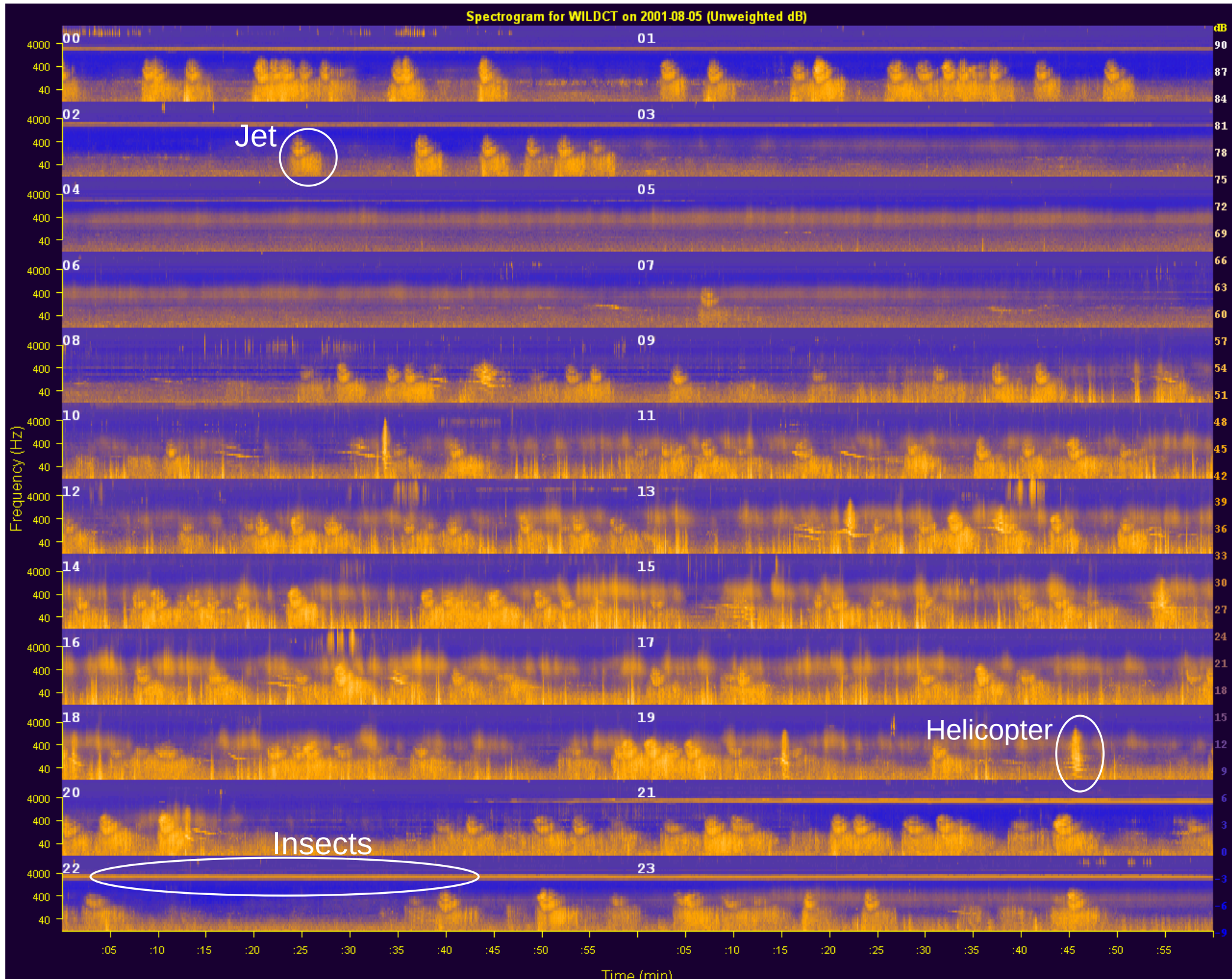
Metrics:

Noise Free Interval:

- Median = 2 minutes 44 seconds
- Mean = 7 minutes 9 seconds
- Max = 3 hours 57 minutes 36 seconds

Percent time above:

- Day (6 am to 6 pm)
 - 38dBA is exceeded 6% of the time
 - 44dBA is exceeded 2% of the time
 - 52dBA is exceeded 1% of the time
 - 65dBA is exceeded 0% of the time
 - 75dBA is exceeded 0% of the time
- Night (6 pm to 6 am)
 - 32dBA is exceeded 4% of the time
 - 38dBA is exceeded 1% of the time
 - 44dBA is exceeded 1% of the time
 - 50dBA is exceeded 1% of the time
 - 65dBA is exceeded 0% of the time



Appendix F. Hourly percent time audible tables for all 2000-2001 and 2008 sites.

Table 16. Average percent of time that extrinsic sounds were audible by hour of the day for front country sites from summer 2008 data.

Hour ¹	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
PNCK	25.8	22.5	15.0	6.3	8.8	17.5	41.3	72.1	89.2	93.8	92.1	95.8	95.4	94.2	95.0	96.7	95.8	94.6	92.9	90.8	85.4	66.3	53.8	39.6
GWT	21.0	25.3	13.9	2.0	1.1	0.0	13.7	31.2	52.9	65.4	75.7	66.4	70.8	65.1	65.1	63.3	66.8	70.8	66.3	62.3	52.5	44.5	31.6	24.8

¹Daytime hours highlighted in light gray, nighttime hours in dark gray

Table 17. Average percent of time that extrinsic sounds were audible by hour of the day for backcountry sites from 2000 – 2001 data.

Hour ¹	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
WILDCT	33.8	38.9	39.3	13.0	2.7	5.8	21.6	22.2	56.2	59.3	59.2	50.9	39.1	31.7	40.9	35.4	32.8	33.5	37.3	31.2	38.5	43.0	24.7	31.3
SCOUTS	33.0	42.9	39.3	17.4	2.2	2.0	51.9	64.6	68.9	77.6	81.6	74.5	66.5	68.7	69.0	64.2	65.2	71.7	68.1	61.3	70.7	61.0	52.9	34.3
NCREEK	21.0	15.1	7.5	5.9	0.0	0.8	2.1	11.6	33.0	36.6	38.9	42.2	35.7	34.0	42.5	30.8	29.9	30.9	33.3	33.3	33.5	32.9	16.5	20.0
LFRKTD	39.1	44.6	36.3	14.7	3.1	15.5	24.6	40.6	55.8	68.4	66.6	70.2	55.1	51.9	45.5	37.6	39.3	42.5	42.4	40.4	50.7	53.5	35.2	31.9
LCREEK	29.2	23.1	19.3	6.4	1.9	4.3	7.5	27.4	46.0	44.0	54.0	44.9	45.7	37.9	44.9	37.9	40.6	42.1	42.9	47.3	46.0	46.9	25.4	30.7
KOLOBC	22.9	13.2	14.2	12.0	9.5	9.2	10.2	22.3	32.2	34.3	35.3	36.9	29.6	30.8	33.4	32.9	38.3	28.0	34.3	28.3	31.3	19.2	23.1	19.4
HOPVAL	18.2	14.0	16.1	9.0	6.0	7.4	20.5	23.7	45.7	47.0	50.3	30.8	37.2	22.5	30.8	16.9	22.1	33.0	26.4	28.0	48.2	48.1	39.4	30.4
EASTRM	56.0	37.7	26.1	9.4	3.0	0.0	70.9	83.2	65.9	37.0	42.4	50.1	34.1	32.3	39.8	36.0	34.5	35.3	37.9	52.7	56.5	63.2	34.1	33.8
CRZQLT	41.6	38.3	19.0	9.8	2.7	0.8	1.7	20.8	47.8	49.9	36.4	50.3	32.0	37.2	44.6	29.8	20.7	31.4	40.2	42.1	41.8	39.6	28.8	33.8
CHINLE	40.7	37.8	22.5	17.6	2.6	3.2	5.9	13.8	40.0	41.2	45.5	54.0	34.9	36.9	33.5	38.8	31.4	36.8	47.1	45.1	45.3	41.5	31.6	33.0

¹Daytime hours highlighted in light gray, nighttime hours in dark gray

Appendix G. Glossary of Acoustical Terms.

Acoustical Environment

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

Alerting distance

The maximum distance at which a signal can be perceived. Alerting distance is pertinent in biological contexts where sounds are monitored to detect potential threats.

Amplitude

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

Atmospheric absorption

The part of transmission loss caused by conversion of acoustic energy into other forms of energy. Absorption coefficients increase with increasing frequency, and range from a few dB to hundreds of dB per kilometer within the spectrum of human audibility.

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.

A-weighted sound pressure level in decibels (dB(A) or dBA)

A frequency-based methodology used to account for changes in human hearing sensitivity as a function of frequency. The A-weighting network de-emphasizes the high (6.3 kHz and above) and low (below 1 kHz) frequencies, and emphasizes the frequencies between 1 and 6.3 kHz, in an effort to simulate the relative response of the human ear. A-weighted decibels are defined as ten times the logarithm to the base ten of the ratio of A-weighted squared sound pressure to the squared reference sound pressure of 20 μ Pa, the squared sound pressure being obtained with fast (F) (125-ms) exponentially weighted time averaging. Alternatively, slow (S) (1000-ms) exponentially weighted time averaging may be specified.

Decibel

Decibel is abbreviated dB, and is a logarithmic unit of sound-pressure-squared level; it is common practice, however, to shorten this to sound pressure level, when no ambiguity results from so doing. 0 dB represents the lowest sound level that can be perceived by a human with healthy hearing. The formula for computing decibels is:

$$L_{\text{dB}} = 10 \log_{10} \left(\frac{P_1}{P_0} \right)$$

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 (also see Intrinsic Sound).

Appendix G. Glossary of Acoustical Terms (continued)

Frequency

Frequency equals the speed of sound divided by wavelength, and can be expressed in cycles per second, or Hertz (Hz). For a function periodic in time, the frequency is the reciprocal of the period, where the period is the smallest increment of an independent variable for which a function repeats itself (also see Hertz).

Ground attenuation

The part of transmission loss caused by interaction of the propagating sound with the ground.

Hearing Range (frequency)

By convention, an average, healthy, young person is said to hear frequencies from approximately 20Hz to 20,000 Hz.

Hertz (Hz)

A measure of frequency, or the number of pressure variations per second. A person with normal hearing can hear between 20 Hz and 20,000 Hz. Kilohertz (kHz) equals 1000 Hz.

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 (also see Extrinsic Sound).

Listening area

The area of a circle whose radius is the alerting distance. Listening area is the same as the ‘active space’ of a vocalization, with a listener replacing the signaler as the focus, and is pertinent for organisms that are searching for sounds.

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 (Percentile –Exceeded Sound Level)

The A-weighted sound level equal to or exceeded by a fluctuating sound level x percent of a stated time period. For example, the symbol L₁₀ represents that sound level which is exceeded 10 percent of the stated time period.¹³

¹³ Hobbs & Downing 2003. Wyle Report WR 03-08.

Appendix G. Glossary of Acoustical Terms (continued)

Masking (of a sound)

Interference with the detection of a sound due to the presence of another sound. More specifically, the number of decibels (dB) by which the intensity level of sound A must be raised above its threshold of audibility to be heard in the presence of a second sound, B. Sound A and sound B may be identical or may differ in frequency, complexity, or time.

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.¹⁴

Noticeable

A signal that attracts the attention of an organism whose focus is elsewhere.

Off-site Listening

The systematic identification of sound sources using digital recordings previously collected in the field.

Percent Time Audible (PA)

The percent of time that a time-varying sound level may be detected in the presence of ambient sound as audible by the human ear.

Spectrum, power spectrum and spectral profile

The distribution of acoustic energy in relation to frequency. In graphical presentations, the spectrum is often plotted as sound intensity against sound frequency.

1/3 octave spectrum

Acoustic intensity measurements in a sequence of spectral bands that span 1/3 octave. The International Standards Organization defines 1/3rd octave bands used by most sound level meters (ISO 266, 1975). 1/3rd octave frequency bands approximate the auditory filter widths of the human peripheral auditory system.

Sound pressure level

Ten times the logarithm to the base ten of the ratio of the time-mean-square pressure of a sound, in a stated frequency band, to the square of the reference sound pressure in gases of 20 μPa , the threshold of human hearing. $\text{SPL} = 10\text{Log}_{10}(p^2/p_{\text{ref}}^2)$, where p^2 = time-mean-square sound pressure and p_{ref}^2 = squared reference sound pressure of 20 μPa .

Spreading loss

More rigorously termed divergence loss. The portion of transmission loss attributed to the divergence of sound energy, in accordance with the geometry of environmental sound propagation. Spherical spreading losses in dB equal $20 \cdot \log_{10}(R/R_0)$, and result when the surface of the acoustic wavefront increases with the square of distance from the source.

¹⁴ McGraw Hill Dictionary of Scientific and Technical Terms, online
<http://www.accessscience.com/index.aspx>

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

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Natural Resource Program Center
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov

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