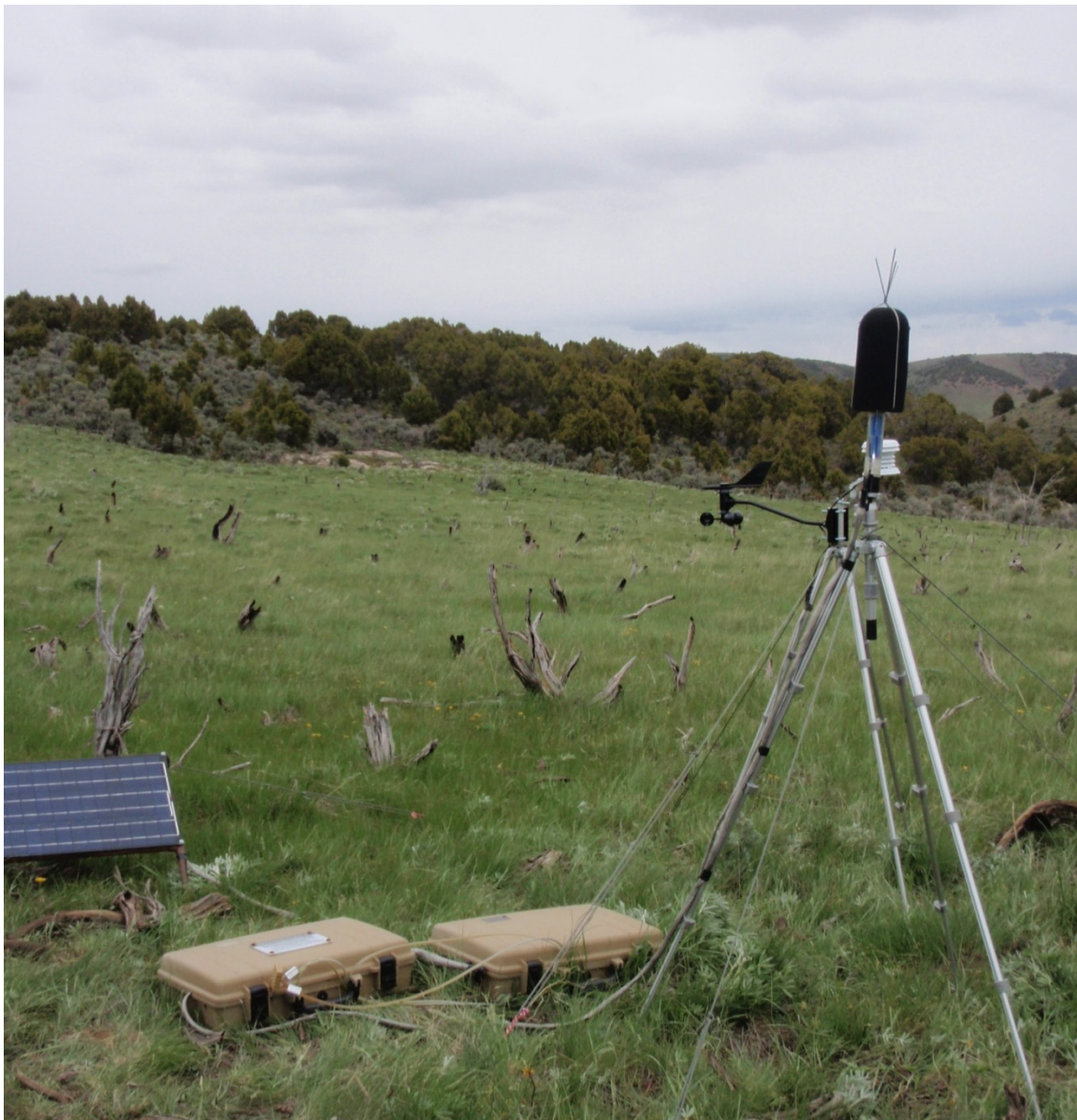




Dinosaur National Monument

Acoustical Monitoring Report

Natural Resource Technical Report NPS/NRSS/NRTR—2013/722



ON THE COVER

Acoustical monitoring equipment at Dinosaur National Monument

Photograph by: Katy Warner, NPS

Dinosaur National Monument

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

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

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The Natural Resource Technical Report Series is used to disseminate results of scientific studies in the physical, biological, and social sciences for both the advancement of science and the achievement of the National Park Service mission. The series provides contributors with a forum for displaying comprehensive data that are often deleted from journals because of page limitations.

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

Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

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

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Executive Summary

This report presents acoustical data that were collected by the National Park Service Natural Sounds and Night Skies Division at Dinosaur National Monument between May 27 and June 29, 2010. 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 acoustical monitoring effort was preceded by a September 1990 examination of sound levels in Colorado Plateau parks (CSTI, 1990). Although techniques, protocols, and monitoring equipment have changed dramatically in the intervening years, our fundamental goals are the same: to gather information about the acoustic environment so that we may better protect acoustic resources.

Natural Sounds and Night Skies Division (NSNSD) deployed sound level meters which collected 1 second L_{eq} data for thirty-three 1/3-octave bands. Each system contained meteorological sensors which collected temperature, relative humidity, wind speed, and wind direction. A continuous audio recorder was also simultaneously deployed to document sound sources. Overall, daytime natural ambient sound levels ranged from about 25 to 42dBA while nighttime natural ambient sound levels ranged from 18 to 38 dBA. The most common source of noise was commercial jet overflights. Natural sources such as wind in vegetation, birds, and insects were also commonly audible.

When 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). Table 1 lists results for these four relevant values and Table 2 lists site locations of acoustical monitoring equipment.

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)

Table 2. Acoustical monitoring site locations

Site	Site Name	Dates Deployed	Vegetation	Elevation	Latitude	Longitude
DINO001	Jossie's Cabin	5/27/2010 – 6/29/2010	Cottonwoods/trees by cabin/ near pasture.	1631m	40.42495	109.17538
DINO002	Rippling Brook Canyon	5/30/2010 – 6/28/2010	Side canyon/ pinion-juniper/ box cedar/ cottonwood	1651m	40.58521	108.98706
DINO003	Ruple Point Trail	6/1/2010 – 6/29/2010	Grassy opening surrounded by pinion-juniper	2276m	40.48393	109.10457
DINO004	West Cactus Flat	6/2/2010 – 6/29/2010	Grassland on Yampa bench	1968m	40.45311	108.64488

Table 3. Percent time above metrics for day and night at each site

Site	Frequency Range (Hz)	% Time above sound level: 0700 to 1900				% Time above sound level: 1900 to 0700			
		35dBA	45dBA	52dBA	60dBA	35 dBA	45dBA	52 dBA	60 dBA
DINO001	12.5-20,000	88.99	35.40	5.29	0.19	57.96	14.82	0.95	0.06
DINO002	12.5-20,000	100.0	8.12	1.84	0.12	100.0	0.23	0.00	0.00
DINO003	12.5-20,000	13.04	0.99	0.20	0.01	6.97	0.83	0.17	0.01
DINO004	12.5-20,000	28.07	6.82	2.24	0.91	13.54	2.73	1.14	0.48

Table 4. Day and night ambient sound levels for day and night at each site

Site	Daytime sound levels (0700 to 1900) in dBA				Nighttime sound levels (1900 to 0700) in dBA			
	L90	Lnat	L50	L10	L90	Lnat	L50	L10
DINO001	36.4	39.0	42.7	48.9	31.0	35.3	36.8	43.0
DINO002	37.2	37.9	38.1	39.5	37.5	38.0	38.0	38.7
DINO003	21.8	25.0	27.3	35.3	16.8	18.5	19.7	28.8

For reference, a list of commonly used acoustical terms is provided below. A more complete glossary can be found in Appendix A.

List of Terms

The table below lists a number of terms that may be used in this report.

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.
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. ¹
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

¹ McGraw Hill Dictionary of Scientific and Technical Terms, online
<http://www.accessscience.com/index.aspx>

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 .
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Introduction

The purpose of this report is to present acoustical data that were collected at Dinosaur National Monument (DINO) in the summer of 2010. 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 four sites by presenting figures, tables, and descriptions of the data; it does not attempt to make recommendations or draw management conclusions.

National Park Service Natural Sounds and Night Skies Division

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 (NSNSD).

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 soundscapes² is represented in 2006 Management Policy 4.9:

The Service will restore to the natural condition wherever possible those park soundscapes that have become degraded by unnatural sounds (noise), and will protect natural soundscapes from unacceptable impacts. Using appropriate management planning, superintendents will identify what levels and types of unnatural sound constitute acceptable impacts on park natural soundscapes. The frequencies, magnitudes, and durations of acceptable levels of unnatural sound will vary throughout a park, being generally greater in developed areas.

² 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.

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 A.

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 DINO in order to inform park decision making, management and planning.

Study Area

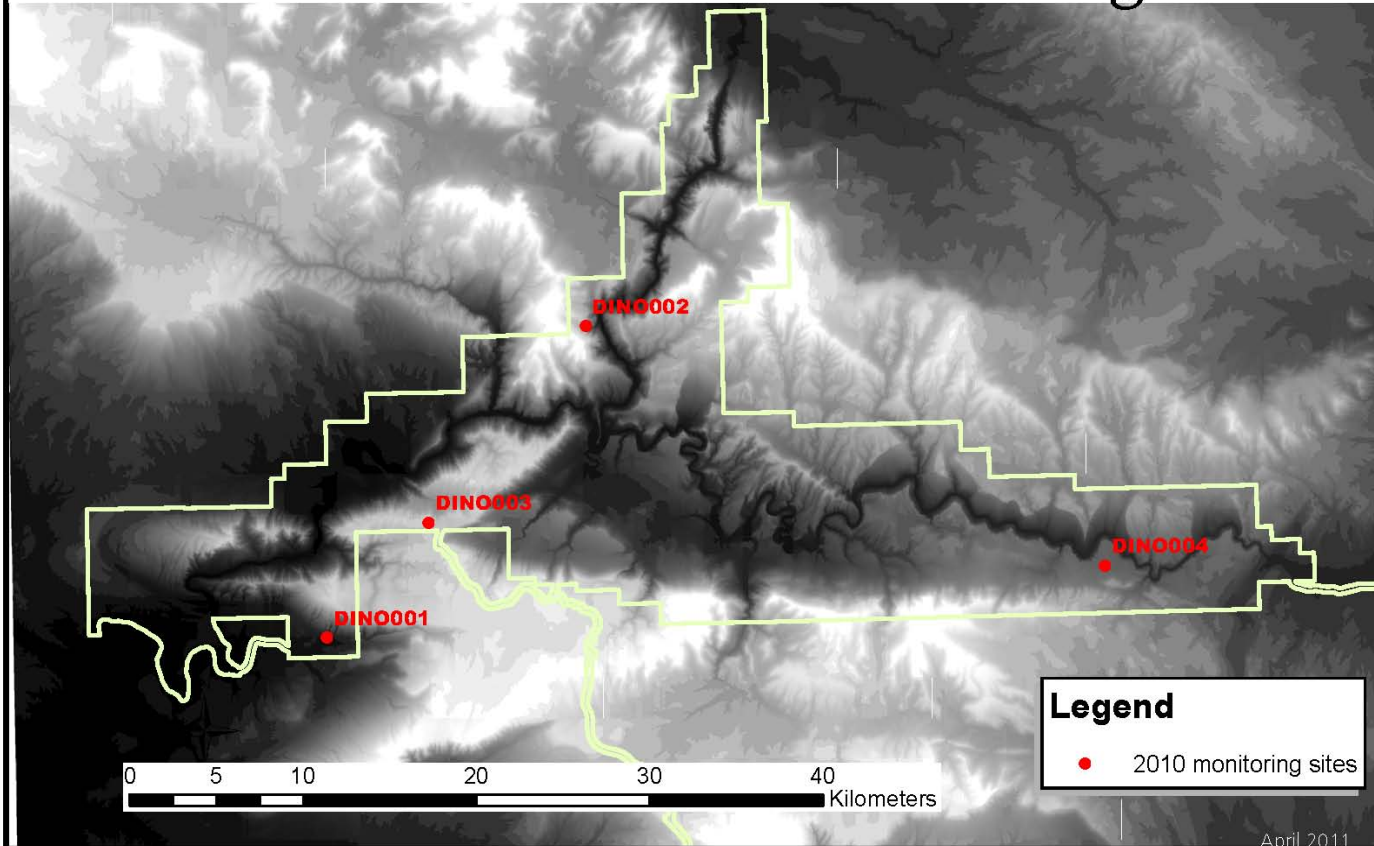
Four acoustical monitoring systems were deployed during the summer of 2010. The sites were selected because they were representative of the dominant vegetation zones in the park, and therefore, typical acoustical environments within the park. Coordinates for sites are listed in the table below, and locations are mapped in Figure 4. Site photos are included in Appendix B. The DINO004 site was destroyed by cows soon after deployment, so limited analysis was performed on this site. Any future re-sampling at this site should involve additional site protections such as enclosure fences.

Table 5. Metadata for summer 2010 acoustical monitoring at DINO

Site	Site Name	Dates Deployed	Vegetation	Elevation	Latitude	Longitude
DINO001	Jossie's Cabin	5/27/2010 – 6/29/2010	Cottonwoods/trees by cabin/ near pasture.	1631m	40.42495	109.17538
DINO002	Rippling Brook Canyon	5/30/2010 – 6/28/2010	Side canyon/ pinion-juniper/ box cedar/ cottonwood	1651m	40.58521	108.98706
DINO003	Ruple Point Trail	6/1/2010 – 6/29/2010	Grassy opening surrounded by pinion-juniper	2276m	40.48393	109.10457
DINO004	West Cactus Flat	6/2/2010 – 6/29/2010	Grassland on Yampa bench	1968m	40.45311	108.64488



Summer 2010 Acoustical Monitoring Sites



FILE: DINO.mxd

Produced by Natural Sounds & Night Skies Division

Figure 1. Map of 2010 acoustical monitoring sites at Dinosaur National Monument

Methods

Equipment

Acoustical monitoring equipment is employed by various trades to determine noise levels in neighborhoods, near airports or roads, and in the workplace. While the Natural Sounds and Night Skies Division utilizes similar instruments, the harsh weather conditions encountered in national parks, long measurement periods, and possibility of wildlife encounters demand that the NSP develop a unique configuration. The systems deployed at DINO included a Type 1 sound level meter (SLM) and a ½” prepolarized, random-incidence, condenser microphone. The Larson Davis 831 sound level meter collected 33 1/3 octave sound pressure level measurements (in dB) every second from 12.5 Hz to 20,000 Hz, which encompasses the nominal range of human hearing. The microphone was deployed in an environmental housing with a wind screen at approximately 1.5 meters above ground (a close approximation of the average height of the human ear). In addition to acoustical information, the SLM was configured to accept instantaneous wind speed, wind direction, temperature, and humidity, in real-time, from attached sensors.

Monitoring period

The variability of sound pressure levels over time and space in national parks is still not well understood. Each additional dataset gathered provides insight into natural variability. The monitoring period used for collection of these data is based on a preliminary statistical study that evaluated long-term datasets from Bryce Canyon National Park and Arches National Park. It was determined that a 25 day monitoring period in either winter or summer months would limit sound pressure level uncertainty to <3 dB (Iyer 2005). It is widely accepted that this is the threshold at which the average, healthy, human ear can detect noise level changes, when actively engaged in listening (Hendriks 1998). In addition to this study, logic dictates that a 25 day monitoring period would be sufficient to capture the inevitable variation in weather patterns in national parks.

Calculation of Metrics

There is no single metric that can be used to characterize the physical sound resources at a particular location (referred to as the *acoustical environment*), so a suite of metrics is employed. Acoustical studies in National Parks incorporate sound pressure level data (SPL), frequency data, audibility data, source identification data, and meteorological data. Perhaps the most fundamental descriptors used are existing ambient (L_{50}) and natural ambient (L_{nat}) sound levels. The L_{50} represents the median SPL, and encompasses spectra (in dB) drawn from the full dataset (although seconds with corresponding wind speeds > 5m/s are excluded to prevent errors from microphone distortion). The natural ambient (L_{nat}) is an estimate of what the ambient levels for a site would be in the absence of all extrinsic (or anthropogenic) sources. 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 the equation

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

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 for that hour. One concern with this approach is that some loud natural sounds, such as thunder, might be removed from the data during calculation of natural ambient, and the resulting L_{nat} levels could be an under-estimate of true natural ambient sound levels. Although this is a valid concern, such events are rare, relative to the 25 day measurement period (NPS 2005). Therefore, removing these data would not likely have a significant impact on calculations of natural ambient sound levels. Because the audibility of both natural and anthropogenic sounds varies so widely across the day, L_x values are reported on an hourly basis.

Calculation of diel L_x values

The Natural Sounds and Night Skies Division 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.

Off-Site Sound Source Analysis

In 2005, the NPS drafted protocols for acoustic studies in National Parks, in cooperation with staff from the Volpe National Transportation Systems Center³. 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 2010 monitoring efforts at DINO.

The 2005 protocol also dictated that during the recommended 25-day monitoring period, investigators would 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. Thus, NSNSD 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. When all events have been identified, NSNSD software calculates the total percent time anthropogenic sounds were audible. This information is then used to calculate the estimated natural ambient sound level for each hour, as discussed in the “Calculation of Metrics” section.

³ National Park Service. 2005. Acoustic and Soundscape Studies in National Parks DRAFT.



Figure 2. An acoustical technician uses software to visually analyze type and duration of sound sources.

On-Site Listening

On-site listening is the practice of placing an observer near an acoustical monitoring station with a handheld Personal Digital Assistant (PDA). The observer listens for a designated period of time (generally, one hour), 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 sessions are also an excellent screening tool for parks initiating acoustic environment studies. They produce an extensive inventory of sound sources, require little equipment or training, and can help educate park staff and volunteers.

Numerous one-hour periods of on-site listening were conducted at DINO in order to discern the type, timing, and duration of events during sound-level data collection. Staff recorded the beginning and ending times of all audible sound sources using custom-designed PDA software. These on-site listening sessions provided the basis for the calculation of metrics, including the period of time between noise events (average noise free interval [NFI]), percent time each sound source was audible, and maximum, minimum, and mean length (in seconds) of sound source events.



Figure 3. An acoustical technician tracks audible sound sources on a PDA during an on-site listening session.

Results

For comparison purposes, results from both summer and winter monitoring efforts will be covered in this section. Table 4 presents a quick summary of the type of data collected at each site.

Table 6. Summary of data collected at DINO from May - June 2010.

Site Name	DINO001	DINO002	DINO003	DINO004
Data collector	NPS	NPS	NPS	NPS
# Days of audio data	30	26.5	22.7	2.9
# Hours / days SPL data	796 / 33.2	697 / 29.0	545 / 22.7	71 / 2.9
SPL meter	LD-831	LD-831	LD-831	LD-831
Frequency range collected	12.5-20000 Hz	12.5-20000 Hz	12.5-20000 Hz	12.5-20000 Hz
Continuous audio	Yes	Yes	Yes	Yes
Electronic noise floor	5.4 dB(A)	6.3 dB(A)	6.4 dB(A)	5.8 dB(A)
Estimated system noise floor	17 dB (A)	17 dB (A)	17 dB (A)	17 dB (A)
Dates of collection	5/27 – 6/29/2011	5/30 – 6/28/2011	6/1 – 6/29/2011	6/2 – 6/29/2011
# Days off-site listening	8	8	8	N/A
# Hours on-site listening	2	1	2	2

On-site listening

The following four tables (Table 5, Table 6, Table 7, Table 8) display the results of on-site listening sessions during the summer and winter seasons. Each audible sound source is listed in the first column. Percent time audible, or PA, is the second column. The third column, Max, reports the maximum event length (in mm:ss) among the sessions for each sound source. Likewise, mean event and min event columns report the mean and minimum length of events. SD reports the standard deviation among event lengths, and count reports the number of times that each sound source was audible. The last row in the table, noise free interval (NFI), is a metric which describes the length of time between extrinsic or human-caused events.

Table 7. Summary of on-site audible sources for two hours at DINO001.

Sound Source	PA	Max Event (mm:ss)	Mean Event (mm:ss)	Min Event (mm:ss)	SD Event (mm:ss)	Count
Jet, commercial	7.0	1:57	0:53	0:10	0:34	10
Aircraft, Propeller	1.0	0:59	0:59	0:59	0:00	1
Vehicle	6.0	2:23	0:22	0:02	0:34	21
Grounds care	23.0	11:43	2:47	0:07	3:42	10
People	3.0	1:12	0:20	0:03	0:22	12
Wind	100.0	59:55	39:48	17:50	21:06	3
Bird	80.0	27:53	2:44	0:06	4:45	35
Insect	46.0	16:34	1:31	0:02	2:52	36
Cracking or popping tree	<1	0:10	0:07	0:04	0:04	2
All Aircraft	8.2					
All Non-natural Sources	35.1					
All Natural Sources	99.8					
Noise Free Interval	64.9	16:02	2:31	0:02	3:47	31

Table 8. Summary of on-site audible sources for one hour at DINO002.

Sound Source	PA	Max Event (mm:ss)	Mean Event (mm:ss)	Min Event (mm:ss)	SD Event (mm:ss)	Count
Jet	28.0	4:33	2:50	1:34	1:18	6
People	1.0	0:48	0:48	0:48	0:00	1
People, Voices	16.0	1:17	0:24	0:05	0:19	25
People, Walking	11.0	3:10	0:59	0:05	1:07	7
Wind	9.0	2:52	1:50	1:07	0:55	3
Flowing Water	94.0	21:39	9:36	1:23	9:00	6
Bird	53.0	5:42	0:47	0:02	1:09	41
Insect	3.0	0:22	0:12	0:02	0:08	10
Natural Other	6.0	1:40	0:52	0:06	0:48	4
All Aircraft	28.0					
All Non-natural Sources	48.0					
All Natural Sources	96.8					
Noise Free Interval	52.0	5:20	1:14	0:03	1:22	26

Table 9. Summary of on-site audible sources for two hours at DINO003.

Sound Source	PA	Max Event (mm:ss)	Mean Event (mm:ss)	Min Event (mm:ss)	SD Event (mm:ss)	Count
Jet	27.0	3:31	0:48	0:03	0:54	40
Wind	99.0	59:57	29:46	0:29	31:45	4
Mammal	9.0	6:18	3:31	0:27	2:56	3
Bird	90.0	50:40	2:43	0:02	7:58	40
Insect	11.0	2:42	0:22	0:02	0:33	35
All Aircraft	27.0					
All Non-natural Sources	26.8					
All Natural Sources	99.8					
Noise Free Interval	73.2	21:22	2:06	0:02	3:45	42

Table 10. Summary of on-site audible sources for two hours at DINO004.

Sound Source	PA	Max Event (mm:ss)	Mean Event (mm:ss)	Min Event (mm:ss)	SD Event (mm:ss)	Count
Jet	13.0	3:04	1:18	0:07	1:03	12
Aircraft, Propeller	2.0	1:54	1:54	1:54	0:00	1
Wind	97.0	43:20	8:20	0:15	11:56	14
Bird	99.0	53:48	8:28	0:03	16:01	14
Insect	10.0	1:29	0:20	0:04	0:20	36
All Aircraft	14.5					
All Non-natural Sources	14.5					
All Natural Sources	99.9					
Noise Free Interval	85.5	42:34	6:51	0:03	11:04	15

Off site analysis

While on-site listening results serve as a snapshot of what a visitor might experience in one hour at the site, off site analysis provides a much wider picture of the acoustical environment over the long-term because it examines noise audibility for all hours over eight separate days. Due to temporal variations in source audibility, results are reported by hour. The lists of audible sound sources differ slightly across monitoring sites. For instance, some sites were occupied by cows, and other sites were more frequently visited by people in motorized vehicles. Despite site specific differences, there are a few universal sound sources that can be compared between the two monitoring periods. Commercial jet traffic was the most common sound source across all sites. This similarity of results suggests a consistently high level of air traffic over DINO, which is a common trend seen in national parks.

Though only extrinsic noises were logged during audibility analysis, a number of remarkable biologic sounds were noted. Along with significant meteorological sounds such as thunderstorms, NSNSD technicians also noted at least one unidentified bat species, great basin spadefoot toads (*Spea intermontana*), and a dusky grouse at DINO003 (*Dendragapus obscurus*). Recordings of these sounds and any part of the rest of the continuous, 30-day recording dataset can be made available to the park. A complete list of audible noise sources is included in the tables below for all sites. As discussed in the methods section, these results are average audibility results for 8 days of careful audio analysis.

Table 11. Summary of off-site analysis for audible sound sources, DINO001 n=8

	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Jet	5.0	7.9	8.7	3.3	0.8	0.0	2.9	5.4	21.2	25.0	29.2	11.3	14.2	9.6	11.7	10.8	4.2	11.7	13.3	23.7	28.7	23.7	15.0	12.9
Propeller	0.0	0.0	0.0	0.8	0.0	7.1	21.7	5.0	4.2	3.8	3.8	2.1	2.5	1.2	1.2	3.8	2.9	1.2	1.7	1.2	2.1	0.0	1.7	0.0
Vehicle	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Automobile	2.5	0.4	3.3	1.7	3.8	7.5	2.1	10.4	9.2	11.7	15.8	23.3	24.2	22.1	28.7	27.5	25.8	17.5	10.8	10.4	5.4	2.5	5.0	5.0
Vehicle horn or alarm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Vehicle door	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.7	0.8	2.1	5.4	8.3	11.7	11.3	12.1	7.9	7.5	7.5	5.0	1.7	1.2	0.0	0.0	0.0
Bus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Truck	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Watercraft	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grounds care	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.4	0.0	0.0	0.0	0.0	0.0	0.0	7.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Voices	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.2	2.9	13.3	21.2	27.5	29.2	32.1	21.2	21.7	23.7	20.4	7.1	2.1	0.0	0.0	0.0
Footsteps	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Portable audio devices	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.8	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0
Dog	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0
Non-natural unknown	4.6	3.8	0.4	2.1	2.5	5.0	1.2	1.7	6.2	5.8	1.2	0.4	0.8	1.2	0.0	1.7	0.4	1.2	1.2	0.4	2.5	2.9	1.2	1.7
Total, non-natural sounds	12.5	12.1	12.5	7.9	7.1	19.6	28.3	24.6	47.1	51.3	60.0	53.8	61.3	57.1	63.3	56.7	57.1	49.6	45.4	40.8	39.2	29.2	22.9	19.6

Table 12. Summary of off-site analysis for audible sound sources, DINO002 n=8

	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Jet	1.2	3.8	2.1	0.8	0.8	0.0	2.1	5.0	10.8	10.4	15.4	10.8	7.1	3.8	9.2	4.6	6.7	10.4	11.7	9.6	9.2	8.3	4.2	2.1
Propeller	0.0	0.0	0.0	0.0	0.0	0.8	0.4	1.2	1.2	0.8	0.4	0.4	0.8	4.2	2.1	0.0	0.8	1.2	0.0	0.4	0.0	0.4	0.4	0.0
Motorcycle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
People	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Voices	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	2.1	3.8	3.8	2.5	0.8	3.8	2.5	0.4	0.0	0.8	2.5	0.0	0.0	0.0
Footsteps	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	1.7	1.7	0.8	0.0	3.3	2.1	0.4	0.0	1.2	0.4	0.0	0.0	0.0
Non-natural unknown	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	1.7	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.4	3.8	0.0	0.0
Total, non-natural sounds	1.2	3.8	2.1	0.8	0.8	0.8	2.5	6.2	12.1	11.7	20.0	17.5	12.5	10.8	12.1	9.2	10.8	12.9	11.7	11.3	12.1	12.5	4.6	2.1

Table 13. Summary of off-site analysis for audible sound sources, DINO003 n=8

	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Jet	5.8	11.3	8.3	3.3	0.0	0.8	1.7	5.8	26.2	23.7	29.2	25.4	19.6	21.2	16.7	10.8	17.1	17.1	16.7	21.7	23.7	27.9	22.5	13.3
Propeller	0.0	0.0	0.0	0.0	0.0	0.8	7.5	0.4	0.8	5.4	0.0	0.8	2.1	0.0	3.8	3.8	2.9	2.5	0.8	0.0	4.2	0.0	1.7	0.0
Helicopter	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.8	2.1	1.2	3.3	0.4	0.0	0.0	5.4	1.2	0.8	1.7	0.0	0.0	0.8	1.7	0.0
Vehicle	2.9	0.4	0.8	0.0	4.6	9.2	21.7	23.7	17.9	9.2	11.3	5.0	2.9	8.3	3.8	3.8	4.6	5.4	5.4	7.1	5.8	2.1	5.0	1.2
Vehicle horn or alarm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0
Motor	0.8	0.0	0.4	0.0	0.0	1.7	1.7	0.0	1.2	5.8	9.6	4.2	4.2	1.7	0.0	1.2	0.0	0.0	0.8	2.5	2.5	0.4	0.4	0.0
Voices	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Footsteps	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0
Domestic animal	0.0	0.0	0.0	0.0	0.0	1.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0
Dog	0.0	3.8	2.1	2.5	2.5	2.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.4
Cow	2.5	1.2	0.8	0.4	1.7	20.8	43.8	32.1	7.1	1.2	1.7	3.3	0.8	0.0	0.8	0.0	2.5	0.0	0.4	9.2	4.6	1.2	1.7	0.0
Horse	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total, non-natural sounds	2.1	16.7	12.5	6.2	8.3	35.8	64.2	53.8	52.1	45.8	51.7	40.0	29.6	31.7	25.0	25.0	28.3	26.2	26.2	38.8	41.3	32.1	34.2	15.0

The following figures compare the total percent time audible of human-caused sounds with the total percent time audible of the most dominant noise source: high altitude aircraft overflights. In the case of DINO001, a number of other sources (such as the common sounds of visitors: voices and vehicles) contributed noise to the acoustical environment during the daytime hours. Notice the marked aircraft “rush hours” near 9am and 9pm in the DINO003 plot. Overall, DINO002 displayed the least amount of anthropogenic activity because of its proximity to the river. It is likely that the sound of moving water masked many anthropogenic sounds.

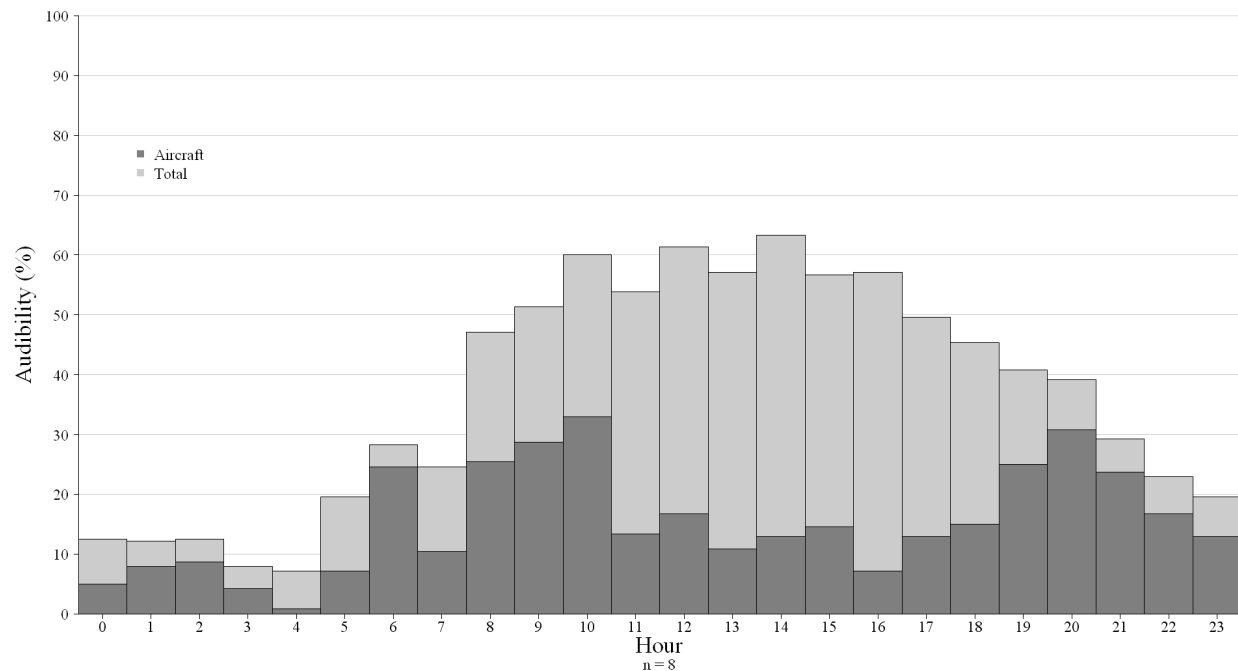


Figure 4. Mean hourly percent time audible statistics for aircraft and all human-caused sources, DINO001

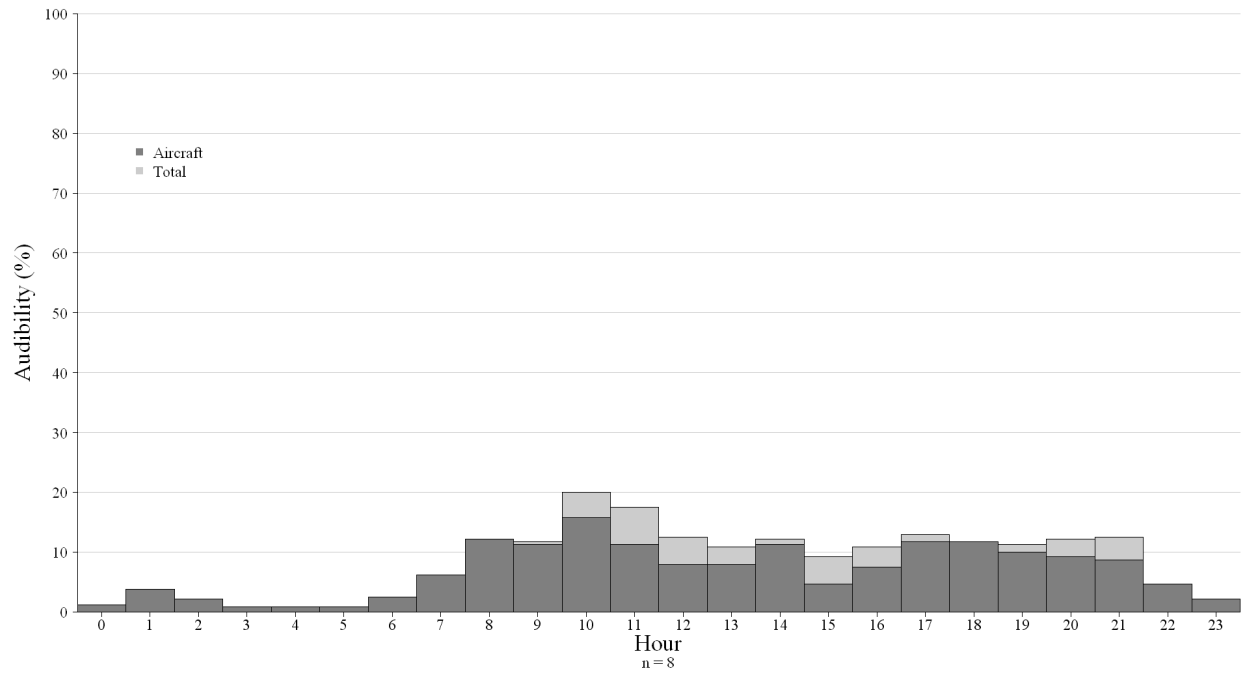


Figure 5. Mean hourly percent time audible statistics for aircraft and all human-caused sources, DINO002

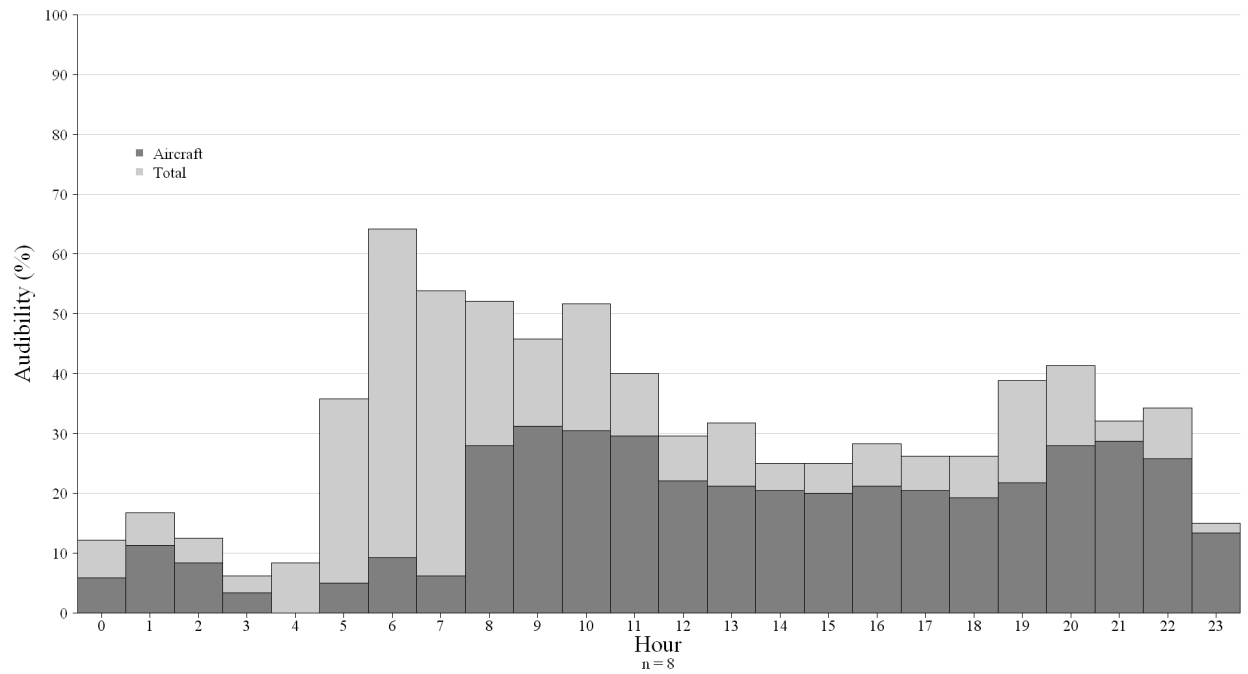


Figure 6. Hourly percent time audible statistics for aircraft and all human-caused sources, DINO003

Metrics

In order to determine the effect that noise audibility has on the acoustic environment, it is useful to examine the median hourly exceedence metrics. On site and off site listening reveal types and characteristics of sound sources, but exceedence metrics allow us to put those ambient conditions in the context of the Decibel (dB) scale. The logarithmic dB scale can be difficult to interpret, and the effects of a seemingly small change in sound pressure level (SPL) can be greater than anticipated. For example, if the ambient SPL is 30 dB, and a noise event raises the ambient to 33 dB (a 3 dB increase), the listening area for humans (as well as many birds and mammals) would be reduced by 50%. Increasing the ambient SPL an additional 3 dB (to 36 dB) would reduce the listening area by half again, to 25% of the initial area. Note however, that changes in SPL do not proportionately translate to changes in perceived loudness. The rate of change of loudness is complex and dependent on the stimulus itself (SPL, frequency, bandwidth, duration, background, etc.). At a minimum, each 10 dB increase in SPL causes a doubling of perceived loudness (Crocker, 1997, p.1481).

Figures 7, 8, and 9 show existing ambient sound levels and natural ambient sound levels at the study site. The existing ambient (or median) level for each hour is marked by the upper limit of the gray boxes while natural ambient levels (L_{nat}) are marked by the lower limit of the gray boxes (see legend). These figures also show exceedence metrics L_{10} and L_{90} , which mark the average maximum and minimum levels over the month-long monitoring period. These results indicate that some locations in Dinosaur National Monument are considerably quieter than others. In fact, some mean hourly sound levels at DINO003 (Ruple Point) were at or near the noise floor (lowest recording limit) of the equipment during the nighttime and early morning hours. Higher summer nighttime sound levels are likely attributable to insects and other vocal nocturnal animals. In all cases, the daytime hours are the most affected by anthropogenic sounds. However, some human-caused sounds were still present during the evening hours. The primary nighttime noise sources were jets.

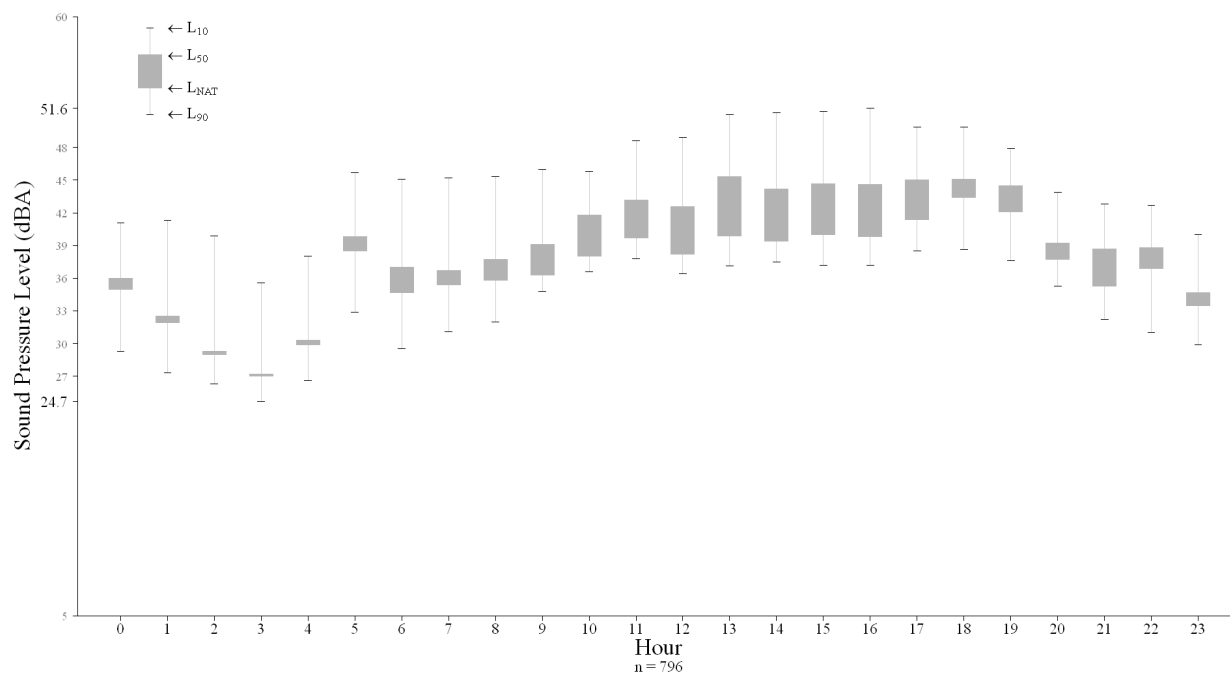


Figure 7. Median hourly exceedence metrics in dBA at DINO001

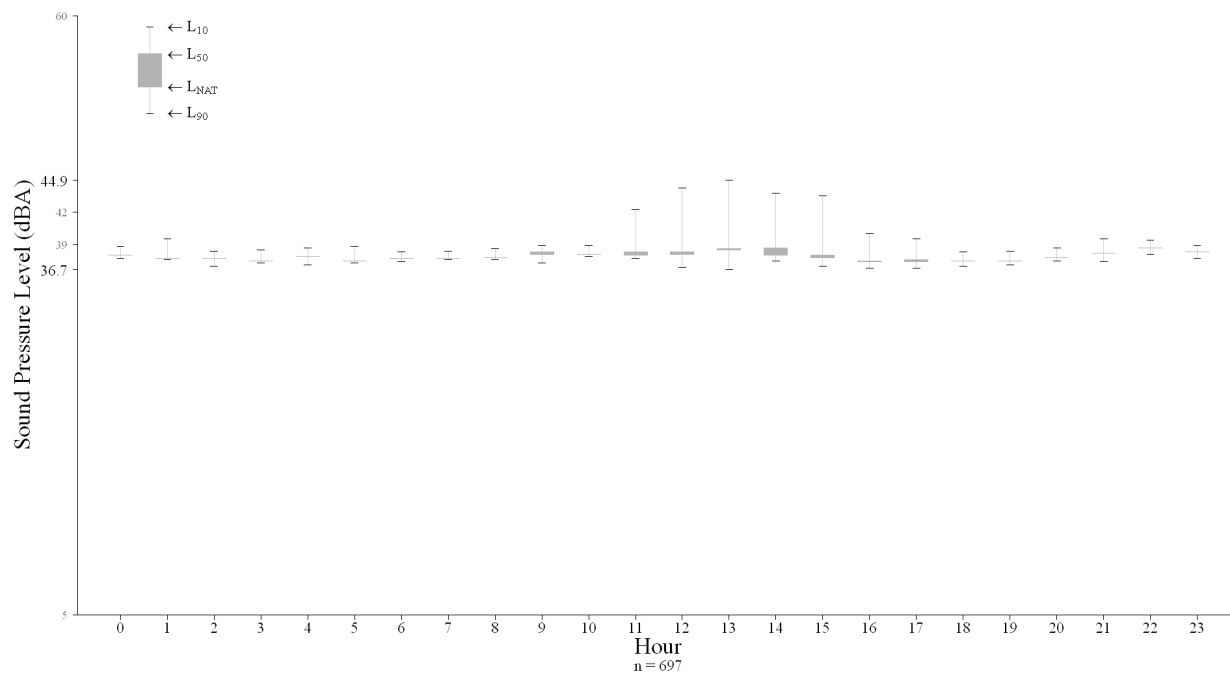


Figure 8. Median hourly exceedence metrics in dBA at DINO002

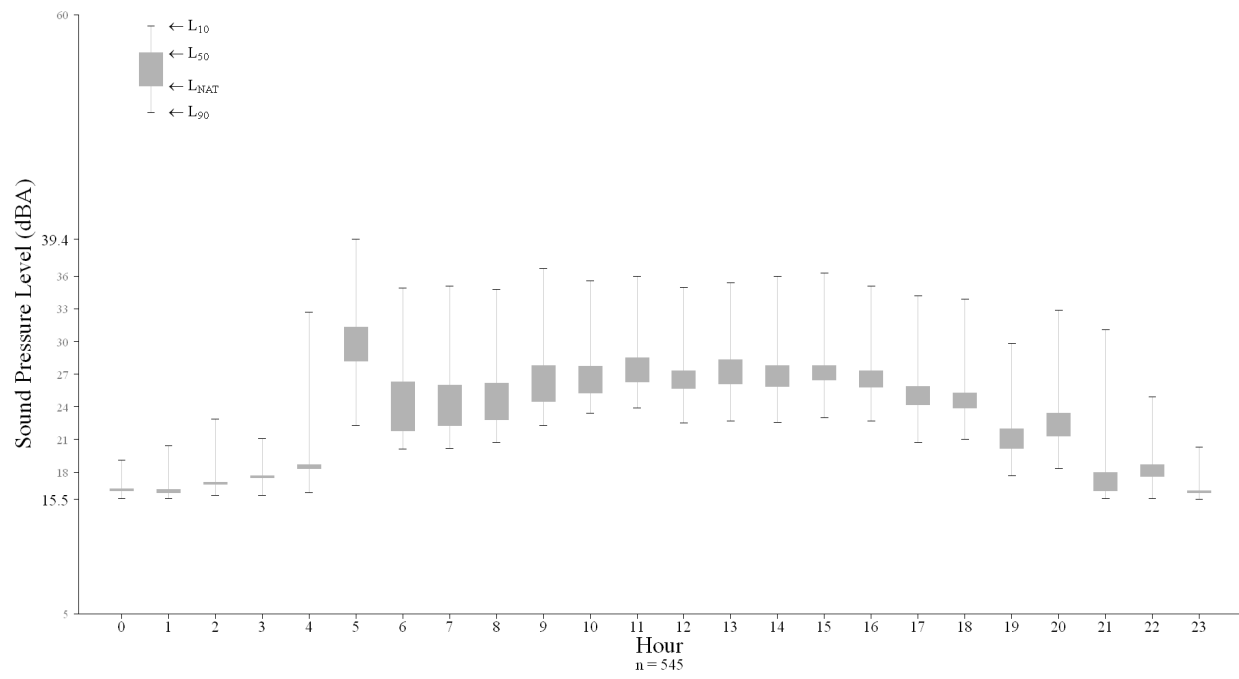


Figure 9. Median hourly exceedance metrics in dBA at DINO003

High frequency sounds (e.g. a cricket chirping) and low frequency sounds (e.g. transportation noise) often occur simultaneously, and do not always occur constantly throughout the day. Figures 10, 11 and 12 illustrate these concepts 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 SPL range for each band. The grayed area in the background of the graph represents sound pressure levels outside of the typical range of human hearing. The typical frequency ranges 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, but do suggest possible sound sources. For instance, the obvious daytime peak in the high frequency bands on the summer plot is likely due to insects (audible 100 percent of the time during the on-site listening session), and birdsong (audible 31% of the time during the on-site listening session).

Plots such as these also provide some insight into the phenomenon of masking. Notice how bird sounds and transportation noise appear at different locations on the frequency spectrum (x axis) in Figures 10, 11 and 12. If two sounds are within similar or overlapping frequency ranges and one sound is louder than the other, some masking may occur. However, if the two sounds have the same dB level, they would not mask each other because they occupy different frequencies. It should be noted that there is evidence to suggest that the combined effect of vehicle noise, wind, and running water can mask distant aircraft, in some cases.

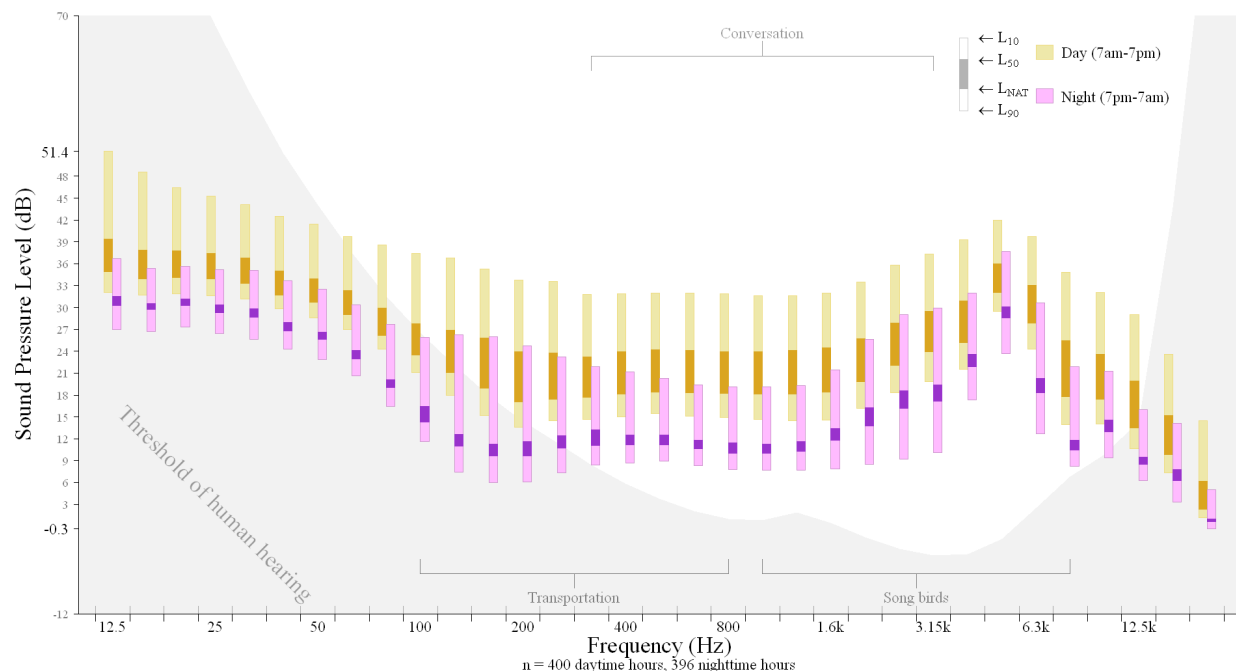


Figure 10. Day and night dB levels for 33 one-third octave bands at DINO001

Notice in Figure 8 that the L_{90} (or the quietest 10% of the measured datapoints) for both daytime and nighttime dip into the gray shaded area. This means that at its quietest, DINO001 had sound levels (in certain frequencies) lower than can be perceived by the average human ear.

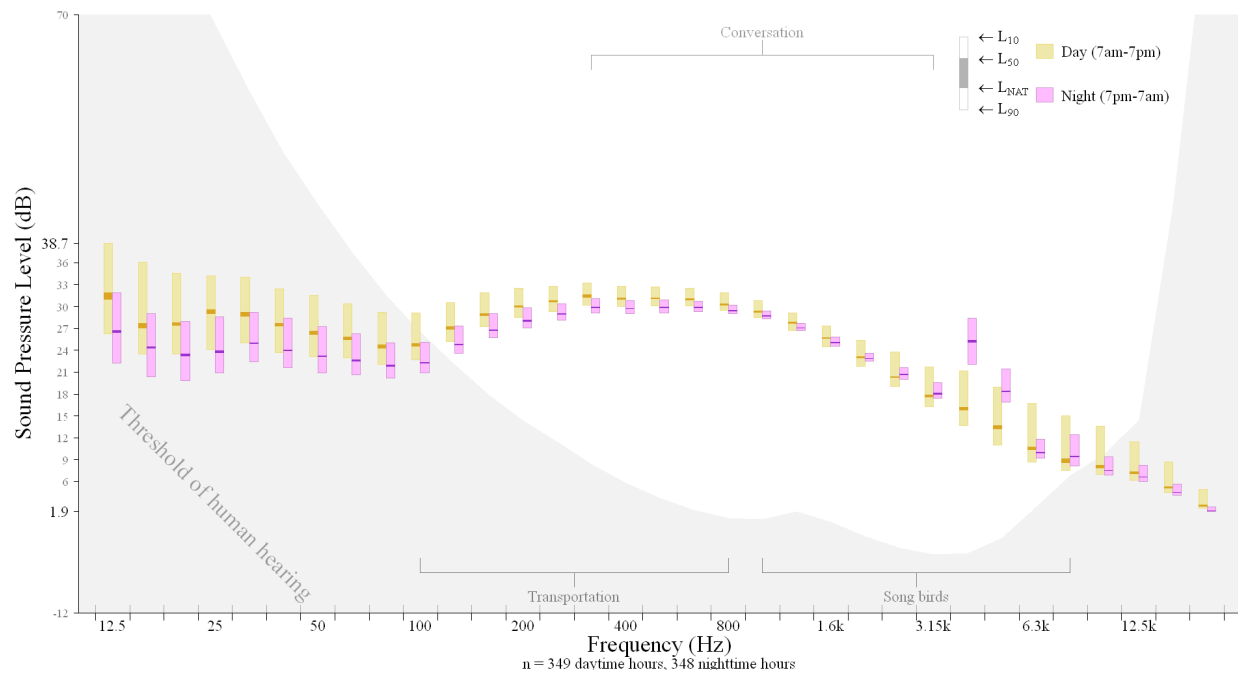


Figure 11. Day and night dB levels for 33 one-third octave bands at DINO002

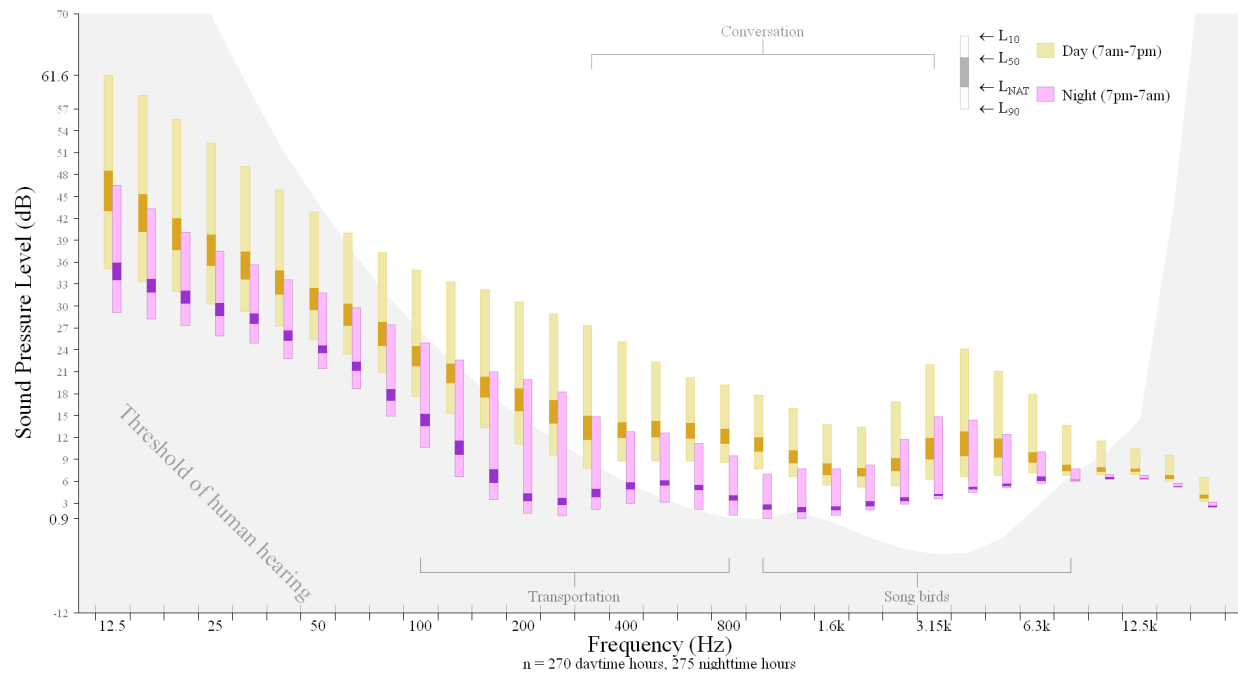


Figure 12. Day and night dB levels for 33 one-third octave bands at DINO003

Conclusion

Acoustical monitoring in national parks not only allows us to gain insight into biologic activity, but also helps us determine the prevalence of extrinsic noise, and perhaps estimate its effects on visitors and wildlife. This study was successful in determining current acoustical conditions at Dinosaur National Monument at three sites (due to cow attack, the 4th site did not collect long-term data and was not fully analyzed). Results included measures of existing ambient levels, calculations of sound source durations, and estimates of natural ambient levels. Median natural ambient sound levels ranged between 25 and 39 dBA during the daytime hours and ranged between 19.7 and 38 dBA during nighttime hours.

Although monitoring techniques have changed dramatically since 1990, we can still extract informative metrics to compare conditions between the 1990 study period and this 2010 study period. Although we do not have data collected at the same site for both study periods, we are fortunate enough to have two long-term datasets from relatively remote sites in DINO, both of which can be described as having relatively few nearby sound sources (CSTI, 1990). At the 1990 monitoring site (West Cactus Flat), the daytime average L90 sound level during the month of May was 30 dBA. In quieter (winter) months, daytime sound levels reached as low as 16 dBA (CSTI, 1990). The 30-day average daytime L90 for a comparable site in June 2010 (DINO003, Ruple Point) was measured to be about 21.8 dBA. Additional investigation (into meteorological conditions during the 1990 study) would have to be conducted in order to tease out the precise differences between the two monitoring efforts, because NSNSD's acoustical monitoring protocol eliminates periods of high wind from sound level calculations, while the 1990 study did not have the capacity to do so. Noise sources were not tracked in the 1990 study, so we are unable to quantify changes in noise source audibility with any certainty. However, we can quantify existing conditions with great certainty. Onsite listening session results indicated that the mean noise free interval for all 2010 sites was approximately 2 minutes, but there are still periods of time of over 40 minutes or more during the daytime hours where visitors can experience tranquility and solitude at some sites in DINO. Audibility of sound sources varied by source and site, but overall, jets were the most commonly heard human-caused sound.

The information gathered within this report will inform park managers as to how to best protect park resources, but it will also serve as a permanent record of what the park sounded like in 2010. Sound pressure level data as well as continuous digital audio recordings will be stored at the Natural Sounds and Night Skies Division office for archiving purposes.

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Appendix A: 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:

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

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).

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 L_{10} represents that sound level which is exceeded 10 percent of the stated time period.⁴

⁴ Hobbs & Downing 2003. Wyle Report WR 03-08.

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.⁵

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

⁵ McGraw Hill Dictionary of Scientific and Technical Terms, online
<http://www.accessscience.com/index.aspx>

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.

Appendix B: Site Photos



Figure 13. DINO001 – Josie’s Cabin



Figure 14. DINO002 – Rippling Brook Trail



Figure 15. DINO003 – Ruple Point Trail

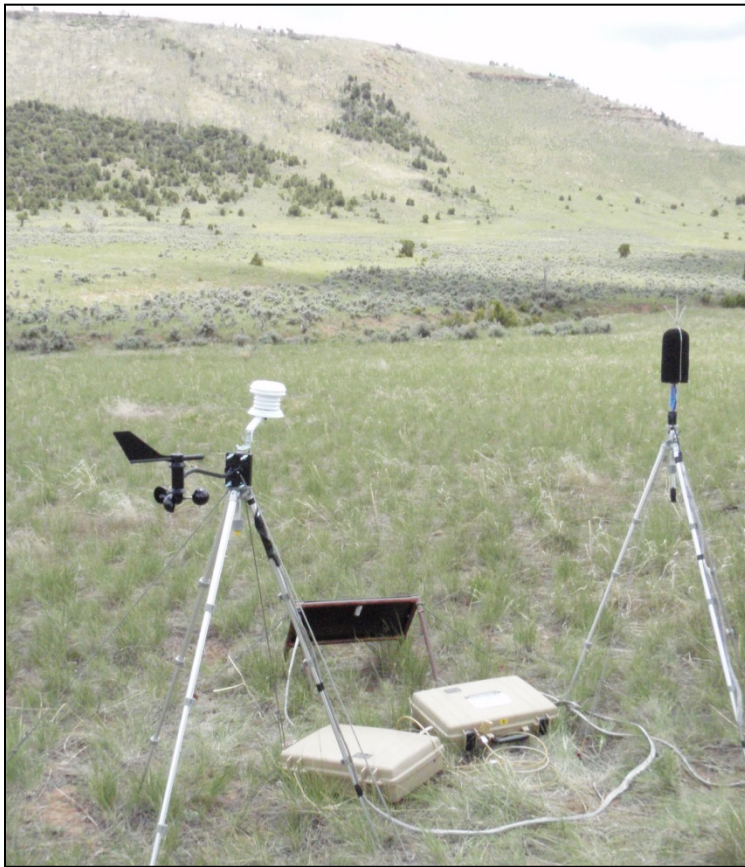


Figure 16. DINO004 – West Cactus Flat

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