National Park Service
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Natural Resource Program Center

Great Sand Dunes National Park and Preserve
Acoustic Monitoring Report

Natural Resource Report NPS/NRPC/NRTR—2008/001

ON THE COVER
Acoustic monitoring system near Crestone, CO
NPS Photo

Great Sand Dunes National Park and Preserve

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Natural Resource Report NPS/NRPC/NRTR—2008/001

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Executive Summary

An acoustic monitoring system was deployed in Great Sand Dunes National Park and Preserve (GRSA) near the Baca National Wildlife Refuge from September 24-October 10, 2008. The purpose of this monitoring effort was to gather data in order to characterize current existing ambient sound levels and estimate natural ambient sound levels, as well as identify audible sound sources. This monitoring effort found GRSA to be exceptionally quiet.

XTable 1. shows existing and natural ambient statistics in dBA for two time periods: day and night. Existing ambient (L_{50}) describes the acoustic environment as is, including both natural and extrinsic sounds. It can also be interpreted as the median sound level. Natural ambient (L_{nat}) estimates what the acoustic environment might sound like without the contribution of extrinsic sounds. When interpreting sound pressure level data, it should be noted that the decibel scale is logarithmic. As such, a 3 dB increase in sound pressure level is actually a doubling of sound energy. Furthermore, raising the ambient by 6 dB in a certain frequency would essentially reduce the detection distance for sounds in that frequency by half for both wildlife and park visitors.

Table 1. Existing and natural ambient statistics in dBA.

Existing Ambient (L_{50})		Natural Ambient (L_{nat})	
08:00-19:00	20:00-07:00	08:00-19:00	20:00-07:00
20.5	15.0	17.3	14.7

In determining the current conditions of an acoustic environment, is also important to examine how often sound pressure levels exceed certain thresholds. XTable 2 reports the percent of time that measured levels were above four key thresholds. The first threshold, 35 dBA is designed to address the health effects of sleep interruption. Recent studies suggest that sound events as low as 35 dB can have adverse effects on blood pressure while sleeping (Haralabidis, 2008). The second threshold addresses the World Health Organization's recommendations that noise levels inside bedrooms remain below 45 dBA (Berglund et al., 1999). The third threshold, 52 dBA, is based on the EPA's speech interference threshold for speaking in a raised voice to an audience at 10 meters. This threshold addresses the effects of sound on interpretive presentations in parks. The final threshold, 60 dBA, provides a basis for estimating impacts on normal voice communications at 1 meter. Hikers and visitors viewing scenic vistas in the park would likely be conducting such conversations.

Table 2. Percent time above metrics for four dBA levels.

% Time above (dBA)	Relevance	Day	Night
35	Adverse health	10.38	2.54
45	Sleep	2.16	0.21
52	Interpretive programs	0.16	0.05
60	Normal conversation	0.01	0.00

Introduction

A 1998 survey of the American public revealed that 72 percent of respondents thought that providing the opportunity 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 and Wakefield 1998). In another survey specific to park visitors, 91 percent of respondents considered enjoyment of natural quiet and the sounds of nature compelling reasons for visiting national parks (McDonald et. al. 1995). Acoustic monitoring provides a scientific basis for assessing the current status of acoustic resources, identifying trends in resource conditions, quantifying impacts from other actions, assessing consistency with park management objectives and standards, and informing management decisions regarding desired future conditions.

National Park Service Natural Sounds Program

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

Great Sand Dunes National Park and Preserve

The section of the park and preserve which will be discussed in this report is known as “The Baca.” This area was deemed vital to the protection of park resources and acquired in 2000 when Congress passed the Great Sand Dunes National Park and Preserve Act. The Baca encompasses a vast array of habitats, ranging from dunefields to wetlands. It harbors numerous archaeological sites and nesting as well as migratory birds. The purpose of this monitoring effort is to characterize the natural and existing ambient sound level near the northwest corner of Great Sand Dunes National Park and Preserve (GRSA). 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 will be measured and evaluated” (NPS 2006b).

Soundscape Planning Authorities

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

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

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

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

Study Area

The acoustic monitoring station was deployed in the northwestern section of Great Sand Dunes National Park and Preserve. The dominant vegetation in this salty shrubland habitat was rabbitbrush. See XTable 3 for detailed site location.

Table 3. Site location

Site	Latitude	Longitude	Elevation
GRSA001	37.89406	-105.72549	2330

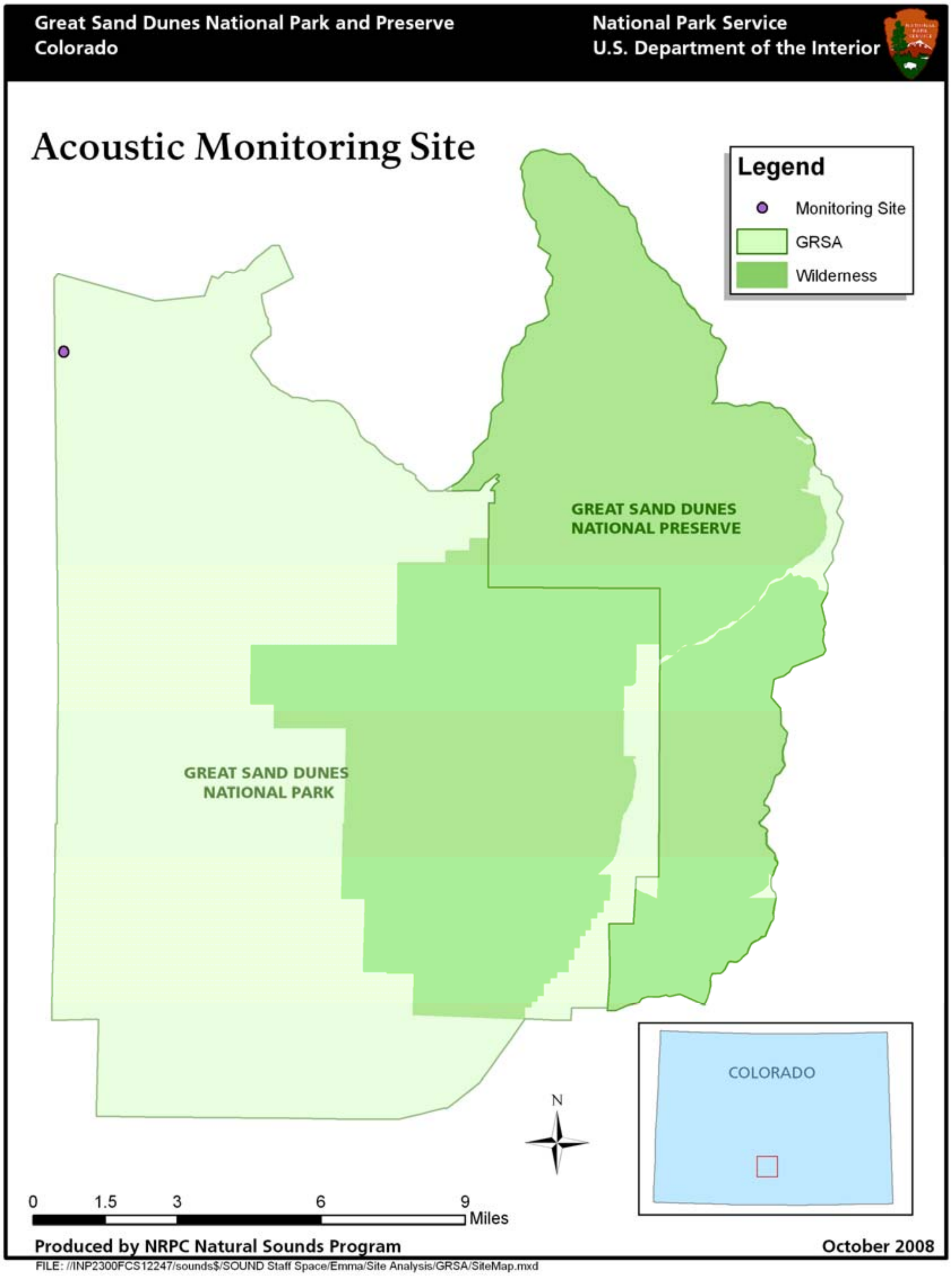

Figure 1. Location of GRSA001 acoustic monitoring site

Methods

Automatic Monitoring

A Larson Davis 831 sound level meter (SLM) was employed over the sixteen day monitoring period at GRSA. The Larson Davis SLM is a hardware-based, real-time analyzer which constantly records one second SPL and 1/3 octave band data, and exports these data to a portable storage device (thumb drive). This Larson Davis-based site met American National Standards Institute (ANSI) Type 1 standards.

Each Larson Davis sampling station consisted of:

- Microphone with environmental shroud
- Preamplifier
- Four 12V gel cell sealed lead acid batteries
- Anemometer
- Meteorological data logger
- MP3 recorder

Each acoustic sampling station collected:

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

Off-Site Listening

For each day of monitoring, Natural Sounds Program (NSP) staff visually analyzed a subset of audio samples (eight days) in order to identify audible sound sources. Audio samples were employed to confirm identification. The total percent time extrinsic sounds were audible was then used to calculate the natural ambient sound level. Bose Quiet Comfort Noise Canceling headphones were used for off-site audio playback to minimize limitations imposed by the office acoustic environment.

Calculation of Metrics

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

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

- Calculate the percentage of all samples containing extrinsic sounds for each hour of the day (P_H).
- Use P_H to complete this formula for every hour: $x = \frac{1 - P_H}{2} + P_H$
- Example: if extrinsic sounds are audible 50% of the time (P_H =0.5), then x_H is 0.75.
- Enter hourly x_H values into a database of all octave band information.
- Exclude SPL samples with local measured wind speed over 5 m/s.
- Compute L_{nat} (the sound level that is exceeded 100*x_H percent of the time).

Results

Off-Site Listening

XTable 4 shows the percent time that certain sound sources were audible based on eight days of visual analysis. The dominant extrinsic sound source at GRSA001 was aircraft. Aircraft were audible nearly 60 percent of the time during daylight hours. Other human-caused sounds such as vehicles were audible but infrequent.

Table 4. Extrinsic sound source results based on eight days of visual analysis.

Sound Source	24 Hour	n Events	Day (07:00-18:00)	Night (19:00-06:00)
Jet	36.5	100.4	47.5	25.6
Propeller	6.5	19.1	9.6	3.4
Helicopter	0.5	1.0	0.9	0.0
Vehicle	0.9	1.5	1.8	0.0
All Aircraft	42.5	119.6	56.3	28.7
All Vehicle	0.9	1.5	1.8	0.0
All Extrinsic Sounds	42.7	120.0	56.7	28.7

XFigure 2. provides more detail about extrinsic sound source audibility by breaking this information down by hour. A pattern of audibility begins to emerge in that there's a peak of audibility for both aircraft and all extrinsic noises around 9:00 and then again around 18:00. This aircraft audibility pattern is common in national parks crossed by high altitude commercial jet paths. XFigure 2. also shows that commercial jets are the most prevalent extrinsic sound source.

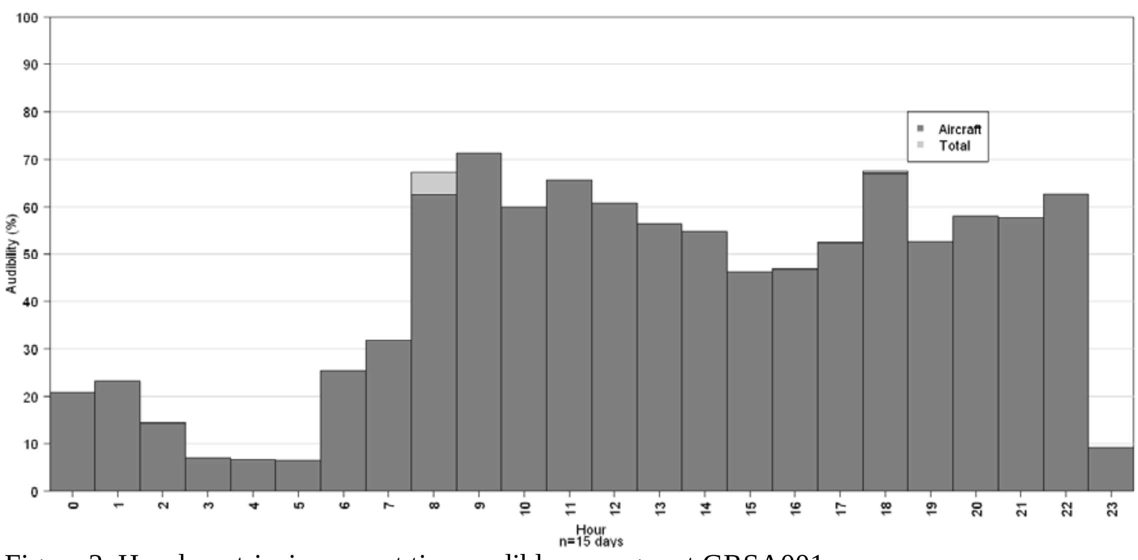

Figure 2. Hourly extrinsic percent time audible averages at GRSA001

In order to determine the effect extrinsic noise audibility has on the acoustic environment, it is useful to examine the median hourly exceedence metrics. XFigure 3 shows existing ambient levels and natural ambient levels. 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. The height of the box is a measure of the contribution of anthropogenic noise to the existing ambient sound levels at this site. The size of these boxes is directly related to the percent time that human caused sounds are audible (see XFigure 2). When boxes do not appear, the natural and existing ambient levels were either very close to each other, or equal for that hour.

XFigure 3 also shows exceedence metrics L_{10} and L_{90} which essentially mark the average maximum and minimum levels over the 15 day monitoring period. As is evident in the figure, human caused sounds raise the natural ambient levels more during the daytime hours than at night. In particular, they raised the natural ambient by about 5 dB during the daytime hours (7am – 7pm).

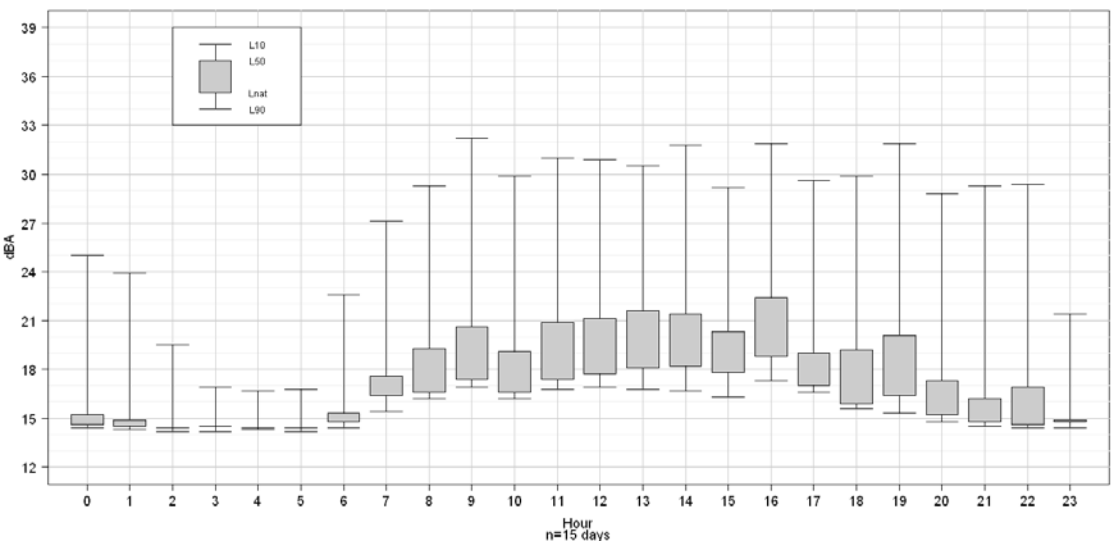

Figure 3. Median hourly exceedence metrics in dBA

Previous Studies

Acoustic monitoring also occurred in Great Sand Dunes National Monument in 1993 and 1994 as a part of a Colorado Plateau-wide monitoring program. The data collection methods and metrics have changed significantly since this first monitoring effort. For instance, whereas the park service once used L90 (the sound level exceeded 90% of the time) to characterize the natural ambient, we now use an adaptive metric called L_{nat} to describe the sound levels of a site without the presence of extrinsic noise. L_{nat} changes for each hour based on the average percent time audible for extrinsic sound sources. While it would be interesting to place historic data side by side with the 2008 data, the results of the historic data (particularly the frequency of noise events over 100 dBA) call into question the validity of historic measurements. As a result, it may be inappropriate to compare them.

Conclusion

Great Sand Dunes National Park and Preserve is extremely diverse, in both geologic and biologic terms. The biologic diversity becomes particularly apparent when long-term acoustic monitoring and continuous recording are employed. This type of unattended monitoring often allows parks to gain insight into biologic activities that might otherwise be difficult to capture. For instance, during analysis, NSP staff discovered days of nearly constant elk bugling. Elk are an excellent example of a species which rely on sound propagation for reproduction. During the mating season, or "rut," bull elk compete for the attention of cows by bugling. Another species which played a prominent role in the nighttime soundscape of GRSA was the coyote. The acoustic monitoring system recorded numerous choruses of coyote howls and yips during the measurement period. These are just a few of the most prominent species which use sound to communicate as a means of reproduction, establishment of territory, and predation, but there are innumerable others which depend on sound for survival.

The existing ambient at this site is so low (often approaching the noise floor of the recording equipment) that even very quiet sound events are audible. Furthermore, the topography surrounding the site creates a basin into which cold air pools, which allows sounds to propagate over large distances. This means that any sound source occurring nearby is likely to heavily influence the existing ambient.

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Appendix A. Glossary of Acoustic Terms.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

L_x
A metric used to describe acoustic data. It represents the level of sound exceeded x percent of the time during the given measurement period.

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

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

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

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

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

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

Soundscape
Human perception of the acoustical environment.

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

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

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

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