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Soundscape Studies in National Parks

The National Park Service (NPS) recognizes the value and importance of natural sounds. NPS management policy 4.9 states: "The National Park Service will preserve, to the greatest extent possible, the natural soundscapes of parks. Natural soundscapes exist in the absence of human-caused sound. The natural soundscape is the aggregate of all the natural sounds that occur in parks, together with the physical capacity for transmitting natural sounds. Natural sounds occur within and beyond the range of sounds that humans can perceive, and can be transmitted through air, water, or solid materials. The Service will restore degraded soundscapes to the natural condition wherever possible, and will protect natural soundscapes from degradation due to noise (undesirable human-caused sound)" (NPS 2000).

NPS has initiated acoustical studies in several national parks in recent years. In many parks, these studies are conducted with acoustics staff from the Volpe Center (part of the U.S. Department of Transportation) to collect acoustical data necessary to develop air tour management plans (ATMPs) with the Federal Aviation Administration (FAA) as called for in the Air Tour Management Act of 2000. For these and other acoustical studies, a scientifically credible, standardized approach to measuring and managing soundscapes is essential. This paper presents an acoustical primer and outlines the NPS approach to studies of national park soundscapes.

"Soundscape" can be defined as the total ambient acoustical environment associated with a given area such as a national park. In a national park setting, soundscapes may be natural sounds only, or both natural and human-made sounds. Sound is measured in terms of frequency content and amplitude, and can be adjusted ("weighted") to match the hearing abilities of a given animal. "Frequency" is defined as the number of times per second (Hz) that the wave of sound repeats itself, and "amplitude" is the relative strength of the pressure level (in decibels, or dB). Humans with normal hearing can hear sounds between 20 Hz and 20,000 Hz, and as low as 0 dB at 1,000 Hz. The range of pressures a human can detect is greater than 1,000,000:1. Because of this very large range, the decibel scale is used. A decibel is the logarithm of a ratio of the measured pressure to a reference pressure.

Figures 1 and 2 illustrate the components of sound; frequency and amplitude. One-third octave band frequency data (31 bands between 20 and 20,000 Hz) are along the X-axis, and amplitude data are along the left Y-axis. The wideband metric (far right) is a single number representing the sum of all the energy in the frequency data. This example is from Jackson Hole, Wyoming, and includes an airplane at 100 Hz and elk bugling between about 1,250 Hz and 5,000 Hz. In Figure 1, all data are flat, or unweighted, and in Figure 2, all data are A-weighted (dBA), or adjusted for the hearing ability of humans. Humans and many other animals do

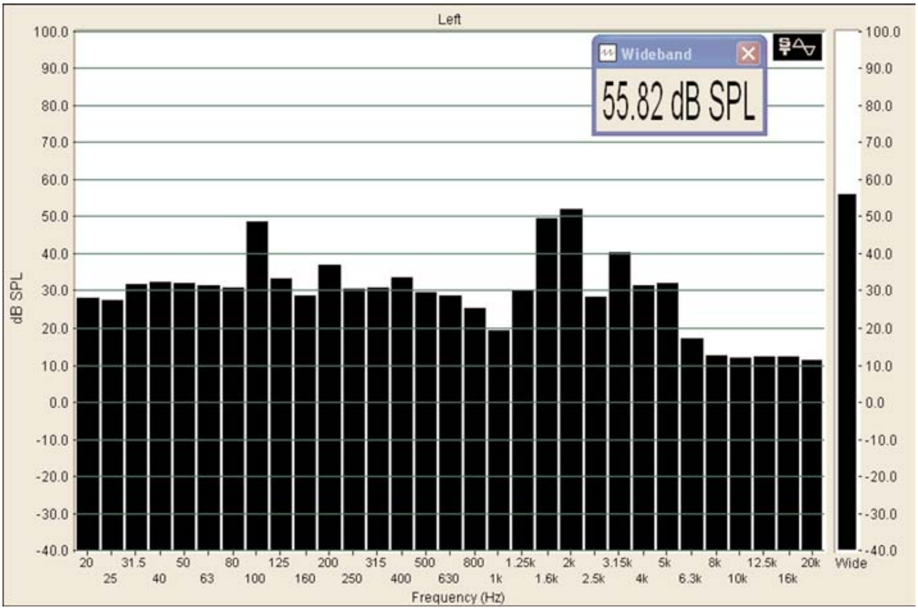

Figure 1. Jackson Hole, Wyoming: airplane (100 Hz) and elk (1,250-5,000 Hz); frequency and wideband: unweighted.

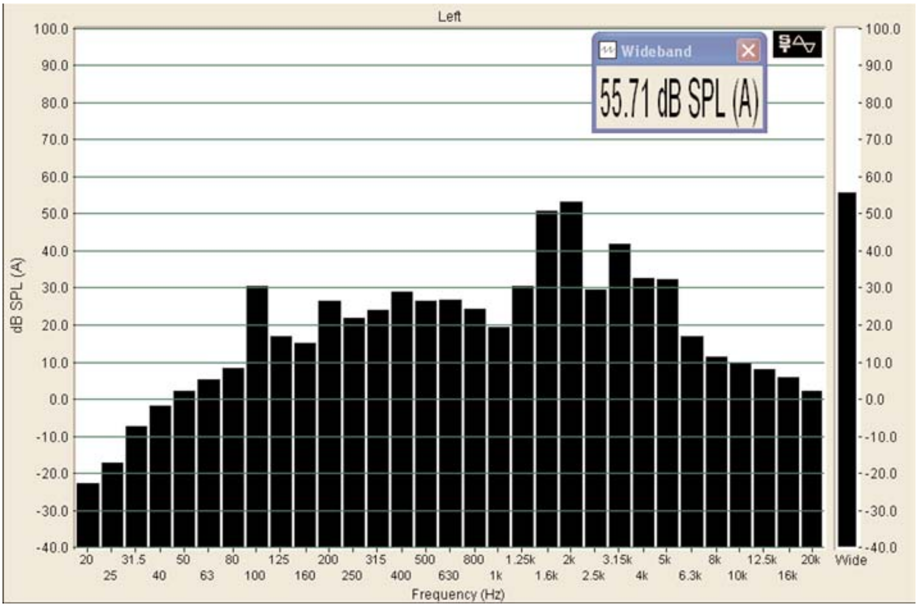

Figure 2. Jackson Hole, Wyoming: airplane (100 Hz) and elk (1,250-5,000 Hz); frequency and wideband: A-weighted.

not hear well at very low or very high frequencies. For example, at 20 Hz, A-weighting subtracts 50.4 dB from the unweighted amplitude, and at 20,000 Hz, A-weighting subtracts 9.3 dB. In the middle frequencies, there is very little adjustment for A-weighting (at 1,000 Hz there is no adjustment).

Although many animals are like humans in that they do not hear well at very high or low frequencies, some species hear very well at low frequencies (whales) while others hear very well at high frequencies (bats).

Sound levels in national parks can be very low. For example, in the crater in Haleakala National Park, minimum sound levels are between 0 and 10 dBA. In Grand Canyon National Park along some remote trails, minimum sound levels measure between 10 and 20 dBA. In contrast, sound levels in a typical suburban area are between 50 and 60 dBA. An increase of 10 dBA represents a perceived (to human hearing) doubling of sound pressure level; hence, 50 dBA would be perceived as 16 times louder than 10 dBA. Examples of sound pressures and dBA measured in national parks are provided in Table 1.

Acoustical Data Collection

Collection of acoustical data in national parks needs to follow specific, standardized methods and protocols. This section provides guidelines for collection of acoustical data in national parks for use in establishing natural ambient sound levels, against which future conditions can be compared and assessment of potential impacts can be modeled. Specifically, this section provides guidelines for planning data collection, selection of measurement locations, determining adequate measurement periods, and identifying acoustic data to be collected.

Measurement locations. Prior to initiating measurements, potential locations should be reviewed by individuals familiar with the park in order to ensure that measurements are made in the primary land/vegetation types of the park, with consideration of park management zones, specific soundscape management objectives of those zones, and any sound-sensitive areas. Areas of like vegetation and topography are often referred to as "acoustic zones," with the assumption that, in general, the same mammals, birds, insects, and other sources of natural sounds (wind, water, etc.) occur in

Table 1. Representative sound levels in some national parks.

	dBA
Threshold of human hearing	0
Haleakala National Park: in volcano crater	10
Canyonlands National Park: leaves rustling	20
Zion National Park: crickets (5 m)	40
Whitman Mission National Historic Site: conversational speech (5 m)	60
Yellowstone National Park: snowcoach (30 m)	80
Arches National Park: thunder (distance unknown)	100
Yukon–Charley Rivers National Preserve: military jet (100 m above ground level)	120

similar habitats, and, as a result, similar habitats will have similar natural sound levels, propagation, and attenuation properties.

In some management zones, patterns of human-caused sounds (originating from travel corridors, visitor centers, air traffic routes, seasonal patterns, etc.) generate different, non-natural acoustical conditions. In developed zones, there is often less sensitivity to noise, and a greater incidence of human sound that may be regarded as consistent with or necessary for park purposes. In backcountry or wilderness zones, the soundscape is expected to be natural, with little if any human-caused noises.

Final selection of places to inventory is made through a screening process that considers access; equipment availability, capability, and maintenance needs; sources of ambient human-caused sound; statistical factors; and availability of personnel. The process's geographic scope depends on the range of alternatives (for example, in the ATMP process, the potential variations in flight paths) and the areas that likely would be affected. If the analysis is park-wide, then it is likely that the acoustic zone selection would cover the entire park. Alternatively, if there is only a small area of the park within the scope of analysis, only the potentially affected acoustic zones would need to be inventoried. In reality, it is often difficult to anticipate what alternatives may be considered in detail in an environmental document, so care must be taken in ruling areas out. It is better (and more efficient) to collect more data at once than to return later and collect additional data for a new area.

Measurement period. The variability of sound pressure level, frequency, and audibility over long periods (weeks, months, seasons, and years) is not well understood. Until it is, measurement periods must be of sufficient duration to ensure statistical confidence in data, and must include all periods of potential acoustical variability (such as diurnal/nocturnal, seasonal, and annual). For the most part, it will not be feasible to collect acoustical inventory data for long periods before planning and management decisions are initiated; however, data that represent all sources of variability should be obtained to the fullest extent possible. Once long-term data are available, an assessment of an adequate measurement period for a given area can be made. For example, initial review of data collected at one site in Hawaii Volcanoes National Park from October 2002 to January 2003 revealed the following. For the 80-day measurement period, variability was such that 50% of the period would need to be sampled to ensure that data collected were representative of the entire measurement period. Additional statistical review of long-term acoustical data from other parks is being conducted, and will aid in estimating future needs for measurement duration. It is almost certain that appropriate measurement periods will vary among parks, and may vary among different areas within the same park, but will also likely result in optimal measurement periods of weeks, not days.

Acoustical data. Acoustical studies in national parks should collect sound pressure level, frequency, and audibility data (adequate to describe natural and existing ambient sound levels, calculate the percentage of time that human-caused noise is audible, determine noise-free intervals, and identify sources of sounds). These data can then be used to characterize natural ambient sound levels and current ambient sound levels, including human-caused noise.

Sound pressure level (SPL) data and frequency data. Sound pressure is the physical characteristic of sound; it is the actual pressure produced by a sound wave. Sound pressure level (SPL) is the logarithmic form of sound pressure; in air, it is 20 times the logarithm (to the base 10) of the ratio of the actual sound pressure to a reference sound pressure (20 micropascals). Acoustical data collected in national parks should include 1-second L_{eq} for 31 one-third octave bands between 20 and 20,000 Hz for the entire measurement period; the appropriate measurement period depends on acoustical variability. From these 1-second L_{eq} data, other acoustical metrics can be calculated (hourly, monthly, and seasonal dB, dBA, L_{max}, L_{min}, exceedences, L_x values, etc.). L_{eq} is an energy-equivalent metric, and is not a good measure of "average" sound level. L_x is a percent exceedence metric, that is, the sound pressure level (L) exceeded x percent of the time, such as L_{50} or L_{90} or L_{66}. The L_{50} is the median, and the L_{90} is the sound level exceeded 90% of the time (or the quietest 10 percent). The term "sound level" is generally used in conjunction with *weighted* sound pressure level data, such as dBA, while *unweighted* "sound pressure level" (dB) is generally used with frequency data. Sound levels in many national parks can be very low, so low that specialized equipment is needed to measure them. Most commercially available sound level meter/microphone combinations measure down to 15 to 20 dBA; however, in some cases, equipment that measures down to 0 dBA will be needed.

Audibility data. Audibility represents the biological aspects of sound. Audibility is the ability of animals, including humans, with normal hearing, to hear a given sound. This ability is affected by both frequency content (different species of animals hear some frequencies better than others) and amplitude (again, species differ in their sensitivity to amplitude). Currently, audibility data are collected and determined using human hearing abilities, but as techniques become available, audibility analysis will be extended to include other animals' hearing abilities. Audibility data are collected by making high-quality recordings either continuously or at regular, frequent intervals (sampling schemes may vary among different habitats or seasons) throughout the measurement period. Recordings should include a representative sample of events that exceed a user-defined threshold and duration. Recordings can be replayed at a later date to identify sources of human-caused noise and natural sounds. The audibility data collected must be of sufficient quantity to provide an adequate representation of audibility of natural and non-natural sounds throughout the measurement periods, including samples during all hours of the day and during all seasons. The standard practice of recording two to four digital audio tapes or one-hour attended logging sessions per season is not sufficient for assessing audibility. In addition to the time that human-caused noise is audible, the time between human-caused noises ("noise-free interval") is important to soundscape management. Audibility data are not intended for use solely to assess impacts on visitors, although interpretations could be made from these data to achieve this purpose.

Source identification data. Data that allow the identification of sources of sounds (both natural and human-caused) must be collected in order to fully understand the soundscape in a given area. For the most part, past acoustical studies in national parks have included the collection of decibel data with limited recordings or attended logging for audibility data and source identification data. A major element of NPS soundscape management (as well as assessment of potential impacts of air tours) will be the percentage of time that human-caused noise is audible. Using source identification data in combination with audibility and sound pressure level data, metrics of natural sounds and human-caused noise can be calculated.

Meteorological data. Meteorological data (wind speed, wind direction, temperature, and humidity) can improve the utility of acoustical data. When appropriate and feasible, these data should be collected with acoustic data.

Biological data. Current acoustical studies often include making high-quality recordings in conjunction with collection of decibel data. These recordings are most often used for assessing audibility and source identification, and also can, with appropriate processing, provide decibel data. However, such recordings also have the potential to provide a wealth of biological information (avian inventories, and mammal and insect vocalizations). Acoustical studies in national parks should make every effort to include collection of biological data that would provide an archival record of natural sounds in the parks.

Natural, Existing, and Traditional Ambient Sound Level

Ambient sound levels (natural, existing, and traditional) are the baseline levels against which potential impacts will be compared during impact assessment. Therefore, it is essential that these levels be clearly defined. The natural ambient sound level of a given area is composed of the natural sound conditions in that area that exist in the absence of any human-caused noise. Natural ambient sound is considered synonymous with "natural quiet," although the former is more appropriate because nature is often not quiet. The existing ambient sound level of a given area is composed of all sources of sound in that area, including natural sounds and human-caused noise. The traditional ambient sound level of a given area is composed of all sources of sound in that area, including natural sounds and human-caused noise, excluding the noise source of interest. In the case of ATMPs, the noise source of interest would be air tour aircraft.

Metrics

Traditionally, acoustical studies and impact assessment in national parks have relied on a single metric, LA_{eq} (A-weighted L_{eq}). L_{eq} is an energy-equivalent metric, and is well-suited for near-continuous noise. However, for measuring a series of distinct noise events, such as aircraft or vehicle noise, the L_{eq} is not a good measure. Further, the A-weighted metric is a single number adjusted for human hearing and can be very misleading. Two very different acoustic states can have the same dBA. Aircraft noise at lower frequencies can have the same dBA as birds singing at higher frequencies. Many countries and organizations (such as the World Health Organization) acknowledge that reliance on a single metric, LA_{eq}, is not appropriate for describing and assessing impacts of certain types of human-caused noise, and that supplemental metrics should be used (Hendin 2001). This is especially true in park-like settings where natural sounds predominate and human-caused noise, such as aircraft noise, consists of several distinct noise events. Supplemental metrics that should be considered for soundscape management in parks include:

- One-third octave band data;
- Exceedence percentiles (L_{50}, L_{90}, L_x);
- Sound exposure level;
- Number of events/time;
- Time above an appropriate baseline or pre-selected level;
- Percent time audible; and
- Noise-free interval.

The use of one-third octave band frequency data is a much more accurate method for describing both natural sounds and human-caused noise. Additionally, the use of one-third octave band data can provide a more accurate assessment of impacts. This is especially true in national parks where assessment of impacts must include consideration of animals that perceive sounds differently than humans.

While selection of appropriate metrics and analysis for soundscape management in parks will be driven in large part by specific objectives of each park, the standard practice of relying on a single metric, such as dBA, is not appropriate. In most parks, soundscape management standards will likely rely on the percentage of time that human-caused noise is audible, the level of human-caused noise when it is audible, and the interval without human-caused noise (noise-free interval).

Acoustical Equipment

A variety of acoustical monitors and recording instruments can collect the data listed above. Sound level meters that collect one-third octave band data are commercially available, as is specialized software that can be programmed to store acoustical data and make high-quality digital recordings. In addition to standard sound level meters, continuous recordings of the entire measurement period can provide acoustical data (through post-processing). Long-term recordings can also provide a wealth of biological data, and are currently the best method to provide an archival record of soundscapes of natural parks. The NPS is working with companies and individuals to develop systems that can make long-term, high-quality recordings. These recordings, if collected properly, can provide both physical and biological characteristics of the soundscape. Additionally, recordings can be an archival record for current and future studies of biological components that generate sound. Acoustical studies in national parks should make every effort to include high-quality recordings. Sound level meters used in Yukon–Charley Rivers National Preserve and Canyonlands National Park are shown in Figures 3 and 4. respectively.

Specific methodologies (standards or protocols) for equipment type; microphone type, placement, and height; and other factors for work in national parks are available from the

Figure 3. Microphone with foam wind screen and bird spike set up in Yukon–Charley Rivers National Preserve, 2002. *National Park Service photo.*

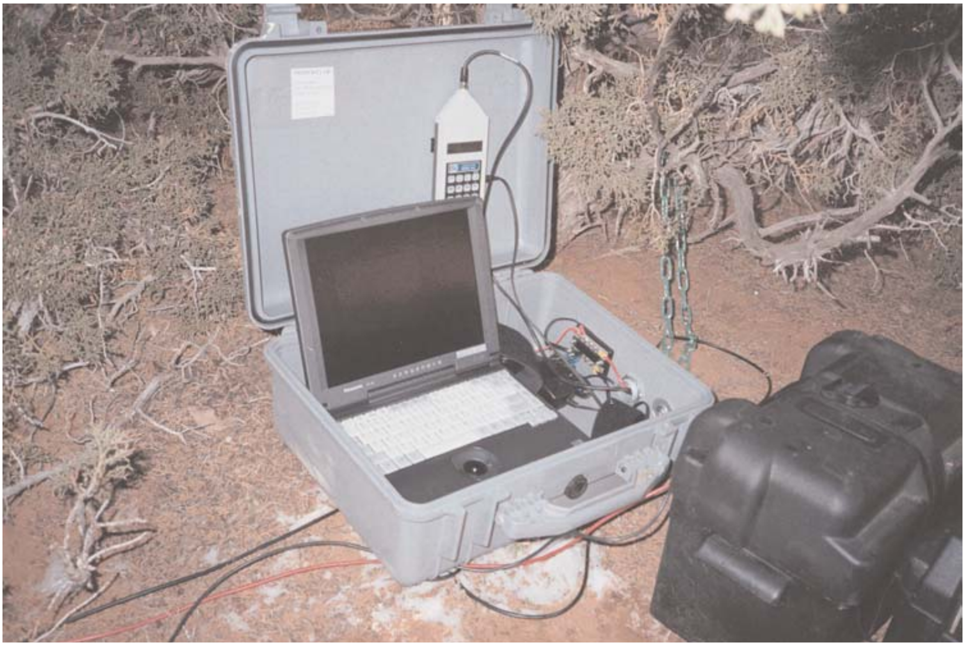

Figure 4. Acoustical monitor: notebook computer and sound level meter set up in Canyonlands National Park, 2002. *National Park Service photo*.

NPS Natural Sounds Program Office. These standards are based in part on American National Standard ANSI S12.9-1992, Part 2, and the FAA's *Draft Guidelines for the Measurement and Assessment of Low-level Ambient Noise* (Fleming, Roof, and Read 1998).

Impact Assessment

Every unit of the National Park System was established for specific purposes, which are described in enabling legislation, general management plans, and the National Park Service organic act. Soundscape management and impact assessment is based on those purposes and plans. NPS management policy 4.9 states: "Using appropriate management planning, superintendents will identify what levels of human-caused sound can be accepted within the management purposes of parks. The frequencies, magnitudes, and durations of human-caused sound considered acceptable will vary throughout the park, being generally greater in developed areas and generally lesser in undeveloped areas. In and adjacent to parks, the Service will monitor human activities that generate noise that adversely affects park soundscapes, 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 or other park resources or values, or that exceeds levels that have been identified as being acceptable to, or appropriate for, visitor uses at the sites being monitored" (NPS 2000).

Impact assessment—determining the level of impact of a human-caused noise on park resources—requires two types of acoustical data: the metrics of the human-caused noise and the metrics of the park soundscape against which the human-caused noise is being compared. The goal of acoustical studies in parks is to provide the data necessary to monitor and manage park soundscapes.

Recent and Ongoing Acoustical Studies in Parks

With passage of the Air Tour Management Act in 2000, acoustical studies were initiated in several national parks. Studies were recently completed in Zion, Hawaii Volcanoes, Haleakala, five small parks in Hawaii, Mount Rushmore, and Badlands. Additional studies are currently underway in Arches, Bryce Canyon, Grand Teton, Yellowstone, and Denali. More than 100 parks have commercial air tours and thus will need acoustical data for preparing ATMPs. Director's Order no. 47 directs all parks to manage park soundscapes, and these parks will need acoustical data as well.

Summary

The National Park Service recognizes the importance of protecting, maintaining, and restoring natural soundscapes. The Natural Sounds Program was established to assist parks in addressing these concerns. As NPS becomes more involved in soundscape management, park staff must become more familiar with acoustics. A scientifically credible, standardized approach to measuring and managing soundscapes is essential. The Natural Sounds Program Office, working with federal and state agencies and private organizations, is developing specific methods and standards for acoustical studies in national parks. New approaches are needed for soundscape measurement and management in national parks, and the Natural Sounds Program Office is working to address those needs.

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