

Features

Measuring and monitoring soundscapes in the national parks

By Kurt Fristrup, Damon Joyce, and Emma Lynch

ATENTIVE LISTENING IS AN immersive experience, and in national park settings it can amplify visitor awareness of resources and their value. Noise disrupts this experience. Accordingly, the sounds of a park unit and superb conditions for hearing them are signatures of park integrity and authenticity. Quiet environments encourage relaxation, observation, learning, and contemplation. For indoor settings, these values are expressed in the protective architectural noise standards that apply to libraries, classrooms, concert venues, and churches (American National Standards Institute, Standard S12.2). In protected natural areas, noise-free environments also provide outstanding opportunities to perceive and identify the sounds of nature, encouraging visitors to expand their auditory as well as visual horizons.

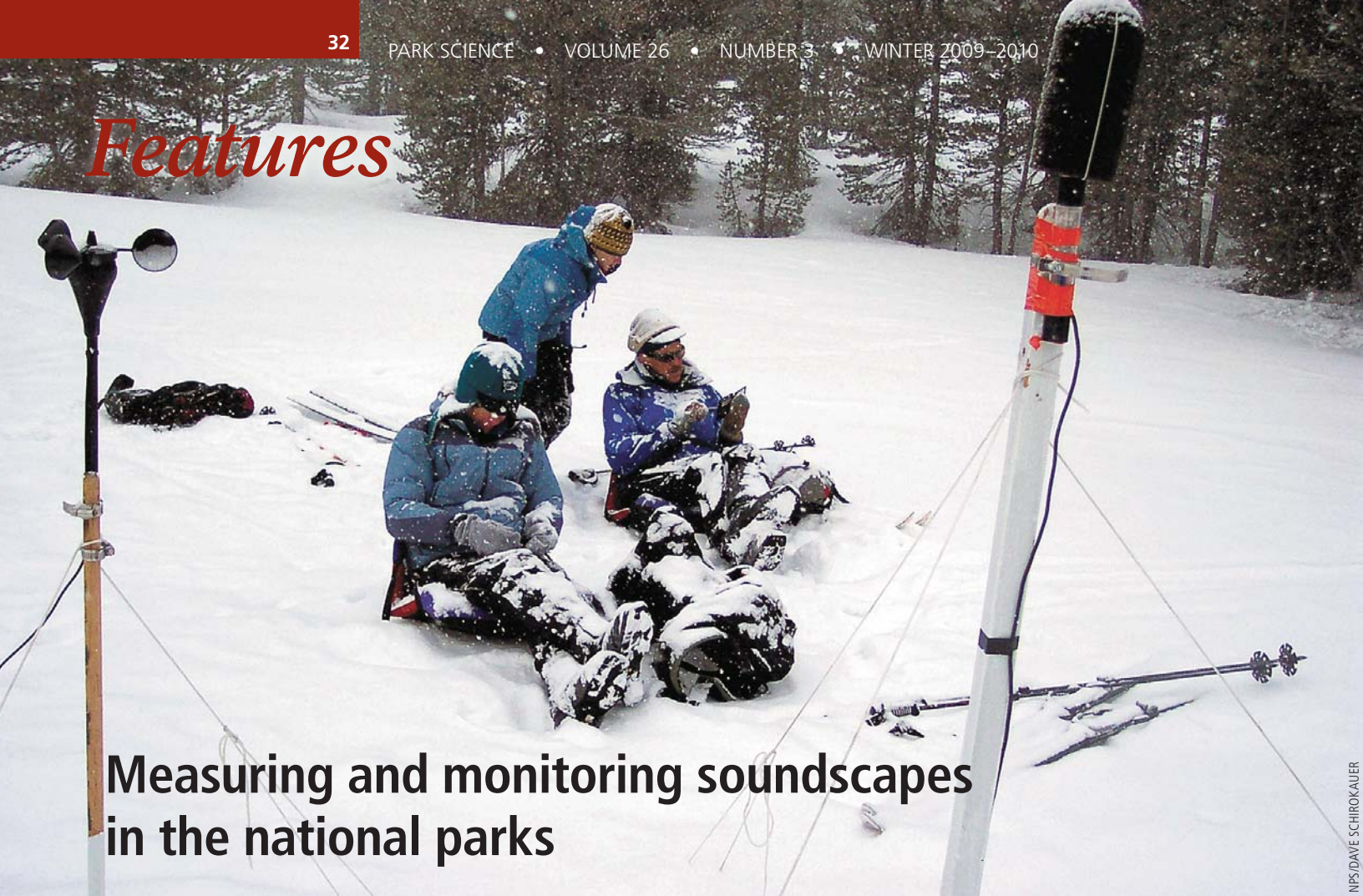
The compelling benefits of natural quiet for park visitors reinforce the importance of noise management for preserving and restoring ecological integrity. Acoustical communication is vital for many species, and hearing alerts animals to nearby events, even when they are sleeping.

Acoustic monitoring is essential for managing noise, and it is a powerful tool to document patterns of wildlife activity and visitor use. Many animals reveal their presence and advertise their behavior using sound. Unattended recording is noninvasive: weeks of data can be obtained with minimal human presence and instrument footprint, and animals do not have to be captured or tagged. Audio recordings can chronicle changes in wildlife behavior in response to visitor use or revised management practices. Acoustic monitoring is an efficient way to track almost any form of traffic: hikers, all-terrain vehicles, snowmobiles, boats, automobiles (and

their types), and aircraft. Finally, acoustic monitoring can identify sources of noise and document daily and seasonal patterns in ambient sound levels.

Basic sound monitoring with a PDA

Sound fluctuates more rapidly than any other environmental variable monitored by the National Park Service—thousands of times a second—but simple methods of collecting data are available. Attentive listeners can identify audible sounds, noting the start and stop times of each. In its simplest form, this monitoring can be accomplished with a watch, notebook,



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Table 1. Winter audibility report generated from Palm PDA monitoring at Lyell Fork of the Tuolumne River, Yosemite National Park

ID	Sound	Percentage of time sound audible	Max event duration (seconds)	Mean event duration (seconds)	Number of events
1	Aircraft, unknown	0.5	108	108	1
1.1	Aircraft, jet	51.5	552	137	88
1.2	Aircraft, propeller	5.7	382	88	15
G100	All aircraft	53.4			
8.3	Skiing	0.4	52	44	2
20	Nonnatural, other/unknown	0.0	6	3	3
21	Wind	31.7	270	47	158
22	Water sounds	0.0	1	1	1
22.1	Rain/Fog drip	0.2	13	3	14
22.3	Snowfall	1.0	22	3	93
25	Bird	16.0	592	23	160
40	Other, natural	13.4	200	7	452
NFI	Noise-free interval	N/A	1,059	123	88
G2000	All human-made sources	53.6			
G4000	All natural sources	50.5			

This table summarizes 29 hours of audibility data collected by Bruce Carter and Tracey Wiese, backcountry rangers at Yosemite National Park. Percentage of time audible documents how often sounds are present, and event-free intervals document the gaps between anthropogenic noise events.

and pencil. To expedite collection and transcription of data, the National Park Service has developed sound logging software that runs on Palm PDAs (personal digital assistants). The listener taps buttons on the PDA screen to indicate the start and end of identifiable sounds. With practice, many overlapping sound events can be monitored. The data are easily downloaded (using Palm HotSync software) into a Microsoft Access database that automatically analyzes the data and generates summary reports. PDA audibility logging is an inexpensive way of engaging volunteers, youth groups, and employees from all disciplines in attentive listening exercises. These foster understanding of parks' acoustic resources, inspire the protection of "natural quiet," and produce valuable monitoring data.

The list of sounds available to assign to PDA "buttons" includes all North American bird species, making these units

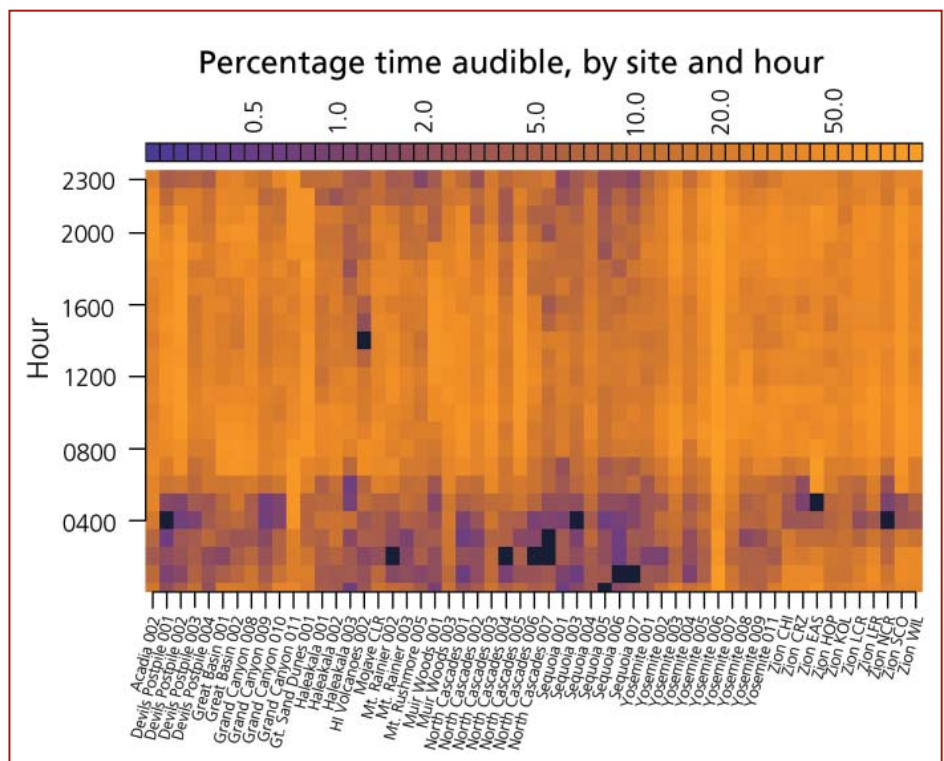


Figure 2. This spectrogram presents the audibility of noise at 55 sites in 13 national park units. Warmer colors indicate a higher percentage of time audible value.

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useful for acoustic avian surveys. The NPS Natural Sounds Program can customize the sound buttons to serve other applications. The PDA records the start and stop time of each sound event, so several acoustic metrics can be derived from these data: percentage of time audible, noise-free interval, number of events, and event durations. Figure 1 depicts PDA-based data collection in winter at Lyell Fork on the Tuolumne River, Yosemite National Park (California), and table 1 presents the results generated from this site.

Figure 2 shows how often noise is audible in 14 national park units. This picture is dominated by yellow blocks, indicating that noise from human activities was audible more than 20% of the time at most sites and hours. Many of these sites are in backcountry or wilderness areas. Noise is a pervasive pollutant in the National Park System.

Greater sophistication in monitoring

Audibility data describe the durations of sound events, but not their intensities. Consumer audio recorders and sound level meters offer many options to measure sound levels. The appropriate amount of data collection will balance complexity (and cost) against accuracy and extent of sampling. Systems can be surprisingly economical: almost 6 days of continuous audio recording can be obtained with a \$30 solid-state, digital MP3 recorder, augmented by a couple of alkaline D batteries and a weather-resistant housing. Recorders with much longer endurance (up to 42 days) and higher-quality recordings can be obtained for \$250 to \$400, with an attendant increase in battery size and weight. Inventory and monitoring of sound sources, number and duration of natural and human sound events, and average length between noise events can all be



Figure 3. Acoustic monitoring station deployed at Great Sand Dunes National Park and Preserve, Colorado. The anemometer on the right is used to determine when wind speeds are too high to obtain reliable measurements. The microphone on the left is topped with a metal spike to discourage birds from perching on the foam windscreens. The unit costs about \$10,000. Data collected at this site were used to document extraordinarily quiet conditions in the park, which were important in subsequent discussions regarding oil and gas development near the park (NPS/Emma Lynch).

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obtained with low-cost digital recording units. Increases in flash memory storage and lightweight battery technology mean these devices can run for weeks without need for service, which is vital in remote backcountry locations.

For situations in which acoustic modeling and compliance with standards are expected, a calibrated sound level meter may be required. ANSI type 2 systems suitable for cross-calibrating audio recorders can be obtained for less than \$1,500.

The Larson-Davis 831 sound level meters used by the NPS Natural Sounds Program cost nearly \$8,000; they are ANSI type 1 systems that can store data for several months. A picture of a Natural Sounds Program monitoring system deployed at Great Sand Dunes National Park and Preserve is presented in figure 3.

Part of the expense of these sound level meters is due to their capacity to make measurements in one-third octave spectral bands. For human listeners, one-third octave approximates how close two signals can be in frequency before one begins to interfere with perception of the other. This spectral resolution is needed to measure or model the audibility of sounds for park visitors. Musicians will recognize that one octave represents a doubling in frequency, and 11 doublings of frequency span the range of human hearing (10–20,000 Hz). Accordingly, NPS acoustic monitoring systems record 33 one-third-octave band level measurements every second, along with an A-weighted summary of aggregate sound level. A-weighted measurements (dB[A]) sum sound energy across the audio spectrum, with weights that account for reduced human sensitivity to low- and high-frequency sounds. The uses of A-weighted measurements are discussed in the “Community noise metrics” Science Notes article (page 21) in this issue. The sound level meter measures one-third-octave and A-weighted sound levels as decibels (dB) relative to a standard sound intensity of 10^{-12} watts/m². In partnership with Colorado State University’s Electrical and Computer Engineering Department, sound pressure level monitors are being developed that will provide real-time data summaries using wireless telemetry.

In addition to providing a basis for modeling the audibility of sounds, one-third octave measurements can be used to create an image that portrays sound events with sufficient detail to identify many kinds of meteorological conditions and

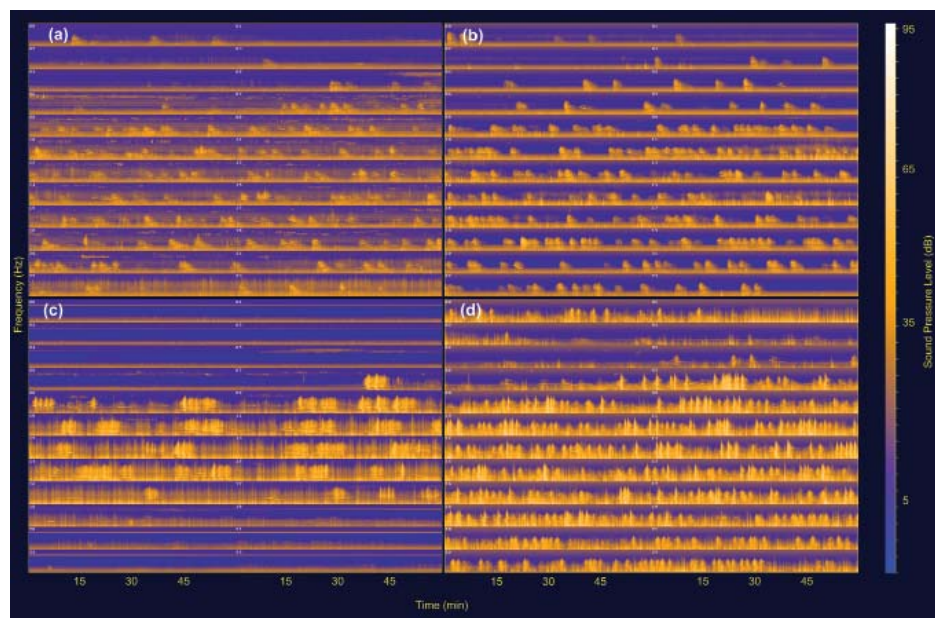


Figure 4. Daily spectrograms of sound levels at four national parks. Each row or band displays 2 hours of one-third-octave sound level data, starting at midnight at the upper left corner of each spectrogram and ending at midnight on the following day at the lower right corner. Minutes past the hour are noted on the X axis, with sound frequency (12.5–20,000 Hz) shown on the logarithmically scaled Y axis. Spectrogram a: A site on Mount Collins in Great Smoky Mountains National Park (Tennessee). Numerous high-altitude jet signatures are evident (examples at 0015, 0035, and 0050 hours), as well as some propeller-driven aircraft (examples near 0752, 0910, and 1235 hours). High-frequency sounds from the dawn chorus of birds begin near 0545 hours. Spectrogram b: Lyell Fork on the Tuolumne River in Yosemite National Park, California. High-altitude jet signatures are numerous, filling more than half of several daytime hours. Spectrogram c: Near Pu'u O'o in Hawai'i Volcanoes National Park. The sounds of helicopter air tours loitering near the eruption site begin at about 0740 and extend through 1700 hours. Spectrogram d: Indian Pass in Lake Mead National Recreation Area (Nevada). Numerous high-altitude jets and low-altitude air tour transportation flights obliterate natural acoustical conditions for all but a few hours of the day.

noise sources. The presence of wildlife sounds can also be indicated, though there is not enough detail to identify species. Four daily spectrograms are presented in figure 4, illustrating the variety and ubiquity of aircraft noise in national parks.

Visual analysis of acoustic data

The collection of several weeks of continuous audio and sound pressure levels has been made far easier by new instruments, but 73 million data points and 600 hours of audio is an overwhelming listen-

ing exercise. One solution is to subsample the data set, and listen to only a few hours of the several hundred. This is the current protocol for complex sites with many layered sound sources, such as Golden Gate National Recreation Area, an urban park unit.

Another method of presenting acoustic data is through the use of spectrograms, a type of plot showing sound level as a function of time and frequency. Traditionally, spectrograms are used to show fine detail in rapidly varying sounds, such as human voice or birdsong. For noise monitoring, events occur on a much longer time scale, and a coarser resolution can be

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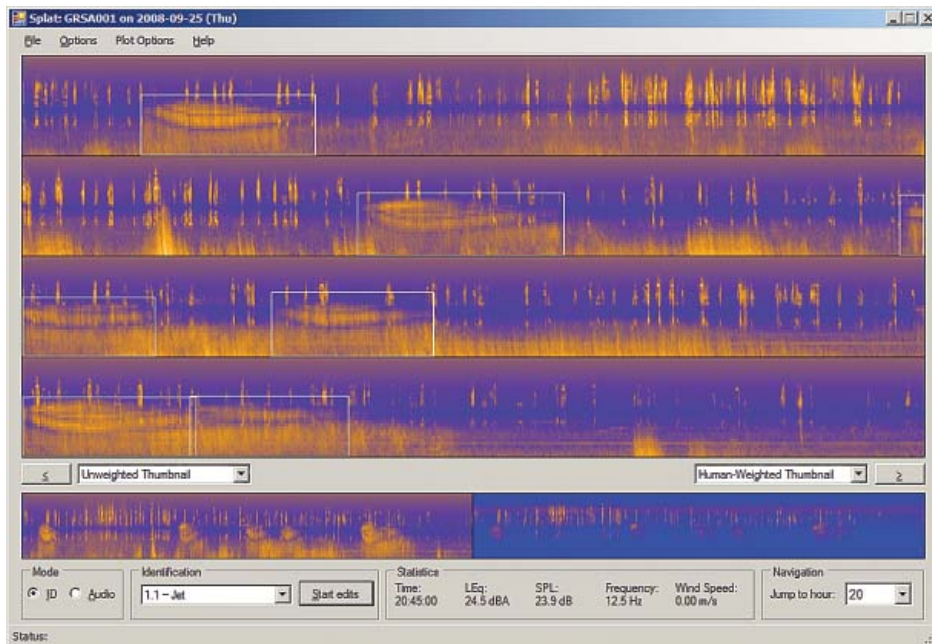


Figure 5. Screen shot of the visual analysis tool developed by the Natural Sounds Program. High-altitude aircraft events have been highlighted. The numerous mid-frequency events are elk bugling.

used. Daily spectrograms do not show nuances of a birdcall, but they do present a “snapshot” of acoustical conditions at that site. Aircraft, vehicles, voices, animal calls, thunder, and other sources are all discernible.

To build on the utility of spectrograms, the Natural Sounds Program developed a visual analysis tool to log events and automatically calculate metrics based on event frequency. A screen shot of the program, called SPLAT (Sound Pressure Level Annotation Tool), is shown in figure 5, with several high-altitude jet events outlined. The continuous audio is also linked to the program, so if the user finds an unknown event, he or she can highlight it and listen to the corresponding audio. Every selected event is logged along with duration, maximum level, and sound exposure level (SEL). Analysis using this tool is anywhere from four to ten times faster than audio subsampling, depending on the complexity of the spectrogram.

Conclusion

The proliferation of tools for audio data collection and analysis offers parks many choices for acoustical monitoring. To navigate these options, parks should identify their objectives and contact the Natural Sounds Program to determine appropriate monitoring plans and equipment. Acoustical monitoring need not be expensive or complicated.

Acoustical monitoring can help protect natural sounds and outstanding conditions for hearing them. In addition, parks can use these methods to count rare or shy species, to track the appearance and spread of endangered species, and to document phenological changes that will accompany climate change. Natural sounds can be startling, haunting, beautiful, and inspirational. They also offer a wealth of ecological information that can advance scientific understanding of park ecosystems and inform park management plans.

About the authors

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