SEKI Natural Soundscape Vital Signs Pilot Program Report

by

Bernard L. Krause, PhD, PI
Wild Sanctuary (WSI)
Glen Ellen, CA

Stuart Gage, PhD, Collaborator
Remote Environmental Assessment Laboratory (REAL)
Michigan State University (MSU)
East Lansing, MI

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Name: *Testing Biophony as an Indicator of Habitat Fitness and Dynamics.*

Location: Sequoia National Park (SEKI), four different sites

Start date: 1 October 2001

Scheduled completion date: 30 September 2002

Abstract: Using the sound signatures of four representative sites within Sequoia National Park to test for evidence of habitat health, the biophonies and geophonies were recorded at selected times during each of the four seasons beginning in October, 1991 and ending in August, 1992, and analyzed with respect to frequency niches, temporal expression of sound, and spatial techniques. It was the objective of this pilot study to determine if there was sufficient information and the ability to analyze the data as indicators of habitat health and relative dynamic equilibrium. Indications support the thesis that organism vocalizations within a given landscape at dynamic equilibrium will exhibit patterns of clear discrimination between frequency niches and/or temporal slots. The clearer the patterns, the more stable the system.

Project Goals:

A landscape's acoustic signature is a unique component of the evaluation of its function (Krause 1987,Krause 2002; Schafer 1977, 1994). While the vocalizations of organisms historically have been studied in an abstract individualized manner, our preliminary evaluation of recorded soundscapes as a means to assess landscape health was focused on the recording of audio samples within the landscape. New methods of evaluating the stability of a landscape from the perspective of bioacoustics combine the sound-producing properties of all the vocal organisms within that habitat to establish base line data of the soundscape signature. A soundscape is a region of acoustic activity homogenous in a feature of interest (Schafer 1977, 1994). In most environments today, soundscape signatures are comprised of two natural components, *biophony* and *geophony*, and a probable human component that includes the third, *anthrophony*. *Biophony* is the combined sound that living organisms produce in a given habitat. *Geophony* is comprised of geophysical sounds in the environment, such as the effect of wind in trees or grasses, thunder, water flow, earth movement, etc. *Anthrophony* is usually comprised of human-generated mechanical sounds, such as signals from aircraft, automobiles, generators, snowmobiles, jet-skis, radios, television sets, boom boxes, or automobile sound systems. This classification will assist in identifying the introduced elements that may cause stress or change not otherwise noticed by traditional visual evaluation. Biophony may also be used to augment data collected by other means. The scope of this project has been to record a limited number of base line recordings of acoustics sampled from each of four sites representing 4 key landscapes in SEKI, and to evaluate them with regard to the indicators present when submitted to broadband spectrogram evaluation.[1]

The *Niche Hypothesis* predicts a positive correlation between species composition and soundscape structure in terms of time, frequency, and amplitude. When a habitat reaches dynamic equilibrium, the spatial structure of the acoustic spectrograms illustrate complex features (both frequency and temporally based) indicative of the relationships between the vocal organisms. Using this as an initial framework, we began to sample the acoustic signatures of four distinct landscapes in SEKI and examine the samples for defining differences and distinguishing features in the soundscapes (Krause 1987,Krause 2002).

Wild Sanctuary, in cooperation with Michigan State University's Remote Environmental Assessment Laboratory (Prof. S. H. Gage) conducted the soundscape assessment in SEKI.

The objectives of the study were to:

1. Record acoustic features (digital recording) of four different landscapes within Sequoia National Park from October, 2001 to July, 2002, to provide a measure of diurnal and seasonal variation within natural soundscapes associated with animal and insect vocalizations within the park
2. Process acoustic samples and characteristics (given season, weather, time of day/night, etc) of each landscape chosen for study;
3. Begin creation of an index of acoustic dynamics (vocalization density, vocalization discrimination, overall amplitude envelope, duration of choruses, etc.) within each habitat to correlate it with more traditional landscape ecology indices;

4. Calculate the potential of bioacoustics as a tool for assessing the health of an ecosystem, possibly by correlating the results with existing data to determine habitat degradation as well as regeneration by examining the degree of niche partitioning in the samples; and
5. Begin to quantify the effect of introduced noise on biophonies.

Protocol

A. Description and Location of Landscapes monitored. The following four sites were selected in conjunction with park personnel based on landscape heterogeneity and year-round accessibility.

1) Foothill Zone Riparian (Buckeye Flat Paradise Creek 2900 ft), N36°31.185/W118° 45.692
2) Foothill Zone Oak savanna (Sycamore Creek flats 2100 ft.); N36° 29.470/W118°51.225
3) Dry Savanna chaparral (Shepard's Saddle, 3000 ft.) N36° 29.470/W118° 51.142
4) Old Growth Site (Crescent meadow north end 7000 ft.) N36 ° 33.364/W118°44.867

B. Personnel and affiliations.

Bernard L. Krause, Ph.D. (WSI)
Stuart Gage, Ph.D. (MSU)
Jack Hines (WSI sub-contract)
Rudy Trubitt (WSI sub-contract)

C. Monitoring Regime

We used a protocol to optimize the sampling logistics while gathering a reasonable volume of data. We selected four seasonal recording periods based on typical weather patterns at approximate seasonal midpoints.

Each of the four personnel sampled one of the four sites simultaneously, resulting in simultaneous samples from each of the four sites at four times of day. We recorded daily samples of approximately 60 minutes of acoustic activity at dawn and dusk, which tend to be the most acoustically active periods, as well as at mid-day and two to three hours after sunset representing night-time, totaling four samples from each location for each season.

We attempted to record in the same location during each of the four daily and seasonal samples. However, in the case of Buckeye Flats, we had to change the position of the recording location after the Fall recordings, as we determined the initial site to be too near the stream (see Figure 1a).

We chose to monitor each site with individual personnel because we wanted first-hand observations of the types of permutations we would likely encounter given the technologies employed. Initially, one person was assigned to a specific site. However, weather and physical limitations dictated some variation as the study progressed, most significantly the exchange between Crescent Meadow (originally Stuart Gage) and Sycamore Springs (originally Jack Hines).

D. Equipment

Selection of equipment was based on a choice of professional quality equipment with low noise/high sensitivity/high transparency characteristics. While other types of systems might also be useful, we felt that the combination of the particular mics, recorders, and pre-amplifiers we selected represented the best and most cost-effective for this type of bioacoustic site monitoring. The frequency response of the system ranged from 40Hz – 20kHz. The noise floor is calibrated 12dBA with a maximum level of 134dBA. Other considerations included flexibility of data based on the M-S (Mid-Side) microphone system format (Krause 2002). M-S systems consist of two separate microphone patterns. M stands for Mid, and includes any pattern from cardioid to hyper-cardioid and which provides some directionality. S stands for Side, and includes a figure-eight patterned mic that splays out broad patterned lobes to each side in relationship to the front axis. The five optional results are:

1. Directional information from the Mid microphone;
2. Instantaneous acoustic data from the right and left capsules of the figure-8 microphone;
3. A very robust stereo signal when processed through a M-S matrix (M+S=left channel, M-S= right channel);
4. Where “surround” encoding of aesthetic studio mixes of the data is an option, the acoustic result is represented more dynamically than any other form of stereo, retaining more of the initial integrity of the acoustical signal;
5. If there has been no signal processing of the stereo data, the stereo signal can be reconfigured into its original M-S data format. This option is especially useful when isolation of species-specific data are present on “Mid” channel and need to be analyzed separately, and where the data has been already mixed to stereo and the original M-S recordings are not immediately available.

Each researcher’s recording system included:

1. Sony PCM M1 DAT recorder
2. Sony MDR 7506 headphone
3. Sennheiser MKH 30 (Figure-8) microphone

4. Sennheiser MKH 40 (cardioid) microphone
5. Sound Devices Mix/preamp
6. Rykote mod. Shock mount suspension units w/pistol grip
7. Rykote zeppelin windscreen
8. Rykote high wind cover
9. Tripod (microphone mount)
10. Cables and connectors
11. Misc. (Batteries and DAT tape)

E. Archiving of Data

The data was first transferred from DAT (44.1kHz sampling, 16 bit) M-S to matrixed stereo on both hard drive (.WAV format) and also backed up to stereo-encoded audio CDs. The data are stored in two separate locations for safety. After receiving the CDs, Gage's Lab copied the samples onto its terabyte server, and entered them into the database and digital library, for later publication on the Clickable Ecosystem project's web site.

F. Analysis of Data

Randomly selected 11.5 second biophonic segments were chosen from each of the site recordings. By testing a number of different sample lengths, the period of time represented in each of the 11.5 second spectrogram samples (x axis) was determined to be within the temporal sample length range necessary to reveal the types of bioacoustic signal discrimination extant in a given biophony. The scale of the spectrogram on the "x" axis is germane to what is revealed in terms of discrimination. In the GW Instruments Superscope 5.1 software program used to produce the spectrogram examples in this report, 11.5 seconds across the horizontal width of the image display is the normal default setting. We have experimented with expanding and compressing time over the width of the display from 10 seconds to a maximum of 15 seconds and found that the default of 11.5 was most likely to reveal the discrimination necessary for preliminary evaluation. If the spectrogram across the width of the page length-wise was reduced in time to 10 seconds, the display began to fragment. Conversely, if compressed in time to 15 seconds the image began to appear too condensed. Thus, we picked a relevant interval of 11.5 seconds we felt to be appropriate for the proper visualization of the acoustic data. This visualization allowed us to examine the information in a manner that minimized errors incurred by compression or fragmentation of the signals. Specifically excluded for this preliminary examination were periods of time that featured noise (such as aircraft, automobiles, domestic animals, generators, gun-shots from the NPS practice firing range located within the park boundaries, etc.) occurring at intervals where these recordings took place.

A sample spectrogram typical of each of the 4 landscape/season/time recordings were made for a total of 64 spectrograms (with additional spectrograms for Shepard's Saddle [ShSa] 31B, 33v2. and 43B). One audio CD is included in this package featuring the recordings from which all of the spectrograms were generated. This type of spectrogram analysis is used to identify an organisms' vocal niches and whether a signal is present or not, to show temporal relationships between vocal organisms and to give an indication of density at any given moment. The theoretical basis for this analysis is that a more effective niche partitioning in the samples represents a healthier and more stable the landscape.

The last three objectives noted at the head of this document refer to the utilization of this initial data as a base-line indicator from which to develop a quantitative analysis.

G. Data slating and calibration

Data slating protocol[2] can be found in Addendum 1. Calibration was A-weighted 65dB re –12 on the M1 DAT metering system at the microphone input for the Fall and Winter recordings. This calibrated input allows for a range of signal, both louder and softer, from a basic setting of 65dB level at the mic capsule and a corresponding –12dB DAT recorder meter reading. This provides a range of amplitude (+12 to maximum and approximately –78dB to minimum levels) that prevents fear of over-modulation and thus distortion. Accurate to +/- 3dB, the calibration is A-weighted at 60dB re –12 on the M1 DAT metering system at the microphone input for the Spring and Summer recording series because of increased density and anticipated increased signal levels overall from each of the selected habitats. These calibrations were carried over to the audio CD copies and are consistent throughout as a sound level reference. The calibrations were chosen to accommodate for a range of anticipated signal levels referenced to seasonal biophonies.

Data Interpretation and Analysis

Because we were interested in examining the available biophony of four given habitats, we did not include spectrogram samples that included or featured jet flyovers, light aircraft, automobile traffic, human or domestic animal samples in this report. It should be noted, however, that interference varied between as many as 10 overflights recorded and observed in any given hour to as few as 1 during the periods recorded with an average 1 – 3 aircraft at a time present and usually visible.

Given the limited data collection possible within our time-frame and the margins of human observation (16 periods of data collection within the established protocol and occasionally one or two periods outside of protocol), we are operating on the assumption that the biophonic dynamics (number and amplitude of biophonic and geophonic sounds present at any given time) are only partially represented. The weather was mild and fairly dry throughout our site visits. The spectral analysis was consistent with these meteorological conditions in several respects. Evidence of geophonic activity related to meteorological events (i.e. rainfall, heavy wind, etc.) was minimal in the spectrograms. Based on the limited data collected, we are

[2] Data slating refers to a voice identification by the recordist at either the head or tail of each tape that references types of equipment being used, location, weather and other pertinent information that comprise useful metadata.

unable to predict how different conditions might affect biophonic dynamic (both organism density and amplitude of the biophony over time). Overall, the biophonies appeared to represent a dynamic component of the landscape consistent with those conditions.

The data collected and the preliminary broadband spectrogram analysis, to which the samples were subjected, provides the opportunity to infer certain characteristics of expression within each landscape.[3]

> Spectrogram Identification (for instance BuFl32.1145):
> BuFl = Buckeye Flat (location),
> 32= Spring midday (first number in the series following location connotes the season [1=fall, 2=winter, 3=spring, 4=summer], the second number connotes the relative time of day [1=dawn, 2=midday, 3=dusk, 4=night])
> .1145 = actual time of day (in military hours)
> CrMe = Crescent Meadow
> ShSa = Shepard's Saddle
> SySp = Sycamore Springs
> BK = Bernie Krause
> SG = Stuart Gage
> JH = Jack Hines
> RT = Rudy Trubitt

A. Qualitative Interpretation
Within the current definitions of biophony and geophony, the spectrograms of **Buckeye Flat (BuFl)** indicate that the vocalizations of the American robin (*Turdus migratorius*) and the American dipper (*Cinclus mexicanus*) in BuFl12.1149, BuFl21.0732, BuFl31.0546, and BuFl32.1152, respectively, are expressed in a manner to avoid masking of the nearby stream. Furthermore, in terms of niches, the dipper vocalizations are contained within a range of between 4kHz and 5.5kHz, while the robin's range is contained mostly 2kHz to 3.5kHz range thus demonstrating a possible biophonic relationship in terms of frequency niches. The unidentified vocalization in BuFl31.0546 is of a longer duration of vocalization (nearly .75 seconds) than the other avian species, tends to be more transient in character, and covers an interim range of the audio spectrum between the two other species. It may be significant that during the periods of observation, 43% (7 of the 16 spectrogram audio data samples) of the spectrograms contain no detectable biophonic information at the site of audio data collection. The insect vocalizations in BuFl14.2120, BuFl41.046 (combined with the house finch [*Carpodacus mexicanus*]), BuFl43.2025, and BuFl44.2248, respectively, establish

[3] (Note: the spectrograms, taken from calibrated audio copies, are not, themselves, calibrated. In order to derive patterns of bird and insect vocalization, it was necessary to augment the signal by as little as 400% and sometimes as much as 1800%. Thus, a significant increase in pre-amp and microphone noise may be noticed both in the spectrograms at the base of the image and/or the spectrogram audio data in terms of increased noise on the enclosed CDs.)

their own clear niches within which their vocalizations are unmasked. At Buckeye Flat, while there seemed to be a direct correlation between the ways in which the American robin and dipper voices were articulated in relationship to the stream noise based on what we observed and discovered in our analysis, there was otherwise no dense pattern of biophonic information present consisting of other birds, insects or mammals. This may be due to a number of factors, not the least of which may be the particular nature of the geophonic stream sound heard virtually year round and from recording sites as far as 100 yards from the stream. This tended to mask otherwise audible organism vocalizations. Other contributing factors may have been the site, season, and times of day/night, weather chosen to sample this habitat.

Crescent Meadow (CrMe) audio data suggested a very different scenario. With biophonic data present in 82% of the collection samples, the spectrograms indicated clearly established niche and/or temporal patterns between bird, insect and amphibian vocalizations. Over time, the ranges vary from approximately 200Hz (CrMe12.1113) for flies to around 9kHz for an avian species in CrMe44.2226. Recording at an edge habitat during all data gathering sessions, we found the density of sound at this site to be relatively light. The California tree frog [*Hyla cadavrina*], in CrMe33.1926, between 600Hz and 2kHz vocalizes in a niche just below the robin (2kHz to 3.3kHz). With the exception of 6 military jet overflights per hour on average, there was little anthropogenic sound and almost no geophonic sound to mask vocalization by organisms.).

Shepard's Saddle (ShSa) audio data at this site demonstrated a high biophonic content[4] (94%) based on our sample. The biophonic content level of this site and Sycamore Springs (noted below) were the same during the times we collected data samples and represent the highest of the four sites monitored. The range of audible biophonic data at this site and at times of data gathering was from approximately 200Hz (flies) in ShSa12.1221, to approximately 8.7kHz (unidentified bird) in ShSa21.0739. Biophonic temporal and/or niche patterns can be found in ShSa11.0711, ShSa13.1809, ShSa31A.0550, ShSa31B.0548, ShSa33v2.1849, ShSa32.1256, ShSa34.2249, ShSa41.0551, ShSa43A.2007, ShSa44.2237, and ShSa14.2054. Jet overflights occurred at an approximate average of 6 per hour over the entire 16 hours during which recorded data was gathered.

Sycamore Springs (SySp) audio data at this site also had a high biophonic content (94%). Niche frequency ranges in this series varied from approximately 500Hz (SySp31.0541) with the mourning dove (*Zenaida macroura*), to in excess of 20kHz (unidentified bird) in SySp44.2326. There is some indication of niche temporal and/or frequency presence in SySp12.1131, SySp14.2059, SySp22.1110, SySp23.1727, SySp31.0541, SySp32.1159, SySp33v2.1848, SySp41.0540, SySp42.1139, SySp43.1957, and SySp44,23,26. Jet overflights

[4] *biophonic content* refers to the audible mix of organism voices within a given habitat.

occurred at an approximate average of 6 per hour over the entire 16 hour period during which data was gathered.

B. Quantitative Analysis

The manual processing of acoustic signals has successfully demonstrated our ability to collect quantifiable high-quality hour-long digital acoustic recordings from different habitats at different times over multiple seasons and to interpret them in a manner that provides information on acoustic activity in the system. This application of new analytical techniques utilizing spatial analysis developed in the REAL at MSU allowed us to begin to quantify the relationships between biophonic activity and ecological health.

Stuart Gage worked with Bernie Krause to incorporate the data collected at SEKI into the analysis system developed by Gage and Napoletano for acoustic research in the Muskegon River Watershed Stevenson and Gage (2001). The objective of this undertaking was to incorporate the SEKI data into an expanding effort to quantify acoustic activity in a manner that provides indices of ecosystem functions and human disturbance (Gage, et al. 2001). Gage and his laboratory began developing these indices by quantifying the acoustic activity in the samples through the development of the mean amplitude. Gage then divided the samples into their eleven respective frequency bands for comparative analyses of frequency domains of the acoustic activity in the samples.

a. Total Acoustic Activity Across the Landscapes (0-22.5 KHz)

Table 1 below is the acoustic statistics derived from sonogram samples for each of the locations according to the season. Note that Buckeye Flats contains the largest volume of acoustic activity relative to the other study sites. This was due to the fact that Buckeye Flats' location was in an acoustically active riparian zone. In our samples, Sycamore Spring ranked second in the amount of acoustic activity but contained only 12% (1.66/13.68) as much acoustic activity as Buckeye Flat. Shepard's Saddle and Crescent Meadow ranked third and forth respectively in terms of the amount of information in the acoustic signal. The most acoustically active season during dawn at each of the four sites was fall (Buckeye Flats where the stream sounds were dominant), spring (Shepard's Saddle and Crescent Meadow) and summer (Sycamore Spring). Three sites in our sample illustration were most quiet in winter (Buckeye Flats, Crescent Meadow and Shepard's Saddle) and Sycamore Spring was most quiet in spring.

The variability in the acoustic signal at each location was determined by computing the coefficient of variation (CV=SD/MEAN x 100). The site with the most overall variability was Shepard's Saddle (91%) followed by Crescent Meadow (65%) and Sycamore Spring (57%). Buckeye Flats CV was only 31% but contained the greatest acoustic signal (13.7).

	N	SUM	MEAN	S.D.

Buckeye Flats	47	642.83	13.677	4.2039
Fall	12	245.45	20.455	0.4373
Winter	12	116.86	9.7382	0.2375
Spring	12	152.62	12.718	1.1555
Summer	11	127.90	11.627	0.3022
Crescent Meadow	48	23.059	0.4804	0.3099
Fall	12	6.2928	0.5244	0.4231
Winter	12	2.5487	0.2124	0.1145
Spring	12	8.3456	0.6955	0.1897
Summer	12	5.8719	0.4893	0.2262
Shepard's Saddle	47	46.578	0.9910	0.8958
Fall	12	21.632	1.8027	0.5521
Winter	12	3.3120	0.2760	0.1216
Spring	12	18.492	1.5410	0.8812
Summer	11	3.1413	0.2856	0.4140
Sycamore Spring	48	79.675	1.6599	0.9451
Fall	12	20.936	1.7446	0.8680
Winter	12	13.366	1.1138	0.1365
Spring	12	11.881	0.9901	0.3016
Summer	12	33.492	2.7910	0.8572
All Sites	190	792.14	4.1692	5.8984

Table 1. A sample statistical summary of the amount of acoustic information contained in 190 sonograms sampled from hour long recordings at dawn from 4 SEKI locations at four seasons. Sound samples of 30 second duration were extracted from each hour at 5 minute intervals.

A graphical summary of the amount and intensity of the acoustic signal recorded at dawn at each site during each of the four seasons is provided in the Figs 1a and b). Buckeye Flats, due to the strong aquatic acoustic signal, dominates in terms of total activity when compared to the other three sites (See Fig 1a). When Buckeye Flats is omitted from the graph, the acoustic character of the other three sites becomes more evident (See Fig 1b).

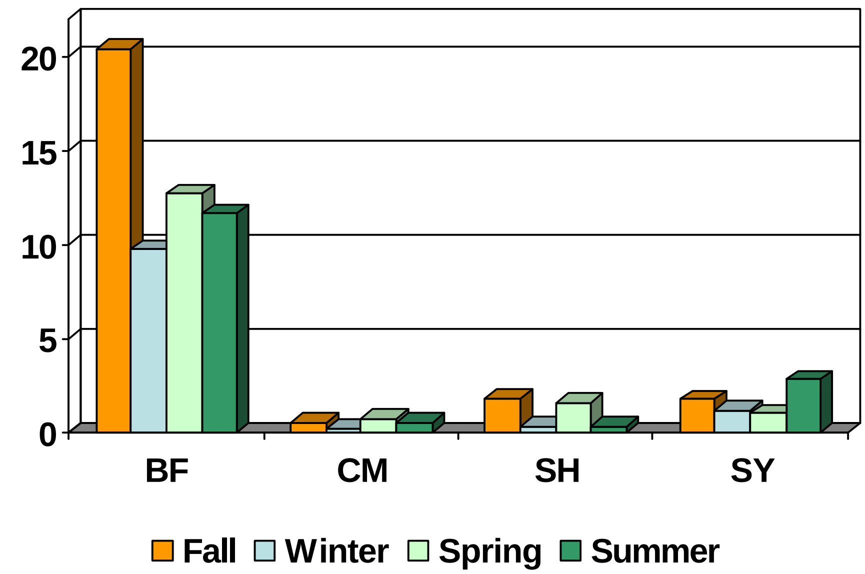

Figure 1a. Acoustic patterns of the dawn chorus recorded in four SEKI sites for 4 seasons (Full sonogram).

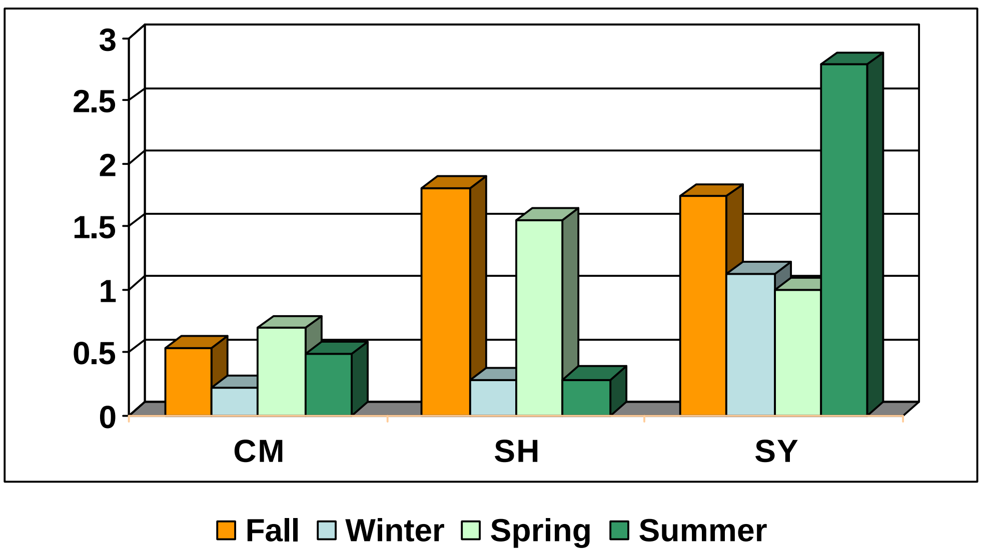

Figure 1b. Acoustical patterns of the dawn chorus recorded in three SEKI sites for 4 seasons (Full sonogram, Buckeye Flats omitted).

Our quantitative analysis provides the means to conduct a statistical comparison of the acoustical recordings made in each of the 4 landscapes. Shown in Table 2 is a comparison of the acoustic values for each season extracted for the spectrograms. Letters associated with the acoustical values represent significance at the 95% confidence level. For example, considering the entire acoustic spectrum, Shepard

Saddle and Sycamore Spring are similar in fall, (b vs. b) different in winter (c vs. b) similar in spring (b vs. b) and different in summer (c vs. b).

Full Spectrum

Season	Buckeye Flats	Crescent Meadow	Shepard Saddle	Sycamore Spring
Fall	20.455a	0.5244c	1.8027b	1.7446b
Winter	9.738a	0.2124c	0.2760c	1.1138b
Spring	12.718 a	0.6955c	1.541b	0.9901b
Summer	11.627a	0.4893c	0.2856c	2.7910b

Table 2. Statistical analysis using Tukey method of means comparison of the four sites across the four seasons for the total acoustic spectrograms.

b. Acoustic Activity Across the Frequency Levels

To determine the degree of biological activity at each of the sites in spring during dawn, the information is computed at each of the eleven frequency classes. The initial signal for analysis has a 22.050 kHz sampling rate. Therefore, the signals have an analytical range of 11.025 kHz, which divides roughly into eleven equal frequency levels (taking into account the low frequency minimum of 20~25 Hz). Each level then is a specific frequency range (i.e. level 1= 0.25 – 1.25 kHz), and level 4 is the dominant biological frequency range (Schafer 1977, 1994) and therefore the criterion for biological activity (3-4 KHz). Crescent Meadow and Sycamore Spring have a peak frequency at level 4. Shepard's Saddle peaks at level 6 but shows an increase in frequency starting at level 3. Buckeye Flats acoustic signal shows a linear decrease quite different in structure and amount of acoustic activity (10 fold greater) than the other locations. In the non-aquatic sites, level 2 (1-2 kHz) is low and provides a useful separation from background and human produced sounds and biological sounds. Level 1 is predominant in at all sites and represents background and human activity sounds. Figure 2 depicts graphical representations of the distribution of acoustic activity.

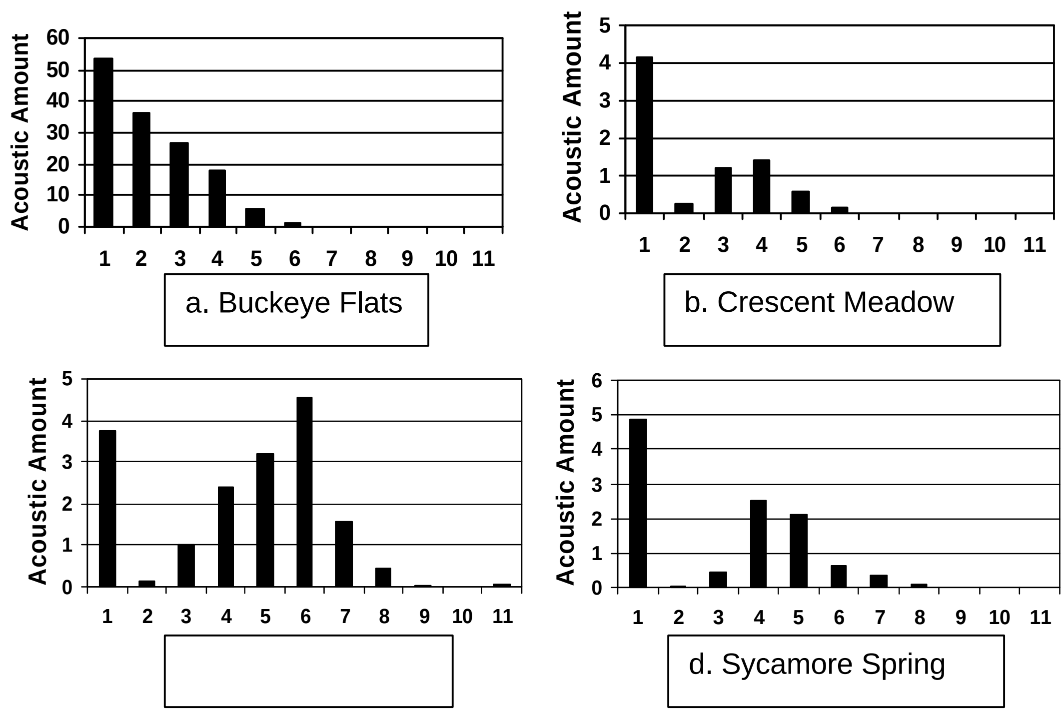

Figure 2 a-d. Distribution of the amount of acoustic information in each 1 kHz frequency class recorded from 4 SEKI locations during dawn in spring.

In this statistical analysis, we compare the acoustical signals for different spectral bands. In band 1 (0-1 KHz) Shepard Saddle and Sycamore Spring are similar in fall (b vs. b), different in winter (c vs. b), similar in spring (b vs. b) and different in summer (c vs. b).

0-1 kHz

Season	Buckeye Flats	Crescent Meadow	Shepard Saddle	Sycamore Spring
Fall	37.945a	4.0925c	12.787b	12.818b
Winter	53.283a	2.1497c	3.0813c	11.358b
Spring	53.883a	4.1327b	3.7631b	4.8709b
Summer	40.429a	1.6757c	0.9259c	8.6276b

2-3 kHz

Season	Buckeye Flats	Crescent Meadow	Shepard Saddle	Sycamore Spring
Fall	28.019a	0.8858b	1.4400b	1.8556b
Winter	15.303a	0.0669b	0.003092b	0.3936b
Spring	27.041a	1.2298b	1.0116b	0.4643b
Summer	23.468a	1.6603c	0.1715d	14.373b

5-6 kHz

Season	Buckeye Flats	Crescent Meadow	Shepard Saddle	Sycamore Spring
Fall	20.043a	0.0339c	1.1258b	0.4309bc
Winter	0.1774a	0.002167a	0.000500a	0.0313a
Spring	1.1597b	0.1698b	4.5473a	0.6385b
Summer	3.6010a	0.0570b	0.0551b	0.0834b

8-9 kHz

Season	Buckeye Flats	Crescent Meadow	Shepard Saddle	Sycamore Spring
Fall	8.7756a	0.004108b	0.1488b	0.0117b
Winter	0.00005000a	0.0000a	0.0314a	0.0128a
Spring	0.0526a	0.0003000a	0.0255a	0.0106a
Summer	0.001855a	0.0000a	0.2650a	0.001808a

Table 3. Statistical analysis of selected frequency levels comparing mean acoustic values with Tukey means separation.

Conclusions:
The use of spatial analysis techniques to process the digital audio files and to produce the images for incorporation into the analysis system enabled the above statistical analysis of the information contained in the sonograms. The frequency statistics (the average and standard deviation of the amount of sound in the image) provided insight into the patterns of sounds observed in the SEKI observation sites. Research conducted by the Remote Environmental Assessment Laboratory (REAL) at Michigan State University on the Muskegon River Watershed yielded a preliminary acoustic analysis infrastructure that aided in the assessment and analysis of the data gathered in this study.

This view of biophony supports the thesis that organism vocalizations within a landscape at dynamic equilibrium will exhibit patterns of clear discrimination between frequency niches and/or temporal slots. The clearer the patterns, the more stable the system.

There are indications from the spectrogram analysis that the birds and insects occupying the riparian Buckeye Flat site where data was gathered not only establish their own vocal niches over time but that these niches reflect a relationship to the white noise characteristics present in the geophony emanating from the nearby stream. Until we have more data from which to make a more thorough analysis from this type of site, we cannot determine with certainty the relationship between organism vocal niches and geophony in this type of complex acoustic environment.

At Shepard's Saddle, aside from clear niche indicators established by birds, insects, and amphibians throughout most of these site samples, the proximity in time of SySa43A.2007 and ShSa43B.2009 (two minutes later) indicates a possible link between the presence of a jet fly-over and the effect of its sound on the biophony. This link may be one of several, although we are not testing for overflight noise effects during this round of analysis. The Shepard's Saddle site seemed to be the richest of the four we chose in terms of the variety and density of organisms as indicated by the audio data collected and the spectrograms produced for this set of data samples. Despite the visible stress on the site landscape by grazing, the spectrograms appear to indicate an overall tendency toward dynamic equilibrium in the system.

Sycamore Springs vocalizations consisted mostly of acorn woodpeckers (*Melanerpes formicivorus*) and occasional common crows (*Corvus brachyrhynchos*) during daytime hours, and a variety of insects and tree frogs at night. The oak forest landscape located near a dry stream bed, in general, exhibited impact signs of domestic animals (mostly horses) and deer, which may have been another contributing factor to the acoustically detectible biophony. Since we have no data to compare "before and after" domestic organism impact, we cannot say, with any authority, what the bioacoustic nature of that impact might be.

Nor do we have published data from other, non-bioacoustic studies, to contrast. Therefore, it would be important to do more data sampling over an extended period in order to establish a bioacoustic site dynamic range for both density and species groupings.

Recommendations

One difficulty encountered during the course of the pilot study was the determination of proper time of season and day to record soundscapes. We attempted to overcome some of the variance by having four individuals record at each of the four locations at the same time of day using the same calibrated equipment. Due to habitat position in the landscape and the diversity of habitats in a large National Park like SEKI, recording during a specific week (i.e. May 11, 2002) and calling it spring has limitations as does a coordinated timing to begin monitoring at 6 AM. For example, spring occurs much earlier at Sycamore Spring that it does at Crescent Meadow, but Crescent Meadow does have an earlier dawn than Sycamore Spring. Given the diurnal and seasonal sensitivity of acoustic events such as the dawn chorus (Kroodsma and Miller 1996), these imperfections in the timing of recordings may result in significant interpretation errors. At higher elevations, the dawn chorus begins earlier than in a valley, of which the high summer acoustic activity at Sycamore Spring is a good example. Human observation determined that the acoustic activity at dawn was actually signals from nocturnal insects, although the coordinated recording time determined that the signals should have been the dawn chorus. Meanwhile, sunrise had already passed at Shepherd Saddle, the higher elevation site.

The best way to circumvent this timing problem is through the placement of stationary automated acoustic recording systems with meteorological tracking capabilities. This would allow us to gather a sufficient volume of information with high temporal capacity and correlate it to the meteorological conditions for comparative analysis.

The second limiting factor in this study has been the amount of labor required for processing and analysis of the information. Without some degree of automation, it would take a researcher one year working12-hour days 7 days per week to produce the information in tables 1, 2, and 3. Fortunately, we were able to utilize the automation system Gage and Napoletano designed for their study in the Muskegon River Watershed. This system, however, is tailored to the MRW data sets, and has limited processing capabilities with the SEKI data. Any further analysis of SEKI data would require changes in the design and development of Gage and Napoletano's program.

To further understand the way that biophony relates to ecological health we will need to conduct additional analyses of the complex spatial characteristics of soundscapes and their relationships to landscapes.

ADDENDUM 1

Recording Slate Protocol
NPS field recordings

<u>Be sure correct (local) time is set on your machine.</u>

Before slate on each tape, record 1k tone for 15 sec. @ -12dB on your recorder as your calibration tone.

Sequoia,	Shepard's Saddle (ShSa) Sycamore Springs (SySp) Buckeye Flats (BuFl) Crescent Meadows (CrMe)
DATE:	(for example: 23 October 2001)
TIME:	(in military hrs. ...0530, etc.)
TAPE:	1 (Fall)...dash...1 (dawn) 2 (Winter)...dash...2 (midday) 3 (Spring)...dash...3 (dusk) 4 (Summer)...dash...4 (evening)

MIC: M-S Sennheiser

RECORDIST:	Gage Krause Trubitt Hines

TEMPERATURE: (in degrees F.)

WIND: (none, light, moderate, heavy)

HUMIDITY: (if known)

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