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Visualization of temporal change in soundscape power of a Michigan lake habitat over a 4-year period

Stuart H. Gage [a,]*, Anne C. Axel [b]

[a] Remote Environmental Assessment Laboratory, Manly Miles Building, Room 217, Michigan State University, East Lansing, MI 48823, USA
[b] Department of Biological Sciences, One John Marshall Drive, Marshall University, Huntington, WV 25755 USA

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ABSTRACT

Soundscape Ecology is an emerging area of science that does not focus on the identification of species in the soundscape but attempts to characterize sounds by organizing them into those produced by biological organisms such as birds, amphibians, insects or mammals; physical environmental factors such as thunder, rainfall or wind; and sounds produced by human entities such as airplanes, automobiles or air conditioners. The soundscape changes throughout the day and throughout the seasons. The soundscape components that create the sound occur at different frequencies. A set of metrics termed soundscape power was computed and visualized to examine the patterns of daily and seasonal change in the soundscape.

Automated recorders were used to record soundscape samples every half hour for one minute duration from six sites on an uninhabited island in Twin Lakes located near Cheboygan in Michigan's northern Lower Peninsula. Each recording was divided into 1 kHz frequency intervals and visualization tools were used to examine the soundscape power in each interval during 48 half-hour time segments from April–October for four consecutive years. Daily patterns of soundscape power change were also examined during the seven month sample period. To synthesize the data set, three dimensional contour plots were used to visualize day of the year (x), time of day (y) and soundscape power (z) for several frequency intervals. A further synthesis was developed to visualize soundscape change using a Normalized Difference Soundscape Index (NDSI) which is a ratio of low to high frequencies.

The visualization of the soundscape revealed discrete patterns in the soundscape including striking changes in the time of the occurrence of dawn and dusk choruses. The patterns in the soundscape were remarkably similar over the four-year investigation. Soundscape power in the lower frequency examined (1–2 kHz) was a dominant feature of the soundscape at Twin Lakes and the low frequency soundscape power was negatively correlated with higher frequency sounds.

The soundscape power metrics and the visualizations of the soundscape produced in this study should provide a means of rapidly synthesizing large numbers of recordings into meaningful patterns to examine soundscape change. This is especially useful because of the need to develop indices of ecological metrics based on soundscape attributes to assist resource managers in making decisions about ecosystem integrity. Visualization can also be of immense benefit to examine patterns in large soundscape time series data sets that can be produced by automated recording devices.

1. Introduction

Ecosystem sounds create a soundscape comprised of acoustic periodicities and frequencies emitted from the ecosystem's biophysical entities (Qi et al., 2008; Schafer, 1977; Truax, 1978, 1999). These sounds are acoustic signals that reflect the dynamics of biological, social, and physical systems of a landscape. Soundscape ecology is "the study of systematic relationships between humans, organisms, and their sonic environment" (Pijanowski et al., 2011a, 2011b; Schafer, 1977, 1994) or "the study of the effects of the soundscape on the physical responses or behavioral characteristics of living organisms in the system" (Truax, 1999).

The types of sound emanating from a landscape depend on land cover type, time of day, and season of the year. Many animals produce sound and use acoustic signals to communicate information such as mating potential, territory size, and potential predation (Bradbury and Vehrencamp, 2011). Increasingly, human activities are dominating our ecological soundscapes. Anthropogenic noise may ultimately disrupt ecosystem function by limiting distribution of some species, and negatively impacting breeding success of others (Krause, 2012; Warren et al., 2006). Vehicular traffic alone is a large contribution to anthropogenic noise in ecosystems. Nearly a quarter of the total land area of the conterminous United States is located within 150 m of a road (Riitters and Wickham, 2003). This figure does not include lands impacted by other forms of transportation including railways, aircraft, and watercraft. Furthermore, the acoustic space of ecosystems is also significantly

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* Corresponding author. Tel.: +1 517 355 2135.
E-mail addresses: gages@msu.edu, stuart.gage@gmail.com (S.H. Gage).

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impacted by machinery related to energy extraction, industry, and residential upkeep (i.e., lawn mowers, snow blowers, leaf blowers).

Acoustic information as an ecological attribute has the potential to increase our understanding of ecosystem change due to human disturbance, as well as provide a measure of biological diversity and its subsequent change over time (Joo et al., 2011; Sueur et al., 2008; Truax, 1984; Wrightson, 2000). Furthermore, the analysis of soundscapes may also produce valuable information on the dynamics of species interactions in heterogeneous landscapes (Carles et al., 1999; Joo et al., 2011; Pijanowski et al., 2011b). Examination of the temporal patterns of the soundscape can provide insight into the timing of the key acoustical events (dawn and dusk chorus), thus enabling assessment of shifts in chorus timing due to changes in climate or disturbance regimes; it may also inform decision makers about the frequency and intensity of soundscape power, thus providing quantitative information regarding noise abatement (Joo, 2008; Joo et al., 2011). Analyzing the patterns of acoustic signals can also provide an insight into phenological patterns, species diversity (Sueur et al., 2008), as well as ecosystem integrity (Qi et al., 2008).

Advances in modern technology and high-powered computation instruments enable novel approaches for processing and quantifying environmental acoustic data (Gage, 2003; Gage et al., 2001; Joo, 2008; Kasten et al., 2007, 2010; Qi et al., 2008; Wimmer et al., 2011) and extracting a variety of ecological information such as species identification (Acevedo et al., 2009; Chou et al., 2007; Kasten et al., 2010; Towsey et al., 2012), diversity metrics (Sueur et al., 2008), and the effects of human noise on natural and human systems (Hannah et al., 1994; Krausman et al., 1986; Neumann and Merriam, 1972; Romano et al., 2004). By advancing our capacity for collecting, organizing and searching large archives of acoustic data, we strive to enable the study of ecological objectives that fall under the soundscape research themes proposed by Pijanowski et al. (2011b). These research themes include questions related to: (1) improving the measurement and quantification of sounds, (2) improving our understanding of spatial–temporal dynamics across different scales and how environmental covariates impact sound, (3) assessing the impact of the soundscape on humans and wildlife, and (4) assessing the impact of human activity on soundscapes.

Automated technologies, such as those developed by Gage et al. (in press), Wildlife Acoustics (www.wildlifeacoustics.com), Procept (2012) (http://www.procept.com.au/customers/organisations/wireless-biophony-sensors), Bedford Technical, 2012 (http://www.frogloggers.com/index.html), and the Bioacoustics Research Program (BRP), Cornell Lab of Ornithology (2012) (http://www.birds.cornell.edu/brp/hardware) enable us to record sounds autonomously by making simultaneous recordings at multiple places throughout the day and across seasons. This technology provides a window on the ecological space-time continuum, and thus provides a tool to obtain data that has long been needed to assess ecological integrity. The objective of this investigation is to visualize temporal patterns in acoustic signals of the landscape during the course of the day (diurnal change) and across seasons to examine changes in the soundscape over time.

To examine this temporal change in soundscape power, we analyzed 1 minute recordings collected at 30 minute intervals from April to October over a four-year period at six locations in a lacustrine forest habitat on an island within a relatively pristine lake. Recordings were not collected from November to March due to inaccessibility of recorder sites during winter conditions.

2. Methods

2.1. Study location

The soundscape analyzed is at the water-vegetation edge of an uninhabited island located on Twin Lakes in Grant Township, in Michigan's northern Lower Peninsula, 20 km south east of the city of Cheboygan, Michigan. The geographic coordinates (latitude and longitude in decimal degrees) of the island center are 45.5401 and −84.2967 at an elevation of 210 m. The island is located within a small residential community with both year-round and summer residents. The island location was selected in particular because there was minimal risk of human interference with acoustic recording devices. None of the recorders was disturbed during this four-year study.

The island vegetation cover consists of a mixture of 50–60 year old deciduous and coniferous vegetations including white birch, trembling aspen, balsam fir, white cedar, tamarack and a few white pines. Extensive wetlands line much of the island's shoreline, and the north-eastern tip of the island overlooks the largest and deepest (30 m) portion of the lakes (Fig. 1).

2.2. Monitoring sites

The soundscape was monitored at six sites on the island. Three sites were established in proximity to the larger wetland areas (Crane Nest Narrows (LA02), Tamarack Flats (LA04), and Cedar Point Bay (LA05)) and three sites were established in proximity to the larger bays Big Lake Point (LA01), Page Bay (LA03) and Godin Circle Bay (LA06).

2.3. Soundscape sampling and data acquisition

Acoustic data was collected at each of the six sampling stations using the Song Meter autonomous recorders (Wildlife Acoustics, 2012). The units were scheduled to record for 1 minute duration every 30 min for a total of 48 samples per day. Recordings were made in monaural at 16 bits in Waveform Audio File Format (WAV) at a frequency of 22,050 kHz, providing a usable frequency range up to 11 kHz. The Song Meters were deployed in April and removed from the sites in October when access to sites became limited by weather conditions. Each unit was secured to a tree with a bungee cord at 2 m height.

A total of just over 202,000 recordings were archived in the Remote Environmental Assessment Laboratory (REAL) at Michigan State University from 2009–2012. A small subset of the recordings were removed from the analysis or were missing for the following reasons: 1) the sensor malfunctioned due to animal damage to the microphone and resulted in recordings of static; 2) the battery died and the recorder stopped recording; or 3) the recorded sounds were inaudible due to sensor malfunction. After filtering unusable recordings, a total of 197,845 recordings, or 97.86% of the observations remained (Table 1).

Recordings were uploaded and archived in the REAL digital library as described in Kasten et al. (2012). This digital library was used to store recordings, compute and display soundscape metrics, and to enable access to soundscape information for subsequent analysis and visualization. Details for uploading, processing, archiving and accessing the soundscape recording and deriving soundscape metrics are described and illustrated in Kasten et al. (2012).

2.4. Soundscape power metrics

Different entities in the soundscape (i.e., birds, amphibians, mammals, wind, and machinery) produce sounds at different frequencies. Therefore, each sound recording was partitioned into 1 kHz frequency intervals. We computed the energy in each frequency interval, termed Power Spectral Density (PSD), as developed by Welch (1967). This measure represents the amount of soundscape power expressed as watts/kHz. The processing module in the REAL web site computed and normalized the PSD value for each 1 kHz frequency interval for each recording, thus providing a soundscape power value ranging from 0 to 1 for each of the 10 frequency intervals (1–11 kHz) (Kasten et al., 2012). We use the term *soundscape power* to characterize this metric. Vector normalization of PSD values provides a standardized PSD (nPSD) which facilitates comparison across recordings made at different locations. Matlab (2006) code was developed to compute nPSD values prior to translating to PHP scripting language for the web. Matlab code