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# Soundscape Dynamics at Anuran Reproductive Sites in Pannonian Biogeographical Region

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**Abstract**

The emerging field of soundscape ecology views ecosystems in terms of biophony, geophony and anthrophony. Soundscape ecology considers the effects of sound on fauna, and this research focuses on anuran breeding lek soundscapes. The sensitivity of anuran breeding leks to acoustic disturbances makes breeding leks an important venue for a comparative soundscape study. We made long-term (> 24 h) sound recordings in three representative wetlands and short-term (< 30 min) recordings in ten sites in the Pannonian Biogeographical Region of the Hungary and Slovakia border. Long-term soundscapes of the floodplain stretch, where there is relatively minor anthrophonical disturbance, showed an obvious circadian change in sound intensities. The site with moderate sound contamination exhibited a disturbed pattern of circadian sound variation, while the site with heavy traffic noise displayed an apparently random temporal soundscape. At different amphibian breeding sites during mating season, our short-term recordings were dominated by anuran calls and wind noise, while bird song, insect calls, and rain were present to a lesser degree. Our study indicates that vehicle traffic noise is a severe imposition to the natural soundscape, and suggests that soundscape monitoring can provide a reliable and sensitive index of environmental change for both short-term and long-term periods.

Key words: soundscape monitoring, anuran breeding site, biophony, geophony, anthrophony.

## Introduction

Soundscape ecology, the science of sound in the landscape, is an emerging field which encompasses the causes and consequences of biological (biophony), geophysical (geophony), and human-produced (anthrophony) sounds (Pijanowski et al., 2011) to understand coupled animal and human dynamics across different scales of distance and time. It is an integrative framework that aims to describe how climate, land transformation, biodiversity patterns, and human activities interact through time to form dynamic acoustic landscapes. Monitoring and studying soundscapes may illuminate physical mechanisms for ecological processes and identify courses of landscape change accurately, sensitively, and economically.

Furthermore, the landscape has been reconceived as a dynamic system composed of matter, structured energy, information and meaning (Cosgrove 2003; Farina 2010), thus expanding upon the more classical, geographical-ecological orientated perspective (Risser et al., 1984; Forman and Godron 1986; Pickett and Cadenasso 1995; Wu and Hobbs 2002; Turner 2005). In detail, sound produced in the landscape derives from various sources including human, weather, geophysical, and bioacoustic sources (Francis et al., 2011). Soundscape ecology overlaps with landscape ecology since some ecological processes occurring within landscapes can be tightly linked to and reflected in patterns of soundcape (Forman and Godron, 1981; Urban et al., 1987; Turner, 1989; Turner et al., 2001; Farina, 2006).

In bioacoustics, four animal taxa are well known for intense acoustic emissions: birds, most anurans, some insects, and a few mammals. Most of these animals produce intense sounds during their breeding seasons to attract potential mates and to repel rivals, and they are usually silent at other times. Those sounds are generally the main components of the local soundscape in areas such as ponds and leks, (Runkle et al., 1994; Catchpole and Slater, 2003; Farina, 2011; Wang JC et al., 2012). The severe consequences of anthropogenic noise on wildlife have been shown recently over a diverse array of taxa (Barber et al., 2010). Nevertheless, ecological changes in response to noise at broad-scales have not yet been examined or tracked over time. In the present study, we compare soundscapes of three wetlands where frogs reproduce in differing levels of anthropogenic noise, and report acoustic analyses of soundscapes at numerous sites around the Pannonian Biogeographical Region.

## Materials and Methods

### *Acoustic recording*

Study areas include floodplains, wetlands and ponds in Pannonian Biogeographical Region in Hungary and Slovakia. Long-term recordings were made at two sites along the River Ipoly (Hugyag and Hont), northeast Hungary and one site at Lake Balaton (Balatonederics). Short-term recordings were made at seven sites in total with some sites containing two ponds (Budapest, Hont, Hugyag, Ipolydamázsd, Ipolyság/Hont, Ipolyszög, Letkés) (Fig. 1).

Long-term acoustic recordings were made with a portable recorder (Sony, Japan) placed in a nearby tree and oriented to the center of the wetland. The recording volume was fixed at the level of 25 and the soundscapes were recorded continuously for more than 24 hours. The frequency response of the Sony recorder was from 100 Hz to 16,000 Hz with the sample rate was set to 44,000 Hz. Fifteen-minute short-term recordings were made with the Marantz PMD670/U1B recorder (USA) connected to an AE3300 microphone (Audio-Technica, USA) at each of ten locations. The recording sensitivity, via the gain knob, was set specifically for each recording to optimize SNR. The frequency response of the Marantz recorder was flat to 20,000 Hz, +/- 0.25 dB. Gain knob settings, address, time, temperature, relative humidity and GPS information were recorded at each site.

### *Data analyses*

For measuring the intensity, creating the sonogram and analyzing the acoustic component, long-term recordings were first segmented manually into sixty-minute sections. Then, the first five-minutes of each one-hour segment was analyzed further. Because the soundscape was changing quite slowly, the five-minute segments represented the complete hour to a large extent.

PRAAT (an open-source program released by University of Amsterdam) was used to measure relative sound intensities in dB and to create sonograms. For intensity measurement, the "To Intensity" function was used with "Down to Intensity Tier" and "Down to Table Of Real" operations. These relative intensity data were saved as txt files which in turn were loaded into MS Excel in order to calculate means for each segment.

PRAAT was also used to create sonograms using the "Analyse Spectrum" function with a Hanning window length of 30 milliseconds. Sonograms were displayed conventionally -- as two-dimensional figures (x-axis: time; y-axis: frequency) with warmer hues indicating frequency-specific energy. Sounds were identified by experimenters through visual inspection of the sonograms and listening to the recordings.

To derive SPL at each site, using the short-term recordings, it was necessary determine the overall sensitivity of the Audio-Technica microphone and Marantz recorder. Since those recordings were made with different gain knob settings, it was necessary to establish the sensitivity of the microphone and the recorder as sounds are picked up by the microphone and digitized by the recorder, and then compare recorded levels to a reference sound level. This was done in two steps – a calibration step, and a measurement step.

In the calibration step, a 1-KHz tone was played into the microphone at 71.3 dB SPL (unweighted), measured by Bruel & Kajer 2250G Integrating Sound Level Meter. Reference recordings were made for a range of recorder gain knob settings ("gain settings") of 3 through 7, in steps of 0.5, and digital RMS levels were computed for each reference recording. Gain settings were plotted against the RMS levels, as shown in Figure 2. An interpolating polynomial (made with Matlab) was fitted to the data to allow computation of digital RMS levels corresponding to the reference 71.3 dB tone for any gain setting between 3.0 and 7.5.

In the measurement step, representative segments of the site recordings were chosen, and average RMS levels were computed for each segment. For each segment, the linear ratio of the segment RMS level to the RMS level of the reference tone recording was computed, taking into account the gain setting used at each recording site. The site-specific unweighted SPL levels were then computed by converting the linear ratios to dB levels, and adding these dB levels to the original SPL measured during the calibration step (71.3 dB). A-weighted SPL levels were computed in exactly the same way, except that the site-specific segments were filtered with an A-weighting filter (in Matlab) before the corresponding digital RMS levels were computed.

## Results

***Different circadian patterns of soundscape***

Circadian soundscape variations were examined at three wetland sites: the Hugyag site, the Hont site, and the Balaton site. The Hugyag site (N 48° 05’ 874”; E 019° 26’ 533”; H 147 m) is located in a remote border area with almost no anthropogenic noise. Similarly, the Hont site (N 48° 03’ 494”; E 018° 58’ 264”; H 119 m) is located along the floodplain of the River Ipoly, near the border between Hungary and Slovakia but, unlike at Hugyag, it is only 120 meters away from highway E77, so there is heavy traffic noise. The Balaton site (N 46° 48’ 231”; E 017° 24’ 226”; H 110 m) is situated along Lake Balaton at Balatonederics, and has a medium level of traffic noise.

The soundscape in Hugyag varied daily in intensity from 50 to 80 dB. The peak sound intensity occurred precisely at 21:30, but no obvious intensity valley could be seen. Low intensities started at 4:30 and lasted to 13:30, with variations between 50.4 and 62.5 dB (Fig. 3A). The relative sound intensities in Hont varied irregularly between 70 to 90 dB (Fig. 3B ). The fact that the minimal intensity in Hont was higher than that in Hugyag was attributed to the difference in high background of traffic noise. At Lake Balaton a 24-hour variation in sound intensities could be found even with masking of the traffic noise (Fig. 3C). Because of the moderate traffic noise, the lowest sound intensity at Lake Balaton was higher than that at Hugyag but lower than that at Hont.

***Temporal changes in biological components***

The dominant species of anuran communities in the Pannonian Biogeographical Region is *Bombina bombina*, a poisonous toad. At Hugyag this species produced advertisement calls nocturnally and diurnally, while circadian variations in intensity peaked around 20:00. The main call energy was concentrated at 470 Hz (Fig. 4A). The species of *Hyla arborea* contributed largely to the soundscape from 21:00 to 1:00, displacing *B. bombina* as the loudest call, with dominant frequency around 2,600 Hz (Fig. 4B). At Lake Balaton *Pelophylax esculentus* and *P. ridibundus* called simultaneously and formed a chorus consisting of two frog species and traffic cars. Interestingly, vocal activities of the two *Pelophylax* species were evoked frequently by the traffic noise (Fig. 4C). Crickets and rain contributed some energy to the soundscape at the Balaton site.

***Varied structures of soundscape at different sites***

Soundscapes at the ten sites in the Pannonian Biogeographical Region show variation in intensity (average, maximum and minimum) and major components (Table 1). For the anuran breeding sites, the principal bioacoustic sources were some anuran species, while birds, insects, and other frogs were minor sound sources (Fig. 4D). Other acoustic sources were direct wind and wind in plants. We found no correlations among biological sounds and environmental elements such as temperature and relative humidity; this was probably due to differences in species composition at each site. Five anuran species' calls were recorded in June in the Pannonian Biogeographical Region: *B. bombina, H. arborea, P. esculentus, P. ridibundus,* and *P. lessonae*, the latter two species contributing only slightly to the soundscapes.

## Discussion

In spatial dimension, a diverse array of sounds produced by mammals, birds, amphibians, and insects might be the main components of the soundscape in forests, grasslands and wetlands (Marler and Slabberkoorn 2004), while the urban soundscapes are composed of sounds generated by vehicles, machines and other human-produced sounds (Botteldooren et al., 2004; Raimbault and Dubois 2005). Abiological parts of the soundscape include gushing rivers flowing over terrain, rain falling through canopies, and wind (Swanson et al., 1988). Time scales of the soundscape vary daily, seasonally and annually in habitats (Tang et al., 2001; Wang et al., 2012), reflecting circadian, reproductive periods, and habitat and/or climate changes, respectively. Soundscapes change dramatically as environments change, and animal vocalizations account for most of these changes. In addition, long-term ecological changes in landscape, e.g., those accompanying desertization, global climate change, construction of transportation thoroughfares and other human activities, are reflected by soundscape changes too.

It is well known that most anurans, if not all, complete for mate selection through vocalization (Kelley, 2004). Wetlands or ponds are commonly leks where anuran vocal advertisement, competition, mating, egg laying, and tadpole development occur. There is usually a high acoustic noise background, since other animals make sounds around these sites. Circadian and seasonal changes in anuran vocalization can be expected in order to mitigate the interference effects of bio-noise.

Many frog-eating waders forage at the sites where we set up our study from 9:00 to 19:00. *Bombina* species secrete poison which protects them from birds, thus allowing this toad to make advertisement calls day and night with a slight decrease during bird predation. *H. arborea*, *P. esculentus* and *P. ridibundus* produced calls most intensively after midnight when birds are at rest. Why these two *Pelophylax* species overlap their calling times, and the breadth of sounds that are observed to elicit calling from the species are both enigmas. At the sites, calling was often initiated by traffic noise, and we could cause males to start calling by orally mimicking their calls.

Man-made noise from vehicles and machines might vary in a circadian rhythm, but not with a seasonal period. No site of nature reserves in the continental US is free from this man-made noise (Barber et al., 2011), and the same is most probably true for Europe. An international road, busy with trucks day and night, crosses the border between Hungary and Slovakia near the Hont site. A national road, occupied with relatively few cars at night, runs along Lake Balaton, while no roads exist near the Hugyag site. Soundscapes at these three sites exhibit different temporal patterns, mostly correlated with the traffic noise. Our study indicates a large influence of noise contamination on the anuran bioacoustic components in the soundscape, which would mask the auditory signals of anurans (Bee and Swanson, 2007). A parallel situation exists for birds (Francis et al., 2011). In general, chronic environmental noise substantially changes animal foraging and anti-predator behavior, reproductive success, and density and community structure (Barber et al., 2009).

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Table 1. Sound intensities and acoustic components of the soundscape recorded at different times from different sites within the Pannonian region.

| Address | GPS | FLAT Weighting | A Weighting | Temper ature | Relative Humidity | Record Time | Major Component | Minor Component |
|---|---|---|---|---|---|---|---|---|
| IPOLYDAMÁSD | N 47° 50' 149"; E 18° 49' 943"; H 105 m | 68.8544 dB | 45.1775 dB | 18.9°C | 71% | 17:00 | Wind, frogs | Birds |
| IPOLYSZÖG | N 48° 03' 704"; E 19° 13' 129"; H 142 m | 65.6312 dB | 56.592 dB | 20°C | 63% | 20:40 | Frogs, birds | Rain |
| HUGYAG | N 48° 05' 867"; E 19° 26' 786"; H 152 m | 51.0225 dB | 53.3395 dB | 18.6°C | 84% | 22:15 | Frogs, birds | Insects |
| HUGYAG | N 48° 05' 877"; E 19° 26' 642"; H 151 m | 61.2634 dB | 57.0121 dB | 16°C | 82% | 22:30 | Wind, frogs | Birds |
| LAKE NAPLAS | N 47° 30' 288"; E 19° 14' 483"; H 121 m | 44.5298 dB | 36.2721 dB | 18.9°C | 72% | 19:30 | Frogs | Birds |
| HONT | N 48° 03' 494"; E 18° 58' 265"; H119 m | 43.305 dB | 32.3396 dB | 24.9°C | 50% | 10:50 | Birds | Frogs |
| IPOLYSÁG/HONT | N 48° 03' 577"; E 18° 57' 299"; H123 m | 49.733 dB | 38.281 dB | 29.4°C | 43% | 12:35 | Wind, birds | Frogs |
| LETKÉS | N 47° 51' 338"; E 18° 47' 561"; H 111 m | 51.0582 dB | 40.1345 dB | 28.4°C | 36% | 14:04 | Winds, frogs | Birds |
| IPOLYDAMÁZSD | N 47° 50' 093"; E 18° 50' 002"; H 109 m | 55.383 dB | 39.5342 dB | 27.6°C | 33% | 15:10 | Frogs | Winds |
| IPOLYDAMÁZSD | N 47° 50' 105"; E 18° 49' 592"; H 109 m | 59.844 dB | 51.4804 dB | 30.8°C | 31% | 15:27 | Frogs, birds | Insects |

Legends

Figure 1. Acoustic recording sites in the Pannonian Biogeographical Region.

triagle: only long-term recording (Balatonederics), circle: only short-term recordings (Budapest, Ipolydamázsd, Ipolyság/Hont, Ipolyszög, Letkés), rhombus: bots types of recording

Figure 2. Plots of recorded root mean square (RMS) in volts to knob settings of the recorder used to compute SPL of site soundscapes.

Figure 3. Circadian changes in sound intensity from three wetlands where anurans reproduce. A. Evident variation in pattern of sine wave in Hugyag; B. Irregular pattern of alteration in Hont; C. A pattern with regular wave disturbed by random noises in Lake Balaton.

Figure 4. Waveforms and spectrograms of advertisement calls from three anuran species. A. Calls of *Bombina bombina*; B. Calls of *Hyla arborea* and *B. bombina*; C. Calls of *Pelophylax esculentus* and *P. ridibundus*; D. Sound recorded from a small pond to show acoustic components. To clearly depict these different vocalizations, sonogram frequencies are from 0 to 5k Hz for A, 0 to 10k Hz for B and C, and 0 to 8.5k Hz for D.