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USE OF ACOUSTIC COEFFICIENTS FOR SOUNDSCAPE ANALYSIS

Art research paper

Contents

Abstract

The work aims to investigate whether contemporary acoustic indicators can be applied to soundscape monitoring with a particular focus on the protection of enclaves of silence present in the urban environments. The study includes the following coefficients: acoustic complexity index (ACI), normalized difference soundscape index (NDSI), bioacoustic index (BI), acoustic diversity index (ADI), acoustic evenness index (AEI). As part of the work, a database of 90 sound recordings was created and subjectively divided into three groups: quiet places, places of entertainment and noisy places. At this stage, it was shown that the most common distinction was between recordings from quiet places and places of entertainment. For the BI coefficient, no group could be distinguished.

Keywords

acoustic complexity index (ACI), normalized difference soundscape index (NDSI), bioacoustic index (BI), acoustic diversity index (ADI), acoustic evenness index (AEI), soundscape and acoustic ecology.

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Introduction

The term soundscape was introduced by Alvin Lucier, but it was actually the composer R. Murray Schafer[1] who defined the concept of the sound environment at a given time and in a given place understood in a holistic manner. The emergence of the concept of 'soundscape' brought to life a scientific discipline that analyses the relationship between humans and their environment through sound.[2] This was followed by the establishment of soundscape ecology, which also deals with the assignment of soundscape to its geographical context. The studies conducted in this field identify anthropogenic and biological sound patterns and the interactions between them. Moreover, researchers emphasise the need to develop tools to study these patterns and their relationship with the environment.[3] The analysis of the entire natural environment in the context of acoustics is defined by the term 'acoustic ecology'. Researchers in this field are organised in two scientific societies: The International Society of Ecoacoustics[4] and the World Forum for Acoustic Ecology.[5] The main area of interest in ecoacoustics is the study of anthropogenic, biophonic and geophonic sounds, as well as their mutual relationships and impact on the environment. One of the tasks of the acoustic ecology is to promote an interdisciplinary approach to the development of tools for data acquisition and analysis by combining competences in microelectronics, signal processing and information technology.

The present paper undertakes the analysis of ninety audio samples. Data was collected in the form of WAV files. Eighty-three recordings from all around the world were downloaded from the BBC Sound Effects website,[6] the remaining ones were recorded in Kraków (Poland) in the autumn of 2021.

The basic tool for analysing the collected data was a library written in the R environment,[7] which enables the calculation of the values of indicators used in acoustic ecology. The established database of sound files was subjectively divided into three groups: quiet places, places of entertainment and noisy places. This division was made by listening to each file and analysing the spectrograms of the recorded soundscapes.

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1   R.M. Schafer, "Muzyka środowiska", transl. D. Gwizdalanka, Kraków 1982, *Res Facta* 9, pp. 288–315; M. Kapelański, "Narodziny i rozwój ekologii akustycznej pod banderą szkoły pejzażu dźwiękowego", *Muzyka*, 50 (2005), no 2, pp. 107–119.

2   S. Bernat, "Perspektywy ekologii dźwiękowej w Polsce", *Problemy Ekologii Krajobrazu*, 25 (2009), pp. 175–182; A. Ozga, K. Czajczyk, D. Mleczko, J. Wierzbicki, M. Nóżka, A. Lyn, J. Idczak, K. Juros, D. Wójcik, "Alternatywne przestrzenie publiczne: Mateczny–Borek Fałęcki: przyszłość dźwięku w mieście", B. Gibała-Kapecka, T. Kapecki (eds), Kraków 2019; B. Gibała-Kapecka, T. Kamisiński, T. Kapecki, *O dźwięku, akustyce i hałasie w przestrzeni miasta*, Kraków 2019.

3   B.C. Pijanowski, L.J. Villanueva-Rivera, S.L. Dumyahn, A. Farina, B.L. Krause, B.M. Napoletano, S.H. Gage, N. Pieretti, "Soundscape Ecology: The Science of Sound in the Landscape", *BioScience*, 61 (2011), issue 3, pp. 203–216.

4   International Society of Ecoacoustics (ISE), website https://sites.google.com/site/ecoacousticssociety/about [accessed: 05/01/2022].

5   World Forum for Acoustic Ecology WFAE, website http://wfae.net/index.html [accessed: 05/01/2022].

6   https://sound-effects.bbcrewind.co.uk/search [accessed: 02/02/2022]

7   L.J. Villanueva-Rivera, B.C. Pijanowski, *Package 'soundecology'*, 5 March 2018, http://github.com/ljvillanueva/soundecology/issues [accessed: 02/02/2022]

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The aim of the conducted research is to verify the usefulness of the method in monitoring soundscapes and specially designed enclaves of silence in cities. Enclave of silence is a space separated from the unwanted sounds of the city. Spaces with such qualities can be created naturally, through the appropriate arrangement of buildings and vegetation in the city.

Due to the rapid development of infrastructure in cities, its inhabitants are increasingly exposed to an unfriendly soundscape, which has a negative impact on their health.[8] The development of research into acoustic ecology can help to design more liveable spaces for urban residents.

Description of indicators used in acoustic ecology

ACI is the index of acoustic complexity. It was developed in 2008 by A. Farina and D. Morri[9] to carry out soundscape analysis from the perspective of birdsong diversity. The definition of this coefficient assumes that biophonic sounds are characterised by a high variability of intensity, while anthropogenic sounds present relatively constant values. ACI is designed to be insensitive to man-made noise interference and the distance of the recorder from the sound source. Studies carried out by the authors of this index in the Tuscan-Emilian Apennines showed a strong positive correlation between the value of ACI and the diversity in the species of birds present in the analysed recordings. This trend increases with the length of the time steps of the samples analysed due to the possibility of including the full singing of a given bird in a longer recording.

ADI [10] is the index of acoustic diversity. Its value increases with the uniformity of the signal for different frequencies. A uniform signal, for example one that is noised over the entire frequency band, will give a high value for this coefficient, while a pure tone (all the energy concentrated in one band) will give a result closer to 0. The highest values of this index occur in the case of recordings with a high content of geophonic and anthropogenic sounds, such as wind or truck passing, or for samples from very quiet recordings representing little variation between the frequency bands. The lowest values were observed for recordings characterised by the dominance of a narrow frequency band, such as the noise of nocturnal insects. According to the study by L.J. Villanueva-Rivera[9] this coefficient can be applied in the frequency range of 0–10 kHz and calculates the Shanon entropy for the given recording. The calculation algorithm involves dividing the frequency spectrum into 10 equal discrete intervals of 1 kHz width and evaluating the proportion of FFT blocks that contain energy above a specified threshold (by default it is 50 dBFS) in each discrete frequency interval.

8   Directive 2002/49/ED of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise.

9   N. Pieretti, A. Farina, D. Morri, "A new methodology to infer the singing activity of an avian community: The Acoustic Complexity Index (ACI)", *Ecological Indicators*, 11 (2010), issue 3, pp. 868–873. doi: 10.1016/j.ecolind.2010.11.005.

10   L.J. Villanueva-Rivera, B.C. Pijanowski, J. Doucette, B. Pekin, "A primer of acoustic analysis for landscape ecologists", *Landscape Ecology*, 26 (2011), issue 9, pp. 1233–1246. doi: 10.1007/s10980-011-9636-9.

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NDSI is the index of normalised difference in soundscape. It enables the determination of the level of anthropogenic disturbance in the soundscape by calculating the ratio of man-made sounds to animal-made sounds in the analysed recording. The NDSI coefficient values at a given location can be variable depending on the time of day and year, so it can be useful for observing changes occurring in the soundscape. The research conducted by S.H. Gage,[11] B.M. Napoletano and M.C. Cooper, which consisted of analysing a number of recordings collected at several locations showed that mechanical sounds occur most frequently between 1 and 2 kHz, while biophonic sounds occur in the 2–8 kHz range. P. Devos assumed in his work[12] a range of sounds emitted by animals in the 2–11 kHz band.[13]

BI is the index of bioacoustics. It was developed by N.T. Boelman.[14] It is calculated on the basis of the occurrence of a spectral power value above the threshold in the frequency band of 2–8 kHz or 2–11 kHz. This is a function of both the amplitude and the number of occupied frequencies in the 2-8 kHz or 2–11 kHz band. It illustrates the bioacoustic activity. The value of the coefficient depends on the quietest discrete frequency interval with a width of 1 kHz. Higher values of this coefficient indicate a discrepancy between the loudest and the quietest range. The highest values of this index were obtained for the sound of cicadas, which are characterised by high amplitude and its minimum variation between the consecutive discrete frequency intervals.

AEI is the index of acoustic evenness[9]. Acoustically rich habitats may represent low values for this coefficient, as there the variation in sound intensity between frequency bands in acoustically saturated landscapes is low. This index is related to ADI, but has an inverse distribution of values: its higher values indicate greater inequality between discrete frequency intervals, while its high values are identified with the dominance of a narrow frequency band. The resulting distribution of the different frequency intervals is indexed with the use of the Gini index. The index ranges from 0 to 1.

Description of the sound samples selected for analysis

The set of the collected sound samples was divided into three categories: quiet places, places for entertainment and noisy places. The recordings mostly came from the Natural History Unit.[15] Sample soundscape recordings classified as quiet places included soundscapes from the following locations:

- St Paul's cathedral in London,

11   S.H. Gage, B.M. Napoletano, M.C. Cooper, "Assessment of ecosystem biodiversity by acoustic diversity indices", *Journal of the Acoustical Society of America*, 109 (2001), issue 5, p. 2430.
12   P. Devos, *Soundecology indicators applied to urban soundscapes*, Conference: Inter Noise 2016, Hamburg, [https://www.ingentaconnect.com/content/ince/incecp;jsessionid=192bkrfsi4e91.x-ic-live-03] [accessed: 02/02/2022].
13   S.H. Gage, B.M. Napoletano, M.C. Cooper, *Assessment of ecosystem biodiversity by acoustic diversity indices*.
14   N.T. Boelman, G.P. Asner, P.J. Hart, R.E. Martin, "Multi-trophic invasion resistance in Hawaii: bioacoustics, field surveys, and airborne remote sensing", *Ecological Applications*, 17 (2007), pp. 2137–2144.
15   BBC.com https://sound-effects.bbcrewind.co.uk/search [accessed: 05/01/2022].

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- African beach on a calm day,

- botanical garden from Oceania,

- Asian forest near the sea,

- Asian meadow at dawn,

- desert in Asia,

- lake area in North America,

- monsoon forest in Asia.

The recorded signals include the singing of different species of birds, the sounds of different species of insects, the sound of the sea, the sound of the wind, the silence in the cathedral and in the library, whispers.

Examples of sound samples classified as places of entertainment include:

- horse racing venue,

- French restaurant,

- bar,

- Barong dance,

- Cameroon music,

- playground,

- excerpts from the festival,

- tribal music in Irian Jaya,

- street music,

- soundscape of the Wawel Hill in Kraków, recordings made by Kinga Sapieja as part of her engineering thesis.

The soundscape of the noisy places included:

- busy street,

- butter factory,

- workshop,

- construction site,

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- motorway,

- car race,

- road works,

- King's Cross railway station.

Indicator analysis with the use of the Kruskal-Wallis test

The calculated acoustic ecology indicators do not come from a population with a normal distribution, which was verified using the Shapiro-Wilk test. The Kruskal-Wallis test[16] was used to verify that sound samples recorded in places characterised by quiet, entertainment and noise were distinguishable. This is a non-parametric version of the classic single-agent ANOVA and analyses more than two groups. According to the documentation, in the MATLAB environment this test assumes that all samples come from a population with the same continuous distribution for observations that are mutually independent.

The null hypothesis and the alternative hypothesis were formulated:

Null hypothesis:

H0: F(x) = F0(x) – all samples come from a population with the same continuous distribution.

Alternative hypothesis:

H1: F(x) ≠ F0(x) – not all samples come from a population with the same continuous distribution.

Conclusion:

In all the cases where the *p* value is less than α = 0.05, it was possible to make a distinction between the adopted groups.

The sound is spatial, which is why the tests were carried out for both right and left channel recordings and for samples created by averaging these channels. In the cases where the *p* value was less than α = 0.05, post hoc tests were performed to show which groups were distinguishable. The results of the analysis are shown in Table 1.

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16   A. BenSaïda, *Shapiro-Wilk and Shapiro-Francia normality tests*, https://www.mathworks.com/matlabcentral/fileexchange/13964-shapiro-wilk-and-shapiro-francia-normality-tests [accessed: 05/01/2022].

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Channel	ACI	NDSI	BI	ADI	AE
Left	No distinction between groups	Distinguishable peace and entertainment	No distinction between groups	Distinguishable noise and entertainment	Distinguishable noise and entertainment
Right	Distinguishable peace and noise	Distinguishable peace and entertainment	No distinction between groups	Distinguishable peace and entertainment	Distinguishable peace and entertainment
After averaging	Distinguishable peace and noise	Distinguishable peace and entertainment	No distinction between groups	Distinguishable noise and entertainment	Distinguishable peace and entertainment

Table 1. Summary of all distinguishable groups for all tested coefficients

Conclusions

ACI is the only index to distinguish between quiet and noise. NDSI coefficient distinguished between recordings from quiet places and entertainment places for each channel and for the channels after averaging. In the case of the BI, it was not possible to distinguish between any of the groups regardless of the channel analysed. The ADI and AEI coefficients distinguished between noise and entertainment or quiet and entertainment depending on the channel studied. The most frequently distinguished groups are quiet and entertainment, and the least frequently distinguished are quiet and noise. In no case were all three sites able to be separated from each other, which means that for further research the sample set needs to be enlarged or research into new coefficients related to acoustic ecology needs to be initiated. After research, it seems that soundscape should be divided into classes in some different way. Classes should be associated with certain groups of acoustic events, such as traffic or street music. However, it is difficult to determine at this point in time how many such groups there should be and which acoustic events should they included. This will be the subject of further work. However, after the conducted research, it is apparent that none of the coefficients mentioned in the article can currently be used to protect the enclaves of silence.

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