EXPLORING URBAN SOUNDSCAPE DIVERSITY IN LARGE METROPOLITAN CITIES: A CASE STUDY OF ATHENS, GREECE

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Abstract

This study investigates the acoustic characteristics of urban soundscapes in Athens, Greece, through the application of four complementary acoustic indices: Acoustic Entropy (H), Bioacoustic Index (BI), Dynamic Spectral Centroid (DSC), and Normalized Difference Soundscape Index (NDSI). A dataset of 36 recordings was collected across diverse urban environments, including traffic-dominated streets, pedestrian zones, and urban parks, and processed under standardized conditions. The analysis revealed distinct spectro-temporal patterns across categories, highlighting variations in soundscape complexity, spectral distribution, and the balance between anthropogenic and biophonic components. Results indicate that the combined use of acoustic indices provides a robust framework for the quantitative assessment of complex urban soundscapes and supports a deeper understanding of their ecological and perceptual dimensions.

Keywords: *Urban acoustic ecology, Acoustic indices, Urban soundscapes*

1. Introduction

A soundscape describes a specific surrounding as a set of both natural and human-driven sounds. R.M. Schafer viewed an environment not only through its visual characteristics but also through its sonic identity. It is well established that it is possible for a soundscape to be constituted by components of different nature [1]. These sources are usually identified by their structure, dynamics, and ecological characteristics [2], and co-exist in order to create a complex and multidimensional environment. The cultural, social, economic, and historical background of a city contributes to the production of a unique soundscape, leading to an acoustic diversity, considering the structure and the morphology of each environment. However, rapid economic, social, and cultural changes seem to have impacted our surroundings, causing changes in the corresponding soundscapes. These changes highlight the need for systematic observation in order to recognize the change, qualitatively and quantitatively analyze it, assess it, and, ultimately, understand it.

Recent developments in eco-acoustic research have identified a variety of acoustic indices as reliable methods for the quantitative assessment of complex soundscape characteristics [3], [4] providing meaningful insights into the qualitative evaluation of the environment [5], [6]. An analysis of 101 environmental soundscape studies revealed acoustic indices to be the most prevalent evaluation method (74.3%), followed by manual audio labelling (23%) and automated call recognisers (14.9%) [7]. However, the existence of over 60 different acoustic indices necessitates the standardization of methods in order to ensure an accurate and reliable representation of soundscapes [3], [8].

Acoustic Ecology has a number of studies focusing on the structure and impact of different soundscapes in modern society from various perspectives. For example, Lin and Lam [9] have examined the acoustic environment of urban open spaces in Hong Kong and suggested that the contextual characteristics and perceived spatial extent of a sound-source within a specific environment are as equally important as its sound level in order to evaluate its quality. In a similar framework, Karapostoli and Votsi [10] note that the scale of observation plays a significant role in feature differentiation within similar acoustic environments. Analyzing a soundscape through soundwalks offers a comprehensive sense of the surrounding field, as it can be perceived in association with the morphology of the urban environment and thus draw attention to its redefining aspects.

Although the sound-marks that shape the acoustic

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identity of an urban environment are mostly generated by human activity, they emerge from the functional use of the city, and dominate in the formation of the acoustic life of the society within it [11]. Natural sounds seem to co-exist with human-driven ones, but prevail only in specific occasions in which the latter are diminished. Overall, sound serves as a key element of an environment's identity, closely linked to its variability and continuous evolution. It creates space for methodical observation and evaluation of the acoustic field, promoting the sustained quality of the acoustic environment and its social dimensions. Hence, soundscape analysis is becoming an increasingly popular research area with active applications in today's society, attracting interest from various scientific disciplines for study and exploration.

This work focuses on the quantitative assessment of the acoustic characteristics of the urban soundscapes of Athens, through the use of four complementary Acoustic indices: the Acoustic Entropy, the Bioacoustic Index, the Dynamic Spectral Centroid, and the Normalized Difference Soundscape Index. The aim is to capture distinct spectro-temporal features of the recorded environments, enabling a detailed examination of soundscape complexity, source dominance, and spectral composition. Such an analysis should reveal how different sound-sources shape the structure of the urban auditory environment of Greece's capital.

2. Urban Soundscape Audition

Listening is a primary, dynamic process through which individuals perceive and interpret their sonic environment, enabling them to decode natural and urban soundscapes. Attentive listening fosters a deeper understanding of everyday micro-events and enhances ecological awareness [12]. In contemporary culture, this is further shaped by the notion of the "overheard", in which listening becomes a socially embedded condition involving both perceiving and being heard [13].

In urban contexts, sound extends beyond background ambience to become an integral component of spatial awareness, shaping atmosphere, rhythm, and social meaning. These characteristics are particularly evident in the urban soundscape of Athens, whose acoustic profile reflects continuous human activity and distinct socio-cultural contexts. Understanding the city depends on identifying sound-marks that define its metropolitan environment [14].

Accordingly, the Athenian listener can extract localized meaning from everyday sounds despite the dominant background of traffic and commercial noise. Green spaces and pedestrian zones form acoustic "pockets" that interrupt the prevailing technophonic landscape, shifting the acoustic structure toward a more human-scale environment and recalibrating the balance between anthrophonic and biophonic elements [15]. Ultimately, the Athenian soundscape illustrates how acoustic variation influences human experience, fostering more meaningful and context-sensitive relationships with the urban environment.

3. Data collection and Standardization

The city of Athens, located in the Attica prefecture, is the capital and the largest city of Greece with a population of 4 million[1]. The Athens Metropolitan Area is the 7^{th} largest Urban Zone in the European Union, covering approximately 400 km^2. It exhibits significant spatial variation, bounded by mountains and characterized by largely continuous built-up areas. Its central municipalities are densely populated, while those located near the mountainous edges have a less compact urban structure, with larger open spaces [16]. Athens has a population of $\approx 664,000$ and extends over an area of 40 km^2. Ongoing urbanization diversifies the urban soundscape, as concentrated human activity, functional networks, and mixed landscape morphology create complex acoustic environments. The city's spatial structure drives variations in dominant sound sources, depending on the dynamic balance between urban fabric and green areas [17].

In order to explore sonic variability in the Athenian soundscapes data collection was performed in diverse locations around the city. The resulting dataset consists of 36 recordings captured at various sites within the urban fabric of Athens, representing the most common sound environments of the city (motorways, pedestrian streets, and parks) and the variations they present (heavy/low traffic, quiet/with amplified disturbance etc.). Audio files were classified into the following categories:

- Heavy-traffic streets: central high-traffic streets
- Light-traffic streets: neighbourhood low-traffic streets
- Regular ambience parks: green areas where natural and human-driven sounds coexist
- Anthrophony-dominated ambience parks: green areas where, due to special occasions, human-driven sounds dominate
- Busy pedestrian streets: central pedestrian streets with high foot traffic and no vehicles
- Music-filled pedestrian streets: pedestrian streets with a strong presence of street musicians

Soundscapes were captured at 96 kHz / 24 bit in First Order Ambisonics (FOA) using a Zoom H3-VR field-recorder. Recording durations lasted 5 to 20 minutes depending on the sonic complexity of each soundscape. Gain levels were manually adjusted in each recording location to account for local ambient sound levels, while in-ear headphones were used for real-time monitoring. Prior to the analysis all files were split into 180 s fragments with no overlap to enhance comparability, high-pass filtered at 170 Hz to remove unwanted low frequency noise caused by the wind [18], and peak normalized at -12 dBFS.

[1]Eurostat: https://ec.europa.eu/eurostat/web/regions-and-cities

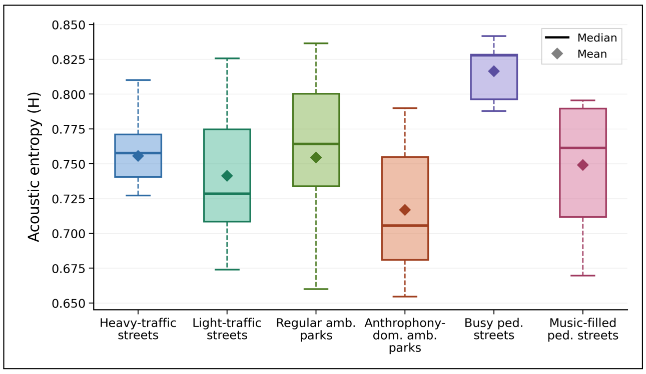

Figure 1: Distribution of the calculated Acoustic Entropy Indices per location category

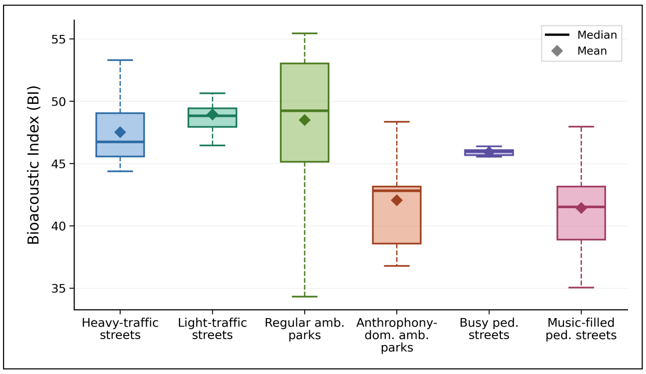

Figure 2: Distribution of the calculated Bioacoustic Indices per location category

4. Soundscape Analysis

For the analysis of the auditory content of these environments, 4 acoustic indices were selected: the Acoustic Entropy Index (H), the Bioacoustic Index (Bi), the Dynamic Spectral Centroid (DSC), and the Normalized Difference Soundscape Index (NDSI). These specialized metrics were considered as the most suitable to highlight the unique spectral characteristics of the Athenian soundscapes and contribute with measurable and comparable data to their qualitative evaluation. All data processing, analysis, and visualizations in this paper were performed in Python, using various libraries including Librosa, Pydub, Matplotlib and Pandas, as well as the FFMPEG framework.

4.1. Acoustic Entropy Index

The Acoustic Entropy Index (H) [18] measures the evenness in the distribution of acoustic energy in the time and frequency domains. Its output ranges between 0 and 1, where 0 represents the simplicity of a pure tone and 1 indicates a complexity and randomness of noise. It is defined as the product of temporal and spectral entropy

$$H = H_t \times H_f \tag{1}$$

where temporal entropy (H_t) and spectral entropy (H_f) are calculated as

$$H_t = -\frac{\sum_{t=1}^{n} A(t)\log_2 A(t)}{\log_2 n} \tag{2}$$

$$H_f = -\frac{\sum_{f=1}^{N} S(f)\log_2 S(f)}{\log_2 N} \tag{3}$$

$A(t)$ is the normalized amplitude envelope in the time domain, $S(f)$ is the normalized mean spectral energy distribution, n is the number of temporal samples, and N is the number of frequency bins.
H was calculated across all data, with the distribution of responses, grouped per category, depicted in Figure 1. As can be seen, H indices across all six soundscape categories fall within a relatively high entropy range, with median values ranging from ≈ 0.72 to ≈ 0.82, indicating sonically rich urban acoustic environments with high complexity. Yet, H values vary systematically across categories reflecting differences in the type and temporal characteristics of the dominating sound-sources. The "Busy pedestrian streets" class exhibits the highest Acoustic Entropy (0.83) and the lowest variability, indicating that the abundance of common anthropogenic sound-sources (mainly voices and footsteps) creates a stable and homogeneous acoustic environment. On the contrary, “anthrophony-dominated parks” (0,71) and "light-traffic streets" (0,73) exhibit the lowest Entropy values, suggesting simpler and evenly distributed soundscapes, with sound-events disrupting the acoustic background. The remaining categories present similar H values and showcase a broader range of entropy.

4.2. Bioacoustic Index

Bioacoustic Index (BI) detects the presence of biophonic (especially avian) activity in the range between 2 kHz and 11 kHz. It is computed as the area under the mean spectrum (above a minimum threshold) within the selected biophonic band

$$BI = \sum_{f=2\,\text{kHz}}^{8\,\text{kHz}} (S(f) - S_{\min}) \tag{4}$$

where $S(f)$ is the spectral magnitude at frequency bin f, and $S_{\min}$ is the minimum dB value of the spectrum [19]. High Bi values indicate avian-rich soundscapes or the constant presence of insects such as cicadas. Low BI values are an expression of poor biophony, often associated with anthropogenic disturbance in the sound environment [20].
As can be seen in Figure 2, the BI analysis differentiates between soundscape types dominated by biophony vs anthrophony in a much clearer manner than Entropy. In general, BI values range roughly between ≈ 35 and ≈ 55, indicating moderate biophonic activity across urban soundscapes, fact which is expected since the said analysis concerns soundscape variations

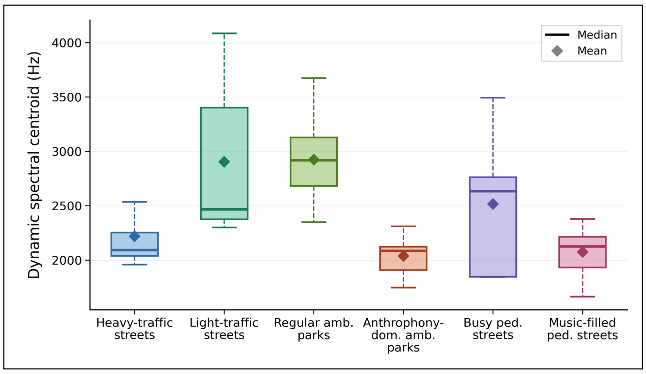

Figure 3: Distribution of the calculated Dynamic Spectral Centroid values per location category

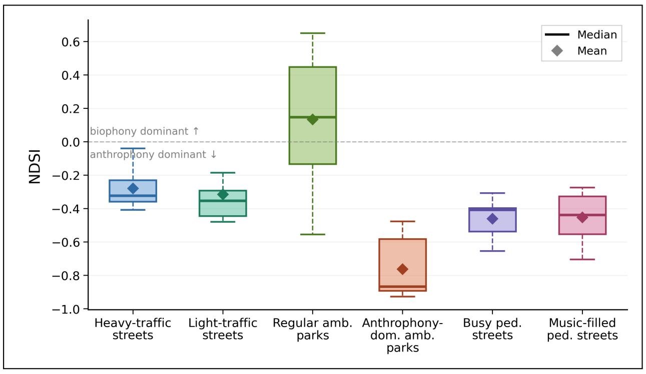

Figure 4: Distribution of the calculated Normalized Difference Soundscape Index values per location category

in a major urban city center. The "Regular ambience parks" category exhibits the highest BI median (48.9), indicating strong biological acoustic presence, followed closely by "Light traffic streets" (48.8), hinting the presence of biological activity in less disturbed urban environments. The observed low BI values of the "Anthrophony-dominated ambience parks" (42.8) and "Music-filled pedestrian streets" (41.5) categories are likely linked to the masking effect caused by the anthropogenic noises that prevail in these soundscapes. "Heavy-traffic" and "Busy pedestrian streets" display intermediate BI levels, implying the persistence of some biophonic activity, even in environments dominated by human and machine-driven sounds. It should finally be noted that Parks exhibit the highest variability in data distribution (std = 5.51), most likely reflecting fluctuations in biological activity over time.

4.3. Dynamic Spectral Centroid

The Dynamic Spectral Centroid Index (DSC) [6] quantifies the frequency point that constitutes the center of spectral energy over time, revealing spectral shifts toward the dominance of either natural sound sources (2 kHz to 8 kHz) or anthropogenic ones (0.1 kHz to 2 kHz). Following [21], the frame-wise spectral centroid was calculated as

$$SC(t) = \frac{\sum_{n=1}^{N} f_n \, S(t, f_n)}{\sum_{n=1}^{N} S(t, f_n)} \tag{5}$$

where f_n denotes the centre frequency of the n-th spectral bin, $S(t, f_n)$ the spectral magnitude at time frame t and frequency bin f_n, and N the total number of frequency bins. The DSC value for each analysed segment was then defined as

$$DSC = \mathrm{median}(SC(t)) \tag{6}$$

DSC values for all audio segments, grouped by category, are shown in Figure 3. They range roughly from ≈1700 Hz to ≈4100 Hz, indicating clear variations in dominant frequency content between soundscape categories. Such variations are characteristic of datasets that contain diverse collections of soundscapes, with DSC values at low-frequencies hinting anthropogenic noise, and others at higher-frequencies implying biophonic or complex acoustic activity. "Regular ambience parks" has the highest median DSC (2919 Hz) implying the strong presence of higher-frequency energy in this soundscape category.
"Light-traffic" and "Busy Pedestrian" streets display the widest distributions, highlighting strong temporal variability in spectral composition. While maintaining equivalent median values (2467 Hz for the former and 2633 Hz for the latter), the distribution of data in "Light-traffic streets" extends towards higher-frequency content indicating that biophonic content is occasionally interrupted by anthrophony (possibly sounds of vehicles and people on the streets), and that of "Busy Pedestrian streets" extends towards lower-frequency content, hinting the sporadic presence of biophonic content in a human-dominated soundscape. The "Heavy-traffic streets", "Anthrophony-dominated ambience parks", and "Music-filled pedestrian streets" categories showed the lowest median DSC values (2093 Hz, 2085 Hz, and 2127 Hz respectively) as well as narrower data distributions, reflecting clear low-frequency dominance in the soundscapes, often associated with the presence of mechanical noise.

4.4. Normalized Difference Soundscape Index

The Normalized Difference Soundscape Index (NDSI) estimates the level of anthropogenic disturbance on a soundscape by computing the ratio of anthrophony to biophony acoustic components. It is calculated as

$$NDSI = \frac{\beta - \alpha}{\beta + \alpha} \tag{7}$$

where β is the acoustic energy in the biophony frequency range (typically 2–8 kHz) and α is the acoustic energy in the anthrophony frequency range (typically 1–2 kHz) [22]. Thus, NDSI ranges from −1 to 1, with higher values indicating a higher proportion of acoustic energy in the biophony band.
As can be seen in Figure 4, all location categories, ex-

cept for "Regular Ambience Parks", maintain negative NDSI values and relatively narrow distributions, confirming the dominance of intrusive human sounds (traffic, voices, music) with the "Anthrophony-dominated ambience parks" category showing the lowest value (-0.87). The "Regular Ambience Parks" category is the only one with a positive NDSI (0.15), and a wide distribution (ranging from -0.56 to 0.65) implying the prevalence of biophony with occasional disturbances by anthropogenic sounds.

5. Discussion

This study focused on the quantitative assessment of the acoustic characteristics of the urban soundscapes in Athens, the capital and largest city of Greece, using four acoustic indices, in order to identify their unique spectro-temporal trends. Thirty-six soundscape recordings were made across the city and grouped into six categories based on their location of capture. The collected data and analysis can contribute to the qualitative assessment of the Athenian soundscapes and provide insights into the city's current environmental conditions.

As seen in Section 4, "Regular ambience parks" stand out as ecologically functional soundscapes within the urban fabric of Athens as they are the only ones with a positive median NDSI value (0.15) and the highest median DSC value (2919 Hz) among all categories. This shows that the spectral presence of natural sounds between 2 kHz and 8 kHz prevails, even marginally, over anthrophony, while the spectral center of gravity approaches 3 kHz, a region that reflects a biophony-dominated sound environment. Nevertheless, the increased variability presented by the NDSI and BI values records the occasional disturbance of these soundscapes by the anthropogenic factor and shows that Athenian Parks are vulnerable to the intrusion of external noise.

"Light-traffic streets" also exhibit a nature-leaning acoustic profile, with the highest median BI (48.8) and the second-highest mean DSC (2904 Hz), indicating an increased presence of bird sounds interspersed with vehicular traffic. This is further reflected in the lower median DSC (2467 Hz), the widest DSC range (2300 Hz–4085 Hz), and a negative median NDSI (-0.35), suggesting that although biophonic activity is relatively high, it remains dominated by traffic noise.

"Busy pedestrian streets" record the highest median H (0.83) with the smallest distribution variability, reflecting a uniform soundscape dominated by a variety of human sounds (footsteps, voices etc.) creating a stable acoustic background without strong spectral events. Yet, the indication of limited, albeit persistent, presence of biophonic activity is supported by the observed BI value (45,95) and the limited variability of the corresponding distribution (std = 0.3).

"Heavy traffic streets" are characterized by intense vehicular traffic which dominates and spreads over an extended spectral field that includes bands far above 2 kHz, the widely adopted threshold between anthrophony and biophony. This observation is important because it can justify the high BI value (47.51) of this specific category, confirming a known limitation of the BI index in separating biophonic sources in environments dominated by anthrophony [23].

"Anthrophony-dominated ambience parks" could reflect the most acoustically degraded category among the six investigated in this study, as it gathers the lowest median H (0.71), DSC (2093 Hz), and NDSI (-0.87) values and the second to lowest BI value (42.8). These results (especially the low H) testify to an unstable soundscape dominated by the irregular presence of intense anthropogenic noises which are imposed against any source of natural origin.

Similarly, "Music-filled pedestrian streets" exhibit an acoustic profile very close to the "Anthropophony-dominated ambience parks" category. They record the lowest median BI (41.5) among all categories, as well as low DSC (2127 Hz) and NDSI (-0.44) values, results that are associated with the masking effect of amplified music that affects the lower to mid-frequency bands and weakens the detection of biophonic sound sources. The somewhat higher median H (0.76) indicates a relatively more stable dispersion of sound events over time, which gives the impression of a more uniform soundscape compared to the previous category.

6. Conclusions and Future Work

This work focused on the assessment of the acoustic characteristics of the urban soundscapes of Athens through the use of four complementary acoustic indices (H, BI, DSC, and NDSI). Their combined analysis provided a comprehensive characterization of the urban soundscape structure. While H values remained relatively high across categories, they were a measure of soundscape complexity rather than a reflection of biophonic presence. A combined index analysis revealed that in several categories this complexity was largely influenced by anthropogenic activity. Yet, acoustic environments with true biophonic presence exhibited more balanced acoustic conditions, despite noticeable temporal variability. There were also environments that reflected a mixture of influences, highlighting the dynamic interplay between nature and human-derived sounds. Overall, these results underlined the importance of multi-index assessment approaches for robust soundscape analyses and characterization.

Future work will expand the dataset to include diurnal and seasonal variations, enabling a more comprehensive understanding of soundscape dynamics. Exploring additional acoustic indices alongside statistical analysis of sound-source annotations could broaden these observations and strengthen the results. Finally, the implementation of some form of perceptual evaluation of the recorded soundscapes could complement the objective analysis and provide further insight.

References

[1] W. Chung and W. To, "Identification of a city's soundscape using soundwalks," *Technical Acoustics*, vol. 35, no. 6, 2016.

[2] C. Guastavino, "The Ideal Urban Soundscape: Investigating the Sound uality of French Cities," *Acta Acustica united with Acustica*, vol. 92, no. 945, p. 951, 2006.

[3] T. Bradfer-Lawrence, C. Desjonqueres, A. Eldridge, A. Johnston, and O. Metcalf, "Using acoustic indices in ecology: Guidance on study design, analyses and interpretation," *Methods in Ecology and Evolution*, vol. 14, no. 9, pp. 2192–2204, 2023. DOI: 10.1111/2041-210X.14194

[4] L. J. Villanueva-Rivera, B. C. Pijanowski, J. Doucette, and B. Pekin, "A primer of acoustic analysis for landscape ecologists," *Landscape Ecology*, vol. 26, no. 9, pp. 1233–1246, Nov. 2011. DOI: 10.1007/s10980-011-9636-9

[5] M. Kotian, S. Biniwale, P. Mourya, Z. Burivalova, and P. Choksi, "Measuring biodiversity with sound: How effective are acoustic indices for quantifying biodiversity in a tropical dry forest?" *Conservation Science and Practice*, vol. 6, no. 6, Apr. 2024. DOI: 10.1111/csp2.13133

[6] R. Benocci, G. Brambilla, A. Bisceglie, and G. Zambon, "Eco-Acoustic Indices to Evaluate Soundscape Degradation Due to Human Intrusion," *Sustainability*, vol. 12, no. 24, p. 10 455, Jan. 2020. DOI: 10.3390/su122410455

[7] K. Turlington, A. F. Suárez-Castro, D. Teixeira, S. Linke, and F. Sheldon, "Exploring the relationship between the soundscape and the environment: A systematic review," *Ecological Indicators*, vol. 166, p. 112 388, Sep. 2024. DOI: 10.1016/j.ecolind.2024.112388

[8] T. Bradfer-Lawrence, N. Gardner, L. Bunnefeld, N. Bunnefeld, S. G. Willis, and D. H. Dent, "Guidelines for the use of acoustic indices in environmental research," *Methods in Ecology and Evolution*, vol. 10, no. 10, pp. 1796–1807, 2019. DOI: 10.1111/2041-210X.13254

[9] H. LIN and K.-c. LAM, "Soundscape of urban open spaces in hong kong," *Asian Geographer*, vol. 27, no. 1-2, pp. 29–42, 2010. DOI: 10.1080/10225706.2010.9684151

[10] A. Karapostoli and N.-E. Votsi, "Urban soundscapes in the historic centre of Thessaloniki: sonic architecture and sonic identity," *Sound Studies*, vol. 4, no. 2, pp. 162–177, 2018. DOI: 10.1080/20551940.2019.1582744

[11] G. A. Güler and A. Ö. Bilen, "Urban soundscape changes in Turkey before and after COVID-19: Eskişehir, an anatolian city," *ArtGRID-Journal of Architecture Engineering and Fine Arts*, vol. 4, no. 1, pp. 30–40, 2022. DOI: 10.57165/artgrid.1070841

[12] D. Brzostek, "Nagrania terenowe jako "techniki siebie"? Wokół etycznych konsekwencji dokumentowania pejzażu dźwiękowego," *AVANT*, vol. 11, no. 3, 2020, ISSN: 2082-6710.

[13] B. LaBelle, *Sonic Agency: Sound and Emergent Forms of Resistance*. London: Goldsmiths Press, 2018, ISBN: 9781906897512.

[14] T. Holmes, "Sound art: Concepts and practices," in New York and London: Routledge, 2022, pp. 28–35, ISBN: 9781138796041.

[15] M. Droumeva and R. Jordan, "Sound, media, ecology: Introduction in three acts," in *Sound, Media, Ecology*, Palgrave Macmillan, 2019. DOI: 10.1007/978-3-030-16504-7_1

[16] A. Faka, K. Kalogeropoulos, T. Maloutas, and C. Chalkias, "Urban quality of life: Spatial modeling and indexing in athens metropolitan area, greece," *ISPRS International Journal of Geo-Information*, vol. 10, no. 5, p. 347, 2021.

[17] D. Markou, "Exploring spatial patterns of environmental noise and perceived sound source dominance in urban areas.: Case study: The city of athens, greece," *European Journal of Geography*, vol. 13, no. 2, pp. 060–078, 2022.

[18] J. Sueur, S. Pavoine, O. Hamerlynck, and S. Duvail, "Rapid Acoustic Survey for Biodiversity Appraisal," *PLOS ONE*, vol. 3, no. 12, e4065, Dec. 2008. DOI: 10.1371/journal.pone.0004065

[19] N. T. Boelman, G. P. Asner, P. J. Hart, and R. E. Martin, "Multi-trophic invasion resistance in hawaii: Bioacoustics, field surveys, and airborne remote sensing," *Ecological Applications*, vol. 17, no. 8, pp. 2137–2144, 2007. DOI: 10.1890/07-0004.1

[20] R. Benocci, A. Potenza, A. Bisceglie, H. E. Roman, and G. Zambon, "Mapping of the acoustic environment at an urban park in the city area of milan, italy, using very low-cost sensors," *Sensors*, vol. 22, no. 9, 2022. DOI: 10.3390/s22093528

[21] G. Peeters, "A large set of audio features for sound description (similarity and classification) in the cuidado project," IRCAM, Technical Report, 2004.

[22] E. P. Kasten, S. H. Gage, J. Fox, and W. Joo, "The remote environmental assessment laboratory's acoustic library: An archive for studying soundscape ecology," *Ecological Informatics*, vol. 12, pp. 50–67, Nov. 2012. DOI: 10.1016/j.ecoinf.2012.08.001

[23] A. J. Fairbrass, P. Rennert, C. Williams, H. Titheridge, and K. E. Jones, "Biases of acoustic indices measuring biodiversity in urban areas," *Ecological Indicators*, vol. 83, pp. 169–177, 2017. DOI: 10.1016/j.ecolind.2017.07.064