Environmental assessment using acoustic complexity indicators

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Abstract The procedure of sound recording offers new perspectives in ecology. Nevertheless, the existing tools that offer high resolution recordings are expensive. The use of acoustic indicators is proposed as an easy-to-use, rapid, non-intrusive, low-cost option in biodiversity assessment as well as in environmental noise management. The purpose of this research is to evaluate and prioritize acoustic indicators in terms of environmental noise management and biodiversity assessment in order to assist the development of a low cost Automated Recording Unit (ARU). The data collection areas are two similar public spaces of Mytilene, with the only difference being a differentiation regarding the levels of urbanization. A series of sound recordings were performed using a specific protocol. Signal analysis was performed using the R Statistics software. A list of spectral complexity indicators were extracted, evaluated and ranked in order for their incorporation to the ARU created. These indicator results were then visualized using the QGiS software in order to produce sound maps. In conclusion, the complexity indicators are the best solution for both biodiversity assessment and environmental noise management.

Keywords: ***Acoustic environment; Soundscape; Biodiversity assessment; Noise assessment; Spectral indicators***

1. Introduction

Acoustic environments are dynamic systems rich in quantifiable material. These sound clues, regardless the human ability of being able to hear them, can reveal several information regarding environmental health. According to the World Health Organization (WHO, 2018), excessive noise exposure can cause mental health problems, hearing problems that impede speech communication, sleep disorders, and even cardiovascular disease. Urban green areas offer a series of ecosystem services to urban dwellers with numerous environmental and social benefits (Kabisch, 2015). Air filtration, microclimate regulation, recreational and cultural value, hydrological services, biodiversity enhancement and noise reduction (Bolund 1999, Elmqvist et al., 2015) are some of the benefits that are attributed to urban green areas (Gozalo et al, 2018). Therefore, their monitoring and preservation are of vital importance (Goddard et al., 2010). Urban form alterations have a direct acoustic impact, highlighting sound as an important tool for detecting environmental differences associated even with climate change (Krause & Farina 2016). The acoustic indicators are great monitoring tool due to their ability to highlight both biological and cultural complexity in an urban system (Kyvelou et al., 2021). Cities are socio-ecological systems and sound can be the medium towards sustainability (Radicchi et al., 2020). Both complexity and biodiversity in cities, meaning the behavioral, biological, ecological, environmental, social and cultural complex nonlinear interactions, can be measured by means of the acoustic indicators (Naeem, 2013; Heymans et al., 2019; Kyvelou et al., 2021). Either intentionally, either as a byproduct, sound can be measured by means of intensity and spectral composition using acoustic indicators. An acoustic indicator can be defined as a statistic that summarizes some aspects of acoustic energy distribution in a recording. The purpose behind the use of acoustic indicators expands from noise monitoring to biodiversity assessment. Alongside the classical ecological indicators, at least 28 different acoustic indicators have been proposed recently (Sueur et al., 2014; Farina, 2014; Krause & Farina, 2016). The concept of noise does not always coincide with the psychoacoustic aspects of sound perception (unwanted sound) but regards all constant sound emissions in terms of time and frequency. The goal of this research is to evaluate and prioritize acoustic indicators in terms of environmental assessment. This prioritization will assist the development of the Automated Recording Unit (ARU) that will be used for environmental noise management and biodiversity assessment.

Amongst the most important and commonly used acoustic indicators are the Acoustic Complexity Indicator, the Acoustic Diversity Indicator, the Normalized Difference Soundscape Index, the L_{eq} noise indicator and the L_{den} 24hour noise assessment index. The Acoustic Complexity Index (ACI) is based on the observation that biotic sounds, such as birdsong, are characterized by a variability regarding intensity, while anthropogenic sounds (environmental noise) have constant intensity values. More specifically, this index calculates the number of large peaks in terms of intensity in a spectrogram (Pieretti & Farina, 2013). Most biotic sounds, unlike most anthropogenic sounds, have an inherent complexity. This indicator calculates the change of recorded intensities in each time-frequency correspondence in a spectrogram, emphasizing the sounds characterized by strong energy differences (intensity), while reducing other sounds with more "stable" energy characteristics. In this way a fast, indirect way of highlighting the complexity of the acoustic environment can be achieved, eliminating steady sounds like most cases of anthropophony and specific cases of geophony (waterfalls). The long-term goal of the Acoustic Complexity Index (ACI) is to be used as a tool for extracting information from an acoustic environment and subsequently identify changes. It also serves as a more efficient and faster monitoring tool regarding animal dynamics in an ecosystem (Pieretti et al., 2011).

2. Methods

2.1. Case study areas and sampling protocol

The case study areas were 4 diverse acoustic environments of Lesvos Island (Greece). The two quiet areas of Mytilene and two areas located in the outskirts of the city were used as case study areas in pursuance of highlighting the strengths and weaknesses of the acoustic indicators (figure 1).

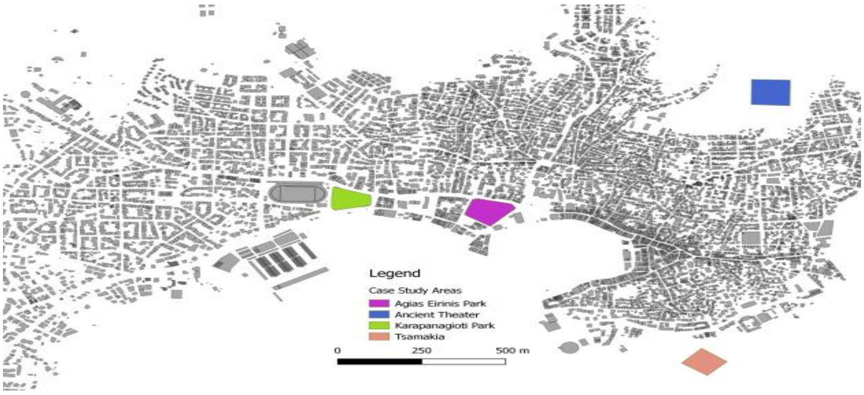

Figure 1. Case study Areas in Mytilene

The dominant vegetation in the case study areas consists mainly of *Pinus brutia* and *Robinia pseudoacacia* resembling similar levels of maturity and canopy. The two quiet areas of Mytilene (Agias Eirinis Park and Karapanagioti Park) are located in a heavily urbanized area of the city's center. Approximately 50 building facades of various uses are located in the west side of the areas. The highest point of these buildings is approximately 20m. The other two areas located in the peri-urban part of the city, are not surrounded by buildings apart from several scarce low height structural characteristics. The dominant bird species in all areas are hooded crows (*Corvus Cornix*) and great tits (*Parus major*). The size of the two urbanized areas is approximately 10.000 m^2, while similar sized plots were chosen in the peri-urban case study areas. All measurements were conducted in the morning time during the bird dawn chorus period (March 2021). For each one of the areas studied, 9 check points were used. In the direction of fully capturing the whole spectrum of sound attenuation in the areas, 8 points were used parametrically and 1 at the core of the area. Due to shortage of sound recording devises the measurements were conducted separately for one day in each area (4 days in total). The sound files collected were processed in order to determine acoustic indices using the R statistics software and the associate packages Seewave, TuneR, Ineq and Soundecology (Villanueva-Rivera et al., 2011; Zeileis & Kleiber, 2014).

2.2. Sound mapping

The QGiS software was used with regard to visualize the propagation of the Acoustic Complexity Indicator. Using inverse distance weighted interpolation (IDW) a cartographic representation for ACI was produced, generating sound maps. The indicator was calculated and imported as a feature into the digitized 9 sampling points of each area under consideration.

2.3 Automated Recording Unit (ARU) Development

The development of the Automated Recording Unit (ARU) constituted a pioneering milestone towards the further development upon the aspect of sound recordings. The versatility and expandability of the module eases the possibility of incorporating novel characteristics such as automated Live Data Feed, remote monitoring, in situ administrating, high level of automation and substantial autonomy. Furthermore, the low-cost development of the specific rig in relation to the commercially available such devices, provides the springboard for knowledge dissemination which may result to the beginning of venture that might allow its use from a broader scientific audience.

3. Results

A thorough evaluation regarding the acoustic indicators mentioned has led to a prioritization regarding their effectiveness in environmental assessment. Previous research has concluded that the Acoustic Complexity Index (ACI) poses as an ideal orientor for biodiversity and environmental assessment (Korkontzila et al., 2020; Matsinos & Tsaligopoulos, 2018; Tsaligopoulos et al., 2018, 2019). Therefore, due to the symbiotic relationship of ACI and biodiversity, along with its effectiveness in describing the cultural complexity of an acoustic environment (Tsaligopoulos et al., 2021) has led to the decision in incorporating ACI as an ideal outcome through the proposed ARU.

The Raspberry Pi ® Boards are small, single-board computers, and were a key part of the automated recorders built. Their high computing power combined with their minimal volume and low power consumption (just 4W) makes them an ideal tool. The combination of these computers with the ConnectAUDIO2/4Audio/MIDI interface sound card, extended the capabilities of the Raspberry Pi ® Boards as enabled a xlr connection with phantom power directly from the usb port of the board, thus solving multiple power supply problems and thus of connection with high-response condenser microphones. Therefore, the device achieves the desired result of high-resolution audio recording (high-res audio up to 24-bit / 192KHz).

To facilitate the in situ management of the Raspberry Pi ® Board, a 7-Inch LCD Touch Screen was connected to the Raspberry Pi ®7-Inch LCD Touch Screen Case, which allows for limited on-site customization.

The power supply is based on the use of a battery ups (7.2 AH) which, given the low consumption, gives great autonomy to the device (figure 2).

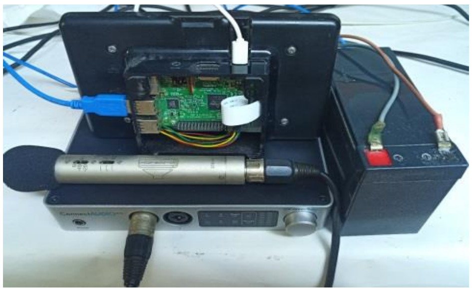

Figure 2. Raspberry Pi ® Board in combination with ConnectAUDIO2/4 Audio/MIDI interface sound card and external microphone

The housing of the device was based on the use of a metal lockable postal letterbox (ELTA), which was modified in order to protect the device from harsh weather conditions, vandalism or theft and also to allow the necessary ventilation of the equipment along with an external access to the microphone.

The recordings made were processed and the ACI levels were produced. By utilizing these results 4 sound maps were exported (figure 3).

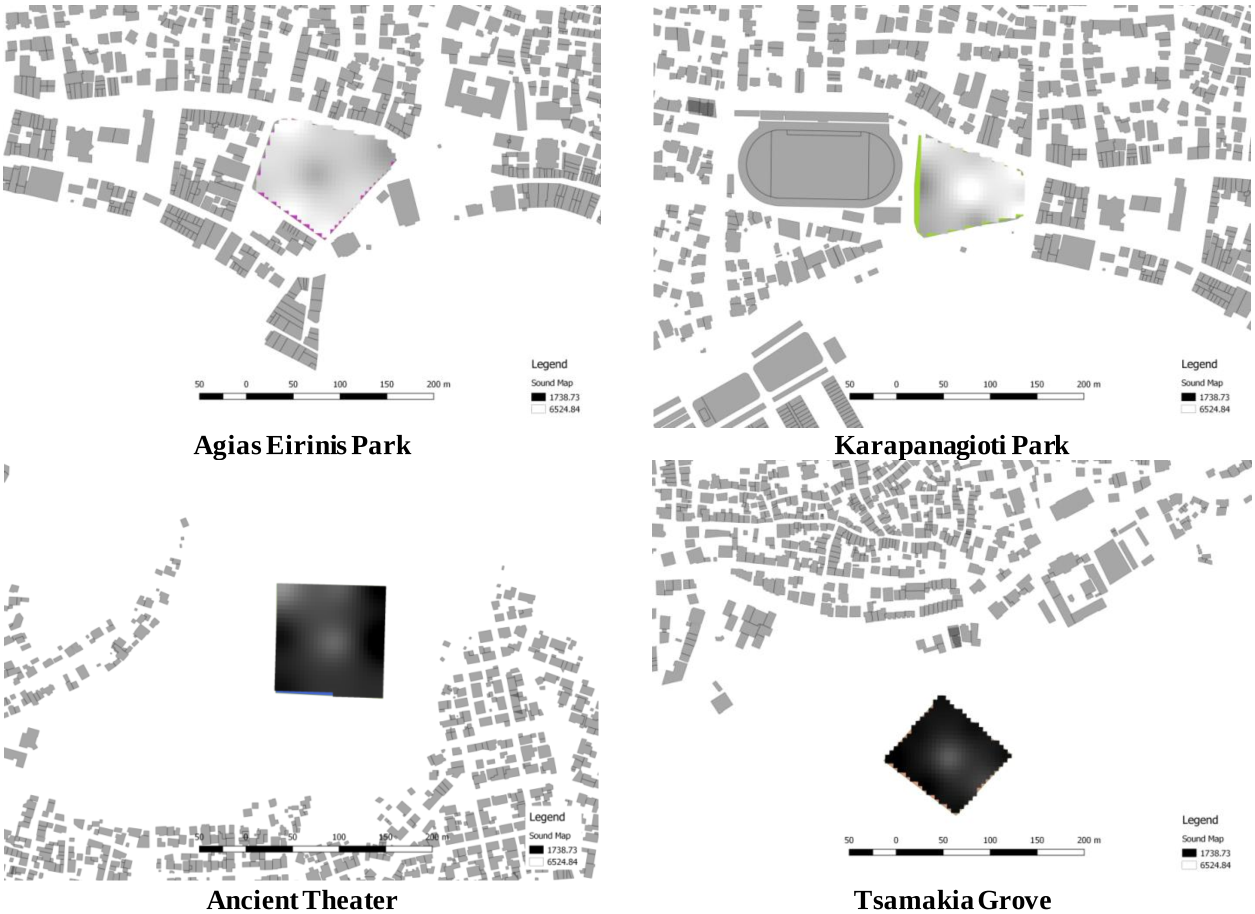

Figure 3. Sound maps of the 4 case study areas. Light colors represent higher levels of complexity, the highest level being 6524 units and the lowest 1738. The peri-urban areas (Ancient Theater and Tsamakia Grove) present lower bio-cultural complexity levels due to the lack of sound intensity variability

The areas located on the outskirts of the city, present lower levels of acoustic complexity. These conflicting results probably occurred due to the ACI's capability of incorporating wider spectrum of acoustic elements deriving from the acoustic environment that fall out of the scopes of biodiversity assessment.

4. Conclusions

The sound maps created highlighted the acoustic complexity levels amongst 4 areas that differ regarding their urbanization levels. We concluded that the Acoustic Complexity Index poses as an excelent orientor of the acoustic environment that incorporates both, biological and cultural complexity. Nevertheless, an assessment using a classical ecological approach in combination with an acoustical one, utilizing the benefits offered from the ARU created will be conducted.

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