EXPLORING THE ACOUSTIC FOOTPRINT OF TOURISM: SPATIAL CAPTURE, ANALYSIS, AND PRELIMINARY EVALUATION OF THE NAXOS' ISLAND SOUNDSCAPE

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ABSTRACT

This study delves into the soundscapes of Naxos, Greece, through the systematic analysis, and evaluation of auditory content, recorded in various locations across the island. The work examines the influence of tourism on the acoustic environment, utilizing FOA recordings and sound pressure level measurements captured across 84 locations. The collected data is grouped per geographical location into six regions to facilitate analysis and comparison of the different soundscapes. The analysis highlighted the impact of human activity, especially tourism-related, on the auditory environment, with mechanical sounds being more prevalent in areas of high tourist activity than in quieter regions. The findings are presented through an interactive application that enables immersive listening with 3D audio technologies, allowing users to experience the spatial characteristics of each soundscape. This research highlights the impact of tourism on Naxos' acoustic environment and aims to preserve its sound heritage, raise environmental awareness, and motivate local stakeholders to take action.

1. INTRODUCTION

Since its inception in the early 1970s by R. Murray Schafer [1], the term "soundscape" has instigated a significant shift in the interdisciplinary field of acoustic ecology, illuminating the intricate relationships between sound and environmental dynamics. From the outset, the field has emphasized the perception and interpretation of sonic environments, underscoring their profound significance to both individuals and societies at large [2]. The legitimacy of the field was further strengthened by the International Organization for Standardization's (ISO) technical committee on acoustics, which formally recognized soundscapes as a perceptual construct —describing them as "the acoustic environment as experienced, perceived, or understood by a person or people, in context" [3]. This recognition by the ISO emphasizes the integral role of soundscapes in assessing auditory experiences within environments, extending beyond basic acoustic analysis to embrace cultural, ecological, and subjective dimensions. It suggests that soundscapes are perceptual constructs rather than mere physical phenomena, thus distinguishing them from acoustic environments. Soundscapes, encompassing the sounds emanating from a landscape, reflect vital ecosystem processes and human activities [4] and serve as a medium through which coupled natural-human dynamics across varied spatial and temporal scales can be understood [5].

Globally, regions undergo rapid transformations due to natural occurrences or economic development, influencing the environment, wildlife, and human endeavors, among others. A direct consequence of these rapid transformations is the modification of the original soundscape. Soundscapes, defined as the auditory environments perceived and experienced by an individual or society, underscore the intricate interplay between natural and anthropogenic sounds. Thus, acoustic ecology, rooted in the concept of the soundscape, provides a vital framework for understanding how human activities impact the environmental acoustics of a place (e.g., [6, 7, 8]).

Known for its attraction to tourists, the island of Naxos is characterized by a diverse range of geomorphological features, climates, patterns of domestic life, tourist facilities, and agricultural activities, all of which contribute to its intricate soundscape. In these areas, where the rapid expansion of tourism may have an influence on the environment, acoustic ecology equips us with an extensive array of tools for examining these effects. It focuses on the ecological processes and human-related activities, notably tourism, that sculpt an area's soundscape, thus facilitating the evaluation of tourism's acoustic repercussions [9, 10, 11, 12]. Moreover, investigating the impact of human activities on soundscapes enables the estimation or simulation of traditional soundscapes before they were altered by human intervention, underlining the necessity of preserving acoustic heritage and advocating for the crucial role of soundscapes in environmental conservation and cultural sustainability [13, 14, 15, 16]. Through meticulous soundscape analysis, researchers are able to identify and document the acoustic footprints left by tourism —crucial for devising strategies to mitigate adverse effects and safeguard the unique sonic identities of places like Naxos. Additionally, the perception of soundscapes profoundly influences the overall tourist experience [17, 18, 19].

While traditional audio technologies have been largely centered on capturing and reproducing the temporal characteristics of the sounds that make up a soundscape, it has become increasingly clear that the spatial attributes of a soundscape are crucial for achieving accuracy and realism, as well as enhancing the immersive experience during playback [20, 21]. The evolution of spatial audio technologies offers promising avenues for the field of acoustic ecology, introducing sophisticated spatial recording tech-

niques such as binaural [22] and ambisonic recordings [23, 12]. These advancements not only facilitate a more holistic capture of the soundscape's essence, but also align with the interdisciplinary narrative set forth by acoustic ecology.

This paper examines the soundscape of Naxos. It extracts and categorizes the sound events from the recordings and explores correlations between the auditory content of the landscape and anthropogenic activities, particularly those related to tourism. Additionally, it provides an overview of an interactive tool that uses spatial audio technology to offer an immersive auditory experience through the aforementioned recordings.

2. METHODOLOGY

2.1. Data collection

In order to ensure a comprehensive representation of the island's soundscape diversity, a total of 84 unique sites were identified for recording. These sites, strategically distributed across the island, include a variety of environments, such as villages of varying sizes, beaches, tourist hot-spots, archaeological sites, and infrastructure projects. The resulting soundscape recordings were organized into six geographical clusters, based on location, accessibility, as well as tourist development. The categorization was informed by discussions with local residents, facilitated by one of the authors who is also from the area. This approach not only simplifies the analysis of spatial distribution, but also approximates the influence of tourism on the authenticity of the soundscape, based on the estimated visitor numbers in these areas.

More specifically, the Chora (City) of Naxos, like other Choras in the Cyclades islands, is the most populated site. During the summer, tourists prefer to stay in Chora or in the southwest part of the island, where the beaches are more accessible and more tourist accommodations are available. Additionally, Central and Northeast Naxos have many villages that are popular to tourists in contrast to those in Southeast and Northwest Naxos. These six groups organized according to the level of touristic activity are presented in the following list according to the numbering and color of Fig. 1.

- High touristic activity
  - Naxos Chora - main town: Positions 1-6, red color
  - Southwest Naxos: Positions 72-84, orange color
- Medium touristic activity
  - Central Naxos: Positions 7-20, yellow color
  - Northeast Naxos: Positions 55-71, purple color
- Low touristic activity
  - Southeast Naxos: Positions 34-54, green color
  - Northwest Naxos: Positions 21-33, blue color

The recording sessions were conducted from July 7^{th} to August 21^{st}, 2023, within the hours of 12:00 PM to 6:30 PM. The duration of each recording ranged from 5 to 20 minutes. During the recording sessions, one of the authors was present to identify and document the sound sources in real-time, a standard practice in the fields of soundscapes and soundwalks. To verify the accuracy of these labels, the same author later reviewed the binaural renderings of the recordings, ensuring that all audible sound sources were correctly identified and labeled. Following this verification, the sounds were systematically organized into categories, which were then grouped into broader classifications, creating a hierarchical structure. This structure is divided into four top-level groups: Human, Nature, Mechanical, and Music, following the classification scheme proposed by [24].

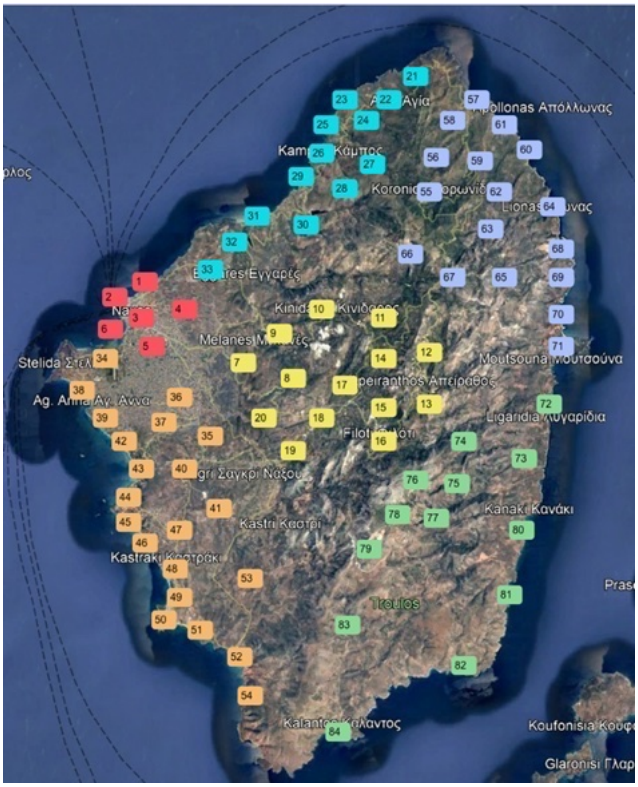

Figure 1: Map of the Naxos island showcasing recording locations, indexed and color-coded by group.

2.2. Recordings

The soundscape recordings of Naxos were captured utilizing the First Order Ambisonics (FOA) technique. This method was chosen for its versatility in enabling immersive playback across various audio configurations, including binaural, 5.1 surround, and custom multi-speaker arrays. Recordings were made with a Zoom H3-VR field recorder, employing its integrated Zoom Ambisonics Player software. To maximize the capabilities of the recording equipment, we opted for the highest available sample frequency (96 kHz) and bit depth (24 bit). Naxos's windy conditions necessitated additional measures to mitigate wind noise during recordings. To this end, a Zoom WSU-1 hairy windscreen was employed, which significantly reduced wind noise. For the measurement of Sound Pressure Level (SPL), the INGCO HETSL01 digital sound level meter was selected, enabling the documentation of maximum and minimum sound levels (dB A-weighted) during each recording. The high temperatures in the island prompted the development of a customized sun-proof setup. This setup involved a large hat-like cover placed several centimeters above the recording equipment, to ensure minimal impact on the sound quality of the recordings.

To maintain consistency and stability in data collection, both the free field recorder and the sound level meter were secured on

Figure 2: Soundscape recordings and measurements across the Naxos island.

a tripod or other firm surface. Prior to conducting measurements, the gain settings on the free field recorder were adjusted according to the ambient sound levels of each location. Quality control of the recordings was maintained through real-time auditory monitoring via in-ear headphones. This allowed for immediate interruption and resumption of the recordings if unexpected noise threatened to degrade the targeted sound quality. This monitoring process enabled detailed documentation of individual sound sources within the soundscape. Each recording session was complemented by a photograph of the surrounding landscape and the precise coordinates provided by a GPS geo-tracking device. Characteristic examples of the recording process are depicted in Fig 2.

2.3. Interactive application

The entire collection of recordings is accessible via an engaging interactive application prototype, created in Max/MSP, that allows users to explore a map of Naxos and select from one of the 84 recorded locations to listen to. For an immersive auditory listening experience that captures the spatial essence of the sounds, the Ambisonics B-format recordings (AmbiX) were decoded into binaural format using the dearVR AMBI MICRO VST plugin. The current version of the application is designed for static listening conditions. However, it can be enhanced to support dynamic head tracking in the binaural rendering process, accommodating changes in listener orientation. Additionally, to account for individual differences in auditory spatial perception, which are influenced by each user's unique morphological characteristics, the application can be extended to incorporate personalized Head-Related Transfer Functions (HRTFs) in SOFA file-format. These modifications allow for a more realistic auditory experience, tailored to each user.

Fig. 3 holds a snapshot of the application user-interface. Upon selecting a site, users are presented with its landscape image (top left), a real-time level meter showing sound pressure level fluctuations (highlighted in green in the center), and a spectrogram (bottom left). Supplementary information concerning the location name, the date and time of the recording, and the maximum, minimum, and average sound levels (dBA) are displayed in an yellow box at the bottom center screen, complemented by a map of Naxos (positioned on the right side). Users can interact with the recording through play, pause, resume, stop, and restart functions, as well as manage the audio level using a gain slider. They can also seamlessly transition between soundscapes at will, simply by selecting a new recorded site and clicking on it on the map.

3. NAXOS SOUNDSCAPE OVERVIEW AND ANALYSIS

As outlined in the methodology section, the sounds of the recordings were identified and noted as individual events during each recording session, without regard to their duration. Fig. 4 presents a comprehensive list of all individual sounds in the recordings in the form of a word cloud. The sounds are color-coded as follows: Human sounds in blue, Nature sounds in green, Mechanical sounds in gray, and Music in yellow.

The most common sound source identified on the island is Voices, clustered under the Human category. However, Nature sounds, such as Wind, Sea, or Cicadas, emerge as the most prevalent when combined together, constituting 53.68% of the soundscape of Naxos. Despite the Mechanical category having the largest number of unique sources, such as Motor Vehicle and

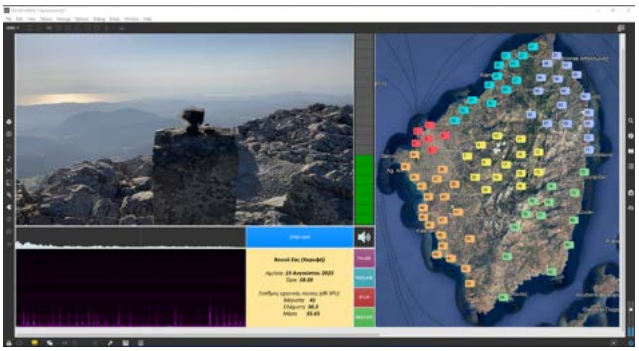

Figure 3: Overview of the application UI, featuring a landscape photo, live sound level meter indications, spectrogram analysis, detailed information box, the map of Naxos, and interactive navigation controls.

Restaurant ambience, it is not as prevailing, comprising only 23.16% of the soundscape. The Music category has a negligible number of occurrences, accounting for only 2.32% of the sounds. Sounds under the Human category account for 20.84% of the recorded content. This suggests that sounds produced by human activity (Mechanical, Human, Music) comprising 46.32% of the total are slightly less common in the soundscape of Naxos compared to Nature sounds alone (53.68%). It is worth noting that these recordings were made during the island's high tourist season, when one would expect human-related sounds to be more dominant. While human and tourist activity indicated by sounds such as Luggage and Beachware, are indeed present and quite prominent in the recordings, based on the collected data, the Naxos soundscape does not appear to be dominated by them.

3.1. Soundscape and human activity

As mentioned in 2.1, the collected data was organized into six geographical regions: the Chora of Naxos (west), Central Naxos, Southwest, Southeast, Northwest, and Northeast. In order to gain more insight into the distribution of observed sound sources and facilitate soundscape content comparisons across the island, data from each region was organized in charts as seen in Fig. 5. As can be observed, in the Chora of Naxos, Mechanical sounds appear to dominate the soundscape, accounting for 46.34% of the auditory content, with Motor Vehicle sounds alone, being the most prevalent source in this category (31.58%). Human sounds, such as Footsteps and Voices, account for 29.27% of the recorded sounds, while Nature sounds make up 17.07%. Music is the least commonly identified content, being observed only 7.32% of the times. It is noteworthy that, despite the prevalence of music in restaurants and bars, it is not a significant contributor to the overall soundscape. This could be attributed to the low playback levels of music, which made it easier to be masked by other sounds. This observation is most likely related to the timing of the recordings, which were conducted in the afternoon when the island's rhythm shifts towards the beaches, and shops/cafes/restaurants either do not play music or opt for low playback levels, diminishing the impact of music on the soundscape.

The Chora of Naxos serving as the capital town of the island, is home to approximately 45% of its permanent residents (19597 individuals) [25]. The remaining of the island is composed of

Figure 4: Word Cloud Representation of sound sources recorded in Naxos, color-coded as follows: blue for Human, green for Nature, gray for Mechanical, and yellow for Music.

smaller villages, such as Filoti in Central Naxos, which is the next most populous area after the Chora, accounting for 8% of its population. Therefore, Music, Human and Mechanical sounds in the Chora can be attributed to both residents and visitors. However, the extent to which each of the two contribute and/or affect the soundscape of the Chora is hard to be determined.

Moving to the Southwest part of the island, where most of the popular beaches are located, we observe a content shift in the soundscape. Mechanical sounds account for 30.19% of the soundscape, with Motor Vehicles continuing to be the most prevalent source of this category. Human sounds make up 27.36% of the auditory content indicating a significant presence of tourist activity, while Music, although still a minor auditory component, occupies 3.77%. Nature sounds emerge as the dominant category, accounting for 36.86% of the soundscape, and include sources such as Sea, Rustling Leaves, Wind, and Wild Birds. This region differs significantly from the Chora in terms of population, housing only about 20% of the island's permanent residents [25]. Additionally, the real estate in this region is considerably smaller featuring numerous tourist settlements, restaurants, and beach bars. This suggests that the sounds primarily associated with human activity, which account for 61.32% of the soundscape in this region, are more closely correlated with tourism. This is further evidenced by the prevalence of specific sounds such as Beach-ware or Restaurant ambience, which underscore the significant impact of touristic

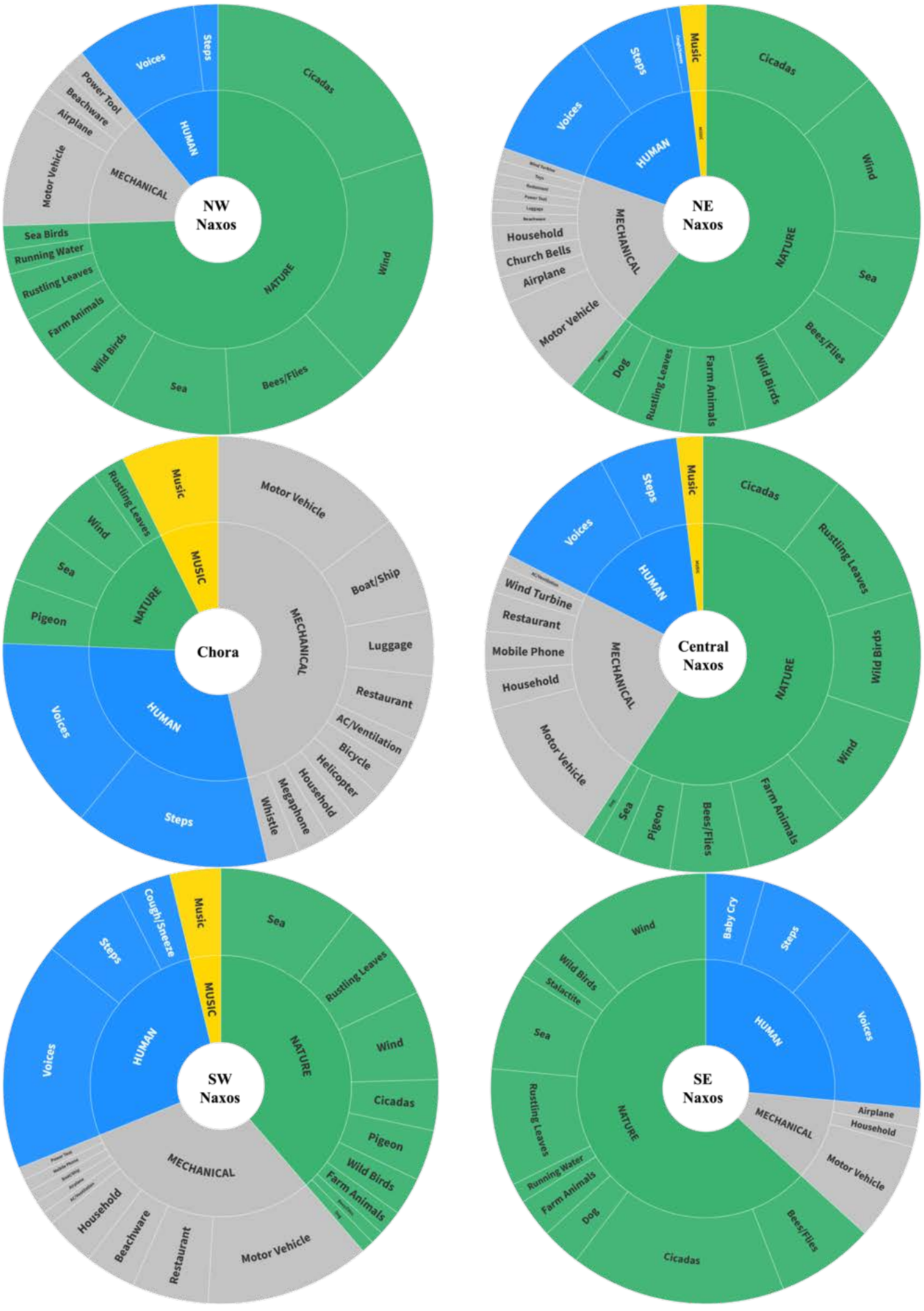

Figure 5: Comparative Analysis of sound sources per category and region in Naxos.

activities on the soundscape in this part of the island.

The soundscape in the Southeast shifts to predominantly Nature sounds (63.24%), such as Cicadas, Bees/Flies, and Farm Animals. Human sounds (26.47%), are represented by Voices, Footsteps and Baby Cry, while Mechanical sounds (10.29%) are mainly from Motor Vehicles. The presence of fewer Mechanical sounds and the absence of Music in this region highlight its relatively untouched nature, suggesting that it is less influenced by tourism compared to other parts of the island.

Similar to the Southeast, despite its larger population, the Northwest region features no Music and only a modest presence of Mechanical sounds (14.55%), which are mainly attributed to Motor Vehicles. Human sounds, predominantly Voices, account for 10.91% of the recorded auditory content and Nature sounds make up 74.55% of the soundscape, including sound sources like Cicadas, Bees/Flies, Dogs, Farm Animals, Running Water, and Sea Birds. As previously stated, the Southeast and Northwest regions are the least tourist impacted areas on the island, as evidenced by the prevalence of nature sounds in the recordings.

In the Central and Northeast parts of the island, which have medium tourist activity, the soundscape composition more closely resembles that of the less touristic areas, rather than the highly touristic ones. In Central Naxos, the soundscape distribution is 59.22% for Nature, 15.53% for Human, 23.30% for Mechanical, and 1.94% for Music sounds. Similarly, in Northeast Naxos the percentages are 60.78%, 19.65%, 19.61%, and 1.96%, respectively.

Overall, with the exception of the Chora, where Nature sounds make up less than one-fifth of the soundscape, Nature sounds occupy between 38.68% to 74.55% (median: 60.78%) throughout the rest of Naxos. This indicates that, although tourists may have an impact on the soundscape of Naxos, Nature sounds still prevail on the island.

3.2. Preliminary loudness analysis

The collected data can also provide an insight into the loudness of sounds on the island. Fig. 6 shows the locations of the recordings alongside the average loudness observed at each point on a color scale from green (30 dBA) to red (80 dBA).

The loudest part of the island is in the Southwest, particularly in Mikri Vigla, in which the recording session took place outside a bus station. Following in terms of loudness is Filoti, located in Central Naxos. It is a popular village among tourists due to its picturesque square, which is shaded by a very old plane tree. Both Filoti and Mikri Vigla, along with some areas in Chora, are known for their high levels of tourist activity and noise. However, as previously mentioned, Filoti has a higher population compared to other villages on the island, which can significantly contribute to the noise level.

The Northwest part of the island, a region characterized by lower tourist activity, has noticeable noisy areas. Increased noise levels have been recorded along the main roads leading to the nearby villages: the Agias-Abram road (71.7 dBA) and the Apollona-Agias road (71.6 dBA). An additional source contributing to noise pollution is situated near the Eggares Reservoir, which is also a popular tourist destination.

The noise heat-map offers a deeper understanding of noise sources across Naxos, especially when considered alongside specific observations of noise levels. It is evident that Chora has several areas with orange markers, indicating areas of louder sounds.

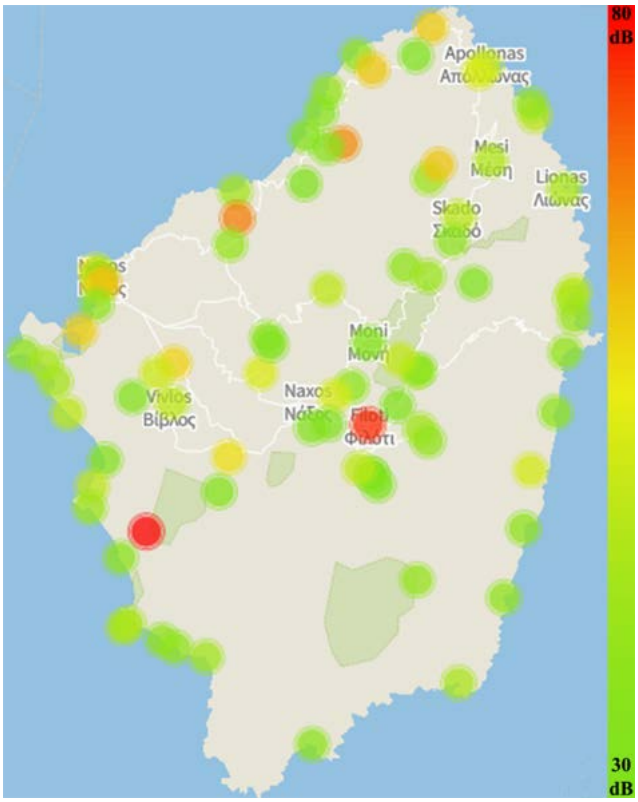

Figure 6: Loudness Heatmap of Naxos illustrating the varying loudness levels across the island. Color gradations from green to red indicate the range of sound intensities from 30 dBA to 80 dBA.

However, except from Mikri Vigla, the rest of the Southwest part of the island has a lower noise profile, despite having a similar sound category ratio to Chora. This difference may stem from the particular locations chosen for the recordings. Additional recordings could shed further light on the factors influencing these variances in noise levels.

It should also be noted that the observation of sound levels solely is not necessarily a descriptive indication of the noise profile of a location, as it may not accurately reflect the sounds present. Stated differently, both the presence of motor vehicle activity as well as a swarm of cicadas can significantly raise the sound levels in a location, albeit one might argue that the two lead to very different kinds of noise. Therefore, more comprehensive analysis taking account of qualitative aspects in the recorded data is necessary in order to gain a better insight on this matter.

4. CONCLUSION AND FUTURE WORK

This study conducted a preliminary analysis of recordings from 84 locations around Naxos, aiming to identify and categorize sounds related to the environment, wildlife, and human activities, with a particular focus on assessing the influence of tourism on the soundscape.

The data indicates that 82.93% of the sounds in Chora originate from human activities (Human, Mechanical, Music), while only 17.07% belong to the Nature category. However, the impact of tourism on sound sources and noise levels in Chora is debatable,

given that almost half of the island's residents live there. Therefore, these sounds cannot be directly attributed to tourists, but can be viewed as evidence of general human activity. To delineate the impact of tourism on the soundscape more clearly, future studies could benefit from conducting additional recordings during other time periods, particularly during low tourist seasons, and comparing these findings to the data of this study.

In contrast to the Chora, the Southwest region, which is also a popular tourist destination, has fewer permanent residents. In this region, Nature sounds represent a significant portion (38.68%) of the soundscape, while the noise profile is not as loud, demonstrating that the natural auditory environment retains its presence amidst human activities. However, sounds associated with human activity - Music, Human and Mechanical sounds - account for 61.32% of the soundscape, including sources such as Beachware, Motor Vehicle, and Restaurant. This suggests that while tourist activities influence the soundscape, they do not entirely overshadow the Nature sounds. Nevertheless, due to the increasing number of tourists on the island, it is crucial to regularly evaluate their impact on the soundscape. Further recordings, especially outside the peak tourist season, will be crucial to assess any shifts in the composition and volume of sounds. In the future, we aim to expand our recording procedures throughout the year, incorporating a greater variety of locations. This will involve a more detailed documentation of environmental conditions to assess their impact on the soundscape. Factors such as season, time of day, wind speed, and temperature will be considered. By capturing these variables, we hope to gain a comprehensive understanding of the dynamic influences on acoustic environments and refine our analysis of how these factors shape the auditory landscape and are related to the tourist activity's impact.

These recordings can contribute to the creation of a comprehensive database of the Naxos' soundscape, offering a valuable resource for tracking its sonic evolution over time. Furthermore, the interactive tool developed as part of this study can facilitate the subjective exploration and analysis of the collected auditory content. Incorporating it into an immersive virtual "sound-travel" experience to Naxos, using spatial sound technology, can be highly advantageous. Consistent with previous research [26], our objective is to further develop this tool and to assess its ecological validity in a controlled environment. The enhancement of the application includes additional audio features such as dynamic binaural rendering that adjusts to head movements and incorporates personalized HRTFs for a more individualized auditory experience. We also aim to introduce visual enhancements, including panoramic photographs and immersive 360-degree video recordings. These developments are designed to enrich the user experience by providing a more realistic and engaging multisensory interaction with the soundscapes. This experiment will provide valuable insight into users' perceptions and expectations of experiencing the spatial characteristics of the soundscape from a distance.

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