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REFEREED PAPER

Cartographic Representation of the Sonic Environment

Kimon D. Papadimitriou[1], Antonios D. Mazaris[1], Athanasios S. Kallimanis[2] and John D. Pantis[1]

[1] Department of Ecology, U.P. Box 119, Aristotle University, 54124, Thessaloniki, Greece.
[2] Department of Environmental and Natural Resources Management, G. Seferi 2, 30100, University of Ioannina, Agrinio, Greece
Email: amazaris@bio.auth.gr

The description of the landscape is based on the visualization of geographic features and the representation of their attributes. Although sound is a major component of any environment, its cartographic representation is limited mainly on noise mapping and in urban or sub-urban areas. Soundscape is a term that describes the acoustic relation between the environment and the individual in a landscape context, considering all kinds of interactions between space, sound and humans. The representation of the soundscape at a spatial level would support many applications such as geographic analysis, ecosystem evaluation, environmental education, landscape management, urban or rural planning and protection of sonic particularities. This paper proposes a methodology for the mapping of both quantitative and qualitative attributes of a rural soundscape, which is described through the study of the acoustic environment around a protected wetland in Greece.

Keywords: sound events, sound pressure level, sound origins, spatial interpolation, soundscape morphology, spatio-temporal variability

INTRODUCTION

Studying the relation between human and the environment involves the description of space and its hosted functions on the scale of an individual's perception (Wiens *et al.*, 1993). Landscape's identity is defined by the capturing of its features, which is facilitated by *in situ* surveying or remote sensing methods and, finally, by their cartographic representation (e.g. topography, land cover, land use etc.). However, any place is characterized not only by its visual feature, but also by its own sonic identity (Velasco, 2000). The various landscape attributes are therefore supplemented by sonic information and furthermore, the uniqueness of locations is accentuated by the sounds which are generated and received there (Cage *et al.*, 2004). The sound arriving at the ear is the analogue of the current state of the physical environment because as the sound wave travels, it is charged by each interaction with the environment (Truax, 1999). The interaction between human and the environment, considering sound as the mediator, is the main research theme of a multidisciplinary academic field, called acoustic ecology (Wrightson, 2000). This relation was described by Truax (1984) using a communication model (Figure 1), where sound acts as both, a messenger of environmental features, as well as an expression medium (mediator) of human activities and inner processes (Doornbusch and Kenderdine 2004; Matless, 2005; Coates, 2005).

What all these approaches have in common is that they are spatially implicit and perceive the sound as the feature of a point in space. Several methods exist to record and represent the ambient sounds of a point. For example, sound recordings of sea turtles laying their eggs in a warm summer night have been used in environmental education and awareness programmes for visually impaired individuals (Minotou *et al.*, 2007). However, recently the spatial dimension of the sonic environment has received increased attention from both researchers and public authorities, opening a whole new playing field.

Public authorities have taken an interest in the spatial pattern of the sonic environment from the perspective of noise pollution, which is considered a dimension of environmental degradation. Since, sounds add a dimension of meaning and emotions (Corbin, 1998; Botteldooren *et al.*, 2006), the acoustic environment has been linked with peoples physiological well being and health (Stockfelt, 1991; Kjellberg *et al.*, 1996; Öhrtröm *et al.*, 2006; Martín *et al.*, 2006). Given the fact that humans might have specific expectations about the sonic environment (Navrud, 2000; Barreiro-Hurle *et al.*, 2005) the acoustic environment

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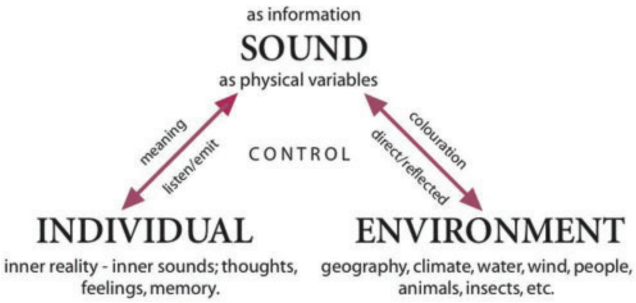

Figure 1. The interaction between human and the environment as described by the Truax's (1984) communication model

could be perceived as an environmental quality (van Poll, 1997; Bonaiuto *et al*., 2003). The European Directive on Environmental Noise (Directive 2002/49/EC) aims to provide a common basis for tackling the noise problem across the EU. In this framework Member States are obliged to draw up 'strategic noise maps'. Therefore, the efforts for the description of space's acoustic dimension are limited mainly at urban and sub-urban environments (Hedfors and Grahn, 1998; Servigne, 1998; Kang and Servigne 1999; Servigne *et al*., 1999; Skanberg and Ohrstrom, 2002; Arkette, 2004) and mainly related to the study of noise (Matless, 2000; EU, 2002; McGregor *et al*., 2002; Klæboe *et al*., 2006).

This focus on noise pollution places undue emphasis on the negative aspects of the sonic environment and ignores its positive aspects. Sounds are not associated only with negative feelings and emotions, as the concept of noise pollutions might imply. Several sounds, such as the song of a bird, might actually invoke positive feelings and emotions and help people relax and unwind. Therefore, the sonic dimension of the landscape has started receiving more attention by researchers and needs to be evaluated on a more thorough basis (e.g. Botteldooren *et al*., 2006; Mazaris *et al*., 2009). In this sense, research focuses on the concept of 'soundscape', a term introduced by Schafer (1977; 1994), which describes the perceived acoustic environment in a landscape scale (Keller, 2000). Soundscape, as a research field is approached in various ways, depending on the scope of each academic discipline. Thus, an emerging issue is the description of soundscape in such a way that would consist of a common reference for any involved discipline. In a similar way the concept of landscape has offered this opportunity for the integrated study of natural ecological processes in combination with social and economic activities and thus the integration of social science and natural science approaches (exp. Chung and Kim, 2007; Manley *et al*., 2009). And even more generally, Farina and Belgrano (2006) demonstrated the need to evaluate and integrate additional (beyond the visual and the acoustic) elements in the study of landscapes, thus to proceed to an organism-centered view leading to the construction of cognitive landscapes of how individuals perceive space with all their senses.

Furthermore, the soundscape concept may have an important implication in the field of environmental planning and wildlife conservation, since not only man reacts to sounds, but animals (and especially species of conservation interest such as large mammals and birds) perceive and respond to sounds. Sounds can act as repellents (e.g. gun shots) or as attractants (e.g. mating calls). Therefore, efficient conservation planning should take into account also the sonic dimension of the environment. Despite the considerable research on urban soundscapes, which aims at managing and reducing noise (Staples *et al*., 1999), studies on the assessment and monitoring of the quality of the acoustic environment in natural and semi-urban systems are scarce (Brown, 2001; Brown and Muhrar, 2004; for an exception see Matsinos *et al*., 2008; Miller, 2008). Previous work on the decomposition of acoustic signals obtained in natural systems has focused on biodiversity (Cage *et al*., 2004), on ecological and biological phenomena (Laiolo and Tella, 2006) and on the wildlife (Brown, 1990). Thus, the recording of the soundscape of rural and especially of protected areas might provide valuable information for conservationists and natural resource managers.

The greatest challenge towards achieving such goals is the virtual lack of tools for the description and representation of the soundscape. Recently, in the course of the implementation of the Environmental Noise Directive, governmental departments have produced noise pollution maps. These maps might be interpreted as evidence that certain aspects of sound data (such as the recorded levels of sound pressure) can be conceived in spatial terms and furthermore they can be visualized. However, the task of actually describing and depicting the soundscape is more complicated than noise mapping, since as the communication model implied by Truax (Figure 1), subjectivity is inserted to the observation (Carles *et al*., 1999; Mace *et al*., 1999; Viollon *et al*., 2002).

A visual representation of the soundscape might be proven to be an efficient method for describing the spatiotemporal variability of the acoustic signals (Tsai *et al*., 2009) (e.g. compared to point sound recordings). Even more importantly the applicability of cartographic tools for decomposing and reconstructing soundscapes offers a great change to link directly soundscape properties with landscape characteristics (Mazaris *et al*., 2009), and simultaneously offers a diverse array of tools and methods for further analysis. Thus, mapping may actually reflect all landscape attributes that function as sound sources and the complementarity between specific sound categories as they are attributed to this landscape throughout the extension of the study area. This additional level of information that is added to the traditional study of the landscapes enables us to proceed with the development of a methodology aiming towards the study of the 'cognitive landscapes' (Farina and Belgrano, 2006).

An emergent issue is to propose a technique that could be used for a description of the interaction between human and space, considering the spatio – temporal variability of sound. This kind of description may be obtained by a map production process (from data capture towards cartographic representation), which could form a common base (medium) among various academic disciplines. Considering sound as a geographic feature that might be described by specific attributes, we could take into account acoustic information with reference to geographic space. Cartography offers the techniques (spatial reference and symbolization) for objective description of geographic features (both qualitative and quantitative), and supports further analysis in combination to other spatial characteristics. For this purpose, sound events are attributed with quantitative and qualitative properties. Spatial and temporal variations of these properties refer to changes in groups of sounds with similar forms or functions when they are considered historically or geographically and describe the morphology of soundscape (Truax, 1999). In this manner, subjective listening is replaced by an observation methodology and furthermore, soundscape description is achieved through its cartographic representation. Additionally as soundscape is an ever-changing expression of a landscape (Hedfors, 2003), it should be treated at both spatial and temporal scales (Frank *et al.*, 1992).

The aim of this paper is to examine if the cartographic toolbox could assist in the comprehension of the soundscape and so to define a methodology for the cartographic description of the soundscape in a rural environment. More precisely, the objectives of this paper (which also represent the required methodological steps for the cartographic description of the soundscape) are:

1. the identification of the quantitative and qualitative properties that characterize an acoustic environment.
2. the definition of a capturing process (surveying) of the selected attributes, for a given spatial and temporal resolution and finally.
3. the cartographic representation (mapping) of soundscape' s morphology for the specific spatio-temporal scales.

METHODOLOGY

Methodological background

According to Truax (1999), soundscape is composed by sound events. The way that sound propagates is a major research field of physics (acoustics and vibrations) and is represented cartographically by sound intensity – sound pressure level (SPL) – or noise mapping. The origins of sound events refer to the reasons of their existence and are associated to the operations and functions of a given space. Those (operations and functions) are affected by the geomorphology (as a scenery) and include the biological and human activities (as actors) that take place in a given landscape. Krause (2002) and Cage *et al.* (2004), who attempted to classify the sounds, taking into account the above three major components of the landscape and based on the origin of sound events, proposed the terms 'anthropophony' (sounds originating from human activities e.g. voices, traffic sounds), 'biophony' (sounds originating from biological organisms e.g. bird song, dog barking) and 'geophony' (sounds originating from geophysical processes e.g. wave sound).

Sounds could also be distinguished in foreground and background. In music, sound events that form the acoustic scenery (at the background) are related to the keynote of a music composition (e.g. city noise), sound signals are the analog of the music theme (e.g. a bird's song) and participate as the actors of a performance (in the foreground).

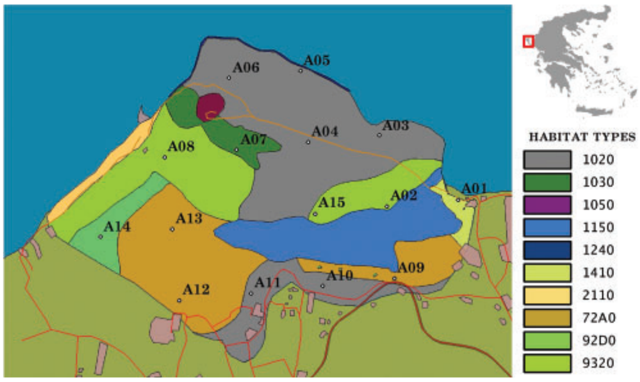

Figure 2. The landscape of the study area is composed by several habitat types, according to Natura 2000 mapping (Hellenic Ministry for the Environment, Physical Planning and Public Works 2001). Various colours refer to: (a) 1020 – arable land, (b) 1030 – reforestation, (c) 1050 – settlements, (d) 1150 – lagoon, (e) 1240 – vegetated sea cliffs of the Mediterranean coasts, (f) 1410 – Mediterranean salt meadows, (g) 2110 – embryonic shifting dunes, (h) 72A0 – reedbeds, (i) 92D0 – Thermo-Mediterranean riparian galleries, (k) 9320 – Olea and Ceratonia forests

In a more natural setting background sounds may refer to continuous sounds that originate from far away from the observer (e.g. the sound of waves crashing ashore), while the foreground sounds refer to distinct sounds that originate near the observer, and which in many cases may cause an instinctive reaction (e.g. a dog barking menacingly nearby).

It should be noted that locations dominated by background sound are likely to receive acoustic signals from the whole surrounding landscape. In contrast, locations where foreground sound is more intense are characterized by *in situ* propagation and production of sound events.

Study area

In order to address the main aim of this project, a case study approach was followed. The case study was located around the lagoon of Antinioti at the northern part of Corfu island, Greece (Figure 2). It extends 2100 m on the East–West axis and 1600 m on the North–South axis with an altitude range varying from 0 to 50 m over a smooth relief. The study area is characterized by a high diversity of land cover and land use types including wetland systems (at the central part of the area), coastal systems (at the north and north-east part of the area), primary forests, cultivation fields, meadows, olive plantations and semi-urban areas (spread across the study area). As a result of its biodiversity richness, this place has been designated as a Natura 2000 site (GR2230001). The acoustic environment of the site combines sounds produced by different human activities (tourism, agriculture, construction and transportation) and natural sounds defined either as biological (i.e. wildlife organisms or domestic animals) or geophysical sounds (i.e. waves, rain and wind).

Data capturing

In order to identify the quantitative and qualitative properties of the acoustic environment, three types of data were collected:

1. classification (categorization) of the sounds' origin and their contribution to the overall soundscape.
2. identification of background and foreground sound events as formulating factors of the acoustic perception.
3. acoustic measurements. Additionally, sound recordings were performed for documentation and post – processing purposes.

As sound varies according to space and time, information for soundscape has to be captured at both spatial and temporal scales. Acoustic data were collected from 15 sampling/recording points located over a grid across the study area (Figure 2). For the exact selection of the sampling sites we initially divided the study area into a grid (4×6 cells). In this grid there were 15 terrestrial replicate sampling sites. Next we performed pilot sound recordings to capture all available sound categories and to associate them with specific landscape characteristics (e.g. roads, construction, coastal zone). Aiming to locate each sampling point at a specific habitat type, thus to define specific landscape characteristics (according to Natura 2000 classification), the exact position and orientation of the grid was optimized to obtain the representation of all existing habitat types. The nearest distance among neighbouring sampling points was 350 m. Pilot study showed that the 350 m distance could ensure the recording of a great variety of sounds from different sources, and allows the interpolation of the collected information. Field recording and data collection were implemented in March, June, September and December of 2006, covering the seasonal variation in the soundscape of the area. During each sampling season, data were collected in eight successive time periods covering the daily sound variation at each sampling site (first time period: 00.00–03.00, second period: 03.00–06.00; third period: 06.00–09.00; fourth period: 09.00–12.00; fifth period: 12.00–15.00; sixth period: 15.00–18.00; seventh period: 18.00–21.00; eighth period: 21.00–24.00). Within each time period, a 10 min sound recording–observation was carried out. Each 10 min observation was further divided into 40 sequential time-steps (of 15 s), generating time series data.

The classification (categorization) of the sounds' origin was based on a three classes (categories) scheme in accordance with Krause (2002) and Cage *et al.*, (2004):

1. anthropophony, which refers to sound produced by human activities.
2. biophony which includes the sounds produced by living organisms.
3. geophony that refers to sounds of natural elements and phenomena, such as wind, rain, sea waves etc.

The contribution of each sound class (category) to the whole soundscape was scored in a three-level scale ranging from one (less intense sounds) to three (more intense sounds). The classification (categorization) of the sounds' origin and the estimation of its contribution to the whole soundscape were carried out in the field by a group of trained observers (experts). However, given the subjectivity introduced by the observers, we will henceforth, refer to this recording process as intensity estimation of the 'perceived' sounds.

The perceived sound events were further decomposed (by a second group of experts) as 'foreground' or 'background' sounds. In each sampling site, the foreground sounds refer to those produced instantaneously and sharply near the sampling site (e.g. birds, insects) while the background sounds refer to those produced far away from the sampling site and originate from the whole surrounding landscape (e.g. traffic noise, long distance sound sea waves). A more detailed description of each sound event was based on empirical identification of cues.

Acoustical measurements were obtained using a Cesva SC-310 integrating–averaging sound level meter and spectrum analyzer, featuring real-time filters of 1/1- and 1/3- octave. The selected device measures the following parameters simultaneously (with frequency weightings A, C and Z): parallel scanning Fast, Slow, Impulse, Max, Min, SEL, Leq, LeqI, statistical distribution L1%, L5%, L10%, L50%, L90%, L95% and L99% Peak. During the field work, the device was set to log the weighted (Leq A and Z) sound pressure level per octave (between 31.5 Hz and 16 kHz) every 15 s for each sampling period. An acoustic index was further calculated based on the acoustical measurements obtained; LAT index (equivalent sound level A-linear weighted: A-weighted decibels), was used as expression of the relative loudness of sounds in air as perceived by the human ear.

Sound recordings were performed (for documentation purposes) using a digital tape recorder (Tascam DA-P1 - DAT with Sony proDAT plus DT-120 tape) and a Schoeps MS microphone system. The system comprized two condenser capsules (the bi-directional CCM-8 and the CCM-5 set to omnidirectional), an elastic suspension system (Schoeps AMS CI with binder plug and the KCY 115/0,25Ig active cable), windshield protection (Rycote) and the Schoeps VMS5U preamplifier.

All categories of collected data (sound recordings, acoustic measurements, observations and documentation material) were organized in a spatial database. Two tables were used for the attribution of sonic events, one with the quantitative properties that have been obtained by the measurements (Table 1) and another with the qualitative properties that have been calculated from the observations (Table 2). In addition, geographic attributes were collected

Table 1. Acoustic measurements (quantitative attributes) collected during the field study

Field	Description	Data type
id	Sampling site id (1–15)	Number (integer)
S	Season (1–4)	Number (integer)
P	Period (1–8)	Number (integer)
rg	Registry (instrument)	Number (integer)
LAT	Frequency weighting A (dB)	Number (single)
F315	SPL at 31.5 Hz (dB)	Number (single)
F630	SPL at 63 Hz (dB)	Number (single)
F125	SPL at 125 Hz (dB)	Number (single)
F250	SPL at 250 Hz (dB)	Number (single)
F500	SPL at 500 Hz (dB)	Number (single)
F1k	SPL at 1 kHz (dB)	Number (single)
F2k	SPL at 2 kHz (dB)	Number (single)
F4k	SPL at 4 kHz (dB)	Number (single)
F8k	SPL at 8 kHz (dB)	Number (single)
F16k	SPL at 16 kHz (dB)	Number (single)

for each sampling position (latitude, longitude and altitude).

Soundscape mapping

The cartographic representation of the spatial variations for selected attributes of soundscape is based on the calculation of the values for any position between the sampling positions. Using the values that describe the recorded and observed attributes at each of the sampling positions, a regularized spline interpolation was performed in order to produce one thematic map per period; total eight maps per attribute per period. Based on this approach, the following maps were produced:

1. spatial variations of human, biological and geophysical sounds.
2. a composite color map of soundscape's origin assuming human as red, biological as green and geophysical as blue.
3. spatial variations of the intensity for background and foreground sounds.
4. spatial variations of the acoustic measurements for SPL.

Moreover, the simulation of the evolution for each attribute (during a day) can be achieved through the playback of the sequence of the time stamped maps or the related multi-dimensional representations. Both spatial analysis and map production were performed using GRASS GIS and QGIS.

RESULTS AND DISCUSSION

Visualization of the soundscape

Using the resulting values for each sound category of all sampling positions, a regularized spline interpolation was performed in order to represent cartographically the spatial variations of anthropophony, biophony and geophony. This resulted in three overlaying thematic maps that visualize the three basic components of the soundscape (Figure 3). Regions with bright red colour are those in which the human sounds are very intense. As the values of red are becoming lighter, human sounds are decreased. The presence of bright red colours indicates plethora of human activities around the study area, while luminous tones of green represent areas with intense biological sounds. The wide spread of light green colour reveals the non-urban characteristic of the study area. In addition, regions with blue colour are exposed to sounds that produced from natural phenomena (e.g. wind).

Table 2. Qualitative attributes collected.

Field	Description	Data type
id	Sampling site id (1–15)	Number (integer)
S	Season (1–4)	Number (integer)
P	Period (1–8)	Number (integer)
An	Anthropophony	Number (integer)
Bi	Biophony	Number (integer)
Ge	Geophony	Number (integer)
Bg	Background	Number (integer)
Fg	Foreground	Number (integer)
Sm	Sound mark	Number (integer)

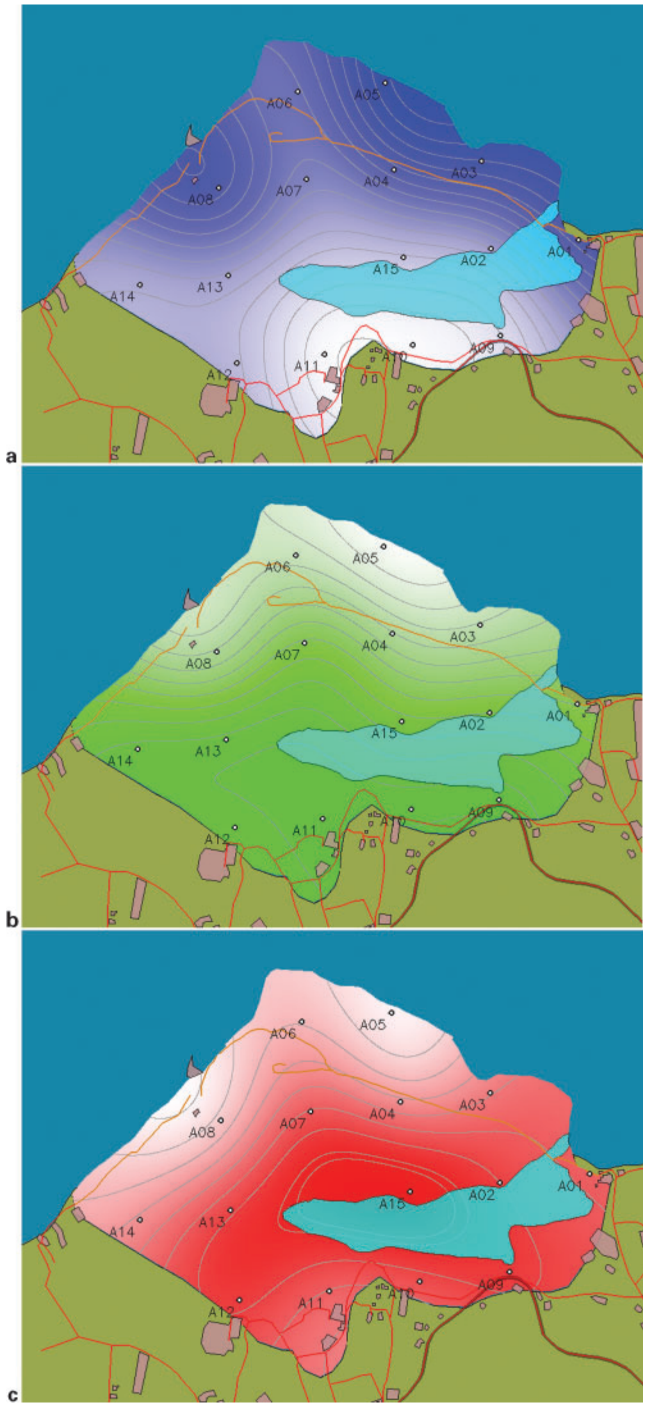

Figure 3. Mapping of (a) anthropophony (red), (b) biophopny (green) and (c) geophony (blue) based on qualitative data collected. Colour brightness is proportional to the intensity of each sound category

Furthermore, the composite color map of the previous three layers (where red=anthropo, green=biological and blue=geophysical) is used for the visualization of the soundscape (Figure 4). Intermediate colours represent intermediate acoustic situations (e.g. yellow areas represent combination of human and biological sounds). In order to

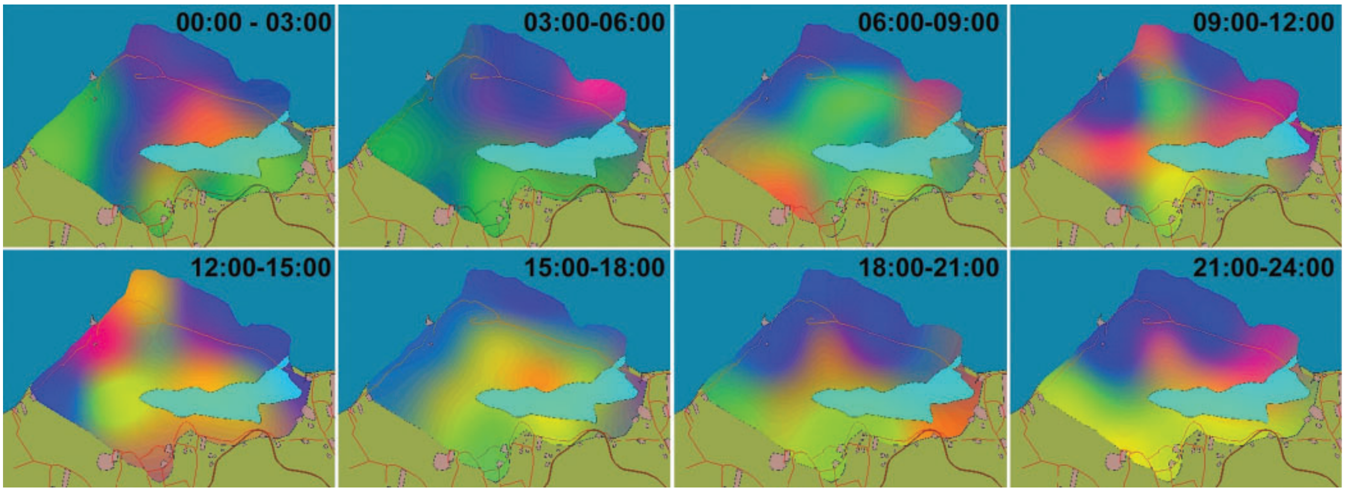

Figure 4. Soundscape origins are described by the composition of anthropophony (red), biophony (green) and geophony (blue). The maps represent the daily variation of soundscape composition during spring (end of March)

give a brief example on the type of information that can be obtained by this analysis we concentrate on the geophysical sounds (i.e. geophony). As shown in Figure 4, the geophysical sounds are more intense at the north part of the study area located close to the coastline. On the other hand, geophysical sounds are almost absent from the southern part of the study area reflecting the relatively long distance from the coastline. Moreover, the geophysical sounds show a significant variation on a temporal basis which is associated with the daily variation in climatic conditions. Furthermore, the temporal variation could also result from the masking of geophysical sounds by other biological or anthropogenic sounds.

The analysis of perceived sound categories shows that the spatial–temporal variations in the sound level of the anthropogenic biological and geophysical sounds reflect the dynamics, operations and activities that take place in the landscape, determining thus its sonic identity. In addition, every site in the landscape operates as a specialized probe – both in spatial and temporal domain – of the soundscape's acoustic information.

In order to examine the meaningfulness of the maps we compared them with the impressions of the people involved in the recording of the sounds and collection of the data. They considered the maps produced to truly bring forward several of the distinctive sound features that they perceived in the field, e.g. the role of the coast in shaping the background geophony sounds.

Intensity of soundscape

By interpolating the calculated sum of the values for anthropophony (A), biophony (B) and geophony (G) a raster map that represents the variations of the intensity of the soundscape over the study area was produced. Figure 5 provides a representation and visualization of the acoustic intensity as it was recorded during the first seasonal sampling period. We developed a series of eight sound

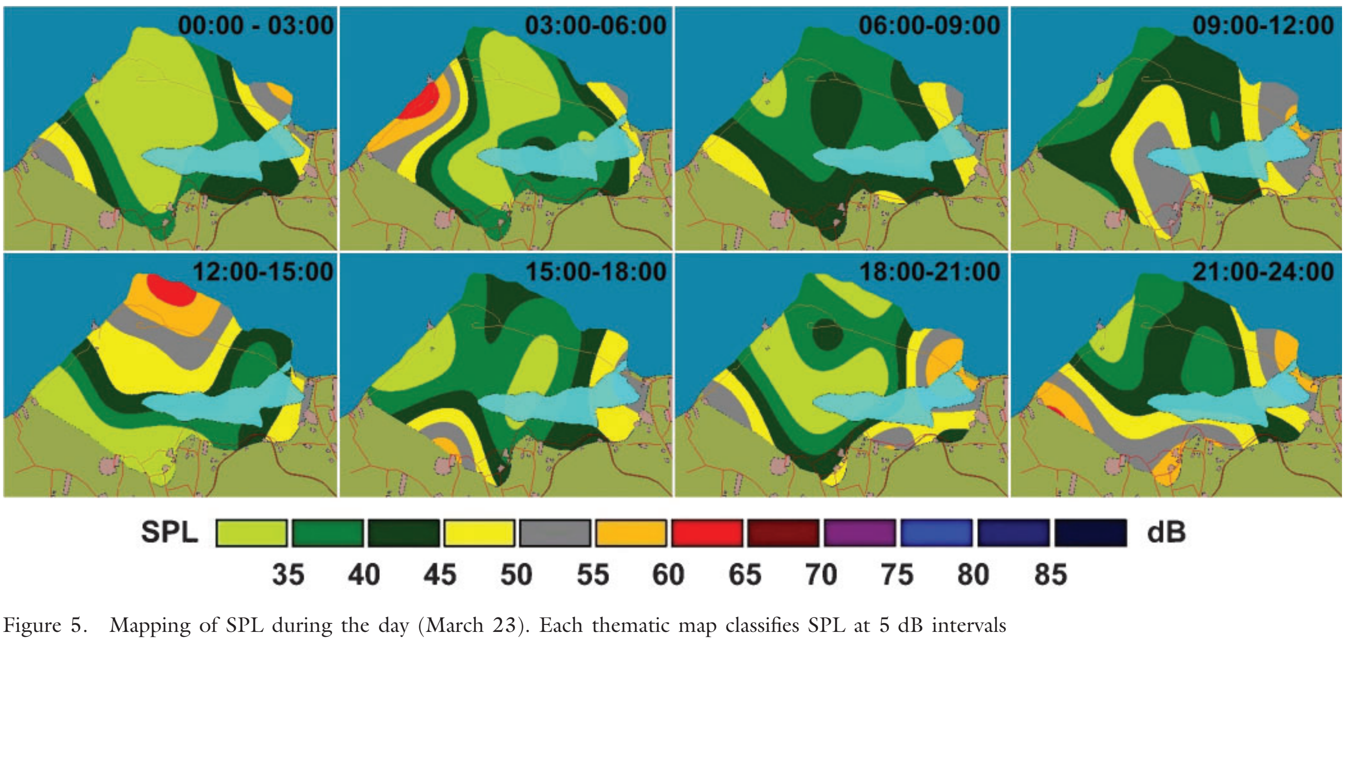

Figure 5. Mapping of SPL during the day (March 23). Each thematic map classifies SPL at 5 dB intervals

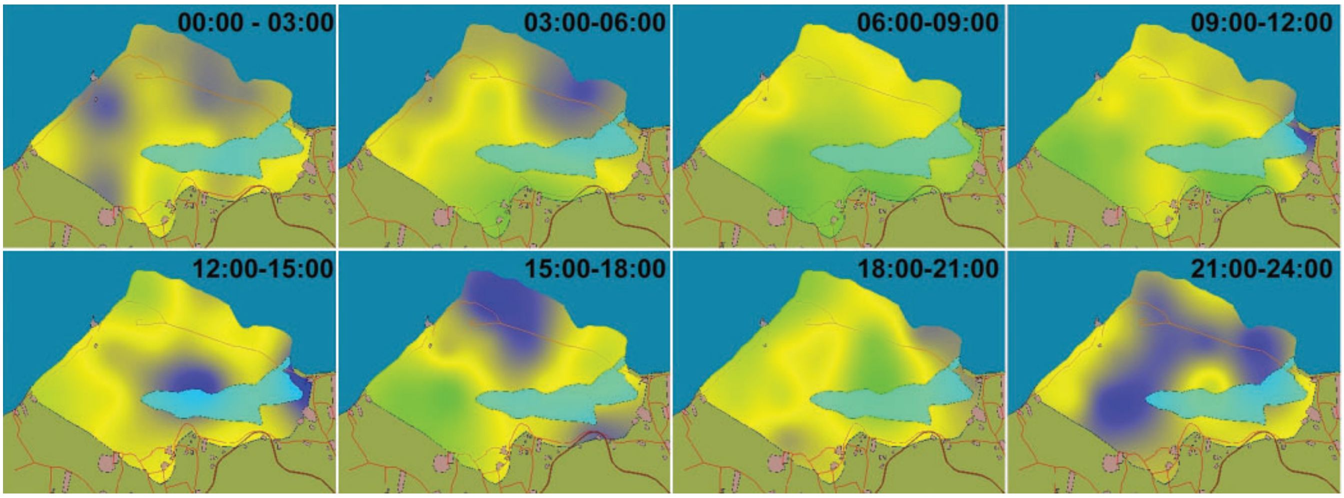

Figure 6. Visualization of the fidelity of the acoustic environment (as calculated by the difference between background and foreground) during the day (March 21). Blue colour represents positive values, green indicates negative values and yellow values close to 0

intensity maps that show the spatial and temporal patterns of LAT values. Those patterns indicate a significant variation of the LAT values across the landscape. Those maps reveal that the study area can be characterized as low to medium sound pressure level area with max LAT values of 55 dB, while its central part consists of an acoustic quiet area with less than 35 dB. These results show that the soundscape heterogeneity in sound intensity variation is associated with the corresponding landscape heterogeneity.

Index of fidelity

As mentioned before, the perceived sounds were also classified into background and foreground and their overall intensity in each sampling site was estimated. These data were then used to calculate the difference between background and foreground sounds. The representation of this index was produced by map algebra (Tomlin, 1990) – subtraction of the foreground layer by the background one (Figure 6). Some of the overall results referring to spatial–temporal variation of the above index during the first seasonal sampling period are presented in Figure 6. This process enables us to define locations of potential hi-fi and low-fi acoustic environments. Index values close to zero (displayed by yellow colors) indicate an equal contribution of background and foreground sound events in the formation of the soundscape while positive index values (displayed by blue tones) indicate a dominance of background sounds. The dominance of foreground sounds (green colour) demonstrates location at which sounds produced instantaneously and sharply nearby. In contrast, the dominance of background sounds represents area were local sound events are masked by surrounding ones.

Methodological issues

A first hurdle we had to overcome in this study was to see if cartography could be applied in the study of soundscapes, since the basis on which sound is measured, raises questions on its objectivity and on the extent to which sound measurements lend themselves to spatial referencing. It is true that the soundscape concept includes several subjective elements (especially regarding sound as stimulus to people's reactions). However, we found that there are several features of the soundscape that lend themselves for objective recording and representation. Such attributes include the sound pressure level, which is recorded with the use of instruments, as well as the identity of the sound source (classified as anthropophony, biophony and geophony), or the distinction of sounds as foreground or background. So as a first step in the comprehension of the soundscape, we focused on simple measures based on loudness, intensity or the cause and origin of sounds which offer easy to use measurement devices, and their information interpolated over the landscape allows the spatial representation of the soundscape in a meaningful way.

In the present study we used traditional cartographic methods to present basic attributes of soundscapes. This approach highlights the soundscape's inherent variability at both spatial and temporal scales (Matsinos *et al.*, 2008). This approach allows the description and identification of several features. For example, we could identify the points with the greatest diversity of sounds, or the points with the greatest intensity. The visualization of the acoustic environment offers a chance to clearly distinguish sound sources and probes. Sound is recorded or perceived at specific places/locations although there is an even more important spatial element in sound input: the diffusion of sound in space and the information it actually transfers to living organisms. Visualization of the soundscape allows the study of its gradients, and thus may link specific spatial elements with their role as sources, barriers, boundaries, corridors and probes of sound to the perceived acoustic environment. The integrated study of visual and sonic attributes could promote the understanding of interactions among biological and geophysical processes and anthropogenic activities. In this sense, even the static features of the soundscape offer insights into the mechanisms that transfer information from different elements of the landscapes and contribute towards the comprehension of the cognitive landscapes (for a synthesis see Farina and Belgrano, 2006). It should also be noted here that similar limitations of using static maps for describing basic features and successive changes are found in traditional landscape analysis; landscapes are dynamic although processes might act in a rather longer time scales than in soundscapes. In any case the presentation of a dynamic system by a snapshot is a common first step in an attempt to capture its basic properties.

Future research

This study highlights some of the possibilities of mapping the soundscape, and the applicability of the cartographic tools for the tasks. We chose to analyze only some simple measures that were the most amenable to analysis with cartographic tools, and we show that the tools work satisfactorily. This is only a first step along the way, and it is by far not definitive or exhaustive. Now there are two new avenues of research opening up.

On the one hand, there are still other qualities of the soundscape that need to be understood and represented, e.g. distinctiveness of sound and people's perceptions of it. Qualities that may well prove difficult to codify and represent, and for which the existing tools may prove insufficient, since the relationship between sound and space is one that may prove too complex to reduce compared with conventional visual type/style mappings. Trying to shoehorn these less tangible characteristics into map like forms may somehow lead us into a trap. In a sense, imposing fairly rigid or strict cartographic techniques on factors that are difficult to grasp or define. Perhaps, as a next step we need to develop new ways of understanding spaces using methods that we are less familiar or comfortable with. The same could be said for methods needed to verify the maps produced. In traditional land cover maps, we can visit the field and verify the point's land cover. However the highly dynamic nature of the sound makes that task difficult if not impossible.

On the other hand, we need to try to comprehend the physical meaning and functional implications of the patterns recorded. For example, could we use the index of fidelity as an index of tranquility, which might estimate the attractiveness of the rural landscape to visitors? Or is the index of soundscape correlated to any ecological patterns or processes, e.g. biodiversity? Perhaps the temporal variability of the sounds in a location might be an indicator of wildlife preference or avoidance. Could we differentiate which human activities are responsible for creating noise, and especially which activities affect the soundscape of the wildlife? How are natural sounds produced? What causes their intensification and so on? The possibilities are endless.

CONCLUSIONS

This paper presents a methodological approach to study the evolution of an acoustic environment in rural landscapes. The decomposition of the soundscape at different acoustic components based on their origin (anthropo-bio-geo), perceived intensity and perceived sound events (background-foreground) provides the basis for an analysis of the mechanisms associated with the qualitative construction of a soundscape. Additional acoustic information based on acoustic measures enables us to study in depth the quantitative characteristics of the soundscape.

This proposed methodological approach combining certain quantitative and qualitative characteristics of soundscape allow us to understand, describe and interpret the complexity of the relationship between sound and landscape. The visualization of sound diffusion in relation to the landscape characteristics can be used to explain patterns of sound origin, to analyze soundscape variations on a spatial basis and to identify the factors that affect the development of the acoustic environment. Furthermore, it briefly refers to the applications in sonic art and education, which stem from the recorded sound component of this research (for such an application see Stratoudakis and Papadimitriou, 2007).

BIOGRAPHICAL NOTES

Kimon Papadimitirou has been working as a GIS specialist and cartographer since 1997 and he has been teaching graduate and postgraduate courses at Aristotle University of Thessaloniki, Greece. His interests include the research of new fields for cartographic applications, interoperability through geoinformation technologies, (including multimedia applications), research of alternative representation methods and techniques of visualization. The last 4 years, he has been dedicated to the study of soundscape. He holds a graduate Diploma in Rural and Surveying Engineering from the Department of Rural and Surveying Engineering, Aristotle University of Thessaloniki (1995), a postgraduate Specialization on the Analysis and Management of Geological Risks from the University of Geneva, Switzerland (2000) and a PhD in Rural and Surveying Engineering from the Department of Rural and Surveying Engineering, Aristotle University of Thessaloniki (2004).

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