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Sonic environment and vegetation structure: A methodological approach for a soundscape analysis of a Mediterranean maqui

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ABSTRACT

Herein we present one of the first attempts to couple the complexity of vegetation and topographic features with the sonic environment to understand the distribution of bird species and individuals in their habitat. To achieve this, the sonic features of a bird community were studied during the spring and early summer of 2011 in a Mediterranean maqui located on the western slope of a remote hanging valley that is dominated by *Erica arborea*, *Quercus ilex* and *Arbutus unedo*.

Species composition, height, vertical foliage profile, canopy density and dispersion of vegetation were utilized as probable proxies for the sonic patterns. The acoustic activity of birds was collected through the use of a regular matrix of 20 audio recorders, spaced 25 m apart, which were placed following the topographic isoclines. The sonic complexity of the soundscape was evaluated using the Acoustic Complexity Index (ACI), which is a recently developed metric.

The PCA applied to the vegetation parameters revealed two principal distinguishing factors, which we were able to define as "vegetation density and structure" and "species segregation." Moreover, the results show that, even in the case of sampling sites that are very close together, sonic patterns vary across the season, highlighting the great variability of the soundscape and confirming the adequacy of the sampling scale of 25 m adopted in this study. The topographic features do not seem to be connected to the sonic environment. The main sonic complexity was found where the vegetation was taller and denser, especially where *E. arborea* was the dominant species. Although this proves that acoustic dynamics can be linked to vegetation structure, even on a small scale, a consistent element of sonic variability cannot be explained by vegetation patterns alone, and a soundtope hypothesis must be invoked.

1. Introduction

The recent field of soundscape ecology (Farina et al., 2011a; Pijanowski et al., 2011a,b; Truax and Barrett, 2011) has revealed new perspectives when it comes to investigating the sonic complexity of the environment, which is an important component of the quality of ecosystems. This has produced a powerful and efficient tool to be used for both the short- and long-term monitoring of biological and ecological dynamics (Bardeli et al., 2010; Depraetere et al., 2012).

The acoustic diversity of biophonies (Krause, 2012, p. 68) has been regarded as an indirect estimator with which to evaluate the biodiversity of different habitats (Gasc et al., 2013; Sueur et al., 2008).

Investigations of the sonic complexity of the environment are considered to be useful when it comes to: understanding the relationship between the structure of vegetation and animal dynamics (Pekin et al., 2012); evaluating the complexity of animal assemblages (Gasc et al., 2013); and investigating the relationship between the structure of the landscape and sonic patterns (Bormpoudakis et al., 2013).

In particular, the biophonic components of the sonic environment provide important information about community diversity and the dynamics of vocal animals (Krause, 2012), as well as more generally about the "health" of ecosystems (Carson, 1962). The acquisition of such knowledge is finally possible today thanks to: the use of autonomous recording systems (Blumstein et al., 2011); a powerful methodology with which to process sonic data (Farina et al., 2012); the availability of new sonic indices (Farina et al., 2011b; Sueur et al., 2012; Villanueva-Rivera and Pijanowski, 2012); and automatic identification algorithms for some groups of species (f.i. Ranjard and Ross, 2008; Skowronski and Harris, 2006; Somervuo et al., 2006; Trifa et al., 2008).

Despite the great potential of the soundscape approach, there are very few studies on terrestrial ecosystems in the literature (f.i. Bormpoudakis et al., 2013; Cellis-Murillo et al., 2009; Joo et al., 2011; Mazaris et al., 2009; Pieretti and Farina, 2013; Slabbekoorn, 2004). Moreover, uncertainty persists with respect to field procedures, such as: the selection of types and numbers of recording devices or their calibration (but see Mennill and Fristrup, 2012); the selection of the spatial and temporal scales with which to collect the sonic information according to the habitat investigated (Mennill et al., 2006); and the best indices and software

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with which to efficiently process the sonic data (Farina, 2014, p. 242; Gasc, 2012).

For instance, the choice of one recorder versus an array of recorders is a controversial argument that requires empirical validation, as the few examples of the use of arrays have been used to gauge the best spatial localization of individuals (f.i. Blumstein et al., 2011; Mennill et al., 2006) and not to intercept sonic patterns across a large area.

Moreover, most of the literature regarding the relationships between vocal animals (in particular birds) is based on aural identification carried out during field surveys. This is an approach that is strongly affected by the skill of the observer and influenced by the disturbance created by observer intrusion (Bibby et al., 1992, p. 24; Gibbons et al., 1996, p. 245).

The soundscape approach has the advantage of allowing the researcher to collect information that will be permanently stored in a digital medium. Moreover, the data are processed automatically, and the aural identification can be repeated whenever necessary, reducing the likelihood of disagreements between people with different species identification skills (Hobson et al., 2002). Finally, human disturbance is strictly limited to the period of the placement of the recording devices.

Of course, the relationship between vegetation complexity and the complexity of the sonic environment has only been investigated infrequently, especially from a bioacoustical perspective. In this context, Morton (1975) was one of first authors to emphasize the importance of vegetation structure on the acoustic adaptation of birds. His approach was followed by Marten and Marler (1977), who confirmed the acoustic adaptation hypothesis, while Laiolo et al. (2008) discussed the role of landscape fragmentation for the maintenance of a differentiated song repertoire in the Dupont's Lark (*Chersophilus duponti*). Later, fragmentation was demonstrated by Briefer et al. (2010) to be an important process that influences the composition of elements in skylark songs, although the number and complexity of these elements seem to be more fixed. Krause et al. (2011), meanwhile, have investigated the complexity of the sonic patterns in four habitats in the Sequoia National Park (US), and Pekin et al. (2012) put the emphasis on the relationship between the acoustic diversity and the structure of vegetation by using a LIDAR approach.

There is evidence that vegetation structure affects sound propagation, and the denser the vegetation is, the more the biophonies are degraded by reverberation and attenuation by leaves and branches (f.i. Embleton, 1963; Padgham, 2004). This produces responses with respect to, for instance, the range capacity of territorial birds, as proved by Morton et al. (1986) and Morton (1987) with respect to Carolina wrens.

In addition, the topographic characters of the environment are rarely considered in terms of the relationship with the sonic environment. For instance, Hunter (1989) has observed that singing birds on steep slopes are generally oriented towards the up-slope direction, with an evident advantage for the diffusion of acoustic waves.

Recently, the relationship between the structure of the landscape and the soundscape patterns has been explained by three different models, the first of which considers a patterned distribution of acoustic cues or sonotopes, defined as the result of the overlapping of the geophonies, biophonies and anthrophonies that are coincident with the structure of the landscape (Farina, 2014, p 17). A second model assumes that the sonotopes are broader than the landscape patterns due to an expected active diffusion of sonic cues that go beyond the borders of the vegetation patches. Finally, a third model states that the sonotopes, as described in the previous model, have an internal spatial variability due to the behavioral dynamics of vocal animals, where competition and cooperation mechanisms produce the spatial repartition of individuals (Farina and Pieretti, 2012; Malavasi and Farina, 2013). This further subdivision would create soundtopes, defined as a coordinated aggregation of biophonic sounds (sensu Farina, 2014, p 19; Farina et al., 2011a) inside each sonotope. Soundtopes represent distinct and emerging sonic aggregations with a great temporal variability.

In particular, our principal aims were:

- To test different field methodologies for collecting information on vegetation structure.
- To verify the efficacy of: a tight spatial scale while carrying out sonic investigations in a Mediterranean maqui characterized by dense vegetation in the first 3–4 m of the soil; the application of an array design for placing recording devices.
- To collect the sonic environment characters in general and, in particular, to compare the complexity of the habitats (topography and vegetation).
- To use such results as a basis for a further discussion of the sonotope/soundtope hypothesis.

2. Study area

The study area (Fig. 1), which is 600 m from the Tyrrhenian Sea and stands at an elevation of 300 m, is westerly exposed on the left side of a small hanging valley, with slopes characterized by an inclination of approximately 26°. It is located close to the small town of Deiva Marina, Eastern Liguria, Italy (44°13′27.6″N, 9°30′30.1″E), at the center of a large secondary dense sclerophyll forest dominated by small trees and *Erica arborea*, *Quercus ilex* and *Arbutus unedo* shrubs. The area, which is well away from permanent human settlements and paved roads, is bordered by some paths that are utilized by tourists from late spring to early fall, and occasionally by hunters in fall and early winter.

The area, which was partially terraced and cultivated until the early 1950s, experienced recurrent wild fires (1980s; see also Solans Vila, 2007) that have interrupted the wood recovery and intervened over the course of the process of land abandonment, as testified by the remnants of old scars along the entire study area.

As a result of a previous investigation of the soundscape of this area based on a recording station operating continuously during 2011 (Farina et al., 2013), we are aware that the major contribution to the sonic environment is represented by bird vocalizations and geophonic sources (wind, rain, thunder). Due to the area's remoteness from human settlements, the few anthrophonic disturbances are mainly produced by the engines of fishing and tourist boats, military and rescue helicopters, and civilian aircraft.

3. Methods

Vegetation sampling and sonic recordings were carried out according to a grid of 20 points (4 × 5) regularly spaced at 25 m, covering an area of 175 × 125 m.

In order to test the potential effects of topographic features on the sonic environment, it was decided to divide the analysis of the matrix into five "vertical lines" (following the maximum slope) and four "horizontal lines" (following isocline lines; Fig. 2).

3.1. Vegetation sampling

According to the different sampling techniques proposed for temperate deciduous forests (Blondel and Cuvillier, 1977; Blondel et al., 1973; MacArthur and Horn, 1964; MacArthur and MacArthur, 1961) and Mediterranean scrubs (Cody and Walter, 1976), we tried to detect the complexity of the vegetation by collecting information about the following parameters:

3.1.1. Vegetation height

The height of the shrubs and trees was assessed by direct measures along two perpendicular transects, each of which was: 8 m-long, centered on each recording station, and oriented according to slope inclination. The details of the height of the vegetation were collected