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Application of landscape and soundscape ecology to the Mediterranean region

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Abstract

Particular investigative tools are needed to understand the ecological dynamics of the complex land mosaic across the Mediterranean region that is the result of human intervention over thousands of years. Landscape ecology and the associated study of soundscape ecology are two disciplines that are able to construe the challenges posed by such human disturbances, which have created distinct and fine-grained, cultural landscapes. The aim of this paper is to consider a research agenda guided by an ad hoc ecological theory that is able to examine and interpret the complexity observed in the Mediterranean landscape.

Introduction

The Mediterranean region is characterized by great environmental complexity due to: 1) its position between Africa and Europe, 2) the presence of a large internal marine basin (2.51×10^6 km^2), 3) a morphology characterized by high mountains and extensive alluvial plains close to the sea, and 4) long-term manipulation of the land by humans that has created a unique and valuable system. In fact, the majority of the terrestrial and marine ecosystems have been greatly impacted by uninterrupted anthropogenic activity (from, at least, 1 Myr). Most of the territories have been affected by human intervention that most notably included slope terracing, river canalization, marshland reclamation, and diffuse deforestation, which have modified the distribution and abundance of species, community composition, and the availability of natural resources at different times in history. The Mediterranean region is densely inhabited and a significant part of the coast is covered by infrastructure that supports large cities (e.g., Alexandria, Egypt: population 4,500,000). The human population is present everywhere, and the majority of territories are under the direct responsibility of local communities.

Due to this human intervention, landscapes across the Mediterranean basin have the common characteristic of a fine-grained mosaic of intact and human altered patches (Grove & Rackham 2003). The Mediterranean area experiences periodical environmental crises like aridity and fires.

The seasonal water deficit is one of the key environmental processes because it affects primary production and community dynamics across a large set of environmental scales.

The fire regime is a further important driver of the vegetation structure and landscape ontogenesis that affects the plant and animal communities (Naveh & Dan 1973, Naveh 1975, 1994). Indeed, fire has been recognized by Walter (1968) "*as one of the major ecological factors which shaped the Mediterranean landscape and affected its present mosaic-like pattern of regeneration and degradation stages.*"

Moreover, several anthropogenic stressors delineate a scenario dominated by political, social, and economic instability and inequities within and among Mediterranean countries, accelerating a process of mass emigration from the south-eastern to the northern parts of the Mediterranean shores. This process is exacerbated by the recent civil wars in regions like Libya and Syria, and are complicated by the decennial conflict in the Middle East.

The high rate of population growth associated with both migration from rural areas to urban centers, and mass tourism have degraded valuable coastal regions by spreading impervious surfaces and created an unrestrainable water deficit. The abandonment of rural areas by local communities, especially in mountain regions, has often been associated with the hydraulic and geological instability of the territories, with unexpectedly extreme rain events in recent decades producing locally-devastating flood events.

Despite such criticalities, the Mediterranean basin is still recognized as a biodiversity hotspot (Myers et al. 2000, Cuttelod et al. 2008) where the flora diversity is outstanding with 15,000 to 25,000 species, where 60% are unique to the region and about one third is endemic (Blondel et al. 2010). To date, a total of 1,912 species of amphibians, birds, cartilaginous fish, endemic freshwater fish, crabs, crayfish, mammals, dragonflies, and reptiles have been assessed in the Mediterranean region. Approximately 19% of these species are threatened with extinction in the near future.

The entire Mediterranean region is a strategic area, like a political ecotone, and acts as a bridge between Africa and Europe. Its global relevance requires special effort to collect information, track changes, and create efficient models to predict its natural and anthropogenic evolution.

All Mediterranean countries are rich in natural beauty and monuments, and it is for this reason that the conservation of the landscape requires a deep knowledge of both the past and recent natural and anthropogenic history. In addition, the cultural landscape itself represents an important source of amenities and a sense of place and identity for a great number of residents and visitors.

Ecology seems to be one of the most important sciences when it comes to adequately approaching the complex interactions between humanity and natural systems. In particular, landscape ecology and the new emerging field of soundscape ecology offer new paradigms, tools, and methods to face the perennial challenges that human dynamics pose to the sustainable use and conservation of natural resources.

The aim of this contribution is to discuss the opportunity to apply the principles and methods of landscape and soundscape ecology for a more efficient approach to investigating the complexity of natural and human-modified Mediterranean systems.

Landscape ecology: state of the art and recent developments

Landscape ecology is a consolidated ecological discipline recognized in recent decades that largely contributes to an epistemological integration of ecosystem paradigms with spatial processes across a broad range of spatio-temporal scales (Naveh & Lieberman 1984, Forman & Godron 1986, Farina 1998, 2006, Turner et al 2001). This approach distinguishes coherent components of the spatial mosaic and investigates the effects of spatial arrangements of natural and man-made objects, such as woodlands or artificial ponds, fluvial corridors, and roads for the functioning of land systems. The discipline also recognizes the semiotic and cognitive dimensions of ecosystems (Farina 2010).

At its epistemic roots, landscape ecology encompasses many ecological theories and models, such as the theory of island biogeography (MacArthur and Wilson 1967), metacommunity models (Hanski & Gilpin 1997), source-sink (Pulliam 1988), percolation models (Stauffer 1985), graph theory (West 2001), and fractal mathematics (Feder 1988, Milne 1991) to explain the spatial dynamics of individuals, populations, and communities.

Landscape ecology is based on two main theoretical perspectives:

a) The landscape is considered to be a mosaic of habitat patches of different sizes and shapes. This vision is very popular in the USA and uses information from field surveys and remote sensors (satellites) manipulated by Geographical Information Systems software (GIS) to create thematic maps and link databases in a georeferentiated way (Turner and Gardner 1991).

b) The landscape is considered to be a cognitive/human-oriented object in which the human semiosis interacts with plant and animal semiosis (Farina 2010). This perspective has its roots deeply set in the stratified culture of the European people.

Landscape patterns

Matrix and patches

According to landscape theory, a landscape is a complex object in which it is possible to distinguish a mosaic of patches (Forman and Godron 1986). When one patch type dominates in terms of extension, we consider it to be the landscape matrix. The matrix represents the dominant land cover and may be of natural origin (e.g., forests and prairies), or of human origin (e.g., croplands). The presence of a matrix may have positive effects if it is natural (i.e. provides habitat and resources for a species) or, when it has human origins, it may be species-hostile (e.g., urban sprawl). However, in the Mediterranean, the majority of the matrices, such as mountain pastures, park-like forests, and olive and sweet-chestnut orchards, are the result of long-term human intervention. This type of matrix is considered to be a cultural landscape (von Droste et al. 1995) that supports complex and stable communities of plants and animals. The Devesa in Spain, the Montado in Portugal, and the cork oak savanna in Sardinia (Italy) are excellent examples of such landscape configuration situated in a rural context. Usually, a matrix is not homogeneous, and patches with different origins and compositions may increase its internal heterogeneity. These patches could be the result of a small-scale disturbances, such as a tree gap in a forest after a wind tempest or larger scale events, like a fire or an intense flood.

Peculiar characteristics of patches, like their size and shape, internal diversity, and temporal dynamics, are important for the composition and diversity of plant and animal communities.

Heterogeneity

Heterogeneity is the main characteristic of a land mosaic that results from the interaction of different and, in some cases, competitive factors that are active in a landscape.

In the Mediterranean region, heterogeneity is very high due to the fine-grained differences in soil structure, a dynamic climate affected by a complex morphology, and various degrees of human intervention that often increase the patchiness of natural mosaics.

Ecotope

The ecotope is a central paradigm in landscape ecology and is the result of the overlap of physiotopes and biotopes after human intervention, and is ecologically homogeneous in space and time. Olive groves or vineyards are examples of ecotopes in a Mediterranean landscape where the planting area are selected according to the habitat preferences of cultivated plants. Soil, slope position, and vegetation (olive, grapes, etc.) create ecologically homogeneous units.

Ecotones

Ecotones have been defined as tension zones, which are areas in which the interchange of energy, material, organisms, and information is high (Hansen et al. 1988). Ecotones are located on the border between two ecotopes or patches, and may have originated from natural or anthropogenic processes. Ecotones have long been well known by ecologists, especially in areas that are particularly rich in fauna. The Mediterranean is especially rich in ecotones and people often increase their distribution, in this way favoring the expansion of the wild fauna living at the edges.

In rural landscapes, ecotones are represented by fences created with thorny trees (e.g., *Crataegus monogyna, Prunus spinosa*) to delimitate fields and protect crops from domestic animals. Often, the vegetation at the edges of fields is also used for foraging livestock.

The amount of ecotones present is an indicator of landscape patchiness. Empirical evidence has confirmed that when the number of ecotones is high, this is a signal of major habitat fragmentation that has negative effects on the distribution and abundance of core species, which are species that require the great extension of habitat patches (Andren 1994). A very homogeneous stand offers few ecotones, with the opposite effect on species diversity. In the Mediterranean, homogeneous stands support a few species of plants and a reduced number of animals. Ecotones are important when positioned between croplands and rivers, functioning as buffer zones, which are areas that are able to absorb the excessive input of nutrients from fertilizers, thus reducing the potential risk of water eutrophication. People in the Mediterranean use marine ecotones (e.g., beaches) intensively for recreation and relaxing, especially in the summer time.

Landscape processes

Fragmentation

The mosaic of the Mediterranean landscape is already, per se, a fragmented system, and this fragmentation does not have a negative impact on biodiversity, like in tropical forests. In fact, fragmentation is a process that occurred thousands of years ago across the Mediterranean, when people were progressively opening primeval forests and creating rural landscapes (Grove and Rackham 2003). Two opposite processes have occurred in recent decades across the Mediterranean: land abandonment and the spread of urban settlements either along coasts or on mountain ranges (sky facilities). Land abandonment reduces the mosaic-like structure of the rural landscape, but roads, railways, and industrial and urban sprawl have dramatically increased the isolation of this landscape having negative effects on several species of plants and animals.

Connectivity

Connectivity is the opposite process to fragmentation and occurs when isolated patches are connected after a secondary succession. The connectivity is guaranteed by corridors, which are structures of linear habitats that allow species to move from one habitat patch to another, thus avoiding hostile conditions.

In the Mediterranean, natural corridors are especially located along mountain ridges, which continue to be residual, remote areas with low human impact and long rivers. Large predators with extensive home range like wolves and ungulates (deer, wild boar) use these corridors for seasonal or migratory movements.

Definitively, mountains and rivers across this region are natural corridors, and their protection represents an important strategy with which to preserve biological diversity and ensure population dynamics.

Disturbance

In landscape ecology, disturbance is considered to be a necessary process to ensure the complexity of the land mosaic. In the Mediterranean, human intervention is the major cause of disturbance and the main contributor to shaping landscapes. Land reclamation, fires, livestock grazing, logging, plowing, and soil tillage are some of the more frequent disturbances found within the Mediterranean region. Due to the small dimensions of land properties, disturbance appears as a random process that occurs without precise rules and creates arbitrary novelties in the landscape. Recent rural abandonment reduces the scale of the anthropogenic disturbance and may encourage large-scale disturbances like wild fires, which through greater connectivity, can find greater large amounts of biomass to burn.

Soundscape ecology

Sounds are vibrations that travel through the air, water, and soil, and can be heard when they reach a person's or animal's ear. Sounds are powerful proxies with which to auscultate the "earth beat" of coupled human and natural systems (Stuart Gage, pers.com.), and explore the rich world of acoustic semiosis and information (Truaux 1999). Every landscape has a peculiar sonic environment that acts like a specific "acoustic signature".

Soundscape ecology, which is part of a broader ecoacoustic science (Sueur and Farina, in press), is a young discipline that studies the ecological role and impact of sounds on individuals, populations, and communities on the landscape scale. It is relevant and complementary to the landscape ecology approach because sounds originated by geophonies (wind, rain, thunderstorm, and volcanoes), biophonies (animal vocalizations and songs), and technophonies (all human sounds produced by tools and vehicles) are mixed together and emerge as a distinct character in every locality (Pijanowski et al. 2011).

Life dissipates energy to stay alive, and produces vibrations which, when captured by special organs (f.i. ears), transmit information that is essential for species survival and reproduction. Sound interpretation is a key feature in intra and interspecific competition for every vocal animal.

The acoustic approach is an efficient tool for describing complex phenomena at the population, community, ecosystem, and landscape level in natural and human-dominated systems (Krause 2012).

Testing new theoretical assumptions based on sound production and diffusion will create strong links between landscape and soundscape ecology, supporting the relationship between geography, land cover, and acoustic patterns.

The complex mosaic that characterizes most Mediterranean landscapes is associated with a mosaic of sounds that can be used by different animal species and humans as a proxy with which to assess favorable habitats and resources or reduce competition.

Mediterranean environments are often difficult to survey, classify, and interpret by only using remote sensing tools due to characteristics like a complex morphology that interferes with reflected light, the un-patterned heterogeneity of vegetation, the extreme density of forest cover, and a fine mosaic of land uses.

Moreover, passive acoustics is a non-invasive technique that could be used in areas in which human disturbance could be a key limitation. In the Mediterranean maqui, where there is denser vegetation that is difficult to cross and investigate, the use of acoustic recorders enables accurate surveys with minimal impact on vegetation and animal communities (Farina and Pieretti 2013).

Currently, very few landscape-soundscape interactions are known or understood, and further research is required. Future research should consider the spatio-temporal scales of sounds and how vegetative structure and landscape morphology can drastically change the behavior of sound sources and sound propagation. The interactions between sounds and natural or man-made objects change sonic properties and sound diffusion. These factors produce an acoustic mosaic that is more fine-grained than the geographical landscape (Farina 2014).

Sonic patterns: sonotope, soundtope, and sonotone

The soundscape is defined by overlapping of geophonies, biophonies, and technophonies within a specific locality. The emergent aggregation from overlapping soundscapes is called a sonotope, which is the result of landscape processes (Farina 2014), and could be regarded as a "sonic patch". Behavioural processes create further sonic patches inside the sonotope. Such additional sub-divisions are called soundtopes (Farina 2014), and are defined as a coordinated aggregation of individual sounds emitted by different interacting species (Malavasi and Farina 2012) and coincident with the recent concept of the "acoustic community" (Farina and James, sub).

We define a sonotone as a sonic environment that is the result of the partial overlapping of adjacent soundtopes. This sonic object is similar in the function to the landscape ecotones but at difference of the ecotone it can occur also in area that are considered homogeneous from a landscape point of view because soundtopes, from which sonotone are originated, can be distinguished also inside an apparent homogeneous landscape.

Techniques and tools in soundscape analysis

The passive acoustic survey allows us to: 1) investigate the complexity of vocal communities across a broad range of spatial and temporal scales (Sueur et al. 2008, 2012, Farina and Pieretti 2013, Gage and Axel 2014), and 2) assess biodiversity (at least of vocal animals).

Acoustic investigations are becoming popular today thanks to new recording devices that can be located in the field for extended amounts of time with support from a consistent power supply, a huge memory capacity in terms of removable secure digital cards, and the possibility of being set according to an appropriate time-scale. In addition, a new generation of low cost recording devices are available, and can be used inconspicuously in areas where the risk of theft or tampering is high (Farina et al. 2014), or when economic restrictions prevent the use of more expensive tools. The acoustic information is processed using new and powerful metrics like the Acoustic Complexity Index (ACI) (Pieretti et al. 2011) or the Soundscape Power (Gage and Axel 2014), but for a detailed comparison between different indices, see Towsey et al. (2014) and Depraetere et al. (2012).

The quality of the soundscapes and their protection

The acoustic quality of a landscape is an important feature in terms of efficiency in animal communication (Brumm and Slabbekoorn 2005), human use and environmental interpretation. Quiet areas have an additional value well demonstrated by a large-scale survey conducted across Greece by Matsinos et al. (2008). These authors have verified on a small-scale the daily dynamics of the sonic environment that reflects biological and human dynamics, while, on a large-scale, the sonic environment is shaped by landscape attributes.

A high fidelity soundscape, by which we mean a sonic environment in which every sound is distinct and not covered by noise, is an important resource for people. Long-term soundscape monitoring in natural areas and parks across the Mediterranean is an important strategy for surveying the level of noise intrusion in landscapes (e.g., Matsinos et al. 2008). This survey can be conducted in either terrestrial and marine or freshwater systems. In marine systems, the acoustic recording is of fundamental importance for tracking biological diversity and dynamics.

In particular, the characterization of the marine and freshwater system using the acoustic approach may be of great help, because landscape ecology does not have enough tools in these types of environments. Submerged surfaces are difficult to analyze and reproduce as classified maps because visualizations are impeded by the dramatic reduction of light in deep waters.

An interesting attempt to characterize the marine soundscape has recently been made by McWilliam and Hawkins (2013), while the stream landscape has been investigated by Tonolla et al. (2011).

The protection of landscapes where sonic attributes are considered by people to be valuable is becoming essential to species conservation. Investigating landscape dynamics using the soundscape approach appears to be an excellent tool because it is not intrusive and demands a limited investment of human and economic resources.

Conclusions

Landscape ecology is an important ecological discipline and is particularly adept for investigating the complexity of the Mediterranean landscape. In particular, the cognitive and cultural aspects of this discipline integrate the geographical and ecosystem dimensions of the landscape with both the perceptions by which organisms intercept resources and the complex interactions between natural ecosystem dynamics and cultural processes. At the same time, the use of soundscape ecology reinforces the capacity to explore complex environments across the Mediterranean approaching similar spatial and temporal components in different way.

We are expecting dramatic changes in the Mediterranean in the coming decades for climatic reasons coupled with political, social, and economic events. One example is the doubling in size of the Suez Canal, which will have a dramatic impact on marine biodiversity due to the entry of tropical species (Galil et al 2014). These changes will create new environmental assets requiring novel political and social action, and both of these approaches will have an impact on the distribution of plants, animals, and resources.

The capacity of landscape ecology to be applied as a research tool across a broad range of temporal and spatial scales should ensure efficient qualitative and quantitative investigations. In particular, the combination of landscape and soundscape ecology methods will be a powerful combination to investigate the changes that occur in both remote and urban areas. It will also be possible to compare maps of land use obtained by sophisticated remote sensing technologies like LIDAR (see Pekin et al. 2012 for an example) with the associated sounds produced by living and non-living agents.

Like for the landscape, the cultural dimension is incorporated in the geographical dimension. Similarly, the sonic dimension of the landscape can be analyzed in terms of either bio, eco or cultural semiosis (*sensu* Farina et al. 2005). The role and importance of soundscapes for local people may be a privileged proxy for evaluating the rate of cultural identity and sense of place.

The combination of landscape and soundscape ecology will allow complex conditions to be surveyed where the weakness of one approach is supplemented by the strengths of the other. In particular, the long-term monitoring of areas of natural or cultural value will be possible either by using visual remote sensing or acoustic approaches. This last methodology, which is based on field surveys, is less expensive, because it does not require satellites or airplanes and can be easily undertaken by non-professionals. Moreover, the economic impact of a long-term survey is not a secondary aspect of the success or failure of this type of research.

Lastly, given that a large number of Mediterranean countries are suffering economic restrictions and facing challenges about job opportunities and healthcare, a long-term survey to provide the information needed by policy-makers and stakeholders will only be possible if these investigations can be conducted at a reduced cost without impacting on the robustness of the methodology applied.

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