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Quantifying spatio-temporal patterns of forest fragmentation in Hymettus Mountain, Greece

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ABSTRACT

The rapid land use/cover change (LUCC) and landscape fragmentation occurring around the world is largely attributed to human induced factors. Landscape fragmentation has become a central issue in landscape ecology and conservation policies due to its direct influence on biodiversity which consequently endangers the sustainability of ecological goods and ecosystem services. Thus, fragmentation monitoring and assessment is a critical issue in land use planning and sustainable environmental management in order to avoid any irreversible negative consequences. This research explores the application of methodologies that employ multi-temporal satellite imagery, combined with geographical information systems and landscape metrics, to assess forest fragmentation. The objective is to determine spatio-temporally the LUCCs focusing on the woody vegetation in Hymettus Mountain of Greece over the last decades. The study area, which has been designated as a Natura 2000 site, is situated near the city of Athens. It faces various perturbations triggered by socio-economic factors and the absence of an ongoing contextual appraisal for conservation. To quantify the LUCCs, nine Landsat images spanning 28 years are classified. Post classification comparison is applied to generate transition maps. Additionally, eight landscape metrics are calculated. The change detection results identify hot-spots of forest fragmentation where mitigation measures should be taken, so that further irreversible alteration of the ecosystem is prevented. The landscape metrics advocate that, during the last three decades, the woody vegetation have steadily been more fragmented. The primary direct causes are economic driven intense anthropogenic activities along with frequent wildland fires whereas the indirect cause is the absence of a sustainable environmental management and conservation strategy.

1. Introduction

Socioeconomic development in Greece has considerably been influenced by land-based economic activities. These are closely related to the structure and function of landscapes, as long as agriculture, grazing, forest harvesting and mining still constitute partially income source for its residents (Papanastasis, Mantzanas, Dini-Papanastasi, & Ispikoudis, 2008). Landscape refers to a mosaic of heterogeneous territory composed of sets of interacting ecosystems (Forman, 1995). It is characterized by dynamics, composition and configuration that are governed by natural processes and human activities (Forman, 1995). The term composition describes the abundance and variety of different patch types, while configuration refers to the physical distribution and spatial character of patches within a landscape mosaic (McGarigal & Marks, 1995).

Over the last century, natural ecosystems in Europe have been substantially transformed because of socio-economic and political changes (Reger, Otte, & Waldhardt, 2007). These transformations are expected to continue. More specifically the structure of forested landscapes has changed as a result of natural and anthropogenic disturbances, ecological succession and degenerative trends (Ji, Ma, Twibell, & Underhill, 2006; Lambin & Meyfroidt, 2010). Human activities have modified the environment to the extent that landscapes are increasingly becoming dominated by human settlements, artificial cultivation fields with only scattered fragments of natural ecosystems (Vitousek, Mooney, Lubchenco, & Melillo, 1997). Most natural conservation reserves are progressively being surrounded by intensively modified environments and in the long-term, are deemed to function as isolated natural ecosystems (Wolter & White, 2002).

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Forest fragmentation is a dynamic process in which contiguous forest tracts are progressively being sub-divided into smaller, geometrically complex isolated patches (Gibson, Collins, & Good, 1988). Caused by either natural or anthropogenic agents, forest fragmentation seriously threatens key features and processes of the earth such as climate, biophysical and hydrological cycles, biodiversity and ultimately ecosystem services. More specifically, the composition and characteristics of the earth's forests, aggregated at a global scale, affect the climate. First the earth's forests can impact the hydrological cycle by impacting the amount of evapotranspiration, infiltration and surface water runoff (Becker & Bugmann, 1999). Second forests affect the atmospheric composition, by determining the moisture content in lower atmospheric layers (Chase, Pielke, Kittel, Nemani, & Running, 1999). Finally, they also determine the emission of greenhouse gases functioning as a natural sink (Falkowski et al., 2000; Rockstrom et al., 2009). Moreover, alterations in the hydrological cycle and climate affect the soil quality, since the latter is gradually being degraded through erosion that progressively leads towards desertification (Le Houérou, 2002). The status of forest ecosystems is also directly related to biodiversity. Rapid changes in health, composition and structure of ecosystems inevitably lead to fragmentation of habitats with multiple effects such as species extinction (Gaston, 2005; Schroter et al., 2005; Tilman et al., 2001). Hence, forests alteration clearly endangers the sustainability of ecological goods and ecosystem services (Costanza et al., 1997).

To face these issues the European legislation via the Habitats and Birds Directives ((92/43/EEC and 79/409/EEC respectively) has identified the need to protect natural ecosystems providing the legal basis to establish the Natura 2000 network. The overall goal of this network is to implement management plans that will preserve high-value natural ecosystems, protect the biodiversity and the ecological functions of natural ecosystems and enhance sustainable management. This network comprises of approximately 26.000 protected areas (Special Areas of Protection and Special Areas of Conservation) and covers a total area of about 850.000 km^2, more than 20% of total EU territory (Apostolopoulou & Pantis, 2009; Dimopoulos, Bergmeier, & Fischer, 2006; Papageorgiou & Vogiatzakis, 2006; Tsiafouli et al., 2013). The effectiveness of protection strategies (namely: conservation conventions, protocols and parks) has attracted the interest of scientists the last decades (e.g. Bruner, Gullison, Rice, & da Fonseca, 2001; Mallinis, Emmanoloudis, Giannakopoulos, Maris, & Koutsias, 2011; Seto & Fragias, 2007).

Understanding the landscape pattern and quantifying its spatial relationships and changes through time, is essential for the continuous monitoring and assessment of ecological processes. Remote sensing (RS) combined with geographic information systems (GIS) and landscape metrics (LM) can successfully provide spatially consistent and detailed information about landscape structure, a prerequisite to study ecosystem services, sustainable resources management and land use planning (Gustafson, 1998; Riitters et al., 1995; Shi et al., 2011).

Recent developments in the field of satellite RS have increased the use of spatially explicit landscape analyses. At the same time, numerous landscape indices have been developed to quantify landscape structure and spatial heterogeneity based on the composition and configuration of landscapes (Chen, 2002; Coppin, Jonckheere, Nackaerts, & Muys, 2004; Liu & Zhou, 2005; Seto & Fragias, 2007). Metrics are calculated at three different hierarchical levels: landscape, class, and patch. The landscape level metrics includes all patches within a defined landscape. The class level metrics represent the spatial distribution and patterns of a land use/cover class, such as a woodland, and mainly involve differences between classes. Finally, the patch level metrics are calculated on the individual patches within each class.

The aim of this study is to identify general trends and subtle patterns of forest extent in Hymettus Mountain, Attica Prefecture, Greece that has been exposed to persistent anthropogenic activities over the last three decades. It is divided into three main complementary axes: (i) Evaluation of the potentials and limits of an integrated earth observation approach as a valuable tool for monitoring. Furthermore, the methodology presented in this paper is literally a cost effective proposal that can be adopted by land use planners and ministry policy makers, management agencies and environmental researchers. (ii) Exploration of the effectiveness of the protection status of the area, since it belongs to the Natura 2000 network. (iii) Provision of important feedback and historical evidence associated with the implications of decision-making being monopolized by economic growth on the one hand and being deprived of effective conservation measures, on the other hand.

Athens, being of the largest conurbation and the most dense populated area of Greece, shows two major contradictions. On the one hand, it concentrates around one third of the total population of the country, a phenomenon triggered by socio-economic developmental needs and the comparative advantages of the city to attract investments and development opportunities (Chorianopoulos, Pagonis, Koukoulas, & Drymoniti, 2010). On the other hand, it is located in a basin where mountains on the three sides and the sea on the other restrict its growth. As a consequence of those economic and demographic pressures, the region is facing urban sprawl problems due to the increasing population and the urgent socioeconomic development that has occurred during the last decades (Weber, Petropoulou, & Hirsch, 2005). The urban, industrial and construction grid is expanding considerably, along with the road network and the relative linear residential developments, in order to serve rapidly growing needs (Chrysoulakis, Mitraka, Stathopoulou, & Cartalis, 2013; Nikolakopoulos, Pavlopoulos, Chalkias, & Manou, 2005). All the above-mentioned changes have led to major environmental implications (Forman & Alexander, 1998). The urban expansion, which is in expense of the natural reserves, is expected to continue as a new road network expansion for the city is scheduled by the Ministry of the Environment, Spatial Planning and Public Works (2006).

It is hypothesized that forest spatial extent, composition and distribution have been changing since the early 1980s, thus leading to fragmentation, shrinkage and attrition of forested areas. The focus is mainly on forest fragmentation induced by human activities, specifically agriculture, unplanned urbanization and industrialization, heavy exploitation and wildland fires. The spatial extent and distribution of LUCCs is assessed to acquire information about the dynamics of the area, by identifying increased fragmentation hot spots.

This paper is organized as follows: First the Hymettus Mountain and the Landsat imagery used are described. Second, the image preprocessing, the classification, employing a machine learning methodology and the accuracy assessment are presented. Following post classification comparisons to assess the periodic LUCC are presented along with the proportion of each class, revealed by the classification of the imagery. Next the time series of eight LM calculated to assess the landscape structure changes are presented. Finally the results are discussed in detail and the main points are highlighted.

2. Methodology and data

2.1. Study site

Hymettus Mountain is located in the south-central part of Attica Prefecture, between the Athens conurbation, Penteli Mountain, Messoghia Plain and Saronikos Gulf. Its north to south length is approximately 20 km and its width ranges from 4 to 6 km. It