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Modeling the ecological niche of long-term land use changes: The role of biophysical factors

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ABSTRACT

Land use/land cover changes (LULCCs) represent the result of the complex interaction between biophysical factors and human activity, acting over a wide range of temporal and spatial scales. The aim of this work is to quantify the role of biophysical factors in constraining the trajectories of land abandonment and urbanization in the last 50 years. A habitat suitability model borrowed from animal ecology was used to analyze the ecological niche of the following LULCC trajectories occurred in Emilia-Romagna (northern Italy) during 1954–2008: (i) land abandonment (LA) and (ii) urbanization (URB), both from agricultural areas (URB_agr) and from semi-natural areas (URB_for). Results showed that the different LULCC trajectories were driven by different combinations of biophysical factors, such as climate, topography and soil quality. In particular, slope and elevation resulted as the main driving factors for rural processes, while slope and temperatures resulted as the main constraints underlying urban processes. This approach may represent a conceptual and technical step toward the systematic assessment of LULCC processes, thus providing an effective support tool to inform decision makers about land use transformations, their underlying causes, as well as their possible implications.

1. Introduction

Land use/land cover changes (LULCCs) represent the result of the complex interaction between socio-economic and cultural conditions, biophysical constraints and land use history (Verburg et al., 1999); they act over a wide range of temporal and spatial scales and involve both changes toward different ecological functions and shifts in intensity within a function, sometimes resulting in a system's resilience unbalance (Álvarez Martínez et al., 2011; Shao et al., 2006; Zurlini et al., 2015). Anthropogenic drivers are relatively active, and are the main determinants of short-term LULCCs. To the contrary, biophysical factors are relatively stable, and control the long-term macro-tendency of regional LULCCs (Shao et al., 2006). While human activity is the major force in shaping LULC, the underlying biophysical structure of the landscape (i.e. climate, soil, topography, hydrology, and vegetation) may constrain LULC, defining the natural capacity or predisposing environmental conditions for land use and influencing the orientations of LULCCs across space and time (Jingan et al., 2005; Lambin et al., 2001; Geist et al., 2006). At finer landscape scales, LULCCs can be related to their constraining factors more or less straightforwardly, but aggregating these changes over broader regions appears as a more difficult task (Verburg et al., 1999). Therefore, a clear understanding of the driving forces that cause LULCCs at regional scale is becoming a key issue (Shao et al., 2006; Van Diggelen et al., 2005; Chaplot et al., 2005).

In the last decades, the dominant LULCC trajectories observed at regional scales in the northern Mediterranean Basin are a biomass increase in marginal areas due to land abandonment (decreased human pressure) and, on the other hand, the sealing of agricultural soils due to urbanization (increased human pressure) (Millington et al., 2007; Bajocco et al., 2012). Land abandonment (LA) determines a progressive decline in agricultural land uses due to rural exodus; as a consequence, shrublands and forests have substantially increased in marginal lands, homogenizing the environmental mosaic, reducing the protection function of land management, altering the agricultural water use balance and increasing the biomass available as fuel for potential wildfires (Moreira et al., 2001; Lozano et al., 2008; Serra et al., 2008; Valipour, 2013, 2014). To the contrary, urbanization (URB) involves the

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wholesale transformation of agricultural and natural ecosystems to more intensive uses, being among the heaviest anthropogenic impacts on earth (Seto and Kaufmann, 2003). A pan-European study highlighted the rapid increase of urbanization particularly in the form of dispersed urban expansion, considering this as an "ignored challenge" for the on- and off-site effects on water storage, soil erosion, loss of organic carbon stock, decrease in biological diversity (Ceccarelli et al., 2014). The environmental consequences of both LULCCs trajectories entail, on one side, the gradual decrease in landscape diversity and complexity, and, on the other side, the increase of vulnerability to certain hazards such as forest fires, erosion, floods, and droughts (Serra et al., 2008).

Understanding the relationships among LULCCs and their constraining factors is thus extremely important for enabling scientists, landscape managers and policy makers to design nature conservation strategies and develop informed and appropriate land use policies with the aim of preserving some of the unique characteristics of both natural and anthropogenic landscapes (Álvarez Martínez et al., 2011; Biazin and Sterk, 2013). In this perspective, regional-scale LULCC modeling represent an essential tool for predicting the probability of occurrence of a specific change (Röder et al., 2008) and for identifying which variables provide the most suitable model (Seabrook et al., 2006; Álvarez Martínez et al., 2011). A variety of LULCC models have been developed to address different processes, scales of analysis and research questions (Shao et al., 2006; Verburg et al., 2009). Like multiple linear regression, ordination or clustering methods, multivariate statistical modeling tools can explain the proximate causes of regional LULCCs (Pan and Bilsborrow, 2005; Purtauf et al., 2005; Lesschen et al., 2005; de Freitas et al., 2013). These techniques can be used for two main purposes: to project future landscapes under different change scenarios (predictive models) and to explain the relationship between LULCC patterns and driving forces (explorative models) (Millington et al., 2007; Álvarez Martínez et al., 2011; Millington et al., 2007). In this framework, the present study uses a multivariate exploratory approach borrowed from ecological niche modeling (Hirzel and Le Lay, 2008; Warren and Seifert, 2010) to quantify the role of biophysical factors in constraining the trajectories of land abandonment and urbanization occurred in the Emilia-Romagna Region (northern Italy) in the last 50 years.

2. Study area

The Emilia-Romagna region covers an area of 22,446 km^2 in northern Italy and hosts about 4.4 million inhabitants. Nearly Emilia Romagna (48%) consists of plains (the Po river valley), while the remaining 52% is hilly or mountainous (the Apennines range) stretching for more than 300 km from the north to the south-east. Altitude ranges from the sea level along the Adriatic coast, to 2165 m a.s.l. (Mount Cimone).

Artificial areas (17% of the study site) are mainly located in the lowland. The Po river valley, which is the result of several reclamations starting from the Etruscan period and ending just after the World War II, is covered with fruit orchards and annual crops. The natural landscape has been severely transformed by humans, particularly in the lowlands. At higher elevations the natural vegetation ranges from oak forests dominated by *Quercus pubescens* and *Quercus cerris* to *Fagus sylvatica* forests, sometimes mixed with *Abies alba*, and grasslands.

The analysis has been performed solely in the hilly-mountain area of the Apennines (10,139.35 km^2 with an altitude >500 m a.s.l.) (Fig. 1) in order to limit the impact of socio-economic drivers related, for instance, to littoralization, tourism, transport and communication routes, that could bias the analysis of the biophysical factors role over LA, URB_agr and URB_for trajectories.

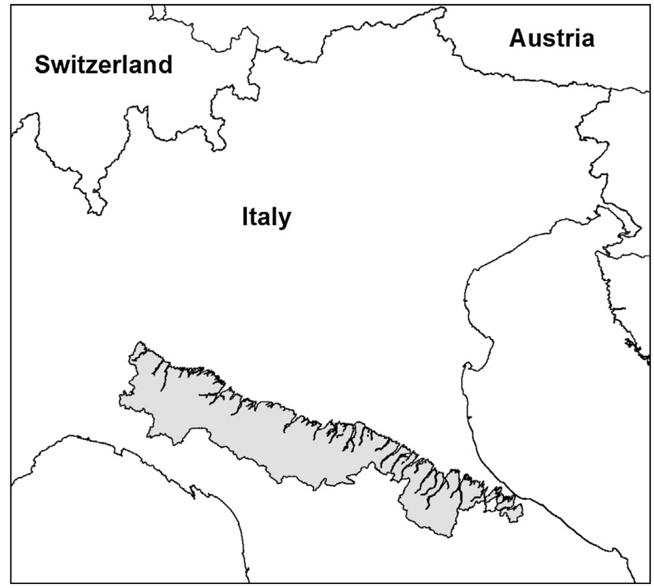

Fig. 1. Location of the study area.

3. Data and methods

3.1. LULCC data

The land cover maps used in this study (scale 1: 25,000) for the years 1954 and 2008 were produced by the Regional Cartographic Service of Emilia Romagna (http://geoportale.regione.emilia-romagna.it/it/download/). Although the original classification scheme of both maps was not identical, their thematic content was harmonized by the Cartographic Service in order to render them comparable (Ceccarelli et al., 2014). The final classification scheme follows the third hierarchical level of the CORINE Land Cover nomenclature (http://www.eea.europa.eu/publications/COR0-landcover).

For this study the following land cover change trajectories occurred between 1954 and 2008 were analyzed: (i) land abandonment (LA) and (ii) urbanization (URB), which altogether involved about 16% of the study area (Fig. 2). LA included all LULCCs from Agricultural areas to more natural land cover types, such as shrublands and forests (1344.73 km^2), corresponding to 82.7% of the changed surface. URB included all LULCCs from Agricultural areas (URB_agr; 230.63 km^2; 14.2% of the changed surface) and from Semi-natural areas (URB_for; 50.98 km^2; 3.1% of the changed surface) toward artificial land uses. URB_agr and URB_for were analyzed separately.

3.2. Background data

Seven biophysical background variables that are thought to influence LULCCs in the study area were considered in the analysis:

I. Minimum annual temperature (TMIN)
II. Maximum annual temperature (TMAX)
III. Total annual precipitation (PTOT)
IV. Aridity index (AI)
V. Elevation (ELE)
VI. Slope (SLO)
VII. Soil quality index (SQI)

The climate variables I–IV (CLIM) were extracted from the National Agro-meteorological Database of the Italian Ministry of Agriculture. The database contains daily gridded temperature and