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Research paper

Landscape sequences along the urban–rural–natural gradient: A novel geospatial approach for identification and analysis

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HIGHLIGHTS

- Landscapes nested in anthropogenic gradients were spatially identified and classified.
- The patterns and dynamics for each landscape along the gradient were explored.
- A particular focus on urban–rural and rural–natural fringe areas was developed.
- The approach can support a better spatial contextualisation of land use issues.

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ABSTRACT

Human influence on the environment differs in terms of distribution and intensity, thus producing a gradient of landscape modifications that translates into different landscape structures. Within this variety of landscapes, fringe areas represent complex spaces where dynamic processes and instable conditions can be observed. In this research Kernel Density Estimation, multivariate spatial analysis, landscape pattern analysis, and Principal Component Analysis (PCA) were combined to model and characterise landscape gradients, and to analyse the structural features of fringe areas. This methodology was applied to a rural area of central Italy, using density indicators associated with urbanisation, agriculture, and natural elements considered to be key components for the identification of landscape gradients. The results highlight not only specific "pillar" landscapes, which are dominated by said components, but also transitional landscapes, where the most relevant forms of interaction between land uses were identified. Characterisation of landscape structures along the gradient illustrated different trends in patch density, shape complexity and landscape diversity, demonstrating greater variability in fringe areas than in pillar landscapes. PCA revealed a partial overlap between the main structural characteristics of the agro-forestry matrix and the medium intensity agricultural landscapes, whereas urban fringes and semi-natural fringes were clearly separated. The discovery of the continuous landscape gradients and an understanding of the gamut of landscape types nested along them is crucial in allowing for more effective land-use planning in which also fringe areas become a relevant part of the process.

1. Introduction

European landscapes are intensively changing due to an unprecedented increase in human impacts on ecosystems (Pearson & McAlpine, 2010). Urban sprawl has been recognised as the cause of many relevant impacts that result in the loss of agricultural and natural land and the fragmentation of forests, wetlands and other natural habitats (EEA, 2006; Piorr, Ravetz, & Tosics, 2011). The intensification of agricultural land uses since the second half of the last century has progressively introduced industrial production, with the consequent effects of landscape simplification, degradation of soil and water quality (Vizzari & Modica, 2013), loss of natural habitat (Matson, 1997; Sodhi & Ehrlich, 2010; Tilman et al., 2001) and diversity of wild species (Maron et al., 2012; Gentili, Sigura, & Bonesi, 2014), and the impairment of ecological functions (Flynn et al., 2009). Conversely, the decline of extensively used agricultural areas due to abandonment and their consequent re-naturalisation has been recognised as a process that may lead to conflicts with biodiversity conservation (e.g., threats to farmland birds) (Henle et al., 2008). Thus, human activities are major forces in shaping landscape structure, creating a mosaic of natural and human-managed patches that vary in type, size, shape and

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arrangement. Relationships between the distribution of energy, materials and species are directly influenced by such structures, which appear critical to understanding ecological processes and landscape functions (Botequilha Leitão & Ahern, 2002; Li et al., 2005; Turner, 1990).

Human influences on landscape composition and configuration are so different in distribution and intensity as to make it necessary to consider them as a gradient of landscape modifications (Godron & Forman, 1983). The environmental gradient paradigm, which was originally introduced by Whittaker (1967), states that environmental variation is ordered in space and drives the distribution of the structural and functional components of ecosystems (McDonnell & Pickett, 1990). Thus both simple and complex gradients can be found in landscapes. The former refer to an environmental series due to a single, measured, environmental factor, whereas the latter are based on several factors (man-made or natural), some of which may interact (McDonnell, Pickett, & Pouyat, 1993). Anthropogenic gradients, generated by the increase of human influences on the structure and functions of landscapes, were identified by Forman and Godron (1986) in the specific succession of natural–managed–cultivated–suburban–urban landscapes. Along such a sequence, typical modifications in the structures and functions of ecological systems can be observed (see e.g., Luck & Wu, 2002; McDonnell & Pickett, 1990): introduced man-made patches increase, whereas patches of natural land cover decrease; patch density increases together with patch shape regularity, whereas the mean patch size and landscape connectivity decrease.

In the gradient view, even the urban–rural dichotomy can be thought of as a landscape gradient shaped by a sliding level of human influence from rural to urban landscapes, including ecological processes, flows and movements of goods, energy, people, capital, and information (Modica et al., 2012). This innovative view implies the identification of fringe regions, those particular land use/land cover (LULC) transitional areas, such as peri-urban and agro-forestry areas, characterised by specific and crucial ecological processes. These interfaces represent complex landscapes where more or less markedly unstable conditions arise involving both the internal configuration of the landscape and the relationships with its surroundings. As a result, different evolving environmental and socio-economic equilibriums can be observed (Cavailhès, Peeters, Sekeris, & Thisse, 2004; Valentini, 2006). Urban sprawl, soil sealing, crop system transformations and the abandonment of marginal areas are typical and recognisable processes in these areas (Agnoletti, 2007). In particular, the urban–rural interface represents an intricate space from the economic, environmental and social viewpoint, especially as regards its proximity to and mutual dependence on cities and rural areas (Ives & Kendal, 2013; Vejre, Jensen, & Thorsen, 2010). Land-use conflicts, species and habitat conservation, preservation of cultural heritage, changes in lifestyles, and products and services from multifunctional agriculture are some of the main topics of the discussion on rural–urban linkages (Cavailhès et al., 2009; Marcheggiani, Gulinck, & Galli, 2013; Von der Dunk, Grêt-Regamey, Dalang, & Hersperger, 2011; Zasada, 2011). Conversely, recent decades have seen an increased awareness of the issues emerging from the complex relationship between agricultural, forestry and pastoral activities in agro-forestry interfaces. The dynamics of post-crop cultivation, arising from cultivations being abandoned, determine an uncontrolled evolution in land cover due to their particular environmental conditions. This phenomenon often appears associated with several changes such as a loss of productive land, an increase in the risk of landslides and a loss of biodiversity associated with traditional agricultural management (Agnoletti, 2007; Gellrich & Zimmermann, 2007).

A considerable body of literature has focused on urban–rural fringe areas as multifunctional landscapes, which include a large variety of activities linked to environmental, social and economic functions (Zasada, 2011). The local production of food and bio-fuel for self-sufficiency of urban communities (Erickson, Taylor Lovell, & Méndez, 2013), the values people assign to the features of the agricultural landscape (Ives & Kendal, 2013) and the structure of the landscape patterns (La Greca, La Rosa, Martinico, & Privitera, 2011) represent some of the many landscape issues explored in such contexts. Moreover, urban fringe areas represent a key topic in the academic debate for their potential contribution to a higher quality of life in Europe and to a more globally competitive European community (Watt, 2012). As a consequence, a wide range of approaches and applications have been developed for the spatial detection and characterisation of urban fringe areas along the urban–rural gradient (see e.g., Murgante, Las Casas, & Sansone, 2008; Myers & Beegle, 1947; Pryor, 1968; Wehrwein, 1942; Yang, Zhou, Gong, & Wang, 2012). Many of them have focused on urban sprawl and change detection using remote sensing techniques (Bhatta, Saraswati, & Bandyopadhyay, 2010; Fichera, Modica, & Pollino, 2010; Ji, Ma, Twibell, & Underhill, 2006; Liu & Zhou, 2005; Luo, Yu, & Xin, 2008; Sun, Wu, Lv, Yao, & Wei, 2013; Yu & Ng, 2007). In the majority of such studies, although the urban–rural gradient appears generally identified and investigated, the main focus is on the urban component and its spatio-temporal evolution in light of the ongoing urban growth and sprawl phenomena. The landscape gradient approach has also been adopted to evaluate biodiversity levels in comparison with agricultural intensity (Boscutti et al., 2015; Culman et al., 2010; Gentili et al., 2014) or urbanisation (Dearborn & Kark, 2010; Goddard, Dougill, & Benton, 2010; Kowarik, 2011).

Despite all of these applications, studies aiming to understand the types of landscape structures along the entire gradient of LULC changes due to the different intensities of anthropogenic landscapes are still missing. Discovering the continuous landscape gradients and understanding the gamut of landscape types nested along them is crucial to allowing effective land-use planning. In fact, if new spatial planning concepts are needed for the rural–urban fringe to integrate gradual densification of built-up areas with preservation of green areas and agriculturally managed open space (Piorr et al., 2011), further attention to rural–natural fringes is required to maintain their relevant functions and related ecosystem services. To this end, the landscape gradient approach proposed by McGarigal and Cushman (2005) in the area of spatial ecology seems promising. This landscape gradient model is based on variable intensities and evaluates a continuous rather than a discrete spatial heterogeneity. Several advantages are recognised in modelling environmental variation as continuous gradients, such as overcoming the subjectivity of defining cut points for variability categorisation and a better description of ecological processes that occur with different intensities in the environment (e.g., organism perception, distribution of resources) (Bridges, Crompton, & Schaffer, 2007).

Among the several analysis tools useful for studying the continuous variation of spatial heterogeneity, density analysis provides a direct assessment and visualisation of phenomena intensity. Density analysis has been widely applied in quantitative geography for many different purposes, for example, urban population analysis (Griffith, 1981), crop yield estimation (Myers & Foale, 1981), forest assessment (Franklin, Michaelsen, & Strahler, 1985), and landscape ecology studies (Farina, 2006). Density analysis tools, available within the GIS environment, allow researchers to transform values measured at specific locations on continuous surfaces to obtain the general trend of the spatial distribution for the considered variable (Bailey & Gatrell, 1995). Kernel Density Estimation (KDE) has already been used to represent and analyse spatial trends generated by landscape features as well as their potential ecological interactions or influences on the surrounding landscape (Cai, Wu, & Cheng, 2013; Modica et al., 2012; Vizzari, 2011a) and for