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Land quality, sustainable development and environmental degradation in agricultural districts: A computational approach based on entropy indexes

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ABSTRACT

Land Degradation (LD) in socio-environmental systems negatively impacts sustainable development paths. This study proposes a framework to LD evaluation based on indicators of diversification in the spatial distribution of sensitive land. We hypothesize that conditions for spatial heterogeneity in a composite index of land sensitivity are more frequently associated to areas prone to LD than spatial homogeneity. Spatial heterogeneity is supposed to be associated with degraded areas that act as hotspots for future degradation processes. A diachronic analysis (1960–2010) was performed at the Italian agricultural district scale to identify environmental factors associated with spatial heterogeneity in the degree of land sensitivity to degradation based on the Environmentally Sensitive Area Index (ESAI). In 1960, diversification in the level of land sensitivity measured using two common indexes of entropy (Shannon's diversity and Pielou's evenness) increased significantly with the ESAI, indicating a high level of land sensitivity to degradation. In 2010, surface area classified as "critical" to LD was the highest in districts with diversification in the spatial distribution of ESAI values, confirming the hypothesis formulated above. Entropy indexes, based on observed alignment with the concept of LD, constitute a valuable base to inform mitigation strategies against desertification.

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1. Introduction

Sustainable agriculture has been assumed to perform a pivotal role in the animal biodiversity and plant conservation (e.g. Weissteiner et al., 2011). Traditional agricultural systems contribute to eco-compatible uses of rural land, preserving soil quality and ensuring long-term ecosystem functioning (Siciliano, 2009). Rural landscapes with high natural value have experienced both crop intensification and land abandonment, with changes of land-use and loss of usual practices and cultural heritage preserved by local communities (Agnoletti, 2007; Navarro and Pereira, 2012; Salvati and Zitti, 2007a). The main socioeconomic consequences of crop intensification and land abandonment have been identified at the local scale, offering original approaches in the analysis of environmental degradation, land management practices and application of existing strategies (Corbelle-Rico et al., 2012; EEA, 2005; Helming et al., 2011; Kosmas et al., 1999, 2015; Recatalá et al., 2000; Strijker, 2005). The improvement of the research on adaptive capacity of agricultural districts allows to understand better complex socio-ecological systems and to clarify the effectiveness of both formal and informal replies to external shocks (Emadodin et al., 2012; Ibarraràn et al., 2010).

Biophysical processes have continuously shaped the socio-environmental profile of rural landscapes and local communities (Salvati et al., 2015). Together with climate aridity, land-use changes and increased human pressure, Land Degradation (LD), as a global problem with negative implications for both humans and nature, has recently expanded in both affluent and emerging countries (Graaff and Epping, 1999; Hermann and Hutchinson, 2005; Perminova et al., 2016; Santos and Cabral, 2003). Increased competition for land resulted in a deterioration of soil quality with relevant decrease of land productivity, biodiversity and ecosystem services (Emadodin and Bork, 2011; Emadodin et al., 2009; Imeson, 2012; Zdruli, 2014; Zinck et al., 2004). Soil degradation, together with the increased land sensitivity to desertification, is a potential result of the combination of biophysical conditions such as arid climate, low vegetation cover, poor soils and water scarcity (Bielsa et al., 2005; Feoli et al., 2003; Ferrara et al., 2014; Garcia Latorre et al., 2001; Geri et al., 2010; Hernández et al., 2015; Kosmas et al., 2000a; Lavado Contador et al., 2009; Moonen et al., 2002; Preiss et al., 1997; Salvati et al., 2011; Saura et al., 2011).

Economically-disadvantaged and marginal rural contexts in dry environmental conditions are typically found in Mediterranean Europe (Salvati and Carlucci, 2011). In those contexts, having an extensive history of human settlement and land-use (Blondel, 2006; Hernández et al., 2015), socioeconomic factors mixed with spatially-variable biophysical conditions, influencing socio-ecological local systems and eliciting complex responses to natural resource degradation (e.g. Berkes and Folke, 1998; Kurttila, 2001; Salvati et al., 2015). In these conditions, land degradation has been demonstrated to be particularly intense, being a consequence of land abandonment, soil erosion, rural poverty and land value loss (Salvati and Zitti, 2009a, 2009b). Land degradation is intimately related to overgrazing, wildfires, unsustainable exploitation of water and soil resources and environmental pollution, e.g. caused by pesticides and herbicides (Salvati and Carlucci, 2011; Santos and Cabral, 2003). Expansion of degraded areas has increasingly involved traditional agricultural systems, determining a progressive depletion of fertile land, loss of biological and economic productivity, soil erosion, habitat fragmentation and reduced ecosystem services (Brandt et al., 2003; Costantini et al., 2009; Gisladottir and Stocking, 2005; Montanarella, 2007; Salvati and Zitti, 2008, 2009a; Salvati et al., 2014; Tanrivermis, 2003).

Depletion of high-quality cropland has been also associated to urban expansion in flat and accessible rural districts (Recatalá et al., 2000). A total of 9000 km^2 of rural land have been transformed for urban functions in the 1990s (EEA, 2010), growing steadily between 2000 and 2006 (Recatalá and Sacristán, 2014). Population growth in urban areas has, in turn, stimulated an increased food demand that may lead to crop intensification (Emadodin et al., 2012; Gardi et al., 2015), which often aggravates LD (Bakr et al., 2012; Kangalawe and Lyimo, 2010; UNCCD, 2002).

Multifaceted relationships between land sensitivity to degradation and basic drivers of landscape transformations have been observed in Mediterranean environments, involving differentiated socioeconomic and biophysical factors (Lal, 2001). An effective assessment of LD requires a comprehensive investigation of the progress of socio-ecological systems, over time and space (Thornes, 2004). Despite extensive research focusing on Mediterranean environments (Basso et al., 2000; Benabderrahmane and Chenchouni, 2010; Brandt, 2005; Kosmas et al., 1999, 2000a, 2000b), relatively few studies were aimed at identifying vulnerable areas over large regions (Lavado Contador et al., 2009; Leman et al., 2016; Salvati et al., 2014; Symeonakis et al., 2014), investigating their spatial dynamics over relatively long time periods (Basso et al., 2012). The Mediterranean Desertification and Land Use (MEDALUS) approach identifies Environmentally Sensitive Areas (ESAs) to LD through a multi-factor approach incorporating vegetation, climate, land and soil management indicators (Kosmas et al., 1999), being ESA a simple, robust and adaptable approach to new information (Brandt et al., 2003; Ferrara et al., 2012; Kosmas et al., 2003). Using a complex index called the ESAI, the land sensitivity degree and the effectiveness of the relative policies combating desertification, can be evaluated following a detailed land evaluation system based on multiple criteria and thresholds (Salvati and Carlucci, 2010).

Agricultural districts, intended as potentially vulnerable socio-ecological contexts to land degradation are suitable spatial units to assess the impact of (regional and local) environmental policies (Salvati and Zitti, 2008). Salvati and Carlucci (2013) studied the latent relationship between productive and ecological attributes of Italian agricultural districts and land sensitivity to degradation. Between 1960 and 2010, the intense growth of sensitive areas to degradation in Italy is the result of an increased human pressure on agricultural soils, coupled with climate aridity and landscape fragmentation (Salvati and Bajocco, 2011; Salvati and Carlucci, 2013). Land Degradation determined serious consequences to traditional cropping systems in the Mediterranean rural landscapes (Bajocco et al., 2012). Decreased crop productivity (Conacher and Sala, 1998; Ibanez et al., 2008; Salvati, 2010; Salvati and Carlucci, 2013) or increased poverty in rural populations (Lorent et al., 2008) are typical outcomes of land degradation (Basso et al., 2000). Nonetheless, recent studies demonstrate that LD can be controlled through adequate land management measures (Bakr et al., 2012).

Based on these assumptions, the present study provides an in-depth investigation of changes in biophysical and socioeconomic conditions of agricultural districts over time with the objective to assess local-scale spatial diversification in the degree of land susceptibility to degradation, taken as a proxy of desertification risk. Mediterranean rural areas are characterized by an evident diversity in agricultural systems (Salvati and Bajocco, 2011). Despite all European countries offer typical agricultural productions, the majority high-quality products are found in Mediterranean countries (Jongman, 2002). Socioeconomic transformations, due to processes of landscape, may reflect in a higher level of homogeneity or heterogeneity in the level of land sensitivity to degradation, representing a possible threat to biodiversity resources (Jongman, 2002).

Assumed that southern Europe rural landscapes have experienced both homogenization and fragmentations processes (Jongman, 2002), an in-depth investigation on the changing distribution of the ESA index, over time and space through the notions of diversification and heterogeneity, may contribute to foresee sensitive contexts to LD. In this sense, Italy represents an attractive case of study, given its complex spatial distribution of areas sensitive to degradation, resulting from the joint action of multiple geographical gradients (Salvati, 2010; Salvati and Zitti, 2008). Being classified as a sensitive country to desertification according to United Nation Convention to Combat Drought and Desertification (UNCCD) Annex IV, Italy has experienced intense evolution of LD, especially in the Southern driest areas (Salvati and Zitti, 2008).