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.

Keywords:
Environmental indicators
Desertification
Sustainable development
Multivariate statistics
Mediterranean basin

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http://dx.doi.org/10.1016/j.eiar.2017.01.003
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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. Weisssteiner 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 (Agoletti, 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, 2000; Helming et al., 2011; Kosmas et al., 1999, 2015; Recatálà 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; Ibarrarán 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; García 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; Kuttitila, 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 Stoking, 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 (Recatálà et al., 2000). A total of 9000 km² of rural land have been transformed for urban functions in the 1990s (EEA, 2010), growing steadily between 2000 and 2006 (Recatálà 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 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).
The increase over time in the level of vulnerability with spatially heterogeneous land-use structures, affects specific uses of land including mixed urban-rural mosaics (Ferrara et al., 2015; Salvati, 2013). Vegetation patchiness at a very local scale is an early-warning indicator of desertification risk (Kefi et al., 2007). Being aware that arid ecosystems are ones of most sensitive ecosystems to climate change (Schröter et al., 2005), diversity and evenness in land-use structures - reflecting homogeneity (or heterogeneity) in the level of sensitivity to land degradation - were proposed as proxies of desertification risk at the district scale, when considering homogeneous socioeconomic local systems. Based on evidences provided by Kefi et al. (2007) at the spatial scale of land patch, a more heterogeneous distribution of sensitive land in agricultural districts is hypothesized to be associated with higher exposure to land degradation and increasing rates of growth in the level of sensitivity to degradation, possibly reducing the effectiveness of regional policies against desertification (Salvati and Carlucci, 2011, 2014). Spatial heterogeneity in the ESAI has frequently indicated the occurrence of degraded areas that may act as hotspots for future degradation processes (Bajocco et al., 2015).

Based on these premises, our study assumes the local districts defined by the Italian National Institute of Statistics (ISTAT) and partitioning Italy into homogeneous agricultural areas as the spatial unit of analysis. Agricultural districts are homogeneous socio-environmental systems that identify clusters of municipalities with similar ecological and agronomic characteristics (Recanatesi et al., 2015). Evaluating latent relationships among the average level of land sensitivity to degradation and its spatial heterogeneity at the agricultural district scale provides interesting information for compiling a regional strategy for the mitigation of desertification risk in European Mediterranean countries. Pielou’s evenness and Shannon’s diversity indexes were used to estimate local-scale diversification in the ESA index at the spatial scale of agricultural districts over the last 50 years (1960-2010) in Italy. The study hypothesizes that a higher level of diversification in the spatial distribution of basic ESAI classes was associated with increased rates of change in the level of land sensitivity over time. Homogeneous agricultural districts are supposed to be less exposed to desertification risk, being possibly more resilient to LD (Thornes, 2004).

2. Materials and methods

2.1. Study area

The area considered includes the whole Italian territory (301,330 km²). Italian land is characterized by undulated topography (23% lowlands, 42% uplands, 35% mountains) and multifaceted rural landscapes with conventional crop systems shaped by spatially-varying environmental conditions. A total of 773 agricultural districts were considered as elementary spatial units of analysis, excluding some smaller islands (e.g. Ponza, Capri, Giglio, Ischia, Procida, Tremittii). Agricultural districts were delineated by the ISTAT (2006) considering biophysical (e.g. topography, climate and soil) and socioeconomic variables (e.g. crop system, land value and human settlements).

2.2. Assessing land sensitivity to degradation

We considered the notion of “land sensitivity to degradation” proposed by Kosmas et al. (1999) in the outline of the MEDITERRANEE DesertiFication And Land USe (MEDALUS) project. “A state of a local system” is primarily subject to (i) quality of natural capital (soil, water, vegetation), (ii) climate regime and (iii) anthropogenic pressures (Kosmas et al., 2000a, 2000b). The MEDALUS project introduced a comprehensive valuation of changes over time considering four quality dimensions (climate, soil, vegetation and land management) as fundamental factors associated to LD along the Mediterranean basin (e.g. Montanarella, 2007; Sivakumar, 2007). Such procedure adopted refers to the Environmentally Sensitive Area (ESA) approach and includes 14 elementary variables, elaborated through basic statistical tools and spatial investigation with the purpose of developing a combined index of land sensitivity, called the ESAI. Four elementary variables were correspondingly measured in the estimation of soil quality (soil depth, texture, parent material, slope) and vegetation quality (protection against soil erosion and drought, wildfire risk, plant cover); three elementary variables were respectively used to evaluate climate quality (precipitation, aridity, aspect) and land management quality (demographic growth, population density, land-use intensity).

The ESA framework identifies four quality indicators: Climate Quality Index (CQI); Soil Quality Index (SQI); Vegetation Quality Index (VQI); and Land Management Quality Index (MQI). These indicators were calculated as the geometric mean of the sensitivity values of every elementary variable (Salvati et al., 2016). Quality indicators assume a value ranging between 1 (lowest sensitivity to degradation) and 2 (the highest sensitivity to degradation). Since the ESAI has been computed as the geometric mean of the four quality indicators with neutral weighting, the land classification adopted was structured in: (i) non-affected areas or very low sensitive areas to LD (ESAI < 1.3); (ii) low sensitivity areas to LD (1.3 < ESAI < 1.4); (iii) areas with medium sensitivity to LD (1.4 < ESAI < 1.5); and (iv) highly sensitive areas to LD (ESAI > 1.5). The ESAI classification system is aimed at identifying critical areas that need specific mitigation actions against LD (Kosmas et al., 1999).

The ESA approach is very used as procedure to categorize land giving to the degree of sensitivity to degradation (Basso et al., 2000; Salvati and Bajocco, 2011; Salvati and Zitti, 2009a, 2009b). The principal benefits of the ESA are (i) elasticity in the utilization of input variables and (ii) easiness of land classification system which relies on the intrinsic degree of sensitivity to selected biophysical and socioeconomic conditions (Ferrara et al., 2012). The results obtained from the ESA model have been widely validated in Mediterranean European contexts (Basso et al., 2000; Kosmas et al., 1999; Salvati and Zitti, 2008). The ESAI represents a proxy of LD, showing important correlations with several soil degradation indicators (Lavado Contador et al., 2009). The variables considered in the present work were derived from consistent, referenced and updatable data sources (Salvati et al., 2012). However, since LD means a multifaceted phenomenon given its acting factors (Hill et al., 2008), some of the latter could be undervalued in the ESA approach (Montanarella, 2007). In this sense, Salvati et al. (2012) have demonstrated that using a larger and independent set of LD indicators leads to the identification of a spatial organization of sensitive land to degradation coherent with the ESAI (Salvati et al., 2012). Multiple correlations between elementary ESA variables and an exhaustive set of LD indicators offered similar outcomes to what was found from the utilization of the standard ESA scheme (Salvati and Zitti, 2009b).

2.3. Standard ESA variables

A total of 14 context indicators based on the ESA scheme (Table 1) were calculated for each study year (1960, 1990, 2000, 2010). Separate figures of averages and coefficients of variation for each quality indicator (CQI, SQI, VQI, MQI) and the ESAI were estimated at each district by means of the “zonal statistics” tool during the elaboration with the ArcGIS software (Salvati and Zitti, 2008). The percent share of land defined as “fragile” and “critical” (respectively 1.225 < ESAI < 1.375 and ESAI > 1.375) in total landscape and the minimum and maximum ESAI value in each agricultural district were finally calculated.

2.4. Entropy indicators

Two entropy indicators were used to assess spatial diversification and heterogeneity in the spatial distribution of the ESAI scores at the agricultural district scale in Italy: Shannon’s diversity (H′) and Pielou’s
evenness (J) indexes. The H′ index (Shannon and Weaver, 1949) was calculated as:

\[ H' = -\sum p_i \log p_i \]

where \( n \) is the number of ESAI score classes and \( p_i \) is the proportion of surface area of each i-th class. This index estimates the average uncertainty in a finite community, ranging from 0 to highly positive values and evaluating the level of spatial diversification of the ESAI for each agricultural district. By dividing \( H' \) by the \( H_{max} \) value depending on the number of ESAI classes in every district, J index assesses evenness of the ESAI values (Pielou, 1966) in a scale ranging between 0 and 1, respectively from low to high evenness:

\[ J = H'/H_{max} \]

where \( H_{max} \) is the logarithm regarding the amount of classes with surface area > 0 (Ludwig and Reynolds, 1988). Following Li and Sun (2000), changes in the ESAI H′ index may indicate landscape processes of interest for desertification assessment; changes in the J index may also report the variable distribution of sensitive land to degradation and its potential growth at the landscape scale. Maps of H′ and J indexes were prepared by means of the ArcGIS software (ESRI Inc., Redwoods, USA).

2.5. Contextual indicators

An ancillary set of indicators were considered to assess the basic characteristics of any given district: (i) Sou (classifying districts on the base of the latitude gradient: “0” indicates northern-central districts, while “1” indicates southern districts in Italy); (ii-iii) two indicators classifying districts on the base of elevation: Low (“0”) indicates hilly or mountainous districts, “1” indicates flat districts) and Mou (“0”) indicates mountainous districts, “1” indicates flat or hilly districts); (iv) Sea (“0”) indicates inland districts, “1” indicates coastal districts); (v) Area (indicating the surface area of each agricultural district, km²).

2.6. Statistical analysis

The analysis framework evaluated changes in the spatial relationship between entropy indicators (H′, J) in the spatial distribution of the ESAI (Section 2.3), standard ESA variables (Section 2.4) and contextual indicators (Section 2.5). Pair-wise correlations between each of the selected ESAI variables and each entropy indicator were assessed using Spearman non-parametric analysis testing for significant coefficients at \( p < 0.05 \) after Bonferroni’s correction for multiple comparisons. Also a Principal Component Analysis (PCA) was run on the dataset including entropy indicators and standard ESA variables distinctly for two time points (1960 and 2010) with the aim at evaluating (i) the role of each ESA variable in the overall level of land sensitivity to degradation in each agricultural district and (ii) latent, multiple relationships between diversification in the ESAI spatial distribution and the level of land sensitivity to degradation. Variables with loading > 0.5 were considered significantly associated with a given component. The Bartlett’s test of sphericity and Kaiser-Meyer-Olkin measure of sampling adequacy were used to evaluate reliability of the factor model, verifying respectively (i) if partial correlations between variables are small and (ii) if the correlation matrix is an identity matrix (Salvati and Zitti, 2009a).

Finally, a hierarchical clustering was performed for 1960 and 2010 on the same dataset submitted to PCA, with the aim of classifying agricultural districts into homogeneous groups by applying a computation strategy, based on Euclidean distances and Ward’s amalgamation rule. Clustering determined which indicators have contributed to the definition of relevant spatial groups characterized by specific environmental conditions and level of diversification in the spatial distribution of the ESAI.

3. Results

3.1. Evaluating the spatial structure of the ESAI in Italy

Results of this study outline the main changes in basic environmental conditions predisposing land to degradation at the territorial scale of Italian agricultural districts. In 1960, ESAs were primarily situated in Southern Italy, except for few districts including some metropolitan regions in central and northern Italy (Fig. 1). A huge intensification in the average ESAI score between 1960 and 2010 was observed in the above-mentioned areas and, more generally, along the Adriatic Sea coast and the Po valley. A descriptive analysis of Shannon’s diversity (H′) and Pielou’s evenness (J) indexes, based on the spatial distribution of ESAI scores at the scale of agricultural districts, provided similar results. The spatial distribution of H′ index values outlines that southern Italy and Apennine districts display the most heterogeneous environmental conditions shaping land sensitivity to degradation. An increasing level of diversification in the ESAI was observed throughout Italy, in contrast with the dominant spatial pattern found in lowland areas, such as the Po valley. These areas support high-input agricultural systems characterized by crop intensification and homogeneous environmental conditions (low values of H′ and J indexes) leading to medium-high ESAI scores. A medium-high value of J index was attributed to many rural districts in upland and mountainous regions, being characterized by a diversified landscape with crop mosaic, agro-forest land and communities established.

Results of a non-parametric Spearman rank correlation analysis corroborate this preliminary finding (Table 2). The J index varied significantly along the latitude gradient (1990, 2000) being higher in northern districts than elsewhere in Italy. At the beginning of the study period, both H′ and J indexes increased with elevation, VQI, average ESAI score and the percent area of “fragile” land in total landscape. Fifty years later, H′ and J correlated positively with coefficients of variation of both VQI and ESAI. The SQI coefficient of variation was stably and positively correlated with the H′ index for both 1960 and 2010. In most recent decades, spatial heterogeneity in the ESAI score increased with percent area of “critical” land and the maximum ESAI score observed in each district.

3.2. Profiling agricultural districts based on entropy indexes

Fig. 1 illustrates the most relevant change over time in the selected entropy indicators assessing spatial diversification of the ESAI scores at
the rural district scale. In 1960, most agricultural districts with medium-high H' index were situated in Southern Italy and in the western side of central Italy. During 1960–2010, the H' index increased homogeneously throughout the country and an analogous pattern was detected for the spatial distribution of the J index, with the highest rates of change being recorded in Sardinia and Sicily. In this sense, both H' and J indexes are spatially-distributed following a latitude gradient with the lowest values of both indexes concentrated in the Po valley.

Spearman analysis (Table 3) indicated that diversification in the spatial distribution of the ESAI was the highest in districts experiencing a rapid increase in the ESAI score in the earlier decades of this study (1960–1990, 1990–2000). The reverse pattern was detected in the last decade, with negative variations in the level regarding the land sensitivity to degradation being analyzed in districts with high diversification and evenness in the spatial distribution of the ESAI score.

3.3. Identifying latent factors influencing the spatial distribution of the ESAI

PCA was run to summarize the environmental variables profiling agricultural districts and to point out the latent relationship with H' and J indexes in the spatial distribution of the ESAI (Table 4). PCA removed the partial correlation between variables incorporating significant information in a limited amount of independent components resulted as a linear combination of the most significant variables. Referring to 1960, component 1 was negatively associated with H', ESAI, CQI, VQI, FRAG, CRIT, MIN, and MAX. The two entropy indicators (H' and J), ESAICV and VQICV received significant loadings to component 2. Moderate changes in the structure of both components 1 and 2 were observed for 2010. VQI and MQI received negative loadings to component 1; H' and ESAICV received positive loadings. Component 2 had positive

<table>
<thead>
<tr>
<th>Variable</th>
<th>Shannon H' diversity index</th>
<th>Pielou J evenness index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960</td>
<td>0.45</td>
<td>0.39</td>
</tr>
<tr>
<td>1990</td>
<td>0.85</td>
<td>0.40</td>
</tr>
<tr>
<td>2000</td>
<td>0.91</td>
<td>0.36</td>
</tr>
<tr>
<td>2010</td>
<td>0.92</td>
<td>0.34</td>
</tr>
<tr>
<td>ESASI</td>
<td>0.58</td>
<td>0.33</td>
</tr>
<tr>
<td>ESAICV</td>
<td>0.69</td>
<td>0.30</td>
</tr>
<tr>
<td>VQI</td>
<td>0.69</td>
<td>0.31</td>
</tr>
<tr>
<td>VQICV</td>
<td>0.65</td>
<td>0.37</td>
</tr>
<tr>
<td>FRAG</td>
<td>0.37</td>
<td>0.39</td>
</tr>
<tr>
<td>CRIT</td>
<td>0.39</td>
<td>0.39</td>
</tr>
<tr>
<td>MAX</td>
<td>0.36</td>
<td>0.37</td>
</tr>
<tr>
<td>Sou</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>Low</td>
<td>-0.44</td>
<td>-0.44</td>
</tr>
</tbody>
</table>

Table 3

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>H'</td>
<td>0.14**</td>
<td>0.13*</td>
<td>-0.26**</td>
</tr>
<tr>
<td>J</td>
<td>-0.04**</td>
<td>0.11*</td>
<td>-0.22**</td>
</tr>
</tbody>
</table>

The spatial distribution of the average ESAI score (left), Shannon's diversity index (H, middle) and Pielou's evenness index (J, right) by year and agricultural district.
loadings for the two entropy indicators and the ESAICV. The changing structure of components 1 and 2 for \( H' \) and \( J \) indexes outlines the increasing complexity of basic environmental conditions in the Italian agricultural districts along the period of study (Fig. 2).

### 3.4. Determining coherent spatial patterns in the ESA variables

A hierarchical clustering (Fig. 3) identified correspondences in the spatial distribution of the elementary variables discriminating land with high or low level of sensitivity to degradation. Two homogeneous groups were identified: the first group is composed by two sub-clusters including respectively four variables (the two entropy indicators, ESAICV, VQICV) and three variables (CQI, SQI, SQICV). Cluster membership was relatively stable over time. The second group was again composed by two sub-clusters: ESAI, FRAG, CQI and MQI clustered together and were clearly separated from CQI, MIN, MAX and CRIT forming a second sub-cluster.

### Table 4

Results of a PCA applied to variables assessing basic environmental characteristics of the Italian agricultural districts in 1960 (left) and 2010 (right). Variable's loadings > |0.5| were shown.

<table>
<thead>
<tr>
<th>Variable</th>
<th>1960 Component 1</th>
<th>2010 Component 1</th>
<th>2010 Component 2</th>
<th>2010 Component 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shannon's diversity</td>
<td>−0.65 0.65 0.58 0.58</td>
<td>−0.72 0.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pielou's evenness</td>
<td>−0.92 0.54 −0.89 0.64</td>
<td>−0.65 −0.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESAI</td>
<td>−0.92 0.54 −0.89 0.64</td>
<td>−0.65 −0.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESAICV</td>
<td>−0.69 0.79 0.64 0.65</td>
<td>−0.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CQI</td>
<td>−0.78 0.70 −0.79 0.76</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VQI</td>
<td>−0.78 0.70 −0.79 0.76</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VQICV</td>
<td>−0.78 0.70 −0.79 0.76</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CQI</td>
<td>−0.69 0.79 0.64 0.65</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRAG</td>
<td>−0.87 0.86</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRIT</td>
<td>−0.65 0.56 −0.55</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIN</td>
<td>−0.70 −0.55 −0.83</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAX</td>
<td>−0.90 −0.57 −0.73</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expl. var %</td>
<td>38.3 19.4 38.6 22.6</td>
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Fig. 2. Dendrogram illustrating similarity in the environmental variables characterizing Italian agricultural districts in 1960 and 2010.

### 4. Discussion

Multiple feedbacks, associated with a spatially-heterogeneous distribution of sensitive land to degradation, require dedicated assessment techniques and place-specific mitigation measures (Ferrara et al., 2015). Analysis should consider the specific characteristics of territorial contexts and local communities, possibly identifying distinctive trends in the levels of land sensitivity thanks to the action of diversified environmental factors and socioeconomic drivers of change. Transformation of rural landscapes in Italy reflects a progressive increase of land sensitivity to degradation (Salvati et al., 2016). Such changes have been influenced by multifaceted drivers, emphasizing the intimate relationship between human activities and land resources (Gleick et al., 2002; Khanji, 2016; MEA, 2005a, 2005b; UNEP, 1994; WCED-CMED, 1987).

According to Hermann and Hutchinson (2005), relevant causes of LD are associated to the spatial-temporal dynamics of four dimensions (climate, vegetation, soil, socioeconomic processes), shaping impacts of land management strategies at local scale (Hermann and Hutchinson, 2005; Salvati, 2014).

The present study proposed the notion of “spatial diversification” in the level of land sensitivity to degradation in Italian rural districts, with the purpose to define latent hotspots for desertification risk (Recanatesi et al., 2015). Empirical findings indicate that the level of land sensitivity to degradation is influenced by spatial heterogeneity in the environmental conditions at the base of LD. Agricultural districts with spatially-homogeneous environmental situations were more exposed to LD in recent decades in respect to the time-period immediately following the World War II. Diversification in the spatial distribution of the ESAI has been related with specific territorial contexts characterized by a high degree of land sensitivity. Cropland demonstrated to be particularly prone to environmental conditions leading to LD when the spatial structure of agro-forest districts (e.g. crop mosaic, landscape fragmentation, traditional forestry systems, agricultural practices and typical productions, rural communities) has been compromised (Colantoni et al., 2015). Human-driven LD has been observed in both economically-marginal rural areas of southern Italy and affluent districts of northern Italy with soil and climate conditions getting worse in the last decades.
According to Salvati et al. (2015), Mediterranean rural areas are considered as increasingly exposed to desertification risk, due to joint action of climate aridity and socioeconomic pressures (Lorent et al., 2008; Mendelsohn and Dinar, 2003; Olesen and Bindi, 2002; Salvati and Zitti, 2009b). Despite Southern Italy is widely recognized as a risky area (Salvati and Bajocco, 2011), LD sensitivity was advancing rapidly also in central and northern Italy. Following Salvati and Carlucci (2013), the spatial distribution of rural districts sensitive to LD was fragmented and heterogeneous.

In this sense, since the early 1950s, urbanization has been the main responsible for the conversion of rural land to urban practices, causing impacts on ecosystem function, structure and dynamics, such as loss of rural areas, soil degradation and landscape fragmentation (Delfanti et al., 2016; Garcia Latorre et al., 2001; Luck and Wu, 2002; McDonnell et al., 1997; Salvati and Zitti, 2007b; Tanrivermis, 2003; Weng, 2007). Landscape fragmentation was a key factor determining increased land sensitivity to degradation (Salvati and Zitti, 2009a). Fragmented landscapes are characterized by weak connections between natural elements causing a deterioration of their ecological functions and negative impacts on biodiversity (Cook, 2002; Hidding and Teunissen, 2002; Jongman, 2002; Serrano et al., 2002; Wilcox and Murphy, 1985). As land fragmentation is commonly observed in agricultural systems on both regional, local, and farm level (Hidding and Teunissen, 2002), natural habitats and traditional crop systems require a sustainable management aimed at reducing patchiness and ecological isolation (Biasi et al., 2015).
determine a progressive erosion of the agricultural base, causing less effective farm support operations and facilities, which raise operating costs (Lapping, 1979; Pfeffer and Lapping, 1995).

With rapidly adjusting crop systems to the globally increasing demand of food, landscapes transformations in the Mediterranean basin reflect contrasting processes involving rural districts, spanning from crop intensification to farmland abandonment (Smiraglia et al., 2016). Especially crop intensification has frequently led to homogeneous rural landscapes with low natural, agronomic and cultural diversity, possibly associated to a high (and spatially homogeneous) level of land sensitivity to degradation (Mancino et al., 2016).

Preserving the spatial structure of high-quality farmland and crop mosaics is therefore a reasonable strategy with the aim to reduce negative environmental impacts of farming. In this sense, the ESAI allows identifying which areas require specific actions mitigating or reversing LD (Glenn et al., 1998; Hermann and Hutchinson, 2005). According to the results obtained, soil and vegetation are the most components related to spatially-heterogeneous conditions predisposing land to high sensitivity to degradation. Imbalanced environmental conditions in terms of natural capital require measures minimizing soil degradation and protecting natural vegetation with the final objective to improve components’ balance and spatial heterogeneity in LD (Hamdouch and Zuindeau, 2010). Together with soil and vegetation, climate quality is considered a component strongly associated with imbalanced ecological conditions possibly leading to LD (Feoli et al., 2003; Lavado Contador et al., 2009; Montanarella, 2007; Sivakumar, 2007). Local climate regimes are only indirectly influenced by environmental policies, suggesting to implement strategies for the mitigation of LD (Hermann and Hutchinson, 2005).

As stated by UNCCD, addressing land degradation and desertification in the Mediterranean region includes: (i) policy reforms and enforcement; and (ii) adequate research on sustainable land-use and restoration of previously degraded lands. In order to implement the UNCCD and the Italian National Action Programme (NAP), regional authorities have to provide specific intervention plans, identifying the most sensitive areas to desertification and ensuring that future generations can benefit from a healthy soil (Artmann, 2016). Policies should incorporate measures reducing impacts of rapid biophysical and socioeconomic transformations particularly in marginal districts with low population density, limited accessibility and a usually rural organization (Esposito et al., 2016; Tan, 2006). Consequently, the present work outlines the pivotal role played by a comprehensive analysis of different components of natural capital as possible targets for combined environmental policies against desertification (Salvati and Zitti, 2008). In this ambit, diversification in the spatial distribution of an index of land sensitivity to degradation may represent an early-warning indicator of desertification risk.

While being spatially-heterogeneous, the increase in the level of sensitivity over the last 50 years requires mitigation actions specifically designed for sensitive districts with high H’ and J index and a medium-high ESAI score. Land sensitivity to degradation is frequently interpreted as: a mixture of “risk exposure and stress, and difficulty coping with them” (Chambers, 1989), the potential loss (Cutter et al., 2003), the capacity to predict, to manage, to preserve against and to recover the pressure of a natural risk (Blakie et al., 2014) and the ability to be damaged (Rayner and Malone, 2001). Foreseeable scenarios should not be limited to the risks linked with climate change and biophysical conditions, but also be extended to the issue of socioeconomic sensitivity (Rayner and Malone, 2001).

Based on local-scale information, adaptive approaches offer a comprehensive framework for policy implementation and mitigation of negative externalities over different temporal contexts (Cushman and McKelvey, 2010; Vernier et al., 2009; Walters, 1986). For example, incentives and subsidies supporting specific farm types or farm-holder groups, individual crop or food products have often determined a spatially-diversified increase in land sensitivity with impact on desertification risk (Juntti and Wilson, 2004). The European Union soil thematic strategy, taken as a pertinent policy combating desertification, has identified threats to soil functions (e.g. erosion, salinization, compaction, sealing and contamination) and suggested regional-wide and place-specific practical actions to mitigate the negative impact of soil degradation (Montanarella, 2007). At the same time, EU subsidies for marginal rural areas sustained agricultural systems with low profits, producing a negative impact on soil quality while preserving biodiversity and traditional practices (Onate and Peco, 2005). In this sense, the results obtained contribute to the development of specific land policies for homogeneous and heterogeneous agricultural districts, informing effective mitigation strategies against desertification.

5. Conclusions

Our approach constitutes a reliable monitoring system that integrates information on the long-term sustainability of rural districts based on a composite index regarding the sensitivity to LD (Feoli et al., 2003). The effective monitoring of soil degradation patterns and desertification risk can use a mixed qualitative and quantitative approach with the intention of describing the evolutionary path of each district (Salvati et al., 2015). According to Bakr et al. (2012), desertification processes should be monitored over time to define more effective sustainable development measures. A high degree of land sensitivity indicates candidate targets for adopting mitigation measures against desertification (Gisladottir and Stocking, 2005). Early-warning desertification indicators, based on diversification in the spatial distribution of the ESAI, are particularly helpful to design strategies specifically adapted to local contexts and place-specific environmental dynamics of change.

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