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FIFTY YEARS ON: LONG-TERM PATTERNS OF LAND SENSITIVITY TO DESERTIFICATION IN ITALY

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ABSTRACT

The Mediterranean region has been regarded as a critical hotspot for desertification due to the impact of soil degradation, the land-use changes and the climate variations. Few large-scale studies have been devoted to analyse trends in land sensitivity to desertification in the northern Mediterranean basin. The present paper contributes to this deserving issue by quantifying the level of land sensitivity to desertification in Italy at seven points between 1960 and 2010 at a fine spatial scale. The approach used followed the Environmentally Sensitive Area scheme that assesses changes in four key themes (climate, soil, vegetation and land management) related to land degradation processes. Italian land was classified into four levels of sensitivity to desertification (non-affected, potentially affected, fragile and critical) according to the Environmentally Sensitive Area framework. Interestingly, although land surface area classified as 'fragile' and 'critical' grew homogeneously in Italy between 1960 and 1990, the increase observed in the most recent time period was spatially clustered and contributed to reverse the polarisation in 'structurally vulnerable' and 'non-affected' regions observed in Italy. The paper discussed these trends in the light of socioeconomic changes that occurred in Italy after World War II. Copyright © 2013 John Wiley & Sons, Ltd.

KEY WORDS: environmental indicators; ESAI; socioeconomic trends; Italy; geographical scale

INTRODUCTION

Land degradation, drought and desertification are phenomena induced by natural and anthropogenic processes occurring in both developed and emerging countries (Conacher & Sala, 1998; Gisladottir, 2005; Johnson & Lewis, 2007; Imeson, 2012). Their ultimate outcome is the drastic reduction of land productivity with ecological and socioeconomic consequences (Fernandez, 2002). The negative effect of natural processes and unsustainable land management was recognised in the USA, probably for the first time, in the 1930s, when most of the Great Plains underwent a prolonged drought that determined, together with intensive agricultural practices, the well-known phenomenon of the 'dust bowls'. Hundreds of thousands of people were forced to leave their land and migrate elsewhere. The adoption of appropriate cultivation methods and sustainable use of water resources avoided similar consequences for drought events, which occurred in the following years (Romm, 2011).

Nowadays, global warming, economic development and population growth are responsible for triggering large-scale soil and land degradation phenomena possibly leading to desertification, a truly worldwide phenomenon that affects about 40% of the Earth's surface including parts of Europe, the USA and Australia (Johnson & Lewis, 2007). Climate aridity is considered as an essential cause of land degradation processes (Salvati & Bajocco, 2011). However, anthropogenic pressures assume a crucial role as mentioned by Bajocco *et al*. (2011). In the Mediterranean basin, one of the world's hotspot for soil degradation, land degradation driven by population increase, crop intensification, urban expansion and soil pollution is associated with biophysical factors including climate aridity, soil sensitivity to degradation and poor vegetation cover (Drake & Vafeidis, 2004). The Mediterranean region is also classified as a hotspot for climate change in Europe. All these factors produce potentially devastating effects on the environment (Conacher & Sala, 1998).

Given these issues, a key assumption is intriguing and possibly underestimated in the current scientific literature: land sensitivity to desertification should be considered as a dynamic attribute of the ecosystem needing permanent monitoring to understand its trajectories (Thornes, 2004). Despite the large mass of studies realised in the framework of the research projects financed by the European Commission and by single countries (Rubio *et al*., 2009; Sommer *et al*., 2011; Vogt *et al*., 2011), scenarios analyses quantifying land degradation processes are scarce in southern Europe. Salvati & Bajocco (2011) identified the joint assessment of biophysical and socioeconomic conditions leading to land degradation as a major concern: (i) to stimulate research addressing specific processes involved in desertification (at vastly different observation and policy

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scales, from local to national and supranational scales) and (ii) to develop a comprehensive policy framework against desertification (Briassoulis, 2011).

A number of methodologies using statistical indicators, remote sensing approaches or field sampling have been proposed recently to monitor soil deterioration and desertification risk and to identify areas sensitive to degradation (Simeonakis *et al*., 2007; Costantini *et al*., 2009; Santini *et al*., 2010; Salvati *et al*., 2013, among others). Both quantitative and qualitative approaches proposed in recent years were aimed at producing indexes of desertification risk or at classifying land according to different sensitivity classes. Unfortunately, in general, all of these approaches have been set up to provide single point-in-time assessments of land sensitivity or desertification risk, whereas large-scale, multitemporal applications were generally neglected because of restricted data availability (Salvati, 2012). The Environmentally Sensitive Areas (ESA) approach is one of the most widely used frameworks, which can be used to quantify the sensitivity of land to desertification in Europe, northern Africa and the Middle East (e.g. Bakra *et al*., 2012; Basso *et al*., 2012; Mohamed, in press). The final output of the ESA process is a composite index of land sensitivity called the Environmental Sensitive Area Index (ESAI).

On the basis of the previous considerations, the aim of this work is to assess, using the ESAI framework, evolution in time and space in the level of land sensitivity to degradation in Italy at points in time between 1960 and 2010, testing convergence (or divergence) processes between prone and non-affected areas. Italy has been considered an example of the environmental complexity typical of the Mediterranean region (Costantini *et al*., 2009). Although desertified areas are not yet occurring in the country, several studies have identified areas, especially in southern Italy, where locally severe conditions have led to high sensitivity to desertification (Fantappiè *et al*., 2011). Moreover, it was hypothesised that climate and land cover changes contributed to the increase of land degradation prone areas during the last 20 years (Antrop, 2000; Juntti & Wilson, 2005; Falcucci *et al*., 2007; Bajocco *et al*., 2011). The present study also investigates the temporal dynamics of the four ESA themes (climate, soil, vegetation and land management quality), determining the level of land sensitivity in Italy as a contribution to understanding the main drivers of desertification in the Mediterranean region. Trends in the indicators examined were discussed in the light of socioeconomic changes, which occurred in Italy after World War II.

MATERIALS AND METHODS

Study Area

Italy is located in the middle of the Mediterranean basin with a coastline of about 7600 km including islands. Northern Italy is separated from Europe by the Alps, and it is divided longitudinally by the Apennine Mountains. The country is divided into three geographical regions (North, Centre and South) with a surface area of 301,330 km^2 and three elevation belts (23% lowlands, 42% uplands and 35% mountains: Salvati & Bajocco, 2011). Because of its geographical position, Italy is characterised by a relatively mild climate with dry and hot summers and temperate and wet winters. The amount of precipitation generally increases with elevation, whereas temperature regimes follow the reverse pattern. In common with other southern European countries, Italy shows a relevant north/south gap in socioeconomic development reflected in differential population density, settlement distribution and natural resource capital (Salvati, 2012). Italy represents a useful case study to understand the intimate relationships between biophysical and socioeconomic factors, which may influence the (changing) level of land sensitivity to degradation.

The Environmentally Sensitive Area Methodology

The ESA approach was launched in 1987 in the UK by the Ministry of Agriculture, Fisheries and Food (now the Department for Environment, Food and Rural Affairs) to encourage farmers and landowners to adopt environmentally friendly land management practices (Wilson, 1996). In the early 1990s, the ESA framework was adapted to monitor desertification processes on the behalf of the Mediterranean Desertification and Land Use project (Kosmas *et al*., 1999). Although possible drawbacks of this framework have been discussed by Basso *et al.* (2000, 2012) and Bajocco *et al.* (2011), the ESA scheme remains one of the most well-used procedures to evaluate the sensitivity of land to desertification (e.g. Kosmas *et al*., 1999; Bakra *et al*., 2012; Mohamed, in press). The main advantages of the ESA are flexibility in the use of the input variables and the simplicity of the land classification based on its level of sensitivity. The outcomes of the ESA model have been extensively validated on the ground at several sites in southern Europe (Kosmas *et al*., 1999; Basso *et al*., 2000; Bajocco *et al*., 2011), and a regional assessment (Lavado Contador *et al*., 2009) based on heterogeneous geographical datasets with different reliability indicates the ESAI as a proxy for land degradation processes and identifies significant correlations with a number of indicators of soil degradation. Finally, Ferrara *et al.* (2012) evaluated the stability of the ESAI by using statistical analysis and the sensitivity to changes in the indicators. Results indicate that the ESAI is a stable and reliable index not significantly affected by spatial and temporal heterogeneity in the composing indicators.

Despite its acknowledged importance as a tool to detect desertification risk, the ESA approach presents some shortcomings (e.g. Salvati *et al*., 2013). The methodology does not provide an assessment of the importance of the individual variables or thematic indicators. In addition, the input variables are oriented towards the description of the biophysical conditions of the area, whereas a number of sociopolitical and cultural factors considered as important in influencing the processes of land degradation are not explicitly formalised through the use of appropriate quantitative variables (Salvati & Bajocco, 2011).

According to the ESA framework, the variables selected to study the level of land sensitivity to desertification in Italy refer to four themes: climate quality, soil quality, vegetation and land-use quality, and human pressure/land management quality (Table I). In our experience, the layers used are the most reliable, updated and referenced data currently available to be used in the regional and country assessment of the ESAI in Mediterranean countries (see also Salvati, 2012 for a discussion on supply–demand of statistical data in desertification matters). Because comparable data needed to develop the full ESAI model (*sensu* Salvati & Bajocco, 2011) with national coverage and detailed spatial scale were available only at limited dates (see Table II), we covered a time period encompassing 50 years by specifically investigating the level of land sensitivity in four specific years (1960, 1990, 2000 and 2010) and providing an estimate for selected variables in three specific years (1970, 1980 and 2005). In particular, whereas climate and human pressure variables were observed at each of the seven points in time, vegetation variables were observed at 4 years and estimated for the three remaining years.

Environmental Variables and Thematic Indicators

Climate quality has been described in the present study by using the following variables: average annual rainfall rate, aridity index and aspect (Basso *et al*., 2000). Rainfall rate and the aridity index were calculated on a 10-year base by using information collected in the Agro-meteorological Database of the Italian Ministry of Agriculture. The database relates to gauging data collected daily from various meteorological and hydrological networks (Italian Ministry of Agriculture, National Hydrological Service, Italian Air Force and some minor networks) operating with nearly 3000 weather stations since 1951. The aridity index was defined as the ratio between rainfall and reference evapotranspiration measured as a 10-year average. The reference evapotranspiration rate was calculated by using the Penman–Monteith formula (Salvati & Bajocco, 2011). Aspect was derived from elaboration on the Advanced Spaceborne Thermal Emission and Reflection Radiometer global digital elevation model at 30-m resolution scale generated from stereoscopic pairs of optical Advanced Spaceborne Thermal Emission and Reflection Radiometer images and freely available online at http://www.gdem.aster.ersdac.or.jp/. Meteorological data were interpolated through geostatistical procedures (using elevation, latitude and distance to the sea as ancillary variables) to ensure the homogeneous national coverage. A grid composed by 544 points with daily data of temperature, precipitation, humidity, solar radiation and wind has been created. Seven analysis periods were selected: 1951 to 1960, 1961 to 1970, 1971 to 1980, 1981 to 1990, 1991 to 2000, 1996 to 2005 and 2001 to 2010.

Soil data derived from the European Soil Database at a 1-km^2 pixel resolution (Joint Research Centre). The following sources of data also provided ancillary information: (i) an Italian database of soil characteristics ('map of the water capacity in agricultural soils') generated by the Ministry of Agriculture and based on nearly 18,000 soil samples (Salvati, 2012); (ii) thematic cartographies including Ecopedological and Geological maps of Italy, obtained from the Joint Research Centre and the Italian Geological Service; and finally, (iii) a land system map produced by the National Centre of Pedological Cartography. These datasets can be considered as the standard, homogeneous soil information available in Italy at 1:250,000 scale. The variables considered in this study include the soil depth and texture, the slope and the nature of the parent material. These variables can be considered as proxy information for other soil quality indicators (e.g. organic matter content, resistance or tendency to compaction). Soil structural characteristics including texture, depth and parent material are determined by the joint action of factors including climate, soil organisms, morphology and

Table I. List of variables used in the ESAI framework by theme, measurement unit and statistical source

Theme	Variable	Scale	Unit of measure	Source
Soil quality	Soil texture	1:250,000	Sensitivity class	Ministry of Agriculture, European soil database
	Soil depth	1:250,000	Mm	Ministry of Agriculture, European soil database
	Parent material	1:250,000	Sensitivity class	Ministry of Agriculture, European soil database
	Rock fragments	1:250,000	Sensitivity class	Ministry of Agriculture, European soil database
	Drainage	1:250,000	Sensitivity class	Ministry of Agriculture, European soil database
	Slope angle	1:25,000	%	Ministry of Environment
Climate quality	Annual mean rainfall rate	1:500,000	mm	Meteorological statistics
	Aridity index	1:500,000	mm/mm	Meteorological statistics
	Aspect	1:25,000	Angle	Ministry of Environment
Vegetation quality	Fire risk	1:100,000	Sensitivity class	CORINE Land Cover maps
	Erosion protection	1:100,000	Sensitivity class	CORINE Land Cover maps
	Drought resistance	1:100,000	Sensitivity class	CORINE Land Cover maps
	Vegetation cover	1:100,000	Sensitivity class	CORINE Land Cover maps
Land management	Population density	1:400,000	People km^{-2}	Census of population
	Demographic variation	1:400,000	%	Census of population
	Land-use intensity	1:100,000	Sensitivity class	CORINE Land Cover maps

Table II. A summary of the variables used in the ESAI framework by time period (see text for acronyms)

Variable	1960	1970	1980	1990	2000	2005	2010
Rainfall	1951–1960	1961–1970	1971–1980	1981–1990	1991–2000	1996–2005	2001–2010
Aridity index							
Land-use intensity	1960 LUM		1990 CLC		2000 CLC	2006 CLC	
Vegetation quality							
Population density	1961	1971	1981	1991	2001	2005	2011
Population growth	1951–1961	1961–1971	1971–1981	1981–1991	1991–2001	2002–2005	2006–2011
Aspect	20-m Digital Elevation Model of Italy						
Soil quality indicators	European Soil Database supplemented with national data sources						

time (Kosmas *et al*., 1999). In our case study, considering the examined time span, these variables have been regarded as static during the study period because they change slowly, if at all or, by their nature, are infrequently measured (Bajocco *et al*., 2011). The long investigated time period and the national coverage of the study prevented us from using diachronic soil mapping available at the very local scale. However, it should be noted that, among the considered variables, soil depth can vary along prolonged time intervals and in places with specific territorial characteristics possibly because of the effect of soil erosion.

The importance of vegetation cover in land degradation processes was evaluated through four variables: the vegetation cover, the fire risk, the protection offered by vegetation against soil erosion and the degree of resistance to drought shown by vegetation (Basso *et al*., 2000). Such variables derived from elaboration on two comparable maps: the Coordinate Information on the Environment (CORINE)-like 'Topographic and Land Cover Map of Italy' (Colamonico, 1971) produced by the National Research Council and the Italian Touring Club in 1960 (LUM60) and three CORINE land cover maps respectively dated 1990 (CLC90), 2000 (CLC00) and 2006 (CLC06). Variables were determined by applying a weighting system (ranging from 1–2 and derived from Kosmas *et al*., 1999) that classifies each observed land cover class according to the level of sensitivity to land degradation. The LUM60 is a standard map covering the whole Italian territory at 1:200,000 scale and classifying land cover in 22 categories according to a nomenclature that is compatible with the CORINE Land Cover (CLC) hierarchical system (Falcucci *et al*., 2007). On the basis of topographic maps provided by the Italian Touring Club and the Italian Geographical Military Institute and dated 1949 to 1962, the LUM60 map was prepared integrating cadastral maps, an extensive field survey together with statistical data at a fine spatial scale. The map was already used for diachronic comparisons with the CLC cartography (Falcucci *et al*., 2007) and for multitemporal analysis of land cover and other environmental indicators (Salvati, 2012). The CLC programme was developed by the European Environment Agency by using satellite imagery to provide Pan-European, diachronic 1:100.000 land cover maps with 25 ha minimum mapping unit. The CLC nomenclature includes 44 land cover classes grouped into a three-level hierarchy.

Because of the lack of comparable land cover maps covering the whole national territory at 3 years (1970, 1980 and 2010), LUM60 and CLC90 were used to estimate the Vegetation Quality Index (VQI), respectively, in 1970 and 1980, whereas CLC06 was used to estimate the VQI in 2010. Although the data material used in the present study has obvious shortcomings, this may be acceptable when the purpose is to study a large region (e.g. a whole country) over a long time interval, because the cost of mapping is insurmountable for an individual research project. It is therefore inevitable that such large-scale studies rely on sources of varying accuracy.

Anthropogenic pressure and land management quality, which can cause land degradation processes, have been quantified as the result of population dynamics and selected land-use changes (Otto *et al*., 2007). Density and annual growth rate of resident population have been used as proxy indicators of human pressure. Demographic density was assessed at the municipal scale in 1961, 1971, 1981, 1991, 2001, 2006 and 2011 on the basis of the National Censuses of Population and the annual Population Register held by the Italian National Institute of Statistics (ISTAT, 2006). Population increase (or decrease) was determined as the annual demographic change observed at the same spatial scale in the following period: 1951 to 1961, 1961 to 1971, 1971 to 1981, 1981 to 1991, 1991 to 2001, 2002 to 2006 and 2007 to 2011. Finally, an indicator of land-use intensity was obtained by applying a weighting system (ranging from 1–2 and derived from Salvati & Bajocco, 2011) that classifies the observed classes according to their intensity of use and potential level of sensitivity to degradation. This indicator was obtained from elaboration on the maps previously cited (LUM60 and CLC90, CLC00 and CLC06).

The Composite Index of Land Sensitivity to Degradation

The ESAI framework quantifies sensitivity to land sensitivity as a combination of unsustainable land management together with environmental factors including poor soil, vegetation cover and dry (or drier) climate (Basso *et al*., 2000; Lavado Contador *et al*., 2009). A scoring system is applied, based on the known relationship between each factors and land degradation processes. The weighting system suggested by Salvati & Bajocco (2011) was adopted in the present study. This system followed the benchmarking system introduced by Kosmas *et al*. (1999), Basso *et al*. (2000) and Lavado Contador *et al*. (2009).

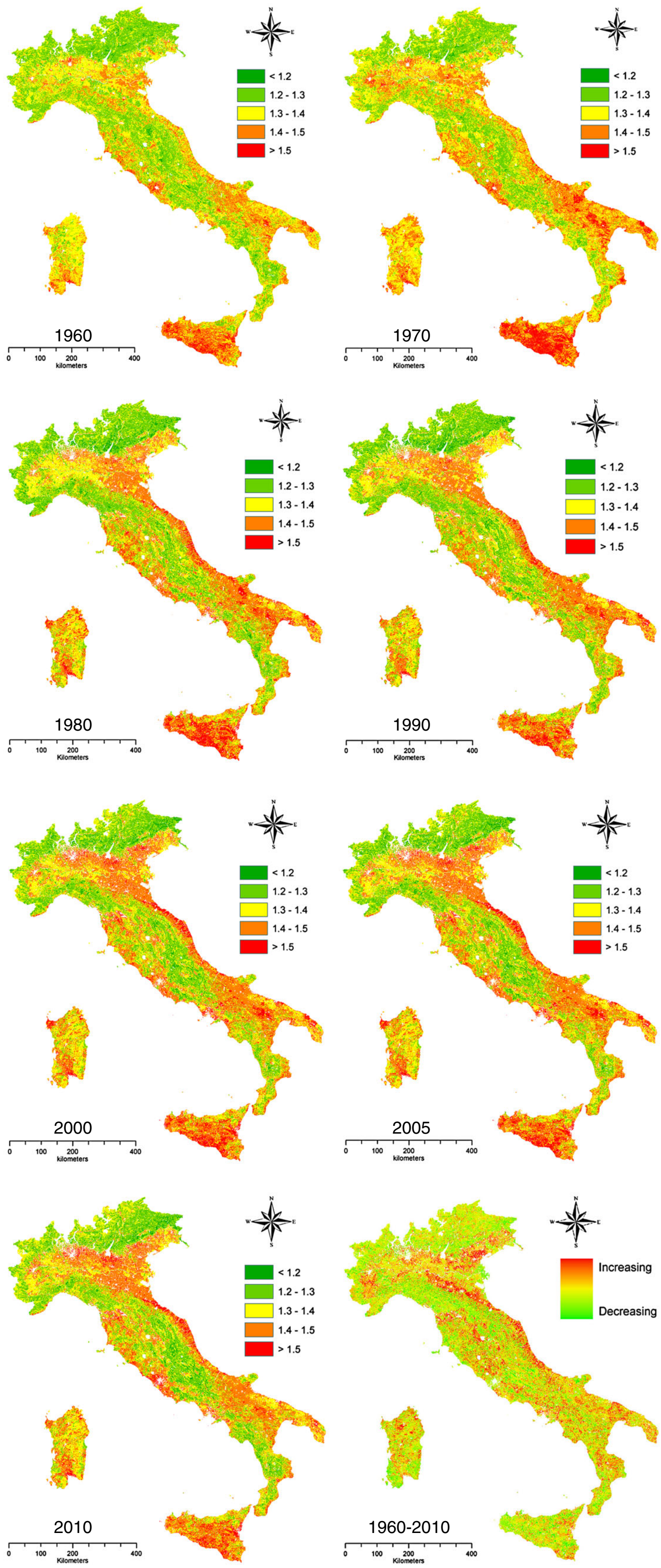

Figure 1. The average ESAI score observed in Italy by year between 1960 and 2010. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

The ESA framework produces quality indicators of climate (Climate Quality Index, CQI), soil (Soil Quality Index, SQI), vegetation (Vegetation Quality Index, VQI) and land management (Land Management Quality Index, MQI) that are estimated as the geometric mean of the different scores assigned to each input variable. Each indicator ranges from 1 (the lowest contribution to land sensitivity to degradation) to 2 (the highest contribution to land sensitivity to degradation). The ESAI was then estimated in each spatial unit and year as the geometric mean of the four quality indicators (CQI, SQI, VQI and MQI) obtaining a score ranging from 1 (the lowest sensitivity to degradation) to 2 (the highest sensitivity to degradation). The four indicators weighted the same in the ESAI procedure (Kosmas *et al.*, 1999). Four classes of land sensitivity were identified that reflect the classification threshold shown in Salvati & Bajocco (2011): (i) areas unaffected by LD (ESAI < 1·17); (ii) areas potentially affected by LD (1·17 < ESAI < 1·225); (iii) fragile areas (1·225 < ESAI < 1·375); and (iv) critical areas (ESAI 1·375). Maps have been produced at 1-km^2 pixel resolution (Salvati, 2012). The elementary spatial unit has been selected according to Basso *et al.* (2000) and is coherent with the resolution of the single layers.

Techniques Used for the Analysis of Data

Following Salvati (2012), the ESAI values were treated as a ratio variable in this paper because they range continuously from 1 to 2 over large sample sizes. In particular, we estimated the ESAI average value and the coefficient of variation at the seven investigated years by using three spatial domains of analysis: (i) five geographical divisions (northwestern and northeastern Italy, central Italy, southern Italy and the two main islands: Sicily and Sardinia) further aggregated in three regions (North, Centre and South); (ii) three elevation belts (lowlands, uplands and mountain areas) defined according to ISTAT (2006); and (iii) 20 administrative regions. These partitions of the national territory are consistent with the characteristics and resolution of the variables selected, and possibly useful for the identification of the strategies contrasting desertification risk. As an example, the Italian National Action Plan to Combat Desertification has designed the 20 administrative regions as the effective spatial unit to coordinate and implement policies against land degradation and for mitigating desertification risk. However, selected statistics on the four above-mentioned ESAI classes were also calculated.

The ESAI average and coefficient of variation were calculated for each considered spatial unit by using the 'zonal statistics' procedure developed in ArcGIS (ESRI, Inc., Redwoods, USA). This procedure computes a surface-weighted average of the ESAI values (i.e. recorded on each elementary pixel) belonging to the spatial unit being analysed. The low deviation from normality in the ESAI distribution, together with the low value of the coefficient of variation, indicates the average as an honest indicator of the central tendency of the distribution. However, as mentioned previously, because of the present study relies on data sources of varying accuracy, only large changes in the ESAI (e.g. with magnitude > 1% per year) were considered as relevant and thus commented on and discussed. This was to limit the (possible) impact of data inaccuracies and differences between sources in the results presented.

RESULTS

Temporal and Spatial Trends in the Environmental Sensitive Area Index

The average ESAI score increased in Italy by 1·5% from 1·34 in 1960 to 1·36 in 2010, indicating increasing sensitivity to desertification. The highest growth rate was observed in the Po valley, along the Adriatic coasts, in flat areas of Tuscany and Latium, and in northern Sardinia (Figure 1). The ESAI growth rate, however, varied in time and space (Table III), increasing rapidly from 1960 to 1990 while being stable (or even decreasing) in the subsequent time period (1990–2010). Between 1960 and 2010, a larger increase in the average ESAI was found in northern Italy (2·3%) and in central Italy (2·0%) compared with southern Italy. Whereas in 1960, the level of sensitivity to desertification was higher in northern Italy (average ESAI = 1·32) than in southern Italy (average ESAI = 1·37), the between-region difference in the ESAI decreased from 4·3% in 1960 to 2·6%

Table III. Average ESAI score in Italy by geographical region and year

Year	North	Centre	South	Italy	South/North*	South/Centre**
1960	1·317	1·328	1·374	1·342	4·3	3·4
1970	1·336	1·344	1·407	1·367	5·4	4·7
1980	1·326	1·355	1·399	1·362	5·5	3·2
1990	1·327	1·342	1·388	1·355	4·7	3·5
2000	1·329	1·345	1·400	1·362	5·3	4·0
2005	1·342	1·355	1·397	1·367	4·1	3·1
2010	1·347	1·355	1·382	1·363	2·6	2·0
Δ(2010–1960)%						
Change in the average ESAI	2·3	2·0	0·6	1·5	−38·6	−41·4
Change in the maximum ESAI	1·7	1·2	2·4	1·9	—	—
ESAI coefficient of variation	1·6	1·4	0·7	1·2	—	—

*The percent ratio of the ESAI score observed in southern Italy to the score observed in northern Italy.
**The percent ratio of the ESAI score observed in southern Italy to the score observed in central Italy.

Table IV. Average ESAI score in Italy by elevation belt and selected years

Elevation	1960	1990	2010
Mountain zones (M)	1·304	1·297	1·305
Uplands	1·354	1·373	1·378
Flat areas (F)	1·375	1·411	1·424
F/M ratio	1·054	1·088	1·091

in 2010 (southern Italy average ESAI = 1·38; northern Italy average ESAI = 1·35). Following the changes observed in the average ESAI score at the regional scale, the highest increase in the ESAI coefficient of variation has been observed in northern Italy (1·6%) and central Italy (1·4%). However, by considering the maximum value of the ESAI observed in the three regions, the highest increase was observed in southern Italy (2·4%) followed by northern Italy (1·7%).

Differences in the average ESAI have been observed in the three elevation zones examined in this study (Table IV). The level of sensitivity to land degradation was found to be low and stable (ESAI = 1·30) in mountain areas while weakly increasing in uplands. On average, flat areas were the most sensitive land to desertification in 1960 and showed the highest observed increase in the ESAI between 1960 and 2010.

The 20 Italian regions have been ranked according to their average ESAI score (Table V). The rank of the most sensitive regions (Sicily and Apulia, both located in southern Italy) was stable during the study period. In both regions, high but stable proportion of critical land was observed. From the third position downwards, the ranking changed drastically in the last 50 years. The third-sensitive region in 1960 (Basilicata, southern Italy) dropped to the fifth position in 2010, whereas the sixth region in 1960 (Emilia-Romagna, northern Italy) moved to the third position in 2010. As a general trend, northern Italian regions showed higher ESAI increases than those observed in southern Italian regions influencing the final ranking in 2010. Conversely, the ranking of less sensitive regions (including internal, mountain regions in both northern and central Italy: Trentino Alto Adige, Aosta Valley, Friuli Venezia Giulia, Umbria and Liguria) remained stable over time.

Between-Region Versus Within-Region Trends in the Environmental Sensitive Area Index

Whereas the between-region differences in the level of land sensitivity to desertification decreased over time (as illustrated in Figure 2), the within-region differences increased considerably and points to the complex geography of degradation processes (Figure 3). A negative trend in the 7 years was observed between the two differences in Italy ($r_s = -0{\cdot}42$, $p < 0{\cdot}05$, $n = 7$). The correlation between the average ESAI score observed at the regional scale and its coefficient of variation (Figure 4) was positive only for 1960 ($r_s = 0{\cdot}45$, $p < 0{\cdot}01$, $n = 20$) and 1990 ($r_s = 0{\cdot}37$, $p < 0{\cdot}05$, $n = 20$).

Trends in the Surface Area of Critical Land Class

According to the ESAI threshold system, the surface area of land classified as critical (Table VI) progressively increased in Italy from 33% in 1960 to 47% in 2010. However, the growth rate observed at the regional scale ranged between 20 and 7% in northern and southern Italy, respectively. The ratio of critical land surface in northern Italy to the same variable observed in southern Italy decreased rapidly from 2·5 in 1960 to 1·4 in 2010, indicating a convergence process between these two areas of the country. Sicily was the region with the largest surface land classified as critical in

Table V. Average ESAI score in Italy by administrative region (S: southern Italy, C: central Italy, N: northern Italy) and year

Region	Average ESAI (ranking position)			% change*
	1960	1990	2010	
Sicily (S)	1·434(1)	1·427(2)	1·431(1)	0·00
Apulia (S)	1·391(2)	1·428(1)	1·404(2)	0·02
Basilicata (S)	1·370(3)	1·384(4)	1·383(5)	0·02
Sardinia (S)	1·367(4)	1·377(5)	1·387(4)	0·03
Molise (S)	1·359(5)	1·384(3)	1·361(6)	0·00
Emilia-Romagna (N)	1·345(6)	1·370(6)	1·390(3)	0·07
Abruzzo (S)	1·338(7)	1·360(9)	1·325(15)	−0·02
Latium (C)	1·338(8)	1·351(10)	1·357(12)	0·03
Campania (S)	1·338(9)	1·361(8)	1·360(11)	0·03
Marche (C)	1·332(10)	1·365(7)	1·369(8)	0·06
Tuscany (C)	1·331(11)	1·338(14)	1·361(10)	0·05
Lombardia (N)	1·326(12)	1·340(13)	1·369(7)	0·07
Calabria (S)	1·326(13)	1·342(12)	1·334(13)	0·01
Veneto (N)	1·321(14)	1·347(11)	1·367(9)	0·07
Piedmont (N)	1·315(15)	1·319(15)	1·331(14)	0·03
Liguria (N)	1·314(16)	1·300(17)	1·313(17)	0·00
Umbria (C)	1·296(17)	1·309(16)	1·318(16)	0·03
Friuli Venezia Giulia (N)	1·294(18)	1·296(18)	1·304(18)	0·01
Aosta Valley (N)	1·289(19)	1·270(19)	1·301(19)	0·02
Trentino Alto Adige (N)	1·273(20)	1·262(20)	1·291(20)	0·03

*Annual percent change in the ESAI score observed in each region during 1960 to 2010.

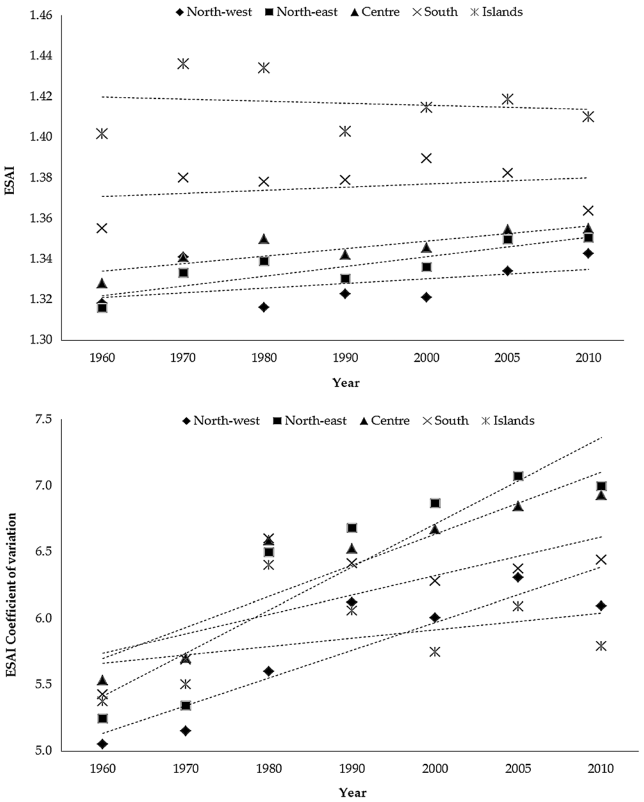

Figure 2. Trends in the ESAI score (*y*-axis) in Italy (upper panel: average ESAI score ranging between 1 and 2; lower panel: percent coefficient of variation of the ESAI) by geographical region between 1960 and 2010.

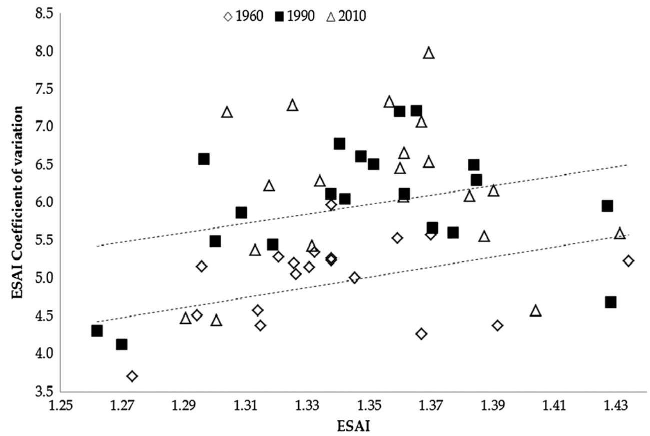

Figure 4. Correlation between the average ESAI (*x*-axis) observed in the 20 Italian regions and its coefficient of variation (*y*-axis) at three selected years (trend lines refer to 1960 and 1990 because 2010 correlation was not significant; see Figure 2 for measurement units).

1960 (77%) being stable in the following 50 years (Figure 5). On the contrary, Emilia-Romagna was the region with the highest increase in critical land (from 33 to 63% of the regional surface between 1960 and 2010).

Changes Over Time in the Four Quality Indicators Composing the Environmental Sensitive Area Index

In Italy, soil and vegetation quality contributed the most to the ESAI (Table VII) showing, on average, the highest indicator's scores (respectively 1·53 and 1·49) compared with climate (1·16) and land management (1·29). However, the quality indicator with the highest increase during the study period (indicating worst environmental conditions) was the CQI (6·5%) followed by the VQI (2·5%). Climate quality decreased more in central Italy (7·5%) and in northern Italy (6·1%) than in southern Italy, whereas vegetation quality decreased more in northern Italy (4·7%) than elsewhere in Italy. Interestingly, land management quality improved in southern Italy (2%).

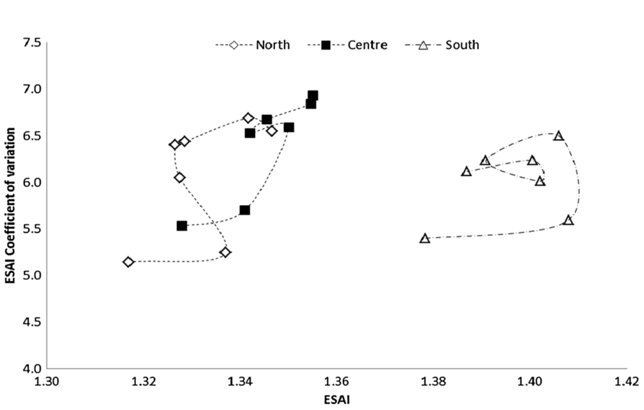

Figure 3. The relationship between the average ESAI (*x*-axis) and its coefficient of variation (*y*-axis) by year and geographical division in Italy between 1960 and 2010 (see Figure 2 for measurement units).

DISCUSSION

The data presented previously shows that the geographical distribution of areas sensitive to land desertification has changed in Italy during the last 50 years. By indicating how the increase in land sensitivity observed at the local scale was spatially clustered, the study points out the synergic effects of biophysical and socioeconomic factors. Previous works demonstrated how the increasing land sensitivity to degradation is associated with long-term ecological dynamics (e.g. climate aridity, soil deterioration, erosion, salinity and land cover changes) together with socioeconomic, cultural and institutional factors that increase human pressure and triggers landscape transformations (Salvati & Bajocco, 2011). In the Mediterranean basin, these conditions may be exacerbated by unsustainable land management practices in rural areas (Moonen *et al*., 2002; Geist & Lambin, 2004; Ibañez *et al*., 2008; Weissteiner *et al*., 2011).

The most visible evolution in the geography of land sensitivity in Italy was the decreasing polarisation in 'structurally sensitive' and non-affected areas. The region defined as structurally sensitive in Italy (i.e. southern Italy, Sicily and Sardinia) has been traditionally defined as a desertification hotspot (Salvati & Bajocco, 2011). However, the sensitivity level in this region remained stable over the time period investigated, because of locally increasing climate quality (Salvati *et al*., 2013), defined land-use changes mitigating desertification processes such as natural forestation (Corona *et al*., 2009) and a relatively low population pressure (Montanarella, 2007).

Table VI. The percent surface of Italian land classified as critical on the total investigated area by year and geographical region

Year	North	Centre	South	Italy	South/North*	South/Centre**
1960	19·7	26·2	49·1	32·8	2·5	1·9
1970	28·3	32·8	64·7	43·7	2·3	2·0
1980	31·4	44·6	60·1	45·5	1·9	1·3
1990	34·2	38·9	56·8	44·2	1·7	1·5
2000	33·9	39·9	59·9	45·5	1·8	1·5
2005	38·7	42·5	60·0	48·0	1·6	1·4
2010	39·8	42·0	56·0	46·7	1·4	1·3
Δ(1960–2010)%	20·1	15·9	6·8	13·9	—	—

*The ratio of critical surface area observed in southern Italy to that observed in northern Italy.
**The ratio of critical surface area observed in southern Italy to that observed in central Italy.

On the contrary, the sensitivity of previously 'non-affected' areas (mainly concentrated in northern and central Italy) increased rapidly during the investigated time period, suggesting that important variations have occurred in climate and socioeconomic conditions in this region. Climate quality was probably the mostly variable factor in the last 20 years, as this work and several other studies document (e.g. Sivakumar, 2007). In northern Italy, both decreasing rainfall and increasing temperature regimes contributed to determine aridity conditions comparable with that observed in some areas of southern Italy. These climate variations have also been reflected in prolonged drought episodes and the lower water availability in the soil (Salvati & Bajocco, 2011). From the socioeconomic perspective, one of the most significant changes was the urbanisation-driven landscape transformation of flat areas in the Po valley, resulting in higher levels of land sensitivity to degradation. Urban sprawl was also a significant factor determining the conversion from agricultural land to peri-urban areas: a shift from 'extensive' to 'intensive' use of agricultural land was observed in that area.

As demonstrated in the present study, the probability that flat land in northern Italy will undergo degradation is higher now than in the past. This indicates the need for more effective mitigation strategies (e.g. developed in the Italian National Action Plan against desertification) specifically designed for economically developed regions such as northern Italy. According to Briassoulis (2011), measures against land

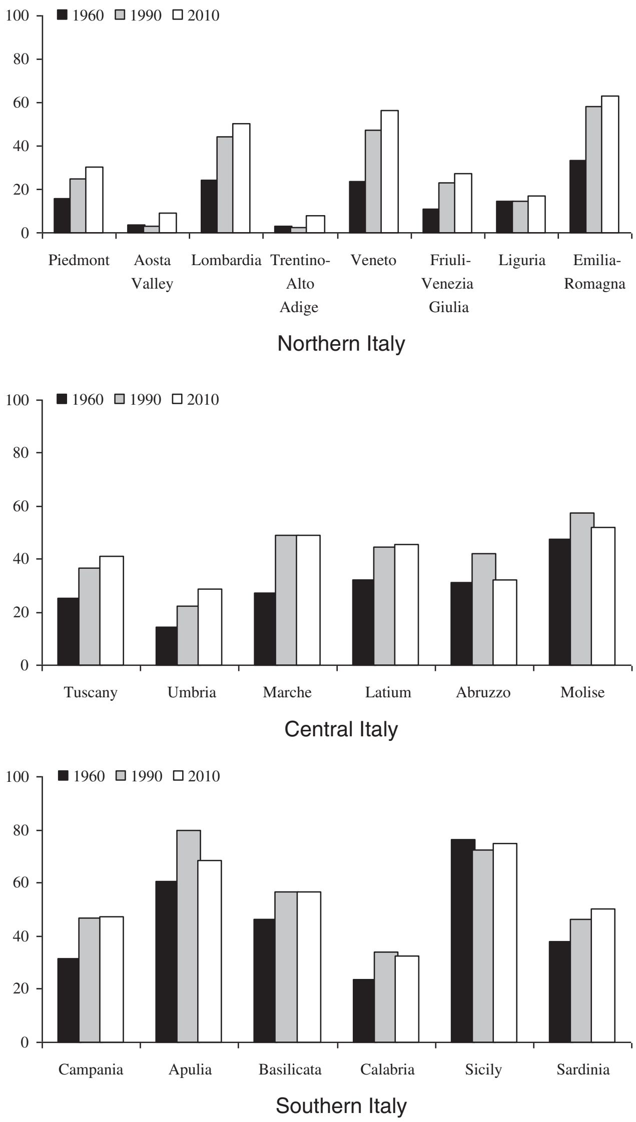

Figure 5. Trends in the percentage of critical land surface (*y*-axis) on total investigated land in Italy by administrative region and selected years.

Table VII. Average score of the four quality indicators composing the ESAI in Italy by three selected years and geographical region

Region	1960	1990	2010	% change*
Climate (CQI)				
North	1·062	1·099	1·127	6·1
Centre	1·079	1·156	1·160	7·5
South	1·194	1·293	1·263	5·8
Vegetation (VQI)				
North	1·440	1·504	1·507	4·7
Centre	1·460	1·499	1·502	2·8
South	1·506	1·496	1·504	−0·1
Land management (MQI)				
North	1·319	1·269	1·314	−0·4
Centre	1·317	1·259	1·307	−0·7
South	1·298	1·271	1·272	−2·1
Soil (SQI)				
North	—	1·517	—	—
Centre	—	1·525	—	—
South	—	1·553	—	—

*Percent change in each indicator's score observed by region during 1960 to 2010.

degradation in Europe should overcome sectoral perspectives (e.g. economic, social and environmental) to achieve a multitarget (e.g. sustainable development) and multiscale approach. At the national level, whereas the between-region disparities in the level of sensitivity decreased during the last 50 years, the within-region variability increased markedly; quite different to what was observed in the early 1960s. This change suggests a polarisation in non-affected and critical land that is less affected by the latitude gradient than in the past. This pattern depends instead on the interaction between changing climate quality and specific land-use trajectories (agricultural intensification, urban sprawl, littoralization and land abandonment, for example) affecting land management conditions (Marathianou *et al.*, 1999; Portnov & Safriel, 2004; Simeonakis *et al.*, 2007; Detsis, 2010; Barbayiannis *et al.*, 2011), confirming the importance of the integrated (socioeconomic and biophysical) assessment of land degradation processes (Conacher & Sala, 1998)

CONCLUSIONS

This paper provides an original contribution to the study of natural and human-derived changes influencing desertification risk in a developed country. Results show, for the first time in Europe, the nonlinear long-term trends in land sensitivity to desertification in Italy, highlighting the convergence between non-affected areas (showing increasing levels of sensitivity) and already sensitive areas. By using a large-scale assessment, these findings illustrate the complex spatio-temporal dynamics in a number of environmental factors leading to land degradation and the decreasing disparities in land sensitivity to desertification among Italian regions.

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