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ASSESSMENT OF VULNERABILITY TO DROUGHT AND DESERTIFICATION IN ITALY: AN LONG-TERM ANALYSIS, FROM 1960 TO 2010

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ABSTRACT

Environmental sensitivity and landscape degradation are affected by rapidly changing ecological and socio-economic conditions. After experiencing recurrent droughts and increasing climate aridity, the Mediterranean landscape has been regarded as a critical hotspot for land degradation and desertification due to the concomitant impact of soil deterioration, land-use changes, human pressure, and climate variations. Unfortunately, relatively few studies have been devoted to analyze, within a sufficiently large time span, trends in land sensitivity to desertification over large areas in southern Europe. This paper contributes to this deserving issue by quantifying at a detailed spatial scale the level of land sensitivity to desertification in Italy at seven years (1960, 1970, 1980, 1990, 2000, 2010). The used approach followed the Environmental Sensitive Area (ESA) scheme that assesses significant changes in four key themes related to land degradation processes (climate, soil, vegetation, and land management). Italian Land was classified into four levels of sensitivity to desertification ('non-affected', 'potentially affected', 'fragile', and 'critical'). Interestingly, while the country area classified as 'fragile' and 'critical' increased quite homogeneously in 1960-1990, the increase observed in the most recent period was moderate and spatially-concentrated reversing the polarization in 'structurally vulnerable' and 'non-affected' regions typical of Italy. The paper finally discussed the observed ESAI trends according to the socioeconomic changes occurring in Italy and the relationships among the four considered themes.

KEYWORDS: Environmental indicators, ESAI, trend, Italy, geographical scale.

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1.INTRODUCTION

Land degradation, drought, and desertification represent complex phenomena induced by natural and anthropogenic processes occurring in both developing and developed countries. Their ultimate outcome is the drastic reduction of land productivity with significant environmental and socio-economic consequences. This negative effects of natural processes and unsustainable land management was recognised in a developed country, likely for the first time, in the 1930s, when most of the Great Plains in the United States of America underwent a prolonged drought that determined, together with intensive agricultural practices, the well-known phenomenon of 'dust bowls'. Without livelihoods, hundreds of thousands of people were forced to leave their land and migrate around the Country. The adoption of more appropriate cultivation methods and sustainable use of water resources, avoided similar consequences for drought events occurred in the following years (National Drought Mitigation Center, 2006).

Nowadays, global warming, economic development, and population growth are responsible for triggering large-scale soil and land degradation phenomena possibly leading to desertification. United Nations Convention to Combat Drought and Desertification (UNCCD) defined desertification as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities". Desertification is a truly worldwide phenomenon and affects about 40 per cent of the Earth's surface including parts of Europe, United States, and Australia (Holtz, 2003). By the UNCCD definition, climate aridity is considered as an essential cause for land degradation processes. However, anthropogenic pressures assume also a crucial role as mentioned by Jagdish at al. (2000): "desertification is a condition of human-induced land degradation that occurs in arid, semi-arid and dry sub-humid regions (...) and leads to a persistent decline in economic productivity (…) of useful biota related to land use or a production system". In the Mediterranean basin, human-derived land degradation (e.g. driven by population density, agricultural intensification, urban sprawl, and soil contamination) was usually associated with natural factors,

including climate aridity, soil sensitivity to degradation, and poor vegetation cover. The Mediterranean region was also classified as an hot-spot for climate change in Europe. All these factors produce potentially devastating effects on the environment.

A number of methodologies was recently proposed to monitor soil deterioration and desertification risk and to identify sensitive areas to degradation (Simeonakis et al. 2007; Salvati and Zitti 2009; Costantini et al. 2009; Santini et al. 2010). The ESA (Environmentally Sensitive Area) scheme is one of the most used procedures to evaluate the degree of LD in Europe, northern Africa and the middle-east. The ESA scheme was developed in the mid 1980s by the UK Department of Agriculture and Rural Development to encourage farmers and landowners to adopt environmentally-friendly land management practices (Wilson 1996).

In the early 1990s, the ESA framework has been adapted to monitor desertification processes in the behalf of MEDALUS project (Kosmas et al. 1999). The main advantages of the ESA are the flexibility in the use of the input variables and the simplicity of the procedure to classify land according to its sensitivity level. The final output of the ESA is a composite index of land sensitivity called ESAI (Environmental Sensitive Area Index).

in such a perspective a key assumption in desertification approaches is particularly intriguing and sometimes underestimated in the current scientific literature: land vulnerability to desertification is not a static attribute of the landscape (Salvati and Zitti, 2009) and therefore needs permanent monitoring to understand its (non-linear) trajectories (Thornes, 2004). Unfortunately, time series and scenarios analyses quantifying the increase of vulnerable and even affected land are relatively poor in southern Europe, despite the large mass of studies realised in the framework of the several research projects financed by the European Union and by the countries itself (Salvati and Zitti, 2008; Salvati et al., 2008a; but see also the discussion in Brandt, 2005). Salvati and Bajocco (2010) identify the assessment of the bio-physical and socioeconomic conditions leading to land degradation as a major concern (i) to stimulate research facing with the specific processes involved in LD (at vastly different observation and policy scales, from local to national and sovra-national) and (ii) to develop a comprehensive policy framework against desertification (Briassoulis, 2004).

Italy has been considered a paradigmatic example of the landscape and environmental complexity typical of the Mediterranean basin (Salvati and Zitti 2009). Although desert areas are not yet occurring in the country, several studies identified areas where locally-severe LD conditions determined high vulnerability to desertification especially in the southern region. Moreover, it was hypothesized that climate and land-use changes contributed to the increase of LD-vulnerable areas during the last twenty years, although data covering long time-periods and large areas at adequate spatial resolution are generally lacking. The aim of this work is therefore to assess, using the ESAI framework, the spatial and temporal evolution of the level of land sensitivity to degradation in Italy at seven years (1960, 1970, 1980, 1990, 2000, 2005, and 2010).

2. MATERIALS AND METHODS

2.1 Study Area

Italy is located in the mid of Mediterranean basin with a coastline of about 7,600 kilometres including islands. Northern Italy is separated from Europe by Alps and it is divided longitudinally by the Apennine mountains. The country is divided into three geographical regions (North, Centre, South) with a total surface area of 301,330 km2. The country surface is composed of nearly 23% lowlands, 42% uplands, and 35% mountains. Due to the geographical position, Italy is characterized by a relatively mild climate. The amount of precipitation generally increase with the elevation while temperature regime followed the

reverse pattern. In common with other Mediterranean countries, Italy shows important regional disparities in economic growth, population density, settlement distribution, social development, and natural resource availability (Salvati et al., 2008) thus representing an interesting case study to address the interaction of bio-physical and socioeconomic factors possibly influencing land sensitivity to degradation.

2.2 *Data and variables*

According to the ESA framework the variables selected to study the level of sensitivity to LD of Italy refer to four themes: climate quality, soil quality, vegetation and land use quality, and human pressure/land management quality (Table 1). At our knowledge, the used layers 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 and Zitti, 2009 for a discussion on supply-demand of statistical data in desertification matters). We investigated seven years from 1960 to 2010 since comparable data, needed to develop the full ESAI model (sensu Salvati and Bajocco, 2010) with national coverage and detailed spatial scale were available only at that dates (see also Table 2).

2.3 Climate quality

Climate quality has been described in this work using the following variables: average annual rainfall rate, aridity index, and aspect (Basso et al., 2000).

Rainfall rate and aridity index were calculated on a ten-year base using basic information available in the National Agro-meteorological Database of the Italian Ministry of Agriculture. The database relates to gauging data collected daily from several meteorological networks (Italian Ministry of Agriculture, National Hydrological Service, Italian Air Force, and some minor networks) working with nearly 3,000 weather stations since 1951 (Venezian Scarascia et al., 2006; Salvati et al., 2008). To ensure the homogeneous and complete regional coverage, the meteorological data were spatially interpolated through kriging/co-kriging procedures (with elevation, latitude, and distance to the sea as ancillary variables) in order to create a grid of 544 points with daily data of temperature, precipitation, humidity, solar radiation, and wind (Salvati et al., 2009). Seven analysis periods were selected: 1951-1960, 1961-1970, 1971-1980, 1981-1990, 1991-2000, 1996-2005, 2001-2010.

The aridity index was defined as the ratio between rainfall and reference evapotranspiration, both measured as a ten-year average. The reference evapotranspiration rate was calculated by using the Penman-Monteith formula. Aspect was derived from elaboration on the ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) global Digital Elevation Model (DEM) at 30m resolution scale generated from stereoscopic pairs of optical ASTER images and freely available online at http://www.gdem.aster.ersdac.or.jp/.

2.4 Soil quality

Soil data were obtained from the soil quality map produced in the framework of DISMED project (Brandt, 2005) and derived from the European Soil Database at a 1 km2 pixel

resolution (Joint Research Center, JRC). The following sources of data also provided ancillary information where necessary: (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 and Zitti 2007); (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. According to the standard ESA model, the variables considered here were: soil depth and texture, slope, and the nature of the parent material. These variables can be considered as proxy information of 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 pedogenesis factors (i.e. macro-climate, soil organisms, morphology, and time: Kosmas et al., 2000). In our case study, considering the examined time span, these variables have been regarded to be static during the study period because they generally change slowly, if at all or, by their nature, are infrequently measured or mapped (Salvati and Bajocco 2010).

2.5 Vegetation and land-use quality

The impact of land cover/land use on LD was assessed through four standard ESA variables: vegetation cover, fire risk, protection offered by vegetation against soil erosion, and the degree of resistance to drought shown by vegetation (Basso et al., 2000). Such indicators were obtained from elaboration on two comparable land-use maps: the CORINE-like 'Land Use 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). The four indicators described below were determined by applying a weighting system (ranging from 1 to 2 and derived from Kosmas et al., 2000) that classifies the observed land-use classes according to the level of sensitivity to LD. The CLC project was coordinated by the European Environmental Agency (EEA) with the aim of providing pan-European, diachronic land cover maps. The CLC inventory is based on satellite images as the primary information source and produces 1:100.000 maps with 25 ha minimum mapping unit and 100 m minimum width of linear elements. The CLC nomenclature includes 44 land cover classes grouped into a three-level hierarchy. The five main (level-one) classes are: (i) urban areas, (ii) agricultural areas, (iii) forests and semi-natural areas, (iv) wetlands, and (v) water bodies.

2.6 Human pressure/land management quality

Anthropogenic pressure and land management quality possibly determining land degradation have been assessed as the result of population dynamics and selected land-use changes (Otto et al., 2007). Population density and annual growth rate were used as summary indicators of human pressure (Geeson et al., 2002). population density was measured at municipal scale in

1961, 1971, 1981, 1991, 2001, 2005, and 2010 on the basis of the National Censuses of Households and the annual Population Register held by the Italian National Institute of Statistics (Salvati and Zitti, 2007). Population increase (or decrease) was determined as the annual demographic change observed at municipal scale in the following period: 1951-1961, 1961-1971, 1971-1981, 1981-1991, 1991-2001, 2002-2005, 2006-2010. Finally, an indicator of land-intensity was obtained by applying a weighting system (ranging from 1 to 2 and derived from Salvati and Bajocco, 2010) that classifies the observed land-use classes according to their intensity of use and potential level of sensitivity to LD. This indicator was obtained from elaboration on the maps previously cited (LUM60 and CLC90, CLC00, and CLC06).

2.7 Deriving a composite index of land sensitivity to degradation

As already stated by Basso et al. (2000), Salvati and Zitti (2008), and Lavado Contador et al. (2009), the ESAI framework evaluates LD condition as a combination of a possibly unsustainable land management together with a particular set of environmental factors including poor soil and vegetation and low-quality (i.e. dry) climate. A score system was then applied, based on the estimated degree of correlation between the various factors and LD. The weighting system suggested by Salvati and Bajocco (2010) was adopted here. This system followed the standard benchmarking introduced by Kosmas et al. (1999), Basso et al. (2000), Motroni et al. (2004) and Brandt (2005), with additional information taken from Salvati et al. (2008a) and Salvati and Zitti (2008).

The ESA framework produces four 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. The ESAI was then estimated in each i-th spatial unit and j-th year as the geometric mean of the four quality indicators as follows:

$$ESAI_{i,j} = (SQI_{i,j}*CQI_{i,j}*VQI_{i,j}*DEN_{i,j})^{1/4}$$

The ESAI score ranges from 1 (the lowest land sensitivity to degradation) to 2 (the highest sensitivity to degradation). According to the obtained ESAI figures, four classes of land sensitivity were identified that reflect the most used classification thresholds (see Salvati and Bajocco, 2010 and references therein): (i) areas unaffected by LD (ESAI < 1.17), (ii) areas potentially affected ($1.17 < ESAI < 1.225$), (iii) ‘fragile’ areas ($1.225 < ESAI < 1.375$), and (iv) ‘critical’ areas (ESAI > 1.375). Intermediate and final maps were produced after the various layers were rasterized, registered, and referenced to the elementary 1 km2 spatial unit (Salvati et al., 2008a). The minimum spatial unit was selected according to Basso et al. (2000).

2.8 Statistical analysis

We estimated the ESAI average value and the coefficient of variation at the seven

investigated years using three spatial domains of analysis: (i) five geographical regions (North-western and North-eastern Italy, Central Italy, Southern Italy, and the two main islands: Sicily and Sardinia) further aggregated in three domains (North, Centre, South), (ii) three elevation belts (lowlands, uplands, and mountain areas) defined according to ISTAT (2006), and (iii) twenty administrative regions. This partition set allows for the classification of the Italian land according to the level of sensitivity to degradation at different geographical and policy levels which are easily interpretable for non-technical stakeholders, consistent with the characteristics and resolution of the variables selected, and possibly useful for the identification of the strategies contrasting desertification risk. As a matter of fact, the Italian National Action Plan to Combat Desertification has designed the twenty administrative regions as the effective spatial unit to coordinate and implement policies against land degradation and mitigating desertification risk.

Statistics on the ESAI (average and coefficient of variation) were calculated for each considered spatial unit using the ‘zonal statistics’ tool provided with the software 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 analyzed spatial unit.

3. RESULTS

3.1 General trends in the ESAI

The average ESAI score increased in Italy by 1.5% from 1.34 in 1960 to 1.36 in 2010. The highest growth rates were 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, greatly varied in time and space (Table II) increasing rapidly from 1960 to 1990 and weakly increasing (or even decreasing) in the following period. During 1960-2010, a larger increase in the average ESAI was observed in northern Italy (2.3%) and in central Italy (2.0%) compared to southern Italy (0.6%). On average, the level of sensitivity to land degradation was higher in northern Italy (ESAI = 1.32) than in southern Italy (ESAI = 1.37). The between-region difference in the ESAI decreased from 4.3% in 1960 to 2.6% in 2010 (southern Italy ESAI = 1.36; northern Italy ESAI = 1.35). Comparable to the average score, the highest increase in the ESAI coefficient of variation was observed in northern Italy (1.6%) and central Italy (1.4%). However, 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%).

3.2 Trends in the ESAI according to elevation

Important differences in the average ESAI have been observed in the elevation zones adopted in this study (Table III). The level of sensitivity to land degradation was found low (ESAI = 1.30) and stable in mountain areas while increasing by 0.04% per year in uplands (ESAI = 1.35 in 1960 and 1.38 in 2010). On average, lowlands were the most sensitive to degradation

in 1960 also showing the highest observed increase in the ESAI during 1960-2010 (0.07% per year).

3.3 Regional trends in the ESAI

The twenty Italian regions have been ranked according to their average ESAI score (Table IV). The rank of the most sensitive regions (Sicily and Apulia, both located in southern Italy) was stable in the study period. In both regions, an high and stable proportion of ‘critical’ land was observed. From the third position downwards, the ranking changed drastically in the last fifty years. The third-sensitive region in 1960 (Basilicata, southern Italy) dropped to the fifth position in 2010 while 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 that observed in southern Italian regions impacting the final ranking in 2010. By the contrary, the ranking of the less sensitive regions to land degradation (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.

3.4 Between-regions vs. within-regions trends in the ESAI

While the between-region differences in the level of land sensitivity to degradation decreased over time (as illustrated in Figure 2), the within-region differences increased significantly indicating the complex geography of the investigated process (Figure 3). At country level, a negative trend in the seven years considered here was observed between the two differences ($r_s = -0.42$, $p < 0.05$, $n = 7$). The correlation between the average ESAI score observed at regional scale and its coefficient of variation (Figure 4) was positive in both 1960 ($r_s = 0.45$, $p < 0.01$, $n = 20$) and 1990 ($r_s = 0.37$, $p < 0.05$, $n = 20$) while not significant in 2010 ($r_s = 0.13$, $p > 0.05$, $n = 20$).

3.4 Trends in the ‘critical’ land surface

According to the ESAI thresholds, the land surface classified as ‘critical’ (Table V) progressively increased in Italy from 33% in 1960 to 47% in 2010. However, the growth rate was different at regional level (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. Sicily was the region with the largest surface land classified as ‘critical’ in 1960 (77%) that, however, remained relatively stable during the study period (Figure 5). By the contrary, Emilia Romagna was the region with the highest increase in ‘critical’ land (from 33% to 63% respectively in 1960 and 2010).

3.5 Trends in the quality indicators composing the ESAI

In Italy the largest contribution to the ESAI came from soil and vegetation quality (Table VI) that showed, on average, the highest indicator’s scores (respectively 1.53 and 1.49) compared to 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%) while the MQI decreased weakly (-1.1%) indicating a

general improvement in land management. At regional level, climate quality decreased more in central Italy (-7.5%) and in northern Italy (-6.1%) than in southern Italy, while vegetation quality decreased more in northern Italy (-4.7%) than elsewhere in Italy. Interestingly, land management quality improved more in southern Italy (2%) than in northern and central Italy.

4. DISCUSSION

In the Mediterranean basin, it was largely demonstrated that the increasing level of land sensitivity to degradation was associated to long-term ecological dynamics (e.g. climate aridity, soil deterioration, erosion, salinity, and land cover changes) together with socioeconomic, cultural, and institutional factors that increases the anthropogenic pressure and triggers landscape transformations. These conditions may be exalted by unsustainable land management in rural areas (e.g. Moonen et al., 2002; Incerti et al., 2007; Salvati and Zitti, 2008). This study verifies how the geographical distribution of land sensitivity has been drastically changed in Italy during the last fifty years and indicates that the increase in land sensitivity observed at local scale was spatially concentrated and associated to either bio-physical and socioeconomic factors. The most visible evolution in the geography of land sensitivity in Italy was the decreasing polarization in ‘structurally vulnerable’ and ‘non-affected’ areas typically observed in the early 1960s. ‘Structurally vulnerable’ regions in Italy (i.e. southern Italy and the two main islands) have been traditionally identified as LD hot-spot (e.g. in the UNCCD Annex IV). The sensitivity degree in this region maintained stable or partly improved due to the locally increasing climate quality, specific land-use changes mitigating LD (e.g. natural forestation), a relatively low anthropogenic pressure, and a more sustainable land management. By the contrary, the sensitivity level of ‘non-affected’ areas (mainly concentrated in northern and central Italy) increased significantly during the investigated time period suggesting that important changes have occurred in the climatic regime and the socioeconomic characters of this region. Climate quality was probably the mostly varying factor in the last twenty years, as this work and several other studies document (Salvati et al. 2009). In northern Italy, both decreasing rainfall and increasing temperature regimes contributed to determine aridity conditions comparable to that observed in some areas of southern Italy. These climate variations have been also reflected in prolonged (and more severe) drought episodes and the lower water availability in the soil. From the socioeconomic perspective, one of the most significant change observed in that area was the urbanization-driven landscape transformation of flat areas in the Po valley determining 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 locally observed in that region. As demonstrated in this study, the probability that flat land in northern Italy underwent degradation is higher now than in past. This indicates the need of more effective mitigation policies specifically facing with

economically-developed regions like northern Italy. According to Briassoulis (2011), measures against LD in Europe should overcome the sectoral perspective to achieve a multi-target and multi-scale approach. This is especially relevant as far as specific LD processes, which are active at local scale, are concerned. At national level, while the between-region disparities in the level of sensitivity decreased during the last fifty years, the within-region variability increased markedly. Differently from what observed in the early 1960s, this suggests a very complex spatial pattern of polarization in 'sensitive' and 'insensitive' land that is less affected by the latitude gradient than in past. This pattern depends instead from the interaction between changing climate quality at local scale with specific land-use trajectories ('agricultural intensification', 'urban sprawl', 'littoralization', 'land abandonment') affecting also land management conditions. Increasing territorial disparities in the level of land sensitivity to degradation was evident especially where the long-term linkages among biodiversity, social factors, and the traditional economic activities strongly characterizes the landscape as observed in developed Mediterranean areas (King et al., 1997). The disparities observed in the present study follows a defined spatial pattern that depends on both landscape composition and transformation, the continuously changing bio-physical conditions, and the urban-rural dynamics observed in the investigated region. We provided an overview of the most significant post-war socioeconomic changes in Italy in order to correlate them to the increasing or decreasing level of land sensitivity to degradation at regional scale (Table VII). From this qualitative analysis it is clear how the synergic impact of bio-physical changes and socioeconomic pressures has determined an higher level of sensitivity in northern Italy compared to the other areas of the country. Taken together these findings emphasize the role of local-scale policies aimed at improving sustainable land management strategies (Patel et al. 2007). The 'local' dimension is crucial in any strategy undertaken at higher spatial levels and the Italian National Action Plan, together with the measures against desertification adopted in each affected region (with special focus on northern Italy land) should incorporate specific actions to face with locally-increasing sensitivity disparities. Spatially- and temporally-relevant information describing the possible impact of the socioeconomic variables on land degradation are therefore needed, together with a permanent monitoring of the most significant bio-physical variables, to inform effective strategies contrasting desertification risk at local scale. Rapidly-changing landscapes due to climate aridity, soil deterioration, and land-use change could especially benefit from those monitoring strategies.

In conclusion, the exercise proposed in this paper provides an original contribution to the study of natural- and anthropogenic-derived changes in desertification sensitivity in a developed nation. Further efforts are needed to move towards cross-regional comparisons and to integrate environmental research with socioeconomic issues with the aim of informing strategies for the thorough conservation of land quality, landscape complexity, and ecosystem stability in the framework of National Action Plans against desertification.

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Table 1. Variables used in ESAI, units of measure and statistical sources.

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
	Erosion protection	1:100,000	Sensitivity class	Corine Land Cover
	Drought resistance	1:100,000	Sensitivity class	Corine Land Cover
	Vegetation cover	1:100,000	Sensitivity class	Corine Land Cover
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

Table 2. A summary of the used variables in the ESAI framework by time period.

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

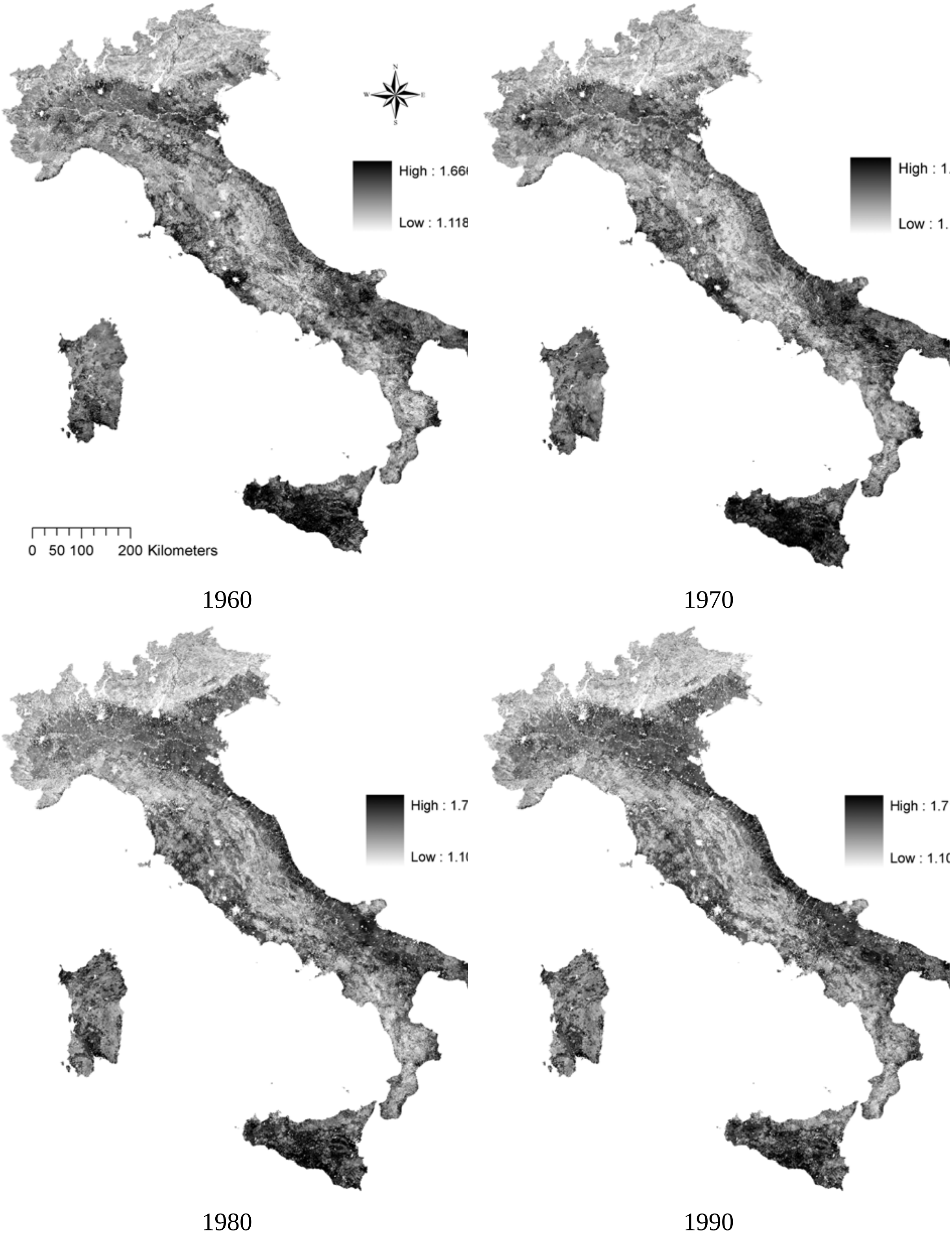
Table II. Average ESAI in Italy by geographical region and year.

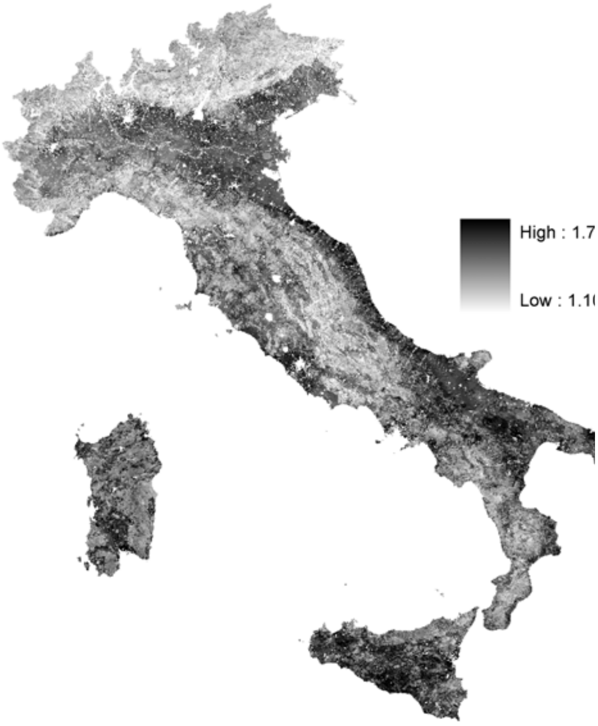
Year	North	Centre	South	Italy	South/North	South/Centre
1960	1.317	1.328	1.374	1.342	4.3	3.4
1970	1.336	1.344	1.407	1.367	5.4	4.7
1980	1.326	1.355	1.399	1.362	5.5	3.2
1990	1.327	1.342	1.388	1.355	4.7	3.5
2000	1.329	1.345	1.400	1.362	5.3	4.0
2005	1.342	1.355	1.397	1.367	4.1	3.1
2010	1.347	1.355	1.382	1.363	2.6	2.0
		(2010-1960)%				
Average ESAI	2.3	2.0	0.6	1.5	-38.6	-41.4
Maximum ESAI	1.7	1.2	2.4	1.9	-	-
ESAI coefficient of variation	1.6	1.4	0.7	1.2	-	-

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

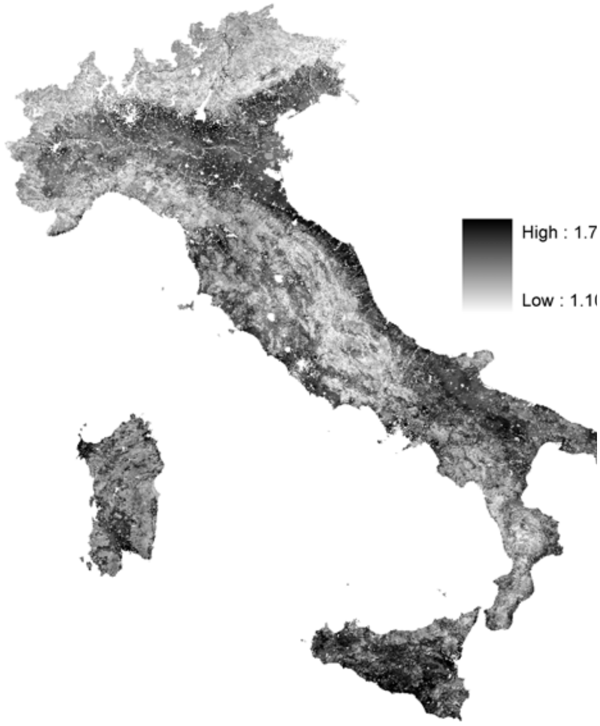
Elevation	1960	1990	2010	%
Mountains (M)	1.304	1.297	1.305	0.002
Hilly areas	1.354	1.373	1.378	0.036
Flat areas (F)	1.375	1.411	1.424	0.072
F/M ratio (%)	5.4	8.8	9.1	-

Figure 1. The average ESAI observed in Italy by year (1960-2010).

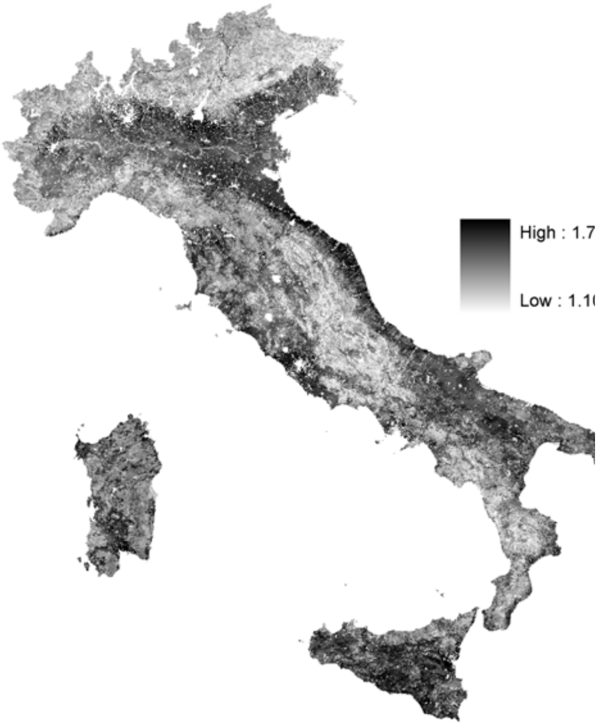




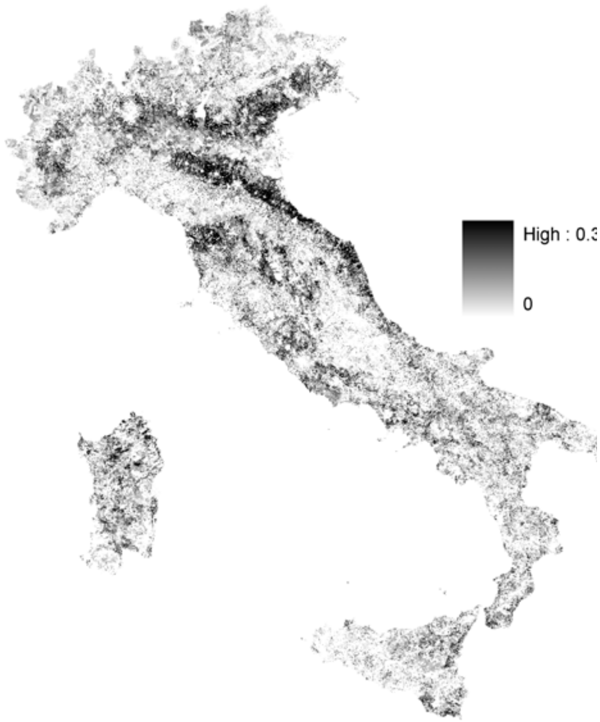
2000



2005



2010



(1960-2010)

Table IV. 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	1.434(1)	1.427(2)	1.431(1)	0.00
Apulia	1.391(2)	1.428(1)	1.404(2)	0.02
Basilicata	1.370(3)	1.384(4)	1.383(5)	0.02
Sardinia	1.367(4)	1.377(5)	1.387(4)	0.03
Molise	1.359(5)	1.384(3)	1.361(6)	0.00
Emilia-Romagna	1.345(6)	1.370(6)	1.390(3)	0.07
Abruzzo	1.338(7)	1.360(9)	1.325(15)	-0.02
Latium	1.338(8)	1.351(10)	1.357(12)	0.03
Campania	1.338(9)	1.361(8)	1.360(11)	0.03
Marche	1.332(10)	1.365(7)	1.369(8)	0.06
Tuscany	1.331(11)	1.338(14)	1.361(10)	0.05
Lombardia	1.326(12)	1.340(13)	1.369(7)	0.07
Calabria	1.326(13)	1.342(12)	1.334(13)	0.01
Veneto	1.321(14)	1.347(11)	1.367(9)	0.07
Piedmont	1.315(15)	1.319(15)	1.331(14)	0.03
Liguria	1.314(16)	1.300(17)	1.313(17)	0.00
Umbria	1.296(17)	1.309(16)	1.318(16)	0.03
Friuli Venezia Giulia	1.294(18)	1.296(18)	1.304(18)	0.01
Aosta Valley	1.289(19)	1.270(19)	1.301(19)	0.02
Trentino Alto Adige	1.273(20)	1.262(20)	1.291(20)	0.03

Figure 2. Trends in the ESAI in Italy (left: average score; right: coefficient of variation) by geographical region from 1960 to 2010.

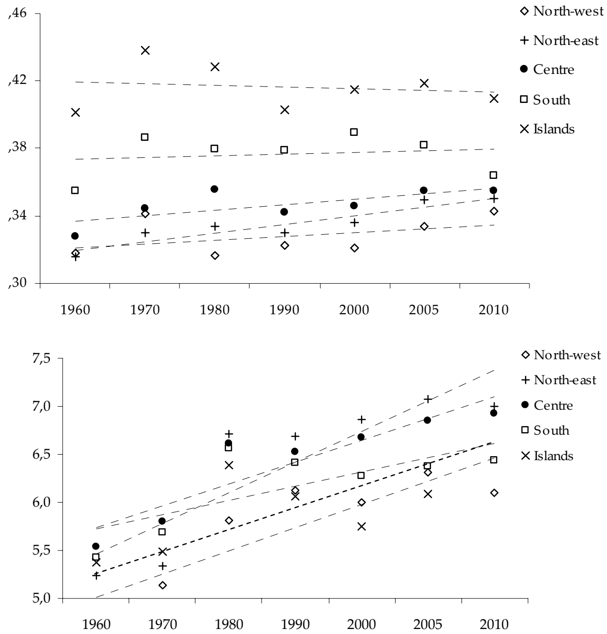


Figure 3. The relationship between the average ESAI (x-axis) and its coefficient of variation (y-axis) by year and geographical area in Italy from 1960 to 2010.

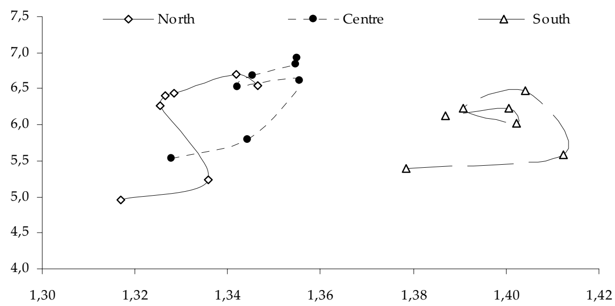


Figure 4. Correlation between the average ESAI observed in the twenty Italian regions and its coefficient of variation at three selected years (trend lines refer to 1960 and 1990 since 2010 correlation was not significant).

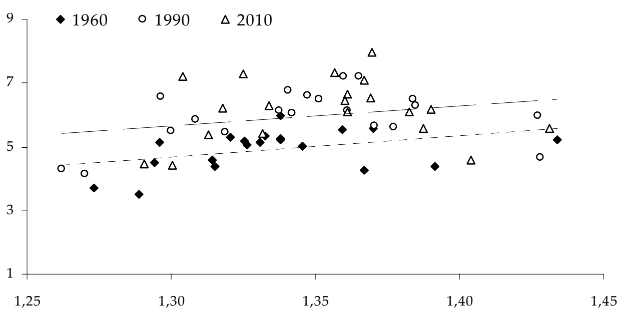
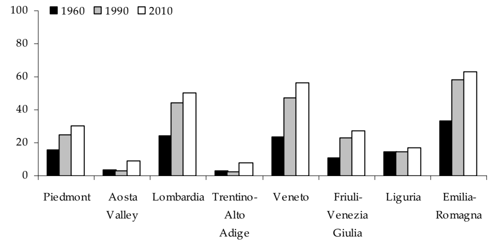
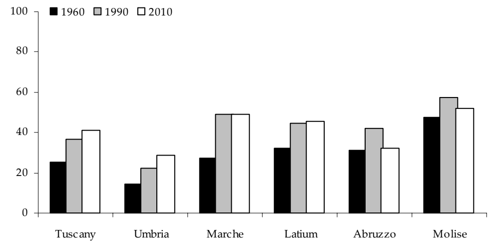


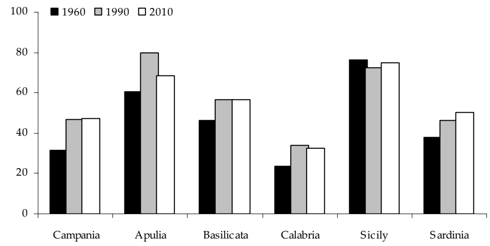
Figure 5. Trends in the ‘critical’ land surface in Italy by region and selected years.



Northern Italy



Central Italy



Southern Italy

Table V. The percent surface of Italian land classified as 'critical' on 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
(1960-2010)%	*20.1*	*15.9*	*6.8*	*13.9*	-	-

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

Region	1960	1990	2010	% change
	Climate			
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			
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			
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			
North		1.517		-
Centre		1.525		-
South		1.553		-

Table VII. A summary of the main socioeconomic facts observed after the second world war in Italy by geographical region.

Region	1950		→		2010
North	Population growth and industrialization around the big cities in north-west areas	Agricultural intensification and irrigation spreading along the Po valley	Tourism development along the Adriatic coast	Polycentric Development And industrial diffusion	Urban sprawl with population decline in the north-east areas
Centre	Population decline and land abandonment in upland and mountain areas	Important land-use changes especially observed in peri-urban areas		Increasing population disparities between urban and rural areas	
South	Population decline and land abandonment in marginal, mountain areas	Internal migration to northern Italy	Urban growth without industrial development	Increasing tourism pressure along coastal zones	Population decline and rural marginalization