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A Diachronic Classification of Peri-urban Forest Land Based on Vulnerability to Desertification

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ABSTRACT: Land vulnerable to desertification increased in the Mediterranean basin since World War II due to several interacting factors including climate variations, land-use changes and growing human pressure. It was hypothesized that the increase in the level of land vulnerability is not distributed homogeneously over time and space while impacting preferentially landscapes surrounding large urban agglomerations. This hypothesis was tested diachronically (1960-2010) in the peri-urban area of Rome (Central Italy) to clarify how different factors causing land vulnerability to desertification impact a fragile landscape close to the city with one of the largest coastal forest in Italy. Four partial indicators (climate quality, soil quality, vegetation quality, land management quality) developed within the Environmentally Sensitive Area (ESA) framework and measuring the level of land vulnerability have been calculated at a detailed spatial scale. The highest growth rate in land vulnerability has been observed in cropland while coastal woodlands showed a relatively high and stable land quality over time. Conservation strategies of relict forest ecosystems considered as 'buffer zones' contrasting land degradation processes are particularly important in Mediterranean peri-urban regions.

Key words: Mediterranean region, Environmental indicators, Land vulnerability, Trends, Rome

INTRODUCTION

Population and economic growth in Southern Europe increased rapidly over the last fifty years impacting both natural landscapes (e.g. forests, shrublands, pastures) and agricultural-specialized areas. The environmental divide between peri-urban and rural areas is becoming wider than in the past (Feoli *et al.*, 2003). Human abuse or misuse of land, which in turn generates territorial unbalances, is supposed to be an important cause of natural resource deterioration (Gisladottir and Stocking, 2005) especially in natural landscapes (Thornes, 2004). Environmental degradation processes depending on the synergic impact of biophysical and socioeconomic variables (Herrmann and Hutchinson, 2005) show complex and hardly predictable dynamics that require original frameworks and interpretative models (Ibanez *et al.*, 2008).

Land Degradation (LD) in the Mediterranean region is an example of the dynamic interaction between the ecological sphere and the socioeconomic system (Montanarella, 2007). Quantitative and narrative approaches have been proposed to classify land according to the level of vulnerability to desertification (Salvati and Zitti, 2008), with special regards to Italy (Salvati and Bajocco, 2011). The Environmental Sensitive Area (ESA) methodology developed in the framework of the EU-funded MEDALUS project, includes a number of input variables and generates various thematic indicators. Due to its simplicity the ESA approach has been largely applied in the Mediterranean socioeconomic context (Basso *et al.*, 2000). Lavado Contador et al. (2009) and Ferrara et al. (2012) provided evidence that the ESA is an effective monitoring system of the level of land vulnerability to degradation at the local scale, showing capability to identify areas potentially affected by LD and to inform mitigation policies against desertification (Basso *et al.*, 2012).

Unfortunately, few studies have been devoted to the multi-temporal classification of vulnerable land in the Mediterranean landscape. Salvati et al. (2012) hypothesized that the increase in the level of land vulnerability in the Mediterranean region was not distributed homogeneously over time and space while impacting preferentially natural landscapes with special regards to regions around the main urban agglomerations. In the present paper, this hypothesis was tested explicitly during a relatively long time-period (1960-2010) in the peri-urban region of Rome (Central Italy). To clarify the importance of factors causing land vulnerability to desertification in a fragile landscape encompassing one of the largest coastal forests in Italy (Salvati and Zitti, 2012), four partial

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indicators (climate quality, soil quality, vegetation quality and land management quality) derived from the standard Environmentally Sensitive Area (ESA) framework and measuring the level of land vulnerability have been compared over different land-use classes. Results inform conservation strategies of relict woodland ecosystems considered as 'buffer zones' and contributing to the containment of land degradation processes in large peri-urban regions (Barbero Sierra *et al.*, 2013).

MATERIALS & METHODS

Rome metropolitan area, one of the largest urban regions in Southern Europe, was considered in this paper as the study site. The investigated area encompasses the boundaries of the municipalities of Rome, Fiumicino and Pomezia (1,600 km^2). The region is characterized by a relatively flat topography and urban settlements actually occupy an important part of the region (Salvati *et al.*, 2012). Despite degraded by summer fires and the high human pressure, the original forest vegetation (i.e. the wood composed of various *Quercus* species) typical of dry Mediterranean landscapes was preserved in the high-quality and biodiversity-rich coastal woodlands of Castelporziano, Castelfusano and Ostia. The climate is typically Mediterranean, with rainfalls concentrated in autumn and spring and mild temperature in winter. The average long-term (1961-1990) annual rainfall and mean daily temperature in Rome were 700 mm and 16°C respectively, with a decrease in rainfall and growing temperatures observed in the most recent years (Salvati *et al.*, 2012).

According to the ESA framework (Basso *et al.*, 2000), the variables selected to classify land in different classes of vulnerability to desertification refer to four themes: climate, soil, vegetation/land-use, and human pressure (Table 1). The indicators selected in this study match a number of requirements including the availability and regularity of time series and the quality and reliability of data sources. The average annual rainfall rate (RAIN), the aridity index (defined as the ratio between rainfall and reference evapotranspiration, both measured as a ten-years average: ARID), and slope aspect (SASP) have been used in this study to assess the level of land vulnerability based on a climate quality indicator (CQI) classifying climate regimes in arid, dry or humid according to the ESA scheme (Lavado Contador *et al.*, 2009). The CQI was formulated as the geometric mean of the three selected variables:

$$CQI = (RAIN*ARID*SASP)^{1/3}$$

These variables have been derived from basic information available in the Agro-meteorological Database of the Italian Ministry of Agriculture. The database relates to meteorological data collected from about 3000 weather stations since 1951 and covering the whole national territory (Venezian Scarascia *et al.*, 2006), supplemented by additional information provided by Salvati et al. (2012). The reference evapotranspiration rate was calculated by using the Penman-Monteith formula (Incerti *et al.*, 2007). To ensure the homogeneous and complete territorial coverage, the meteorological data were spatially interpolated through kriging/co-kriging procedures (with elevation, latitude, and distance to the sea as ancillary variables) with daily data of temperature, precipitation, humidity, solar radiation and wind (Salvati *et al.*, 2008). Four analysis periods were selected: 1951-1960, 1981-1990, 1991-2000 and 2001-2010.

Table 1. Descriptive statistics of the ESAI in the investigated area by selected year and local municipality (*n* indicates the number of observations: see 'methods' paragraph for further details)

	ESAI						Partial indicators			
Year	n	Average	CV	Min	Max	Range	CQI	VQI	MQI	SQI
Rome										
1960	1151	1.47	4.21	1.25	1.63	0.38	1.10	1.63	1.80	1.47
1990	889	1.45	3.54	1.25	1.56	0.31	1.16	1.69	1.56	
2000	874	1.48	3.61	1.28	1.61	0.33	1.21	1.69	1.64	
2010	870	1.49	3.74	1.26	1.65	0.38	1.20	1.56	1.72	
Fiumicino										
1960	212	1.47	3.69	1.35	1.57	0.23	1.12	1.56	1.83	1.46
1990	184	1.46	2.62	1.27	1.54	0.27	1.18	1.72	1.54	
2000	182	1.49	2.62	1.29	1.60	0.31	1.25	1.72	1.57	
2010	175	1.50	2.66	1.31	1.59	0.28	1.25	1.58	1.63	
Pomezia										
1960	87	1.38	3.76	1.28	1.45	0.18	1.13	1.61	1.42	1.41
1990	71	1.46	2.32	1.35	1.53	0.17	1.19	1.74	1.59	
2000	70	1.47	2.35	1.36	1.54	0.18	1.26	1.74	1.53	
2010	66	1.51	2.54	1.39	1.60	0.20	1.23	1.61	1.80	

Soil data were obtained from the soil quality map produced in the framework of DISMED project covering the whole national territory (Brandt, 2005) and derived from the European Soil Database at a 1 km^2 pixel resolution (Joint Research Center, JRC). 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, 2008), thematic cartographies (Ecopedological and Geological maps of Italy, respectively obtained from JRC and the Italian Geological Service, as well as Land System maps produced by the National Centre of Pedological Cartography), and additional sources at the local scale have been used as ancillary information.According to the standard ESA model, variables including soil texture (TEXT), depth (DEPT), slope (SLOP), and parent material (PMAT), regarded as *proxies* for soil structure, have been selected. As concern the pedological data, this issue introduces the problem of temporal variability of soil in a territory. Soil fundamental characteristics like texture, depth, parent material and slope are determined by the joint action of ‘pedogenesis factors’ that are macroclimate, organisms, morphology, and time (Kosmas *et al.*, 2000a; 2000b). In our case study, considering the examined time span, these variables can be regarded as static, as they change slowly or rarely and by their nature are infrequently measured or mapped (Salvati and Zitti, 2011). According to the ESA framework, a partial indicator of soil quality (SQI) has been obtained by extracting the geometric mean of the four selected variables:

$$SQI = (TEXT*DEPT*SLOP*PMAT)^{1/4}$$

The possible impact of land-use changes on LD was assessed through four standard ESA variables (Basso *et al.,* 2000): (i) fire risk (FIRI), (ii) vegetation protection from soil erosion (VEGP), (iii) drought resistance of vegetation (DRRE), and (iv) plant cover (PLAC). Such indicators were obtained from the Corine Land Cover cartography produced by the Italian Institute of Environmental Research and Protection (Ispra) at 1990, 2000, and 2006 and the Corine-like Land-use map produced in 1960 by Touring Club Italiano. Ancillary land cover cartography exploring the local scale (i.e. the topographic map provided by Italian Istituto Geografico Militare produced during 1949-1962 and the land cover map developed by the Cartographical Service of Regione Lazio in 1999) has been used as an internal check for evaluating the quality of the selected data sources. According to Kosmas et al. (2000a), a weight was attributed to each land-use class to obtain a classification of the investigated area based on different levels of vulnerability to desertification shown by vegetation (Salvati and Zitti, 2012). According to the ESA framework, an indicator of vegetation quality (VQI) has been obtained by calculating the geometric mean of the four selected variables:

$$VQI = (FIRI*VEGP*DRRE*PLAC)^{1/4}$$

Finally, anthropogenic pressures possibly triggering LD processes have been assessed as the result of demographic and land-use intensification processes (Otto *et al.*, 2007). Taken as an indicator of human pressure on the landscape, population density (PDEN) was measured at the municipal scale in 1961, 1991, 2001 and 2011 on the basis of the National Censuses of Population and Households. The annual rate of population growth (PGRO) was measured at the same spatial scale during the four time periods (1951-1961, 1981-1991, 1991-2001 and 2001-2011) using the same data source. Finally, an indicator of land-use intensity (LINT) was obtained by applying a weighting system (ranging from 1 to 2 and derived from Salvati and Zitti, 2012) that classifies the observed land-use classes according to their intensity of use and potential level of vulnerability to LD. This indicator was obtained from elaboration on the four maps previously cited. According to the ESA framework, a partial indicator of land management quality (MQI) has been obtained by extracting the geometric mean of the three selected variables:

$$MQI = (PDEN*PGRO*LINT)^{1/3}$$

Severe forms of LD generally result from a combination of inadequate land management together with a particular set of environmental factors, especially soil, climate and vegetation (Lavado Contador *et al.*, 2009). A quantification of the different levels of land vulnerability can be performed by evaluating the influence that single variables have on the phenomenon under investigation (Simeonakis *et al.*, 2007). A score system was then applied, based on the estimated degree of correlation between the selected variables and LD processes. The weighting system introduced by Salvati and Zitti (2008) was adopted in the present study. This system followed the standard benchmarking introduced by Kosmas et al. (2000a, 2000b), Basso et al. (2000), Madrau and Zucca (2008), Salvati and Zitti (2012), with additional information taken from Salvati and Zitti (2008). A composite index quantifying the degree of land vulnerability to desertification (ESAI) has been estimated in each *i*-th spatial unit and *j*-th year as the geometric mean of the different scores for each partial indicator 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 level of vulnerability) to 2 (the highest level of vulnerability). According to the obtained ESAI values, four classes of land vulnerability have been identified that reflect the most used classification thresholds (Salvati and Zitti 2008): (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). Intermediate and final maps have been produced after the various layers were rasterized, registered and referenced to the elementary 1 km^2 spatial unit. The minimum spatial unit has been selected according to Basso et al. (2000) and is adequate to purposes of a diachronic analysis dealing with environmental processes and to the spatial resolution of the cartographical data used in the present study. Following the analytical procedure illustrated above, an average ESAI score was estimated at four different points in time (1960, 1990, 2000 and 2010) in the three municipalities belonging to the investigated area (Rome, Fiumicino and Pomezia).The three municipalities show different environmental and human pressure conditions in the peri-urban region of Rome. Average ESAI scores have been calculated in each spatial unit on the basis of the 'zonal statistics' tool provided with the ArcGIS package (ESRI Inc, Redwoods, USA): this procedure computes a surface-weighted average of the ESAI values belonging to that spatial unit. An average score for the four partial indicators considered in this study and measured in each of the four selected years was also calculated. Strictly urban areas were excluded from the analysis.

RESULTS & DISCUSSION

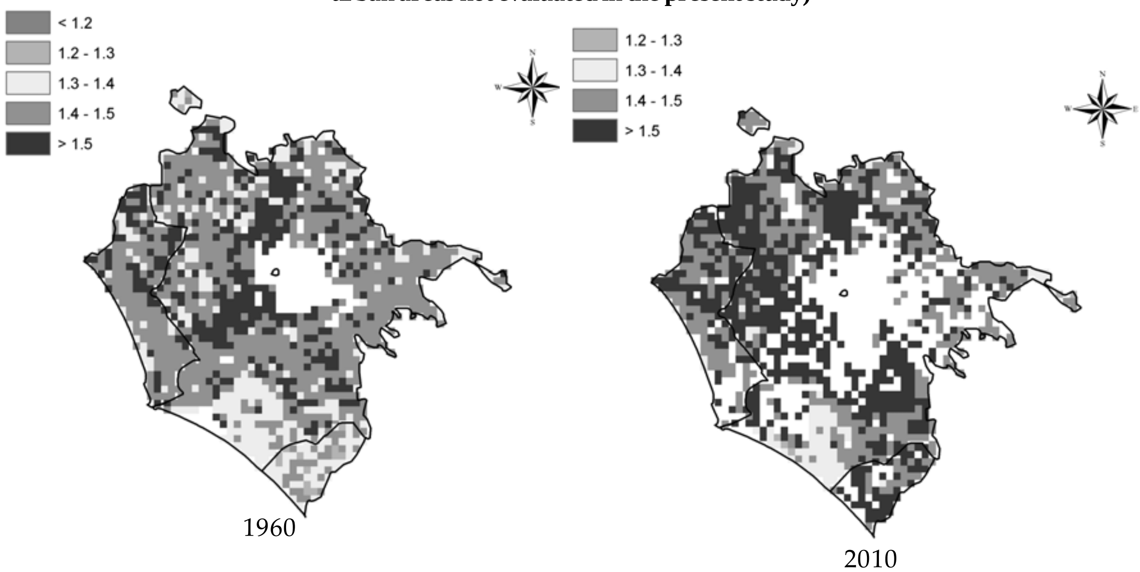
Descriptive statistics of the ESAI have been reported in Table 1 by selected year and municipality. On average, ESAI scores increased in the three municipalities over the whole investigated period. However, the increase was more evident in the peri-urban municipalities of Pomezia and Fiumicino than in Rome with a parallel decrease in the coefficient of variation indicating convergence processes in the level of land vulnerability at the local scale. The highest ESAI score was recorded in Rome (1.65) in 2010. While the MQI and VQI contributed the most to the ESAI (possibly indicating the growing impact of the socioeconomic drivers), soil and climate quality resulted, on average, less important in shaping the vulnerability profile of the investigated land. However, CQI showed the highest growth rate in all examined municipalities possibly indicating the importance of climate variations in the study area.

According to Fig. 1, vulnerable lands concentrate in the area west to Rome and increase over time especially during the last decades. Interestingly, the lowest scores of the ESAI have been recorded in the coastal forest environment. To assess the (increasing) spatial divergence in the degree of land vulnerability observed in Rome, the average ESAI observed in the agricultural areas and in the coastal woodlands around Rome was compared in four points in time (Fig. 2). The analysis shows contrasting trends in the average ESAI with a moderate increase observed over the last fifty years in coastal woodlands and a marked increase in peri-urban cropland. The statistical distribution of the ESAI scores in the four analyzed periods differs significantly in the two examined land-use classes (Mann Whitney U test, $p < 0.01$).

Different environmental indicators obtained from a number of data sources have been combined to quantify the level of land vulnerability to desertification at vastly different geographical scales (Kosmas *et al.*, 2000a). In the present study more than ten variables have been considered at four points in time between 1960 and 2010 with the aim of classifying land on the basis of the intrinsic level of vulnerability and its trend over time. Results identified areas where the level of vulnerability is increasing (or decreasing), indicating as well the factors involved in this process (Basso *et al.*, 2000). Interestingly, a continuous growth in the surface area of land classified as highly vulnerable to desertification was observed in the investigated municipalities during the examined period. The analysis of four partial indicators (climate quality, soil quality, vegetation quality, land management quality) also suggests the existence of important correlations among the considered variables (Salvati and Zitti, 2008).The peri-urban region around Rome resulted as fragile especially in the last time period (from 2000 to 2010) due to the increase in climate aridity and the huge human impact on landscape primarily due to urban expansion in the form of dispersed residential settlements causing land fragmentation (Salvati and Zitti, 2012; Salvati *et al.*, 2012). This is particularly true in the rapidly expanding peri-urban municipalities of Fiumicino and Pomezia compared to the central municipality of Rome. The observed trends in land vulnerability suggest that substantial mitigation policies should be undertaken in the region. However, environmental conditions diverged at the local scale, with a local municipality experiencing a marked increase in land vulnerability over the whole investigated time period and the remaining two municipalities showing moderate increases only during the last decade.

Although differentiated in time and space, the contribution of the four partial indicators to the composite index of land vulnerability is relatively similar in the three examined municipalities, with the largest contribution attributed to the MQI. This indicator testifies the high (and possibly increasing) human pressure observed in the area due to urbanization and settlement sprawl fragmenting the peri-urban landscape. On the contrary, CQI shows the lowest contribution to the level of land vulnerability in the area. However, the indicator shows the highest

Fig. 1. Trends in the average ESAI score in Rome metropolitan area by year (white pixels indicate strictly urban areas not evaluated in the present study)



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rate of growth especially in the last two decades suggesting the importance of climate variations and aridity observed in Central Italy (Moonen *et al.*, 2002; Venezian Scarascia *et al.*, 2006; Salvati *et al.*, 2008).

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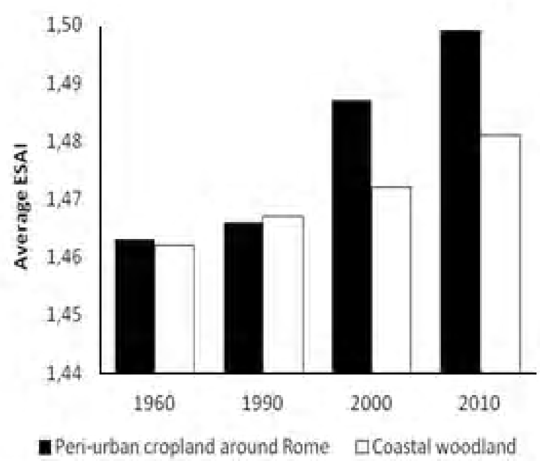

Fig. 2. Trends in the average ESAI (1960-2010) in the investigated area by selected year and land-use

Fiumicino and Pomezia compared to the central municipality of Rome. The observed trends in land vulnerability suggest that substantial mitigation policies should be undertaken in the region. However, environmental conditions diverged at the local scale, with a local municipality experiencing a marked increase in land vulnerability over the whole investigated time period and the remaining two municipalities showing moderate increases only during the last decade.Although differentiated in time and space, the contribution of the four partial indicators to the composite index of land vulnerability is relatively similar in the three examined municipalities, with the largest contribution attributed to the MQI. This indicator testifies the high (and possibly increasing) human pressure observed in the area due to urbanization and settlement sprawl fragmenting the peri-urban landscape. On the contrary, CQI shows the lowest contribution to the level of land vulnerability in the area. However, the indicator shows the highest rate of growth especially in the last two decades suggesting the importance of climate variations and aridity observed in Central Italy (Moonen *et al.*, 2002; Venezian Scarascia *et al.*, 2006; Salvati *et al.*, 2008).

CONCLUSION

In the study area the highest rate of growth in the level of land vulnerability was found concentrated in cropland while the coastal woodland ecosystem maintained a relatively high land quality over time. Based on these results, conservation strategies of relict forest ecosystems considered as 'buffer zones' for containing land degradation processes (Madrau and Zucca, 2008) are particularly important when developing multi-scale policies aimed at mitigating desertification risk in large peri-urban regions.

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