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COASTAL FOREST ECOSYSTEM NEAR ROME

Coastal vs inland sensitivity to desertification: a diachronic analysis of biophysical and socioeconomic factors in Latium, Italy

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Abstract The present study assesses the spatial distribution of a composite index of land sensitivity to desertification (called ISD) in the coastal area of Rome, including natural areas such as Castelporziano forest, compared with inland areas of Latium region, central Italy. Based on two partial indicators integrating 10 elementary variables (five biophysical attributes investigating climate, soil and vegetation, and five socioeconomic attributes assessing population pressure, changes in the use of land and human pressure), the ISD was calculated for two reference years (1970 and 2000) and at the municipal scale in Latium region. Results indicate a positive trend in the ISD in both coastal and inland areas with territorial disparities widening significantly over the studied period. Interestingly, coastal urban and peri-urban municipalities showed the highest growth rate in the ISD. These finding possibly reflects rising human pressure in lowland and coastal areas experiencing urbanization compared to internal hilly and mountain areas.

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1 Introduction

Most urban agglomerations in southern Europe have featured population growth and economic development in the last years (Longhi and Musolesi 2007). This process has sometimes determined the degradation of soil and water resources preserved in fringe natural areas (Portnov and Safriel 2004). Urban expansion and the consequent environmental pressure are the most dynamic drivers of desertification risk in the Mediterranean basin (Loumou et al. 2000; Iosifides and Politidis 2005; Khresat et al. 1998). Settlement expansion has become a matter of concern for regional and local planning (Verhoef and Nijkamp 2002) and needs to be considered in local strategies for sustainable development (Arrow et al. 1995; Christopoulou et al. 2007; Polyzos et al. 2008).

Land degradation is defined as a 'reduction or loss of the biological and economic productivity' resulting from land uses (mismanagement), or a combination of processes, such as soil erosion, deterioration of soil properties, and long-term loss of natural vegetation (MEA 2005). Land degradation is hence an interactive process involving multiple factors, among which climate and land use play a significant role (Puigdefabregas and Mendizabal 1998; Lambin et al. 2001; Reynolds and Stafford Smith 2002; Geist and Lambin 2004). Sensitivity to desertification in coastal, peri-urban areas and the relationship with land-use changes and urban sprawl have been studied only in defined socioeconomic contexts (Salvati and Zitti 2007). Previous studies have addressed (1) the role of land consumption, especially determining the decline of cropland,

(2) the loss of semi-natural vegetation and (3) the increased risk of soil and groundwater salinization (Loumou et al. 2000; Tanrivermis 2003; Atis 2006; Giordano and Marini 2008). However, there is certainly scope for an in-depth investigation of the underlying factors, with special regards to socioeconomic variables. Moreover, it is not clear yet in what measure a spatially unbalanced environmental pressure impacts desertification risk and which processes linked to socio-spatial structures and economic polarization have a role in shaping the geography of land sensitivity (Boyce 1994; Slottje et al. 2001; Zuindeau 2007). The present study hypothesizes that increased territorial disparities and socioeconomic polarization in high- and low-human pressure areas are reflected in a higher land sensitivity to desertification on a regional scale (Salvati and Zitti 2008). Divergences in land sensitivity could increase over time along defined geographical gradients (e.g., coastal-inland, urban–rural) due to the joint effect of climate aridity, poor soil attributes, low plant cover or vegetation degradation and increased human pressure (Montanarella 2007). As a matter of fact, it was demonstrated that climate aridity, vegetation cover and human pressure, among others, form worse environmental conditions in coastal areas than in internal, hilly and mountain areas (e.g., Garcia Latorre and Sanchez Picon 2001; Atis 2006; Salvati and Zitti 2007, 2008). Sensitivity to desertification increased due to the impact of recurrent drought, poor soil management, rising water demand owing to urban and agricultural uses, increased forest fires, urban sprawl and demographic pressure especially in coastal areas (Khresat et al. 1998; Mairota et al. 1998; Portnov and Safriel 2004). As a consequence, such dynamics may determine a spatially unbalanced natural resource distribution contributing to the unsustainable development of entire regions (Makhzoumi 1997; Tanrivermis 2003; Atis 2006; but see also Loumou et al. 2000).

We analyze empirical results collected for two reference years (1970 and 2000) with the aim to quantify changes in coastal vs inland sensitivity to desertification in the metropolitan area of Rome compared with the larger reference area of Latium region (central Italy). Changes in the level of land sensitivity were estimated as a consequence of both ecological and socioeconomic processes using 10 proxy indicators observed on a municipal scale (Salvati and Zitti 2007). The metropolitan area of Rome is considered an emblematic case for coastal municipalities in Europe (Attorre et al. 1998) preserving traditional agricultural and forest areas, including the Castelporziano forest (Recanatesi et al. 2013). Results of the exploratory data analysis carried out in the present study were analyzed to quantify the environmental disparities and describe the socioeconomic polarization observed along the coastal-inland gradient in Latium. Explorative frameworks are particularly needed since they represent the basis for more sophisticated geographical and statistical models (Huby et al. 2007). Implications for policies mitigating the negative impact of the increased human pressure on soil and landscapes are finally discussed.

2 Methodology

The study area encompasses Latium region, one of the 20 Italian administrative regions (the NUTS-2 level according to the European Nomenclature of Territorial Statistical Units). In 2000, Latium territory was administered by five NUTS-3 provinces (Viterbo, Rieti, Rome, Latina, and Frosinone) and 377 NUTS-5 municipalities in 2000 (Fig. 1). It covers an area of approximately 17,065 km^2 with different climate regimes depending on the distance from the sea and the complex topography. Climate along the coastal zone is typically Mediterranean with dry and hot summers and mild winter. Inland climate, especially on hilly areas, is more temperate with relatively constant rainfall along the year (Salvati and Zitti 2007).

The level of sensitivity to desertification was assessed through the scheme described in Basso et al. (2000). The proposed approach interpreted land sensitivity as the result of the joint impact of a number of socioeconomic and biophysical factors (Rubio and Bochet 1998; Mairota et al. 1998; Salvati et al. 2008). Although a number of indicators and assessment systems were used in the Mediterranean

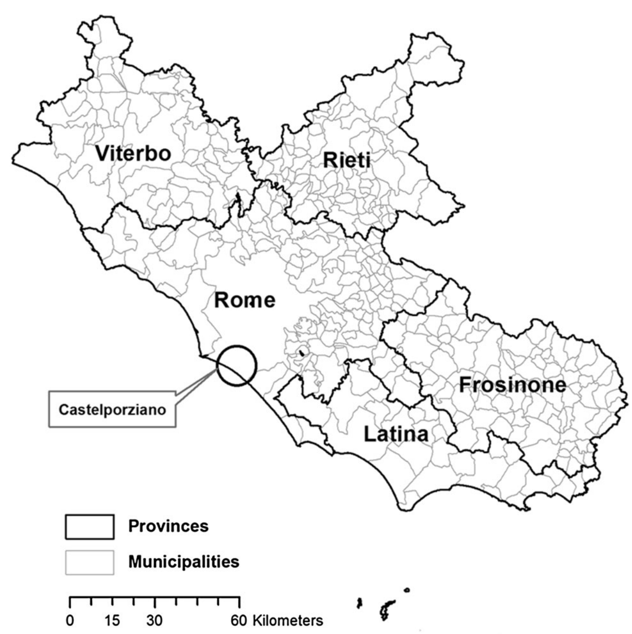

Fig. 1 A map illustrating Latium region, the five provinces and the boundaries of local municipalities (the location of Castelporziano forest within Rome's municipality is *highlighted*)

Table 1 List of variables used in the present study

Theme	Variable	Measurement unit	Relation with land sensitivity	Source
Biophysical factors	Climate aridity index	mm/mm	+	CRA
	Maximum soil water content	mm/mm	−	CRA
	Soil erosion rate	ton/ha/year	+	ISPRA
	Woodland cover	%	−	ISTAT
	Growth rate of cropland	%	−	ISTAT
Socioeconomic factors	Crop intensification	%	+	ISTAT
	Population density	inhabitants/km^2	+	ISTAT
	Population growth	%	+	ISTAT
	Industrial concentration	Equivalents	+	ISTAT
	Tourism pressure	workers/km^2	+	ISTAT

basin to monitoring sensitivity to desertification, the selected approach appears to be particularly suited for land with semi-dry climates and exposed to high anthropogenic pressure (Salvati et al. 2008). An indirect estimate of land sensitivity was set up by integrating 10 variables regarded as *proxies* of environmental and socioeconomic factors considered as candidate drivers for desertification risk. They concern climate and soil quality, land-use changes, demography and human pressure (see list in Table 1). Each variable was computed through a cardinal scale and transformed into a sensitivity indicator ranging from 0 (the lowest contribution to land sensitivity) to 1 (the highest contribution to land sensitivity) using the normalization equation (Salvati and Zitti 2007):

$$x_{\mathrm{norm}} = (x_{\mathrm{i}} - x_{\mathrm{min}})/(x_{\mathrm{max}} - x_{\mathrm{min}})$$

where x_{norm} is the value of the transformed indicator in the range 0–1, x_i is the value observed for each variable, municipality and year, x_{max} and x_{min} are, respectively, the maximum and minimum values observed for the same variable and year in the studied municipalities. This equation was applied to variables showing a documented positive relationship with land degradation based on literature (see Salvati et al. 2008 and references therein). The equation was modified in the following form for variables showing a documented negative relationship with land degradation:

$$x_{\mathrm{norm}} = 1 - (x_{\mathrm{i}} - x_{\mathrm{min}})/(x_{\mathrm{max}} - x_{\mathrm{min}})$$

A composite index (called ISD, Index of land Sensitivity to Degradation) was then calculated at the municipal level as the arithmetic mean of the 10 standardized indicators. The ISD ranges between 0 (the lowest sensitivity to desertification) and 1 (the highest sensitivity to desertification). Municipalities were grouped into different classes based on the ISD score which illustrates the increasing level of land sensitivity (Salvati and Zitti 2007): scores lower than 0.3 indicate low sensitivity, scores ranging from 0.3 to 0.5 indicate moderate sensitivity, and scores higher than 0.5 indicate a high level of land sensitivity.

The distribution of the ISD was analyzed through descriptive statistics, including average, coefficient of variation and range estimated for two reference years (1970 and 2000). According to elevation, coastal-inland gradient and urbanization degree, Latium municipalities were classified into eight homogeneous groups: (1) Rome coastal municipality (taken as baseline in the subsequent analysis and where Castelporziano forest is located); (2) four urban municipalities placed in the remaining four NUTS-3 Latium provinces (Viterbo, Latina, Rieti and Frosinone); (3) 13 and (4) 10 coastal municipalities, respectively, belonging to Rome province and the remaining four NUTS-3 provinces; (5) 69 and (6) 161 rural (100 m < mean elevation < 600 m) municipalities, respectively, belonging to Rome province and the remaining four NUTS-3 provinces; and (7) 36 and (8) 83 mountain (mean elevation > 600 m) municipalities, respectively belonging to Rome province and the remaining four NUTS-3 Latium provinces.

Municipalities were considered the elementary spatial unit in all statistical elaborations (Salvati and Zitti 2007). Regional disparities in land sensitivity to desertification were estimated in 1970 and 2000 by computing the pairwise difference between the ISD score measured in Rome municipality and those measured in the remaining municipalities of Latium classified as previously described. Distribution maps of the ISD score in all municipalities of Latium by year were produced using the ArcGIS 9.2® software based on a shapefile depicting the administrative boundaries of Italian local municipalities provided by the Italian National Institute of Statistics (Istat). A map illustrating the (2000–1970) absolute difference between the ISD score in each Latium municipality and the ISD score

Table 2 The average score of the ISD by year and groups of municipalities in Latium

	N	1970	2000	Δ (2000–1970)
Rome province				
Rome (municipality)	1	0.42	0.48	0.06
Coastal municipalities	13	0.39	0.48	0.09
Rural upland municipalities	69	0.33	0.40	0.07
Rural mountain municipalities	36	0.31	0.28	−0.03
Rome province	*119*	*0.36*	*0.41*	*0.05*
The remaining four NUTS-3 provinces of Latium				
Urban municipalities	4	0.33	0.37	0.04
Coastal municipalities	10	0.33	0.41	0.08
Rural hilly municipalities	161	0.31	0.36	0.05
Rural mountain municipalities	83	0.31	0.27	−0.04
The four provinces	*258*	*0.32*	*0.35*	*0.03*
Latium	**377**	**0.34**	**0.38**	**0.04**

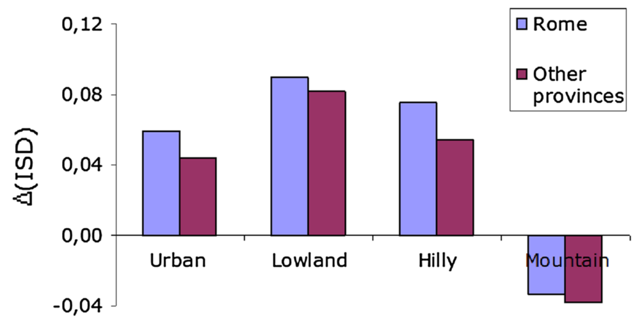

Fig. 2 Changes in land sensitivity to degradation estimated as the variation of the ISD score (2000–1970) in Latium provinces by elevation class

Table 3 Summary statistics of the ISD by year and NUTS-3 province in Latium

Year	Rome province			The other provinces		
	Mean	CV	Range	Mean	CV	Range
1970	0.33	0.142	0.266	0.31	0.113	0.236
2000	0.37	0.224	0.364	0.34	0.189	0.359

measured in Rome municipality (and taken as a baseline) was finally produced to illustrate the territorial disparities existing in the spatial distribution of land sensitivity to degradation in the study area.

3 Results and discussion

The spatial and temporal distribution of the ISD was analyzed in Latium by municipality (Table 2). In 1970, the highest ISD scores were observed in Rome (0.42) and in coastal municipalities of Rome province (0.39), decreasing slightly in mountain municipalities. On average, the ISD score was lower in the remaining provinces of Latium (0.32) with similar disparities recorded between coastal and inland municipalities. Both the ISD average and coefficient of variation increased in Latium during 1970–2000 and maintained higher in Rome and in coastal municipalities compared with the remaining municipality classes. The ISD increased more in Rome province (+0.05) than in the remaining provinces (+0.03), rising along both coastal-inland and urban–rural gradients (Fig. 2). The highest increase was observed in coastal municipalities and, at a lesser pace, in urban municipalities and in rural, hilly municipalities. Both ecological and socioeconomic factors contributed to determine this time path, with an important role played by those variables influencing the use of land and regulating the level of human pressures on the environment (Salvati and Zitti 2007). For example, in 1970 the coastal municipality of Rome showed the highest land sensitivity score, and 30 years later at least 10 coastal municipalities belonging to Rome province reached the same level of land sensitivity. Notably, this trend was found also on a larger scale: the highest disparities in the ISD were recorded in Rome province compared with the remaining Latium provinces (Table 3).

The spatial distribution of changes in the ISD observed between coastal and inland municipalities (Fig. 3) indicates the increased spatial polarization in land sensitivity to desertification. For example, in 2000 the highest differences in the ISD score with Rome municipality concentrated in economically marginal, inland mountain areas of both Rome province and the remaining four Latium provinces. Coastal municipalities showed a moderate difference with Rome as far as the ISD score is concerned. This means that a lower spatial variability in land sensitivity to degradation was observed in coastal areas during the studied period. The lowest differences were observed between municipalities belonging to the same NUTS-3 province and elevation zone (Table 4). The pair-wise differences in the ISD calculated between Rome and the remaining municipality classes reflect the geographical distance among municipalities. On average, differences in the ISD score estimated between Rome and the remaining municipalities amounted to 0.1 within the municipalities belonging to Rome province and to 0.15 within the municipalities belonging to the remaining four Latium provinces. The average difference in the ISD score increased at the regional scale from 0.11 to 0.14 during the study period.

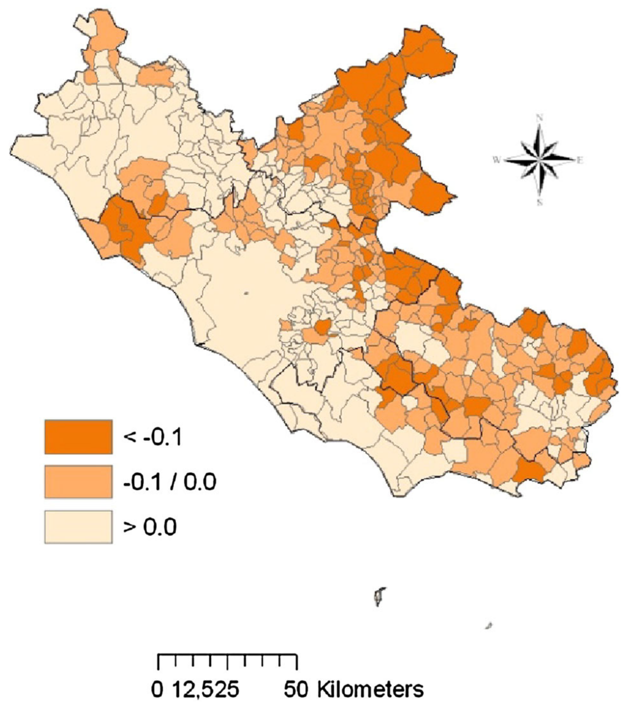

Fig. 3 A map illustrating the difference between the ISD score of each municipality and the score measured in Rome municipality taken as the baseline (each score was calculated as the difference between ISD_{2000} and ISD_{1970})

Table 4 Absolute score difference between the ISD measured in Rome municipality and those observed in the remaining municipalities of Latium by group of municipalities

	1970	2000	Δ (2000–1970)[a]
Rome province			
Coastal municipalities	0.034	0.040	0.006
Rural hilly municipalities	0.098	0.082	−0.016
Rural mountain municipalities	0.109	0.202	0.093
The remaining NUTS-3 provinces of Latium			
Urban municipalities	0.098	0.114	0.016
Coastal municipalities	0.102	0.070	−0.032
Rural hilly municipalities	0.116	0.121	0.005
Rural mountain municipalities	0.114	0.212	0.098
Latium	**0.108**	**0.136**	**0.028**

[a] Positive delta means that the ISD score gap between Rome and the tested group of municipalities is increasing (environmental sensitivity increases more in Rome than in the tested municipalities)

4 Conclusions

As observed in other Mediterranean coastal areas (e.g., Garcia Latorre and Sanchez Picon 2001; Iosifides and Politidis 2005), worse environmental conditions affecting land sensitivity to desertification were observed along the coastal-inland gradient in Latium (climate aridity, drought, vegetation cover degradation, forest fires and specific soil degradation processes including salinization, compaction and sealing, among others). Serious environmental effects of urbanization and population densification on the agricultural and semi-natural areas in Rome province, as well as around the major coastal cities of southern Europe, include (1) the consumption and degradation of soils with high agricultural potential, (2) the impoverishment of groundwater resources due to overexploitation and (3) the abandonment of land in the neighborhood of built-up areas with a consequent increase in marginal and unproductive land (Portnov and Safriel 2004). The increased fire severity and the concentration of tourism and industrial activities in coastal areas negatively contribute to environmental degradation (Loumou et al. 2000; Garcia Latorre and Sanchez Picon 2001; Iosifides and Politidis 2005). Moreover, land fragmentation driven by urbanization reduces connectivity among natural patches and represents an additional underlying factor of desertification (Khresat et al. 1998; Puigdefabregas and Mendizabal 1998; Incerti et al. 2007). The increased territorial disparities observed in the ISD confirm our hypothesis predicting worse environmental conditions which consolidate in coastal and flat areas driven by the rising anthropogenic pressure exerted on the natural habitats surrounding the main urban centers.

Environmental problems related to resource unbalance, socioeconomic polarization, and regional disparities are of outstanding interest in the Mediterranean region (Puigdefabregas and Mendizabal 1998; Tanrivermis 2003; Iosifides and Politidis 2005). Their assessment needs a comprehensive, multidisciplinary framework (Glenn et al. 1998; Herrmann and Hutchinson 2005). To this end, our study highlights the importance of integrating ecological and socioeconomic data to identify the underlying factors of changes which are responsible of territorial disparities in land resource distribution. This is particularly important in the decision-making process of coastal areas, which are particularly sensitive to climate land-use changes, soil degradation and desertification processes, and that require specific management strategies in the cases when coastal areas encompass dense urban settlements and natural land, as in the case of Rome and Castelporziano forest.

The approach illustrated here proved suitable to assess levels and trends in land sensitivity to degradation at an adequate spatial and temporal scale. Such an approach represents an effective tool to inform mitigation policies specifically designed for coastal regions (Garcia Latorre and Sanchez Picon 2001; Iosifides and Politidis 2005; Atis 2006) and aimed at mitigating the effect of land degradation in peri-urban contexts mixing urban settlements and high-quality natural areas. Quantitative methodologies require permanent monitoring of the basic environmental conditions (climate, land use, soil) at detailed spatial and temporal scales. While municipalities represent an interesting, but relatively course, assessment scale, the availability of diachronic, high-resolution environmental data covering large areas should be improved.

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