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ANALYSIS OF THE RELATIONSHIP BETWEEN LAND USE CHANGES AND LAND DEGRADATION DYNAMICS IN COASTAL SARDINIA

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1. Introduction

Land degradation affects the earth's arability, thus reducing the wealth and economic development of nations. It lowers the agricultural production and cancels out gains advanced by improved crop yield. The causes of land degradation are mainly anthropogenic and agriculture-related, and include land clearance, deforestation, depletion of soil nutrients, urban conversion, irrigation and pollution. Land degradation is affecting more than 1900 million hectares of land world-wide. The rate at which arable land is being lost is increasing and the loss of potential productivity due to soil erosion world-wide is estimated to be equivalent to some 20 million tons of grains per year (Balabanis et al., 1999).

In the developing and developed countries, the expansion of urban areas and infrastructure is encroaching on productive land and natural habitats. Resolution of land use conflicts is essential for sustainable development. Identifying the causes of land-use change requires understanding both how people make land-use decisions (decision-making processes) and how specific environmental and social factors interact to influence these decisions (decision-making context). It is also very important to understand that land use decisions are made and influenced by social and environmental factors across a wide range of spatial scales - from household level decisions that influence local land use practices to policies and economic forces that can alter land use regionally and even globally.

It has been largely studied and demonstrated (Thornes and Brandt, 1995; Thornes and Brandt, 1995; Kosmas et al., 2000; Symeonakis et al., 2007) that, during the last decades, the Mediterranean region has been subjected to major changes in Land Use and Land Cover (LULC) as a result of the relocation of people to the coastal border, forest fires, the abandonment of farms and grazing land, the rapid expansion of tourism-related activities, and the intensification of agriculture. Many studies demonstrated that LULC changes have led to an acceleration of desertification and land degradation processes (Thornes and Brandt, 1995; Drake and Vafeidis 2004; Wainwright, 2004).

The definition of desertification that we are using for the purpose of this paper is the one from the United Nations Convention to Combat Desertification (UNCCD, http://www.unccd.ch/), where "desertification" means land degradation in arid, semi-arid and dry subhumid areas resulting from various factors, including climatic variations and human activities. Overgrazing, for example, leads to trampling and compaction of the soil, which reduces the infiltration and thus increases the amount that leaves as runoff. Deforestation due to wildfires or clearcutting also leads to increased land degradation because it removes the vegetation, favouring soil erosion. The magnitude of the environmental and social consequences of soil erosion and land degradation in semiarid areas of the Mediterranean region has long been recognized and studied. Although a number of EU-funded projects, such as MEDALUS, ERMES, EFEDA, etc., have looked into the link between LULC changes and desertification (Thornes and Brandt, 1995), rarely the researchers focussed into the context of desertification as a dynamic process (Hawkes 2004).

Actually it is of basic importance to assess trends of change in various categories of land use systems and to determine levels of land degradation in these systems in order to know how land use changes leads to land degradation (Symeonakis et al., 2007). Currently there is no methodology of how to use land use change analysis to assess changes in land degradation. The work presented here is intended to contribute to this deserving need.

The main aim of this research is therefore to study the interrelationship between LULC change and land degradation over a Mediterranean coastal area using multitemporal land use cartography and land sensitivity data in a Geographic Information System (GIS) framework. Maps portraying LULC and their changes with time capture the combined effects of environmental and socio-economic policies on the territory and allow the characterization of artificialization and urban pressure, therefore being a fundamental indicator for integrated coastal zone management (ICZM) and land quality assessment over time (Freire et al., 2009). In particular, this paper focuses on the province of Oristano, a typical Mediterranean coastal zone in Sardinia (Italy), characterized by several natural and anthropogenic challenges, including lack of effective planning and management, pollution, coastal erosion, pressure from population growth and urbanization. These problems and pressures are often inter-related (CNADS, 2001), as illustrated by the distribution of the human settlements close to the shoreline being threatened by coastal erosion.

The results identified potential degradation hot-spots where mitigation measures should be taken to prevent further degradation. The readily implemented methodology, based on modest data requirements as demonstrated by this study, is a useful tool for catchment to regional scale land use change and land degradation studies and strategic planning for environmental management.

2. Study Area

The study area (**Figure 1 and 2**) covers the coastal area of the province of Oristano (Sardinia, Italy), which has a surface area of 3040 km^2 with 167,941 inhabitants. It borders on Sardinia see on the west, Sassari province on the north, Nuoro province on the east and on the Medio Campidano plain on the south. The geomorphology of the study area is very variable: Campidano plain on the south-west, mount Arci (812 m) on south-east, mount Ferru (1050 m) on north-west, and the Abbasanta plateau on the north-east. The coastal landscape consists both in sandy beaches and calcareous cliffs, and it is often characterized by ponds, sources of both animal and plant biodiversity.

In the mountain belts there are dense forests *Quercus ilex* and *Quercus pubescens*. The Mediterranean maquis is dominant along the coasts and the inner plateaus; it is mainly composed by *Olea europaea sylvestris*, *Pistacia lentiscus*, *Arbutus unedo*, *Myrtus communis* and *Cistus salvifolius*. The ponds are instead dominated by alophylous vegetation.

As concerns climate, the study area can be classified as typical "Mediterranean", with mild and wet winters, and hot and dry summers. Precipitations occur mainly during the fall and winter months, and follow both a latitudinal and orographic gradient. Winter temperatures rarely are less than 0° C, while summer temperatures can also exceed 30 °C.

Figure 1: Location of the study area (indicated by the arrow).

Figure 2: Coastal landscape of the Oristano Gulf.

3. Material & Methods (1)

The datasets available for the analysis were (a) historical LULC change maps, from LaCoast (LC) and CORINE Land Cover (CLC) projects (**Figure 3**), (b) a land degradation sensitivity map derived according to the Brandt et al. (2005) procedure. Each of the abovementioned datasets were resized over the area of interest.

LaCoast map

The aim of the project LaCoast (LAnd cover changes in COASTal zones) was to quantify changes of land cover and/or land use in European coastal zones especially due to human activities. It uses the Corine Land Cover database and scale (1:100,000) over coastal zones. This project is carried out by the Agricultural Information Systems Unit (AIS) of the Space Applications Institute (SAI) of the Joint Research Centre (JRC) of Ispra (Italy). It refers to the changing in LULC during the period 1975-1990.

CORINE Land Cover map

CORINE Land Cover is a digital vector map representing land use and land cover using a three-level hierarchical nomenclature with 44 classes at the third level (Bossard et al. 2000). Two of the CLC databases used in this study, CLC1990 and CLC2000, have identical technical features (Buttner et al. 2002): scale of 1:100000, minimum mapping unit (MMU) of 25 ha. The issue of MMU is more complex in the CLC-Changes database: while the smaller polygons in the database approximate 1 ha, these have to be contiguous to others in order to represent an area of change with at least 5 ha. The CLC products are the most recent and comparable data on LULC for Italy, providing a good snapshot of the landscape for both periods and allowing the characterization of changes that occurred in a time span of ten years.

Figure 3: Distribution of the change polygons of LaCoast (LC75-90) and CORINE Land Cover (CLC90-00) maps.

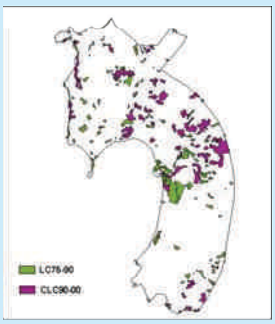

Table 1: Variables used in the ESAI.

Theme	Variable	Scale	Unit of measure
Soil quality	Soil texture	1:500,000	Sensitivity class
	Soil Depth	1:500,000	mm
	Available Water Capacity-AWC	1:500,000	mm
	Slope	1:25,000	%
Climate quality	Annual mean rainfall rate	1:500,000	mm
	Aridity index	1:500,000	mm/mm
	Aspect	1:25,000	Angle
Vegetation quality	Fire risk	1:100,000	Sensitivity class
	Erosion protection	1:100,000	Sensitivity class
	Drought resistance	1:100,000	Sensitivity class
	Plant cover	1:100,000	Sensitivity class
Land management quality	Population density	1:500,000	People km-2
	Population growth rate	1:500,000	%
	Agricultural intensity	1:100,000	Sensitivity class

Table 2: Land classification in the investigated area (modified from Motroni et al., 2004).

ESAI score	Sensitivity class	Land description (examples)
< 1.175	Not affected (NA)	Areas not threatened by LD
1.175 – 1.225	Potentially affected (PA)	Areas threatened by LD under significant climate change, if a particular combination of land use is implemented or where off-site impacts will produce severe problems elsewhere
1.225 – 1.375	Fragile (F)	Areas in which any changes in the delicate balance of natural and human activities is likely to bring about LD. As an example, the impact of predicted climate change could affect vegetation cover, intensify soil erosion, and finally shift the level of sensitivity of the area to the 'critical' class. A land use change (e.g. a shift towards cereal cultivation on sensitive soils) might produce immediate increase in runoff and soil erosion, and perhaps pesticide and fertiliser pollution down-stream
> 1.375	Critical (C)	Areas already degraded through past misuse, showing a threat to the environment of the surrounding land (e.g. badly eroded areas subjected to severe runoff and sediment loss).

Table 3: Total and percent surface of each change class (first CORINE level) related to LC75-90 and CLC90-00.

	LC75-90		CLC90-00	
Change classes	Surface (ha)	Surface (%)	Surface (ha)	Surface (%)
1-1	22,421	1.1	-	-
1-2	5,052	0.3	-	-
1-3	-	-	54,872	1.9
2-1	445,887	22.6	554,454	19.0
2-2	787,068	39.9	1814,824	62.1
2-3	75,314	3.8	387,850	13.3
3-1	251,026	12.7	36,896	1.3
3-2	75,543	3.8	-	-
3-3	308,229	15.6	71,482	2.5
Total	1970,541	100.0	2920,378	100.0

3. Material & Methods (2)

Environmentally Sensitive Areas map

According to the Environmentally Sensitive Area (ESA) framework, the variables selected in this study to build the land degradation sensitivity map refer to four themes: climate, soil, land cover, and human pressure (see **Table 1**).

Climate characteristics were described in the ESA framework by mean annual rainfall rate, aridity index (defined as the ratio between annual average rainfall rate and reference evapotranspiration), and aspect (see Basso et al. 2000). These indicators were calculated using basic information available in the National Agro-meteorological Database of the Italian Ministry of Agriculture (Salvati et al. 2008). The database relates to meteorological data collected from about 3.000 weather stations and in this work, in order to ensure a homogeneous and complete land coverage, the meteorological data were spatially interpolated through geostatistical procedures to create a grid of 544 points with daily data of temperature, precipitation, humidity, solar radiation and wind (see Salvati et al., 2008 and references therein). The two analysis periods chosen encompassed 1961-1990 and 1971-2000 (Salvati and Zitti, 2008). The average annual reference evapotranspiration was calculated using Penman-Monteith formula (Incerti et al., 2007).

Soil data were obtained from: (i) the soil quality map produced in the framework of the DISMED project (Brandt, 2005) and derived from the European soil database at a 1 km2 pixel resolution (ii) an Italian database of soil characteristics ('Carta nazionale della capacità idrica dei suoli agrari'), generated from geological and soilscape maps and over 18,000 soil samples (Salvati and Zitti, 2008), and (iii) ancillary information (Salvati et al., 2008) taken from thematic cartography (Ecopedological and Geological maps of Italy) and additional sources (Digital Elevation Models and land use maps) (Venezian Scarascia et al., 2006, Incerti et al., 2007). Variables including soil texture, depth, slope, and the available water capacity, regarded as a proxy for additional soil structure influencing factors such as organic matter and compaction, were selected. According to Basso et al. (2000) some variables can be considered as static as they change slowly or rarely and by their nature are infrequently measured or mapped. This is the case for soil quality, which was regarded as constant in the following analyses (Salvati and Zitti, 2008).

Impact of land cover on LD was assessed through four standard ESA variables, including fire risk, protection from soil erosion, drought resistance of vegetation, and plant cover (Basso et al., 2000). Such indicators were obtained from Corine Land Cover maps referring to both early-1990s and early-2000s. A weight was attributed to each land use in order to obtain a classification of the territory based on its different level of sensitivity related to vegetation and landscape characteristics (Kosmas et al., 2000).

Finally, the impact of human pressure on LD was assessed as a result of processes such as relocation of people along the coastal areas, increasing population density around the major cities, and the intensification of agriculture (e.g. Otto et al., 2007). A simple proxy representing human factors is given by population density measured at the municipality level in 1991 and 2001 by the National Census of Households (Salvati and Zitti, 2007). Moreover, a demographic variation index calculated for a time horizon of ten years (i.e. 1981-1991 and 1991-2001) was defined at the same geographical scale (Salvati and Zitti, 2005). An index of agricultural intensification was further obtained from Corine Land Cover maps in both 1990 and 2000; a weight was attributed to each land use in order to obtain a classification of the territory based on crop intensity (Salvati et al., 2007).

A score system was applied, based on the estimated degree of correlation between the various factors and LD. The standard weighting system suggested by Basso et al. (2000), Motroni et al. (2004) and Brandt (2005) was adopted with additional information taken from Salvati et al. (2007, 2008). Four partial indicators, depicting environmental quality in terms of climate (Climate Quality Index, CQI), soil (Soil Quality Index, SQI), vegetation (Vegetation Quality Index, VQI), and land management (land Management Quality Index, MQI), were estimated as the geometric mean of the different scores for each variable; the ESAI score ranges from 1 (the lowest land sensitivity to desertification) to 2 (the highest sensitivity to desertification).

Based on ESAI values (**Table 2**), it's possible to identify four classes of land sensitivity which refers to the most used classification thresholds (Basso et al., 2000; Brandt et al., 2003; Brandt, 2005). (e.g. Basso et al. 2000; Salvati et al. 2008). According to the described procedure, we derived two ESAI maps related to the land quality status of the study area during 1990 (ESAI90) and 2000 (ESAI00) with minimum pixel size of 1 km^2.

3. Material & Methods (3)

GIS and statistical analysis

In order to assess the land degradation sensitivity trend associated with the LULC changes occurred in the Oristano coastal area from 1975 to 2000, we match the ESAI maps of 1990 and 2000 with the LULC change maps of LaCoast (LC75-90) and CORINE Land Cover (CLC90-00). Since the spatial scales of the LULC and ESAI maps are very different, in order to allow a reliable comparison between them, we resampled the ESAI maps by means of ArcGis "Resample" tool and obtained a minimum pixel width comparable with the minimum LULC polygon width, i.e. 100 m^2.

We then calculated the average ESAI90 and ESAI00 values associated, respectively, to each LC and CLC polygon in order to identify which LULC change has led to different degree of land sensitivity to degradation; we excluded from further analysis the polygon associated to null ESAI pixel and to the CORINE categories 4 and 5 (wet lands and water bodies). We aggregated the LULC maps at the second CORINE level in order to easily interpret the results reducing the number of records, but still keeping the information on the landscape variability.

4. Results

A preliminary overview of the LC and CLC changed polygons shows that during 1975-1990 (**Table 3**) a larger number of polygons (52) have changed with respect to the ones in 1990-2000 (16), which, on the contrary, covered a larger surface (2,920,378 ha of CLC90-00 vs. 1,970,541 ha of LC75-90). In particular, according to the first CLC level, in both transition periods (1975-1990 and 1990-2000), the major changes interested the land conversion from agricultural to artificial areas (class 2-1), and from a type of agricultural use of the territory to another (class 2-2), mainly from non-irrigated fields to more complex cultivations (e.g. permanent crops, rice fields, heterogeneous cultivations). On the contrary, the conversion from natural and seminatural areas to artificial areas highly practiced during the 15-years from 1975 to 1990 (12.7%) has been sensibly reduced in the decade 1990-2000 (1.3%); while the LULC change from crops to shrubs and prairies strongly increased from 1975-1990 (3.8%) to 1990-2000 (13.3%), expression of a progressive land abandonment more and more rising in the last years.

We deepened the evidence gained with the previous investigation adding the information related to the land vulnerability and passing to the second CORINE level of detail. The results obtained from the analysis of the mean ESAI values for each LULC change class occurred in 1975-90 and 1990-00 (**Table 4 and 5**) showed that the most critical land use conversions are those from crops to heterogeneous agricultural lands (21-24), from permanent cultivations to crops (22-21) and heterogeneous agricultural lands (22-24), from heterogeneous agricultural lands to industrial areas (24-12), from heterogeneous agricultural lands to grasslands/shrublands (24-32), and finally from grasslands/shrublands to mines, pits and dumps (32-13).

preserving the environmental quality of the coastal areas.

Table 4: Mean ESAI values for each LULC change class of LC75-90.

LC75-90	ESAI90 LC	ESAI class
11-24	1.33	F
12-21	1.27	F
13-11	1.36	F
21-11	1.30	F
21-12	1.32	F
21-22	1.35	F
21-24	1.38	C
21-31	1.19	PA
21-32	1.26	F
21-33	1.30	F
22-11	1.28	F
22-21	1.29	F
22-24	1.28	F
24-11	1.37	F
24-12	1.39	C
24-21	1.34	F
24-22	1.29	F
24-32	1.43	C
31-21	1.20	PA
32-11	1.35	F
32-12	1.25	F
32-13	1.41	C
32-21	1.33	F
32-33	1.27	F
33-21	1.32	F
33-32	1.32	F

Table 5: Mean ESAI values for each LULC change class of CLC90-00.

CLC90-00	ESAI00 CLC	ESAI class
13-32	1.26	F
21-11	1.30	F
21-12	1.33	F
21-24	1.37	F
21-32	1.29	F
22-11	1.24	F
22-21	1.39	C
22-24	1.38	C
24-11	1.36	F
24-13	1.32	F
24-32	1.29	F

5. Discussion

"The Changing Face of Europe's Coastal Areas" published by the European Environment Agency (EEA 2006) draws the attention to the fast increase of coastal space use, stimulated mainly by the tourist and leisure industries and representing a threat to the delicate balance of coastal ecosystems. According to this report, the population's density on coastal zones is, on average, 10% higher than inland, reaching 50% in some countries. Even more worrying is the rate of change of natural coastal areas into artificial ones, being faster than the increase of population density (Alves et al., 2007). In Italy, especially in the southern regions, these evidences are particularly marked and the consequent impact on the dry landscapes is a major concern both from an ecological and socio-economic perspective, due on one hand to the resulting loss of natural areas, reduction in biodiversity, landscape fragmentation, soil impoverishment, and on the other hand to the consequential decrease in land productivity and quality status (Salvati and Zitti, 2007).

This study, focussed on the western coastal areas of Sardinia (Italy), analysed the impact of LULC changes occurred from 1975 to 2000 over the trend of land sensitivity to degradation in the decade from 1990 to 2000. The results demonstrated that there are two main factors affecting the land vulnerability of the study area: (i) the land abandonment and (ii) the anthropic over-exploitation of the territory, which both represent the primary LULC conversions that led to an increase of the land sensitivity to degradation. The evidences emerged in this paper, providing provisional models able to foresee the land vulnerability response to changing land use scenarios, can effectively contribute to land management policies targeted to preserving the environmental quality of the coastal areas.

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