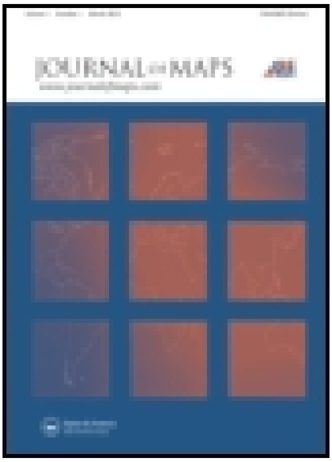

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SCIENCE

Sensitivity to desertification of a high productivity area in Southern Italy

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Calabria (Southern Italy) is one of the Italian regions most affected by desertification phenomena. This study presents a detailed analysis of the sensitivity to desertification of an economically important agricultural area in the province of Crotone. The Environmentally Sensitive Areas methodology, developed during the European Union MEDALUS project, has been applied by means of a consistent set of pedological, vegetation, climatic and management data of the study area. Analysis of 15 biophysical and social-economic indicators and an evaluation of 4 Quality Indices allowed the classification of the study area into potential, fragile and critical areas in relation to desertification. The main result is a pronounced sensitivity to desertification of the area: about 46% of the land emerges as being already affected by degradation phenomena, falling within the worst class ('critical'), while about 39% of the area belongs to the 'fragile' class.

Keywords: soil; desertification; Calabria

1. Introduction

Desertification is a dynamic, temporally distributed process, which negatively influences ecosystems, reducing the productivity of natural resources. The main causes can be identified in climate change and human activity, as stressed by the definition of desertification given by United Nations Environmental Program (UNEP, 1992): 'land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities'. This definition was adopted by the United Nations Convention to Combat Desertification (UNCCD, 1994).

Several studies have highlighted that Italy is affected by desertification mainly in some coastal areas of the southern regions (Apulia, Basilicata, Calabria), and on the main islands (Sicily and Sardinia). A number of studies have been carried out in Calabria to identify desertification-sensitive areas. Frega, Piro, and Mangiardi (2003) and Piro, Carbone, and Frega (2007) applied the Environmentally Sensitive Areas (ESAs) methodology, which was developed in the context of the European Union MEDALUS project (Kosmas, Kirkby, & Geeson, 1999) and identified areas of Calabria with the lowest quality index values (Kosmas et al., 1999). Iovino, Ferrari, Aramini, Paone, and Vasta (2005), following the methodology of the Agua

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Institute of Lisbon (Pimenta, Santos, & Rodrigues, 1997), identified the northern Ionian coast, the area of the 'Marchesato' around Crotone and the Ionian coast of the province of Reggio Calabria as the main areas vulnerable to desertification. The Environmental Protection Agency of Calabria (ARPACAL), in the context of the DESERTNET project funded by the European Regional Development Fund (FESR), through an application of the MEDALUS methodology, has produced the Chart of Areas Sensitive to Desertification of the Calabria region at 1:250,000 scale (ARPACAL, 2005). This has shown that the Ionian side of the region is more exposed to these phenomena. In particular, three extremely critical areas have been identified: the coastal and hilly strip of the upper Ionian area, from the Sibari plain to the northern border of the region; the Marchesato of Crotone; and the strip of the southern Ionian coast between Reggio Calabria and Capo Spartivento.

The aim of this study is a detailed analysis of the sensitivity to desertification of an economically important agricultural area in the province of Crotone (Calabria, southern Italy) which can be considered potentially at risk of desertification for many reasons: its geomorphologic, climatic and vegetation characteristics, the current intense agricultural activity, and the climatic trends toward aridity conditions as indicated in recent studies (Brunetti et al., 2012; Caloiero, Coscarelli, Ferrari, & Mancini, 2011; Coscarelli & Caloiero, 2012; Ferrari, Caloiero, & Coscarelli, 2013).

2. Data and methods

The study area is located in the eastern foothills of the Sila Plateau and out to the Ionian coast. It extends for about 25 km along the coast and for more than 10 km inland (municipalities of Carfizzi, Ciro, Ciro Marina, Crucoli and Melissa).

The study area was subject to intense human activity, characterized by a strong agricultural and pastoral activity: agriculture (olive growing and viticulture, in particular) and sheep farming have been the main source of employment for the population until the middle of the last century. At the end of the last century, sheep farming was largely supplanted by viticulture, as well as there was an increase in the number of areas covered by Mediterranean Maquis, and a widespread reforestation by plantations of eucalyptus.

Olive trees are principally present in the northeastern sector of the study area, while vineyards are mainly located along the coast and along the flat areas bordering a stream present in the study area (Lipuda Torrent). The arable land is mainly distributed along the western side of the study area and pastures are largely present in the southern sector of the area. The Mediterranean Maquis is present almost exclusively in the central sector of the study area and close to the inland towns. The reforestation has mainly occurred in the southern portion of the study area.

During the past century, the main inland municipalities (Ciro, Melissa, Crucoli) underwent rapid depopulation; by contrast, the coastal urban areas, such as Cirò Marina, have witnessed random urbanization. In the last years, the economy of the area has been mainly based on wine production; in fact, it is known as the wine district of Cirò D.O.C.

In order to characterize the study area sensitive to desertification, the ESAs methodology (Kosmas et al., 1999) has been applied. The ESAs methodology is the most used and its results can be easily compared to those achieved in similar studies in other areas of the world based on the same methodology. This method, because of the way the indices calculation system is computed, regardless of the number of information layers, proves to be extremely flexible since it allows the integration of any possible further indicators, also with the purpose of performing surveys with different aims and/or in more depth (Kosmas et al., 1998). As Basso et al. (2000) outline, the ESA framework allows identification of the factors that combine and accelerate land degradation in order to adequately manage the land and its resources. With this aim, cross-analysis techniques are applied to the data in the information layers even if based on different scale data. The information in these layers comes from a variety of sources, some based on preexisting themes, some based on combinations of these themes, and some created from other analyses. Each layer must be simple, robust and widely applicable, and the selection of information layers is made not only on the basis of their relationship with the phenomena under study, but also as a function of the ability to obtain and easily update the data (Symeonakis, Karathanasis, Koukoulas & Panagopoulos, 2014). For this reason, on the basis of data quality and data resolution, this method can be applied at different spatial scales (from catchment to regional scale).

In the context of the MEDALUS project, the ESAs methodology was first applied to three target areas: the island of Lesvos – Greece (Kosmas, Gerontidis, Detsis, Zafiriou, & Marathianou, 1999), the Agri basin in Basilicata – Italy (Basso et al., 1999) and the Alentejo region – Portugal (Roxo, Mourao, Rodrigues, & Casimiro, 1999).

The two-phased scheme of the ESAs methodology is shown in Figure 1. The first phase consists of the parameterization of a series of desertification indicators (information layers), grouped into four categories (Soil, Climate, Vegetation and Social-Economic factors), and in the determination of the quality indices for the considered categories (Soil Quality Index – SQI; Climate Quality Index – CQI; Vegetation Quality Index – VQI; Management Quality Index – MQI). The first three quality indices provide a representation of the environmental conditions, while the last one assesses the effects of anthropic activities on the area. The methodology is based on the classification of each quality index obtained as the geometric mean of the available environmental and anthropic parameters. The available parameters are quantified in relation to

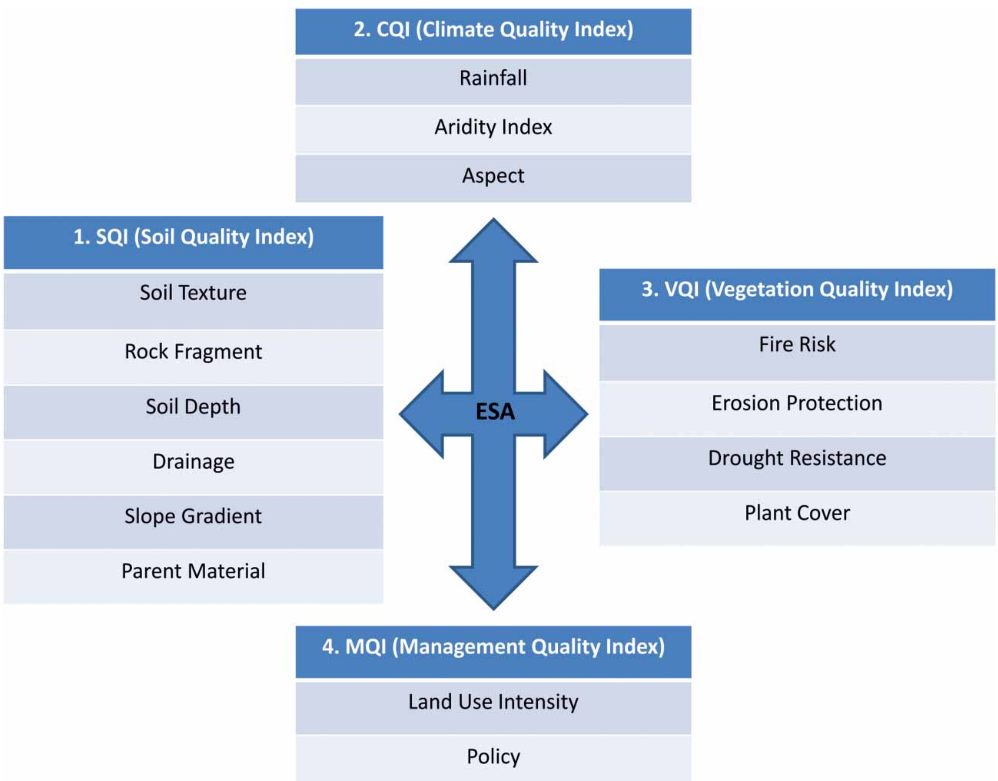

Figure 1. Revised scheme of ESAs methodology, with the change of MQI proposed by SAR (2004).

their influence on the desertification processes by assigning each a score. The desertification indicators and the score attributed to the various classes are those introduced by the European Commission (Kosmas et al., 1999). In this study, the quality indices were calculated for a 20 m × 20 m grid as the geometrical mean of the scores attributed to the single parameter belonging to each category, according to the following calculation:

$$\text{Quality Index } X_{ij} = \left(\text{layer 1 } (x)_{ij} \cdot \text{layer } 2(x)_{ij} \cdot \ldots \cdot \text{layer } n\,(x)_{ij}^{1/n}\right), \quad (1)$$

where X is the generic quality index, ij represent the 'coordinates' (lines and columns) of a single elementary unit and n is the number of information layers (parameters) used for the determination of each quality index.

The second phase consists of the calculation of the ESA Index as the geometrical mean of the Quality Indices :

$$\text{ESAI} = \left(\text{SQI} \cdot \text{CQI} \cdot \text{VQI} \cdot \text{MQI}\right)^{1/4}. \quad (2)$$

The ESAs final index indicates areas with increasing sensitivity to desertification from areas not affected by critical conditions, where land degradation is already ongoing. In particular, four classes to desertification are identified: not affected (N), potentially affected (P), fragile (F) and critical (C) (Table 1). The areas not affected by desertification (N) are characterized by land in good chemico-physical conditions where conservative agricultural practices are carried out, or where good vegetation cover is present.

The areas potentially affected by desertification (P) include those territories where profound climatic changes (e.g., prolonged periods of drought), or drastic changes in soil use leading to the application of unsustainable agricultural techniques, can cause the onset of degradation phenomena. In the fragile areas (F), in turn subdivided into three sub-classes indicating an increase in the sustainability to desertification (fragile 1 – F1, fragile 2 – F2, fragile 3 – F3), precarious equilibrium conditions between natural resources and anthropic activity (cultivation methods, deforestation, overgrazing, etc.) are present. In these areas, even minimal changes to this equilibrium are likely to cause progressive desertification of the land.

The critical areas (C), also subdivided into three sub-classes (critical 1 – C1, critical 2 – C2, critical 3 – C3), show marked degradation phenomena (accelerated erosion, soil loss, formation of surface crusts, loss of biodiversity) which affect soil productivity.

The application of the ESAs methodology needs pedological, vegetation, climatic and management data of the study area, as indicated in Table 2. In this study, the pedological data were

Table 1. Different ESAs classes with increasing sensitivity to desertification and unclassified areas.

Type	Range	Subtypes	Range
Non-affected (N)	<1.17	–	
Potential (P)	1.17–1.22	–	
Fragile (F)	1.23–1.37	F1	1.23–1.26
		F2	1.27–1.32
		F3	1.33–1.37
Critical (C)	>1.37	C1	1.38–1.41
		C2	1.42–1.53
		C3	>1.53
Unclassified			

Table 2. Data set and sources used for the indexes computation.

Type	Name of dataset	Format	Scale of resolution	Source
Soil	Soil Texture	Map	1:25,000	ARSSA, 2002
	Rock Fragment	Map	1:25,000	ARSSA, 2002
	Soil Depth	Map	1:25,000	ARSSA, 2002
	Drainage	Map	1:25,000	ARSSA, 2002
	Slope Gradient	DEM	20m × 20m	–
	Parent Material	Map	1:25,000	Burton, 1971
Climate	Rainfall	Data	–	http://www.cfd.calabria.it/
	Aridity Index	Data	–	http://www.cfd.calabria.it/
	Aspect	DEM	20m × 20m	–
Vegetation	Fire Risk	Map	1:50,000	ARSSA, 2002
	Erosion Protection	Map	1:50,000	ARSSA, 2002
	Drought Resistance	Map	1:50,000	ARSSA, 2002
	Plant Cover	Map	1:50,000	ARSSA, 2002
Management	Land-use Intensity	Map	1:50,000	ARSSA, 2002
		Data	–	Istat, 2000
	Policy	Data	–	http://www.regione.calabria.it/abr/
		Data	–	http://www.corpoforestale.it/

provided by the ARSSA-Calabria (Regional Agency for the Development and for Services in Agriculture), which conducted a survey campaign to characterize the soils and wine-growing zoning of the Cirò D.O.C. (ARSSA, 2002). On the basis of the information derived from the pedological survey, and as a result of the subsequent laboratory analyses, ARSSA classified the soils, according to the Soil Taxonomy and the World Reference Base, with 29 Pedological Cartographic Units at 1:25,000 scale. The lithological data of the study area and of the slope gradient were obtained, respectively, from the Geological Map of Calabria at 1:25,000 scale (Burton, 1971) and from a Digital Terrain Model (DTM) with 20 m cell-size. The vegetation cover and soil use data were taken from the Real Soil Use Map of the D.O.C. Cirò district (ARSSA, 2002), produced at 1:50,000 scale. The classification used follows the guidelines of the Corine European Land Cover Project. These data were used for the calculation of the VQI, which evaluates the different vegetation typologies as a function of the respective intrinsic characteristics of protection from erosion, drought resistance and fire risk, and for the calculation of the MQI, concerning the identification of the classes of land-use intensity. Hydrology data, such as precipitation and temperature, for the definition of two out three parameters necessary for the calculation of the CQI, were gathered from five rain gauges of the Italian Hydrographical Service: Crucoli, Cirò Marina, Montagna C.C., Scala Coeli and Strongoli. The aspect of the slopes, included in the calculation of the CQI, was taken directly from the DTM. As regards the MQI, and in particular the policy data, the information regarding some protection measurements was obtained from several Regional and National Authorities such as: the National Parks; the sites belonging to the Nature 2000 Project – Bioitaly, subdivided into SIC (Community Importance Sites) and ZPS (Special Protection Zones); the Hydrogeological constraints (RDL 3267/1923) and the Hydrogeological Risk (DL 180/1998). ISTAT (2000) supplied the data concerning the extent of pasture cattle, taken from the fifth Census on Agriculture.

As reported in Table 2, several sources have been employed with different format and scale resolutions. For this reason, all the data have been pre-processed in order to allow management within a Geographic Information System (GIS).

In particular, the main pre-processing operations performed on the collected data were:

(1) Conversion between different data structures (e.g., from vector to raster).
(2) Georeferencing and geometric corrections.
(3) Conversions between different projections and coordinate systems.
(4) Rotations and translations.
(5) Spatial interpolation.

After these pre-processing procedures, for each data set, a layer, in raster format, was produced. Through the use of Boolean operators within a GIS, the different layers were classified and, for each quality index, a layer, in raster format, was produced using Map Algebra. With the same procedure, using Map Algebra, the Environmentally Sensitive Areas Index (ESAI) layer was produced from the quality index layers.

3. Results and conclusions

ESAs methodology showed its versatile ability to determine and identify the most sensitive areas to desertification and the main territorial weaknesses at a local scale (Motroni, Canu, Bianco, & Loj, 2009). The analysis of 15 bio-physical and social-economic indicators and the evaluation of four Quality Indices allowed the classification of the study area into potential, fragile and critical areas in relation to desertification, through the application of the ESAs methodology. The map shows the distribution of the Quality Indices for soil, vegetation, climate and management, and of the ESAI (see Main Map in 1:60,000 scale).

The SQI and CQI maps present values that fall in the range of medium and high degree for almost all the study area. On the contrary, more than half of the area presents low quality values in terms of vegetation and management. Only the area in the northern inland sector, covered by olive and eucalyptus trees, has shown high quality values as regards management and medium quality values in terms of vegetation.

The main result is a pronounced sensitivity of the study area to desertification. In fact, 46% of the land emerged as being already affected by degradation phenomena, falling within the class 'Critical' (C) to desertification. The critical areas, divided into three sub-classes (C1, C2 and C3), are concentrated in the northwestern, central and southeastern zones. These areas are mostly made up of Miocene marly clay. Their characteristics are: slopes from slight to moderate; prevalent northerly aspect; textured soils ranging from moderately coarse to moderately fine; percentage of surface rock fragments varying from absent to high. The critical areas are primarily used for vineyards and, secondarily, for annual crops and pasture and offer a medium degree of cover and very low resistance to erosion. Moreover, in these areas, environmental protection policies are only partially applied.

The areas defined as 'Fragile' (F), subdivided into three sub-classes (F1, F2 and F3), represent 39% of the study area, mainly located in the central northern area and, partially, in the southwestern portion. These areas are mainly made up of Miocene clays and silt with sandstone intercalations, Quaternary conglomerates and sands. The soils have a prevalently good texture, ranging from medium to fine, the percentage of rock fragments varies from absent to frequent, the depth of soil is extremely variable. These areas are mainly covered by olive plantations or by Mediterranean Maquis, with low intensity use, which offers a medium–high degree of cover and good resistance to erosion. In these areas, there is a moderate application of environment protection policies.

The areas potentially affected by desertification (P) are mostly located in the central northern part, covering about 13% of the study area. This land is mainly lying over Miocene sandstones and clays, with medium–high slopes. The soils have a texture ranging from moderately coarse to medium-fine, with fragments of rock at the surface less than 20%; depth is variable from very deep to moderate. These areas are predominantly exposed to the North. The dominant vegetation is Mediterranean Maquis (50%) and olive trees (40%). These vegetation types are characterized by a sufficiently high protection against erosion and a good resistance to drought. The degree of vegetation cover is variable. These areas have a fairly low intensity of soil use with a partial application of environment protection policies.

Minimal land (about 1%) is made up of areas currently not affected (N) by desertification. These soils, developed on a Miocene sandstone parent rock, lie along the boundaries of the areas of the previous category, generally on the plain. They have a texture ranging from medium-fine to moderately coarse. Rock fragments are in some cases absent and in others abundant. The vegetation cover, more than 40%, is almost exclusively Mediterranean Maquis and, partially, new plantation of eucalyptus trees. The Mediterranean Maquis offers high protection from erosion and has a great resistance to drought. These areas are characterized by a partial application of environmental protection policies and by a low intensity of soil use.

The results show the negative influence of territory management and of vegetation quality in the sensitivity to desertification of this case study. Although the physical characteristics (soil, exposure, climate, etc.) of the area do not seem to be able to trigger soil degradation phenomena, the latter can be produced by anthropic factors such as soil overexploitation and absence of protection policies. In fact, the areas with ESAI values falling in the 'Critical' classes are those characterized by partial or incomplete application of environmental protection policies and land used intensively for vineyards and annual crops and pasture. Moreover, some of the 'Critical' areas were affected in the past by wild fires and then subject to reforestation with unsuitable plant species.

These results confirm the conclusions of Santini, Caccamo, Laurenti, Noce, and Valentini (2010), who, by applying a different procedure for desertification risk assessment to Sardinia, highlighted that the interaction between soil overexploitation and low vegetation cover predispose the territory to future degradation processes. In a large analysis involving several regions of Southern Italy, Costantini et al. (2009) also revealed that in this part of Italy the agro-environmental measures for row crops and pastures have been applied insufficiently and cover low percentages of the area potentially at risk of desertification.

Salvati and Bajocco (2011) noted that the ESA framework, even though requiring a large database with information which is not always easy to collect, does not address specific land degradation processes, but instead indicates which areas need further monitoring and attention from policy-makers and stakeholders. The application of this methodology enables users to construct scenarios of desertification on the basis of current land use and also to simulate changes that could be brought about by enacting different land management policies. For instance, the application of good practices in the case study presented here can reduce both the sensitivity to desertification of fragile areas and the risk of complete desertification of critical areas. For these reasons, the results obtained in this study could be useful to territory planners and to users of soil as a strategic resource.

Software

The integration, management and processing of data were performed using Esri ArcGIS 9.3.1.

Disclosure statement

No potential conflict of interest was reported by the authors.

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