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Long-term land cover changes and climate variations – A country-scale approach for a new policy target

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ABSTRACT

This study provides a framework for the joint analysis of long-term land cover changes and climatic variations at regional scale. The land cover distribution observed in Italy in 1960, 1990, and 2006 was compared with trends in annual precipitation and the aridity index estimated during 1951–2007. Annual rainfall decreased by 0.41% per year during the examined period with the consequent increase in the aridity index (0.48% per year). Both rainfall decrease and aridity increase followed a non-uniform spatial distribution impacting differently the Mediterranean landscape mosaic. Land cover classes with higher precipitation rates and moderate to low aridity regimes experienced larger climate variations. Natural and semi-natural areas (including forests, shrublands, pastures, mountain zones with glaciers and rocky areas) resulted as the most vulnerable to climate aridity. Croplands were associated to moderately dry conditions in 1951–1960 but underwent only mild climate variations during the following fifty years. Results may inform sustainable regional planning for peri-urban and rural land experiencing aridity and contribute to the implementation of national action plans against climate changes in the Mediterranean basin.

Introduction

The mismanagement of drylands coupled with climate change may lead to unsustainable socioeconomic development (Galeotti, 2007). On the one hand, climate change is a key driver of land degradation especially in arid and semi-arid regions and stimulates landscape transformations at various observation scales (Olesen and Bindi, 2002; Danfeng et al., 2006; Sivakumar, 2007; Verstraete et al., 2008; Lindner et al., 2010). On the other hand, land-use changes influence local climate and may have an impact on climate variations at regional scale (Pielke et al., 2002; Solecki and Oliveri, 2004; Zhou and Wang, 2011). The northern Mediterranean basin is considered a paradigmatic case study to assess the environmental and socioeconomic implications of changes in both climate and landscape (Garcia Latorre et al., 2001; Brunetti et al., 2002; Helldén and Tottrup, 2008).

Evidence for climate variations across southern Europe includes local warming, the growing probability of droughts and waterlogging, the decrease of total annual precipitation and the increase of days with intense rainfalls (e.g. Brunetti et al., 2000, 2001, 2004, 2006; Incerti et al., 2007; Salvati et al., 2008; Founda and Giannakopoulos, 2009). All these changes have important consequences on the soil water budget determining an increase of soil aridity and a possible reduction of land productivity (Olesen and Bindi, 2002; Maracchi et al., 2005; Moriondo et al., 2006; Lindner et al., 2010). Land cover changes are also common in Mediterranean countries due to the high human pressure especially concentrated along the coastal rim, the uneven urban expansion, and the millenary linkages between the human system and the natural ecosystem (Antrop, 2000, 2004; Feranec et al., 2007, 2010; Gerard et al., 2010; Verburg et al., 2010). Changes in land cover during the last fifty years included cropland reduction and forest recovery due to land abandonment in mountain areas, as well as dispersed urban fabric expansion in lowlands (Petit and Lambin, 2002; Tanrivermis, 2003; Falcucci et al., 2007; Simeonakis et al., 2007; Lorent et al., 2008; Bajocco et al., 2011; Salvati and Bajocco, 2011).

Both research and policy are actively engaged, at various geographical scales and institutional levels, in providing strategies that reduce the impact of climate and land-use changes on ecosystems (Kelly and Adger, 2000; Nuissl et al., 2009; Dunlap, 2010; Azadi et al., 2011), for example by increasing the landscape resilience to marked variations in precipitation or temperature regimes or by mitigating the risk of soil degradation and desertification at both local and regional scales (Pielke et al., 2002; Rodriguez Diaz et al., 2007; Piccarreta et al., 2006). Research should also

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improve decision support systems capable to monitor long- and medium-term climate variations and their impact on landscapes in complex environments such as the Mediterranean-like ecosystems (e.g. Fussel and Klein, 2006). Unfortunately, up to now relatively few studies examine the changes in both land cover and selected climate variables over large areas at an adequate detailed spatial scale and over a long time period.

This study analyses the land cover distribution observed in Italy in 1960, 1990, and 2006 in parallel with precipitation and aridity trends estimated during 1951–2007, and assumes that climate variations in rainfalls and temperatures are not uniformly distributed across the country and thus impact differently on sub-humid, dry, or arid lands (Venezian Scarascia et al., 2006; Salvati et al., 2008, 2009). The picture is complicated by the uneven and rapid changes that could make some landscapes more vulnerable to aridity than others. This study may therefore inform sustainable land management coping with increasing climate aridity. The contribution to the practical implementation of national (or regional) action plans against climate change and desertification risk in the northern Mediterranean region was finally discussed.

Methods

Study area

Italy covers a surface area of 301,330 km^2. Topography, latitudinal extension, and proximity to the sea account for a great deal of variation in climate, soil, vegetation, and landscape (further details on the study area were provided in Salvati and Bajocco, 2011). The analysis undertaken here is based on a detailed study dealing with land cover changes from 1960 to 2006 combined with a climate analysis from 1951 to 2007. We used the following information layers: (i) three digital land cover maps respectively dated 1960, 1990, and 2006 covering the whole country and the meteorological data recorded from 1951 to 2007 by a dense network of gauging stations measuring daily rainfall and (minimum and maximum) temperatures (Salvati et al., 2008).

Land cover data

The land cover data used in this paper were obtained from three digital maps: (i) the CORINE-like 'Land Cover Map of Italy' developed by the National Research Council and the Italian Touring Club in the early 1960s (Falcucci and Maiorano, 2008) and (ii) the CORINE (COoRdinate INformation on the Environment) Land Cover (CLC) maps of Italy available for 1990 and 2006 at 100,000 scale with Minimum Mapping Unit (MMU) of 25 ha and minimum width of linear elements of 100 m. The CLC inventory, co-ordinated by the European Environment Agency (EEA), is based on computer assisted visual interpretation of satellite images as the primary information source (European Environmental Agency, 2006). Raw satellite images (together with topographic maps and orthophotos when necessary) were pre-processed and enhanced to produce a geometrically correct document in national projection. Ortho-corrected Landsat-7 ETM satellite images provided with an error below 25 m were also used to achieve this accuracy. Geospatial information were validated on the field according to sampling procedures (European Environment Agency, 2006). Since the land cover classification used in the three maps is comparable, land cover types were reclassified into ten classes (see Table 1).

Climate data

The climatic variables analyzed are rainfalls, (min–max) temperatures, reference evapotranspiration, and an aridity index. We used a dataset containing daily precipitation, temperature, wind, air humidity, and solar radiation time series from a number of meteorological networks including the Italian Air Force, the Hydrological service, the national and regional Agro-meteorological services, and some additional gauging stations from standard networks held by public research institutions. Almost 2000 meteorological stations were considered covering homogeneously the investigated area (Venezian Scarascia et al., 2006).

To obtain a regional distribution and spatial coverage of rainfall and temperature over the investigated period (1951–2007), kriging and co-kriging procedures were applied, respectively, to cumulated precipitation and (min–max) temperature calculated by means of a Geographical Information System (GIS). Ordinary kriging was applied to monthly rainfall over the investigated period producing raster maps at 1 km spatial resolution (see also Salvati et al., 2008). Grid size was chosen according to the density and the spatial distribution of gauging stations with the aim of producing maps with the associated estimation error below 5%. Results from

Table 1
The Land Cover CORINE-like classification used in this study.

Code	CORINE description	The code used in this study	This study's description
111	Continuous urban fabric	1	Urban
112	Discontinuous urban fabric	1	
121	Industrial or commercial units	1	
122	Road and rail networks	1	
123	Port areas	1	
124	Airports	1	
131	Mineral extraction sites	1	
132	Dump sites	1	
133	Construction sites	1	
141	Green urban areas	1	
142	Sport and leisure facilities	1	
211	Non-irrigated arable land	2	Non irrigated arable land
212	Permanently irrigated land	3	Irrigated arable land
213	Rice fields	4	Rice field
222	Fruit trees and berry plantations	5	Orchards
221	Vineyards	6	Vineyards and olive groves
223	Olive groves	6	
241	Annual crops	7	Heterogeneous agricultural areas
242	Complex cultivated patterns	7	
243	Agricultural 'mosaic' with and some natural vegetation	7	
244	Agro-forestry areas	8	Woodlands
311	Broad-leaved forests	8	
312	Coniferous forests	8	
313	Mixed forests	8	
324	Transitional woodland-shrubland	8	
231	Pastures	9	Shrublands and pastures
321	Natural grasslands	9	
322	Moors and heathland	9	
323	Schlerophyllous vegetation	9	
333	Sparsely vegetated areas	9	
331	Beaches, dunes, sands	10	Other uses
332	Bare rocks	10	
334	Burnt areas	10	
335	Glaciers and perpetual snow	10	
411	Inland marshes	10	
412	Peat bogs	10	
421	Salt marshes	10	
422	Salines	10	
423	Intertidal flats	10	
511	Water courses	10	
512	Water bodies	10	
521	Coastal lagoons	10	
522	Estuaries	10	
523	Sea and ocean	10	

other procedures (e.g. Inverse Distance Weighting or Spline indicators) were used to check for reliability in the obtained climatic figures (Salvati et al., in press).

Minimum and maximum temperatures were regionalized according to a co-kriging model using elevation, latitude, longitude, distance to the sea, and slope as ancillary variables. All these variables were derived from a Digital Elevation Model (DEM) available at 20 m-cell size resolution (Salvati et al., 2008). Based on the available DEM cartography and gauging station density, the co-kriging procedure applied to minimum and maximum temperature produced raster maps at 500 m spatial resolution. The reference evapotranspiration, ET_0 (mm day^{-1}), was computed using the Penman–FAO methodology (Incerti et al., 2007). Following United Nations Environment Programme (UNEP) approach, we adopted the standard aridity index (AI) defined as:

$$AI = \frac{P}{ET_0}$$

where ET_0 is the reference evapotranspiration and P is the annual precipitation. P and ET_0 are expressed in the same unit (mm) and are calculated as annual averages (Venezian Scarascia et al., 2006). The AI ranges from 0 to ∞: higher values indicate wetter conditions. According to the standard UNEP classification (e.g. Salvati and Bajocco, 2011), the investigated area was divided into four AI classes as follows: (i) $AI < 0.50$: dry areas, (ii) $0.50 < AI < 0.65$: dry sub-humid areas, (iii) $0.65 < AI < 0.80$: sub-humid areas, (iv) $AI > 0.80$: humid areas.

Geographical and statistical analysis

In this study, we considered the single land cover polygons as the elementary analysis unit (Salvati et al., in press). The ArcGIS (ESRI Inc., Redwoods, USA) zonal statistics procedure was applied to the available raster maps (average annual rainfall and average aridity index) in order to attribute a mean value of both layers to each polygon separately for the three study years (1960, 1990, and 2006). To assure comparability with the land cover layers, both climate variables were calculated as average values in 1951–1960, 1981–1990, and 1998–2007.

To evaluate the impact of climate variations on the changing landscape, we computed the range (max–min) of the two climate variables (rainfall and aridity index) observed in the ten land cover types examined. The relationship between the average annual rainfall (or aridity index) observed during each time period and the percent rainfall decline (or percent aridity increase) recorded in the following period was explored using linear regression analysis. A landscape sensitivity index to climate variations was finally proposed by averaging the annual change in rainfall and aridity index observed for each land cover class in two time windows (1951–1990 and 1981–2007). The absolute value of the index ranges from 0 to 1 respectively indicating, for each land cover class, the lowest and the highest sensitivity to climate aridity.

Results

Summary trends in rainfall and aridity in Italy (1951–2007)

In Italy, annual rainfalls decreased during the investigated time period from 968 mm observed in 1951–1960 to 779 mm in 1981–1990 and to 741 in 1998–2007. Per year rainfall decreasing rate was found higher in 1951–1990 than in 1981–2007 (Table 2). The same pattern was observed for the average aridity index decreasing by almost 30% per year during the whole examined period. More specifically, aridity index was 1.06 in 1951–1960, and dropped to 0.83 in 1981–1990 and to 0.77 in 1998–2007. Again, as in the case of rainfalls, the decreasing rate for the aridity index was higher during 1951–1990 (−0.71%) than during 1981–2007 (−0.44%).

Long-term land cover changes and climate variations in Italy

The CLC change analysis identified some types of landscape transformation in Italy. The most important changes observed from 1960 to 2006 have been reported in Table 3. Urban areas increased from 1.4% in 1960 to 4.9% in 2006. The annual rate of increase was 7.2% in 1960–1990 and 0.6% in 1990–2006. Non-irrigated arable lands slightly decreased from 26.3% to 26.0% with annual decrease rate amounting to 0.02% over the examined period. Orchards decreased from 1.9% in 1990 to 1.3% in 2006 with annual decrease rate of 0.65%. Vineyards and olive groves showed an annual decrease rate of 0.4%, while heterogeneous agricultural lands decreased by 0.1% over the whole period.

In 1960, agricultural areas covered 53.7% of the investigated area, in 1990 this rate dropped to 48.0%, and in 2006 it increased slightly to 48.7%. The observed annual rate was −0.30% and −0.03% in 1960–1990 and 1990–2006, respectively. To the contrary, semi-natural areas remained quite stable over the whole investigated time span. Forests increased from 19.4% to 29.5% with an annual growth rate of 1.1%, while shrublands and pastures decreased from 22% in 1960 to 11% in 2006.

The variations in long-term climate conditions observed for each land cover class are reported in Tables 4 and 5. More specifically, Table 4 shows the average annual rainfall in Italy broken by land cover class and ten-year period, while Table 5 focuses on the average aridity index again broken by land cover class and ten-year period. In summary, data reveal that, over fifty years, natural and semi-natural cover classes experienced important decreases in both average annual rainfalls and aridity index.

In urban areas, annual precipitation decreased, on average, from 1013 mm in 1951–1960 to 821 mm in 1981–1990, and to 764 mm in 1998–2007. The decrease rate per year was found higher in 1951–1990 than in 1981–2007 (−0.63% and −0.40%, respectively). As to the average aridity index, urban areas recorded an annual decrease rate of 0.69% during 1951–1990 and 0.55% during 1981–2007.

Taken together, the agricultural land cover classes showed a marked decrease in both rainfall and aridity in 1951–1990 followed by a milder decline in 1981–2007. The average annual rainfalls declined from 968 mm in 1951–1960 to 748 mm in 1981–1990 and to 728 in 1998–2007, with a per year decreasing rate of 0.76% during 1951–1990 and 0.16% during 1981–2007. The same applies to the average aridity index which dropped from 0.93% in 1951–1960 to 0.72% in 1998–2007, with the highest per year decreasing rate recorded during 1951–1990. Among the examined cropland classes, heterogeneous agricultural land (including cropland intermixed with semi-natural areas) resulted as the most sensitive to rainfall reduction and aridity increase in both investigated periods.

To the contrary, semi-natural areas recorded a considerable decrease in the aridity index and a relatively milder decrease in precipitation rates. Particularly woodlands experienced a considerable decrease in both rainfall (−0.81%) and the aridity index (−0.88%) that was concentrated in the first time period (1951–1990). However, a similar pattern was observed for shrublands and pastures. The residual land cover class including non-productive mountain areas with bare land, rocks, and glaciers, experienced the highest observed decrease in both climate variables over the whole investigated time period.

Finally, the range (max–min) observed in the distribution of the two studied variables at different land cover types reduced drastically from 1951–1960 to 1998–2007 (Table 6). As far as rainfall is concerned, the range between the most wet and the most dry land

Table 2
Annual precipitation and aridity index in Italy (1951–2007).

Variable	1951–1960	1981–1990	1998–2007	*Annual change (%)*	
				1951–1990	1981–2007
Rainfall (mm)	968	779	741	−0.65	−0.29
Aridity index[a]	1.06	0.83	0.77	−0.71	−0.44

[a] Decreasing values of the Aridity Index (AI) indicate increasing climate aridity.

Table 3
A summary of land cover changes observed in Italy (1960–2006).

Land cover class	1960	1990	2006	*Annual change (%)*	
				1960–1990	1990–2006
Urban areas	*1.4*	*4.4*	*4.9*	*7.21*	*0.64*
Non-irrigated arable land	26.3	26.0	26.0	−0.03	−0.01
Irrigated arable land	4.0	0.1	0.1	−3.22	−0.03
Rice fields	0.4	0.9	0.9	4.99	0.21
Orchards	1.9	1.3	1.3	−1.01	−0.01
Vineyards and olive groves	7.2	5.8	5.6	−0.66	−0.18
Heterogeneous agricultural land	14.0	14.8	14.8	0.19	−0.01
Agricultural areas	*53.7*	*48.9*	*48.7*	*−0.30*	*−0.03*
Woodlands	19.4	29.3	29.5	1.69	0.06
Shrublands and pastures	22.3	11.8	11.4	−1.56	−0.23
Semi-natural areas	*41.7*	*41.1*	*41.0*	*−0.04*	*−0.02*
Other uses	3.2	5.5	5.4	2.44	−0.11

Table 4
Average annual rainfall in Italy by land cover class (see Table 1) and time period.

Land cover class	1951–1960	1981–1990	1998–2007	*Annual change (%)*	
				1951–1990	1981–2007
Urban areas	*1013*	*821*	*764*	*−0.63*	*−0.40*
Non-irrigated arable land	875	741	724	−0.51	−0.13
Irrigated arable land	977	870	827	−0.36	−0.29
Rice fields	1057	909	858	−0.47	−0.33
Orchards	803	728	677	−0.31	−0.42
Vineyards and olive groves	877	689	692	−0.72	0.02
Heterogeneous agricultural land	977	774	745	−0.69	−0.22
Agricultural areas	*968*	*748*	*728*	*−0.76*	*−0.16*
Woodlands	1102	833	777	−0.81	−0.40
Shrublands and pastures	976	746	696	−0.79	−0.39
Semi-natural areas	*908*	*808*	*755*	*−0.37*	*−0.39*
Other uses	1094	803	726	−0.89	−0.35

Table 5
Average score of the Aridity Index in Italy by land cover class (see Table 1) and time period.

Land cover class	1951–1960	1981–1990	1998–2007	*Annual change (%)*	
				1951–1990	1981–2007
Urban areas	*1.08*	*0.86*	*0.78*	*−0.69*	*−0.55*
Non-irrigated arable land	0.89	0.75	0.71	−0.54	−0.30
Irrigated arable land	1.03	0.79	0.74	−0.76	−0.41
Rice fields	1.13	0.94	0.87	−0.55	−0.44
Orchards	0.80	0.73	0.66	−0.30	−0.56
Vineyards and olive groves	0.89	0.67	0.66	−0.82	−0.10
Heterogeneous agricultural land	1.02	0.80	0.75	−0.72	−0.36
Agricultural areas	*0.93*	*0.76*	*0.72*	*−0.63*	*−0.30*
Woodlands	1.27	0.94	0.85	−0.88	−0.52
Shrublands and pastures	1.12	0.85	0.77	−0.81	−0.52
Semi-natural areas	*1.19*	*0.91*	*0.83*	*−0.78*	*−0.52*
Other uses	1.42	0.94	0.82	−1.14	−0.74

Table 6
Range (max–min) of annual precipitation and aridity index observed in Italy by land cover class and year.

Variable	1951–1960	1981–1990	1998–2007	*Annual change (%)*	
				1951–1990	1981–2007
Rainfall (mm)[a]	299	220	181	−0.88	−1.04
Aridity index[b]	0.62	0.27	0.21	−1.86	−1.28

[a] Calculated as the difference in rainfalls recorded in the most rainy and dry land cover class.
[b] Calculated as the difference in the aridity index recorded in the most wet and arid land cover class.

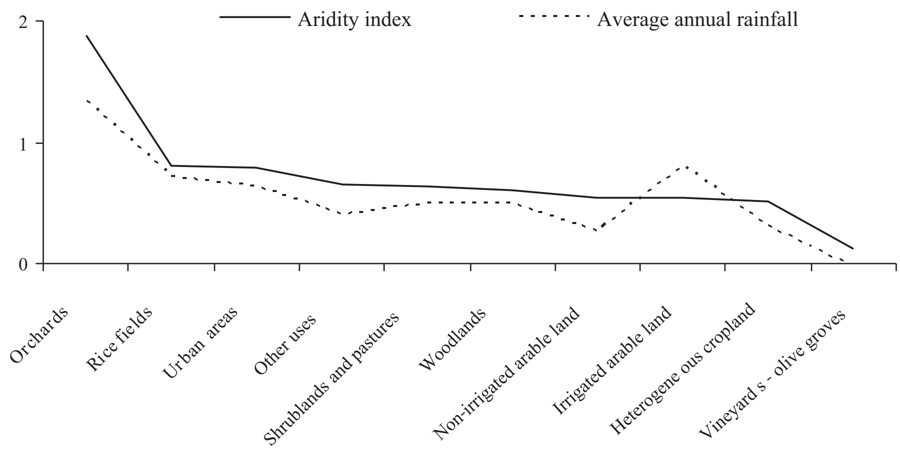

Fig. 1. The ratio of 2007–1981 annual change to 1990–1951 annual change by climate variables and land cover classes (see Table 1).

cover in Italy was 299 mm in 1951–1960 and decreased rapidly to 220 mm in 1981–1990 and to 181 mm in 1998–2007. The same pattern was observed for the aridity index with a difference recorded between the maximum and minimum value by land cover type decreasing from 0.62 in 1951–1960 to 0.21 in 1998–2007.

Correlation analyses

Fig. 1 compares the percent changes in rainfall and aridity observed during the two investigated periods for each land cover considered and indicates similarities and differences in climate regimes during the last fifty years. It was observed that the largest changes in rainfall and aridity were observed, on average, during 1951–1990 for all land cover classes apart from orchards that experienced a higher decrease in rainfall and increase in aridity during 1981–2007 compared to the previous study period. The relationship observed at land cover class level between the average rainfall and the variation recorded in the same variable during the following time period was reported in Fig. 2. A negative correlation was recorded between the two variables in both examined periods with an higher coefficient observed in the first sub-period (1951–1990). In other words, the analysis suggests that land cover types with higher annual rainfall have experienced an higher rainfall reduction over time (Fig. 3). The same analysis was undertaken for the aridity index and provided similar findings. A larger decrease in the aridity index (i.e. indicating higher aridity) was observed for land cover types experiencing, on average, wetter climate conditions.

A landscape sensitivity index to climate aridity

The sensitivity index to climate variations illustrated in Fig. 4 classifies the twelve investigated land cover types according to their exposure to changes in rainfall regimes and aridity index considered together along the whole study period. Natural and semi-natural land cover classes (especially woodlands) resulted as the most sensitive to climate variations followed by urban and peri-urban areas, while agricultural land cover classes were found less vulnerable to the long-term alterations in rainfall and aridity regimes. Among them, the cover types that experienced the milder climate variations were orchards and non-irrigated arable land.

Discussion

This study deals with the on-going landscape transformations observed at regional scale, and their spatial relationships with changing climatic variables. Given the current debate on the environmental impacts of climate change, the topic is of interest to an international audience. The observed trends in selected climate variables in Italy were analyzed with the aim of monitoring the level of sensitivity of different land cover classes to rainfall variations and increasing aridity. Using two indicators (average long-term rainfall and a standard aridity index), a country-scale assessment exercise was illustrated covering a long time period (fifty years from 1960 to nowadays). The proposed analytical framework, mainly based on GIS techniques and exploratory statistics analysis, is suitable to analyze the spatial relationships between land-use and climate changes and highlights the importance of comparative approaches based on quantitative methodologies. Such information plays a key role in sustainable land management, regional planning, and natural resource conservation (European Environment Agency, 2006).

Results indicate that total rainfalls have significantly decreased and climate aridity has increased in Italy from 1951 to 2007 with a different impact on forests, pastures, croplands, and urban areas. The semi-natural land cover classes were the most affected by climate variations. Findings highlighting a possibly regime shift between climate and land-use spatial distribution are particularly interesting from the policy perspective. They also contribute to depict a scenario for Mediterranean regions characterized by frequent drought episodes, growing temperatures, and aridity that could selectively impact land with high ecological quality.

Implications of this scenario involve the conservation of semi-natural areas (forests, shrublands, pastures, and economically-unproductive land with high environmental value) coupled with sustainable management of the traditional agricultural 'mosaic' landscape (Lorent et al., 2008). As an example, climate aridity may negatively impact farms by increasing management costs (e.g. irrigation, mechanization, pesticides, fertilizers, etc.) and triggering a land abandonment spiral which may determine soil degradation and a reduced landscape resilience to climate change (Salvati and Bajocco, 2011). This spiral could be stimulated by (and stimulates as well) increasing land prices with the possible degradation of low-quality soils and the consequent land consumption and fragmentation (Giannakourou, 2005).

Regional planning should definitely address the feedback relationships between medium-term climate variations and land cover changes. In such a perspective, Mediterranean regions suffering both types of change represent a challenge for sustainable land management (Basso et al., 2000; Marathianou et al., 2000; Tanrivermis, 2003; Simeonakis et al., 2007; Catalàn et al., 2008). These processes claim for effective multi-scale policies contrasting landscape transformation and environmental degradation (Briassoulis, 2008).

To be really effective, a permanent monitoring scheme should inform environmental policies by facing multifaceted targets (e.g.

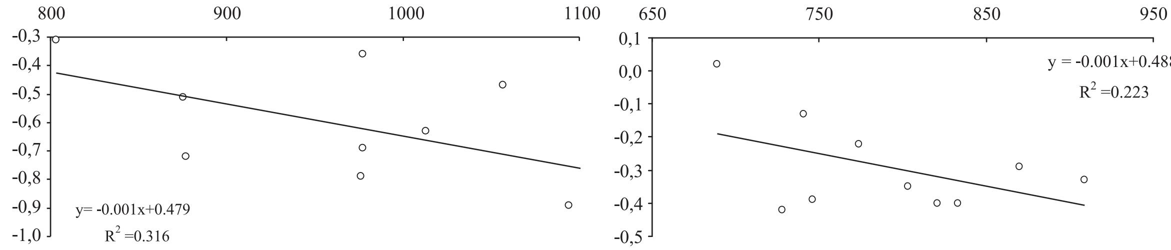

Fig. 2. Linear regression analysis between (left) average annual rainfall (mm) in 1951–1960 (*x*-axis) and rainfall reduction (% per year) during 1951–1990 (*y*-axis) and between (right) average annual rainfall (mm) in 1981–1990 (*x*-axis) and rainfall reduction (% per year) during 1981–2007 (*y*-axis) by land cover class in Italy.

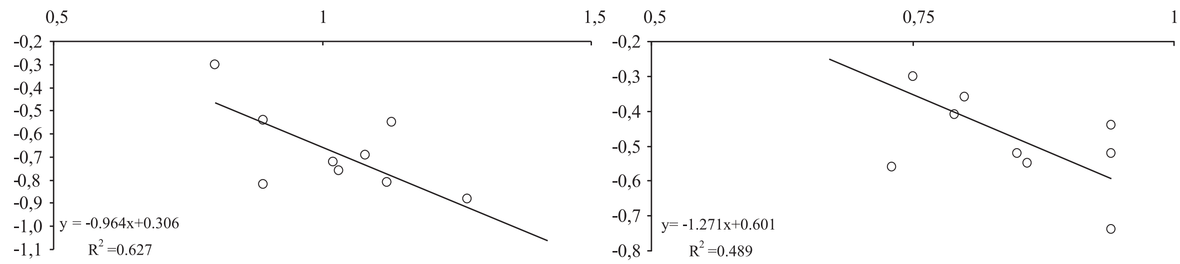

Fig. 3. Linear regression analysis between (left) average aridity index in 1951–1960 (*x*-axis) and its decrease (% per year) during 1951–1990 (*y*-axis) and between (right) average aridity index in 1981–1990 (*x*-axis) and its decrease (% per year) during 1981–2007 (*y*-axis) by land cover class in Italy.

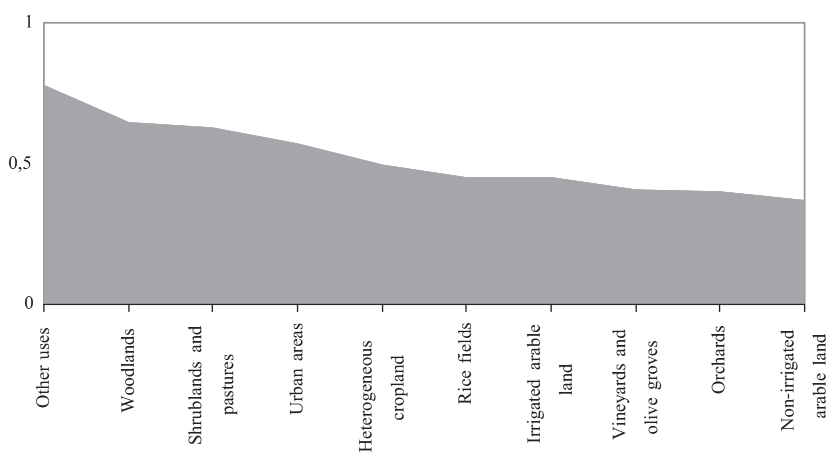

Fig. 4. The cumulated sensitivity index to climate variations by land cover class.

Rounsevell and Reay, 2009). The procedure illustrated in the present paper is suited to fill this objective, since it quantifies climate and land cover changes by using easily accessible data from official statistics and digital maps. In Fig. 4 we provided an example of a potentially useful tool contributing to the assessment of climate aridity impact on the land cover types examined. This approach could inform regional policies aimed at managing, among others, landscape transformations, natural areas, water demand and supply, e.g. by (re)orienting agricultural practices to a more sustainable use of water resources. Due to its versatility, the illustrated procedure represents a tool for regional planning, land management, habitat conservation, and rural development especially in sensitive or degraded regions.

National Action Plans to mitigate climate changes and combat drought and desertification should integrate multi-scale environmental and socioeconomic policies in order to control the impact of climate aridity on the natural ecosystems that are sensitive to climate variations in the Mediterranean region. These measures should reverse the possible downward spiral between aridity and landscape degradation triggered by climate change and anthropogenic factors and contrast the process of 'migration' of specific land cover classes toward 'high-quality' climate regions.

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