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Human activity impact on the heterogeneity of a Mediterranean landscape

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ABSTRACT

The Mediterranean area is one of the most significantly altered hotspots on Earth, since it has been intensively affected by human activity for millennia. As a result, only 4.7% of its primary vegetation remained unaltered and the landscape has been repeatedly transformed. In this paper, we aimed at detecting both the direction and the rate of landscape change focusing on the effects of human activity on the environmental heterogeneity of the Mediterranean landscape under study. In particular, we carried out an analysis of landscape changes occurred in a Mediterranean area from 1954 to 2000, by means of a comparative examination of a historical and a recent land use map. Land use changes have been quantified by landscape metrics coupled with topographical information. Results underline: i) a general homogenisation of the landscape, ii) modification of the arrangements for exploitation of the territory, particularly in the plain areas, iii) a trend of recovery of the territory by the forest to the detriment of semi-natural and agricultural areas in hilly and mountain parts. The analysis of the complex phenomena related to land use changes can be a useful tool to define effective strategies for natural resources management and biodiversity conservation.

Introduction

Land use changes are among the most important transformations of the Earth's land surface and they may be the most significant cause of global environmental change (Gillanders, Coops, Wulder, Gergel, & Nelson, 2008). Currently in many parts of the world, human activities are the main forces shaping land use changes (Serra, Pons, & Saurì, 2008). In particular the areas of the Mediterranean basin are being profoundly transformed by human activity. As a result only 4.7% of its primary vegetation remained unaltered (Antrop, 2004; Debussche, Lepart, & Dervieux, 1999; Falcucci, Maiorano, & Boitani, 2007; Serra et al., 2008). In fact, agricultural lands, evergreen woodlands and maquis habitats, that dominate the present landscape of the Mediterranean basin, are the result of anthropogenic disturbances over millennia (Blondel, 2006; Blondel & Aronson, 1995).

Many factors contribute to landscape modifications: crops pulling-out, population migration, mechanization of rural system, urban-sprawl etc. (Jongman, 2002; Meeus, 1995; Meeus, Wijermans, & Vroom, 1990; Van Eetvelde & Antrop, 2004; Vos & Meekes, 1999).

The abandonment of the countryside in the last decades is due to socio-economic changes occurred during the last decades; these changes were linked with the shift from a traditional agricultural system, characterized by a high landscape

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complexity, to a new agricultural scheme supported by modern technologies (Rühl, Pasta, & La Mantia, 2005). In many developed areas, a specific pattern of land-use change has taken place during the last decades: plains are being increasingly utilized for human activities, while mountain areas are being abandoned and undergo natural reforestation processes (Ales, Martin, Ortega, & Ales, 1992; Debussche et al., 1999; Garcia-Ruiz et al., 1996; Lambin et al., 2001; McDonald et al., 2000). This generalized trend is independent from planned conservation strategies but it is expected to seriously impact biodiversity distribution and conservation (Ales et al., 1992; Covas & Blondel, 1998). The comparison between past and present land use represents a straightforward approach for identifying landscape changes and for quantifying the relationships among anthropogenic, agricultural and forest systems (Turner & Ruscher, 1988). Several studies show the connection between landscape transformation and biodiversity decrease (Antrop, 2004; Baessler & Klotz, 2006; De Aranzabal, Schmitz, Aguilera, & Pineda, 2008; Stephens, Koons, Rotella, & Willey, 2003; Van Eetvelde & Antrop, 2004).

For this reason, one of the key topics in ecological diversity is the analysis of landscape dynamics (Braimoh, 2006). The use of aerial photography in landscape studies is well established (Skanes & Bunce, 1997). The overall advantage of aerial photographs is the combination of a high spatial resolution and a synoptic view of the landscape. Changes in landscape structure may be quantitatively described by the interpretation of aerial photographs acquired in different dates (e.g., Armenakis, Leduc, Cyr, Savopol, & Cavayas, 2003; Carmel & Kadmon, 1998; Rocchini, Perry, Salerno, Maccherini, & Chiarucci, 2006). Planners are increasingly interested in the interactions between natural and anthropogenic environmental systems, aiming at generating predictions about future rates of change and at designing appropriate spatially explicit conservation policies (Lambin, 1994; Nagendra, Munroe, & Southworth, 2004).

A large amount of information is necessary to monitor landscape changes and develop plans for proper management of natural resources (Pelorosso, Leone, & Boccia, 2009).

Traditional field data are spatially limited and are difficult to apply at a regional or global scale; consequently remote sensing is considered an essential technology for ecological and conservation-related applications (Gillespie, Foody, Rocchini, Giorgi, & Saatchi, 2008). For many studies remote sensing data and information represent the only available source for measuring habitat characteristics and monitoring environmental change (Turner, Gardner, & O'Neill, 2001).

The main objective of this paper is to analyse land use change in a Mediterranean area from 1954 to 2000, by means of a comparative examination of historical and recent land use maps. In particular, we aim at detecting both the direction and the rate of landscape change focusing on the effects of human activity on the environmental heterogeneity of the Mediterranean landscape under study.

Material and methods

Study area

The study area is the Siena Province (Fig. 1), a ca. 3700 km^2 area situated in Tuscany (Italy, centroid coordinates: longitude 11° 26′ 54″ E, latitude 43° 10′ 12″ N, datum WGS84), mainly represented by hilly morphology, the highest elevation being approximately 1000 m.

The annual mean temperature in a period of 10 years ranges from 12.96 °C to 14.3 °C, while the mean precipitation value per year equals 738.7 mm, the highest value per month (August) equalling to 243.2 mm.

The Siena Province is currently characterised by herbaceous agricultural land, covering ca. half of the territory while forests cover ca. 40% of the entire territory. Forests are mostly dominated by oak formations (mainly *Quercus cerris*, Q. *pubescebs*, Q.*ilex*), while beech (*Fagus sylvatica*) and chestnut (*Castanea sativa*) woods occur at higher elevations.

Map derivation: land use classification

In order to examine the landscape at second post war, a series of 123 aerial photographs of Siena Province taken in 1954 have been acquired, georeferenced and digitised within a geographic information system (GIS). The 1954 aerial photos are grey scale images taken in 1954–1955 by IGM (Military Geographic Institute) with a 1 metre pixel dimension (spatial resolution). In lowland areas the frames were taken at altitudes around 5000 m, resulting to a scale of approximately 1:30,000. This sequence represents the first example of cartographic data from aerial photo covering the entire Italian territory. The aerial photos were scanned in geotiff images of 8 bit radiometric resolution, orthorectified by a 10m Digital Elevation Model (DEM) and 1:10,000 topographic maps and they were merged through a mosaicing operation, with an average numeric balancing of overlapping areas.

The digitalisation procedure used can be defined as semi-automatic: it is composed by a first operation of automatic segmentation and a second part of manual photo interpretation. Segmentation means the grouping of neighbouring pixels into regions (or segments) based on similarity criteria (digital number, texture; Meinel & Neubert, 2004). The automatic segmentation process used is mostly defined as a bottom-up process: cluster of pixels with similar characteristics are aggregated into a series of successive stages up to reach a threshold factor defined by the operator (Blaschke, in press; Burnett & Blaschke, 2003; Carleer, Debeir, & Wolff, 2005). We applied a size control of the resulting segments equaling 0.5 ha (Minimal Mapping Unit, MMU). The use of a completely automatic segmentation has not been taken into consideration given the poor spectral resolution of the grey scaled aerial photos that made it difficult to obtain satisfactory data (Marignani, Rocchini, Torri, Chiarucci, & Maccherini, 2008; Müllerová, 2004). Hence, the thematic attribution of each polygon was carried out manually by a visual

Fig. 1. Study area.

identification of classes based on the Level 2 of the CORINE Land Cover nomenclature system (Bossard, Feranec, & Otahel, 2000, see Table 1and 2). The photo interpretation was mainly based on recognition of the different pixel tones and different geometries of patches, but the low spectral resolution of old aerial photographs did not allow a more detailed identification and recognition.

As a reference map we made use of the CORINE Land Cover 2000 from which we extracted the thematic classes described in Table 1, by grouping polygons lying within the same land use class.

In order to guarantee the comparability between the 2 datasets in terms of minimum mapping unit (MMU), we smoothed both datasets by a majority filter. The size of majority filter moving window was calculated through the evaluation of the difference of MMU of the two datasets. The dimension of the moving window corresponded to the largest MMU recorded by comparing the datasets, equally to 25 ha, so the moving window used was 50 m side. The resulting maps (Fig. 2) were further imported in Idrisi Andes GIS software for spatial analysis (Eastman, 2006).

Change detection and spatial analysis

The two datasets (1954–2000) were compared through an overlay image processing operation, with the aim of identifying the direction and the rate of transformations. A cross-tabulation analysis was performed, using the CROSSTAB module of

Table 1
Description of land cover classes.

Land cover class	Description
Forest	Areas that show more than 45–50% of forest covering
Semi-natural areas	Shrub areas, grassland, bare reliefs (mountains, “biancane”, etc….)
Agriculture areas	Herbaceous cultivation, orchard, vineyard
Water areas	Vast expanse of water such as Montepulciano and Chiusi lakes
Urban areas	Vast urban conglomeration in the Province, airports, industrial areas easily identificable

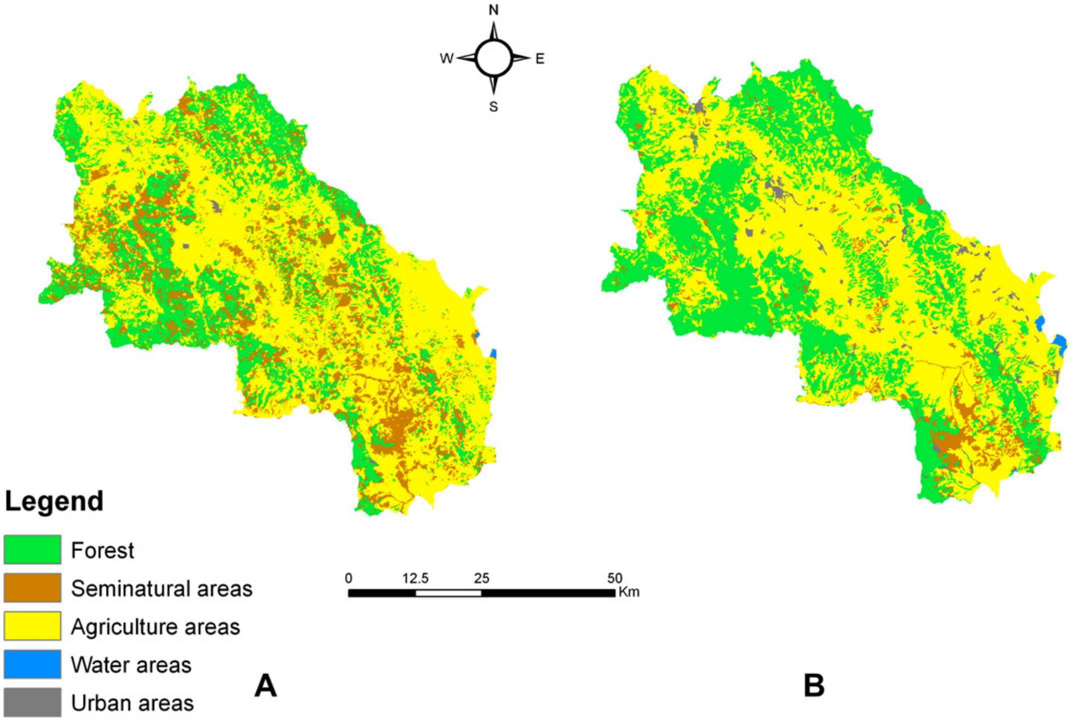

Fig. 2. (A): 1954 land use map, resulting from automatic segmentation and manual photo-interpretation processes on panchromatic aerial photos; (B): 2000 land use map, extracted from CLC 2000.

IDRISI Andes software (Eastman, 2006), to analyse the spatial distribution of land use changes (Shalaby & Tateishi, 2007). Hence, two main outputs were generated: *i*) a transition matrix (contingency matrix), which expresses the amount of change of each class from one land-use class in 1954 to any other class over the projected period, ii) a cross-classification map which is a multiple overlay showing all the combinations using logical "AND" operation. The two procedures took into account three land-use classes: "Forests", "Agricultural areas" and "Semi-natural areas" out of the five classes shown in Table 1. The "Water" and "Urban areas" categories were not taken into account because of the extremely small size of the patches.

In order to measure the similarity between the comparison map and the reference map, kappa index of agreement was calculated for each land use class (Rosenfield & Fitzpatrick-Lins, 1986).

Relationship between landscape dynamics and topography

In order to link land use changes and topographic variables, the 10m Digital elevation Model (DEM) of the Siena Province was resampled by a nearest neighbour algorithm at a spatial resolution of 50m, in order to speed up spatial analysis and to enable the comparison between datasets.

The cross-classification polygon themes were overlaid with the 50m DEM of the Siena Province in order to check for relationships between forest, agricultural and semi-natural areas transformations and topography. The DEM was divided into 5 elevation classes and the percentage of land use variation per class was calculated. Table 2.

Landscape metrics

Landscape metrics are focused on the description of the geometric and spatial properties of categorical map patterns and allow the characterization and the investigation of land use change processes (see e.g. Herzog & Lausch, 1999; Imre & Rocchini, 2008).

Table 2
Correspondence between CORINE land cover Classes and the classification used in this study.

Land cover class	CLC 2000 (level II)	New class
Forest	3.1	1
Semi-natural areas	3.2–3.3	2
Agriculture areas	2.1–2.2–2.3–2.4	3
Water areas	4.1–4.2–5.1–5.2	4
Urban areas	1.1–1.2–1.3–1.4	5

Table 3
Contingency matrix (values in ha and %). It represents the percentage of unaltered area per each class during the considered period of time (frequency on the diagonal) as well as changes from one class to another (frequency out of the diagonal).

	2000 ha (%)				
	Land cover class	Forest	Semi-natural areas	Agriculture areas	Total
1954 ha (%)	Forest	84,324 (94.05)	1064 (1.19)	4101 (4.58)	89490
	Semi-natural areas	31,278 (55.36)	5233 (9.26)	19,989 (35.57)	56501
	Agriculture areas	27,495 (12.53)	7810.39 (3.56)	184,122 (83.91)	219428
	Total	143,097	14,109	208,213	

A series of non-redundant landscape metrics was calculated to analyse the configuration of land-use mosaic and to objectively describe the temporal patterns of landscape change (Turner et al., 2001):

- *Number of Patches* (NumP): Total number of patches of each class.
- *Mean Patch Size* (MPS): Mean size of patches per each class.
- *Mean Core Area* (MCA): Core area is defined as the area within a patch beyond some specified depth-of-edge influence (i.e., edge distance) or buffer width. We calculated the mean size of core areas in order to analyse the trend of fragmentation/de-fragmentation of patches, mainly concerned with forest and semi-natural patches.
- *Euclidean nearest-neighbour distance* (ENN): ENN equals the distance (m) to the nearest neighbouring patch of the same type, based on the shortest edge-to-edge distance. Euclidean nearest-neighbour distance is perhaps the simplest measure of patch context and has been used extensively to quantify patch isolation.
- *Area Weighted Mean Shape Index* (AWMSI): AWMSI is a measure of geometrical shape complexity, weighted on patch shape size. Values close to 1 are related to a general simple patch shape, while higher values correspond to more complex patch shapes.
- *Total edge* (TE): Total Edge equals the sum of the edge lengths of all the patches per land use type.

To calculate the afore mentioned indices we used Patch Analyst 1.1 (Rempel, Carr, & Elkie, 1999) and the Fragstats 3.3 software (McGarigal & Marks, 1995).

Results

Change detection and spatial analysis

Following the contingency matrix (Table 3), the conservation percentage for the “Forest” class equals ca. 94%%, while less then 5% of the entire surface covered by “Forest” class in 1954 has undergone a change in another class. The area preserved for the “Agriculture areas” class equals about 83.21%; ca. 12% of the crops turned into forest, while only 3.56% changed into semi-natural areas. These results prove a high stability (conservation) of both “Forest” and “Agriculture areas”. On the contrary “Semi-natural areas” showed an opposite trend: only 9% of the semi-natural surface occurring in 1954 has been conserved, while 55% of this class has been forested and 35% has been converted to crops.

This is confirmed by the Kappa index of agreement between the 1954 and the 200 maps (Table 4), with the lowest value (0.26) belonging to “Semi-natural areas”, which indicates a high spatial change of this class.

Fig. 3 shows four maps representing the main change processes (Fig. 3A, 3B, and 3C) and the land cover persistence (Fig. 3D). The cross-classification images are overlaid with the DEM of the Siena Province; darker grey tones represent an increase in altitude. Cross-classification images are a useful tool because they allow to reveal spatial patterns quickly and easily (Pontius & Cheuk, 2006). Analyzing the general trend of forestation and forest conservation that characterizes the Siena Province (Fig. 3A and 3D) it is possible to highlight that these processes are located basically along the main mountain chains. The processes of deforestation and the increase of agricultural land is concentrated mainly in the lowland. The map concerning semi-natural areas variations highlights a decrement of this class of the whole study area, with a partial increase in the south part of the Province (Fig. 3C).

Table 4
Kappa Index of Agreement (KIA) resulting from the overlapping of the 1954 and 2000 maps.

Land cover classes	KIA
Forest	0.46
Semi-natural areas	0.26
Agriculture areas	0.71

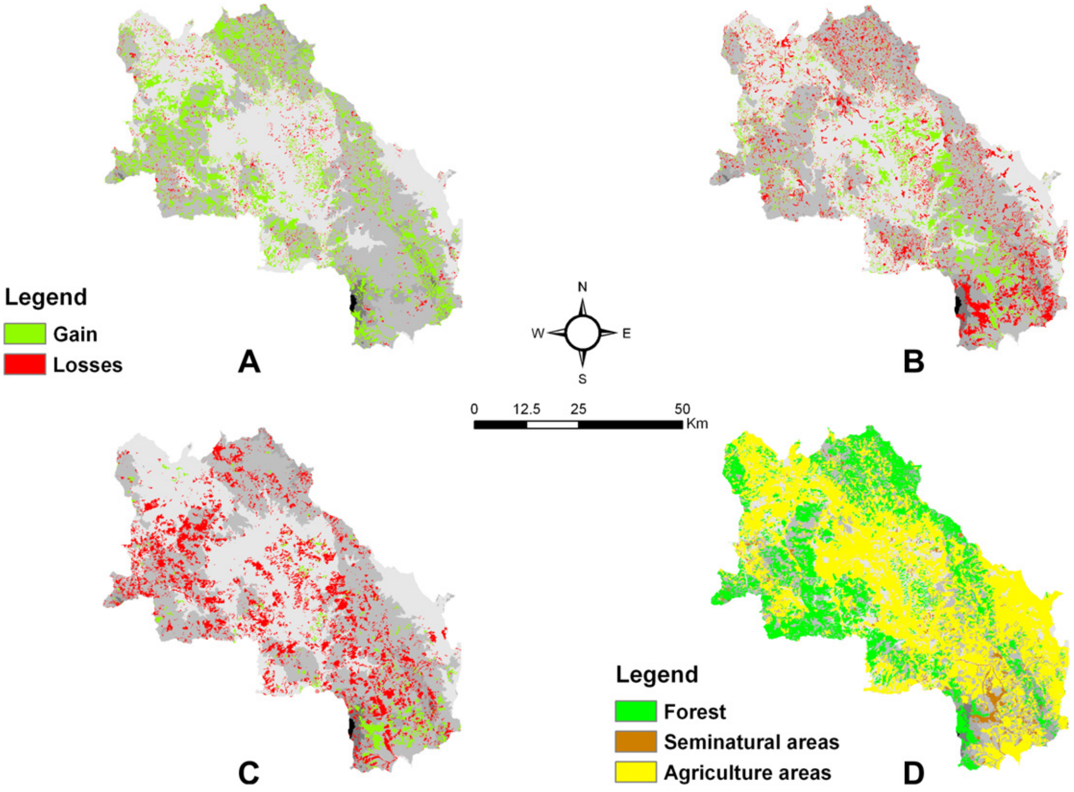

Fig. 3. Map of land use changes from 1954 to 2000. (A): "Forest"; (B): "Semi-natural areas"; (C): "Agriculture areas"; (D): maintenance.

Relationship between forest dynamics and topographic variables

The relationships between change processes and topography (as summarised by dividing the DEM into five elevation classes) are shown in Table 5. Notice that percentage values represent the territory surface of each altitude class covered by the change process of each of three land use classes. The forest conservation has occurred mainly in the most elevated areas (>1200 m, Table 5). On the other hand agricultural conservation has occurred in connection with lowest altitude values. The forestation process has occurred in higher altitudes than those of the agricultural conservation but lower than those of the forest conservation (between 901 and 1200 m). Comparing the dynamic changes in agriculture areas it is possible to point out that the loss of forest areas occurred primarily at low altitudes, corresponding to the highest gain of agriculture areas. Semi-natural areas tended to decrease and the gain process occurred only within 600–1200 m altitude.

Table 5
Relationship between change process and altitude.

Elevation zone	Conservation (%)	Loss (%)	Gain (%)
A. Forest			
60–300	11.02	1.41	10.12
301–600	30.27	1.48	18.96
601–900	39.52	0.54	30.08
901–1200	56.22	0.11	31.59
>1201	91.89	0.00	7.28
B. Natural and semi-natural areas			
60–300	0.54	10.76	0.91
301–600	1.88	16.23	3.01
601–900	3.99	17.35	7.79
901–1200	1.47	13.87	7.54
>1201	0.00	2.36	0.00
C. Agriculture areas			
60–300	68.14	5.80	6.79
301–600	37.89	11.05	6.79
601–900	14.51	22.34	2.15
901–1200	1.60	25.99	0.84
>1201	0.00	4.92	0.00

Landscape metrics

Landscape metric analysis shows how shape, composition and spatial configuration of the land-use patches changed after the Second World War to present day.

All classes showed a considerable decrease in the number of patches (Fig. 4a) with an increase in the patch average size (Fig. 4b).

The *core area* and *Euclidean nearest-neighbor distance* analysis (Fig. 4c, d) enabled a better understanding of the fragmentation process: the core area average size of "Forests" and "Agriculture" categories increased considerably, while the "Semi-natural" class showed a slight decrease. An opposite trend was found for the ENN distance.

The Area Weighted Mean Shape Index (AWMSI) showed an increase in the geometrical complexity of all the three classes (in particular of that of "Forests"), while the length of edges, detected by the Total Edge index showed a marked change (i.e. a slight decrease) only for "Natural and semi-natural areas" (from 447 km to 1109 km).

Discussion

The results achieved in this paper showed a general homogenisation of the Mediterranean landscape under study, with a relevant process of forestation, to the detriment of semi-natural and agriculture areas,. The resulting patterns of change

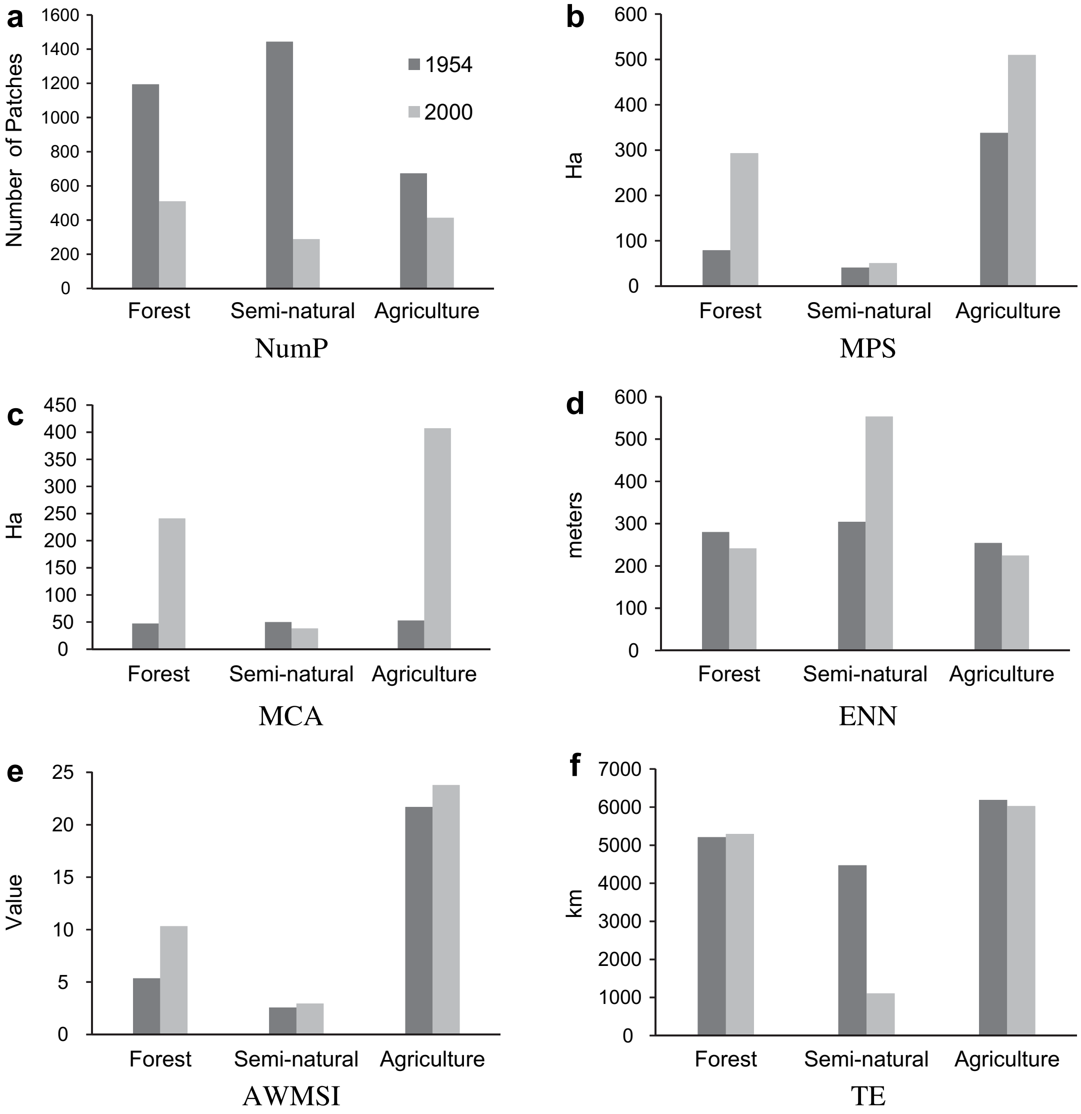

Fig. 4. Landscape metrics change in the time period considered (a): NP; (b): MPS; (c): MCA; (d): ENN; (e): PARA; (f): TE.

confirm the finding of many studies focused on the Central and West areas of the Mediterranean region (De Aranzabal et al., 2008; Falcucci et al., 2007; Mazzoleni, Di Pasquale, Mulligan, Di Martino, & Rego, 2004; Pelorosso et al., 2009; Serra et al., 2008). Studies focused on the South and East areas of the Mediterranean basin, however, have highlighted different driving forces of land use change, due mainly to different socio-economic state (Berberoglu & Akin, 2009; Onur, Maktav, Sari, & Snmez, 2009).

It is possible to distinguish two main trends: i) the expansion of forest areas in mountainous and hilly areas due to the abandonment of agricultural areas, ii) a general process of fragmentation and expansion of agricultural and artificial areas, due to a recent development of an industrial economy (Chauchard, Carcaillet, & Guibal, 2007; Liotta, Mouat, Kepner, & Lancaster, 2008).

In particular, the rapid expansion of forests in Italy and in the Siena Province, has profound implications in terms of natural resource management and biodiversity conservation.

The abandonment of agricultural areas in the hilly and mountain landscapes, and the consequent rapid spread of the forest through the mechanism of natural succession, have led to situations generally characterised by low biodiversity (Bengtsson, Nilsson, Franc, & Mengozzi, 2000). This results in a dramatic simplification and homogenisation of the landscape mosaic, particularly in hill and mountain areas, where the forest is growing, while the spread of monocultures in the plain is the main factor reducing the diversity (Geri, Rocchini, Giordano, Nucci, & Chiarucci, 2008).

For this reason studying effects of land use changes, and in particular of afforestation on abandoned agricultural areas, can be an essential support in establishing effective policies to conserve and protect biodiversity. These policies may include restoration measures for semi-natural habitats that contain species of special conservation interest, wich disappear as a result of the land use change processes (Critchley, Burke, & Stevens, 2004).

Cross-classification images and the analysis of the relationship between landuse dynamics and elevation highlighted a specific topographical pattern in landscape changes: forests at higher altitudes generally remain almost unaltered while forestation occurs at lower elevation, where agricultural areas have been abandoned. This is usually the case of morphologically complex areas that are not suitable for agricultural purpose (Tugac & Torunlar, 2007). On the other hand it should be noted that the areas characterized by a lower altitude (and probably slope) have lost their role of typical rural areas with a general intensification of agriculture, i.e. with the exploitation of agricultural resources through a rise in the usage of phytosanitary products and a resulting increase in farm products (Lambin et al., 2001). These areas have to be uniform, easy to access and usable (Vos & Stortelder, 1992).

Landscape metric analysis showed how change dynamics (ecological process) have a clear effect on the spatial pattern being observed. Landscape mosaic is now characterized by a lower number of larger patches, thus reducing fragmentation rate.

Concerning forests, this pattern can be interpreted as a slow regaining of natural vegetation and woodland thus including isolated fragments in larger cores (Geri et al., 2008; see *core area index* values). This process has consequently caused an increase of the complexity of the geometry of new patches of forest, that are created through a spontaneous recolonization of secondary woodland formations.

Agricultural areas showed a de-fragmentation process and an increase in mean size of the larger cores. This is a consequence of a different land-use method. Typical small farming fields used in 1954 have been abandoned due to a difficult access to the modern mechanical technology, while lowland crops have been increasingly used (Agnoletti, 2007; Geri et al., 2008; Vos & Stortelder, 1992).

Semi-natural areas showed a similar trend of that of forests but with a great reduction of total surface area (showed also by *total edge index*) and a consequent increase of isolation of remnant patches (see *ENN index* values).

Conclusions

Most of the North-Mediterranean area underwent relevant changes during the last 50 years, mostly related to an increase in forests and an abandonment of mountain agricultural and pastoral activities (see e.g. Agnoletti, 2007; Antrop, 2004; Romero-Calcerrada & Perry, 2004; Vos & Stortelder, 1992).

This allowed for the regaining of natural vegetation in mountain areas, causing a loss of semi-natural and cultural entities and consequently a homogenisation of landscape structure with a potential loss of species and habitat of conservation interest (Jongman, 2002).

In this paper we proved that the abandonment of typical human activities is leading to the conversion of a complex landscape matrix into a completely homogeneous system, adversely affecting the total diversity of the study area (Baessler & Klotz, 2006). The new landscape is characterised by homogeneous large areas dominated by semi-natural forests or modern agricultural settlements.

The analysis of the complex phenomena related to land use changes for identifying the driving forces of landscape structure can be a useful tool to define effective strategies for natural resources management and biodiversity conservation. These policies may include, for example, the restoration of natural habitats and incentives to promote the use of non-intensive agricultural areas.

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