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Wildfires and landscape patterns in the Eastern Iberian Peninsula

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Abstract

The relations between disturbance regime and landscape patterns have been developed from a theoretical perspective, but few studies have tested these relations when forces promoting opposing heterogeneity patterns are simultaneously operating on a landscape. This work provides quantitative evidence of these relations in areas dominated by human activity, showing that landscape heterogeneity decreases disturbance spread. In turn, disturbance introduces a source of landscape heterogeneity, but it is not enough to counterbalance the homogeneity trend due to agricultural abandonment. Land cover changes and wildfire occurrence (fires larger than 0.3 km^2) have been monitored in the Tivissa municipality (208.4 km^2) (Catalonia, NE Spain) from 1956 to 1993. Land cover maps were obtained from 1956, 1978 and 1993 and they were overlaid with fire occurrence maps obtained for the 1975–1995 period from 60 m resolution remote sensing images, which allow the identification of burned areas by sudden drops in Normalized Difference Vegetation Index (NDVI). Changes in landscape patterns in relation to fire regime have been analyzed considering several parameters: patch density, mean patch size, mean distance to the nearest neighbour of the same category, edge density, and the Shannon diversity index. In the 1956–1993 period there is a trend to increasing landscape homogenization due to the expansion of shrublands linked to a decrease in forest surface, and to the abandonment of agricultural lands. This trend, however, is not constant along all the period. Fires are more likely to occur in woody, homogenous areas, increasing landscape heterogeneity, as observed in the 1978–1993 period. This increase in heterogeneity does not counterbalance the general trend to landscape homogenization as a consequence of agricultural abandonment and the coalescence of natural vegetation patches.

Introduction

Landscape ecology assumes that the spatial arrangement of land cover patches has ecological implications. Disturbances, which have a spatial dimension spreading through the territory, have revealed essential processes by modeling ecosystem functioning and structure. In fact, disturbance regime and landscape pattern are assumed to have strong mutual interactions, which need to be empirically supported. Disturbances spread across landscapes as a function of the abundance and arrangement of disturbance-susceptible habitats (Turner et al. 1989). In turn, landscape patterns are conspicuously determined by disturbance frequency, intensity and extension (Pickett and White 1985; Krumel et al. 1987); in such a way that these are main contributors to the patterns of the patch-matrix mosaic by promoting different successional stages and post-disturbance replacements of natural communities (Turner 1989; Forman 1995). These mutual interactions between disturbance regime and landscape structure may become complex, resulting in dynamic patterns through time (Roberts 1996), particularly when, in addition to disturbances, other processes promote opposing homogeneity patterns on a landscape.

Empirical evidence of the relationship between a disturbance source, such as fire regime, and landscape pattern, is mostly based on natural landscapes with low human activity, which introduces a new source of complexity to landscape dynamics. Studies on the interactions between fire and man-induced land cover changes are, however, much more scarce. Here we study the dynamics of landscape patterns related to disturbance regime in an area where fire occurrence is driven by an accumulation of fuel as a consequence of land use changes. The main objective of this study is to analyze the mutual relationships between landscape patterns of heterogeneity and wildfires in a rural region of the eastern Iberian peninsula over the last two decades of the 20th century. We hypothesize that fires are more prone to burn in homogeneous areas. However, the role of fire in promoting landscape heterogeneity may be more complex due to its interaction with other successional processes linked to land use change.

Among other disturbances, wildfires are widely common in boreal forests, temperate grasslands, tropical savannas and Mediterranean woodlands (Kozlowski and Ahlgren 1974; Attiwill 1994). The relation between fire regime and landscape patterns has been explored from theoretical and modeling approaches (DeAngelis et al. 1985; Baker 1994; Roberts 1996). If we consider landscape scales which include a series of fires occurring through time, we expect to find a mosaic of patches in different successional stages (Turner 1989; Haydon et al. 2000) which have different responses to the variability of fire severity (Turner et al. 1997). Therefore, fire may act as a source of landscape heterogeneity. Romme (1982) showed that fire promoted landscape diversity in subalpine forests, and Knick and Rotenberry (1997) found in shrub steppe that fire increased fragmentation by decreasing the area of remaining shrublands and increasing the distance between remaining shrub patches. Alternatively, fires may be so extensive and severe that they may cause a landscape homogenization within the burned area, in comparison to the pre-burned situation (Turner et al. 1994). This effect is a consequence of biomass losses and the transient uniformity of the environmental conditions after fire.

Fewer problems appear when considering the effect of landscape pattern on fire regime. Fire spread is determined by fuel arrangement in the territory, and there is a close relationship between the type of land cover and the fuel characteristics (Turner and Romme 1994). Therefore, we expect that fire occurrence across the landscape will be influenced to some extent by the arrangement of the different types of land cover, in which the probability of ignition will be also different (Burgan et al. 1998). Discontinuity of fuel types will produce changes in fire propagation rates. Weir and Johnson (2000) found that the fire cycle in boreal forests became longer in areas with higher fragmentation due to settlement.

Mediterranean ecosystems are recognized to have been modeled by fire for a long time (Trabaud et al. 1993). In the last decades, wildfires have increased in the Mediterranean region, and particularly in the Iberian peninsula (Moreno et al. 1998). This increase has been due to a combination of (1) fuel accumulation as a consequence of the abandonment of cultivated fields or the change in traditional agriculture and cattle raising (Giralt 1990; Debussche et al. 1999), (2) raising climatic fire risk (Piñol et al. 1998), and (3) an increase of ignition sources (Terradas et al. 1998).

In cultural landscapes, the relationship between fire regime and landscape pattern may be highly influenced by the ability of human societies to promote rapid changes in land cover (Johnson et al. 1998). For example, in the Mediterranean region, burned forests may be transformed to grazed pastures. Therefore, in this region, characterized by a mosaic of cultivated fields (consisting of vineyards, olive groves, cereal crops, etc.), shrublands and evergreen forests, it may be expected that landscape heterogeneity will limit fire spread. As in many other countries, the landscape has been rapidly changing in the northwestern Mediterranean countries in recent decades. There is a general trend to the abandonment of less fertile areas and to an increase of the human activity in the more fertile ones (Naveh and Leiberman 1990; Douglas et al. 1996). However, changes in the landscape patterns may be quite complex, with the disappearance of small patches of natural vegetation in the matrix of agricultural dominated land, and the increase of the continuity of natural vegetation patches due to afforestation in the less fertile, abandoned areas (Fernández-Ales et al. 1992).

In this study, we analyze in an area of the eastern Iberian peninsula the changes in land cover from 1956 to 1993, and the spatial patterns of fire occurrence from 1975 to 1995. We specifically address the following questions: Does landscape heterogeneity influence fire occurrence? Do fires increase heterogeneity trends? To accomplish these purposes we use remote sensing and GIS techniques. Satellite image analysis provides an efficient methodology to obtain regional level data on fire occurrence, and it has been widely used for mapping burned areas (Kassischke et al. 1993; Pereira and Setzer 1996; Fernandez et al. 1997; Haydon et al. 2000). From all sensor bands and indices, NDVI is the most commonly used in studies of burned areas detection (Salvador et al. 2000; Díaz-Delgado et al. 2002). GIS techniques allow us to combine this information to land cover layers obtained from pre-existing maps in order to assess the relationships between fire regime and landscape structure (Quattrochi and Pelletier 1991; Davis and Burrows 1994).

Study area

The study was performed in the Tivissa municipality, which has an area of 208.4 km^2, and is located in Catalonia (NE Spain), near the Mediterranean coast (between 40°54'37" N and 41°21'30" N, and between 0°28'34" E and 0°52'53" E). The area ranges from the coast to the Ebre river banks in the inland, and it is crossed by several mountain reaching 910 m. The climate is Mediterranean (mean year temperature: 15 °C, mean minimum temperature: 7 °C in January, mean maximum temperature: 24 °C in July, mean year rainfall 600 mm, 10% of which in summer). The majority of the study area bedrock consists of marls and limestones. Vegetation is dominated by shrublands ("garrigue") and Aleppo pine (*Pinus halepensis* Mill.) forests, which in many cases are the result of secondary succession after the agricultural abandonment occurring during the 20th century. The number and extension of fires have been very high during the last decades, the area having one of the highest rates of fire recurrence in Catalonia (Díaz-Delgado 2000). This fire regime is a consequence of fuel accumulation and of the hot, dry conditions of summer, which are exacerbated by frequent, strong northwestern winds. The human population has decreased during the 20th century and currently it is approximately 1700 people, most of them living in the main town (Tivissa). Agriculture is an important economic activity, currently based on dry farming (olive tree, vineyards, almond and hazel tree), especially in the northern and western areas of the territory. The resulting mosaic of agricultural land and natural vegetation (Figure 1), where fire occurrence is common, appears appropriate to analyze the relationship between landscape structure and fire regime in temperate, rural areas.

Data and methods

Land cover sources

Three land cover maps (corresponding to years 1956, 1978 and 1993) were obtained from different sources. The 1978 map (MAPA (1980), Mapa de Cultivos y Aprovechamientos, Ministerio de Agricultura, Pesca y Alimentación, Spain) was done from field surveys and ∼1:18000 aerial photographs. The scale of publication is 1:50000 and the minimum patch size is about 4 ha. The 1993 map (DARP 1998) was elaborated by photointerpretation of colour orthophotographs with a pixel size of 2.5 m and a scale of publication of 1:25000 (Figure 2). The minimum patch size is about 0.1 ha. The 1978 and 1993 maps were available in a vector, digital format. The 1956 land cover map was created by us by photointerpretation of aerial photographs (1956, flight scale ∼1:30000), which were scanned and orthorectified using a digital elevation model (Figure 1). The scale of the resulting map can be considered about 1: 25000, based on the 2 m pixel size of the orthophotos and the planimetric error of the orthorectification process. To allow comparisons among the three maps, the vector format was transformed to raster format with 4 and 16 m pixel resolution. The finer resolution represents a common scale that preserves the detail of the 1956 and 1993 maps, but exaggerates the actual detail of the 1978 map. Conversely, the coarser resolution represents the actual detail of the 1978 map, but it causes loss of detail on the 1956 and 1993 maps. Land cover limits were visually elaborated and digitized on screen in vector format. The 1956 map was not likely to provide relevant information about the relationship between landscape structure and fire regime during the 1975–1993 period, but it was useful to describe the land cover dynamics of the area in the last half of the twentieth century.

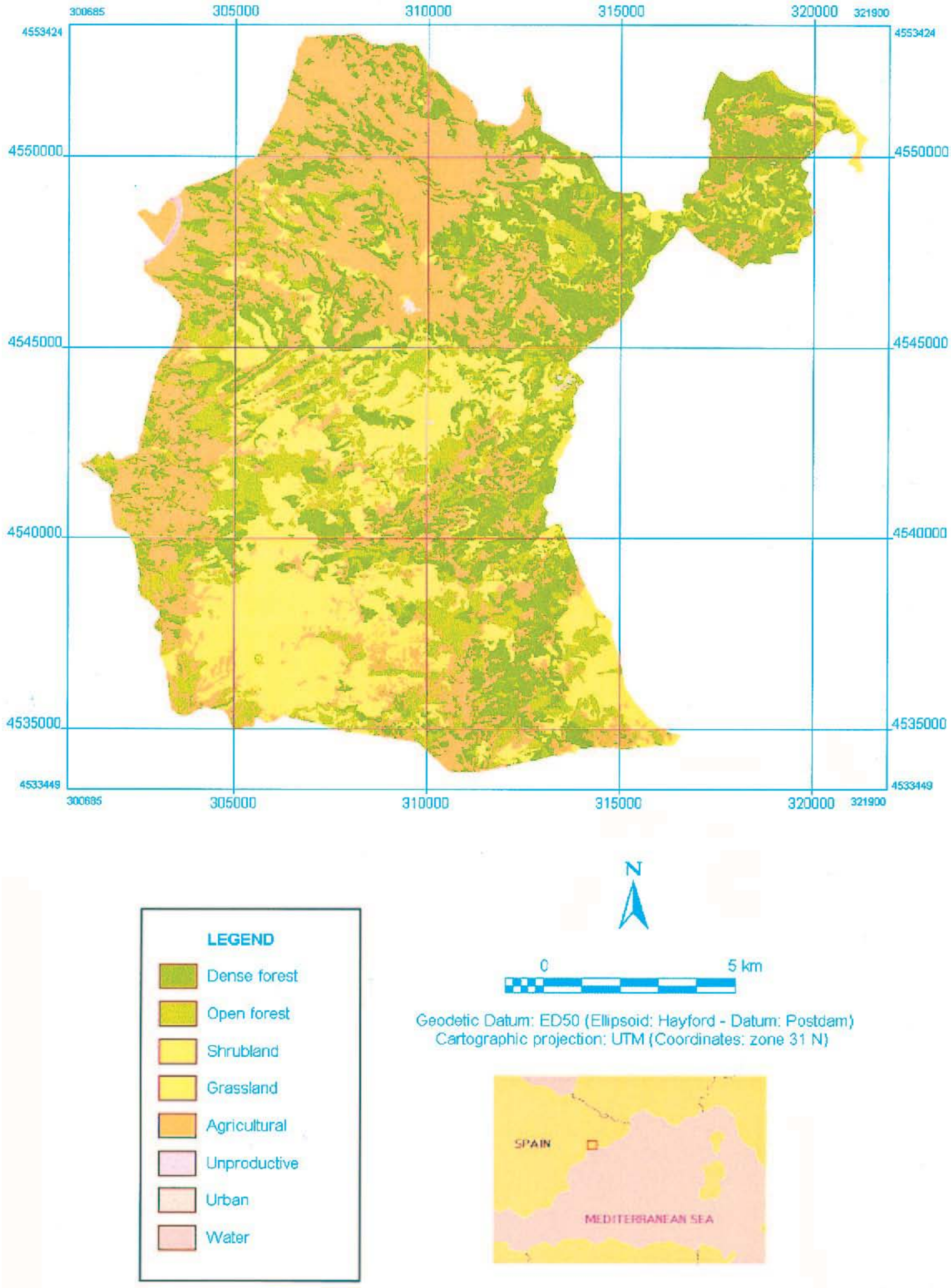

Figure 1. Land cover map of the Tivissa municipality in 1956.

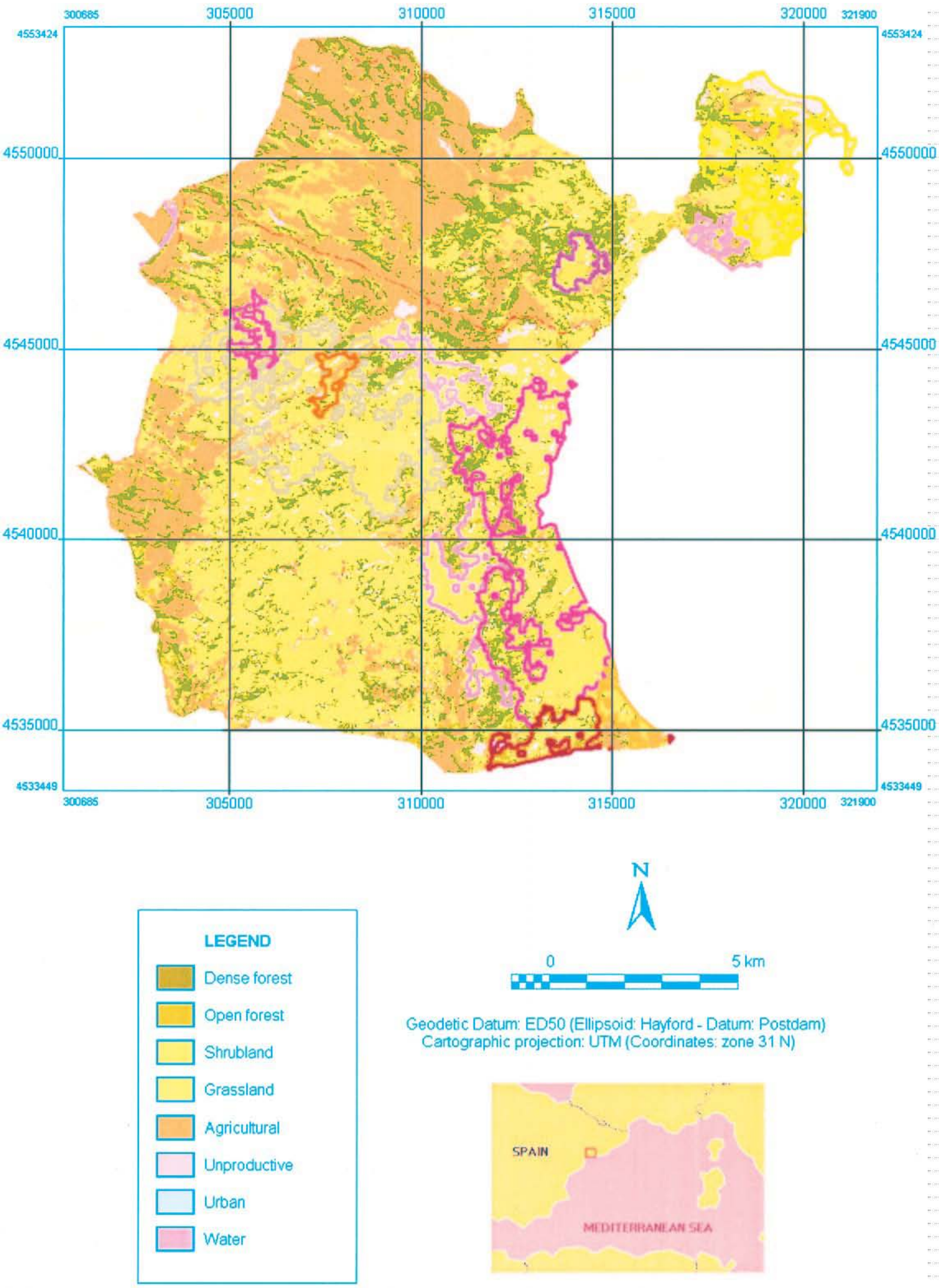

Figure 2. Land cover map of the Tivissa municipality in 1993. Fire perimeters of the 1978–1993 period are drawn.

Given the discrepancies between the land cover legends of the different maps, we built a common legend by including the different categories in the following nine groups: dense forest (canopy cover > 20%), open forest (5% < canopy cover < 20%), shrubland, grassland, agricultural lands, unproductive, urban, continental water, and freeways. The two categories of forest correspond in fact to distinct parts of the gradient from shrublands to forests: open forests are shrublands with scattered trees. More categories were defined for natural vegetation than for agricultural lands, because fires mostly occur on areas of natural vegetation.

Landscape dynamics estimations

Changes in land cover were analyzed by building transition matrices from the 4 m pixels (raster format) of the nine cover categories between 1956 and 1978, and between 1978 and 1993. The MiraMon GIS software (Pons 2000) was used to calculate the transitions between categories.

The FRAGSTATS program (McGarigal and Marks 1995) was applied to the resulting 16 m pixel raster images in order to obtain the following descriptors of landscape pattern:

- patch density (#/100 ha): number of patches in relation to the total area
- mean patch size (ha)
- mean distance to the nearest neighbour of the same category (m): considering the distance from the edge of each patch to the closest edge of any patch of the same category
- edge density (m/ha): sum of the perimeter edge of all patches in relation to the total area
- Shannon diversity index H':

$$H' = \sum_{k=1}^{s} p_k \ln p_k,$$

where s = number of categories, and p_k = proportion of the area in category k.

Patch density and diversity measures, such as the H' index, are spatially independent estimations of the heterogeneity of a landscape, while distance to nearest neighbour is dependent on the abundance of patches and their location relative to one another (Forman 1995). Patch size and edge length are landscape attributes related to fragmentation, and they have particular ecological significance (Forman 1995).

Burned areas detection

For the 1975–1995 period, burned areas larger than 30 ha were determined by Multi-Spectral Scanner (MSS) and Thematic Mapper (TM) images from Landsat 1 to 5 satellites (spatial resolution 79 × 59 m and 30 × 30 m, respectively). More than one hundred images, distributed through the considered period, were employed after applying geometric and radiometric corrections (Pons and Solé-Sugrañes 1994; Palà and Pons 1995). Near-infrared and red bands were used to calculate NDVI images (Normalized Difference Vegetation Index, Mather (1999)), which can be considered as an estimation of vegetation cover (Gamon et al. 1995; Anderson et al. 1993). To avoid confusions between burned areas and other surfaces that yield a sudden drop of NDVI, a set of masks was applied for clouds and crops from the 1:250000 Corine-Land Cover Map (CORINE 1991). Therefore, the analysis of fire effect on landscape patterns in agricultural areas was not performed. Areas greater than 0.3 km^2 were considered to have burned when the difference of consecutive NDVI images was greater than threshold values. The aim of these thresholds was to detect as many fires as possible but avoiding misinterpretation of NDVI decreases due to land cover changes other than fires. The threshold values were obtained from empirical regression models adjusted to 21 fires whose surface was previously known from the Catalonia region (see Salvador et al. (2000) for details of fire scar detection). Finally, fire validation was obtained from the records from regional administration (Díaz-Delgado 2000) and from ground survey. This procedure allowed us to recognize areas that have burned more than one time during the study period (Salvador et al. 2000; Díaz-Delgado 2000). For each burned area, fire size and perimeter, and time interval between two fires were included in a database. The spatial analysis of this information was carried out by using the MiraMon GIS software (Pons 2000).

Landscape-fire relationships

Fire occurrence was analyzed for the period 1978–1993; this means that fires detected before 1978 (two fires) and after 1993 (two fires) were disregarded. The GIS was used to overlay the unburned and burned areas with the land covers. The surface of the different categories in burned areas were estimated from the map previous to the respective wildfire. Then, a proportion of burned area for each type of land cover was calculated as the ratio

$$\frac{b_i / s_i}{s_i / s_t}$$

where s_t was the total area of the territory, s_i was the area of each land cover category *i*, and b_i the burned area in each land cover category *i*. This ratio describes how common fire is in each land cover type in relation to the respective land cover area, without consideration of differences attributable to climate or topography within or between land cover types.

We also calculated, for burned and unburned areas, the 1978–1993 transition matrices between land cover types. We only considered the four more abundant categories: dense forest, open forest, shrubland, and agricultural land (see Table 4). The transitions from agricultural land cover were, however, not considered, because this land cover was excluded from the fire occurrence map.

We evaluated the differences of landscape pattern in 1978 between areas that were burned in the 1978–1993 period and areas that remained unburned. We established a grid of 256 samples of 1 km^2 (quadrats), regularly arranged, covering all the Tivissa territory. This grain of resolution has been shown to be appropriate to study historical landscape changes (Delcourt and Delcourt 1996). Quadrats were considered as burned if fire was detected in at least 80% of its surface, and as unburned if this percentage was not attained. Therefore, these unburned quadrats were considered as controls to evaluate the relation between landscape structure and fire occurrence.

Neighbour quadrats may show similar landscape patterns due not only to fire effects, but because of similar climate, topography or any spatial-dependent factor. To assess the degree of relationship among spatially autocorrelated landscape variables, we used a Partial Mantel test (Fortin 1999). We performed a three-way model using the R package (Casgrain and Legendre 1999), in which the "variable distance matrix" was built from the differences between the landscape pattern parameters in the 1978 map for each pair of quadrats of the matrix, that is the 256 quadrats covering all the Tivissa territory. The "design matrix" expresses the differences in fire occurrence between the two quadrats of each pair of the matrix. It was built from the coincidence of fire occurrence in the 1975–1998 period. The "geography distance matrix" was built from the Euclidean distance between the center of each pair of quadrats of the matrix (Fortin and Gurevitch 1993). This partial Mantel test takes into account the spatial autocorrelational effects in the model, and tests whether there are significant differences of landscape parameters in the two types of fire history (burned and unburned areas in the 1978–1993 period) when the effects of the spatial location are kept constant. The parameters of landscape pattern considered were patch density, mean patch size, mean distance to nearest neighbour of the same category, and H' diversity index. The significance of the normalized Mantel statistic *r* was assessed by performing 500 iterations after randomly permutating the arrangement of the elements of the distance matrix.

Differences of landscape patterns in 1993 between burned and unburned areas during the 1978–1993 period were examined by the same analyses explained above. In this case, the "variable distance matrix" was built from the differences between the landscape pattern parameters in the 1993 map for each pair of quadrats of the matrix.

Results

Land cover dynamics

The extent of the different types of land cover in 1956, 1978, and 1993 is shown in Figure 3. The percentage of land covered by shrubland increased from 5292 ha to 11609 ha, being the most important increase in the period 1978–1993. From 1956 to 1978, the area which experienced the successional transition from shrublands to forests (mainly pine forests) was similar to the area of forests that became shrublands. In the 1978–1993 period, however, the area that showed a transformation from forest to shrublands was much higher than the area that became forests from shrublands (Table 1).

If we discriminate between open and dense forests, we observe that open forests became very rare (Figure 3). Most open forests (about 80%) and many dense forests (about 30%) became shrublands in the 1978–1993 period, while successional transitions from shrublands to open or dense forests only covered 4 and 20% of these losses, respectively (Table 1).

Agricultural land shows a moderate decrease during this period (Figure 3). The transition matrices (Table 1) show that, in the 1956–1978 period, a great amount of agricultural lands were abandoned and be-

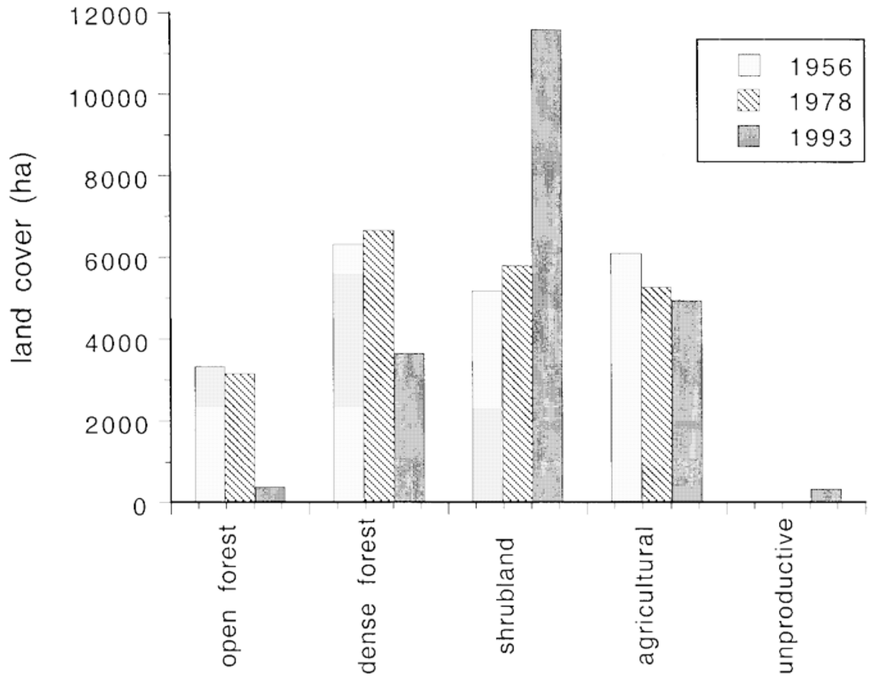

Figure 3. Area (ha) of the different land cover groups in 1956, 1978 and 1993. Values of the less abundant groups (grassland, urban, freeways and continental water) are shown in Table 1.

came shrublands or forests. This transformation was not balanced by the area of forests or shrublands that became farmed, which represented approximately half of abandoned farmland. In the 1978–1993 period, this trend continued with lower intensity. Changes between other categories were quantitatively much lower. For example urban land raised from 9 ha in 1956 to 16 ha in 1978 and 40 ha in 1993, or freeways increased from 0 ha in 1956 and 1978 to 33 ha in 1993. They are low values, but note that the study area was rural, with a concentrated type of urbanization in few, small villages, and where population (about 1700 people in 1991) does not show a trend of fast increase.

The changes in the parameters of landscape pattern show that during the 1956–1993 period there was a trend of decreasing heterogeneity and fragmentation, with lower values of patch density and edge density, and higher mean patch size at the end of the period (Table 2). However, from our data we can recognize two consecutive, opposite trends. First, in the 1956 to 1978 period, we observe an increase of landscape homogeneity with declining patch density and edge density, and an increasing mean patch size and mean distance to nearest neighbour. This homogenization trend shifted to heterogeneity and fragmentation in the 1978–1993 period, when patch density and edge density increased, and mean patch size, distance to the nearest neighbour and the H' index diminished. The exact values of the 1978 map should be considered with caution due to its lower original spatial resolution. However, the results support that the global trend towards landscape homogenization is not constant during all the period.

Fire patterns

In the 1975–1995 period, thirteen wildfires larger than 30 ha burned inside the Tivissa municipality. The burned surface by wildfire within the Tivissa territory ranged from 81 to 1702 ha. The burned area was continuous (one compact patch) in seven of the fires, it was comprised of two patches in four cases, and it was comprised of five or more patches in only two fires. The total burned area was 6750 ha, (28% of the Tivissa area). The twice burned area in this period was 3% of the Tivissa surface, and the three-times burned area was around 1%. Fires before 1978 were rarer. From the satellite images we detected two fires in 1976 and 1977 (819 ha and 112 ha, respectively), that were not included in our analysis. Fires previous to the studied period were more scarce. There are

Table 1. Transition matrices between land cover categories in the 1956–1978, and 1978–1993 periods (ha).

		From 1956									TOTAL 1978
		Dense Forest	Open Forest	Shrubland	Grassland	Agricultural	Unproductive	Urban	Water	Freeways	
To 1978	Dense Forest	3439	1172	850	0	1046	9	0	0	0	6516
	Open Forest	843	605	1301	0	377	1	0	0	0	3127
	Shrubland	1025	1234	2921	0	620	2	0	0	0	5802
	Grassland	6	0	0	0	5	0	0	0	0	11
	Agricultural	568	249	220	0	4397	1	1	4	0	5440
	Unproductive	8	4	1	0	38	2	0	0	0	53
	Urban	0	0	2	0	6	0	8	0	0	16
	Water	0	0	0	0	4	0	0	0	0	4
	Freeways	0	0	0	0	0	0	0	0	0	0
	Total 1956	5889	3264	5295	0	6493	15	9	4	0	20969
		From 1978									Total 1993
To 1993	dense forest	2001	362	726	1	469	13	0	0	0	3572
	open forest	160	63	99	1	51	0	0	0	0	374
	Shrubland	3632	2470	4593	6	905	3	0	0	0	11609
	Grassland	3	0	2	0	2	0	0	0	0	7
	Agricultural	617	160	210	4	3970	26	3	3	0	4993
	Unproductive	96	69	169	1	11	3	0	0	0	349
	Urban	0	0	0	0	5	9	13	13	0	40
	Water	0	0	0	0	7	0	0	0	0	7
	Freeways	9	3	1	1	18	1	0	0	0	33
	Total 1978	6518	3127	5800	14	5438	55	16	16	0	

Table 2. Landscape pattern parameters along the 1956–1993 period for the whole Tivissa surface.

	1956	1978	1993
patch density (#/100 ha)	3.65	1.18	2.77
mean patch size (ha)	27.4	84.6	36.1
mean distance to nearest neighbour (m)	135.7	207.5	193.5
edge density (m/ha)	93.3	42.3	68.8
H' diversity index	1.37	1.38	1.05

Table 3. Burned areas of the different lane cover categories in the 1975–1994 period. The proportion of burned area was estimated as $(b_i/s_i)/(s_i/s_t)$, where s_t was the total area of the territory, S_i was the area of each land cover category i, and b_i the burned area in each land cover category i.

	burned area (ha)	proportion of burned area
Dense Forest	2500	1.32
Open Forest	1512	1.88
Shrubland	2467	1.00
Grassland	2	0.90
Agricultural	246	0.16
Unproductive	16	0.30
Urban	0	1.00
Water	0	1.00
Freeways	0	1.00

records from fires in 1919 (about 100 ha), 1924 (about 800 ha), 1937 (about 50 ha), and 1967 (about 500 ha, burning in the SW corner of the Tivissa municipality) (Castellnou 1997).

Landscape-fire relationships

Fire and land cover

Dense forest and shrublands were the most commonly burned type of land cover, followed by open forests (Table 3). The proportion of burned area occurring in pine forests, particularly in open forests, was larger than the proportion of pine forests land cover. The proportion of burned shrubland was the same as the proportion of shrubland cover in the overall territory. Unproductive land cover burned in a lower proportion than their surface represented. A very small area of grasslands burned, but it was proportional to their surface in the territory.

A large percentage of burned pine forests changed to shrublands after fire, this change being more relevant than in unburned areas (Table 4). The percentage of forests remaining in the same category was lower in open than in dense forests. Most shrublands

Table 4. Transition matrix of the percentage of the area of the four dominant land covers between 1978 and 1993 for unburned and burned areas.

UNBURNED AREAS (%)				
		From 1978		
		Dense Forest	Open Forest	Shrubland
To 1993	Dense Forest	36.3	13.1	14.5
	Open Forest	2.4	1.6	1.4
	Shrubland	48.4	77.2	78.3
	Agricultural	11.4	6.2	4.2
BURNED AREAS (%)				
		From 1978		
To 1993	Dense Forest	16.4	9.4	8.3
	Open Forest	2.7	2.7	2.3
	Shrubland	74.3	81.7	81.0
	Agricultural	4.7	3.4	2.4

remained in the same category after being burned. In fact, wildfires decreased the change rate of both open forests and shrublands to dense forests. Although the total surface of burned agricultural lands was low (246 ha), most of it shifted to shrubland, and only about 25% of it remained as cultivated. Fire might have enhanced the abandonment of cultivated areas which were later occupied by woody vegetation. However, fire did not increase the transformation from woody vegetation to farmlands, this change being lower in burned than in unburned sites.

Effect of landscape patterns on fire occurrence

When considering the one km^2 quadrats across all the territory, and keeping constant the effects of the spatial location, burned areas in the 1978–1993 period were those with lower patch density and H' diversity index (partial Mantel test, $r = -0.106$, $p = 0.002$; $r = -0.061$, $p = 0.052$, respectively), but with a higher mean patch size (partial Mantel test, $r = -0.150$, $p = 0.004$) (Figure 4) in the 1978 landscape. Differences in the distance to nearest neighbour between burned and unburned areas were not significant ($r = -0.086$, $p = 0.064$).

Effect of fires on landscape patterns

In 1993, burned areas had larger patch size and mean distance to nearest neighbour (partial Mantel test, $r = -0.127$, $p = 0.016$; $r = -0.149$, $p = 0.006$, respectively), and lower H' index (partial Mantel test, $r = -0.077$, $p = 0.020$) (Figure 4). Patch density was

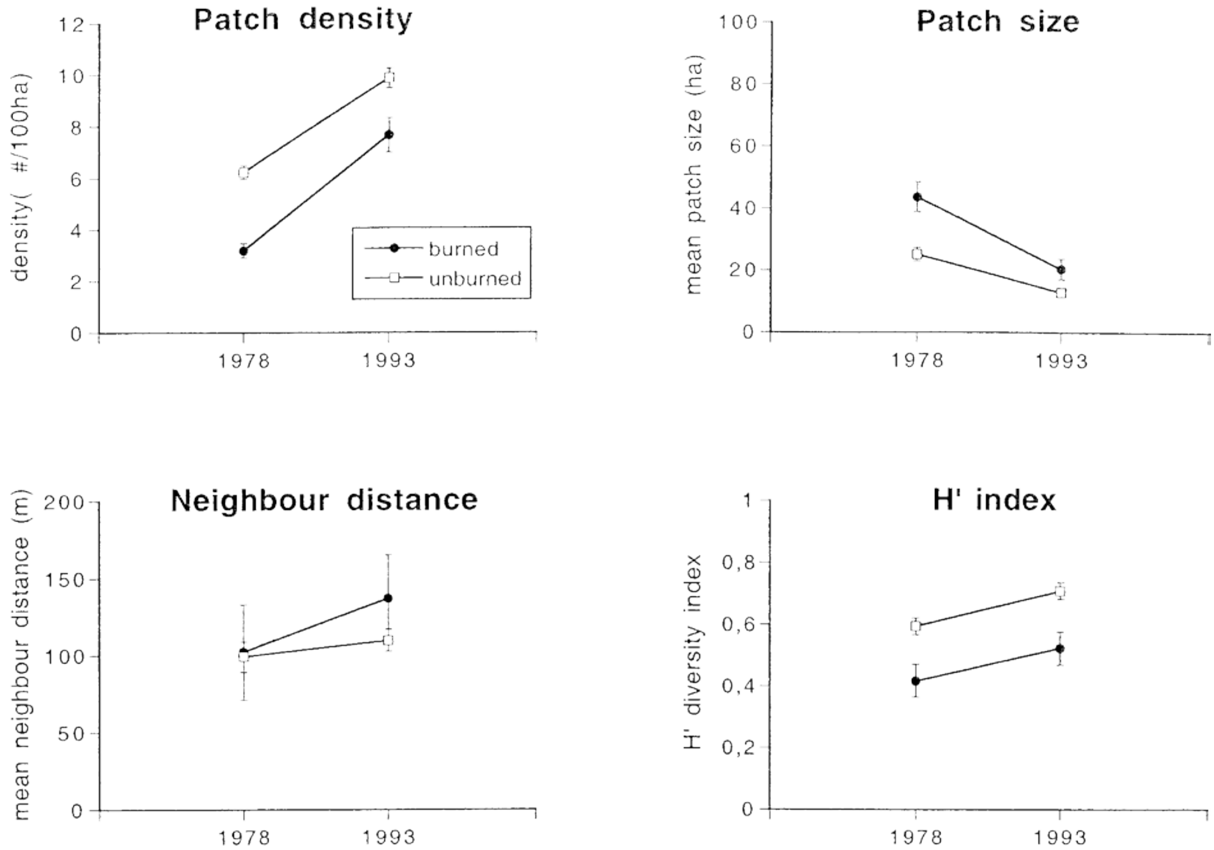

Figure 4. Mean (SE) values of the different landscape pattern descriptors in 1978 and 1993 for burned and unburned areas during the period 1978–1993. The values were obtained from 256 one km^2 quadrats covering all the territory.

lower in burned areas than in unburned ones, but these differences were not significant (partial Mantel test, $r = -0.026$, $p = 0.198$). The ratio of change of landscape pattern between 1978 and 1993 was different in burned and unburned areas (Figure 4). Patch density and neighbour distance increased more in burned than in unburned areas, while the opposite trend is observed for patch size. No differences in the H' increase was observed between burned and unburned areas.

Discussion

Land cover changes

Our study documents important changes in the natural vegetation during the second half of the 20th century in the northwestern Mediterranean region, with an important decrease of forested surface which became shrublands. This result is important because more emphasis has been placed on the recent increases in forest cover, already documented in the region (Douglas et al. 1996; Debussche et al. 1999). Concern about a negative effect on animal diversity as a consequence of the loss of open habitats have arisen (Pino et al. 2000; Real 2000). However, our results indicate that, in the Tivissa area, the increase in natural vegetation is moderate, and a considerable part of the forest surface has become shrubland. Aridity in the Tivissa area is higher than in northern sites and it may limit forest development. However, we find that fire occurrence in the 1975–1995 period also played a substantial role in this process. The effects of previous fires are not negligible but, overall, fire occurrence in Tivissa was lower in the 1870–1975 period (Castellnou 1997), except for two fires in 1967 (ca. 500 ha) and 1974 (ca. 200 ha), which may have also contributed to this pattern.

Our results also show a decrease in area occupied by agricultural lands. The estimation of the surface which has become natural vegetation from cultivated land may have been overestimated in our study because some transitions could actually be due to inaccuracies in matching patch edges in consecutive maps. Abandonment of agricultural lands, however, has been well documented in the northern Mediterranean region (Barbero et al. 1998), and it can be attributed to changes in traditional agricultural practices (Debussche et al. 1999). The secondary succession occurring in abandoned cultures leads to shrublands, and finally to forests (Escarré et al. 1983; Masalles and Vigo 1987). Holm-oak (*Quercus ilex* L.) forests in moister locations, and wild olive (*Olea europaea* L.) and carob tree (*Ceratonia siliqua* L.) woodlands near the coast have been traditionally considered as the climax formations of the region (Bolós 1967). Pine forests, however, are the most dominant type of forest as a successional transient, or as a community maintained by man (Barbero et al. 1998). Different from other Mediterranean communities of the Iberian peninsula, grasslands are irrelevant in the area.

The result of these processes is an increase of landscape homogeneity in relation to the pattern existing during the previous periods of maximum agricultural use. The role of shrublands and forests in structuring the landscape pattern is not identical. Mean patch size in 1993 is greater than in 1956 due to the loss of some cultivated areas with a fine grained spatial pattern surrounded by natural vegetation, but mostly because of shrubland dominance. The coalescence process of natural vegetation, particularly shrublands, can also explain the decrease in patch density and edge density and the increase of the mean distance to the nearest neighbour. Since the number of land use categories does not change very much along the 1956–1993 period, changes in the H' diversity index will be mainly related to the relative abundance of the different categories. Therefore, the dominance of a single land use type (shrublands) would produce a decrease in the value of this diversity index.

Landscape-fire relationships

Fire and land cover

We find that fires strongly influence the pattern dynamics of the whole landscape, and the dynamics of the different land covers. The percentage of land cover remaining in the same category after fire ranges from 2.7% for open forests to 81.0% for shrublands. This is an estimation of the resilience of the different land cover types. Resilience may be high in shrublands, as known from many studies in Mediterranean ecosystems which have described autosuccessional processes (Hanes 1971; Trabaud and Lépart 1980) from post-fire mechanisms of regeneration (resprouting, enhanced germination, see Keeley (1986) and Trabaud (1987)). Given the slower growth rate of trees, forests are expected to recover more slowly than shrublands. We find that this post-fire recovery from forests is very low in open forests, which mostly became shrublands. The percentage of remaining open forests is lower than the percentage of remaining dense forest, perhaps because the seed bank is not enough to restore pine populations (Herranz et al. 1997). However, in some cases (about 10%), open forests may change to dense ones, perhaps because of local, massive recruitment after fire. Many factors are involved in fire regeneration after fire: seed bank availability, seed ability to resist fire, seed and seedling predators, site quality, and climatic condition in the year immediately after fire (Nathan and Ne'eman 2000). *P. halepensis* has been considered to successfully regenerate after fire in the Eastern Mediterranean region (Arianoutsou and Ne'eman 2000). However, our data show that this fast forest recovery is not a regular pattern across the whole distribution area of *P. halepensis* (Trabaud 2000).

When comparing unburned versus burned areas, we also observe that fire promotes the transformation from pine forests, and particularly open forests, to shrublands. These tendencies were hypothesized from synchronic studies (Masalles and Vigo 1987), but rarely from diachronic studies like this one. Fire also interrupts the successional transition from shrublands to forests. However, in our study area, fire can not be considered a way to increase farmland: less surface of dense forest changed to agricultural lands in burned areas than in unburned areas. There is also an important transition from forests to shrublands in unburned areas

The surface of burned forests, particularly open forest, was larger than expected from the relative abundance of these land covers. The dominant tree (*Pinus halepensis*) is highly flammable (Trabaud 2000). In addition, this plant community usually shows a vertical fuel continuity between the overstorey (shrubs) and the trees canopy, making this community very prone to burn (Terradas et al. 1998). Fuel load in the overstorey may be lower in dense forests than in open ones, explaining the lower values of fire occurrence in dense forests. In spite of the high flammability of the Mediterranean shrublands (Valette et al. 1979), fire does not seem to have a predilection for this kind of community among the different kind of land cover types existing in the area.

Fire and landscape pattern

Results indicate that, considering 1 km^2 units of landscape, more homogeneous landscapes, (i.e., with fewer but larger patches), are more prone to burning. The lower H' value also indicates that the different land covers are more evenly represented. This pattern will be justified if fuel load is correlated with the different land covers.

We observe that the increase in patch density and the decrease of patch size is steeper in burned than in unburned areas (considering 1 km^2 units of landscape) in the 1978–1993 period. Therefore, in burned areas the number of small patches increases more than in unburned areas. As shown by other studies (Romme 1982), fire promotes different successional stages to coexist in the same landscape. In our study area, crown fire enhances the transition from pine forests to shrublands as seen above. This fire effect, however, is not enough to modify the general pattern observed in 1978: the burned areas remain more homogeneous in 1993 than the unburned ones, as seen by their higher patch size and lower H' diversity index and patch density (though, patch density was not statistically significant). This inertia may be due to the resilience of Mediterranean ecosystems after fire, which tends to reproduce the community existing before fire (Keeley 1986; Trabaud and Lépart 1980; Trabaud 2000).

Conclusions

In the study area (Tivissa), important transformations of the land cover have occurred during the second-half of the 20th century: a substantial increase of the surface occupied by shrublands correlated to a decrease in forest surface, and to a moderate abandonment of agricultural lands. These processes have promoted a landscape homogenization. The succession following agricultural abandonment rarely achieved the final forest stage, and instead shrublands remain dominant. Fire plays a major role in these changes by moving back the successional process. The transition from woody vegetation to farmland by fire is negligible. Fires are more prone to occur in woody, homogenous areas. Fires also promote landscape heterogeneity by increasing the number of small patches, but it is not enough to counterbalance the general trend to landscape coalescence, mostly due to the agricultural abandonment and the shrubland increase. Our study provides empirical, quantitative evidence on the role of landscape homogeneity, which increases disturbance spread, and on the effects of fire as a source of landscape heterogeneity. However, this effect should be considered in combination with other drivers of landscape structure, such as land use by man, which may produce opposite effects. This evidence is particularly relevant because of the scarcity of quantitative, empirical studies considering the importance of the mutual interactions between the disturbance regime and landscape dynamics when both are driven by human activity.

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