Landscape Ecology vol. 11 no. 4 pp 215–224 (1996)
SPB Academic Publishing bv, Amsterdam

Effects of fire frequency on plant communities and landscape pattern in the Massif des Aspres (southern France)

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Keywords: fire, landscape diversity, Aspres, southern France, *Quercus ilex, Quercus suber*

Abstract

Fire frequency can affect pattern and diversity in plant communities and landscapes. We had the opportunity to study changes due to recurring wildfires on the same sites over a period of 50 years in the "Massif des Aspres" (southern France). The study was carried out in areas occupied by *Quercus suber* and *Q. ilex* series. A comparison of historical and cartographical documents (vegetation maps covering a 50 year interval and an accurate map of major wildfires during this period) allowed us to determine the changes occurring over time with or without fire action. Plant communities were grouped into three main vegetation types: forests, treed shrublands and shrublands. The passage of three successive wildfires on the same site led to a decrease in forest areas and an increase in shrublands; however, shrublands were already present before the first fire of the period under consideration. Less frequent fire occurrence induced more complex heterogeneity and greater landscape diversity. In the study region as a whole, with or without fire action, a significant decrease in forest surfaces was recorded, whereas there was an increase of unforested communities such as treed shrublands and shrublands. In some parts of the Massif fires increased the homogeneity of the landscape, in other parts they created a greater heterogeneity and diversity of plant communities.

Introduction

Mediterranean landscapes are the result of the combined action of climate, kinds of substrate, topographical forms, vegetation and historical human activity going back thousands of years. Fire of natural or anthropogenic origin has also contributed to the formation of these landscapes. It is clear that fire is a major ecological force which has played and continues to play a significant role in modeling, fashioning and developing numerous Mediterranean plant communities. Long used by Humans to reclaim virgin land or to maintain already burned sites, fire associated with other human activities (tree-felling, domestic animal grazing, cultivation) has had a significant impact on shaping the current landscapes of the Mediterranean region.

During the last two decades plant successional patterns after fire have been closely studied in the countries of the Mediterranean basin, including Spain (Garcia-Novo 1977; Casal 1985; Tarrega and Luis-Calabuig 1987); France (Trabaud 1970, 1983a; Trabaud and Lepart 1980, 1981; Prodon *et al.* 1984); Italy (De Lillis and Testi 1990; Mazzoleni and Pizzolongo 1990); Greece (Papanastasis 1977; Arianoutsou 1984; Thanos *et al.* 1989); Israel (Naveh 1975). All these authors agree that plants reappear quickly after fire and constitute an "autosuccession" model (Hanes 1971): the reestablishment of the original plant communities is a rapid process and the communities that regenerate are similar to the previous ones.

However, the authors mentioned above have only considered the effect of a single fire on vegetation; none of them has carried out research dealing with repeated fires on the same sites. What is the effect of fire on plant communities when it recurs in the same zone at frequent intervals? What changes does it induce in the vegetation? Does this recurrence create modifications in the communities leading to a degradation of their ecosystem? What are the likely effects on the landscape: greater heterogeneity or greater homogeneity (according to the types of communities burned and given that fires destroying all vegetation can promote landscape homogeneity)?

Such studies have not been carried out in the Mediterranean basin. Several difficulties are at the root of this problem. Despite an abundance of statistics and a superabundance of fires and areas burned, there is a lack of precise knowledge of the areas really affected by wildfires and of detailed chronological series for suitably located sites with a known fire history. On the other hand, in North America several studies have been carried out showing the effects of repeated wildfires on landscape composition and diversity: Romme 1982; Foster 1983; Baker 1989a, 1989b.

We had the good luck to possess precise historical and cartographical documents for a small mountain range in southern France. These allowed us to assess the effect of recurrent wildfires on plant communities and landscapes: the vegetation had been mapped over a 50-year interval and the number and extent of large fires were well-documented for the period between the two mapping surveys.

Study area

The "Massif des Aspres" (42°30–40'N; 2°35–45'E) is a secondary mountain range located at the eastern end of the Pyrénées, close the coastal plain. It stretches between 15–30 km SW of Perpignan in southern France. It is formed by several rolling hills from 100 m to 780 m high and surrounded by plains and valleys. The geology of the study area – old hercynian massif – is essentially made up of metamorphic siliceous rocks: schists, gneiss, pegmatites, forming shallow soils (generally < 50 cm deep) with an acid pH (5.2; Zeller 1958). The study area is situated on slopes covered by communities belonging to two typically Mediterranean vegetation series: *Quercus suber* (cork oak) and *Q. ilex* (holm oak). It covers 23,880 ha.

The climate of the area according to Emberger's classification (1955) belongs to the mild subhumid mediterranean climate. Annual rainfall ranges between 600 and 1100 mm according to elevation. Mean annual temperatures are from 12 to 15°C. Depending on sites the mean maximal temperatures in July (the warmest month) can reach 26°C; whereas the mean minimal temperatures of the coldest month (January) can go down to 0°C (Galtié 1992).

Table 1. Major wildfire chronology and areas burned in the Massif des Aspres.

Years	Area burned (ha)
1949	8500
1966	1800
1976	6600
1978	1850
1981	520

Fire is a frequent phenomenon and characteristic of the Massif: as a mean, 794 ha were burned by 14 wildfires each year during the period 1974–1986 (Galtié 1992). All the townships of the Massif are affected. To the extensive wildfires that stand out during the second half of the 20th century (years 1949, 1966, 1976, 1978, 1981; Table 1 and Fig. 1) numerous smaller wildfires have to be added.

Materials and methods

For fire fighting and prevention purposes, the first step towards protective planning for the Massif des Aspres was the establishment of a map of plant communities as fuels (Galtié 1992).

An interpretation of aerial photographs (Inventaire Forestier National, 1988, Infra-Red, false color, 1/18,000 scale) was carried out to establish isophenic zones, *i.e.* areas of equal tone, color and structural appearance with the aim of identifying different communities. Then a systematic field survey of the whole Massif was carried out in 1991, with the aim of describing the structure (stratification and fuel types) and the species constituting the communities identified.

The field cartography was drawn up according to the method already used (Trabaud 1973, 1974) on a 1/25,000 scale (Galtié 1992; Galtié and Trabaud 1992/1993 provide an example). To facilitate

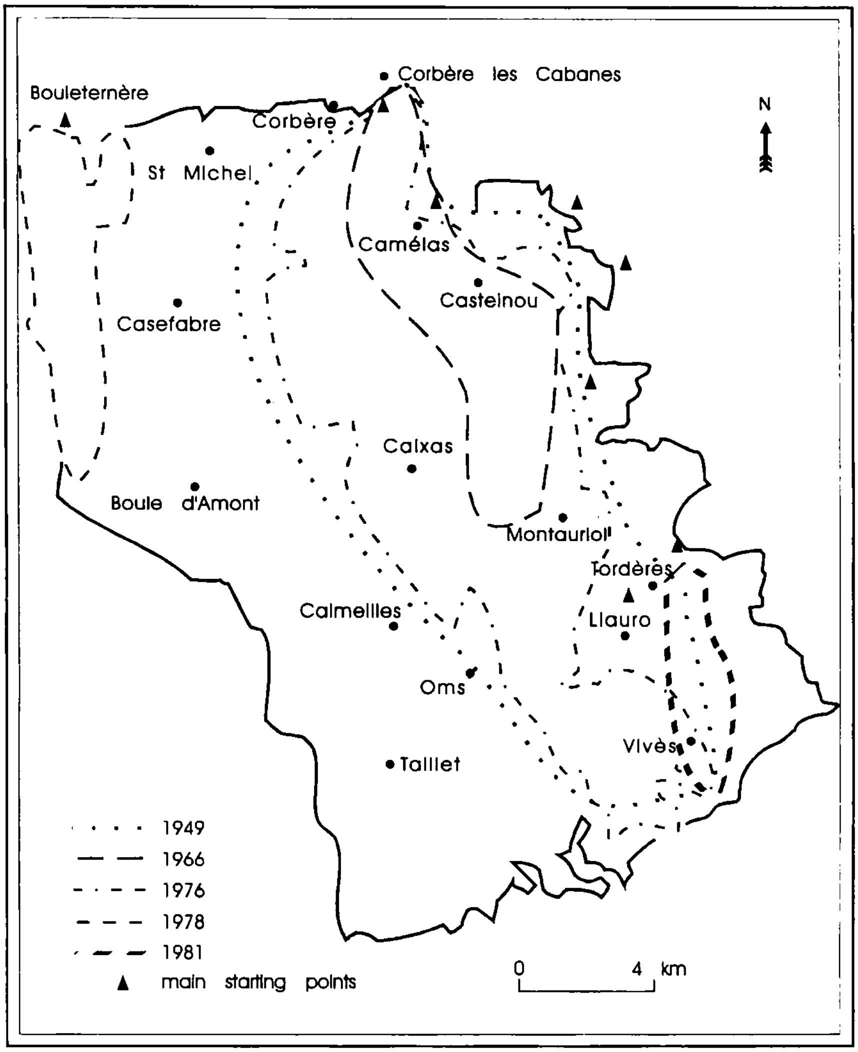

Fig. 1. Locations and areas of the last major wildfires in the Massif des Aspres (from Amigo 1981).

use and synthesis, all the mapped sheets were assembled and reduced to a 1/50,000 scale.

At the same time, Gaussen's 1/50,000 field map drafts of 1938–1942 – interpreted on the basis of aerial photographs taken in 1942 and then used to draw up the 1/200,000 vegetation map of the Perpignan region (Gaussen 1945) – were used to create a new 1/50,000 map of the plant communities of the Massif. This new cartography was necessary because the scale and scientific aim of Gaussen's study was not the same as for our mapping of plant fuels: his study was less detailed and identified only broad types and dominant species within the vegetation series.

Lastly, a precise mapping of areas burned by extensive wildfires of known date (Amigo 1981) which had swept the Aspres during the last 50 years, allowed us to identify with certainty the areas which had burned several times (Fig. 1) and map them very accurately on a 1/50,000 scale.

The time lapse between the last major wildfires (1978, 1981) and the vegetation survey for the fuel map (1991) was long enough to allow the burned communities to recover and reestablish themselves practically as they were before the fires (see recovery time for Mediterranean communities in Trabaud 1983; Trabaud and Lepart 1980).

As the Massif had been traversed by several

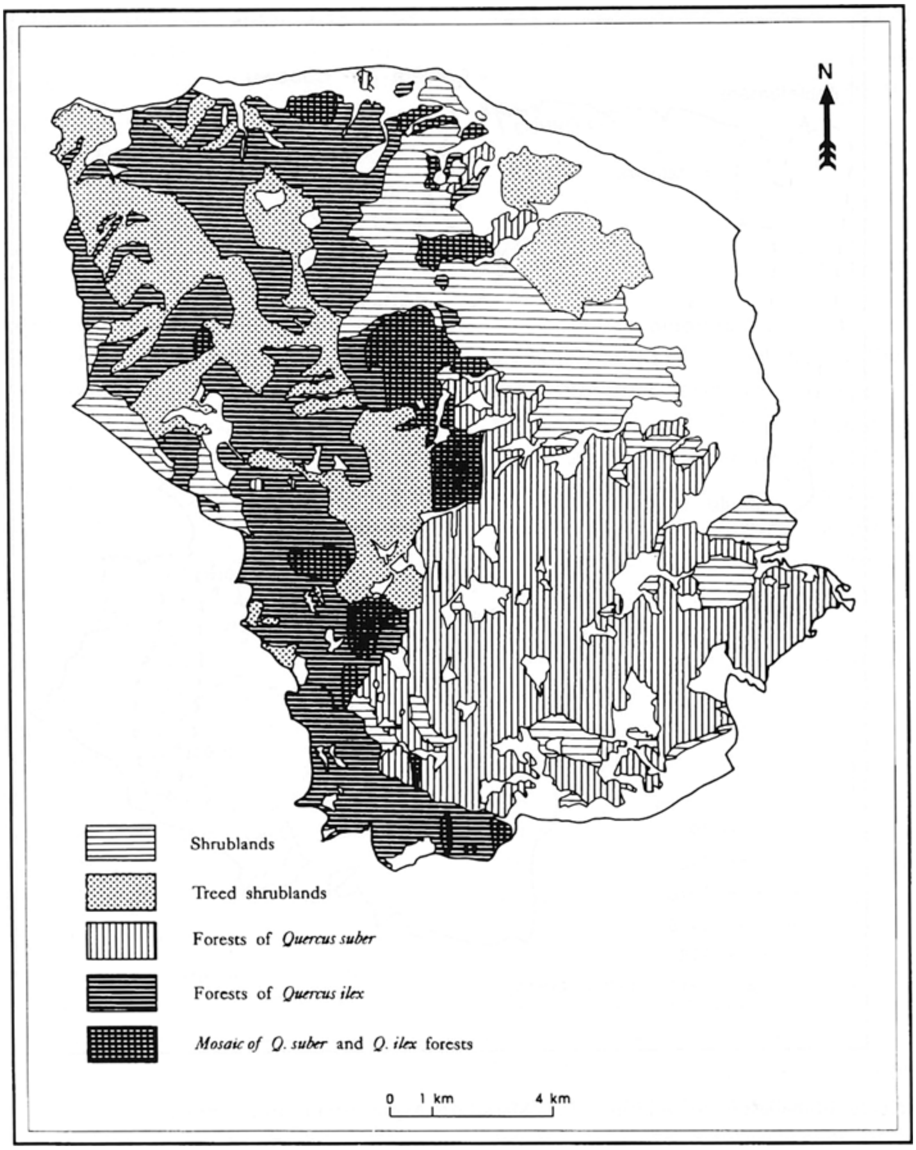

Fig. 2. Main vegetation types existing in the Massif des Aspres in 1945 (from Gaussen's field map).

wildfires, four types of area were identified according to their fire history. The limits of each large wildfire were marked on both maps. On the map containing the communities existing before the occurrence of known fires (1945), areas not burned by any wildfire were called: Zone 0; those crossed by one fire: Zone 1; by two fires: Zone 2; and by three fires: Zone 3. On the map drawn after the fires (1992) the equivalent areas were coded as: areas without fire: 0-Fire; areas with one fire: 1-Fire; areas with two fires: 2-Fire, and areas with three fires: 3-Fire, corresponding to the number of times the sites had been burned.

A grid of evenly distributed points with an identical interval equivalent to a distance of 500 m in the field was inventoried. By using transparent overlays the sampled points were precisely located on both maps.

To avoid any bias and/or influence between the authors of this paper, the preparation of both maps was carried out by one of us (JFG), and the plant communities were coded according to a numbered system. The point sampling was undertaken by the other author (LT), who decoded the community types afterwards.

In order to compare data between maps, the plant communities (mainly those described in Galtié's (1992) map) were grouped according to three vegetation types: forests covered and dominated by trees (tree cover between 50–100%); treed shrublands of the maquis and garrigue type with sparse trees (tree cover between 25–50%); and shrublands of the maquis and garrigue type with practically no trees (tree cover less than 25%). To give an account of the dynamics of vegetation the observed community changes occurring during the period were analyzed according to transition matrices (see Waggoner and Stephens 1970). The results are presented in percentages of land occupation.

The percentage values corresponding to the different history areas were compared in pairs using the reduced deviation (ε) method following the normal distribution (Schwartz 1994) allowing to test for significant differences at the 0.05 level.

Results

For purposes of presentation, both maps have been reduced to 1:125,000 scale, conserving the three main vegetation types, but dividing the forest types into those dominated by *Q. suber* and *Q. ilex*, a difference that had only been mentioned in passing in Gaussen's (1945) map (Fig. 2 and 3).

In static synchronic terms, in 1945 (Fig. 2) the vegetation landscape of Zone 0 and 1 areas was very similar (Tables 2a and b). No significant difference existed between the percentage values of the identified vegetation types (all ε were < 1.8). For Zone 0, 1 and 2 areas (Tables 2a, b and c), the percentages of forested sites were similar. The extent of the sites occupied by shrublands and treed shrublands in respect of Zone 2 and 3 areas was different from that of the Zone 0 and 1 areas. The Zone 3 areas (Table 2d) presented a forest occupation rate significantly lower (ε always at least $>$ 4.07) than that of the Zone 0, 1 and 2 areas; shrubland communities were consistently larger ($\varepsilon >$ 2.7). Thus, even before the period of known wildfire dates, Zone 3 areas were the most covered by shrublands (60.0%) and the least forested (27.5%).

With regard to cultivated land (mostly vineyards) mapped in 1945 and no longer in 1992 (given a reversion to more or less "natural" vegetation), the surfaces occupied in each Zone area were similar and made up 6.2% of the Aspres territory as a whole.

In 1992 (Fig. 3), there was a progressive decrease in forest area ratios according to fire frequency, *i.e.* 42.5% for 0-Fire areas (Table 2a), and 2.2% for 3-Fire areas (Table 2d). By contrast, there was a continuous and significant ($\varepsilon = 3.6$) increase in the proportion of areas occupied by shrublands, according to the number of wildfires: from 16.2% for 0-Fire areas (Table 2a) up to 71.0% in the 3-Fire areas (Table 2d). However, the proportion of treed shrublands was relatively constant between the four areas (no significant differences at 0.05 level; $\varepsilon < 1.9$), but with a lower rate of decrease as areas were more frequently burned: 2-Fire and 3-Fire areas (Tables 2c and d).

In dynamic diachronic terms (Fig. 2 and 3), what was the situation 50 years later, in 1992? In Zone 0, no Fire areas (Table 2a) a large proportion of forests remained forests and still dominated, whereas forested land had significantly decreased overall ($\varepsilon > 2.1$). A large part of this land changed into treed shrublands, while some treed shrublands reverted to forest (as did some shrublands). Only a quarter of original shrublands remained as shrublands. Some fields remained fields, but a large proportion of them (60%) turned to treed shrublands and forests. However, the proportion of shrublands has not significantly increased ($\varepsilon = 1.71$); in contrast treed shrublands have significantly increased in area.

All changes were significant (all $\varepsilon > 1.96$) for vegetation types corresponding to the Zone 1 and 1-Fire areas (Table 2b): increase of shrublands and treed shrublands, decrease of forests. Several forests became treed shrublands and shrublands. This decrease was partly compensated for by large areas of treed shrublands and shrublands reverting to forest.

In the Zone 2 and 2-Fire areas (Table 2c), forested surfaces have diminished, changing into shrublands. A few old treed shrublands remained unchanged, but treed shrublands increased in area in proportion to the disappearance of old burned forests. Practically all shrublands remained as

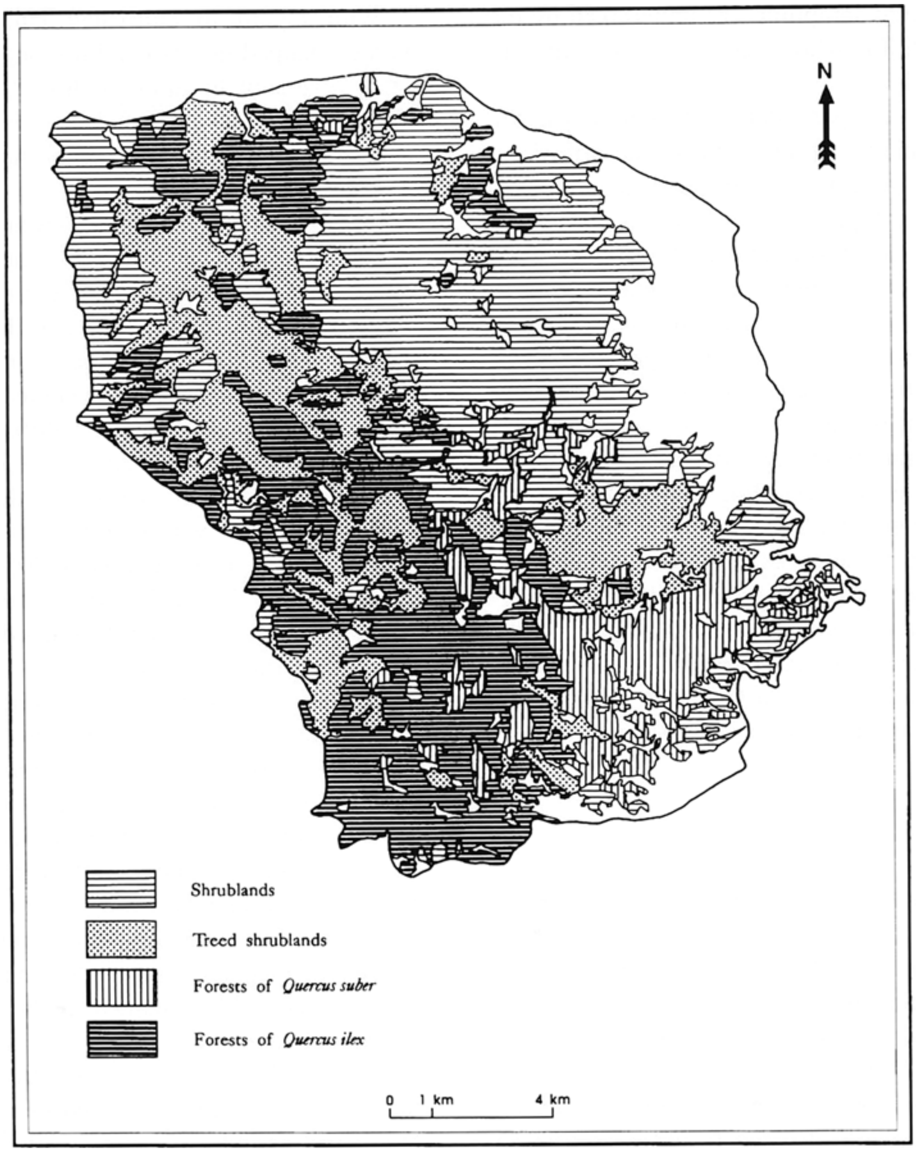

Fig. 3. Main vegetation types existing in the Massif des Aspres in 1992 (from Galtié's field map).

shrublands, while the surfaces they covered increased dramatically in regard to the 1945 figures ($\varepsilon > 3.2$). This was due to forest and treed shrubland transformations.

Curiously, in all three burned Zones there were no fields reclaimed from natural communities. With the exception of Zone 3, 3-Fire areas (in which the proportion was larger) half the abandoned fields transformed into natural communities (Tables 2b, c and d).

The most drastic transformations have occurred in Zone 3 and 3-Fire areas (Table 2d) in which forests have practically disappeared giving way to treed shrublands and shrublands. The surfaces occupied by shrublands have increased. However, there is no significant difference between the percentages ($\varepsilon < 1.43$) in 1945 and 1992. All treed shrublands changed into shrublands. Curiously, a small part of the shrublands reverted to forest, and most of the treed shrublands came from forests and old fields.

Table 2. Transition matrices of the territory (%) occupied by the main vegetation types in the Massif des Aspres at two dates 50-years apart, according to different wildfire regimes.

A-Zone 0, 0-Fire areas

Vector 1945		Forests	Treed shrublands	Shrublands	Fields	Vector 1992
60.5	Forests	71.2	20.9	6.8	1.1	42.5
19.7	Treed shrublands	20.2	64.1	15.7	0.0	36.1
10.2	Shrublands	40.5	27.5	23.7	8.2	16.2
9.6	Fields	39.5	20.6	7.6	32.3	5.2
(Σ = 100%)						(Σ = 100%)

B-Zone 1, 1-Fire areas

Vector 1945		Forests	Treed shrublands	Shrublands	Fields	Vector 1992
61.3	Forests	60.8	23.3	15.9	0.0	26.4
22.9	Treed shrublands	42.8	38.5	18.7	0.0	38.0
11.3	Shrublands	48.7	0.0	51.3	0.0	34.2
4.5	Fields	15.8	14.1	14.9	55.2	1.4
(Σ = 100%)						(Σ = 100%)

C-Zone 2, 2-Fire areas

Vector 1945		Forests	Treed shrublands	Shrublands	Fields	Vector 1992
63.5	Forests	16.5	18.3	65.2	0.0	9.0
8.3	Treed shrublands	5.1	4.3	90.6	0.0	29.8
20.8	Shrublands	2.1	0.0	97.9	0.0	59.0
7.4	Fields	12.5	19.7	24.1	43.7	2.2
(Σ = 100%)						(Σ = 100%)

D-Zone 3, 3-Fire areas

Vector 1945		Forests	Treed shrublands	Shrublands	Fields	Vector 1992
27.5	Forests	26.2	15.9	57.9	0.0	2.2
5.0	Treed shrublands	0.0	0.0	100.0	0.0	23.7
60.0	Shrublands	2.6	2.1	95.3	0.0	71.0
7.5	Fields	0.0	12.4	62.5	25.1	3.1
(Σ = 100%)						(Σ = 100%)

Discussion

Has time, with or without fire, contributed to modification of the landscape diversity? Over the years, the landscape of the Massif has become more simple in the north-east, has diversified in the north-western and south-eastern parts and has homogenized in the south-west.

In 50 years the landscape pattern of the Massif des Aspres has changed. The plant communities are probably the same but their proportions have altered: several vineyards (6%) have disappeared, forest areas have diminished (from 58.6% to 28.8%) while surfaces occupied by shrublands and treed shrublands have increased from 19.0% to 36.2% and from 16.4% to 34.7% respectively. Considerable reduction of forested areas has occurred even in the absence of fire. In fact, the changes were most marked in the Zone 1 and 2 areas (Tables 2b and c) _ maybe because formerly they suffered less from the impact of wildfires or because their original cover was more forested.

In 1945, there were three main regions (Fig. 2). The first, to the north-east, was mainly covered by unforested communities: shrublands and treed shrublands; with some patches of *Q. suber* and *Q. ilex* forests in mosaics. The second, in the south-east, was almost exclusively occupied by forests of *Q. suber*. The third region, to the west, was markedly dominated by forests of *Q. ilex* and by treed shrublands in which holm oak was the dominant tree.

Fifty years later, in 1992 (Fig. 3), these three main regions still exist, but the landscape has changed to a slight extent. The north-eastern part, which was especially affected by three wildfires (those of 1949, 1966, and 1976) is now almost exclusively covered by shrublands. The south-eastern part is more diversified. A decrease in the area once occupied by *Q. suber* can be observed, although part of it has been transformed into treed shrublands in which cork oak still remains the principal tree species. But the extreme eastern end, east of Tordères (Fig. 1, 2 and 3), remains shrubland. The western part can be divided in two subparts; in the northern one, the area of forest has diminished, even without any fire action, and consequently the treed shrublands have increased; on the other hand shrublands now cover the part burned in 1978, at the north-western top of the Massif. In the southern subpart, the area occupied by forests of *Q. ilex* has increased – especially at its old eastern border – to the detriment of *Q. suber* forests. The absence of fire and the abandoning of the cork oak forests during the last 50 years (Barello 1983) have allowed this encroachment.

The question of how fire affects the heterogeneity of a landscape is complicated by the fact that spatial heterogeneity exists on different scales. Fires can increase landscape heterogeneity by fragmenting continuous blocks of older forests and by introducing younger successional stages into the landscape mosaic. There can also be a pattern of burned and unburned patches in a given landscape and burn severity can vary over a given patch. Sometimes, fires are so extensive and so severe that they induce less heterogeneity in burned landscapes than existed in the previous plant mosaic.

In this kind of study, the problem – at least in Europe – is to find similar research that can be used as a basis for comparison. This is perhaps due to the lack of early basic material – old maps, accurate landscape descriptions, photographs – detailing landscape occupation and giving an insight into the composition of earlier plant communities and those that have replaced them. Studies dealing with fire history report on fire frequency and intervals, but not on landscape changes. For the recent period, most of the research on widland fire history has been carried out in the United States and Canada (Arno 1976; Tandé 1979; Romme 1982; Arno and Gruell 1983; Foster 1983; Romme and Despain 1989; Baker 1989a, b; Clark 1990). All these authors conclude that fire regimes affect landscape in a non steady-state system and that over time landscapes are characterized by changes in community structure, composition and diversity.

Has fire frequency had an influence on the types of communities? In the areas burned once or twice, it seems that fire has had an effect on plant communities (Tables 2b and c), changing them into treed shrublands and shrublands. But these types of communities already existed before 1942. In the same way, the areas burned three times (Table 2d) show the largest dominant shrubby communities; however, it is interesting to note that in 1945 these areas had the largest proportion of shrublands and the percentages of areas occupied do not differ significantly between 1945 and 1992 ($\varepsilon = 1.43$). Has the frequency of fire produced the presence of the shrublands or has the existence of the shrublands allowed the occurrence of repeated wildfires? Is this type of vegetation due to wildfires or does the vegetational type induce wildfires? Or is it a question of both processes acting synergetically? As there is no precise evidence as to the landscape situation and physiognomy before 1945, one hypothesis is that wildfires swept this part of the Massif long before that date. Large portions of the Aspres were formerly cultivated, then abandoned towards the end of the 19th century (Barello 1983).

In the north-eastern part of the Massif the recurrence of fires has apparently induced a homogeneous landscape dominated by shrublands and some treed shrublands. In contrast, in the 1-Fire and 2-Fire areas, the decrease of forests and the increase in treed shrublands has led to an increase in diversity: the term "treed shrubland" covers many different types of communities, dominated by species such as *Erica arborea, E. scoparia, Arbutus unedo, Cistus monspeliensis,* etc.

The decrease in cork oak extent raises the question of the climax notion for certain species at certain times. With or without fire action there is a considerable decrease in cork oak forests: 60.1% have disappeared, transformed into treed shrublands or holm oak forests. The reason for this phenomenon could be that many *Q. suber* forests had been planted during the 19th century on old fields outside its natural range (Barello 1983, 1989). Due to the competition of new cork-substitutes, new producer-countries, and over-exploitation of the cork oak forests, profits fell (Barello 1983), and the careful maintenance of the past gave way to abandonment of cork oak stands. Then *Q. ilex* would have reoccupied its old natural extent area, in which it was the climax species – but in which it could not take hold 50 years earlier because of economic conditions favoring the cork oak and the artificial expansion of this latter due to cultivation.

Another question: why, throughout the area without fire disturbance, has a progressive dynamics not followed its "natural" process, with a reversion to primeval forest? With or without fire, communities and landscapes have not reached a stable equilibrium.

We also note for the whole Massif the disappearance of large vegetation units between 1945 and 1992, due to their ongoing subdivision. For example, during this period, fragmentation of the holm oak forest took place in the absence of fire in the north-western part of the Massif, resulting in the expansion of treed shrublands (Fig. 2 and 3). Can this be explained by the fact that the 1992 mapping method paid more attention to details than that of 1945? The aims of these two cartographies were not the same; the first (1945) set out to characterize vegetation in terms of series and belts; the second (1992) sought to give specific information useful in fire prevention and fire fighting activities.

Another explanation of the increase in treed shrublands in all areas with or without fire action (when forest maintenance abandonment is not the cause of this change) could be that Gaussen's concept of forest stands was not sufficiently rigorous or did not correspond to our criterion: we considered forest stands as being only those with a tree cover higher than 50%. Another hypothesis is that the 1942 photographs were not as precise and detailed as the present ones.

Time and fire have an influence on vegetation diversity. Two types of diversity exist: one corresponding to landscape, the other to plant communities. In landscape terms, going by communities existing in 1945 and their fire history, some parts (NE and SW) of the Massif are now more homogeneous, whereas with or without fire, other parts are now more heterogeneous (SE and NW). As far as communities are concerned, 55 vegetation types have been identified in the 0-Fire areas, 19 in the 1-Fire areas, 28 in the 2-Fire areas, and 10 in the 3-Fire areas. Thus the present diversity of the Massif's landscape depends upon the diversity of the communities existing before the fires.

Acknowledgments

The authors are grateful to the Centre d'Ecologie des Ressources Renouvelables (Toulouse) and the Institut de Géographie, Univ. de Toulouse, which gave permission to consult Professor Gaussen's field map drafts. The Inventaire Forestier National, Montpellier Division, lent the Infra-red aerial photographs. We would also like to thank R. Ferris, C. Lacombe and D. Lacombe for their help in the final cartographic work.

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