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Land-use legacies: multi-centuries years-old management control of between-stands variability at the landscape scale in Mediterranean mountain forests, France

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ABSTRACT: Traditional land use has shaped the Mediterranean region for a long time and has resulted in present-day complex landscapes. The land abandonment dating from the 19th century at a site located in the southwestern Alps (France) makes it possible to analyse how present-day forest stands inherit from past land uses. Tree composition and tree age structure were analysed in three stands resulting from different former land uses, i.e. ancient coppice, formerly grazed area and formerly tilled area. The ancient coppice contains the densest tree cover and is dominated by *Fagus sylvatica*, whereas the formerly ploughed and grazed areas are less dense, both dominated by *Pinus sylvestris*. Forest stand in the ancient coppice is older than in the formerly grazed area, and forest stand is the youngest in the formerly ploughed area. These stand differences are largely explained by former land use and the abandonment process. Albeit strong changes result from the land abandonment, these landscapes inherit aspects of their land use during the 19thcentury at least and the dynamics does not match the expected pattern of soil fertility.

Keywords: age structure; dendrochronology; forest stand; landscape; land-use change

Since the 19th century, large secondary forests resulting from the abandonment of land previously dedicated to different activities have continued to bear the imprint of their land-use history (Foster et al. 2003). These secondary forests have no clearly defined function, although they might be conserved for several environmental services (Benjamin et al. 2005). However, in landscapes where open area biodiversity and cultural landscape conservation are advocated, the increasing forest cover may appear as a threat to species conservation, landscape heterogeneity and thus landscape value (Höchtl et al. 2005). Accordingly sustainable management practices of secondary forest landscapes that result from the land abandonment require an understanding of the effect of land-use history on the modern forested landscape.

The structure and dynamics of secondary forests can be affected by land-use history. Firstly, the type, spatial pattern and intensity of previous land uses

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determine the composition and the spatial distribution of both seed source and colonisable patches (Mouillot et al. 2005). Secondly, the pattern of abandonment (location, surface, date, kinetics, etc.) may create spatial and temporal variability in tree recruitment between the stands at the landscape scale (Chauchard et al. 2007). Last, both the former land-use and the land abandonment process influence the spatial pattern and dynamics of forest (Kulalowski et al. 2011).

The centuries or even millennia of human management within the European Mediterranean have resulted in traditional landscapes that are outstandingly heterogeneous (Atauri, De Lucio 2001). Due to the considerable duration and impact of agricultural history, this area provides a relevant ecological model to analyse the imprint of land-use history on the modern forested landscapes. Because the abandonment processes are documented (Chauchard et al. 2007), it is possible to explore how the legacies of past land uses have affected the community dynamics of the modern forest. In the present paper, dendrochronology is used to analyse the consequences of former land-use practices and the timing of land abandonment on the forest structure, dynamics of the Mediterranean mountain forest landscape.

MATERIAL AND METHODS

Study area

The study area is located on the summit plateau of the Malay Massif, within the foothills of the south Mediterranean French Alps (43°42'N, 6°38'E; Fig. 1). The Malay Massif is an east-west oriented limestone mountain. Within the study area, the slope is gradual (1,300–1,424 m a.s.l.; Fig. 1) with the relief containing frequent dolines (bowl-shaped depressions caused by karstic weathering) with > 70 cm deep and loamy-clayish soil (Tartary 2012). The climate is of Mediterranean mountain type, with warm and dry summers (18.7 ± 1.3°C in July) and cold and snowy winters (2.4 ± 1.7°C in January), with the mean annual precipitation of 988 ± 262 mm (1907–2004, meteorological station of Comps-sur-Artuby, 2.5 km away, 943 m a.s.l.).

Land-use history

In the 1840s, according to Napoleon's land survey, forests covered 56% of the study area (Fig. 1); pasture covered 42%, whereas tilled areas covering less than 2% were located in the dolines (Chauchard et al. 2007). In 1886, land use was widely dedicated to livestock breeding, sheep and goats comprised more than 80% of the total livestock. The local number of inhabitants and the grazing intensity peaked during the middle of the 19th century. Afterwards, rural exodus began with a conspicuous population decrease from the 1880s. Between 1880 and 1914, rural decline increased with a drop in the numbers of sheep and goat. During the First World War (1914–1918), both local populations and livestock dramatically decreased. Then, the numbers of sheep and goat remained low until the 1970s, whereas the population decline followed a rate similar to that of the period 1880–1914. By 1970, when the study area belonged to the Canjuers Military Camp, grazing had become low. Today, the whole

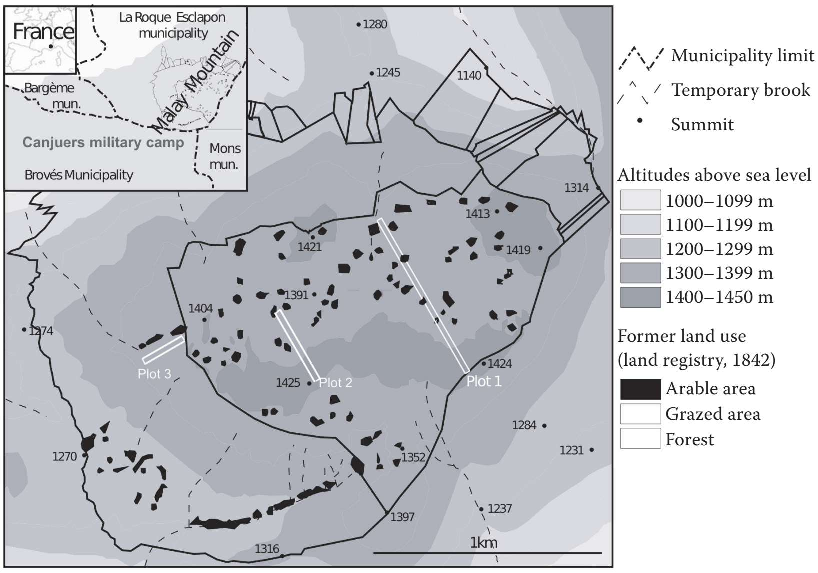

Fig. 1. Location of the study site and map of the former types of land use of the Plaine du Malay (1842, Cadastre Napoleon). The grey area in the inserted figure corresponds to the land of the Canjuers military training camp

area is wooded, except for a narrow rocky crest at the summit of the massif.

Sampling design

Plot 1 measuring 20 × 775 m was initiated (Fig. 1) to test a relationship between forest expansion and land abandonment in the study area. This first plot crossed both the formerly grazed areas (1.33 ha cumulated) and the formerly tilled areas (0.22 ha cum., Fig. 1). Two other plots, measuring 20 × 320 m and 20 × 250 m, respectively, were added to extend our first analysis and identify possible spatial pattern of tree colonisation (Fig. 1). Plot 2 consisted of a formerly grazed area (crest and slopes). Plot 3 was situated in the ancient coppice and allowed to analyse the third type of former land use (Fig. 1). The formerly grazed parts of the first and second plot were analysed and plotted together due to the absence of a spatial pattern of tree recruitment between the two areas.

The soils in this area are calcareous. In the formerly grazed area and the ancient coppice, they are superficial and poor (0–20 cm thick; rendisol, calcosol or calcisol), whereas in the formerly tilled area, corresponding to karstic depressions or dolines, they are moister, nutrient-rich, loamy-clayish and deeper (> 70 cm; brunisol).

The dolines are characterized by *Brachypodium rupestre* grassland colonized by a treed matorral (secondary pine forest). The grazed area is a mosaic of semi-natural dry grassland and scrubland facies (Festuco-Brometelia), and treed matorral with *Juniperus* (secondary pine forest) whereas the ancient forest is a medio-European limestone beech forest (*Cephalanthero-Fagion*) (Tartary 2012).

In the three plots, all individuals (trees, saplings and seedlings) were identified and labelled. For each tree (height > 1.3 m) the circumference was measured at ca 30 cm above the ground; to determine their age, a disc was cut from the stumps using a chainsaw, whereas living trees were cored using an incremental borer. Each sapling (0.1 m < height < 1.3 m) was cut. The age of the seedling (h < 0.1 m) was estimated by counting branch whorls. In plot 3, only 40% of the measured beech population was cored due to coring difficulties (hard wood). The cored trees (40%) were considered to be representative of the stand. To examine the relationship between the former land uses and the effect on the structure and dynamics of the forest, the data were analysed with respect to the three former land uses or land statuses, i.e. the formerly ploughed area, the formerly grazed area, and the ancient coppice. We assumed that each land-use area has a common pattern of tree colonisation.

Age estimation and age structure

The sampled discs and cores were smoothed by using progressively finer sandpaper. Tree rings were counted and cross-dated using a skeleton plot under a dissecting microscope. Cross-dating was impossible for saplings because they were too young and therefore offered a small number of rings; therefore only tree rings were counted. When incremental coring failed to reach the pith, we estimated the length of the missing radii by matching the curvature of the innermost rings to concentric circles drawn on paper. Then, the number of missed rings was estimated on cores with pith by calculating the mean ring number for the corresponding radii lengths.

Age structures were plotted by ten-year classes (expressed in trees·ha^{-1}) for each former land-use type, with an emphasis on the three main species (i.e. *Pinus sylvestris*, *Abies alba*, *Fagus sylvatica*). Because only 40% of all *F. sylvatica* was cored in the ancient coppice (plot 3), the age of the other (not cored) beeches was estimated. The cored beeches were chosen to represent each diameter class. The poor age-circumference relationship did not allow assessing the age of undated beech from the single circumference. The total number of beeches was estimated in each age class. First, we calculated the ratio of each age class (10-year class) in each beech circumference class (20-cm class), then the number of beeches in each age class was calculated.

The Kolmogorov-Smirnov two-sample test, Kruskal-Wallis test, and Behrens-Fisher post-hoc multiple comparisons test were used to determine whether the sets of age data were significantly different from each other.

RESULTS

Stand characteristics

The formerly tilled area contains only two tree species (*Pinus sylvestris*, *Crataegus monogyna*), the formerly grazed area consists of ten species, i.e. *P. sylvestris*, *Abies alba*, *Fagus sylvatica*, *Acer campestre*, *Prunus avium*, *C. monogyna*, *Rhamnus catharticus*, *Sorbus aria*, *Quercus pubescens*, *Tilia platyphyllos*, whereas the ancient coppice contains nine species, i.e. *F. sylvatica*, *P. sylvestris*, *A. alba*, *A. campestre*, *Acer opalus*, *Corylus avellana*, *C. monogyna*, *Q. pu-*

bescens, and *S. aria* (Table 1). The total density is higher in the ancient coppice than in the formerly grazed and tilled areas. The forest communities in the formerly tilled areas and in the formerly grazed areas are widely dominated by Scots pine (*P. sylvestris*) in terms of basal area, whereas the forest community situated in the ancient coppice is widely dominated by European beech (*F. sylvatica*) (Table 1).

Age structure versus former land uses

The recruitment of the ancient coppice, formerly grazed and formerly tilled areas began in the 1800s, 1870s and 1890s, respectively (Fig. 2). Pines are the oldest trees in the ancient coppice in the 1820s with a marked peak of the tree abundance in the 1860s. Recruitment of pine in the formerly grazed and tilled areas was delayed, starting in the 1870s and the 1890s, respectively (Fig. 2). Recruitment of pine in the formerly grazed areas shows two maxima in the 1900s and 1930s, whereas in the formerly tilled area only one maximum is observed in the 1950s. Recruitment of beech was contemporaneous with pine regeneration in the ancient coppice whereas it was delayed until the 1960s in the two other areas. Beech recruitment density was higher in the ancient coppice than in the formerly grazed area (Fig. 2). Fir (*A. alba*) recruitment began in the ancient coppice in the 1840s but showed the first peak in the formerly grazed areas only in the 1960s (Fig. 2). In the formerly tilled area, seedlings and saplings of beech and fir are absent. Recruitment of the other species has been low and delayed since 1970.

The age structures of *P. sylvestris* are significantly different among the land-use types (KW statistic = 157.74, df = 2, $P < 0.001$). The age structures of *F. sylvatica* and *A. alba* are significantly different between the formerly grazed area and the ancient coppice (KS test: D = 0.75, $P < 0.001$ and D = 0.71, $P < 0.001$, respectively), whereas the age structure of the other species is erratic. The recruitment of the three main species (*P. sylvestris*, *A. alba* and *F. sylvatica*) started first in the ancient coppice, second in the grazed areas, and third in the tilled areas.

DISCUSSION

In the Malay mountains, while land abandonment started more than 100 years ago, several significant differences are observed between the forest stands that had expanded from the three former land-use areas. The tree age structures illustrate differences in the forest dynamics, i.e. forest stand in the ancient coppice is older than in the formerly grazed area, and forest stand is the youngest in the formerly ploughed area (Fig. 2). That does not match the expected pattern that should follow the fertility gradient naturally offered by the areas, i.e. tree recruitment should have first occurred in the formerly tilled area followed by the two other areas. Moreover, the ancient coppice where recruitment started is located on the southern slope of

Table 1. Stand characteristics in the three former types of land use. The density of *Fagus sylvatica* is not estimated in terms of the number of trees but in terms of the number of stems per hectare

Species	Basal area					
	formerly tilled area		formerly grazed area		ancient coppice	
	($m^2·ha^{-1}$)	(%)	($m^2·ha^{-1}$)	(%)	($m^2·ha^{-1}$)	(%)
Abies alba (Silver fir)	0.0	0.0	1.5	4.4	1.3	2.0
Acer campestre (Field maple)	0.0	0.0	< 0.1	< 0.1	0.0	0.0
Acer opalus (Italian maple)	0.0	0.0	0.0	0.0	0.2	0.3
Crataegus monogyna (Hawthorn)	0.2	0.8	< 0.1	< 0.1	0.0	0.0
Fagus sylvatica (European beech)	0.0	0.0	0.2	0.6	47.9	71.5
Pinus sylvestris (Scots pine)	30.0	99.2	33.0	94.9	17.4	25.9
Prunus avium (Wild cherry)	0.0	0.0	< 0.1	< 0.1	0.0	0.0
Quercus pubescens (Downy oak)	0.0	0.0	0.0	0.0	0.2	0.3
Rhamnus catharticus (Buckthorn)	0.0	0.0	0.0	0.0	0.0	0.0
Sorbus aria (Whitebeam)	0.0	0.0	0.0	0.0	0.0	0.0
Tilia platyphyllos (Broadleaved lime)	0.0	0.0	0.0	0.0	0.0	0.0
Total	30.2	100.0	35.0	100.0	67.1	100.0

the mountains and is thus the driest area, which is counterintuitive. Consequently, density and age structure differences between stands rather illustrate the persistence of past land-use diversity in the modern secondary forest than the gradient of environmental factors.

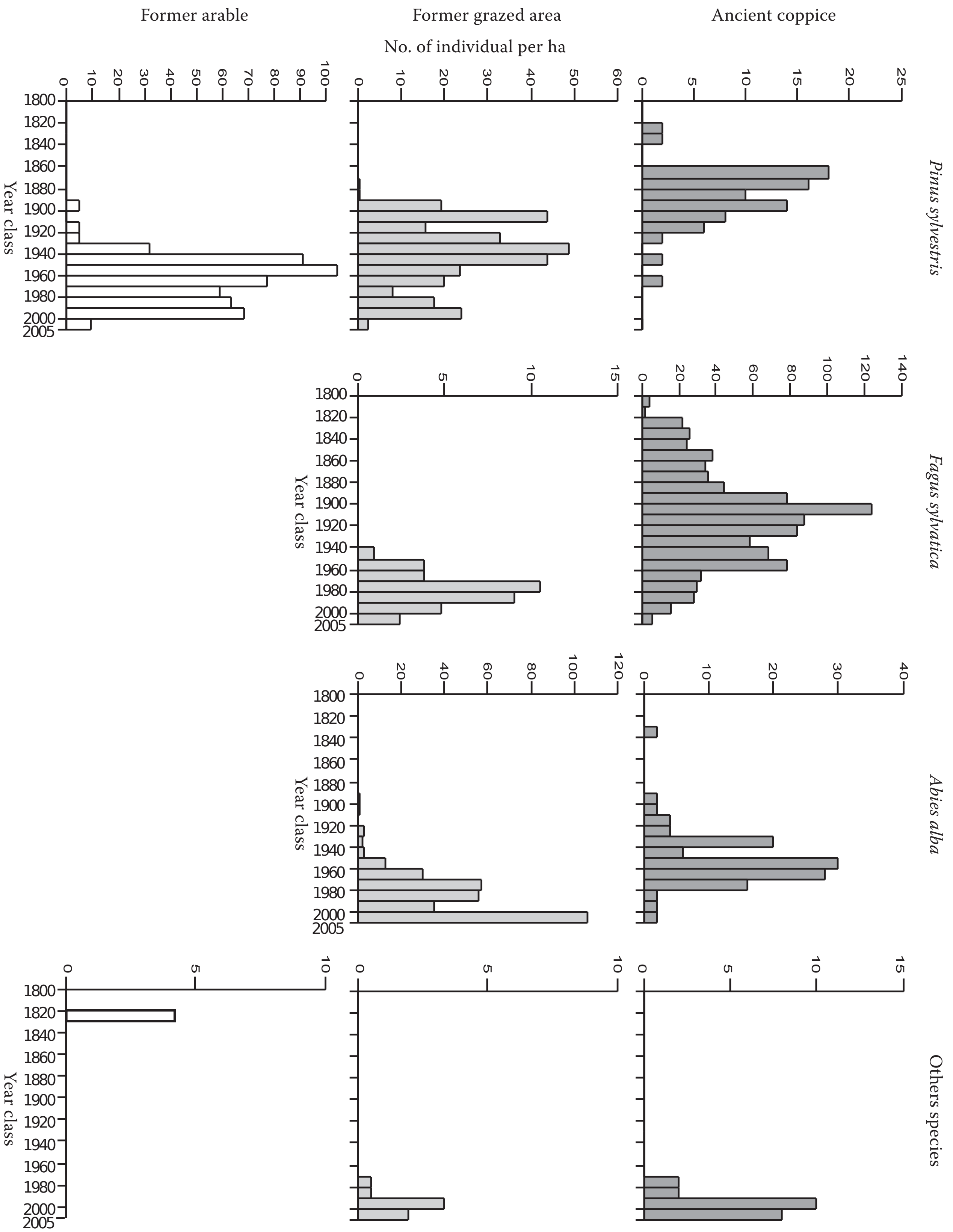

Fig. 2. Age structure in the ancient coppice, the tilled and the grazed areas for *Pinus sylvestris*, *Fagus sylvatica*, *Abies alba* and the other species

Former land uses and seed dispersion pattern may explain between-stand variability

Differences in the structure and dynamics of the forest can be explained by the pattern of seed-tree and seed dispersion (Clark et al. 1999; Nathan et al. 2000). Agricultural activities and forest management practices (by eliminating or promoting tree species) may have affected the spatial distribution of seed trees and thus the spatial availability of propagules (Mouillot et al. 2005). Previous land-use practices associated with the dispersal mode and autecology of trees can thus affect the present forest structure and dynamics. The short seed dispersal, the distance of seed trees and the shade-tolerant status of beech likely explain its low density in the formerly grazed and tilled zones (Table 1), whilst the high reproductive rates, the long-distance seed dispersal, and the pioneer status of Scots pine (Castro et al. 1999) explain its present-day forest dominance in the former open areas (Table 1). In the ancient coppice, the dominance of beech may be explained by ancient coppicing practices that enhanced specific life traits offering economic interest for the traditional forest rotation of 30 years and/or by their shade-tolerant status. Nevertheless, firs that are also a shade-tolerant species are rare. In this area beech easily re-sprouts after cutting and rapidly forms a dense coppice (Fig. 2), whereas the inability of fir and pine to re-sprout seems to explain their lower stem density. But although previous land uses associated with dissemination or vegetative reproduction traits and ecology of tree species explain the present-day dominance of certain species, they cannot explain all the differences in structure and dynamics.

Temporal patterns of land abandonment explain forest dynamics

Different temporal patterns of abandonment among the stands, linked to the previous land use, probably lead to different forest dynamics explaining the present differences in composition and density. In the ancient coppice, it is expected that beeches re-sprout rapidly after cutting due to former coppicing practices, and pines colonize rapidly after the abandonment onset. The quasi-absence of trees in the ancient coppice before the 1820s suggests that the last clear-cut or the forest initiation likely dates back to this period at least, whereas the agricultural and traditional practices began to decline in the middle of the 1860s favouring tree recruitment (Chauchard et al. 2007). The first peak of beech recruitment is contemporaneous with the first peak of tree recruitment observed in the formerly grazed area, i.e. the 1900s (Fig. 2). These observations suggest that a land-use change was synchronous in the ancient coppice and in the formerly grazed area. The peak of tree recruitment observed in the 1900s in the ancient coppice and in the formerly grazed area follows the local decline of grazing pressure suggesting that the ancient coppice was also grazed. This issue has not been found in the local archives, although it was commonly reported at a regional scale, i.e. the Pre-Alps area (Rinaudo 1980). The recruitment in the formerly tilled area, which started in the 1930s, evidences that the land abandonment occurred later there, compared to the two other areas, and clearly started a few decades after the main period of local abandonment. Only progressive and different processes of abandonment can explain this observed delay. The progressive and different abandonment is not evidenced within the documentary sources and can only be explained by the former land use. In the formerly tilled areas, deeper soils and plough practices favoured the growth and expansion of grasses (mainly *Brachypodium rupestre*), increased the quality of fodder and delayed the land abandonment. Grasses can also create a dense layer that prevented the encroachment of pine (Castro et al. 2002) through passive competition or allelopathic processes, while different fodder qualities associated with progressive land abandonment attracted wild and domestic herbivores inside the formerly tilled areas. The date, the situation and the speed of land abandonment are largely controlled by the previous type of land use, with different land uses leading to different spells of land abandonment, which better explain the modern structure and dynamics of the forest.

Increase of tree species richness

The lower number of tree species present in the former open areas might be due to the inability of trees to quickly colonise them. Recent forest dynamics tends to smooth the differences between sites that inherit from different practices, a process that broadly affects the Mediterranean region (Vallejo et al. 2005). In the formerly grazed area, the recent dynamics shows the recruitment of late successional species, i.e. beech and fir. The recent fir and beech recruitment in the formerly grazed area is not directly related to land-use history, as their recruitment appears to be delayed long after the land abandonment. It rather results from their seed dispersal traits, the distance of fructifying trees and their shade-tolerant status. In the future, beech and fir are expected to dominate the forest overstorey owing to their present-day efficient regeneration and capacity to grow under dense overhead cover (Aussenac

2002; Kunstler et al. 2005). Consequently, differences in composition between the formerly grazed area and the ancient coppice should be reduced with a decrease in dominant pines. Moreover, the recent recruitment of deciduous broadleaved trees in the formerly grazed area and in the ancient coppice increases tree diversity and should decrease the between-stands structural differences. Nevertheless, the delayed recruitment in the formerly tilled area prevents any definitive conclusion stating that a convergence in the tree composition has occurred.

CONCLUSIONS

Forest composition and structure within the same landscape have inherited a long history of land uses more than 100 years after the land use abandonment. Different former land uses shape the forest stands through overabundance of species and through the process of land-use abandonment. The knowledge of previous land uses (type, distribution, history) and their consequences for the patterns of forests that are prone to land abandonment is crucial in understanding and predicting the dynamics of wooded communities in Mediterranean mountain landscapes that have supported profound social and economic transformation since the industrial era.

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