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Threshold of land-use abandonment controls the rate of *Pinus sylvestris* recruitment and the forest dynamics in a Mediterranean mountain (Provence, S-E France)

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Introduction

Mediterranean ecosystems have been impacted for millennia by human activities such as permanent agricultural and pastoral practices (Pons & Quézel 1985, Blondel & Aronson 1999). Since the end of the 19th century, the traditional land-use has largely changed. In the northern rim of the Mediterranean basin, these changes are characterized by two opposite trends, namely intensification in the coastal areas, plains and valleys, and land abandonment in marginal areas that are generally situated in the mountains (Debussche et al. 1999). Land abandonment has lead to the settlement and expansion of scrublands and forests that result in a decrease in landscape heterogeneity, changes of spatial distribution of rare or endemic species (Höchtl et al. 2005), and progression of the species typical of central or northern Europe (Covas & Blondel 1998, Marty et al. 2003). The sustainable land management of former agricultural areas needs to decipher the temporal mechanism of woody expansion to predict the future vegetation pathways. Because land was exploited for several usages that could have been abandoned at different periods, we hypothesize that vegetation dynamics are controlled by these past land-uses. Consequently, we need to analyse the societal transformations back to the 19th century to precisely estimate its influences on present-day forest-cover and its dynamics. The present study aims to investigate the origin, the establishment and the kinetic of the tree community with respect to land-use history.

Study area

The study area is located in the Malay Massif (Fig.1), within the foothills of the Southern Alps (France, 43°42'N, 6°38'E, elevation: 1300-1416 m a.s.l.). The area has belonged to the Canjuers military camp since 1970. The topography is heterogeneous, showing a series of gentle slopes and dolines (bowl-shaped depressions caused by karstic weathering). The dolines contain deeper (>70 cm) and stone-free soils and are surrounded by visible man-made rock piles. They were traditionally ploughed, whereas the stony slopes were only grazed (Fig.1). The climate is of the Mediterranean mountain type, i.e. warm and dry in summer, cold and snowy in winter.

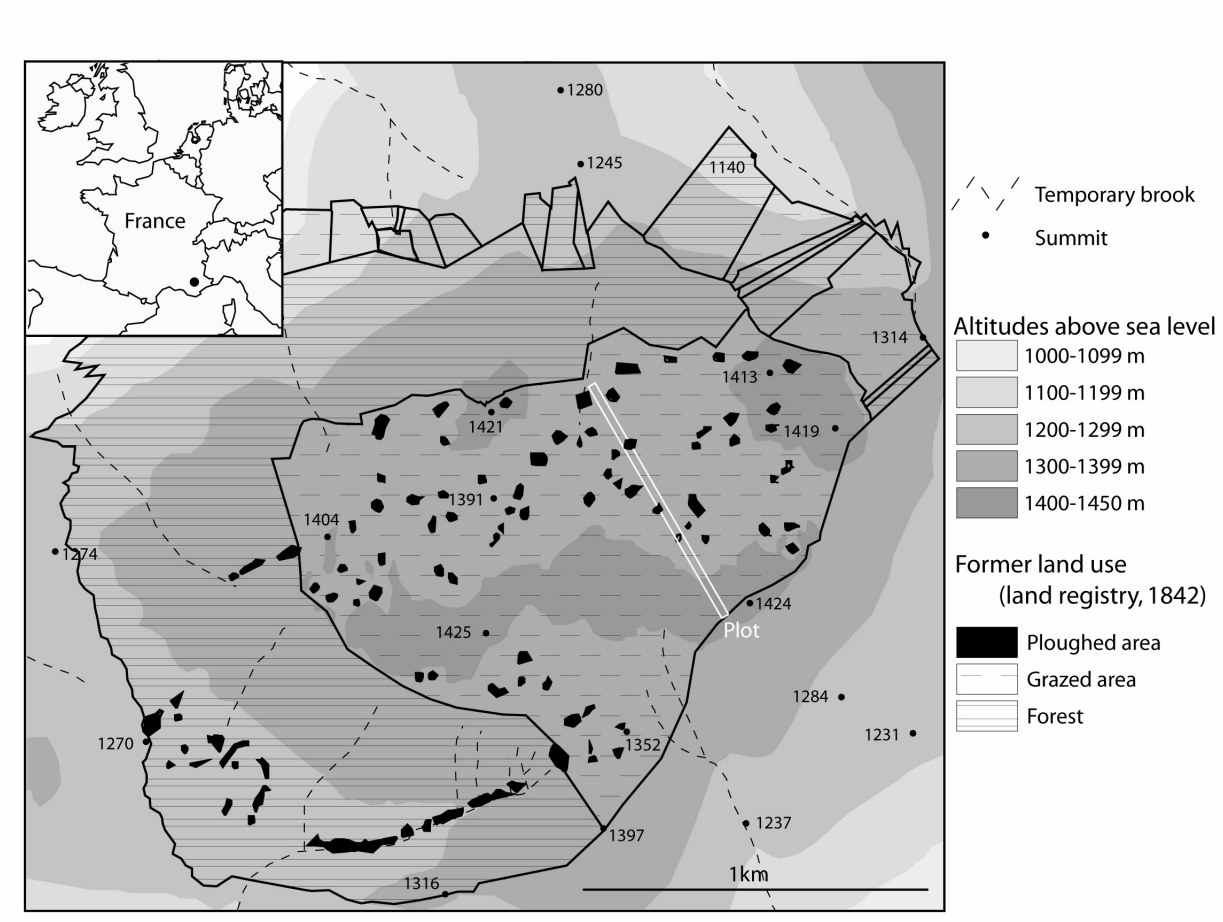

Figure 1: Location of the study site and former land-use of « Plaine du Malay » (Land registry,1842).

Methods

The approach includes analysis of land-use history combined with analysis of forest dynamics. We used population and agricultural census to reconstruct former land use, date, rate and pattern of land abandonment. Forest dynamics was assessed in a 1.55-ha plot perpendicular to the slope and to the ancient forest. In the plot, all trees were identified, labelled and mapped. For each tree a disc was cut from base of stumps using a chain-saw to determine their age, or an increment borer was used. Samples were sanded, then, growth rings were counted and cross-dated by visual observation under a binocular microscope (Schweingruber 1988). Age structure graphs were plotted for the three main species (i.e. *Pinus sylvestris*, *Fagus sylvatica* and *Abies alba*) with respect to the human population and flocks (sheep, goats) data in order to test the relationship between land-use history and stand dynamics. To asses the possible effect of climate on pine establishment, Spearman correlation rank was used between tree establishment (sum of regeneration in 5-year class) and a series of climatic variables (5-year mean) (Miller & Halpern 1998). The relationship between the total regeneration (sum of regeneration in 5-year class) *versus* the mean number of sheep and goats (5-year mean) was tested to estimate the possible effect of grazing pressure change on the recruitment dynamics. We also test the possible effect of former land-use and topography on pine establishment by comparing age-class distribution between the dolines (deeper soil, fertile and traditionally ploughed) and the slopes (thin soil, stony to rocky, traditionally grazed).

Results and discussion

Forest dynamics follows the local land-use abandonment

The age structure and the land-use history both show that the study area has been under severe transformations since the 1880's (Fig. 2).

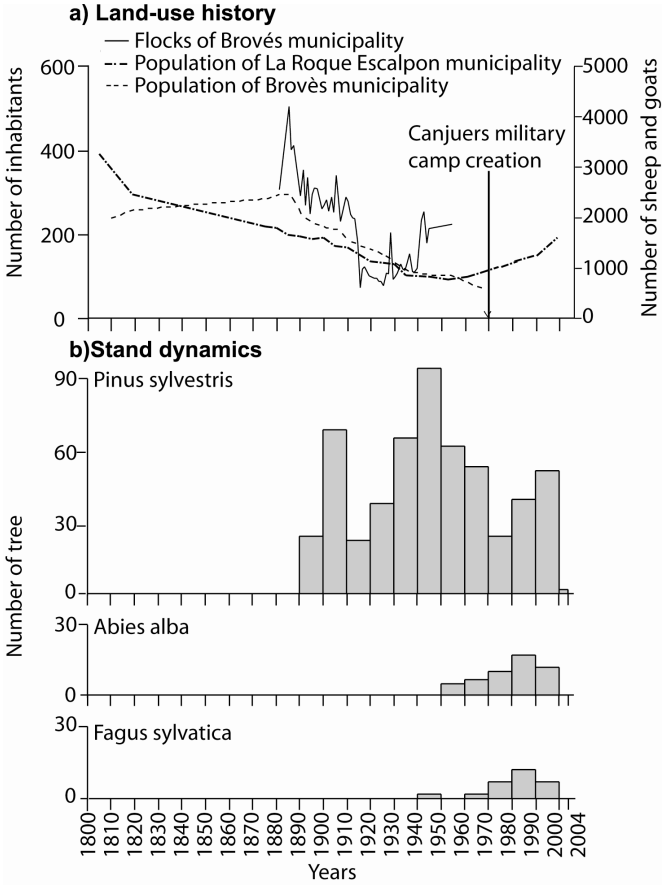

*Figure 2: Land use history and stand dynamics of the study site. (**a**) Land-use history: inhabitant numbers of the municipalities surrounding the Malay massif and flock numbers of Brovès municipality. (**b**) Stand dynamics: age structure of* Pinus sylvestris*,* Abies alba *and* Fagus sylvatica*.*

Stand dynamics is characterized by three main phases: (1) initial colonisation by *Pinus sylvestris*, (2) development of pioneer stands, (3) recruitment of post-pioneer stands, e.g. *Abies alba* and *Fagus sylvatica* (figure 2b) associated with a rise of tree diversity (not shown here). The first two phases of the forest dynamics are clearly linked with the land-use history. The initial colonisation by pine (*Pinus sylvestris*) started in 1879, against a background of local human population decline, which began 20 years before (Fig. 2a). Efficient pine recruitment started in the 1890s when the livestock underwent a significant drop. After that, pine density irregularly increased: recruitment shows two maxima in 1900-1910 and 1940-1950 separated by 30 years of lower recruitment (1910-1940). Although the initiation and start of efficient pine recruitment follow land abandonment, land-use history does not clearly explain the different stages of pine density increase and the recruitment of post-pioneer cohorts. Recruitment of *Fagus sylvatica* and *Abies alba* is delayed long after the beginning of the land abandonment: they start to regenerate in the 1940s and 1950s respectively.

Consequently, the recruitment of *Abies* and *Fagus* does not seem directly related to land-use history. The delay between the recruitment of *Pinus sylvestris* and that of the two others species may be explained by differences of seed dispersal mode and successional status: *Pinus sylvestris* has higher reproductive rates, a more efficient short- and long-distance dispersal, and higher survival rates of seedlings in open area than *Fagus sylvatica* and *Abies alba* (Castro et al. 1999, Debain et al. 2003) whereas the latter have the capacity to persist in shade under pine canopy (Aussenac 2002, Kunstler et al. 2005). In the coming years, beech and fir should thus play a more important role in the forest dynamics.

Climate and tree recruitment

Precipitation or temperature variation can influence several development stages in *Pinus*: seed production, germination, emergence, seedling mortality, growth (Despland & Houle 1997, Castro et al. 2005) and therefore could explain episodic pine recruitment (League & Veblen 2006). However, in this study no relationship is detected between regeneration and precipitation or temperature patterns (Tab. 1). Although climate does not seem to control pine dynamics, we cannot rule out that the response to land-use abandonment may over-ride the climatic response of recruitment.

Table 1: Spearman rank correlation between Pinus sylvestris *establishment (sum of regeneration 5-year class) and various climatic variables (5-years means) derived from monthly data of Comps sur Artuby meteorological station (distant of around 2.5 km, 943 m a.s.l.).*

Climatic variables	Spearman correlation	p-value	Degree of freedom	Significance
Precipitation (1907-2004)				
Annual	-0.039	0.871	18	n.s.
October-September (growing season)	-0.063	0.792	18	n.s.
June-August (summer)	0.004	0.987	18	n.s.
March-May (spring)	-0.237	0.313	18	n.s.
Temperature (1952-2004)				
Annual	-0.510	0.114	9	n.s.
October-September (growing season)	-0.492	0.129	9	n.s.
June-August (summer)	-0.487	0.133	9	n.s.
March-May (spring)	0.023	0.946	9	n.s.

Grazing rate and differential land-use abandonment influence tree recruitment

The start of tree encroachment is clearly linked to the start and stressing of land abandonment but pine recruitment shows a temporal variability that is not completely explained by the process of land abandonment. Grazing rate better explains the recruitment variability: according to Mountford and Peterken (2003) when grazing rate is high the recruitment is lacking and, when grazing rate decreases recruitment increases. Our observations support such scenario but when grazing rate is very low recruitment of pine also is low. The net pine recruitment peaks when the sheep and goats numbers are on

moderate levels (Fig. 3). The herbivores consume, trample seedlings and therefore increase mortality (Scott et al. 2000, Zamora et al. 2001) but the herbivores also can reduce density and biomass of herbaceous layer creating favourable microhabitat to pine seedling regeneration (Scott et al. 2000, Castro et al. 2002). Consequently pine recruitment appears controlled by grazing pressure and only a medium level rate of grazing allows massive pine regeneration (Fig. 3).

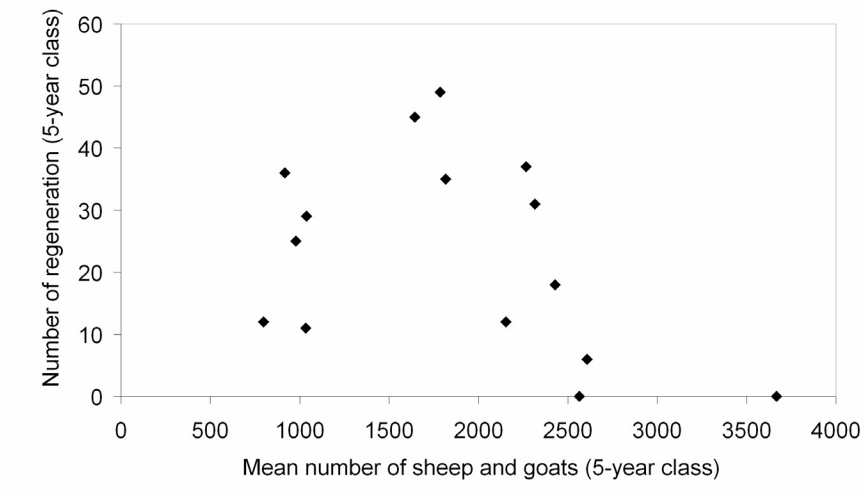

Figure 3: Relationship between grazing mean number of sheep and goats and effective pine regeneration.

The effects of topography are complex, involving differences in soil and air temperature, evaporation and irradiance and, in our site, differences in land-use.

The dolines with deeper and richer soils are less affected by extreme climatic events and are more favourable for regeneration than the slopes. As a result, it would be expected that after land abandonment, pine recruitment started inside the dolines before on the slopes. However, on the contrary, the regeneration starts on the slopes formerly grazed, afterwards inside formerly ploughed dolines, and reaches a maximum on the slopes in the 1940s then inside the dolines in the 1950s (Fig. 4). Different previous land-uses leading to different times of land abandonment, combined with variable herbaceous competition may explain the contrasting recruitment patterns (Fig. 4). Inside formerly ploughed dolines, deeper soils favour grass development, increases the quality of fodder and delay land abandonment. Herbs can form a dense layer that prevents pine encroachment, and different fodder quality associated with progressive land abandonment can attract herbivores inside the dolines.

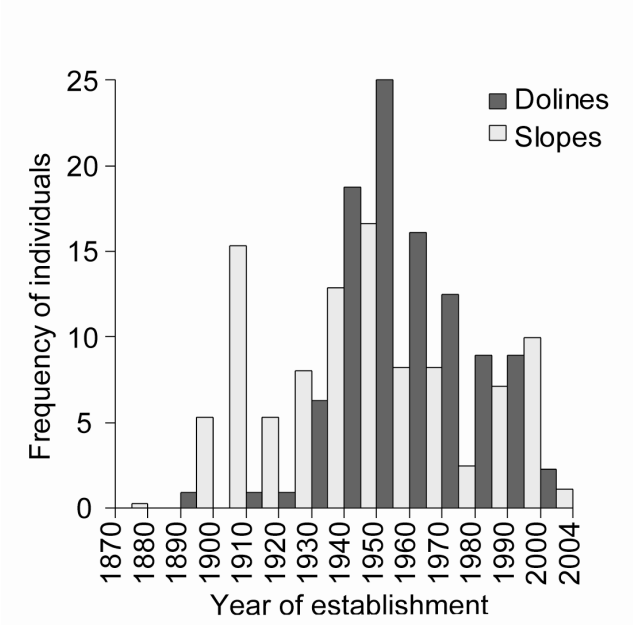

Figure 4: Age structure (%) of Pinus sylvestris *inside the dolines (n=111) and on the slopes (n=452).*

Conclusion

Land-use history provides various insights to understanding forest colonization as revealed by forest structure and temporal patterns of tree establishment. The sequence of forest encroachment agrees well with the dates of abandonment, and contrasting former land-uses are highlighted by subsequent different tree dynamics. In a Mediterranean mountain ecosystem, agricultural history and the rhythm of land-use abandonment are significant driving forces explaining present day forest dynamics. Knowledge of the agricultural history and former land-use is critical to understanding and predicting forest dynamics in the Mediterranean mountains following land abandonment.

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