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Núria Roura-Pascual, Pere Pons, Michel Etienne, and Bernard Lambert

Transformation of a Rural Landscape in the Eastern Pyrenees Between 1953 and 2000

In the mid-20th century, the southern parts of the Madres and Mont Coronat massif (Eastern Pyrenees, France) were characterized by a Mediterranean landscape shaped by human activity. Long-term use of these mountains for crops, livestock, and forestry led to an increase in grassland areas at the expense of forest. However, socioeconomic transformation (abandonment of agriculture and a decrease in the rural population) in recent decades has caused profound changes in this massif. Interpretation of aerial photographs (1953, 1969, 1988, and 2000) made it possible to detect and analyze the changes produced in the study area (6787 ha) during this period. In 1953 most of the massif landscape consisted of grasslands (38%) and open forests (18%), with some areas of dense forest (15%). By 2000, dense forest cover had doubled in size (31%), and grassland had decreased considerably (by 73% of the initial area). Since 1953, the study area has become more homogeneous, with a few local exceptions. The results of this study suggest that socioeconomic factors might be the main cause of landscape transformations in this period of approximately 50 years.

Keywords: *Landscape change; aerial photography; GIS; afforestation; Eastern Pyrenees; France.*

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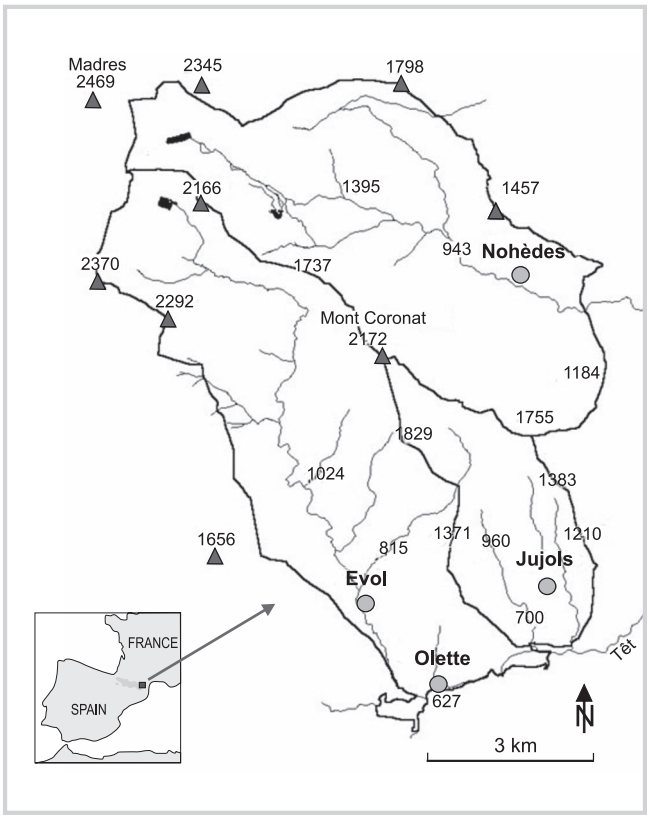


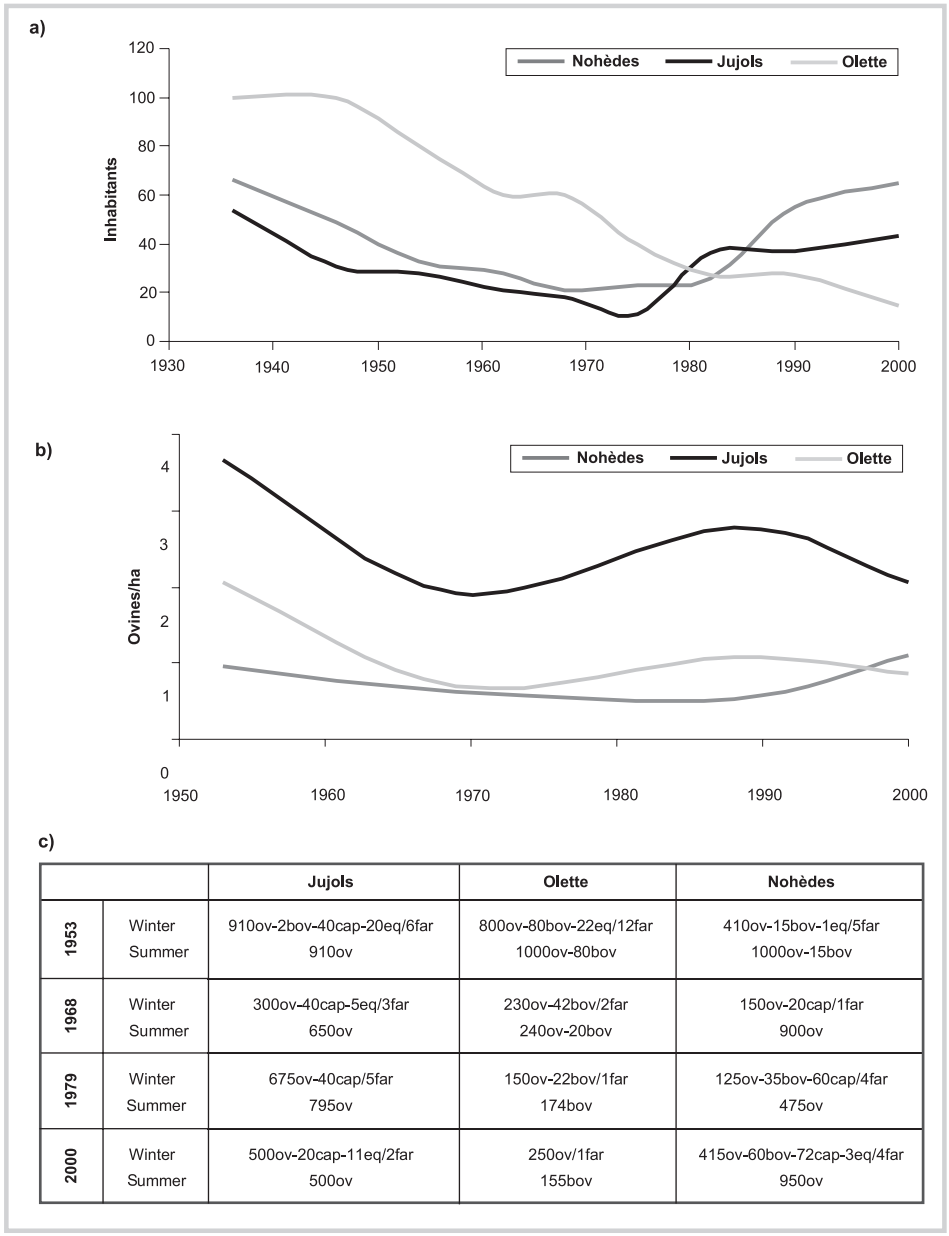
FIGURE 1 Study area of Madres and Mont Coronat massif in the Eastern Pyrenees, Département des Pyrénées Orientales, France. The gray color in the inset shows altitude above 1000 m in the Pyrenees. (Map by authors)

Introduction

Interactions between society and the environment play an important role in the configuration of "cultural landscapes," ie landscapes subject to human influence in which socio-ecological patterns and feedback mechanisms govern biodiversity (Farina 2000). The maintenance of biological diversity in cultural landscapes, which is often higher than in remnants of natural landscapes, depends on the spatial heterogeneity created by natural forces and human actions (Naveh and Lieberman 1994; Burel and Baudry 2000; Farina 2000). Traditional land use practices in the European mountains of the Mediterranean region have shaped an organized system regulated by seasonal cycles and spatial patterns of human activity (García-Ruiz and Lasanta-Martínez 1990). Agriculture, livestock grazing, and forest management have created a highly integrated and structured landscape mosaic (Farina 2000). However, during the last decades, socioeconomic globalization has induced profound transformations in rural areas (Barbero et al 1990; Debussche et al 1999; MacDonald et al 2000). Land abandonment has reduced the extent of open space and induced an expansion of woody vegetation, at least in the central Pyrenees (García-Ruiz et al 1996; Mazars and Gers 1997; Molinillo et al 1997), with repercussions for the disturbance regime and ecological diversity (Barbero et al 1990; Trabaud and Galtié 1996; Preiss et al 1997; Lloret et al 2002).

In this context, landscape changes and their consequences have become a matter of concern for environmental managers (Burel and Baudry 2000). Land abandonment, maintenance of biodiversity, fire management policies, and enhancement of traditional economies have led to a growing concern that environmental management of rangeland is required in the Eastern Pyrenees (Morvan et al 1995; Rigolot et al 2002; Pons et al 2003). Therefore, the environmental consequences of landscape dynamics have become an interesting and important subject of study (Burel and Baudry 2000). Although this form of landscape dynam-

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c)

		Jujols	Olette	Nohèdes
1953	Winter	910ov-2bov-40cap-20eq/6far	800ov-80bov-22eq/12far	410ov-15bov-1eq/5far
	Summer	910ov	1000ov-80bov	1000ov-15bov
1968	Winter	300ov-40cap-5eq/3far	230ov-42bov/2far	150ov-20cap/1far
	Summer	650ov	240ov-20bov	900ov
1979	Winter	675ov-40cap/5far	150ov-22bov/1far	125ov-35bov-60cap/4far
	Summer	795ov	174bov	475ov
2000	Winter	500ov-20cap-11eq/2far	250ov/1far	415ov-60bov-72cap-3eq/4far
	Summer	500ov	155bov	950ov

FIGURE 2 Demographic and livestock evolution in the municipalities of Jujols, Olette and Nohèdes of the Madres and Mont Coronat massif. (a) Demographic trends; (b) ovine density trends (previous conversion of 1 bovine to 6.6 ovines, and 1 equine to 7 ovines); (c) human and livestock statistics ("Winter" refers to pasturing in the lowlands, and "Summer" to highland grassland). Abbreviations: ov = ovines, bov = bovines, eq = equines, cap = caprines, and far = farmers). (Elaborated from data in Becat 1974; Alcaraz 1993; Cahner 1996; and personal interviews)

ics is common in almost all European mountain areas (Gunilla et al 2000), only a few local studies exist in the Eastern Pyrenees (Vila and Welch 2001).

The purpose of the present article is to quantify vegetation changes in the Madres and Mont Coronat massif between 1953 and 2000, and to understand the influences of socio-ecological constraints (environmental factors, pastoral structures, and public policy in mountain areas) on these changes. Further knowledge of these dynamics is necessary to determine future land use and maintain the biodiversity of the site.

Study area

The study area is located in the Eastern Pyrenees, covering the South of the Madres and Mont Coronat massif, hereafter referred to as Madres (Figure 1). The limits of the site were chosen in accordance with livestock management units (*estives*) corresponding to 3 municipalities: Jujols, Nohèdes, and Olette (Département des Pyrénées Orientales, France), providing a total of 6787 ha and 200 inhabitants. Each *estive* belongs to one municipality, which rents the land to local farmers. Furthermore, the Madres is included as a site in the EU Habitats Directive. Situated on the Mediterranean side of the Pyrenees, the area has a hilly topography (400 to 2469 m) in the transition zone of 3 macroclimates: alpine, Atlantic, and Mediterranean. The average annual rainfall in Nohèdes (1000 m) and Olette (615 m) ranges from 500 mm to 750 mm, falling all year round except during winter and summer when rain is scarce. The average temperature is 4.5°C in winter and 19°C in summer. In the lower valley, stands of *Quercus ilex* are located on the sunny slopes, and stands of *Fagus sylvaticus* and *Pinus sylvestris* on the shady ones; *Pinus uncinata* is abundant on the upper mountain.

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TABLE 1 Vegetation types used to characterize the landscape dynamics for the period 1953–2000. The vegetation types are ordered on a scale of increasing lignification. CF = complex formation. Cover categories are: 0 (0%), 1 (1–10%), 2 (10–25%), 3 (25–50%), 4 (50–75%), 5 (75–100%).

Vegetation types	Cover categories		
	Grass	Shrub	Tree
Barren land	0-1-2	0-1-2	0-1-2
Grassland	0-1-2	0-1-2	3-4-5
Open shrubland	0-1-2	3	3-4-5
Dense shrubland	0-1-2	3-4-5	0-1-2-3
Open woodland	3	0-1-2	0-1-2
CF tree–grass	3	0-1-2	3-4-5
CF tree–shrub–grass	3	3-4-5	3-4-5
CF tree–shrub	3	3-4-5	0-1-2
Open forest	4	0-1-2-3-4-5	0-1-2-3-4-5
Dense forest	5	0-1-2-3-4-5	0-1-2-3-4-5

The landscape of the Madres has been shaped by human presence. Between 1861 and 1914, the population decreased considerably, leading to abandonment of the furthest cultivated lands and a decrease in livestock. Consequently, shrubs and trees started to encroach upon open areas. From 1945 to 1965, croplands were transformed into rangelands, and herds became the only managers of the territory. At the end of the 1960s population decline was at its greatest, and land abandonment became more pronounced (Becat 1974; Alcaraz 1993). At the end of the 1980s, some new breeders established themselves in the study area, favored by mountain policy, which in 1995 applied the European Commission's Agri-environment Measures (Figure 2).

Materials and methods

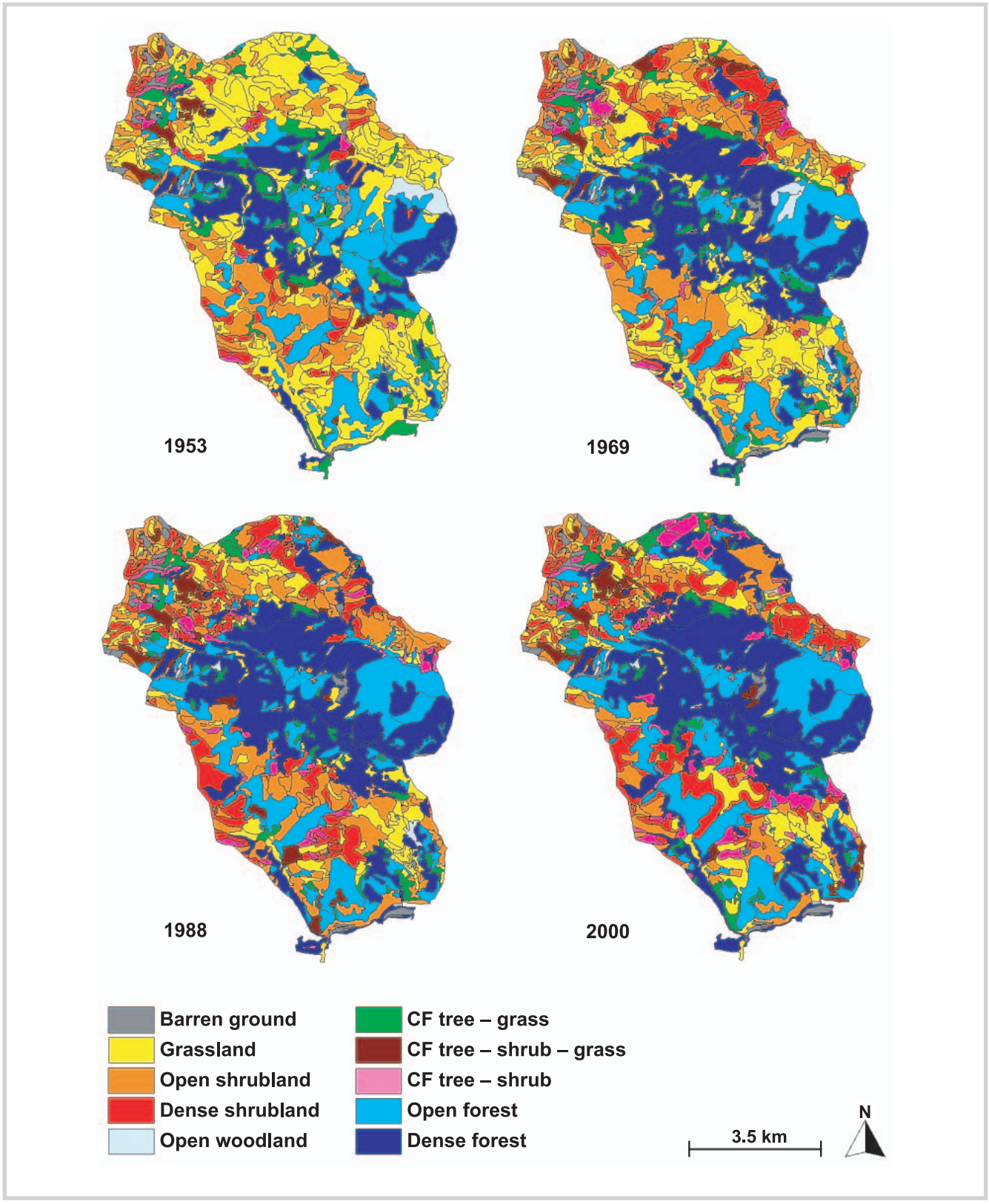
Landscape changes were evaluated by manual photo interpretation of aerial photographs, taken more or less every 15 years since 1953 (Dunn et al 1991; Delcros 1993; Carmel and Kadmon 1999; Cohen and Barth 2000). Photographs were used to produce vegetation maps to monitor landscape dynamics. Years were chosen according to the availability and quality of the images, in order to reconstruct the history of the area. The photographs were at different scales (1:25,000 in 1953; 1:15,000 in 1969; and 1:17,000 in 1988 and 2000) and in panchromatic color, except the first one, which was in black and white.

Landscape patches were defined as areas of vegetation of homogeneous height and cover; the minimum mapping unit was approximately 1 ha. The percentage of grass, shrub (up to 2 meters) and tree (more than 2 meters) cover was estimated for each patch (Etienne and Prado 1982). Estimation was based on 5 categories: 0 (0%), 1 (1–10%), 2 (10–25%), 3 (25–50%), 4 (50–75%), 5 (75–100%). The height and cover distinction probably had some associated errors, so comparisons with other cartography of the region (Alcaraz 1993; JP Métailié pers. com.) and field surveys were made to confirm and/or correct the photo interpretation. This process was performed on the most recent photographs (2000) and extrapolated to the other 3 years. Afterwards, interpretations of the aerial photographs were digitized in vector format with the MapInfo Professional geographical information system. We used a digital topography map to correct distortions in aerial photographs. Following the method of Godron et al (1968), the initial descriptions of the patches were classified into 10 categories (Table 1).

Landscape data were analyzed using MapInfo and Excel software. The following variables were calculated for each of the 4 years, for each of the 10 vegetation types, and for the whole study area: (i) total area, (ii) total number of patches, and (iii) mean patch size. To examine landscape changes between different dates, we transformed the landscape patches into raster data at 0.49 ha of spatial resolution (lower than the minimum mapping unit for retaining all information). We overlapped each pair of consecutive land covers pixel-to-pixel to obtain different transition matrices (53–69, 69–88, 88–00, and 53–00). As a result of this operation we calculated: (i) the area belonging to a vegetation category on a given date that also belonged to the same category on the previous dates, plus (ii) the area of a vegetation category on a given date that originated from other categories on the preceding dates (Moreira et al 2001). Additionally, we jointed all matrices (53–69, 69–88, and 88–00) to obtain a unique descriptor of vegetation transitions for the whole period (Cohen and Barth 2000). Possible transitions were: stability (S = no change), progression (P = vegetation lignification according to Table 1), and regression (R = vegetation openness according to Table 1). For example, SPR means stability between 1953–1969, progression between 1969–1988, and regression between 1988–2000. Finally, to estimate the relationships between socioecological conditions and landscape dynamics, we overlapped the vegetation maps with the cartography of different socioecological factors. Carmel and Kadmon (1999) and Debussche et al (1999) indicate that Mediterranean vegetation dynamics can be accurately explained by socioeconomic changes, some important environmental variables (especially those related to topography), and initial vegetation cover. Therefore, we additionally took into

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FIGURE 3 Vegetation maps of the study area in 1953, 1969, 1988, and 2000, produced with the help of a manual photointerpretation method (CF = complex formation).



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Vegetation types	1953		1969		1988		2000	
	ha	%	ha	%	ha	%	ha	%
Barren land	133	2	151	2	150	2	152	2
Grassland	2549	38	1558	23	714	11	688	10
Open shrubland	795	12	1149	17	1291	19	801	12
Dense shrubland	286	4	530	8	750	11	786	12
Open woodland	87	1	67	1	32	0	20	0
CF tree–grass	497	7	380	6	250	4	250	4
CF tree–shrub–grass	112	2	126	2	182	3	179	3
CF tree–shrub	65	1	116	2	214	3	390	6
Open forest	1240	18	1077	16	1290	19	1448	21
Dense forest	1024	15	1633	24	1914	28	2074	31

TABLE 2 Evolution of landscape categories in the study area (6787 ha) from 1953 to 2000.

account the aspect, fire frequency, and pastoral and administrative units to understand the landscape changes in the study area.

Results

During the period 1953–2000, the vegetation cover of the Madres experienced an important transformation (Figure 3 and Table 2). Grassland areas showed a large shift to dense forests. Grassland declined by 73% across 47 years (from 2549 ha to 688 ha), but the rate of decline gradually reduced during this period. Losses between 1953 and 1988 were related to patches disappearing and the mean patch size decreasing (Figure 4), but the relative stability until 2000 occurred due to attrition, ie the disappearance of small patches and an increase in the patch size of those remaining (Forman 1999). Conversely, shrubland and forest increased, more or less depending on the category considered. Dense forest increased by 50% and open forest by 13%, although there was a slight decrease for the period 1953–1969. Dense forest increase was due to both the number and the mean size of forest patches increasing. Like the forests, dense shrubland increased in both the number and size of patches, but there was a slight trend to attrition between 1988 and 2000. Moreover, bare ground remained unchanged throughout the period, while open shrubland, open woodland, and complex formations (tree–grass, tree–shrub–grass, tree–shrub) presented high temporal and spatial variation.

In general, grasslands decreased whereas forests, woodland and shrubland increased during the study period. However, transition matrices (Table 3) showed differences between the 3 periods: considerable reduction of grassland and increment of woodland from 1953 to 1988; and stability between 1988 and 2000. The transition matrix from 1953 to 1969 shows the transformation of grassland to shrubland, and the replacement of open woodlands and open forests with dense forests. This trend continued for the period 1969–1988, but the increase in dense forest was lower. During the period 1988–2000 there was a slight shift in the vegetation trend: grasslands remained stable and forests (open as well as dense forests) reduced the rate of increase. Although most transitions were essentially towards more ligneous vegetation, there was some transition towards more open vegetation. This is interesting from the point of view of cattle management and conservation management. The period 1953–1969 showed a slight transformation from open shrubland to grassland, the period 1969–1988 from dense shrubs to open shrubs, while the period 1988–2000 showed both transformations.

Taking into account the descriptor of vegetation transitions between years (S = stability, P = progression, and R = regression; Cohen and Barth 2000), the most relevant transitions (≥5% of the study area) for the period 1953–2000 were: SSS (36%), PSS (15%), SPS (10%), SSP (6%), PPS (5%), and SPP (5%). Dense and open forests were the most stable categories (63% of the area remained stable for the whole period), followed by grassland (16%) and open shrubland (6%). Transitions that imply patch lignification are changes from grassland to open shrubland, and from open forest to dense forest. On the other hand, the most relevant transitions (>2%) suffering a regression in the lignification process were: PRS (3%), SPR (2%), PRP (2%), RPS (2%), and PSR (2%). Because of the relationship between the disturbance regime and landscape patterns (Lloret et al 2002), we compared zones suffering regression in the lignification process with data on the fires that occurred in these areas (prescribed burn-

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TABLE 3 Transition matrices showing the vegetation changes in the study area, for 3 time periods (1953–1969, 1969–1988, and 1988–2000). Columns refer to the formations of the year *t* and rows to the formations of the year *t+i*. Each value indicates the proportion (%) of hectares of a given vegetation category in the year *t* that belonged to a given category in the year *t+i*. The vegetation categories are: barren ground (bare), grassland (grass), open shrubland (open shr), dense shrubland (dense shr), open woodland (open wood), complex formation tree–grass (CF tr–gr), complex formation tree–shrub–grass (CF tr–shr–gr), complex formation tree–shrub (CF tr–shr), open forest (open for), and dense forest (dense for).

	1953									
1969	Bare	Grass	Open shr	Dense shr	Open wood	CF tr–gr	CF tr–shr–gr	CF tr–shr	Open for	Dense for
Barren land	100	0	0	0	0	2	0	0	0	0
Grassland	0	50	21	20	0	4	8	4	1	1
Open shrubland	0	24	57	16	0	2	7	0	0	0
Dense shrubland	0	12	13	46	0	0	0	0	0	0
Open woodland	0	2	0	0	8	2	0	0	0	0
CF tree–grass	0	5	1	0	0	50	0	0	0	1
CF tree–shrub–grass	0	1	2	1	0	3	60	0	0	0
CF tree–shrub	0	1	1	6	0	1	24	67	0	0
Open forest	0	3	2	5	92	11	1	9	64	4
Dense forest	0	3	2	7	0	25	1	20	34	95
	1969									
1988	Bare	Grass	Open shr	Dense shr	Open wood	CF tr–gr	CF tr–shr–gr	CF tr–shr	Open for	Dense for
Barren land	96	0	0	0	0	1	0	0	0	0
Grassland	1	37	7	2	0	2	0	0	1	1
Open shrubland	0	28	56	35	0	2	5	4	0	0
Dense shrubland	0	17	21	44	0	1	3	0	0	0
Open woodland	1	0	0	0	30	0	0	2	0	0
CF tree–grass	0	4	3	1	0	35	17	1	0	0
CF tree–shrub–grass	0	2	3	1	0	3	55	26	0	0
CF tree–shrub	0	2	5	9	0	4	0	42	0	0
Open forest	0	6	4	6	70	37	10	11	82	2
Dense forest	1	3	1	3	0	16	10	14	17	97
	1988									
2000	Bare	Grass	Open shr	Dense shr	Open wood	CF tr–gr	CF tr–shr–gr	CF tr–shr	Open for	Dense for
Barren land	98	1	0	0	0	0	0	0	0	0
Grassland	0	66	14	4	0	0	2	0	0	0
Open shrubland	0	13	42	19	0	1	0	2	0	0
Dense shrubland	0	3	29	50	0	0	0	0	0	0
Open woodland	1	0	0	0	42	0	0	2	0	0
CF tree–grass	0	8	2	0	0	39	12	0	1	2
CF tree–shrub–grass	0	3	3	1	0	3	59	0	0	0
CF tree–shrub	0	3	6	19	0	4	8	57	1	0
Open forest	0	2	2	4	30	41	13	25	88	3
Dense forest	0	2	1	3	27	12	6	14	10	95

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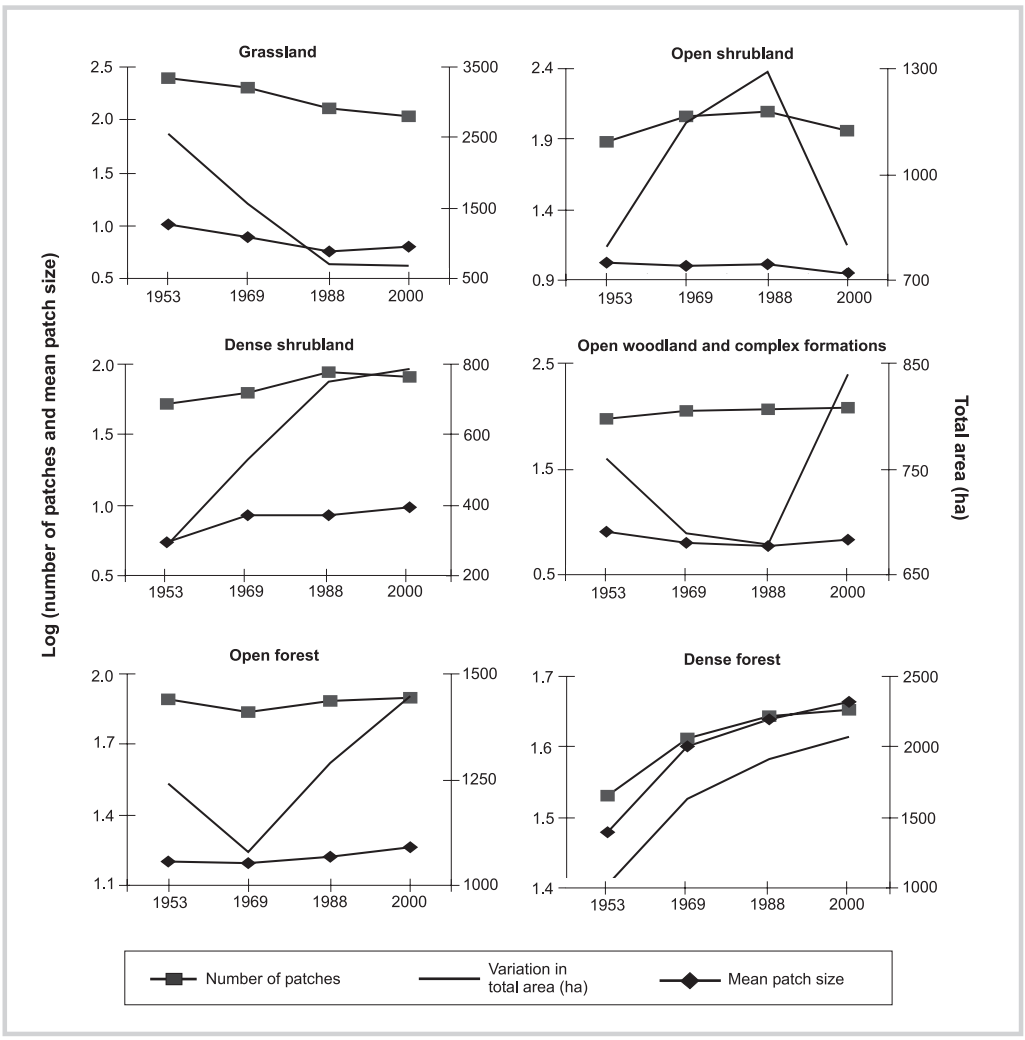


FIGURE 4 Number of patches and mean patch size in ha on the left y1-axis; and total area (ha) on the right y2-axis per vegetation type. The log10 transformations were applied to the y1-axis to illustrate the variables by reducing differences in magnitude.

ings and wildfires). From the results, we found spatial similarities between them (Figure 5).

To understand the relationship between landscape dynamics and environmental variables, we examined aspect and pastoral units because of their importance in the area. Our results indicated that north-facing slopes (NO, N and NE) favored forest cover and forest activities, while south-facing slopes (O, SO, S, SE and E) were dominated by grasslands and pastoral activities. North-facing zones passed from an open forest to a closed forest landscape (dense forest increased from 28% to 52% of the study area, and grasslands decreased from 19% to 2%). South-facing zones also followed this trend to lignification, changing from an herbaceous-dominated landscape to a landscape where all the vegetation types were present (dense forest increased from 11% to 24% and grassland decreased from 43% to 12%). On the other hand, although summer and winter pastures had similar evolutions, there were some important divergences. In summer pastures, grasslands decreased during the period (from 37% to 9%); in winter pastures, grassland decreased until 1988 (from 39% to 8%) and then increased slightly (from 8% to 11%). Moreover, open shrubland in summer pastures progressed in lignification earlier (covering 11% in 1953 and diminishing from 19% to 11% during 1969–2000) than in winter pastures (covering 12% in 1953 and diminishing from 21% to 12% in the period 1988–2000). While dense forests were more dominant in summer than in winter pastures, open forests presented a major extent in winter ones.

Discussion

Landscape changes that occurred in the Madres between 1953 and 2000 consisted mainly of a significant decrease in herbaceous cover and an increase in forests. To understand these dynamics, interactions between environment and society must be taken into account (Carmel and Kadmon 1999; Debussche et al 1999). Loss of grasslands was high until 1988, and then the coverage stabilized. This resulted from changes in exploitation systems and rural emigration. Emigration from 1861 to 1914 helped to transform the traditional agropastoral system into a pastoral system. This reduced the extent of cultivated areas, which became concentrated in the main agricultural valleys near villages. Some of them were still present in 1953. The rural depopulation of the 1960s also explains the pronounced landscape changes in the study area.

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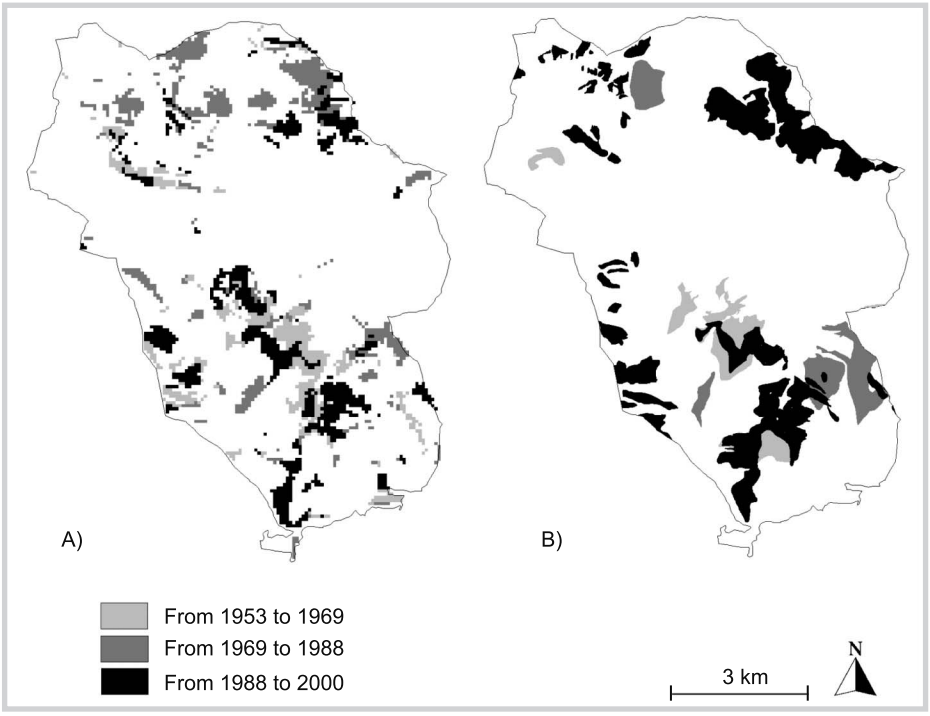


FIGURE 5 (A) Areas with a regression in the lignification process, where vegetation has returned to a more open stage. (B) Areas burned by prescribed burning or wildfires.

Similarities with other studies (Lasanta-Martínez 1988; García-Ruiz and Lasanta-Martínez 1990; Mazars and Gers 1997; Moreira et al 2001) suggest that isolated and less productive fields were the first to be abandoned, followed by the more productive ones. On the other hand, the initiation of French mountain policy in the 1980s favored the installation of new cattle farmers and the common use of prescribed burning to control shrub encroachment. Although this stopped the regression of herbaceous cover, it was not enough to reverse the former trend. The apparent relationship between herbaceous cover and pastoral activities (Carmel and Kadmon 1999) suggests that lignification is due to: (i) a decrease in livestock numbers, (ii) changes in herd diversification, and (iii) changes in herd management and pastoral practices. Forested areas, particularly dense forests, increased throughout the period because of land abandonment and the reduction in forestry activities. The greatest increase of dense forest was between 1953 and 1969, due to lignification of open forests. These open forests were the result of extensive wood-cutting practices carried out until the 1950s for charcoal production and mine exploitation. Since then the introduction of new combustibles, especially gas for cooking and heating, and a more competitive economy have induced the decline and transformation of forest activities.

Aside from the general trends in the study area, there are also local landscape particularities explained by their own socio-environmental constraints. Although the role of initial vegetation and topographic conditions is important in understanding landscape dynamics, socioeconomic factors play a crucial role. The most relevant factor is the capacity of traditional activities to adapt to the new socioeconomic transformations and land ownership. The southeastern part of the study area (which corresponds to Jujols) is situated on the south-facing slopes and presents a soft relief, where the cattle dealers kept herds of ovines and owned the most productive lands. These factors have made it possible to maintain pastoral activity and, therefore, an open landscape. However, the northern area (Nohèdes) has a wilder topography and the traditional activities underwent profound changes (transition from ovines to bovines or caprines, under utilization of the productive fields and economically non-viable forest activity). This favored a more pronounced lignification in the northern areas and reduced the erosion process, still visible on barren areas at the top of Mont Coronat. On the other side, in the southwestern part (Olette), farming activity was residual at the beginning of the 1950s and the most important activity was the cutting of forests, which is still practiced today. Continued forestry explains the reduced increase in forest stands.

As a result of these interactions between environment and society, the landscape of the Madres presents a mosaic composed of natural, semi-natural and cultural environments that change in space and time, while a high level of natural and cultural diversity is maintained (Pino and Rodà 1999). The general trend to vegetation lignification implies concurrent synergies. Lignification has positive effects in controlling soil erosion and surface runoff, which were accentuated on the steep slopes of the massif, ensuring soil conservation and improving soil characteristics (García-Ruiz et al 1996). Conversely, while the reduction of disturbance frequency (by land abandonment) and the lignification process increased landscape heterogeneity at the beginning of the process, their persistence favors the development of a simplified mosaic dominated by contiguous forest patches.

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This landscape homogenization means reduction of open habitats (crops, grasslands, and shrubland), difficulty in the maintenance of agropastoral activities (Molinillo et al 1997), and increasing risk of wildfires due to reduction in fragmentation (Moreira et al 2001; Lloret et al 2002). Moreover, from the biological perspective, an increase in forest species and core habitat specialists is expected to the detriment of open-habitat and ecotone species (Preiss et al 1997; Atauri and de Lucio 2001; Rigolot et al 2002; Pons et al 2003).

Certainly, the sustainability of management on the Madres and Mont Coronat massif depends on the maintenance of traditional activities: extensive agropastoral exploitation and the rational management of forests. Extensive grazing, allowing an acceptable number of sheep and cattle and avoiding their concentration in reduced areas, prevents soil erosion and vegetation impoverishment, increases mosaic diversity, and maintains open-habitat patches. Selective logging appears to be an environmentally integrated and viable economic activity that reduces wildfires by promoting landscape fragmentation.

To guarantee the sustainability of these activities, measures such as clear cutting and prescribed burning to create open habitats, improvement of forest access, increment of public awareness about mountainous areas, and agro-environmental measures need to be adopted at regional, national and European levels (Debussche et al 1999). The environmental, cultural and economic integration of agropastoral and forestry activities seems fundamental (Farina 2000) to ensure the conservation of this landscape mosaic, which is essential to the diversity of the Madres and Mont Coronat massif.

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