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The Case of a Mediterranean Mountain Area (Catalan Pre-Pyrenees)

*Land cover mapping obtained from photointerpretation of aerial photographs and orthophotographs was used to quantify land cover changes between 1957 and 1996 in a Mediterranean middle mountain area. Expansion of forested area is clearly the main land cover change caused by the abandonment of traditional agricultural activities and by the use of other materials and energy sources instead of forest resources. As a result, about 64% of the area was covered by forest by 1996, whereas in 1957 forests accounted for only 40% of the land cover. Spontaneous afforestation of abandoned fields with Scots pine (*Pinus sylvestris *L.) in terraced areas and areas of sparse scrub vegetation, coupled with an increase in the density of forest canopies, has been responsible for this expansion of woodland. The influence of physiographic factors in land cover change processes in the terraced areas of the catchment was also considered. The results demonstrate that within the terraced areas, north-facing and more elevated steeper slopes are more intensely afforested. However, an accurate analysis of the role played by these factors in land cover change cannot be carried out because the pattern of land abandonment is not independent of these physiographic characteristics. Furthermore, field observations at the terrace scale are evidence of the relevant influence of local topography in afforestation dynamics.*

Keywords: *Land use–land cover change; GIS; photointerpretation; afforestation; terraces; Mediterranean mountains.*

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Introduction

Rural abandonment, especially of marginal and less productive cultivated land, has become the most important trend in land use and land cover change in most industrialized societies (Ramankutty and Foley 1999). An example of this is the abandonment of agropastoral activities in Spanish mountainous areas, resulting in the general replacement of cropland and pastures with woodland (García-Ruiz et al 1996). The hydrological implications of this land use and land cover change are of major importance in relation to headwaters, given the possible consequences for water supply in more populated downstream areas. The study area (Cal Rodo catchment, Catalan Pre-Pyrenees, Spain) is an example of this rural abandonment process, which has taken place in most middle mountain areas of the Iberian Peninsula, specifically the Pyrenees (García-Ruiz and Lasanta 1990; García-Ruiz et al 1996; Ubalde et al 1999; Molina 2000).

The Cal Rodo catchment has been used for more than 10 years as a research site for the study of hydrological and geomorphological processes affected by land abandonment, such as hydrological functioning, runoff generation (Latron et al 2003), rainfall interception (Llorens et al 1997), and hydrological consequences of land cover change (Llorens et al 2003). Located in a region where terraced areas are frequently found at midelevations, the catchment is undergoing a significant process of spontaneous afforestation (Llorens et al 1997). An accurate assessment of land cover change in the past 50 years, therefore, is of great importance in establishing the general dynamics of land abandonment in this area and in recognizing the influence of terraced topography on processes of land cover change. Using a classical and widely used methodology (photointerpretation), this article has a 2-fold objective:

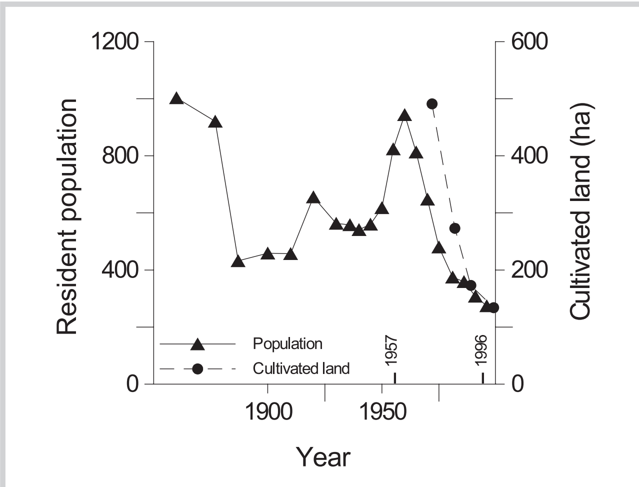
- To assess land cover change in the Cal Rodo catchment after abandonment of agropastoral activities.
- To study the role played by hillslope-scale physiographic factors and microtopography in land cover dynamics on long-established agricultural terraced areas.

Study area

The Cal Rodo catchment (4.2 km^2) is located in the headwaters of the Llobregat River, on the southern margin of the Pyrenees (Catalonia, northeastern Spain) at 42°12′N, 1°49′E. The catchment, with altitudes between 1100 and 1700 m, is characterized by a sub-Mediterranean climate with a mean annual rainfall of 924 mm. The northern part of the catchment, largely underlain by mudstones, was partially deforested and terraced in the past for agricultural use. It is now covered by mesophyle grasses and some pine (*Pinus sylvestris* L.) forest patches as a result of spontaneous afforestation after abandonment of agriculture.

Cereal crops and sheep herding were the main traditional economic activities in the area, whereas forests provided local people with timber and fuelwood. Demographic pressure led to an increase in cultivated land resulting from terrace construction. Later, migration to seek more attractive industrial jobs caused a rapid decrease in population, starting in 1860 (Figure 1). In the first half of the 20th century, coal mining in the

FIGURE 1 Demographic development and change in cultivated land cover in Vallcebre (municipality including Cal Rodo area). (Source: Centre d'Estudis Demogràfics, UAB; Censo agrario de España 1972; Cens Agrari 1982, 1989 and 1999)



area contributed to population increase, but this disappeared progressively as mining became less profitable after the 1950s (Molina 2000). As a result, the amount of agricultural land declined rapidly during the second half of the 20th century (Figure 1).

TABLE 1 Land cover classes in the Cal Rodo catchment

Land cover	Description
Grassland and crops	Areas heavily covered by grasses (pastures and cultivated or abandoned fields)
Sparse scrub vegetation	Areas covered by scattered scrub (*Genista scorpius, Juniperus communis*) or trees (*P. sylvestris*) with poor grass cover
Open forest	Discontinuous woodlands with open canopies (between 40% and 90% crown cover)
Dense forest	Areas covered by trees with closed canopies (more than 90% tree crown cover)
Badlands	Highly eroded (sparse plant cover)
Bare rock	Limestone outcrop (no plant cover)

Methodology

Photointerpretation of a stereoscopic pair of black and white hardcopy 1:28,000 aerial photographs dating from 1957 (Servicio Fotográfico y Cartográfico del Ejército) and the 1996 Digital Orthophotograph of Catalonia, at a scale of 1:5000 (Institut Cartogràfic de Catalunya, ICC), together with ground checking, made it possible to quantify land cover changes between 1957 and 1996 in the Cal Rodo catchment. Digitized vector coverages were converted to raster format, with a pixel resolution of 20 m. Cartalinx v.1.0 (Clark Labs) software was used for digitizing and Idrisi32 v.1.0 (Clark Labs) for vector-raster conversion, geographic information treatment, and cross-tab analysis. Six land cover categories were identified (Table 1), depending on the vegetation cover. Two forest categories were distinguished because of different density of cover, noticeable in the photographs. Differences in quality and scale between the 2 sources (aerial photographs and orthophotograph) may have led to specific types of misinterpretation in some areas.

Land cover information was complemented with a map of terraced areas in the catchment, obtained from photointerpretation and field work (Figure 2C). Furthermore, the 20-m resolution digital elevation model of the catchment that overrides the terraced topography was used to derive elevation, slope gradient, and aspect maps (Latron 2003) to assess the role played by these physiographic factors on land cover change in the terraced area. Chi-square tests were used to statistically verify the distribution of land cover change in accordance with each factor. Finally, photointerpretation of a 1977 aerial photograph was used to study the afforestation process at the terrace scale.

Results

Land use and land cover change in the Cal Rodo catchment (1957–1996)

In 1957, grassland and crop area represented 28.3% of the catchment and was the most abundant land cover category (Figure 2A; Table 2). Sparse scrub vegetation occupied an extensive area in the southeastern part of the catchment and also was found forming scattered patches adjacent to badland areas or covering steep slopes. Dense forest was restricted to the southwestern part of the catchment, representing a small percentage of the total area. Less dense canopies were also observed, gradually turning into sparsely vegetated areas toward the east. Some scattered afforestation patches also existed already throughout the terraced area in 1957. In all, open forest covered 22.5% of the catchment.

The most substantial change in land cover between 1957 and 1996 involves a significant increase of *P. sylvestris* forest area at the expense of grassland, cropland, and scrub vegetated areas (Figures 2A,B; Table

FIGURE 2, A AND B Land-use maps of Cal Rodo catchment in (A) 1957 and (B) 1996. (C) Situation of terraced areas within the catchment.

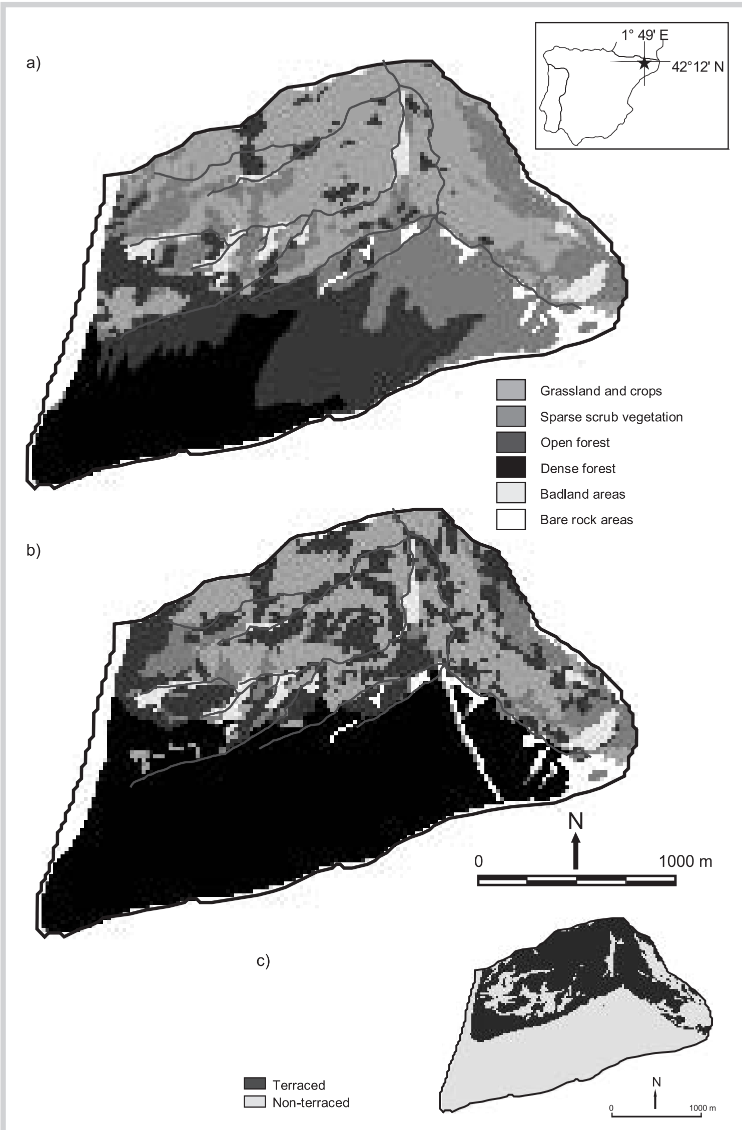


TABLE 2 Land cover distribution in the Cal Rodo catchment in 1957 and 1996, expressed as a percentage of total catchment area

Land cover classes	% of catchment area	
	1957	**1996**
Grassland and crops	28.3	18.1
Sparse scrub vegetation	23.2	8.3
Open forest	22.5	18.8
Dense forest	16.9	45.3
Badlands	2.8	2.8
Bare rock	6.3	6.8

TABLE 3 Land cover distribution on terraced areas of the Cal Rodo catchment in 1957, expressed as a percentage of total terraced area

Land cover classes	% of terraced area	
	1957	**1996**
Grassland and crops	73.6	47.0
Sparse scrub vegetation	9.7	3.7
Open forest	16.7	38.4
Dense forest	0.0	10.9

2). During this 39-year period, 25.1% of the catchment underwent afforestation. In 1996, forested area (dense and open forest) represented 64.1% of the catchment, whereas in 1957 it accounted for only 39.4%. This expansion of forest area was accompanied by a significant increase in woodland density. As a result, dense forest occupied 45.3% of the catchment in 1996 (16.9% in 1957), whereas open forest showed a slight reduction in the same period. Afforestation affected mainly sparse scrub vegetated areas in the southeastern part of the catchment, and also grassland and crop areas that represented 18.1% of the whole study area in 1996, as against 28.3% in 1957. During the same period, the slight increase in bare rock areas was the result of clearing of surroundings for an electric power line installed after 1957. Badland areas showed no change in extension.

Land use and land cover change in terraced areas (1957–1996)

Terraced areas in Cal Rodo (Figure 2C) occupy 38.5% of the catchment (Latron, unpublished data). Grassland and crops, which represented 73.6% of the terraced area in 1957, covered only about 47% of the area in 1996 (Table 3). Open forest cover greatly increased during the period under study; there was a similar increase in the area of dense forests, which did not exist in 1957 but covered 10.9% of the whole terraced area in 1996.

Cross-tab analysis of land cover changes (Table 4) shows that in the terraced area 36.2% of grassland and crop areas were afforested between 1957 and 1996. Afforestation occurred even more intensively in sparse scrub areas, about 80.5% of which have undergone afforestation. Finally, more than half of the original open forest cover in the terraced areas remained unchanged in 1996, whereas 37.5% increased in density.

Local observation of the afforestation process over a 2.5-hectare terraced site within the study catchment (Figure 3) shows that forest patches growing strictly on

FIGURE 3 Development of forested area on a terraced site in the study area: (A) 1957, (B) 1977, and (C) 1996.

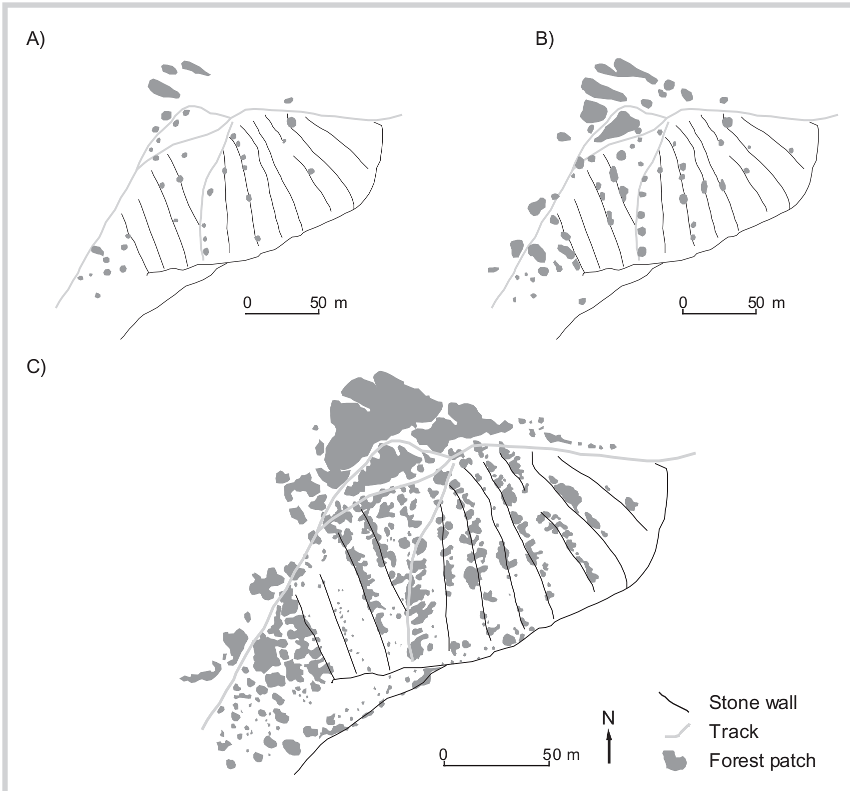


TABLE 4 Land cover changes on Cal Rodo terraced areas between 1957 and 1996, expressed as a percentage of each original land cover class in 1957. Changes not confirmed by field observations (3% of the overall terraced area) are not shown

Land cover in 1957	Change (by 1996)	% of 1957 land cover class
Grassland and crops	Unchanged	60.5
	Sparse scrub	3.3
	Open forest	30.4
	Dense forest	5.8
Sparse scrub	Unchanged	8.4
	Open forest	77.2
	Dense forest	3.3
Open forest	Unchanged	51.3
	Dense forest	37.5

the terraces increased significantly between 1957 and 1996. Forest cover on this set of terraces increased from 1.6% in 1957 (4.3% in 1977) to 17.8% in 1996. Pine colonization along the stone walls of the terraces was often observed in this area, whereas the outer part of the terraces still showed little forest cover (Figure 3).

Land cover change distribution in terraced areas by physiographic factors

Overlay of land cover changes and slope gradient, aspect and elevation maps, made it possible to draw histograms classifying terraced areas according to the 3 physiographic factors mentioned above (Figure 4A,C,E) and thus show the percentage of each land cover change process with respect to the overall terraced area. Only 4 categories of land cover change (unchanged grassland and crops, unchanged open forest, afforestation, and increasing density of existing forest) were considered. Other minor changes—totaling 6% of the terraced areas—were disregarded because they were not confirmed by field checking. All the distributions obtained were shown to be highly significant (c^2 test, $P < 0.001$). Likewise, land cover change distribution within each gradient, aspect, and elevation class (Figure 4B,D,F) shows which processes are dominant in relation to these characteristics.

Slope gradient: The distribution of terraced area according to gradient (Figure 4A) shows that more than 85% of the area has a slope gradient under 30% and that the 4 categories of land cover change are represented within the entire gradient range. However, there are significant differences between the relative importance of each type of land cover change with respect to slope. On gently sloping areas, the conserva-

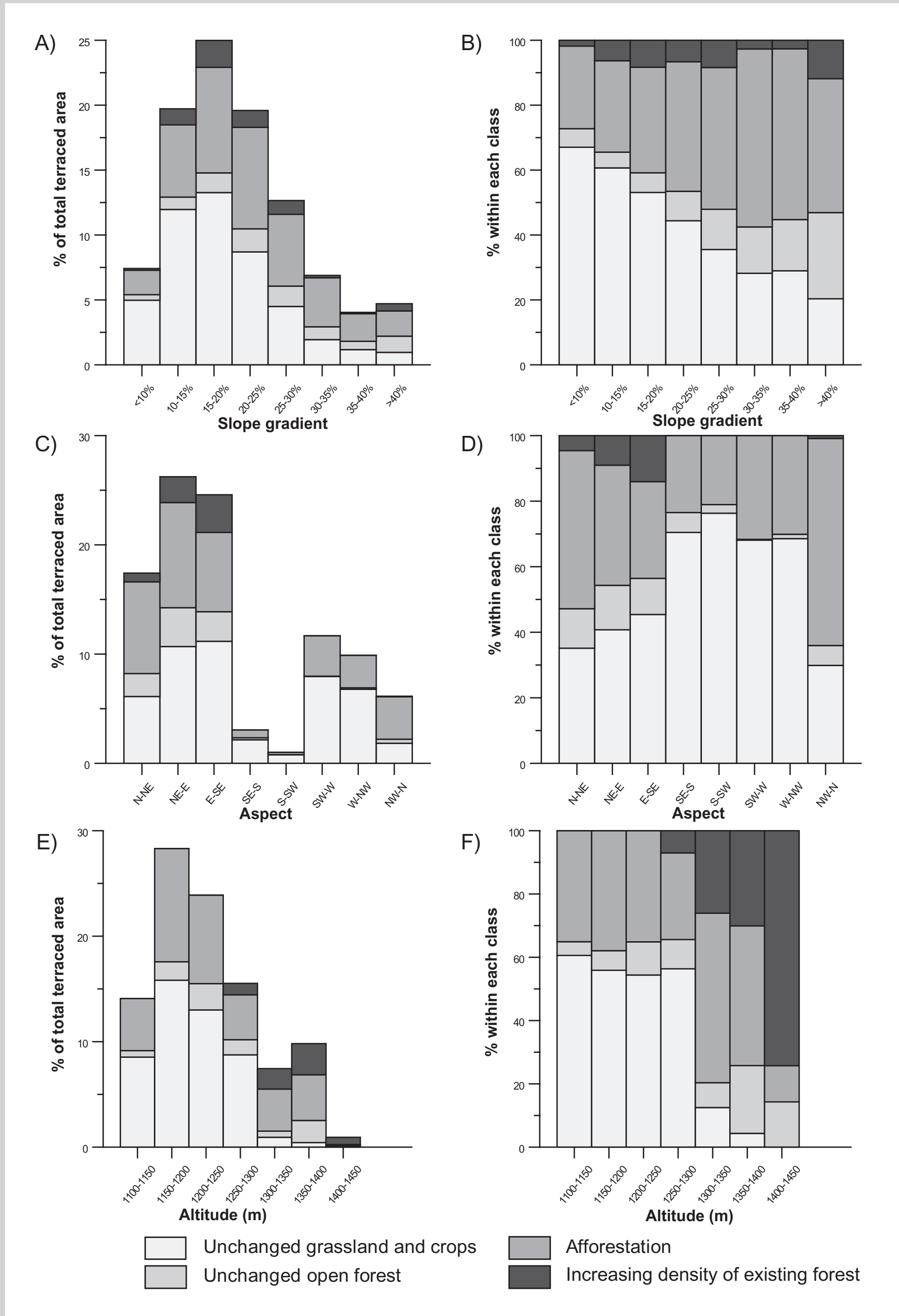


FIGURE 4, A–F Distribution of land cover change on terraced sites in the study area according to slope gradient (A, B), aspect (C, D), and altitude (E, F). Other minor changes—totaling 6% of the terraced areas—were disregarded because they were not confirmed by field checking.

tion of grassland and crop cover seems to prevail, whereas afforestation is progressively dominant on steeper slopes.

Aspect: North- and east-facing hillslopes are the most frequent in the catchment (Figure 4C). These areas, where afforestation is predominant, are also the only ones where increasing forest density was observed during the study period (Figure 3). This indicates that north- and east-facing terraces were probably the first affected by pine afforestation. Unchanged grassland and crop areas represent 30% to 45% of north- and east-facing terraces and up to 60% of terraces with southern and western aspects (Figure 4D).

Elevation: Less than 20% of the total terraced area is found above 1300 m (Figure 4E), where afforestation and increasing density processes become more important (Figure 4F). Below 1300 m, land cover distribution shows similar percentages for every altitude class:

unchanged grassland and crops (60%), afforestation (36%), and unchanged open forest (4%). In contrast, in higher areas, forests have invaded former agricultural terraces, causing montane grasslands to almost disappear above 1300 m.

Discussion

During the 19th century, cultivated areas occupied an average of 28% of the land below 1600 m in the Pyrenees region (García-Ruiz et al 1996). Most of this land was terraced to overcome the difficulties posed by topographic conditions. The present extension of terraced areas in Cal Rodo reflects the intensity of this agropastoral land use in the past. Hence, the study of land cover change in these areas becomes essential to assess the hydrological and geomorphologic consequences of land abandonment and afforestation.

Land cover dynamics in Cal Rodo catchment during the period studied can be summarized in terms of 2 main processes:

- Increasing density of forests already present in 1957.
- Spontaneous afforestation of abandoned fields and sparsely vegetated areas.

The area affected by these processes accounts for more than 43% of the entire catchment, indicating that the magnitude of these changes cannot be ignored. Afforestation of areas with sparse scrub vegetation may be due to an important decline in the sheep population of the area during the second half of the 20th century (Molina 2000). The increasing density of the forest reflects the decreasing use of fuelwood and timber because of population decline and the replacement of forest resources by other energy sources and materials during the same period. On the terraces, pine colonization of former grassland and crop areas has taken place to a lesser extent than in zones covered by sparse vegetation. In some cases, this may be explained by occasional grazing because livestock grazing is an important factor in the survival of *P. sylvestris* seedlings (González-Martínez and Bravo 2001).

When analyzing the relationships between physiographic factors and land cover changes in terraced areas, human influence must be taken into account because of its implications for the spatial and temporal pattern of abandonment. After the maximum expansion of cropland, the first areas to be abandoned were those in which the conditions for cultivation were the worst, that is, the north-facing steep slopes or those situated at higher elevations. For this reason, expansion of forest is more important on these terraces. On the contrary, grass cover is still predominant on gently sloping, south-facing lower terraces, as observed by Ubalde et al (1999) in a nearby Pre-Pyrenees area. Moreover, drier conditions on south-facing slopes may also limit the development of *P. sylvestris* forests. Hence, physiographic factors play an important role in land cover change after complete abandonment of agropastoral exploitation (Thomlinson et al 1996), but relationships between land cover evolution and the physical attributes per se cannot be separated from the previous pattern of land use and subsequent abandonment (Pascarella et al 2000).

Finally, other local factors can influence afforestation patterns. For instance, it has been observed that Scots pine tends to grow adjacent and parallel to the terrace walls in the inner part of the terrace, whereas the outer parts are only densely covered by grass. Terraces modify hydrological functions in the catchment and consequently change soil moisture patterns. As a result, the inner parts of the terraces are more frequently saturated, whereas the outer parts retain less water (Gallart et al 1994). This higher water deficit in the outer part of the terraces can enhance competition from well-established permanent pastures in a nutrient-rich environment (because of fertilization during previous agricultural use) (Davis et al 1998). Thus, well-established grass cover can pose serious difficulties for tree growth, especially during characteristic Mediterranean annual summer droughts, when *P. sylvestris* can be highly sensitive to soil water deficits (Martínez-Vilalta and Piñol 2002). However, even without this drought effect, inhibition of seedling establishment by compact layers of herbaceous vegetation has been reported as an important factor in regulating afforestation processes in secondary meadows in central Europe (Prach et al 1996).

Conclusions

Information obtained from aerial images can provide very valuable knowledge about general trends in land use and cover change. Rapid socioeconomic changes in the second half of the 20th century have led to a general abandonment of mountain agropastoral activities and consequently resulted in a new landscape predominantly covered by forest. Afforestation of terraced and scrub-vegetated areas and increasing density of existing forest canopies have helped increase the overall forest cover of the study area from 40% to 64% in 40 years. Physiographic attributes have been shown to be relevant in land cover evolution after abandonment. Nevertheless, these factors cannot be separated from either the anthropogenic-terraced topography or the influence of time since the land was last cultivated or grazed.

The hydrological effects of afforestation are well known from catchment experiments throughout the world (Bosch and Hewlett 1982). Changing from grassland to forest cover can cause a decrease in water resources as a result of the increase in rainfall interception. Recently, after surveying 250 catchment yield studies, Zhang et al (2001) even reported a relationship between mean annual precipitation and the increase in actual evapotranspiration that would result after complete afforestation of a grassland-covered catchment. In the area studied, pine rainfall interception, evaluated experimentally, represents up to 25% of bulk rainfall (Llorens et al 1997), and results from a water balance model application show a reduction in runoff up to 18% when changing from a scenario where pastures are the dominant cover to one where pine trees are dominant (Llorens et al 2003). As noted by Dirnböck and Grabherr (2000), mountain areas play a major role in regulating water availability in general because the headwaters of mountain systems are important water resources. In the case considered in this study, runoff reduction caused by afforestation might reduce water availability in the Llobregat River, which is 1 of the sources of water supply for the city of Barcelona.

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