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FROM VEGETATION MAPPING TO A PREDICTION FOR LANDSCAPE EVOLUTION IN THE CATALAN PYRÉNÉES

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ABSTRACT

In the Pyrénées, as in other Alpine mountain systems, various strong ecological gradients, together with old land use, have produced a high level of diversity both between landscapes and within individual areas. Mapping these landscapes during recent years has revealed dynamic trends thorough the area, mainly related to the general abandonment of traditional land use. At low and medium altitudes, former rangelands and crop fields show encroachment following secondary succession and, as a result, expanding scrubs and immature forests. In the high mountain, coniferous forests expand in the subalpine belt and reduce the area of pastures and other landscape units. However, no general altitude progression of the subalpine forest may be documented for the last half century, nor can it be envisaged in the medium term.

RÉSUMÉ

Quelques estimations sur l’évolution du paysage des Pyrénées catalanes à partir de la cartographie de la végétation. Dans les Pyrénées, des forts gradients écologiques, ainsi que les anciens usages du terrain, ont produit une grande diversité dans les paysages et aussi à échelle regionelle. La cartographie de ces paysages pendant la deuxième partie du XXème siècle montre des tendances dynamiques, surtout en relation avec l’abandon massif des usages traditionnels. Les anciens pâturages extensifs et les cultures sont soumis à l’envahissement des espèces ligneuses lié à la succession secondaire, de tel façon qu’ils deviennent fruticées et fourrés, surtout en basses et moyennes altitudes. Concernant l’haute montagne, les forêts de conifères de l’étage subalpin se trouvent en expansion aux dépens des prairies et d’autres habitats, bien que pendant la dernière cinquantaine d’années on n’ait pas pu constater une

progression en altitude de la limite de la forêt; cette progression n'est pas non plus attendue à moyenne échéance.

INTRODUCTION

The vegetation of the Catalan Pyrenees is now well known, thanks to a wide range of phytocoenological studies. These clearly started with the classic study carried out by BRAUN-BLANQUET (1948), focusing on the Alpine vegetation of the eastern Pyrenees, and has been developed through a number of monographs and short papers. During the last 15 years, various mapping projects and the compilation of their particular results have allowed us to build a comprehensive landscape GIS of the Pyrenean area within Catalonia (Tab. 1).

Our cartographic compilation includes the mapping of European biotopes and of vegetation in phytocoenological terms (both at scale 1:50.000), a general survey on potential vegetation (BOLÒS *et al.,* 2004) and various partial maps of sub-areas or of particular features (timberline, rare habitats, etc.). From this information, we have obtained diverse results on landscape evaluation aimed at describing patterns or conservation priorities.

The Catalan Pyrenees constitute a complex, mountainous area, which stretches over 9,430 km^2, from 240 to 3,143 m a.s.l. (Fig. 1). This area includes from Mediterranean, pre-Pyrenean peripheral ranges to the Alpine, axial main chain, and from eastern, maritime outskirts to central, inner valleys. Therefore, it represents a concentration of hugely diverse landscapes, consisting of five vegetation belts, i.e. basal, submontane, montane, subalpine and alpine (and subnival), which in turn can be differentiated into sectorial forms.

The creation of vegetation maps revealed changing landscapes in various locations and observation scales. The main driver of change in the area is the generalised abandonment of traditional land use, which mainly from the 1960s has left former rangelands and crop fields to recover following secondary succession, and has allowed exploited forests and tree plantations to progress toward more natural systems. Moreover, climatic change is expected to modulate these succession events, and would also produce a general upslope displacement of plant communities and vegetation belts (GUISAN *et al.*, 1995). In this paper we will present and discuss aspects of landscape dynamics, first shown during the mapping works, and later analysed more precisely. This may help predict future changes, and principally the research planning aimed at carrying out a more thorough study of the ongoing landscape changes.

Tab. 1. Main cartographic facilities relative to the Pyrenean landscape.

Document	Scale	Year	Legend basis
Vegetation map of Catalonia	1:50.000	1994-2006...	Phytosociology
Local vegetation maps (Ribes valley, Aigüestortes National Park)	1:50.000	1996 & 1997	Phytosociology
Habitats map of Catalonia	1:50.000	1998-2005	CORINE biotopes
Potential vegetation map of Catalonia	1:250.000	2004	Phytosociology
Timberline in the Catalan Pyrenees	1:50.000	1995	
Infrared orthoimages	pixel 2.5 m	1996-1997	
Colour orthoimages	pixel 0.5 m	2000-2003	

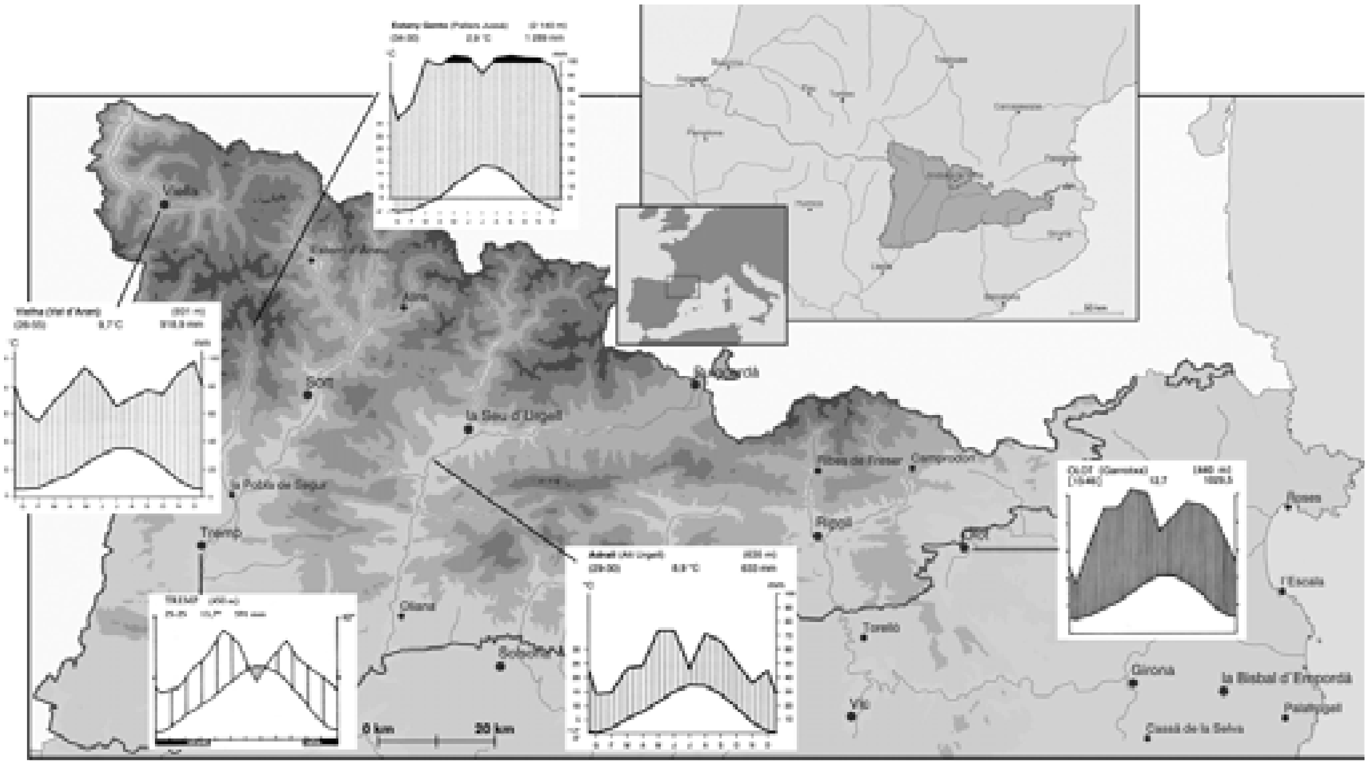

Fig. 1. Map of the Catalan Pyrenees, with some contrasting climatic diagrams.

Some measures of landscape change

The more marked changes in the Pyrenean landscape are occurring from the 1960s onwards. These may be analysed at an approximate level through the comparison of the first aerial photographs (1956) with more recent imagery or vegetation maps. MONJE (2003) used this approach to study the land use changes in an Eastern Pyrenean valley, and highlighted the main dynamic trends. Among them, the advance of deciduous forests and dense pinewoods and the complementary decrease of herbaceous communities (chiefly fields and pastures) is the most evident as far as the main units are concerned (Fig. 2). As for the topographic distribution of changes, the general trend consisted of a gradient from strong to weak landscape changes with increasing altitude. Consequently, fields and extensive pastures have grown into pinewoods, scrubs or deciduous forests mainly in the submontane belt, progressively less in the montane and subalpine belts, and changes are barely noticeable in the alpine belt (Fig. 3). This pattern, which seems very generalised in the Pyrenees, reflects greater vegetation dynamics at lower altitudes, due to both a lower degree of landscape naturalness and a longer growing period.

An indirect measure of landscape change was given in FERRÉ *et al*. (2005) as a landscape comparison of Andorra and the neighbouring valleys of Vallferrera and Cardós. Since both areas are very similar in terms of physiography and vegetation, it may be assumed that the landscape in Andorra is more evolved than in the other valleys, due to far more pronounced socio-economic changes during recent decades. Consequently, the greater decrease in traditional land use (mainly pasture abandonment and a lower level of forest exploitation) is producing in Andorra the changes we might expect to see in the other Pyrenean valleys.

The data compiled in Tab. 2 refer to the landscape units exhibiting greater differences between the two areas compared, as well as covering noticeable to high surface percentages. From these figures, and taking into account the landscape struc-

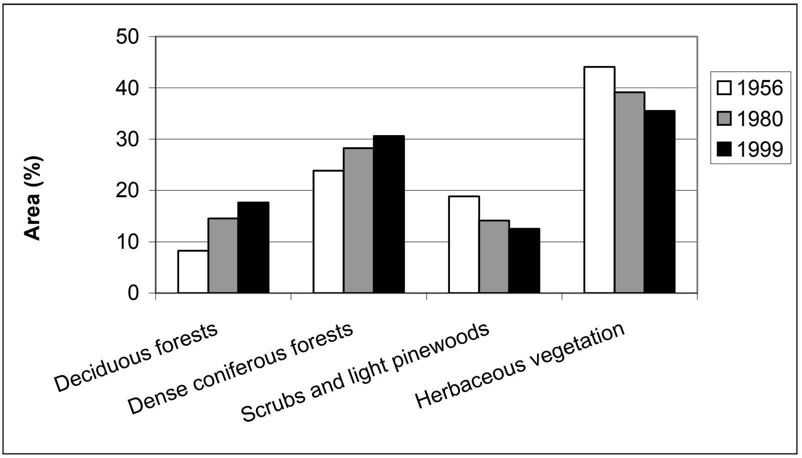

Fig. 2. Main changes in the landscape of the Ribes valley in the last half century, expressed as percentage cover of broad units (from MONJE, 2004, modified).

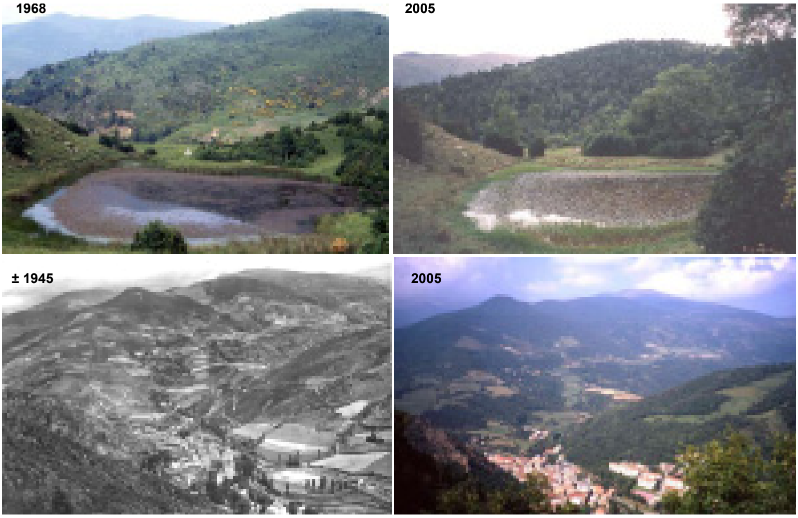

Fig. 3. Changes in the landscape of the Ribes valley. Forest advance over pastures and fields is particularly evident at lower and medium altitudes (bottom views), but is also noticeable in the upper montane belt (top views). *[en couleur à la page 785]*

ture of the valleys considered (DMAH, 2003; NINOT *et al.*, 2003), three general aspects may be highlighted:

- the greater urbanisation in Andorra grew at the cost of low altitude and riparian deciduous woods;

- some secondary units related to extensive pasture (and occasional fires) maintain a larger coverage in the Vallferrera and Cardós valleys;

- extensive, xerophilous coniferous forests cover larger areas in Andorra, mainly due to the abandonment of pasture and clear-cutting.

The trend of increasing forest area is also analysed by PIQUÉ & GRÀCIA (2004) in the subalpine belt of the National Park of Aigüestortes i estany de Sant Maurici (Central Pyrenees), based on a comparative study of aerial photographs taken in 1956 and in 1997. In spite of the extent of surfaces that are unsuitable for the subalpine forest (rocky, scree, very steep, etc.), a clear advance of *Pinus uncinata* woods is documented during this 40-year period, mainly on the north-facing aspects and on gently sloping areas. Non-forested surfaces remain chiefly on south-facing slopes, due to the combination of steeper relief, greater ancient deforestation, and more limiting environmental constraints for plant succession (NINOT, 1998). As for the density of the tree cover, whereas in 1957 most of the forest surfaces exhibited light to very light tree cover (more than 60% of the forest surface showed *Pinus* cover values lower than 30%), in 1997 a general densification of the tree cover was evident (more than 60% of the same surface with *Pinus* cover higher than 30%), including a noticeable increase of the 'dense forest' category (tree cover greater than 90%) (PIQUÉ & GRÀCIA, 2004).

This trend of spontaneous subalpine afforestation is growing under the present conditions of abandonment of traditional land use, more clearly in protected areas (more than the half of the Catalan Pyrenees). The complementary decrease

Tab. 2. Comparison of the percentages occupied by certain landscape units in Andorra and in Vallferrera and Cardós valleys (from FERRÉ *et al*., 2005).

Units mapped	**Andorra**	**Vallf. & Cardós**	**Ratio**
Anthropised units			
Reclaimed areas (sky areas)	0.764	-	**-**
Urban and industrial areas	1.598	0.099	**16.141**
Deciduous montane forests			
Quercus spp. forests (*Quercus petraea*, *Q. pubescens*, *Q. subpyrenaica*...)	0.562	6.765	**0.083**
Riparian deciduous forests and thickets (*Alnus glutinosa*, *Corylus avellana*...)	0.143	0.481	**0.297**
Secondary dry heaths and pastures			
Genista balansae heaths	0.917	13.369	**0.069**
Calciphugue, semi-dry grasslands with *Agrostis capillaris*	0.514	1.953	**0.263**
Xerophilous mountain forests			
Calciphugue, xerophilous *Pinus uncinata* forests	6.959	5.009	**1.389**
Calciphugue, xerophilous *Pinus sylvestris* forests	4.488	2.071	**2.167**

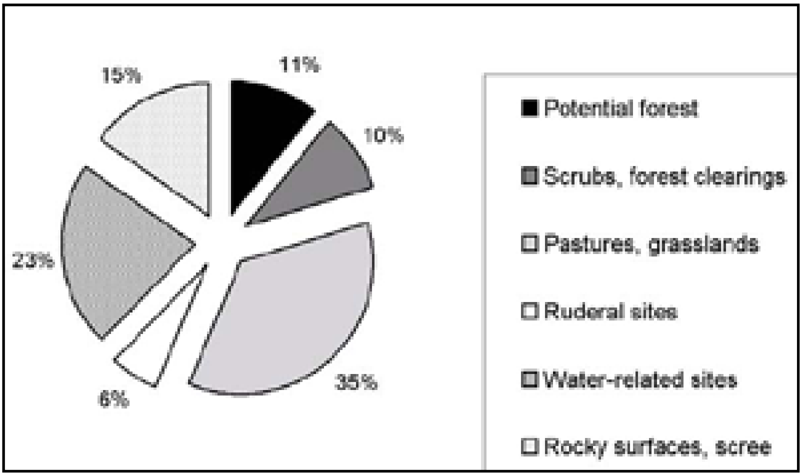

Fig. 4. Ecological division of the vascular flora (389 taxa) of a small subalpine area (Peguera valley, 'National Park of Aigüestortes …') into 6 main habitats (elaborated from the floristic data included in CARRILLO & NINOT, 1992).

of non-forest vegetation would mean fragmentation of pasture surfaces and other secondary units. In the subalpine belt, the forest expansion over species-rich, contrasting pastures will lead to the lowering of plant diversity at community and landscape levels. As is shown by the example drawn in Fig. 4, almost 90% of plant diversity in this belt is provided by non-forest habitats, and herbaceous vegetation from pastures and water-related sites accounts for almost 60%. Therefore, the less common taxa of pastures, and secondly of water-related vegetation, scrubs and clearings, are facing population decrease and isolation, which may eventually lead some of them to local extinction.

CASE STUDY: THE TIMBERLINE

Subalpine timberlines are natural ecotones identified as particularly sensitive to global change (HEIRI *et al*., 2006, HOLTMEIER & BROLL, 2005). In the Pyrenees, a hypothetical rise of the subalpine forest due to the combined effect of climate warming and decreased land use would cause a significant reduction and fragmentation of the alpine surface. This would particularly affect pastures and scrubs, forced to retreat to higher elevations, since most of the alpine belt is made of rocky substrata, mainly in the Central Pyrenees.

With the aim of assessing these dynamics, we have studied the vegetation structure of the *Pinus uncinata* timberline in semi-natural locations, where the main effect of old land use has produced moderate downward displacements of the line (NINOT *et al*., 2005). We analysed 12 plots spread across the central and eastern Pyrenees. In each plot - a rectangle set along the altitude gradient, including terrain ranging from closed forest to typical alpine pasture - three data sets were recorded: tree structure (including explicit individual location), vegetation (small, intensive plant relevés throughout the rectangle) and substrate characteristics (plant cover, bare rocky outcrops, slope).

Our data show a general upslope rise in species richness on a small scale (a-diversity), which increases slightly above the timberline, coinciding with the decline of dwarf-shrubs. Parallel to this, topographic heterogeneity becomes more apparent since it produces medium-scale patching in the herbaceous vegetation, which raises b-diversity. On a regional scale, site conditions (bedrock type, topography, land use) are reflected in the general aspects of each plot, such as plant diversity or particular ecotone communities.

As regards the dynamic aspects, the diachronic comparison of aerial photographs of the plots and the analysis of the population structure of *Pinus uncinata* (Fig. 5) show a generalised densification of this species around the timberline. This is based almost exclusively on the increase of young individuals (from abundant seedlings to the more scarce poles), with new adult trees appearing at very low rates. Therefore, in most of the plots studied the timberline (forest limit) has essentially remained static during the last half century, in spite of the upslope advance of sparse trees or krummholz (low-growing forms of *Pinus*), i.e. of the treeline (tree limit). This is not the expected outcome of the documented climate warming and the marked change in land use during the period analyzed.

The present abundance of *Pinus uncinata* seedlings and saplings above the timberline may be connected to the decrease in pasture pressure in the area and the parallel increase in small heterogeneity of ground and low vegetation (pasture, low heath). This could cause the timberline to rise in the near future. However, the fate of seedlings and juveniles becomes very irregular over space, and uncertain. In the example shown in Fig. 5, a period of cold winds in February 2005 swept away the protecting snow cover, producing severe frost damage and eventually killing seedlings, saplings and krummholz. It is however very likely that both survival of these low individuals and seedling emergence are irregular from year to year, thus rendering any prediction very uncertain.

In conclusion, although the expansion of the subalpine forest over pastures and other non-forest vegetation is noticeable where the timberline had previously been dropped, forest advance becomes irregular and largely unnoticeable near the

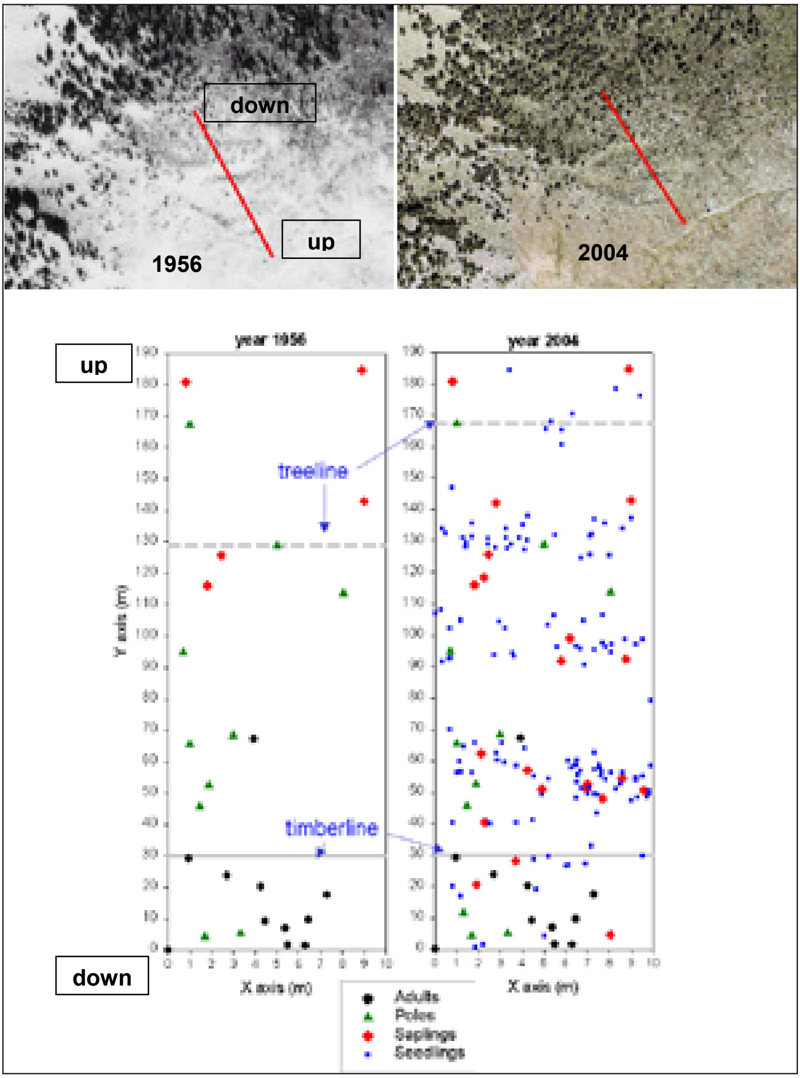

Fig. 5. Aerial views (up) of one plot for the study of the timberline in the Vallferrera valley, central Pyrenees, with the plot sudied (indicated as one line); and population structure of *Pinus uncinata* (down) recorded in 2004 and deduced for 1956 (from BATLLORI, 2005). *[en couleur à la page 786]*

potential forest limit. This inertia in the forest recovery may presumably be caused by increasing inter-annual climate irregularities, which have a negative effect on tree colonisation, and by the increasing effects of environmental constraints and natural disturbance above the timberline.

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