DIACHRONIC VEGETATIONAL ANALYSIS COUPLED TO ECOLOGICAL SAMPLING IN A GIS FRAMEWORK. EXAMPLE OF THE COSTIÈRE DU GARD, FRANCE

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RÉSUMÉ

Des inventaires de terrain (flore, strates végétales et régénération) ont été associés a une analyse diachronique de la végétation basée sur l'analyse de 6 photographies aériennes prises entre 1946 et 1996, dans un Système d'Information Géographique composé de 497 polygones représentant une superficie d'étude de 269 ha. En seulement un demi siècle, l'abandon de l'agriculture et des activités traditionnelles associées ont induit des changements considérables dans la végétation des Costières du Gard (CDG) en France méditerranéenne. En particulier, la forêt occupe maintenant des zones qui étaient auparavant des pelouses ou des friches. En 1946 il n'y avait pas de forêts, et les vignes et les pelouses occupaient chacune 41 % de la zone d'étude. En 1996 la forêt représentait 33 % de la zone d'étude tandis que les vignes et les pelouses ou les friches représentaient respectivement 26% et 17%. Le recouvrement de la strate arborée est proportionnel à la date d'abandon des parcelles agricoles. Aujourd'hui, trois espèces d'arbres sont dominantes dans le paysage : *Pinus pinea*, *Quercus ilex* et *Q. pubescens*. Ces trois espèces utilisent des stratégies d'occupation de l'espace différentes. La plus abondante des trois, *P. pinea*, montre une stratégie d'espèce pionnière héliophile. Le recouvrement plus important de *Q. pubescens* comparé à celui de *Q. ilex* s'accentue avec le temps et est également en relation avec la proximité des talwegs.

SUMMARY

Fields inventories (flora, vegetation strata and regeneration) were related to a diachronic analysis of vegetation cover based on 6 aerial studies between 1946 and 1996 of a 269 ha study area represented by 497 digitalized polygons by means of a Geographical Information System (GIS). In only half a century, the abandonment of agricultural and related traditional activities have led to considerable changes in the vegetation of the Costière du Gard (CDG), in Mediterranean France. Specifically, forest now occupies zones that were previously grass-

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lands or fallow lands. In 1946, there was no forest, and vineyards and grasslands occupied 41% each of the study area. In 1996, forest represented 33% of the study area whereas vineyards and grasslands/fallow lands accounted for 26% and 17%, respectively. The amount of the tall woody stratum cover is proportional to what would be expected given the dates of abandonment of the agricultural parcels. Today, three tree species are dominant in the landscape: *Pinus pinea*, *Quercus ilex* and *Q. pubescens*. These three species use different space occupation strategies. The most abundant of the three, *P. pinea*, exhibits a pioneering, light-demanding strategy. Conversely, *Q. ilex* and *Q. pubescens* are shade-tolerant species. The greater proportional cover of *Q. pubescens* compared to *Q. ilex* is increasingly evident over time and in relation to proximity to thalwegs.

INTRODUCTION

Since the Neolithic, agricultural and related traditional practices such as clearing of land, slash and burn, and forest exploitation have profoundly modified the Mediterranean vegetation (Vernet, 1997). During the first half of the twentieth century, the Bas-Languedoc landscape has been dominated by pasture lands and vineyards. The forest, long exploited for wood and the manufacture of charcoal (Fabre, 1996), was and is still today represented largely either in the form of “garrigue” or oak coppice woods. After the Second World War, the rate of abandonment of traditional agricultural practices dramatically increased leading to considerable regression of pasture lands and exploited forest. From 1970 onwards, the occupation of land by vineyards also decreased due to removal of grapevines. The abandonment of the aforementioned modes of exploitation has “liberated” spaces and allowed the progressive reinstallation of natural vegetation (Debussche *et al.*, 1987). Over the course of the last decades, the Bas-Languedoc landscape, similar to that of the French Mediterranean region in general, has experienced a rapid increase in forest cover (Hamza & Pignard, 1997). These changes are the result of a secondary successional vegetation process (Lepart & Escarré, 1983). The dynamics of succession are central to an understanding of the community structure of plant communities (Huston & Smith, 1987).

There are two basic methods for the study of vegetation dynamics. One is “direct” or diachronic and involves observing successive modifications of vegetation at a given site over time; this may be done by comparing photographs taken at different times at a given site (Lepart *et al.*, 1996). The principal constraint of this method is the time variable, because it is difficult, if not impossible, to continuously monitor a site. The use of old aerial photographs unaccompanied by concommitant field surveys also introduces a source of error in that the fine structure of vegetation composition can only be inferred by comparison to existing vegetational forms. The other method is “indirect” or synchronous, and consists of *in situ* analysis (including the use of historical evidence) of spatial and temporal variations of the principal vegetational and floristic components of a given site. The different communities or vegetation successional stages are in this way described, grouped and organized into one or more successional sequences (Escarré *et al.*, 1983; Lepart & Escarré, 1983). The major criticism of this method is that it is assumed that the biophysical factors influencing the milieu have a uniform effect over the entire study region.

The aim of our study is to apply both of these methods to a vegetation dynamics study and to integrate results in a Geographical Information System (GIS) framework. Because GIS is a highly sensitive technique, it allows us to finely analyse relationships between and among measured variables (Mast *et al.*, 1997; Olsson *et* *al.*, 2000; Wickham & Norton, 1994). Field data on vegetation structure, composition and regeneration from a synchronous study are combined with a diachronic analysis of vegetation cover spanning half a century. The study site, the Costière du Gard (CDG) in Mediterreanean France, was previously intensively exploited for animal husbandry, vineyards and fruit orchards. Today, the spontaneous vegetation of the CDG is dominated by *Pinus pinea*. This species has recently been proposed as a climax species in the CDG (Neff & Frankenberg, 1995), a concept that challenges the long-held notion that *Quercus ilex* and/or *Q. pubescens* are climax species but not *P. pinea*. Our work represents a novel approach to the study of the vegetation dynamics of the region and provides decisive evidence as to which of these dominant tree species should be considered as climax in the CDG.

MATERIALS AND METHODS

The Costière du Gard and study site

The Costière du Gard is situated a few kilometers south of Nîmes between the Camargue and the Vistre river. It is a plateau, the highest point of which is 145 m, and is constituted of Pliocene and Quaternary formations. The Pliocene portion is represented by the Plaisancian marles and lagunal sands of the Astien. After the Pliocene marine phase, several successive deposits were laid down: first there was material from the Cévennes Massif, then marine formations and finally a Durance alluvial deposit. During the Quaternary, the large ravines or "vallats" (local term) were formed by erosion, especially in the south of the Costière. The cutting of the ravines led to the production of numerous colluvial and alluvial deposits which reshaped the existing surface formations (Bazile, 1976). As a consequence, present day soils lie directly on Pliocene sands or restructured fine textured predominately clay deposits, or fine textured sandy clay recent alluvial deposits.

The study site is in the southern part of the CDG between 43°40'22" and 43°41'39" North and 4°17'34" and 4°9'14" East. The total surface area is 2,689 km^2 and altitude is 40-90 m. The site comprises two large thalwegs oriented NNE-SSW known locally as the "vallat des Marchands" and "vallat de Listerne", which cut the Costière plateau (Fig. 1). Today, vineyards and fruit orchards grow on the plateau whereas spontaneous vegetation dominates slopes. The latter lands appear as a mosaic composed of fallow lands, horse or sometimes Carmargue bull pasture, low garrigue, and *Pinus pinea* L. (Italian Stone Pine) and *Quercus pubescens* Willd. (Downy Oak) forests.

Diachronic analysis and vegetation types

All data were integrated into a GIS in vector mode (Map Info 5.5 software program, Map Info Corporation, Troy, New York, USA). The diachronic analysis of the vegetation was done using six series of aerial photographs (Institut Géographique National missions 1946, 1956, 1963, 1978, 1985 and 1996). The geo-referenced photographs were scanned with a Hewlett Package (Scanjet 4C) with a mean resolution of 1 m. Even today, the agricultural parcels determine the physionomic units

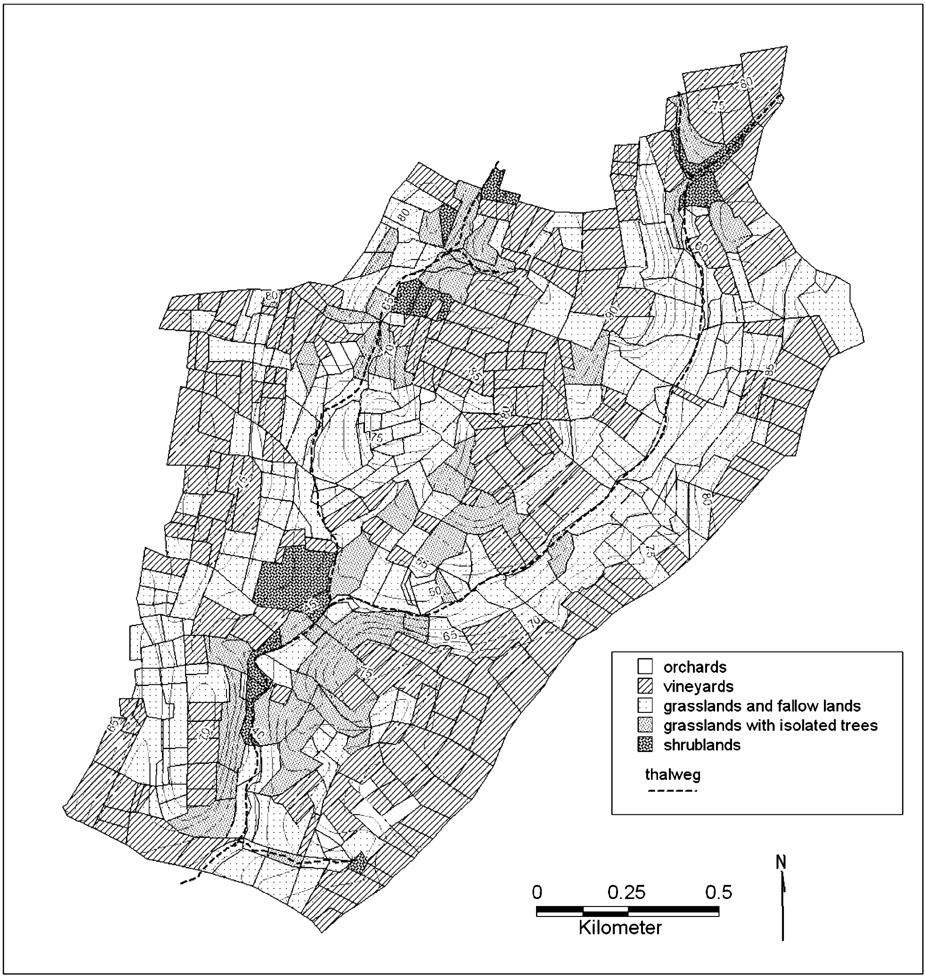

Figure 1. — Map of the vegetation in 1946.

of the landscape. It is for this reason that the parcel is taken both as a reference unit in our vector analysis (it is conceptualized as a polygon) and as the basis for sampling in the field inventories. A series of polygons of variable size corresponding to agricultural parcels in 1946 were digitalized. This served as our base map. Using this map of polygons overlaid on photographs of successive years we noted vegetation type as deduced from the photographs. In the field we verified the limits of the polygons and made detailed observations of vegetation composition. This information allowed us to determine the correspondence between actual and photographic images of vegetation type.

For each polygon, vegetation type was determined on the basis of 6 series of aerial photographs. Tall woods are defined as having a height more than 2 m, low woods have a height between 0.5 and 2 m. Six basic vegetation types are recognized: vineyard, fruit orchard or olive grove, grassland or fallow land, wooded grassland (talls woods cover < 25%), preforest state (low wood cover < 75% and tall woods < 50%), forest (tall wood cover > 75%).

SYNCHRONIC ANALYSIS, *IN SITU* OBSERVATIONS AND FIT WITH TOPOGRAPHY

Inventories of the vegetation and the woody flora were done *in situ* to provide information on each of the polygons (parcels). The vegetation was described as a measure of the species cover belonging to each of the three strata currently recognized for the Mediterranean region: tall woods, low woods, herbaceous (C.E.P.E., 1968). These three strata are well represented over the entire study site. In each parcel, relative abundance (rare, moderately frequent, frequent) of the saplings of the three principal tree species (*Quercus pubescens*, *Q. ilex* L. (holm oak) and *Pinus pinea*) were estimated by transecting the parcel randomly along its length and width, then roughly noting the relative frequency and kind of saplings two metres either side of the transect.

The study site included two principal thalwegs and three secondary ones corresponding to small affluents of the former. The GIS allowed us to define four equidistant isolines at each thalweg. The first three equidistant lines (0-50, 50-100, 100-150 m) cover the base and sides of the each thalweg, the fourth (150-200 m) is on the plateau. For each equidistant interval, the software calculated the corrected means of cover of the three principal tree species, taking into account the precise position and exact surface area of each parcel.

RESULTS

There were a total of 497 parcels, and their surface area varied between 394 and 27,292 m^2. In 1946 (Fig. 1), the landscape was essentially agricultural. Grapevines were predominately on the plateau and grasslands on the slopes of thalwegs. Only a few parcels showed isolated trees or some shrubby vegetation. In 1996 (Fig. 2), grapevines were still present on the plateau, but the slopes and bottoms of thalwegs were colonized by forest. Presently, 154 of the 497 study sites are wooded. Grasslands and fallow lands which were well represented in 1946 (214 parcels), now only occupy 88 parcels.

Vegetational changes from 1946 to 1996 are graphed in Figure 3. Forest, absent in 1946, occupies nearly 90 ha in 1996, i.e. 33% of the total surface area. It has developed to the detriment of grasslands and fallow lands, which previously surpassed 110 ha (1946), and which became reduced to 40 ha (1996). In 1946, all grasslands were used as pasture, over time this changed such that the grassland vegetation type can no longer be strictly considered as pasture although it frequently is. The surface area occupied by vineyards, stable between 1946 and 1978 has been reduced by nearly 40% from 1978 to 1996. Shrubby vegetation increased between 1946 and 1965, followed by reduction and stabilization since 1978 at about 9% of the total area. The surface area occupied by grassland with isolated trees has remained stable between 1946 and 1996, and accounts for about 15% of the total surface area today.

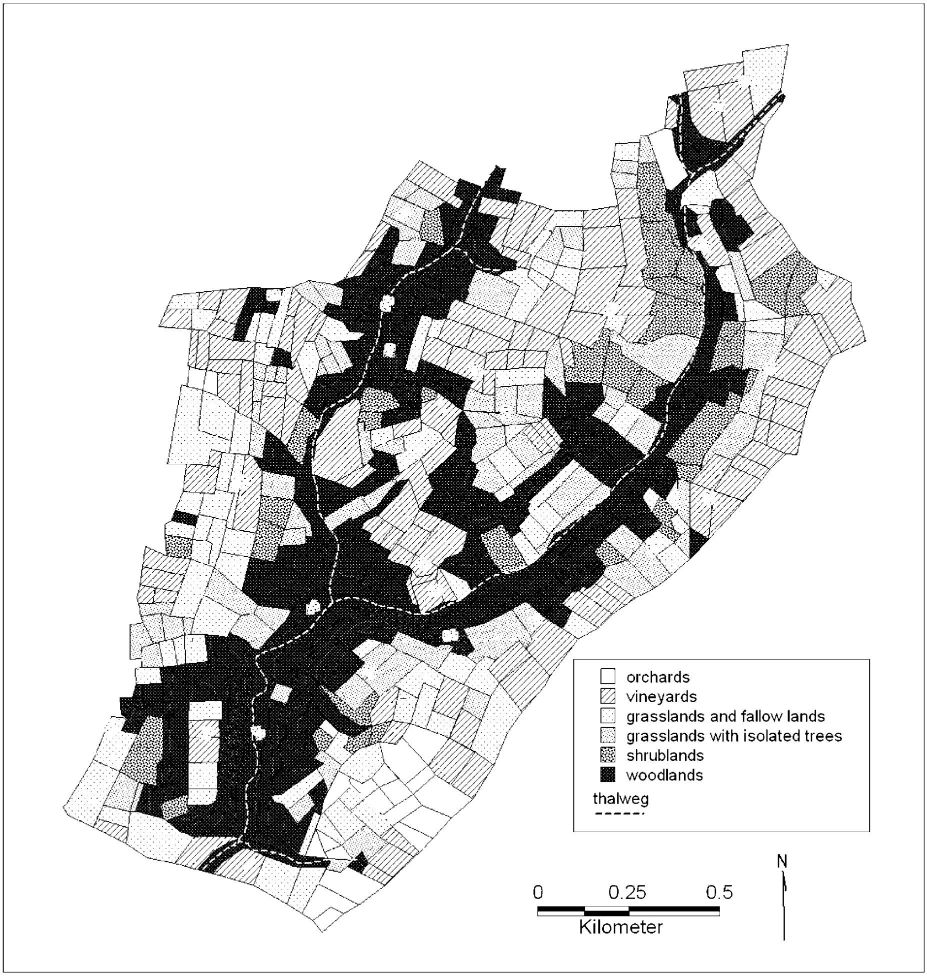

Figure 2. — Map of the vegetation in 1996.

Analysis of vegetational change, polygon by polygon, allows the determination of the dates of abandonment of each parcel. For example, if one parcel was cultivated as a vineyard in 1963 and then in 1978 was a grassland or fallow land, 1963 fixes the date of abandonment. In this way, for 241 parcels, it was possible to determine the year of abandonment (Table I). Two hundred and fifty-six parcels remained in culture or pasture since 1946. This presupposed that a parcel abandoned between time was not recultivated or vice versa, which is a reasonable supposition given the limits or given the precision of our technique. The lack of aerial photos prior to 1946 explains the large number of apparently “abandoned” parcels listed for this date, 182 out of 241. Four parcels have for their date of abandonment 1996, which corresponds to the most recent available aerial photographs. In this last case, the state of abandonment was confirmed by field examination.

The cover of the tall woody stratum changes as a function of the date of parcel abandonment (Table I), the earlier the date, the greater the cover. Conversely, the

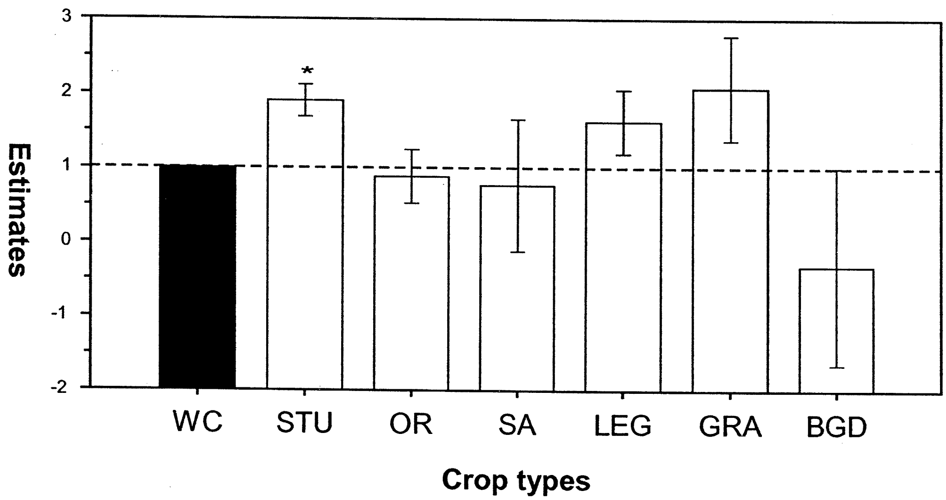

Figure 3. — Vegetational changes from 1946 to 1996.

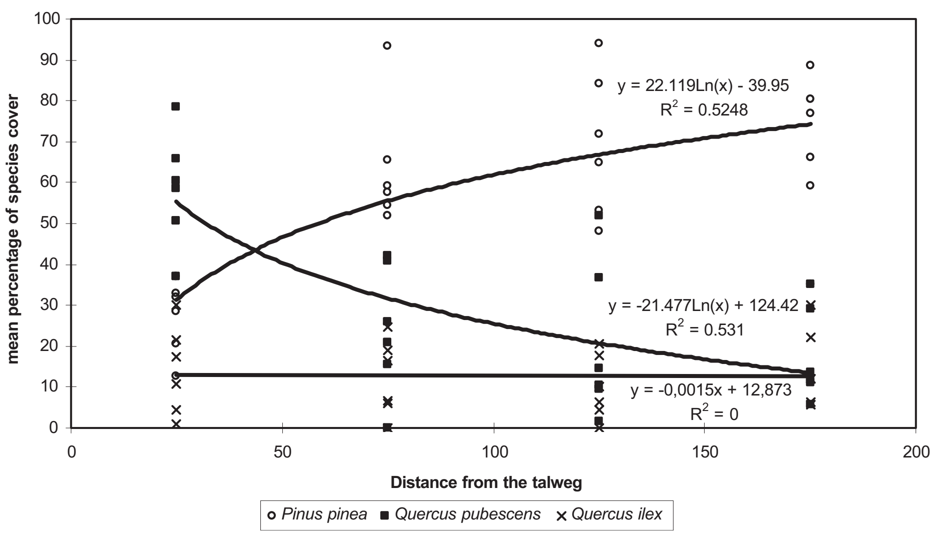

Figure 4. — Change in the tree species cover as a function of thalweg distance.

TABLE I

Cover percentage of trees and shrubs in function of the date of abandonment

Date of abandonment	1946	1954	1963	1978	1985	1996
Total area (m^2)	1,121,596	76,054	55,433	45,222	56,769	73,917
Number of parcels	184.0	18	19	11	13	16
Mean tree cover	66.9	51.4	42.4	30.5	17.0	1.3
Pinus pinea	42.5	34.3	63.7	66.6	82.4	90.0
P. halepensis	3.1	22.2	3.0	1.6	0	0
Quercus pubescens	37.9	31.4	25.6	15.6	6.8	5.0
Q. ilex	16.5	12.1	7.7	16.2	10.8	5.0
Mean shrub cover	40.4	27.5	25	28.3	19.6	0.6
Quercus coccifera	37.7	19.1	24.9	9.3	2.6	40.0
Cistus monspeliensis	18.8	25.8	34.3	17.8	17.2	40.0
Quercus ilex	10.5	13.0	14.3	15.1	5.7	0
Q. pubescens	5.5	8.4	11.1	13.3	5.3	0
Ulmus minor	5.5	11.8	7.3	3.6	3.1	0
Spartium junceum	3.5	10.6	0	21.3	50.7	20.0
Viburnum tinus	6.4	3.1	0	1.8	0.2	0
Juniperus oxycedrus	4.3	3.8	3.1	6.2	0	0
Crataegus monogyna	2.6	0.9	3.1	1.8	0	0
Pinus pinea	2.0	3.5	1.9	9.8	15.0	0
Prunus spinosa	2.5	0	0	0	0.2	0
Laurus nobilis	0.7	0.0	0	0	0	0

cover of the low woody stratum always is at about 30%, excepting for the parcels abandoned in 1996. For trees, the contribution of *Pinus pinea* to the mean cover is more important in recently abandoned parcels than in others. This tendency is just the inverse for *Quercus pubescens* and no regular pattern is discernible for *Q. ilex*.

In the low woody stratum, *Quercus coccifera* L. and *Cistus monspeliensis* L. are dominant. The high frequency of *Q. ilex* and *Q. pubescens* in this stratum reflects the importance of the role played by these species in the reforestation process. *Pinus pinea* has a very low (1.9-3.5%) contribution to the low woody stratum although this value is somewhat higher in parcels abandoned in 1978 and 1985 (10 and 15%, respectively). *Spartium junceum* L., nitrophile and pioneer plant, predominates in recently abandoned parcels. Other shrubs (e.g., *Viburnum tinus* L., *Juniperus oxycedrus* L., *Crataegus monogyna* Jacq., *Prunus spinosa* L. and *Laurus nobilis* L.) make up a lower percentage of cover as compared to *S. junceum*, and their relative contribution to the low woody stratum does not coincide neatly with dates of parcel abandonment.

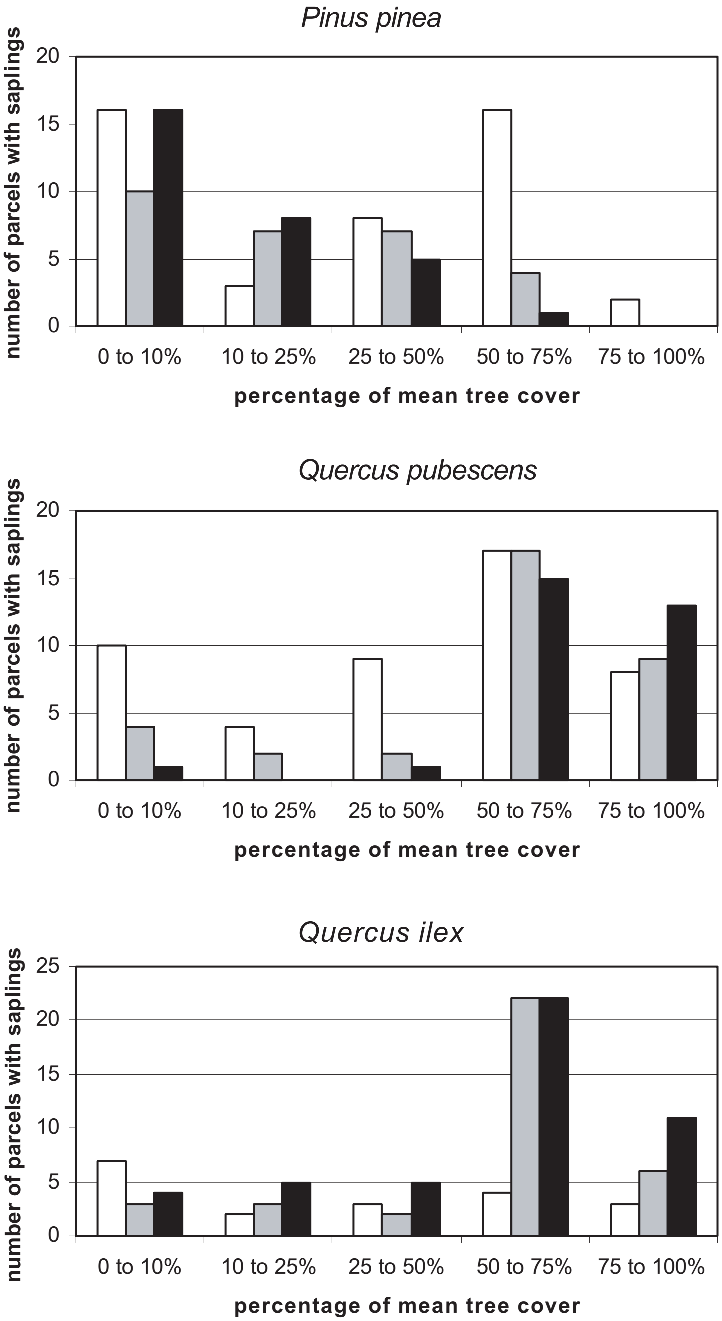

Figure 5. — Change in the frequency of tree saplings as function of mean tree cover (white: rare saplings, grey: non frequently observed saplings, black: frequently observed saplings).

The three major tree species evince ecological preferences as revealed by toposequence position (Fig. 4). The mean percentage of cover of *Pinus pinea* increases with distance from thalwegs. Inversely, *Quercus pubescens* is distinctly more prevalent in thalwegs than on plateaus. As for *Q. ilex*, its mean cover is independent of distance from thalwegs. Finally, the majority of *P. pinea* saplings are found on parcels with little cover (less than or equal to 25%) of the tall woody stratum. Conversely, saplings of the two oak species are primarily present on well covered parcels (greater than or equal to 50%) of the tall woody stratum (Fig. 5).

DISCUSSION

The diachronic analysis highlights the progressive and rapid changes after abandonment of pastured or cultivated vegetation types to forest in the CDG. This return of the forest is part of a general phenomenon occuring in the French Mediterranean region, where since the 1950's, there has been an abandonment of milieux, particularly those lands used for traditional activities such as pastoralism, wood cutting for the fabrication of charcoal, viticulture, and olive cultivation. Further, in the CDG, the decline of viticulture greatly increased from 1978 onwards. Vineyards have disappeared because they are too small to be profitable, difficult to reach, or because growers have retired without being able to pass on their exploitations. However, it is important to mention that over the last few years in the Languedoc-Roussillon region there has been a revival of viticulture and olive cultivation but the trend has been to produce quality wine and hence there has been no significant increase in planted surface area.

The present forest of the CDG is dominated by *Pinus pinea* and *Quercus pubescens*. *Quercus ilex* is only well represented in a few localized parcels. These parcels are often used for part of the year as grazing land for a breed of Camargue cattle; the grazing pressure of these animals leads to the maintenance of a very particular ecosystem of grassland under holm oak. For this reason we propose a hypothesis related to human action on the environment to explain the presence of *Q. ilex*; its exploitation by repeated cutting could lead it to be favoured locally over *Q. pubescens* because it stumps sprouts more readily. *Pinus pinea* is the most widespread species in the CDG. This species, indigenous to the south of France (Bazile-Robert, 1981), may have colonized the Costière plateaus from neighbouring large littoral populations. It is also possible that this tree was favoured by humans because it is a popular ornamental species and its edible seeds often collected for use in Mediterranean dishes and deserts. These days, it appears that this activity has completely disappeared in our region. The repartition of *P. pinea* contrasts sharply with that of *Q. pubescens*. Whereas *P. pinea* is well established on plateaus, *Q. pubescens* is primarily on thalwegs. It seems likely that edaphic conditions play a large role in determining species repartition in this case. *Quercus pubescens* is associated with deep soils (Plaisance, 1984; Quézel, 1976). Seed germination in this species occurs more readily under vegetation cover (Bran *et al*, 1990) and seedling establishment depends upon the presence of humid conditions (Bacilieri *et al*., 1993; Vuillemin, 1982). Our parcel regeneration results indicate that pine seedlings are primarily present in open environments and oak seedlings in closed; this last includes pine forests. For this reason, we think that the distributions of these two species are best considered part of a successional process wherein *P. pinea* is a light demanding colonizing species comparable to the *P. halepensis* Mill. (Aleppo Pine). The zone principally populated by Downy Oak represents regions that have been abandoned for a longer time than the zones occupied principally by Italian Stone Pine. In time, the vegetation of these last zones, if undisturbed, will become dominated by *Q. pubescens* as previously suggested (Barry, 1960; Kuhnoltz-Lordat, 1949). We do not agree with Neff and Frankenberg's view (Neff & Frankenberg, 1995) that *P. pinea* can be a climacic forest species in the CDG, for the simple reason that it does not regenerate well in forest here no matter what the dominant tree species.

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