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Original article

Effect of site quality and thinning management on the structure of holm oak forests in northeast Spain

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Summary — In the holm oak forests of NE Spain, the variability of thinning intensity, together with the great heterogeneity of site quality, due to the rough topography of the region, gives rise to important structural differences among stands. In this paper, we analyze the effect of site quality and thinning management on the structural heterogeneity of holm oak stands at the end of the cutting cycle in different areas of the Montseny and Les Guilleries massifs (NE Spain). These two factors influence the main structural variables of the stands in various ways. Height was used as an indicator of site quality, because it was relatively unaffected by thinning management, while density and total number of stems per stool were strongly affected. Mean tree diameter reflected the effect of both site quality and thinning. The type of forest management was found to be the most important factor determining forest structure. Site quality was a constraint of stand development, contributing in poor stands, to increased differences due to thinning management.

holm oak / *Quercus ilex* / forest structure / site quality / thinning

Résumé — **Effets de la fertilité de la station et de l'intensité d'éclaircie sur la structure des forêts de chêne vert du nord-est de l'Espagne.** *Dans les forêts de chêne vert du nord-est de l'Espagne, la variabilité de l'intensité d'éclaircie et la grande hétérogénéité de fertilité des stations, dues à leur topographie montagneuse, provoquent d'importantes différences de structure des peuplements. Dans cet article, nous analysons l'effet de la fertilité de la station et de la gestion sylvicole sur l'hétérogénéité structurelle des forêts de chêne vert dans différentes zones des massifs de Montseny et les Guilleries (nord-est de l'Espagne). Ces deux facteurs influencent de différentes manières les principales variables descriptives de la structure des peuplements. La hauteur a été utilisée comme indice de fertilité de station car elle est très peu modifiée par le type de gestion sylvicole, tandis que la densité* *et le nombre total de brins par souche sont très affectés par le type de gestion. La diamètre moyen synthétise l'effet de la fertilité de la station et de l'intensité d'éclaircie. La gestion sylvicole est le facteur le plus important pour expliquer les différences de structure de peuplement, tandis que la fertilité de la station peut être un facteur limitant du développement des peuplements, contribuant, dans les stations de moindre qualité, à augmenter les différences dues à la gestion sylvicole.*

chêne vert / Quercus ilex / structure de la forêt / fertilité de la station / éclaircie

INTRODUCTION

Heterogeneity is an intrinsic feature of the Mediterranean landscape (Naveh and Lieberman, 1984; Barbero, 1988). This heterogeneity appears not only in the variation of species composition associated with gradients of aspect, elevation or soil depth (Aschmann, 1973; Rabinovitch-Vin, 1983; Quezel and Barbero, 1989; Pigott and Pigott, 1993), but also in the changes of stand structure and architecture of trees observed within the same stand. It is therefore necessary to carry out a description of these forests based on structural, architectural and physiognomic features on the different vertical strata of the canopy, that provide information about this dynamic environment, which is a habitat of animal communities (Cody, 1985; De Garnica and Robles, 1991), liable to suffer disturbances (Sousa, 1984; Lorimer, 1989; Oliver and Larson, 1990), and potentially be used and exploited in numerous ways (Ducrey, 1992).

Holm oak *(Quercus ilex)* coppice forests are one of the most representative communities in the western part of the Mediterranean basin (they cover more than 120 000 ha in Catalonia alone; Montoya, 1988). In this type of forest, the inherent heterogeneity of Mediterranean ecosystems has multiple origins that overlap on different temporal and spatial scales (David et al, 1979; Floret et al, 1989; Barbero, 1988; Romane et al, 1988). In addition to this environmental heterogeneity, there is one another caused by human influence, as this type of forest ecosystem has been subjected for decades or even centuries to frequent coppicing (Di Castri, 1973; Terradas, 1991; Barbero et al, 1992).

In this study we analyze the effect of site quality and thinning management on the structural heterogeneity of holm oak forests at the end of the cutting cycle. The initial response of holm oak forests to different thinning, fertilization and irrigation practices has been previously studied by measuring parameters such as growth of remaining trees, production and dynamics of sprouts, etc (Cartan-Son et al, 1992; Ducrey, 1992; Ducrey and Turrel, 1992; Floret et al, 1992; Mayor and Rodá, 1994). Nevertheless, these studies are relatively recent, and it has not yet been possible to evaluate the relative importance of these factors in the structural features of the stands in the medium term.

STUDY AREA AND METHODS

This study was carried out in three different areas: Gualba, in the southwestern sector of the Montseny Massif (40 km from Barcelona, Spain), Arbúcies, in the northern sector of the Montseny Massif (90 km from Barcelona), and Susqueda, in the southwestern sector of the Les Guilleries Massif (110 km from Barcelona). The climate of the region is subhumid Mediterranean. Mean annual precipitations range from 600 to 800 mm and mean annual temperatures from 10 to 15 °C. Soils are developed on a bedrock of granite and metamorphic schists. The main vegetation type of the area corresponds to the montane holm-oak forest *(Quercetum mediterraneo-montanum)*, with *Q ilex* as the main component at the tree layer, and *Erica arborea* and *Arbutus unedo* as the main components of the shrub layer. Holm oak forests of this region are managed by coppicing through selective cutting at intervals of approximately

30 years (Retana et al, 1992). Together with this variability in management practices, there is a spatial heterogeneity in site quality due to the rough topography of the region. To distinguish between the effects of management and quality, plots which differed in only one of these two factors have been compared.

In each area, two adjacent stands with different thinning management were chosen: one qualified as 'conservative thinning', and another as 'intense thinning'. In the area of Susqueda, a third stand, referred to as 'old forest' was also included. The three stands corresponding to conservative thinning belonged to the same owner, and were managed by selective thinning. This practice involved a period of about 25–30 years between harvests, a variable harvest of basal area (40–60%), and special care in the selection of the remaining trees. These stands had a similar age from last thinning. The three stands corresponding to intense thinning were all characterized by a less careful management. The high cutting intensities of these stands had the characteristics of clear felling practice in some cases. They presented a longer period between harvests than stands which were thinned conservatively. The stand of old forest in Susqueda was a portion of the conservatively thinned stand that was not cut in the last thinning period. Therefore, its age from last thinning was 70 years instead of 35.

In each stand, and within the limits of the same slope, several plots which seemed to be representative of the best and the worst qualities were chosen. The selection of plots was based on an assessment of the general aspect of the plot and the size and physiognomy of holm oaks. Table I summarizes the main features of the different plots considered in the present study. To evaluate the effect of site quality on forest structure, plots of different stands with the same thinning management (including criteria of stem selection, intensity and age from last thinning), have been compared. To evaluate the effect of thinning management, plots of different stands of the same area with similar quality were compared. Dominant height has been chosen as site index, based on data obtained in a previous study (Gracia, in preparation), because it attains several objectives: 1) it shows significant relationships with site variables; 2) it is the structural variable that is most closely correlated with other structural variables, especially mean diameter, when management is constant; and 3) it stabilizes very quickly after thinning, and is not affected by thinning intensity. In each of the tree areas, groups of plots of similar site quality (plots which did not show significant differences in height from an analysis of variance) have been established. A group of low quality plots and another of high quality plots have been distinguished in each area.

Circular plots with a 12 m radius (450 m^2) were established. In each plot, the following measures were taken:

- topographic factors: elevation, aspect, slope and position on the slope (low, medium and high)
- diameter at breast height (dbh) of all standing trees larger than 5 cm dbh
- height of the ten tallest trees in the plot

Forest structure has been described using the following variables:

- density of stems above 5 cm dbh
- basal area
- mean dbh of stems above 5 cm dbh
- dominant height
- number of stems per stool
- stool equivalent diameter, which is the diameter that has the same basal area as the sum of the basal areas of all stems from the stool.

To elaborate on the diameter distributions, stems of each plot were grouped in width intervals of 2.5 cm, starting from the initial lowest value of 5 cm dbh. Diameter distributions have been compared by means of the Kolmogorov–Smirnov test.

RESULTS

Overall analysis of the three stands of conservative thinning

In order to analyze features in stands with similar thinning management, the nine plots of the three stands with conservative thinning have been considered together. Mean values of structural features for these plots are summarized in table II. Differences among plots were significant for all structural variables (F-test, $P < 0.0001$), although the Fisher LSD multiple-comparison procedure (Ott, 1988) showed different trends: a) mean height of different plots had a

Table I. Topographic and structural characteristics of the studied plots in each stand and area.

Plot	*Stand*	*Area*	*Type of thinning*	*Time from last thinning (years)*	*Elevation (m)*	*Slope (°)*	*Aspect*	*Density (stems/ha)*	*Basal area (m^2/ha)*	*Dominant height (m)*
cA1	cA	Arbucies	Conservative	30	710	38	S	2 254	31.8	8.2
cA2	cA	Arbucies	Conservative	30	670	25	S	2 525	36.1	8.5
cA3	cA	Arbucies	Conservative	30	660	25	S	1 591	31.2	10.9
cA4	cA	Arbucies	Conservative	30	630	20	E	1 304	44.6	16.3
iA1	iA	Arbucies	Intense	50	640	20	S	2 472	35.2	7.0
iA2	iA	Arbucies	Intense	50	610	25	S	2 077	29.9	9.6
cG1	cG	Gualba	Conservative	30	720	30	S	3 024	35.0	7.1
cG2	cG	Gualba	Conservative	30	640	29	S	2 833	35.9	7.7
cG3	cG	Gualba	Conservative	30	620	31	S	1 559	47.3	11.5
iG1	iG	Gualba	Intense	56	740	25	S	5 761	23.4	7.4
iG2	iG	Gualba	Intense	56	700	16	S	4 615	28.0	10.2
cS1	cS	Susqueda	Conservative	35	880	26	O	3 469	44.0	7.1
cS2	cS	Susqueda	Conservative	35	880	30	O	2 673	42.6	10.0
iS1	iS	Susqueda	Intense	75	1 040	25	N	4 042	53.8	8.9
iS2	iS	Susqueda	Intense	75	1 040	27	N	3 119	54.0	13.9
oS1	oS	Susqueda	Old	> 70	860	30	O	2 419	34.9	7.1
oS2	oS	Susqueda	Old	> 70	860	29	O	2 928	63.9	11.7

Table II. Mean values of the main structural variables of the forest in all plots of conservative thinning.

Plot	*Height (m)*	*Diameter (cm)*	*Number of stems per stool*	*Equivalent diameter*
cS1	6.6[a]	12.1[a]	1.4[a]	13.3[a]
cG1	7.1[ab]	11.8[a]	1.6[a]	14.7[ab]
cG2	7.7[abc]	11.3[a]	1.6[a]	14.7[ab]
cA1	8.2[abc]	11.9[a]	1.6[a]	15.7[bc]
cA2	8.5[bc]	11.8[a]	1.5[a]	15.9[bc]
cS2	9.6[cd]	14.4[b]	1.1[b]	14.6[ab]
cA3	10.9[de]	14.3[b]	1.1[b]	14.8[ab]
cG3	11.5[e]	15.0[b]	1.2[b]	18.0[cd]
cA4	16[f]	18.0[c]	1.2[b]	20.0[d]
F-test	$F = 14.2$ $P = 0.0001$	$F = 7.8$ $P = 0.0001$	$F = 5.9$ $P = 0.0001$	$F = 4.4$ $P = 0.0001$

In each column, different letters indicate significant different values (at the $P = 0.05$ level) according to the Fischer LSD test.

continuous gradient, which makes it impossible to define independent groups, except for the one composed by plot cA4, of highest quality; b) three different groups of plots were identified according to mean diameter; once again the cA4 plot formed an independent group of exceptionally large mean diameter; c) the results concerning the number of stems per stool were even more simplified, because only two independent groups of plots could be identified: those with a large number of stems per stool, which also had the smallest mean diameters and mean heights, and those with a small number of stems per stool, which also had the largest mean diameters and mean heights; and d) it was not possible to identify different groups for the stool equivalent diameter because the values of different plots were quite similar, excepting those of the plots of highest quality (cA4, cG3).

A correlation analysis between the main structural variables of the nine plots with conservative thinning has been carried out (table III). Height was correlated with most other variable, especially with the mean diameter ($r = 0.98$), but also with the total density of stems ($r = -0.89$) and the stool equivalent diameter ($r = 0.88$). The relationship between height and the number of stems per stool was lower ($r = -0.62$), while the relationship with basal area was not significant. The mean diameter also displayed accurate correlation coefficients with the other variables, even with basal area, which was not significantly correlated with the other structural variables in this analysis.

Comparison of different stands within the same area

In each of the groups of plots with similar site quality, we have compared the different variables considered. In the areas of Arbúcies (table IV) and Gualba (table V), the plots of stands managed by conservative thinning and those managed by intense thinning were clearly distinguished in both low and high quality sites. Plots from stands

Table III. Coefficients of correlation *(r)* between the main forest structural variables in the nine plots of conservative thinning.

	Den	*Baa*	*Nst*	*Hei*	*Dia*	*Edi*
Den	*	ns	ns	–0.89	–0.80	–0.82
Baa		*	ns	ns	0.63	ns
Nst			*	–0.62	–0.68	ns
Hei				*	0.98	0.88
Dia					*	0.83
Edi						*

Den, total density of stems; Baa, basal area; Nst, number of stems per stool; Hei, mean height; Dia, mean dbh; Edi, stool equivalent diameter. ns, nonsignificant for $P = 0.05$.

Table IV. Mean values of the main structural variables of the forest in the plots of same quality of Arbúcies.

Plot	*Diameter*	*Numbef of stems per stool*	*Equivalent diameter*
A) Plots of high quality			
cA3	14.3[a]	1.1[a]	14.8[a]
iA2	12.1[b]	1.7[b]	15.8[a]
Student's *t*-test	$t = 1.9$ $P = 0.056$	$t = 3.7$ $P = 0.0003$	$t = 0.7$ $P = 0.45$
B) Plots of low quality			
cA2	12.3[a]	1.5[a]	15.9[a]
cA1	12.2[a]	1.5[a]	15.7[a]
iA1	10.2[b]	2.1[b]	13.5[a]
F-test	$F = 4.1$ $P = 0.018$	$F = 4.7$ $P = 0.01$	$F = 2.9$ $P = 0.055$

In each column, different letters indicate significant different values (at the $P = 0.05$ level) according to the Fisher LSD test.

under intense thinning had smaller mean diameters and a greater number of stems per stool than plots from stands under by conservative thinning. In the area of Susqueda (table VI), plots of similar quality did not show significant differences in mean diameter, and only differed in the mean number of stems per stool between the stand of intense thinning and the stands of conservative thinning and old forest. The

Table V. Mean values of the main structural variables of the forest in the plots of same quality of Gualba.

Plot	Diameter	Number of stems per stool	Equivalent diameter
A) Plots of high quality			
cG3	15.1[a]	1.2[a]	18.2[b]
iG2	10.6[b]	1.7[b]	13.3[b]
Student's *t*-test	$t = 5.1$ $P = 0.0001$	$t = 2.5$ $P = 0.012$	$t = 3.5$ $P = 0.0005$
B) Plots of low quality			
cG2	11.3[a]	1.66[a]	14.7[a]
cG1	11.8[a]	1.67[a]	14.7[a]
iG1	9.2[b]	2.74[b]	14.1[a]
F-test	$F = 12.7$ $P = 0.0001$	$F = 12.1$ $P = 0.0001$	$F = 0.1$ $P = 0.8$

In each column, different letters indicate significant different values (at the $P = 0.05$ level) according to the Fisher LSD test.

stool equivalent diameter, in general, did not vary in plots of similar quality and different type of management, excepting those of high quality in Gualba and Susqueda (tables IV and VI).

Relationship among the structural variables considered

Another correlation analysis has been carried out with all plots of different thinning intensity (table VII). In general, correlation values decreased with respect to those obtained with only the plots of conservative thinning (table III). Height maintained good correlations with the stool equivalent diameter ($r = 0.81$) and the mean diameter ($r = 0.76$), but not with the total density of stems or the number of stems per stool. The mean diameter was the variable most closely correlated with the other structural variables, showing similar values to those obtained with only the plots under conservative thinning (table III). Basal area alone presented a significant, but low, correlation with height ($r = 0.47$).

Diameter distribution in the different plots

Within the same stand, the low quality plots displayed a greater number of small stems than the high quality plots. The shape of the distribution changed severely. The differences between the extreme situations were significant in all stands (Kolmogorov–Smirnov test, $P < 0.10$). This trend is shown in figure 1, where the diameter distributions of the four plots of stand cA are in ascending order from cA1 to cA4.

Table VI. Mean values of the main structural variables of the forest in the plots of same quality of Susqueda.

Plot	*Diameter*	*Numbef of stems per stool*	*Equivalent diameter*
A) Plots of high quality 1			
oS2	15.3[a]	1.0[a]	15.5[a]
cS2	14.4[a]	1.1[a]	14.7[a]
Student's *t*-test	$t = 1.1$ $P = 0.28$	$t = 2.3$ $P = 0.79$	$t = 0.9$ $P = 0.36$
B) Plots of high quality 2			
oS2	15.3[a]	1.0[a]	15.5[a]
iS2	14.2[a]	1.8[b]	19.3[b]
Student's *t*-test	$t = 1.2$ $P = 0.24$	$t = 7.4$ $P = 0.0001$	$t = 2.5$ $P = 0.01$
C) Plots of low quality			
oS1	13.4[a]	1.1[a]	14.2[a]
cS1	12.1[a]	1.4[a]	13.3[a]
iS1	12.2[a]	2.0[b]	16.3[a]
F-test	$F = 1.3$ $P = 0.27$	$F = 12.3$ $P = 0.0001$	$F = 2.7$ $P = 0.07$

In each column, different letters indicate significant different values (at the $P = 0.05$ level) according to the Fisher LSD test.

Table VII. Coefficients of correlation *(r)* between the main forest structural variables in all the plots of Arbúcies, Gualba and Susqueda ($n = 17$).

	Den	*Baa*	*Nst*	*Hei*	*Dia*	*Edi*
Den	*	ns	0.68	ns	–0.67	ns
Baa		*	ns	0.47	ns	ns
Nst			*	ns	–0.73	–0.48
Hei				*	0.76	0.81
Dia					*	0.75
Edi						*

Den, total density of stems; Baa, basal area; Nst, number of stems per stool; Hei, mean height; Dia, mean dbh; Edi, stool equivalent diameter. ns, notsignificant for $P = 0.05$.

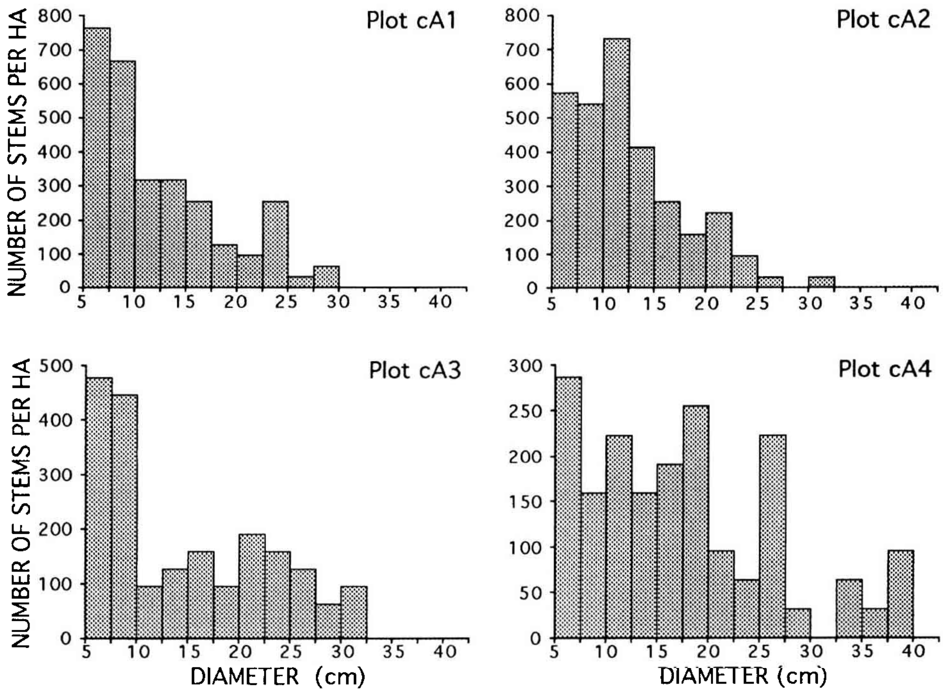

Fig 1. dbh distributions of stems in the four plots of the conservative thinning stand cA in ascending order of quality from cA1 to cA4.

The comparison of plots of similar site quality and different management showed several differences: a) in high quality plots (fig 2), differences due to management were only significant in the area of Gualba (Kolmogorov–Smirnov test, $P < 0.05$), but not in the other two areas (Kolmogorov–Smirnov test, $P > 0.10$); and b) in low quality plots, there were significant differences among plots of the two areas due to management (fig 3) (Kolmogorov-Smirnov test, $P < 0.05$): conservative management led to an almost normal distribution, while intense management led to a unimodel distribution. The effect of thinning even reversed the usual trend of a decreasing number of small stems with increasing site quality: plot cS2 presented a distribution closer to normal than the higher quality plot iS2 (fig 3). Diameter distributions in plots under conservative thinning and old thinning of Susqueda (fig 4) were not significantly different (Kolmogorov–Smirnov test, $P > 0.10$), although there were fewer intermediate-sized stems in the more recently cut plots.

DISCUSSION

Effect of site quality and thinning on the structural variables of the holm and stands

The changes in site quality and management have different effects on the structural variables of the stands: several variables, such as height, can be considered as plot

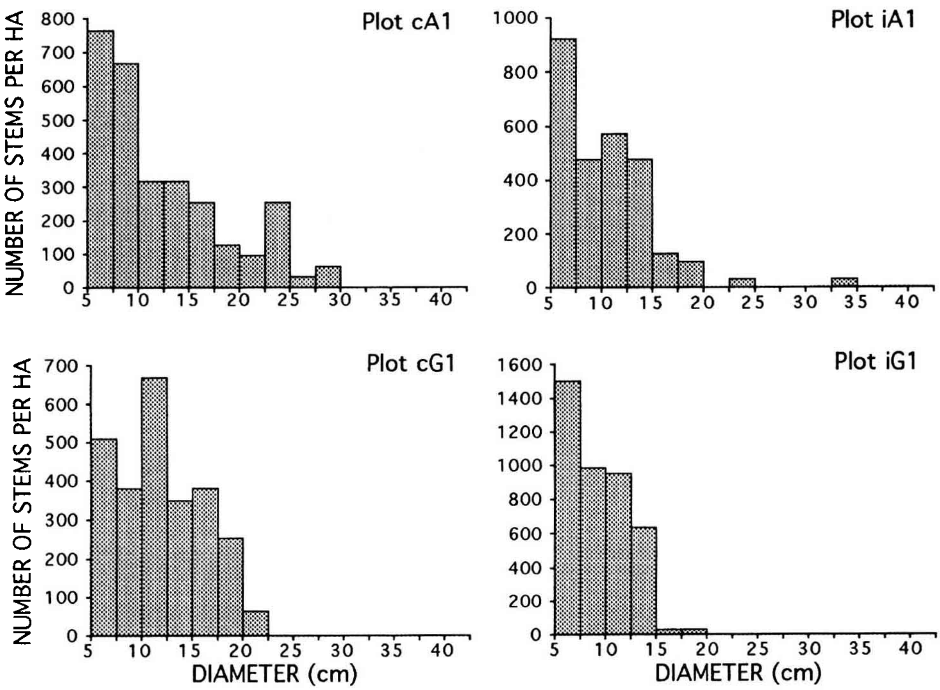

Fig 2. dbh distributions of stems in the high quality plots of stands managed by conservative and intense thinning in the three study areas.

characteristics and, within certain limits, only depending on site quality (Gracia, in preparation); nevertheless, the majority of variables are more or less affected both by site quality and by management. Density is related to site quality, as can be deduced from the correlation obtained between the plots with conservative thinning. This result agrees with the one given by Lledó et al (1992) for a holm oak forest in Prades (Tarragona), where the differences in density found between the low and high elevation zones of the same slope have been attributed to differences in productivity (ie, site quality). This close relationship between height and density disappears when all plots are taken into account, because of the oversiding effect of management on density. A high thinning intensity would lead to low densities, as would a decrease in site quality. The number of stems per stool is also strongly affected by management, as can be deduced from the comparison of stands within the same area. It is less affected by site quality than density and can thus be considered a more suitable variable for discriminating between different thinning managements.

Data obtained in this study (ie, the high correlation between height and diameter for the plots with conservative thinning, which decreases when all plots of different management are considered) support the strong dependence with diameter on both site quality and managements described in other studies (Cartan-Son et al, 1992; Ducrey and Turrel, 1992; Mayor and Rodá, 1993). That is why this variable is probably the one that

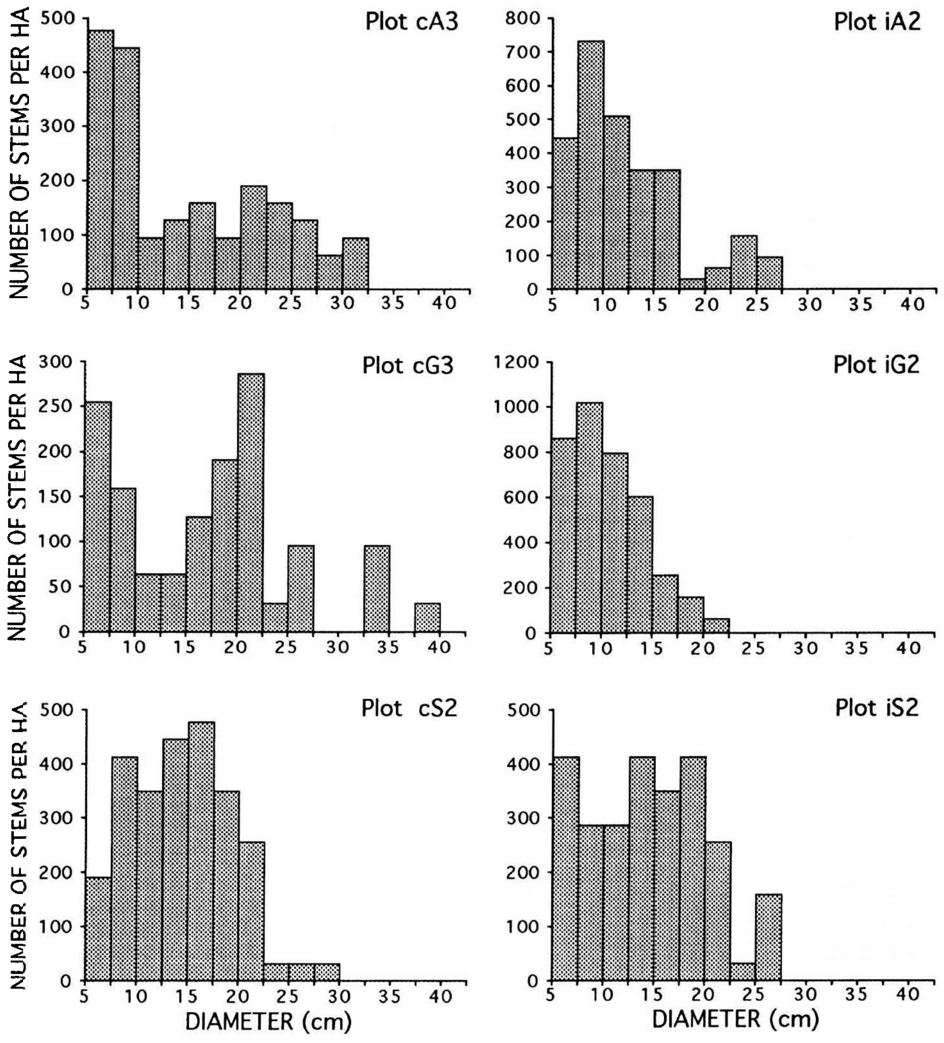

Fig 3. dbh distributions of stems in the low quality plots of stands managed by conservative and intense thinning in the areas of Arbúcies and Gualba.

yields the most information about forest structure. Nevertheless, and for the same reason, it does not allow, on its own, an analysis of the role played by different factors on the actual forest structure.

Nothing has been said about basal area, one of the most important variables from the silvicultural point of view (Montero, 1992). Although basal area is the variable most closely related with forest biomass (Bengoa, 1993), its extrapolation to productivity is quite difficult, because it would be necessary to include a time factor and to know, for selective thinning, the amount of timber harvested. In the studied plots, basal

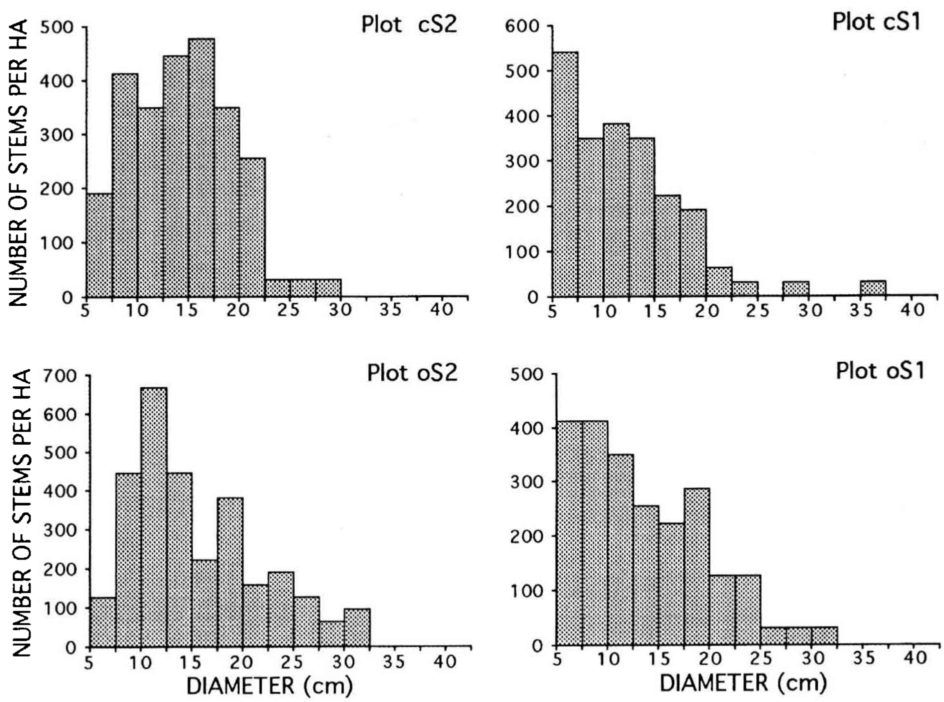

Fig 4. dbh distributions of stems in the plots of the conservative stand and the old-cut stand of Susqueda. Plots of high quality (cS2 and oS2) and plots of low quality (cS1 and oS1) are considered separately.

area was a very unpredictable variable, which only showed a slight tendency to increase with site quality.

Site quality and thinning management as factors conditioning the structural development of holm oak forest

Ducrey (1992) proposed a theoretical cycle of development of holm oak forests, with a coppice stabilized by clear felling practices, and a maturity stage that would be reached after a long period of time without disturbances. This idea of a structural maturity of holm oak forests is also used by other authors (Barbero, 1988; Lledó et al, 1992), and could be defined as a forest formed by one-stemmed stools of large size, with low density and a tendency towards uniformity. The similarity between the structural features of the studied plots and this ideal, mature state allows us to discuss the role of site quality and management as factors slowing down, stabilizing or accelerating the developmental process of holm oak forests. When other factors are similar, site characteristics move this development towards mature forest. In high quality plots, forest structure is similar to that of a theoretically mature forest. This is particularly evident in the old thinning stand. Lledo et al (1992) also observed in holm oak forests in Prades (Tarragona) that high quality areas show a greater degree of maturity than low quality areas, with smaller densities and greater mean diameters.

This pattern is also clearly observed in the diameter distributions. For a given stand, the lower quality plots show a greater number of small diameter stems than those of higher quality. Courraud (1987) explains this fact by considering that in low quality sites very few trees attain superiority in size in relation to their neighbors sufficient to exclude them. In high quality sites, there is a decrease in individuals in the smaller classes, with a tendency to normality which is clearest in the old forest stand (oS). Barbero (1988) describes this pattern in monospecific holm oak forests with complete cover by means of a multistrata structural model, characterized by having several dominant sprouts per stool and a greater number of suppressed sprouts, which, in high quality sites, are very quickly eliminated.

In the studied plots, managements is an essential factor affecting structural development. The old plots are obviously the closest to our ideal of a mature forest and particularly the high quality plot has a high forest physiognomy, with one-stemmed stools, a monospecific composition in the overstory, and an almost completely absent understory. The stands under conservative thinning show values of the structural variables similar to those obtained for the old thinning stand. It is quite surprising how quickly the holm oak forest recovers from thinning, which suggests that this type of management stabilizes the forest in a state very similar to the one described as mature forest. In contrast, the plots exploited by intense thinning show large differences compared with the mature forest model with respect to the number of stems per stool, density, multispecific composition of the overstory and degree of development of the understory.

The results obtained suggest that both site quality and thinning management are responsible for the heterogeneity of the studied holm oak forests. Given the range of variation among these factors in the region, management probably has a larger importance in this heterogeneity. Site quality either favors or limits forest development, as suggested by the greater differences between types of management found in low quality plots than in high quality plots. In extreme situations with incomplete cover, we could find what Barbero (1988) defined as the progressive architectural model, characterized by stools with a great number of stems which coexist from the subhorizontal to the vertical position. However, in the study area, this pattern is only found in very disturbed forests or in very rocky areas. The results presented in this paper suggest the role of site quality and thinning management on the structure of holm oak forests. A deeper knowledge of these topics will make it possible to provide basic information for a more coherent forest management design.

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