

The Effects of Silviculture on the Structure in Mature Scots Pine Stands

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Abstract

The aim of this paper is to assess the influence of silvicultural treatments on the structural diversity of Scots pine stands in Spain. Two mature Scots pine stands (80–100 years) with different origin and silviculture applied were chosen to develop the study. Spatial pattern, diameter distribution, diameter, height and crown length differentiation, foliage height diversity (FHD) and coarse woody debris (CWD) are compared in both stands. More structural diversity was found both in the spatial pattern and CWD of the forest where the shelterwood system was applied over a longer period, although the forest where silviculture is more intensive had greater FHD. Different aspects of silviculture influence different aspects of stand structure, in a rather logical way, while other structure characteristics remain constant.

Keywords: silviculture; stand structure; diversity; Scots pine

1. Introduction

Biodiversity has become one of the main topics in forest management and conservation, since the earth Summit in Río de Janeiro in 1992. However, biodiversity is an abstract and often complex concept which should be specifically defined according to the context in which the term is used (Parviainen et al. 1994). The term can be used at several biological levels from landscape diversity to genetic diversity. Moreover, each biodiversity level covers three aspects: composition, structure and function.

The structural diversity of the forest ecosystem is an important component, since it can be partially modified by silvicultural treatments. Forest structure seems related to the habitat of many plants and animals (Mac Arthur and Mac Arthur 1961; Degraaf et al. 1998; Ferris-Kaan et al. 1998), and can be used joint to other factors, such as the site quality, the successional

gradient or the tree species composition (Wiens 1989; Bersier and Meyer 1994; Pitkänen 2000) as indicator of biodiversity (Kuuluvainen et al. 1996). Nevertheless, complex forest structures do not always mean high diversity and often the opposite may be found (Hunter 1990). Stand structure is also directly related to many fundamental aspects of the forest, like stability, production, soil protection, landscape, etc. Therefore, an adequate knowledge of the forest structure and its dynamics is necessary to guarantee sustainable management. Usually, the forest structure is characterized by considering four aspects: spatial pattern, mixture and diversity of species, horizontal and vertical differentiation and coarse woody debris (Gadow and Hui 1999; Lähde et al. 1999; Weber 2000).

Management objectives for *Pinus sylvestris* L. forests in Spain are, in general, to guarantee the survival and stability of the stand, to optimise multiple use, and to achieve sustainability of yield, including indirect benefits like soil protection, recreation, etc. These objectives vary according to the ecological characteristics of the stands and the social needs of the area. In the same way, the silvicultural treatments must be adapted to these conditions and objectives.

The Scots pine is one of the most studied forest species in Spain, including extensive studies regards its ecology, genetics, stability, production, etc., and the effects of silviculture on these aspects (Cañellas et al. 2000; Montero et al. 2001). However, some fundamental aspects for sustainable management are poorly documented, such as, prevention of global warming and CO₂ fixation, maintenance and increase of biodiversity, conservation of genetic diversity, etc. (Bastien and Alía 2000; Caparrós et al. 2001; Río et al. 2003).

Given the necessity for research in these areas, this study was developed to increase our knowledge on the influence of silvicultural treatments on the current structural diversity of Scots pine stands in Spain. Firstly, the structural diversity of both forests will be described and secondly, the relationship between this diversity and the silvicultural treatments applied will be analysed.

2. Material and methods

2.1 Study site

Two natural and even aged Scots pine stands were chosen in the Central mountain range of Spain to carry out the study: Navafría (4436 ha) and Valsaín (7627 ha) forests. Both forests have similar ecological conditions (altitude range from 1200 m to up to 2200 m; north facing; acid soils) but different silvicultural systems have been applied over the last century. In the Navafría forest the shelterwood system was used, being the trees removed in a few heavy fellings and the shelter-phase 20 years. If natural regeneration has no success, the fellings were followed by soil preparation and seedling or plantation. An intensive thinning regime is also applied. In contrast, the shelterwood system applied in the Valsaín forest was much more gradual and regeneration was allowed to take place naturally, leading to a long regeneration period (often over 40 years). The thinning regime was less intensive than the one applied in Navafría. The management plans started in 1898 in Navafría and 1889 in Valsaín, and the rotation is 100 and 120 years respectively.

The use of large plots is common in recent studies focused on forest structure assessment (Ferris-Kaan et al. 1998; Aguirre et al. 2003; Kint 2003). It allows the precise characterization of the stand structure, although it often means to give up the replication of the trial. A plot of 0.5 ha were established in the 80–100-year aged block of each forest to compare stand structure diversity of mature stands in both forests. Places where the silviculture applied is representative of the silvicultural system used throughout the forest were chosen: in

Table 1. Main characteristics of the Valsain and Navafría plots.

Plot	Trees/ha	G	Mean Age	Dg (min/max)	Ht (min/max)
Navafría	183	24.09	101	40.94 (15.4/54.4)	20.53 (16.4/25.1)
Valsain	275	26.86	105	35.30 (28.8/66.8)	22.16 (16.6/29.9)

G: basal area (m²/ha); Dg: Mean diameter (cm); min: minimum dbh; max: max dbh; Ht: mean total height (m); min Ht: minimum total height; max Ht: maximum total height.

Table 2. Characteristics of wood and subplots size for each fraction of coarse woody debris (CWD) considered.

CWD type	Size	Subplot size (m ²)	Subplots/plot
Dead standing trees	Ø ≥ 10 cm	5000	1
	10 cm > Ø > 5 cm	100	4
Stumps	Ø ≥ 30 cm	5000	1
	30 cm > Ø ≥ 5 cm	100	4
Fallen logs and branches	Ø ≥ 10 cm	5000	1
	10 cm > Ø ≥ 5 cm	100	4
	5 cm > Ø	25	4

Navafría the origin of the stand is a plantation made about 1910, whereas in Valsain the natural regeneration has established. Plots were located similar altitudes (1400 m in Navafría and 1200 m in Valsain) and with similar site qualities (23 m in Navafría and 26 m in Valsain). Stand density is still high at this stage of development with an absence of regeneration or shrubs. Consequently, the diversity of the stand has been analysed by considering the structure formed by the trees and the abundance of different types of coarse woody debris (CWD). Diameter at breast height (cm), crown diameter (m), total height (m), crown length (cm) and position of all trees were measured in each plot. Age was taken using increment borer in a random sample of 30 trees with the same diametric distribution than the stand within the plot. Table 1 shows the main characteristics of the plots (number of trees, basal area, mean, age, mean diameter and height).

The number and size of subplots used to measure CWD vary according to the CWD types from 25 m² to 0.5 ha (Table 2).

2.2 Stand evolution

From the compilation of the management plans and their successive revisions, we have obtained data regarding the number of trees per diameter class, information about cutting, seedlings, natural regeneration and other silvicultural treatments for these forest compartments over the last century.

From the available data it is not possible to ascertain the diametric distribution prior to the shelterwood cuttings, but the description of the previous stand tells us that there was advanced regeneration and that the upper strata did not form a closed canopy, but rather a

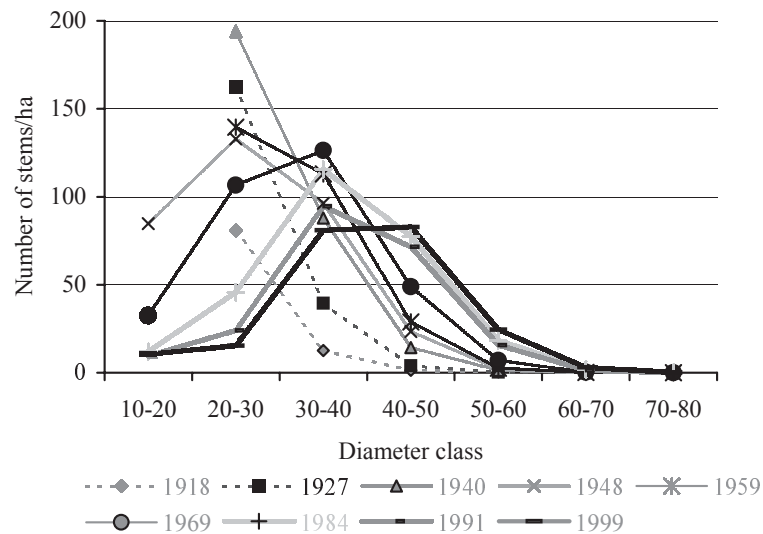


Figure 1. Variation of diameter distribution in block 1A1 of Pinar de Navafria between 1918 and 1999. There were no data about stems in the 10–20 diameter class in the inventories of 1918, 1927, 1940 and 1959.

sparse canopy of older trees. In the Navafria forest compartment (Figure 1), the release of upper strata was carried out over a 20-year period and regeneration was established throughout the forest compartment. Natural regeneration had to be helped with plantation in some places. This promoted a dense regular stand. Since then, an intensive thinning regime has led to a decrease in stand density. As stated above, the stand within the experimental plot comes from plantation.

In Valsain things happened differently: the Management plan (1889) was dropped eight years later in favour of an individual tree selection system (Donés 1994). From 1948 to 1965 felling followed the initial Plan with some delay (Montes et al. 2003). Figure 2 shows how regeneration established itself since 1941 to 1965, simultaneously to the development of the stand established before. Since 1988 the group selection system has been applied in the forest. In Figure 2, stem distribution in 1988 and 1998 is related to part of the initial forest compartment because due to the high heterogeneity within the forest compartment, it was divided, and the other part started regenerating in 1988. The experimental plot was located in a 90 aged stand within the forest compartment. It can be noticed that the diameter distribution at forest compartment level (Figure 2) is skimmed to the left in comparison with the diameter distribution within the plot (Table 1 and Figure 5), because the mixture of different aged stands due to the long duration of the regeneration process for the whole forest compartment. This increases the structure heterogeneity at scales larger than the plot, which this study is focused.

2.3 Plot structure characterisation

The structural diversity has been analysed by considering two aspects: the structure formed by living trees and the abundance of different types of coarse woody debris (CWD). The spatial

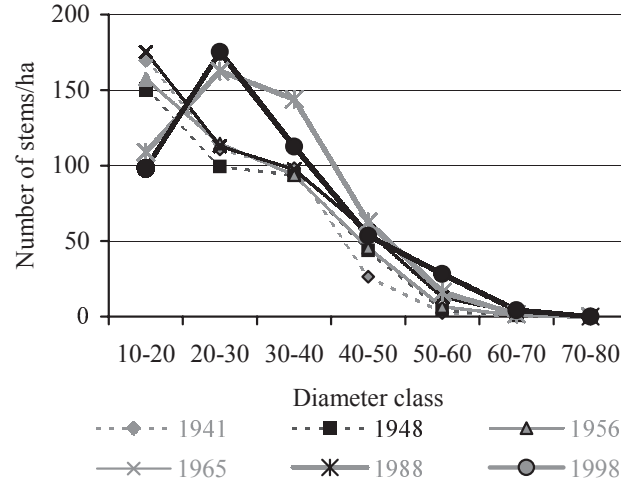


Figure 2. Variation of diameter distribution in block 1A1 of Pinar de Valsain between 1941 and 1998.

pattern, diameter distribution, microstructure, horizontal and vertical differentiation and foliage height diversity (FHD) have been used to characterise the structure related to living trees. In computing distance dependent indices, problems arose with those trees considered border trees (trees with neighbours out of the plot). Those trees which were nearer to the boundary of the plot than to the farthest neighbour being considered for each index were excluded. The CWD has been characterised through volume of dead trees, stumps, logs and snags and weight of litter.

2.3.1 Spatial pattern

The $k(d)$ Ripley's function has been used to study the spatial pattern of trees in each plot (Ripley 1981). In this function the expected number of trees within a radius d with a random distribution is compared to the empirical function $\lambda K(d)$:

$$\lambda K(d) = \sum_{i=1}^n \sum_{j=1}^n \frac{\delta_{ij}(d)}{n}, i \neq j, \quad (1)$$

$$\delta_{ij}(d) = \begin{cases} 1 & \text{if } d_{ij} \leq d \\ 0 & \text{if } d_{ij} > d \end{cases}$$

where λ is the density, d_{ij} distance from i tree to j tree, and n the number of trees in an area with radius d . The k value is compared to the expected value of a Poisson distribution obtained through 99 Monte Carlo simulations. In order to represent graphically the Ripley's function, the transformed function $L(d)$ has been used:

$$\hat{L}(d) = \sqrt{\frac{\hat{K}(d)}{\pi}} - d \quad (2)$$

Gadow's angle uniformity index has been used to assess the symmetry of the spatial distribution

$$I_G = \frac{1}{n} \cdot \sum z_{ij} \quad z_{ij}(d) \begin{cases} 1 & \text{if } w_{ij} \leq w \\ 0 & \text{if } w_{ij} > w \end{cases} \quad (3)$$

where n is the number of neighbours considered, w_{ij} is the angle formed by lines from the tree of reference to i and j neighbours and w is the ratio of 360° to n .

2.3.2 Diameter distribution and size differentiation

Diameter distribution has been analysed within the plot. In order to characterise the microstructure situation the vertical and horizontal differentiation are estimated with the Gadow's differentiation index (Gadow, 1993):

$$TD3 = \frac{1}{N} \sum_{i=1}^N TDn_i \quad TD3_i = \frac{1}{3} \sum_{j=1}^3 \left(1 - \frac{x_{\min}}{x_{\max}} \right)_j \quad (4)$$

where $TD3$ is the mean differentiation calculated with 3 neighbours, N the number of trees analysed, $TD3_i$ the differentiation index for tree i calculated with 3 neighbours and $x_{\min}$ and $x_{\max}$ are the smallest and the largest value of the feature analysed (diameter, height or crown length) when comparing reference tree i and its 3 nearest neighbours.

2.3.3 Foliage height diversity

Foliage height diversity (FHD) is estimated using the Shannon index (H') (MacArthur and MacArthur, 1961).

$$H' = - \sum p_i \cdot \ln(p_i) \quad (5)$$

where p_i is the relative abundance of foliage in strata i . To estimate the relative abundance of foliage the crown has been assimilated to an ellipsoid with the y axis equal to crown length and the x axis equal to crown diameter. The ellipsoid volume has been calculated within height strata through the following integral:

$$V_i = \int_{h_{i1}}^{h_{i2}} \pi \cdot r^2 dh \quad (6)$$

$$r^2 = (d_c/2)^2 - \frac{(d_c/2)^2 \cdot [h - (h - l_c/2)]^2}{h_i^2}$$

Table 3. Rot classes of coarse woody debris.

Rot class	Stage of decomposition
I	Freshly dead, at most one year old
II	Wood hard, bark partly loose but >50% remaining
III	Wood hard or soft in the surface, <50% of the bark remaining
IV	Wood soft in the surface or throughout
V	Wood soft throughout or with a hard core only, the outer surface hard to distinguish or completely or partly covered by forest floor mosses

where V_i is the crown volume for the tree in the i strata (from h_{i1} height to h_{i2}), r is the radius of the cross section of the ellipsoid at h , d_c is the crown diameter, l_c is the crown length and h_t is the total height of the tree. Lower strata comprises from ground to 2 m height, second from 2 to 5 m, third from 5 to 15 m and upper strata above 15 m height. These strata are the same as those used by Ferris-Kaan et al. (1998) to assess vertical structure in managed Scots pine forests in Britain.

2.3.4 Coarse woody debris

In order to study CWD 8 classes of elements (Table 2) and 5 rot classes (Table 3) have been established (Siitonen 2000). Volume of branches and logs (estimated from length and mean diameter) and number of stumps by size class and rot class is used to characterised the CWD.

3. Results and Discussion

3.1 Spatial pattern

Figure 3 represents the distribution of the trees in the two plots through the crown projection. Spatial patterns of trees studied through the transformation $\hat{L}(d)$ of Ripley's K are presented in Figure 4. Light lines indicate 90% confidence interval boundaries of function $\hat{L}(d)$ of a Poisson distribution. When $\hat{L}(d)$ function for real distribution of the trees (bold line) falls above the confidence interval upper boundary the distribution is clustered; if it falls under the lower boundary the distribution is regular. The spatial patterns are similar in both plots for smaller distances (<10 m) with a tendency towards regularity. Up to 11 m the spatial pattern in the Valsain forest is significantly aggregated, while in the Navafría forest it is random in the studied scales. These results show the possible effect of the natural regeneration way on stand structure in Valsain, with regular and random patterns on a small scale due to competition and remaining a cluster pattern on larger scales. This aggregated pattern hasn't been found in Navafría the stand comes from a plantation. It is interesting to note that the effects of the regeneration way continue up to an age of 80–100 years in the Valsain plot, because the spatial pattern tends towards regularity through the phases of stand dynamic (Moeur 1997). The variation of the spatial pattern will be studied by comparing the results of the 6 age classes in each forest.

Gadow's uniform angle index, calculated with three neighbours is 0.65 for the Navafría plot and 0.63 for Valsain, which shows that very similar pattern is found in both forests at microstructure level. It is likely that microstructure is more related to species growth and competition, and that the pattern at larger scales is more influenced by the silviculture system.

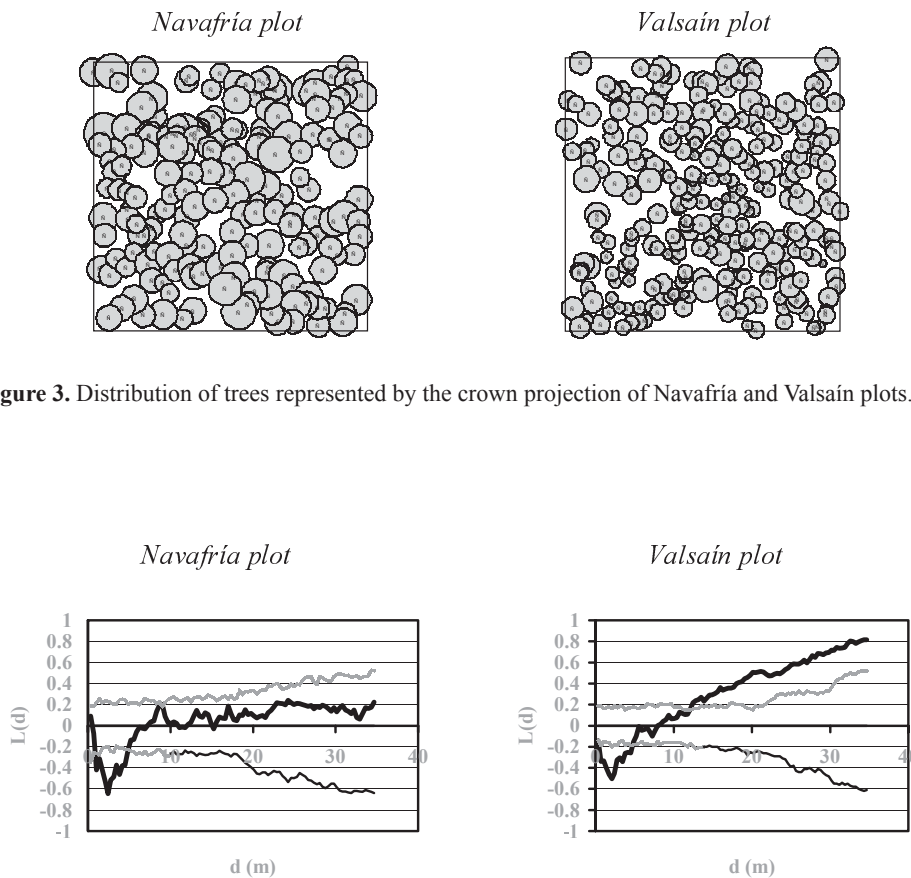


Figure 3. Distribution of trees represented by the crown projection of Navafria and Valsain plots.

Figure 4. Analysis of spatial pattern using the transformation $L(d)$ of Ripley's function $K(D)$ in Navafria and Valsain plots. Bold lines: K function value for the real distribution of the trees; Grey lines: 90% confidence interval boundaries of $L(d)$ of a Poisson distribution.

3.2 Size spatial arrangement

Figure 5 shows the diameter distribution within the plot. In both plots the diameter distribution corresponds to a single-cohort stand, but in Valsain it is less regular: Coefficient of variation of diameter (CvDbh) is equal to 19.6%. In Navafria CvDbh value is 15.1%.

Another important aspect of structural diversity is the degree of mixture of different sizes or differentiation. Gadow's index shows the differentiation of the microstructure because it is calculated with the 3 nearest neighbours. Mean values of Gadow's indices for Navafria and Valsain are 0.14 and 0.16 calculated for diameter, 0.07 and 0.07 for total height and 0.24 and 0.26 for crown length. These low values for Gadow's indices correspond to a low level of differentiation according to the scales proposed by Fuldner (1995) and Aguirre et al. (1998), which is typical of mature stages of single-cohort stands. The regularisation is caused by self-thinning and favoured by the application of low thinning. Differences between plots in the distribution of values for Gadow's index are greater when the index is calculated using crown lengths (Figure 6), indicating that the plot of Valsain shows a lower degree of regularisation with more social differentiation.

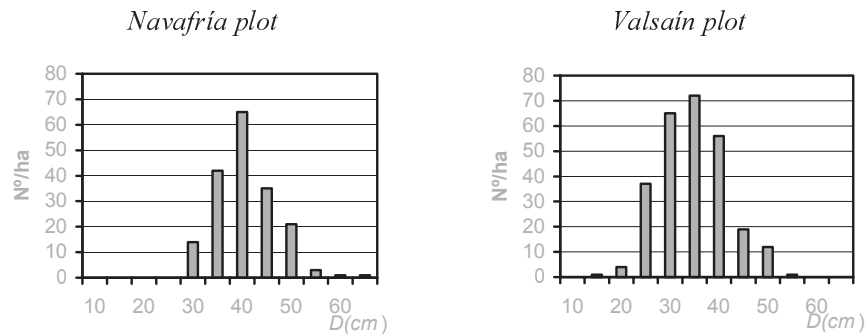


Figure 5. Diameter distribution of the Navafría and Valsain plots.

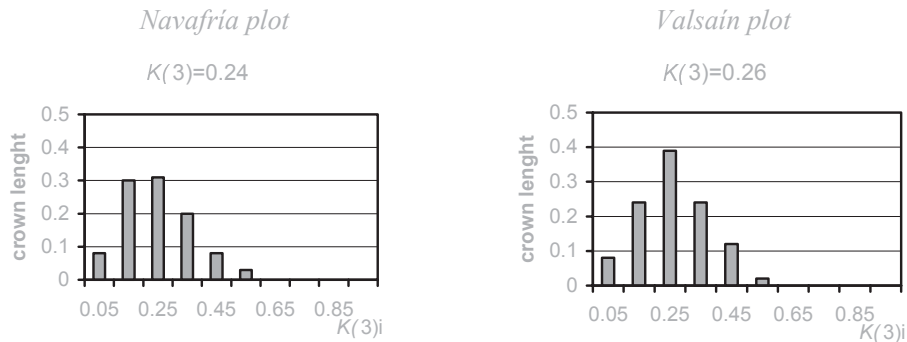


Figure 6. Mean value $K(3)$ and distribution of Gadow's differentiation index (1993) calculated for crown length with the 3 nearest neighbours in Navafría and Valsain plots.

FHD gives very low values since both are one-storied dense stands without shrub strata. The FHD value is 0.43 in Navafría, and 0.19 in Valsain. The thinning regime has led to lower density at the Navafría plot, allowing the remaining trees a greater crown development. The canopy occupies a great part of the strata from 5 to 15 m and the strata above 15 m height. In Valsain the crowns are less developed because the high density and the canopy occupy mainly the upper strata. The results obtained in other reports (Barbour et al. 1997) suggested that thinning could accelerate the development of some aspects of stand structure found in late seral stage forests. The distribution of Scots pine crops in the four height strata considered is similar to that found in Scots pine mature stands in the British lowlands bioclimatic zone (Ferris-Kaan et al. 1998).

3.3 Coarse Woody Debris

The characterisation of CWD in the plots is presented in Table 4. The volume of CWD is higher in Valsain than in Navafría, with more CWD types and rot classes. The low quantities

Table 4. Coarse woody debris (CWD) per types and rot classes in Valsain and Navafría plots. Dead standing trees and stumps are quantified by number of items/ha and logs and branches by volume (m³/ha).

CWD class	Size	NAVAFRÍA					VALSAÍN				
		Rot class									
		I	II	III	IV	V	I	II	III	IV	V
Dead standing trees (n/ha)	Ø≥10 cm			0					4.0		
	10 cm>Ø>5 cm			0					0		
Stumps (n/ha)	Ø≥30 cm	0	6.0	0	18.0	72.0	16.0	24.0	14.0	12.0	2.0
	30 cm>Ø≥5 cm	0	0	0	0	0	0	25.0	37.5	62.5	25.0
Fallen logs and branches (m³/ha)	Ø≥10 cm	0	0	0	0.24	0.03	0.14	0.14	0.02	0	0
	10 cm>Ø≥5 cm	0	0	0	0.10	0.04	0	0	0.13	0.03	0.01

of CWD in Navafría and the absence of some types of CWD, as stumps smaller than 30 cm, is explained by the intensive thinning program carried out in this forest.

4. Concluding remarks

These are the preliminary results of a permanent trial which will provide us information on the variation of structural diversity through the development phases. Each one of the analysed indices provide a valuable information about the forest structure. For this reason we think fit the join use of all of them to tackle these kind of studies.

We have identified in the 80–100 age class slight differences in some components of the structural diversity. This could point to the structural differences that the regeneration method produced initially decline with time elapsed, at least in this case, with large rotation period. It is necessary to analyse all plots in order to explore adequately the variation of the structure throughout the forest dynamic under the two silviculture systems.

In the future, the study of the relationships between flora, genetic and stand structure diversities we will enhance our knowledge of the effect of silviculture and regeneration method used on biodiversity. In the future, other components of biodiversity should be incorporated into the trial to improve the scientific basis for sustainable management of Scots pine forests in Spain.

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