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JUVENILE-MATURE WOOD EVALUATION ALONG THE BOLE CONSIDERING THE INFLUENCE OF SILVICULTURAL TREATMENTS

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ABSTRACT

Wood used for structural purposes has increased in the last decade in Spain. However, as raw material, wood needs to comply with requirements that are not always present. Knowledge about the wood quality from the trees on the stand is essential for providing feedback to forest managers and for taking the required actions to obtain suitable silviculture treatments. Two of the main wood species used in construction in Spain, *Pinus nigra* and *Pinus sylvestris,* have been studied in order to determine the amount of juvenile wood, which has been identified as a harmful characteristic for its decrease in quality of the physical-mechanical properties of these species. Being relevant for the best quality of timber in the part along the bole where the logs are obtained, the distribution of juvenile wood at different heights and the effect of several silvicultural treatments have had on juvenile wood formation has been considered. The juvenile-mature wood boundary (transition year) was calculated through segmented linear mixed models employing as variables annual latewood density, obtained through micro X-ray densitometry, silvicultural practices, and a drought index. The results show how juvenile and mature wood is distributed along the bole and the proportion of juvenile wood. Its reduction according to the different thinning and pruning silvicultural practices is presented.

Keywords: Juvenile wood, *Pinus sylvestris*, *Pinus nigra*, silvicultural treatments, X-ray densitometry, wood quality.

INTRODUCTION

On wood used for structural purposes, the properties from round wood lumber are decisive in terms of complying with construction standards. With the increasing demand in Europe for construction timber, the importance of wood quality in the sawn timber industry is essential.

Due to changes in forest management and improved genetic material, rotation periods have been reduced as growth rates have increased. However, as a result of this, the trees have a different proportions of anatomical and wood structures deriving into a significant reduction in their mechanical properties (Dowse and Wessels 2013, Wessels *et al.* 2014, Hermoso *et al.* 2016). As these problems arose, there have been several researches carried out on wood quality, related to wood density and MFA (micro fibril angle) being the two most influential properties for predicting mechanical properties (Tsoumis 2009, Burdon *et al.* 2001, Auty *et al.* 2014, Moore *et al.* 2015, Mäkinen and Hynynen 2012). The impact of silvicultural interventions and planting density not only affects growth and therefore, wood volume; but also, how straight the bole is, the type and amount

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of branches, as well as its internal characteristics (Ulvcrona and Ahnlund 2011, Mörling 2002, Barbour *et al.* 1994, Rais *et al.* 2014, Erasmus *et al.* 2018).

One characteristic of conifers is that on the first rings growing near the pith, the wood that is formed has different properties than that which is farther from it. This area of wood is called juvenile wood (JW), which is distinguished by less dense and higher MFA, among other properties, and thus, poorer elasto-mechanical properties (Larson 1969, Burdon *et al.* 2004). When density, MFA and the other properties stabilizes over the years, it is considered to be mature wood (MW).

Although JW it's the name still used by users of this material in Spain, on the wood scientific community the nomenclature for this inner part of the bole has been modified, calling it corewood (CW) and the outer part outerwood (OW) (Burdon *et al.* 2004). The new nomenclature allows explaining the variation that happens along the bole as the hydraulic and mechanical demands change through the life of the tree (Lachenbruch *et al.* 2011). In this paper, the terms JW/MW will be used to differentiate two areas of the density radial pattern along the bole. The JW will be defined as the area where its density increases really fast and the MW the area when the density values more or less stabilizes.

As density can be measured easily with high resolution using micro X-ray densitometry, this study was carried out using this methodology considering the annual variation in latewood density (LWD) as the dependent variable (Sauter *et al.* 1999, Gapare *et al.* 2006) on a segmented mixed linear model for estimating the transition between JW and MW.

The objective of this paper is to analyze the proportion of juvenile wood along the bole and compare results between plots that have different silviculture regimes on two of the *Pinus* species used for structural purposes in Spain, *Pinus nigra* (Black pine) (*P. nigra*) and *Pinus sylvestris* (Scots pine) (*P. sylvestris*).

MATERIALS AND METHODS

Sampling

Two different thinning and pruning trials established by INIA-CIFOR at the end of the past century, were used for obtaining the wood samples.

The first site is a pure plantation of *Pinus nigra* Arnold subsp. *Pinus nigra* (Black pine) (*P. nigra*) located in the municipality of Zarzuela de Jadraque (Guadalajara, Spain) (41°1´N, 3º4´W). It was planted in 1962 and consists of a control, thinning (CFSP) and thinning and 5 m pruning (CFCP) regimes. The silviculture operations were carried out in 1993 and 2006. It is located at an altitude of 1005 meters above sea level (m.a.s.l.), on a generally flat area with a 1 % - 10 % slope in the NW direction. In this area, the average annual rainfall is 489 mm and the average annual temperature is 10,9 ºC (AEMET 2017).

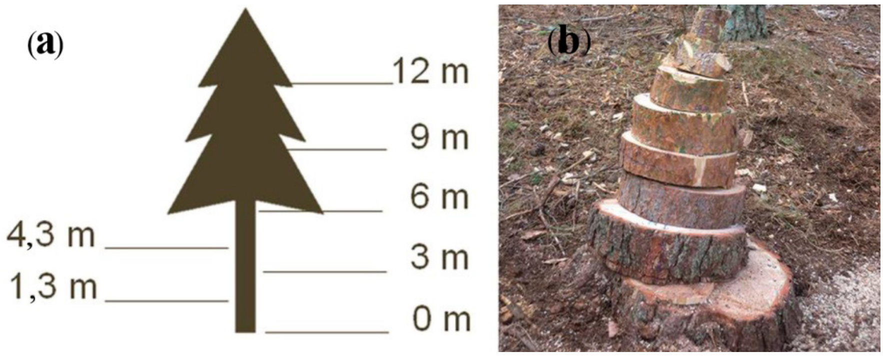

Figure 1: Disk sampling from each tree. (a) Sketch showing the sampled heights (b) Disks obtained from a sampled tree.

For the *P. nigra* 12 trees were felled, four trees per treatment. Then disks at basal height (0,2 m) and at every 3 m were extracted until the diameter was less than 7,5 cm, plus another two disks were extracted at 1, 3 m and at 4,3 m as described in Figure 1. These extra heights represent breast height and the sampling at 4,3 m was chosen to have more information of the most valuable sawlogs, which usually is 6 meters. In this paper, the study was carried on up to a height of 12 m, which all trees reached.

The second site is a *Pinus sylvestris* L. (Scots pine) (*P. sylvestris*) pure plantation located in the Guadarrama mountain range, in the La Morcuera Forest (Madrid, Spain) (40º50´N, 3º5´W). This forest stand comes from a plantation done in 1954 where control, light thinning (CDSP), light thinning and 3 m pruning (CDP3), heavy thinning (CFSP) and heavy thinning and 5 m pruning (CFP5) trials had carried out the silviculture treatments in 1991 and 2001. It is located at an altitude of 1550 m.a.s.l. on the northern face of the mountain with a NE orientation and a 10 % – 50 % slope in the trial area. In this area, the average annual rainfall is 1062 mm and the average annual temperature is 7 ºC (AEMET 2017).

Here, 15 trees were felled, three trees per treatment, and disks were extracted as in the black pine methodology described above, except for the disks at heights of 1,3 m and 4,3 m.

The silviculture specific data are detailed in Moreno *et al.* (2014), since here the main goal is just to compare different silvicultural treatments.

From all the disks, 2 mm-thick and 40 mm-wide strips, cut from the cross section were sawn, avoiding compression wood if possible. This was done by obtaining the strips perpendicular to the slope and visually checking for compression wood. Once these strips had been obtained, they were immersed in n-Pentane for 48 h to eliminate extractives (Gapare *et al.* 2006, Rodríguez and Ortega 2006). Then, the samples were stored in a climatic chamber at 20 ºC and at 65 % RH until their moisture content was 12 %. Later they were scanned with an X-ray to assess the microdensity of the strip using the same equipment as described in Rodríguez and Ortega (2006). The images were processed using LIGNOVISION™ and TSAP-Win™ software. A fixed boundary between earlywood and latewood was set as being half the variation in density in each ring, and other average values for each growth ring such as ring width, mean ring density, earlywood width, earlywood density, latewood width, latewood density and, texture were obtained.

Juvenile wood ratio

In order to assess the proportion of juvenile-mature wood, the transition year (TY) between them needs to be accurately determined. To do so, latewood density (LWD) was the wood characteristic selected, based on previous studies and results (Ruano *et al.* 2019, Sauter *et al.* 1999, Gapare *et al.* 2006).

A two-step procedure was carried out. First, an initial TY was estimated with the "segmented" (Muggeo 2008) package in R (R Core Team 2017) linking yearly LWD at each height to the Standardized Precipitation Evapotranspiration Index (SPEI) (Beguería *et al.* 2014, De Cáceres *et al.* 2018) and age, excluding the treatment. This was done to account for the density variation produced by severe droughts (Arzac *et al.* 2018). Next, the best fitted model was run through the function developed in R for mixed segmented models (Muggeo *et al.* 2014, Muggeo 2017), taking into account all the variables (SPEI, age, slope, distance from the crown, sampled height, distance to the top and silvicultural treatments).

In this way the TY was obtained and, in turn, the proportion of JW from the average of both diametrical strips of the disk (one on each side of the pith) along each bole was calculated.

The percentage that resulted at each height was calculated taking into consideration treatments in order to analyze if these had an influence on juvenile wood growth patterns. The volume was also calculated between each tree height sampled using the Smalian method for cubication. Also, the taper was calculated by the angle produced between each disc extracted.

RESULTS AND DISCUSSION

The results will be presented separately for each species.

Pinus nigra

Figure 2 shows TY for different treatments and heights on *Pinus nigra* Arn. and over the boxplot the average transition age per treatment. When these results were analyzed, they showed that TYs were produced before the first silvicultural intervention was carried out. Due to this, the result regarding how silvicultural influenced TY occurrence, cannot be evaluated.

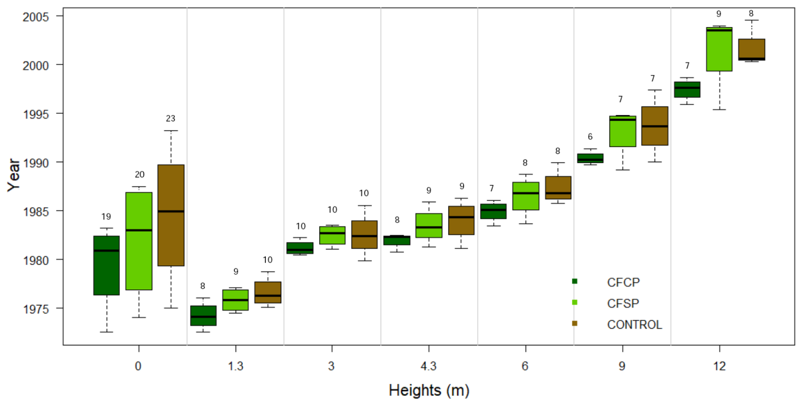

Figure 2: Transition year per treatment on *P. nigra* plots and average transition age.

However, this figure expresses the TY progress produced at different heights. At the basal height the TY varied a lot among trees, being achieved sometimes even later than further up the bole, this could be due to the mechanical demands and the proximity to the root system (Lachenbruch *et al.* 2011), if only one measurement can be done per tree, basal height should not be the height chosen. At a height of 12 m, a slight difference between the CFCP and the control group was observed, but the crown proximity might have influenced this result.

To the better analysis of JW produced at each height, in Figure 3 the percentage of JW is compared per plot type and some differences could be observed. Due to the increase in radial growth brought about by late thinning, the extent of MW length at each height increased and so the percentage of JW in respect to the total reduced. There also seemed to be a difference between thinning and 5 m pruning (CFCP) and thinning (CFSP) inside the crown at a height of 12 m, which occurs because in the thinned without pruning plots the percentage of JW increases slightly more compared with the pruned ones. This effect is in keeping with the findings of Larson (1969).

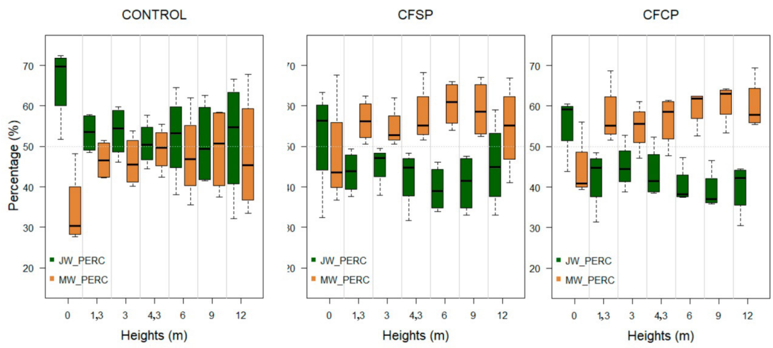

Figure 3: *P. nigra* percentage in the radial length of JW and MW at each height per treatment.

An analysis from a perspective of volume is presented in Table 1. Note the difference in terms of total volume per treatment applied in comparison with that for the control group, as the MW is affected by late thinning, as mentioned previously. There is not a significant difference between CFSP and CFCP in terms of total volume and the percentage of JW.

Table 1: *P. nigra* average volume in m^3 per plot type and JW volume percentage.

Height	Plot type	JW Volume	MW Volume	Tree Volume	% JW Volume	SD
0 - 12	CONTROL	0,057	0,132	0,189	30	5,9[a]
0 - 12	CFSP	0,062	0,269	0,331	19	4,3 [b]
0 - 12	CFCP	0,065	0,286	0,351	18	3,4[b]

[a,b] Statistical Significance groups, equal letters indicate no significant difference between treatments, according to Tukey HSD Test ($p \leq 0{,}05$).

Figure 4 shows a reconstructed tree per treatment with its radial section area of JW-MW along the bole based on the medium length strips from the disks extracted at the different heights.

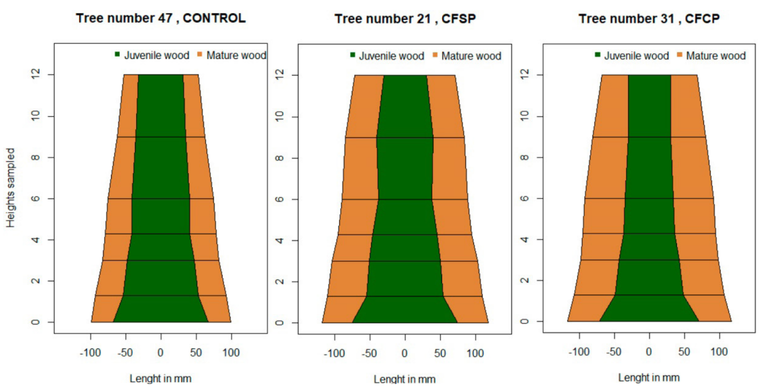

Figure 4: *P. nigra* JW/MW tree reconstruction along the bole.

In this figure is also detected better results on taper for CFCP treatment than those for CFSP, mainly in the 3 m - 6 m section of the bole, where when bucked to a specific merchantable length, sawmills can obtain products for structural use and therefore high quality is required.

There have been reports in the literature concerning the effects of thinning and pruning but depending on the variable measured, the age at which they are applied and their intensity, different effects can be seen (Peltola *et al.* 2007, Amateis and Burkhart 2011, Ulvcrona and Ahnlund 2011, Vincent *et al.* 2011, Pape 1999, Mazet *et al.* 1990, Moore *et al.* 2015, Mörling 2002, Dobner *et al.* 2018, Barbour *et al.* 1994, Burkhart and Amateis 2020, Paul 1958). Even so, most of these reports conclude that these effects are limited to the following few years after treatment. So, if this is considered, clearly thinning and pruning operations applied after the TY is reached, in addition of increase total volumes in Mediterranean forests also will increase the percentage of quality wood obtained from them.

Pinus sylvestris

Similar to the *P. nigra* results, the TY determined in *P. sylvestris* was produced before silviculture treatments so it cannot be used to detect differences between them and control plots.

Figure 5 presents results of TY tendency obtained according to treatment and heights and over the boxplot the average transition age per treatment. At 12 m, there is a significant difference between the pruned and the control trees, but there is none for the heavy thinned trees (CFSP) without pruning.

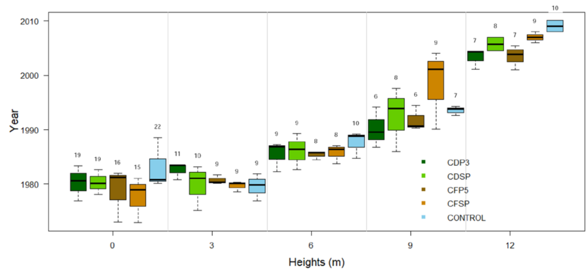

Figure 5: TY per treatment on *P. sylvestris* plots and average transition age.

On comparing the percentage of JW to MW at each height when the plot type is taken into consideration, some differences can also be observed (Figure 6). Due to the increase in radial growth produced by late thinning, the MW length at each height increased, so the percentage of JW decreased, as in *P. nigra*. No explanation has been found for the marked variations of both wood percentage at 9 m in the control group.

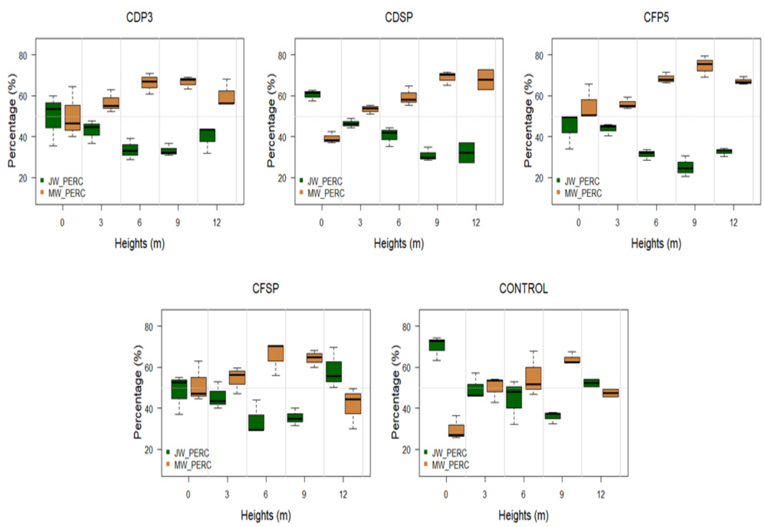

Figure 6: *P. sylvestris* percentage in radial length of JW and MW at each height per treatment.

Regarding the total volume of each wood type, significat differences can be observed in terms of the volume per treatment in Table 2. Note the JW volume percentage decrease with the silvicultural treatments applied versus control. This is due to the mentioned increase in the volume of MW with respect to the total volume, but with very similar results between light thinning and strong thinning.

Regarding the percentage of JW obtained from different pruning for *P. sylvestris* trees, it can be observed close results between both, 17 % for 3 meters and 15 % for 5 meters pruning.

Table 2: *P. sylvestris* volume in m^3 per plot type and JW volume percentage.

Height	Plot type	JW Volume	MW Volume	Tree Volume	% JW Volume	SD
0 - 12	CONTROL	0,065	0,150	0,215	30	3,8 [a]
0 - 12	CDSP	0,069	0,255	0,325	21	1,5 [b]
0 - 12	CDP3	0,061	0,396	0,476	17	4,4 [bc]
0 - 12	CFSP	0,056	0,251	0,307	19	4,0 [bc]
0 - 12	CFP5	0,063	0,369	0,432	15	1,5 [c]

[a,b] Statistical Significance groups, equal letters indicate no significant difference between treatments, according to Tukey HSD Test ($p \leq 0,05$).

Maderas. Ciencia y tecnología 2021 (23): 21, 1-10

In Figure 7 it is presented a reconstructed tree with the area of JW-MW on a radial section based on data yielded from the medium length strips obtained for each height and silvicultural treatment.

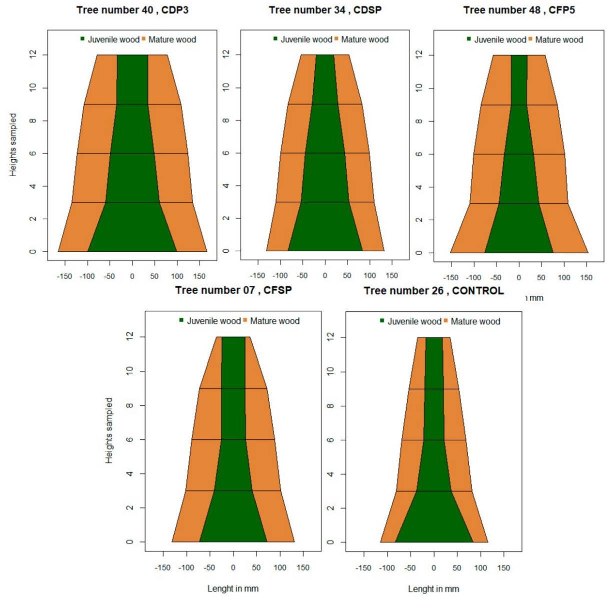

Figure 7: *P. sylvestris* JW/MW tree reconstruction along the bole.

Furthermore, it can be seen again that the volume of JW reduces with treatments applied versus control due to the previously mentioned increase in the volume of MW with respect to the total volume. Stronger thinning combined with 5 m pruning produces a greater reduction in the volume of JW (CFP5). Another advantage of applying this latter treatment is that it generates clearwood, wich is important in terms of wood quality for structural use. This was observed on plots on both species which is also in accordance with the findings of Larson *et al.* (2001).

On *P. sylvestris*, while pruning at 5 m seems to influence the degree of taper, pruning at 3 m seems to have no clear effect on it probably because the branches removed were declining or dying branches (Larson 1969) or already dead, as carrying out this treatment is costly, either performing late pruning enhanced up to 5 m or not doing it at all, should be considered.

CONCLUSIONS

The Juvenile wood volume of *P. nigra* and *P. sylvestris* is not significantly decreased at most heights of the bole when thinning and pruning treatments are performed after the TY occurrence. However, due to the tree volume increase produced in the MW on the thinned trees, the total tree percentage of JW volume is reduced. Related to *P. nigra*, the pruning influence on the JW volume is only significant at 12 m height but the crown might be an influencing factor of this result. Nevertheless, thinning and pruning to 5m is costly but they reduce juvenile wood, tapper and knots which makes this silvicultural practice worth it. For *P. sylvestris*, the results of JW volume percentage are very similar for 3 m and 5 m pruning, but it has to be considered also the better wood quality production (knotless and tapper). As stated in many papers in the literature, results may vary with the intensity and time of the thinning, as well as on the amount of green pruning carried out. Additional research is required to support these results, for example using MFA analysis or being supplemented with some destructive sampling. Studies should be also performed when silviculture treatments are previous to reach the TY.

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LIST OF ABBREVIATIONS

MFA - Micro Fibril Angle

JW - Juvenile Wood

MW - Mature Wood

CW - Corewood

OW - Outerwood

LWD - Latewood density

CFSP - Plots with the thinning trials for the black pines

CFCP - Plots with the thinning and 5 m pruning trials for the black pines

m.a.s.l. - Meters above the sea level

CDSP - Plots with the light thinnings trials for the Scots pines

CDP3 - Plots with the light thinnings trials and 3 m pruning for the Scots pines

CFSP - Plots with the heavy thinnings trials for the Scots pines

CFP5 - Plots with the heavy thinnings trials and 5 m pruning for the Scots pines

TY - Transition year

SPEI - Standardized Precipitation Evapotranspiration Index