Effects of crown size on wood characteristics of Corsican pine in relation to definitions of juvenile wood, crown formed wood and core wood

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Summary

Current use of the terms ‘juvenile wood’, ‘crown formed wood’ and ‘core wood’ is confusing: some authors have used the terms synonymously, while others have used each term in a more restricted sense to imply the region of a log where wood structure and properties are influenced by ring number from the pith (or distance from it), or by crown size. The present work was designed to clarify the use of these terms, since their definition is relevant to interpretation of the influence of silvicultural management on the wood quality of a log. Wood production and properties were studied in 23-year-old suppressed, co-dominant and dominant Corsican pine (Pinus nigra var. maritima) trees, in relation to crown size as determined by leaf dry weight profiles. At comparable ring number from the pith, differences in crown size from suppressed to dominant tree class resulted in a substantial increase in average ring width, decrease in mean percentage latewood, MOR, MOE and maximum compression strength, inconclusive differences in mean specific gravity, and negligible differences in tracheid length. From these trends, it is here suggested that ‘juvenile wood’ should be defined as the region around the pith in which there are inherent changes in structural characteristics associated with cambial age, independent of crown influences. The term ‘crown formed’ wood should be used to describe fluctuations in wood structure associated with the size of the crown, which are superimposed upon the inherent trends due to cambial age. The term ‘core wood’ should be retained for use in a more generalized sense, indicating the central region of the log where structure and properties are variable and differ from those of the outer wood.

Introduction

It has long been appreciated that the properties and structure of wood close to the central pith of a log differ to some extent from those of wood further from the pith (Rendle, 1960; Zobel and Sprague, 1998). The region of growth rings close to the pith has often been termed ‘juvenile wood’,...
in contrast to the ‘mature wood’ zone that is formed later in time, further from the pith. Confusingly, a range of other terms have also been used for the central zone, including ‘core wood’ or ‘pith wood’ (from its position in a log), and ‘crown formed wood’ (from its association with the vicinity of the live crown at the time of its development) (Paul, 1957; Larson, 1969). Similarly, wood further from the pith has been termed ‘mature wood’, or ‘outer wood’ from its position in the log, or ‘stem (or trunk) formed wood’ as it is produced in the stem below the crown. It is not clear from the literature whether previous authors have considered the various terms they used for the central (or the outer) region of a log to be synonymous, or whether there are nuances in the terminology that are intended to imply influence of cambial ageing, or influence of crown size, or both, upon wood properties. A multiplicity of ideas that previous authors have had about the nature of this central zone was reviewed helpfully by Zobel and Sprague (1998) without coming to clear conclusions about the confused terminology: they themselves used the terms synonymously.

However it is defined, the central region is generally appreciated to be a zone where many wood characteristics vary with distance from the pith, while in the outer zone they are more stable. It should be noted that the boundary between central and outer zones is not usually a sharp one, and that the position of change from one to the other varies according to the characteristic being studied (Cown, 1992). Thus the boundary between the central core and outer zone defined for tracheid length is not necessarily the same as that defined for specific gravity.

Changes in wood properties and structure outwards from the pith are well documented for a wide range of species (Fielding, 1967; Bendtsen, 1978; Thomas, 1984; Brazier, 1985; Haygreen and Bowyer, 1989; Zobel and Sprague, 1998). However, the mechanism of that change is still doubtful; most definitions of ‘juvenile wood’ and ‘mature wood’ (or whatever terms the authors used for the central and outer zones) are based on subjective criteria rather than biological understanding of xylem cell development. Inherent changes in wood structure have been shown to occur with ageing of the cambium (Duff and Nolan, 1953; Thomas, 1984; Denne et al., 1999) and also with ageing of the apical meristem (Olesen, 1977; Dodd and Walker, 1988). In addition, environmental factors have been shown to exert a profound influence on wood structure, either directly, or indirectly through their influence on the extent or efficiency of the crown (Larson, 1969; Denne, 1979; Denne and Dodd, 1981).

Therefore, the characteristics of wood cells developed from the cambium are functions of the age of the cambium, and/or age of the apical meristem from which the particular cambium cell is derived, and/or environment around the tree, and/or size of the crown. Understanding the underlying control of these within-tree patterns of wood properties is important for the implementation of the silvicultural management of wood quality, for environmentally induced aspects of wood formation may be regulated by management practices that control the size of the crown, whereas presumably the inherent ageing processes are not directly affected by the same practices.

The main objectives of the present study were first to distinguish wood properties that are influenced solely by inherent trends (such as ageing of the cambium) from those that are also influenced by crown size, and secondly to clarify the terminology used to define juvenile wood, crown formed wood, and core wood. Using trees from a plantation of Corsican pine (*Pinus nigra* var. *maritima*), variations in ring width, specific gravity, tracheid length, percentage late wood, modulus of rupture, modulus of elasticity and maximum compression strength were considered in relation to crown size and to ring number from the pith. Since even-aged trees were used for the present study, it was assumed that those growth ring characteristics that remained similar over different crown classes may be attributed to inherent trends in wood formation. Characteristics that varied with amount of crown may be attributed either to extrinsic factors, or possibly to a genetic link between vigour and wood property: given statistically significant differences between replicated samples, it is more likely that these differences are associated directly with a crown influence than indirectly through genotype.

**Materials and methods**

Corsican pine (*Pinus nigra* var. *maritima*) trees 23–24 years old were obtained from a plantation...
with yield class 14 in Coed Môr woodland, Anglesey. Nine trees with straight non-leaning boles were selected from a 2 ha block, choosing three from each of three crown classes: suppressed (S), co-dominant (CD) and dominant (D) trees. The crown class was estimated on the basis of crown volume as perceived from the ground before felling, and the trees selected within each crown class approximated to the mean diameter of that class at breast height.

After felling, annual growth internodes were identified and labelled, starting the numbering from the leader. Leaves were stripped from the branches and dried at 85°C until a constant weight was obtained. Leaf dry weight of each branch was measured to the nearest 0.1 g.

Measurement of anatomical properties and specific gravity
A cross-sectional disc of 15 mm thicknesses was removed from each odd-numbered internode down to internode 21 (11 positions). Two adjacent radial strips of 7 mm tangential width were cut across the diameter of each disc. One strip was used to obtain sections for measurement of ring width and percentage latewood, and the other strip was used for the measurement of specific gravity and tracheid length. Transverse sections 30 µm thick were cut using a sledge microtome. Sections included all growth rings from pith to bark, along two opposite radii. Ring width was measured using a light microscope fitted with an eyepiece graticule at 40 magnification. Measurements were taken from both radii, from every odd-numbered ring counted from pith to bark, in each sampled internode. Percentage late wood of the rings was also measured according to Mork’s (1928) definition (Denne, 1989) using the same transverse sections; these latewood percentage data were not available from trees S3, CD3 or D3.

Tracheid length was analysed in the same growth rings: strips 2 mm thick were removed from each ring, including the whole width of both earlywood and latewood. These strips were taken at an angle to the radial axis in order to avoid the whole sample being produced from the same cambium initials. After being sliced into narrower sections, the strips were macerated using a 1 : 1 mixture of glacial acetic acid and 20 vol. hydrogen peroxide. The macerated tracheids were stained with methylene blue and mounted in glycerol jelly. Fifty tracheids per ring (25 from each of two opposite radii) were measured using a light microscope fitted with a ×40 eyepiece graticule.

Specific gravity was determined from the same rings that had been sampled for ring width, using the maximum moisture content method (Smith, 1954). At each ring sampled, 3 mm thick strips were removed at an angle to the radial axis, including the whole width of both earlywood and latewood.

Measurement of physical and mechanical properties
Following the methods established by Wood (1970), 10 × 10 × 160 mm size samples were extracted for static bending tests, and 10 × 10 × 30 mm samples were extracted for compression tests, using even-numbered internodes from internodes 6–20.

Static bending parallel to the grain tests were carried out using the samples in green condition on an Instron Universal Testing machine, series 4301. Tests were carried out as soon as possible after felling and conversion to maintain moisture content at fibre saturation point. The strength properties determined from this test were modulus of rupture (MOR) and modulus of elasticity (MOE). Compression parallel to the grain was tested on an Instron Universal testing machine, series 1195, again using the samples in green condition as soon as possible after felling and conversion.

Data analyses
Using MINITAB, analysis of variance (ANOVA) was carried out to test the association between the above wood properties and crown classes, tree dimensions or leaf dry weight; full details of this ANOVA procedure are discussed in Amarasekera (1990).

Results
Table 1 shows mean leaf dry weight and other growth characteristics for S, CD and D trees. Leaf dry weight values were significantly higher in D
than CD and S trees (Table 1). D trees were significantly taller than CD and S trees, and diameter at breast height (d.b.h.) increased from S to D tree class.

**Ring width**

Mean ring width increased from S to D tree class (averaging 2.37 mm in S, 3.91 mm in CD and 6.10 mm in D) and these differences were highly significant at \( P < 0.05 \) (Table 2). Mean ring width values were highly correlated with the total and current year leaf weight of the individual trees (Table 3). The widest rings were found in tree D1, which carried the heaviest total leaf weight (Tables 1 and 2). A strong linear regression equation (\( R^2 = 0.935 \)) fitted between ring width and total leaf dry weight (Figure 1a). Correlations between ring width with height, and ring width with d.b.h. were also very high (Table 3).

Since total leaf dry weight at the time of felling may more justifiably be related to the wood qualities in the outermost complete growth sheath than to the mean wood property values in the whole tree, leaf weight profiles and axial variation of wood properties of the outer growth sheath of trees are plotted in Figure 2. The ring width profile from apex to base along this outermost sheath was largely associated with the amount and distribution of leaf on the trees (Figure 2a, e); rings were very narrow throughout the most suppressed tree, S3, and wider throughout the dominant trees. Maximum ring width (which occurred a few internodes below the apex) was wider in the trees with more leaf than in suppressed trees: the maximum was highest in D1 and lowest in S3 (Figure 2a). Figure 3 indicates the extent of the central zone of variable characteristics compared with the more stable outer zone in years (or distance) along a radius of a log: ring width data are plotted against ring number from the pith in Figure 3a, and against distance from the pith in Figure 3b. The central zone of variable ring width was almost twice as wide in the dominant than in the suppressed trees (Figure 3b).

**Specific gravity**

Although the mean specific gravity of S trees (0.390) was higher than those for CD (0.363)

<table>
<thead>
<tr>
<th>Suppressed trees</th>
<th>Co-dominant trees</th>
<th>Dominant trees</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaf dry weight (g)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td>69.5</td>
<td>130.4</td>
</tr>
<tr>
<td>S2</td>
<td>14.8</td>
<td>29.8</td>
</tr>
<tr>
<td>S3</td>
<td>11.5</td>
<td>9.8</td>
</tr>
<tr>
<td>Current year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>12.7</td>
<td>11.2</td>
</tr>
<tr>
<td>d.b.h. (cm)</td>
<td>11</td>
<td>11.2</td>
</tr>
<tr>
<td>Height (m)</td>
<td>11.5</td>
<td>9.8</td>
</tr>
</tbody>
</table>

Table 1: Mean leaf dry weight and growth characteristic values in suppressed (S), co-dominant (CD), and dominant (D) trees.
Figure 1. Regressions between wood properties and total leaf dry weight of Corsican pine. Each point represents the mean of all sampling positions within a tree.
and D trees (0.356), these differences were not significant at \( P \leq 0.05 \) level (Table 2). For example, mean specific gravity of trees S2 and D3 was similar (Table 2), though the total leaf weight of D3 was 13 times that of S2 (Table 1). However the highest specific gravity was observed in S3, which carried the lowest amount of leaf material.

Specific gravity was inversely related to other growth parameters (Table 3), but correlation coefficients between specific gravity and leaf parameters, height or d.b.h. were low (Table 3). The data for specific gravity in relation to leaf dry weight fitted more closely to a second order polynomial than to the linear regression, although even for that polynomial curve the fit was poor (\( R^2 = 0.229 \), as shown in Figure 1b).

The mean profile of specific gravity was higher for S trees than for CD and D trees (Figure 2b), although this was mainly associated with the very high specific gravity of the most suppressed tree (S3) throughout its profile compared with S1 and S2. Because the specific gravity crown-class means were so strongly influenced by variation between trees (Figure 2b), trends in mean specific gravity across logs are not included in Figure 3.

### Percentage latewood

Mean percentage latewood decreased from S (7.4%), CD (3.6%) to D (1.8%) trees, and the differences were significant at \( P < 0.05 \) level (Table 2). Percentage latewood values were inversely correlated with total leaf dry weight, current year leaf weight, height and d.b.h. of the individual trees (Table 3). A curvilinear regression equation between percentage latewood and leaf weight (\( R^2 = 0.923 \)) gave a better fit than the linear regression (\( R^2 = 0.683 \)) (Figure 1c).

In co-dominant and dominant trees, percentage latewood values were very low within the region of the crown, increasing in the region below the crown (Figure 2c and e). Percentage latewood was lowest close to the apex in the suppressed trees (Figure 2c). Figures 3c and d suggest there was a similar percentage latewood in all crown classes for the first few rings from the pith, followed by a more rapid rate of increase in suppressed than in dominant trees.

### Table 2: Mean wood property values in suppressed (S), co-dominant (CD) and dominant (D) trees

<table>
<thead>
<tr>
<th>Suppressed trees</th>
<th>Co-dominant trees</th>
<th>Dominant trees</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>2.92</td>
<td>0.001</td>
</tr>
<tr>
<td>S2</td>
<td>2.06</td>
<td>0.720</td>
</tr>
<tr>
<td>S3</td>
<td>2.13</td>
<td>0.347</td>
</tr>
<tr>
<td>S1</td>
<td>3.83</td>
<td>5.19</td>
</tr>
<tr>
<td>S2</td>
<td>3.68</td>
<td>6.02</td>
</tr>
<tr>
<td>S3</td>
<td>7.08</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Note: Each value is derived from the mean of all sampling positions within a tree. Latewood % values for S3, CD3 and D3 not available.
Table 3: Correlation coefficients between leaf weight (or other tree size parameters) and wood properties based on mean of all sampling positions within all trees

<table>
<thead>
<tr>
<th></th>
<th>Ring width</th>
<th>Specific gravity</th>
<th>% latewood</th>
<th>Tracheid length</th>
<th>MOR</th>
<th>MOE</th>
<th>MCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total leaf weight</td>
<td>0.967</td>
<td>-0.378</td>
<td>-0.826</td>
<td>0.046</td>
<td>-0.843</td>
<td>-0.355</td>
<td>-0.796</td>
</tr>
<tr>
<td>Current year leaf weight</td>
<td>0.923</td>
<td>-0.396</td>
<td>-0.833</td>
<td>0.065</td>
<td>-0.888</td>
<td>-0.316</td>
<td>-0.845</td>
</tr>
<tr>
<td>Height</td>
<td>0.926</td>
<td>-0.249</td>
<td>-0.923</td>
<td>-0.001</td>
<td>-0.756</td>
<td>-0.308</td>
<td>-0.731</td>
</tr>
<tr>
<td>d.b.h.</td>
<td>0.980</td>
<td>-0.421</td>
<td>-0.932</td>
<td>0.061</td>
<td>-0.799</td>
<td>-0.344</td>
<td>-0.717</td>
</tr>
</tbody>
</table>

Figure 2. Axial variation of wood properties of the most recent growth sheath (a–d), and leaf dry weight (e) of Corsican pine trees. Suppressed (S), co-dominant (CD), and dominant (D) crown classes. Individual trees: S1 ▲, S2 △, S3 ◆, CD1 ●, CD2 O, CD3 ◇, D1 ■, D2 ◊, D3 ✗. Means for S trees solid line, CD trees dotted line, D trees dashed line.
Mean tracheid lengths of S, CD and D trees were not significantly different at $P \leq 0.05$ (Table 2). Mean tracheid length difference between trees was independent of amount of leaf, height or d.b.h. of the trees (Table 3, Figure 1d). Axial tracheid length profile was also similar in all trees.
and did not appear to be associated with the leaf weight profile (Figure 2d, e). Similarly, Figure 3e shows no apparent influence of crown size when tracheid length was plotted against ring number from the pith. However, when plotted against distance from the pith (Figure 3f), tracheid length increased more rapidly across the log in suppressed than in dominant trees (as would be expected, being the consequence of having narrower rings in the suppressed trees). Hence, although tracheid length appears to be independent of crown size, for a log of a given diameter the distribution of tracheid length within it will depend on the number of years it has taken to achieve that diameter, and so is indirectly affected by the growth rate.

**Mechanical properties**

Modulus of rupture (MOR) decreased from S to D tree class (40.17 Nmm$^{-2}$ in S, 36.50 Nmm$^{-2}$ in CD, 31.40 Nmm$^{-2}$ in D), and these differences were highly significant at $P \leq 0.05$ (Table 2). Mean MOR values were inversely correlated with the total and current year leaf weight, height and d.b.h. of the individual trees (Table 3). The linear regression between MOR and leaf weight ($R^2 = 0.711$) is shown in Figure 1e. Similarly, maximum compression strength decreased significantly ($P \leq 0.05$) from S to D tree class (17.06 Nmm$^{-2}$ in S, 15.77 Nmm$^{-2}$ in CD and 13.83 Nmm$^{-2}$ in D) (Table 2). Here too, differences between trees were negatively correlated with leaf dry weights, height and d.b.h. (Table 3); the linear regression between maximum compression strength and total leaf dry weight ($R^2 = 0.633$) is shown in Figure 1f. Although modulus of elasticity (MOE) was lower in D trees (3900 Nmm$^{-2}$) than in CD (3992 Nmm$^{-2}$) and S (4311 Nmm$^{-2}$) trees, these differences were not significant at $P \leq 0.05$ (Table 2). Correlations of MOE with leaf weight, height or d.b.h. were poor (Table 3), the $R^2$ value for the linear regression coefficient with leaf dry weight being only 0.126 (Figure 1g).

**Discussion and conclusion**

Previous work has shown that there are consistent patterns of change in wood cell dimensions with ring number from the pith, which have been attributed to the inherent ageing processes in the cambium (Rendle, 1960; Denne, 1999). This inherent variation must account for at least part of the variation in wood quality within a log, since many wood properties are influenced by cell dimensions. In much of the previous literature (as discussed in the Introduction) inherent trends in wood properties have not been clearly distinguished from environmental influences upon them, although that distinction may be of considerable practical importance, being pertinent to the impact of silvicultural treatments on wood quality. Hence a major objective of the present work was make this distinction for a number of wood properties, investigating the extent to which inherent trends are likely to be modified by silvicultural practices through their influence on crown size.

For Corsican pine, the striking increase in tracheid length with ring number across a log appeared to be independent of crown size or leaf dry weight. Previous reports about the influence of environment (or growth rate) upon tracheid length seem contradictory: some reported a slight decrease in tracheid length with increase in growth rate (Elliott, 1960; Megraw, 1983), some showed a positive relationship (Echols, 1958; Manwiller, 1972), while others found no significant effect (DeBell et al., 1998; Dutilleul et al., 1998). Some of these apparent inconsistencies may be associated with genus studied, or method of sampling or method of analysis: Echols (1958), for example, compared tracheid lengths of *Pinus sylvestris* from different origins, Elliott (1960) variations within a single tree of *Picea sitchensis* and DeBell et al. (1998) analysed fibre length in *Populus* spp. Furthermore, where effects of environment on the tracheid length of comparable rings have been reported, they tend to be statistically insignificant, or relatively minor (Elliott, 1960; Yang and Hazenberg, 1994; DeBell et al., 1998; Dutilleul et al., 1998). However, it should be noted that, in the present work, tracheid length did vary with crown size when actual distance from the pith was considered, being indirectly affected through the influence of the crown on ring width (as shown in Figure 3e, f). This suggests that a silvicultural treatment designed to increase rate of wood production would have some effect on the distribution of tracheid length across a log, though
this effect is likely to be relatively minor and limited to those rings close to the pith, where tracheid length is increasing (Figure 3f).

In contrast, several of the other wood characteristics analysed here (including ring width, percentage latewood and some mechanical properties) were strongly correlated with the leaf dry weight of individual trees. Presumably such characteristics are regulated in part by the quantity of photosynthates and/or growth regulators produced by the crown, superimposed on any inherent trends with cambial ageing. These wood properties would be expected to be strongly influenced by silvicultural techniques that influence crown size, such as spacing and thinning regimes.

Whether specific gravity is influenced by the factors that affect crown size, is a question frequently discussed in the literature (Megraw, 1983). In the present study, though mean specific gravity of suppressed trees was higher than that of CD and D trees, this difference was not significant and did not change consistently between the trees of different crown sizes, correlations with leaf weight parameters being poor. Though the highest specific gravity profile was observed in the tree carrying the least leaf weight (S3), tree S2 (which carried a little more leaf than S3) had the lowest mean specific gravity of all sample trees (Table 2). It is not surprising that the relationship between specific gravity and crown size is a complex one, for specific gravity is determined by several parameters (including the dimensions and wall thickness of cells in earlywood and latewood as well as earlywood/latewood percentages, and also extractive content): some of those parameters are likely to vary mainly with cambial ageing, while others may be more strongly influenced by crown size (Denne, 1999). Furthermore, several of the components that affect specific gravity have been shown to be strongly heritable (Nyakuengama et al., 2000).

Based on these trends, it seems logical to suggest that the various terms employed to describe the central region of a log (juvenile wood, core wood or crown formed wood) should be used differentially rather than synonymously, to distinguish the region of changes in a characteristic affected by cambial ageing from that influenced by the crown. We suggest that the terms ‘core wood’ and ‘outer wood’ should be retained as general terms to distinguish the core region – where most wood properties tend to vary outwards from the pith – from the outer zone closer to the bark – where wood properties are more constant. The term ‘juvenile wood’ could then be used in a more restricted sense than it often has been in the past, to refer to the region of wood close to the pith where there is an inherent pattern of change in a particular property (associated with a juvenile cambium) as distinct from ‘mature wood’ produced by a more mature cambium. This is in line with the definition of juvenile wood by Fukazawa (1984). Then the term ‘crown formed wood’ could be used to describe the region where fluctuations associated with the proximity and size of the crown are superimposed upon the inherent change from juvenile to mature wood.

Making distinctions between these terms is not merely pedantic, for there are important implications. Thus, the ring number in the ‘juvenile’ wood core is likely to be standard for a particular characteristic in a particular genotype, while it is the extent of ‘crown formed wood’ that varies with growing conditions. Such a distinction between these terms would clarify understanding of the physiological and developmental processes that determine differentiation of wood cells from the cambium, and hence control variation in wood properties within trees. Knowledge about such basic growth processes is vital when quantifying the extent to which the various wood properties are affected by silvicultural management, indicating (for example) the prospect of achieving volume growth without substantial change in a particular aspect of wood quality. For Corsican pine, the present work suggests that tracheid length varies mainly within the juvenile wood zone and is little affected by crown size, while some other parameters (such as percentage latewood and MOR) are strongly influenced by the crown, and so have a greater potential to be controlled by silvicultural management. It has yet to be established whether the same holds true for other tree species.

References
Bendtsen, B.A. 1978 Properties of wood from improved


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