

# WOOD PROPERTIES OF *EUCALYPTUS NITENS* GROWN IN NEW ZEALAND

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## ABSTRACT

Some solid wood evaluations (including internal checking assessment, shrinkage, collapse and tension tests) were carried out on 15-year-old *Eucalyptus nitens* (Deane et Maiden) Maiden trees. There were significant differences between the density classes in basic density and moisture content, with the low density class having significantly lower earlywood density than the medium and high density classes. Significant differences were observed between all three classes in average ring density and latewood percentage. The extent of the internal checking observed will present a definite problem to many solid wood products. Collapse occurred readily and could be severe, but steaming effectively restored the collapse. The scanner used gave an accurate and reliable estimate of radial and tangential shrinkage combined. The tension test results were positively correlated with density and moisture content.

**Keywords:** wood properties; wood density; internal checking; collapse; *Eucalyptus nitens*

## INTRODUCTION

Since 1976 *Eucalyptus nitens* has been planted for pulpwood production in the Bay of Plenty and Southland regions. Approximately 520 ha of pure stands of various age classes were established by 1989 (Miller *et al.* 1992). It is tolerant of frosts, and the timber is suitable for general construction, joinery, and handles in Australia (Bootle 1986). *Eucalyptus nitens* grows well (especially the initial growth) in New Zealand (Miller *et al.* 1992) and has wood properties (at 30 years) similar to mature Australian *E. nitens*. The kraft pulping properties of young plantation-grown *E. nitens* have been examined in Australia and New Zealand, with pulp yields being slightly lower than eucalypts such as *E. fastigata* and *E. regnans* (Miller *et al.* 1992). So far, pulping studies have not examined individual tree variation in pulping properties, which makes it difficult to investigate relationships between specific wood characteristics and end-product properties.

Limited sampling for wood characteristics has been undertaken in New Zealand. Wood property analyses have been carried out on *E. nitens* previously by G. D. Young (pers. comm.) in which seven trees were extensively measured for a range of wood properties. Young indicated that more work was necessary, especially in the area of internal checking, as this was the major factor that excluded the timber from many solid wood end-uses.

## MATERIALS AND METHODS

The trial was planted in Cpt 1217 of Kaingaroa Forest as single-tree plots at  $3 \times 3$  m spacing. Treatment included weed control as required and thinning to about 50% of original stocking at age 5. The trees were from *E. nitens* progeny trial No. R1977, planted in 1979 and 15 years old in 1995 at the time of sampling.

One hundred 15-year-old *E. nitens* trees were screened by taking two 5-mm pith-to-bark increment cores from each stem at breast height. Wood density was calculated in 50-mm segments using the maximum moisture content method (Smith 1954), weighted to give whole-tree density. Diameters over bark were also recorded. These densities and diameters were then used to select 29 trees to cover the full high, medium, and low density range. Twenty of the trees were grouped to reflect low (six trees), medium (eight trees), and high (six trees) density classes. This was done by selecting six trees at either end, and eight around the mean of the density spectrum, which were large enough ( $>200$  mm diameter) for pulping. The remaining nine trees (the largest) were used for individual log pulping across the density range giving three trees for each of low, medium, and high density classes.

Two 50-mm-thick discs were taken from all heights (0, 1.4, 6.4, 11.4, 16.4, 21.4 m) from the 29 trees. A stem section, 1.0 m long, was taken from directly below the breast height (1.4 m) discs on the 20 trees for an assessment of stability and internal checking.

The following properties were measured on the first disc from each level:

*Diameter and stem volumes:* Inside-bark diameters (dib) were recorded with diameter tapes to calculate log and tree volumes.

*Heartwood:* The heartwood diameter for each disc was measured in millimetres and converted into a percentage of the cross-section. Definition of heartwood was by visual assessment.

*Moisture content:* Disc moisture content was calculated from the fresh (green) and oven-dry weights as it expresses the ratio of water to oven-dry wood. Moisture content was also determined on the heartwood and sapwood of the breast height samples of the nine individually pulped trees.

*Density:* Green and basic (oven-dry) densities were calculated for the all discs, using green weights and volumes (by immersion) and oven-dry weights after drying at  $103^{\circ}\text{C}$  for 3 days.

*Extractives content:* Extractives content of the heartwood and sapwood was determined from the breast height samples of the nine individually pulped trees. The pieces were weighed before and after extraction using methanol in a Soxhlet extractor for 72 hours.

*Internal checking on discs:* The green discs were cut in half diametrically to release drying stresses and tensions before weighing, volume calculation, and kiln drying at  $40^{\circ}\text{C}$  and 60% RH for 10 days. All internal checks were assessed by the following criteria: number of rings affected, number of checks in each ring, whether checks crossed latewood bands, and the severity of checking. After the checking assessment, the discs were oven-dried and re-weighed to complete the density and moisture content measurements.

The following properties were assessed in the second disc from each level:

*Spiral grain:* On two diametrically opposed sectors spiral grain was measured at every second growth ring by exposing the latewood with a chisel and scribing along the grain

direction with a “swinging arm grain scribe” (Harris 1989). Grain angle was measured in relation to the lower surface of the disc using a perspex protractor.

*Densitometry*: Strips for densitometric analysis were cut from the discs to yield samples from all stem heights (special blades were required to achieve good results with *E. nitens*). The strips were extracted using methanol in a Soxhlet extractor for 72 hours and stored for a week in constant 50% RH. Strips were then machined to 5 mm in height and 1.5 mm in thickness and conditioned at 50% RH (10% m.c.) for several days prior to scanning in the New Zealand Forest Research Institute X-ray densitometer (Cown & Clement 1983). Strips were scanned at a radial interval of 0.3 mm.

*Tension wood*: Tension wood was both visually (recording especially dark and thick latewood bands) and microscopically assessed on breast height samples. Sections were examined with a light microscope to detect tension wood, primarily by looking for gelatinous (G) fibres, and a visual assessment was made of the proportion of G-fibres to normal fibres. The relative proportion of G-fibres was estimated by visual assessment over a number of fields of view. Tension wood was also assessed on hand sections cut from each growth ring using a razor blade and then stained with toluidine blue. A visual assessment was made of the proportion of G-fibres to normal fibres in each hand section (L.A. Donaldson pers. comm.).

*Vessel number*: The number of vessels per square millimetre was determined for rings 5 and 10 at breast height on each tree. Transverse sections were prepared using a 20- $\mu$ m sledge microtome and stained with safranin before examination with a light microscope. The number of vessels within a known area was determined on five separate areas and converted to vessels per square millimetre before averaging (Donaldson pers. comm.).

*Coarseness*: Fibre coarseness was determined on cross-sectional images of fibres obtained with a scanning electron microscope. Micrographic images were scanned using a Mustek hand scanner connected to a personal computer and cell wall area was determined by image analysis (Donaldson pers. comm.). Cell wall area was then converted to coarseness using 1500 kg/m<sup>3</sup> as an estimate of cell wall density.

To reduce sample numbers only 13 trees were assessed for vessel number, coarseness, and tension wood (microscopically).

The following properties were examined in the stem section recovered from directly below the breast height disc:

*Internal checking on boards*: One board (25 mm thick) was cut from each of the 1-m bolts (taken directly below breast height) across the full diameter including pith. The boards were end sealed and had shrinkage points marked (toward one end), and green and air-dry measurements were taken on radial and tangential measurement points.

The boards were air-dried for 3 months to 30%, forced-air-dried for 2 weeks to below 20%, and finally placed in a 12% m.c. equilibrium room for 2 weeks. They were then cross-cut to give a m.c. sample and an internal checking sample, and one cut end was scanned for collapse. The remaining section with the shrinkage measurement positions was steamed and then re-equilibrated to 12% m.c. and shrinkage was remeasured to give an estimate of collapse recovery.

*Tension testing*: From each bolt a 65 × 65-mm board was cut to allow a tension test perpendicular to the grain. Three pieces 5 × 5 × 5 cm were measured green and dry (as

per ASTM Standards 143). These samples were taken from the same radial position for all trees (close to the outerwood without any wane).

Anova was used in statistical testing, with differences being significant at the 5% level unless stated otherwise.

### RESULTS AND DISCUSSION

The breast height increment core densities from the prescreening stage had a range of 156 kg/m<sup>3</sup>, from 376 kg/m<sup>3</sup> to 532 kg/m<sup>3</sup> (Fig. 1).

Young (pers. comm.) found variation in basic density within-site of about 100 kg/m<sup>3</sup> which indicates that our sample was representative of the variance in the population. From the weighted breast height densities, nine low, 11 medium, and nine high density trees were selected (Table 1). The correlation between pith to bark core density and whole tree density calculated from the discs ( $r^2$  0.87; outerwood core to whole tree  $r^2$  0.78) indicated that breast height cores can be readily used for survey, ranking, and screening purposes.

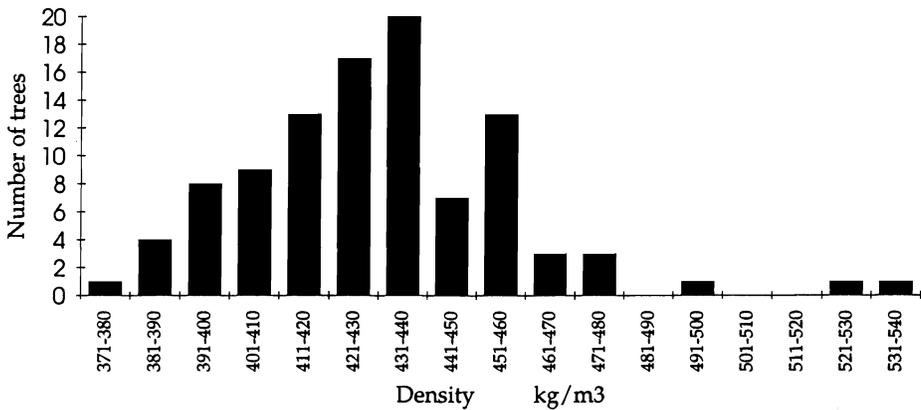


FIG. 1—Breast-height density v. number of trees.

TABLE 1—Average and range in density for each class.

	Density class		
	Low	Medium	High
No. of trees	9	11	9
Average stem density (kg/m <sup>3</sup> )	390	431	485
Range (kg/m <sup>3</sup> )	376–404	427–435	456–532

### Wood Properties

#### *Diameter and stem volume*

Tree volume averaged 1.06 m<sup>3</sup> {range 0.52 m<sup>3</sup> to 1.86 m<sup>3</sup>. Taper was very high from butt to breast height but decreased strongly above there (Fig. 2, Table 2). Taper for first log (approx. 6 m) was 15.3 mm/m which agrees with Purnell’s (1988) first log taper of 14.7 mm/m.

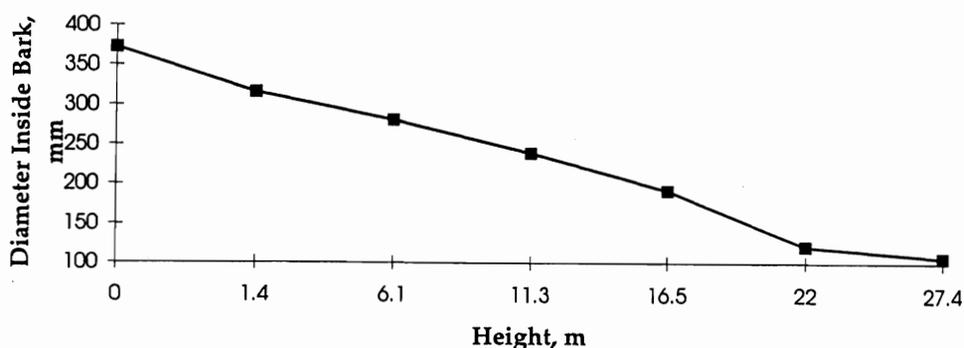


FIG. 2—Average diameter inside bark with height (data for 27.4 m from five trees only).

TABLE 2—Averages and ranges for diameter inside bark (dib) at all heights (data for 27.4 m from five trees only)

Height (m)	dib (mm)		Taper (mm/m)
	Mean	Range	
0	372	276–466	
1.4	315	241–399	41
6.1	280	212–376	7
11.3	239	173–320	8
16.5	192	124–269	9
22	121	92–197	13
27.4	106	90–114	3

### Heartwood

Heartwood content decreased with height (the slight increase around breast height was not significant at 5% level) (Fig. 3, Table 3). On average, heartwood exceeded 50% to approximately 12 m after which it decreased dramatically to 4% at 27.4 m. There was a large variation between trees, specifically at heights 11.3 and 16.5 m. Heartwood differs from sapwood in the amount and type of extractives and tyloses and it causes major problems with (a) penetration of waterborne preservatives, (b) some pulping liquors, and (c) the extra bleaching needed for some pulps (Nicholls & Pedrick 1979). The advantage of heartwood is that, unlike sapwood, it is not susceptible to insect attack (Haslett 1988).

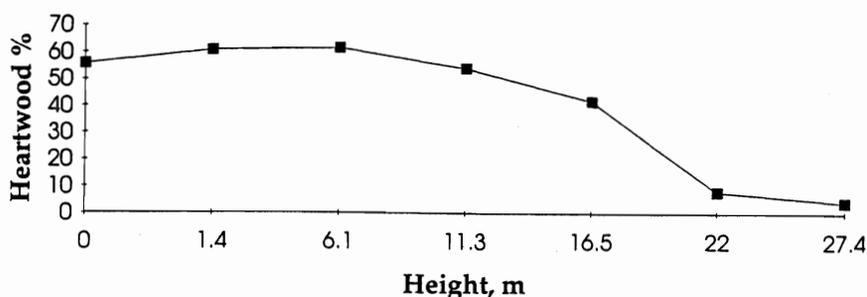


FIG. 3—Average heartwood percentage with height.

TABLE 3—Average and range for heartwood at all heights (data for 27.4 m from five trees only)

Height (m)	Heartwood (%)	
	Mean	Range
0	56	42–70
1.4	61	29–73
6.1	61	50–75
11.3	54	14–65
16.5	42	0–72
22	8	0–40
27.4	4	1–7
Tree	54	24–65

### Moisture content

Moisture content decreased with height (the slight increase around breast height was not significant at the 5% level) (Fig. 4, Table 4). Moisture content changed gradually with height up the stem although there was considerable variation in range between individual trees. Purnell (1988) found a linear decrease in moisture content from 2.4 m to 12 m and this agrees with our study in which moisture content decreased linearly from breast height to top height.

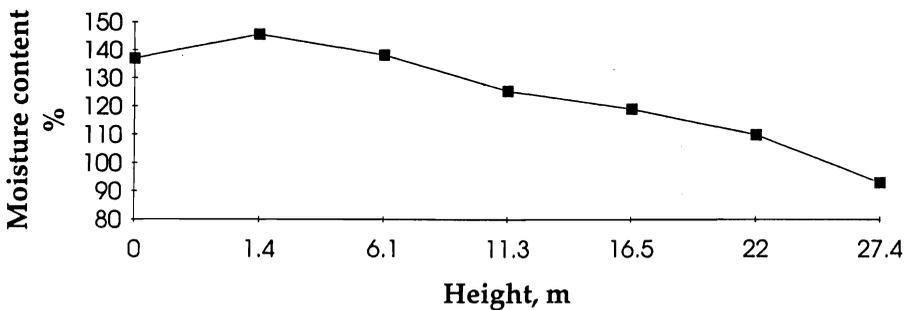


FIG. 4—Average moisture content with height.

TABLE 4—Average and range for moisture content at all heights.

Height (m)	Moisture content (%)	
	Mean	Range
0	137	89–166
1.4	145	108–177
6.1	138	113–171
11.3	125	102–156
16.5	119	96–149
22	110	86–143
27.4	93	79–116
Tree	133	106–162

### Green density

Green density decreased rapidly with height (a slight increase at 16.5 m was not significant at the 5% level) from butt to about 6 m, above which it levelled off until the top

sampling height where there was another decrease (Fig. 5, Table 5). This trend supports that found by Young (*pers. comm.*).

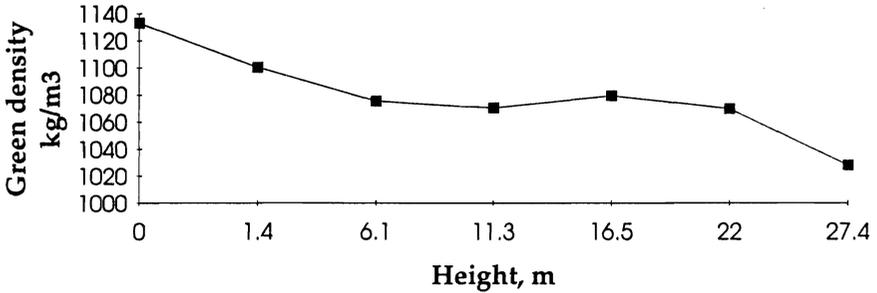


FIG. 5—Average green density with height.

TABLE 5—Average and range for green density at all heights.

Height (m)	Green density (kg/m <sup>3</sup> )	
	Mean	Range
0	1133	1086–1267
1.4	1100	1059–1168
6.1	1075	1042–1121
11.3	1071	1011–1122
16.5	1079	1013–1165
22	1070	971–1156
27.4	1028	988–1070
Tree	1084	1043–1140

*Basic density*

When whole-tree density was calculated from discs it was found that two trees (35 and 13) had changed to the medium density class, one from each of the high density and low density classes respectively.

Basic density initially decreased (significant at the 5% level) with height to 1.4 m and then increased with height (Fig. 6, Table 6). There was a linear increase in basic density after 6 m, just as Purnell (1988) found a linear trend in basic density above 2.4 m.

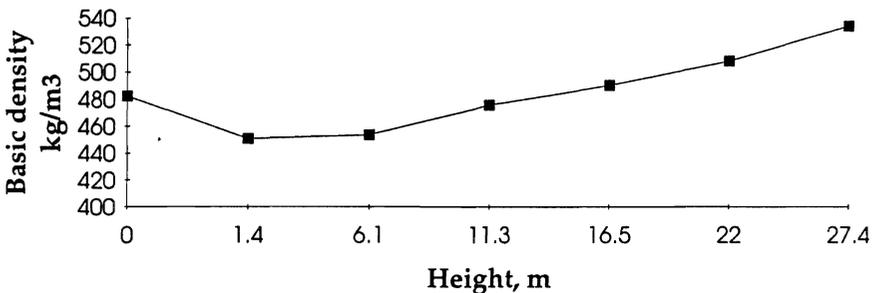


FIG. 6—Average basic density with height.

TABLE 6—Average and ranges for basic density at all heights.

Height (m)	Density (kg/m <sup>3</sup> )	
	Mean	Range
0	482	414–624
1.4	451	397–545
6.1	453	389–509
11.3	476	409–523
16.5	490	425–557
22	508	456–583
27.4	535	495–572
Tree	467	409–533

### Correlations

The strongest correlations, using individual disc data, were an  $r^2$  value between diameter-inside-bark and heartwood of 0.55, and an  $r^2$  value between basic density and moisture content of 0.83.

Correlations between sampling points and whole-tree wood property values showed that sample heights 11.3 m or 6.4 m (for respective properties) had higher correlation to whole tree properties than breast height (Table 7). Similarly, Purnell (1988) found the best sampling positions to be between 10% and 30% of the total tree height. Although samples at 6.4 m or 11.3 m provided better estimates of whole-tree values, there was little loss in accuracy from sampling at breast height and there were substantial improvements in cost and ease of sampling.

In nine trees heartwood and sapwood were measured separately for moisture content, extractives content, and green and basic density (Table 8). The heartwood had a significantly lower percentage of extractives (at the 5% level) and lower green density (at the 1% level) than the sapwood. Sapwood had a significantly higher basic density (at the 10% level) as found also by McKimm (1985) who reported that basic density in 8.5-year-old *E. nitens* was

TABLE 7—Breast height (1.4 m) and optimal sample height  $r^2$  values for whole-tree properties

Property	$r^2$ values for sample heights		
	Breast height	Best sample position	
		Height (m)	$r^2$
Diameter	0.91	11.3	0.97
Heartwood	0.71	11.3	0.81
Moisture content	0.88	6.4	0.92
Green density (kg/m <sup>3</sup> )	0.82	6.4	0.82
Basic density (kg/m <sup>3</sup> )	0.87	6.4	0.91

TABLE 8—Wood properties for heartwood and sapwood

Wood type	Moisture content (%)	Extractives (%)	Density (kg/m <sup>3</sup> )	
			Green	Basic
Heartwood	137	2.2	1054	449
Sapwood	123	3.1	1109	503

significantly higher in sapwood than in heartwood. There was no significant difference detected between the respective moisture contents, indicating that the visual boundary between heartwood and sapwood is dictated by colour and extractives and not by a moisture change.

When the whole-tree averages were compared there were significant differences (at the 5% level) between the density classes for moisture content and basic density (Table 9). No significant differences (at the 5% level) were found between the density classes in volume, heartwood percentage, or green density. Since export chips are sold by “green tonnes per BDU” (bone-dry unit = 1088 kg oven-dry material), that measurement was also calculated. The high density class had the lowest green tonnes per BDU owing to its high density and high average volume per tree.

TABLE 9—Average wood properties for the three density classes.

Density class	Volume (m <sup>3</sup> )	Heartwood (%)	Moisture content (%)	Green density (kg/m <sup>3</sup> )	Basic density (kg/m <sup>3</sup> )	Green tonnes/BDU
Low	1.09	57	149	1068	429	2.71
Medium	1.02	55	132	1081	466	2.52
High	1.15	54	118	1101	505	2.37

*Internal checking in discs*

Internal checking assessed from all the discs showed some definite trends. The majority of the internal checks occurred toward the edge of the heartwood/sapwood zone and very rarely occurred completely in the sapwood zone (Fig. 7). There was large variation between

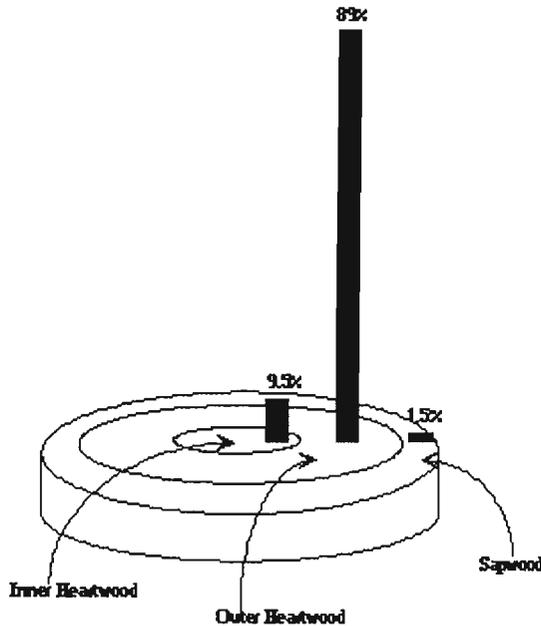


FIG. 7—Percentage of checks in relation to the heartwood zone.

trees in number of checks observed. Outer heartwood was defined as the last six rings of heartwood and the rest as the inner heartwood.

When the heartwood/sapwood boundary did not follow ring boundaries, the internal checks followed the heartwood boundary shape rather than ring contours. Only 1.5% of checks occurred outside the heartwood zone, 89% occurred in the outer six rings of heartwood, and 9.5% occurred in the inner heartwood area. Since the number of checks in each ring was assessed on whole discs, the proportion of checks in each ring was correctly weighted for volume. When the discs were cut in half perpendicular to the longitudinal direction many more internal checks were apparent. The checks were in the same areas and in the same proportions but occurred in numbers approximately five times higher than on the surface (Fig. 8). This was probably due to end effects on the surface of the discs changing the stresses present.

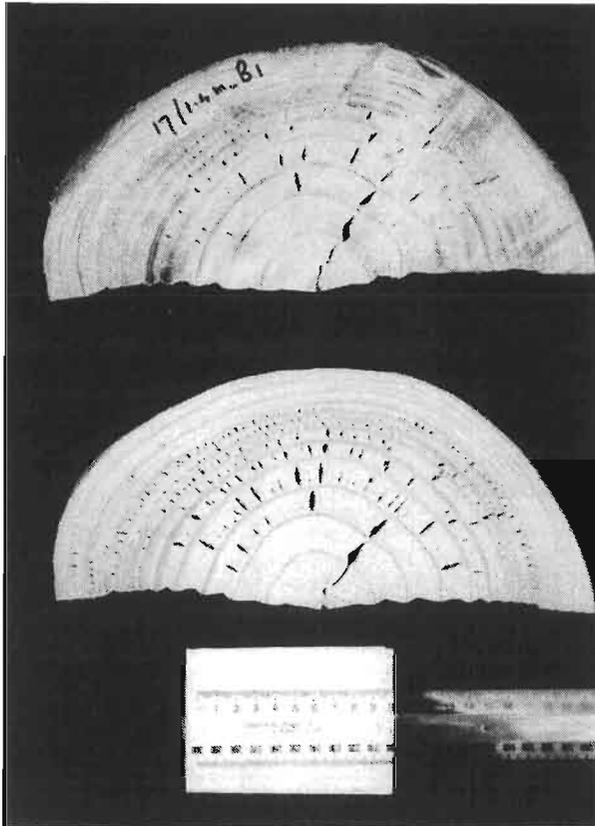
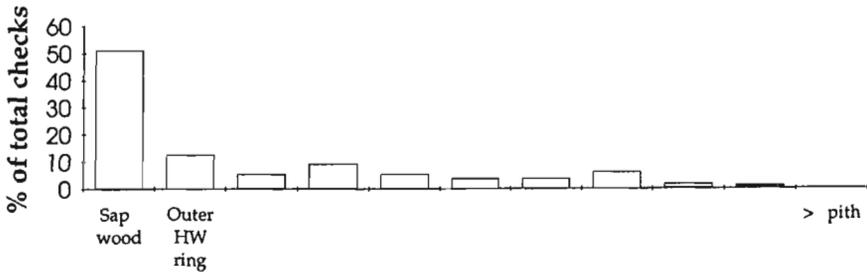


FIG. 8—Internal checking in a disc both externally (upper) and internally (lower).

#### *Internal checking in boards*

In sample strips cut from the sample boards, the majority (51%) of the checks occurred in the sapwood rather than the heartwood zone as described above for the discs (Fig. 9). The internal checks in the boards closed after steaming (Fig. 10) but the discontinuities will remain, leading to problems in later machining, especially turning (Haslett & Young 1992).



**Heartwood zone by annual increments toward the pith**

FIG. 9—Percentage of checks in relation to the heartwood zone (boards).

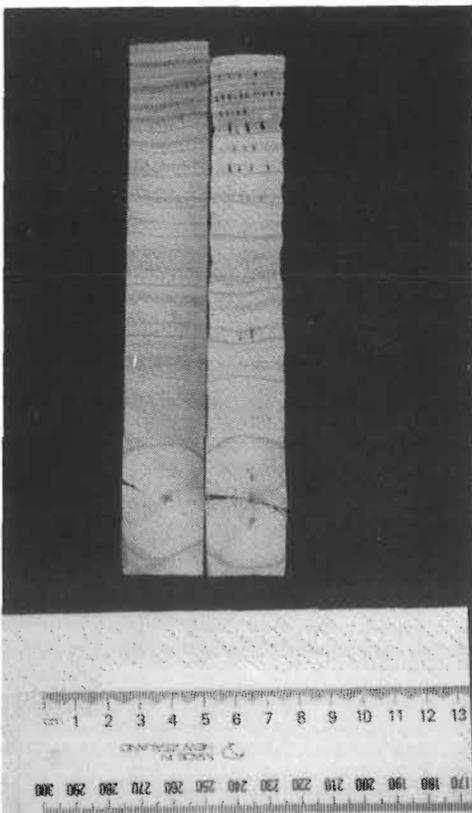


FIG. 10—Internal checking in a board shown before (right) and after (left) steam reconditioning.

*Internal checking in discs v. boards*

These two methods of assessing internal checking gave contradictory results, possibly because the discs were kiln dried while still saturated but the boards were allowed to air-dry. The difference could also be attributed to the respective dimensions of the samples since the discs were cut at 50 mm along the longitudinal direction axis, while the boards were only 25 mm thick in the tangential direction. Boards are more representative of end products and uses and therefore it is more likely that internal checking will be observed in the sapwood.

### Spiral grain

There was considerable between-tree variation, including variation in direction of spirality. Absolute values rather than directional were used when calculating averages as it was the magnitude of the grain angle which was relevant in the context of this report, rather than grain direction.

Spiral grain angles decreased slightly in magnitude with increasing height from the base of the stem (Fig. 11). Spirality increased with increasing ring number from the pith in the butt samples only but it was fairly constant at 2°–3° in samples from other heights. This pattern shows spiral grain in *E. nitens* to be quite opposite to *Pinus radiata* which has generally positive angles, increases with height up the tree, and decreases with increasing ring number from the pith after about ring 6 (Cown 1992).

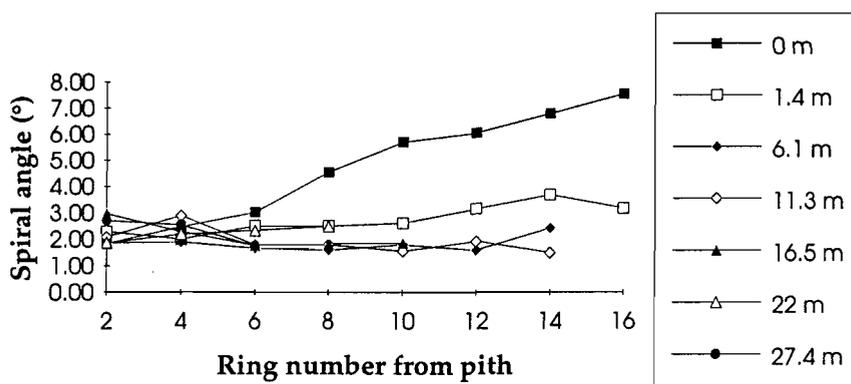


FIG. 11—Average spiral grain, both radially and vertically.

Interlocking grain was also observed in some of the trees assessed for spiral grain. The grain angles in regions of interlocking grain tended to alternate dramatically from negative to positive. In one sector of one tree (No. 35) the spiral grain changed by 50° (from  $-28^{\circ}$  to  $+21.5^{\circ}$ ) in the space of two rings. The presence of this characteristic gives highly variable and less predictable spiral grain angles. Interlocking grain tended to be observed toward the outer few rings and occurred in the butt and breast-height samples only.

### Densitometry

Density increased with height in the stem (Fig. 12), confirming the pattern described by disc density assessment. Densitometry showed a drop in ring density from ring 1 to ring 3 at all stem positions, followed by a density increase, with some levelling out apparent around ring 10 for the lower sample heights. Butt density declined slightly after ring 12.

Radial and vertical density trends were similar in the low, medium, and high density classes (Fig. 13). The low density class had significantly lower earlywood density (at the 5% level) than the medium density class, but no significant difference in earlywood density (at the 5% level) was detected between the medium and high density classes.

Significant differences (at the 1% level) were observed between all three classes for average ring density and latewood percentage. However, no significant differences in latewood density were detected at the 5% level.

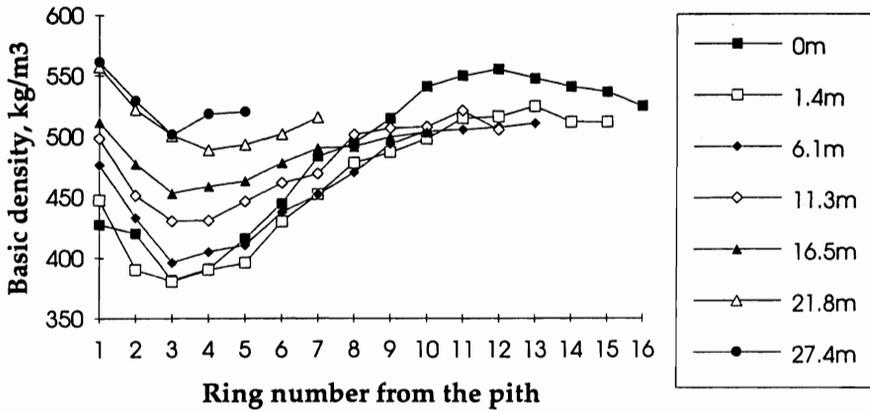


FIG. 12—Average radial and vertical density trends.

*Tension wood*

Tension wood was visually assessed on the discs and also microscopically on the breast-height strips (Table 10). There were no visual indications of tension wood where it was detected using the microscopic technique to estimate the percentage of gelatinous fibres.

These results indicate that future tension wood assessments in *E. nitens* will need to be undertaken using microscopic methods unless other as yet untried methods prove successful.

TABLE 10—Microscopic level of tension wood—Percentage of gelatinous fibres to normal fibres in breast-height strips

Tree No.	Ring number from pith					
	2	5	6	9	11	13
35	1					
42		1	80			
63						20
76				5		
77					5	

*Vessel characteristics*

The number of vessels per unit area decreased with age, and coarseness increased with age (Table 11). McKimm & Ilic (1987) also reported a decrease in vessel frequency with increasing distance from the pith, with an initial rapid decrease levelling off to 12–14 vessels/mm<sup>2</sup> in 8.5-year-old trees. They noted large within- and between-tree variation, and this, along with the low sample age, could explain their high value for vessel frequency compared to our results.

*Shrinkage and collapse*

Shrinkage and collapse were measured with callipers radially and tangentially on the boards sawn from the 1-m bolt recovered below breast height (Table 12). Collapse was also measured on strips cut from the boards. The calliper measurements gave an estimate of shrinkage and collapse for the latewood only since that shrinks less than the earlywood and

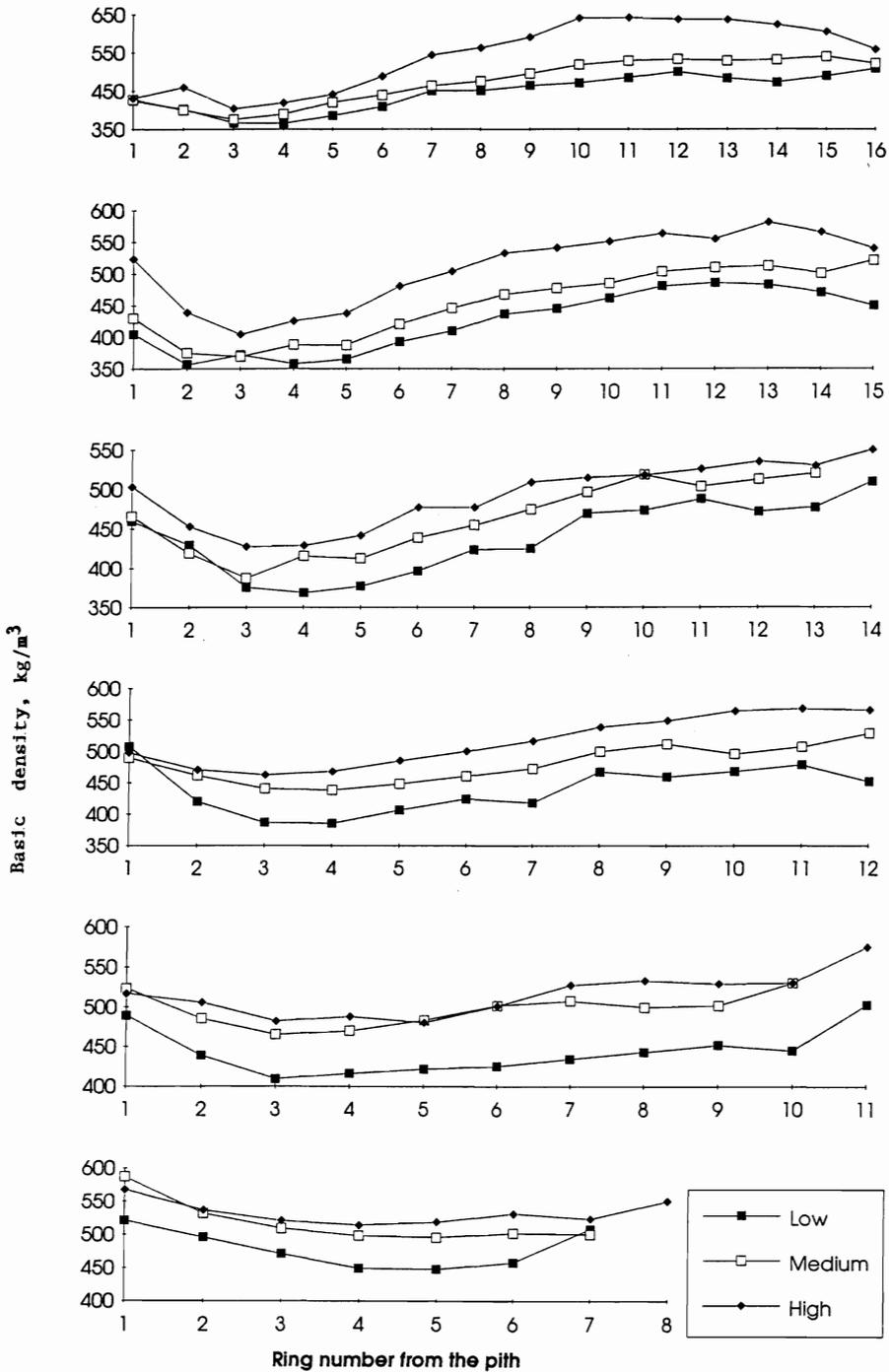


FIG. 13—Radial density trends for the three density classes at 0, 1.4, 6.1, 11.3, 16.5, and 21.8 m.

TABLE 11—Vessels per square millimetre and coarseness, measured on breast-height samples

Tree No.	Vessels/mm <sup>2</sup>		Coarseness (μg)	
	Ring 5	Ring 10	Ring 5	Ring 10
3	6	4	9.7	14.2
9	4	3	13.1	13
13	4	4	9.5	10.9
17	5	5	12.7	11.9
49	3	5	10.4	12
57	7	4	12.2	13.3
63	6	4	10.6	9.4
68	6	5	11.8	12.5
73	3	5	14.6	12.4
76	5	—	12.5	—
85	7	4	11.2	13.5
90	8	6	9.3	16.8
93	6	4	13.5	13.1
Average	5	4	11.6	12.7

TABLE 12—Radial and tangential shrinkage and collapse

	Radial shrinkage			Tangential shrinkage		
	Green to air-dry (%)	Green to air-dry steamed (%)	Collapse recovery (%)	Green to air-dry (%)	Green to air-dry steamed (%)	Collapse recovery (%)
Average	4.87	2.26	2.61	5.15	3.72	1.42
Maximum	7.87	3.34	4.75	9.36	6.15	4.93
Minimum	3.24	-0.01	1.03	0.26	1.18	-1.77

the callipers measured the widest or thickest sections. The boards reached an equilibrium moisture content of 13.9% before steaming and after steaming re-equilibrated to 13.2%, giving a change in moisture content of only 0.7%. All of the collapse that occurred before steaming was recovered after treatment and it should therefore not pose a problem in drying.

Shrinkage from green to air-dry after steaming gave values with minimal collapse, whereas shrinkage from green to air-dry before steaming gave a measure of shrinkage including associated collapse. As expected, shrinkage was higher in the tangential direction and the levels of shrinkage were lower than those found by Young (*pers. comm.*), possibly because the method adapted for our study only estimated latewood shrinkage. The strips that were used for collapse measurement were sorted into before- and after-steam-treatment pairs which were photocopied together. Software developed for the scanner (Tian *pers. comm.*) allowed areas to be calculated for the before- and after-steaming samples, giving an estimate of collapse. The photocopy was used for scanning to ensure that the two samples in each pair were scanned at the same rate, since the scanner is hand operated and differing scan speeds would result in different area estimates. The estimate of collapse was for both radial and tangential directions combined (Table 13). Longitudinal shrinkage was not measured but it was significantly lower than shrinkage in the other two directions—Young (*pers. comm.*) found longitudinal shrinkage to be less than 1%.

TABLE 13—Collapse calculated using the scanner

Collapse (%)	
Average	10.42
Maximum	18.09
Minimum	2.86

As a check on the operation of the scanning technique, the volumes of two pairs of samples were calculated by immersion in water to give change in volume due to steaming. The scanning method accurately and reliably matched those tests, with the difference in collapse between the two systems being less than 1% for any particular piece.

### Tension test

Tension tests perpendicular to the grain were performed on both green and air-dried (12% moisture content) blocks. Three samples per tree and six to eight trees per density class were assessed to give average strength and density values for each density class (Table 14). The three trees (35, 85 (high density class) and 68 (medium density class)) with the highest strength readings were the only trees that exhibited interlocking grain in the test samples.

TABLE 14—Tension test values and densities for green and air-dried blocks

Density class	Green (MPa)	m.c. 12% (MPa)	Green density (kg/m <sup>3</sup> )	Basic density (kg/m <sup>3</sup> )
Low	3.17	4.18	1084	411
Medium	3.54	4.97	1103	446
High	4.65	6.02	1127	486

Strength perpendicular-to-ring direction increased with increasing density. The green and 12% test values had an  $r^2$  0.49 when correlated together. The correlation between density and moisture content was higher for the air-dried samples than for the green samples. The green tension test results had  $r^2$  values of 0.38, 0.36, and 0.26 for green density, basic density, and moisture content respectively. The 12% tension test results had  $r^2$  values of 0.56, 0.54, and 0.44 for green density, basic density, and moisture content respectively. The results do not correlate strongly (less than 0.16  $r^2$  values) with diameter, heartwood, spiral grain, or number of internal checks. The results show that the interlocking grain has a positive affect on the strength properties tested.

## CONCLUSIONS

Pith to bark cores were strongly correlated ( $r^2$  0.87) to whole-tree density, and breast height was an efficient disc sampling position as all properties correlated with whole-tree values ( $r^2$  values 0.71 or better). There were significant differences (at the 5% level) between the density classes for basic density and moisture content: the low density class had significantly lower earlywood density (at the 5% level) than the medium and high density classes, and significant differences (at the 1% level) were observed between all three classes for average ring density and latewood percentage.

Examining internal checks in boards (with checks predominantly in the sapwood) is more representative of what will occur in solid wood products. The extent of the checking observed

will present utilisation problems for many solid wood end-use situations unless new drying methods can reduce the problem. In the longer term, genetic selection could also influence the severity of checking. If the wood is used for paper making the internal checks will pose no problems.

Collapse occurred readily and in some samples was severe, but steaming effectively restored the collapse in all instances and, as it is a simple process, overcoming collapse should not be a problem when drying *E. nitens*. Shrinkage would be better measured using a dial gauge than with callipers since callipers only measured shrinkage in the latewood. The scanner was useful and gave an accurate and reliable estimate of the combined radial and tangential shrinkage.

The tension test results were complicated by the presence of interlocked grain in both green and air-dried samples and by the internal checking occurring in the air-dried samples. The tension test results correlated with basic density and moisture content ( $r^2$  0.54 and 0.44 respectively). The interlocking grain also affected the spiral grain results.

The large variation in wood properties observed shows the potential for selection in breeding to improve certain wood characteristics including density, spiral grain, and internal checking severity.

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