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WOOD PROPERTIES OF *EUCALYPTUS NITENS* (Deane *et* Maiden) GROWN IN NEW ZEALAND

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Lausberg, M.J.F., Gilchrist, K.F. and Skipwith J.H.

Abstract

Eucalyptus nitens (Deane *et* Maiden) Maiden trees used in this study were 15 years-old. Some solid wood evaluations were performed, specifically internal checking assessment, shrinkage, collapse and tension tests. There was found to be significant differences between the density classes for basic density and moisture content. The low density class was found to have significantly lower earlywood density than the medium and high density classes. Significant differences were observed between all 3 classes for average ring density and latewood %. The extent of the internal checking observed will present a definite problem to many solid wood products. Collapse occurred readily and in some cases was severe, but steaming effectively restored the collapse. A scanner was used and gave an accurate and reliable estimate of radial and tangential shrinkage combined. The tension test results correlated to density and moisture content.

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

Introduction

Since 1976 *Eucalyptus nitens* (Deane *et* Maiden) Maiden has been planted for pulpwood production in the Bay of Plenty and Southland regions. There was approximately 520 ha of pure stands established of various age classes in 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). *E. nitens* has been shown to grow well (especially the initial growth) in New Zealand (Miller *et al* 1992)and has wood properties (at 30 years-old) similar to mature Australian *E. nitens*. The kraft pulping properties of young plantation-grown *E. nitens* has been examined in Australia and New Zealand with pulp yields slightly lower than other 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 have been undertaken in New Zealand. Wood property analyses have been carried out on *E. nitens* previously by Young (*pers comm*) in which seven trees were extensively measured for a range in wood properties. Young (*pers comm*) 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

The trial was planted as single tree plots with a 3 m x 3 m spacing. Treatment included weed control as required and thinning to about 50% of original stocking at age 5. The trees were from Kaingaroa forest compartment 1217, *E. nitens* progeny trial experiment number R 1977, planted in 1979 and 15 years-old in 1995 at the time of sampling.

Methods

Prescreening: This involved 100 *E. nitens* trees that were 15 years old. Two 5 mm breast height pith to bark increment cores were taken from each stem. Wood density was calculated by 50 mm segments using the maximum moisture content method (Smith, 1954) and weighted to give volume. Diameters overbark were also recorded. These densities and diameters were then used to selected 29 trees to cover the full high, medium and low density range. Twenty of these trees were grouped to reflect low (6 trees), medium (8 trees) and high (6 trees) density classes. This was done by selecting 6 trees at either end, and 8 around the mean of the density spectrum, which were large enough (>200 mm diameter) for pulping. The remaining 9 trees (the largest) were used for individual log pulping across the density range giving 3 trees for each of low, medium and high density classes.

Study

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

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

Diameter and Stem volumes: Inside bark diameters (D.I.B.) were recorded from the discs using diameter tapes. These measurements enabled the calculation of log and tree volumes.

Heartwood %: The heartwood diameter for each disc was measured in mm and converted into 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. Moisture content is expressed as a percentage and relates to the ratio of water to oven dry wood. Moisture content was also measured determined on the heartwood and sapwood portions of the breast height samples of the 9 individually pulped trees.

Density: Green and basic (oven-dry) densities were calculated for the all discs by using green weights and volumes (by immersion) and oven-dry weights after drying at 103°C for 3 days.

Extractive content %: Extractive content of the heartwood and sapwood was determined from the breast height samples of the 9 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 then were weighed and had volumes taken before being kiln dried at 40^{o} C and 60 % RH for 10 days. All internal checks were assessed by the following criteria: number of rings effected, number of checks in each ring, whether checks cross latewood bands and the severity of checking. Following the checking assessment, the discs were oven-dried and re-weighed to complete the density and moisture content measurements.

The second disc from each level was used for the following properties:

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 by using a perspex protractor.

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

Tensionwood: Tensionwood 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 tensionwood, primarily by looking for gelatinous fibres and a visual assessment was made of the proportion of G-fibres to normal fibres. The relative proportion of gelatinous fibres was estimated by a visual assessment over a number of fields of view. Tensionwood was also assessed by cutting hand sections from each growth ring using a razor blade and then stained with toluidine blue. Each section was assessed for gelatinous fibres and a visual assessment was again made of the proportion of G-fibres to normal fibres (*pers comm* Donaldson).

Vessel number: The number of vessels/mm^2 was determined for rings 5 and 10 at breast height for each tree. Transverse sections were prepared using a 20 Um sledge microtome and stained with safranine before examination with a light microscope. The number of vessels within a known area was determined on 5 separate areas and counts were converted to vessels mm^2 before averaging (*pers comm* Donaldson).

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 as described by Donaldson (*pers comm*). Cell wall area was then converted to coarseness using 1500 kg/m^3 as an estimate of cell wall density.

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

The stem section recovered from directly below the breast height disc was used for the following properties:

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 to include the pith. The boards were end sealed and had shrinkage points marked (toward one end) and green and air-dry measurements taken (on 2 dimensional measurement points). The boards were first air-dried for 3 months to 30%, then forced air dried for 2 weeks to below 20 %, and finally placed in a 12 % m.c. equilibrium room for 2 weeks. The boards were then cross-cut to give a m.c. sample, 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 remeasured to give an estimate of collapse recovery.

Tension testing: From each bolt a 65 x 65 mm board was cut to allow a tension test perpendicular to the grain. Three pieces of 5 x 5 x 5 cm (2 inches) 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 having any wane).

Anova 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 were shown to have a range of 156 kg/m^3 from 376 kg/m^3 to 532 kg/m^3. Figure 1 shows a histogram of the distribution of weighted breast height core densities.

Figure 1: Histogram of breast height density class versus number of trees

Young (*pers comm*) found variation in basic density within site of about 100 kg/m^3 showing that the current sample is representative of the variance in the population. From the weighted breast height densities, 9 low, 11 medium and 9 high density trees were selected as shown in Table 1. The correlation between pith to bark core density and whole tree density calculated from the discs was an r^2 of 0.87 (outerwood core to whole tree had an r^2 of 0.78), indicating that breast height cores can be readily used for survey, ranking and screening purposes.

Table 1: Average and range in density for each class.

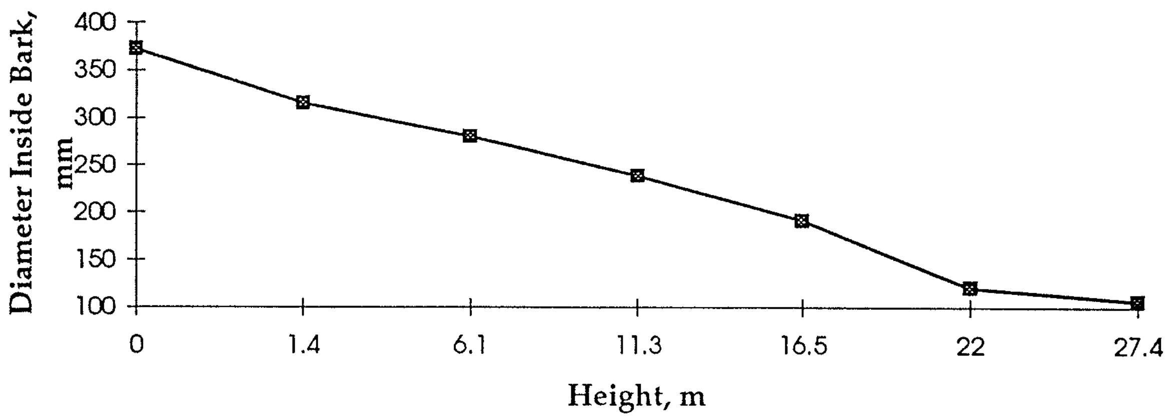
	Density class		
	Low	Medium	High
No. of trees	9	11	9
Avg. Stem Density kg/m^3	390	431	485
Range kg/m^3	376-404	427-435	456-532

Wood Properties

For the following Tables and Figures the data for the 27.4m position was provided from 5 trees only.

Diameter and Stem volume: Figure 2 shows the average D.I.B. at all heights and Table 2 gives the average and range between individual trees.

Figure 2: Average Diameter Inside Bark with height



Tree volume averaged 1.06m^3 and ranged from 0.52m^3 to 1.86m^3. Taper was very high from butt to breast height but decreased strongly above there. Taper for first log (approx. 6m) is 15.3 mm/m which agrees with Purnell (1988) who found first log had a taper of 14.7 mm/m.

Table 2: Averages and ranges for D.I.B. at all heights

Height	D.I.B. mm		Taper
m	Mean	Range	mm/m
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 %: Figure 3 shows the average heartwood at all heights and Table 3 gives the average and range for individual trees.

Figure 3: Average Heartwood % with height

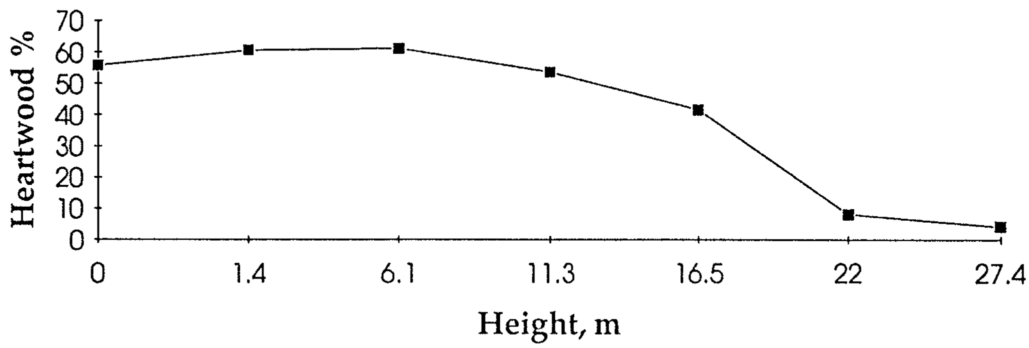


Table 3: Average and range for heartwood % at all heights.

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**

Heartwood content decreases with height (the slight increase around breast height is not significant at 5% level). On average heartwood exceeded 50% to approximately 12m after which it dramatically decreased to 4% at 27.4m. It can be seen that there was large variation between trees specifically at heights 11.3 and 16.5m. Heartwood differs from sapwood in amount and type of extractives and tyloses. The major disadvantage of heartwood is problems with penetration of waterborne preservatives, and some pulping liquors, and the extra bleaching needed for some pulps (Nicholls *et al* 1979). The advantage of heartwood is that, unlike sapwood, it is not susceptible to insect attack (Haslett 1988).

Moisture Content: Figure 4 shows the average moisture content % at all heights and Table 4 gives the average and range for individual trees.

Figure 4: Average moisture content % with height

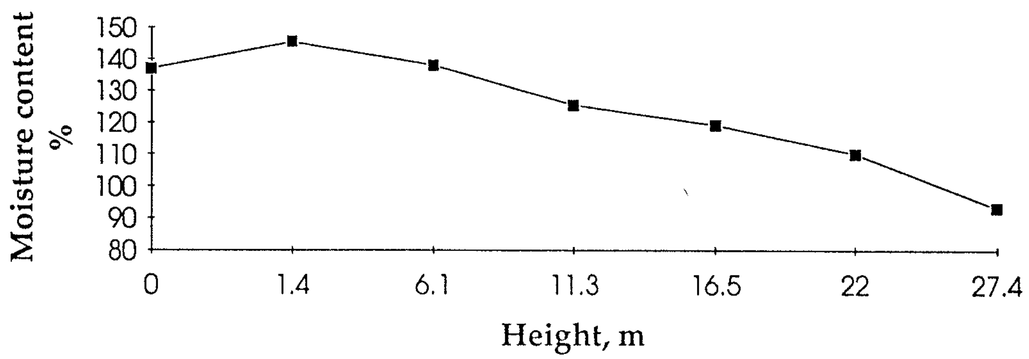


Table 4: Average and range for moisture content % at all heights.

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**

Moisture content decreases with height (the slight increase around breast height is not significant at 5% level). Moisture content changes gradually with height up the stem although there is considerable variation between individual trees shown by the range. Purnell (1988) found a linear decrease in moisture content from 2.4 m to 12 m and this agrees with the current study in which moisture content decrease linearly from breast height to top height.

Green Density: Figure 5 shows the average green density at all heights and Table 5 gives the average and range for individual trees.

Figure 5: Average green density with height

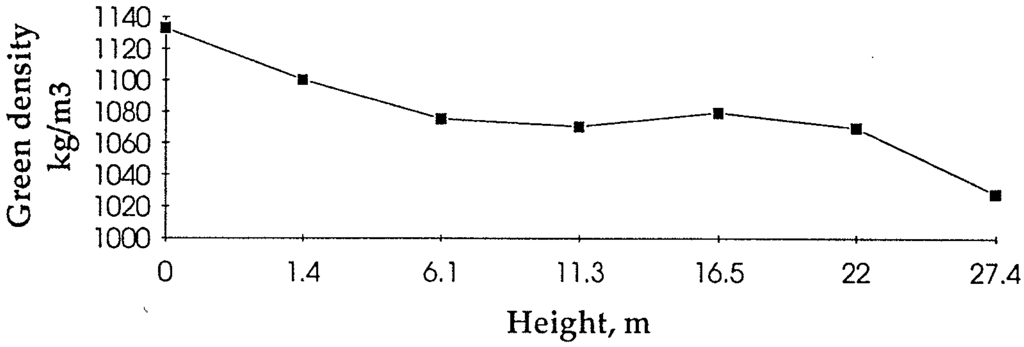


Table 5: Average and ranges for green density at all heights.

Height m	Green density kg/m^3	
	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**

Green density decreases with height (slight increase at 16.5 m is not significant at the 5% level). Green density decreases rapidly from butt to about 6m above which it levels off until the top sampling height where there is another decrease. Green density trend supports the trend found by Young in unpublished work (*pers comm*).

Basic Density: Figure 6 shows the average basic density at all heights and Table 6 gives the average and range for individual trees. After calculating whole tree density 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.

Figure 6: Average basic density with height

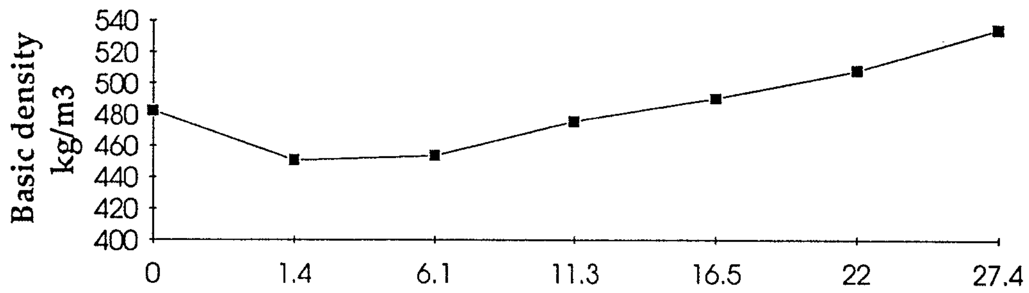


Table 6: Average and ranges for basic density at all heights.

Height	Density kg/m^3	
m	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**

Basic density initially decreases (significant at the 5% level) with height to 1.4 m then increases with height. There was a linear increase in basic density after 6 m which agrees with Purnell (1988) who found a linear trend in basic density above 2.4 m.

Correlations: The strongest correlations, using individual disc data, that were found were an r^2 value between D.I.B and heartwood of 0.55, and an r^2 value between basic density and moisture content of 0.83.

Table 7 shows r^2 values between whole tree wood property values and both breast height and the best predictive sample heights.

Correlations between and sampling points and whole tree wood property values showed that sample heights 11.3 m or 6.4 m (for respective properties) have a higher correlation to whole tree properties than breast height. The current results agree with Purnell (1988) who 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 provide better estimates of whole tree values there is little loss in accuracy sampling at breast height and substantial improvement in cost and ease of sampling.

Table 7: r^2 values for breast height and optimal sample height to whole tree property

Property	r^2 values for sample heights to whole tree		
	breast height 1.4m	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/m3	0.82	6.4	0.82
Basic Density kg/m3	0.87	6.4	0.91

For the 9 trees in which heartwood and sapwood were measured separately for moisture content, extractives content, green and basic density, Table 8 presents the results.

Table 8: Wood properties for heartwood and sapwood

Wood Type	Moisture content %	Extractives %	Density kg/m^3	
			Green	Basic
Heartwood	137	2.2	1054	449
Sapwood	123	3.1	1109	503

The heartwood had a significantly lower extractives % (at the 5% level) and green density (at the 1% level) than the sapwood. Sapwood had a significantly higher basic density (at the 10% level) which is supported by McKimm (1985) who found the sapwood to have significantly higher basic density than the heartwood for 8.5-year-old *E. nitens.* 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 not a moisture change.

The whole tree averages for the 3 density classes are presented in Table 9.

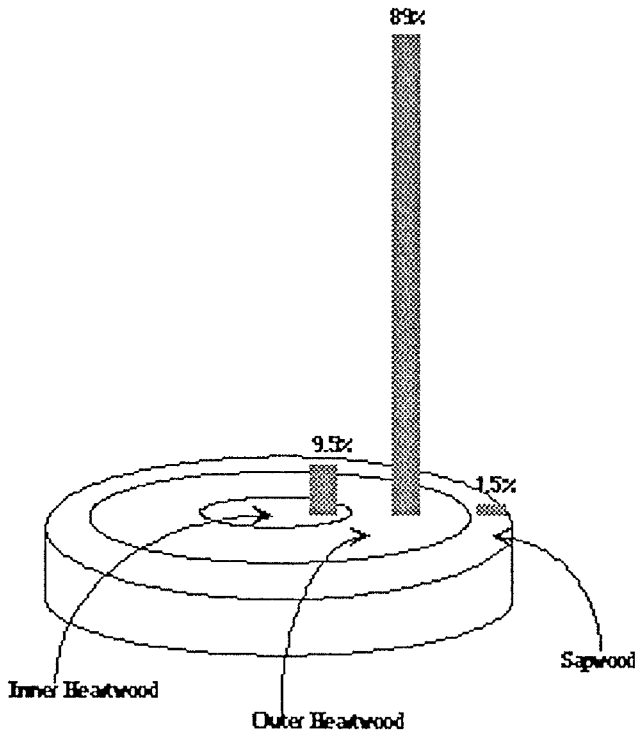
Table 9: Average wood properties for the 3 density classes.

Density Class	Volume m^3	Heartwood %	Moisture content %	Green density kg/m^3	Basic density kg/m^3	Green tonnes per 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

Significant differences (at the 5% level) were found between the density classes for moisture content and basic density. No significant differences (at the 5% level) were found between the density classes for volume, heartwood % or green density. Bone dry units (BDU) are important as export chips are sold and valued by green tonnes per BDU. The value of Green Tonnes/BDU translates to number of green tonnes needed to give one BDU (which is defined as 1088 kg oven-dry material). It can be seen that the high density class has the lowest value for Green Tonnes/BDU due to both its high density and high average volume per tree.

Internal checking in discs: Internal checking assessed from all the discs showed some definite trends. The majority of the internal checks occurred in the toward the edge of the heartwood/sapwood zone and very rarely occurred completely in the sapwood zone. There was large variation between trees in number of checks observed. Figure 7 shows the location of checks in relation to the heartwood zone. Outer heartwood was defined as the last 6 rings of heartwood with the remaining heartwood being defined as the inner heartwood.

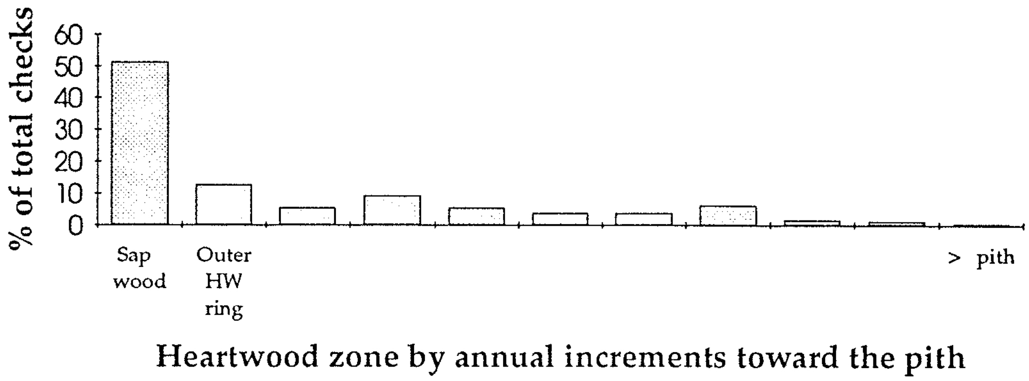
Figure 7: Percent of checks in relation to the heartwood zone



It was noticed that 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 occur outside the heartwood zone. 89 % of checks occurred in the outer 6 rings of heartwood while 9.5 % of the checks occurred in the remaining heartwood area. Since the number of checks in each ring was assessed on whole discs the proportion of checks in each ring is correctly weighted for volume. It was found that 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 with the same proportions but occurred in numbers approximately 5 times higher than on the surface. This observation is probably due to end effects on the surface of the discs changing the stresses that are present. Photo 1 in Appendix A shows top of disc and cut face from the middle of the disc.

Internal checking in boards: Internal checking was also assessed from sample strips cut from the sample boards. The majority of the checks for this assessment occurred in the sapwood rather than the heartwood zone as described above for the discs. Photo 2 in Appendix A shows the scanned image of board sections before and after steam reconditioning (note location of checks and collapse recovery). Figure 8 shows where the checks occurred in relation to the heartwood zone. This method of internal checking assessment shows that 51 % of the checks occurred in the sapwood zone. The internal checks in the boards closed after steaming but the discontinuity's will remain leading to problems in later machining, especially turning.

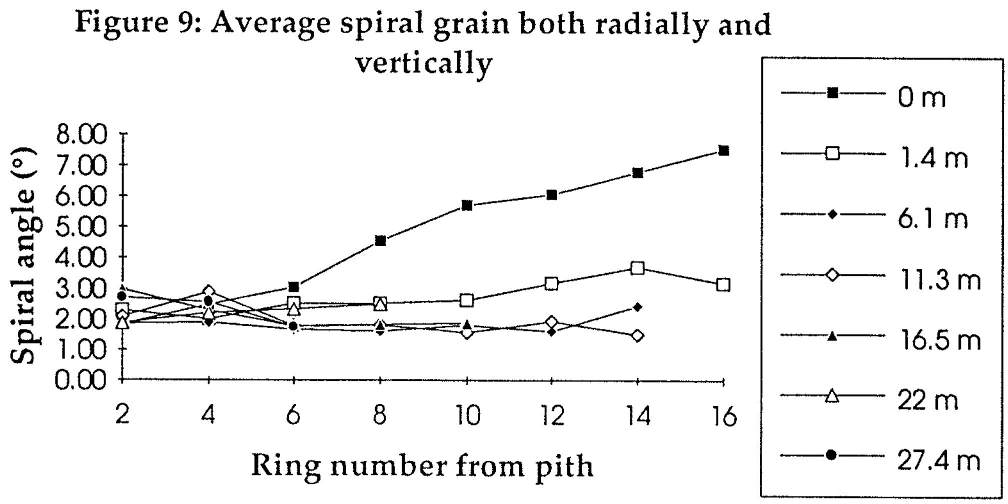
Figure 8: Percent of checks in relation to heartwood zone (boards)



Internal checking in the Discs versus Boards: These two methods of assessing internal checking have given contradictory results. This may be due to the fact the two sample types were dried differently since the discs were kiln dried while still saturated but the boards were allowed to air-dry. The difference may 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 will be more representative of end products and uses and therefore it is more likely that internal checking will observed in the sapwood.

Spiral grain: It should be noted that there was considerable between-tree variation, including variation in direction of spirality. Absolute values rather than directional, were used when calculating averages as it is the magnitude of the grain angle which is relevant in the context of this report, rather than grain direction.

Figure 9 shows the average spiral grain variation from pith to bark and increasing height up the stem.



It can be seen from Figure 9 that spiral grain angles decrease slightly in magnitude with increasing height from the base of the stem upwards. Spirality is shown to increase with increasing ring number from the pith in the butt samples only. The other sample heights show fairly constant spirality around 2 to 3 degrees. 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) 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 degrees (from -28 ° to +21.5 °) in the space of 2 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: Figure 10 shows the average radial and vertical density trends.

It can be seen that density increases with height in the stem confirming the pattern described by disc density assessment. Densitometry shows 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. The butt density trend shows a slight decline after ring 12.

Figure 10: Average radial and vertical density trends

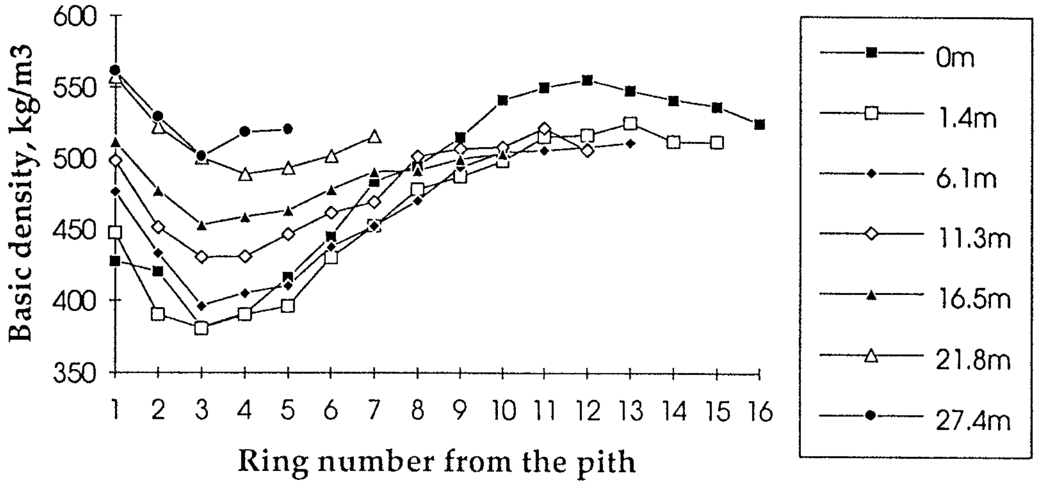


Figure 11 show the radial and vertical density trends for the low, medium and high density classes at each sampling height.

From the Figure 11 it can be seen that the 3 density classes have similar trends. The low density class was found to have significantly lower earlywood density (at the 5% level) than the medium density class. No significant difference in earlywood density (at the 5% level) was detected between the medium and high density class. Significant differences (at the 1% level) were observed between all 3 classes for average ring density and latewood %. However no significant differences in latewood density were detected at the 5% level.

Tensionwood: Tension wood was visually assessed on the discs and also microscopically assessed on the breast height strips. It was found that there were no visual macroscopic indications of tension wood where it was detected using the microscopic technique. Table 10 only shows where tensionwood was detected microscopically for all trees and rings at breast height, and an estimate of the % of gelatinous fibres to normal fibres recorded.

Table 10: Microscopic level of tension wood- % of gelatinous fibres to normal fibres

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

The above results indicate that future tensionwood assessments in *E. nitens* will need to be undertaken using microscopic methods unless other yet untried methods prove successful.

Vessel characteristics: The number of vessels per unit area and coarseness were measured on breast height samples. Table 11 shows the number of vessel per mm^2 and coarseness for rings 5 and 10.

Table 11: Vessels per mm^2 and coarseness

Tree Number	Vessel per mm^2		Coarseness	
	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**

It was found that number of vessels per unit area decreases with age and coarseness increases with age. Vessel frequency was also found to decrease with increasing distance from the pith by McKimm *et al* (1987) who reported a rapid decrease initially and then levelling off to 12-14 vessel mm^{-2} in 8.5-year-old trees. They reported large within and between-tree variation which could, along with the low sample age, explain their high value for vessel frequency compared to the current results.

Shrinkage and Collapse: Shrinkage and collapse were measured radially and tangentially on the boards sawn from the 1m bolt recovered below breast height using callipers. Collapse was also measured from strips cut from the boards. The calliper measurements gave an estimation of shrinkage and collapse for the latewood only since the latewood shrinks less than the earlywood and the callipers measured the widest or thickest sections. Table 12 shows the radial and tangential shrinkage and collapse recorded using the calliper measurement method. The boards reached an equilibrium moisture content of 13.9 % before steaming and after steaming then re-equilibrated to 13.2 % giving a change in moisture content of only 0.7%. All of the collapse that occurred prior to steaming was recovered following the steaming treatment and should therefore not pose a problem in drying.

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

Shrinkage from green to air-dry after steaming gives the shrinkage values with minimal collapse, whereas the shrinkage from green to air-dry before steaming gives a measure of shrinkage including associated collapse. As expected shrinkage is higher in the tangential direction and the levels of shrinkage are lower than those found by Young (*pers comm*) possibly due to the fact that the method adapted for the current study is only estimating latewood shrinkage. The strips cut from the boards that were used for collapse measurement were sorted into before and after steam treatment pairs. These pairs were then photocopied and the photocopy subsequently scanned. This was done in order to ensure that the two samples were scanned at the same rate, since the scanner is hand operated and differing scan speeds would results in different area estimates for the same sample. Scanning both samples simultaneously removed the chance of scan speed causing error. 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. This estimate of collapse is for both the radial and tangential directions combined. Longitudinal shrinkage was not measured but it is significantly lower than shrinkage in the other two directions (Young (*pers comm*) found longitudinal shrinkage to be less than 1 %). Table 13 shows the amount of collapse measured using the scanner.

Table 13: Collapse calculated using the scanner

	Collapse %
Average	10.42
Maximum	18.09
Minimum	2.86

There were some manual tests done to check the operation of the scanning technique. Two pairs of samples had their volumes calculated by immersion in water to give change in volume due to steaming. It was found that the scanning method accurately and reliably matched these 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. Table 14 shows the average strength and density for each density class. The averages are for of 3 samples per tree and 6 to 8 trees per density class. The 3 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 Class	Green (MPa)	12 % (MPa)	Green Density kg/m^3	Basic Density kg/m^3
Low	3.17	4.18	1084	411
Medium	3.54	4.97	1103	446
High	4.65	6.02	1127	486

From Table 13 it can be seen that strength perpendicular-to-ring direction increases with increasing density. The green and 12% test values had and r^2 of 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 and 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 and 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

It was found that pith to bark cores were strongly correlated (r^2 of 0.87) to whole tree density. It was found that breast height was an efficient disc sampling position as all properties correlated with whole tree values (with r^2 values being 0.71 or better). Significant differences (at the 5% level) were found between the density classes for basic density and moisture content. The low density class was found to have significantly lower earlywood density (at the 5% level) than the medium and high density classes. Significant differences (at the 1% level) were observed between all 3 classes for average ring density and latewood %.

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 influenced 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 cases was severe but steaming effectively restored the collapse in all cases, 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. It was found that 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 to basic density and moisture content (r^2 values of 0.54 and 0.44 respectively). The interlocking grain also affected the spiral grain results.

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

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