UTILISATION OF 25-YEAR-OLD *PINUS RADIATA* PART 1: WOOD PROPERTIES

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ABSTRACT

Wood properties were examined in 50 trees of *Pinus radiata* D. Don growing in Kaingaroa Forest in the central North Island of New Zealand. The stand was selected as "typical" of current silvicultural regimes and as being at the lower end of the age range for expected rotations of this species. Average whole-tree wood property values were determined from discs cut at the butt and the top of each log. Assessments were also made of compression wood, and within-tree variation in tracheid length and spiral grain.

Generally, the wood property values were similar to previous studies and to predictions for trees of this age grown in the region.

Keywords: wood properties; wood density; moisture content; heartwood; shrinkage; tracheid length; spiral grain; resin; corewood; bark; conversion factors; *Pinus radiata*.

INTRODUCTION

Silvicultural and tree breeding research, driven by the need to reduce growing costs, continues to produce increased growth rates and hence shorter rotations for *P. radiata*. However, there are limitations to the potential of young pine for high-quality solid wood products. Reports by Cown & McConchie (1982) and Haslett & McConchie (1986) have highlighted some of the problems of reduced rotation lengths. These include higher moisture contents which increase logging, transport, and drying costs, reduced mean density resulting in decreased strength and pulp yields, and increased corewood percentage which, due to higher levels of spiral grain and variation in longitudinal shrinkage in this portion of the tree, increases the percentage of pieces which warp in drying.

The sawing process yield-prediction model SAWMOD calculates the physical and financial yields from *P. radiata* logs (Whiteside & McGregor 1987). Currently the program deals with timber to the green sawn stage only, but there is evidence that crop age can have a dramatic influence on handling losses in the mill and during wood drying. A utilisation study of 14-year-old production thinnings (Haslett & McConchie 1986) indicated that drying schedules need to be carefully controlled to avoid problems with young low-density wood. Since it is anticipated that an increasing proportion of wood will need to be kiln dried in future, it is important to extend the sawing model by establishing factors to deal with interactions of age and log grade with secondary processing in the mill.

Major objectives of this project were to saw a range of log grades to provide sufficient sawn timber for commercial-scale drying trials and to establish relationships between basic wood properties and the behaviour of timber during processing. To establish the interactions of age and log grade with secondary processing in the mill and later utilisation, it is important that the wood properties of the stands under investigation are adequately determined. In addition to the "normal" wood property evaluations (density, moisture content, heartwood content), spiral grain was highlighted as a major property to be investigated because of its link with drying degrade.

The wood properties of a 25-year-old stand of *P. radiata* are reported here. Drying properties are presented in Part 2 (Haslett *et al.* 1991).

MATERIALS AND METHODS

Stand 02 of Cpt 1013 in Kaingaroa Forest was selected as representative of future silvicultural regimes. The 25-year-old stand had been high pruned and thinned to a final-crop stocking of 350 stems/ha (Table 1).

TABLE 1–History of sample stand

Date	Operation	Stocking (stems/ha)
1965	Established	2500
1968	Waste thinned	1320
1971	Low pruned to 2.2 m (360 stems/ha)	
1972	Waste thinned	690
1973	Medium pruned to 4.0 m (260stems/ha)	
1974	High pruned to 5.8 m (275 stems/ha)	
1975	Waste thinned	350

Fifty trees were selected to provide logs representing large- and small-branch classifications and a range of diameters as described by the New Zealand Forest Research Institute (NZ FRI) standard log grades (Appendix 1). After felling, the stems were cross-cut to produce a 6-m butt log from the pruned trees and 4.9-m logs from the unpruned lengths to a minimum small end diameter of 200 mm. At the time of cross-cutting, discs were collected from the butt and from the top of all logs produced from the selected trees. For each disc the diameters, bark thickness, heartwood content, corewood content (where corewood was defined as the 10 innermost rings), and incidence of compression wood were measured using standard procedures. In the laboratory the discs were sectioned to provide additional information on basic and green density, and green moisture content.

Spiral grain was also measured and a full description of these assessments is reported by Cown, Young & Kimberley (1991).

Ten trees, representative of the diameter range of the 50 trees felled, were selected for detailed analyses using an NZ FRI (in-house) program CONFAC. This required the collection of a second disc at each sampling point and provided additional information on weight/volume conversion factors.

On a further five trees, again representative of the range felled, a second disc was collected at each sampling point for analysis of dimensional shrinkage characteristics by five-ring groups from the pith. Assessments were made of resin content as a percentage of extracted weight on separated sapwood and heartwood portions. Tracheid lengths were also assessed on these discs. Samples from each tree were bulked to represent rings 2, 5, 10, 15, and 20 from the pith, for each height interval. The techniques used were basically the methods described by Harris (1966).

RESULTS

Although *P. radiata* exhibits wide between-tree variation in many properties (usually attributed to the effect of genetic variation), this paper is concerned with "typical" values to enable comparisons with previous and future studies. Therefore, discussion of results deals with mean values only. In Table 2 wood property values obtained from the individual discs have been used to calculate results for logs and whole trees.

TABLE 2–Average log and tree values by log height class

Log height class	No. in sample	Volume (m^3)	Heart-wood (%)	Comp.* wood (%)	Core-wood (%)	Basic density (kg/m^3)	Moisture content (%)	Green density (kg/m^3)
Butt	50	1.18	11	7	34	393	136	927
2	50	0.70	15	7	50	377	144	920
3	49	0.56	14	5	59	375	148	930
4	47	0.41	10	5	75	373	153	944
5	33	0.27	6	3	90	373	159	966
Tree	50	2.98	12	6	51	382	144	932

* Compression wood

Tree Volume

Smalians formula was used for calculation of volume. Although not as accurate as other methods (e.g., the 3-D formula of Ellis 1988), it is considered sufficiently accurate for applying weighted wood-property values to establish log and tree estimates.

In these 25-year-old trees, sawlog volume was averaging just under 3 m^3/tree (Table 2). Over a third of this was in the pruned butt logs. In an earlier study, Cown & McConchie (1983) examined ten 24-year-old trees from Cpt 1060 of Kaingaroa Forest. Both stands are in the same area of forest and so have comparable site conditions. In that study the trees were selected for density variation rather than as a cross-section of the stand in terms of a wider range of log characteristics, but at only 1.8 m^3 per whole tree the mean growth rate of the sample trees was less than that in the current study.

Heartwood Content

Over-all, 12% of the sawlog volume in this study was heartwood (Table 2), which is very similar to the 1983 study which recorded 11%. Cown, McConchie & Young (1991) reported a very close relationship for *P. radiata* between the total number of growth rings at breast height and the average number of heartwood rings. The direct relationship between tree age and heartwood percentage was more tenuous meaning that heartwood percentage was dependent on the relative growth rates within the heartwood and sapwood zones. Given the difference in growth volume, the heartwood percentages of these two studies were remarkably similar.

Compression Wood

Compression wood gives excessive longitudinal shrinkage, causes weakening and unpredictability of timber strength, encourages machining defects (usually woolly grain), and is also undesirable in the manufacturing of paper products. The occurrence of compression wood in the sample trees peaked at 6 m (top of first log) but was low throughout the tree (Table 2). The maximum individual recording was 20% which was noted on seven samples, five of which were at 6 m. Severe occurrences of compression wood are normally caused by tree lean or extreme stem wobble. However, successive thinnings in this stand appeared to have been successful in eliminating trees with such defects as the final logs had a very low incidence of sweep. Minor levels of compression wood may be formed by particularly rapid growth or through correction of minor deviations from vertical in stem form, and the levels recorded here (7% or less for all log height classes) may simply be a result of these two causes.

Corewood

Corewood is the central zone around the pith where the wood typically has wide growth rings, a low percentage of latewood, low density, short tracheids, high spiral grain angles, and high longitudinal shrinkage. In *P. radiata* it is normally described as the wood within 10 rings of the pith (Cown 1992). Corewood is considered to be the wood most likely to cause problems during processing and utilisation.

The silvicultural regime prescribed for this stand had, at 25 years, produced more than 50% of the sawlog volume as corewood (Table 2). If one considers that a proportion of the denser, more warp-resistant outerwood is lost as slabwood in the sawmilling process, the percentage of corewood in the sawn timber is even greater.

Basic Density

The average whole-tree basic density of 382 kg/m^3 (Table 2) was also very similar to that reported for Cpt 1060 (Cown & McConchie 1983). In the earlier study the average density of the 10 trees was 376 kg/m^3 although the trees were selected to encompass the density variation (three high-density, three low-density, and four medium-density). Cown, McConchie & Young (1991) made predictions of density of whole trees at various ages on three site/density classifications. The site in our study is classified low density and the report predicts that, at 25 years of age, density should be around 390 kg/m^3. Results here support that prediction and the stand can therefore be considered reasonably typical for the area.

Variation in basic density between trees followed accepted trends, ranging from 345 kg/m^3 to 426 kg/m^3. This range in density for the site represents the type of genetic variation encountered in selection programmes for *P. radiata*.

Moisture Content and Green Density

The 24-year-old trees from the 1983 study had an average green moisture content of 153%, which agrees well with the data obtained from this study. The values for moisture content and basic density have been used to calculate a green density value (Table 2). These data show the expected increase with increasing height in the tree which is attributable to the reduction of the drier heartwood in the upper logs. Mean whole tree green density was 932 kg/m^3 compared with 942 kg/m^3 for the earlier study.

Log Grades

Analysis of data by log height class has proved to be a reasonably practical method of describing and comparing within-tree wood property variation. In addition to this format, because the logs had been assigned a grade, it was possible to rework the data to give values by log grades (Table 3). Although the NZ FRI log grades (Appendix 1) are not in general use in industry, they provide a basis for comparisons with other grading systems. In brief, log grade "P" represents pruned logs, "S" those with small branches (<6 cm), "L" logs with branches between 6 and 14 cm, and "R" pulp logs (rejected as sawlogs because of size, branch diameter, or sweep); the notations 1 to 4 represent decreasing log diameters.

TABLE 3–Average log and tree values by log grade

Log grade	No. in sample	Volume (m^3)	Heart-wood (%)	Comp.* wood (%)	Core-wood (%)	Basic density (kg/m^3)	Moisture content (%)	Green density (kg/m^3)
P	42	1.23	12	8	35	396	136	933
S1	8	1.05	14	6	46	373	147	921
S2	26	0.59	15	6	52	382	140	915
S3	30	0.31	11	3	76	372	149	925
S4	4	0.17	5	3	98	345	184	979
L1	24	0.82	12	8	49	376	153	948
L2	46	0.58	14	6	62	375	148	925
L3	41	0.35	8	4	81	377	154	953
L4	3	0.22	5	4	93	374	165	991
R	3	0.25	7	3	87	352	178	980

* Compression wood

The pruned logs were all butt logs and so similarities are to be expected between the results for these and the data for the butt logs in Table 2. In the "S" and "L" grades the decreasing diameter range follows the patterns for log height class, but the mix of log height classes within each grade and in some grades the small representative number of logs have resulted in minor abberations.

In the "S" and "L" grades there were few practical differences in wood density between grades, indicating that for strength purposes average wood density would have little bearing on timber strength which would be determined by the branch size and condition in the log and therefore knot characteristics in the timber. There was still the very strong trend of increasing corewood percentage with decreasing size, which for a sawmiller or eventually a reprocessor could have a bearing on the quality of product because of the problems associated with this material. For example, from this particular stand felled at this age, a miller obtaining "S3" or "L3" logs would be producing timber of close to 100% corewood. These two log grades would generally come from the upper portion of the tree and therefore the timber from them would be more prone to warp on drying. With reduced conversions from these smaller logs, mill managers should have a good understanding of these types of effects when establishing log prices.

Resin Content

Resin content has a marked effect on density values, particularly in the heartwood and to a greater extent at lower levels in the tree. Five trees were selected for this examination and the results are presented in Table 4.

TABLE 4–Mean resin content

Disc height (m)	Heartwood (%)	Sapwood (%)	Whole sample (%)
0	19.9	1.9	3.5
6	5.0	1.7	2.2
11	4.2	1.8	2.2
16	5.2	1.9	2.3
21	9.1	2.0	2.5
26	4.8	1.9	2.0
Whole tree	7.1	1.9	2.5

The heartwood in the butt contained larger amounts of resin and, as expected, the heartwood also consistently contained greater amounts of extractives than the sapwood. The sapwood resin contents averaged 2% or less, which is slightly below the levels reported by Cown & McConchie (1983) but marginally above the "typical" figure of 1.5% suggested by Cown (1992). When the heartwood and sapwood resin contents are weighted by the proportions of heartwood and sapwood at the various heights in the tree, disc values range from 2% to 3.5%. For whole logs these values translate into 3.0% for the butt log, 2.2% for both the second and third logs, and 2.4% and 2.3% for the fourth and fifth logs respectively. The weighted mean for the whole tree is 2.5% which is close to the 2.9% of Cown & McConchie (1983) for Cpt 1060.

Dimensional Shrinkage

The intensive measurements of dimensional shrinkages to the air-dry (12% moisture content) condition are presented in Table 5. The negative values for longitudinal shrinkage represent expansion, a relatively common occurrence in *P. radiata*, particularly to the air-dry condition.

There is a trend for radial and tangential shrinkage to decrease with increasing height in the tree owing to the positive relationship between shrinkage and wood density. In a practical sense the amount of variation is negligible and the over-all mean whole-tree values are comparable to figures for the earlier study by Cown & McConchie (1983). Those 10 trees averaged –0.02%, 1.8%, and 4.0% respectively for longitudinal, radial, and tangential

TABLE 5–Mean dimensional shrinkage to air-dry

Height (m)	Shrinkage (%)		
	Longitudinal	Radial	Tangential
0	−0.25	1.8	4.4
6	−0.02	1.1	3.2
11	0.00	1.2	3.4
16	0.07	1.2	3.1
21	−0.04	1.1	2.9
26	−0.04	1.1	2.8
Tree	−0.06	1.3	3.5

shrinkages to air-dry. The values for the trees from this study are generally lower than those of the 1983 study, or those recorded as typical for *P. radiata* by Cown (1992) of 0.1%, 2.0%, and 4.0%.

Tracheid Length

Mean within-tree tracheid length distribution is shown in Table 6. The earlier study (Cown & McConchie 1983) included analyses of tracheid length only at breast height and at the 10-growth-ring sampling heights. The disc containing 10 rings roughly corresponds with the sample cut at 11 m in this study, and lengths of 2.4, 3.1, and 3.9 mm for growth rings 2, 5, and 10 are very close to those recorded here.

The trends and mean values presented in Table 6 are also very similar to those of Cown (1975) who examined in some detail the tracheid dimensions in a single 26-year-old tree from a stand grown in the vicinity of the one described in this report.

TABLE 6–Mean tracheid length (mm)

Height (m)	Ring number from the pith				
	2	5	10	15	20
0	1.6	2.6	2.9	3.4	3.7
6	2.1	2.8	3.6	4.2	
11	2.5	3.0	3.7	3.8	
16	2.2	3.0	3.8		
21	2.2	3.1	3.5		
26	2.7	3.0			

Bark Percentage and Conversion Factors

Bark data and weight to volume conversion factors were recorded for the 10 trees on which CONFAC investigations were carried out (Table 7).

The highest proportion of bark was found in the butt logs owing to presence of the thicker, corky, more mature bark in this region of the tree. But this bark holds less moisture than the spongy thinner bark of the upper logs, and so when bark is expressed as a proportion of total log weight there is little difference between log classes and the whole-tree figure of 7% seems a fairly accurate general guide.

TABLE 7–Conversion factors and bark information

	No.	Mean length (m)	Volume		Weight		Bark		Conversion factor (m^3/tonne)
			ob* (m^3)	ub† (m^3)	ob (kg)	ub (kg)	Volume (%)	Weight (%)	
Pruned butt logs	10	6.0	1.37	1.15	1214	1115	16	8	0.95
Sawlogs	36	5.0	0.55	0.50	518	486	9	6	0.96
Pulplogs	12	5.3	0.17	0.16	172	159	11	8	0.91
Whole trees	10	30.4	3.56	3.13	3286	3057	12	7	0.95

* Over bark
† Under bark

Logs are generally sold by calculating their under-bark volume from their over-bark weight on truck. Therefore, accurate conversion factors are essential to ensure both buyer and seller get their expected economic returns. The combination of bark proportions and weight, basic wood density, green moisture content, and heartwood percentage all combine to affect the over-all conversion factor expressed as the volume under-bark/weight over-bark. Note that these calculations assume no bark loss which in a normal situation varies depending on season, length of haul to the skid site, and type of handling. Therefore, these conversions may not be directly applicable in a practical sense. They do serve as a comparative guide with other studies of this type to indicate the effects of tree age and log height class on costs of log transportation and pricing.

The most comprehensive study of weight-to-volume conversion factors, measured using this method, was carried out on 78 sites covering much of the Bay of Plenty supply region (central North Island, including approximately 366 000 ha of plantation forest—New Zealand Forest Owners' Assn 1992). A total of 390 trees were assessed, covering a wide range of ages (Cown *et al.* 1984). For trees of this age, and in this area, very similar conversion factors were found with the predictions being 0.94 m^3/tonne for the butt log, 0.97 m^3/tonne for all sawlogs, 0.92 m^3/tonne for pulplogs, and 0.97 m^3/tonne for the whole tree.

Comparing bark percentage by volume, the predicted figures are 20%, 14%, 10%, and 13%. Generally, the bark percentages of this study were lower. Bark proportion as a percentage of weight was not reported in the 1984 study but reworking the original data gave an estimated bark percentage calculated on a weight basis over bark as 8.2%, 8.5%, and 7.5% for whole tree, sawlogs, and pulplogs respectively. Again, these are reasonably consistent with the findings of this study.

Spiral Grain

The current assessment involved a detailed investigation on variation of spiral grain within and between trees.

The stand averages are listed in Table 8 and confirm earlier findings that grain angles are at their greatest near the pith. The patterns of variation shown are similar to the accepted normal pattern for *P. radiata*. This typically shows a rapid increase of spiral grain angles to Rings 2 or 3 from the pith with average values around 5°, followed by a steady decrease to about Ring 10 from the pith where angles are approximately 2° dropping to near 0° by year

TABLE 8–Mean variation of spiral grain within trees

Disc height (m)	Spiral grain (°) by ring number from the pith.										
	2	4	6	8	10	12	14	16	18	20	22
0	3.59	2.45	3.12	2.53	2.30	1.29	0.53	0.64	0.21	0.33	0.22
6	5.17	4.77	4.70	4.73	2.98	2.18	1.40	0.39	–0.38		
11	6.04	6.87	6.77	5.58	4.68	3.06	2.44	1.76			
16	6.82	6.96	6.05	5.63	4.35	3.83	4.53				
21	5.24	6.26	5.87	6.09	4.82						
26	6.47	7.10	6.16	6.27							

30 (Cown 1992). The current study highlighted the fact that severity of spirality increases with height in the stem so that timber cut from the defect core in the butt log will have less propensity to twist than that cut from similar positions in upper logs. Both the article by Cown, Young & Kimberley (1991) and the companion paper to this work (Haslett *et al.* 1991) discuss the importance of spiral grain in more detail.

CONCLUSIONS

The data presented here confirm the decription of corewood as being any wood within 10 growth rings of the pith. Previous work at NZ FRI had indicated that density variation of *P. radiata* plantations in New Zealand might allow a definition of corewood based on density levels. High-density sites reach a base requirement level in 5 or 6 years whereas at low-density sites up to 30 years might be required. This assumes that the worst effects of spiral grain are included within the first five growth rings from the pith. However, the data from this study indicate that on average the first 10 years produce levels of spirality severe enough to cause processing problems, suggesting that the initial estimate of corewood as being 10 growth rings was more valid.

The stand selected for this study appears to be typical of *P. radiata* at this age and grown in this locality. The wood property results are in agreement with previous studies and with available predictions using the current database.

The study established some new techniques which have become standard procedures for detailed examinations of this type. The estimation of compression wood should provide useful data for identifying potential degrade due to this defect, and calculation of corewood values will aid in the prediction of the extent of this low-grade wood in logs of a given age (within certain boundaries of silvicultural extremes). Information about spiral grain within and between trees has been only briefly covered in this paper as it is reported in more detail by Cown, Young & Kimberley (1991). Information such as this provides a basis for attempting to establish non-destructive sampling and measurement techniques to screen cheaply and quickly for this property and to serve as a selection tool in tree breeding programmes.

These basic techniques will be incorporated into future studies examining the effect of age on the utilisation of *P. radiata* to expand the present database on wood properties and their effects.

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Appendix 1

NEW ZEALAND FOREST RESEARCH INSTITUTE LOG GRADES

A. Specifications

Log grade (mm)	Pruned/ unpruned	Small-end diameter (cm)	Largest branch index	Sweep class	Minimum internode
P1	Pruned	400+	NA	1	NA
P2	Pruned	300–399	NA	1	NA
S1	Unpruned	400+	6	1	NA
S2	Unpruned	300–399	6	1	NA
S3	Either	200–299	6	1	NA
S4	Either	150–199	6	1	NA
L1	Unpruned	400+	14	1	NA
L2	Unpruned	300–399	14	1	NA
L3	Unpruned	200–299	14	1	NA
L4	Unpruned	150–199	14	1	NA
I	Unpruned	300+	14	1	0.6
R	Either	100+	NA	2	NA

Internode index is the sum of lengths of internodes of 0.6 m or longer expressed as a ratio of the log length.

B. Maximum Permissible Sweep by Sweep Classes

Sweep class	Log length (m)			
	<3.7	3.7–4.8	4.9–7.6	>7.6
1	D/8*	D/4	D/3	D/2
2	D	2D	3D	4D

* D = diameter at top of section being assessed for sweep.

Sweep is defined as the maximum deviation from straightness along the length of the log.

After Whiteside and Manley 1987.