ROTATION AGE AND SILVICULTURAL EFFECTS ON WOOD PROPERTIES OF FOUR STANDS OF PINUS RADIATA

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ABSTRACT

Increment core and wood disc samples were collected from 10 **Pinus radiata** D. Don (radiata pine) trees in each of four age-classes in Kaingaroa State Forest in the central North Island. The samples represented (a) young thinnings (12 yr), (b) two stands which had received silvicultural treatments (24 and 34 yr), and (c) an unthinned old-crop stand (52 yr). Intensive measurements were made of green density, basic density, moisture content, tracheid length, and resin content.

Over the 40-year age span covered, the average wood properties changed considerably, e.g., green density 1025–815 kg/m^3, basic density 325–420 kg/m^3, moisture content 215–95%, tracheid length 2.5–3.5 mm, resin content 3.3–2.9%. Average values were calculated for sawlogs, top logs, sawn timber, and slabwood. It is concluded that the change in raw material supply from untended old-crop to thinnings and produce from intensively managed stands will be accompanied by age-related changes in intrinsic wood properties, to which industry will have to adjust. For instance, logs will be heavier because of a higher average moisture content, but will nevertheless have a lower basic density.

INTRODUCTION

The utilisation of radiata pine has passed through stages defined by the nature of the resource. During the 1940s and 1950s, the industry had access to 20- to 30-year-old untended crops. By the 1970s the bulk of the resource was still made up of produce from early plantings (by now 40–60 years old and untended) and thinnings from younger stands. The period 1980–90 will see a gradual transition to a new type of material from 25- to 30-year-old tended crops, and its quality will be judged against that of the now-familiar "old crop".

The intrinsic wood characteristics of radiata pine (green density, basic density, moisture content, heartwood percentage, tracheid length, and resin content) are known to be highly dependent on tree age as well as geographic location (Cown & Kibblewhite 1980) and hence the move to shorter rotations will have a predictable influence on these properties.

Early work on the density and moisture content of radiata pine by Hughes & Mackney (1949) established patterns of horizontal and vertical variation in these features in

22-year-old trees from the central North Island. Basic density at all stem levels was shown to increase almost linearly outwards from the pith, a pattern disrupted only by resin accumulation near the centre of the stem in the heartwood zone. The average increase was from 330 kg/m^3 in the innerwood to 430 kg/m^3 in the outerwood at breast height level. The reduction in the number of growth rings with increasing height in the stem resulted in a decrease in average density. Green density increased from 560 kg/m^3 at the stem centre to 1070 kg/m^3 at about the mid radius and thereafter remained constant. The moisture content increased from 40–50% in the heartwood to 150–190% in the sapwood. Loe & Mackney (1953) described variations in density and moisture content of radiata pine trees ranging from 24 to 40 years old, growing in the central North Island. Results showed that the radial increase in basic density was maintained for at least 40 rings from the pith and that the patterns established by Hughes & Mackney (1949) applied in general to all ages sampled. Mean tree density increased from 385 kg/m^3 at 24 years to 435 kg/m^3 by age 40 years. Green density decreased slightly over the same period (980 to 930 kg/m^3) because of the progressive development of heartwood. Mean moisture content varied from 131% at 30 years to 99% at 40 years. Buckland *et al* (1953) examined resin content in 70 trees, 24–40 years old, but failed to establish a clear trend with age. The over-all average was about 2%.

The effects of tree age on wood density, tracheid length, and heartwood development have been discussed by Cown (1980), and a detailed description of old-crop properties has been given by Cown & McConchie (1980).

Recent work on pulp and paper properties of radiata pine has shown that both basic density and tracheid length have a strong influence on such paper characteristics as tear and burst factors (Kibblewhite 1980).

In view of the influence of crop age on the patterns of wood property variation within stems, and the age range of raw materials currently available (from young thinnings to old crop at 40–60 years), there was a need for a comprehensive study of age-related effects on tree component (i.e., sawlog, sawn timber, slabwood, and top log) properties.

MATERIALS AND METHODS

Stands were selected in northern Kaingaroa Forest to represent (a) young thinnings, (b) two ages of managed second-growth stands, and (c) an old-growth crop. Stand histories are given in Table 1 and indicate that at the time of felling the crop ages were 12, 24, 34, and 52 years. The samples were growing on the Kaingaroa plateau in close proximity (Fig. 1).

In each stand, breast height increment cores (three per tree) were collected from 50 to 200 trees and basic wood density was determined on the outer five rings of the cores (20 rings in the old crop) by the maximum moisture content method devised by Smith (1954). Trees were ranked by core density values and 10 individuals were selected from each stand to represent three density classes – high (three), medium (four), and low (three). The sample trees were felled and discs collected from the butt and breast height levels and at 5-m intervals (3 m in the young stand) to a top diameter of 100 mm. In the laboratory the discs were broken down into five-ring sector blocks from the pith outwards for intensive wood property assessment.

TABLE 1—Stand histories

Crop Type	Compartment	Treatment	Date
Young thinnings	1047	Regeneration established	1969
		Waste thinned to 1100 stems/ha	1973
		Pruned, 0-2.4 m, 390 stems/ha; waste thinned to 440 stems/ha	1976
		Pruned, 2.4-4.3 m, 335 stems/ha	1978
		Pruned, 4.3-6.1 m, 300 stems/ha; sample trees felled	1981
Second crop (24 yr)	1060	Regeneration established	1956
		Waste thinned to 930 stems/ha; pruned, 0-2.4 m, 930 stems/ha	1960
		Pruned, 2.4-4.3 m, 300 stems/ha	1962
		Pruned, 4.3-6.1 m, 300 stems/ha	1965
		Thinned to 350 stems/ha	1969
		Sample trees felled	1980
Second crop (34 yr)	1099	Planted 1.8 × 1.8 m	1947
		Pruned 300 stems/ha	1956
		Waste thinned to 600 stems/ha	1957
		Thinned to 300 stems/ha	1966
		Sample trees felled	1981
Old crop	1022	Planted 1500 stems/ha	1927
		Clearfelled - samples taken	1980

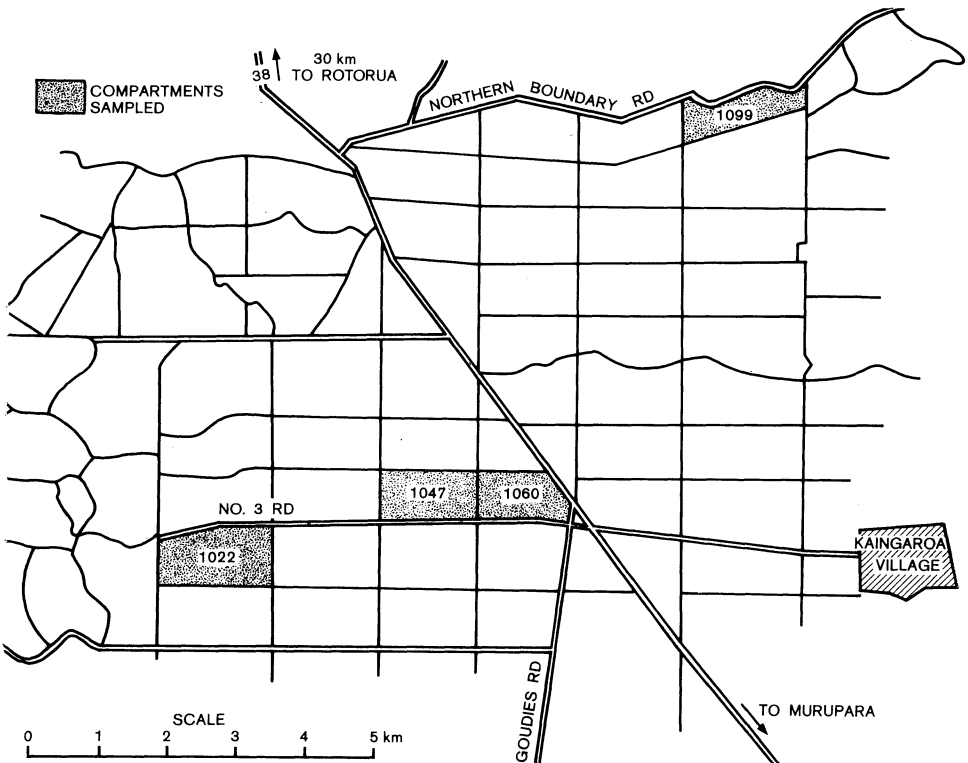

FIG. 1—Location of sample crops in northern Kaingaroa Forest

Data collected for each block included:

(1) Green density
(2) Basic density } by gravimetric weight and volume measurement
(3) Moisture content
(4) Tracheid length (*see* Harris 1966)
(5) Resin content (by weight loss after methanol extraction)

The data for each tree were initially used to calculate sawlog (> 250 mm s.e.d.) and top log (< 250 mm s.e.d.) properties, then the sawlog component was further divided into slabwood (outer 50 mm of each sawlog disc) and sawn timber portions (Fig. 2). Average crop values were derived from the tree component data, adjusted for differences in outerwood density between the sample trees and the crop as a whole.

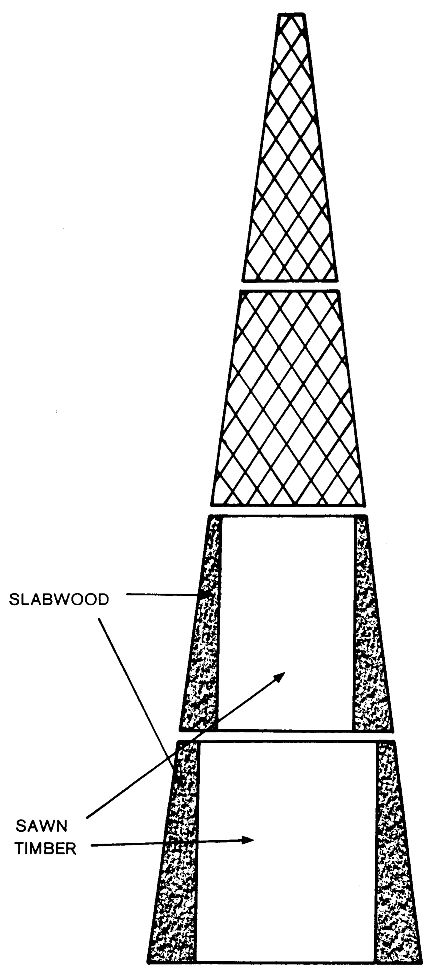

FIG. 2—Schematic diagram of tree components

RESULTS

Breast Height Outerwood Density

The distribution of outerwood density values approximated the normal distribution in each sample, and mean crop values ranged from 348 to 469 kg/m³ with standard deviations 22–35 kg/m³ (Fig. 3). While the over-all effect of tree age is apparent and corresponds to the patterns described by Cown & Kibblewhite (1980) for Rotorua

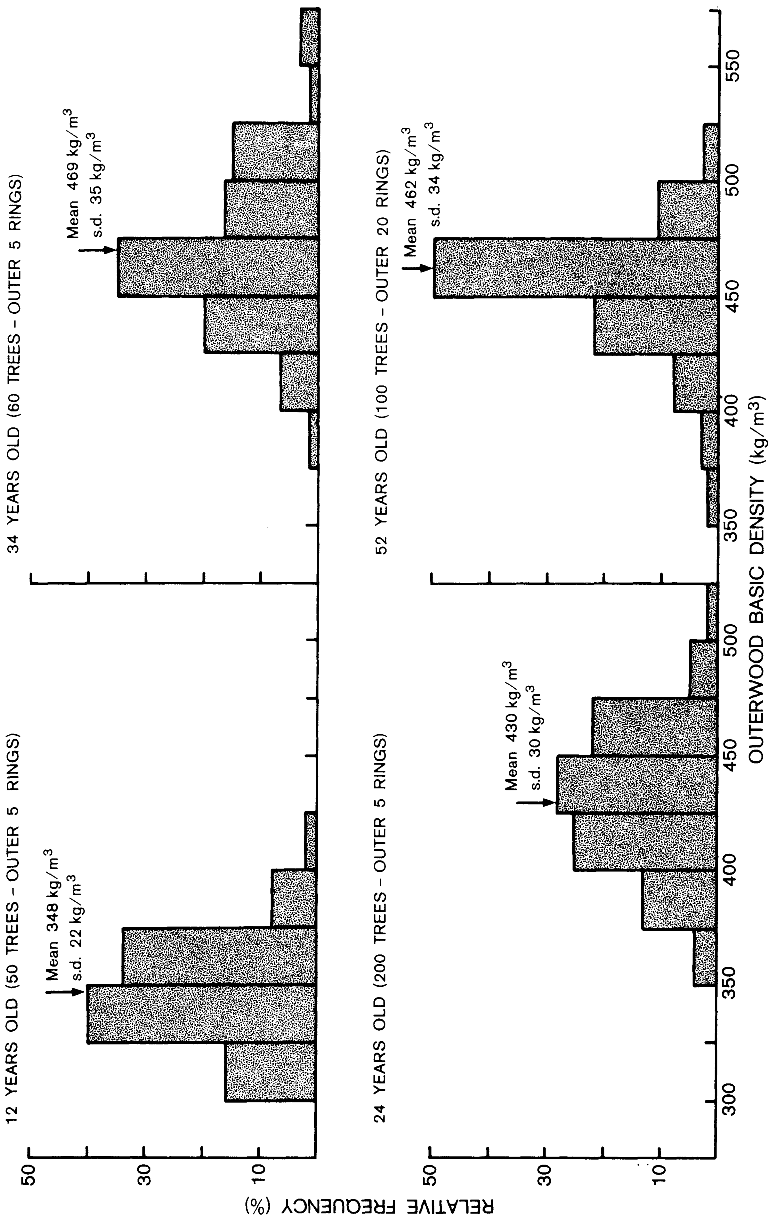

FIG. 3—Distributions of breast height outerwood densities

Conservancy, there were apparent anomalies in the means and ranges of the two older stands which were largely attributable to changes in the sample size (20 rings in the 52-year-old stand, necessitated by the prolonged growth suppression).

Relationship of Breast Height Density to Tree Component Densities

Regression analyses were performed using the breast height outerwood density values (from the increment cores) and individual tree component densities, to test the feasibility of predicting component values from cores. Linear models were found to be statistically significant in all tests (Table 2) and the following were observed:

(1) The accuracy of the predictions for individual tree component densities decreased slightly with increasing tree age. However, even for the old-crop most regression equations were significant at the 1% level.

(2) Regressions relating breast height outerwood density to top log densities were significant at only the 5% level in the 24-, 34-, and 52-year-old stands.

TABLE 2—Prediction of tree component densities from increment cores

Age (yr)	Independent variable	Dependent variable	Regression coefficient	Constant	Correlation coefficient	Standard error (kg/m^3)
12	Breast height outerwood density (5 rings)	Whole tree	0.79	52	0.96**	8
		Top log density	0.79	52	0.96**	8
24	Breast height outerwood density (5 rings)	Whole tree	0.32	237	0.92**	7
		Top log density	0.21	265	0.70*	10
		Sawlog density	0.37	220	0.91**	8
		Sawn timber density	0.44	174	0.88**	12
		Slabwood density	0.75	199	0.98**	7
34	Breast height outerwood density (5 rings)	Whole tree	0.47	194	0.87**	13
		Top log density	0.43	199	0.65*	23
		Sawlog density	0.51	181	0.86**	14
		Sawn timber density	0.57	127	0.88**	15
		Slabwood density	0.69	125	0.99**	4
52	Breast height outerwood density (20 rings)	Whole tree	0.47	205	0.90**	12
		Top log density	0.34	232	0.66*	21
		Sawlog density	0.48	202	0.91**	12
		Sawn timber density	0.39	213	0.78**	16
		Slabwood density	0.69	154	0.90**	18

* Significant at the 5% level

** Significant at the 1% level

The analyses have shown that (a) good component predictions can be made from increment core densities, and (b) crop age has an important influence on the coefficients of the predictive equations.

These relationships were used to derive tree component values for the stands as a whole, using the average outerwood densities as the independent variables.

Whole-tree Properties

A summary of the whole-tree wood properties is given in Table 3(a). Figure 4 shows the differences in average stem size between the sample crops and illustrates another of the important age-dependent phenomena, i.e., the development of heartwood. Only one of the 12-year-old trees showed any sign of incipient heartwood formation, whereas by age 52 years an average of 45% of the stem was heartwood.

The green density is an expression of the weight of freshly cut wood, but gives no indication of the dry wood content (Cown & McConchie 1980). Knowledge of both green and basic densities allows the calculation of dry weight yield, i.e. –

$$\text{Yield (dry wt/green tonne)} = \frac{1000}{\text{Green density}} \times \text{Basic density}$$

Crop mean yield values ranged from 315 kg/tonne at age 12 years to 515 kg/tonne at 52 years, an increase of 63%.

Patterns of tracheid length variation in the sample stands followed well-established trends (Cown & McConchie 1980). Data for individual growth rings were weighted by ring area to give disc means and tree means and the resultant estimates for the four crops showed the expected increase in length with age. There was a very significant change from 2.5 mm in the thinnings to 3.4 mm in the 24-year-old stand, but only a slight increase to 3.5 mm in the old crop. This is probably due to the suppression of growth in the outerwood zone of the untended stand and the consequent small volume occupied by the long-fibred portions of the stems.

Despite the increase in average heartwood content from zero to 45% between 12 and 52 years, the weighted whole-tree resin contents appeared to decrease with crop age. Two factors have contributed to this effect:

(1) Within-tree variations. Sapwood resin content was observed to increase slightly with height in the stem and decrease with tree age. Resin in the heartwood decreased with distance from the pith and height up the bole.

(2) Method of measurement. The figures in Table 2 are based on the percentage of resin to o.d. weight of wood, but if these data are converted to weight of resin per green cubic metre (using the tree mean basic density values) a different pattern emerges, i.e., 12 yr – 10.7 kg/m^3, 24 yr – 10.9 kg/m^3, 34 yr – 7.9 kg/m^3, 52 yr – 12.2 kg/m^3. Thus on a green volume basis, the results, like those of Buckland *et al.* (1953), are inconclusive.

Prior to the onset of heartwood formation, the sapwood had a very high moisture content (215%). As the trees age and heartwood becomes more extensive, the average moisture content decreases (150% at 24 years to 95% at 52 years).

TABLE 3—Summary of wood properties by crop ages and tree components

Tree component	Crop age (yr)	Density (kg/m³)* Green	Density (kg/m³)* Basic	Moisture content (%)†	Yield (o.d. kg/ green tonne)	Tracheid length (mm)	Resin content (%)
(a) Whole tree	12	1025	325	215	315	2.5	3.3
	24	945	375	150	395	3.4	2.9
	34	955	415	130	435	3.4	1.9
	52	815	420	95	515	3.5	2.9
(b) Sawlogs (>250 mm)	12	Not applicable					
	24	940	390	140	Not applicable		
	34	945	420	125			
	52	810	430	90			
(c) Sawn timber	12	Not applicable					
	24	810	365	120	Not applicable		
	34	820	395	105			
	52	620	400	55			
(d) Slabwood	12	Not applicable			Not applicable		
	24	1100	420	160	380	3.6	2.5
	34	1100	450	145	410	3.8	1.6
	52	1100	475	130	430	4.0	1.5
(e) Top logs (<250 mm)	12	1025	325	215	315	2.5	3.3
	24	950	355	170	375	3.0	3.0
	34	980	400	145	410	3.1	2.6
	52	920	410	125	445	3.2	2.0

* Rounded to the nearest 5 kg/m³

† Rounded to the nearest 5%

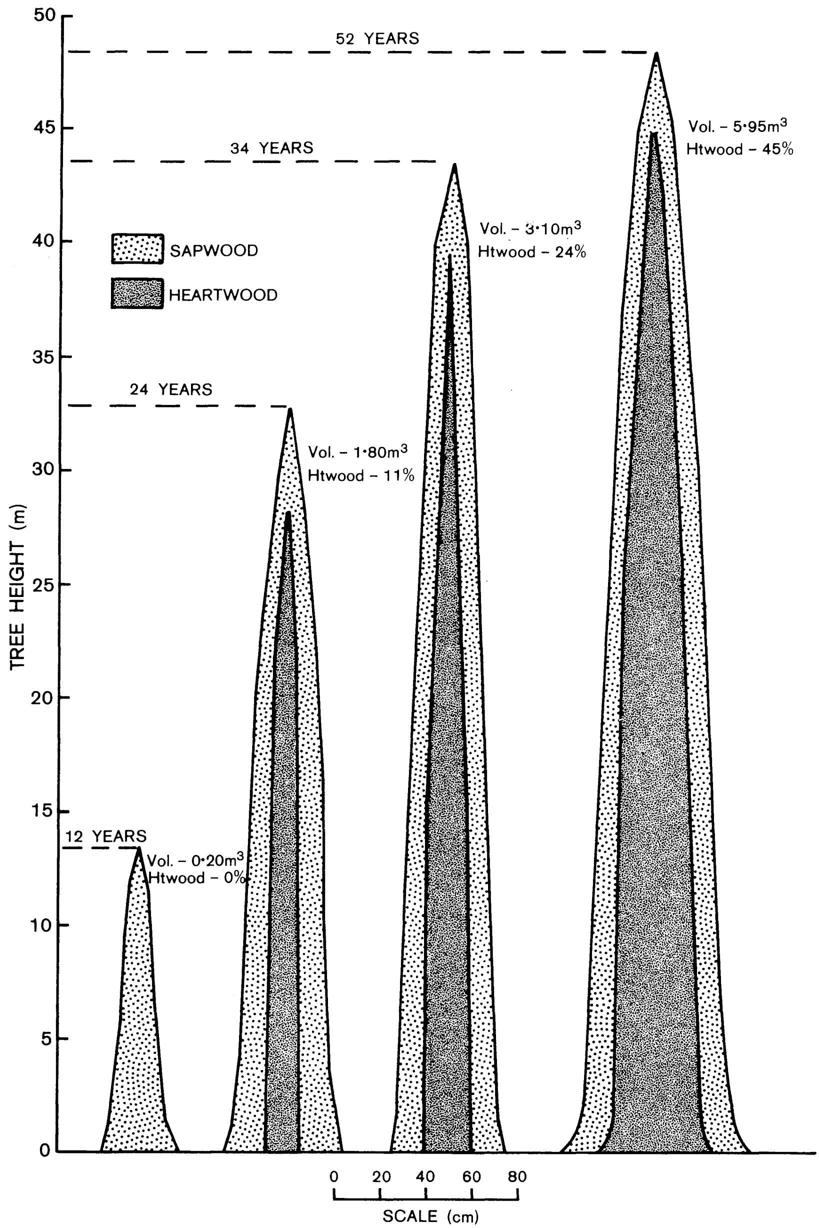

FIG. 4—Mean tree profiles

The green density of wood is dependent to a large degree on the moisture content and hence increases with height in the stem and decreases with increasing crop age. Basic density, on the other hand, always increases with distance from the pith and decreases upwards in the stem (Fig. 5). In the sample trees used in this study, average basic density increased by 29% and green density decreased by 20% between ages 12 and 52 years.

The effects on wood properties of position within the tree and tree age can be considerable. Mean values for tree components in the sample stands are given in Table 3 (b)–(e) and Figs 6–9.

Sawlogs

Sawlogs (all logs > 250 mm s.e.d.) from the 24-year-old and older stands showed a decrease in green weight with age from around 940 to 810 kg/m^3, accompanied by a 10% increase in average basic density from 390 to 430 kg/m^3.

The significance of these results lies mainly in the fact that the transition from old-crop to younger stands will mean harvesting and transporting smaller logs which will weigh more for a given log volume. Thus, logging trucks under load weight restrictions will be carrying smaller volumes of wood to the mills. The average moisture content of sawlogs will be in the region of 120–140%, compared to 90–100% in logs from older stands.

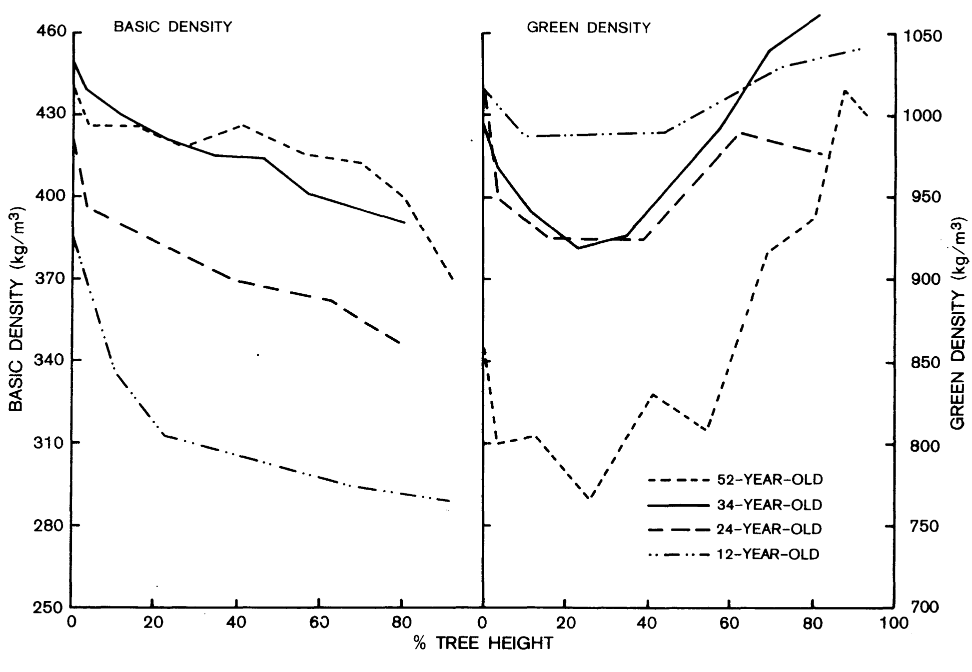

FIG. 5—Vertical density variation

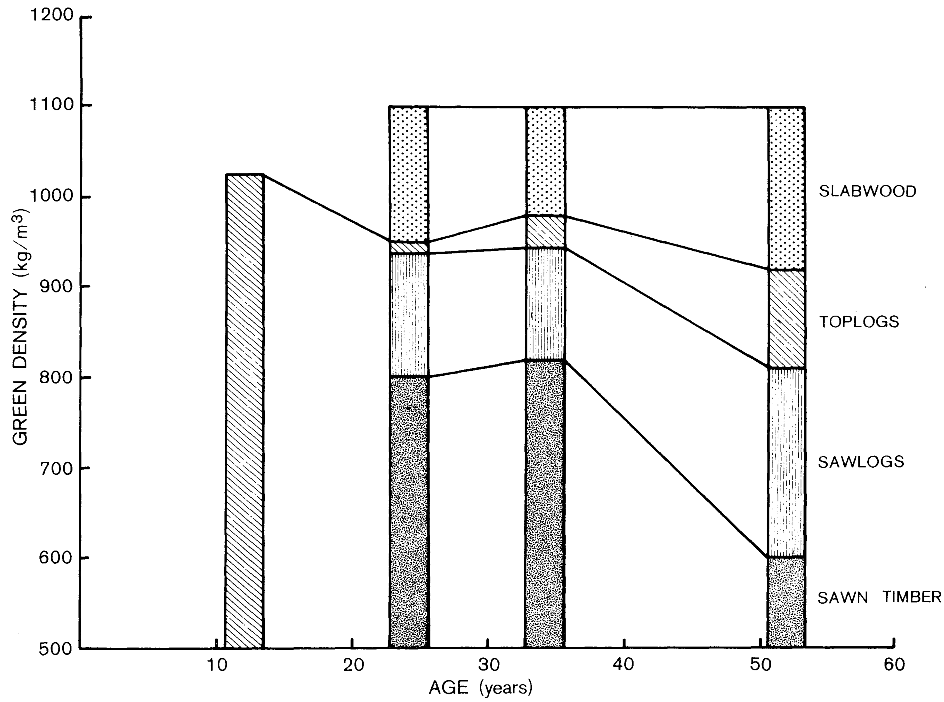

FIG. 6—Tree component green densities

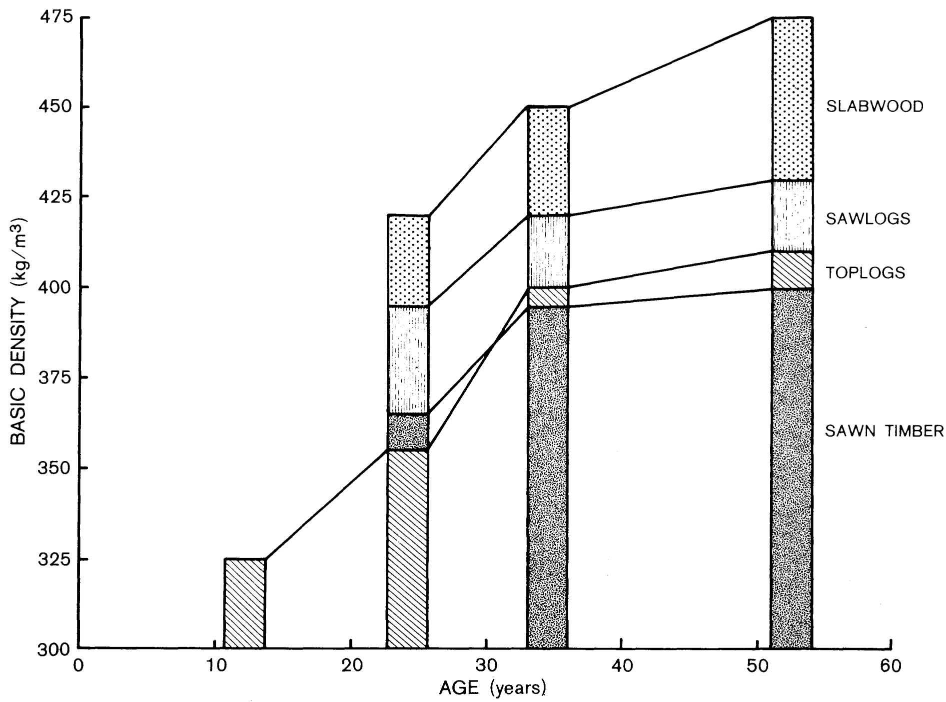

FIG. 7—Tree component basic densities

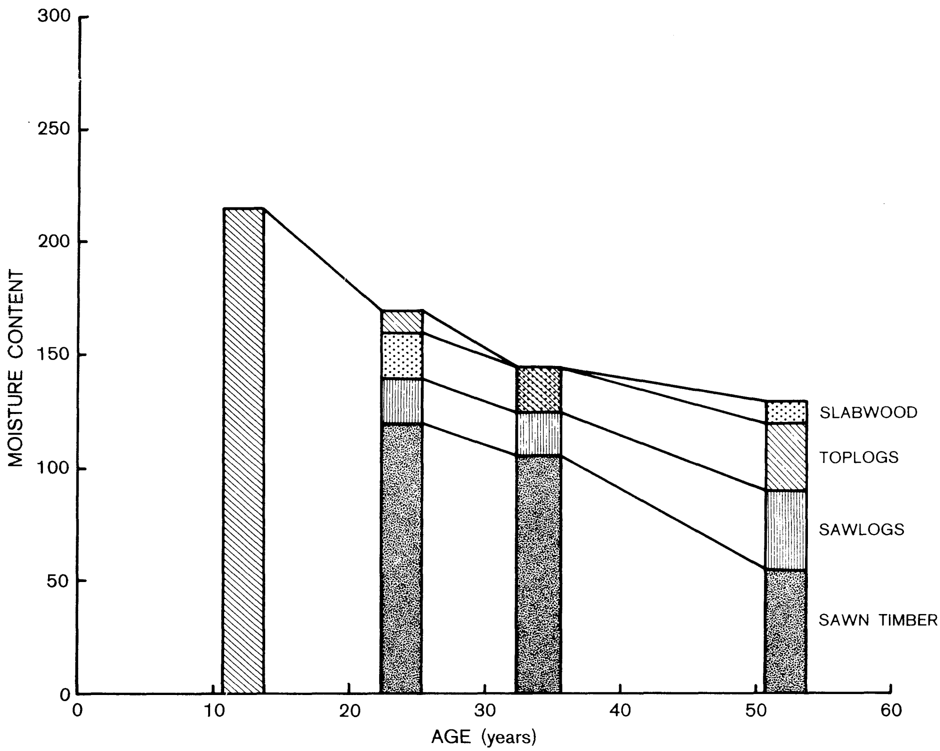

FIG. 8—Tree component moisture contents

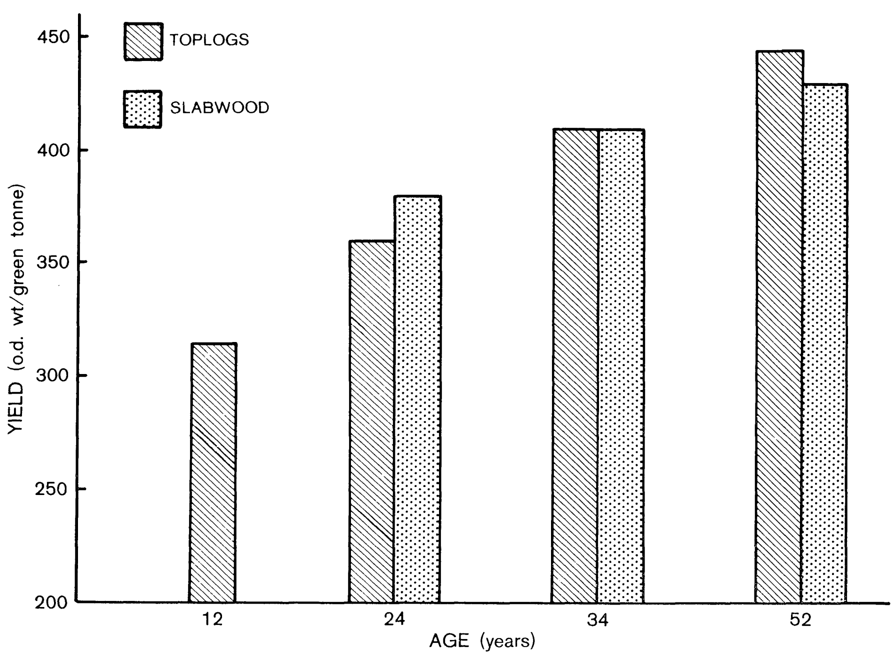

FIG. 9—Effect of age on dry weight content of pulpwood

Sawn Timber

Sawn timber from old-crop trees is mainly heartwood (moisture content 55%, green density 620 kg/m^3) and hence difficult to treat with preservatives. Material from younger stands will contain a large proportion of sapwood which, although of much higher moisture content, is easy to treat and does not require longer drying periods to reach its equilibrium moisture content (J. A. Kininmonth, pers. comm.).

It is expected that the butt logs of future stands will mostly be pruned to yield a significant portion of full-length clears and factory grade which should attract premium prices irrespective of the intrinsic properties of the wood. The pieces containing defects, however, will tend to be from near the centre of the log, and so visually graded board and framing grades from 25- to 35-year-old pruned logs will tend to have wider growth rings and lower wood density than comparable grades from old-growth material. Studies have shown that the two principal factors affecting the strength properties of structural timber are knots (size and position) and basic density (Harris *et al.* 1976).

Timber from above the butt log in stands grown on a direct peeler/sawlog regime will inevitably have larger knots and lower density than from untended crops. However, interactions between knot size, density, log diameter, and sawing pattern may make it possible to recover a proportion of clearwood, from the larger logs at least. Hence, although structural members will have less average strength, the over-all value of the unpruned logs has not yet been established.

Pulpwood (Top logs and slabwood)

The wood supply for pulp mills is currently obtained from (a) young thinnings, (b) top logs from semi-mature or old-growth stands, and (c) slabwood from sawmills. While this material does not vary much in green density (920–1100 kg/m^3), there are important differences in basic density (325–475 kg/m^3), moisture content (125–215%), yield (315–445 kg/tonne), and tracheid length (2.5–4.0 mm).

The effects of some of these factors on kraft paper properties have recently been discussed (Cown & Kibblewhite 1980; Kibblewhite 1980). It is sufficient here to emphasise that a reduction in the age of the wood resource, accompanied by substantial changes in the above properties, will give lower yields and pulps with greater burst index but reduced tear factor. As tear is perhaps the most critical of the properties of market kraft pulps, the raw material may have to be monitored to ensure that an optimum ratio of slabwood chips to top log chips is maintained. The trend to shorter rotations and greater use of thinnings will result in high-density slabwood becoming a premium product for kraft pulp manufacture.

Low-density wood from thinnings and top logs is intrinsically a suitable resource for making light-weight high-density papers and tissues (Cown & Kibblewhite 1980). Thus, the range of tree components available could be efficiently used to produce a number of pulp types, provided effective raw material segregation can be carried out at the pulp mill.

The influence of wood characteristics on the properties of mechanical pulps has not yet been well defined, although indications are that relationships are similar to those outlined for kraft pulp (Corson & Foster 1981). It is apparent that a wide range of paper grades could also be produced in mechanical pulp mills by varying both the raw materials and the process parameters.

Influence of Silviculture

The 52-year-old-stand can be considered to be typical of the untended old-growth crops in northern Kaingaroa Forest. Future rotations are anticipated to range from 25 to 35 years and to incorporate thinning and pruning schedules. The principal factor affecting intrinsic wood properties is tree age which strongly controls wood density and heartwood development. Growth rate *per se* has been shown to have a minimal effect on wood density, but several studies have shown that stocking levels and density are weakly negatively correlated (Cown 1973, 1974, and unpublished data). This appears to be the result of the removal during thinning of large numbers of stems from the lower end of the diameter range. As there is often negative correlation between tree size and density (Table 4) the crop trees may be of lower density than those removed.

TABLE 4—Correlations between tree d.b.h. and densities†

Crop age (yr)	Treatment	No. trees	Correlation	Significance
12	Thinned and pruned	50	-0.02	n.s.
24	Thinned and pruned	200	-0.28	**
34	Thinned and pruned	60	-0.51	**
52	Untended	100	-0.27	**

† Estimated from outerwood density values (Table 2)
n.s. Not significant
** Significant at the 1% level

Pruning produces a slight increase in wood density (Cown 1973) and hence tends to offset the effect of thinning.

The net result of thinning and pruning operations may be a slight reduction in tree density (e.g., 1–3%), which is overshadowed by the well-documented effects of site and rotation age.

CONCLUSIONS

Silvicultural regimes now being implemented are designed to produce sawlogs and veneer logs as the principal products on a 25- to 35-year rotation. Future stands will therefore yield smaller logs with different characteristics from those typical of produce from untended old-growth crops. The data presented here quantified age and silvicultural effects on the intrinsic (clearwood) properties of four stands from northern Kaingaroa Forest. The samples were selected to represent different types of wood supply, i.e., young thinnings, old crop, and producc from managed stands. Even after allocation to tree components (sawlogs, top logs, sawn timber, slabwood) there were important differences in wood properties between stands. Some of these differences will affect the quantity and quality of manufactured products, but as they are largely predictable (dependent on rotation age), industry should be able to make the necessary allowances for anticipated changes.

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