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EFFECTS OF WOOD QUALITY VARIATION IN NEW ZEALAND RADIATA PINE ON KRAFT PAPER PROPERTIES

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Variation in wood density, tracheid length, resin content, and incidence of compression wood in radiata pine are documented and discussed with respect to their potential influence on pulp and paper manufacture.

In general terms, each of the properties mentioned tends to decrease southwards within New Zealand. Tree average wood density, for instance, drops 20% from Auckland to Canterbury Conservancies (455 to 380 kg/m^3). This decrease will result in increased handling costs and wood consumption per tonne of pulp produced, and reduced chemical pulp digester yields.

For paper quality, variations in tear index as a consequence of wood property changes are predicted to be substantial. Thus regional wood resource qualities need to be matched with those paper and paperboard products which can be most effectively manufactured from them. Packaging grades of kraft pulps which require high tear strength should, therefore, be produced from the higher density wood found in parts of the Auckland, Rotorua, and Nelson Conservancies.

INTRODUCTION

Variations in wood properties can have far-reaching effects on the quantity and quality of pulp and paper products. In any pulping operation, higher wood basic density should give economies in harvesting and transport as costs will be lower on an oven-dry weight basis and benefits will accrue from the lower wood consumption per tonne of pulp produced.

In addition to the quantitative aspects of the pulping process, wood properties can influence the quality of the paper produced. Kraft pulp and paper characteristics have been shown to be highly dependent on the wood cell morphology of the raw material resource. Comprehensive reviews have been prepared dealing with the effects of cell diameter, wall thickness, and length, and the proportion of latewood within the annual ring (Dadswell & Wardrop 1960; Dinwoodie 1965). Recent work on the kraft pulping of radiata pine has shown that the two most important wood parameters are basic wood density (expressing the combined effects of cell diameter, wall thickness, and percentage latewood) and tracheid length (Nelson *et al.* 1980; Kibblewhite 1980). These properties tend to vary in a more or less regular fashion within stems (Cown 1980b; Cown & McConchie 1980), and less predictably between trees and sites. Clearly,

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both genetics and environment play important roles in influencing wood properties. Harwood & Uprichard (1969) were of the opinion that variations in these factors have more effect on pulping and papermaking than variations in the chemical composition of radiata pine.

Several workers have established close correlations between wood density and tear index (Kibblewhite 1973, 1980; Farrington 1980; Uprichard 1980), such that pulps from high density material have high tearing strength with acceptable burst and tensile properties. The effects of tracheid length are more obscure and secondary to those of density but it is generally acknowledged that there is a positive correlation between tracheid length and tear index. Kibblewhite (1980) found that prediction of tear index from wood density can, under some circumstances (e.g., for slabwood), be improved if tracheid lengths are also known.

In many of these published reports the wood variables measured were not independent of one another and the effects observed need not be due entirely to parameters discussed. For instance, it is well known that there are strong positive correlations between tree age, wood density, and tracheid length in material from any given area.

Other wood properties which might be expected to influence pulp yields and quality are resin content (Nelson & Hemingway 1971) and the incidence of compression wood (Kibblewhite 1973, 1980). The yields of kraft pulps from compression wood are low and paper extensibilities are high when compared to those of normal wood from radiata pine.

WOOD DENSITY

Early work on radiata pine from the central North Island established the fundamental within- and between-tree patterns of wood density variation and suggested that site would also have an influence on tree mean density (Hughes & Mackney 1949; Loe & Mackney 1953). Harris (1965) carried out an extensive investigation of outerwood density, involving the collection of increment core samples from some 1800 trees, 30–35 years old, on 37 sites in the major forest areas. Basic density of the outer 10 growth layers was shown to be very highly related to mean annual temperature of the site ($r^2 = 0.88$) and hence there was an overall pattern of density decrease with increasing altitude and latitude.

More recent work (Cown 1980 and unpubl. data) has confirmed and expanded on the results of previous workers. By collecting pith-to-bark cores from 235 sites throughout the country, patterns of variation have been established on a regional basis. From Fig. 1 it can be concluded that:

1. There is a consistent pattern of density increase outwards from the pith, with a tendency to level off as trees reach 15–20 years of age.
2. Regions exhibit differences in mean density levels.
3. Density of the inner growth rings is less subject to regional variation.

As the ages of the sample trees surveyed varied considerably, site comparisons were made on density data from 2 clearly defined positions within the stems, i.e., rings 1–10 (corewood) and rings 16–30 from the pith (outerwood). Fig. 2 shows regional averages and illustrates that whereas corewood density (resin-extracted) ranged from 360 to 406 kg/m^3 (Southland and Auckland respectively) average outerwood levels varied from

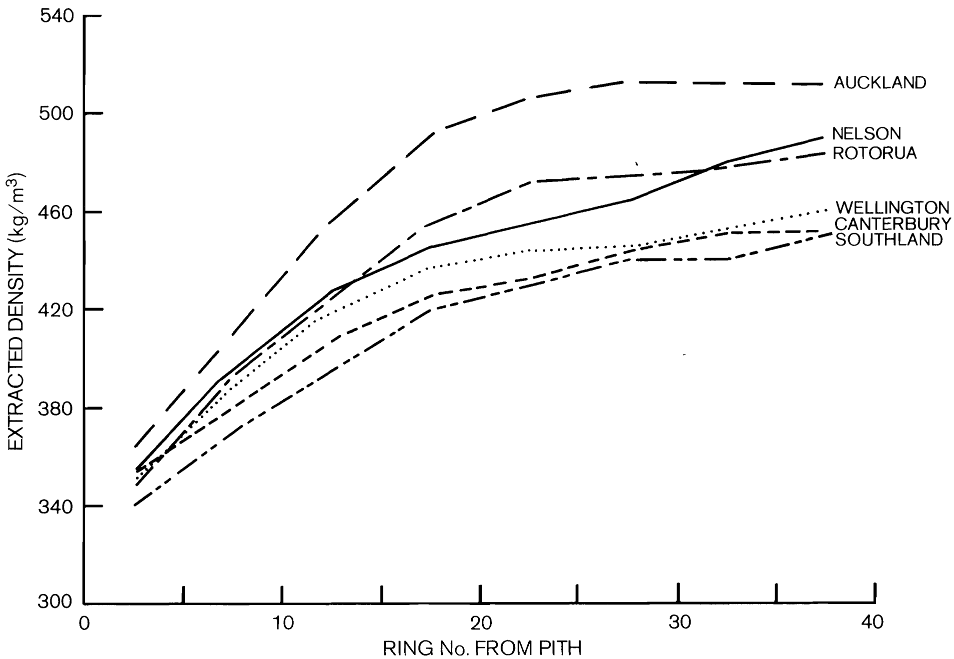

FIG. 1—Regional breast height density trends.

423 to 500 kg/m^3 (Awatere Valley, Nelson Conservancy, and Auckland). The figure also serves to illustrate the wide site-to-site variability evident within the broadly-defined regions. The relationships between latitude, altitude, and wood density confirm the trends described by Harris (1965).

Data from large numbers of sectional measurements on felled trees have established consistently high correlations between the density of the outerwood at breast height (b.h.) and that of the entire stem (to 100 mm s.e.d.) in all regions. These relationships can be used to predict average tree densities on a conservancy basis as shown in Table 1.

The extreme values (Auckland 455 kg/m^3 and Canterbury 380 kg/m^3) demonstrate the very significant differences in the mean values. Conservancy averages vary by up to 20%. The b.h./whole-tree regressions can also be applied to individual site data to give information on density variation on a geographic basis (Fig. 3). This clearly illustrates the extreme variation in Nelson Conservancy where, for example, sites can range from over 450 kg/m^3 to under 400 kg/m^3, compared to the relative uniformity of Canterbury and Southland.

TRACHEID LENGTH

Harris (1965) showed that tracheid length in radiata pine varies countrywide in a manner similar to that for wood density, i.e., a general decrease from north to south.

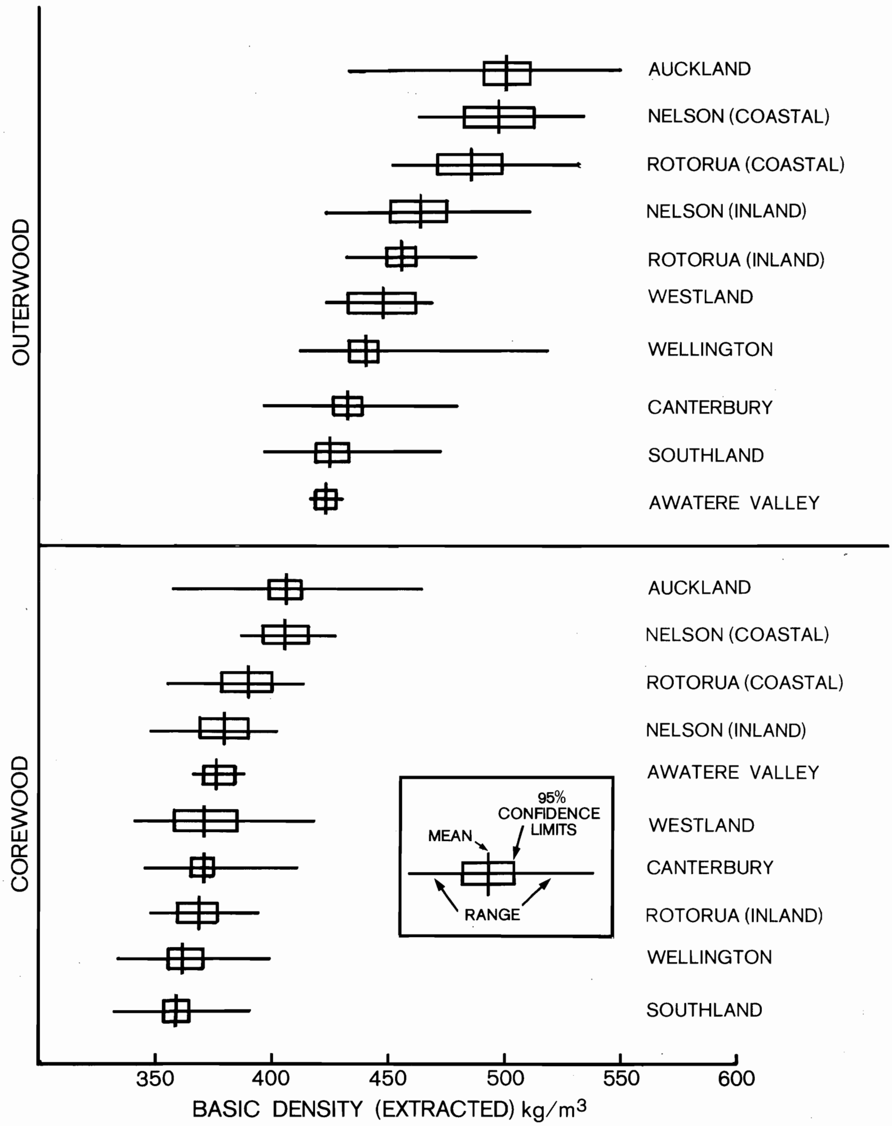

FIG. 2—Mean corewood and outerwood density by regions.

TABLE 1—Average densities of 30-year-old trees by regions

Region	Average tree density (kg/m^3)
Auckland	455
Rotorua (coastal)	425
Rotorua (inland)	405
Wellington	390
Nelson (coastal)	450
Nelson (inland)	425
Westland	410
Canterbury	380
Southland	395

However, correlations with annual temperature and altitude were less significant ($r^2 = 0.56$ and 0.59 respectively).

Fig. 4 gives the results of some recent tracheid length assessments. Average differences between conservancy means for Auckland and Canterbury were of the order of 0.75 mm. As noted by Harris (1965), the regional trends were not as regular as for wood density, and there was very considerable site-to-site variation. It appeared from the results that Wellington Conservancy tracheids were longer than would have been anticipated on a purely geographic basis.

RESIN CONTENT

Patterns of resin content variation within trees and the effects of increasing stand age were examined by Buckland *et al.* (1953). This work demonstrated the high resin content of the inner-heartwood rings and the tendency to an increasing level of extractives with advancing age. Harris (1965), in his countrywide study, did not identify any important differences between regions.

Samples for wood density determination are treated with methanol as a matter of course at FRI so that material can be compared on an extractive-free basis. This procedure gives data on resin content which, in combination with wood density, can be used to calculate the weight of resin per unit volume of wood. Table 2 gives data on the radial resin content variation in 30-year-old trees (with an average of 7 heartwood rings).

There was little sign of differences in the inner rings but there is a trend towards lower sapwood levels in southern forests. Fig. 5 shows that Southland trees produce sapwood with about 4 kg/m^3 methanol extractives compared to 5–6 kg/m^3 in other areas. The highest levels were recorded for Auckland and Rotorua Conservancies.

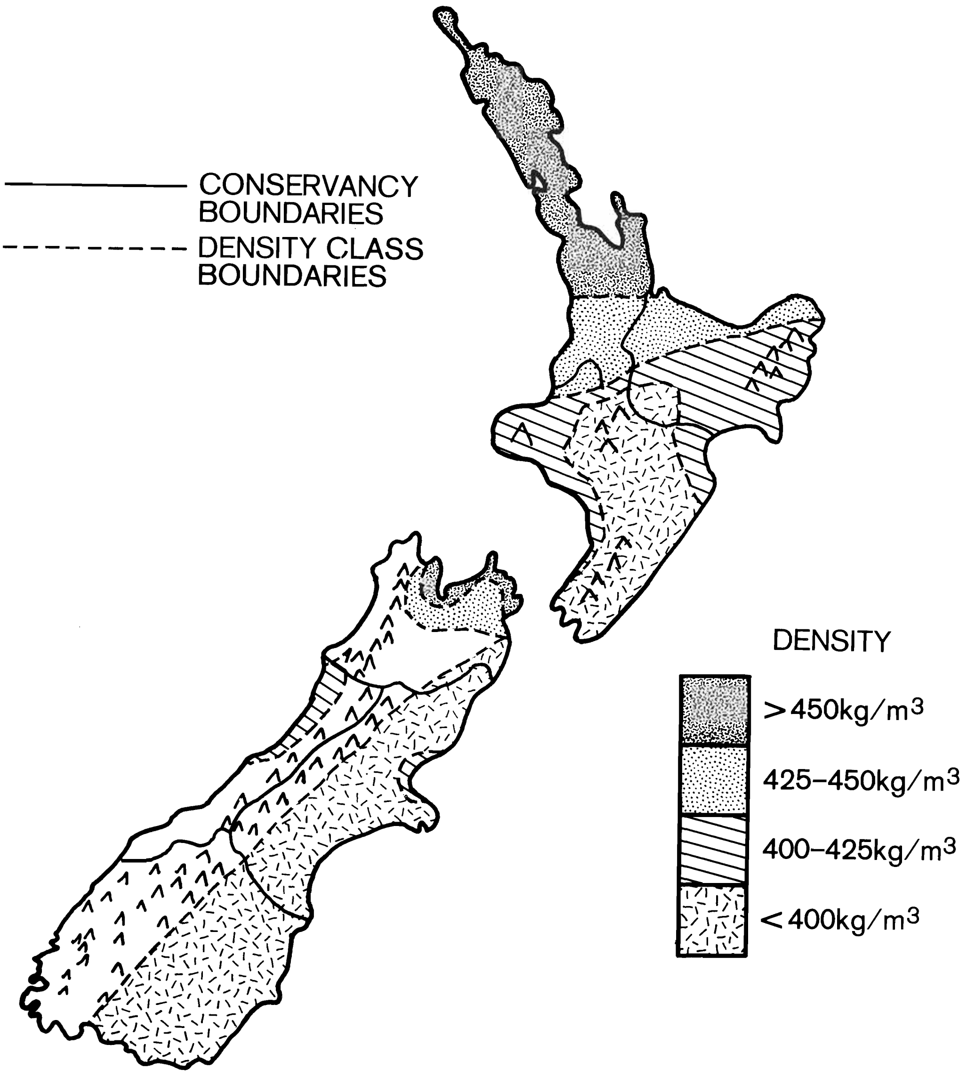

FIG. 3—Radiata pine density classes (age 30 years).

COMPRESSION WOOD

Little information is available on the incidence of reaction wood in New Zealand radiata pine, although it is often observed to be prevalent in old untended stands and associated with stem malformation. It can be expected that levels of the "classic" compression wood (darker coloured wood and eccentric radial growth) will become less evident through the use of genetically-improved planting stock and the adoption

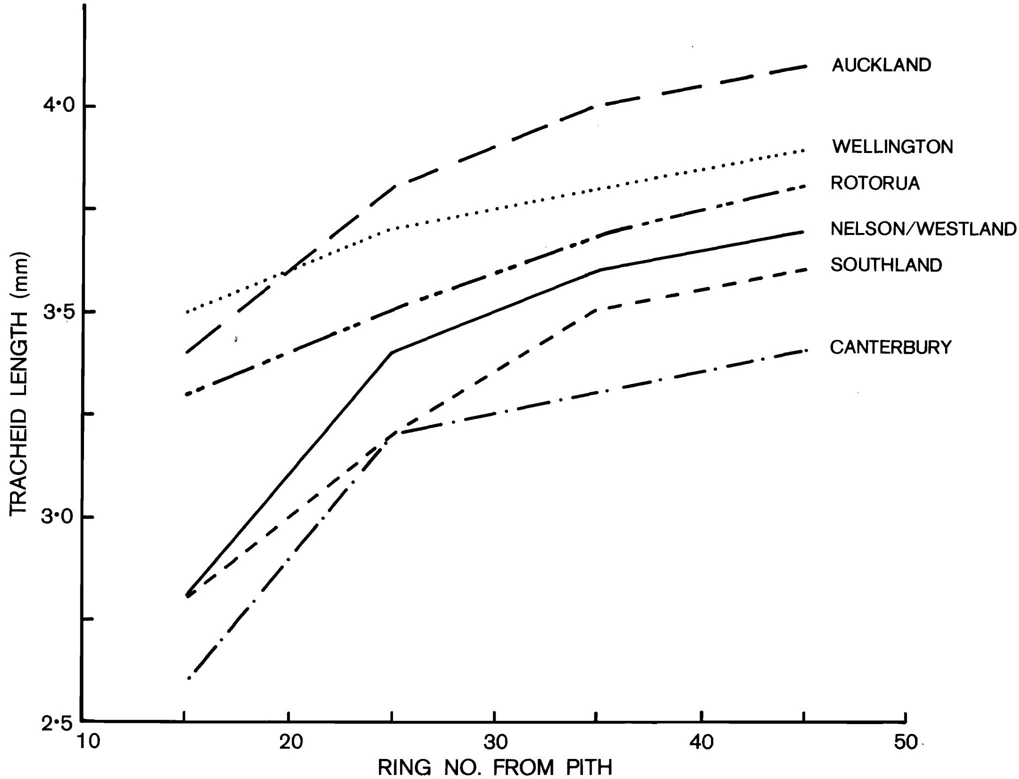

FIG. 4—Regional tracheid length trends.

TABLE 2—Breast height resin contents of 30-year-old trees

Conservancy	No. of sites	Resin content (%) at ring no.				
		1–5	6–10	11–15	16–20	21–25
Auckland	10	9.8	2.9	1.3	1.3	1.2
Rotorua	13	8.5	3.1	1.4	1.4	1.3
Wellington	15	8.5	3.2	1.5	1.3	1.3
Nelson/Westland	10	7.9	2.3	1.6	1.3	1.3
Canterbury	15	9.7	3.1	1.4	1.2	1.1
Southland	13	8.4	1.8	1.0	0.9	0.9

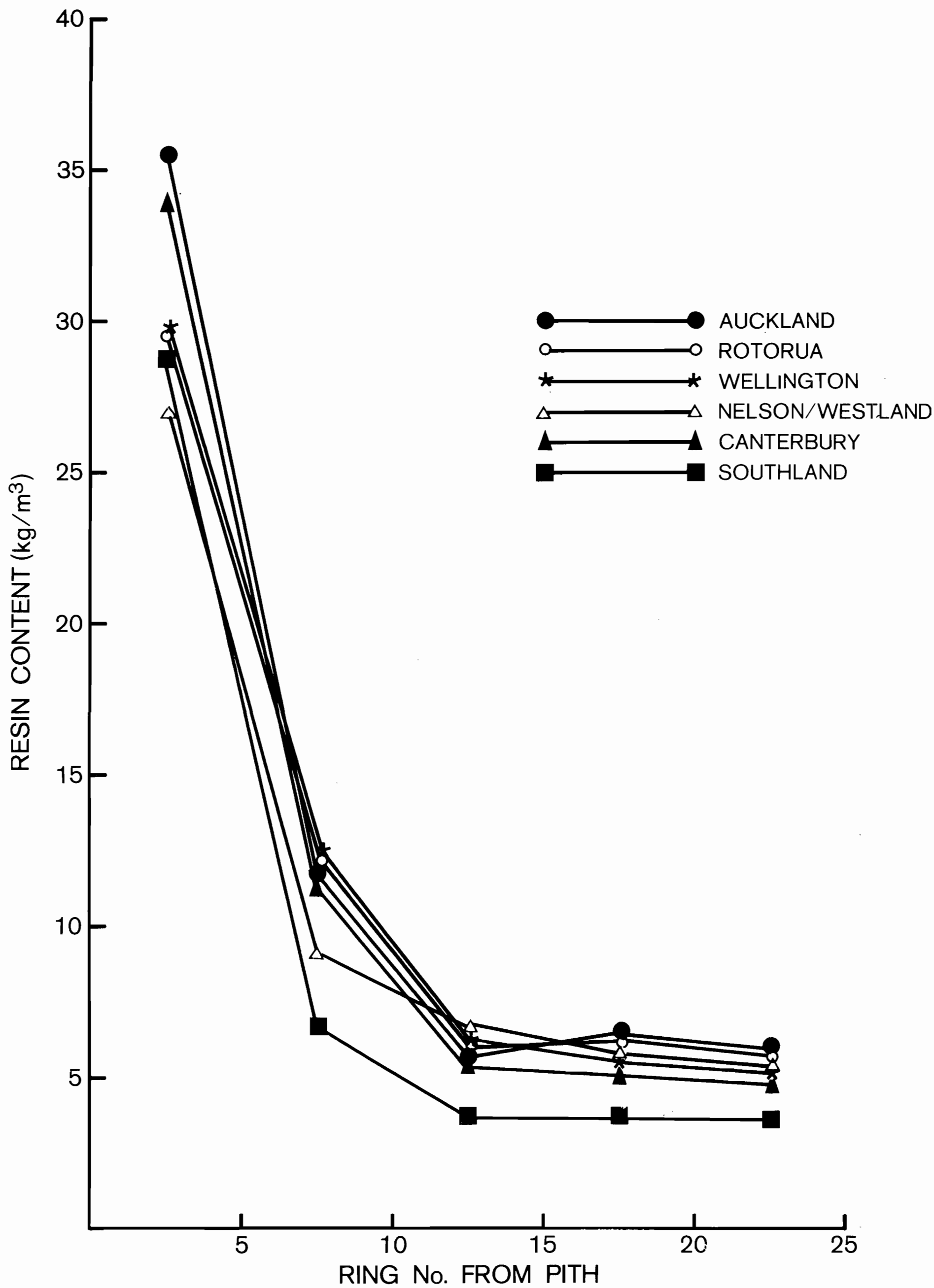

FIG. 5—Breast height resin content by regions.

of strict silvicultural regimes. However, it has been noted that a mild form of compression wood may form circumferentially after growth stimulation (Cown 1974). Some fragmentary data to hand suggest that compression wood levels are currently highest in the areas of above-average density, i.e., Auckland, coastal Rotorua, and coastal Nelson.

PREDICTION OF PAPER PROPERTIES FROM WOOD PROPERTIES

Kibblewhite (1981) used corewood, slabwood, and composite samples to derive models for the prediction of paper properties from wood properties. Based on this material from 9 52-year-old trees from Kaingaroa Forest, the data showed good correlations, and it was suggested that information on wood properties could be used to predict paper quality countrywide.

Slabwood density was shown to be highly significantly correlated with tear index ($r^2 = -0.58$) and together with tracheid length, gave a good predictive model ($r^2 = 0.86$). In corewood samples, density alone gave the best regression ($r^2 = 0.43$). For burst index, density explained most of the variation in slabwood ($r^2 = 0.90$) but with corewood both density and tracheid length were influential, together explaining 64% of the variation.

The data in Table 3 were calculated using regional property averages and the predictive models for corewood and slabwood.

Data from several unpublished Forest Research Institute studies confirm the trends shown in Table 3. Lloyd (pers. comm.) pulped slabwood (409 and 410 kg/m^3) and pulplogs (339 and 354 kg/m^3) from Rankleburn and Catlins Forest in Southland and recorded tearing strengths of 15.6–18.4 $mN.m^2/g$ (slabwood) and 12.4–13.8 $mN.m^2/g$ (pulplogs). Representing the other end of the density scale, kraft pulps from 13-year-old Northland radiata (slabwood — 416 kg/m^3; pulplogs — 370 kg/m^3) also indirectly confirmed the predictions (Corson, unpubl. data). Additional data for Southland and Bay of Plenty export chips and for 25-growth ring roundwood samples from throughout New Zealand show similar overall trends (Uprichard, pers. comm.).

Tear index is considered to be a factor of critical importance for several grades of paper and it can be seen that both site and wood age (position in the stem) have a very significant effect. Data given for the high and low density sites in each conservancy help show the extent of variability anticipated. For slabwood, there appear to be 3 broad regions capable of producing pulp with different inherent characteristics under the conditions specified in Table 3 (i.e., 2000 PFI rev., 10% consistency, and 1.77 N/mm applied load); these are Auckland (tear 28–34 $mN.m^2/g$), Rotorua, Wellington, and Nelson/Westland (tear 20–27 $mN.m^2/g$), and Canterbury/Southland (tear 14–21 $mN.m^2/g$). Differences in tear appear to be less pronounced for pulp logs and values were estimated to range from 17 for high-density northern sites to 12 for low-density southern sites. At the same time, burst values were calculated and showed reverse trends ranging from 5.3 to 6.9 $kPa.m^2/g$ in slabwood samples and 7.2 to 8.2 $kPa.m^2/g$ in pulp logs (Auckland and Southland data respectively). It is noteworthy that the minimum burst which can be obtained (before refining) by many of the 9 corewood pulps was about 7 $kPa.m^2/g$ (Kibblewhite 1980). Thus, corewood tear index cannot be determined by extrapolation of tear/burst relations below this burst value.

TABLE 3—Predicted kraft pulp paper properties

Conservancy	Average wood properties: Density (kg/m³)	Average wood properties: Tracheid length (mm)	Handsheet properties at 2000 PFI rev.: Tear index (mN.m²/g): Mean[1]	Tear index: Mean[2]	Tear index: Low density site[2]	Tear index: High density site[2]	Burst index (kPa.m²/g)[1]
Slabwood[3]							
Auckland	485	4.5	30	31	28	34	5.3
Rotorua	450	4.1	26	23	20	26	6.0
Wellington	425	4.3	23	23	20	27	6.6
Nelson/Westland	450	4.1	26	23	20	27	6.0
Canterbury	415	3.8	22	16	15	21	6.8
Southland	410	3.9	22	17	14	20	6.9
Pulplogs[4] (200 mm s.e.d.)					[1]	[1]	
Auckland	420	N.A.	16		15	17	7.2
Rotorua	400	N.A.	15		13	16	7.6
Wellington	380	N.A.	14		13	15	8.0
Nelson/Westland	400	N.A.	15		14	16	7.6
Canterbury	375	N.A.	14		13	15	8.0
Southland	365	N.A.	13		12	15	8.2

N.A.: Data not available

[1] Based on wood density alone

[2] Based on wood density and tracheid length

[3] Slabwood densities estimated from breast height (b.h.) outerwood values by subtracting 15 kg/m³. Tracheid lengths derived from b.h. outerwood values by adding 0.5 mm to allow for the increase with stem height

[4] Densities derived from a regression relating b.h. outerwood and pulplog densities (unpubl. results)

Differences between the kraft handsheet properties of pulplogs from throughout New Zealand are generally small when compared with slabwood material (Table 3). Thus, wood utilisation options must be greatest in regions which can produce high density slabwood and low to medium density pulplogs and thinnings.

CONCLUSIONS

Of the wood properties affecting the pulping process and paper properties, wood basic density is by far the most important, both as an independent variable and also because of its close association with other wood properties within stems. Basic density influences transport costs, energy inputs in pulping, and handsheet quality. In radiata pine there are highly significant variations in density within and between geographic regions, and these are reflected in the conservancy tree mean values (at age 30 years) which range from 455 kg/m^3 (Auckland) to 380 kg/m^3 (Canterbury), i.e., a difference of 20%. In simplistic terms this represents a 20% increase in wood consumption per tonne of pulp between the two extremes.

Tracheid lengths have also been shown to decrease from north to south but in a less predictable fashion than for density. Similarly resin content and compression wood tend to have lower values at higher latitudes.

These close associations between wood and paper properties, with regard to kraft pulps, means that the wood from different regions has very different potentials for papermaking. To make maximum use of the raw material and to make quality end products it is essential that the wood resource is matched with the end-product requirements. For instance, it would be unrealistic to expect that high tear kraft pulp could be consistently produced from Canterbury or Southland radiata pine wood. Alternatively, the low density wood from these regions would be an excellent raw material for producing light-weight, high density papers, tissues, and other specialty products such as "saturating base" and the softwood component of "fine writings" (Kibblewhite 1981).

One of the factors which has not been quantified, but is known to be significant is the uniformity of the wood supply. Both wood density gradients and site-to-site variations are less apparent in Canterbury/Southland than elsewhere, and hence inputs to mills will have more uniform properties. This may well increase the overall efficiency of the pulping and papermaking processes.

Variations in resin content would affect the yields of pulp and tall oil. As extractives decrease, pulp yields increase and recovery of oils decreases. The change in sapwood resin content from north to south would affect pulp yields only marginally but could reduce tall oil production considerably.

The incidence of severity of compression wood in future radiata pine wood supplies is expected to be less than in the old-crop material (e.g., up to 10–15% by volume). Consequently the deleterious effect of compression wood on pulp yields will be minimal.

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