EVALUATION OF WOOD QUALITY IN NEW ZEALAND RADIATA PINE

DR. JOHN WILKES

1987 GOTTSTEIN FELLOWSHIP REPORT

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Bill Gottstein was an outstanding forest products research scientist working with the Division of Forest Products of the Commonwealth Scientific Industrial Research Organization (CSIRO) when tragically he was killed in 1971 photographing a tree-felling operation in New Guinea. He was held in such high esteem by the industry that he had assisted for many years that substantial financial support to establish an Educational Trust Fund to perpetuate his name was promptly forthcoming.

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INTRODUCTION

The Fellowship provided an opportunity for the author to assess the methodology and role of radiata pine wood quality research in New Zealand (NZ). The study tour involved discussions with researchers - regarding the techniques used in past projects, and with representatives of industry - concerning the extent to which the research results have benefitted those processing the resource.

Concept of Wood Quality

The quality of wood - its suitability for particular purposes - is governed by a variety of anatomical and chemical characteristics. In softwoods, three structural attributes have attracted most attention: the cross-sectional dimensions of tracheids (crudely reflected in gross wood density), tracheid length and grain inclination. Numerous papers describe the pronounced effects of these factors on the performance of wood in both solid and reconstituted form (e.g. Bamber & Burley 1983, Kibblewhite 1985). Chemical factors such as extractives content and the proportions of cellulose and lignin are typically seen as somewhat less important in the utilisation of coniferous species.

In this report the term wood quality is used in the conventional sense to refer to the attributes of clear wood. Attention is directed in particular towards wood density.

History of Wood Quality Assessment in Australasia

Reviews such as those of Bamber & Burley (1983), Lavery (1986) and Wilkes (1987) cite numerous studies of the wood properties of radiata pine grown in Australia. However, the majority of these works could be classified as 'intensive', dealing with a relatively small number of trees, and covering such topics as within tree variation and heritability of wood characteristics. There have been few 'extensive', resource assessment type studies.

Conversely, in NZ there is a solid history of forest assessment for wood quality (e.g. Harris 1965, Cown & McConchie 1982, 1983, Cown et al. 1984). Not only have the broad scale geographic patterns been quantified, but attempts have been made to determine the causes of the variations through assessment of environmental factors. Some of this work appears to have been of considerable practical importance as suggested by the involvement of industry in certain of the studies.

The Study Tour

It was the contrast in experience between countries noted above that provided the impetus for the trip. Clearly, before considering in depth resource assessment in this country we should examine the relevant methodologies used in NZ. Even more important is the gaining of an industry perspective on the subject e.g. what wood properties deserve most attention, and in what detail do the variations in these properties need to be understood? The wood processing industries in NZ are relatively consolidated and most have a long history of close association with a centralised research station [the Forest Research Institute (FRI), Rotorua]. Such a system is readily amenable to outside scrutiny in that it is of manageable complexity and both research and industry personnel are 'informed'.

Against this background a programme was developed to allow discussions with a wide cross-section of research and industry representatives. While the talks touched on numerous aspects of the forestry/forest products interface, this report is confined to the wood quality theme. Inevitably an overview such as this belies the considerable divergence of opinion that exists in relation to many of the topics addressed. Virtually all discussions with industry personnel concerned sawmilling and pulp and paper, a fact reflected in the structure of this report.

STUDIES OF THE WOOD PROPERTIES OF RADIATA PINE IN NZ

Methodology

Essentially standard laboratory procedures are used at the FRI for determination of wood properties e.g. the maximum moisture content technique for density. These methods need not be discussed further. What is unique in NZ is the development (by D. Cown and co-workers) of highly efficient field procedures enabling the detailed prediction of resource properties in a reasonable time frame. Wood density has received most attention, and the discussion below refers particularly to this characteristic.

The initial step is to subjectively stratify the forest(s) and locate stands which give a satisfactory coverage of the resource as a whole. Stands which are in some way unusual because of site or management factors may also be included. Thus depending on the extent and purposes of the survey, areas of forest smaller than 1 ha may be chosen in some cases, while in others the sampling intensity may be lower than 1 site per 1000 ha. Stands > 15 yrs old are usually selected.

A two stage sampling procedure is employed:
* Stage 1 - Increment Cores. Approximately 20-30 trees are randomly selected per site. From each stem, one or two increment cores are removed at breast height (BH). These may extend from bark to pith, or include the outer rings only. After subdivision into five ring components, the samples are treated with methanol to remove resin, and finally saturated with water to allow determination of density. It is then possible to group sites into broad density classes e.g. on the basis of the outer five rings of 25 yr old trees, mean values > 475 kg m-3 might be taken to indicate high, 450-475 medium and and < 450 low density. Outerwood density/age regressions are then derived for each density class and/or for individual forests (Fig. 1).

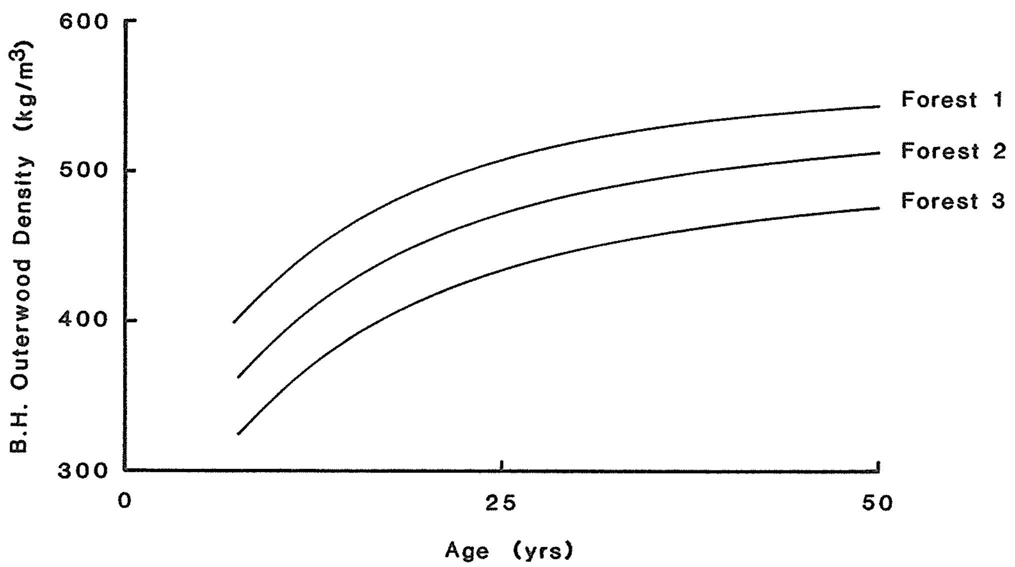

Fig. 1. An example of the associations between age and BH outerwood density for three forests.

* Stage 2 - Discs from Felled Trees. Selected trees are subsequently felled in stands representing each of the chosen density classes. Here the sampling intensity is much lower e.g. 10% of the original sites, and five trees per site. Discs 3-4 cm thick are removed at stump height, BH and at 5 m intervals along the bole to a top diameter of 10 cm. In the field, the diameters of each disc under and over bark, and of the heartwood, are recorded. A portable electronic balance facilitates rapid field determination of disc weight with and without bark. For determination of disc volume, a deep, narrow trough is filled to maximum capacity with water; the disc is then submerged and the water flowing through an outlet pipe collected and weighed. Discs are finally weighed oven dry in the laboratory.

On the basis of the disc information, a computer program calculates properties such as basic density, green density, moisture content and heartwood percentage for individual logs and cumulatively for each tree. Various useful ratios can also be readily derived e.g. under bark green volume to over bark green weight and under bark dry weight to under bark green weight. Wood properties such as volumetric shrinkage, tracheid length and resin content are often determined selectively on the disc samples.

The following assumptions are made:
* The sole distinguishing characteristic between saw and pulp logs is size; the boundary is 25 cm small end diameter (SED).
* For sawlogs, all wood within a cylinder equivalent in width to the SED will be sawn; slabwood lies outside this boundary. Extra discs may be collected and split into slab and saw wood for separate wood property determinations.
* For each wood property, the average for a log is given by the mean of the values from the discs at either end, weighted by cross-sectional area.

The final step in the analysis is to develop regressions linking BH outerwood density to the density of the various tree components (Fig. 2).

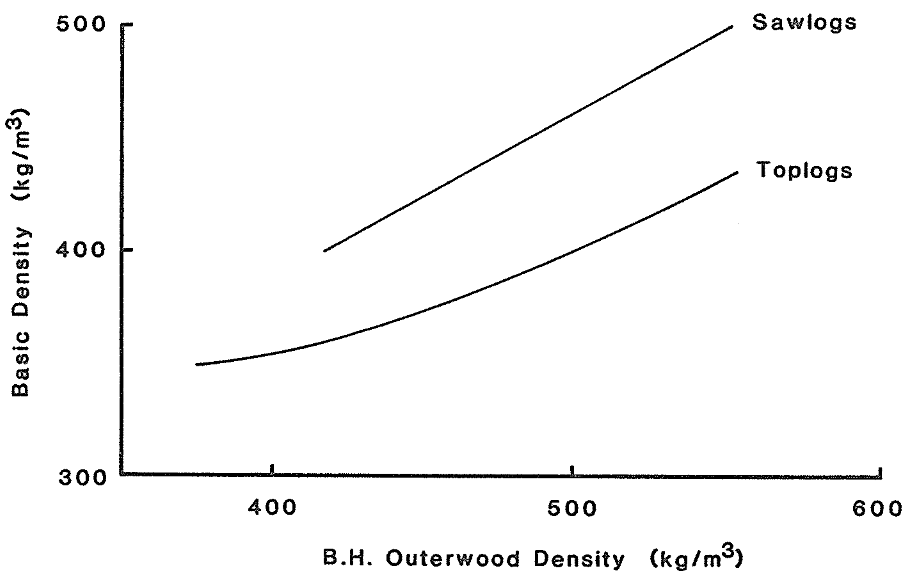

Fig. 2. An example of the association between BH outerwood density and the density of stem components.

It is then possible to predict component densities for any stand given that the relationship between BH outerwood density and age is known from Stage 1 (Fig. 3).

Stage 1

↓

Broad scale variation in BH density across the resource

Stage 2

↓

Relationship of BH density to stem component densities for comparatively few trees

↘ ↙

Detailed prediction of stem component densities across the resource

Fig. 3. The two stage sampling technique for density.

Results

There are numerous reports detailing wood property variations in NZ grown radiata pine (e.g. Harris 1965, Bamber & Burley 1983, Cown & McConchie 1983, McConchie & Cown 1984). The results relating to structural characteristics are briefly summarised here for reference in this report. Pronounced variations have been found at three levels - within stems (age effect), between trees (genetic effect) and between sites (environmental effect).

* Age-related variation. At all levels in the stem, density and tracheid length increase through a juvenile period, and eventually tend towards a constant value in mature wood (Fig. 4). Grain angle is at a maximum near the pith and minimal in mature wood.

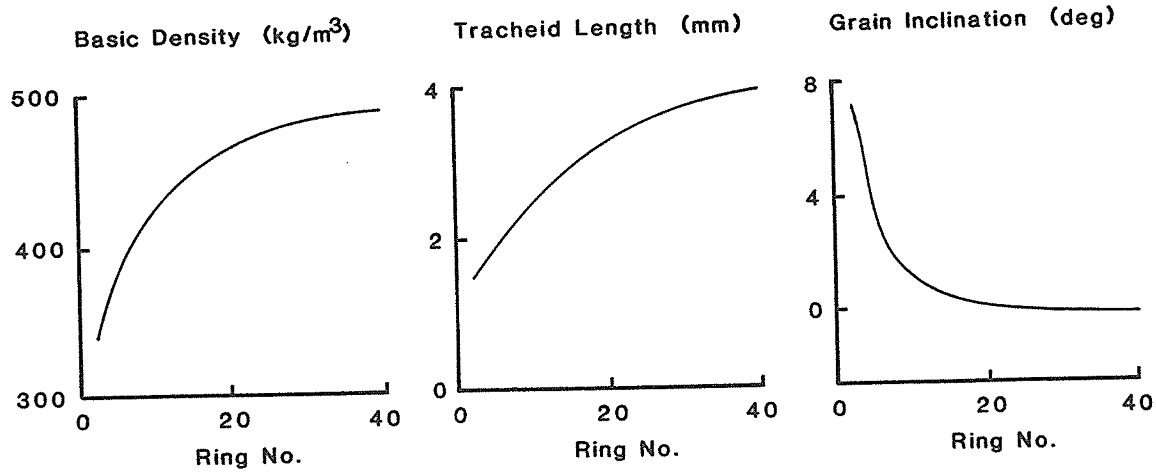

Fig. 4. Radial variation in wood properties of radiata pine.

* Genetic variation. For each of the three structural characteristics, variations between neighbouring trees in a stand can easily exceed 20%.

* Geographic variation. While there is little evidence of major effects of the environment on grain angle, differences between sites in density and tracheid length can be striking (> 20%). Both properties appear to be substantially influenced by temperature. Outerwood density decreases by ca. 10 kg m-3 per 1° rise in latitude or 100 m rise in altitude, with the result that relatively simple density zones can be defined across the country (Fig. 5).

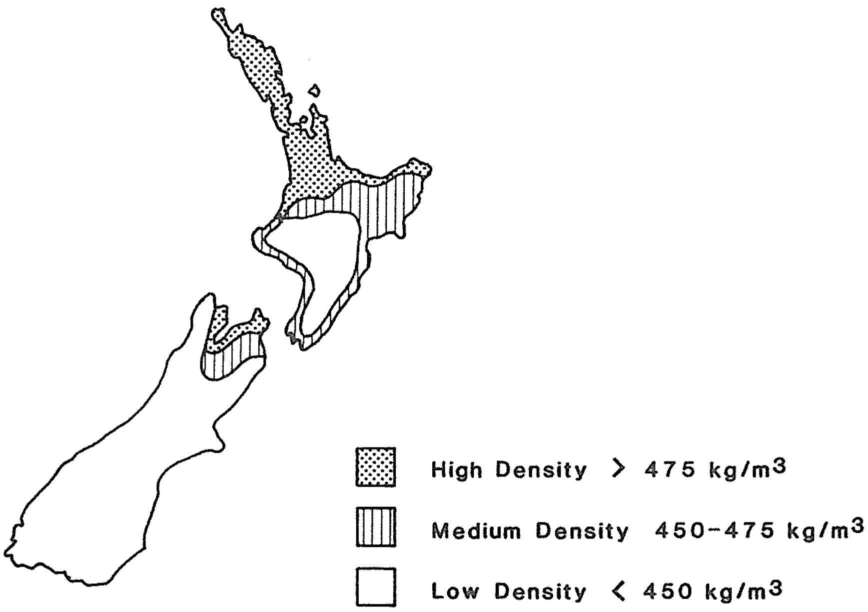

Fig. 5. Outerwood density zones in NZ.

A similar, although somewhat weaker, positive association has been detected between mean annual temperature and tracheid length such that radiata pine growing in the northern locations tends to produce wood with the longest tracheids.

Information concerning tree component densities, encompassing effects of tree age and site, is presented in many forms; Figures 6 & 7 are examples.

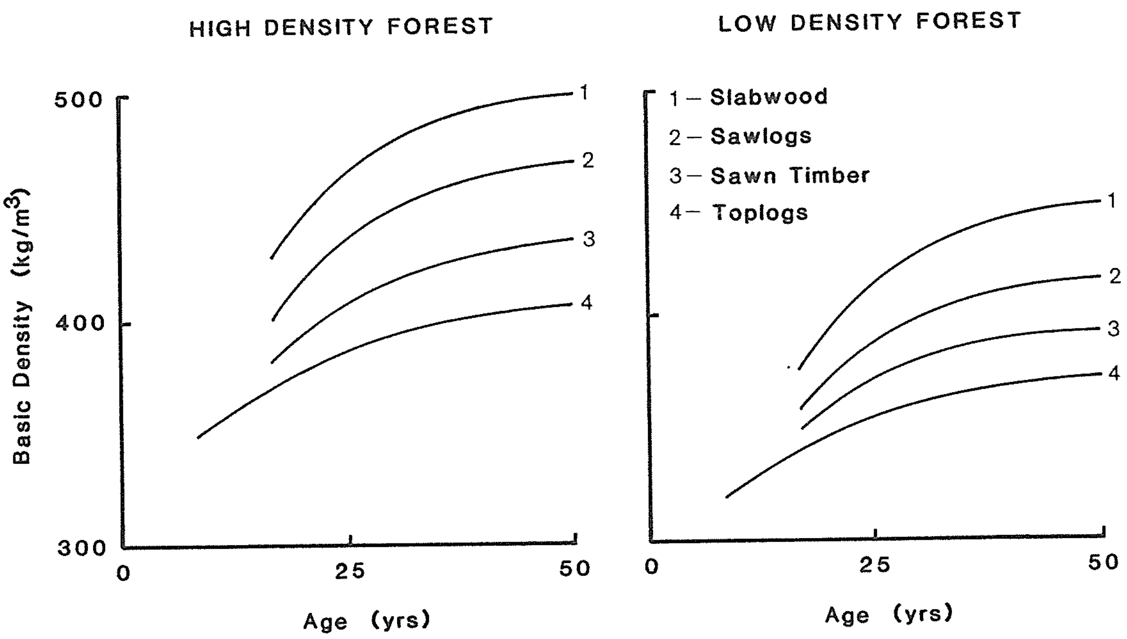

Fig. 6. Examples of the effects of tree age on the density of stem components for high and low density forests.

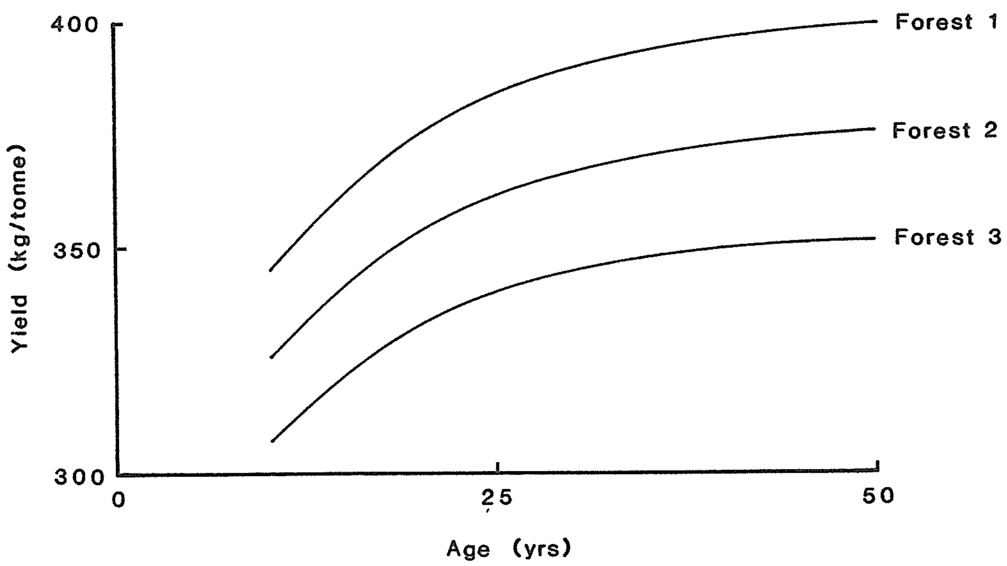

Fig. 7. Example of the effect of tree age on yield (kg dry per tonne green) from toplogs in different forests.

The more extensive surveys have also provided useful information in relation to other wood properties. Most importantly:

* The rate of heartwood development varies relatively little with site although it is apparently somewhat reduced in southern latitudes.
* Environmental variation in the resin content of sapwood and heartwood (1-2% and 2-10% respectively) is similarly limited, although sapwood values may be slightly lower in southern locations.
* The moisture contents of heartwood and sapwood are ca. 40% and 140-180% respectively. The degree of saturation in sapwood is relatively constant at 85-95%, and thus an inverse relationship exists between basic density and moisture content i.e. the variations in basic density described earlier are accompanied by converse variations in sapwood moisture content.

The findings suggest that the current trend of reducing rotation lengths from > 50 yrs to 20-30 yrs will have major ramifications in relation to wood quality. These flow from the inevitable increases in the proportions of juvenile wood and sapwood in harvested material. Averaged across the resource, effects (of ca. 5-10%) will include an increase in green density and decreases in basic density and tracheid length. It can also be assumed that average grain angles will increase significantly in the relatively juvenile material.

BENEFITS TO INDUSTRY FROM THE PROVISION OF WOOD QUALITY DATA

While obviously a fundamental adjunct to wood quality research, it is exceptionally difficult to accurately assess the extent to which findings have affected industrial practice. It is frequently said that a resource can only be utilised effectively if its properties are thoroughly understood, but do the benefits of procuring the information match the costs involved? As noted previously, the link between industry and research has traditionally been strong in NZ and hence if the generation of wood quality data can aid significantly in the conversion and utilisation of radiata pine, this should now be evident.

Different sectors of the industry are, of course, in different positions to respond to advances in understanding the nature of their raw material. For the purposes of this discussion, the industry is assumed to be comprised of sawmilling and pulp/paper manufacture.

Sawmilling

The sawmilling industry in NZ is generally not sophisticated and, for a variety of reasons including the comparative strength of the NZ currency, is in financial difficulty at present. Related to this is the fact that machine stress grading (MSG) has undergone a dramatic decline in recent years. Two factors are involved:

* There is a long history of visual grading in NZ, and it is well understood in the construction industry. Consequently, when the local market is depressed, as at present, visually graded material is most easily sold. Machine graded timber for local consumption requires a visual over-ride (to remove apparently unacceptable pieces), making the whole process inefficient.
* The countries to which the timber is being exported are generally not demanding MSG. This is largely because the lumber is typically of low grade e.g. F5 structural timber to Australia and packaging to Japan. High quality timber is also exported, but as finishing grades where strength classification is not important.

Thus sawmillers are much more concerned with defects (such as knots and resin pockets) which affect the appearance of timber than the intrinsic properties of clear wood. As a result, an appreciation of the considerable effect of density on the strength of both clear and knotty timber is not matched by actions to take this property into account in processing and marketing.

There is, nevertheless, a widespread view that while radiata pine is a very versatile raw material, it is marginal by world standards for many applications. In Australia and NZ we have learnt to cope with it. Importers in other countries have not, and are quick to compare radiata pine with traditional timbers exhibiting close rings and small knots, including Douglas fir and spruce. This represents a major problem for the NZ industry in that production of radiata pine will double by the year 2000 (to ca. 20 mill. m-3 p.a.) and the domestic market is already saturated. Gaining the necessary access to many of the potential markets for structural grade timber will require a high level of quality control including certification of stress grade. MSG will therefore probably be resurrected in the not-to-distant future, and concomitantly, density variations should attract more attention. It is significant that certain operators are already pondering the advantages of locating future mills in the higher density (northern) zone of the country. Australian millers have shown considerable interest in software produced at the FRI which, amongst other things, predicts grade outturn from logs where various characteristics, including basic density, can be specified. Presumably the NZ operators will eventually follow suit.

Some researchers are concerned that susceptibility to distortion during drying may be considerably greater in new than old crop timber. However the industry is generally content to contribute this entirely to the greater proportion of juvenile wood (and hence greater average grain angles) in the raw material. Thus existing technology, in particular high temperature drying, can be used to minimise the problem. Indeed there is a recognition that when radiata pine was first harvested in significant quantities in NZ, the average age of the material (20-30 yrs) was similar to that of today's 'new crop'. If the propensity for juvenile pine to warp could be dealt with 30 years ago, it should not cause major problems now. What is probably more important than the drying degrade is the higher average moisture content of new crop timber, resulting in increased energy requirements, and schedules 25-50% longer for seasoning. The industry accepts that it will simply have to live with this problem i.e. their plight is improved little by researchers reminding them of what to expect.

Pulp and Paper

In the pulp and paper industry there is a much stronger appreciation of the effect of anatomical properties on efficiency of conversion and product quality. This is understandable in view of the fact that paper producers work almost exclusively with a raw material reduced to its cellular components. The recognition of the importance of wood quality is reflected most obviously in the segregation of mill input into density lines e.g. high - > 410 kg m-3, medium - 400±10 kg m-3 and low - < 390 kg m-3. This differentiation is effected, not by assessing the density of each load of delivered wood, but by reference to established age-density curves. In some cases, geographic location of the supply forests is also taken into account. The gains to be made by the segregation are seen as easily outweighing the very considerable handling costs involved e.g. in the maintenance of three separate chip piles.

The principal benefits of the segregation are seen as follows:

* Processing efficiency. The two main mills in NZ are sufficiently large to have a number of options as to how the incoming raw material is processed. For example, low density, short fibred juvenile wood may be directed to stone groundwood pulping (to which it is particularly suited) in preference to refiner treatment which is more appropriate for mature wood. It has been found that juvenile wood does not pulp as well as mature wood in continuous digesters and hence there can be gains in directing young material through a batch system. There are numerous other examples, however it is clear that to maximise the production efficiency of technologically advanced processing equipment, careful division of the raw material on the basis of variations in intrinsic wood properties is essential.
* Product quality. The outstanding effects of tracheid dimensions on the quality of radiata pine pulps and papers have been well established (e.g. Kibblewhite 1985). Thus the long, thick walled tracheids of mature wood favour tear strength and therefore the production of sackkraft, while writing papers with good surface properties are best produced from a lower density material where tracheids are relatively thin walled and conformable. Such effects are so pronounced that it has been found impossible to produce satisfactorily uniform lines of paper when different raw material types are mixed indiscriminantly. In this respect, the industry has no choice but to accept segregation according to formative age.

Pulp and paper manufacturers are also acutely aware of the importance of geographic variation in wood properties in locating processing plants. Thus, any future sackkraft mills will preferentially be situated in the northern (high density, long tracheid) zone, while the production of tissue and fine writing papers is likely to occur elsewhere.

In all quarters there is much interest in the major effects of density on transport costs and processing variables such as digester throughput (Hall 1981). The related factor of sapwood moisture content is important both because of its 'nuisance value' in the selling and transport of roundwood, and because it influences pulpability. It is unfortunate that in these areas, many logistical factors (e.g. the inevitable mixing of incoming chip lots) impinge, such that relatively little can be gained by knowledge of variations in density and moisture content in the resource.

The traditional view that dense wood is generally superior to lower density material in paper manufacture is gradually being replaced by the realisation that most of the important grades of paper (including fine writings and newsprint) are best made from a low-moderate density resource. The gradual decline in the market for high strength kraft (wrapping paper) has reinforced this change in emphasis. Delineation of wood density zones across the resource will thus take on a new importance if efforts are made in the future to concentrate the production of papers and structural timber in low and high density regions respectively.

The pulp and paper industry of Australasia is technologically advanced at least in comparison with most other forms of wood processing. As a consequence there is, in NZ, a body of opinion that rather than growing trees to suit existing technology, it is preferable to develop processing methods to suit the raw material. In either case, variations in wood quality must be clearly defined.

Other Processes/Products

The significance of variations in wood properties in the production of plywood, medium density fibre board, particle board and the like appears to lie variously between the extremes of sawmilling and pulp and paper. However, as a broad generalisation, it seems that processing factors, e.g. press characteristics and the quantity of adhesive, easily over-ride wood properties as determinants of mill efficiency and product quality.

CONCLUSIONS

Summary of Information Gathered

* Through the efforts of wood quality researchers at the FRI, a great deal is now known concerning variations in the intrinsic wood properties of radiata pine in NZ. The work culminated a few years ago in the development of a highly efficient two stage sampling technique which allows detailed prediction of density and other technologically important properties for various components of stems, including sawn timber, slabwood and pulplogs.

* The sawmilling industry in NZ is less than enthusiastic regarding traditional wood quality research. This situation is largely a consequence of the failure to employ MSG, with the result that variations in strength relating to the same in density are not recognised. Defects which affect appearance are all-important. There is a 'lukewarm' interest in geographic variation in density and in the extent of the spirally grained core in new crop trees.

* The pulp and paper industry is vitally concerned with age-related and geographic variations in density; tracheid length, which varies similarly with age and environment, is less critical. Segregation of raw material according to density (and tracheid length) class is standard practice, a process which involves the use of a large portion of the data generated at the FRI e.g. tree component properties for various stand ages and sites.

* In relation to density, tracheid length and spiral grain, there is a general view in the industry that resource evaluation work done at the FRI has been excellent, both in quality and quantity. Thus, for tracheid length and grain inclination, only a relatively broad picture of within tree and geographic variations is needed, while much more is required for density where pulp operations are involved e.g. stem component analysis. However there is also recognition of the fact that further work of the same type would not be cost effective. This was realised some years ago at the FRI with a resultant shift in emphasis from wood quality to wood processing.

Implications for Australia

* As a broad generalistaion, it seems that the practical importance of variations in the wood quality of radiata pine is similar in Australia and NZ. For the large part Australian pulp mills have less options in processing than their NZ counterparts, and interest in wood property variations is possibly reduced on that count. However, this is counterbalanced by a greater use of MSG and consequential concern regarding the non-uniformity of density in structural timber.

* The tour has reinforced the author's view that there is a need for extensive study of environmental and age-related variations in the density of Australian radiata pine. This should preferably take the form of a single project, even if it is necessary to limit sampling intensity in each state. Were political or funding considerations to prohibit an Australia-wide effort, intra-state studies could be readily justified. Current work by the author involving the detailed analysis of samples from 22 sites across N.S.W. should go some way towards meeting the needs of industry.

* Australian researchers and those potentially supporting studies of the wood quality of radiata pine in this country should not be discouraged by what might be perceived as complexities in the NZ approach e.g two stage sampling and stem component evaluation. A much simpler method such as increment coring alone could be used to great effect. Indeed it would seem that the marginal rate of return of wood quality studies (in terms of benefit to industry) tends to decrease as sampling intensity increases. The important point is that results are presented in a form meaningful to industry e.g. a graph showing pith to bark variation in density at breast height is not nearly as valuable as one indicating change in average tree density with age (yet the curves may appear very similar).

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