WOOD QUALITY OF RADIATA PINE ON FARM SITES — A REVIEW OF THE ISSUES

Piers Maclaren
(Piers Maclaren & Associates Ltd)

Report No. 80 **May 2002**

FOREST & FARM PLANTATION MANAGEMENT COOPERATIVE

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EXECUTIVE SUMMARY

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Given that more than 60% of the stumpage value of clearwood regimes lies in the pruned butt log, and that clearwood regimes are the most popular current choice, it is imperative to establish and guarantee the quality of this key component. The downgrading effect of one inferior consignment is not limited to that consignment, but—in the absence of product segregation—can adversely affect the whole market. The main features that limit the marketability of pruned butt logs, other than Pruned Log Index, are resin pockets and other resinous features, internal checking and stability in processing-and-use.

Regarding resin pockets, there is no evidence at time of writing that the incidence is greater on farm sites, except where such sites coincide with low stockings. Correlation of external resin bleeding/lesions and log end pockets/blemishes with internal resinous patches may offer a relatively simple way both of segregating the resource and (later) identifying clues as to the causes of this problem. Severely affected trees could be eliminated at time of pruning and crop selection, and mid-rotation inventories could include a quality assessment based on resin incidence.

Regarding internal checking, there is no evidence that checking is worse on farm sites than elsewhere. Internal checking can possibly be reduced by increasing the rotation age and/or development of more appropriate drying schedules. For the latter, there needs to be a cost comparison of decreased inventory turnover as against market degrade. More work needs to be done on establishing the basic causes of checking. A minority view implicates nutrient deficiencies, including boron deficiency.

Stability in processing and in use is a major issue for all types of solid-wood product, whether for structural or appearance. There are many causes of wood instability, ranging from the macro to the molecular scale. Pending basic physiological work on the topic, it may be important to minimise compression wood by ensuring straight trees and balanced crowns. Extreme microfibril angles can be identified by SilviScan-2 technology and minimised by resource segregation or ultimately by tree breeding. On farm sites, there is good evidence that some causes of instability and distortion are

more prevalent: these include spiral grain, steep microfibril angles, high moisture content and compression wood. Wood density is also lower, but this should improve stability, all else being equal.

The unpruned logs on farm sites appear to present an intractable problem. They are particularly unsuited for structural uses, and—due to short internodes both as a result of genetic selection and of farm sites—do not yield a good outturn of cuttings grades. Persistence of high nitrogen levels could cause second-rotation crops on ex-farm sites to exhibit similar properties, but the problem could be ameliorated in future plantings through genetic control. Research should be intensified into genetic stock suitable for farm sites. No suggestions are offered for the existing resource of unpruned logs on farm sites. Unless there is an unexpected upswing in demand for pulpwood or biofuels, there may be no market for much of this material.

Lastly, wood quality is of sufficient importance to affect the whole sector, but is only one of the issues scrutinised by the Forest & Farm Plantation Management Cooperative, which has a budget corresponding to just over one full-time scientist-year. The Coop's best approach may be to co-ordinate fundamental research with the proposed FIC Wood Quality Initiative, which plans to operate on a budget ten times the size. The Coop's most useful contribution may relate to the farm-site effect.

Contents

Introduction

New Zealand radiata pine is a superior species for many uses. In a NZFRI study it performed as well as, or better than, 13 common North American species, for planing, shaping, turning, cross-cutting, boring, sanding, gluing, and hardness[1]. It was quite good at mortising, finger-jointing, nail-withdrawal, nail-splitting, and screw-splitting. In stability, it performed similarly to many species but significantly inferior to sugar pine and Douglas-fir. Other studies have compared radiata pine to "high performers" of target Asian species[2] or other species[3,4,5] with similar results.

When discussing the (few) deficiencies of New Zealand radiata pine clearwood especially with challenging sites or regimes, the debate should be kept in context. It is rational to focus on problems, because that is the way progress is made, but care needs to be taken to avoid highlighting the problems unduly.

Why a review?

Current practices of new land planting on farm sites, possibly combined with short rotation lengths, low stockings and genetic stock selected primarily for improved growth and form, have frequently raised concerns relating to the internal wood quality of this expanding resource. The Forest & Farm Plantation Management Cooperative has commissioned this review to summarise and clarify the issues.

In keeping with the FRST and FR policy directions, the Coop has recently increased its emphasis on internal wood quality. It is self-evident that a low quality product may not achieve good prices, and—indeed—may even be unmarketable. There are concerns relating to the existing resource, much of which has been planted on ex-farm sites, but there are also concerns regarding the future resource, most of which is expected to occur on such sites.

There have been four Wood Quality workshops and a large number of papers and Coop reports on this theme, so there is a need to condense the information into a single document. Most Coop members have wider interests and cannot take the time to read and summarise the material in its entirety.

Lastly, there are also (perceived) conflicts in attitude among the protagonists. It is human nature to place greater importance on research results in one's own specialist area of expertise and to discount the findings that occur elsewhere. To some extent, a useful review should not "take sides" but identify the critical discoveries regardless of their origin.

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[1] Anon 1994
[2] Turner 1998
[3] Kerr 1996
[4] MOF 1988
[5] Young 1988

Brief background to the wood quality debate

The issue of wood quality has been approached from different directions, and the backgrounds of researchers or foresters may influence their current attitudes. At the one extreme there are specialists in wood quality who (naturally enough) tend to rank the issue as being of paramount importance. Some traditionalists may regard the 1960's "old crop" (long rotation ages, tight stockings, unimproved genetics) as being the pinnacle of wood quality, and that progress has been retrograde ever since.

It is certainly true that the quality of structural wood from the old-crop was superior, given the limits of radiata pine. The trees were grown to long rotation ages at high stockings on relatively infertile sites. Consequently, they had small branches, with a low volume of juvenile wood and a large volume of relatively dense outerwood. Problems such as excessive taper, compression wood, high microfibril angle and spiral grain were minimised. As for appearance-grade products, clearcuttings were easily obtainable from the long internodes that commonly occurred in unimproved genetic stock.

In the other corner of the ring, there are proponents of farm-site planting, who argue that wood quality is only one of several issues relating to profitability, and that profitability is only one of the reasons for growing trees. Other potential drivers include shelter for livestock, erosion prevention, carbon sequestration, and riparian protection for water quality.

Even if the debate focuses entirely on profitability, they argue that wood quality does not necessarily take centre stage. Profitability of a tree crop depends on the stumpage price per cubic metre of wood, which presumably will—at least over the long term—have a close connection with its intrinsic properties. But profitability is also related to cost (eg lower stockings), wood volume (farm sites and modern genetics), and rapid turnover of capital (short rotation lengths). There is also the factor of risk, which includes marketing risk (eg the flexibility that clearwood provides). The "Sutton" philosophy[6] has consistently argued that the future prospects for clearwood look bright, but the world has abundant pulpwood. The argument extends to say that structural timber will not be in short supply to the same extent as clearwood[7], and that radiata pine is in any case a poor species with which to grow structural wood (medium density, large branches, weak corewood).

Being a multinodal species with persistent branches, the production of a large proportion of clearwood from radiata pine implies pruning of the butt-log. Pruning is ineffective if stockings are high, or unpruned trees (followers) are allowed to compete with crop trees for a protracted period. Pruning ties up considerable capital, increasing the pressure to reduce rotation age. It can easily be demonstrated that using prevailing costs, prices and economic criteria, the "Fenton-Sutton" direct-clearwood regime is currently the most profitable. The widespread adoption of this regime—now 51% of the entire radiata resource[8]— has resulted in a large pruned element, but with problematic top logs. This is especially the case on ex-farm sites where spectacular diameter growth of the stems is mirrored in similar growth of the branches, there being a well-known correlation between the two. Structural out-turn from top logs is further compromised in that farm sites and some modern genotypes both lead to lower density wood.

[6] Sutton 1975
[7] Sutton 2001
[8] MAF statistics 2001

The NZ Forest Accord, the Resource Management Act 1991 and the Forests Act 1993 Amendment have restricted planting of new land to ex-farm or ex-scrub sites. This occurred simultaneously with a new "planting boom" which was driven largely by small-scale forest owners or those seeking superannuation schemes. These "new players" may have assumed that they would be able to hitchhike on markets pioneered by the Corporates, and would obtain similar stumpage prices. To complicate the debate, there are some cultural differences between the traditional foresters and the new farm foresters.

What do we mean by "ex-farm" sites?

The previous land cover influences the growth of a tree crop in many ways. Ex- farm sites are characterised by a lengthy history of intensive farming, typified by fertiliser application (superphosphate), improved species of grasses and legumes, and vigorous nutrient recycling by grazing animals. Farm sites display a "High" basal area growth, as defined in the model EARLY, a module in the STANDPAK suite. Forest sites without serious nutrient or water limitations are "Medium", although the range can be Medium ±20%. Records from a number of PSPs have shown that the mere presence of grass prior to planting does not constitute a "farm site" with a High level of BA.

Available nitrogen is the element that most clearly distinguishes "farm-sites" with "forest sites". Needles on nitrogen-rich soils are longer, fatter and darker green. Presumably, they contain more chlorophyll per needle and photosynthesise more efficiently. The extra biomass of foliage generates larger branches and stem diameters. Basal area growth rates are perhaps 40% higher at least up to canopy closure, and 20% higher at harvest[9]. The average Productivity 300 Index for ex-farm sites (1737 observations) is 30.7 m^3/ha/yr, as opposed to 24.4 for ex-forest sites (3593 observations)[10]. Although it is too early for a definitive statement, it seems likely that the "farm-site effect" will persist into the second rotation, given that nutrient levels (as evidenced by the Tikitere Agroforestry Trial) are still high at the end of the first[11].

By way of contrast, a forest site may have a number of regenerating woody understorey species that compete with the planted trees. It has often received no deliberate fertilisation, and has not usually been grazed. The soil composition, structure, fauna and mycorrhizae differ[12], with some forest soils being traditionally described as *mor* whereas most grassland soils are *mull.* In New Zealand, forests have historically been sited on land unsuited to agriculture, often because of inferior soils or higher elevations. The low-nitrogen soils have tended to produce relatively straight trees with relatively small branches.

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[9] Maclaren 2000
[10] Leith Knowles, pers. comm.
[11] Knowles *et al* 2000
[12] Knowles *et al* 2000

What do we mean by internal wood quality?

Wood quality can be divided into characteristics that are externally visible on a tree, and those that are not. The former includes straightness and lack of forking; branch size and branch distribution. The latter comprises a wide range of attributes, including those at the scale of the individual fibre or cell. Among the most prominent are stiffness, strength, stability, hardness, wood density, microfibril angle (MFA), compression wood, spiral grain, internal checking, resinous characteristics (including resin pockets, blemishes, streaks and patches), needle fleck, heartwood, and colour. Some of the attributes (eg density, MFA, compression wood and spiral grain) are causative agents affecting others (eg stiffness, strength, and stability). Some defects (resinous patches, needle fleck and colour) are important only if the wood is to be used for appearance grades.

Although internal wood quality is mostly discovered only in the course of processing, some internal features can be inferred from external clues: for example, young trees grown at high altitudes in Southland are likely to have low wood density; trees with an unbalanced crown or a marked lean are likely to have compression wood; old trees have a high heartwood content; trees with external resin bleeding are more likely to have higher degrade in clearwood due to resinous characteristics.

A pruned log can contain a wide or narrow clearwood sheath, depending on when it was pruned and the small-end diameter, straightness, and the centrality of pith. Good silvicultural records, or independent assessment by the Pruned Stand Certification scheme, can enable calculation of Pruned Log Index (PLI)[13], an index of the size of the clearwood sheath. PLI can also be directly determined by appropriate sawing studies or cross-sectional analysis of pruned logs.

The realisation that farm sites differ substantially from forest sites prompted the Coop to install a large number of farm-site plots. The external characteristics of the trees could be measured relatively easily and were soon incorporated into stand silvicultural models. New data justified model refinement as recently as November 2001[14], but the branching habits of radiata pine on farm sites are reasonably predictable and have been known for many years. Comparative MARVL assessments, where characteristics of forking, stem size, straightness, and branch size are assessed at an individual tree level, have provided independent support for the STANDPAK suite of models and have enabled informed regime choices[15]. Most foresters are already well aware of the obvious deficiencies in tree wood quality of unpruned logs from farm-site trees, which is why this report focuses on internal wood quality.

The magnitude of the "problem"

The area of resource involved

This report concerns farm-site radiata pine. Although there was some planting on such sites prior to the 1990s, the bulk coincided with the latest planting boom, which commenced in 1992. Table 1 (from MAF's website, November 2001) illustrates the trends.

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[13] Park 1995
[14] Kimberley 2001; Kimberley *et al* 2000
[15] Knowles *et al* 2000

Table 1: New Land Planted (000 ha) in Production Forest since 1981

Year ended 31 Dec	State	Private	Total
1981	22	23	45
1982	19	30	49
1983	20	31	51
1984	20	36	56
1985	18	30	48
1986	15	25	40
1987	10	20	30
1988	3	17	20
1989	N/a	N/a	21
1990	-	16	16
1991	-	15	15
1992	-	50	50
1993	-	62	62
1994	-	98	98
1995	-	74	74
1996	-	84	84
1997	-	64	64
1998	-	51	51
1999	-	40	40
2000	-	31	31
2001		34 (est)	34 (est)
Total 1992-2000		588	588

The political background to the decline in state planting is well known. It is also widely acknowledged that the larger corporates invested considerable capital in purchasing the state assets over the period 1992-96 and in general either did not have the capital or were not inclined to undertake further resource expansion by new-land planting.

In contrast, there is lack of hard evidence to explain why the "third" boom in new-land planting started in 1992 (one year before the export-driven price spike of 1993). Non-corporate, private investors were the main drivers. Many of the new foresters were small landowners or members of partnerships. Changes in taxation (or, rather, perceived changes in taxation) are often postulated as a driver. Their motivation may often have been to create a superannuation fund, given the prevailing mood of uncertainty over traditional government-led schemes. Legislation in 1991 and 1993, as well as the Forest Accord, severely restricted the conversion of indigenous forest to plantations, and thereafter all new planting was undertaken on "scrub"[16], unimproved or improved pasture. Table 2 provides a breakdown of land cover prior to planting, for six successive years in the 1990s.

[16] "Scrub" can be a pejorative term, but here it is intended to include not only exotic woody weeds but also immature indigenous pioneer species that may be highly regarded by some New Zealanders.

Table 2: Land Cover prior to New Planting (Year ending Dec 31st)
(source: MAF statistics)

Previous Land Cover	1993	1994	1995	1996	1997	1998
Improved pasture	28%	49%	67%	36%	42%	44%
Unimproved pasture	56%	35%	22%	50%	44%	47%
Scrub	16%	16%	11%	14%	14%	9%

Using and extrapolating the above figures, and assuming that 90% of the new-land planting since 1992 has been radiata pine, the total area of radiata pine on improved pasture planted in the calendar years 1992-2000 inclusive is in the order of **235 000 ha**. (There may, or may not, be superior statistics available to refine this figure).

The nature of the farm-site resource

Unfortunately, current MAF statistics do not allow a detailed description of the recent resource planted on farm sites. The NEFD database is known to be weak in its treatment of small-scale growers (40-1000 ha), and in particular very small-scale growers (1-40 ha). Such growers commonly do not participate in the regular NEFD questionnaires, may not give a good response rate to irregular surveys, and often cannot accurately describe their resource in terms of Net Stocked Area, Age Class and Crop Type.

It is understood that MAF is attempting to attain better information on this component or the national estate, given its critical importance in calculations under the Kyoto Protocol. A survey of all growers with forestry > 1 ha is planned for 2002, with a sample to determine Age Structure and Crop Type in 2003. In the meantime, we must rely on subjective evaluations based on field-days and travel observations.

The debate over wood quality has been confused by failure to distinguish between the terms "farm forestry", "forestry on farm sites", "agroforestry", and "understorey grazing with low stockings". Wood quality problems may be associated with low stockings, or the combination of low stockings and farm sites, but this may not necessarily implicate all plantings on farm sites, let alone all plantings done by farmers or other small-scale growers. In the author's assessment, farm forestry in New Zealand is highly variable, with some excellent stands (well formed trees, silviculture performed on time, appropriate stockings) and also some very poor examples. The spectacular nature of the poorest component should not be allowed to dominate our thinking with regard to the entire resource.

The farming community, under the leadership of the late Neil Barr, gave rise to the Farm Forestry Association, which encouraged the planting of trees on farms. The possibility of integration of trees and pasture, including understorey grazing, was actively promoted[17]. Some proponents of this approach, including Neil Barr, strongly advocated low initial and final stockings. This was seen as a way to reduce costs and maximise the benefits of understorey grazing, while simultaneously maximising clearwood growth on individual trees.

[17] By regular columns in the NZ Farmer, and the NZ Tree Grower. Also, by the Agroforestry group at the Forest Research Institute (Maclaren 1986), and by notables such as Duncan McIntyre and Kenneth Cumberland.

In areas where there was a combination of high site index (ie height growth) and low fertility (ie basal area growth), low stockings did not seem to create major problems. Branch size was restricted by both the low fertility and the high site index. (It is still not generally appreciated that branches stop growing as a result of shading, and that most of the shading in a branch comes from the same tree: in other words, higher site index lowers branch size.) An example of a location where this fortuitous combination may occur could be Auckland Clays (eg Kaukapakapa, home of Neil Barr).

On the other hand, where there was a medium or low site index, and where the fertility levels were high (eg a Southland farm?), the effect of low stockings was disastrous. Even at the Tikitere Agroforestry Trial, which has a reasonable site index and is not extremely fertile, the disadvantages of low stockings became apparent halfway through the rotation. With a reduction in stocking, there was a loss of height growth, increase in wind damage, and an increase in branch size—even larger than originally predicted[18]. In the mid 1990s, the message went out from FRI, and was soon taken up by farm foresters, that regimes on farm sites would benefit from *higher* stockings than on equivalent forest sites, all else being equal.

The critical importance of final stocking to wood quality on farm sites is such that it would be very useful, for resource planning purposes, to use final stockings for crop-typing the national estate. In other words, rather than dividing the resource into just four categories (with and without production thinning, with and without intensive tending), further categories (eg final stocking less than 250 s/ha, 250-400 s/ha, above 400 s/ha) may be needed.

With regard to the tree-breeding programme, it is now well known that the '850' series (GF12-14) tended to have 5-10% lower density wood, largely through the dominance of Clone 55. Although the selection of plus trees commenced in 1950, the Tikitere Agroforestry Trial was one of the first to be planted (1973)in this material (GF 13-14), which was used mainly between 1971 and 1985[19]. By the 1992 planting boom, the use of '850' stock had been largely discontinued, and most new plantings were of the '268' series. The new material had largely restored the wood density. The implications are that, while the Tikitere Agroforestry Trial is immensely valuable, caution should be used to apply the results nationally if they arise from genetic factors linked to the '850' stock.

In addition to the (readily apparent) large branches on farm sites, trees on such sites tend to be crooked, especially if the planting stock is not physiologically aged. The effect on straightness of a slight increase in available nitrogen is the most obvious result from the Lincoln University Agroforestry Trial[20]—the difference is clearly visible by casual observation, without the need for statistics. Furthermore, one of the major causes of lean and sweep is toppling, which has been recognised by Coop members as a key concern on farm sites.

Nevertheless, branch size and lack-of-straightness are features that are externally visible. Provided that log specifications are sufficiently tight, they should be quantifiable in Pruned Stand Certification or in a routine MARVL inventory, and should come as no surprise to buyers and sellers. Internal wood quality is a more insidious issue, and is the focus of this report.

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[18] Knowles *et al* 2000
[19] Ridoutt 1997, p.iii
[20] Mead *et al* 1993

The wood density of farm-grown trees has often been assumed to be lower than for forest sites, as evidenced by studies at Ngatira[21] and Tikitere[22]. Until recently, it was not clear how much of this was attributable to the genetic stock ('850'), how much to the regimes (low stockings) and how much to the farm sites *per se*. Thanks to the work of Peter Beets[23] and others, we now realise that there is a negative relationship between nitrogen levels and wood density. Despite earlier assumptions that low stockings would result in low wood density, the opposite is true for whole-tree density, although the statement still holds true for outerwood density[24]. There has also been a recent trend to downplay the strategic importance of wood density *per se*, because it is not well correlated with international prices of other species and because it is only one causative agent of features (eg stiffness) of more direct interest. Density, however, still remains an easily measured surrogate for various other characteristics.

Another key concern about farm sites is resinous characteristics. The Fletcher Challenge Taupo Sawmill rejected Tikitere pruned logs because the first consignment (from the lower stockings) was full of resin pockets (G. Young, pers. comm.) The well-known Waikite shelterbelt trial[25] had an estimated 18% loss in pruned log value because of the high incidence of resin pockets (2.51/m^2).

Other internal wood quality issues that may threaten the original valuations of farm-site timber include spiral grain, internal checking, and stability. These are covered individually in later sections.

Regarding the top (unpruned) logs, the Ngatira sawing study[26] in 1990 alerted Coop members to the less-than-expected outturn in both structural and cuttings grades. Grade recovery of No.1 Framing was only 8-10% (the previous prediction was 20%) and clearcutting grades were almost absent. This discovery is likely to be confirmed by recent studies of Tikitere[27], some of which have not been completed at time of writing.

The pruned butt log

The Forest Owners' Association publishes an annual "Facts & Figures" booklet, in which it states that 60% of the value of a typical direct sawlog regime is from the 5.2 m pruned butt log. This corresponds with the results of Maclaren & Knowles[28], who calculated a figure of 65% for the proportion of stumpage value in the 6.0 m pruned butt of the 400 stems/ha treatment at Tikitere, and a much higher proportion in lower stockings. Both reports agree that industrial logs, ie pulpwood,

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[21] Cown & Knowles 1990, Knowles & McConchie 1996
[22] McKinley *et al* 2000a
[23] Beets *et al* 2000
[24] Cown & McConchie 1982. Low stockings result in "fast diameter growth rates" or large ring widths, factors which are popularly believed to lead to lower density. Confusion arises because large rings in a piece of structural timber usually originate from corewood, and invariably have lower density compared to the narrow rings of outerwood. The public debate is hopelessly muddled by the use of the term "fast growth rate" to refer to other things, such as rapid height growth, high MAI for volume or—especially—short rotation length.
[25] Tombleson & Inglis 1986
[26] Cown &Knowles 1990, Knowles & McConchie 1996
[27] McKinley *et al* 2000a
[28] Maclaren & Knowles 1999

are of negligible importance to the grower. The implication is that forest-growing in New Zealand (especially with pruned regimes on farm sites) will sink or swim on the marketability of pruned logs and the premium that they receive.

Acknowledging the dominance of pruned logs in stumpage returns, and assuming an across-the-board percentage improvement in price as a result of wood quality research, the greatest impact on the grower would seem to be in research focussed on pruned logs. Put another way, if pruned logs merely maintain their current (Dec 2001) prices (c. $\$177/m^3$ at mill or $\$147/m^3$ stumpage[29]) and all other logs achieve a zero stumpage net of clean-up costs, the result is not necessarily disastrous. Assuming a pruned volume of 149 m^3/ha at age 30[30], this equates to a stumpage of $21 903/ha. While nowhere near the $50 000 or more that some investors may have been expecting, it may still leave investors with an adequate superannuation fund. In contrast, a collapse of pruned log prices could be catastrophic for many investors.

One reviewer of the draft of this report pointed out that, in terms of physical volume, pruned logs do not dominate the resource. The implications are that downstream processing sectors may be more affected (for better or worse) by changes that occur in unpruned logs, especially if these require more intensive processing per cubic metre. The same reviewer noted that the current relativity of pruned prices to unpruned prices may not persist, and that an extra dollar of research may yield greatest benefit in improving the quality of unpruned logs. Obviously, it would be advantageous to improve the quality of all grades of wood, but given a shortage of resources it seems wise to focus on the grades that are likely to provide the most cost-efficient results.

Table 3 gives the breakdown of the entire radiata estate in terms of the four major regime types:

Table 3: Radiata management regimes as of 1999
(Source: NEFD April 1999)

Regime	Proportion
Pruned without production thinning	50%
Unpruned without production thinning	27%
Pruned with production thinning	19%
Unpruned with production thinning	4%

It can be seen that pruned regimes account for 69% of the entire estate, although it is not known whether this proportion is higher or lower on farm sites.

The quality of the pruning is likely to be variable, with many earlier stands having a high or variable DOS. Even the Tikitere Trials had an average DOS of 24-29 cm depending on stocking[31], because the principles behind timely pruning were not discovered until later. Current best practice, however, is to schedule pruning based on DOS and calliper size, to maintain good and credible stand records, and to utilise the Pruned Stand Certification scheme.

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[29] MAF mid-range statistics for Dec 2001 quarter, domestic prices
[30] Maclaren 2000
[31] Maclaren, J. P., unpublished data

Assuming that a farm-site stand has been pruned according to modern standards, and recorded for defect core (which takes into account sweep[32]), what further issues of wood quality are likely to arise? Given that the main virtue of pruned logs is the production of appearance grades, and that such grades do not traditionally demand structural qualities, we must also consider:

- Resinous characteristics
- Internal checking
- Stability in processing and in use
- Other (more minor) considerations such as needle-fleck, bark and other blemishes, discoloration.

The appearance grade market is the fastest growing market for New Zealand radiata pine[33], a fact that is recognised by the FIC Wood Quality Initiative in their proposal to promote appearance-grade research at the expense of structural grades. The key driver behind the demand is the United States, obtaining clearwood either directly from New Zealand or from clearcuttings via China and other Asian countries. This development supports the "Sutton" philosophy with its emphasis on clearwood, but it should be noted that reliance on a single market might be risky. Note also that much of the expansion of clearwood market is in short lengths, not necessarily from pruned logs. Some 70% of clearwood uses are in 1.5 m lengths or less[34].

There are the obvious risks of exchange rate fluctuations, and a downturn in the U.S. economy, although it is likely that a recession in the U.S. would soon become a worldwide event. Market diversification would therefore provide little protection. But there are less obvious risks of reliance on a single market. According to one report[35], there is a limited sale potential for furniture from NZ clear radiata pine as there is a traditional U.S. preference for hardwoods and for knotty pine (but with small knots!). Much of the clearwood market is for Do It Yourself outlets, such as the Home Depot, which may impose arbitrary rules on suppliers.

Another critical factor with suppliers to outlets such as the Home Depot is the retail customers' paramount concern with quality. One dissatisfied customer can counteract the goodwill from many satisfied ones[36]. It is noteworthy that 90% of the problems are caused by 10% of the logs[37]. This emphasises the importance of product segregation: the need to separate out the bad element and give the highest possible assurance of quality to the remainder, at all points in the supply chain. Without quality control, the presence of internal checking or resin pockets in 10% of the pieces could downgrade the value of the whole consignment or even make it unmarketable. This point needs to be highlighted.

[32] Park 1995
[33] Bosman & Burger 2000
[34] L. van Wyck, unpublished data cited in Carson 1988
[35] Maplesden 1988
[36] Gaunt 2001a
[37] Wayne Miller, FIC Roadshow on Wood Quality Initiative

The unpruned top logs

Unpruned logs comprise up to 40% of the stumpage value in a typical tree and can be used for both structural and appearance grades. The latter are obtained mainly from clearcuttings, both from internodes and from gaps between the branches in a whorl (this applies particularly in large logs).

Appearance grade potential

The Ngatira study yielded almost no clearcutting grades, due to the highly multinodal habit of the stand[38]. A comparative study of 26 farm versus forest sites by Knowles and McConchie[39] showed that internode lengths were considerably less than expected from their locations (internode length tends to increase towards the south of the country)[40,41]. This was particularly the case at low stockings. The Bay of Plenty forest sites had a mean internode index of 0.25, and the farm sites a value of only 0.195. Low stockings on farm sites had particularly low values. Whatawhata (GF 8) had an index of 0.12 and Tikitere (GF 14) had an index of 0.04, both at 100 s/ha. The authors attributed the cause to greater whorl depth and to an increase in the number of whorls per metre. The large number of whorls at Ngatira can be attributed, at least in part, to the low stocking (210 s/ha), because at such stockings more sunlight reaches each tree. Madgwick[42] says that "shading decreases cluster production …with seedlings grown in 15% of solar radiation having less than 30% of the number found on seedlings in full sunlight". Madgwick also cites several studies to show that fertility *per se* does not increase the number of whorls per tree, although high stockings may have been used in his examples. In other words, there may be a stocking x fertility interaction which explains the above findings of Knowles and McConchie, but which does not contradict Madgwick's conclusions.

Low stockings also result in severely depressed height growth[43], with Tikitere experiencing a site index difference of seven metres across the stocking range. In some situations, it is possible to explain reduced internodes merely by a height reduction. In order to fully attribute the decline in clearcuttings to the farm effect, we must rule out the confounding influence of low stockings – which often tends to occur on such sites.

If we accept the observations of Knowles and McConchie, it seems that the possibility of substantial clearwood from upper logs on farm sites from the existing resource in the Central North Island or further north is remote.

In addition to the farm and stocking effects, a major problem has arisen from the choice of genetic stock in recent years. In the quest for good growth and form, and for small shallow-angled branching, popular modern seed selections are considerably more multinodal than unimproved stock. Carson and Inglis[44] argued in1988 that "much greater yields of clearwood can be obtained

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[38] Cown & Knowles 1990
[39] Knowles & McConchie 1996
[40] Cown 1999, p. 15
[41] Grace and Carson 1993
[42] Madwick 1994
[43] Maclaren *et al* 1995
[44] Carson and Inglis 1988

from a long-internode breed, but this will be at some cost in gains for growth and form traits when compared to the most advanced multinodal tree type". Since then, the debate over multinodality appears to have become dichotomised: extreme multinodality *or* extreme long internodes, with very little industry support for the latter. Although the possibility of intermediate-length internodes has been always been present in the breeding population, this opportunity has not been developed. It is hoped that a farm-site breed, incorporating clones with intermediate-length internodes, will become available shortly.

Of course, we cannot change the existing multinodal resource, but we can address the absence of upper-log clearcuttings in future plantings on farm sites. The move to physiologically aged material may make no difference, as they have the same branching characteristics[45]. The stocking rate is also irrelevant, except in its influence on height growth and therefore whorl number per log[46]. Genetic manipulation is the obvious way forward. Another approach, suggested by Leith Knowles, is to artificially create longer internodes in the second log by selective removal of whorls with small branches. Presumably, these minor branches contribute little to the tree's growth. With the maturation of the Ngatira internode pruning trial, this theory can be tested. At time of writing, resources appear to have been found to enable measurement to proceed before the trial is felled.

Heritability of branching habit is high (h^2=0.4-0.6) compared to other growth and form traits[47]. Barker *et al*[48] state that "clonal trial evidence shows that a reduction from eleven whorls in the second log to six will allow sufficient clearcuttings to dramatically change the appearance grade recovery". Vincent and Ballekom[49] state that, although there is little current demand for seed from the Long Internode breed, there is potential for a "mid-internode breed" with a score of around 10 to 15 on the GF Plus Scale, but this would take "3 or 4 years" to market after commencement of the programme.

Structural grade potential

As previously mentioned, radiata pine is not a preferred species for structural grades, especially when grown on "modern" regimes[50]. The typical grade recovery of all structural grades for New Zealand structural mills is about 50%[51], as opposed to 80% for Australia, 90% for the US South and 95% for BC Interior[52]. New Zealand averages 420 kg/m^3 in density[53], but the figure can be substantially lower than this in younger trees, on colder sites and in the corewood. Radiata pine branches tend to be large, especially on farm sites and at low stockings. The combination of farm sites and low stockings results in particularly large branches.

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[45] Holden 2001
[46] Barr and Tetzlaff 2001
[47] Carson 1988 p. 3
[48] Barker *et al* 2000
[49] Vincent G. and S. v. Ballekom quoted in discussion on p. 81 of NZRPBC Report No 118
[50] Planting 600-1500 s/ha, thinning to 200-400 s/ha (often by year 10), and clearfelling by age 25-35
[51] It is hoped that log segregation by the use of sonics can substantially improve this figure
[52] BIS Schrapnel, Benchmarking Study 2001. Cited at FIC Roadshow
[53] Cown 1999 for whole-tree density. Sawn lumber is closer to 400 kg/m^3.

Although the branching habits of farm-site trees were reasonably well known prior to the Ngatira Sawing Study (1990) of 18-year-old trees, the poor grade outturn came as an unpleasant shock. Although the predicted outturn of No.1 Framing was 20%[54], the actual results were reported to be less than half the SAWMOD prediction (either10%[55] or 8%[24,56] depending on the source of information). These poor results appear to be supported by other studies[57], but the definitive Tikitere (26 year old trees) evaluation is still pending.

A key question remains: why is the structural outturn from New Zealand radiata pine so poor on farm sites? Given that SAWMOD predictions are made on the basis of green, rough-sawn visual grades, the poor performance is not related to drying degrade and must be attributable to the size, location and/or orientation of branches. This is despite the observation by Kimberly, Barr and Knowles that "the over-predictions by SAWMOD on farm sites cannot be explained by differences in branch size distributions"[58]. They stated that in terms of frequency of branch in any diameter class, trees from Tikitere 400 sph were almost identical to Rotoehu 250 sph, and would have been identical to a 200 sph stand from the Northern Boundary trial, if it had existed at exactly that stocking. In other words, trees with an identical branch index will produce different grade outturns depending on whether they are from farm or forest sites. Further investigation is required to identify the cause of this inconsistency.

Another problem is the poor performance of radiata pine after drying. On farm sites, there is a greater tendency to exhibit degrade such as crook, bow or twist[59]. The solution may not lie in a better understanding of the geometry of the problem logs, but may be found in features such as microfibril angle, proportion of corewood, spiral grain, compression wood and moisture content.

In contrast to the growth potential of appearance grades, the market for solid structural wood does not seem to be growing outside New Zealand and Australia[60]. In view of its limited future, the proposed FIC Wood Quality Initiative seeks to reduce the proportion of research for this type of product. During review, it was pointed out that many appearance-grade uses (eg banister railings) demand excellent structural as well as appearance qualities. This is true, but for many other uses (eg mouldings) stiffness, strength and even hardness are not usually important.

Export logs are not an option for the type of material produced on farm sites. Although some logs may theoretically meet the Japanese, Korean or Chinese specifications, there are "gentleman's agreements" that consignments be considerably "well within spec"—in other words, the majority of logs must be about 11-12 m long with reasonably small branches (only a few as large as 10 cm).

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[54] Knowles & McConchie 1996
[55] Cown & Knowles 1990

[56] Cox *et al* 1995
[57] For example, the comparative analysis of machine graded wood from Tikitere reported in Gaunt 2000 or Gaunt 2001a
[58] Kimberly *et al* 2000
[59] McKinley *et al* 2000a
[60] Bosman and Burger 2000

Laminated Veneer Lumber offers a promising alternative to solid sawn timber. In the Forest Research Value Recovery presentation of August 1998, the samples of LVL produced 90% F5 and better, and were 12% stiffer than solid sawn. The veneers were 3 mm thick, but an intermediate technology—Laminated Sliced Lumber—used slices 13 mm thick. The LaSL had disappointing results. Although LVL shows "real growth potential"[61] it is costly to produce relative to solid sawn, and its quality depends greatly on the quality of the original feedstock. Why would processors choose to establish LVL plants to process New Zealand farm-site wood when there must be superior raw material elsewhere?

Specific quality problems

Wood density

Wood density has long been regarded as one of the leading quality issues in timber. There may have been excessive emphasis on this feature, given that, as Wayne Miller says, "density (per se) is NOT important for many uses"(original emphasis)[62]. Many of the traditional species for joinery, eg ponderosa pine, Eastern white pine, Western red cedar and redwood, have lower density than New Zealand radiata pine. For one thing, stability tends to be improved with lower density. On the other hand, the "official FRI view" is that density is of high priority for component furniture, dry structural, and plywood[63].

Whole-tree wood density is known to increase with tree age, and to decrease with latitude. Higher altitudes also have lower density. The reason is probably related to temperature, and in particular the length of the growing season[64] and the ratio of latewood to earlywood[65], however defined. Despite these regional differences, it is worth emphasising that the differences between trees in the same stand can be even more pronounced[66], thus underlining the opportunities for segregation based on individual trees or logs, as well as stands.

It is widely recognised that '850' genetic stock (GF12-14 planted mainly between 1971 and 1985) is 5-10% lower in wood density[67,68] than previous or subsequent material. A comparison of climbing select trees at Rotoehu (an ex-forest site) with GF14 showed a 6.3% reduction in density as a result of the '850' stock[69]. There does not seem to be a major genotype x site interaction for wood density[70].

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[61] Bosman and Burger 2000
[62] Miller, in FIC 2001
[63] Meder *et al* 1995
[64] Cown *et al* 1991
[65] Beets *et al* 2000
[66] M. McConchie pers. comm.
[67] Ridoutt 1997
[68] Kumar et al 2001
[69] Knowles and McConchie 1996
[70] Kumar *et al* 2001

Wood density at Ngatira and Tikitere was lower than for forest sites at the same latitude and tree-age[71,72]. This is partly attributable to the use of '850' planting stock and partly due to the farm-site effect. Ex-farm sites have higher available nitrogen. Indeed, this is almost their defining characteristic. Work by Cown and McConchie (no reference available), the Australian Biology of Forest Growth trials, Peter Beets[73,74] and by Barr & Kimberley[75] has shown that high foliar nitrogen levels caused by fertilisation, or—more permanently—by a history of intensive farming, will result in reduced density. Despite earlier reports, boron fertilisation appears to have no influence on wood density[76].

Contrary to common perception, lower stockings result in marginally *higher* whole-tree density, because corewood occupies a similar volume between stockings[77] (trees are largely unconstrained in growth as they fully occupy the site) but there is a greater volume of outerwood at lower stockings. Wood density has also been shown to decrease as a result of thinning[78], but this is likely to be the result of removal of suppressed trees that are denser than average. Were it not for this effect, enhanced tree growth following thinning is likely to increase the proportion of outerwood relative to corewood and therefore increase density in crop trees.

Wood density and moisture content

Wood density and moisture content are inversely related, in that the volume of green wood is occupied by either woody material or by liquid[79]. The liquid is evaporated during oven-drying in the analysis of basic density. Thus wood with a high moisture content will weigh less after drying, and therefore have lower basic density. A high moisture content is an additional problem in that it involves extra transport and drying costs, and that drying schedules may be inappropriate for an anomalous consignment of logs with excessive moisture content.

The higher moisture content of farm sites, compared with traditional forest site trees of a similar age, has been noted at Tikitere[80].

Stiffness

One of the main reasons for the historical concern over wood density[81] was the supposition that it was a surrogate for stiffness. (Stiffness is more important for structural radiata pine[82] than either strength or hardness, but all three are influenced by density). Radiata pine is disadvantaged on world structural markets by its low stiffness[83].

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71 McConchie 1995
72 McKinley *et al* 2000a
73 Beets 1997
74 Beets *et al* 2000
75 Barr and Kimberley 2001
76 McKinley *et al* 2000b
77 McKinley *et al* 2000a
78 Cown and McConchie 1982
79 Kininmonth and Whitehouse 1991
80 McKinley *et al* 2000a
81 Dickson and Walker 1997a
82 H. Bier, quoted at Wood Quality Workshop 2000
83 Dickson and Walker 1997a

It is known that wood density alone is only a moderate indicator of stiffness, explaining 65% of the variation for clears[84]. When microfibril angle (MFA) is added to the picture, some 94% of the variation (for clears) is explained[85]. To be precise, the Modulus of Elasticity is directly proportional to the density divided by MFA. The contribution of these two factors to stiffness, as measured by the Modulus of Elasticity (MOE), appears to vary between juvenile wood and outerwood. Cown *et al*[86] provided "robust" statistical evidence to indicate that both density and MFA were "very significant" in determining MOE in the juvenile wood of radiata pine, but that density had an overwhelming effect in the mature wood. They stated that this supported traditional thinking and justified past and present efforts to document factors affecting wood density in *P. radiata* and to improve the average levels through tree breeding. Also, density can be measured and predicted with precision but MFA is currently more difficult to measure and use.

It is possible to obtain accurate stiffness measurements quickly and easily on felled logs, or whole but de-limbed stems, with acoustic tools such as the Hitman®[87] or SWAT. The technology has not yet been perfected for standing trees. This development has considerable potential for maximising the potential of a resource for machine-stress-graded lumber, but has less of an application for appearance-grade material such as pruned butts. This is not to say that stiffness is totally unimportant for appearance grades, merely that it is less important.

Longitudinal Shrinkage

There is a correlation (r^2=74%)[88] between stiffness and shrinkage, which is important in all types of solid-wood. A Weyerhauser patent demonstrates that when stiffness falls below about 7.0 Gpa there is a noticeable increase in longitudinal shrinkage[89], a characteristic which is substantially worse in the butt log compared to the second log. Differences in longitudinal shrinkage between edges will cause boards to crook or bow. This is especially important for these high value clearwood products.

Stiffness and longitudinal shrinkage appear to share a causative agent – microfibril angle[90]. The quest to enhance stiffness in corewood by reducing MFA could conceivably create a lesser incidence of distortion in processing.

Stability in processing and in use

Distortion and stability behaviour is a complex amalgam of: drying stresses, longitudinal shrinkage differences, creep, moisture response rate, compression wood, etc.[91]. It is poorly understood at both the research and applied levels.

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[84] Evans, R., Ilic , J. and C. Matheson. Rapid estimation of solid wood stiffness using Silviscan. Unpublished paper.
[85] Evans and Ilic 2001
[86] Cown *et al* 1999
[87] Carter and Lausberg 2001
[88] Sorensson 2001
[89] Walker 2001
[90] Megraw *et al* 1997
[91] Miller 2001

Stability is an issue for all types of solid wood. Wood that distorts in processing is difficult to process further, even if it comprises otherwise defect-free clearwood. Wood that distorts or moves in use reduces the functionality of the product. For example, distortion has been identified as a major reason why Swedish building contractors were converting to steel framing[92]. Instability has been identified as a likely reason why radiata pine performs worse than species such as ponderosa pine[93]. Given the density of the species (remembering that in general the *lower* the density the more stable) its stability is poorer than expected. The reasons are not well understood.

Compression wood

One major cause of instability and distortion is compression wood. Compression wood is a reaction to stresses in the tree, and counterbalances uneven weight loadings in the stem or crown[94]. Radiata pine is a large-branched species (perhaps this is the price we must pay for the spectacular growth rates), a factor that may result in unusually high levels of compression wood. Also, New Zealand is a windy country, which is a major cause of stress, unbalanced crowns and leaning stems. Thinning and slope instability may compound the problem.

There is more compression wood at Tikitere compared to forest sites[95,96]. This could be due to the windiness of the site and the lean of the trees (the marked butt-sweep resulted from Cyclone Alison but there was also damage from two subsequent cyclones), and by the weight imparted by the huge branches at low stockings. Compression wood tends to decrease with increasing height in the stem[97], indicating that the problem is particularly relevant to the all-important butt logs. McConchie also points out that clonal differences exist, indicating that there may be some help from altered genetics. Cown[98] has shown that compression wood is related to thinning, with the incidence proportional to the growth response from thinning. One mechanism he suggested was that thinning makes the stems more prone to windsway.

Another reason for the recent upsurge of interest in stability is the reduced dimensions of final wood products. Some products are now only 3 mm in thickness![99] This has major implications for a species, and for regimes, where growth rings can be 25 mm or more apart. With these product sizes, the relationship between earlywood, latewood and compression wood become very important.

Internal checking

Checking is a major cause of degrade in clearwood. It is particularly prominent in the butt log[100], usually does not appear until after drying, and can be invisible on the surface of the wood. Booker[101] states that the internal checking occurs when, due to water tension forces, the earlywood with its thin cell walls contracts more that the latewood with its thicker cell walls, and the resulting tensile

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[92] Ridoutt 1997
[93] Wayne Miller in FIC 2001
[94] Kininmonth and Whitehouse 1991
[95] McConchie 1995
[96] McKinley *et al* 2000a
[97] McConchie 1997
[98] Cown 1974
[99] Wayne Miller, FIC 2001
[100] McConchie 2000
[101] Booker 1995

force in the earlywood causes it to split. Don McConchie (Feb 2002, pers. comm.) says that checking appears to be worse on sites exposed to drought, waterlogging or frost. Drying schedules can be modified to reduce internal checking if such sites are identified in advance.

It may be noteworthy that the incidence of checking increased with the increase of stocking at Tikitere[102], perhaps because water or other resources were more limiting. The sample size at Tikitere was small (eg 7/26 trees checked at 100 s/ha compared to 9/27 at 200 s/ha and 13/27 at 400 s/ha) and the results were greatly influenced by the large number of checks in a single tree, so we should treat these results with caution.

Boron deficiency is an obvious candidate as an explanation, given the well-known importance of this element in cell-wall structure and the evolution of radiata pine as a coastal species (boron levels are high in salt spray). In support of this hypothesis, checking seems to be worst at sites (like Eyrewell and Golden Downs) known to be boron-deficient[103]. Nevertheless, a study of a boron trial at Rerewhakaaitu[104] showed almost identical levels of checking in the control and the boron treated trees.

Despite these results, Boron is still the preferred hypothesis of Bill Dyck[105]. He dismisses the Rerewhakaaitu results (pers. comm. December 2001) with the argument that foliar analysis and weather information based on monthly climate figures are inappropriate for indicating short-term boron levels in the cambial meristem. Be that as it may, the implications are not straightforward. Dyck argues that the only way to prove that boron deficiency is the cause is to study it at the physiological and particularly the cellular level. Moreover, Dyck's suggested remedies (assuming that the boron theory is correct) include the unexciting options of avoidance of radiata on boron-deficient sites, and conservation of organic matter on marginal sites. As checking is not a problem with structural grades, another option is to restrict these sites to structural rather than clearwood regimes.

To fully grasp the problem of checking, a large dataset is necessary. To achieve reasonably precise results, large numbers of discs are required[106]. Creating this dataset could therefore imply a costly piece of research, but considerable progress has already been made (D. McConchie, Feb 2002 pers. comm.).

There is promise for reduction of checking via genetic improvement. Ball *et al*[107] calculated heritability (h^2) for the total number of checks and the number of rings with checks as 0.64 and 0.60, but the "95% credible" range was 0.15-0.996 and 0.06-0.997 respectively. Note that this range covers almost the full span of possibility, from checking almost not being inherited to it being fully under genetic control!

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[102] McConchie 2000
[103] McConchie & McConchie 2001
[104] McKinley *et al* 2000b
[105] Dyck 2002
[106] McConchie *et al* 2001
[107] Ball *et al* 2001

If checking can be modified by genetic improvement, this heralds well for the future resource, but does not help the present situation, unless it emphasises the fact that most trees do not have checking and that a few trees have most of the incidence. A technique for segregating check-prone wood prior to processing could be of major benefit.

If checking cannot be reduced in the forest, can it be overcome during processing? One possibility is to modify the drying schedule. Tony Haslett (pers. comm. 9 Nov 2001) stated that checking could be reduced to 8-10% of former values by drying at the standard 90/60°C schedule. He further stated that checking could not be totally eliminated, even by block stacking green wood. Slower drying is of course more expensive than rapid drying, if only because storage and inventory costs are increased. This author, however, has never seen a cost/benefit comparison of rapid drying followed by marketing wood with a relatively high level of checks, as against slower drying and fewer checks.

If it cannot be totally overcome during processing, can it be identified and isolated in the mill? To enable segregation of boards in the sawmill, Forest Research started work on a system of detection to provide on-line quality control[108], although results were disappointing and the work seems to have been discontinued. Even if successful, this approach may not be entirely satisfactory, as the best strategy may be to divert check-prone logs *before* sawing. Such logs could, for example, be processed into veneer, where checking is not such an issue.

A final possibility under active research is the elimination of checking by allowing the formation of heartwood. It appears that most checks occur within five rings of the heartwood boundary[109] and that checks are very rare in heartwood. Thus a solution could conceivably be found by merely extending the rotation age by a few years. Heartwood heritability is relatively high, at 34%[110] and therefore there may be possibilities via genetic manipulation. Heartwood, however, is not usually desirable for other reasons (eg colour, treatability).

Spiral grain

Spiral grain can be a major defect, resulting in distortion during processing or in use. Cown[111] states that "it has, in fact, been documented that the greatest source of drying degrade in processing young logs is twist as a direct result of spiral grain in excess of 5 degrees. Spiral grain in the inner growth rings also causes the higher longitudinal shrinkage observed in juvenile wood."

A reviewer of this report pointed out that the relationship was one of correlation, not causation. In other words, it is still unproven that spiral grain was the primary cause of the distortion rather than being merely associated with it. (An alternative explanation may lie in MFA[112].) Spiral grain is more extreme near the pith and is significant only for the first 10 growth rings (true for all families examined[113,114,115]), and is therefore relatively less important with longer rotation ages. It increases with height in the stem.

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[108] Ridoutt 1997
[109] McKinley et al 2000a
[110] Barker *et al* 2000. (The true figures are double the published figures).
[111] Cown 1999, p.13
[112] Megraw *et* al 1997
[113] McConchie 1998
[114] Kumar *et al* 2001

There appears to be a north-south trend towards decreasing spiral grain[116] although—with only seven locations examined—it may be too early to form a definitive judgement. Tikitere trees have higher levels of spiral grain than would be expected from trees of a similar age on ex-forest sites[117,118]. There is no obvious explanation for this, except perhaps that spiral grain may be one response to wind-stress.

The heritability of spiral grain has been variously described as very low[119,120] to high[121], but it is well to remind ourselves that heritability is only meaningful when applied to a specific population. The variability of a given trait in one population could be the result of mainly genetic differences, and therefore be highly heritable, whereas the same variability in another population could be caused mostly by environmental influences, and therefore not greatly heritable. For example, hair colour in a mixed group of Europeans would have a high genetic component (Scandinavians with fair hair, and Mediterranean peoples with dark hair etc), but the same study among, say, Japanese would indicate a low heritability (older people with white or grey hair, younger people with black hair, almost regardless of genes). This realisation could partly explain the conflicting results in spiral grain and other wood quality characteristics. An alternative explanation may be that spiral grain is very difficult to measure with any accuracy, particularly at breast height[122]. Nevertheless, a clonal study of wood properties[123] showed major differences between clones (from 2.6° to 5.8°), unlike other characteristics examined, which had a smaller range. This finding indicates that good progress could be achieved by genetic manipulation.

Before condemning spiral grain as an unmitigated evil, and attempting to eliminate it with tree breeding, it may pay to first discover its evolutionary importance. Kubler[124] says that "Compared with straight-grained trees, spiral-grained stems and branches bend and twist more when exposed to strong wind, in this way offering less wind resistance and being less likely to break.... but the main function of spiral grain is the uniform distribution of supplies from each root to all branches, and from each branch to many roots." Total elimination of spiral grain could therefore make trees more susceptible, for example, to drought.

Microfibril angle

Microfibril angle (MFA) interacts with density and grain angle to determine the stiffness, strength and shrinkage properties of wood[125,126]. Although density is the most important determinant of these properties for outerwood, MFA is of greater importance in juvenile wood and the base of the stem[127,128]. The stiffness of wood increases five-fold as the helical winding angle of the cellulose

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[115] Cown 1999. p.13
[116] Kumar *et al* 2001
[117] McConchie 1995
[118] McKinley *et al* 2000a
[119] Barker *et al* 2000. (True figure is 4%).
[120] Kumar *et al* 2001
[121] Kubler 1991
[122] Lausberg 1995
[123] McConchie 1988
[124] Kubler 1991
[125] Donaldson and Frankland 1977
[126] Evans and Ilic 2001
[127] Dickson and Walker 1997b
[128] Cown 1999, p.14

(the MFA) decreases from 40° to 10°. Given the short rotations that are currently employed, juvenile wood can account for a substantial part of the log volume in butt logs, and therefore MFA is critically important.

Booker[129] states that his previous theoretical work[130] shows that MFA may be implicated in internal checking and collapse, but two reviewers of this draft (from Fletcher Challenge Forests, who have conducted work on this topic) deny there is proof of any such link.

Measurement of MFA is difficult, requiring 5 minutes per sample under a microscope[131] using methods developed at Forest Research, or 1 minute per sample using the Australian SilviScan-2[132]. Preparation time of the samples is lengthy, and the equipment (microscopes and Silviscan2) is expensive. Whereas the Australian technique takes a pith-to-bark sample of a 12 mm core, the Forest Research technique involves only a few cells. Some work is required to amalgamate readings so that the results are meaningful in real-world situations and for products of a size that are normally traded.

Evans and Downs[133] stated, "in general fertiliser resulted in lower density, higher microfibril angle (MFA) and slightly lower stiffness". Therefore we would expect this problem to be more extreme in fertile farm sites. MFA is affected by physiological ageing (angle reduction of 1° for every year of ageing)[134] so the problem can be mitigated somewhat by using aged cuttings.

Genetic effects can account for up to 70% of between-tree variation in microfibril angle within sites[135], so there may be hope for improving the future resource, despite reports of "low to very low heritability"[136,137]. One of the latter reports has now been discredited by its own author[138], but the former report is also suspect[139]. This issue is currently under active investigation by the Radiata Pine Breeding Cooperative, CSIRO and Forest Research.

Like spiral grain, MFA may serve an evolutionary purpose and it may be unwise to encourage across-the-board reductions in MFA for the sake of superior wood quality, while ignoring the costs in terms of growing trees. A high MFA makes for a very flexible juvenile stem[140], which may be advantageous in withstanding wind and snow damage in early years or at the top of the tree. A complementary evolutionary strategy is to have a low MFA in outerwood to impart stiffness. The cautious approach may be to eliminate the "outliers" (ie trees with exceptionally high MFAs) while maintaining the existing median MFA. On the other hand, the normal distribution of MFA in the New Zealand land-race of *Pinus radiata* implies that there are number of strategies that may benefit survival[141].

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[129] Booker 1995
[130] Booker 1993, Booker 1994
[131] Donaldson and Frankland 1977
[132] Evans and Ilic 2001
[133] Evans and Downs 2001
[134] Donaldson 1995
[135] Donaldson 1995
[136] Wilcox P., untabled paper at 4th Wood Quality Workshop, Oct 2001
[137] Burger, F. Discussion on p. 70 of NZRPBC Report 118
[138] Denis Albert, March 2002, pers. comm.
[139] Mike Carson, March 2002, pers. comm.
[140] John Walker, November 2001, pers. comm.
[141] Denis Albert, March 2002, pers. comm.

Resinous features

It is conceivable that resin exudation has evolved as a protective mechanism against insect attack and other injuries. Although resin pockets (the most serious form of resinous feature) are disadvantageous for human use of clearwood, they could confer benefits to tree survival in extreme conditions. Stressed trees exude resin (although the exact nature of the stress is not very clear[142]), which may explain the high incidence in the drought and wind-prone Canterbury Plains, and in lower, more wind-exposed stockings at Tikitere. The drying effect of the wind could be more important that the exposure *per se*. Shelterbelts may also be at risk, as evidenced by the Waikite study[143], although this was not shown in one indicative study at Kaharoa[144]. Thinning and pruning may constitute a form of "stress", and there is evidence[145] that they (especially in combination) increase the number of resin pockets.

Somerville[146] has provided the definitive summary of the state of knowledge regarding resin pockets. He classified resin pockets into three types: Type 1 is contained and does not exit to the cambium. Type 2 appears to originate as Type 1 but erupts through the cambium, and Type 3 is a small defect resulting from a lesion through the cambium.

There are three items of good news in recent work on resin pockets by Don McConchie[147]. The first is that the incidence of resin pockets appears to increase with log height class[148]. This means they are not as severe in butt-logs (ie appearance grades where they are very important) as top-logs (partly or mostly structural grades where they are of lesser or no importance). Secondly, they decrease as stocking increases, indicating that silviculture can perhaps be used to mitigate the effects. (This also applies to blemishes.) Thirdly, there are significant clonal differences, indicating that the problem can be overcome in the next generation of trees by tree breeding or clonal forestry. As for some other wood quality traits, however, there appears to be little consensus on heritability. This problem, for many of these traits, is due to the lack of robust protocols for measurement. Without reliable repeatable measurement criteria it is not possible to generate reliable estimates of heritability.

It would be very useful to develop a large dataset of the incidence of resinous characteristics. This would include factors such as occurrence, location, aspect, genetics, stocking, thinning and pruning history, season, and climate. The history of forestry research in New Zealand shows that large datasets are often necessary to overcome the "noise" of anomalous results. From such a dataset, it may be possible to predict the incidence of resinous characteristics with a view to segregating the resource for optimum market performance. A second objective is to determine more precisely the mechanisms behind the formation of resin, so that it can be minimised in the future. Jim Park (Interface Forest & Mill) has already accumulated a useful dataset (although it restricts itself entirely to resin pockets rather than all resinous characteristics) but correspondence with him (6 Feb 2002) indicates that this dataset has already been transferred to the School of Forestry, and does not wish it to be available for Coop use.

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[142] Somerville 1997
[143] Tombleson 1986
[144] Horvath, Tombleson and McConchie 1998
[145] Dean *et al* 2001
[146] Somerville 1997
[147] McConchie 1997
[148] McConchie 1997

The key to building the requisite dataset is to develop a simple, cheap, practical and reliable indicator of resin problems in standing trees or felled logs. McConchie has recommended external resin bleeding or lesions in standing trees as one such indicator. This technique needs to be further developed and implemented by independent researchers, as there has been criticism that it is impractical ("can't see the resin bleeding if the trees are wet") or unproven. It may not be useful in situations where Type 1 resin pockets predominate (eg the Canterbury Plains?). These criticisms are easy to evaluate objectively in a field trial, and definitive results from Tikitere trees should be available soon.

For felled logs, Dean and Barker[149] and Dean *et al*[150] examined the use of log-end resin at Tikitere as a guide to major internal defects, and it appeared to be a practical approach despite some mud on the logs. Barker and Tombleson[151] examined the sawn timber and produced results that were similar (incidence is worse at lower stockings but acceptable at high stockings) although not entirely comparable. McConchie argues that resin pockets in log ends are so rare that it is important to include minor blemishes as a supplementary indicator, even though there is not yet hard proof that log-end blemishes are related to internal resin pockets. Note also that the use of resin pockets and blemishes by McConchie himself explained only 49% of the resin pocket presence in sawn boards[152,153]. At time of writing, this work has been repeated with further trees, and provisional results look promising. Provided that an objective set of standardised criteria can be formulated, and taught to independent field workers, this is a worthwhile discovery. The same applies to external resin bleeding or lesions.

Trees prone to resinous characteristics could be eliminated at time of crop selection (typically ages 4-9) provided that a link can be established between external characteristics visible at this age and properties of the mature logs. This work has yet to be started.

Other features detrimental to clearwood

If pruned logs are straight, have a high Pruned Log Index, few resinous features, no internal checking, and are processed with minimum distortion, what other quality constraints may there be? Needle-fleck and discoloration have been mentioned.

Discoloration can be caused by the presence of heartwood or compression wood. The former typically appears after age 12-14 in radiata pine[154],[155] and grows at the rate of half a ring per year, although this varies greatly between trees and with location. A 28-year old butt log is likely to have heartwood in the innermost 8 growth rings near the base of the tree, reducing to five or fewer rings near the small-end diameter. Although imparting a (usually undesirable) brown colour, the positive effects of heartwood may counteract some deficiencies of juvenile wood (eg moisture content, checking). This is not to say that heartwood is on balance desirable (difficulty of preservative treatment, necessity to segregate for drying, extractives in pulping, etc).

[149] Dean and Barker 1999
[150] Dean et al 2001
[151] Barker and Tombleson 1999
[152] McConchie 1998
[153] McConchie & McConchie 2001
[154] Cown 1999
[155] Kininmonth and Whitehouse 1991

Compression wood also causes discoloration by providing darker regions within the earlywood. The most obvious cause is stress provided by tree lean or by windy conditions, but a perfectly straight tree in a sheltered environment can also contain compression wood. This may be the result of an unbalanced crown, or individual large branches. Note that farm sites, especially those at low stockings, tend to have exceptionally large branches and are therefore likely to contain more compression wood.

Some forestry companies in Southland are marketing their trees as being exceptionally white relative to the rest of the country. Undoubtedly, whiteness confers a benefit, not just for papermaking but also for clearwood. Many modern householders, especially in the U.S., prefer lighter coloured furniture. This author, however, has not seen evidence to substantiate the claims of Southland growers, nor can conceive of a reason why Southland wood should be whiter, unless perhaps there is a low ratio of darker latewood to whiter earlywood (thus also explaining the low density of those trees).

Recommendations

[Recommendations are included because they were part of the original brief. Needless to say, they are merely the opinion of the author, formulated during the course of writing this review. Their inclusion in this report does not imply endorsement by the membership of the Forest & Farm Plantation Management Research Cooperative]

1. **To co-ordinate wood quality work with the proposed FIC Wood Quality Initiative. The Coop cannot, and should not attempt to, address wood quality issues "across the board".**

The Coop "punches above its weight" in the quantity and quality of research results it provides relative to its budget, on the basis that it leverages the large FRST-funded Forest Growth and Quality Programme. Only a quarter of the total budget is currently allocated to wood quality, because the Coop has a broader agenda. Members have historically directed funds to such diverse topics as Silviculture of New Breeds, Toppling, Alternative Species, and Shelterbelts. The mission statement includes provision of knowledge and tools to "*select and manipulate site, silviculture and genetics to achieve targets in terms of wood volume, quality & value, and both economic and environmental sustainability*".

The Coop may be the most appropriate forum for applied wood-quality work related to plantation management, while the FIC Wood Quality Initiative (with a proposed budget some ten times that of the Coop) addresses some of the broader goals and longer-term initiatives.

2. **To focus on wood quality in the existing resource, rather than in a postulated future resource.**

In this author's opinion, the existing resource is arguably more important than the future resource, because small-scale growers tend to be both sceptical of predictions and trusting of proven results. In other words, the commercial success of neighbouring woodlots is the necessary and sufficient condition to ensure continuing afforestation by such growers. If the existing resource fails to live up to expectations, pleas of "we can do better next time" will fall on deaf ears.

There are obviously limits to the changes we can make to the existing resource. The genetics are fixed and in many cases it may be too late to alter the thinning or pruning regimes. There is always scope for lengthening the rotation age (climatic and market risks permitting) but this will be determined by market forces at the time, not directly by research.

The main wood-quality research focus on the existing resource should be to identify and predict the incidence of the main defects. From there, it should be possible to create tools to enable buyers to predict the locations, sites or regimes where problems are likely to be encountered. This will allow for resource segregation, and for those with a good quality product to obtain commensurate prices and/or an assured market. As a further step, a fundamental research goal should be to determine *why* certain areas or regimes are adversely affected, so as to avoid these problems in the future.

3. To focus on wood quality on ex-farm sites.

Because the FIC Wood Quality Initiative is largely driven by the major corporates, whose estate mainly consists of "ex-forest' sites rather than "ex-farm" sites, and because the Coop has special expertise on the latter type of sites, it makes sense to leave broader considerations to the larger body and to concentrate on the farm-site resource. The network of farm-site Permanent Sample Plots—partly or mainly established by the Coop—is a key factor in this recommendation.

4. To focus on wood quality in the pruned butt log.

Pruned regimes are the major component of the national estate, and the pruned butt log earns the bulk of stumpage revenue. Indeed, if pruned log prices fall to the same level as unpruned sawlogs, the result would be disastrous. Conversely, if pruned butt logs maintain their prices but all other logs become unmarketable, the result would be poor but not catastrophic. A figure of $21 903/ha has already been mentioned as the current average stumpage revenue for pruned logs alone.

5. To focus on resinous features and internal checking in butt logs on ex-farm sites. To assemble a matrix of data on the incidence of these defects from PSPs and replicated trials.

As mentioned, the Coop cannot attempt to deal with all wood-quality issues. Some—such as stability or microfibril angle—have a longer-term payoff horizon and are likely to be funded by FRST and FIC. Resin pockets and internal checking are the most obvious features that need attention. Don McConchie's work on external resin bleeding or log-end blemishes as indicators of internal problems could—if validated by independent workers—provide a low-cost way of collecting large quantities of data. Data collection for checking could be obtained from disks at the time of thinning.

6. To concentrate on segregating the worst performing individuals rather than improving the average or above-average logs, trees, stands or forests.

Given that "90% of the problems are caused by 10% of the logs"[156], the best "bang for the buck" lies in a focus on the poorer end of the spectrum. Also, some of the undesirable characteristics have evolved as an evolutionary response to stress, and it may not be wise to ignore this in the long-term.

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156 Wayne Miller, FIC 2001

For example, a certain degree of spiral grain may enhance strength and water uptake; relatively high MFAs may prevent wind damage in young trees; limited resin bleeding may be essential in resisting a new insect pest.

7. To support the analysis of the mature Ngatira internode pruning trial.

In view of the bleak future for upper logs on farm sites, there is a need to increase internode length in future plantings. This may be achievable by genetic manipulation, but if this approach encounters difficulties, the possibility of selective pruning of the second log should not be dismissed out of hand. Given that there is a mature internode-pruning trial about to be felled, it would not be expensive to assess the costs/benefits of this option.

Discussion and conclusions

[A personal perspective]

Wood quality research should not dominate the Coop (ie beyond the current 25%), which has valid research objectives in other areas. On the other hand, it is sufficiently important to merit a prominent place in future work projects. The Coop does not have the resources to address all wood-quality concerns, and therefore it should focus on key areas where it has special expertise and where there is likely to be a significant return for the investment, within an acceptable timeframe. Clearly, the question of resinous features and internal checking in the pruned butt-logs of ex-farm sites falls into this category.

Pruned logs are absolutely critical to the profitability of modern New Zealand forestry, and new planting is mainly on ex-farm sites. A large dataset is necessary to enable product segregation and to maintain international and domestic confidence in the quality of this resource. The Coop is well placed to conduct this important research.

Areas that the Coop are well advised to avoid include those that are highly complex, unlikely to yield practical or early results, and expensive to pursue. In this category falls research into wood density and microfibril angle using SilviScan-2 technology (or equivalent). This is because a successful result would cast light mainly on stiffness and stability. Stiffness is not a key property of appearance grades or the all-important pruned butts, unless they are downgraded to structural uses. Moreover, it may not be simple to take results from SilviScan-2 samples (7 mm x 2 mm) and to translate this into results applicable to the practical forester or mill-worker[157]. Other areas to avoid are the fundamental mechanisms behind instability or internal checking.

[157] No doubt it can be done, using Autosaw or equivalent, but this is beyond the role of the Coop.

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