UNDERSTANDING AND MANAGING WOOD QUALITY FOR IMPROVING PRODUCT VALUE IN NEW ZEALAND

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ABSTRACT

Pinus radiata D.Don comprises about 90% of New Zealand's plantation forests. Management practices evolved rapidly during the twentieth century, and are regarded as advanced in terms of the application of sound scientific and economic principles. However, since the 1970s, forest managers in New Zealand have become more aware of the impacts of genetic selection for growth and stem form, and the adoption of more aggressive silvicultural techniques, on the nature of the resource.These trends have resulted in a significant reduction in rotation lengths from more than 40 years to around 25 years. Growing space, tree age, and geographic location create very pronounced patterns of wood property development and, while growth rates can be impressive, some of the resulting wood characteristics are somewhat limiting for demanding end uses.

Scientific studies over the past 20 years or so have defined the important wood characteristics (knot size and distribution, resin pockets, intra-ring checking, density, spiral grain, microfibril angle) that affect product appearance, stiffness, and stability. Two distinct approaches have been adopted to improve the plantation resource:

(1) Identifying and managing variability in the forest

(2) Breeding to manipulate specific characteristics

Value recovery from harvesting is in rapid change from a system based on volume to one based on quality. There is now a strong emphasis on tools for log and lumber segregation, and reliable methods are available for assessing stiffness at all stages from forest to lumber. For the immediate future, traditional forest inventory methods are being enhanced by the inclusion of wood property information such as wood density and predicted stiffness. Acoustic tools in particular have become common for standing tree and log

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stiffness assessment and a similar approach is being used for lumber and veneer grading; spectroscopic tools are also under development. Tree breeders are actively selecting material to improve future generations, and fortunately the heritabilities of wood properties are generally high. However, many of these features are costly to evaluate on a routine basis and the search is on for more sophisticated tools to assess performance capability directly. The next challenge is to develop similar cost-effective techniques for predicting product stability. Faster progress will be made when wood processors reward growers for quality wood.

Keywords: wood properties; variation; segregation tools; *Pinus radiata.*

INTRODUCTION

Definition*: Silviculture involves "the art and science of controlling the establishment, growth, composition, health and quality of forests and woodlands to meet the diverse needs and values of landowners and society on a sustainable basis"* (Helms 1998).

Forest Development

Before human settlement (only about 1500 years ago) the temperate climate of New Zealand supported rich indigenous forests, both hardwoods and softwoods — many unique to the region. In fact, around 90% of native plants are not found elsewhere. Dense natural forest covered 75% of the land, the rest being occupied by mountains, lakes, swamps, and alluvial plains. After the arrival of the Maori people some 1500 years ago, the forests were the primary source of food, shelter, tools, and medicine. One of the earliest forms of silviculture was the use of forest fires to flush out the large flightless moa birds for food. However, this contributed in a major way to the extinction of the birds in the eighteenth century and to a reduction of the forest area by about 30% (NZ Forest Service 1964).

After the arrival of Europeans, from about 1800 onwards, there was a dramatic reduction in the area of natural forest because of requirements for settlement, the export log trade, and agriculture. The forests were regarded as a barrier to progress and again fire was used to clear land for development. Little thought was given to preservation of the indigenous forest or renewing the forest resource. But while there was a great surfeit of timber initially, the very foresighted Government in the late nineteenth and early twentieth centuries recognised the potential for international trade in wood products and for employment in commercial forestry. Tree planting on a small local scale had been encouraged, but the Forests Act of 1921-22 set out to change things dramatically. Early efforts by keen foresters resulted in the planting of a large number of introduced species, mainly conifers, from around the world. Initially the forests were located in areas considered undesirable for farming, but it was recognised that fast growth was essential for commercial success. The

New Zealand Forest Service was established to administer Crown lands and one of the first tasks was to document and protect the native forests and initiate professional forestry training and research. Such was the added interest that private forest companies also began to establish plantations. By 1960, production from plantations equaled that from the natural forests, and a second "planting boom" occurred to capture future benefits from the expected export trade. The average growth rates achieved attained about 18 m^3/ha/year nationally, with some sites recording over 40 m^3/ha/year.

During the decades since the Forest Service was established, the industry has gone through many changes, one of the most dramatic being the privatisation of the Crown estate and its subsequent purchase by a range of mainly international players. However, it is still recognised that the concept of growing trees which are "fit for purpose" is vital. "Identifying important wood quality traits and quantifying achievable gain is obligatory for customers who demand high returns on investments" (Olsen 1997). As time progresses, the need for quality becomes even more apparent, and is just as important as growing costs.

Over the first 1500 years or so of human occupation in New Zealand the forest resource (now almost entirely commercial exotic plantations), while reduced to about 30% of the land area, developed into one of the main platforms of the economy. During the 1970s and 1980s, planning conferences were upbeat about the potential employment opportunities and processing expansion about to occur. Some companies even bought forests overseas to extend their resources. From the mid 1980s forest establishment slowed and the Government ceased direct involvement. However, in the twenty-first century the forestry and wood products scene in New Zealand has changed dramatically from the atmosphere of optimism over the rapidly expanding plantation estate. The forestry sector now faces a number of issues:

- Lowest rate of planting for 15 years
- Falling export prices in real terms
- Harvest reductions
- Receiverships
- Rural unemployment
- Conversion of some forests to farms
- Failure to really develop offshore markets against competition from others.

At the same time, the public perception is of a building industry in disarray over issues such as "Leaky Homes" (*see* section on Wood Processing) and preservative treatment (lack of). A dramatic turnaround? Regardless of the debate over poor company leadership in New Zealand forestry (Gaynor 2004), and "boom" or "bust" scenarios (Manley 2003), there are some fundamental wood quality issues which can, and should, be addressed to help turn the industry around.

There is no doubt that in international terms, the growth rates of our major species, *P. radiata*, are outstanding. This has been capitalised on in terms of the development of management regimes, most of which now concentrate growth on the pruned butt log. In theory, this part of the tree yields 24% of the volume and 60% of the value (NZFOA 2005). The reality can be very different, depending on a multitude of factors, but the most consistent influence is variability of the wood quality itself. This is the dimension that has received too little attention in strategic planning.

MANAGEMENT FOR WOOD QUALITY

Choice of Species

Early settlers from about 1850 introduced a wide range of plant species into New Zealand for food, shelter, and amenity. Wood quality was not a major consideration in the first instance, and it very soon became apparent that only a small number of species, mainly from temperate zones, could survive and grow well in commercial plantations. Forest pests and diseases, while relatively uncommon, have selectively reduced the number of options (e.g., Sitka spruce — *Picea sitchensis* (Bong.) Carr.). From the numerous trials of species from around the world, the two most favoured species are now *P. radiata* which grows in most locations, and Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) in cooler, windier, and moister areas. Both can be used for wood products with desirable properties in world trade. Many other softwoods (and a few hardwoods) occur in small areas, often managed by "farm foresters" for amenity, soil protection, or specific wood properties. The more popular "special purpose species" include cypresses (*Cupressus macrocarpa* Gordon, *C. lusitanica* Mill., ×*Cuprocyparis leylandii* (A.B.Jacks. & Dallim.) Farjon), temperate eucalypts (*E. nitens* (Deane & Maiden) Maiden, *E. fastigata* Deane & Maiden, *E. delegatensis* R.T.Baker), redwoods (*Sequoia sempervirens* (D.Don) Endl., *Sequoiadendron giganteum* (Lindl.) Buchh.), Australian blackwood (*Acacia melanoxylon* R.Br.), poplars (*P. deltoides* Marshall, balsamea), and willows (*Salix* spp.).

Monoculture has been accepted as standard practice, despite arguments for greater diversity. Supporting this decision are the relative lack of forest pests and diseases, the genetic variability in crops, and the high priority placed on border security. Nevertheless, the risk remains that devastating pathogens could appear in the plantations.

Pinus radiata now comprises 90% of the New Zealand plantation resource because of the high volume production (up to 50 m^3/ha/year) and the high recoverable volume (85%).

The final choice of species has been pragmatic — only species which thrive, are cheap to grow with low risk, and can be harvested on a "short rotation" are worthy of selection.

Site Selection

Several aspects of site can affect the choice of species — latitude, altitude, climate, exposure, slope, soil type, and depth. These have predictable effects on general forest growth, and New Zealand is fortunate in having a temperate climate, which is generally favourable to tree growth. Research has shown that site can have a significant effect on wood properties, independent of the effect of tree growth (Cown, McConchie & Young 1991), to the extent that it can influence the product mix (Cown 1999).

One of the features of commercial forestry in recent decades has been a significant trend to establish plantations on fertile ex-farm land, sometimes in combination with cattle grazing. The immediate result was a significant increase in growth rates, which augured well for profitability. However, experience has since shown that the wood from such sites can have somewhat different characteristics. As a general rule, soils rich in nitrogen (e.g., ex-farm sites) tend to be planted at wider spacings to take advantage of the growth rates, but produce logs with larger branches (in the unpruned portion of the stem), more juvenile wood, and lower wood density and stiffness. There is no hard evidence to indicate that other quality features such as resin pockets or intra-ring checking are different on fertile sites.

Breeding

The introduction of exotic forest species began haphazardly soon after European colonisation, but around 1950 a systematic approach was adopted for both species and provenance testing (Burdon 1995). The tree breeding efforts to support an expanding forest industry concentrated initially on growth rate, stem form, branch habit, and disease resistance. From 1970 another goal was to produce knot-free timber from unpruned stems (Jayawickrama *et al.* 1997). While "improved" seed-orchard seed first became available in 1970, it was not until 1985 that there was sufficient seed for the national planting requirements. The results of early breeding efforts gave about 30% gain in volume (Matheson *et al.* 1986). Since then, a huge amount of information has been collated on the growth and wood properties of desirable individual parent trees (Sorensson, Cown, Ridoutt, & Tian 1997; Ridoutt *et al.* 1998), and the advantages of "designer breeds" have been discussed (Carson 1991). Wood properties did not feature in these early selections. The connection with wood stiffness was recognised early; this trait has been included in some selections from 1975, and spiral grain from 1995. White *et al.* (1999), Shelbourne *et al.* (1997), and Jayawickrama & Carson (2000) argued that breeding objectives should be set, along with the selection criteria. Breeding objectives were proposed for two major types of crops in New Zealand:

- General Purpose (volume production, disease resistance, straightness, stiffness, stability)
- Appearance (as above but with high clearwood recovery).

To achieve these targets, selection indices were discussed, whereby traits are weighted by their economic value. The main dichotomy in selection criteria between the two product types involves branching habit (Carson 1988) — uninodal (longer clear lengths but poorer form and growth and larger branches) *vs* multinodal (faster growth with more numerous, but smaller, branches). In addition to these "gross" features, many specific wood properties contribute to the goals of stiffness, stability, and appearance (Ball *et al.* 2001; Burdon 1975; Sorensson, Burdon, Cown, Jefferson, & Shelbourne 1997; Young 2004). The good news is that most of the wood properties are highly heritable — the bad news is there are many of them! It has been recognised that the traits considered should cover the whole production system and also be robust in the face of changing harvesting and processing technology and wood products markets — a major challenge with commercial tree crop rotations. From 1987, there has been a seed certification scheme, based on growth and form (GF) data (Forest Research Institute 1987). Now there is a GF Plus system in operation (Vincent & Buck 1998) whereby individual traits are ranked (growth, straightness, branch frequency, disease resistance, wood density, and spiral grain). Among the wood traits, wood density has been accorded the highest priority for *Pinus radiata*, as for other species worldwide (Zobel & van Buijtenen 1989).

Efforts to improve the major forest species *(P. radiata* and Douglas fir) are ongoing, under the auspices of an industry/research "consortium". Major issues involve dealing with the large tree-to-tree variability in wood properties, and addressing the divergent needs of individual companies. Vegetative propagation methods are a means of tackling these, and currently account for about 50% of the planting stock. Deployment of "aged cuttings" (physiological age 3 or 4 years), while slightly more costly, has additional advantages in terms of stem form, stability, and wood quality (Menzies & Aimers-Halliday 1997). The use of control-pollinated stock and availability of vegetatively propagated cuttings offer growers new options to increase productivity and customise selection criteria. However, this places more responsibility on forest owners to consider future markets.

For practical reasons, breeders are focusing on early assessments (ages 5 to 10 years), as the greatest need for improvement is in the juvenile wood. A major need in the drive to improve wood performance is better knowledge of juvenile:mature correlations for wood properties, and cost-effective tools for the early assessment of important wood and/or performance properties. Increasingly, breeders are using equipment such as SilviScan (Evans & Downes 2001) and standing tree acoustic tools (Carter & Lausberg 2004). The promise of DNA technologies to speed up the tree improvement process is yet to be proven and may take some time (Dickson & Walker 1997).

It must also be remembered that no matter how "good" the genotype, it must be matched by appropriate silviculture. The combined effects of tree breeding and modern silviculture have reduced rotations from around 50 years to 30 years or less. Unfortunately, there are unfavourable genotypic and phenotypic correlations between some important characteristics (notably branch size and wood density) and stem diameter growth, which have implications for end product value (King & Burdon 1991).

Silviculture

The earliest plantations in New Zealand were established using unimproved genetic stock and traditional European methods — high initial stocking and minimal tending. It quickly became apparent that there was a great variety of stem and crown form, and competition resulted in depression of individual stem growth. This approach necessitated rotations of 40 years or more to reach a large piece size. Plantations established after about 1960 contained increasing proportions of genetically improved stock, and spacing and thinning were adopted to maintain diameter growth — resulting in significant recovery of merchantable volume at 25 to 30 years. Initial stocking has commonly been around 700 stems/ha. However, in common with many softwood species, major differences occur between the wood in the first 10 or so rings from the pith — "corewood" or "juvenile wood" — and the outer rings — "outerwood" or "mature wood" — (Cown 1980; Harris & Cown 1991; Burdon *et al.* 2003; Nicholls 1986). The former tends to be of much lower density, and has shorter tracheids, greater grain spirality (Cown, Young, & Kimberley 1991), and higher microfibril angle (particularly near the base of the stem — Donaldson 1992), all of which mitigate against satisfactory mechanical properties (Burdon *et al.* 2001; Xu & Walker 2004), although juvenile wood can have advantages for certain types of pulp (Evans *et al.* 1999).

Pinus radiata may not have the level of density attained by some other species, particularly on short rotations (around 25 years) and on cooler sites (Cown 1999), but it does have many good characteristics which are favourable for manufacturing and finishing. In broad (international) terms, the highest value of lumber is obtained for quarter-sawn clear boards. It follows that control of branching (pruning) and radial growth (spacing and thinning) are the keys to producing the highest value ***logs*** capable of yielding this kind of material. Most companies have adopted these principles to a greater or lesser degree. Interestingly, some studies have shown that the lower stocking used to encourage growth of butt logs is less conducive to formation of resin blemishes. However, the issue becomes one of balance — treatments designed to maximise the value of the pruned butt log tend to degrade the upper logs by increasing the juvenile core and branch size. Thinning regimes are common, even in "structural" regimes, with the main objective of attaining both log size and stand volume targets in the shortest time on a given site. The trade-off between log size and branch diameter must be considered to maintain log grade (based on diameter and branch size). The highest value ***stands*** produce large-diameter well-pruned butt logs, with the upper logs having small knots and high density. Integrated companies (of which there are now fewer) are more conscious of the specific needs of their processing plants. Several companies have adopted the "target tree" concept where certain attributes are sought and silvicultural options selected to promote them. For instance, greater clearwood yields are obtained from second-log pruning and growing the stands to around 30 years as opposed to the usual 25 years. Integrated companies (growers and processors) tend to have more incentive to get this right. A high level of trust in future technology was shown by Carter Holt Harvey in 1998 (Dyck 1999) when they announced a fresh new approach to forest management. The new strategy involved planting selected stock at 550 stems/ha and harvesting (without selection thinning) at about age 23 years. The goal was to produce structural logs at minimal cost and/or to use the best future technology to recover clearwood for remanufacturing from between the knots.

A common strategy is to manage medium- and high-fertility sites for clearwood production, involving early pruning and thinning to restrict the knotty core and maintain diameter growth. Under this regime, pruned butt logs represent about 60% of the value of the stand. On less-fertile sites, denser stocking may be maintained to restrict branch growth.

WOOD PROCESSING

The optimistic early predictions that the world will be queuing at our borders has proved flawed, as we now realise there may not be a real international shortage of economically available fibre, at least in the short term, and the current crop has some limitations in terms of quality and particularly uniformity. It has been observed by several companies that log quality has declined somewhat in recent years (Drummond 2004). There are several reasons for this:

- Lower stockings leading to larger branches (poorer log grades)
- Planting of more fertile sites, leading to shorter rotations, more juvenile wood, and shorter internodes
- Widespread use of the "850" (low density) breed in 1970s plantings
- Variable quality of pruning.

From a processing point of view the trees have been planted and tended, and the wood quality of the existing resource is fixed. Stem grading, crosscutting, and log allocation are crucial in making sure processors can extract the maximum value from logs. Growers have a vested interest to ensure that the needs of the processors are met, and that the good logs are not contaminated by a few bad logs. A small amount of unstable lumber or lumber with excessive defects can contaminate complete production batches or shipments. There is now a trend for processors to pay a premium for logs which better meet their specifications, and a recognition that the standard log grades developed 20 years ago are no longer ideal as they do not cater well for *intrinsic* wood quality (Young 2004).

Getting an economic return from the available log supply is a challenge facing growers and sawmillers as they have to match the market demand in terms of grade and size with the quality zones in the logs. The grades recovered from logs are crucial to the profitability of sawmills. If the logs are not capable of yielding the required grades, or if the log quality is too variable, quality lumber products cannot be economically extracted from the available logs. For instance, sawmills often recover only a portion of the potential clearwood from the pruned zone of a log because of variability in the defect core diameter and other defects such as resin pockets, resin streaks, compression wood, and internal checking (Young 2004). The mills which are successfully processing pruned logs are very discerning about where they source their logs and they continuously monitor the grade recoveries from different log sources.

The recovery of structural lumber grades is also an issue. Based on recent industry data, only about 10% of the New Zealand harvest will produce good structural logs*. The result is a shortage of sawn lumber meeting international structural strength and stiffness requirements. This, combined with the "Leaky Homes Syndrome"† has lead to a lack of confidence in wood. For example, steel and concrete are increasingly replacing wood for use in residential construction. Overseas, the situation is similar in that building industries are turning to substitutes in many areas. Classic examples are the use of plastic or wood-plastic composites for roofing, decking, and window joinery.

The classic solution to variable wood quality has been the development of sophisticated engineered wood products and this is one of the few areas in which

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* Information about structural logs is not generally available but Fletcher Challenge Forests reported that 9% of their harvest volume will be structural logs (Fletcher Challenge Forests, Annual Review 2001, Supplementary Forest Information, p.16).

† Poor building practices, allowing ingress of moisture. The use of preservative-treated lumber in home construction is no longer legally required, and this can lead to subsequent rotting of wooden components.

processors have recently invested in New Zealand with two relatively new plants, one in Whangarei* and one in Nelson†. Both plants have been located in areas that produce wood of relatively high density.

TOOLS FOR MATERIAL SELECTION AND LOG SEGREGATION

Value recovery starts with an accurate assessment of the physical characteristics of the forest. Techniques have been refined to permit the sampling and accurate prediction of the volume of traditional log grades (Whiteside & Manley 1987). While the system of national log grades has been adopted over the past 20 years, and served as the basis for planning, no account is taken of intrinsic wood quality. Variability in wood properties is a major issue for plantations worldwide, and particularly for fast-growing pines with pronounced juvenile wood (Zobel & Sprague 1998). There is an acceptance that significant changes to resource quality would take several decades to achieve through silvicultural and genetic manipulation. Short-term measures to control variability are needed and there has been a strong push to develop non-destructive stem, log, and lumber technology. There is now an increasing arsenal of tools available for the assessment of wood quality at various stages of forest development: early selection for breeding; stand inventory; log segregation; lumber segregation. These new developments are a reflection of the importance now placed on intrinsic wood properties.

Stiffness

Stiffness is a key property for softwood plantations, and a characteristic which is subject to extreme variability under the influence of biological and environmental factors. Studies have consistently shown that there is often more variation within a stand than between stands, and so the greatest benefit is achieved by log sorting. Research has confirmed the indirect effect of intrinsic properties such as density and microfibril angle on product stiffness (Downes 2004), but from an operational point of view, processors rely on automated systems to recover mechanically acceptable structural lumber — often by machine stress-grading. New tools are now rapidly emerging which can predict stiffness more directly, and companies are increasingly adopting acoustic tools for segregating stands and logs prior to processing for lumber or Laminated Veneer Lumber production, according to "dymanic MoE" (Carter & Lausberg 2004; Dickson, Matheson, Joe, Ilic, & Owen 2004; Dickson, Joe, Harris, & Holtorf 2004; Gaunt & Emms 2004; Wang *et al.* 2004). The new tools use sound velocity to estimate stiffness from standing trees

* Carter Holt Harvey Futurebuild LVL, Marsden Point. Part of International Paper, USA.

† Nelson Pine Industries, part of the Sumitomo Forestry Company, Tokyo, Japan.

and resonance technology for logs*. Relationships to lumber stiffness are generally good, and the tools can be used in combination to pre-screen forest stands and segregate logs in the mill yard prior to processing. Such tools will also have a dramatic impact on tree breeding, where non-destructive samples are required at an early age (Matheson *et al.* 2002). The adoption of these tools by the Australasian industry is now well under way, and sampling strategies are being developed to match use situations (e.g., comparison of stands *vs* individual trees).

Stability

One of the disadvantageous features of wood is the propensity to change dimension with changes in moisture content. The wood characteristics which contribute to this phenomenon are grain angle, microfibril angle, longitudinal shrinkage, compression wood, and elastic modulus. Researchers have been using an arsenal of tools to assess some of these in order to predict unstable wood as early as possible (Evans & Downes 2001; Evans & Ilic 2001; Hagman 1997; Nyström 2002). Studies have documented the contribution of spiral grain and compression wood to drying distortion (Haslett *et al.* 1991) but the challenge remains to identify and segregate lumber in the "green" state. The application of SilviScan (Evans & Downes 2001) to young genetic material allows the early prediction of stability for breeding programmes.

Appearance

A feature of the "new crop" which was not anticipated is the intermittent occurrence of intra-ring checking. This was not observed until about 1990, but has since become relatively frequent in the butt logs of pruned stems, reducing the value significantly. The only way to evaluate a crop has been to destructively sample pruned logs and collect discs for laboratory analyses (McConchie & McConchie 2001). The search is now on for a rapid non-destructive approach using increment core samples.

Resinous defects (resin pockets, streaks) are a source of degrade of high value lumber which is little understood. Regional variation has been recognised for some time (Clifton 1969; Cown 1973; Park 2004). However, more recent studies have shown that external signs, such as resin bleeding, are indicative of internal blemishes and a procedure has been developed for classifying stands (McConchie 2004). This can be used as an input into thinning decisions.

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* The dynamic Modulus of Elasticity is computed from:

$$E_d = pV^2$$

where, E_d = Dynamic MoE
p = wood density (at test)
V = velocity through wood.

CONCLUSIONS

There have been rapid advances in the understanding of the factors driving wood quality of *P. radiata* plantations worldwide. The initial benefits of significantly improved growth and form have been tempered by some of the other features associated with vigorous growth — larger branches, more juvenile wood, and a greater expression of variability within and between stems. The wood quality of *P. radiata* forests has long been recognised to be a function of site, genetics, and silviculture, and there are sophisticated models available for predicting the outcomes of silvicultural options (Whiteside & Sutton 1983). However, there is a new focus on developing practical tools to perform two major functions:

(1) Measuring variability in key quality parameters in mature stands to assist with strategic decision-making and segregation of material if warranted;

(2) Screening young material in breeding programmes.

A key point is that the improvement in wood quality is a two-way process — purchasers of logs and lumber need to reward suppliers with price differentials for quality sufficient to encourage the development and use of new segregation tools and forest management practices geared to producing higher quality raw materials.

The rapid development of non-destructive testing tools for segregating trees, logs, and lumber into quality classes earlier in the processing cycle takes away some of the pressure on foresters to ensure that "wood quality" is suitable for markets several decades in the future. There is a growing expectation that tools will be available to identify quality in growing trees and to segregate for a range of products at the end of the rotation.

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