IMPROVING THE RELEVANCY OF BREEDING FOR WOOD QUALITY IN *PINUS RADIATA**

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ABSTRACT

Improving wood quality of softwoods using selective breeding ("Family" or "Varietal Forestry") will improve the efficiency of plantation pine forests at meeting future society's fibre needs, providing improved material is deployed into forests on a sufficient scale. Only by such deployment does wood quality breeding become practically relevant. Although breeding for wood quality is not without its challenges, there are many reasons to attempt it, and some genetically improved material already exists. Unfortunately some foresters hesitate to pay price premiums for such improved planting stock. One issue is that wood qualities such as log velocity may not benefit growers if they are used only to audit whether a log may remain in a visual structural grade or be downgraded. Some processors already have mechanisms for sharing added value of high log velocity with growers, and such mechanisms should gain widespread acceptance over time.

Breeders can help by providing clear examples to growers and processors of the wood quality improvements possible from genetic selection through to crop maturity, and of the resulting value impacts on stumpage and through processing. A new series of proposed demonstration forests, Forest+, would also help by showcasing to investors and policy makers the very best plantation forest practices. These plantings would naturally utilise the best silviculture and genetics, and present financial returns could be assessed regularly. Greater net incomes possible through the use of elite '2Q' (quantity & quality) genetics will help forestry compete with intensive animal production systems such as dairy that drive current deforestation trends in New Zealand.

Keywords: wood quality; breeding; sustainability; profitability; plantation forest.

INTRODUCTION — WHY IMPROVE WOOD QUALITY USING BREEDING?

Establishment foresters traditionally purchase genetically improved treestocks to ensure young stands grow fast and produce well-formed, healthy stems (gross early

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yield), often without regard to wood properties. Published log-grade descriptions are defined simply (i.e., small-end diameter (SED), sweep, length, maximum branch diameter) for practical reasons, and tend not to include internal wood qualities. Because price-quality responses on log price (stumpage) for wood qualities such as log velocity are not yet clear, foresters feel exposed to a risk that they will not be rewarded fairly in higher stumpage prices if they plant improved treestocks. Add a long time to harvest, market and political uncertainties, mid-rotation changes in forest ownership, competition from wood substitutes, increasing energy and land rental costs, etc., and it becomes understandable when some risk-averse foresters overlook the more costly "new genetics".

This confusion over the "relevancy" of wood quality improvement from genetics, and the value thereby generated that can be shared with forest growers, is a serious problem for the industry. Relevance (R) is defined herein as the rapidity with which industry uplifts new solutions into production forests (Eqn. 1). Insofar as it involves genetically improved trees that truly add value to forests, relevance is directly proportional to forest estate NPV.

$$R = \begin{array}{c}\text{Rate of Uptake}\\ \text{to Forest}\end{array} \times \begin{array}{c}\text{Rate of Value}\\ \text{Capture}\end{array} \qquad \text{(Eqn. 1)}$$

Foresters do not deny the importance of wood quality; indeed, they tend to be "wood smart" quality-sensitive consumers of wood products. Even people lacking a technical background in wood science or manufacturing still often appreciate the need for improving wood quality — if only to reduce the likelihood that their wood product purchases will later prove faulty in service. Most people intuitively understand that improving wood qualities raises conversions from logs to high-value products and renewable-resource fibre by reducing low-value wood residues. Fast-grown plantation softwoods all variously suffer from wood quality problems, such as unacceptable appearance, dimensional instability, and low stiffness. The conundrum is this: plantation softwood forests need to generate fibre fast, but trees that grow fast tend to be deficient in the wood qualities required to successfully convert that raw fibre into high-value commodity and specialty products.

Tree breeding can meet this challenge, as it has in the horticultural, agronomic, and animal husbandry industries. Dairy (milk and cream) exports from New Zealand have risen from No. 4 to No. 1 position since the 1980s, due largely to the greater efficiency of milk solids production of genetically superior herds. These industries have benefited from many generations of breeding, but plantation softwood species have benefited from only two to four generations of breeding and, as such, timber trees are still largely "wild" and under-domesticated. Although some people are shocked by that fact, the upside is that any genetic improvement process that rapidly domesticates a tree crop will transform future industry, and provide the solid platform needed for stable industry growth. The emphasis on stability is intentional — few here need reminding of the high social cost of industry volatility.

Breeders have long been interested in the genetic control of wood properties, and the potential for capturing significant gains in them (Zobel & Jett 1995), with studies dating back six decades (e.g., Jacobs 1939; Champion 1945; Fielding 1947). Neither is interest in wood quality from commercial foresters particularly new — in the welcome address to the largest *Pinus radiata* D. Don genetics conference between 1982 and 2007, Carson (1997) emphasised "new perceptions of appropriate breeding goals from client emphasis on wood quality vs. volume yield". Industry interest in wood qualities was apparently sparked by independent observations in both New Zealand and Australia that some improved orchard seedlots were inferior in wood quality (e.g., a 3% loss in conversion into MSG lumber in Australia from second-generation selections; Dean 1990).

Opportunities for capturing wood quality gains from breeding are described in nearly all the softwood literature as "good". For example, a review of over 90 different wood and product qualities of *P. radiata* showed that the vast majority of these traits were under mostly strong genetic control and offered good potential from gains from breeding, with gains limited primarily by lower coefficients of variation (Shelbourne 1997). Similar results were reported in contrasting softwood species such as western hemlock (*Tsuga heterophylla* (Raf.) Sarg. (heritabilities 50% to 90%; King *et al.* 1998). While some easily-captured gains in wood properties are small, financial benefits can sometimes be leveraged considerably via manufacturing (Shelbourne 1997), and magnified further through deployment of more uniform crops such as vegetatively propagated "SE Varieties" propagated via somatic embryogenesis to enable cryo-storage (syn. clones; Sorensson & Shelbourne 2005).

In the absence of public clarity over the financial impact of wood quality improvement on future stumpage prices, some forest growers remain reluctant to pay the price premiums for elite treestocks bred for balanced improvements in the '2Q's — quantity and quality. This unwillingness benefits foresters in the short term to the extent that their job performance is measured, in part, by their ability to reduce forest-growing costs. Foresters are judged also by their ability to deploy the very "best" genetics to the forest, but it does not immediately follow that treestocks with the greatest improvements in wood qualities are necessarily the "best" for a particular site, given their premium cost. Some foresters have taken the non-intensive route, combining low-cost open-pollinated genetics and conservative tending practices — practices that are familiar to foresters from high latitude regions.

Thus, wood quality breeders have to first convince foresters of the technical merits (i.e., risk and gains) of the "new genetics", and then convince managers of their financial merits. Though the arguments for improving softwoods for wood qualities are impressive and many apply to growers only selling stumpage, they can still prove insufficient to drive strong product sales, and relevancy. Such foresters will not respond to additional arguments such as enhanced forest sustainability unless governments first recognise these other values (as proposed by the "6-Point Kyoto Policy"; NZFOA website April 2007). Hard-nosed foresters need and deserve real unequivocal examples of the genetic gains and financial upsides realisable from wood quality breeding.

Fifteen Reasons to Improve Wood Quality of Plantation Softwoods

(1) Although some breeding programmes have periodically screened many candidates for properties such as density, most have not had enough market pull to "breed" aggressively for them. In this case, a few existing high-growth selections may still prove to have unexpectedly high wood quality. This "low hanging fruit" can provide foresters with early access to new selections improved in the '2Q's.

(2) Genetic wood qualities are typically 2–3 times more heritable across sites than is growth (e.g., Shelbourne 1997; Wu *et al.* 2008) and exhibit less G×E (genotype × environment rank interaction; Zobel & Jett 1995) than other important traits such as growth. From the grower's standpoint, this means genetic wood quality improvements are low in risk (e.g., Sorensson, Nepveu, & Kimberley 2004), being more predictable than traits such as growth rate, especially across diverse sites (Cown & Ball 2001).

(3) Substantial improvements in wood quality are possible, particularly with clonal crops (Cown 2002). Risks associated with varieties deployed monoclonally are manageable by deploying a mosaic of genotypes. The required number of genotypes to manage risk can be quite small (Libby 1982; Bishir & Roberds 1997). High clonal gains, when present, help buffer clones from any mild underperformance risks, including G×E.

(4) Excessive variability in wood and log quality is a headache for forest planners, as well as wood processors and market developers. The defining feature of undesirable corewood of softwoods is its steep radial gradient in wood qualities (Walker & Nakada 1999). Better wood quality, particularly in this young wood, improves the consistency of log/fibre quality.

(5) Crops improved sufficiently in growth and wood quality can be harvested earlier than normal if desired. This gives forest managers greater flexibility in harvest planning and greater ability to raise cut levels when demand for logs is high. Benefits from decreased rotation age include more frequent updating of genetics and silviculture in forests. Particularly important are savings in forest growing costs and land rentals.

(6) Genetic improvements in wood qualities decrease the proportion of low-quality residual wood generated during processing. Improving the conversion of log

to product effectively means growers produce more valuable wood without additional silvicultural inputs such as site prep, weed control, and fertiliser. This makes wood quality improvements more eco-friendly than downstream practices such as log and lumber segregation.

(7) With less production of "waste wood", fibre needs can be met with a smaller land base, itself an important goal of modern forests (Fries & Ericsson 2006). That would be particularly attractive to owners of HBU ("higher and better use") land that is profitable to sell (especially if that land may later be subjected to Government-imposed penalties on deforested Kyoto land, as has been proposed in New Zealand).

(8) Better tracking of log to final product, and better information on internal wood qualities of logs, will give mills ever-greater financial transparency between their profitability and log qualities. This should, over time, generate a greater demand for high-quality logs.

(9) Tracing log value back to stand and stump (as is already done by Weyerhaeuser Timberlands), and appending that information to GIS maps of forest stands, will allow foresters to identify the actual bottlenecks of crop value in each stand. A "shopping list" of required improvements can then be issued, by stand, that will value bottlenecks and build market pull for specific wood quality genetic solutions.

(10) Better wood qualities would improve the suitability of wood for diverse high-value products (specialty papers, furniture components, sawn lumber, LVL, furniture components, etc.). Increasing their "Future Market Flexibility" is already recognised by some forest growers as an important goal, much as "Flexible Manufacturing Systems" have become an important strategy of some electronics and automotive manufacturers.

(11) Most wood scientists believe that future processing technologies will not be able to transform a poor-quality fibre resource into high-value products at a low cost. If such technologies do emerge, they will likely be very specific to certain problems. Gross defects, such as resin pockets, seem unlikely to be "solved" by processing, for example.

(12) With highly advanced lumber segregation such as for warp propensity (Weyerhaeuser 2008), processors will be able to craft wood products with impressive performance warranties. Such products should command strong premiums from such quality-sensitive markets as DIY. Market demand for these specialty products will then feed down the value chain towards breeders.

(13) It has been said that roughly 20% of the logs poorest in wood quality account for 80% of the value losses caused by poor wood quality. Any relevant genetic improvements that result in the elimination of the worst-performing trees can add disproportionately high improvements to log value.

(14) High-density fast-growing trees capture carbon faster than others, with potentially greater forest revenues from carbon credits. At the carbon prices and exchange rates of March 2007, Kyoto forests in New Zealand should generate more than $1 billion between 2008 and 2012 (Fallow 2007).

(15) As significant improvements in wood qualities are captured by breeding and varietal development, the ongoing overhead costs of genetic research and development can be reduced relative, say, to the ongoing costs of log and lumber segregation. Tree breeding is surprisingly cost-efficient — early returns on investment in *P. radiata* breeding were estimated at 40:1 (Shelbourne *et al*. 1989, based on Carson 1990). Benefits in Australia from *P. radiata* breeding will reach $141 million per annum by 2025 (Sultech 1999). By comparison, the biotech sector in the USA has lost money over the past 25 years, with the average cost of launching a new drug roughly US$1.2 billion (Schuster 2007).

LOG VELOCITY

Log velocity has quickly become an important wood quality trait, and it may well attract more attention from softwood breeders worldwide over the next decade than any other trait, including wood density. The resonance velocity of green logs (or its squared value; Andrews 2002) is positively correlated to the average stiffness of softwood logs and to microfibril angle and tracheid length, and inversely correlated to excessive longitudinal shrinkage and some forms of warp like crook (spring) and bow. Velocity is increasingly recognised by breeders not just as a surrogate for wood stiffness but as a breeding objective trait in its own right because log velocity is used in logyards and mills to verify structural quality.

Most, if not all, of the large structural sawmills in New Zealand have conducted detailed return-to-log (RTL) studies that clarify the added-value response from different log velocities, by size class, of structural “S” logs (Wynn Daniell pers. comm.), and the same is increasingly true overseas. An indicative set of RTL functions is shown for the three main size classes of *P. radiata* structural logs, but log RTL has been halved already to provide for an equal value share to grower and processor (Fig. 1). Large logs are less sensitive than small ones to velocity because their value is buffered by the presence of outer wood in these typically older logs, and because large log size *per se* improves conversion from logs to lumber. The high value of small-diameter, high-velocity logs probably reflects a small proportion of very growth-suppressed, old logs with high numbers of growth rings. Such logs are often straight and fine branched, high in density and stiffness, and higher in value than similar-sized small logs that have fewer growth rings.

Velocity is a compound trait, as is wood density, but it is nevertheless well-behaved genetically, and most breeders have concluded the opportunities for breeding are

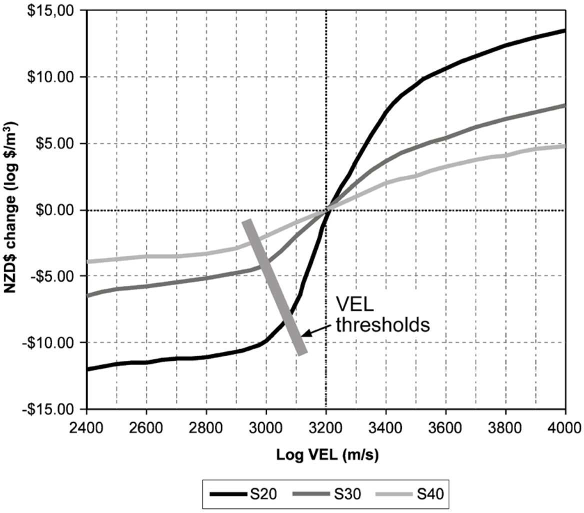

FIG. 1–Indicative pricing response of structural *Pinus radiata* logs to log sonic velocity. Prices of domestic sawlogs S1 and S2 averaged \$85/m^3 from 2004 to 2007 (NZMAF 2007), and so a pricing adjustment of \$5 above is a change in log RTL of \$10/m^3 or ±12%. Curves are based on confidential mill surveys, and apply a 50:50 value share between processor and log grower.

good (e.g., Kumar *et al.* 2006). Microfibril angle in the dominant S2 cell wall layer and tracheid length are the two wood anatomy traits most strongly related to log and standing-tree velocity, particularly in young pines, and both traits are moderately or highly heritable (Shelbourne 1997; Dungey *et al.* 2006; Wu *et al.* 2008). ArborGen Australasia has had a long history of involvement using standing-tree velocity tools (Sorensson 2004) and many of the production varieties provide substantial gains over control-pollinated seedlings in both growth and velocity. ArborGen's highest rated SE varieties have BLUP-derived estimates for sonic tree velocity ranging from 31 to 37 on the "0 to 30+" scale (Vincent 1997) that is used to market the performance of seedling seedlots derived from New Zealand seed orchard parents.

Velocity is used by structural lumber and LVL mills, and by log or stem processing yards, to audit log quality for structural products. In vertically integrated forest companies, log velocity knowledge has become crucial to strategic forest planning — e.g., to determine where in a forest estate to apply structural timber regimes. Several forestry companies have already mapped and modelled standing velocity and/or log velocity across much of their estate. That information is then appended as a layer, along with outerwood density, into GIS maps of forests and used in forest planning.

Four log-velocity levels were proposed for inclusion into a revised set of structural log grade descriptions for New Zealand *P. radiata* (Treloar 2005), but with little acceptance. Some attribute this to a reluctance of companies with low-density sites to accept the resulting write-down in forest value, or to a focus on appearance-grade products. However, in the new "Verified Visual Grading" system (NZS 3622 & NZS3603), visual grades of structural lumber like VS8 are required to be audited objectively for bending stiffness, and failure to meet specification results in price penalties. Thus, accepting velocity as a grade criterion should not be a major stumbling block *per se*, even to forest growers with "low-velocity" forests. Increasingly, too, these forest owners choose either not to produce structural log grades, or to plant Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco), so it seems unlikely that they would resist accepting velocity-based log grades even if their forests have become classed as "non-structural".

A better explanation may lie in how many log grades can be managed practically at skid sites, at stem yards, or at mills. Having more than a few physical log grade piles quickly becomes costly and inefficient. Generally New Zealand already has too much complexity in its number of physical log grades, given an optimum of five or fewer log sorts (Murphy *et al*. 2003). In-forest segregation of stems or logs for velocity is/has been done, but mostly to cull logs that look visually structurally in-grade, but which internally are not. This process does not normally increase the number of physical log sorts, but it is costly.

Given the costs and logistics of complex log sorts, mills have responded with forms of "continuous log grading". The Carter Holt Harvey structural sawmill at Mt Gambier, for example, velocity-tests all incoming logs just before the primary breakdown. Velocity information is used alongside each day's order list to optimise sawing patterns. This adds value by improving product recovery without increasing the number of distinct log grades. In principle, a mill could add additional features (e.g., via log-end scans) to further optimise how it cuts up each log. Depending on final customer and the forest source of the logs, velocity thresholds could also be adjusted up or down during the day to adjust outturns of particular end-product grades, providing the mill more flexibility than it would if it adhered to a nationally published set of velocity classes.

It probably matters less to breeders whether wood quality traits such as velocity get published into new national log grades or not, than whether the industry can agree to price-quality gradients for wood qualities that "ensure" forest growers receive a share of the value impact through sawmilling of those wood qualities. Without price-quality responses akin to that in Fig. 1, breeders and crop modellers cannot directly incorporate wood qualities such as velocity into financial analyses of forest-growing profitability.

Adverse Genetic Correlations of Growth and Wood Quality

For selling genetically improved treestocks at a premium (recovering the genetics research and development investment plus a profit margin), gains must be sufficient to generate strong market demand. In other words, gains must exceed prescribed minimum targets (say 1 GPa stem modulus of elasticity (MoE, stiffness), 100 m/sec in log velocity, or 20 kg/m^3 outerwood density at age 20) to give growers certainty that the improvements are substantial enough to be risk-free.

Adding any new trait carries penalties in the form of diverted selection pressure from traditional mainstream traits such as growth, form, and disease tolerance. In addition to this challenge, some key wood quality traits can be adversely correlated to fast growth, particularly stem diameter. A hypothetical example of two normal traits with a weak adverse genetic correlation of $r_g = -0.3$, is visualised in Fig. 2. The cloud of points is laterally compressed and internally slanted, which is why adverse intertrait correlations impede one's ability to find superior genetic selections achieving prescribed gains simultaneously in both traits. Having even one moderately adverse intertrait correlation can reduce the expected ratio of trees that meet specifications for both traits by about half (Appendix 1).

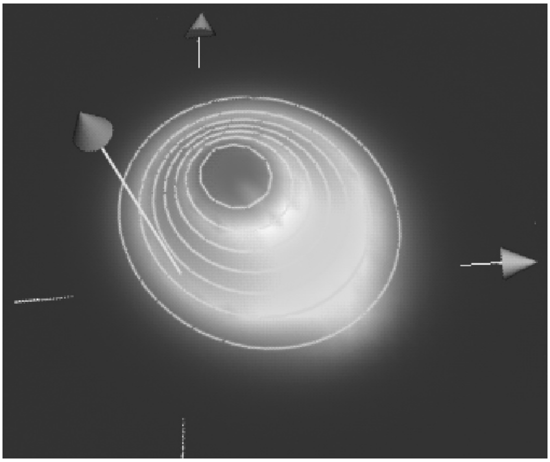

FIG. 2–Topographical map of a bivariate normal distribution with a moderate adverse inter-trait correlation (R = –0.3). Source: L. Hansen.

A similar intertrait correlation is shown in Fig. 3, but this is based on real data of 264 mature *P. radiata* assessed for diameter at breast height and basic wood density in the first 20 to 25 m height from 1246 wood discs. There is a moderately strong adverse correlation between diameter at breast height and outerwood basic density ($R = -0.35$, $Pr<0.001$) and a less adverse correlation between diameter at breast height and volume-weighted resin-extracted basic density ($R = -0.22$, $Pr<0.001$). This trend sounds weak — i.e., a 10-cm increase in stem diameter at breast height is accompanied on average by less than a 10 kg/m^3 loss in outerwood density. However, as Low & Smith (1997) noted "the highest genetic density selections

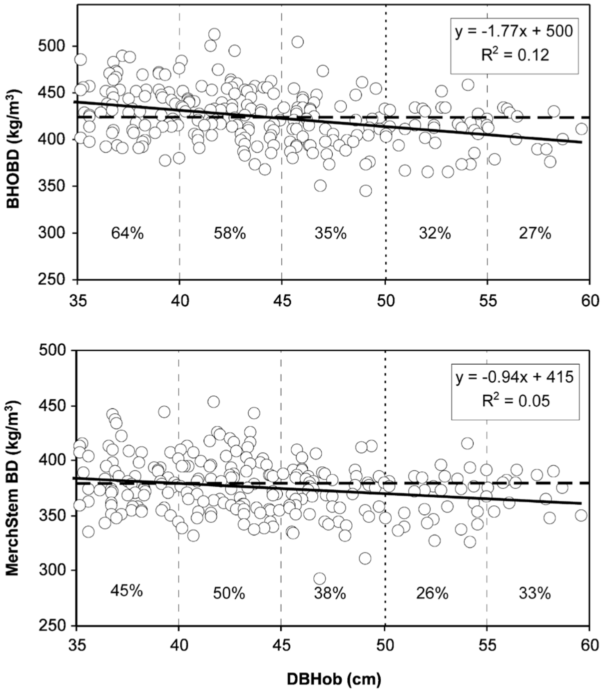

FIG. 3–Stem size (dbh) *versus* wood density of 264 age-28 *P. radiata* stems in a plantation forest in New Zealand's central North Island (confidential industry source). Solid line = trendline. Dashed line = designated density threshold. BHOBD = outerwood basic density.

tend to be just average in growth rate". By applying a subjective threshold for "acceptably high" wood density, it is seen that the potentially most valuable dominant stems in the crop typically fail to meet the density threshold. Foresters are sufficiently aware of this quantity-quality conundrum for many to bias their wood quality inventories at the 100 dominant stems/ha, an approach not typically used by wood scientists.

Some pine species were reported to be relatively free of these adverse correlations. They include slash pine (*Pinus elliottii* Engelm., Kain 2003), Scots pine (*Pinus sylvestris* L., Hannrup *et al.* 2000), and some loblolly pine (e.g., *P. taeda* L. clones, Eckard *et al.* 2006). Also, most of the early studies on growth and wood density in conifers did not find adverse correlations (reviewed by Zobel & Jett 1995). One possible explanation could be a superior ability of some fast-growing pines to intercept soil moisture. Increasing soil moisture (by irrigation and/or weed control) resulted in simultaneous increases in stem diameter, wood density, and latewood percentage of loblolly pine growing on drought-prone southern US sites (Clark 1997). In some conifers where the influence of microfibril angle is particularly great on wood stiffness, adverse intertrait correlations between growth and stiffness have not been found (e.g., in Japanese sugi (*Cryptomeria japonica* (L.f.) D. Don) Fujisawa *et al*. 1992).

In *P. radiata*, however, almost all reports from both New Zealand and Australia suggest that the true intertrait genetic correlation is moderately adverse for both density and velocity *vs* stem diameter growth, r_g averaging about –0.4 to –0.5 (Wu *et al*. 2004, 2008), and in some cases very severe (e.g., $r_g = –0.7$ for outerwood density *vs* diameter at breast height of mature *P. radiata* in a high-stocked pulp regime; Li & Wu 2005).

How then can *P. radiata* breeders achieve multitrait "2Q" gains? The primary response is to increase genetic diversity of parents (in the hope of finding gene combinations that are not competitive) and candidate population size (to get more gain through increased selection pressure). One can also try moving selection pressure from diameter at breast height to height growth, as height is thought to be positively correlated with wood stiffness in at least some conifers, perhaps mediated by taper and proximity to green crown (Lassere 2005; Bascuñan *et al*. 2006). Another approach is to select only to maintain density, which may be why the second-generation "268" parents did not exhibit the density losses (Cown *et al*. 1992) observed in the first-generation "850"-series orchards. Breeders may develop special breeds or elites for wood quality (and curiously there is some evidence emerging that New Zeasland's high-density breed may somehow avoid the expected adverse correlation with growth; Luis Gea pers. comm.).

The strategy that "Varietal Forestry" companies like Forest-Genetics CellFor and ArborGen employ is to select superior individual offpsring and deploy them as clones directly, instead of selecting parents and predicting the average performance of their control-pollinated offspring through additive breeding values. Even in small clonal populations one can find "by chance" rare genotypes with significant simultaneous gains in diameter at breast height growth and outerwood density or velocity (Fig. 4). In this example the success rate was low, only 1.5%, a rate close to the 1% used previously for clonal *P. radiata* (Sorensson 2004) and for clonal eucalypts (Verryn 2008). Even at these low rates, however, a relatively small candidate population of ca. 3000 genotypes can still generate enough top selections to meet early needs of varietal developers.

DISCUSSION

The "vision" of modern softwood plantation forests to efficiently provide fit-for-use fibre is strongly aligned with wood quality breeding, particularly regarding softwood crops that will be harvested on aggressively short cycles (Lindström *et al*. 2005). More broadly, it has relevance to the roughly 80% of tree volume not in pruned clearwood that attracts only "about 40% of the stem value" (NZFOA 2006). While these messages seem to be broadly "appreciated", they nevertheless

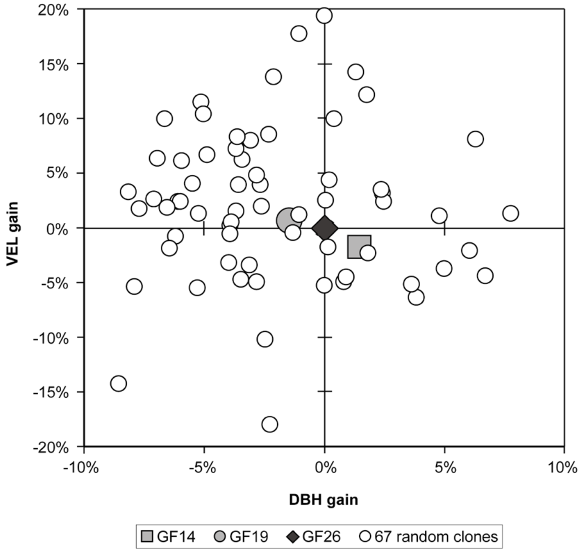

FIG. 4–Seedlot and clone-mean gains for growth (dbh) and velocity (ST300 standing tree time-of-flight) before thinning at tree age-12.5 years at Tarawera Forest in the North Island of New Zealand. Clones were genetically unselected, and had been established as monoclonal plots of 36 trees at 615 stems/ha, with a live stocking of about 590 stems/ha. The correlation amongst all clonal points is weakly adverse (R = –0.07 ns). GF refers to "Growth and Form" ratings given by the NZ Seed Certification Service (Vincent 1997). Most points are represented by about 50 trees.

can be insufficient to entice cash-flow conscious forest managers to invest in premium treestocks improved simultaneously in growth and wood quality. They face too much uncertainty.

Perhaps there is a problem of "lamb dressed down as mutton", i.e., media hunger for glitz rarely falls favourably on relatively "old fashioned" approaches such as breeding (Hocking 2000). Also, some log buyers are relatively reluctant to admit they could pay more for high-quality logs, while they can "just say no" to logs of insufficient quality. This generates ill feelings between growers and log buyers. Breeders and crop modellers have also been slow to translate the added value from genetic gain from "new genetics" into stumpage dollars or dollars ex-mill, and effectively communicate that value story to the media, investors, and policy makers.

Our children's generation will inherit the legacy of decisions made or overlooked today. Breeding is certainly distanced in time from harvest (Fig. 5) but that alone does not make it irrelevant, particularly now that there are more tools than ever to monitor genetic shifts of wood quality in stands well before mid-rotation age. Dramatic gains in wood properties such as stiffness and velocity are capturable

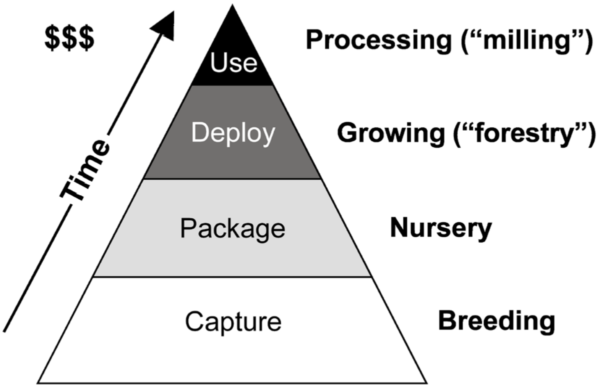

FIG. 5–The value-adding pyramid shows that breeding may be perceived as less relevant than other activities because it has the greatest time-lag from forest harvest.

from parental or clonal selection, as was shown years ago in Japan (e.g., Yamashita *et al.* 2002), and it is clear that deploying those gains to production forests starts a cascade of direct and indirect benefits across the value chain. Breeding for wood qualities makes sense.

Where breeders will struggle most is in meeting customers' demands for genetic gains in a wide array of traits. I have seen foresters taken to clonal plots improved in diameter at breast height and velocity then spend their time expressing concerns over the quality of branching or signs of bark bleeding. Genetic gains in individual traits are highly sensitive to both the number of traits a breeder is trying to simultaneously improve and the between-trait genetic correlations. Verryn (2008) makes the point that "Occam's Razor" had better be applied to family breeding or little gain will be made in the traits that matter most. Breeding-objective approaches for family breeding typically emphasise no more than about four traits on which to make significant gains (e.g., Ivkovich *et al.* 2006).

This paper emphasises the need and opportunity to "make wood quality breeding of softwoods relevant", i.e., to persuade non-breeders that wood quality improvements are worth pursuing and deploying to forest. Breeders can take only small steps towards this goal, notably by publishing better analyses of the financial value of improved wood qualities (e.g., Olsen *et al.* 1997; Sorensson, Bian, Wellauer, & Alley 2004) and generating readily accessible forest demonstrations to educate the public. The simplest of the forest demonstrations are indeed largely "political" devices, but still critically important as physical proof that genetics works (Ken Eldridge pers. comm.).

It is time to consider a more comprehensive set of demonstrations modelled after "Industry Best Practices" trials. These "Forest+" trials would specifically provide examples for investors and policy makers of the profitability of superbly managed softwood plantation forests. Sites representing all key forest-growing areas would be needed, and would include both highly productive sites (i.e., mean annual increments of 35 to 43 m^3/ha/yr; Shula 1989) and sites needing "transformational" solutions from wood quality genetics, i.e., to lift a non-structural forest to a structural one. Financial analyses would be scheduled across a series of crop ages to ensure early results delivery. Remote sensing and spatial analysis could provide up-to-date performance of each stand to a worldwide network of researchers. Deployed internationally, these demos could help to "brand radiata" into overseas markets. A range of peripheral studies could easily be incorporated, e.g., carbon sequestration, biodiversity, and impacts of climate change, not to mention the valuable unforeseeable opportunities that inevitably emerge from long-term genetic experiments "overtaken by events" (Mayo 1997). The time for such a proposal may be propitious as governments around the world look for ways to "use forest offsets" (Anderton 2007).

One control in these demos would be low-cost-genetics-plus-conservative-silviculture, which has become a common industry response in New Zealand to concerns over log quality. Since 2004, when the average rotation age of *P. radiata* was about 27 years (reviewed by Lasserre *et al.* 2005), rotations have increased to about 30 years (NZFOA 2007), and are often accompanied by higher initial and final stockings to better capture light in the young crop, reduce branch size, and raise stem stiffness (e.g., Wang *et al.* 2001; Zhang *et al.* 2002; Lasserre *et al.* 2005). Some experts are in favour of conservative silviculture (Mason 2002), but others are strongly opposed to it (Maclaren 2003) and point out that any increase in log quality from conservative silviculture is achieved directly as a result of induced slower growth. This is why '2Q' breeding is so important — to break the growth *vs* quality conundrum.

To efficiently and rapidly produce fibre that is "fit for purpose" from modern plantation softwood forests will require powerful genetic solutions. In their absence, future returns will be limited by having to employ long rotations and/or accept the high volumes of residual wood that current regimes always generate. There is abundant proof from a range of genetic studies in many tree species that genetics works. In time, molecular geneticists will tease out how growth and wood quality genes interact, and they will advance genetics even further, probably deploying them via superior clones.

In the meantime, a repeating lesson from clonal studies seems poignant: that trees already exist in every forest, albeit rarely, with an extraordinary genetic capacity to grow fast and produce superior log/wood quality. If breeders could sufficiently enrich the incidence of these already existing types of trees in production forests, this alone would transform modern softwood plantation forestry.

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Appendix 1

IMPACT OF ADVERSE CORRELATIONS ON ABILITY TO FIND SUPERIOR GENETIC SELECTIONS WITH MINIMUM LEVELS OF MULTI-TRAIT GAINS.

Model developed by M.O.Kimberley, Scion, Rotorua (2007) for Horizon2.
Assumption of normality for all trait distributions.

Changing just one inter-trait correlation from 0 to –0.3 reduces the likelihood of finding superior selections by the same proportion (34%) in each scenario (Fig. 6). Adding additional selection traits dilutes the impact of a single non-zero inter-trait correlation considerably in its impact on gain.

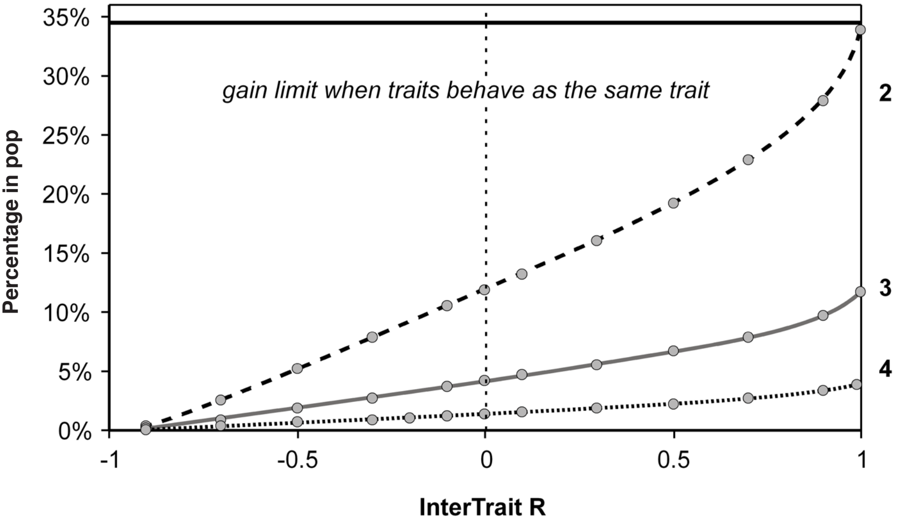

FIG. 6–Probability of finding superior genetic selections for 2, 3, or 4 traits, across the theoretically possible range of intertrait genetic correlations (–1 to +1) applied to one trait pair. Identical traits (mean 400, s.d. 50, CoV 12.5%), and a minimum prescribed gain of 5% (20 units). Individual trait probability is 34.5%. Combined probabilities for 2, 3, and 4 traits of 11.9%, 4.1%, and 1.4% respectively, for mostly independent (R=0) traits.

Example 2

The impact of non-zero R has been magnified in this biologically unlikely scenario that allows for all R to change in tandem, for 2, 3, or 4 traits. Moving from R of 0 to –0.3 reduced the frequency of superior selections by 34% (2 traits), 83% (3 traits), or 92% (4 traits).

Example 3

Adding another adverse inter-trait correlation to the first case decreases the chances further of finding superior selections, but these opportunities are boosted by adding weak positive intertrait correlations (Case 3) (Table 1). When the varying R term changes from an R of 0 to –0.3, the likelihood decrease is fairly similar in each case: by 54% (Case 1), 58% (Case 2), or 50% (Case 3). The most realistic but complex scenario, Case 3, is the most favourable for breeding success due to the presence of several weakly positive correlations.

TABLE 1–Simulation settings for three scenarios, each involving four traits.

Trait	units	Mean	s.d.	CoV%	Gain min.	Gain (trait units)	Gain (min. in units)
dbh	mm	300	45	15.0%	10%	30.0	330.0
straightness	score	3.5	0.9	25.7%	10%	0.35	3.9
velocity	m/sec	2000	190	9.5%	10%	200	2200
density	kg/m^3	370	35	9.5%	5%	18.5	388.5

Case	Trait	Density	Dbh	Straightness
1	density			
	dbh	0		
	straightness	0	0	
	velocity	0	varied	0
2	density			
	dbh	-0.15		
	straightness	0	0	
	velocity	0	varied	0
3	density			
	dbh	-0.15		
	straightness	0.05	0.05	
	velocity	0.15	varied	0.10

In every scenario, changing the inter-trait correlation of dbh and VEL from 0 (independent) to adverse (–0.3) reduced the likelihood of breeders finding the superior selections by about half.