Improving the Relevancy of Breeding for Wood Quality in Softwoods

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Abstract

Improving wood qualities of softwoods using breeding (Family or Varietal Forestry) will improve the efficiency of plantation pine forests to meet future society's fibre needs, providing improved products are deployed into forests on a sufficient scale. Doing so is the key performance indicator of the practical relevancy of wood quality (WQ) breeding. Although breeding for WQ is not without its challenges, there are many reasons to attempt it, and some improved products already exist. Unfortunately some foresters remain hesitate to pay price premiums associated with these improved products. One issue is that wood qualities like log velocity do not benefit growers if they are used only to audit whether a log may remain in grade or be dropped to a lower grade. Some processors have already provided mechanisms that share the 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 genetics through to crop maturity, and of the resulting value impacts on stumpage and through processing. A new series of demonstration forests, Forest+, would also help by would showcasing to investors and policy makers the very best plantation forest practices. These demos would naturally utilise the best silviculture and genetics, and regularly assess present financial returns. Greater net incomes possible through the use of elite '2Q' genetics will help forestry compete with intensive animal production systems like dairy that are the driver of current deforestation trends in New Zealand.

Why Improve WQ Using Breeding?

Establishment foresters traditionally purchase genetically improved treestocks to ensure young stands grow fast and produce well formed, healthy stems (gross early yield), and they neither see nor measure wood qualities (WQ). Published log grade descriptions are defined simply (*i.e.* SED, sweep, length, maximum branch diameter) for practical reasons, and tend not include internal wood qualities. Because price-quality responses on log price (stumpage) for WQs like 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/political uncertainties, mid-rotation changes in forest ownership, competition from wood substitutes, energy costs, increasing land rentals … and it becomes understandable when some risk averse foresters overlook the more costly 'new genetics'.

This confusion over the "relevancy" of WQ improvements, and the value thereby generated that can be shared with forest growers, is a serious problem for the industry. Relevancy (R) is defined herein as the rapidity that industry uplifts new solutions into production forests (eqn. 1). Insofar as it involves products that truly add value to forests, relevancy is directly proportional to forest estate NPV.

$$\mathbf{R} = \begin{matrix}\textbf{Rate of Uptake}\\ \textbf{to Forest}\end{matrix} \;\mathbf{x}\; \begin{matrix}\textbf{Rate of Significant}\\ \textbf{Value Capture}\end{matrix} \qquad \text{(eqn. 1)}$$

Foresters do *not* refute the importance of WQs; 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 WQ – if only to reduce the likelihood that their wood product purchases will not later prove faulty in service. Most people intuitively understand that improving wood qualities improves the efficiency of conversion from log to high-value product, and land-based fibre production efficiency by reducing low value wood waste. Fast-grown plantation softwoods all variously suffer from WQ problems like 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 WQs required to be successfully convert that raw fibre into high-value commodity and specialty products.*

Tree breeding is surely capable of meeting this challenge, as it has been in the horticultural, agronomic and animal husbandry industries. Dairy (milk and cream) exports in New Zealand (NZ) jumped from being number four to number two since the 1980s due, most say, 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 un-domesticated. Although some are shocked by that fact, the upside is that any genetic improvement process that *rapidly* domesticates a treecrop will *transform* future industry, and provide the solid, requisite 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 been interested for a long time in the genetic nature of WQs, and the potential for capturing significant gains in them (Zobel and Jett 1995), with studies dating back six decades (*e.g.* Jacobs 1939; Champion 1945; Fielding 1947). Neither is interest from commercial foresters in WQs particularly new — in the welcome address of the largest radiata pine 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 NZ and Australia that some improved orchard seedlots were inferior in WQ (*e.g.* a 3% loss in conversion into MSG lumber in Australia from 2nd-generation selections; Dean 1990).

Opportunities for capturing WQ 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 radiata pine 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 (heritabilities 50% to 90%; King *et al.* 1998). Whilst some easily-captured gains in WQs 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 (syn. clones; Sorensson & Shelbourne 2005).

In the absence of public clarity over the financial impact of WQ 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 WQs are necessarily are 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 latititude regions.

Thus, WQ breeders have to first convince foresters of the technical merits (*i.e.* risk and gains) of their 'new genetics', and then also convince seniour managers of the financial merits of the 'new genetics'. Though the arguments for improving softwoods for WQs are impressive (box), and many apply even to growers selling stumpage, they can still prove insufficient to drive strong product sales, and relevancy. Such foresters will not respond to additional arguments like 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, indeed deserve, real and unequivocal examples of the genetic gains and financial upsides realisable from WQ breeding.

Fifteen Reasons to Improve Wood Quality of Plantation Softwoods

1. Although some breeding programmes have periodically screened large progenies for WQs like density, most have not had enough market pull to "breed" aggressively for them. In this case, a few existing high growth selections may prove to have unexpectedly high WQ. This "low hanging fruit" can provide foresters early access to new selections improved in the '2Q's, quality and quantity.
2. Genetic wood qualities are typically 2-3 times more heritable across sites than is growth (*e.g.* Shelbourne 1997) and exhibit less GxE (genotype x environment interaction; Zobel & Jett 1995) than other important traits like growth. From the grower's standpoint, this means genetic WQ improvements are low in *risk* (*e.g*. Sorensson *et al.* 2004a) and more highly predictable than traits like growth rate, even across a range of diverse sites (Cown & Ball 2001).
3. Unusually great improvements in WQs are possible, especially but not exclusively from SE Varieties. High gains reduce the risk of underperformance. Risks associated with varieties deployed monoclonally are manageable by deploying a mosaic of genotypes. Under some circumstances the required number of genotypes to manage risk can be quite small (Bishir & Roberds 1997).
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 WQs, particularly in this young wood, improve the *consistency* of log/fibre quality.
5. Crops improved sufficiently in growth and WQ can be harvested earlier than normal if desired. This gives forest managers greater flexibility in harvest planning and the ability to raise cut levels when demand for logs is high. Other 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 WQs decrease the proportion of low quality "waste" 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 WQ improvements more eco-friendly than downstream practices like 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 can be profitable to sell (and especially if that land may later subjected to government-imposed penalties on deforested Kyoto land, as has been proposed in NZ).

8. 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 clarify opportunities for specific WQ genetic solutions.
9. Better tracking of log to final product, and more comprehensive information on internal WQs 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.
10. Better WQs would improve the suitability of wood for processing into diverse high value products (specialty papers, furniture components, lumber, LVL *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 certain 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 like resin pockets seem unlikely to be “solved” by processing, for example.
12. With highly advanced lumber segregation such as for warp propensity, processors will be able to craft wood products with impressive performance warranties. Such products should command hefty premiums from such quality-sensitive markets as DIY. Market demand for these specialty products should feed back down the value chain towards breeders to produce exceptionally high quality logs.
13. It has been said that roughly 20% of the logs poorest in WQ account for 80% of the values losses caused by poor WQ. Any genetic improvement approaches that result in the elimination of the worst performing trees can add a disproportionately high improvement to log value, either from breeding (genetic gain) or Varietal deployment (gain & uniformity).
14. High density fast-growth trees capture carbon at faster than normal rates, raising the possibility of greater forest revenues from carbon credits. Kyoto forests in NZ should generate more than $1 Bn between 2008 and 2012 at March-2007 carbon prices and exchange rates (Fallow 2007).

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

Log Velocity

Log velocity has quickly become an important WQ 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 strongly correlated both to the average stiffness of softwood logs, as well as 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 NZ have conducted detailed return-to-log (RTL) studies that clarify the added-value response from different log velocities, by size class, of structural logs (Wynn Daniell 2007 *pers. comm.)*, and the same is increasingly true overseas. An indicative set of RTL functions is shown for the three main size classes of radiata pine structural logs (Fig. 1). Large logs are less sensitive than small ones to velocity because their value is buffered by the presence of mature wood in these typically older logs, and because large log size *per se* improves conversions from log to lumber. The seemingly odd high value added to small logs of high velocity is thought due to the consistently small incidence in forests of suppressed stems that tend to be extremely fine branched and high in internal wood qualities like stiffness.

Although velocity is a compound trait (as is wood density), it is nevertheless well behaved genetically, and most breeders have concluded the opportunities for breeding are 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 as well (*e.g.* Shelbourne 1997; Dungey *et al.* 2006). Horizon2 has had a long history of involvement using standing-tree velocity tools (Sorensson 2004) and our current SE Varieties of radiata pine varieties offer strong improvements in growth and velocity to age 8. The top seven varieties for velocity have BLUP-derived estimates for STV ranging from 31 to 37 on a quasi "0 to 30+" scale directly akin to that of Vincent (1997) that is used normally as the performance scale of seedlots involving top NZ seed orchard parents.

Velocity is used by structural lumber and LVL mills and log or stem processing yards to audit structural log quality. 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 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 wood 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 NZ radiata pine (Treloar 2005). However, these revised log grade proposals failed to gain traction. Some think this is due to a reluctance of companies with low-density sites to accept the resulting write-down in forest value. 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 spec results in certain downgrading and consequent 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 either choose not to produce structural log grades, or respond by planting Douglas-fir, so it seems unlikely that they would resist accepting velocity-based log grades just because their forests are non-structural.

Perhaps a better explanation is the number of different log grades that can be managed practically at skid sites, stem yards, or at mills. Having more than a few physical log grade piles quickly becomes costly and inefficient, and generally NZ already has too much complexity in its number of physical log grades given the optimum is five or fewer log sorts (Murphy *et al.* 2003). In-forest segregation of stems or logs for velocity is/has been done, but its application there is mostly to cull out those logs that look visually structrually in-grade but which internally are not. Fortunately that process that does not increase the number of physical log sorts.

Given the natural reluctance to increase the complexity of log sorts, mills have responded with forms of "continuous log grading". The CHH structural sawmill at Mt. Gambier, for example, velocity tests all their incoming logs just before they reach the primary breakdown saw. This velocity information is used alongside each day's order list to optimise the cut patterns applied to log. This adds value by improving product recovery, and it does so without increasing the number of physically separated log grades. In principal, a mill could add additional features (obtained through log scans such as log-end Near Infra-Red) to further modify 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 account for such features as site density that velocity is relatively insensitive to, and providing the mill with more flexibility in its operations that it would have if it had had to adhere to a nationally-published set of velocity classes.

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

Adverse Genetic Correlations of Growth and Wood Quality

Commercial tree breeding broadly involves four steps: find genetically-diverse plus trees, progeny test them, demonstrate that some are superior enough to generate superior commercial forests, either via specific families or vegetatively-propagated individuals, and produce and sell the young improved treestocks.

Since improved trees are sold at a premium (recovering the genetics R&D investment plus a margin of profit), the gains have to be sufficient to generate market demand. In other words, gains must exceed some minimum gain targets (say 1 Gpa stem MoE, 100 m/sec in log velocity or 20 kg/m3 outerwood density at age-20) to give growers certainty that the improvements substantial enough to be risk-free, and justify the treestock price premium.

Adding any new trait carries penalties in the form of diverted selection pressure from traditional mainstream traits like growth, form and disease tolerance. In addition to this challenge, some key WQ traits can be adversely correlated to fast growth, particularly for stem diameter. Figure 2 visualises a hypothetical example of two normal traits with a weak adverse correlation of r = - 0.3. 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 reduces the likelihood of a breeder finding superior selections by about half (Appendix 1).

A similar intertrait correlation is shown in Figure 2, but this time based on real data. In this example, 264 mature radiata pine were assessed for DBH and for basic wood density in the first 20 to 25 m height from 1,246 wood discs. There is a moderately strong adverse correlation between DBH and outerwood basic density (r = -0.35, Pr<0.001) and a somewhat less harsh correlation between DBH 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 DBH is accompanied on average with less than a 10 kg/m3 loss in outerwood density. However, as Low and Smith (1997) noted: "the highest density selections tend to be just average in growth rate", and by applying a subjective threshold for "acceptably high" wood density, it is evident that the potentially most valuable dominant stems in the crop suffer from often not achieving the density threshold. Indeed, foresters are sensitive enough to this that many aim their wood quality inventories primarily at the 100 dominant stems per hectare, in rather sharp contrast to the approaches typically taken by wood scientists doing similar studies.

There are some pine species that seem free of these adverse correlations, including slash pine (*Pinus elliottii*, Kain 2003), Scots pine (Hannrup *et al.* 2000) and some loblolly pine (*e.g. P. taeda* clones, Eckard *et al.* 2006), and most of the earlier 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 (*i.e.* caused by irrigation 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 role 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; Fujisawa *et al.* 1992).

In radiata pine, however, the vast majority of reports from both NZ and Australia suggest that the true intertrait genetic correlation is moderately adverse for both density and velocity *vs.* stem diameter growth, averaging about r = - 0.4 (Wu *et al.* 2004) and in some cases very severe (r = - 0.7 for outerwood density vs. DBH of mature radiata pine in a high-stocked pulp regime; Li and Wu 2005).

In these latter cases, how can 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 DBH to height growth, as height is thought to be positively correlated to wood stiffness in at least some conifers, perhaps mediated by taper and proximity to green crown (Lassere 2005; Bascuñan *et al.* 2006). A common approach is also to select only to only *maintain* density, which may be why the 2nd-generation '268' parents did not exhibit the density loss (Cown et al. 1992) observed in the 1st-generation '850'-series orchards. Breeders also may develop special breeds or elites for wood quality (and curiously there is some evidence emerging that NZ's high-density breed may somehow avoid the expected adverse correlation with growth; Luis Gea 2007 *pers. comm.).*

The strategy that Varietal Forestry companies like Horizon2, CellFor, ArborGen, and Forest-Genetics employs is to select superior individual and deploy them directly, instead of selecting parents and *predicting the average performance* of their control-pollinated offspring through additive breeding values (Family Forestry). Even in small clonal populations one can find "by chance" rare genotypes with significant simultaneous gains in DBH growth and outerwood density or velocity (Figure 4).[1] In this example the success rate was low, only 1.5%, a rate close to the 1% used previously for clonal radiata pine (Sorensson 2004) and for

[1] Figure 4 plots genetic gains in growth (DBH) vs stiffness (ST300 STV) for three seed orchard seedlots rated from good to very good (GF14-GF26) and 67 random clones (rated on average to GF26) in a 12½-year-old stand in a structural forest in New Zealand's North Island just south of Whakatane (Tarawera Forest Cpt 26). Clones and seedlings had similar silvicultures (initial stocking 600-615 spha, production thinned at age 13). Our company generated the clones as plantlets from a micropropagation lab without any prior genetic screening, and the Radiata Pine Breeding Company developed the seedling test. Over 10,000 clonal and seedling treestocks were established in July 1994 adjacent to one another on a flat, relatively homogeneous and productive site - seedlings in single-tree-plot designs and clones in replicated largeplots of 36 trees. Most points in Figure 4 are based on about 50 trees.

clonal eucalypts (Verryn 2007), and even at these low rates, a relatively small candidate population of just 3,000 genotypes should still generate enough top selections to meet the early needs of varietal developers.

Discussion

The “vision” of modern softwood plantation forests to efficiently provide fit-for-use fibre is strongly aligned with WQ 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 Facts & Figures 2005/2006). While these messages seem to be broadly “appreciated”, they nevertheless can be insufficient to entice cash-flow conscious forests to invest in premium treestocks improved simultaneously in growth and WQ. There is simply too much uncertainty.

Unquestionably there is the problem of “lamb dressed down as mutton”, *i.e.* media hunger for glitz rarely falls favourably on relatively “old fashioned” approaches like breeding (Hocking 2000). It is also true that some log buyers’ are relatively unwilling to admit they could pay more for high-quality logs, and ‘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 is a poor excuse for assuming it is irrelevant, particularly now that there are more tools than ever before to monitor wood quality changes in stands well before mid-rotation age. Wood qualities like wood stiffness and velocity *are* capturable from parental or clonal selection, as was *done* 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*.

The area where breeders will struggle the most is to meet customer’s demands for genetic gains in a wide array of traits. I have seen foresters taken to stands dramatically improved in DBH and velocity spend their time expressing concerns over the size of branches. Genetic gains are highly sensitive to both the number of traits a breeder is trying to simultaneously improve, and Verryn (2007) makes the point that Occam’s Razor better be applied to family breeding or very little gain will be made in the traits that matter most. Breeding objective approaches typically emphasise no more than about four traits on which to make significant gains (*e.g.* Ivkovich *et al.* 2006).

The objective of this paper was to emphasise the need and opportunity to "make WQ breeding of softwoods more relevant"; *i.e.* to persuade others outside the rather insular community of breeders that WQ 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 *et al.* 2004b) and generating readily accessible forest demonstrations to better educate the public. The simplest of the forest demos are largely "political" devices, but still critically important as such as physical proof that *genetics works* (Ken Eldridge 2007 *pers. comm.*).

It is perhaps time to consider a more comprehensive set of demos modelled after "Industry Best Practices" trials. These 'Forest+' demos 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, but would include some very high productivity sites (*i.e.* MAIs of 35 to 43 m3/ha/yr; Shula 1989) and some sites needing transformational solutions from WQ genetics, *i.e.* to lift a non-structural forest to a structural one. Financial analyses would be hard-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 a species" into overseas markets. A range of peripheral studies could easily be incorporated like carbon sequestration, biodiversity and impacts of climate change, not to mention valuable unforeseeable opportunities that inevitably emerge from long genetic experiments "overtaken by events" (Mayo 1997). Timing for such a proposal could be good as governments around the world look for ways to "use forest offsets" (Anderton 2007.

One appropriate control in these demos would be low-cost genetics-plus-conservative silviculture, which has become a common industry response in NZ to concerns over log quality. Since 2004 when the average rotation age of radiata pine was about 27 years (reviewed by Lasserre *et al.* 2005), but it has since jumped back to about 30 years (NZ Forest Owners Assoc., April 2007) and is typically accompanied by higher initial and final stockings to better capture light in the young crop, reduce branch size, and raise stem stiffness (*e.g.* Lasserre *et al*. 2005; Wang *et al.* 2001; Zhang *et al.* 2002). Some experts are vocally in favour of this conservative silviculture (Mason 2002) but others are strong opposed (MacLaren 2003), pointing out that any increase in log qualities 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:quality conundrum.

The 'vision' of modern plantation softwood forests to efficiently and rapidly produce fibre that is 'fit for purpose' is still viable, but clearly requires powerful genetic solutions. In the absence of this, future revenues will be limited by the long rotations and high volumes of waste wood that current regimes always generate. There is *abundant* proof from a range of clonal studies in many tree species that genetics works. In time molecular geneticists will have teased out how various wood quality and growth genes interact, and then there will be new opportunities to push genetics further. In the meantime, I find myself reflecting on the repeating lesson from clonal studies 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 types of trees in production forest, this alone would transform modern softwood plantation forestry.

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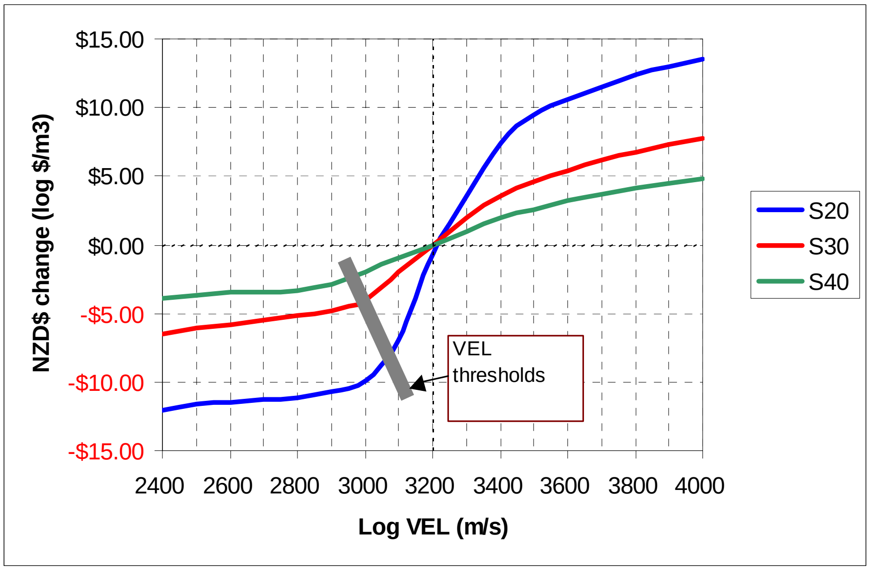


Figure 1. Indicative pricing response of structural radiata pine logs to log (resonance) velocity. Prices of domestic sawlogs range from $72 NZD to $106/m3, and average about $85/m3 (WoodReport 2007) so a pricing adjustment of $5 equates to a log price change of about 6%. Curves are based on confidential mill surveys, and apply a 50:50 value share between processor and log grower.

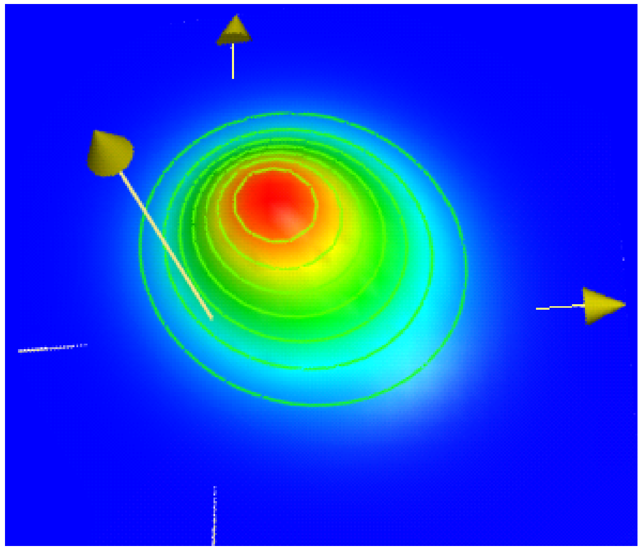
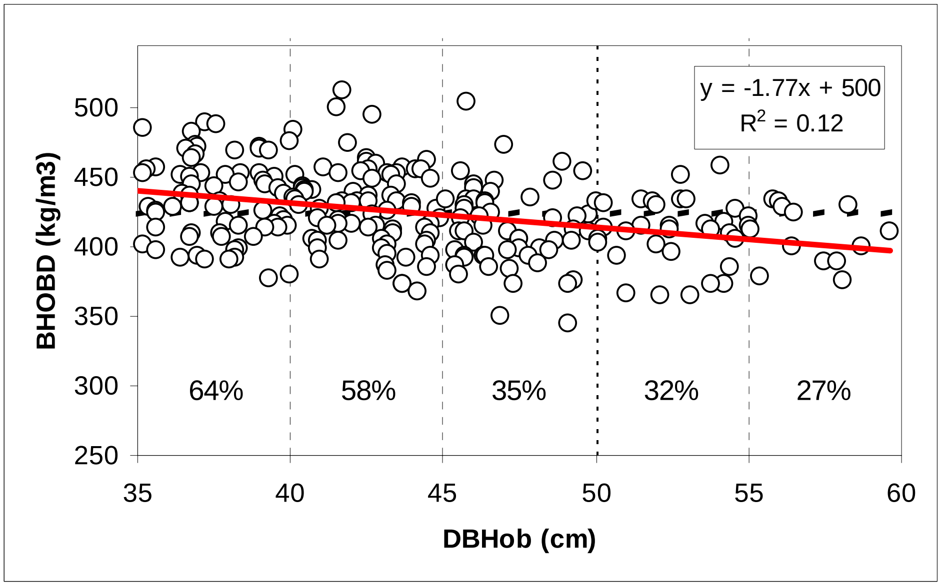


Figure 2. Topographical map of a bivariate normal distribution with a moderate adverse inter-trait correlation (R = - 0.3). *Source*: L. Hansen.



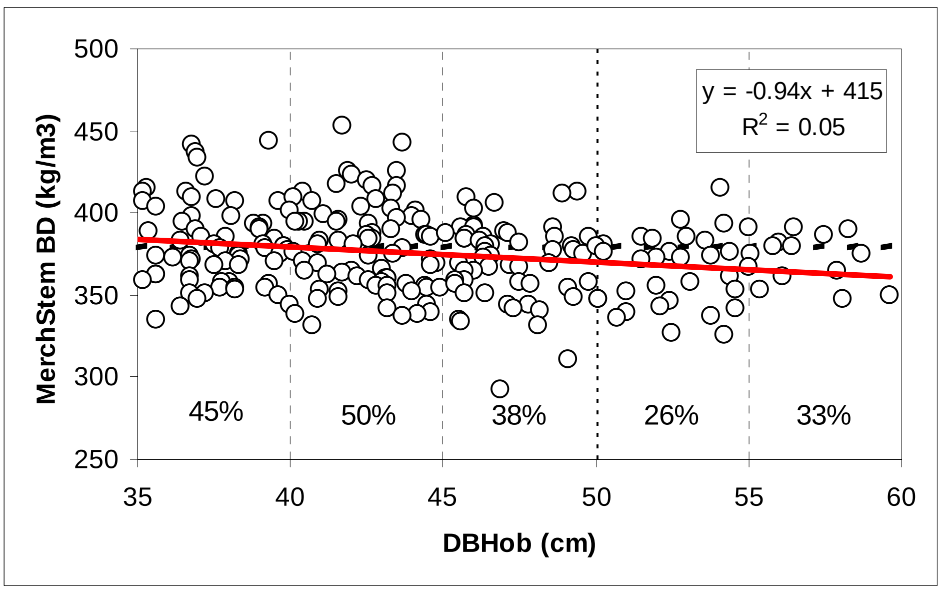


Figure 3. Stem size (DBH) versus wood density of 264 mature radiata pine stems in a plantation forest in NZ's Central North Island (confidential industry source). Solid line = trendline. Dashed line = density threshold.

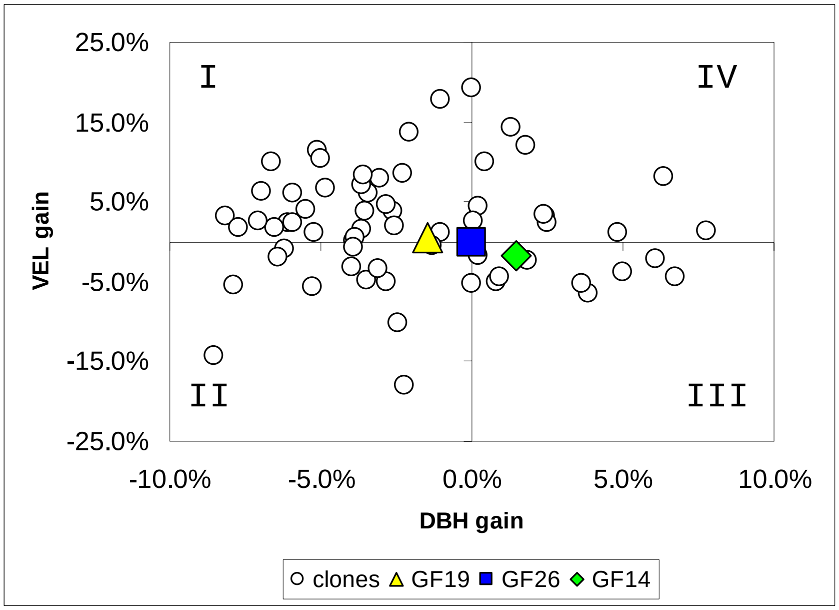


Figure 4. Seedlot and clone-mean gains for growth (DBH) and velocity (ST300 standing tree time-of-flight) before thinning at age 12½ at Tarawera Forest in the North Island of NZ. Clones were genetically un-selected, and had been established as monoclonal plots of 36 trees at 615 spha. The correlation amongst all clonal points was weakly adverse (R = - 0.07 *ns*).

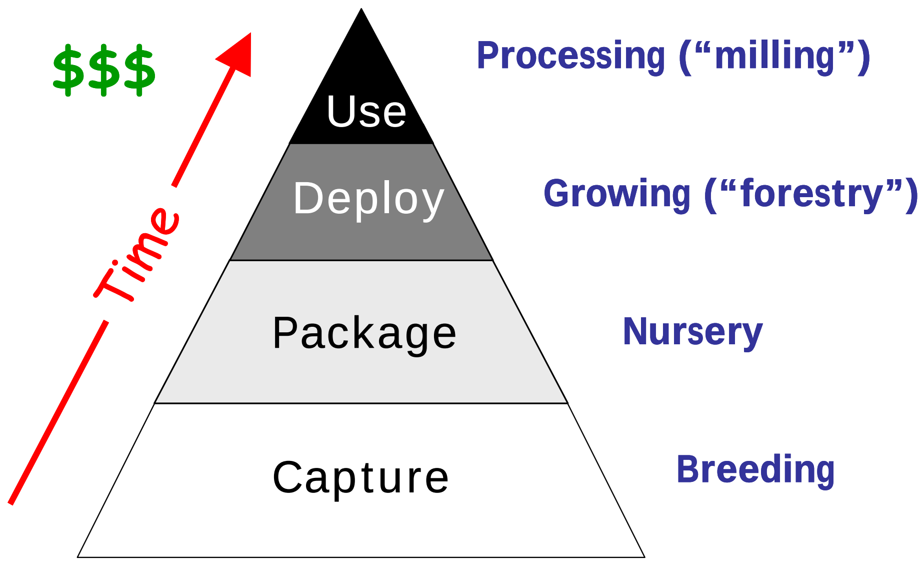
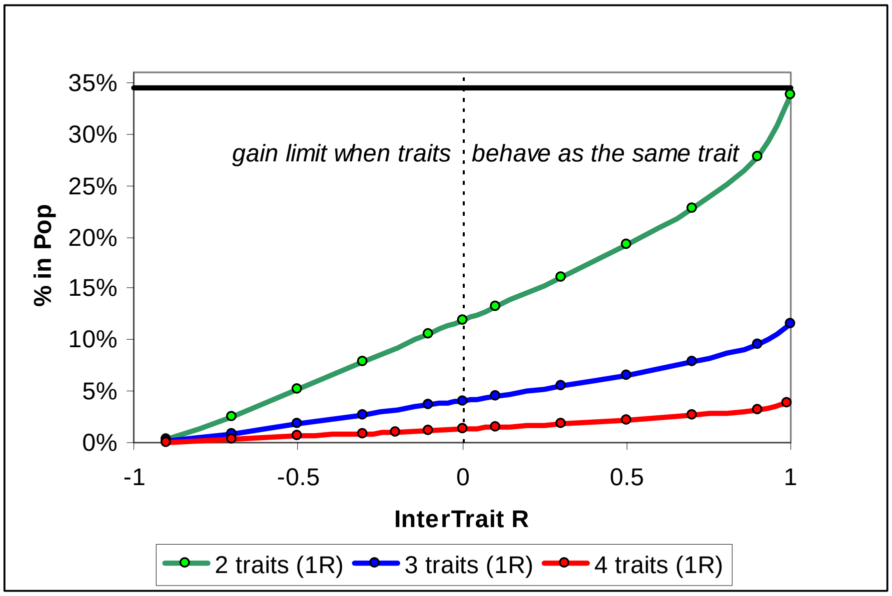


Figure 5. The value-adding pyramid shows that breeding may be perceived as less relevant than other activities because it has the greatest time-lag from forest harvest.

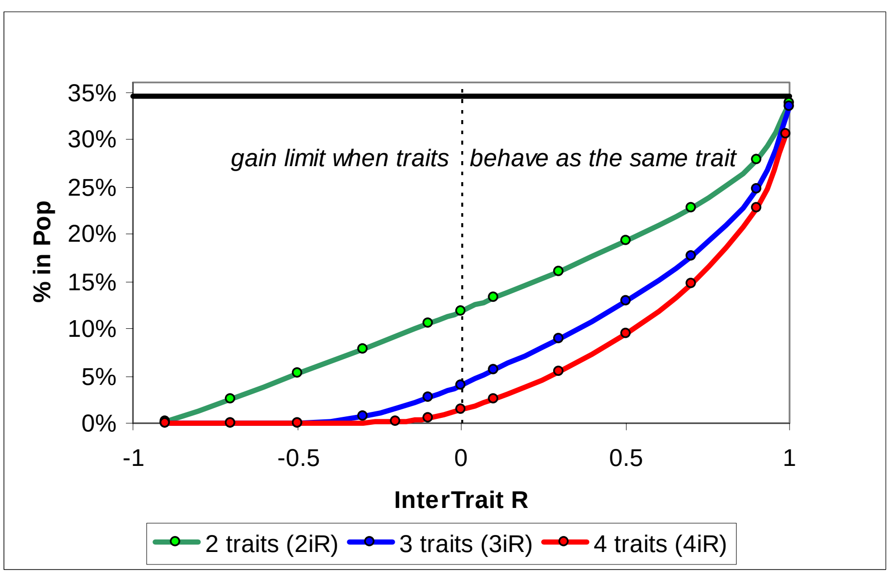
Appendix 1. Impact of adverse correlations on ability to find superior genetic selections with minimum levels of multi-trait gains. Model developed by M.O. Kimberley, Ensis Rotorua (2007) for Horizon2.

Example 1. Identical traits (mean 400, STDEV 50, CoV 12.5%) all with minimum gains 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.

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



Example 2. Like Example 1 except that all inter-trait correlations change in tandem. Combined probabilities for all R = 0 remain unchanged. The impact of non-zero R has been magnified in this biologically unlikely scenario. 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. Simulated realistic multi-trait scenarios for growth (DBH), stem form (STR), and two wood qualities related to stiffness (VEL, DEN) for pines assessed at age 8 years. Case 1 has one non-zero intertrait correlation, case 2 has two, and case 3 has six.

Adding another adverse inter-trait correlation to the first (case 1) decreases the chances further of finding superior selections, but these opportunities are boosted by adding weak positive intertrait correlations (case 3). 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.

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.

Trait	units	Mean	STDEV	CoV%	Gain min.	Gain (trait units)	Gain (min. in units)
DBH	mm	300	45	15.0%	10%	30.0	330.0
STR	score	3.5	0.9	25.7%	10%	0.35	3.9
VEL	m/sec	2000	190	9.5%	10%	200	2200
DEN	kg/m3	370	35	9.5%	5%	18.5	388.5

Case	Trait	DEN	DBH	STR
1	DEN			
" "	DBH	0		
" "	STR	0	0	
" "	VEL	0	varied	0
2	DEN			
" "	DBH	-0.15		
" "	STR	0	0	
" "	VEL	0	varied	0
3	DEN			
" "	DBH	-0.15		
" "	STR	0.05	0.05	
" "	VEL	0.15	varied	0.10