Juvenile wood and its implications

Dave Cown and Leslie Dowling

Abstract

Juvenile wood has been known as a concept since the 1960s, but its full impact has not been felt until it comprises a major proportion of the wood harvested. A conservative estimate would put it currently at around 50 per cent by volume of wood in a standing tree. Its characteristics vary according to a number of internal and external factors but it consistently represents the lowest density, highest microfibril angle, and highest spiral grain within each individual stem. For most high value wood products it is considered undesirable. Unless there are changes in the overall approach to management of wood quality in radiata pine, it will have an increasing financial impact on plantation forestry due to the proportion of the harvest that will not meet users' requirements.

What is juvenile wood?

Much of the research that has been done on wood quality in New Zealand has been concerned with aspects of juvenile wood. The term 'juvenile wood' is a convenient method of describing the wood formed around the pith in radiata pine and it has loosely been defined as the inner 10 to 15 rings (Burdon et al., 2004). This has significant ramifications for tree growers and wood processors when silviculture and breeding approaches are adopted to enhance growth. This is because of the resulting wide annual rings, low wood density (DENS), high microfibril angle (MFA), high spiral grain (SGA) and knot frequency (Cown, 1992), which collectively result in high variation in stiffness and strength (Watt et al., 2013).

Wide juvenile growth rings. Source: Scion Digital Image Library

Despite its economic importance, there is no universally accepted definition of juvenile wood and hence it has been difficult to quantify its real importance in forest management. We know that the zone occupies a very significant proportion of radiata pine stems at rotation age, and effectively it means that upper logs in particular comprise predominantly juvenile wood. Wood property gradients – strength and stiffness, stability – are greatest within this zone and tend to stabilise afterwards in the mature wood.

What determines the extent of juvenile wood?

Given that juvenile wood occupies the inner part of the tree, to what extent can its impact be modified? Evidence to date suggests that the extent is strongly biologically controlled rather than by external influences. This means that the internal patterns of wood properties will remain constant, although the actual values will vary according to site, silviculture and genotype.

Management practices that encourage early growth rates – fertilisation, initial spacing, weed control, thinning – will increase the physical volume of juvenile wood produced as well as the proportion at harvest. In the worst case scenario rapid early growth followed by stagnation, e.g. highly stocked un-thinned stands on poor sites, will result in stems comprised of mostly juvenile wood. Standing tree acoustic tools may indicate 'high stiffness' in such stands, but this only applies to the outer shell of mature wood which will likely be lost during solid wood processing.

Recent analyses of spacing trials have indicated that early growth rates are not highly influenced by spacing except at the extremes (Carson et al., 2014). The greatest impact on juvenile wood content is therefore thinning and the rotation age – thinned and older stands will have a greater proportion of mature material with better stem average wood properties.

Figure 1: Location of the installations from the 1987 silviculture breeds trial selected for simulation using Forecaster

Aids for forest managers

Modern forest management practices emphasise efficient land use and maximum productivity, using wider initial spacing together with improved breeds so that rotation ages can be substantially reduced. This has been spectacularly successful, but not without significant loss of quality (Burdon, 2010), the most obvious being negative correlations between wood density and growth rate and the decrease in mechanical properties with reduced rotation ages, particularly on fertile ex-farm sites (McConchie, 1997; Gaunt, 1999).

During the 1980s, the Conversion Planning Programme (Kininmonth, 1987) started to tackle log quality by proposing standard grades, and soon realised that branch size and wood density were vital for determining sawn timber values for both visual and machine grades (Cown et al., 1987). However, forest management tools to account for wood quality factors have been developed, starting from early models for predicting average log densities (Tian et al., 1996).

Since then, other wood quality activities with industry, including the Value Recovery Project (Cown, 2002), Wood Quality Initiative (Cown, 2003) and Future Forests Research, have accumulated a large amount of information on properties affecting the value of both structural and clearwood timber. These activities have dealt with things such as spiral grain, microfibril angle, branching, intra-ring checking and resin blemishes. Several of those characteristics are associated with juvenile wood, particularly MFA and SGA.

Forest management modelling systems are increasingly catering for wood properties, with the ultimate objective of allowing users to evaluate strategies for producing stems and logs of known wood quality (Snook, 2010). We now have a fairly good handle on average regional properties, for instance, whereby the average stiffness properties forests can be predicted based on location, rotation age and to some extent genotype. The same knowledge base tells us that the most important sources of variation in stiffness are individual stems and log height classes, and that even in the most suitable forests there will be a proportion of unsuitable logs.

However, sophisticated models require good data. A new Scion initiative has commenced to employ radically new and more cost-effective wood property assessment methods to amass data on regional and silvicultural influences on the key variables for the purpose of better predicting performance attributes (Moore et al., 2013b). Traditionally, comparisons of wood properties often only give average values or proportions of variation, which obscures the absolute variation involved. Modern tools can go further (Forecaster Forest Growth Simulator – Snook, 2010) and are capable of providing both inter-stem and log level variation.

Juvenile wood and wood quality in a silviculture breeds trial

To get a handle on how modern forest management tools can help forest managers, a small validation study was undertaken using the wood properties models available within Forecaster. Combinations of three seedlots (not selected for contrasting wood properties) and three stocking levels were selected across the five sites of the 1987 silviculture breeds trial (Carson et al., 2014) shown in Figure 1. Wood quality measurements of outerwood density and acoustic velocity were taken at age 17 years (Carson et al., 2014) and breast height diameter and height measurements at age 27 years, except for the Tahorakuri site where trees were measured prior to catastrophic wind damage in 2008 at age 21. These wood quality and forest growth measurements were input into Forecaster and growth was simulated through to age 28 years using the latest available forest growth and wood quality models, as shown in Table 1.

Logs were cut in the simulation to current New Zealand domestic log specifications (MPI, 2014). Environmental characteristics of the sites were extracted from spatial layers based on plot locations. Data giving the size and wood properties for each log at harvest was produced and the distribution of wood properties for each log was summarised for each of the genetic, site and silvicultural treatments. In this case we examined diameter, juvenile wood proportion (based on the 10 inner rings), DENS, SGA, MFA and acoustic velocity, as all have been linked to wood performance and value.

Table 1: Models used to predict growth and wood properties in Forecaster

Growth model	300 Index FCP version 4.08 (Kimberley et al., 2005)
Acoustic velocity	WQI Acoustic Velocity (Woollons et al., 2008)
Density	FFR Density (Palmer et al., 2013)
Microfibril angle	FFR MFA (Moore et al., 2013a)
Spiral grain	FFR SGA (Moore et al., 2013a)

Exploratory Factor Analysis was used to group input variables correlated with the juvenile wood proportion and the average DENS of logs. Input variables were grouped by common variance into one of 'Fertility', 'Genetic', 'Environmental', 'Stocking' or 'Soil C:N ratio' categories. The percentage of variation explained by these categories for juvenile wood proportion and log DENS are shown in Figure 2. It shows that juvenile wood content (inner 10 growth rings) predicted by Forecaster is driven by stocking and site fertility. Conversely DENS is driven by a large number of inputs that feed into the density model, with environmental inputs as the most significant category.

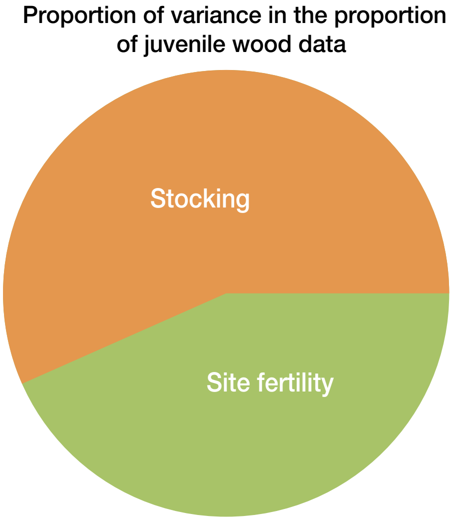
There was no significant variation in the proportion of juvenile wood in the bottom two logs between seedlots, but variation was evident between sites and there is clearly an increasing proportion of juvenile wood with increasing stocking (Figure 3). Interestingly, there was no significant variation in the large end diameter (LED) of the bottom two logs between the three seedlots examined (Figure 4). There is, however, the expected variation between sites and stocking treatments.

Seedlot, environment (site) and silviculture all show an effect on log density (Figure 5). The striking feature of the data is the large spread of density values within all treatments and across sites, which is much greater than the relatively small differences in the mean values between seedlots and silvicultural regimes. The only very significant effect in this data set is the high density of the Woodhill site, corresponding with known site effects (Palmer, et al., 2013). The simulations also show that there is huge variability in log average microfibril angle (Figure 6). An interesting feature is the apparent significant increase of log average MFA with increasing stocking. This can potentially be explained by the suppression of mature wood growth and the dominance of juvenile wood lowering the log averages. Since the differences between seedlots are almost non-existent, and silviculture has an apparently strong influence, it is tempting to suggest that the site differences are due to different growth patterns resulting in varying proportions of juvenile wood.

Simulated values for acoustic velocity of the bottom two logs also varied considerably between individual logs (Figure 7). Average values are generally over the commonly requested guide level of three kilometres per second, but significant numbers of logs fail to reach this level across all situations. Similarly, log-average values of spiral grain angle varied considerably between individual logs (Figure 8). The predominant trend was for grain angle to increase with increasing stocking, driven by the higher proportion of juvenile wood.

Discussion

New Zealand has made excellent progress in breeding plantation trees fulfilling the primary demands of improved volume growth, stem straightness and branching characteristics, tolerance to pests and diseases, and general adaptability. However, existing forests contain an incredible amount of tree-to-tree variation in wood quality which affects wood users significantly.



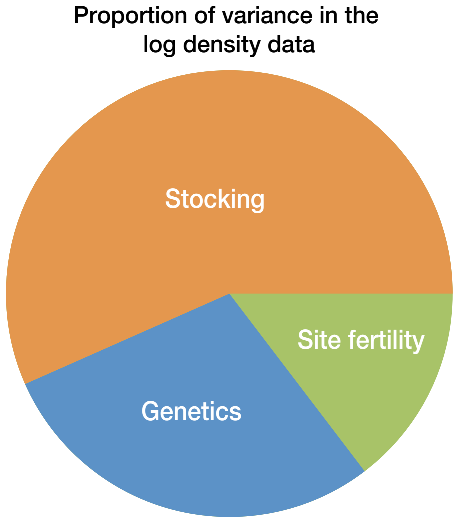


Figure 2: Results of Exploratory Factor Analysis showing the component of total variance made up by groups of variables correlated with the proportion of juvenile wood in each of the bottom two logs and the average density of the bottom two logs

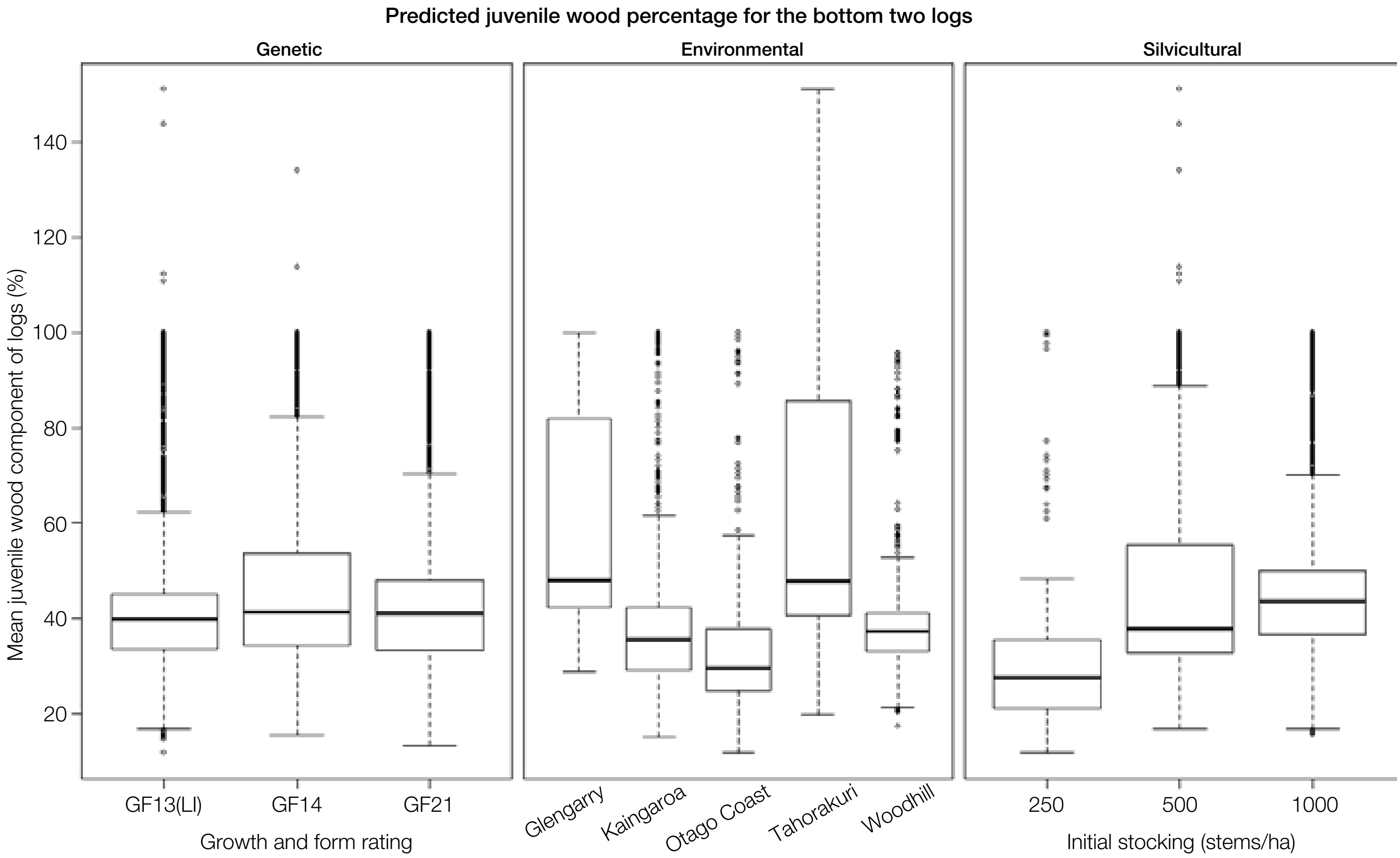


Figure 3: Box and whisker diagram showing the variation in predicted juvenile wood content between seedlots, sites and silvicultural regimes. The box represents the interquartile range (difference between 25th and 75th percentile), while the whiskers extend to the most extreme data point which is no more than 1.5 times the interquartile range from the box

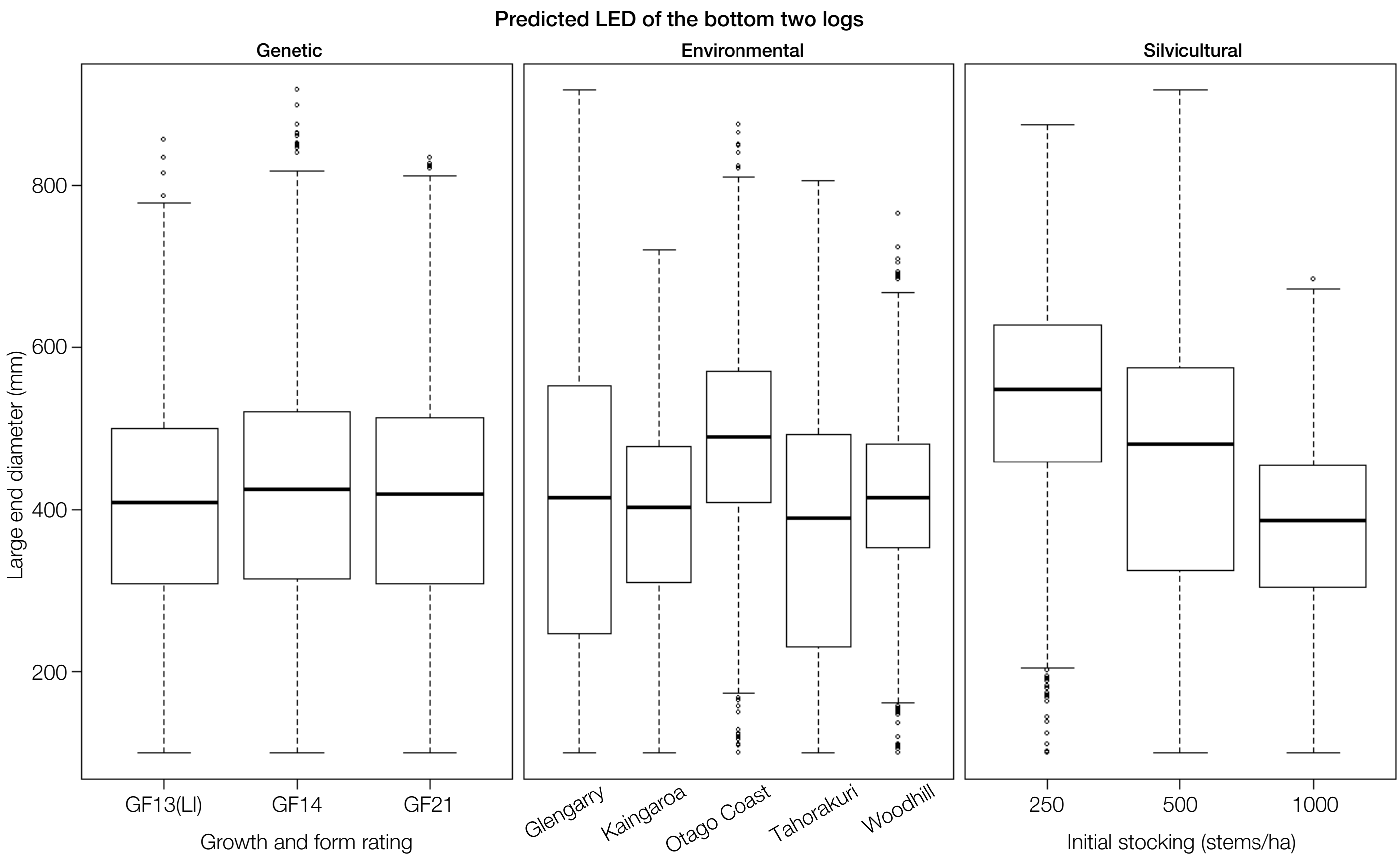


Figure 4: Box and whisker diagram showing the variation in predicted large end log diameter between seedlots, sites and silvicultural regimes

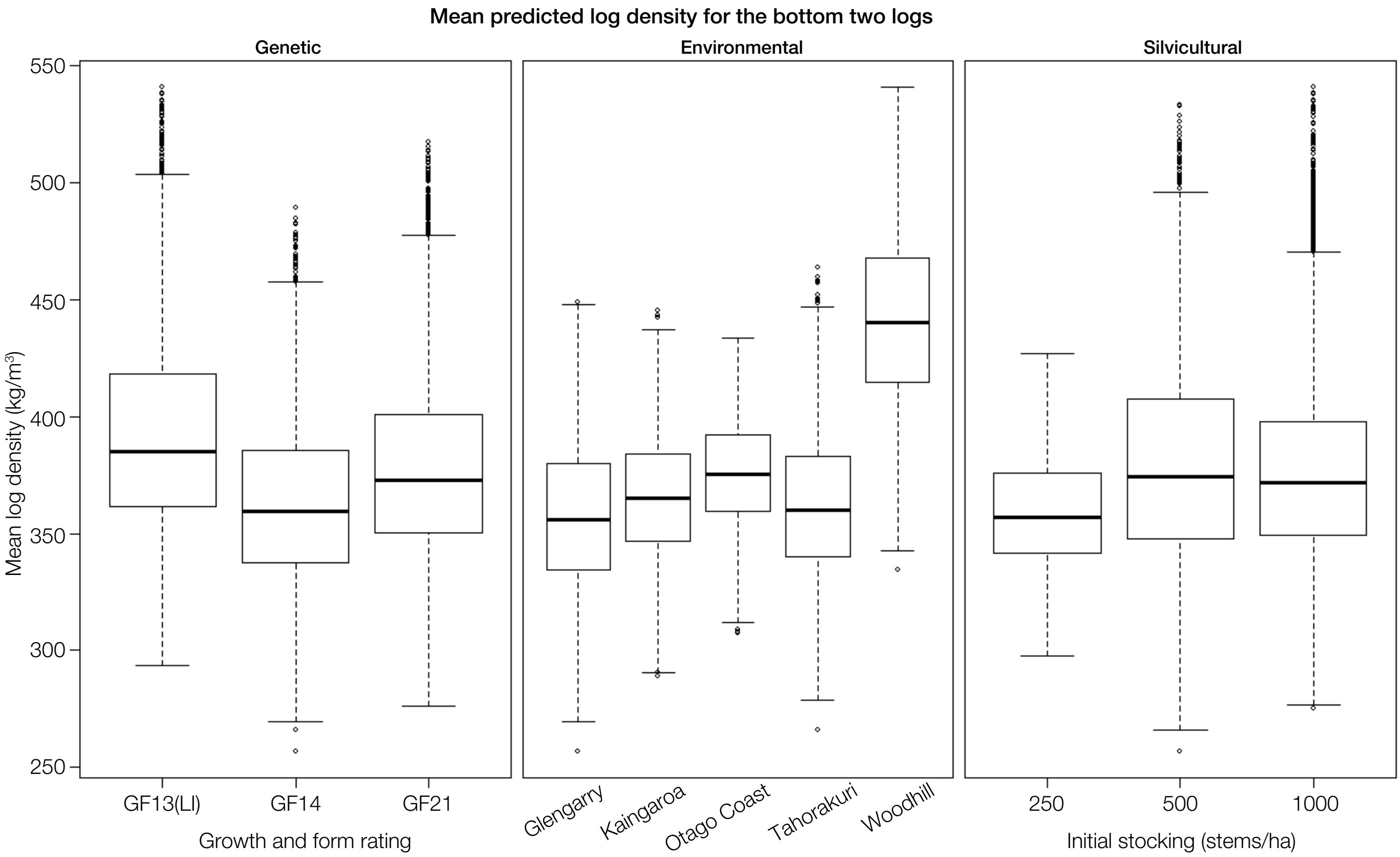


Figure 5: Box and whisker diagram showing the variation in predicted log average wood density between seedlots, sites and silvicultural regimes

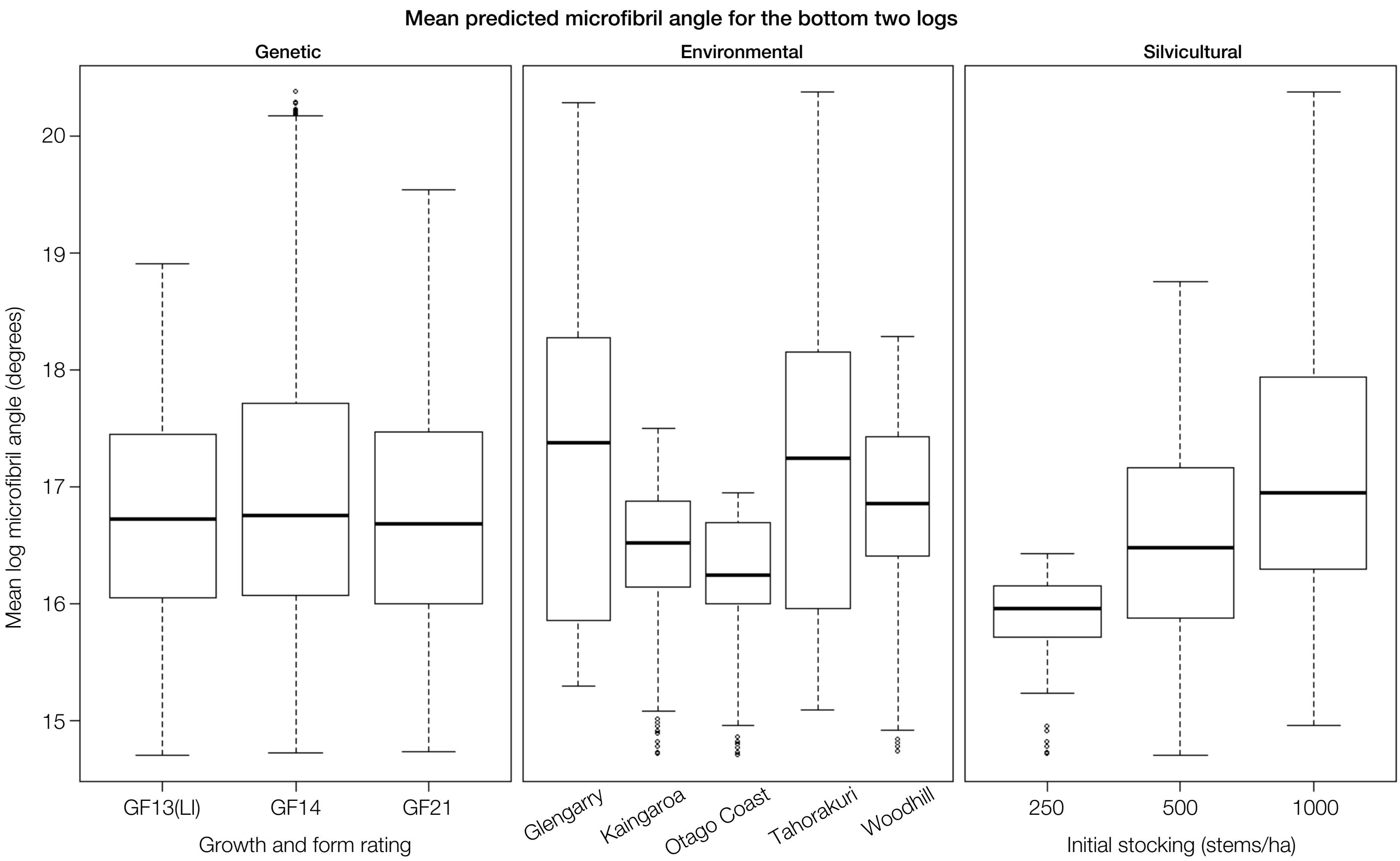


Figure 6: Box and whisker diagram showing the variation in predicted log average microfibril angle between seedlots, sites and silvicultural regimes

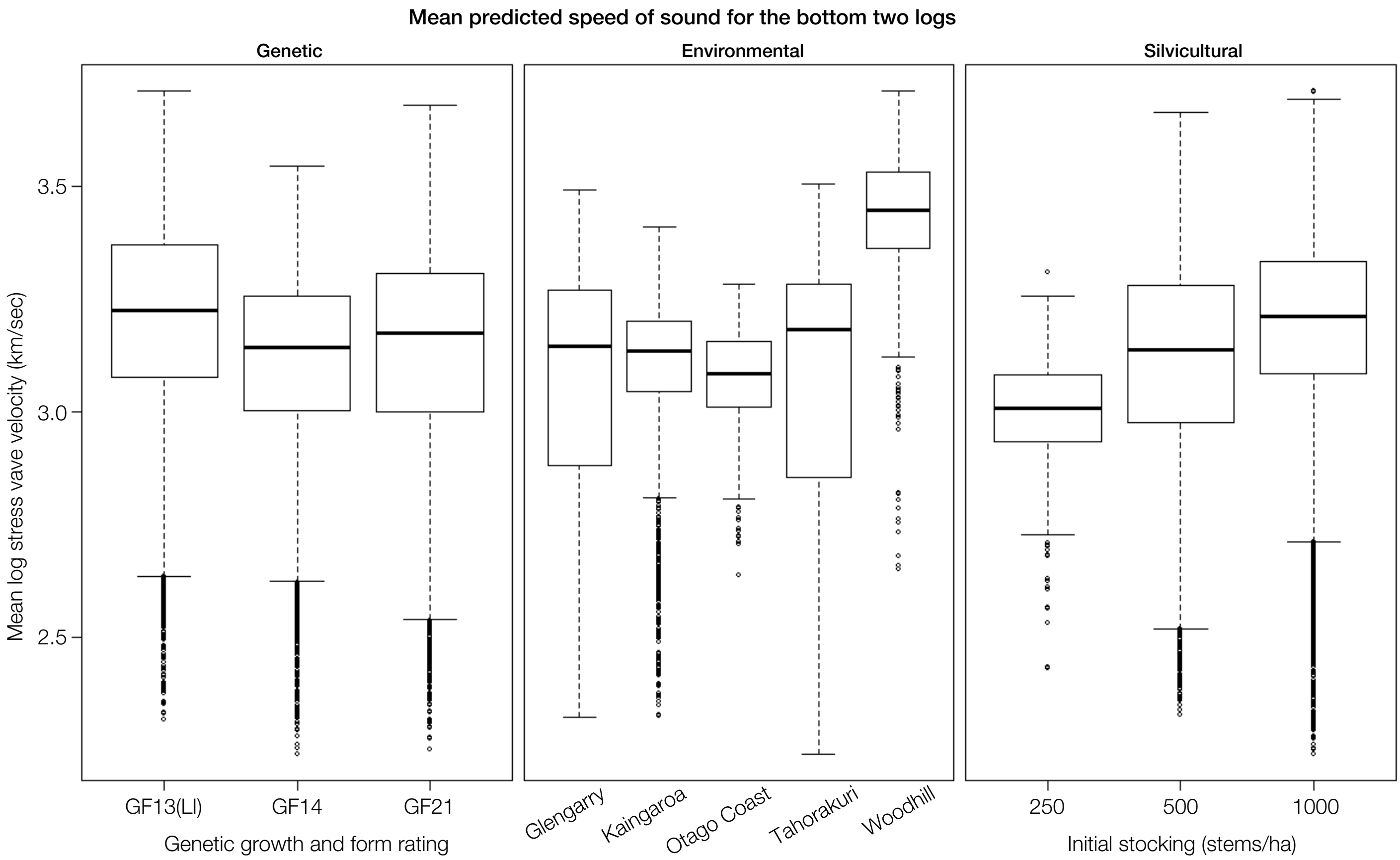


Figure 7: Box and whisker diagram showing the variation in predicted acoustic velocity between seedlots, sites and silvicultural regimes

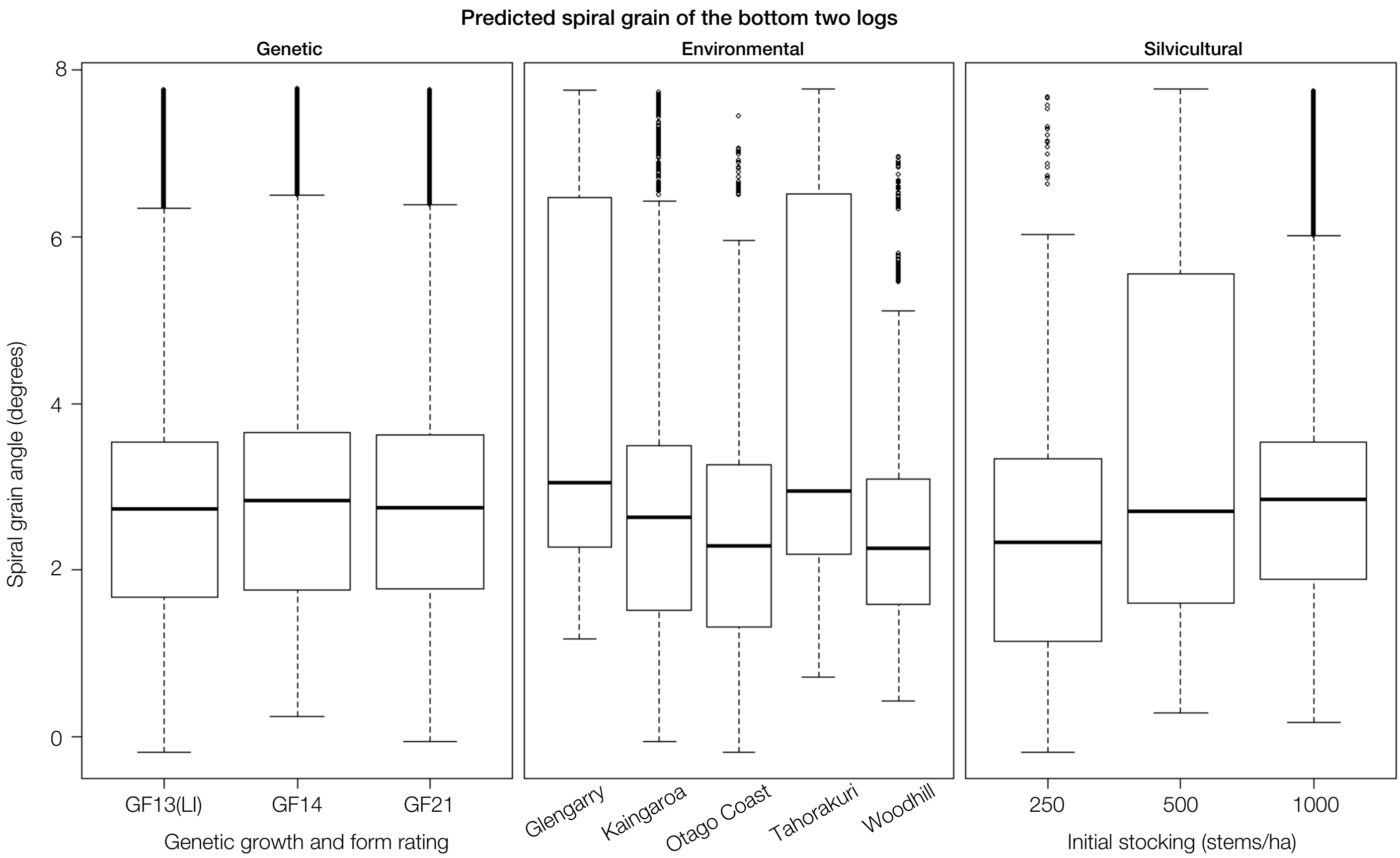


Figure 8: Box and whisker diagram showing the variation in predicted log-average spiral grain angle between seedlots, sites and silvicultural regimes

Tree breeding and intensive silviculture together promote an extension of the amount of juvenile wood produced, resulting in plantations with an increased proportion of lower quality wood in the harvest, some of which is below the standards required for manufacturing products of consistent quality. This is mainly due to the predominance of juvenile wood in the stems at harvest age. The small analysis presented here suggests that there is a large amount of tree-to-tree variation in wood characteristics (after averaging out the within-tree variation), which exceeds site and silvicultural influences on stand-level averages.

Opportunities exist for the breeding programmes to focus on characteristics of the juvenile wood zone such as the levels of key properties and the age of transition to mature wood. In addition, early selection methods are already being introduced, employing acoustic technology (Chauhan et al., 2013) which, with the known age:age correlations, should ensure better wood quality in the future. Interest in clones is increasing and offers an opportunity to potentially increase quality, reduce variation and break the negative growth rate/density relationship (Lindstrom et al., 2005; Mason, 2006). However, much remains to be done to raise the priority of wood traits in the breeding programme. Rarely are technical market requirements considered ahead of planting or silviculture. The feasibility and market needs seem to be obvious, yet the economic case has not convinced many growers to invest in superior genotypes or select for superior wood quality traits.

Where the forest characteristics do not all suit the market needs, for instance the stiffness criteria, neither log seller nor buyer can achieve their goal with bulk sales, particularly for forest growers in areas where harvest costs are high. As remote hill country increasingly becomes a more common forest land type, we may find the margin between cost of harvest and revenue per cubic metre is squeezed for an increasing number of our log grades.

Material segregation can remove the lower quality logs from the supply chain, either in the forest or at the processing plant, but this comes with a cost and wastes a portion of our variable forest resource. Studies have shown that for any particular wood property the variation within stands is at least as great as that between regional averages. There is therefore a lot of scope for sorting stems and logs prior to processing, as long as a convincing economic benefit can be shown (Nurminen et al., 2009).

Available studies linking variations in quality variables to economic recoveries in large wood processing studies, such as that carried out in South Africa recently (Wessels et al., 2014), are rare. There have been numerous small-scale studies investigating links of particular wood properties to solid timber and veneer recoveries, but most do not consider many of the practical considerations such as the cost of segregating logs for demanding end uses. To create most impact, studies need to consider the full range of costs and benefits involved and to whom they accrue, including the cost of planting stock and possible material segregation.

Furthermore, studies should be publicly available. Much of the research in New Zealand in recent years has been jointly funded by various industry/research associations and the results not openly published due to client confidentiality reasons. To have a wider positive impact studies should incorporate the viewpoints of different participants in the supply chain – forest owners, harvesting and transport logistics providers, and wood processors. The mill manager's goal of obtaining suitable logs at the lowest possible price is clearly at odds with the desire of forest owners to secure the highest price for their stock.

Conclusion

Using large-scale wood quality studies, opportunities for breeding programmes, instruments to select a superior crop, and tools like Forecaster to design silvicultural regimes around the desired quality of logs, foresters have the potential ability to reduce variation and improve the quality and consistency of the New Zealand forest resource. Back in 1992, it was suggested that we should be concerned about the extent of low quality juvenile wood in our forests. Now it can be argued that the situation has not improved and may in fact have deteriorated. In the longer term, a more serious collective effort will need to be made to counteract the potentially negative effects of increasing growth rates throughput the rotation and placing radiata in an even more disadvantageous position in global structural markets.

Juvenile wood boards

References

Burdon, R.D. 2010. Wood Properties and Genetic Improvement of Radiata Pine. *NZ Journal of Forestry*, (August): 22–27.

Burdon, R., Walker, J., Megraw, B., Evans, R. and Cown, D. 2004. Juvenile Wood (Sensu Novo) in Pine: Conflicts and Possible Opportunities for Growing, Processing and Utilisation. *New Zealand Journal of Forestry*, 49(3): 24–31.

Carson, S., Cown, D.J., McKinley, R.M. and Moore, J.R. 2014. Effects of Site, Silviculture and Genetics on Wood Density and Stress-Wave Velocity in Radiata Pine at Mid-Rotation. *New Zealand Journal of Forestry Science*, 44. DOI:10.1186/s40490-40014-40025-40494.

Chauhan, S., Sharma, M., Thomas, J., Apiolaza, L.A., Collings, D.A. and Walker, J.C.F. 2013. Methods for the Very Early Selection of *Pinus radiata* D. Don. for Solid Wood Products. *Annals of Forest Science*, 70: 439–449.

Cown, D.J. 1992. Corewood (Juvenile Wood) in *Pinus radiata* – Should We Be Concerned? *New Zealand Journal of Forestry Science*, 22(1): 87–95.

Cown, D.J. 2002. Value Recovery Project (1995–98) – What Did We Learn? *New Zealand Journal of Forestry*, 47(3): 14–16.

Cown, D.J. 2003. Wood Quality Initiative Ltd. *FRI Wood Processing Newsletter*, 33.

Cown, D.J., Kimberley, M.O. and Whiteside, I.D. 1987. Proceedings of the Conversion Planning Conference, Rotorua, NZ, 1986. *FRI Bulletin No. 128:* 147–161.

Gaunt, D. 1999. Machine Stress Grading Revisited. *New Zealand Timber Design Journal*, 1(8): 10–18.

Kimberley, M.O., West, G. and Knowles, L. 2005. The 300 Index – A Volume Productivity Index For Radiata Pine. *New Zealand Journal of Forestry*, 50(2): 13–18.

Kininmonth, J.A. 1987. Proceedings of the Conversion Planning Conference. *New Zealand Forest Institute Bulletin No. 128:* 382.

Lindström, H., Evans, R. and Reale, M. 2005. Implications of Selecting Tree Clones with High Modulus of Elasticity. *New Zealand Journal of Forestry Science*, 35(1): 50–71.

Mason, E. 2006. Influences of Silviculture, Genetics and Environment on Radiata Pine Corewood Properties: Results from Recent Studies and a Future Direction. *New Zealand Journal of Forestry*, 53(2): 26–31.

McConchie, D.L. 1996. *Wood Quality of Radiata Pine on Farm Sites*. New Zealand Forest Institute Bulletin, Proceedings of Wood Quality Workshop, Rotorua, NZ: 201: 38–45.

Ministry for Primary Industries (MPI). 2014. *Forestry Statistics: Specifications and Prices for New Zealand Log Grades, 12 Month Average* (current at October 2014). Available at: www.mpi.govt.nz/forestry/statistics accessed on 26 October 2014.

Moore, J., Cown, D., McKinley, R., Sabatia, C., Harrington, J. and Clement, B. 2013a. Modelling the Variation in Spiral Grain Angle and Microfibril Angle in Radiata Pine. *Future Forests Research Report R-074*. Rotorua, NZ: Future Forests Research.

Moore, J.R., Harrington, J.J., Cown, D.J., Pont, D. and West, G.G. 2013b. Linking Forest Management, Wood Quality and End-Product Performance in Radiata Pine. *Presented at the International IUFRO Conference MeMoWood – Measurement Methods and Modelling Approaches for Predicting Desirable Future Wood Properties, Nancy, France, October 2013.*

Nurminen, T., Korpunen, H. and Uusitalo, J. 2009. Applying the Activity-Based Costing to Cut-To-Length Timber Harvesting and Trucking. *Silva Fennica*, 43(5): 847–870.

Palmer, D.J., Kimberley, M.O., Cown, D.J. and McKinley, R.B. 2013. Assessing Prediction Accuracy in a Regression Kriging Surface of *Pinus radiata* Outerwood Density Across New Zealand. *Forest Ecology and Management*, 308: 9–16.

Snook, J. 2010. Using Forecaster to Maximise Your Forest Investment. *New Zealand Tree Grower*: (May).

Tian, X., Cown, D.J. and McConchie, D.L. 1996. Modelling of Radiata Pine Wood Properties. Part 2: Wood Density. *New Zealand Journal of Forestry Science*, 25(2): 214–230.

Watt, M.S., Adams, T., Marshall, H., Pont, D., Lee, J., Crawley, D. and Watt, P. 2013. Modelling Variation in *Pinus radiata* Stem Volume and Outerwood Stress-Wave Velocity from Lidar Metrics. *New Zealand Journal of Forestry Science*, 43, 1–7.

Wessels, C.B., Malan, F.S., Nel, D.G. and Rypstra, T. 2014. Variation in Strength, Stiffness and Related Wood Properties in Young South African-Grown *Pinus Patula*. *Southern Forests*, 76(1): 37–46.

Woollons, R., Manley, B. and Rawley, B. 2008. *Revision of Some Equations in the WQI Acoustic Velocity Model* (Vol. No. INT 13): WQI.

Dave Cown has recently retired as a Senior Scientist at Scion where he specialised in wood quality. He now has an Emeritus role with Scion. Leslie Dowling is a Forestry Scientist at Scion as well as a MForSc thesis candidate at the New Zealand School of Forestry, University of Canterbury working on stochastic forest growth modelling. Corresponding author: dave.cown@scionresearch.com.