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Development of non-destructive methods for the prediction of growth stress and internal checking in the sawing and drying of *Eucalyptus nitens* lumber.

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EXECUTIVE SUMMARY

Growth stress-related sawing difficulties and internal checking on drying are among the most economically-important areas for genetic improvement of eucalypts for solid wood products. Variation and relationships of wood properties with sawing conversion and degrade (as growth stress) and with drying degrade (as internal checking and collapse) were further investigated in a wood properties and sawing study of 23-year-old *E. nitens*). It was attempted to develop simple, reliable and non-destructive methods of assessing these traits on standing trees for purposes of tree selection and progeny testing.

Growth stress, as microstrain measured by the Nicholson method, was consistently moderately positively correlated at the tree mean level with flitch movement off the saw, and with bow, crook and board-thickness variation (r = 0.59 to 0.68). However IML sound velocity, measured between points one metre apart in height position across the same sampling points as for microstrain, also showed consistent moderate correlations with flitch movement off the saw, bow, crook and board thickness variation (r = 0.54 to 0.68). The IML tool for measuring sound velocity, a completely non-destructive and quicker method than the direct measurement of microstrain, could therefore be used to predict "sawability" in progeny tests and for selection of plus trees.

Correlations of tree mean board checking and disc checking with tangential shrinkage and tangential collapse, measured by electronic scanning of 5mm increment cores, were not sufficiently consistent and strong to make this method useful at this stage, though further work is planned with larger diameter cores.

INTRODUCTION

The ability to assess wood quality and wood product performance non-destructively is a critical challenge facing many parts of the forest industry, e.g. in forest management, in processing of logs and in the context here of tree breeding. The cost of evaluating the pulp and/or sawn lumber properties of individual trees is prohibitive in selection of individual plus trees and in tests of their progeny. Disc-based sampling is destructive of genetic material and often too costly for use in breeding programmes, though can be applied more easily in clonal testing, as clones are replicated by several ramets, some of which may be destroyed without loss of that genotype.

Non-destructive methods are needed in eucalypt breeding for selecting trees with reduced checking and growth stresses. Understanding the relationships of non-destructively measured traits with product quality in *Eucalyptus nitens* (Dean & Maiden) Maiden is the first step towards developing these methods for other eucalypts that have potential as high-value appearance-grade timbers.

Eucalyptus nitens is a fast-growing, cold-hardy species grown in plantations in south-eastern Australia, New Zealand, Chile, and South Africa and used mainly for pulp. However logs from natural stands in Australia have been sawn in the past for framing, flooring, panelling and joinery (Miller *et al.* 1992; Turnbull and Pryor 1984), and in Tasmania, *E. nitens* is being grown in plantations for the production of appearance-grade sawn timber and veneer (Wardlaw & Neilsen 1999).

In New Zealand (NZ), *E. nitens* was not planted commercially until the late 1980s because of severe defoliation by the beetle *Paropsis charybdis,* and by leaf-spot fungi on sites with a warm and humid summer (Gadgil & Dick 1983; Shelbourne *et al.* 2000; Hood *et al.* 2002). The introduction of a parasitic wasp has partially controlled the beetles, and *E. nitens* is now being grown commercially in Bay of Plenty and Southland regions for kraft pulp and for export wood chips.

Wood properties, chemistry, kraft and chemi-mechanical p ulping, and fibre and handsheet properties have been intensively researched in NZ for this species at the individual-tree level, as well as for *E. fastigata* and *E. regnans* (Downes *et al.* 1997; Kibblewhite *et al.* 1997; Jones & Richardson 1999; Kibblewhite & Riddell 2000; Kibblewhite & Shelbourne 1997). In consequence, defining the wood properties and log characteristics that are important for breeding for kraft and mechanical pulp production is well advanced.

In eucalypts and other hardwoods, log end-splitting and difficulties in sawing result in low conversion percentages of sawn timber. Distortion of the log and sawn boards during sawing is caused by longitudinal growth stresses in the peripheral growth layers of the tree, combined with compression stresses towards the pith.

During drying, collapse and internal checking can cause a washboard effect on the surface and cracks in the face of boards which makes them unacceptable for appearance grade lumber (Jacobs 1979). Collapse and checking can be partially reversed by steam reconditioning, but the final drying usually leads to surface checks reopening (Campbell & Hartley 1984). Chafe *et al.* (1992) suggest that when reference is made to collapse, what is meant, generally is collapse that is recoverable by steam reconditioning, calculated as:

Collapse = S_v-S_r

S_v = shrinkage before steam reconditioning

S_r = shrinkage after reconditioning.

High levels of internal checking after drying have been reported in NZ. Number of checks were counted in discs taken at height intervals from 20 trees of 15-year-old *E. nitens*, and in corresponding sawn board cross-sections from basal 1.4-m billets from the same trees (Lausberg *et al.* 1995). Number of checks decreased to near zero above height 11.4 m. Checking was also widespread in breast-height discs of 9 and 10 year-old trees at six widely-distributed sites from latitude 36ºS-46°S. Checking was much more prevalent on the sites with higher mean annual temperatures and poor crown health. Extreme low wood density was associated with nutrient-rich sites and high rainfall (Shelbourne *et al.* 2002).

Checks were counted in height-6-m discs of ten 11-year-old trees per species in a trial of *E. nitens, E. globulus* and *E. maidenii* in Northland, NZ, and checks were found in all trees of *E. nitens*, one tree of *E. globulus* and none of *E. maidenii* (McKinley *et al.* 2002). Haslett & Young (1992) found large numbers of checks, as well as collapse, in quarter-sawn-boards of 30-year-old *E. nitens*, even though timber was carefully air-dried before being kiln-dried. In Victoria Yang & Waugh (1996), using a similar drying schedule for timber from 15-, 25- and 29-year-old *E. nitens*, also recorded high levels of internal checking. They reported that *E. regnans* showed worst drying degrade, followed by *E. nitens* and *E. globulus*, in terms of number and length of surface checks and percentage of boards with >5 surface checks. However timber from a Victorian study of 20-year-old trees of *E. nitens* showed minimal internal checking (McKimm *et al.* 1988).

In a recent NZ study (McKenzie *et al.* 2003 a & b), 15 individual trees of 15-year-old *Eucalyptus nitens* were each evaluated for production of appearance grade lumber and rotary-peeled veneer. A 5m butt log was sawn as well as a

one-metre billet from immediately above, with veneers peeled from the upper logs. Wood properties of each tree were evaluated on standing trees, from increment cores and from discs. Microstrain was measured at two positions at breast height via the Nicholson method. Boards sawn from the billet were air- or dehumidifier-dried, and discs were oven- or dehumidifier-dried and the effect of drying on wood in each sample was assessed. Mechanical strength properties were determined from small clear wood samples cut from the one-metre billet. Density, microfibril angle (MFA) and fibre dimensions were measured by SilviScan2 on a strip cut from a disc at 6 m height.

Relationships amongst tree means of log, timber and wood properties were explored to investigate possibilities for predicting butt-log sawn board and veneer quality from disc and one-metre billet sampling and by non-destructive methods. Checking of boards from the billet from height 6-7m, and from dehumidifier-dried discs correlated well with checking and collapse in butt-log boards. Shrinkage measured on one-metre boards and discs, correlated moderately with checking and collapse. Clearwood modulus of elasticity (MoE) was moderately correlated with veneer MoE and with density and MFA (from SilviScan) and more strongly with density/MFA. Growth strain, measured non-destructively at breast height, correlated well with "sawability" characteristics of log end-splitting, bow, crook and timber conversion.

Frequency of internal checking in dried timber was unacceptably high overall but was negligible in timber from some trees. Stiffness of veneer sheets, an important attribute for products such as lamimated veneer lumber (LVL), also varied significantly between trees and correlated well with estimates of clearwood MOE and with predicted MOE from SilviScan density and microfibril angle. High tree-to-tree variability in product characteristics and wood properties indicated possibilities for genetic improvement. There were good correlations of sawing and sawn-timber properties, with those measured on the tree, the log and from discs and one-metre billets. It was apparent that effective evaluation of species, populations and individual trees could be done without full-scale sawing studies and that there were possibilities for assessing some of these traits non-destructively on standing trees.

The present study again used *E. nitens* as a model species, and was initiated to further develop methods of predicting growth-stress-related sawing and sawn board defects, and of predicting internal checking of dried lumber from measurements on standing trees.

MATERIALS AND METHODS

Twenty trees were chosen for the study from a 23-year-old seed stand of *Eucalyptus nitens*, of mixed central Victorian provenances. The stand was planted in 1979 at an altitude of 400m at Tram Road, Kinleith Forest (Carter

Holt Harvey Forests) and had been heavily thinned for seed production (current stocking 200 spha). This had enabled the growth of large-diameter stems for their age (DBH from 380 to 516mm).

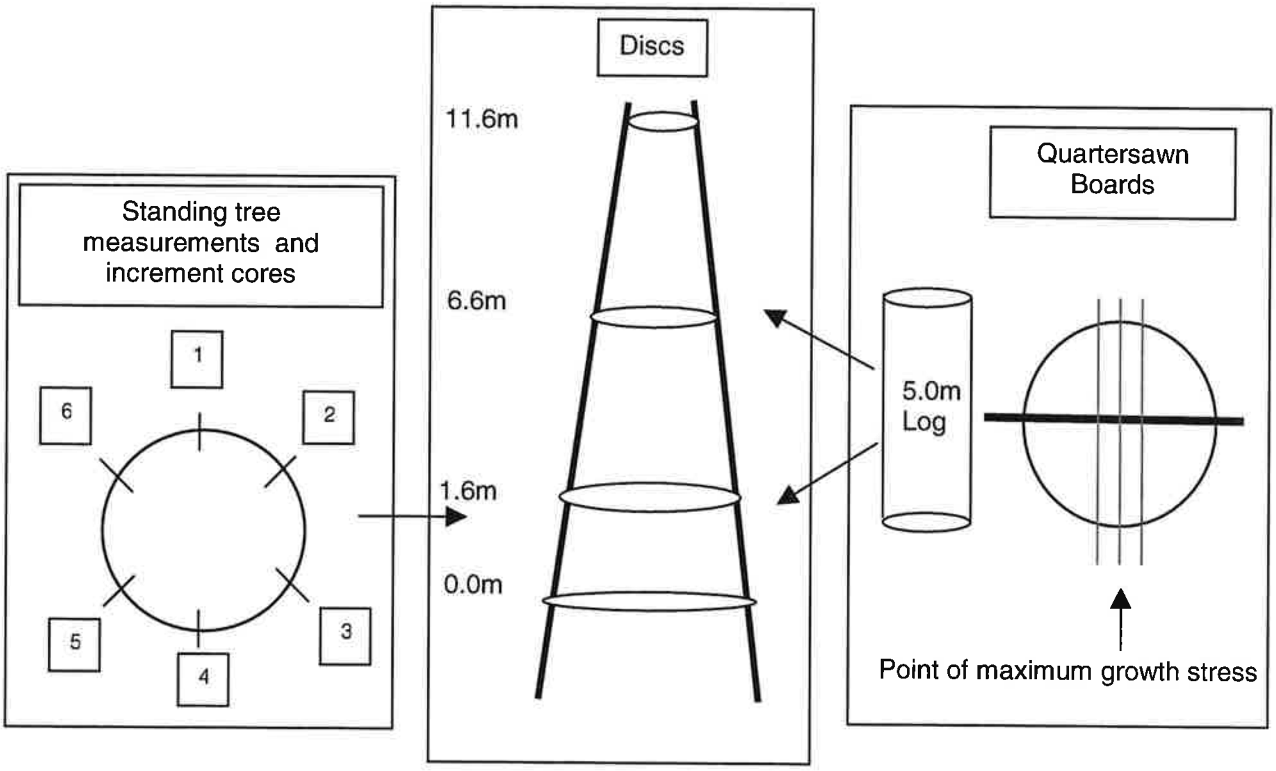
Longitudinal growth strain in the outermost growth rings was measured by the Nicholson method at six equidistant points on the circumference of the bole at height 1.4m (Nicholson 1971). Measurements at the same points were made of outer-wood basic density from 5mm increment cores, sound velocity across those points by IML hammer, and NIR spectra were recorded on a Foss 6500 NIR spectrometer. The Nicholson method has been shown to relate well to sawing and sawn board characteristics of the tree (McKenzie *et al.* 2003) but is too destructive and time-consuming for extensive use, so other properties were measured to investigate their correlation with growth strain and related sawing and sawn-board properties.

Two 5mm pith-to-bark increment cores were taken at the point in the circumference of each tree of highest measured growth strain, and diametrically opposite. Tangential diameter of the core, as projected onto a flat surface, was measured repeatedly at 0.17mm intervals by a scanner when green, after oven drying and after steam reconditioning. These measurements were used to derive tangential shrinkage and 'collapse' (Chafe *et al.* 1992 define collapse = (tangential diameter green - tangential diameter oven-dry) - (tangential diameter green - tangential diameter after steam reconditioning)/ tangential diameter green). McKenzie *et al.* (2003) showed that shrinkage and collapse correlated moderately with internal checking, assessed on dried discs and boards. Variation along the core in width after oven drying (tangential diameter), was characterised by the standard deviation of tangential diameter, and investigated as a measure of visible collapse in the core.

50mm discs were removed from the butt (0.0m), at 1.6m, 6.6m, and 11.6m heights up the stem for measuring basic density and internal checking. Checking frequency was scored subjectively on a 1-10 scale, separately in six sectors of each disc. Two strips were cut from a disc at height 1.6m at the points of highest and lowest growth strain, as measured by the Nicholson method. These were analysed by SilviScan2 at repeated radial pith to bark positions for air-dry density and microfibril angle, and MOE was predicted at each point. A 5.0m log from each tree at height 1.65 to 6.65 m was quarter-sawn and movement of the first flitch from the saw was measured. Crook, bow, and board thickness variation were measured on the first two 25 mm-thick boards that were cut from each flitch. After drying, the four sample boards were cross cut at four positions each and the number of checks per square cm and number of rings were counted (Figure 1).

Analysis of variance was used to examine variation in all traits among trees as well as within trees where characteristics had been repeatedly sampled, such as from pith to bark, with height up the stem and circumferentially around the stem. Relationships among traits were explored by simple correlations among tree means.

Figure 1. Location of samples.



RESULTS AND DISCUSSION

Variation among and within trees

A group of 20 trees of 23-year-old *E. nitens* demonstrated substantial variation (Table 1) both among and within trees in a number of wood properties and sawing and sawn board characteristics, including internal checking (assessed in boards and in discs), and shrinkage and collapse, measured in cores. Some of the characteristics were measured in several sub-samples per tree, and in these cases variance among trees is expressed as a ratio of variance among plus variance within trees i.e. repeatability. The number of samples required to achieve a standard error of 10% of the mean is also given.

Diameter at breast height averaged 435mm and ranged from 380-516mm, sufficient to indicate if stem size had an influence on growth strain. MFA and density, measured by SilviScan at 1.6m height on two strips, were both variable enough among trees to generate a wide range in MOE from 13.8 to 20.7GPa. Microstrain showed a lot of within-tree variation, with repeatability of 16% and so did sonic velocity, measured by the IML hammer, yet there was sufficient among-tree variation to only require one sample to achieve a standard error of 10% of the mean.

When the logs from 1.6-6.6m height were sawn, the movement of the flitch of the first cut in each tree was at least 7cm and up to 15cm, providing an initial indication of the longitudinal growth stress present within each log. The thickness variation of the first board cut from each of the two flitches reflected the amount of growth stresses, and so did the amount of bow and crook in the sample of four boards that were measured. Each of the boards was cross-cut four times to reveal the number of internal checks in each cross section, and trees averaged from 0.1 of a check per cm^2 of board cross-section to 1.6 checks/cm^2. The trees' discs at 1.6m height varied widely in internal-check-frequency score, from 1.8 to 10. Drying degrade in the form of numbers of checks per cm^2 of board end, and in subjective scores of numbers of checks was evidently highly variable among trees, and had relatively low variation within trees, with repeatabilities of ca. 60% for discs and 30% for boards.

RECOMMENDATIONS AND CONCLUSIONS

Results of this second sawing and wood properties study on young plantation-grown *E. nitens*, confirm that there is much tree-to-tree variation in growth stress (measured as microstrain by the Nicholson method). This determines, to a large extent, the amount of bow and crook in resulting sawn boards, and the severity of sawing problems and losses of conversion. Sound velocity, measured by the IML hammer outside the bark at several positions, appears to show similar magnitude of positive correlation as microstrain with bow, crook, flitch movement and board thickness variation. The IML tool could therefore be used to measure the "sawability" trait in progeny tests and for selection of plus trees. High wood density also appears to be associated with bad bow and crook in boards.

The moderate correlation (r = 0.76 & 0.66) between number of checks/m^2 of cross section of boards, with checking in kiln and air-dried discs gives some warning that checking in the final product may not be well predicted by check numbers in discs. However no non-destructive means has as yet been developed to predict the amount of internal checking in the wood of *E. nitens* trees. Variation from pith to bark in tangential dried core width (as standard deviation) which should describe the amount of visible collapse in a core, did not show any relationship with checking in boards and in discs, and neither did tangential shrinkage, measured by scanning cores. This result could be influenced by sampling larger diameter increment cores instead of the 5mm cores used for this study.

Amongst the 20 sample trees, three trees had an initial flitch movement of 7cm (versus 10-15cm for the rest) and these three had correspondingly-low bow, crook and board thickness variation. The three trees had microstrains of

7.1, 7.6 &7.5 (versus the mean of 7.6) and IML sound velocities of 24, 28 & 30 $\times 10^2$ (versus the mean of 30). Selecting for board quality and high conversion % using IML (and Nicholson microstrain) should provide adequate selection differentials, but heritability of this trait is still unknown.

Similarly, three trees out of 20 had board check numbers of 0.09, 0.19 & 0.24/cm^2 (versus mean of 0.72). These trees had disc checking scores (1-10) of 3.2, 3.8, & 4.7 (versus mean of 5.6). Thus there was plenty of variation for selection among the 20 trees in board checking, and the disc checking scores would be adequate to use as a correlated selection trait. None of the core-determined traits, collapse, standard deviation of core diameter, tangential shrinkage nor subjective score of core collapse were of any use in selecting for low checking. However, the three low checking trees also had high flitch and board distortion and IML sound velocities greater than the mean. There is some indication that a high sound velocity reading may identfy trees with low checking and conversely high growth stress. It is thus possible that in a larger population there may be adverse phenotypic and genetic correlations between checking and growth stress-related problems.

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