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Eucalyptus nitens thinning trial: solid wood quality and processing performance using conventional processing strategies

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Prepared for

Forest and Wood Products Australia

by

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Executive summary

Objective

The objective of this study was to determine the sawn product recovery and quality of plantation-grown *Eucalyptus nitens* sawlogs using conventional processing methods.

Methods

21-year-old trees, pruned at age six years to a height of 6.4 m, were selected from a silvicultural trial in north-east Tasmania which tested five stockings (100, 200, 300, 400 stems per hectare (SPH) and un-thinned control with ~700 SPH. Sets of up to ten trees per treatment, spanning a range of diameters and matched for diameter across treatments as closely as possible, were chosen for back-sawing (tree diameter at breast height over bark (DBHOB) less than 43 cm) and quarter-sawing (tree DBHOB greater than 43 cm).

Two sawlogs per tree, each approximately 2.7 m in length, were cut from 81 selected trees, 42 of which were back-sawn and 39 quarter-sawn. A total of 161 logs were processed in a conventional sawmill at St. Helens, Tasmania with the aim of maximizing board width and grade. A sub-sample of green boards from a marked centre cant in each log was intensively measured for a range of characteristics associated with processing. All sawn boards were pre-dried, reconditioned and kiln-dried using normal industry practices for native forest ash eucalypts. They were dressed and graded to meet the requirements of the Australian Standard AS 2796.1 (given several grading assumptions detailed in the report) and potential value limiting defects recorded and recoveries and product values calculated. The intensively measured boards were also re-measured. General linear models, taking into account experimental strata (tree, log and board) and applying transformations of the data as appropriate for some variates, were fitted to evaluate the significance of potential explanatory factors including sawing method, DBHOB, stocking treatment, tree identity, log position, and the interaction of sawing method and log position on product recovery and value and a number of board characteristics.

Key results

Total volume recovery of select, standard and utility grade boards was higher for back-sawing (30.5 per cent) than quarter-sawing (27.4 per cent). Mean dry board width was higher for back-sawing (14.1 cm) than quarter-sawing (10.6 cm). However, lower percentage recovery of select and standard grades from back-sawing more than countered these advantages of back-sawing, largely because of down-grading due to surface checking. As a result, product value was significantly higher for quarter-sawing than back-sawing (mean value AUD $185 and AUD $153 per cubic metre of log input respectively). It is emphasised that assumptions about grading rules, in particular those relating to surface checking, and price schedules, have a strong influence on grade recoveries and product value. Product value per cubic metre of log input was substantially higher (54 per cent higher, across both sawing methods) for the upper logs than the lower logs, again primarily because of less downgrade due to surface checking.

For some important variables, including log and board end-splitting, spring in dried boards, shrinkage, total and select-grade volume recovery, and value per cubic metre of log input, individual tree differences were significant, indicting the possibility of identifying superior trees for processing and possibly for breeding. Stocking treatment was generally not significant as an explanatory factor.

Application of results

The results give a detailed picture of the recovery, board quality and defects, and value recovery per cubic metre of log input from pruned 22-year-old *Eucalyptus nitens* grown at one plantation location in north-eastern Tasmania, using conventional industry processing techniques. They enable us to identify factors which limit processing performance, and to identify priorities for further research and possible changes in processing techniques for future evaluations and to improve profitability for growers and processors.

Further work

This report will link to other CRC for Forestry reports currently being finalised on tree crown characteristics and log taper of plantation-grown *E. nitens* at the Goulds Country trial as affected by stocking, and on the potential of a range of non-destructive evaluation techniques for predicting product recovery and value.

Additional information on board stiffness and hardness is being gathered from a sub-sample of the dry boards and will be available shortly. This will have important implications for market suitability. Further analysis of the results presented here will be undertaken once these additional data are available. An individual-tree competition index will be used in place of stocking treatment as a potential explanatory variable. This will be done because; (i) the sampled trees are not truly representative of the five stocking treatments; and, (ii) stocking varied considerably within the treatment plots, so the follow-up analysis will provide a better examination of the impact of stocking and associated competition on wood properties and processing.

The following further processing trials on the remaining trees still standing at Goulds Country are recommended to test ways of increasing product value per cubic metre of log input and to determine processing methods for future evaluations within the CRC for Forestry:

1. Assess the impact of back-sawing thin (18 mm green) sections on surface checking.
2. Assess the impact of a microwave pre-treatment on drying of back-sawn boards.
3. Process longer length logs in the HewSaw R200 (small logs) and the mill at St. Helens (larger logs) to assess the impact of longer log length on reduction of log end splitting and the trade-off with greater board deflection and associated processing problems (as outlined in original proposal, with some refinements).
4. Trial quarter-sawing of larger logs with a HewSaw R250.

Introduction

This report describes solid wood processing trials conducted within the CRC for Forestry as part the CRC for Forestry's ongoing assessment of Forestry Tasmania's silvicultural trial plantations of *Eucalyptus nitens*.

Over 20 years ago Forestry Tasmania embarked on a program to establish formal trials that could be used to assess the potential of a number of species of eucalypts to be grown in plantations and ultimately supplement supply of logs to the Tasmanian hardwood solid wood processing industry. Of the species used in the trials *E. nitens*, a species from mainland Australia is the most suited with good growth rates and suitability to the climate, including good frost tolerance. With the exception of sapwood susceptibility to the *Lyctid* borer, the wood produced from *E. nitens* also has similarities to Tasmanian native forest ash eucalypts (primarily *E. delegatensis* and *E. regnans*) which make up the bulk of the log supply from native forests to the existing processing industry. As such *E. nitens* has potential to supplement supplies from native forests and meet the demands of domestic and international markets already established for the ash eucalypts.

The trials established by Forestry Tasmania included thinning, fertiliser and spacing trials. These are distributed across a number of locations throughout Tasmania. The oldest of the *E. nitens* trials is the Gould's Country trial in northeast Tasmania (see Figure 1). The Gould's Country trial was established as a thinning and pruning trial. At the time of this assessment it was 22-years-old and several of the treatments had produced logs of a size that suggested this could be a suitable rotation age for harvest to supply logs to the existing processing industry.

The work described here is the first of a series of processing studies to be conducted on trees from the Gould's Country trial and the other trials established by Forestry Tasmania.

The processing trials conducted in this project are primarily aimed at assessing the effect of the silvicultural treatments on wood quality, product recovery (and value) and processing performance. However, the trials were also designed to do this assessment using conventional native forest eucalypt sawing and wood drying systems processing both back and quarter-sawn boards to meet existing market requirements. The trials were intended as a first step in understanding the critical log and wood quality issues that may limit the potential for conventional processing of *E. nitens* from stands managed to produce pruned ('clearwood') logs.

At this point many would expect a detailed discussion about the ability of conventional processing systems and conventional appearance product markets to handle the adverse effects of growth stress release, tension wood, branch related defects and poor wood drying performance. However, recent trials in similarly managed stands of *E. globulus* (Washusen *et al.* 2004) which has some similar attributes to *E. nitens*, suggests that early thinning coupled with pruning has a major impact on improving wood and log quality to a point where these issues appear to be much less critical than in unmanaged stands primarily grown for pulpwood production. For this reason, this initial research in the CRC for Forestry represents something of a scoping trial to assess which are the key wood quality issues to assess, and to develop non-destructive evaluation strategies for their assessment.

This report concentrates on the former (key wood quality issues) along with an assessment of the effect of the silvicultural treatments on wood quality, product value and processing performance; a second technical report will describe the results of the development of non-destructive evaluation technologies.

Materials and methods

The plantation and silvicultural trial

The trial site was located 27 km northwest of St. Helens (northeast Tasmania) in the Goulds Country block (E 593300 N 5450850) at an elevation of 120 m above sea level (Figure 1). The site was originally native forest, dominated by *E. regnans* and *E. obliqua*. The soils were yellow podsols formed over adamellite granites (Gerrand *et al.* 1997a). A full soil profile description was carried in August 2006 (Forestry Tasmania, unpublished data), details are available in Wood *et al.* (in prep). Based on the nearest meteorological station at St. Helens, mean annual rainfall for the locale was 776 mm, mean daily maximum and minimum temperatures were 18.4^{o}C and 7.4^{o}C respectively. Mean prevailing wind direction at 0900 hrs and 1500 hrs was north-west (Australian Bureau of Meteorology 2006). Gerrand *et al.* (1997b) estimated annual rainfall at the trial site to be in the order of 1,000 mm, similarly Medhurst *et al.* (2007) suggested that mean temperatures at the site were in reality a little cooler.

The site was cleared, broadcast burned and windrowed and then planted with Toorongo provenance *E. nitens* (paper-pot stock) spaced at approximately 3.5 x 2.5 m (1,143 SPH) in 1984. The site received a routine fertiliser application in the first year after establishment; 250 g per tree (tree^{-1}) of nitrogen, phosphorous and potassium (N:P:K) at a ratio of 11:5:0 respectively. No cultivation or weed control was carried out and under-story species dominated by *Acacia verticillata* (L. Her.) Willd., *Pomaderris apetala* Labill. and *Olearia lirata* (Sims.) Hutch., competed vigorously with the planted *E. nitens* (Gerrand *et al.* 1997a). This necessitated the use of brush-cutters for access during planting, and again during routine measurement of the trial at age nine years.

Table 1. Gould's Country trial details and silvicultural treatments

Age (2006)	22 years
Thinned	Six years
Pruned	Six years (single lift). Expect large defect core in butt log.
Thinning treatments	100, 200, 300, 400 trees ha^{-1} and unthinned ~ 700 trees ha^{-1}
Plots	0.1 ha; 25 x 40 m
Replicates	Four; two pruned, two unpruned

Some details of the plantation and silvicultural treatments are given in Table 1. The silvicultural trial was established in November 1990 (age six years). The trial was a randomised complete block design including four replicates of five thinning treatments; no thin and thinning to either 100, 200, 300 or 400 SPH, each plot was 25 x 40 m (0.01 ha) in size (Figure 2). Following the initial measurement and tree selection in December 1990, thinning treatments (thinning to final stocking) were applied motor-manually. Thinning was from below to remove small and defective trees which resulted in uneven spacing within the treatments (the effect of the thinning treatments on tree geometry and crown architecture is being assessed in CRC for Forestry Project 2.2). Shortly after in June 1991, two of the four replicates of each treatment were pruned to 6.4 m in a single operation using pruning saws. At this time the height to the first green limb was on average 5.6 m. Each plot was surrounded by a two-row buffer; these were thinned to an average of the two adjacent treatments. The trial was measured annually between 1990 and 2006.

Figure 1. Thinned to 100 SPH (left) and unthinned control (right) treatments in the Gould's Country thinning and trial pruning

In this initial study conventional processing strategies were employed with the aim of production of high quality appearance grade timber. A recent Forest and Wood Products Research and Development Corporation (FWPRDC) review suggested that plantation grown eucalypts must be pruned if they are to produce sawlogs suited to the existing processing industry (Nolan *et al.* 2005). For this reason only the pruned treatments and the pruned stem itself were included in the trial.

Diameter distribution and their implications for tree selection

Tree DBHOB distributions at January 2005 for each thinning treatment and the un-thinned control are shown in Figure 2. There was an expected difference between treatments in the DBHOB distribution with a shift to larger diameter trees as the spacing intensity declined.

The diameter distribution difference between treatments presented a number of sampling issues for a trial in a conventional south-eastern Australian hardwood sawmill equipped with break-down and resaws with single circular or band saws. For example, it is well known that log diameter has a major influence on processing characteristics for a given sawing strategy. During sawing the release of a given magnitude of longitudinal growth stress at the log periphery will generally produce greater board deflection; log, flitch and board end splitting; and greater difficulties maintaining sizing accuracy, as log diameter declines. Another difference that may be attributed to size is the percentage of sapwood (which in the case of *E. nitens* is susceptible to *Lyctid* borer). In small diameter logs the defect core as a percentage of the diameter of the log is larger and the curvature of the growth rings greater, which may contribute to increases in the incidence of branch (knots, kino pockets, decay) and drying related defects (cupping, surface checking).

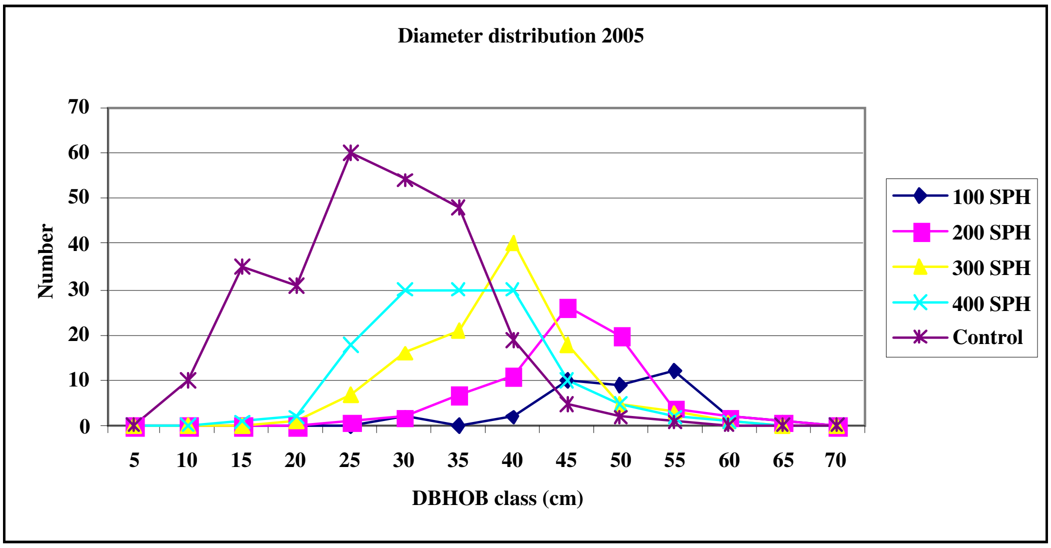

Figure 2. Gould's Country trial DBHOB distributions for the pruned treatments

There is also an issue relating to the sawing strategies that may be applied that will influence results of research trials. Most conventional sawmills processing ash-type eucalypts apply a quarter-sawing strategy (as apposed to back-sawing) as standard procedure. Quarter-sawing strategies are applied in order to minimize drying defects and possibly produce more stable products "in-service". It is well known with quarter-sawing that when log diameter declines recovery is adversely affected because the effect of growth stress release described above is compounded by the board dimensions in the radial direction. In effect the gradient in stress, that is a normal characteristic of hardwood logs (Jacobs 1938), produces a higher differential in stress as the radial dimension within the log increases. Also quarter-sawing producers a larger percentage of very narrow (low value) boards because the distance between the pith and log periphery declines with log diameter. For this reason most sawmills in south-eastern Australia prefer logs with a mid-diameter above about 40 cm.

In the case of small diameter logs back-sawing will produce better results than quarter-sawing by producing higher volume recovery and wider boards. However, drying is far more challenging and it is difficult to dry back-sawn boards without surface checking and cupping limiting product recovery and value.

For this trial it was acknowledged that a simple random selection would show these differences between treatments and it was decided to apply a stratified sampling strategy that attempted to eliminate this diameter effect.

Tree selection strategy

The sampling strategy was structured to assess differences in processing performance and wood properties between treatments for given diameter ranges and for two specific processing strategies, which had their own diameter limits. To obtain the two samples trees were selected for either the back-sawing or quarter-sawing trial (i.e. the logs within each tree were to be sawn by the same method) based on an estimate of the small end diameter under bark (SEDUB) of the pruned part of the stem. This allowed an assessment of differences in log height within the stem for both sawing strategies and simplified the log segregation process at the mill. It was anticipated that SEDUB for quarter-sawing would be approximately 35-45 cm and for back-sawing

25-35 cm. The two samples were selected based on the DBHOB after allowing for taper and bark thickness to estimate the SEDUB.

In January 2006 all trees in the plantation were measured to determine the current DBHOB. A stratification and accrual selection strategy was applied with the target number of trees for each stratum cell being 10. The stratification = thinning treatment x DBHOB class of 30.0-42.9 cm DBHOB (for back-sawing) and 43.0-60.0 cm DBHOB (for quarter-sawing). Further details of the stratification are given in Appendix A. It was not possible to fill either the 400 SPH or control in the 43.0-60.0 cm DBHOB range or the 100 SPH in the 30.0-42.9 cm DBHOB range.

Where it was possible to fill the stratum cells, before harvesting the trees were initially selected from spreadsheet data so that each stratum cell had trees evenly distributed across the diameter range.

Standing tree assessment and harvesting

When the trees had been selected from the January 2006 DBHOB data they were inspected in the field and eliminated from the trials if they were defective for the following reasons:

- If after harvest the trees produced logs with sweep or were likely to produce sweep that exceeded 20 per cent of the log diameter over any 2.4 m length.
- If they had obvious stem damage of sufficient severity that would qualify as a defective quarter using the Victorian Forest Service log grading rules i.e. the defect width or combined defect width exceeded 33 per cent of surface distance of the log quarter on which it was located.

Where a defective tree was located it was replaced with a tree with a similar DBHOB at January 2006.

Figure 3. Mechanical harvester used to harvest the selected trees

In May 2006, after the trees were selected, growth strain was measured with the Cirad Foret strain gauge at breast height (1.3 m) at the south-west, north-west, north-east and south-east orientations. Acoustic wave velocity was measured over a distance of 1.2 m with the Fakopp microsecond timer at the south-west and north-east orientations, and 12 mm diameter radial cores were extracted at 0.6 m and 1.3 m above ground from the south-west side of the stem with the CSIRO Trecor motorised corer. This work is reported in greater detail in another technical report.

The trees were harvested by mechanical harvester in May 2006 (Figure 3). To reduce the impact of the felling operation on log end-splitting the felling operators were under instruction not to use excessive force on the boom to control the direction of fall.

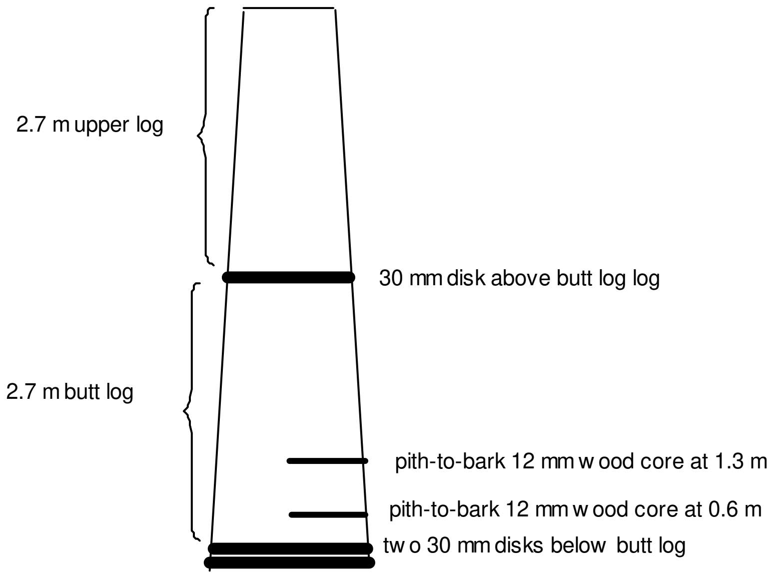

Figure 4. Diagram showing the location of logs and discs used for the various studies on the Goulds Country trial

From the lower stem a number of disks and logs were to be cut as indicated above. The disks were used in work reported elsewhere. In the case of the sawlogs the aim was to ensure that the lower core hole (0.6 m) was 100 mm above the end of the butt log so that each log was taken from the same height in the stem. On occasions the log height varied primarily because it was not possible to locate the lower core hole. For research purposes, where it is desirable to have as much control over a sample as possible, this was not ideal. Along with splitting induced at felling this was attributed primarily to the mechanical harvesting operation because with a remote harvesting head it is difficult for the operator to control the height of the felling cut. In future trials this can be overcome with the addition of a mark on the tree stem that corresponds to the location where the felling cut is to be made plus the vertical dimension of the felling head. This will put the mark above the felling head so it is easily visible to the operator.

Immediately after felling the butt end of the trees were end sealed with Dussek Campbell Technimul wax emulsion, tagged, numbered and gang nailed to prevent extension of end splits (Figure 5). They were cross cut at a minimum length of 5.7 m as shown in Figure 5, debarked and the top end sealed with sealing compound, gang nail plates applied and tagged and numbered as for the butt end.

Figure 5. The felling cut after application of end-sealing compound with the gang nails and identity tag applied immediately after felling

In late May 2006 the full length bush logs were transported to the McKays Timber sawmill in St. Helens and placed under water sprays.

There were a number of trees retained at the Gould's Country trial for subsequent processing experiments outlined in Appendix A.

Log preparation and measurement

At the sawmill the logs were cross cut to produce two 2.7 m long sawlogs and discs as required for other studies in Programme Two. Where possible, cross-cuts were made so that the 0.6 m core hole was 100 mm from the end of the large end of the butt log. Where this was not possible the distance was measured or its location was estimated from the core-holes at 1.0 m (i.e. this was necessary where the felling cut was made above the 0.6 m core location).

Immediately after the logs were cross cut the south-west location and log identification number was written on the large end with black water proof pens (Figure 6). The smallest and largest diameters were measured at both ends of the logs and defective quarters recorded where they were found. Both log end split length on the log ends (Figure 6) and extension of the splits up the stem, were recorded.

Figure 6. Log end splitting immediately after removal of discs (top) and transfer of log identity code to the freshly sawn face after collection of discs

From the diameter information and log length log volumes were calculated using equation (1):

$$\textbf{(1)} \qquad V = \left[\frac{D_1 + D_2 + D_3 + D_4}{4} \times \frac{1}{2} \right]^2 \times \pi \times L$$

Where:

V = log volume (m^3);

D_1 = small end diameter 1 (m); D_2 = small end diameter 2 (m);

D_3 = large end diameter 1 (m); D_4 = large end diameter 2 (m)

L = log length (m)

From the measurements of splits the Log End Split Index 2 (Yang 2005) was calculated for each log end using equation (2). The symbols used in equation (2) are also shown in Figure 7.

$$\textbf{(2)} \qquad SI\text{-}2 = [(SL_{END} \text{ X } A/2) + (SL_{SURFACE} + B) \text{ X } SL_{END}/2] \;/\; R^2_{MEAN}$$

Where:

SI-2	= Log End Split Index 2
SL_{END}	= split length on the log end
$SL_{SURFACE}$	= split length on the log surface
R_{MEAN}	= mean radius of the log end
A	= equal to SL_{END}
B	= equal to $SL_{SURFACE}$

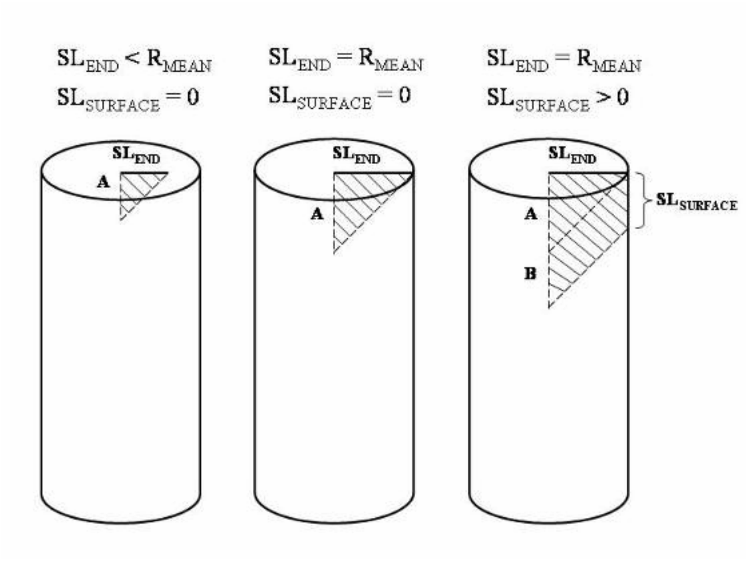

Figure 7. Illustration of the symbols used in calculating Log End Split Index 2. The shaded area is the split plane (from Yang 2005)

In addition, acoustic wave velocity was measured using a Director HM 200 on the full length bush log prior to cross cutting and disc collection and again on each sawlog after cross cutting. Some characteristics of the grain were recorded on each log end, including the slope using a protractor and the straightness of the grain, being wavy, intermediate or straight.

Finally the logs were colour coded on the large-end using a sequence of eight colours (Figure 8) and on the small end the position of a cant on the southwest side of the log was painted in yellow for quarter-sawn logs and a single yellow line in the case of back-sawn logs (Figure 8).

Figure 8. Colour codes on the log large end (top), and position of centre cant boards on back-sawn logs (centre) and the centre cant on quarter-sawn logs

Sawing methods

Sawing was conducted at The McKay Timbers sawmill at St. Helens. The sawing line has two log break-down saws and a two-man bench resaw. The first break-down saw is a Canadian circular saw and the second a single circular saw with a McKee carriage. The first saw is used to breakdown the log into flitches of a manageable size for the second breakdown saw. This system was set up to process large diameter native forest logs normally longer than 3.0 m. The short length of the plantation-grown logs (2.7 m) meant that only two of the three dogs could be used to secure the logs. On occasions this resulted in excessive distortion of flitches requiring more frequent straightening cuts than would normally be applied, had three dogs been used. Fortunately because of a combination of the short length and low stress of the logs this was not a major problem.

The sawing process for the trial involved a single cut with the first saw to either halve the logs for quarter-sawing (Figure 9) or to produce a flat face to help secure the log for back-sawing (Figure 10).

Figure 9. Quarter-sawing logs on the second break-down saw

Figure 10. Back-sawing logs on the second break-down saw

The sawing strategies applied during log break-down viewed from the small end are shown in Figure 11. Before the first cut was made the logs were either aligned so that the painted cant was horizontal (for quarter-sawing) or the painted line was vertical (for back-sawing). Boards were selected from this zone for detailed assessment at the conclusion of sawing.

During back-sawing the logs were turned 90º three times to complete the sawing and produce a centre cant for sawing on the resaw. Two of these three turns are shown in Figure 12.

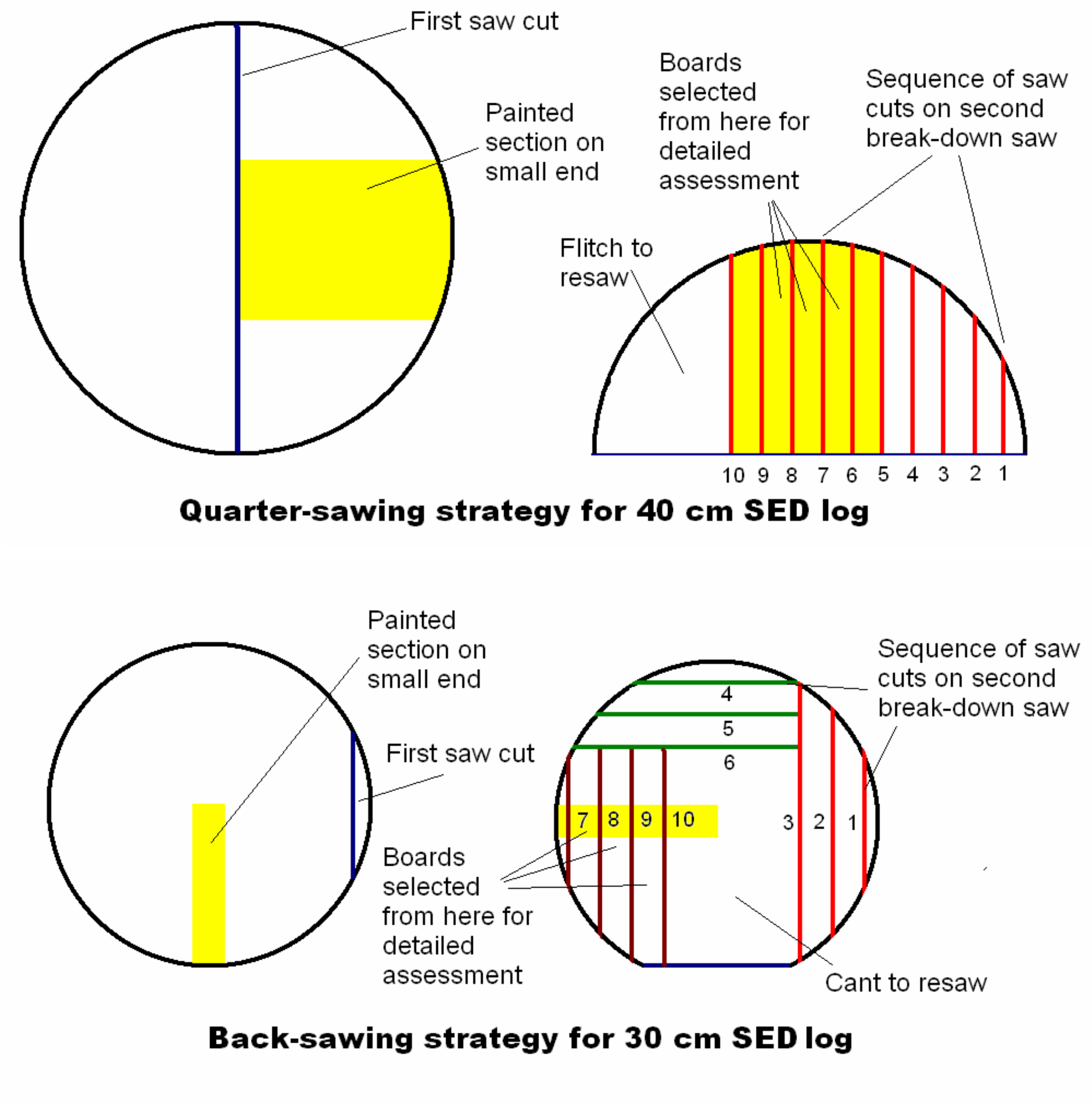

Figure 11. Sawing strategies applied during log break-down. (SED = small end diameter)

Figure 12. Log rotation sequence used for back-sawing. Note the end dog is unused in the 2.7 m logs

Measurement of distortion in flitches during quarter-sawing

During quarter-sawing distortion was measured on two occasions. The first measurement was made immediately after the logs were halved on the first breakdown saw. The distortion was measured as shown in Figure 13 using a straight edge with metal rods at each end to set the straight edge at a fixed height. The distortion from a straight line was then measured with a wedge at the centre. The distortion in each half of the log (the south-west and north-east halves) was measured to the nearest mm.

Distortion in the form of spring was then measured to the nearest mm in the centre slab from each half of the log immediately after it was sawn on the second break-down saw. A straight edge was used as shown in Figure 13.

Both distortion measurements were used to assess differences between treatments and a comparison was made between the two to determine if there was a change in the magnitude of distortion as the sawing process progressed.

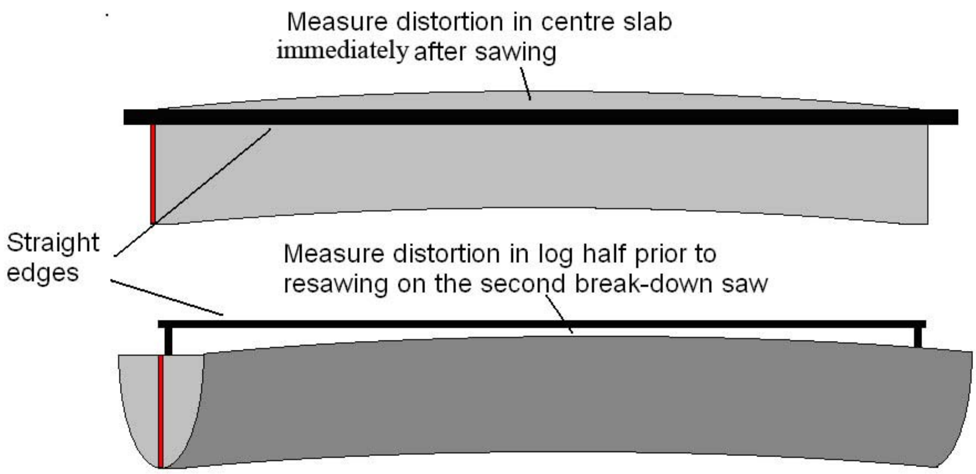

Figure 13. Measurement of distortion in log halves and the centre slab during quarter-sawing

The sawing process was completed on the two-man bench single saw. Boards were not docked so as to retain the log colour code at the large end and the yellow paint on the small end. The sawing strategy for both back-sawing and quarter-sawing aimed to produce 25 mm thick dried boards and the widest board possible. For back-sawing nominal dimensions for dried boards were 35, 50, 75, 100, 125, 150, 175, 200 and 225 mm. For quarter-sawing the widths were 50, 75, 100, 125, 150 and 175 mm.

Board identification and green measurements

After completion of sawing each board was identified by the colour code applied to the large end of the log and the sequence in which the log entered the mill. For example, the first red log was given the code R1 and when the second sequence was sawn the red log was given the R2 code. This was repeated for each of the eight colours and for the 22 colour groups. By doing this each board could be traced back to the log of origin. These boards were immediately block-stacked and wrapped in plastic.

In addition a minimum of two boards were selected with yellow paint on the small end from the quarter-sawn logs and with the yellow painted line on the back-sawn logs. These boards were either perfectly quarter-sawn or back-sawn and given the log code and a unique board number eg. R1-1, R1-2……R1-X. Examples of the code written on the boards are shown in Figure 14. These boards underwent the following procedure and measurements (Figure 14):

The length of any end split was permanently marked with a black water-proof pen. This mark was used after drying to measure end split length before and after drying. Comparisons were made between treatments and log height.

Permanent marks were placed at 25 per cent of the board length from each end of the full length board and at mid board length. At these points, the green width and thickness were measured. This information was used to determine differences in sawing accuracy between treatments and log height. At these marked locations width and thickness shrinkage were also calculated after repeating the measurement at conclusion of drying. Comparisons of shrinkage were made between treatments, sawing methods and height in the tree in shrinkage. The shrinkage data was also used to determine the suitability of the green sizes processed.

Spring and bow were also measured. In the case of bow the boards were laid on their wide face on a flat surface and bow measured where it was apparent.

Figure 14. Board identification code on back-sawn boards and measurement of dimensions and spring and bow immediately after sawing

Pre-drying

Following the measurements all remaining boards were wrapped in plastic (Figure 15) and transported to Launceston for drying. The measured back-sawn boards were dried in the University of Tasmania experimental pre-dryer and the remaining back-sawn boards together with the quarter-sawn boards were pre-dried in the Forests and Forest Industry Council kiln at ITC Timbers in Mowbray.

The back-sawn boards were stacked to distribute boards from any log randomly across the width and height of the stack, and pre-dried using the schedule shown in Table 5. Pre-drying was continued until average moisture content was below 20 per cent as indicated by sample boards and confirmed by using a resistance moisture meter. The quarter-sawn boards were initially pre-dried using similar conditions to those used for the back-sawn boards.

Figure 15. Boards packed and ready for transport to Launceston for drying at the University of Tasmania kilns and at NST Timbers in Mowbray

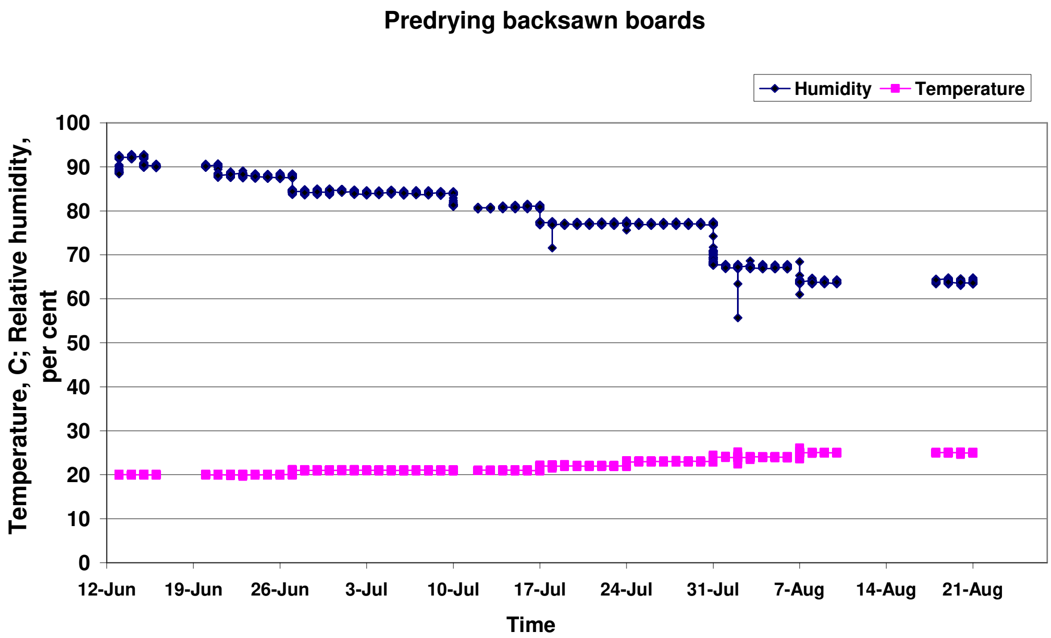

Figure 16. Pre-drying schedule for back-sawn *E. nitens* in the University of Tasmania kiln in Launceston

Table 5. Drying schedule used to dry back sawn *E. nitens* in the University of Tasmania kiln in Launceston

Time (days)	Dry bulb temperature (°C)	Wet bulb temperature (°C)	Air speed (m/s)
0	23.0	21.5	0.5
7	23.0	21.0	0.5
14	24.0	21.5	0.5
21	24.0	21.0	0.5
28	24.0	21.0	0.5
35	25.0	20.5	0.5
42	25.0	20.0	0.5
49	25.0	20.0	0.5
54	25.0	20.0	0.5

Final drying

Once below fibre saturation point the back-sawn and quarter-sawn boards were reconditioned and kiln dried in an ITC kiln using ITC's conventional practices for native forest ash eucalypts with some modifications as appropriate for the experimental material. During reconditioning and final drying the experimental material was of necessity stacked with mill production material of similar size and type. The pre-drying, steaming and kiln drying records have not yet been made available so are not reported here.

Dry board assessment

At conclusion of drying all boards were transported to the McKay Timber drymill in Hobart. Examples of the condition of boards after drying are shown in Figure 17 and 18 for back-sawn and quarter-sawn boards respectively.

Before any measurements or further processing was undertaken the code written on the board face was transferred to the edge (Figure 19). At this point the boards which had been measured green were re-measured for thickness and width at the marked locations (Figure 20), end splitting before and after drying and spring. In addition cupping was also measured. This information was used to determine shrinkage, end-splitting, spring and cupping differences between treatments and log height.

In addition to the above a sample of two boards per log were selected for board hardness and stiffness measurement. This data will be presented in a subsequent report.

Figure 17. Dried back-sawn boards

Figure 18. Dried quarter-sawn boards

Figure 19. Board identification code transferred from the face to edges of boards

Figure 20. Measuring spring, bow, cupping, product dimensions and end split severity on the intensively measured boards before planning

Product grading

The boards were planed on the face and back with an Opticut 200 moulder (Figure 21) and defects docked and the boards graded by McKay Timbers graders (Figure 22) to meet the requirements of Australian standard 2796.1. The grades produced were select, standard (medium feature grade) and utility (high feature or common grade).

Board volumes were calculated on the basis of 25 mm thickness after planning, with nominal dry product widths in the following categories: 35, 50, 75, 100, 125, 150, 175, 200 and 225 mm. For volume calculation, board widths were reduced to the nearest of these size categories below actual board width.

The board volumes x grade were tallied for each log to determine recovery of select and standard grade and total recovery. Product values for the recovered volume were determined for each log, and based on this, the product value per cubic metre of log input calculated. The schedule of prices used to determine the product value were obtained from ITC and were used in the FWPRDC Economics of Processing project so the results could be compared. The prices are given in Table 7. A discount of 10 per cent was applied to boards of Select and Standard grades ≥ 1.8 m and < 3.0 m and a discount of 50 per cent was applied to select and standard grade boards < 1.8 m.

Table 7. Wholesale prices for native forest ash timber used for product value estimation

		Wholesale price		
Width (mm)	Thickness (mm)	Select* (AUD $ m^3)	Standard* (AUD $ m^3)	Utility (AUD $ m^3)
50	25	1215	970	350
75	25	1360	1005	350
100	25	1455	1120	350
125	25	1460	1165	350
150	25	1510	1190	350
175	25	1650	1360	350
200	25	1790	1535	350
225	25	1790	1535	350

*Discounts of 10 per cent and 50 per cent were applied to boards of select and standard grades ≥ 1.8 m and < 3.0 m and < 1.8 m respectively

Recovery and product value comparisons were made between treatments, sawing method and log height.

In addition the defects present on graded faces and edges were recorded for each board. The defects included green and dead knots, surface checking, under sizing, kino pockets, insect damage, sapwood and decay. The percentage of boards of select and standard grade combined and utility grade affected by the most severe of these defects were calculated for each log and comparisons made between treatments, sawing methods and log height.

Figure 21. Opticut 200 planer used to skip dress boards on the face and back

Figure 22. McKay Timbers staff grading boards

Internal check assessment

At the conclusion of grading the boards used for detailed assessment were docked at the marked locations and the number of internal checks and the length and width of the worst check measured (Figure 23). This information was used to assess differences in internal checking between treatments, sawing methods and height in the tree.

Figure 23. Detailed assessment of selected boards from the centre cant

Statistical analysis

Data sets relating to trees, logs, green and dry boards were imported as separate tables into Microsoft Access, and tables linked in the database through tree, log and board identities. This enabled output of composite tables for statistical analysis.

The experimental strata relevant to the analyses of processing performance were as follows:

- Tree
- Log (upper/lower log, two logs per tree)
- Board within log
- Base stratum (within boards) for measurements such as internal checking and shrinkage, for which there were multiple measurements on each board

The stratum at which a measurement or treatment is located, and the nature of its distribution (normal distribution of residual errors, non–normal or category) has important implications for statistical analysis. Table 8 summarises the stratum positions and characteristics of the experimental factors, non-destructive evaluation (NDE) measurements and processing variates.

Table 8. Stratum positions of measurements and potential explanatory factors

	Continuous distribution	Category
Tree stratum	DBHOB	Stocking treatment
	Longitudinal growth strain	Sawing method (back- or quarter-sawing)
	Standing tree acoustics	
	Bush log acoustics	
	Grade recoveries, by tree	
	Product value per m^3 of log input, by tree	
Log stratum	Sawlog acoustics	Log position (upper/lower)
	Log taper	
	Log splitting index (upper and lower ends of log)	
	Grade recoveries, by log	
	Product value per m^3 of log input, by log	
Board or within-board stratum	Bow	
	Spring	
	Cup	
	Total length of board split	
	Surface checking	
	Internal checking area (two measurements per board)	
	End split (sum of upper and lower ends of board)	
	Variation in green board thickness and width relative to mid-point value (two measurements per board)	
	Shrinkage in board thickness and width (three measurements per board)	

As sawing method and tree DBHOB are confounded (trees of less than 43 cm DBHOB were back-sawn and the larger trees were quarter-sawn) it is appropriate to fit sawing method as the first explanatory factor in the statistical analysis, but it must be understood that the comparison of the sawing methods is not a "fair" comparison made with identically-sized logs. As expected, for most response variates there was a highly significant difference between the two sawing methods.

Stepwise linear fixed-effects models fitting sawing method, then DBHOB and spacing treatment, followed by tree identity and log position, then the interaction of sawing method and log position, and finally individual log identity (tree.log) were run using the Genstat 9.0 software package. Plots of residual errors versus fitted values were used to check that residuals from this analysis were normally distributed and to identify outlying data values for investigation. Although error distributions were not normal for some of the variates, there were no genuine outlying values needed to be removed from the data sets.

Square root transformations resulted in normal distributions of residuals for some variates, so were used for testing explanatory factors for these variates. Poisson distributions with a log link function were appropriate for some other variates, while conversion to category data was required for others. Category response variates were analysed using a binomial distribution and a log link function. Using Poisson and binomial distributions resulted in an analysis of deviance (as opposed to an analysis of variance) and chi-squared probabilities for potential explanatory factors.

To enable statistical testing at the correct stratum level, variance ratios for testing sawing method, DBH and spacing treatment (tree stratum factors) were calculated using the tree identity mean square and degrees of freedom from the analysis, not the default residual mean square and residual degrees of freedom. Similarly, variance ratios for testing log position and the interaction of sawing method and log position (log stratum factors) were constructed using the log identity mean square and associated degrees of freedom.

The potential for thinning treatment and NDE measurements such as growth strain, sonic measurements and characteristics of small wood samples to predict individual defects and overall processing performance will be reported separately in CRC for Forestry Project 2.4.

Results and analysis

The effectiveness of the tree selection strategy

The numbers of logs processed, the mean log diameters and the mean overall taper for each log are shown in Table 9, 10 and 11. Taper is expressed as decrease in log diameter (in cm) per metre of log length. As expected, taper was less in the top logs than in the butt logs. The mean sawlog diameter distributions are shown in Table 12 for back-sawn butt logs, Table 13 back-sawn top logs, Table 14 quarter-sawn butt logs and Table 15 for quarter-sawn top logs.

Table 9. The numbers of logs processed after application of the tree selection strategy

		Spacing treatment Trees ha^{-1}				
Sawing method	**Log height**	**100**	**200**	**300**	**400**	**Control**
Back-sawn	Butt	2	10	10	10	10
Back-sawn	Top	2	10	10	10	10
Quarter sawn	Butt	10	11	10	6	2
Quarter-sawn	Top	9	11	10	6	2

Table 10. The range and mean of log mean diameter (in cm) of logs processed

		Spacing treatment Trees ha^{-1}				
Sawing method	**Log height**	**100**	**200**	**300**	**400**	**Control**
Back-sawn	Butt range	37.3 – 39.9	28.3 – 38.4	29.9 – 39.5	27.4 – 39.6	28.1 – 37.4
	Butt mean	38.6	33.1	34.7	33.8	32.9
Back-sawn	Top range	31.6 – 32.6	23.1 – 34.5	26 – 35.9	24.6 – 35.1	24.5 – 33.1
	Top mean	32.1	29	30.8	29.1	28.5
Quarter sawn	Butt range	41.6 - 53	38.5 – 51.3	40.2 – 57.1	39.2 – 47.5	42.3 – 42.3
	Butt mean	46.4	44.4	45.2	42.7	42.3
Quarter-sawn	Top range	35.1 – 45.3	34.4 – 45.9	34 – 49.5	35.1 – 41.6	35.9 – 37
	Top mean	40.3	38.6	39.3	37.5	36.4

Table 11. The taper of processed logs (in cm of diameter per metre of log length)

		Spacing treatment Trees ha^{-1}				
Sawing method	Log height	100	200	300	400	Control
Back-sawn	Butt	3.9	2.4	2.3	2.6	2.4
Back-sawn	Top	0.6	0.6	0.6	0.7	0.7
Quarter sawn	Butt	3.4	3.5	3.1	2.6	3.9
Quarter-sawn	Top	0.7	0.8	1.0	1.1	0.9

Table 12. Individual log mean diameters (smallest to largest) for back-sawn butt logs

Treatment (Trees ha^{-1})				
100	200	300	400	Control
	25.4	26.2	25.2	24.9
	27.0	27.1	27.4	25.3
	28.0	29.3	27.8	27.6
	28.9	30.3	28.3	28.8
	29.0	30.3	29.9	28.9
	29.9	33.0	31.5	30.5
	31.0	34.2	32.3	31.0
32.5	31.7	34.3	32.5	32.3
34.0	33.4	35.3	33.0	32.3
	35.3	35.8	36.0	34.8

Table 13. Individual mean log diameters (smallest to largest) for back-sawn top logs

Treatment (Trees ha^{-1})				
100	200	300	400	Control
	21.8	25.3	24.0	23.7
	26.0	26.7	25.2	24.0
	26.4	26.8	25.8	25.8
	27.0	28.2	26.3	26.8
	27.3	29.5	26.8	26.9
	28.5	31.5	28.8	28.3
	28.8	32.3	30.0	28.4
30.9	30.0	32.7	30.4	29.5
31.8	32.0	32.9	30.7	30.5
	33.9	35.0	34.0	32.0

Table 14. Individual mean log diameters (smallest to largest) for quarter-sawn butt logs

Treatment (Trees ha^{-1})				
100	**200**	**300**	**400**	**Control**
37.5	34.2	35.9	36.7	
38.3	36.1	36.1	36.9	36.9
38.9	37.3	37.3	37.5	37.3
40.0	38.5	39.4	39.3	
40.2	39.5		40.3	
	40.2	40.3		
43.3	40.5	41.1		
43.7	40.8	42.0		
44.0	42.0	42.3	44.5	
46.2	42.2	45.0		
46.8	46.1	51.8		

Table 15. Individual mean log diameters (smallest to largest) for quarter-sawn top logs

Treatment (Trees ha^{-1})				
100	**200**	**300**	**400**	**Control**
34.4	33.0	33.5	33.3	
36.8	33.6	34.0	34.3	34.8
36.9	34.3	34.5	34.9	35.8
37.3	35.6	36.4	37.1	
38.5	36.7	36.6		
	36.9	38.5	37.8	
	38.5	38.8	38.8	
40.6	38.9	39.2		
41.4	39.8	40.8		
42.7	40.8			
44.8	44.7	48.0		

The implications of log numbers and log diameter ranges

The tree and log selection strategy was primarily designed to accommodate the requirements of the conventional processing system that was being used in these trials. These requirements were discussed in general terms in the introduction, the most important issue being the point at which conventional quarter-sawing system efficiency falls away. It is generally accepted that this occurs at about 40 cm mid-diameter and below this diameter back-sawing strategies must be applied in order to produce products of dimensions with high demand in conventional markets, and high product recoveries. Also within each sawing method it is well known that diameter has an important bearing on processing performance and product recovery and value.

For these reasons it was considered that random or representative selection of trees would only show the shortfalls of the processing system and not true treatment effects. To overcome this, the diameter ranges were deliberately selected to ensure similar diameter ranges for each thinning treatment and the control. However, this selection strategy also has important implications for the analysis and interpretation of the data.

Firstly, the selection strategy produced very few logs in some stratum cells. For this reason it is difficult to make comparisons between some treatments for a given sawing method. For example, the 100 tree ha^{-1} treatment and control have only two trees selected for back-sawing and quarter-sawing respectively.

Secondly, in order to select samples with similar log diameter ranges, trees were selected from different parts of the DBHOB distribution. For example, at the extreme, within each sawing method selection for the 100 trees per hectare treatment was biased towards smaller trees, and selection from the control was biased towards larger trees. Similar but more subtle differences occurred for the other stocking treatments. This bias means that either (i) proportions of selected trees from different dominance classes (primarily dominant or co-dominant trees) differed in each treatment, and/or (ii) because the spacing was not uniform within the treatment plots, trees were selected from parts of the plots where the effective tree stocking rate was higher or lower than the average for that treatment. Regardless, the samples of logs sawn from each stocking treatment are not truly representative of that treatment. However, it is possible to examine the effect of a range of tree or log diameters across each stocking treatment and sawing method (except for those treatment–by-method combinations that are poorly represented, with only two trees present). It is also possible to test statistically the interaction between tree/log diameter and stocking treatment.

It would be important if, after accounting for log diameter, there were significant differences between treatments in processing performance, product recovery and value for either or both of the sawing strategies. This might indicate, for example that processing characteristics of logs from large, dominant trees grown at high levels of stocking differed from those of logs cut from co-dominant trees of similar diameter in the heavily thinned treatments, which would have important implications for stand management.

An alternative approach that may resolve some of the complexity discussed above is to model the effect of the thinning treatment as a local competition index for each individual tree that was processed. This will be carried out in a follow-up study.

Product recovery, value and value limiting defects

The most important results for industry partners in the CRC for Forestry are the overall product recovery, value and value limiting defects. These results are presented first, followed by the detailed statistical analysis outlined in the methods.

Product recovery and value

The product recovery by grade as a percentage of log volume for each sawing methods and log height are given in Figure 24 a-d and product value in Figure 26. An indication of product quality for the three board grades of back-sawn boards is also shown in Figure 25.

Figure 24 a-d indicates better recovery of high quality select and standard grade boards (high value boards) for quarter-sawing than back-sawing and for top logs compared to butt logs. This is reflected in the product values shown in Figure 26 and Table 16. This information will be analysed statistically in the next section. However, except for perhaps the quarter-sawn top logs, the recovery of select and standard grades was low, resulting in modest product value. The reasons for this are outlined below in "Assumptions made during grading" and "Value limiting defects".

Assumptions made during grading

As indicated in the methods all boards were skip-dressed on the face and back and graded by staff at McKay's Timber. As such they were oversized boards in both width and thickness intended for subsequent processing into flooring products. In applying the criteria the graders used the following assumptions for some boards:

- They allowed surface checks on select and standard grade boards if it were considered they could be removed with subsequent processing to 19 mm thickness.
- Some skip as a result of under-sizing due to inaccurate sawing, high shrinkage or collapse was also allowed if this too could be removed with further planning.
- Some back-sawn boards were also downgraded to standard grade despite the absence of grade-limiting defects. This is a conventional practice in some mills where the target product is quarter-sawn.

Immediately after grading, staff from the CRC for Forestry recorded the incidence of defects on the graded surfaces. These defects included knots, surface checking, sapwood, kino pockets, kino veins, insect damage, heart defect, decay, stain and under-sizing (un-recovered collapse/skip). This information was intended to be used to determine which were the most important value limiting defects. However, after consultation with mill management and in view of the assumptions made above, this information was used to adjust the grading so that select and standard grade boards were free of surface checking and skip on the graded surfaces. Also the back-sawn boards that were free of defect and graded as standard grade were re-graded as select grade.

These adjustments meant that; (i) the boards of select and standard grade were of a dimension that would be suitable for furniture, joinery and flooring giving the product the maximum market flexibility; and, (ii) there was a more rigorous test of the processing performance, particularly with regard to surface checking, high shrinkage and sawing accuracy.

The adjustments overall meant that the recoveries of select and standard grade reported here may be lower than would normally be the case where flooring products alone are the final target product.

It should also be noted that two logs of 3.0-3.1 m length could have been cut per tree, if sample disks had not been cut for associated wood quality studies. This would have given a 10 per cent increase in the price of many of the select and standard grade boards (Table 7) and an associated increase in product value per cubic metre of log input.

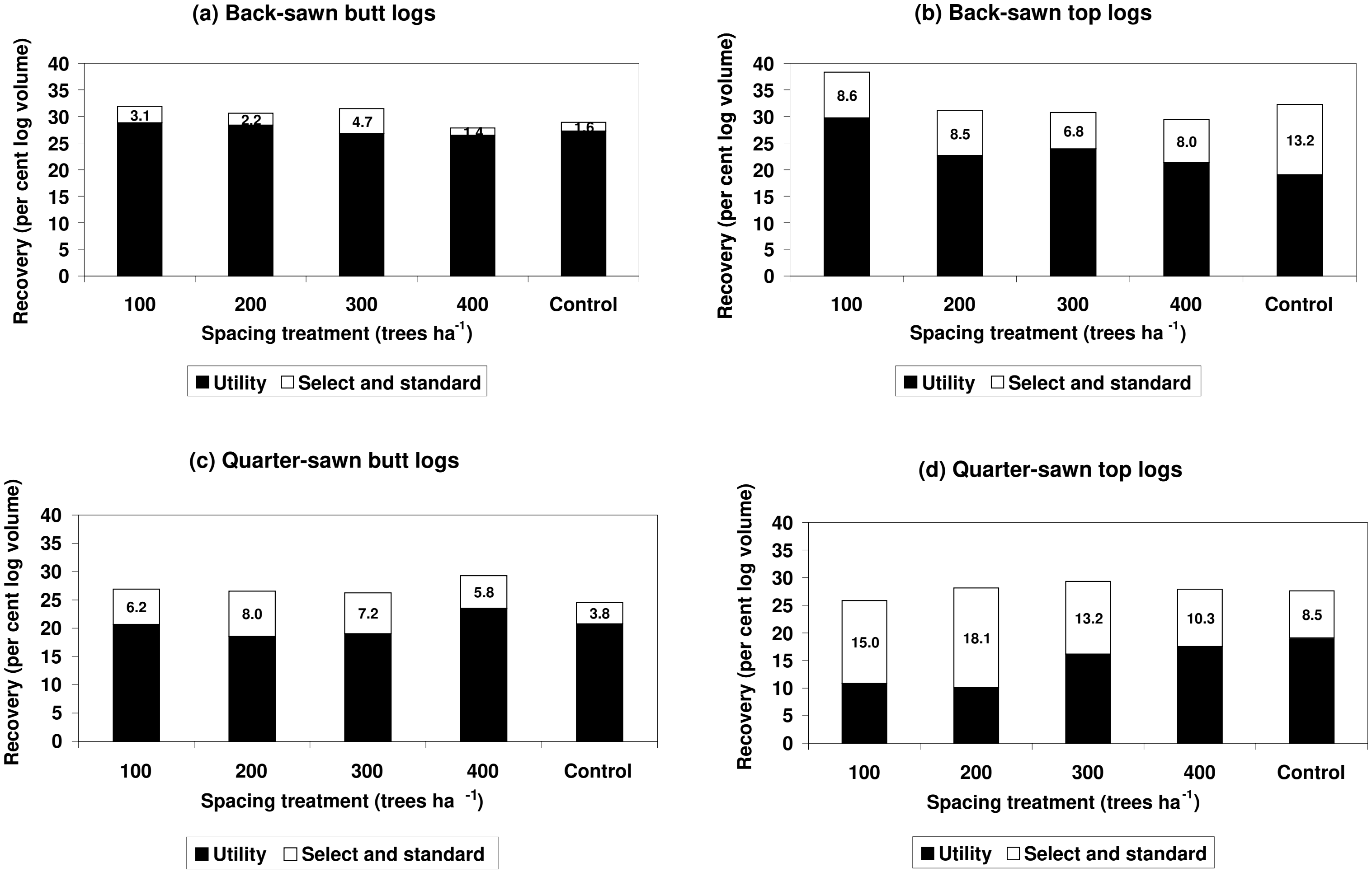

Figure 24. Mean recovery as a percentage of log volume for each treatment (a) back-sawn butt logs, (b) back-sawn top logs, (c) quarter-sawn butt logs and (d) quarter-sawn top logs for each treatment

Figure 25. Select grade back-sawn boards (left), Standard grade back-sawn boards (centre) and Utility grade back-sawn boards (right)

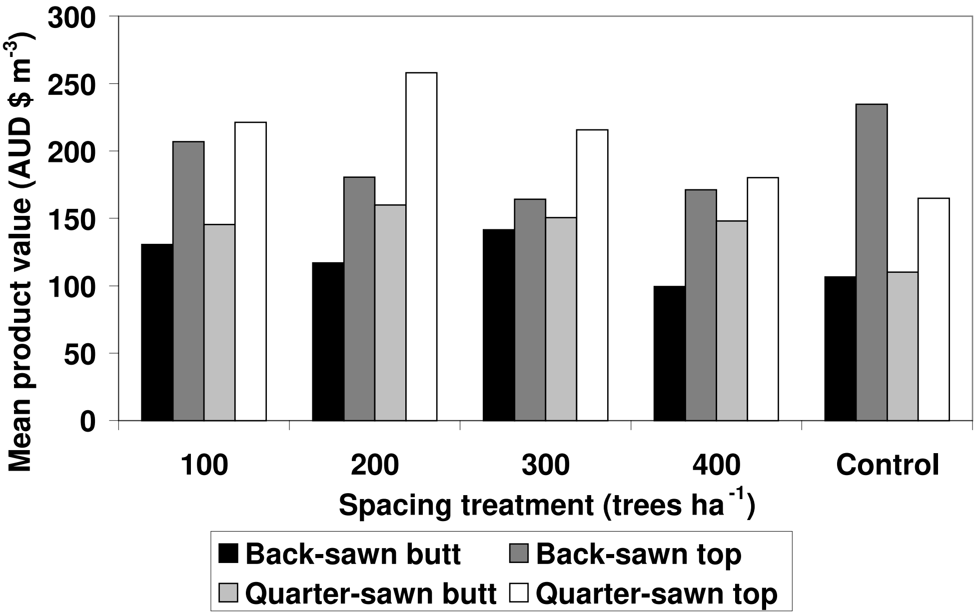

Figure 26. Mean log value (AUD \$ m^{-3} log input) from back-sawn and quarter-sawn butt and top logs for each treatment

Table 16. Mean log value (AUD \$ m^{-3} log input) from back-sawn and quarter-sawn butt and top logs for each treatment

	Back-sawn logs		Quarter-sawn logs	
Thinning treatment	Butt log	Top log	Butt log	Top log
100 SPH	130.6	206.9	145.4	221.2
200 SPH	117.0	180.5	160.0	258.0
300 SPH	141.6	164.2	150.6	215.8
400 SPH	99.4	171.2	148.2	180.3
Unthinned	106.6	234.7	110.2	165.0

Value limiting defects

After adjusting the grading the most important value limiting defects in the boards were surface checking, under-sizing, un-recovered collapse and sapwood. In particular, surface checking was found on a very high percentage of boards. Surface checking, under-sizing and un-recovered collapse are of prime importance for this project, which was concerned with evaluating the processing performance of plantation grown *E. nitens*. Much of the discussion to follow will concentrate on these processing related defects.

Lyctid susceptible sapwood is another issue altogether as it is unlikely to be eliminated during processing unless it is segregated out during sawing, resulting in a large recovery loss. Alternatively, boards should be treated to alter the sapwood's susceptibility. There was very little colour differentiation between sapwood and heartwood in this material, and it was considered unlikely that treated sapwood would lead to consumer resistance based on product appearance.

Other defects recorded included insect damage, termite damage, heart related defects, tight kino, kino pockets and decay. However, these defects were scarce and affected a low percentage of boards. This may have been because they were eliminated during the sawing process.

Knots

Knots were also recorded on a high percentage of boards but often these were small and of little consequence in limiting product value. For example, knots were present in select grade boards. However, they were small and infrequent in line with the requirements of the grading criteria.

From the data collected it was not possible to quantify the impact of knots other than to say they were very common in each of the grades. This was because knot defects were recorded only as being present or absent on the graded surfaces. In past Commonwealth Scientific and Industrial Research Organisation (CSIRO) trials, the size, frequency and condition of the knots have been quantified by grading the knots and other defects (for example see Washusen *et al.* 2000) so their impact on the overall product quality (and value) was known with some precision. In these current trials this was not done for three reasons; (i) the volume of sawn timber was very large; (ii) quantifying defects is not a normal practice of industry graders; and, (iii) there was a shortage of staff experienced in the CSIRO grading practices in the CRC for Forestry. However, an understanding of the condition of knots and the impact of pruning will be conducted by others in Programme Two.

Surface checking, under-sizing, un-recovered collapse and sapwood

The importance of surface checking, under-sizing, un-recovered collapse and sapwood can be quantified by an analysing their frequency in utility grade boards because these defects are not allowed on appearance products in most current Australian hardwood markets. To illustrate their importance the overall percentages of all the boards affected are given in Figure 27 a-d for each stocking treatment x log category where there were more than 20 boards produced.

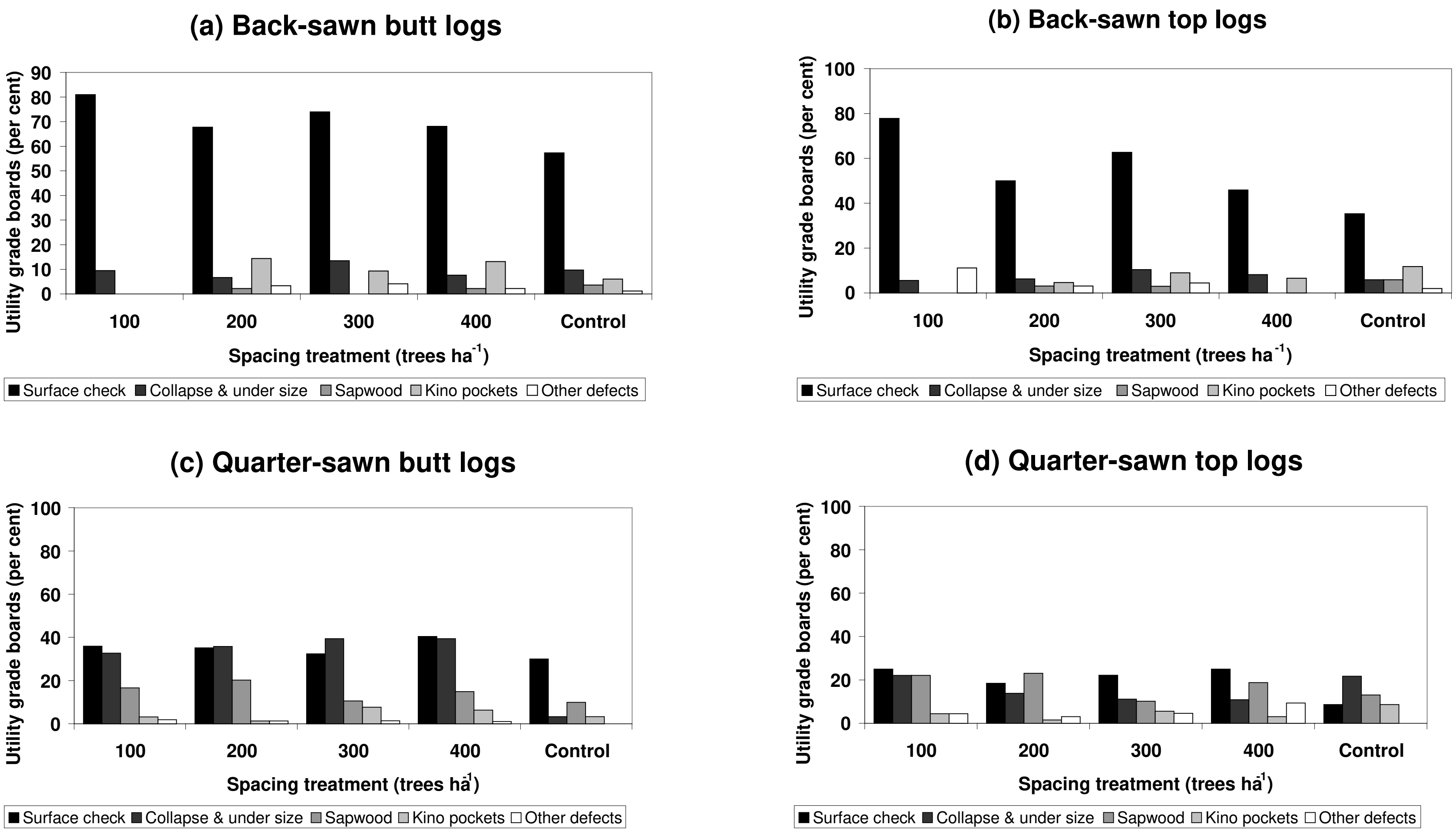

Figure 27 a-d. Percentage occurrence of value-limiting defects in standard grade boards from (a) back-sawn butt logs, (b) back-sawn top logs, (c) quarter-sawn butt logs and (d) quarter-sawn top logs (data not presented for spacing treatments where fewer than 20 boards were available)

These figures illustrate the difference that may be attributed to sawing method in this project. However, the quarter-sawn logs were larger in diameter so there may be some processing differences attributable to size. Also related to diameter is the percentage of sapwood, which is probably lower in the larger logs.

Surface checking was common with both sawing methods. This was unexpected for quarter-sawing because it would not normally be expected that quarter-sawn boards would have a lot of surface checking. However, it should be noted that the quarter-sawing strategy applied has a partial through-and-through pattern that produces some back-sawn and mixed-sawn boards.

The very high incidence of surface checking is a major concern and the processing methods may need to be improved if the defect is to be reduced in occurrence. It was proposed in the project plan that this should be undertaken in subsequent work if surface checking was a major problem for the back-sawn boards (Appendix A). Application of sawing strategies that produce thinner boards and treatment with microwaves prior to drying may be useful strategies to apply. Given that the Gould's Country trial produced a majority of trees that would be best processed with back-sawing strategies in the 300, 400 and control stocking treatments, this should now be a high priority for research within the CRC for Forestry.

Figure 28. Undersized back-sawn and quarter-sawn boards down-graded to utility grade

Under-sizing and un-recovered collapse (Figure 28) were relatively minor problems in comparison with surface checking. This resulted either from; high shrinkage, cupping, poor sawing accuracy or poor collapse recovery that resulted in 'skip' during planning.

Processing performance - summary of statistical analysis

Table 17 summarises the significance of potential explanatory factors in determining individual log and board traits and defects, product recovery, and product value per cubic metre of log input. In summary, it can be seen that sawing method (back-sawing versus quarter-sawing) had a highly significant impact on many processing variables, log position (lower versus upper log) was important for checking, product recovery and product value, spacing treatment had little effect on most variables. Individual variables are considered in more detail in the following sections.

Table 17. Significance of explanatory variables for log and board traits, product recovery and value
N.S - not significant, * - P <0.05, ** - P 0<.01, *** - P<0.001
Transformations applied or distributions modelled for statistical analysis are shown

Dependent variable	Explanatory factors						
	Sawing method	DBHOB	Spacing	Tree	Log position	Sawing method * log position	Transformation/ distribution
Log end-splitting							
Butt-end	***	*	N.S	**	***	N.S	Square root
Top end	**	**	N.S	***	**	N.S	Square root
Board end-splitting							
Per cent of boards displaying splitting	N.S	*	N.S	**	N.S	N.S	Binomial
Loss of green volume from docking splits	*	**	N.S	***	**	N.S	Square root
Bow, spring and cup							
Green bow	***	N.S	N.S	***	***	N.S	Square root
Dry bow	***	N.S	N.S	N.S	N.S	N.S	Square root
Green spring	**	N.S	N.S	N.S	N.S	N.S	Square root
Dry spring	N.S	N.S	N.S	*	N.S	N.S	Square root
Dry cup	***	N.S	N.S	N.S	***	***	Poisson
Dry cup per cm of board width	***	N.S	N.S	N.S	N.S	N.S	Poisson
Board width and thickness variation							
Large end thickness relative to middle	N.S	N.S	N.S	**	***	N.S	None
Small end thickness relative to middle	***	N.S	N.S	**	N.S	N.S	None
Large end width relative to middle	N.S	N.S	N.S	*	N.S	N.S	None
Small end width relative to middle	N.S	N.S	N.S	N.S	N.S	N.S	None
Shrinkage in board width on drying							
Lower end of board	***	N.S	**	***	N.S	***	None
Middle of board	***	*	*	*	N.S	***	None
Upper end of board	***	N.S	N.S	*			None
Shrinkage in board thickness on drying							
Lower end of board	***	N.S	N.S	***	N.S	*	None
Middle of board	N.S	N.S	N.S	***	*	N.S	None
Upper end of board	***	N.S	N.S	***	N.S	N.S	None
Surface checking							
Per cent of boards with surface checking	***	N.S	N.S	N.S	***	N.S	Binomial
Cm of check per m^2 of board area	***	N.S	N.S	*	***	N.S	Poisson
Internal checking							
Per cent of boards with internal checking	N.S	N.S	N.S	N.S	***	N.S	Binomial
Number of internal checks per board	***	*	N.S	N.S	***	N.S	Poisson
Product recovery							
Total recovery	***	N.S	N.S	*	N.S	N.S	None
Recovery of standard + select grades	***	N.S	N.S	N.S	***	N.S	None
Recovery of select grade	***	N.S	N.S	*	***	N.S	None
AUD $ value per m^3 of log input	**	*	N.S	*	***	N.S	None

Thinning treatment (specified as a factor, with four stocking levels and an un-thinned control treatment) did not produce significant differences for most of the response variates (defects, grade recoveries and product value per cubic metre of log input).

The effect of thinning treatment, modelled as a competition index for each individual tree will be evaluated in follow-up studies. As explained above, this may prove to have greater predictive value than thinning treatment modelled as five stocking classes as; (i) sampled trees are not truly representative of the stocking classes as explained earlier; and, (ii) there is substantial variation in stocking within the plots.

Processing performance - individual log and board traits and defects

Detailed log, flitch and board behaviour as a result of harvest, log handling and sawing, and board behaviour as a result of drying were assessed either prior to sawing, during sawing, at completion of sawing and/or at completion of drying. The boards used to assess some of these characteristics were the intensively measured boards obtained from the south-west side of the stem. There were a minimum of two boards per log and they were as close to perfectly back-sawn or quarter-sawn as possible.

Results are summarised as means in two-way tables or graphs (log position by sawing method) for individual variates. The means shown are the arithmetic means from tabulation of the data. Significance of treatment effects (sawing method, DBHOB and log position, and the interaction of sawing method and log position) are summarised in Table 17.

Log end-split severity

Means of the log end-split index are given in Table 18. There was a progressive and significant increase in the splitting index progressing upwards from the butt of the lower log to the top of the second log.

Table 18. Mean log end-splitting index by sawing method and log position

Log end-splitting index - butt-end of logs		
	Lower log	Upper log
Back-sawn logs	0.31	1.49
Quarter-sawn logs	0.37	2.48

Log end-splitting index - top end of logs		
	Lower log	Upper log
Back-sawn logs	1.26	2.67
Quarter-sawn logs	1.80	4.13

Board end-split severity

The percentage of boards displaying end-splitting after drying is shown in Table 19. Over half of all boards displayed some splitting at either or both ends after drying, for both back-sawn and quarter-sawn processing methods. For the upper ends of the boards, back-sawing produced a significantly higher proportion of end-splitting than did quarter-sawing, this difference being more pronounced on boards from the upper log.

Table 19. Percentage of board-ends displaying end-splitting after drying

Butt-end of board	Lower log	Upper log
Back-sawn	33.3	38
Quarter-sawn	32.5	32
Upper end of board	**Lower log**	**Upper log**
Back-sawn	35.2	60.2
Quarter-sawn	30.6	31.4
Either end of board	**Lower log**	**Upper log**
Back-sawn	54.3	68.5
Quarter-sawn	53.1	52.1

The mean percentage loss in green volume that would result from docking end-splits is shown in Table 20. End-splitting is clearly an important defect, requiring docking and loss of significant merchantable volume, ranging from 4.2 per cent of green volume in the quarter-sawn boards from the lower logs to 9.5 per cent for back-sawn boards in the upper logs.

Table 20. Mean percentage loss in green volume resulting from docking end-splits

	Lower log	Upper log
Back-sawn boards	5.0	9.5
Quarter-sawn boards	4.2	4.7

It should be noted that end-splitting of boards may be more common in this trial than in a commercial operation. This was because we asked the sawyers to orient the log relative to the south-west direction. Even though the splits were often oriented differently on each end of the log there was potential to orient logs so that strategically placed cuts could be used to eliminate some splits. Despite this end-splitting was a major source of loss of recovery. Processing longer log lengths may be worth trialling in an attempt to reduce this loss.

Half log and slab deflection during quarter-sawing

Slabs distorted significantly more than half-logs (Table 21). This indicates that distortion increases as the sawing process continues. There was significantly more deflection in the half-logs and slabs from the upper log than for those from the lower log.

Table 21. Half-log and slab distortion during quarter-sawing

	Half-log distortion (mm)		Slab distortion (mm)	
	South-west	North-east	South-west	North-east
Lower log	4.9	5.9	9.3	11.3
Upper log	7.8	7.2	14.1	14.8

Board spring, bow and cupping

Tables 22 and 23 summarise the bow, spring and cupping of the boards.

Table 22. Bow and spring

Mean green bow (mm)	Lower log	Upper log
Back-sawn	6.14	9.13
Quarter-sawn	1.08	1.71

Mean dry bow (mm)	Lower log	Upper log
Back-sawn	8.97	10.95
Quarter-sawn	3.38	3.16

Mean green spring (mm)	Lower log	Upper log
Back-sawn	3.29	4.16
Quarter-sawn	3.82	2.31

Mean dry spring (mm)	Lower log	Upper log
Back-sawn	6.48	5.75
Quarter-sawn	5.91	6.26

Table 23. Cupping, expressed in mm and in mm per cm of board width, and mean board widths

Mean cupping of dry boards (mm)	Lower log	Upper log
Back-sawn	2.27	1.99
Quarter-sawn	1.01	0.23

Mean cup of dry boards (mm per cm of board width)	Lower log	Upper log
Back-sawn	0.154	0.149
Quarter-sawn	0.088	0.023

Mean board width	Lower log	Upper log
Back-sawn	14.6	13.6
Quarter-sawn	11.5	9.8

As expected, bow was greater for back-sawn than for quarter-sawn boards, while sawing method produced little difference in spring. Cupping was significantly greater in back-sawn than in quarter-sawn boards. This was still the case when cupping was expressed in mm of cup per cm of board width, although the difference was less pronounced because back-sawn boards were on average about 30 per cent wider than quarter-sawn boards. There was little difference between lower and upper logs for bow and spring in dried boards, although for quarter-sawn boards cupping was substantially greater in the lower log.

The quarter-sawing pattern was partially "through-and-through" which produces a number of back-sawn boards. These could well be the ones that cupped.

Variation in board width and thickness

Green board width and thickness variation at the large end and small end of the board, relative to the middle of the board, are summarised in Table 24. Overall, mean green board thickness and width were slightly less at the 25 per cent and 75 per cent of length positions than at the mid-point of the board. No significant differences between sawing method and log position could be detected for these variates.

Table 24. Mean thickness and width variation in green boards

Large end thickness relative to middle (mm)	Lower log	Upper log
Back-sawn	-0.36	-0.42
Quarter-sawn	-0.25	-0.42
Small end thickness relative to middle (mm)	**Lower log**	**Upper log**
Back-sawn	-0.37	-0.43
Quarter-sawn	-0.13	-0.25
Large end width relative to middle (mm)	**Lower log**	**Upper log**
Back-sawn	-0.36	-0.35
Quarter-sawn	-0.20	-0.44
Small end width relative to middle (mm)	**Lower log**	**Upper log**
Back-sawn	-0.09	-0.37
Quarter-sawn	-0.43	-0.43

Shrinkage on drying

Patterns of shrinkage in board width and thickness on drying, expressed on a percentage basis, are shown in Figures 29.

Quarter-sawn boards displayed significantly ($P<.001$) lower percentage shrinkage in board width than back-sawn boards for all three measurement positions (lower, middle and upper) on both lower and upper logs. Back-sawn boards from the upper log had significantly ($P<.05$) greater shrinkage in board thickness than back-sawn boards from the lower log.

From this data we can calculate the green sizing requirements and recommend sizing for future trials for a given target dry size.

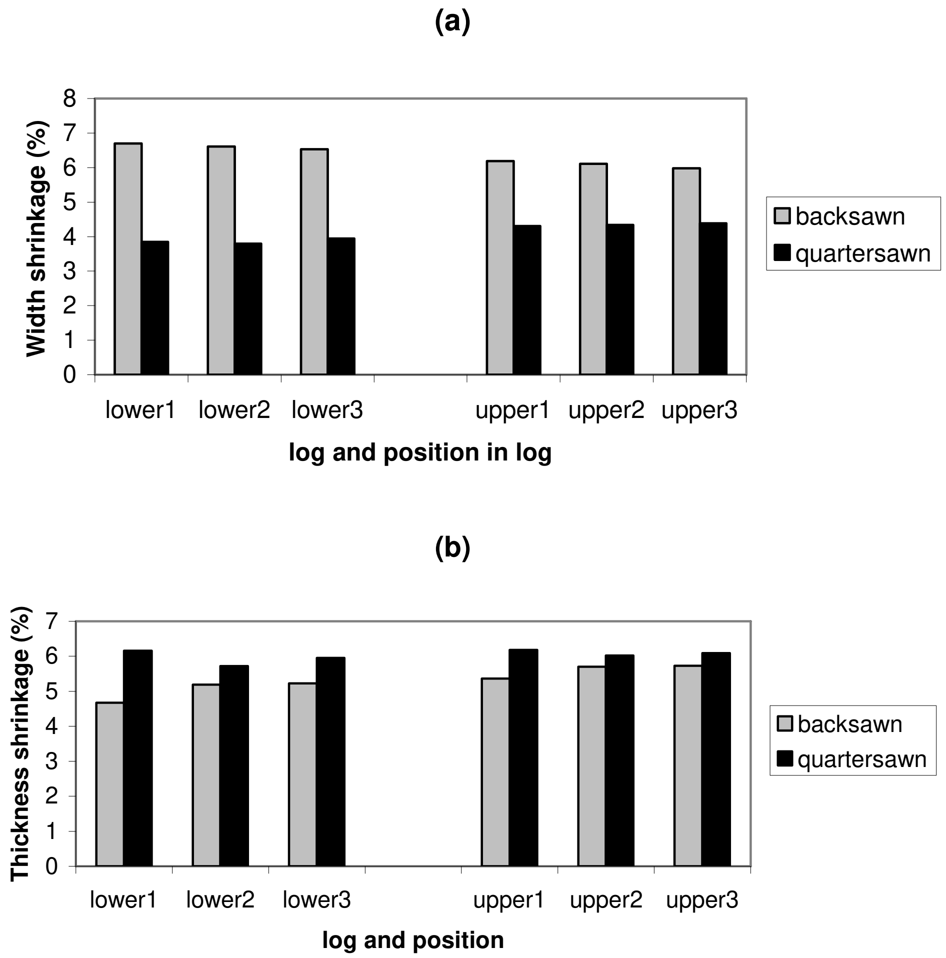

Figure 29. Percent shrinkage in boards on drying; (a) width; (b) thickness

Dry board surface checking

Both surface checking and internal checking of the dried boards (when it is exposed to the board surface through machining) if they occur on any graded surface are very important value limiting defects in current markets. Thus the analysis focussed on presence/absence of these defects. Surface checking was recorded as occurring if total length of checks on the graded face of the board exceeded 20 mm, and internal checking as occurring if any visible checks were present at either of the two cross-sections where the assessments were made.

Table 25 shows the percentages of boards with surface checking for the different swing categories and log positions.

Table 25. Percentage of boards displaying surface checking

	Percentage of boards with surface checking	
	Lower log	**Upper log**
Back-sawn	69.5	45.4
Quarter-sawn	21.9	11.8

Surface checking was far more severe on back-sawn boards than on quarter-sawn boards, and was more severe on the lower logs than the upper logs for both sawing methods.

Table 26. Severity of surface checking expressed as mm of check length per m^2 of board area

	Mean extent of surface checking, mm per m^2	
	Lower log	**Upper log**
Back-sawn	1110	440
Quarter-sawn	120	80

Table 26 shows the mean severity of checking expressed as mm length of checking per m^2 of board area. Clearly, the extent of checking is much greater in the back-sawn boards, and is worse in the lower logs for both sawing methods.

Dry board internal checking

Internal checking was a common defect (Figure 30), and was significantly more prevalent in boards from the lower logs than from the upper logs, but frequency of occurrence did not differ significantly between the two sawing methods (Table 27). However, the mean numbers of internal checks per board was significantly greater for back-sawn boards than quarter-sawn boards, as well as there being significantly more checks in the boards from the lower logs than the upper logs for both sawing categories (Table 28).

Table 27. Percentage of boards displaying internal checking

	Percentage of boards with internal checking	
	Lower log	**Upper log**
Back-sawn	73.3	34.3
Quarter-sawn	73.1	23.1

Table 28. Mean number of checks per board (sum of checks at the two assessment positions)

	Mean number of internal checks per board	
	Lower log	**Upper log**
Back-sawn	7.58	1.99
Quarter-sawing	4.10	0.74

Figure 30. Internal checking in utility grade boards

Recommendations and conclusions

A clear priority for further research is to test methods for reducing the surface checking and the impact of log end-splitting on recovery, to refine processing methods for the *E. nitens* sawlog plantations that will become available during the next decade.

This will require a program of research similar to that outlined in the original research plan, but with some refinements.

1. Assess the impact of back-sawing thin sections on surface checking
2. Assess the impact of a microwave pre-treatment on drying of back-sawn boards
3. Process longer length logs in the HewSaw R200 (small logs) and the mill at St. Helens (larger logs) to assess the impact of longer log length on reduction of log end splitting and the trade-off with board deflection and associated processing problems
4. Trial quarter-sawing with a HewSaw R250. This trial will not require a large sample (perhaps 20 logs) as long as growth stress levels cover a suitable range. Data on the range of growth strain needed for an effective trial is available from earlier trials run by Ensis

The data presented here, together with non-destructive evaluation measurements and the product stiffness and strength data that will be obtained by the University of Tasmania Timber Research Unit, will be used for further analysis that will be reported in subsequent CRC for Forestry Technical Reports.

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