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Processing Pruned and Unpruned *Eucalyptus globulus* Managed for Sawlog Production to Produce High Value Products





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Managed for Sawlog Production to Produce High Value
Products**

Prepared for the

**Forest & Wood Products
Research & Development Corporation**

by

**R. Washusen, K. Reeves, R. Hingston, S. Davis,
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EXECUTIVE SUMMARY

Objective

Processing trials were conducted in conventional mills using logs from plantation-grown *Eucalyptus globulus* to produce appearance-quality solid timber. The trees harvested were selected to represent final harvests from three different management regimes; (i & ii) 21-22 year-old pruned trees thinned at age 3-5 years to 150 trees ha⁻¹ and 225 trees ha⁻¹; (iii) 32 year-old unpruned trees thinned at age 18 years to 200 trees ha⁻¹. These trials were part of a series conducted for the Victorian Department of Primary Industries (DPI) in plantation-grown and regrowth eucalypts using common product evaluation methods.

The objectives were to:

- Determine log quality and yields based on Victorian log grades from the three stands.
- Calculate the recovery of dried timber and mill door log values using back-sawing and quarter-sawing strategies.
- Compare product quality and log values of pruned and unpruned logs.
- Identify factors limiting recovery and processing efficiency.

Key Results

The major results of the trials were:

- The pruned stands:
 - Based on harvested volumes in the 150 and 225 tree ha⁻¹ stands respectively; 56% and 66% of total volume were sawlogs; 68% and 100% of sawlog was C-grade or better; MAI's were 9.6 and 11.1 m³ ha⁻¹ yr⁻¹ for sawlogs and 7.7 and 5.9 m³ ha⁻¹ yr⁻¹ for pulp logs.
 - Generally, back-sawing strategies produced wider and quarter-sawing produced thicker boards. All wood dried with little degrade. There was no significant difference in recovery between sawing methods and product values based on Victorian Ash wholesale prices were similar.
 - For a given log grade, recovery and timber value was greater for pruned logs than unpruned plantation-grown logs in a number of the trials conducted for DPI, and higher than mills in Victoria expect from the same grade regrowth logs. This was possibly because of better wood quality and short log length of pruned logs and the sawing strategy applied by the less conventional McKee twin saw used in the trials.
 - Using a nominal processing cost of \$650 m³, we estimated the mill door log values for pruned logs to be \$145, \$98 and \$78 for B, C and D-grade logs respectively.
- The unpruned stand:
 - Sawlog quality was comparable to earlier trials conducted for DPI in unpruned plantation-grown *E. nitens*. Most logs were C-grade and only 10% of the stand volume was C-grade or better.
 - Recoveries using quarter-sawing were higher than the unpruned plantation-grown *E. nitens*, possibly because earlier thinning produced more defect free wood over naturally shed branches. However, recoveries were almost 10% lower than pruned logs of the same log grade.
 - Using a nominal processing cost of \$650 m³ we estimated the mill door log values to be \$80, \$71 and \$53 for B, C and D-grade logs respectively.
- Growth stresses and tension wood:
 - In all trials log end splitting was minor, although some spring was evident in quarter-sawn boards.
 - In back-sawn and quarter-sawn boards minor drying degrade was evident in the unpruned stand and the 225 tree ha⁻¹ pruned stand. The degrade was associated with tension wood. However, tension wood volumes were relatively small and boards could be processed with commercially acceptable drying schedules. This agrees with earlier screening trials that suggested tension wood is scarce or volumes reduced to acceptable levels in dominant/co-dominant trees in thinned stands.
 - In all samples tested drying defects were associated with regions where cellulose crystallite width measured on SilviScan-2 exceeded 3.4 nm.

Application of Results

These trials demonstrated that managed stands of plantation-grown *E. globulus* will produce logs of a quality acceptable to the existing processing industry in southern Australia. The stand management strategies employed in the three stands limited branch defects and defects attributed to tension wood (growth stress related defects and drying defects) to acceptable levels in logs that were of conventional sawlog quality. However, tension wood was still common in the later thinned stand indicating that the timing of thinning may be critical in reducing tension wood occurrence.

The estimated mill door log values for the higher quality logs suggest some optimism for profitable growing. This was most pronounced where early non-commercial thinning was combined with pruning. Based on the results from these and the other trials conducted for DPI, pruning is recommended to improve sawlog yields, wood quality and product value. An economic analysis is warranted taking into account the differences in mill door log values, sawlog yields and potential improvement in processing efficiency to support this recommendation.

The high recovery recorded for the pruned logs raises the issue of sawing system efficiency. Conventional systems apply asymmetrical cutting patterns where normal growth stress release may produce sufficient distortion to significantly affect recovery. They combine single-saw break-down and resawing stages that are well suited to highly variable long-length native forest logs with large taper and where grade sawing is an advantage, but they are less suited to uniform plantation-grown logs. This is particularly so where the length of logs is restricted by the pruned stem height, as was the case in these trials. Resawing systems, such as those used for the unpruned logs, which resaw oversized flitches to an acceptable quality are often wasteful and cumbersome to use and limit log throughput and timber recovery. In plantations, if markets can be developed for relatively short-length high quality products, twin saw systems and other multi-saw systems, which apply symmetrical cutting patterns and profile logs with chippers prior to sawing, may reduce distortion and produce higher recoveries. Given the demonstrated capacity for multi-saw systems to process pruned *E. globulus* in these trials there is potential to produce higher volume throughput, and given appropriate economies of scale, reduce sawing costs. The greatest advantage may be obtained with the application of linear type systems where logs flow in one direction as apposed to the reciprocating carriage system used in these trials.

Multi-saw systems are best suited to back-sawing, highlighting the importance of the good drying results in back-sawn wood from the pruned stands. However, high unit shrinkage across the wide face of back-sawn boards is common for plantation-grown *E. globulus*, which may reduce marketing flexibility. Reducing unit shrinkage would be a priority if this were the case. Alternatively, experimentation during these trials suggested that multi-saw systems can be adapted to produce quarter-sawn boards where unit shrinkage is lower across the wide face of boards.

Processing pruned and un-pruned *Eucalyptus globulus* managed for sawlog production to produce high value products.

R. Washusen, K. Reeves, R. Hingston, S. Davis, D. Menz and A. Morrow

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INTRODUCTION

Eucalyptus globulus Labill. is the major plantation-grown hardwood species in southern Australia. Most of the plantations have been targeted for pulpwood markets, however, there is interest in growing the species for solid wood products, particularly with the reduced availability of sawlogs from native forests. Numerous trials conducted across southern Australia have indicated some of the existing resource, and future *E. globulus* plantations, have potential to be used for solid wood processing. However, because of the age of the resource there has been limited tree availability for trials to assess this option. Most trials have been conducted in immature stands with either small numbers of selected trees that do not adequately represent the potential resource, or in plantations that have not been managed to produce high-quality sawlogs.

These numerous trials have indicated that branches and growth stress related defects and drying defects associated with tension wood are two main problem areas for wood quality and processing efficiencies:

- Branches are the major source of defect in timber in immature un-pruned plantations. The defects include large and numerous green and dead knots, decay and kino. There are two management options that may reduce these problems. Firstly, prune selected trees and thin either commercially for pulpwood or non-commercially to promote diameter growth of the pruned stems. Secondly, allow branches to naturally shed and commercially thin to promote diameter growth in residual trees. The potential for this latter option has been demonstrated in *E. nitens* in earlier trials in this series. This species has similar branching defect characteristics to *E. globulus*.
- Tension wood has also been shown to be a major problem during processing in some trials producing growth stress related and drying defects. However, recent research has suggested that early thinning will reduce tension wood occurrence (Washusen 2002) and in later thinned stands dominant trees may have sufficient volumes of normal wood to counteract tension wood where it occurs (Washusen *et al.* 2002).

Clearly there are two management steps that have potential to improve wood quality. These are; (i) thinning to promote growth and reduce tension wood severity, and (ii) through pruning or natural branch shedding coupled with tree selection to reduce defects associated with branches. It would assist plantation establishment and the development of management options to assess potential wood quality and financial returns from final clearfall harvests of stands managed by thinning alone as well as thinning and pruning. This report describes processing trials conducted in existing mills in Victoria and Western Australia in three different plantations and/or management regimes that were considered to be full rotation based on log diameters. These were; (i) a 21-22 year-old pruned stand located in south-west Western Australia thinned to 150 trees ha⁻¹ at age 3-5 years; (ii) from the same plantation a 21-22 year-old pruned stand thinned to 225 trees ha⁻¹ at age 3-5; and (iii) a 32 year-old unpruned stand located in Gippsland, Victoria that had been thinned to 200 trees ha⁻¹ at age 18 years.

This work was part of a series of trials in plantation-grown and regrowth eucalypts conducted with common assessment strategies for the Victorian Department of Primary Industries (DPI). These reports including the original reports on these current trials are available through DPI.

MATERIALS AND METHODS

The plantations and tree selection

The pruned stand

The plantation comprised a single seedlot of *E. globulus* ssp *globulus* of unknown provenance. It was located near Busselton in southwest Western Australia. The plantation was established as a farm forestry spacing trial in 1981 making it 21-22 years old at harvest. The spacing trial was a 7-row belt design initially planted at 1,666 trees ha⁻¹ within the belt. At age 3-5 the plantation was thinned to produce stands spaced to 100, 150 and 225 trees ha⁻¹. All of the residual trees were progressively pruned to

approximately 10.0 m to produce a defect core of about 15 cm diameter. For the processing trials the 150 and 225 trees ha⁻¹ stands were available for harvest. At age 17 years a total of 5 trees were harvested from these two stands for a small processing trial, which reduced the stocking rate slightly. These stands were specially selected for the trials because they contained rare examples of a large diameter pruned trees in Australia. The stands were considered to be full rotation based on diameter requirements for economic production of sawlogs from projections produced from trials in 10-year-old pruned *E. nitens* (Reid and Washusen 2001).



Figure 1. Pruned trees in the 225 tree ha⁻¹ stand.

Harvesting was conducted in March 2003. Twenty trees were randomly selected to simulate a clearfall harvest with 9 and 11 trees selected from the 150 tree ha⁻¹ and 225 tree ha⁻¹ stands respectively. The pruned portion of the stems ranged in length from 5.8 m to 10.0 m and they were transported to the Auswest Timbers Pemberton mill.

The unpruned stand

The plantation selected for the assessment was owned by Grand Ridge Plantations Pty Ltd. The plantation was located south of Traralgon in Central Gippsland. The trees were a seedlot of Jeeralang provenance origin. They were planted in 1971 making them 32-years-old at harvest. The plantation had been thinned to approximately 200 trees ha⁻¹ in 1989 from approximately 1,000 trees ha⁻¹. The plantation was scheduled for harvest for a high density pulping trial and this presented the opportunity to evaluate sawlog quality from a full rotation stand that had been thinned at a relatively late age.

The plantation was part of a larger plantation estate located in the Silver Creek area south of Traralgon comprising the same genetic material and stand management. Prior to tree selection for the processing trials CSIRO and the Victorian Forest Science Center (FSC) conducted an assessment of tension wood occurrence (Washusen *et al.* 2002) and stand productivity (Bandara *et al.* 2002) in a nearby stand. The tension wood occurrence information was used to develop selection methods that eliminated trees with severe tension wood from this processing trial. Sawlogs were estimated to make up 20% of the stand volume and MAI to age 30 years was approximately 10 m³ ha⁻¹ yr⁻¹ (Bandara *et al.* 2002).

Harvesting was conducted in April 2003. The selection methods were similar to procedures adopted for other similar DPI supported trials in unpruned *E. nitens* and *E. cladocalyx*. This more or less simulated a selective logging operation where larger diameter trees were selected for sawlogs and smaller trees for pulpwood. However, to minimize the risks of the selected mill processing logs with large amounts of tension wood, some screening of trees was undertaken to reduce tension wood occurrence. Initially 52 larger diameter trees representing approximately 40% of the trees in the stand were selected. This eliminated smaller diameter trees (<38 cm DBHOB) likely to have proportions of tension wood that would cause problems during processing. From the 52 larger diameter trees a single core-sample the length of the radius was extracted from the south-west side of the stem 1.1 m above ground level to assess

tension wood occurrence. Based on this assessment a further ten trees were eliminated from selection due to possible high volumes of tension wood. From the remaining 42 trees 30 were selected at random for harvest. Bush log length varied between 6.0 m and 11.4 m because of the height of the crown. Minimum small end diameter was approximately 25 cm under bark. The bushlogs were debarked and transported to the Black Forest Timbers sawmill near Woodend in Victoria and placed under water sprays. A sub-sample of these logs formed the basis of an associated project “The Impact of Log End Splitting of 32 year-old Plantation Blue Gum” which was supported by the FWPRDC.

Log preparation and grading

Sawing of the pruned logs was conducted in May 2003 at Auswest Timbers Pemberton and the unpruned logs in July 2003 at Black Forest Timbers. The pruned bushlogs were cross-cut to produce 2.8 m lengths (Figure 2) and the unpruned logs cross-cut to produce predominantly 3.0 m sawlog lengths. The lengths selected were half the length of the shortest bush log and represent typical sawlog lengths from pruned stands. Maintaining this consistent length allowed comparison between all trials in the series conducted for DPI that used predominately 3.0 m lengths.

Each log was given the tree number and a letter (A, B, C or D sequentially up the stem). The log number and a number of log characteristics were recorded on CSIRO-FFP log diagram sheets and the position referenced to the north side of the stem. On the log ends the characteristics included: small and large end diameter and sapwood width, and the size and location of tight and loose kino, knots, decay, insect damage and termite damage. On each quarter of the log surface the characteristics included location and size of bumps, swellings, green and dead branch stubs, holes, epicormic shoots, grain angle, bole damage and sweep. From these diagrams Victorian log grades were assigned to each log. Prior to sawing the log ends were painted in a sequence of colours to enable material to be tracked through the mill.



Figure 2. Pruned *E. globulus* logs prepared for sawing.

Sawing and drying methods

The pruned logs

Two sawing strategies were applied at Auswest Timbers. The first was a conventional back-sawing strategy on a McKee twin band saw equipped with chipper heads and overhead end-dogging carriage and downstream processing on a multi-saw. This system incorporated a computer optimizer to enable the sawyer on the break-down saw to select a sawing strategy that produced the highest recovery while maximizing product dimensions and value. The saw kerf was 4.5 mm for both the twin saw and multi-saw. The second sawing strategy was an experimental quarter-sawing strategy on the McKee twin saw and a 2.5 mm kerf single band resaw equipped with a line bar. The back-sawing strategy was applied to the bulk of the logs and the quarter-sawing strategy to a subset of 15 A and B-grade logs to compare drying performance and recoveries from back-sawing on a matched sample of logs. The approximate log breakdown sawing pattern for back sawing is shown in Figure 3a and break-down and resawing for quarter-sawing in Figure 3b-c.

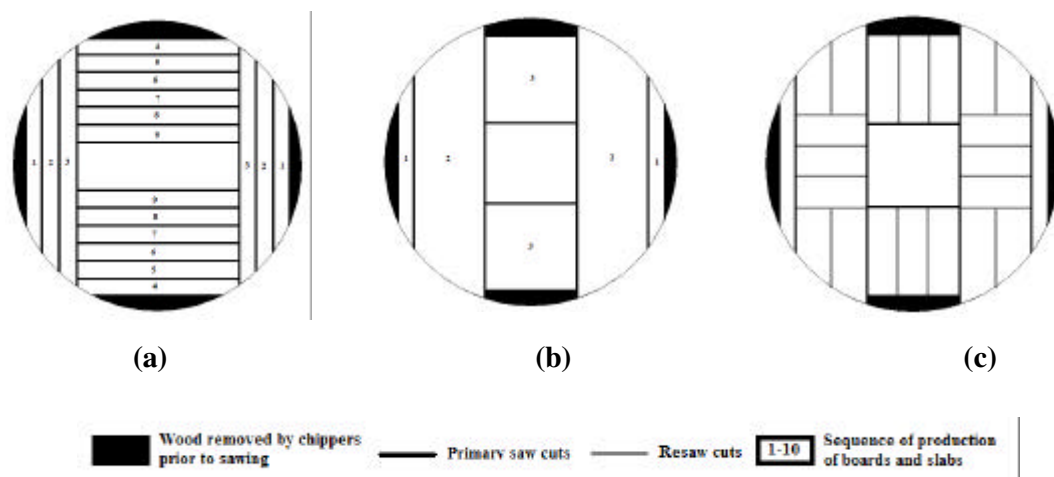


Figure 3. Back-sawing and quarter-sawing strategies used at the Auswest Timbers Pemberton mill (viewed from the small end); (a) back-sawing log break-down on the McKee twin saw; (b) quarter-sawing log break down on the twin saw; and, (c) quarter-sawing resawing strategy.



Figure 4. Sawing pruned *E. globulus*. Clockwise from top left; back-sawn log on the twin saw carriage; back-sawn slabs; quarter-sawn flitches for resawing on the single band saw; 106 x 43 mm quarter-sawn boards.

This sawing system is an unconventional system for southern Australia. Most sawmills operate with single line-bar carriage systems or conventional twin saws with single and multi-saw resaws. The McKee twin saw applies a symmetrical cutting pattern and much of the product can be dimensioned on the break-down saw. Where slabs were produced on the twin break-down they were resawn on the multi-saw to produce one or more boards. After preliminary trials it was decided to maximize board width so that a single board was produced from most slabs, this reduced problems of spring. It was considered that if cupping occurred in very wide boards they could be ripped after drying.

Green target sizes for back-sawing were 225 x 28 mm, 168 x 28 mm, 140 x 28 mm, 106 x 28 mm, 78 x 28 mm and 57 x 28 mm. The aim was to maximize the recovery of boards >125 mm wide. Green target

sizes for quarter-sawing were 168 x 43 mm, 140 x 43 mm, 106 x 43 mm, 168 x 28 mm, 140 x 28 mm, 106 x 28 mm, 78 x 28 mm and 57 x 28 mm. With quarter-sawing the aim was to maximize the recovery of 43 mm thick boards and boards wider than 106 mm. Each board was numbered to identify the log it came from. Green board volumes were not tallied.

Once sawing was completed the boards were block stacked, wrapped in plastic and transported to the Forest Products Commission, Timber Technology Centre at Harvey. At Harvey the boards were dipped in Boron diffusion treatment (Diffusol Wood Preservative Concentrate) to obtain the recommended proportion of approximately 10% m/v to treat *Lyctid* susceptible sapwood. The wood was wrapped in plastic and left for 4 weeks.

The timber was racked out for drying and dried in a solar heat/vent kiln assisted with electric heaters and dried to approximately 18% moisture content using a standard drying schedule for 38 mm thick Marri (*E. callophylla*). At 18% moisture content the timber was transferred to a separate steaming chamber and steamed for 7 hours, returned to the kiln and dried to final moisture content of 12%. The schedule is shown in Table 1. The total time for drying was 65 days.

Table 1. Drying schedule used at Timber Technology to dry back-sawn and quarter-sawn pruned *E. globulus* timber

Dry bulb (°C)	Wet bulb depression (°C)	Relative humidity (%)	Equilibrium Moisture Content (%)	Air Velocity (m/sec)	Moisture Content (%)
30	1.5	89	19.6	0.5	Green
30	2.5	86	18.0	0.5	60
40	3.0	82	16.0	0.5	45
45	4.0	78	14.2	0.5	35
50	5.0	75	12.8	0.5	30
50	8.0	62	9.9	0.5	25
55	10.0	57	8.6	0.5	20
60	15.0	43	6.4	0.5	15
60	5.0	77	12.7	0.5	12

The unpruned logs

A conventional quarter-sawing strategy was applied at the Black Forest Sawmill (Figures 5 and 6). Log break down was conducted on a conventional twin circular saw with overhead end-dogging carriage. Saw kerf was 6 mm. The flitches were resawn on a two-man bench and multi-saw with 5 mm kerf saws. The 2-man bench produced mostly slabs that were resawn to produce dimensioned boards on the multi-saw resaw. Green target sizes were 163 x 28 mm, 140 x 28 mm, 105 x 28 mm. Other sizes produced were 77 x 28 mm, 57 x 28 mm, 105 x 22 mm and 77 x 19 mm. Each board was numbered to identify the log it came from. Green board volumes were not tallied.

Following sawing the boards were block-stacked, dipped in Boron diffusion treatment (Diffusol Wood Preservative Concentrate) to obtain the recommended proportion of approximately 10% m/v to treat *Lyctid* susceptible sapwood. The wood was wrapped in plastic and left for 4 weeks. The wood was dried using the schedule shown in Table 2a and 2b. This is a standard schedule used for drying 28 mm thick back-sawn regrowth *E. obliqua*. The timber was initially racked out for drying in a Mahild predryer in early September 2003 for 60 days. At approximately 17% moisture content the timber was placed in a Windsor kiln, reconditioned in steam and dried to final moisture content of approximately 12%. The total time for drying was 63 days.

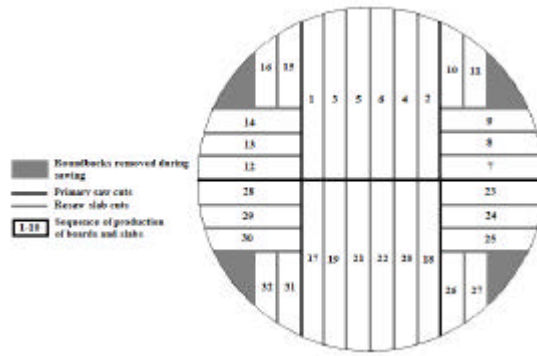


Figure 5. Quarter-sawing strategy used at Black Forest Timbers (viewed from the small end) showing the approximate location of primary saw cuts on the twin saw and resaw cuts that produced slabs on the two-man bench.



Figure 6. Sawing the unpruned *E. globulus* at Black Forest Timbers. Clockwise from top left; end dogging on the twin edger; quarter-sawn flitches for resawing; treating *Lyctid* susceptible sapwood.

Table 2a. Pre-drying schedule used in the Mahild pre-dryer at Black Forest Timbers to dry unpruned quarter-sawn *E. globulus*.

Time	Dry bulb (°)	Wet bulb (°)	Moisture Content (%)
1 day	25.0	24.0	60.8
14 days	30.0	28.0	49.9
16 days	35.0	32.0	37.7
5 days	40.0	36.0	33.4
5 days	45.0	40.0	26.7
9 days	50.0	42.0	21.9
10 days	55.0	45.0	17.0

Table 2b. Kiln-drying schedule used in the Windsor kiln at Black Forest Timbers to dry quarter-sawn unpruned *E. globulus*.

Time	Dry bulb (°)	Dry bulb ramp (°/hour)	Wet bulb (°)	Wet bulb ramp (°/hour)	Fan speed (%)
Reconditioned 4 hours + 2 hours heat up	98.0				
45 hours	95.0	1.00	70.0	6.00	100.0
24 hours	95.0		90.0		100.0
2 hours	95.0		92.0		100.0

Timber grading and product recovery assessment

CSIRO-FFP Appearance grading

The grading and docking methods were identical to other trials in this series in plantation and regrowth *E. nitens* (Washusen and McCormick 2002) and *E. cladocalyx* (Washusen *et al.* 2003) enabling the results from these trials to be compared.

Following drying each board was graded using the modified CSIRO-FFP Appearance Grading Criteria. The criteria are presented in Appendix A. The minimum length of boards was 0.9 m for Standard grade and higher. Defects were visually docked to produce boards of Standard grade or higher with length increments of 0.1 m. Lower grade products had minimum lengths of 2.4 m with increments of 0.3 m. The minimum quality of the backs of boards was Cover grade. To achieve this quality dead knots were docked if they failed to meet the criteria for Cover grade. Some spring exceeded the maximum allowable in the CSIRO Criteria and where this occurred the boards were docked to a minimum of 1.2 m and put through ‘four-sider’ planers to see if spring could be taken out before grading. In general there was sufficient oversizing to remove most spring in both trials.

The grading criteria were applied to produce recoveries very similar to the way many mills apply the current Australian Standard (AS 2796.1). The advantage of using the CSIRO criteria is that defect allowances for each grade are precisely defined, whereas the Australian Standard (AS 2796.1) only gives the minimum requirements to meet the criteria (and which may not meet market requirements).

Recovery calculations

Log volumes were determined from the mean log diameter calculated from two measurements taken at each end of the log. These measurements were recorded on the log diagram sheets. Dried board sizes used to calculate recovery were 150 x 25 mm, 125 x 25 mm, 100 x 25 mm, 75 x 25 mm, 50 x 25 mm, 100 x 19 mm and 75 x 16 mm. The recoveries calculated for each log and logs grouped on log grade were:

- Grade recovery: recovery of all in-grade products as a % of log volume
- Recovery of select grade and better as a % of log volume

The percentage of the volume of boards of select grade and better less than 1.8 m in length were calculated, and percentage of the volume of boards of select grade and better greater than 1.8 m in length and 125 mm wide were also calculated for each log grade. Recoveries of pallet grade timber, wood chips and sawdust were not determined.

Statistical analysis

For the pruned logs a factorial analysis of variance was calculated using STATISTICA software to determine if for a given log grade there were significant differences in recovery due to sawing methods, log height in the stem, and spacing.

Product value

Wholesale values (at May 2002) for Victorian ash were applied to determine the value of the dried wood and allow comparison with earlier trials in this series. A discount of 25% was applied to the volume of boards of select and standard grades that were shorter than 1.8 m where the volume of short boards exceeded 10% of the recovered volume. Comparisons were made with the previous work in plantation

grown *E. nitens* (Washusen and McCormick 2002) and plantation-grown *E. cladocalyx* (Washusen *et al.* 2003).

Wood microstructure evaluation

Wood samples were taken from boards where drying defects were evident and at random from boards where wood quality was acceptable, and prepared for SilviScan-2 evaluation. Wood microstructure was assessed at 5 mm steps. Comparisons of wood microstructure were made between both drying performance of back and quarter-sawn boards, and plantations. The evaluation assessed the relationship between drying degrade and cellulose crystallite width, which is an indicator of tension wood (Washusen and Evans 2001a, b, 2002).

RESULTS AND DISCUSSION

Log yields and quality from the pruned stands

The sawlog and pulplog volumes for the two stands in the pruned plantation are given in Table 3. The volumes were calculated from actual volumes measured from the harvested logs once they had been cross-cut to sawlog length, and then volumes extrapolated to a per hectare basis. The figures for pulpwood include the heavily branched top logs down to a small end diameter of 20 cm and some logs from the pruned stem that had been badly affected by termites and which were clearly below sawlog quality. The figures are based on the original stocking rate after the initial thinning and do not take into account the small harvest at age 17 that reduced the stocking rates slightly in both treatments.

There was a total harvested volume of 373 m³ ha⁻¹ and 356 m³ ha⁻¹ for the 150 tree ha⁻¹ and 225 tree ha⁻¹ stands respectively. In general log quality was better in the 225 tree ha⁻¹ stand which was reflected in the large volume of A and B-grade logs. This was because termite damage had affected a number of logs in the 150 tree ha⁻¹ stand (Figure 7). Table 4 gives the Mean Annual Increment (MAI) of sawlogs and pulp logs using the harvested volumes from the two stands based on a 21-year rotation. Overall MAI's were 17.3 m³ ha⁻¹ yr⁻¹ and 16.9 m³ ha⁻¹ yr⁻¹ for the 150 tree ha⁻¹ and 225 tree ha⁻¹ stands respectively and sawlog MAI's were 9.6 m³ ha⁻¹ yr⁻¹ and 11.1 m³ ha⁻¹ yr⁻¹ for the 150 tree ha⁻¹ and 225 tree ha⁻¹ stands respectively.



Figure 7. Severe termite damage in pruned logs from 150 tree ha⁻¹ stand

Table 3. Harvested sawlog and pulp volumes extrapolated to a per hectare basis for the two stands and as a single stand. Logs graded to Victorian specifications.

Trees ha ⁻¹	A grade (m ³ ha ⁻¹)	B grade (m ³ ha ⁻¹)	C grade (m ³ ha ⁻¹)	D grade (m ³ ha ⁻¹)	Below grade (m ³ ha ⁻¹)	Pulp logs (m ³ ha ⁻¹)	TOTAL (m ³ ha ⁻¹)
150	48.5	81.9	4.3	42.1	25.4	161.2	373.1
225	39.1	174.8	18.8	0.0	0.0	123.3	355.9
Combined	45.3	126.5	11.1	23.7	14.3	147.6	368.5

Table 4. Mean annual increment (based on 21 year rotation and harvested volumes) and percentage sawlogs and pulp logs for the two stands and as a single stand.

Trees ha ⁻¹	Sawlog (m ³ ha ⁻¹)	Pulp logs (m ³ ha ⁻¹)	Total (m ³ ha ⁻¹)	Sawlog (%)	Pulp logs (%)
150	9.6	7.7	17.3	55.5	44.5
225	11.1	5.9	16.9	65.7	34.3
Combined	10.5	7.0	17.5	60.0	40.0

Recovery and product value from the pruned stand

Overall recovery and product length

Overall mean dried product recovery for the 2 stands and as a single stand are given in Table 5. Good recoveries were recorded for both stands and grade recovery approached 40% of log volume in the 225 tree ha⁻¹ stand. Of note in Table 5 is the relatively high percentage of lengths shorter than 1.8 m. This high percentage in both stands can be attributed to the relatively short log length, the docking strategy that eliminated dead knots from products in accordance with the grading criteria, and the attempt to maximize recovery from the defect core. However, there was a high percentage of boards of select grade longer than 1.8 m and 150 mm wide or wider. These products would attract high prices in existing markets.

Table 5. Mean dried sawn recoveries for the two stands and as a single stand.

Trees ha ⁻¹	Grade recovery (% log vol)	Select recovery (% log vol)	Percentage select <1.8 m in length (%)	Percentage select >1.8m length and >0.125m width (%)
150	35.7	33.7	30.8	25.4
225	39.8	36.6	24.7	31.9
Combined	38.1	35.3	27.3	29.1

The influence of log height on recovery is given in Table 6. In general these trends are similar to the whole log groups and show little difference between log height. An analysis of variance found that for a given log grade there was no significant difference between log height or stand. However, there was a higher percentage of short lengths (49.3%) in the top logs (approximately 7-10 m height) in the 150 tree ha⁻¹ stand than in any other group of logs. This is just over double the percentage recorded for the top logs from the 225 tree ha⁻¹ stand, and indicates more frequent or larger branches in the 150 tree ha⁻¹ stand prior to pruning at this height and that the defect core was greater than 15 cm diameter at this height in these trees. It would appear that if trees are to be pruned to this height it may be better to do so earlier at these lower stocking rates, as long as sufficient crown can be retained to maintain volume growth.

Table 6. Mean dried sawn wood recoveries for the two thinning treatments.

Trees ha ⁻¹	Log location in stem	Grade recovery (% log vol)	Select recovery (% log vol)	Percentage select <1.8 m in length	Percentage select >1.8m length and >0.125m width
150	Bottom	32.9	32.4	27.9	20.4
150	Middle	38.0	35.4	25.4	29.7
150	Top	34.6	31.6	49.3	23.5
225	Bottom	38.4	37.3	20.5	26.9
225	Middle	41.8	37.2	29.1	33.3
225	Top	38.9	32.9	24.2	38.7

The influence of diameter on recovery

The correlation between recovery as a percentage of log volume and mean log diameter for logs of C-grade or better was $r = +0.15$ (not significant at $p < 0.05$) (Figure 8). This is a poor correlation in comparison to the significant positive correlation ($r = +0.61$) recorded by Reid and Washusen (2001) in smaller diameter 10-year-old pruned *E. nitens*¹.

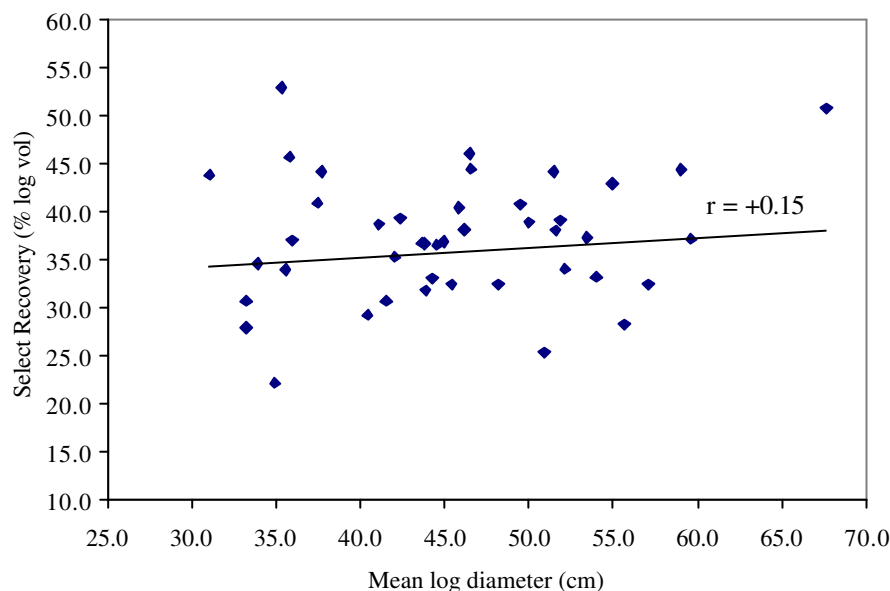


Figure 8. Recovery of select grade (% log vol) against mean log diameter for 21-22 year old pruned *E. globulus*.

The lack of significance in the correlation for the *E. globulus* logs suggests that these two stands had produced logs of a diameter where it would be difficult to achieve higher recoveries. The correlation also suggests that the milling system was at its maximum output in this trial for a given volume intake. Therefore, milling costs were lowest where log volume throughput was at its highest. This most likely occurred where mean log diameter was at about 45-50 cm and not where log diameter was larger. This was because several of the largest diameter logs, particularly from the 150 tree ha⁻¹ stand, had excessive taper and uneven buttressing and it was difficult to commence processing these larger logs on this milling system and volume throughput was slowed. However, logs with mean diameter of greater than 50 cm were primarily A-grade logs. These had a recovery advantage over the smaller diameter logs, while

¹ The data from the 10-year-old *E. nitens* is based on green product grading results using nominal dried dimensions and assuming drying degrade was negligible. Presented this way the data is compatible with the data from the pruned *E. globulus*.

product values were maintained at about the same level (see Tables 10 and 11 in the following discussion). This suggests that even though there was slower throughput, the economics of processing may not have been affected. Even so, improvements in throughput may be achieved with the addition of log centering devices on the twin saw, and trimming logs to remove uneven buttressing.

The comparison between back-sawing and the experimental quarter-sawing strategy

The recovery results, mean log diameter, log grades and product values for back-sawing and the experimental quarter-sawing strategies are given in Table 9. The grade recovery, select recovery, percentage of short lengths and product value were similar and there was no significant difference in recovery between sawing methods. This contradicts conventional understanding that suggests that quarter-sawing will produce lower recovery. However, quarter-sawing is usually applied to much longer length logs where distortion in the form of spring in flitches and slabs will be more pronounced. During resawing of the flitches and slabs a lot of material is edged off to produce straight boards and this reduces recovery. In contrast, in this trial the experimental quarter-sawing strategy was applied to very short length logs that did not react badly as growth stresses were released and spring was minimal (see later sections of this report). The only major difference between the two strategies was the larger percentage of boards longer than 1.8 m and wider than 125 mm produced by back-sawing. This was because of differences in target product widths. This difference did not affect the overall product value because of high value for the thicker quarter sawn boards.

Table 9. Mean dried rough sawn wood recoveries for the quarter sawing v back sawing comparison and dried rough sawn product values for each log group.

	Quarter sawing	Back sawing
Mean log diameter (cm)	50.8	48.4
Grade recovery (% log vol)	39.9	40.2
Select recovery (% log vol)	38.5	36.1
Percentage select <1.8 m in length	27.7	28.8
Percentage select >1.8m length and >0.125m width	4.3	47.1
Number of A-grade logs	3	4
Number of B-grade logs	12	11
Total number of logs	15	15
Product values / m³	\$1036	\$994

Log grades, dried recovery and product value

Given that the analysis of variance found no significant differences between stands or sawing strategies in timber recovery for a given log grade the following discussion considers logs grouped by log grade only. The mean diameter, recovery, percentage of short lengths and percentage of long and wide boards for each log grade are given in Table 10 and product values in Table 11. Table 10 shows an expected decline in recovery and increase in the percentage of short lengths as log grade declines, and Table 11 shows that product value was relatively uniform.

These recoveries are high in comparison to earlier trials in this series (Washusen and McCormick 2002, Washusen *et al.* 2003) and higher than some sawmills expect from native forest logs. For example, grade recovery for B and C grade logs was approximately 38-39 (% of log. vol.) and Victorian mills often expect recoveries as low as 35% for similar quality native forest logs (Tregoning *pers comm*²). This 3-4% difference could be due to better log quality for pruned logs for a given log grade, however, it may also be due to the less conventional sawing strategies employed at Auswest Timbers. The main differences between the processing at Auswest Timbers and conventional processing methods were:

- Most mills in southeastern Australia processing ash-type eucalypts use single saw line-bar carriage sawing systems that produce asymmetrical cutting patterns. With these systems resawing is a critical process designed to remove distortion and produce straight boards. The McKee twin saw and the multi-saw resaw apply a symmetrical cutting pattern that releases growth stresses simultaneously from both sides of the log or slab (timber that has been dimensioned in thickness

² Ms Diane Tregoning, General Manager, Black Forest Timbers, Woodend, Victoria, Australia

but not width) reducing problems associated with uneven stress release. This cutting pattern also allows a lot of the material to be dimensioned to both thickness and width on the break-down saw. This is critical because where boards are resawn to width on single saw systems they are either straightened (in the case of quarter-sawn boards), or they are dimensioned and straightened with a complex series of cuts (in the case of back-sawn boards). In both cases a significant volume of wood is lost to high value products and sold as wood chip.

- Many of the single saw breakdown and resawing systems have a 6 mm or at best 5 mm kerf (width of saw cut) in comparison to 4.5 mm kerf for the sawing system at Auswest Timbers.
- Where slabs were resawn on the multi-saw resaw the aim was to produce maximum width boards. This meant that in many slabs only two cuts were applied to produce one board. This eliminated distortion from boards.
- The short length of the logs (2.8 m) prevented many of the problems that develop during growth stress release with asymmetrical cutting patterns. This is because board distortion is approximately proportional to log length, the longer the log the greater the distortion. The short length also prevented taper from becoming a critical factor in recovery for the twin saw system that can only take cuts parallel to the pith.

Table 10. Mean recovery of dried sawn boards for each log grade.

Recovery	A grade	B grade	C grade	D grade	Below grade
Mean log diameter (cm)	56.7	44.9	33.3	62.6	48.6
Grade recovery (% log vol)	44.8	39.8	37.0	22.3	21.6
Select recovery (% log vol)	40.3	37.4	31.9	22.3	21.1
Percentage select grade <1.8 m length	27.8	24.5	24.3	34.2	52.8
Percentage select grade >1.8 m length and > 0.125 m width	30.6	26.1	45.1	34.1	24.9
Number of Logs	7	31	5	3	3

Table 11. Recovery of dried sawn boards and product value for logs grouped by grade.

Log Grade	Grade Recovery (% log vol)	Product value (\$ m ⁻³)
A	45.5	1004
B	38.9	1023
C	36.7	918
D	21.9	1006
Below grade	21.1	958

Log stumpage and grower returns

Using the stand productivity (Table 3), product recovery (Table 10) and product values (Table 11) stumpage values and returns per hectare were calculated. The results are shown in Figure 9 (stumpages) and Figure 10 (returns per hectare). In order to calculate stumpages a number of processing cost scenarios have been used. These range from \$600 m³ of final product to \$750 m³. This is the margin between product value and wood input costs at the mill door. It was suggested in earlier work (Washusen and McCormick 2002) that some mills may be profitable at a processing cost of \$600. However, others have stated that \$750 is closer to production costs. A nominal harvest and transport cost of \$55 m³ was also used. To calculate returns per hectare a minimum stumpage of \$20 m³ was applied i.e. if sawlog

stumpage values fell below \$20 m³ then they have been assigned a pulp log stumpage value of \$20. Stumpages were calculated using equation 1:

Equation 1: $S = \{(PV-PC)/(100/R)\}-C$
Where:
 S = stumpage (\$ m⁻³)
 PV = Product value (\$ m⁻³)
 PC = Processing costs (\$ m⁻³)
 R = Product recovery (%)
 C = Harvest and transport costs (\$ m⁻³)

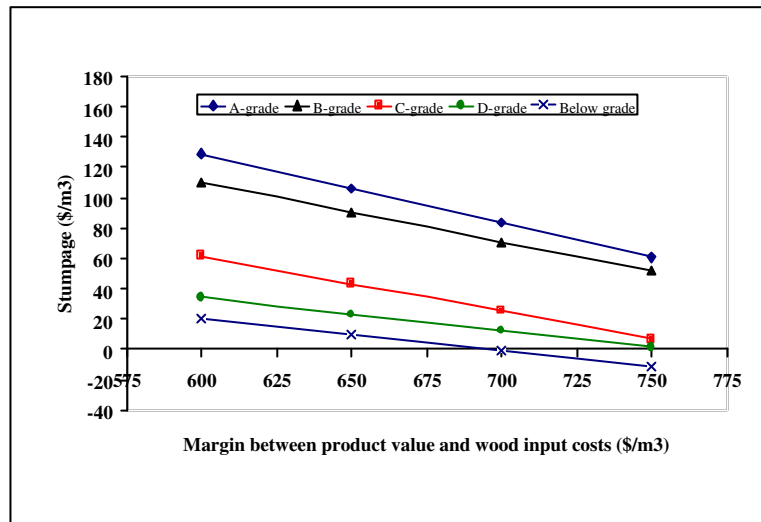


Figure 9. Estimated stumpage values for graded logs from pruned trees. Stumpages determined from recovery, product values, estimated processing costs ranging from \$600 to \$750 and harvest and transport costs of \$55.

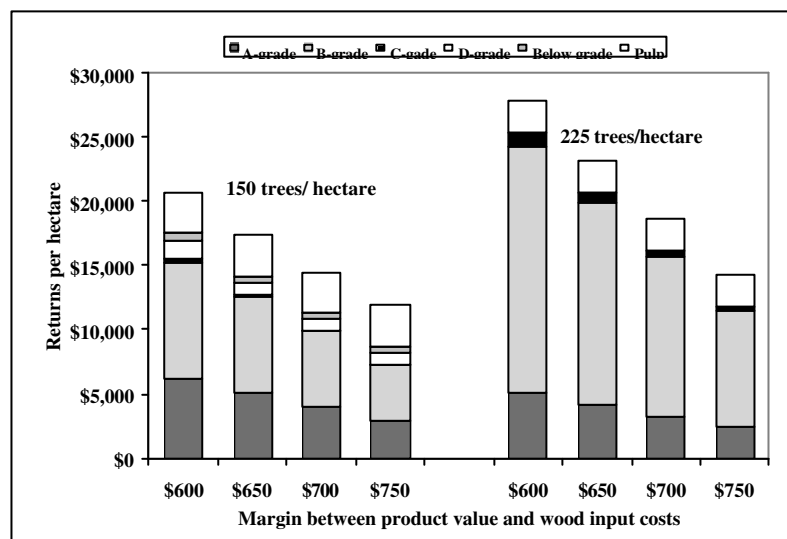


Figure 10. Returns per hectare for the 150 tree ha⁻¹ stand (left) and 225 tree ha⁻¹ stand using margins ranging from \$600 to \$750 and stumpage price determined from Figure 9.

Figure 9 shows the range in potential stumpages for logs grouped by log grade and Figure 10 the returns to growers based on the stumpages from Figure 9. The differences between the two stands (indicated in Figure 10) is due to the presence of termite damage. This damage was not considered to be a major problem (see discussion later) and the results suggest considerable potential for profitability with both stocking rates given existing market opportunities.

Most importantly, Figures 9 and 10 show that processing costs are a major consideration in profitability. On current estimates it appears that the sawmilling industry in Australia has a wide range of processing costs that are determined by mill efficiency, its capital and operating costs and workforce skills. It would be beneficial for future research to focus on finding ways of reducing costs and improving recoveries. It has already been suggested that it may be possible to improve recoveries with the adoption of innovative sawing techniques and alternative processing systems, particularly where log quality was uniform. If these improvements can be realized consistently then there is potential for improved returns to both growers and processors.

Recovery and product value from the un-pruned stand

Log grades, dried recovery and product value

The mean diameter, recovery, percentage of short lengths and percentage of long and wide boards are given in Table 12. As with the results for the pruned logs, Table 12 shows a general decline in grade recovery and select recovery with log grade indicating that existing Victorian log grading rules can be applied to plantation-grown *E. globulus*. However, there appears to be a clear difference in wood quality for a given log grade between unpruned and pruned logs. The log grading method also produces poor differentiation between lower quality logs and those below sawlog quality. This appears to be a common characteristic of unpruned plantation-grown eucalypts and probably indicates that surface defects are poor indicators of log quality in the lower log grades.

Table 13 gives the product recoveries and values for logs grouped by log grade indicating similar product values. Overall the recoveries for the better quality logs were good in comparison to past trials in plantation-grown *E. globulus* (Northway and Blakemore 1996, Washusen *et al.* 2002) and the quarter-sawing and drying strategies were effective despite the common occurrence of small volumes of tension wood.

Table 12. Mean recovery of dried sawn boards for each log grade.

Recovery	B grade	C grade	D grade	Below grade
Mean log diameter (cm)	40.8	38.9	36.8	35.3
Grade recovery (% log vol)	27.8	26.4	23.5	24.0
Select recovery (% log vol)	26.4	24.0	20.9	22.1
Percentage select grade <1.8 m length	21.4	27.9	25.7	28.8
Percentage select grade >1.8 m length and > 0.125 m width	4.9	6.3	1.4	2.6
Number of logs	8	26	18	23

Table 13. Recovery of dried rough boards and product value for logs grouped by grade.

Log Grade	Grade Recovery (% log vol)	Product value (\$ m ³)
A		
B	28.1	936
C	26.7	917
D	22.8	885
Below grade	23.7	920

The lower recoveries and lower product values for the unpruned logs in comparison to pruned logs of the same log grade result in much lower stumpages for unpruned logs (Figure 11). For example, for B and C-grade logs stumpages are \$25 and \$16 at a processing costs of \$650 respectively compared to \$90 and \$43 for equivalent quality pruned logs (from Figure 9).

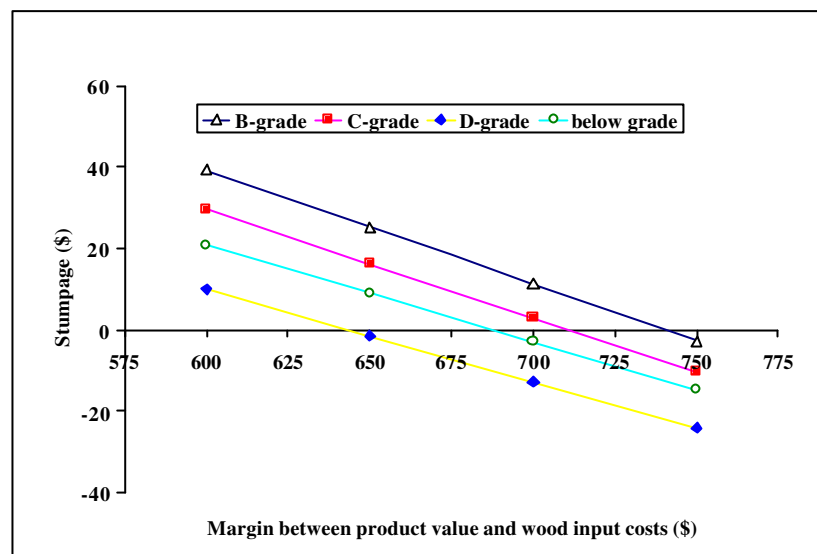


Figure 11. Estimated stumpage values for graded logs from unpruned trees. Stumpages determined from recovery and product values and estimated processing costs of ranging from \$600 to \$750 and harvest/transport costs of \$55.

Comparison between trials and potential for improved stumpages

Table 14 gives a comparison of stumpage values for a number of DPI supported trials in managed plantations where the product evaluation methods were identical and where quarter-sawing was applied to at least part of the sample. In each of these trials thinning had been undertaken to promote diameter growth, however, pruning had only been conducted in the 21-22 year-old *E. globulus*. There are a number of trends in these trials that are of interest for growers i.e. the more intensive the management and the earlier it was initiated the shorter the rotation age and the higher the recovery, product value and stumpages. Given that there was also a higher yield of high quality sawlogs in the pruned stands, pruning must be recommended to growers.

To determine these stumpages a nominal processing cost of \$650 m⁻³ was used. In reality processing costs may vary considerably particularly with adoption of improved sawing methods and economies of scale. It is likely that improved stumpages may be achieved by reducing processing costs if mills have the capacity to pass on benefits to growers. In Australia, conventional processing costs for eucalypts appear to be relatively high. For example, Shield (*pers comm*³) has indicated that in Uruguay, with appropriate economies of scale, processing costs for uniform pruned plantation-grown eucalypts may be as low as \$US 64 m⁻³ to produce 1 m³ of dried graded boards. While there are differences in labour costs between the two countries there is clearly an opportunity to improve the economies of scale in processing eucalypts in Australia. The demonstrated capacity to apply chippers prior to sawing and symmetrical cutting patterns in pruned *E. globulus* in these trials, suggests good potential to apply modern linear type sawing systems to short length pruned logs to substantially reduce sawing costs. In this respect the demonstrated potential to produce back-sawn boards in the trials using the McKee twin saw system is an important result because most emerging sawing systems that have symmetrical cutting patterns produce back-sawn timber. Even so, given the results in these trials it appears feasible to adapt multi-saw systems to produce mainly quarter-sawn boards.

³ Mr Evan Shield, Brisbane, Queensland, Australia

Table 14. Comparison of stumpage values using \$650 m⁻³ processing costs for B, C and D-grade logs from recent comparable processing trials.

Grade recovery (% of log volume)					
Species	Age at harvest	Management	B-grade	C-grade	D-grade
<i>E. globulus</i>	21-22	Thin and pruned age 3-5	38.9	36.7	21.9
<i>E. globulus</i>	32	Thin age 18 unpruned	28.1	26.7	22.8
<i>E. nitens</i>	34	Thin age 26 unpruned	25.0	24.5	27.9
Product value (\$ m ⁻³)					
Species	Age at harvest	Management	B-grade	C-grade	D-grade
<i>E. globulus</i>	21-22	Thin and pruned age 3-5	1023	918	1006
<i>E. globulus</i>	32	Thin age 18 unpruned	935	917	884
<i>E. nitens</i>	34	Thin age 26 unpruned	833	716	735
Estimated stumpage using \$650 processing costs (\$ m ⁻³)					
Species	Age at harvest	Management	B-grade	C-grade	D-grade
<i>E. globulus</i>	21-22	Thin and pruned age 3-5	90	44	23
<i>E. globulus</i>	32	Thin age 18 unpruned	25	16	-2
<i>E. nitens</i>	34	Thin age 26 unpruned	-9	-39	-32

Defects and processing characteristics in pruned and un-pruned *E. globulus*

Knots and branching defects

As with all trials in plantation-grown *E. globulus* knots and other defects associated with branches had a major bearing on product quality. It was the lack of these defects that contributed to the very high recoveries recorded for the pruned *E. globulus*. In the unpruned stand wood quality was clearly better than some other recent trials in the species, but still contributed to higher rates of defect than is expected from native forest logs and pruned logs of the same log grade.

Termites

Termite damage was a major problem in the pruned stand (Figure 12) and contributed to substantially poorer log quality and recovery in the 150 tree ha⁻¹ stand. Six logs with significant termite damage were graded D and lower, and recoveries were significantly reduced and the percentage of short lengths increased as the defect was docked from dried boards (Table 6).

In general termites are common in plantation eucalypts in areas where termites are active. However, in past trials the damage observed has been restricted, probably because of the young age of the stands. The extensive damage observed in the pruned eucalypts suggests that growers should be aware of this potential problem and take steps to reduce infestations if they occur. In this particular instance, the termites may have originated from Jarrah logs left in windrows from previous land use and removing this debris may have reduced the infestations.



Figure 12. Termite damage in a cant that fell from the carriage at the completion of break down on the twin saw at the Auswest Timbers Pemberton mill.

Growth stresses

Growth stresses were not a major problem in either the pruned or unpruned logs (Figure 13). The short length of the logs and absence or reduced volumes of tension wood contributed to this especially where small diameter logs (<40 cm mid diameter) from the unpruned stand were processed using a quarter-sawing strategy. In general there was only minor log end splitting in either stand, distortion during sawing was minor and while some splitting was observed in back-sawn slabs in the pruned logs it was rare.

Even so, distortion in the form of spring was relatively common in products from both pruned and unpruned logs. In the pruned logs the major source of spring came from resawing back-sawn slabs where multiple boards were produced. This was overcome to some extent by producing very wide single boards from most of the slabs. The major source of spring in the un-pruned logs was where products were sized to width on the single saw resaw rather than the multi-saw resaw.

In both cases spring was usually within the allowance for the grading strategy that was employed and would meet the requirements of the Australian Standard (AS 2796.1). Where it exceeded this requirement, products were docked to a length where they could be put through a 'four-sider' planer to remove distortion. The green product dimensions selected ensured that most of the spring could be removed.



(a)

(b)

(c)

Figure 13 a-c. Evidence of the limited effect of growth stress release (a) minor end-splitting in pruned logs; (b) very little deflection during sawing of pruned logs (c) a rare example of end-splitting in a back-sawn slab.

Tension wood

Tension wood was a relatively minor problem in both pruned logs and unpruned logs. In the case of the unpruned logs this was because of the selection methods that eliminated trees suspected of having the most severe tension wood. However, tension wood was still identified in a number of boards. In the pruned logs tension wood was found in three logs from the 225 tree ha⁻¹ stand. In both the pruned and unpruned logs where tension wood occurred, drying degrade was pronounced and tension wood zones easily identified. Most importantly it was the only significant drying degrade that was observed in both the pruned and unpruned logs if drying degrade associated with the pith was ignored.

The losses attributed to tension wood were quantified in the three pruned logs where tension wood was found. The three logs were B-grade logs that produced 36.0% recovery indicating approximately a 4.0 % reduction in recovery over all B-grade logs as a group (Table 15). The relatively high recovery was because the tension wood was easily isolated and removed during grading. This was a similar situation for the unpruned logs and indicates that the tension wood volume was relatively small in both the unpruned and pruned logs. The relatively minor tension wood problem in the pruned stand supports earlier screening trials that suggest that early thinning will restrict tension wood formation (Washusen 2002).

Table 15. Comparison of recovery and product length for B-grade logs with tension wood and all B-grade logs as a single group from the pruned plantation.

Recovery	B grade logs with tension wood	B grade all logs
Grade recovery (% log vol)	36.0	39.8
Select recovery (% log vol)	33.7	37.4
Percentage select grade <1.8 m length	21.2	24.5
Number of logs	3	31

Location and detection of tension wood

While tension wood was a minor problem in these trials this may not always be the case in managed stands. Recent evidence has emerged to suggest that under some circumstances tension wood may be a major problem in other non-commercially thinned and pruned stands (Washusen *et al.* 2004). In order to assist the refinement of detection methods for tension wood, several samples of normal wood and tension wood were collected for analysis of wood microstructure on SilviScan-2. The results indicated that in both the pruned and unpruned logs, drying degrade occurred in back-sawn and quarter-sawn boards when cellulose crystallite width was >3.4 nm. Where peaks of this magnitude occurred drying degrade was

consistently observed. Examples of quarter-sawn and back-sawn boards with and without tension wood zones are shown in Figures 14a (quarter-sawn boards) and 14b (back-sawn boards).

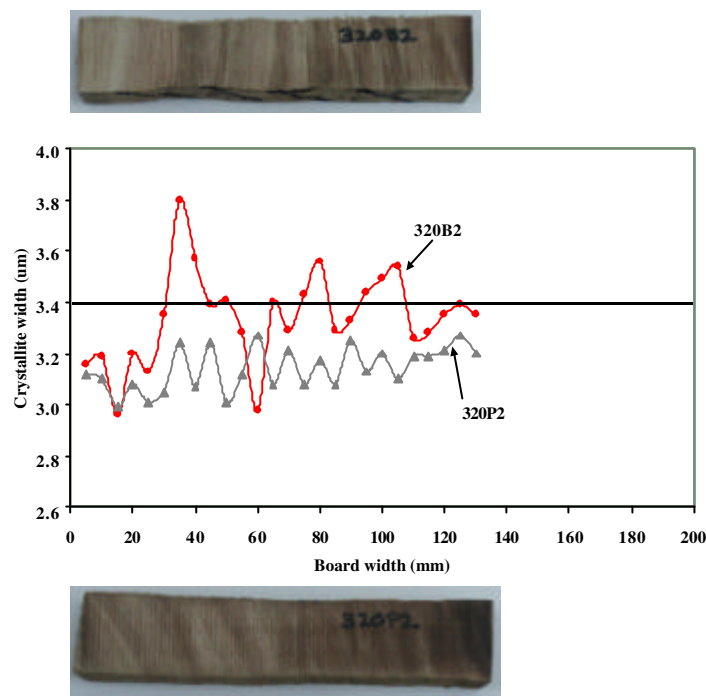


Figure 14a. Plots of cellulose crystallite width and matching cross sections of quarter-sawn boards with tension wood (top) and normal wood (bottom). Tension wood sufficiently severe to produce drying defects occurs above 3.4 nm.

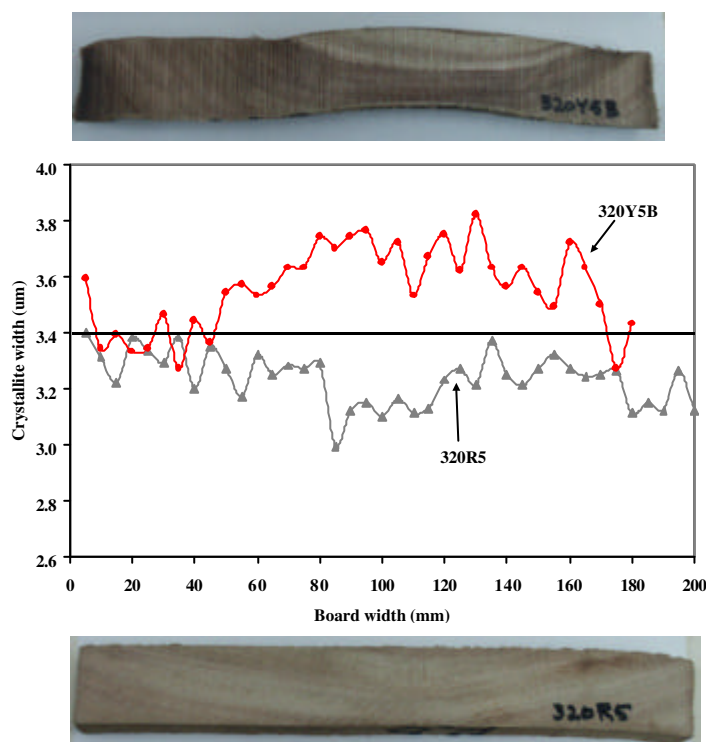


Figure 14b. Plots of cellulose crystallite width and matching cross sections of back-sawn boards with tension wood (top) and normal wood (bottom). Tension wood sufficiently severe to cause drying defects occurs above 3.4 nm.

RECOMMENDATIONS AND CONCLUSIONS

These trials, and earlier work particularly in *E. nitens*, show a trend of increased recovery, product quality and value as the length of time since thinning increases. This is most pronounced where pruning and thinning were combined at 3-5 years of age. Given the large differences in stumpage values found, pruning should be recommended to improve wood quality and product value. An economic analysis of pruning is warranted to support this recommendation.

The high recovery recorded for the pruned logs raises the issue of processing systems and sawmill efficiency. Conventional systems, which combine single-saw break-down and resawing stages may be well suited to highly variable long length native forest logs with large taper, but they may be less suited to uniform plantation-grown logs. The resawing systems are integral to mitigating problems associated with growth stress release during log break-down. These systems take oversized flitches and resaw them to an acceptable quality, however, they are often wasteful and cumbersome to use and limit log throughput and recovery. In plantations if log taper can be minimized and markets maintained for relatively short length high quality products, twin saw systems and other multi-saw systems may produce good recoveries and faster throughput and still mitigate problems associated with growth stress release. For a similar capital investment processing costs may be reduced considerably, increasing the potential for higher returns to growers and hence the viability of the industry. This should be investigated through future trials and modeling of sawmill system productivities based on trial results. However, many multi-saw systems produce back-sawn wood and under these circumstances high unit shrinkage may reduce marketing flexibility. Reducing unit shrinkage would be a priority if this were the case. Alternatively, multi-saw systems may be adapted to produce quarter-sawn wood with lower unit shrinkage across the wide face of boards. Experimentation during the trials suggests that this is feasible.

In future work it will also be essential to explore the possibility of reducing tension wood occurrence possibly through genetic selection or through gaining an understanding of the implications of site and silviculture on tension wood occurrence. Exploration of the potential for sawing systems to mitigate problems associated with growth stress release and to understand the limits of processing systems and set parameters for resource improvement should be a priority.

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APPENDIX A Modified CSIRO-FFP Grading criteria

CSIRO Hardwood Appearance Product Assessment Criteria

Modified June 2002

Scope

Specifications apply to sawn eucalypt products for appearance applications and can be applied to dressed or dry rough sawn products.

Grade Descriptions

(a) Polishing grade:

The wood will be graded in its entirety, on the worst defect and will be free of decay, stain, kino pockets, knots, borer and termite attack, end splits, wane and Lyctus-susceptable sapwood. The following specifications shall apply:

- (i) *Product orientation* - Back-sawn products are acceptable only if graded dry, in which case, the prescribed allowance for checks will not be exceeded.
- (ii) *Product sizing* - Minimum dimensions for dry rough-sawn products must be 3 mm greater than final dressed size and allowance must be made for shrinkage when grading green wood. Green sizing over a parcel must not vary by more than 2 mm.
- (iii) *Product length* - Minimum 0.9 metre.
- (iv) *Moisture content* - Average moisture content of 10%, with all pieces within the range of 7% to 12%.

In addition, the following imperfections will be allowed:

- (i) *Tight kino veins* - Up to 1 mm in width and no greater than 1.5 mm on the graded surface. No greater than 600 mm in length for every square metre of surface and individually not exceeding 200 mm.
- (ii) *Spring* - 8 mm in 3 metres length.
- (iii) *Bow* - 10 mm in 3 metres length.
- (iv) *Surface checks* - Of less than 1 mm in width and 2 mm depth, in aggregate length not more than 250 mm in 1 square metre and no more than one surface check in any 0.04 square metre (400 x 100 mm) area.
- (v) *Internal checks* - As appearing on freshly docked ends. Must be confined to the middle of the thickness of the piece, not exceeding 1 mm in width and not exceeding 4 mm radially or extending through the late-wood. No more than 1 on any cross section less than 0.005 square metre (100 x 50 mm) area, or 2 in any larger cross-section.
- (vi) *Sloping grain* - Not exceeding 1 in 20.

(b) Moulding grade:

The wood will be graded in its entirety, on the worst defect and will be free of decay, stain, kino pockets, borer and termite attack, end splits, wane and Lyctus-susceptable sapwood. The following specifications shall apply:

- (i) *Product orientation* - Back-sawn products are acceptable only if graded dry, in which case, the prescribed allowance for checks will not be exceeded.
- (ii) *Product sizing* - Minimum dimensions for dry rough-sawn products must be 3 mm greater than final dressed size and allowance must be made for shrinkage when grading green wood. Green sizing over a parcel must not vary by more than 2 mm.
- (iii) *Product length* - Minimum 0.9 metre.
- (iv) *Moisture content* - Average moisture content of 10%, with all pieces within the range of 7% to 12%.

In addition, the following imperfections will be allowed:

- (i) *Tight kino veins* - Up to 1 mm in width and no greater than 1.5 mm on the graded surface. No greater than 1 metre in length for every square metre of surface and individually not exceeding 300 mm.
- (ii) *Spring* - 8 mm in 3 metres length.
- (iii) *Bow* - 10 mm in 3 metres length.
- (iv) *Surface checks* - Of less than 1 mm in width and 3 mm depth, in aggregate length not more than 300 mm in 1 square metre and no more than one surface check in any 0.02 square metre (200 x 100 mm) area.
- (v) *Internal checks* - As appearing on freshly docked ends. Must be confined to the middle half of piece thickness, not exceeding 1 mm in width and not extending through the late-wood. No more than 1 on any cross section less than 0.005 square metre (100 x 50 mm) area, or 2 in any larger cross-section.
- (vi) *Sloping grain* - Not exceeding 1 in 20.

(c) Select grade:

The wood will be graded on the best face and both edges, which must be free of decay, borer holes, kino pockets, termite galleries, end splits, wane and Lyctus-susceptable sapwood. The back will be graded to cover grade (see below) except for the exceptions listed below. The following specifications shall apply:

- (i) *Product orientation* - Back-sawn products are acceptable but must be sawn so that all wood is at least 60 mm or half product width, or whichever is the greatest from the pith.
- (ii) *Product sizing* - Minimum dimensions for dry rough-sawn products must be 3 mm greater than final dressed product and due allowance made for shrinkage when grading green wood. Green sizing over a parcel must not vary by more than 3 mm.
- (iii) *Product length* - Minimum 0.9 metre.
- (iv) *Moisture content* - Average moisture content of 10%, with no more than 10% of pieces being within the range of 12% to 15%, all remaining pieces within the range of 7% to 12%.

In addition, the following imperfections will be allowed:

- (i) *Tight kino veins* - Up to 1.5 mm in width and no greater than 2.5 mm on the graded surface. No greater than 1.5 metre in length for every square metre of surface.
- (ii) *Light stain only*
- (iii) *Spring* - 10 mm in 3 metres length.
- (iv) *Bow* - 25 mm in 3 metres length, except for lining boards and strip flooring sizes, when up to 40 mm is allowable.
- (v) *Wane and Lyctus susceptible sapwood* - On lining boards and strip flooring only. On the opposite face to that graded, for 25% of the width and lower edge only, for a maximum of 25% of the sawn face.
- (vi) *Knots* - Tight green knots only, less than 20% of product width and no more than three per square metre of surface area.
- (vii) *Surface checks* - Of less than 1 mm in width and 3 mm depth, in aggregate length not more than 1 metre in 1 square metre of surface area.
- (viii) *Internal checks* - As appearing on freshly docked ends, not exceeding 1 mm in width and not extending through the late-wood. No more than 3 in 0.005 square metre (100 x 50 mm) area.
- (ix) *Holes* - No more than 2 mm in diameter and no more than 10 per square metre of surface area.
- (x) *Sloping grain* - Not exceeding 1 in 15.

(d) Standard grade:

The wood will be graded on the best face, which must be free of decay, borer holes of more than 5 mm diameter, kino pockets, termite attack, end splits, wane and Lyctus-susceptable sapwood. The following specifications shall apply:

- (i) *Product orientation* - Back-sawn products are acceptable but must be sawn so that all wood is at least 60 mm or half product width, or whichever is the greatest from the heart (or pith).
- (ii) *Product sizing* - Minimum dimensions for dry rough-sawn products must be 3 mm greater than final dressed size and allowance must be made for shrinkage when grading green wood. Green sizing over a parcel must not vary by more than 3 mm.
- (iii) *Product length* - Minimum 0.9 metre.
- (iv) *Moisture content* - Average moisture content of 12%, within the range of 9% to 15%.

In addition, the following imperfections will be allowed:

- (i) *Tight kino veins* - Up to 1.5 mm in width. No greater than 3 metre in length for every square metre of surface.
- (ii) *Light stain only*
- (iii) *Spring* - 10 mm in 3 metres length.
- (iv) *Bow* - 25 mm in 3 metres length, except for lining boards and strip flooring sizes, where up to 40 mm is allowable.
- (v) *Wane and Lyctus susceptible sapwood* - On the opposite face to that graded, for 25% of the width and lower edge only, for a maximum of 25% of the sawn face.
- (vi) *Knots* - Tight green knots and epicormic shoots (burls) only, no greater than 30% of product width and no more than six per square metre of surface area.
- (vii) *Surface checks* - Of less than 1 mm in width and 5 mm depth, in aggregate length not more than 2 metre in 1 square metre of surface area.
- (viii) *Internal checks* - As appearing on freshly docked ends, not exceeding 1 mm in width. No more than 6 in 0.005 square metre (100 x 50 mm) area.
- (ix) *Holes* - Up to 2 mm in diameter and no more than 20 per square metre of surface area. From 2 mm to 5 mm, no more than 5 per square metre of surface area. In combination, one larger hole equates to four smaller holes.
- (x) *Sloping grain* - Not exceeding 1 in 10.

(e) Utility grade:

The sawn product will be 2.4 metre length or longer and graded on the best face, which must be free of decay, holes greater than 8 mm diameter, kino pockets, termite galleries, wane and Lyctus-susceptable sapwood. Back-sawn products are allowable but must be sawn so that the wood is a minimum distance of 50 mm from the pith. Average moisture content of 12%, with all pieces within the range of 9% to 15%.

In addition, the following imperfections will be allowed:

- (i) *Kino veins* - Tight kino veins up to 1.5 mm in width unlimited. Wider, but tight kino veins, not exceeding the length of the piece.
- (ii) *Stain* - Brown
- (iii) *Spring* - 10 mm in 3 metres length.
- (iv) *Bow* - 40 mm in 3 metres length.
- (v) *Wane and Lyctus susceptible sapwood* - On the opposite face to that graded, for 25% of the width and lower edge only.
- (vi) *Knots* - Tight green knots and epicormic shots (burls) only, no greater than 40% of product width. Partially dead knot (tight on at least 50% of the knot perimeter) up to 30% of product width.
- (vii) *Surface checks* - Of less than 1 mm in width unlimited. Wider checks to 2 mm in width, in aggregate length not more than 1 metre in 1 square metre of surface area.
- (viii) *Internal checks* - As appearing on freshly docked ends. Of less than 1 mm - unlimited. Wider checks to 2 mm - no more than 3 per 0.005 square metre (100 x 50 mm) area.
- (ix) *Holes* - Up to 2 mm in diameter unlimited. Larger holes to 8 mm diameter - no more than 10 per square metre.
- (x) *Sloping grain* - Not exceeding 1 in 10

(h) Cover grade:

The sawn product will be 2.4 metre length or longer and graded on the worst defect or combination of defects on a piece, which must be free of termite attack, decay, wane and Lyctus-susceptable sapwood. Back-sawn products are allowed but must be sawn

so that the wood is a minimum distance of 50 mm from the pith. Average moisture content of 10%, with all pieces within the range of 7% to 12%.

In addition, the following imperfections will be allowed:

- (i) *Kino veins* - Tight kino veins unlimited.
- (ii) *Stain* - Brown
- (iii) *Spring* - 10 mm in 3 metres length.
- (iv) *Bow* - 10 mm in 3 metres length.
- (v) *Knots* - Tight green knots and epicormic shots (burls) only, no greater than 40% of product width. Partially dead knot (tight on at least 50% of the knot perimeter) up to 30% of product width.
- (vi) *Checks* - Both internal and surface, individual checks not exceeding the lesser of half of piece thickness or two growth rings, or wider than 3 mm.
- (vii) *Holes* - Up to 8 mm in diameter unlimited. Up to 20 mm, no more than 10 per square metre.
- (x) *Sloping grain* - Not exceeding 1 in 10