Technical Report 202

Evaluation of thin-section quarter-sawn boards and rotary veneer from plantation-grown *Eucalyptus nitens*

Public report

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September 2010

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Summary

This report presents the findings of two wood processing trials using plantation-grown *Eucalyptus nitens*. One trial explored whether reducing board thickness of quarter-sawn boards (from pruned trees) to 9 mm could completely eliminate internal checking. A small-scale rotary veneering trial was also conducted to evaluate the potential of pruned and unpruned logs for producing appearance-grade veneers.

Objectives

The objectives of the two wood-processing trials described in this report were:

(1) to evaluate whether checking in quarter-sawn boards cut from pruned plantation-grown *E. nitens* (shining gum) could be eliminated by reducing board thickness to a very thin section (< 10 mm green-sawn thickness). Surface and internal checking had been identified as significant value-limiting defects in earlier CRC for Forestry processing studies on this species (refer to CRC for Forestry Technical Reports 168 and 200)

(2) to provide a preliminary assessment of the veneer-grade recoveries and the stiffness of veneer sheets cut from pruned and unpruned plantation-grown *E. nitens* logs in a rotary veneer mill.

Methods

Pruned and unpruned logs were harvested from a 21-year-old silvicultural trial in a fast-growing *E. nitens* plantation near Lisle, in north-east Tasmania. The best 300 trees per hectare had been pruned to a height of 6.4 m at age six years. Four thinning treatments applied at age nine years gave post-thinning stocking densities of 100, 250 and 600 stems/ha and about 1000 stems/ha, the last an unthinned control treatment.

Bush logs from a total of twelve pruned trees from the 100, 250 and 600 stems/ha treatments were transported to the Creswick Timber Training Centre in Victoria, where they were cross-cut to produce two 2.7m sawlogs. Each sawlog was sawn to produce clearwood flitches suitable for re-sawing, with the central knotty core of the log excluded. The flitches were re-sawn to produce quarter-sawn boards of 9 mm green thickness and 75 mm width. Boards were racked and air-dried in a research kiln at CSIRO's Clayton laboratories (Melbourne), using ambient air conditions with fan movement of air after the first four weeks. Following drying to average moisture content of <15%, the boards were cross-cut at mid-length and the cut ends of a total of 1240 boards assessed for the presence of internal checking. One half of each cross-cut board was then steam-reconditioned and dried to final moisture content of 12%. A second cross-cut was then made 50 mm in from the original cross-cut and assessed for internal checking.

Bush logs from five pruned and five unpruned trees, all from the 250 stems/ha treatment, were transported to the Ta Ann Tasmania rotary veneering mill near Smithton in north-west Tasmania. Each bush log was cross-cut to produce three 1.91m-long billets, which were processed to produce veneer sheets of 2.4 mm thickness, with dimensions of 1.83 m (longitudinal) × 0.91 m (tangential). Veneer sheets were dried according to standard operational procedures to a moisture content of 12%. All sheets were graded according to AS/NZ Standard 2269:2004, which identifies four veneer grades (A–D) of decreasing quality and rejects sheets that fail to make grade D. Two veneer sheets per billet, one from the inner heartwood and one from the outer heartwood, were taken to CSIRO's Clayton laboratories, where dynamic stiffness was estimated from measurements of specific gravity and acoustic wave velocity.

Key results

(1) Quarter-sawn boards

The quarter-sawn boards were free from surface checking. Levels of internal checking were extremely low, with 94.5% of boards check-free prior to reconditioning and 98.3% of boards having no visible checks following reconditioning. These results represented a marked improvement from the levels of surface and internal checking recorded in previous studies.

(2) Veneer

Percentage recovery of appearance-grade veneer sheets (A and B grade) from pruned logs (12% of green volume) was higher than from unpruned logs (6%), and recovery of all grades (A–D) was also higher for pruned logs at 58% compared with 45% for unpruned logs. Green recoveries were highest from the first 1.9 m billet from the bottom of the logs, progressively reducing for the next two billets, for both pruned and unpruned logs. There was substantial variation in grade recoveries from tree to tree, indicating the need for larger scale trials to reliably estimate green recoveries.

Dynamic stiffness of veneer sheets was in the range of 8–11 GPa (gigapascals), increasing significantly from the inner heartwood to the outer heartwood and from the first billet through to the third billet above ground.

Application of results

Surface and internal checking in boards cut from plantation-grown *E. nitens* can be virtually eliminated by quarter-sawing to a thickness of 9 mm (green) and then following appropriate drying and reconditioning schedules. Depending on the sawing system and the final products, an intermediate board thickness in the range of 10-15 mm (finished) might offer an optimum balance between an acceptable level of checking defects, and acceptable recovery and processing costs.

Recoveries of useable grades of veneer from *E. nitens* will be higher from pruned than from unpruned plantations. Veneer stiffness from plantation-grown *E. nitens* will be relatively low, compared with veneers cut from native forest eucalypt logs.

Further work

Whether there is an economic application for defect-free thin-section quarter-sawn boards cut from pruned plantation-grown *E. nitens* will need to be determined by industry.

Studies on the manufacture of plywood products from veneer of plantation-grown *E. nitens* and on the properties of these products are warranted, although such work is outside the scope of the CRC for Forestry research program.

Introduction

Wood completely free of internal checks is required for a range of high-value appearance applications such as fine furniture making (Blakemore 2009).

This is the third CRC for Forestry technical report examining the potential for processing sawn wood and recovering appearance-grade products from pruned plantation-grown *Eucalyptus nitens* (shining gum).

In the first study (Washusen *et al.* 2008, 2009), pruned logs from 22-year-old *E. nitens* harvested from a silvicultural trial at Goulds Country in north-east Tasmania were sawn, dried and reconditioned with conventional processing methods. Surface checking was the major grade-limiting defect, particularly on back-sawn boards. Internal checking (not visible on the board faces), while not scored as a defect in the grading system used, was present and could lead to rejection of processed boards for some downstream processing applications.

The second study (Blakemore *et al.* 2010) used pruned logs from the Goulds Country trial, and unpruned logs from a Forests NSW progeny trial at Tumut, NSW. Logs were sawn using a linear mill (HewSaw R250). A range of drying and reconditioning strategies designed to reduce internal checking in 24 mm boards were tested. Surface and internal checking in boards of plantation-grown *E. nitens* was substantially reduced, but not eliminated, and different drying strategies all gave similar results. Internal checking was greatly reduced following reconditioning; many checks closed and were no longer visible. Reducing the thickness of back-sawn boards to 19 mm did not reduce levels of internal checking, relative to 24 mm boards.

This third study included two processing trials. A trial using very-thin-section quarter-sawn boards was conducted to determine whether further reduction in board thickness could completely eliminate internal checking. The board thickness chosen (9 mm green) was thinner than that used in commercial practice.

Also reported here is a small-scale rotary veneering trial that was conducted to evaluate the potential of pruned and unpruned plantation-grown *E. nitens* logs for the production of appearance-grade veneers.

These two processing trials used logs from a silvicultural research trial established in a plantation at Lisle, in north-east Tasmania. This plantation was characterised by much faster growth than the trial at Goulds Country. Mean annual volume increment of the unthinned plantation at age 9 years was 26.2 m^3/ha at Lisle, compared with 10.1 m^3/ha at Goulds Country (Medhurst *et al.* 2001).

Materials and methods

The plantation

Trees were selected from a Forestry Tasmania *E. nitens* (Toorongo Plateau provenance seed source) silvicultural trial established in a plantation at Lisle, in north-east Tasmania (latitude 41°13'S, longitude 147°22'E, 220 m above sea level). The site previously carried native forest. Details of the trial establishment are provided by Medhurst *et al*. (2001). The plantation was established at the site in 1987. Trees were spaced at approximately 3.5 × 2.4 m (1190 stems/ha).

A summary of silvicultural treatments is given in Table 1.

Table 1. Establishment and management details for Lisle silvicultural trial

Year planted	1987
Provenance	Upper Toorongo
Fertiliser	No fertiliser applied
Initial spacing	3.0 x 2.4 m
Pruning	6 years after planting (single lift, to 6.4 m) (best 300 stems/ha)
Thinning	1996–7, 9 years after planting
Thinning treatments	100, 250, 600 stems/ha and unthinned control
Plots	0.08 ha; 15 × 55 m
Plantation age at harvest (2009)	22 years

Six years after planting, the best 300 trees per hectare were pruned to 6.4 m in a single lift using pruning saws. The trial was a randomised complete block design with three replicates of four thinning treatments; unthinned (stocking was 1031 stems/ha at thinning), and thinned to 100, 250, or 600 stems/ha. The thinning treatments were applied in December 1996 – January 1997, approximately nine years after planting. Following the initial measurement and tree selection in December 1996, third-row out-rows were felled in each thinned plot, followed by further removal of trees in the remaining rows to achieve the designated stocking density. Each experimental plot was 15 × 50 m (0.08 ha) in size, with an external buffer row thinned to the same stocking. The thinning method resulted in all trees in the 100 stems/ha treatment being pruned, while the remaining treatments contained both pruned and unpruned trees.

Tree selection, harvesting and transport

In September 2009, trees were selected to be of appropriate diameter at breast height (DBH) for the processing trials (Table 2) and with acceptable straightness of the butt log, which was to be at least 6 m long (displacement of the butt log from the vertical to be no more than 0.2 × small-end diameter).

Twelve pruned trees were selected for the sawing trial were all pruned, with five logs sourced from each of the 100 and 250 stems/ha thinning treatments and two logs sourced from the 600 stems/ha treatment (Table 2).

The ten trees selected for the veneering trial were sourced from the 250 stems/ha treatment; five trees were pruned and five unpruned.

Mean DBH of the trees for the sawing trial (53.0 cm) was very similar to that of the trees for the veneering trial (50.6 cm).

Table 2. Pruning and thinning treatments and tree diameter at breast height (DBH) of trees sampled for the sawing and veneering studies

Pruning treatment	Thinning treatment	DBH (cm)
Logs used in sawing study		
pruned	100	54.8
pruned	100	57.9
pruned	100	58.3
pruned	100	60.3
pruned	100	63.1
pruned	250	44.8
pruned	250	47.7
pruned	250	48.6
pruned	250	54.2
pruned	250	55.4
pruned	600	44.0
pruned	600	47.2
	mean	**53.0**
Logs used in veneering study		
unpruned	250	49.3
unpruned	250	50.0
unpruned	250	50.2
unpruned	250	50.4
unpruned	250	51.8
pruned	250	49.7
pruned	250	50.0
pruned	250	51.3
pruned	250	51.5
pruned	250	52.0
	mean	**50.6**

Trees were felled using a 608 Timber Jack harvester. Stump heights were as low as was practically possible, and were generally below 30 cm. Stumps of a few of the largest trees were slightly higher than this because the harvester was operating at its size limit.

Trees for the veneering trial were felled on 1 October 2009. A bush log at least 6.1 m long was cut from the butt end of each felled tree. Both ends of each bush log were sealed with Dussek-Campbell Technimul clear log grease to reduce moisture loss prior to processing, and gang-nailed to prevent end-splitting. Logs were labelled using cattle-tags. Trees for the sawing trial were felled on 30September or 1 October 2009and sealed and gang-nailed in the same way.

Sawing trial

The twelve bush logs for the sawing trial were transported in a shipping container to the Timber Training Centre at Creswick, Victoria, where sawing took place on 2–4 November 2009. Each bush log was first cross-cut into two 2.7m-long sawlogs (Figure 1).

Figure 1. 2.7m-long sawlogs following cross-cutting of bush logs at Creswick Timber Training Centre, with log-end templates affixed prior to sawing

Log-end templates were attached to enable matching of boards to individual logs and the position of boards within logs to be determined if necessary.

Logs were then sawn on a line-bar carriage using a single bandsaw, to produce clearwood flitches (cut from the clearwood outside the unpruned knotty core of the log) for re-sawing (Figure 2). Flitches were resawn on a smaller band saw with a 3 mm saw kerf, to produce quarter-sawn boards with 9 mm green thickness and at least 75 mm green width (Figure 3). Estimation of green recovery of sawn boards was not attempted because the primary research focus of the trial was the elimination of checking.

The sawing strategy was designed to give samples of clearwood quarter-sawn boards from a known location within the log for experimental drying and reconditioning trials. This meant that the sawing strategy was somewhat wasteful, because board width was not optimised, production of back-sawn boards was avoided and recovery products were sought only from the quarter-sawn flitches.

Figure 2. Sawing to produce flitches for re-sawing, at Creswick Timber Training Centre

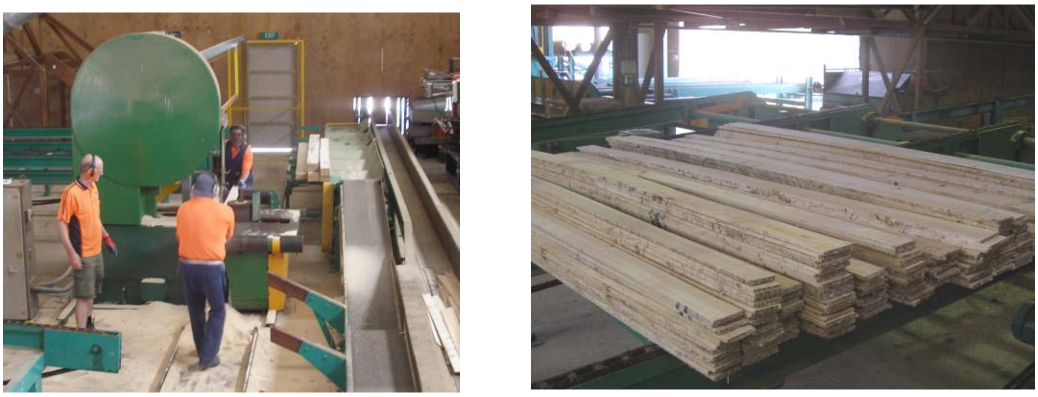

Figure 3. Resawing of flitches to produce 9mm-thick quarter-sawn boards

Sawn boards were block-stacked, wrapped in plastic and transported immediately to CSIRO's Clayton laboratories. They were racked for drying and air-dried in an experimental kiln. Racked stacks were approximately 1.3 m wide and 1–1.3 m high (Figure 4). There was no airflow for the first 4–6 weeks. Fans were then turned on to provide approximately 0.5 to 1 m/s airflow of ambient air.

Figure 4. Two stacks of boards, outside the drying kiln, prior to reconditioning

Moisture content of boards was monitored by weighing sample boards during air-drying over a period of 16 weeks (sections were cut from ends of sample boards and oven-dried to estimate the oven-dry (OD) mass of the sample board). When moisture content of most of the boards had fallen below 15% (percentage of OD mass basis), assessment of checking was carried out, followed by steam-reconditioning and final drying. At this stage, a small proportion of the boards in the central positions of the lower layers of the stack still had moisture content greater than 15% (see shaded cells in Table 3, below).

Table 3. Moisture content (percentage of OD mass) of sample boards from four layers of one of the drying stacks, immediately prior to reconditioning. Approximate vertical position of each layer in the stack is shown.

	Board position across stack															
% of stack height	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
90%	12.8	12.2	12.8	12.2	12.7	13.0	13.3	13.4	13.8	12.8	12.6	13.1	9.1	13.7	12.9	missing board
70%	12.6	12.0	11.9	12.2	11.9	11.0	11.3	12.0	12.2	12.3	11.6	12.6	12.7	12.3	11.4	11.6
50%	14.9	15.7	13.6	12.7	12.1	14.2	29.5	17.8	19.8	17.7	15.6	16.8	17.1	14.0	12.7	12.4
20%	14.4	13.7	12.6	14.8	19.3	16.4	16.5	19.3	18.8	17.5	16.2	15.3	14.5	13.3	16.1	12.7

Following air-drying, visual inspection of the boards revealed that surface checking was completely absent, so this trait was not formally assessed. Internal checking was assessed using the methods described in the previous CRC for Forestry studies (Washusen *et al.* 2009; Blakemore *et al*. 2010). After air-drying and prior to steam reconditioning, each board was cross-cut to give two half-length board sections approximately 1.3 m long. Internal checking was scored by visually inspecting one of the cut ends and recording the number of visible internal checks. On a sub-sample of approximately 10% of the boards, a 1 mm-thick cross-section was cut from one of the board halves, and labelled. A digital camera was used to capture an image of each of these 1 mm slices for image analysis using Image Pro software. The software was used to measure the total cross-sectional area of the slice and the number of internal checks.

Steam-reconditioning was carried out in a research kiln at Clayton on one half-section of each board. The cut ends of these board halves were end-sealed with silicon sealant. Boards were steamed for approximately two hours after the temperature in the chamber reached 98 °C.

Following reconditioning and final drying, reconditioned board sections were cross-cut approximately 50 mm in from the cut at the board mid-point that had been made prior to reconditioning. Internal checking was visually assessed on the newly cut cross-section of each reconditioned board. Matching 1mm-thick slices from the subsample of boards that had been sampled prior to reconditioning were cut, labelled and assessed using automated image analysis as described above.

Veneering trial

The five pruned and five unpruned bush logs for veneering were transported by road to the Ta Ann Tasmania rotary veneering plant at Smithton, in north-west Tasmania. Each bush log was cross-cut to produce three 1.91 m billets. The largest and smallest diameters at each of the log-ends were measured using callipers , and the volume of each billet was calculated using the following formula

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

where V = billet 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) and L = billet length (m).

Log identities and billet position within the log (butt, middle or top) were maintained for each of the 30 billets, using numbers and position coding on the billet surface (Figure 5).

Figure 5. Billets on the in-feed conveyor line prior to veneering

The bush logs were all placed into the log merchandiser large end first, so that the butt billet was always first through the lathe. Log numbers were recorded from the billets on the infeed to the lathe (log no. 10 was first through, in Figure 5). Veneer colour codes were always sprayed on the large (butt) end of the billets because, during initial rounding up, recovery of a half-sheet from this end of the billet was more likely.

The veneering plant used Tahei lathes to peel the billets (Figure 6). Veneer sheet thickness was set to 2.4 mm green thickness.

Figure 6. Lathe, with partly peeled *E. nitens* billet

Veneer sheets collected and graded were 6' × 3' (1.83 m longitudinal × 0.914 m tangential). During the rounding-off process, the sheets coming off were split in two so that 3' × 6' (longitudinal × tangential) veneers could be collected from the butt end of the billet. Once the top part of the sheet was solid, the machine automatically cut 6' by 3' sheets. In this trial only the 6' × 3' sheets were collected and none of the 3' × 6' sheets. Green volume recovery, based on sheet dimensions and numbers of sheets, was calculated as a percentage of billet volume. Because 3' × 6' sheets were not collected, there was a small and variable negative error (mostly related to taper) in the recovery calculation.

Billet identity of all individual veneer sheets was tracked by paint traces applied using a set of nozzles designed and developed by the University of Tasmania's Centre for Sustainable Architecture in Wood. This system enabled adjustable setting of the different paint nozzles to give a unique colour combination for each billet (Figure 7).

Figure 7. Billet identity of individual veneer sheets maintained using paint colour combinations applied by paint nozzles

Following peeling, the veneer sheets were dried to approximately 12% moisture content (% of OD mass) according to standard operational practice in the dryers at Ta Ann Tasmania. After drying, all sheets were graded for appearance use, according to AS/NZ Standard 2269:2004 Plywood: Structural for hardwood veneer. The veneer grades that were assessed and the associated grading criteria are reproduced in Appendix 1.

Following grading, an inner and outer heartwood sheet were collected by sampling veneer sheets 5 and 25 from each billet, or sheets adjacent to these if the target sheets failed to make the grade. The selected sheets were transported to CSIRO's Clayton laboratories and dried to 4–6% moisture content in a research kiln there. The two selected sheets from each billet were then evaluated for basic density and stiffness (dynamic modulus of elasticity, MoE) as follows.

Acoustic wave velocity (AWV) over a distance of 0.5 m in the longitudinal direction on defect-free sections was measured along two transects on each sheet, spaced at ⅓ and ⅔ of the sheet width, as shown in Figure 8, using a sound-wave oscilloscope with an initiating and receiving probe that measured time-of-flight of ultrasonic impulses. The average of the two AWV measures for each sheet was calculated.

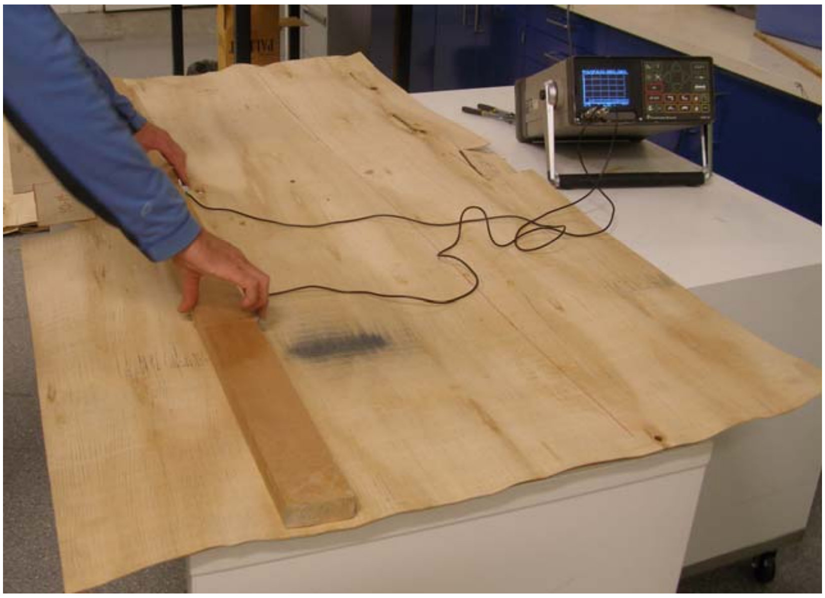

Figure 8. Measurement of acoustic wave velocity in longitudinal direction

Two defect-free sample panels were cut from each sheet, each sized approximately 150 mm × 120 mm, and positioned at the two sides, midway along the sheet in the longitudinal direction, as shown in Figure 8. Basic density was determined using the method described by Smith (1955). Each sample was saturated by submersion in distilled water, weighed, oven-dried to constant weight at 105 ºC and then reweighed.

Basic density G_f of each sample, termed specific gravity by Smith (1955), was estimated as follows:

$$G_f = \frac{1}{\frac{m_m - m_o}{m_o} + \frac{1}{G_{so}}}$$

where m_m is the mass of the saturated sample, m_o is the mass of the oven-dry sample and G_{so} is the specific gravity of the dry cell-wall matter, assumed to be 1.53 (Smith 1955). The air-dry density of veneer sheets in the Clayton laboratory was predicted by assuming a moisture content of 12%, and multiplying G_f by a factor of 1.2. This multiplication factor uses the empirical relationship between air-dry and basic density determined for wood samples of many *Eucalyptus* species by Greenhill (1940).

Dynamic modulus of elasticity (MoE) was calculated as follows:

$$\text{MoE} = G_f \times 1.2 \times \text{AWV}^2$$

Mean values of G_f, AWV and MoE were calculated for each of 60 veneer sheets (2 pruning treatments × 5 trees × 3 billets × 2 radial positions in the heartwood per billet). The three response variates were subjected to analysis of variance using the software package Genstat Release 12 (VSN International, United Kingdom), according to the following linear fixed effects model:

$$Y = \mu + \text{pruning/pruning.tree} \times \text{billet position} \times \text{radial position} + \varepsilon$$

where individual sheet observations Y are predicted by the nested treatment structure of (pruning treatment / individual tree within pruning treatment) in factorial combination with billet position and radial location of the veneer sheet, and ε is the residual variance for the individual observations.

Results and discussion

Quarter-sawing trial

No surface checking was visible on the sawn boards produced in the quarter-sawing trial.

Variable shrinkage was evident in the boards prior to reconditioning. Bands of early wood (the lighter coloured, lower density wood laid down during the spring and early summer, when growth is more rapid) displayed greater tangential shrinkage than the darker coloured late wood, giving a ‘washboard’ appearance (Figure 9). Most of this variable shrinkage was recovered on reconditioning, so that the boards recovered a uniform cross-section (Figure 10).

Figure 9. Board cross-sections after drying and prior to reconditioning (displaying ‘washboarding’)

Figure 10. Board cross-sections after reconditioning

Internal checking was virtually eliminated in the thin-section quarter-sawn boards, using the processing methods that were adopted. Reconditioning reduced the number of visible internal checks, as was found in the previous CRC for Forestry study (Blakemore *et al.* 2010), with the proportion of check-free boards increasing from 94.5% prior to reconditioning, to 98.3% after reconditioning (Figure 11). While it must be kept in mind that the green-sawn cross-sectional area per board was reduced approximately four-fold relative to the previous study (75 mm × 9 mm compared with 100 mm × 28 mm), the sample size of boards examined was very large (a total of 1240 boards in two large stacks) so the result is robust. This demonstrates that the strategy of sawing thin-section quarter-sawn boards followed by careful air-drying and reconditioning is technically viable and can indeed produce check-free boards.

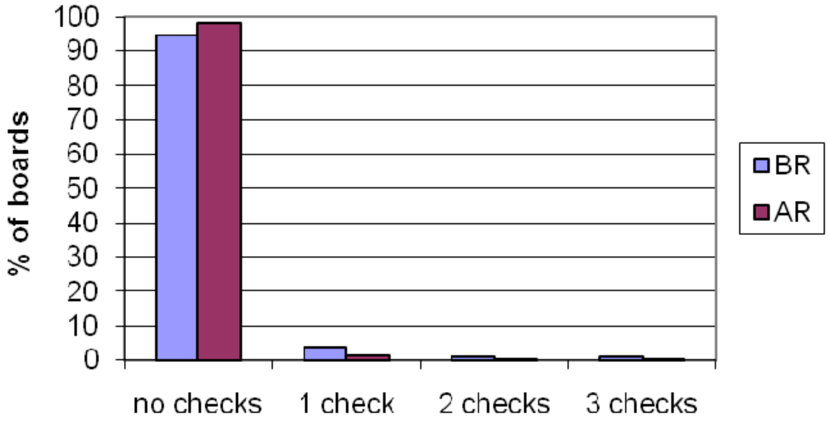

Figure 11. Occurrence of internal checks in two stacks of quarter-sawn boards, before (BR) and after (AR) steam reconditioning

Figure 12 shows matched cross-section images from five typical boards, before and after steam reconditioning. Volume recovery on reconditioning is evident, and closure of two small internal checks in board number 160 can also be seen.

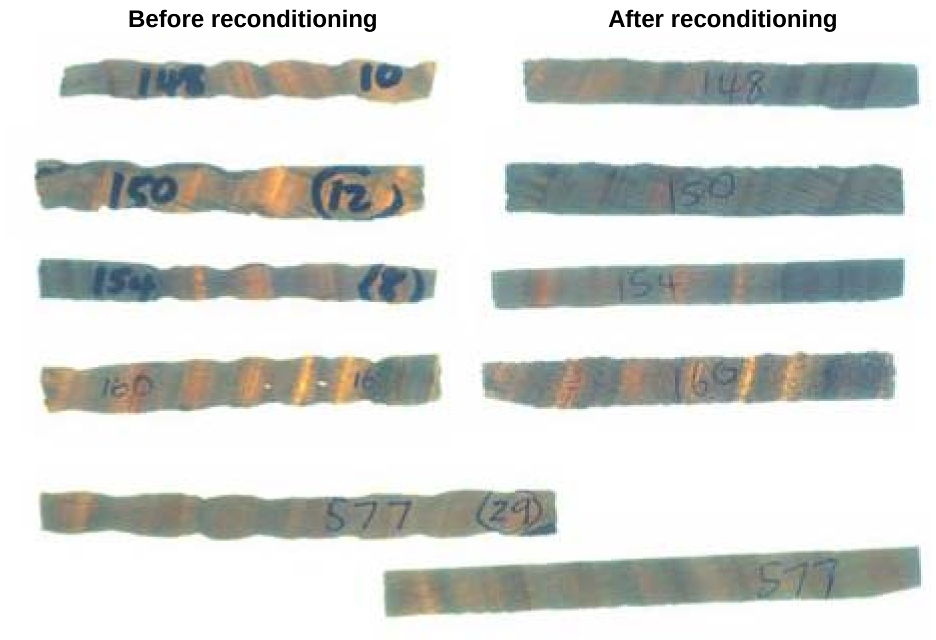

Figure 12. Matched cross sections of five boards, before and after reconditioning

Veneering trial

A total of 663 veneer sheets from the pruned logs and 590 sheets from the unpruned logs were graded. Detailed results for the grading of individual billets are shown in Appendix 2.

Grade recoveries

As expected, pruned logs gave higher recoveries of the best veneer grades, A and B, compared with unpruned logs (Table 4, Figures 13–14).

Table 4. Total number of veneer sheets (1.83 m longitudinal × 0.914 m tangential) of different grades recovered from (a) five pruned logs and (b) five unpruned logs

	Veneer grades				
	A	B	C	D	Reject
			(a) pruned logs		
First billet	21	49	164	12	1
Second billet	16	38	78	49	31
Third billet	1	4	54	101	44
Total	38	91	296	162	76
			(b) unpruned logs		
First billet	0	44	116	52	12
Second billet	0	17	81	60	37
Third billet	0	2	44	29	96
Total	0	63	241	141	145

For both pruned and unpruned logs, the first (lowest) of the three billets yielded higher recoveries of better veneer grades than the second billet, and the third billet gave the lowest recoveries of good grades.

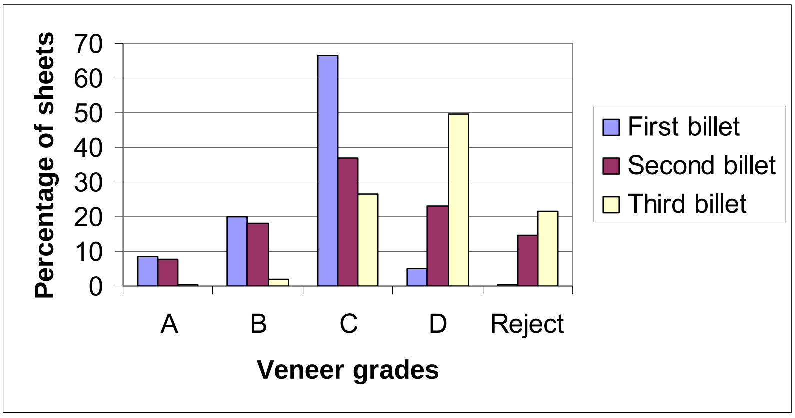

Figure 13. Percentage recovery of veneer grades from first, second and third billets of pruned logs

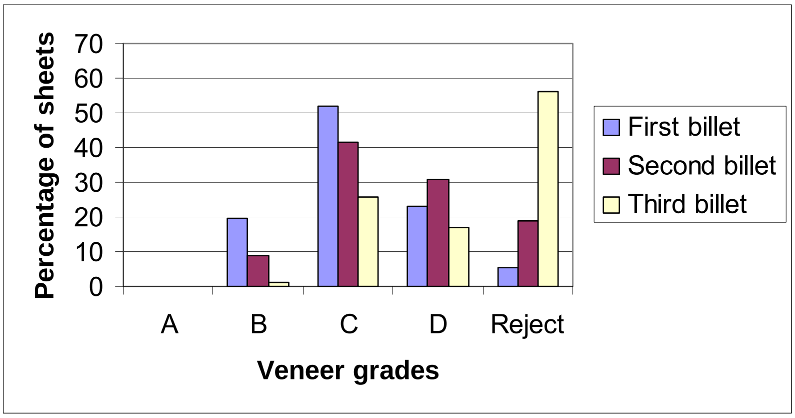

Figure 14. Percentage recovery of veneer grades from first, second and third billets of unpruned logs

A chi-squared test, based on the sheet numbers as shown in Table 4, was conducted to test the null hypothesis that the proportional recoveries of different veneer grades did not differ between pruned and unpruned logs. The null hypothesis was rejected (Pearson $\chi^2 = 71.2$, 4 df, $p<0.001$) confirming that grade recoveries of pruned and unpruned logs differed significantly.

For both pruned and unpruned logs, the effect of billet position on grade recoveries was similarly tested using chi-squared tests. Again, the tests confirmed that billet position had a significant impact on the proportional recoveries of different veneer grades for both pruned logs (Pearson $\chi^2 = 271.9$, 8 df, $p<0.001$) and unpruned logs (Pearson $\chi^2 = 172.5$, 6 df, $p<0.001$).

The percentage of green volume recovered as veneer grades A and B, and as veneer grades A–D, was higher for pruned logs than for unpruned logs, as summarised in Table 5.

Table 5. Recovery of grade veneer sheets as a percentage of green volume, for pruned and unpruned logs

	Pruned logs	
	Grades A&B	Grades A–D
First billet	18	64
Second billet	17	56
Third billet	2	55
average	12	59

	Unpruned logs	
	Grades A&B	Grades A–D
First billet	12	58
Second billet	6	54
Third billet	1	27
average	6	46

As noted in the Methods section of this report (p. 10), green volume recoveries are slightly underestimated because a small and variable number of 3' × 6' (longitudinal × tangential) sheets cut from the butt end of some of the billets during rounding-up were excluded from the count of recovered sheets.

The pruning treatment applied in this study consisted of a single pruning lift to a height of 6.4 m at age 6 years. This meant that many of the branches would have already died prior to pruning. The pruned logs therefore may have had higher levels of grade-limiting defects associated with dead and rotted knots than would have been the case if the pruning treatment had consisted of three successive lifts each of 2.1 m, as is now standard practice for Forestry Tasmania's pruned plantations (Wood *et al.* 2009).

The recovery of different grades of veneer from individual logs varied greatly, as can be seen by inspecting the differences among logs, noted in Appendix 2. A study on a larger sample of logs from a range of sites would be needed to precisely determine the grade recoveries obtainable from pruned and unpruned *E. nitens* grown to the target size range. It should also be noted that there could be major differences in grade recoveries for *E. nitens* grown to different log sizes, and site could also influence recoveries.

Levels of green recovery achieved in this first trial compare favourably with those from unpruned plantation-grown logs of five subtropical eucalypt species where mean recoveries of veneer grades A–D were below 50%, for all species examined (Thomas *et al.* 2009). These authors found that percentage of green recovery increased significantly with increasing small-end diameter of the veneer logs. This factor could not be evaluated in our trial on a tree-to-tree basis because there was minimal tree-to-tree variation in the small-end diameter of the bush logs (Table 2).

Basic density and stiffness of veneer

Analysis of variance of the subsample of veneer sheets used to study basic density and dynamic MoE showed that (i) pruning had no effect on basic density, AWV or MoE; (ii) basic density of veneer sheets varied significantly between radial positions in the billet and between trees within pruning treatments; (iii) AWV varied significantly between billet positions and between trees within pruning treatments; and (iv) dynamic MoE varied significantly between billets, between radial positions and between trees within pruning treatments (Table 6). There was also a significant, but less important ($p<0.05$), interaction between pruning treatment and billet position for MoE.

Basic density increased from the inner heartwood to the outer heartwood, which is laid down in later years. AWV increased with increasing height, while dynamic MoE increased both with increasing billet height and from inner to outer heartwood (Table 7). Radial and longitudinal trends for basic density, AWV and stiffness, and the significant differences between trees in these traits, were generally consistent with the patterns of variation in these traits described in earlier CRC for Forestry studies on plantation-grown *E. nitens* (Valencia 2008; Washusen *et al.* 2009).

Dynamic MoE tends to be slightly higher than static MoE, which is determined by bending tests and is used as a measure of stiffness in product standards (Ilic 2001). The values of dynamic MoE in Table 7 are slightly lower than those for static MoE determined on short clear sections cut from sawn boards from 22-year-old *E. nitens* trees from a silvicultural trial at Goulds Country, north-east Tasmania, which averaged 11–13 GPa (Washusen *et al.* 2009). They match very closely with whole-board static MoE values determined by testing sawn boards cut from unpruned 13-year-old *E. nitens* trees from Tarraleah in central Tasmania (Blackburn *et al.* 2010). These relatively low levels of stiffness, compared to native-forest eucalypt wood and plantation logs of subtropical eucalypt species such as *E. cloeziana*, *E. dunnii* and *E. pilularis* (Thomas *et al.* 2009; Warren *et al.* 2009), indicate that plywood products manufactured from *E. nitens* veneers would be of low-to-moderate stiffness and strength.

Table 6. Analysis of variance of veneer sheet basic density, acoustic wave velocity and dynamic modulus of elasticity, determined for two veneer sheets from each billet. df = degrees of freedom, vr = variance ratio, ms = mean square, F pr = F-probability. 'tree' refers to variation between trees within each pruning treatment.

	Basic density		
Source of variation	df	vr	F pr
pruning	1	0.28	n.s.
billet	2	0.34	n.s.
radial position	1	45.38	<.001
tree	8	4.93	0.003
pruning.billet	2	2.26	n.s.
pruning.position	1	0.07	n.s.
billet.position	2	0.66	n.s.
tree.billet	16	1.81	n.s.
tree.position	8	1.29	n.s.
pruning.billet.position	2	3.31	n.s.
residual	16		

	Acoustic wave velocity		
Source of variation	df	vr.	F pr
pruning	1	0.21	n.s.
billet	2	12.94	<.001
radial position	1	0.13	n.s.
tree	8	5.92	0.001
pruning.billet	2	1.6	n.s.
pruning.position	1	0.22	n.s.
billet.position	2	0.87	n.s.
tree.billet	16	0.55	n.s.
tree.position	8	0.41	n.s.
pruning.billet.position	2	0.64	n.s.
residual	16		

	Dynamic modulus of elasticity		
Source of variation	df	vr	F pr
pruning	1	0.06	n.s.
billet	2	24.25	<.001
radial position	1	10.52	0.005
tree	8	8.35	<.001
pruning.billet	2	4.93	0.021
pruning.position	1	1.05	n.s.
billet.position	2	0.26	n.s.
tree.billet	16	1.48	n.s.
tree.position	8	0.19	n.s.
pruning.billet.position	2	3.34	n.s.
residual	16		

Table 7. Mean basic density, acoustic wave velocity and dynamic modulus of elasticity of veneer sheet, for three billet positions (1 = butt, 2 = middle and 3 = uppermost) and inner and outer heartwood positions (average of pruned and unpruned treatments)

	basic density (g cm^{-3})		
billet	inner heartwood	outer heartwood	mean
1	0.47	0.51	0.49
2	0.46	0.52	0.49
3	0.47	0.52	0.50

	acoustic wave velocity (km s^{-1})		
billet	inner heartwood	outer heartwood	mean
1	3.67	3.76	3.72
2	4.06	3.93	4.00
3	4.16	4.13	4.15

	dynamic modulus of elasticity (GPa)		
billet	inner heartwood	outer heartwood	mean
1	7.6	8.7	8.1
2	9.1	9.7	9.4
3	9.9	10.7	10.3

Further work

Sawn boards

This study has shown that it is technically feasible to produce check-free quarter-sawn boards cut from pruned plantation-grown *E. nitens*, if green board thickness is reduced to 9 mm. Whether there is an economic application for such quarter-sawn boards is beyond the scope of the report. Finished thickness after drying and planing would be reduced to about 7 mm. Volume losses to sawdust, and sawing costs, are clearly much higher than would be the case for boards of more conventional thickness, and wholesale price of select-grade thin-section boards would be lower. Previous studies (Blakemore *et al.* 2010) found little reduction in internal checking for back-sawn boards of 19 mm finished thickness, relative to 24 mm back-sawn boards. An intermediate board thickness in the range 10-15 mm (finished) might give an optimum balance between an acceptable level of checking defects, and acceptable processing costs and volume recovery. Such a balance will depend on the sawmilling system and the end uses for the boards.

Samples of the thin-section quarter-sawn boards free from surface and internal checks will be provided to interested manufacturers to enable them to evaluate this material.

Veneer

Studies on the manufacture of plywood products from veneer of plantation-grown *E. nitens* and the properties of these products are warranted, although such work is outside the scope of the CRC for Forestry research program.

Acknowledgements

Support from several organisations made these trials possible. Forestry Tasmania supplied logs from its plantation at Lisle, and the assistance of Mr Dion McKenzie during harvest and consignment of logs was most valuable. The Timber Training Centre at Creswick, Victoria carried out the sawing. Ta Ann Tasmania made available its rotary veneering plant at Smithton, Tasmania for the veneering study, and carried out veneering of the logs and drying of veneer sheets. The assistance of Mr David Ridley in planning the veneering trial is particularly acknowledged. The assistance of the University of Tasmania's Centre for Sustainable Architecture in Wood (CSAW), and in particular Mr Ross Farrell, who made available CSAW's identity-tracking system for veneer sheets (designed and constructed by Mr Stephen Wright), is gratefully acknowledged.

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Appendix 1: Veneer grading criteria

The grading criteria used in this study produced veneer grades equivalent to those specified in the Australian/New Zealand Standard AS/NZS 2269:2004 Plywood – Structural for hardwood veneer (August 2006).

The standard specifies five veneer grades: A, S, B, C and D. For this evaluation only the four grades A, B, C and D were used. Each of these grades may be face grade veneers for various applications listed below or for internal (core) veneers which are usually of a minimum quality of Grade D.

The standard was applied in order to quantify defects on each sheet of veneer that was produced. The criteria and allowances for each defect for each grade are listed in Table A1 below. These defect allowances approximate those allowed in AS/NZS 2269:2004, with some modifications where defects are not explicitly listed.

Grade A is an appearance-grade veneer where the surface appearance is a primary consideration and where no surface coating or overlay is applied. This veneer carries the least amount of defect of the four grades.

Grade B is also an appearance-grade veneer carrying slightly more defect than Grade A. In final use this may have a painted surface.

Grade C is a non-appearance grade that may be used for plywood surfaces where all open defects are filled. This may be used for structural applications where a decorative overlay is applied.

Grade D is a non-appearance grade with open imperfections up to 75 mm wide, and is designed specifically for structural applications.

Table A1. Defect limitations applied to the four grades of veneer

	Grade A	Grade B	Grade C	Grade D
Free of active insect attack	✓	✓	✓	✓
Aggregate width of defects in any 300 mm line across the grain	45 mm	45 mm	75 mm	75 mm
Tight cut	✓	✓	✓	✓
Sheet in one piece	✓	✓	✓	✓
Kino pockets	X	X	X	As for unfilled holes
Unfilled holes	X	X	X	<75 mm across the grain, <15 000 mm^2; no limitation
Unfilled splits	X	X	X	<5 mm across the grain, <100% sheet length <15 mm across the grain, <50% sheet length <25 mm across the grain, <33% sheet length
Tight kino veins	X	<3mm across the grain, <750 mm^2	No limitation	No limitation
Knots, dead or loose	X	X	As for holes	No limitation on size and number
Knots, tight	<4mm across the grain, <4 per sheet	<25 mm across the grain, unlimited # >25<40 mm across the grain, <4 per sheet	<50mm across the grain, no limitation	No limitation on size and number
Filled holes	<6 mm across the grain, <4 per sheet	<20mm across the grain, <600 m^2 per sheet	<50 mm across the grain, no limitation	See unfilled holes
Pin holes	<2mm across the grain	Unlimited	Unlimited	Unlimited
Filled splits	<3 mm across the grain, <450 mm^2	<3mm across the grain, <750 mm^2	<9mm across the grain, <50% sheet length, or <12 mm across the grain and 600 mm length	See unfilled splits
Sloping grain	<1:7 over 25% of the sheet; no limitation near permitted defects	<1:7 over 25% of the sheet; no limitation near permitted defects	<1:7 over 25% of the sheet; no limitation near permitted defects	<1:7 over 25% of the sheet; no limitation near permitted defects
Roughness	Slight	Slight	Slight	Associated with local imperfections; no limitation
Discolouration	Slight	No limitation	No limitation	No limitation

Appendix 2: Recoveries of different veneer grades by sheet, billet volumes and recovery of green volume for 30 individual billets in veneering study

Pruning treatment	*Billet position*	*Log no.*	**Number of sheets recovered per grade**					**billet volume** (m^3)	**% recovery of green volume**	
			A	*B*	*C*	*D*	*reject*		*grades A&B*	*grades A–D*
unpruned	lower	1			24	4	10	0.277	0	41
unpruned	middle	1				9	15	0.219	0	17
unpruned	upper	1					30	0.198	0	0
unpruned	lower	2		18	20	9		0.288	25	65
unpruned	middle	2			24	16	1	0.239	0	67
unpruned	upper	2		2	14	15	6	0.209	4	59
unpruned	lower	3			41	7		0.317	0	61
unpruned	middle	3			18	16	12	0.258	0	53
unpruned	upper	3			1	2	29	0.226	0	5
unpruned	lower	4			9	32	2	0.292	0	56
unpruned	middle	4			17	18	6	0.222	0	63
unpruned	upper	4				7	28	0.197	0	14
unpruned	lower	5		26	22			0.296	35	65
unpruned	middle	5		17	22	1	3	0.236	29	68
unpruned	upper	5			29	5	3	0.206	0	66
							mean	**0.245**	**6**	**47**
pruned	lower	6		1	46	2		0.307	1	64
pruned	middle	6			16	14		0.258	0	47
pruned	upper	6			24	7	5	0.223	0	56
pruned	lower	7	20	7	19	5	1	0.308	35	67
pruned	middle	7	16	7	2	3	20	0.258	36	44
pruned	upper	7			4	20	20	0.233	0	41
pruned	lower	8		3	46	2		0.321	4	64
pruned	middle	8		25	15	6	1	0.268	37	69
pruned	upper	8	1	4	7	30		0.246	8	69
pruned	lower	9	1	29	16	3		0.312	39	63
pruned	middle	9		4	29	10		0.258	6	67
pruned	upper	9			11	30		0.230	0	72
pruned	lower	10		9	37			0.292	12	63
pruned	middle	10		2	16	16	10	0.249	3	55
pruned	upper	10			8	14	19	0.227	0	39
							mean	**0.266**	**12**	**58**