High-value wood resources

Technical Report 223

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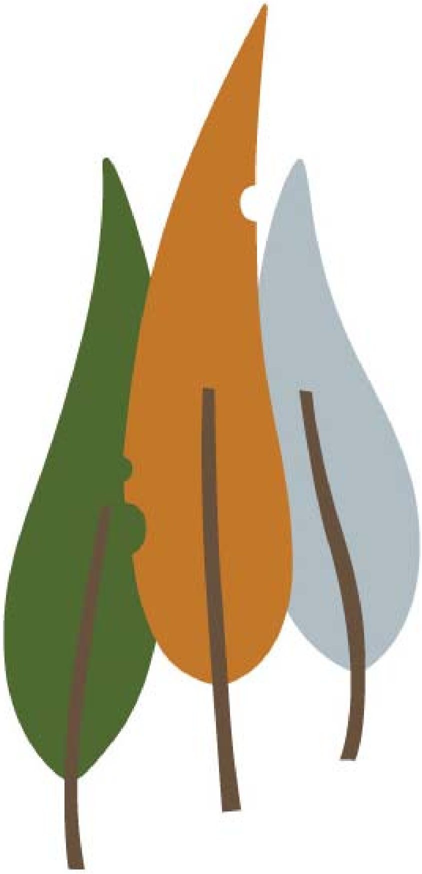
CRC for Forestry
Researching sustainable forest landscapes



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Public report

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Summary

This report evaluates the wood and veneer properties of plantation-grown spotted gum (*Corymbia citriodora* subsp. *variegata*, or CCV) and Dunn's white gum (*Eucalyptus dunnii*), grown at different stockings, in thinning trials near Ellangowan in north-east New South Wales (mean annual rainfall 1050 mm) and Kingaroy in south-east Queensland (mean annual rainfall 873 mm).

Thinning trials were established at age seven years. Both species showed a significant increase in stem diameter growth of the dominant trees in response to thinning. At age 10 years, trees from the unthinned (950–1270 stems ha^{-1}) and 300 stems ha^{-1} treatments were selected for veneering.

Five dominant trees were felled from each combination of species × sites × thinning treatment. Diameter at breast height over bark of the selected trees ranged from 20 cm to 27 cm at Ellangowan, and 19 cm to 26 cm at Kingaroy. From each tree, 1.5 m long billets were removed at two positions: a butt billet from 0.3–1.8 m above ground and a top billet from approximately 5.5–7.0 m. Log end splitting was assessed 24 hours after harvesting and again after steaming, approximately four days after harvesting. Disks from just above both billets were collected for assessment of wood properties.

Billets were peeled on a spindleless veneer lathe to produce a full veneer ribbon with a target green thickness of 2.8 to 3.0 mm. The 1.55 m wide (tangential dimension) veneer sheets were dried and graded according to AS/NZ Standard 2269:2008, which describes four veneer grades. Veneer samples taken along the length of the veneer ribbon, at regular intervals of 1.55 m, were tested for stiffness, shrinkage and density. Veneer length measurements were used to calculate the radial distance of each sample from the central axis of the billet.

Overall veneer gross recoveries ranged from 50% to 70%. They were significantly lower at the Kingaroy site, for both species. The veneer recoveries achieved were 2–3 times higher than typical green off saw recoveries from small plantation hardwood logs of similar diameter.

Most of the veneer recovered was classified as D-grade. CCV trees from the Ellangowan site yielded up to 38% of the better C-grade and higher grade veneers. The main limiting factors that prevented veneer from meeting higher grades were the presence of kino defects and encased knots. Splits in *E. dunnii* veneer also contributed to reduced grade quality.

Log end splits were higher for *E. dunnii* than for CCV, and logs from Ellangowan exhibited more severe splitting. Split index was generally higher for top than for butt billets. Split index was strongly correlated with the average veneer grade from corresponding billets.

The Ellangowan site, where rainfall was higher and trees grew faster, yielded significantly denser and stiffer veneers than did the drier sites near Kingaroy, where tree growth was slower. The difference was more pronounced for *E. dunnii* than for CCV.

Differences in measured wood properties between thinned and unthinned treatments were generally small and not significant. On average, 10% of billet volume was lost during the peeling rounding-up process. Much of the wood laid down following thinning was

removed during rounding-up, meaning the effect of thinning on veneer properties could not be effectively assessed.

CCV was confirmed as having high veneer density and very good veneer stiffness, exceeding 15 GPa, making it very suitable for structural products. *E. dunnii* also demonstrated good potential as a useful structural plywood resource, achieving stiffness above 10 GPa.

Veneer stiffness and density in CCV increased from pith to bark at both sites, while for *E. dunnii* there was a radial increase in these properties at the Ellangowan site only. At the drier Kingaroy site, veneer stiffness and density declined from mid-radius to the log periphery. This may be associated with prolonged drought from 2005 to 2009, corresponding to the later years of tree growth at the Kingaroy site. CCV appeared to be less sensitive to drought conditions.

Standing tree acoustic velocity, determined by the Fakopp time-of-flight method, provided a reliable prediction of average veneer stiffness for both species (R^2=0.78 for CCV and R^2=0.90 for *E. dunnii*) suggesting that the Fakopp method may be a useful indicator of tree and stand quality, in terms of veneer stiffness in standing trees.

Introduction

Subtropical eucalypt plantations established in Queensland and New South Wales total slightly less than 150 000 ha, which is 15% of Australia's hardwood plantation estate (Gavran and Parsons, 2010). The rate of plantings accelerated after 2000, when private forestry companies, many using managed investment schemes (MIS), became active in the region. The two most important species by area are Dunn's white gum (*Eucalyptus dunnii*) and spotted gum (*Corymbia citriodora* subsp. *variegata*, CCV), which together comprise approximately 54 000 ha of the subtropical plantation estate. Much of the *E. dunnii* plantation area was established for pulpwood production, whereas plantations of CCV have been targeted more at solid wood production (Nichols *et al.* 2010).

The transition from mature native forest hardwoods to a young plantation-grown resource presents some notable challenges for the industry, among them the suitability of the plantation resource for current products and choosing appropriate processing technology. One of the obvious differences is the smaller log size. Australia's hardwood sawmilling industry has evolved from relatively large diameter feedstock, and the pricing structures for end products have been based on volume recoveries of about 35% and relatively high proportions of durable, deeply coloured heartwood. By comparison, plantation-grown wood requires different handling and processing systems and the recoveries of sawn products are generally lower.

New processing technologies provide an opportunity for the development of roundwood and engineered wood products from young plantation wood. Small spindleless veneer lathes are a promising technology to produce veneer sheets from relatively small diameter logs, as an alternative processing option to optimise the recovery and use of this plantation resource. Early results from trials currently underway at the Forestry Science research unit of the Queensland Department of Agriculture, Fisheries and Forestry in Brisbane indicate that the subtropical and tropical plantation hardwoods have suitable attributes for a range of engineered wood products, including plywood and laminated veneer lumber. Defects within individual knotty veneer sheets can be evened out within the laminated product, allowing consistent product grades to be achieved. This is in contrast to sawn board products processed from similar aged trees, which display high proportions of low-grade boards.

Thinning trials were established by the CRC for Forestry to investigate the effect of thinning on growth response and wood properties in CCV and *E. dunnii* in two contrasting locations: drier sites near Kingaroy in south-east Queensland, and a wetter site near Ellangowan in north-east NSW. Both species showed a significant increase in the rate of stem diameter growth after thinning at both sites (Glencross *et al.* 2011).

This report provides an assessment of wood properties, peeling performance and veneer quality of logs from trees of both species, sourced from two contrasting thinning treatments (thinned to 300 stems ha^{-1}, and unthinned control) in these trials. Billets from two different tree heights were peeled. This enabled an examination of the effects of site, species, thinning treatment and billet height and their interactions. Standing tree acoustic wave velocity was assessed before the selected trees were felled, and the effectiveness of this non-destructive assessment method in predicting veneer stiffness was evaluated.

Material and Methods

Site selection

This study examined *Corymbia citriodora* subsp. *variegata* (CCV) and *Eucalyptus dunnii* (E. dunnii) (Figure 1). For each species, two sites with known and similar management histories were selected within the plantation estate of Forest Enterprises Australia in subtropical eastern Australia. The sites were Reids plantation at Ellangowan, located 50 km south-west of Lismore in north-east NSW, Barron plantation, located 15 km south-west of Kingaroy in south-east Queensland, and Tingoora plantation, located 40 km north of Kingaroy (Table 1). The sites provided contrasting rainfall conditions during the life of the plantations. The mean annual rainfall for the 2001–2010 period at Ellangowan, 1096 mm, was close to the long-term average (97% of long-term mean rainfall), whereas at Kingaroy, the mean annual rainfall for 2001–2010, 783 mm, was 23% below the long-term average.

Plantations were established in February–March 2001 at 4 m × 2 m spacing. A post-planting fertiliser of 100 g of di-ammonium phosphate per tree was applied. Weed control was conducted after planting, using Verdict 520® (0.5 l/ha) and Verdict® (0.8 l/ha) herbicide sprays. The identities of seed sources used at each site are not known with certainty, so any within-species genetic differences between the sites could not be accounted for.

Table 1. Summary information for CCV and *E. dunnii* plantations from two sites (sourced from Glencross *et al*. 2011)

Parameters	Ellangowan		Kingaroy	
Species	CCV	*E. dunnii*	CCV	*E. dunnii*
Site	Reids	Reids	Tingoora	Barron
Stocking prior to thinning (spha)	1050	1270	950	930
Age thinned (year, month)	7 y 9 m	7 y 9 m	6 y 9 m	6 y 9 m
Date harvested (month, year)	Aug 2011	Aug 2011	Sep 2011	Sep 2011
Mean annual rainfall (mm)	1096	1096	783	783
Elevation (m)	52	52	449	465
Soil type	Kurosol	Kurosol	Ferosol	Ferosol
Latitude (° ‘ S)	29 02	29 02	26 22	26 34
Longitude (° ‘ E)	153 05	153 05	151 48	151 45

Thinning trials

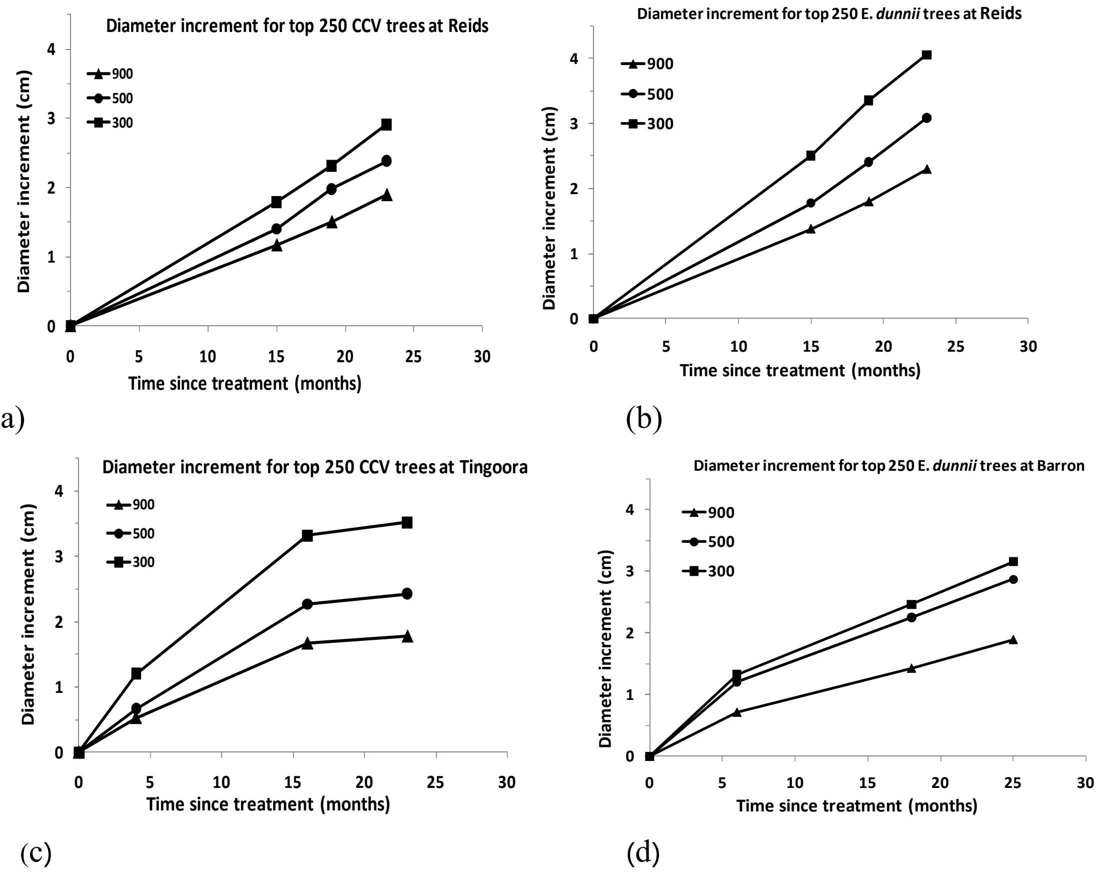
Thinning treatments had been imposed at age seven years and nine months and six years and nine months respectively at the Ellangowan and Kingaroy sites (Table 1). For each site, the thinning treatments of 300 stems/ha and 500 stems/ha and an unthinned control treatment (with stocking in the range 950–1270 stems/ha) were applied in a randomised complete block design with four replicates. Treatment plots were square and 0.06 to 0.07 ha in size. Each net treatment plot was surrounded by a two-row buffer, to which the same thinning treatment was applied. The commercially valuable stems that were retained in the thinned plots were not evenly distributed; therefore, the spacing of retained trees in the thinned plots was somewhat uneven.

The diameter at breast height over bark (DBHOB) of all trees was measured at six-monthly intervals after thinning (Glencross *et al.* 2011).

Figure 1. Thinned plots at Reids site: a) CCV plantation; b) *E. dunnii* plantation

Selection of trees for destructive sampling

For both species, thinning significantly increased diameter growth of the top 250 trees per hectare in the 24-month period after treatment, at both sites (Glencross *et al*. 2011, Figure 2). For the current study, two contrasting treatments—300 stems ha^{-1} and unthinned control—were sampled, to investigate whether significant differences would also be observed in processing performance and wood properties of trees selected from those treatments.



(a) (b)

(c) (d)

Figure 2. Diameter increment (cm) by treatment for the top 250 stems/ha: a) CCV at Ellangowan; b) *E. dunnii* at Ellangowan; c) CCV at Kingaroy; d) *E. dunnii* at Kingaroy (source: Glencross *et al.* 2011)

For each species and thinning treatment, at each site, five dominant trees with above-average stem diameters were selected. The aim was to assess the potential of trees that would be retained as final crop trees for veneer log production. Consequently, the diameter distribution of the selected trees was not truly representative of the diameter distribution of all retained trees within the investigated treatment, but rather of the diameter of the best 250 trees per hectare within treatments. A visual assessment in the field identified dominant trees with acceptable log straightness and minimum sweep. Some of the trees were selected from outside the net treatment plots, but within the buffer rows of the gross plots, thinned to the same stocking. This was done to maintain, as far as possible, the integrity of the thinning trials for further study.

At each site and for both species, mean DBHOB (1.3 m) of the five selected trees in the thinned treatments was larger than those from the unthinned treatment, although the differences were not statistically significant because of the small sample sizes (Table 2). DBHOB of the selected trees ranged from 20 cm to 27 cm at Ellangowan, and 19 cm to 26.3 cm at the drier Kingaroy sites. On average, selected trees from Kingaroy were one to two cm smaller in DBHOB, with the differences being more evident for *E. dunnii*. Site differences were more pronounced for total tree height for both species, with selected trees from the Kingaroy sites being five to six m shorter than those from Ellangowan.

Table 2. Means and ranges of breast height over bark tree diameter (DBHOB) and total tree height (TH) of trees sampled for veneering study

Location	**Ellangowan**				**Kingaroy**			
Trial	**Reids**				**Tingoora**		**Barron**	
Species	**CCV**		***E. dunnii***		**CCV**		***E. dunnii***	
Treatment (spha)	**300**	**control**	**300**	**control**	**300**	**control**	**300**	**control**
DBHOB mean (cm)	23.8	23.5	23.3	21.9	22.5	20.9	20.9	20.4
DBHOB range (cm)	22.7-25.0	22.5-24.4	21.8-27.0	20.0-25.6	20.9-26.3	20.1-22.3	19.0-24.1	19.5-21.3
TH mean (m)	24.5	24.7	24.1	23.6	18.8	18.8	17.6	18.0
TH range (m)	22.7-26.2	23.0-25.7	23.3-24.7	20.4-24.5	17.3-21.5	18.0-19.9	16.0-19.6	16.9-18.9

Standing tree assessment

Prior to sampling, time-of-flight for an acoustic signal was assessed on each selected standing tree, using a Fakopp (Agfalva Hungary) microsecond timer. The readings were taken at four circumferential positions. Acoustic wave velocity (AWV) values for each tree were obtained from the ratio of the distance between the two probes (1.2 m) and the average time-of-flight of the signal.

Destructive sampling

The selected trees were manually harvested in August 2011 (Ellangowan) and September 2011 (Kingaroy) when the trees were approximately 10.5 years old. In total, 40 trees were harvested: 2 species × 2 sites × 2 treatments × 5 trees per treatment. From each tree, two 1.5 m long billets were removed: a butt billet from 0.3–1.8 m above ground and a top billet from a height of approximately 5.5–7.0 m at Ellangowan, or 4.5–6.0 m at the sites near Kingaroy (Table 3). Top billets were positioned 1 m lower at the Kingaroy sites because of the lower total tree heights there, relative to Ellangowan.

In addition, 50 mm thick disk samples were removed just above both billets for further evaluation of wood properties. A 100 mm disk cut from the butt section was sampled for assessment of interlocking grain. All disks and billets were labelled and sealed in plastic bags for transport and storage. Billets were debarked and end sealed with a wax emulsion, 24 hours after cross-cutting; that is, after initial splitting, score assessment was completed. Figure 3 shows sampling and typical sample billets.

The billets were transported to the DAFF (previously DEEDI) Salisbury Research Centre, Queensland for veneer processing.

Figure 3. Destructive sampling and collecting billet and disk samples

Table 3. Sampling strategy for billets and disk sample recovery from each tree

Cross-cut	Cross-cut height (m)	Billet/disk samples	Test
1	0.3 1.8	1.5 m butt billet	Split assessment, peeling
2	1.8 1.85	50 mm disk	Heartwood proportion, basic density
3	1.9 2.0	100 mm disk	Interlocking grain
4	5.5 (4.5) 7.0 (6.0)	1.5 m top billet	Split assessment, peeling
5	7.0 (6.0) 7.05 (6.05)	50 mm disk	Heartwood proportion, basic density

Note: Heights sometimes were varied slightly to avoid defects. The value in parentheses is the height of billet and samples for the Kingaroy sites

Log end splitting assessment

Splitting was assessed at two stages: 24 hours after felling and after steaming (approximately four days after felling). The length of end splits on both the log ends and any extension of the splits along the log were recorded. The following methods were used to calculate log end split area index (SAI) for each log end:

(Equation 1) $$SAI = [(SL_{END}^2/2) + (SL_{SURFACE} * SL_{END})] / R^2$$

Where: SL_{END} = split length on the log end; $SL_{SURFACE}$ = split length on the log surface; R = mean radius of the log end

The symbols used in Equation 1 are also shown in Figure 4.

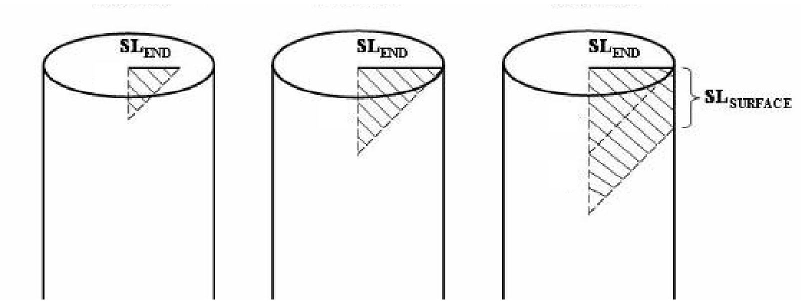


Figure 4. Symbols used in Equation 1 to calculate log end split area index (The shaded area is the split plane, adapted from Yang 2005)

Billet stiffness assessment

Prior to steaming, all billets were acoustically tested, using the CIRAD Forêt Bing device as described by Brancheriau and Baillères (2003). Bing allows the determination of dynamic modulus of elasticity (MOE_{dyn}) by analysing the natural vibration spectrum, as pictured in Figure 5. The dynamic MOE is estimated from the measurement combination of vibration signal and wood density.

Figure 5. Acoustic testing of peeling billets to obtain dynamic MOE using Bing device

Disk assessment

Wood disk samples collected just above the butt and top billets (Table 3) were further processed for assessment of heartwood proportion and basic density.

Heartwood measurements were visually assessed as heartwood is clearly distinguishable from sapwood for both species, on the basis of colour. Sapwood width was measured in the radial direction. Heartwood and total cross-sectional areas were calculated using their respective radial dimensions, and heartwood proportion was calculated as a percentage of disk basal area under bark.

Basic density was measured on two wedge samples, cut from opposite positions from a single disk and positioned to minimise the inclusion of tension wood or other defects. Each wedge sample was further sectioned into two pieces, representing the sapwood and heartwood zones. Basic density was assessed using the water displacement method described in *AS/NZS 1080.3:2000* (Standards Australia, 2000). Average basic density for the whole disk was estimated by dividing the combined oven-dry weights by the combined green volume of sapwood and heartwood sections.

Interlocking grain ratio was also measured on an additional 100 mm thick disk, removed just above the butt billet, using the method described in Thinley *et al*. (2005). Fresh disks were split through the pith, using an axe and block buster so the natural grain direction was exposed by the split. Once split, wavy grain pattern was recorded for each sample and further analysed, using an image analysis program to measure the total distance of wavy grain edge, which was further divided by the actual sample diameter of a straight edge (Equation 2).

(Equation 2) $$\text{Interlocking grain ratio} = \frac{\text{Total split (wavy) edge distance (mm)}}{\text{Radial length of straight edge (mm)}}$$

If there is no interlocked grain, this ratio will equal 1.0. The higher the value of this ratio, the larger the amount of interlocked grain.

Veneer processing

Mean diameters (average of shorter and longer axis) were measured at both billet ends. Billet volumes were calculated using Smalian's formula (Equation 3). These were used in veneer recovery calculations.

(Equation 3) $$V = [\frac{(LEDUB + SEDUB)}{2} \times \frac{1}{2}]^2 \times \pi \times L$$

Where: V = billet volume (m^3); LEDUB = large end diameter under-bark (m); SEDUB = small end diameter under-bark (m); L = billet length after merchandising to 1.3 m.

The taper of each processed billet was calculated as the difference between LEDUB and SEDUB, divided by the billet length. Lower taper will tend to increase recoveries as less wood is lost from rounding-up during the peeling process.

The billets were heat-treated to a core temperature of 90 °C prior to peeling, to facilitate easier peeling. Core temperature elevation was achieved by exposing the billets to full steam conditions for 24 hours before peeling. After heat treatment, the billets were assessed again for splitting, using the method described above, and then merchandised to 1300 mm in length (trimmed equally from both sides to reduce any end splitting).

The billets were peeled on an Omeco spindleless lathe (Figure 6a). The peeling started with rounding-up, to obtain a cylindrical log and to remove any taper and eccentric shape in the log. All the fragments recovered during the rounding-up process were discarded. Once the peeled sheet was solid, the full ribbon was produced with a target green thickness of 2.8 to 3.0 mm (Figure 6b). The veneer ribbon was peeled until a core diameter of approximately 45 mm was attained. Two billets (one top CCV billet and one butt *E. dunnii* billet, both from Kingaroy sites) could not be peeled beyond 80 mm, due to increased splitting. The full length of ribbon was laid out on the conveyor for easy evaluation.

a) b)

Figure 6. Processing of CCV billets into veneer sheet using an Omeco spindleless lathe

After peeling, the ribbon was photographed, and trimmed into 1.55 m wide (tangential dimension) sheets and 0.15 m wide veneer assessment samples. The first assessment sample was removed from the ribbon position closest to the peeler core, with the others removed later, after each 1.55 m veneer sheet. Some of the veneer sheets recovered closest to the bark were less than 1.55m in width. These were also included for analysis in recovery calculations.

Each sample was labelled with the tree-identifying details and its position from the peeler core (Figure 7). The exact location of each veneer sample was recorded as the length from the peeler core. Veneer length measurements were then converted to radial distance from the central axis of the billet, using Equation 4:

(Equation 4) $R_x = 2*\mathrm{SQRT}\ (L_x * T/\pi + (R_c/2)^2)$

Where R_x is radius at radial position; L_x distance from peeler core; T is the green veneer thickness; R_c is the radius of the peeling core (22.5 mm).

This calculation assumes that the billet is cylindrical; having a perfect circular profile in cross section (this was not the case for all billets).

a) b)

Figure 7. Examples of veneer sheet sample with labelling: a) CCV; b) *E. dunnii*

After peeling, the veneer sheets were dried by a commercial veneer company, Austral Ply (Brisbane), using a Jet box dryer with 180 °C infeed and 150 °C outfeed temperatures. The transit time was approximately nine minutes, with a target final moisture content of less than 10%.

Veneer visual grading and recovery

The veneer sheets were visually graded to Australian/New Zealand Standard AS/NZ 2269:2008, to establish grade recovery in accordance with the existing industry standard. This standard is designed essentially for face veneer grade segregation only, as the majority of plywood panel products are manufactured with D-grade (the lowest grade) veneer in the core. Each veneer sheet was assessed for presence and severity of defects such as knots, gum veins, holes, splits, discolouration, compression and roughness. The final veneer grade was assigned based on the worst limiting defect. A-grade is the highest grade followed by B, C and D.

The recovery data were calculated and defined as:

1) Gross recovery: the percentage by volume of dried veneer, recovered from its respective billet volume, meeting AS/NZS 2269 D-grade and higher. The veneer volume is measured from dimensions taken in its dry condition.

2) Grade recovery: the percentage by volume of each grade of veneer, assessed according to AS/NZS 2269, from its respective billet volume. The veneer volume is measured from dimensions taken in its dry condition.

Veneer assessment sample

The 150 mm wide veneer assessment samples were cut into two specimens: (i) a specimen for veneer stiffness and density; (ii) a specimen for veneer surface shrinkage.

Veneer stiffness samples were conditioned to equilibrium moisture content of 12% (at controlled environment conditions of 21 °C and 65% relative humidity). After drying, they were evaluated for air-dried density and acoustic resonance frequency. Wood density was determined by measuring actual veneer volume and dividing by its air-dried mass. Although there was an attempt to recover defect-free samples from the veneer ribbon, this was not always possible (especially for the veneer peeled from the inner, knotty section of the billet).

Resonance frequency was measured using the Bing system (Brancheriau and Baillères, 2003), which measured vibration in the longitudinal direction. Following air-drying to 12% moisture content, each test specimen was placed on an elastic support, in order to generate as much free vibration as possible. An exciting impulse was made by lightly striking the specimen with a hammer at the opposite end to the acoustic microphone. The dynamic MOE was then determined from the frequency and wood density, using Equation 5:

(Equation 5) $MOE_{dyn} = ADD*(2*L*f)^2$

Where MOE_{dyn} is the dynamic modulus of elasticity (stiffness) in MPa; ADD is air-dried veneer density (kg m^{-3}); L is the length of the veneer (m); and f is the frequency of the veneer specimen (Hertz).

Veneer surface shrinkage (tangential × longitudinal face) was assessed only on two samples from each veneer ribbon: one piece from the outermost sample from the log and one piece from the innermost sample adjacent to the core. Shrinkage of the sample was scanned using a precise image scanner at different moisture contents (green, conditioned to 16%, 12% and oven-dried to 0% moisture content). The image analysis software was then used to calculate the area of the sample. Surface shrinkage in the tangential × longitudinal face was then calculated using Equation 6:

(Equation 6) Shrinkage = 100* (Green surface area—conditioned surface area) / green surface area (%)

Where green surface area is measured area of shrinkage sample at green condition; conditioned surface area is area of shrinkage sample conditioned to moisture content (16%, 12% and oven-dried to 0% moisture content).

Statistical analyses

Scattergrams were used to present much of the quantitative data in this report. Scattergrams are a visual representation of quantitative results and are particularly useful for visually comparing paired numerical data. Individual disconnected symbols represent data on scattergrams. The plot allows the reader to observe the distribution of individual quantitative data points around the treatment means, represented by a red line.

Mean values of properties for disk, billet and veneer were calculated for each combination of site, species, thinning treatment and billet position. The significance of species, thinning treatment and billet was tested by analysis of variance, using GenStat version 14 software, according to the linear fixed effects model:

(Equation 7) $Y = \mu + site*thinning\ treatment*billet\ position + \varepsilon$

Where Y = the mean value for a particular combination of site, species, thinning treatment and billet position and ε is the residual random error. The small numbers of samples (only 5 logs for each site–species–treatment combination) reduced the likelihood of detecting statistically significant effects.

Because major differences between species were anticipated, CCV and *E. dunnii* were analysed separately.

Results and discussion

Billet and disk samples

Mean diameters of butt and top billets (Table 4) followed the same trends as DBHOB, returning slightly larger results for selected trees from the thinned treatments than the unthinned controls, for each species at each site. Mean diameters of top billets were approximately 3–4 cm smaller than those of butt billets. As expected, taper was less in the top billets and also smaller for *E. dunnii*. There was no consistent effect of thinning treatment on taper.

Table 4. Means and the range of mean billet diameter (D) and taper (T) of the processed billets (butt and top) for veneering study

Location	**Ellangowan**				**Kingaroy**			
Trial	**Reids**				**Tingoora**		**Barron**	
Species	**CCV**		***E. dunnii***		**CCV**		***E. dunnii***	
Treatment (spha)	**300**	**control**	**300**	**control**	**300**	**control**	**300**	**control**
Butt billet								
D mean (cm)	20.9	21.0	20.1	19.4	20.1	18.8	18.2	17.2
D range (cm)	19.2-22.5	19.1-23.3	19.0-22.9	17.6-23.5	18.4-23.9	17.9-19.9	17.1-19.8	16.7-17.9
T mean (cm/m)	1.2	1.9	1.1	1.6	1.7	1.8	1.2	0.9
T range (cm/m)	0.6-1.6	1.0-3.1	0.1-2.2	0.8-2.5	1.2-2.2	1.3-2.0	0.9-1.4	0.5-1.2
Top billet								
D mean (cm)	17.9	17.3	15.9	15.7	16.1	14.6	14.4	13.8
D range (cm)	16.5-20.3	16.5-18.6	14.6-17.5	14.3-18.8	14.7-19.2	14.1-15.4	13.4-17.2	13.4-14.5
T mean (cm/m)	0.7	0.8	0.5	0.4	0.8	0.6	0.8	0.7
T range (cm/m)	0.1-1.2	0.6-1.0	0.4-0.7	0.1-0.5	0.5-0.9	0.2-1.0	0.6-1.0	0.5-0.9

Wood properties assessed in standing trees, billets and wood disk samples are summarised in Table 5.

Table 5. Mean and standard deviation of measured characteristics for two species at two sites and two different treatments for butt and top log position (AWV-Fakopp standing tree acoustic velocity; BD-basic density; HW-heartwood; SW-sapwood)

Location	**Ellangowan**				**Kingaroy**			
Trial	**Reids**				**Tingoora**		**Barron**	
Species	**CCV**		***E. dunnii***		**CCV**		***E. dunnii***	
Treatment (spha)	**300**	**control**	**300**	**control**	**300**	**control**	**300**	**control**
Butt billet								
AWV mean (km s^{-1})	4.3	4.3	4.1	4.2	4.1	4.1	3.7	3.6
AWV STDEV (km s^{-1})	0.11	0.16	0.15	0.12	0.20	0.04	0.14	0.10
BD-SW mean (kg m^{-3})	675	686	593	581	688	713	519	540
BD-SW STDEV (kg m^{-3})	38	55	19	36	25	30	26	26
BD-HW mean (kg m^{-3})	607	645	544	511	605	631	469	500
BD-HW STDEV (kg m^{-3})	67	54	39	22	38	24	23	23
BD-disk mean (kg m^{-3})	665	675	572	552	662	688	498	523
BD-disk STDEV (kg m^{-3})	41	55	27	24	29	17	23	24
HW mean (%)	16.4	26.9	42.3	41.9	30.1	26.5	40.5	41.5
HW STDEV (%)	8.2	5.8	4.1	6.5	6.6	9.6	4.8	2.6
SW width mean (mm)	56	46	32	31	39	41	30	28
SW width STDEV (mm)	5.5	6.2	2.3	4.7	8.2	6.2	3.6	3.4
Billet MOE mean (GPa)	18.2	17.4	14.3	14.1	14.9	15.4	11.2	11.1
Billet MOE STDEV (GPa)	1.4	2.5	1.6	1.3	2.4	1.2	1.1	1.0
Interlock grain ratio mean	1.08	1.07	1.10	1.09	1.16	1.09	1.05	1.13
Interlock ratio STDEV	0.03	0.03	0.04	0.05	0.07	0.05	0.03	0.08
Top billet								
BD-SW mean (kg m^{-3})	655	648	593	577	674	713	529	555
BD-SW STDEV (kg m^{-3})	49	62	18	38	49	23	19	38
BD-HW mean (kg m^{-3})	616	636	547	514	622	662	505	512
BD-HW STDEV (kg m^{-3})	60	40	28	37	56	7	26	19
BD-disk mean (kg m^{-3})	650	646	576	555	662	702	520	540
BD-disk STDEV (kg m^{-3})	48	57	19	31	49	17	20	26
HW mean (%)	14	15	33	33	20	19	32	33
HW STDEV (%)	10	8	3	7	7	5	5	2
SW width mean (mm)	55	49	30	31	41	37	29	26
SW width STDEV (mm)	13	9	1	7	10	3	3	3
Billet MOE mean (GPa)	19.5	19.2	17.7	17.4	16.6	17.6	13.2	13.2
Billet MOE STDEV (GPa)	1.3	1.8	1.2	1.7	2.2	1.3	0.6	1.2

Standing tree acoustic velocity

The scattergram of AWV values is presented in Figure 8. Each point on the graph is the average value of four readings taken around the stem circumference of an individual tree. Fakopp provides the time-of-flight reading between two probes, driven approximately 25 mm into the outer wood layers of the standing trees, corresponding to the outer wood laid down after thinning; so the assessment aims to detect if there were any differences in AWV in the wood laid down since the thinning treatments were applied.

As observed from the graph and from Table 6, there was no significant difference in AWV between thinned and unthinned treatments, for both species at both sites. There was a clear site effect influencing AWV, which exhibited lower values at the drier Kingaroy sites (p<0.001). This was more pronounced for *E. dunnii*. When compared to *E. dunni*, CCV had stiffer outer wood, as lower AWV corresponds to lower wood stiffness.

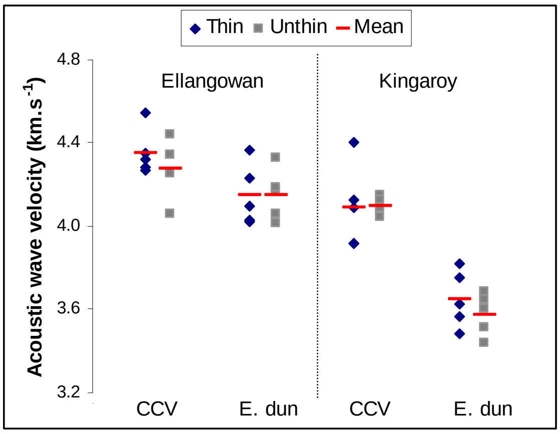


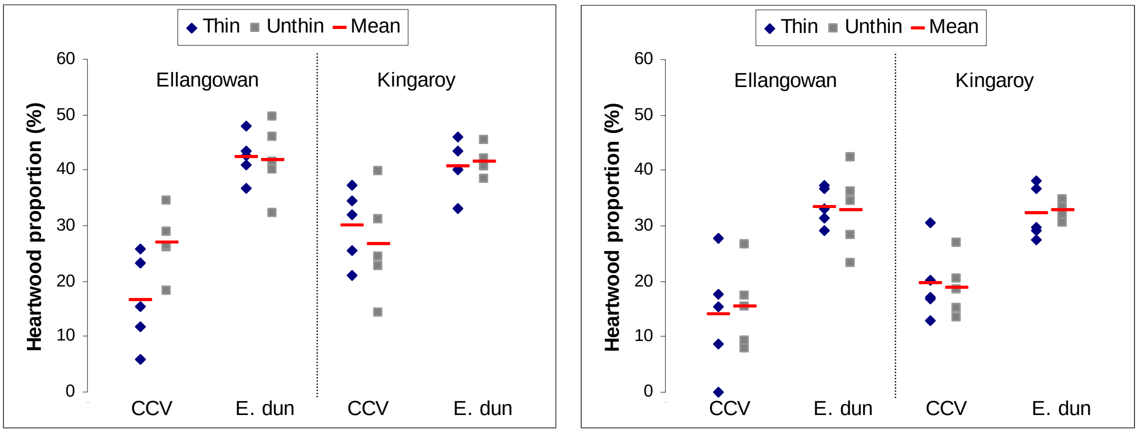
Figure 8. Scattergram of standing tree acoustic wave velocity for two thinning treatments for CCV and *E. dunnii* from two sites

Table 6. Analysis of variance of standing tree acoustic velocity for CCV and *E. dunnii*

Source of variation	CCV			*E. dunnii*		
	df	Sum Sq	F-prob	df	Sum Sq	F-prob
Site	1	0.482	<0.001	1	2.876	<0.001
TMT	1	0.012	NS	1	0.012	NS
Site.TMT	1	0.020	NS	1	0.015	NS
Residual	15	0.290		16	0.016	

Heartwood proportion

CCV displayed a low heartwood proportion, ranging from 5% to 35% (Figure 9) for butt disk sample. Heartwood for *E. dunnii* was higher, averaging about 40% at butt disk samples and 30% at top disk samples. Site significantly affected heartwood for CCV species only (p<0.05), with heartwood proportion being lower at the wetter Ellangowan site (Table 7). There was no effect of thinning treatment on heartwood proportion on either species. As expected, heartwood significantly decreased along tree height position (Table 7).



a)

b)

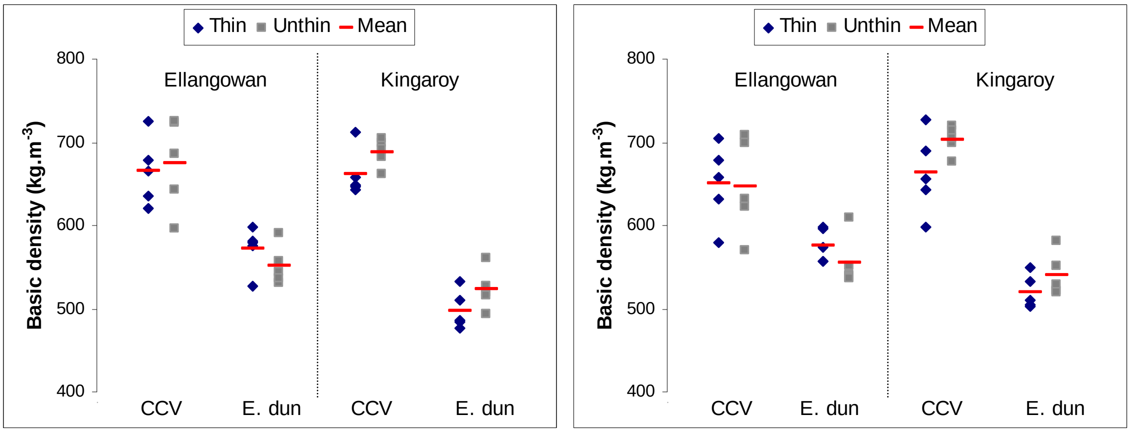
Figure 9. Heartwood proportion above butt log position at 1.8 m (a) and above top billet position at 7 m (b) for two treatments for CCV and *E. dunnii* from two sites

Table 7. Analysis of variance of heartwood proportion for CCV and *E. dunnii*

Source of variation	CCV			*E. dunnii*		
	df	Sum Sq	F-prob	df	Sum Sq	F-prob
Site	1	317	<0.05	1	7.9	NS
TMT	1	37.5	NS	1	0.1	NS
Position	1	653	<0.05	1	763	<0.001
Site.TMT	1	159	NS	1	3.4	NS
Site.Position	1	10.9	NS	1	0.5	NS
TMT.Position	1	23.2	NS	1	0.3	NS
Residual	32	1895		32	729	

Basic density of disk samples

Mean basic density ranged from 480 to 600 kg m^{-3} for *E. dunnii*, and from 620 to 725 kg m^{-3} for CCV. For both species, at both sites, basic density did not differ significantly between thinned and unthinned treatments (Figure 10 and Table 8).



a)

b)

Figure 10. Whole disk basic density above butt log position at 1.8m (a) and above top billet position at 7m (b) for two treatments for CCV and *E. dunnii* from two sites

Basic density did not differ at the two height positions (butt and top). Site did not have any marked effect on basic density for CCV but, for *E. dunnii,* it was significantly lower (p<0.001) at the Kingaroy site, compared with the Ellangowan site.

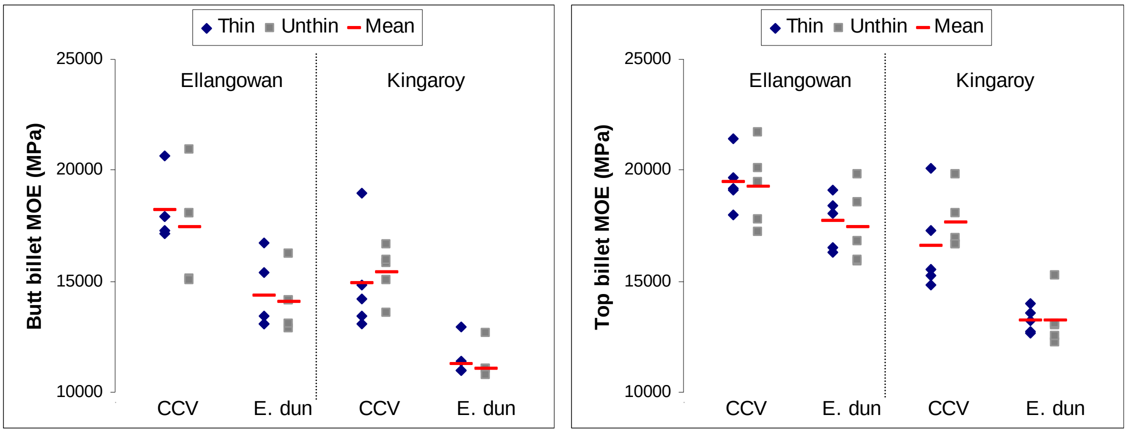
Sapwood had higher basic density than heartwood for both species (Table 4).

Table 8. Analysis of variance of disk basic density for CCV and *E. dunnii*

Source of variation	CCV			*E. dunnii*		
	df	Sum Sq	F-prob	df	Sum Sq	F-prob
Site	1	3938	NS	1	19115	<0.001
TMT	1	3312	NS	1	8.9	NS
Position	1	465	NS	1	1439	NS
Site.TMT	1	2311	NS	1	4679	0.009
Site.Position	1	2151	NS	1	679	NS
TMT.Position	1	0	NS	1	22	NS
Residual	32	56553		32	19396	

Billet stiffness

The results of dynamic billet MOE followed similar trends to those observed for standing tree acoustic velocity, as these two methods were highly correlated (r=0.94). As with AWV, thinning treatments did not significantly influence billet stiffness (Figure 11, Table 9). However, site had a significant effect on billet stiffness for both species (p<0.001). MOE was lower at the Kingaroy site; 25% lower for *E. dunnii* and 20% lower for CCV. There was also a significant interaction between site and thinning treatment for CCV only. When compared to butt billets, billets from the higher stem position were, on average, 10% stiffer for CCV and 20% stiffer (p<0.001) for *E. dunnii*.



a) b)

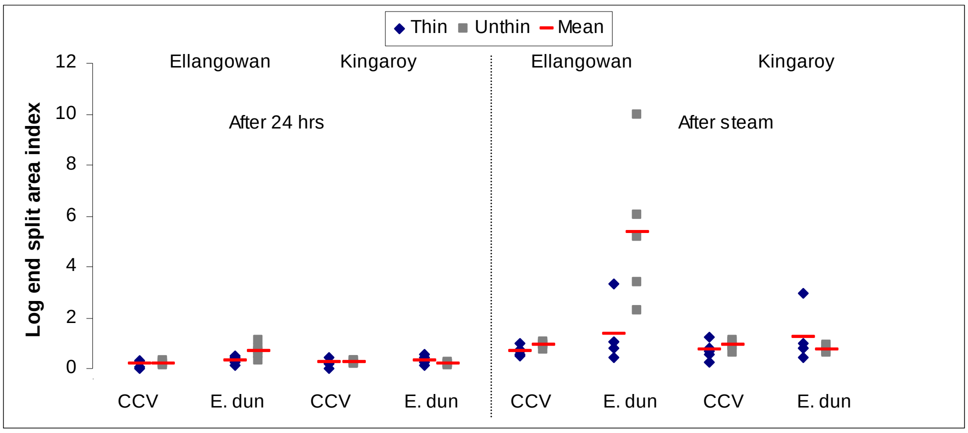
Figure 11. Dynamic MOE, as assessed by the Bing tool for butt log (a) and top log (b), for two treatments for CCV and *E. dunnii* from two sites

Table 9. Analysis of variance of billet dynamic modulus of elasticity for CCV and *E. dunnii*

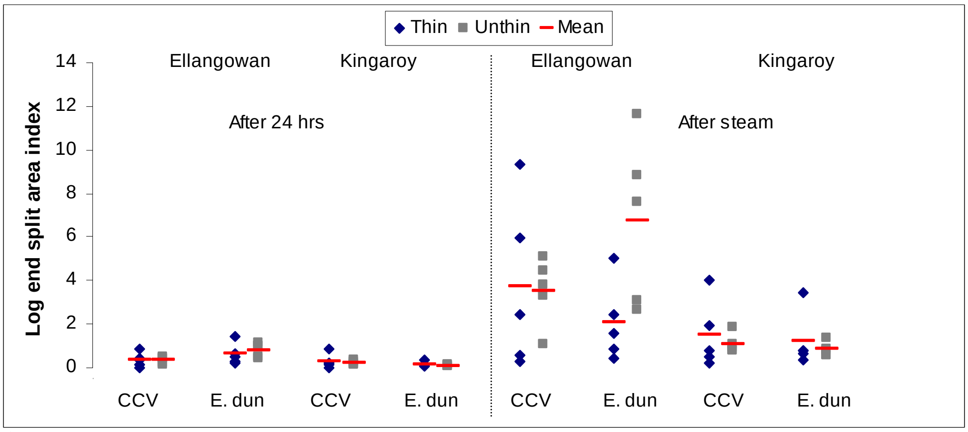
Source of variation	CCV			*E. dunnii*		
	df	Sum Sq	F-prob	df	Sum Sq	F-prob
Site	1	5985620	<0.001	1	135805090	<0.001
TMT	1	174475	NS	1	306286	NS
Position	1	30852222	NS	1	73360913	<0.001
Site.TMT	1	3896393	0.004	1	56265	NS
Site.Position	1	432723	NS	1	4008434	NS
TMT.Position	1	670960	NS	1	9133	NS
Residual	32	105399270		32	52008484	

Billet end split area index

For both species, splitting index was relatively low 24 hours after sampling and there were no differences evident between billets from thinned and unthinned treatments (Figure 12a and 12b). Severity of splitting increased after steaming, but with large differences among trees. Interestingly, *E. dunnii* billets from the wetter site (Ellangowan) exhibited more severe splitting than billets from the drier Kingaroy site. A similar effect was also observed for CCV top billets. In addition, the splitting index values recorded for *E. dunnii* from Ellangowan appear to be greater in the unthinned billets. Genetic differences and the specific growing conditions of individual trees may both contribute to variations in splitting index among trees within sites, as well as their response to thinning treatments. Seed source differences might also contribute to differences between sites. Splitting index after steaming was generally higher in the top billets than in butt billets.



a)



b)

Figure 12. Log end splitting area index for butt log (a) and top log (b) for two thinning treatments, 24 hours after felling and after steaming, for CCV and *E. dunnii* from two sites

Peeling and veneer samples

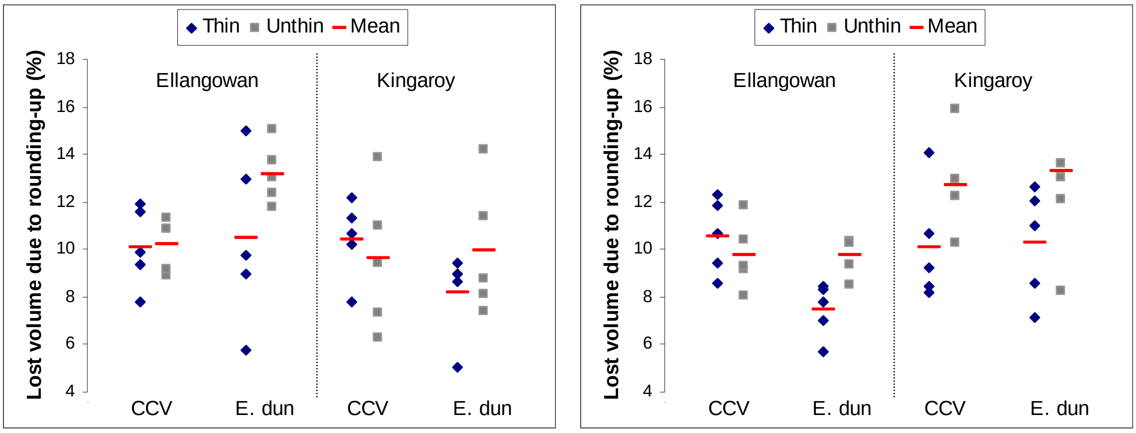
Lost volume due to rounding-up

On average, 10% of billet volume was lost during the rounding-up process (Figure 13). Losses were variable at the individual tree level, ranging from 4% to 16%. There was no significant difference between sites for either species (Table 10). However, lost volume was significantly affected by the thinning treatment for *E. dunnii* (p=0.004). Logs from the unthinned treatment had, on average, a higher percentage of lost volume than logs from the thinned plots. Butt billets and top billets had a similar lost volume due to rounding-up. There was a strongly significant interaction between site and billet position for *E. dunnii*.

It would be logical to assume that taper would have a significant effect on lost volume percentage but these two parameters were very poorly correlated at the tree level (r<0.01). Lost volume was attributable to both log form (taper and sweep) and cross-sectional log shape, with a cylindrical shape being preferable for peeling.

Absolute values of lost diameter ranged from 2 mm to 20 mm, when comparing small end diameter before and after rounding-up. In some trees, this lost diameter was comparable to the increments laid down after the thinning treatment was applied (Figure

2). This suggests that a high proportion of the wood laid down after thinning was removed during the rounding-up process. Consequently, the comparison of veneer properties between thinned and unthinned treatments should be interpreted with caution.



a) b)

Figure 13. Volume loss due to rounding-up for butt billet (a) and top billet (b), for two treatments for CCV and *E. dunnii* from two sites

Table 10. Analysis of variance of lost volume due to rounding-up for CCV and *E. dunnii*

Source of variation	CCV			*E. dunnii*		
	df	Sum Sq	F-prob	df	Sum Sq	F-prob
Site	1	3.07	NS	1	0.48	NS
TMT	1	0.73	NS	1	59.7	0.004
Position	1	4.95	NS	1	0.76	NS
Site.TMT	1	3.85	NS	1	0.04	NS
Site.Position	1	4.86	NS	1	87.5	<0.001
TMT.Position	1	3.93	NS	1	0.41	NS
Residual	32	122.4		32	194.2	

Overall veneer gross recovery

The gross recovery from individual billets varied substantially for individual species–site combinations, as can be seen in Figure 14. Overall veneer gross recoveries, as site averages, ranged from 50% to 70%. The age and diameter of the logs harvested for these trials was quite young, compared with traditional plywood resources, so higher recoveries should be achievable from older, larger diameter logs. In this sense, the veneer recoveries reported herein are quite encouraging as they are two to three times higher than typical green off saw recoveries from sawing logs of similar diameters (Leggate *et al*. 2000).

For both species, overall gross recovery was significantly influenced by site (Table 11). This effect was more pronounced for top logs, with recovery being lower from the drier Kingaroy site. The thinning treatment significantly affected recovery for *E. dunnii* only, with unthinned trees producing less veneer recovery than those from the 300 spha thinning treatment.

The main factor affecting recovery was a short radius measured at the billet small end (r=0.52). Recovery is expected to be less from small diameter trees, as the diameter of the core is fixed, regardless of the billet size, so proportionally less of the billet volume can produce veneer.

By way of comparison, green recoveries from billets from plantation-grown *E. nitens* in Tasmania, of larger diameter and aged 22 years, were no higher, at around 47% for unpruned and 58% for pruned trees (Blakemore *et al.* 2010). Thomas *et al.* (2009) reported that green off lathe recovery for *E. dunnii* for three age classes (12 year old, 17 year old and 34 year old) ranged from 30% to 55%. However, the veneering systems used in these trials were different, with larger diameter residual cores remaining after peeling, accounting in part for their lower recoveries.

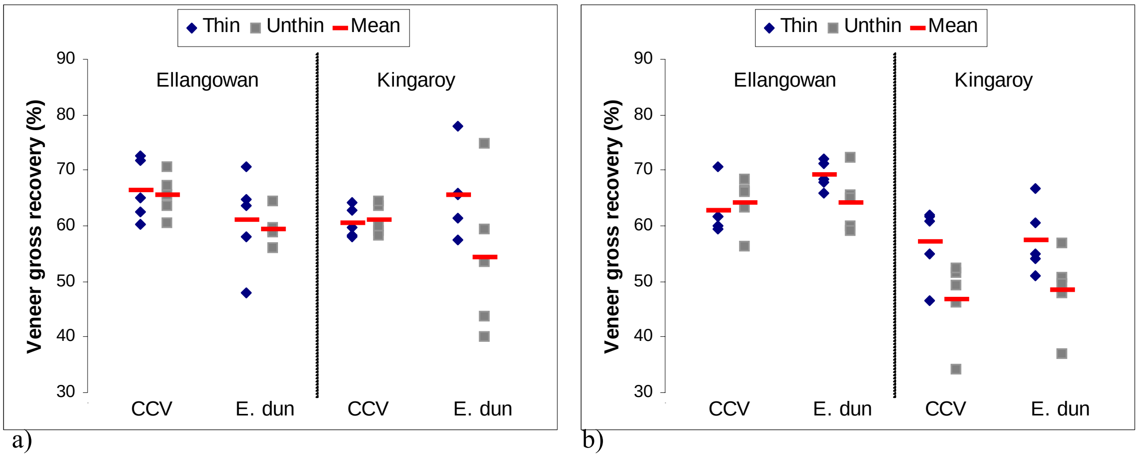


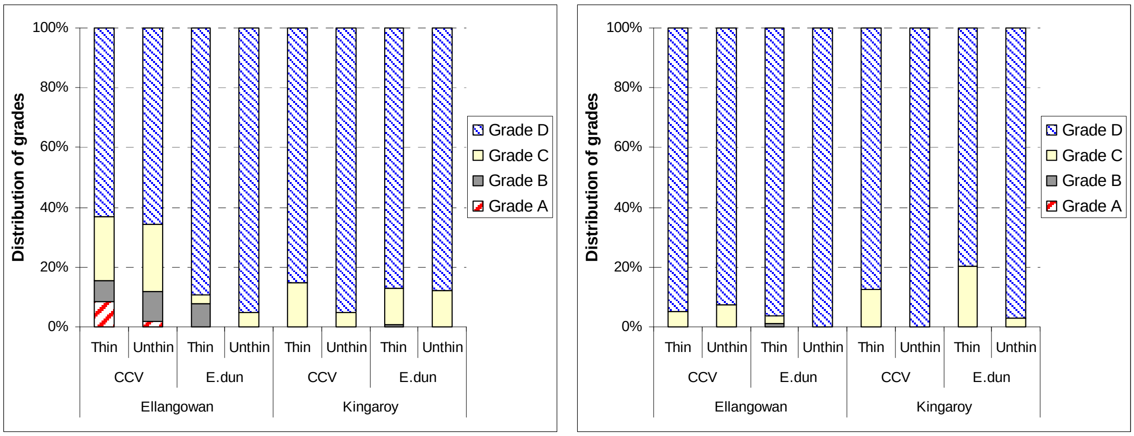
Figure 14. Veneer gross recovery for butt log (a) and top log (b) for two treatments for CCV and *E. dunnii* from two sites

Table 11. Analysis of variance of overall gross recovery for CCV and *E. dunnii*

Source of variation	CCV			*E. dunnii*		
	df	Sum Sq	F-prob	df	Sum Sq	F-prob
Site	1	681.8	<0.001	1	492.7	0.006
TMT	1	55.2	NS	1	443.5	0.009
Position	1	328.2	NS	1	0.7	NS
Site.TMT	1	70.8	NS	1	125.7	NS
Site.Position	1	99.9	NS	1	449.2	0.009
TMT.Position	1	46.5	NS	1	0.8	NS
Residual	32	803.8		32	1828.2	

Grade veneer recovery

Most of the veneer recovered was D-grade, the lowest grade quality (Figure 15). This is not unexpected, given the known presence of knots and other defects in plantation eucalypt logs of the size and age processed. Up to 38% of CCV trees from the Ellangowan site were C-grade or better. Slightly higher percentages of better grade were recovered from the thinned treatments, in the majority of species–site combinations. Top billets yielded less of the higher veneer grades than butt billets, which may reflect a higher incidence of knots from branches in the upper parts of the stem.



a) b)

Figure 15. Proportions of different veneer grades recovered from butt logs (a) and top logs (b) for two treatments for CCV and *E. dunnii* from two sites

Among the major limiting factors preventing veneer from meeting higher grade qualities was the high presence of kino defects and encased knots (Figure 16). Splits were also common in *E. dunnii* veneer and degraded its quality. The average veneer grade for individual billets, based on splits assessment, was strongly correlated with average billet end split area index from both ends (Figure 17). Logarithmic relationship provided a better fit to data from butt billets with R^2 of 0.68, whereas the relationship between log end split area index and veneer grade for top billets was better modelled by linear relationship (R^2=0.48).

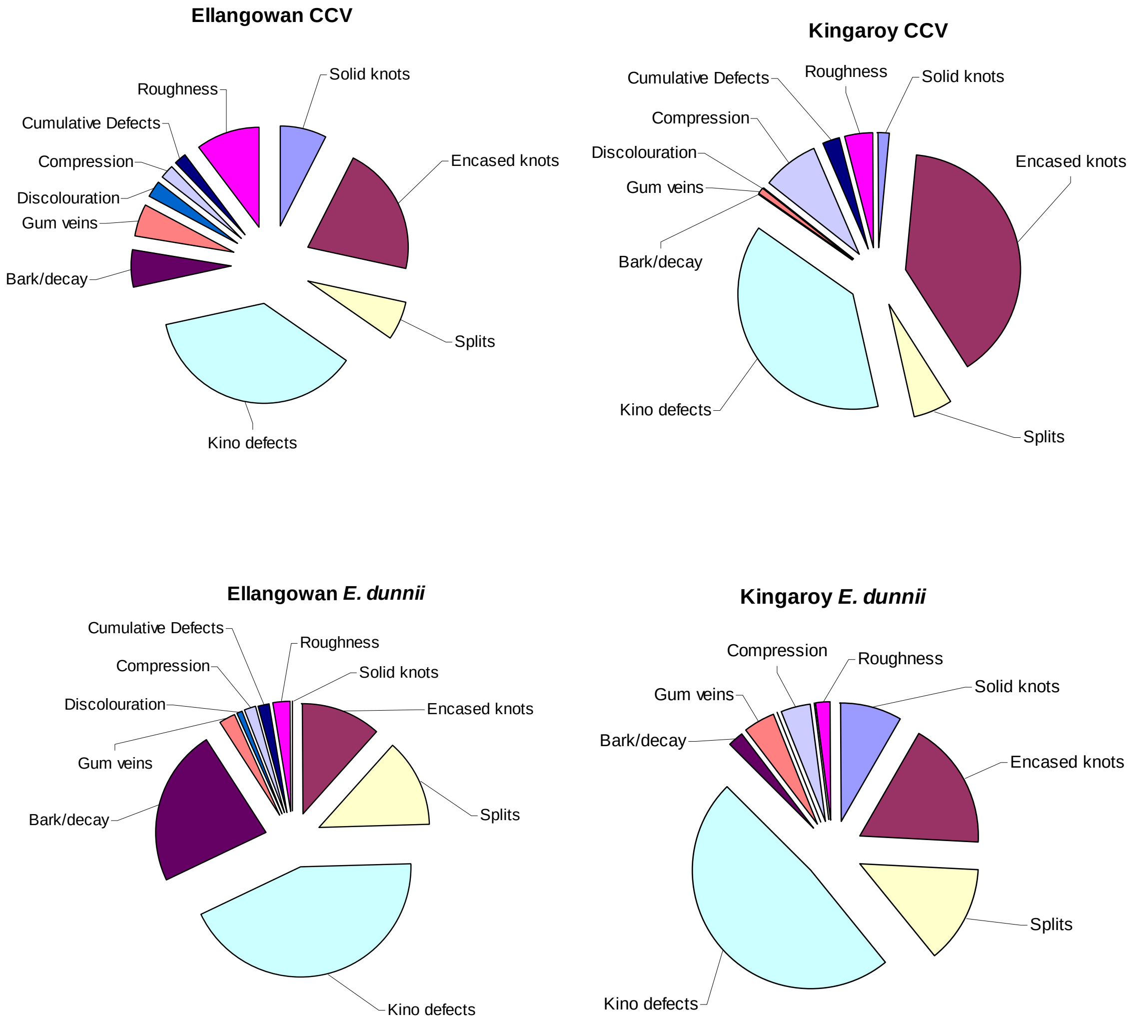


Figure 16. Grade limiting features presented separately for species and sites.

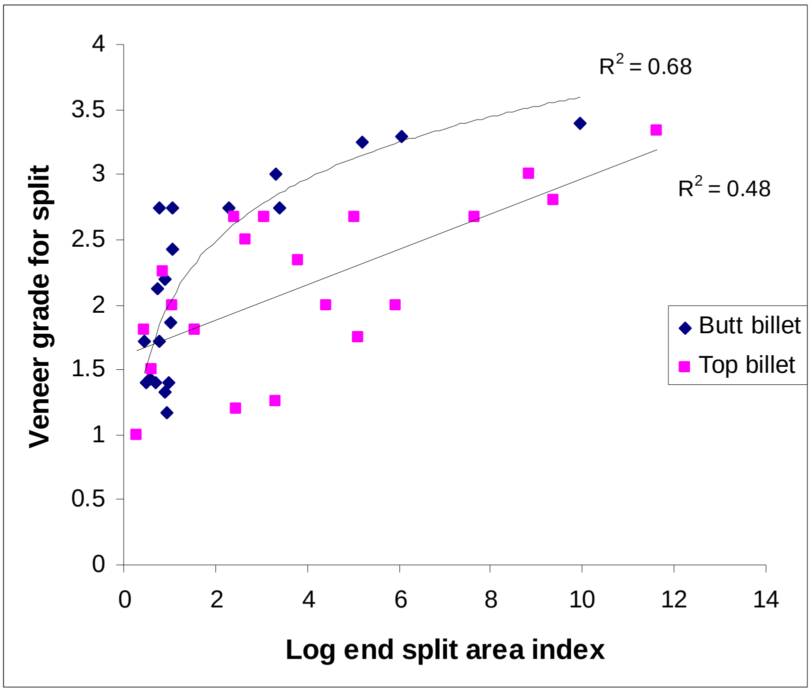


Figure 17. Effect of log-end split area index of *E. dunnii* on veneer grade, based on split assessment only (veneer grade 1 corresponds to Grade-A, 2 to Grade-B, 3 to Grade-C).

Veneer properties

A total of 193 samples of CCV and 164 samples of *E. dunnii* were assessed for veneer stiffness and air-dry density. Mean and standard deviations of veneer properties for butt and top billets are summarised in Table 12. The results are presented as average values across the whole length of the ribbon for each tree, and were not weighted to account for the greater proportion of billets derived from outer wood, rather than inner wood.

Average veneer air-dry density ranged from 775 to 800 kg m^{-3} for CCV and 606 to 699 kg m^{-3} for *E. dunnii.* ANOVA results provided in Table 13 indicated that site was a significant factor influencing veneer density for *E. dunnii*. Veneer density for both species was not significantly affected by thinning treatment, billet position or their interactions.

Surface shrinkage (from green to oven-dry) was very variable and ranged from 10.3 to 18.9% (Table 12). Shrinkage tended to be higher in *E. dunnii*, which is surprising given that *E. dunnii* showed lower veneer densities and shrinkage is usually positively correlated with wood density. There was a slight effect of thinning treatment on shrinkage of *E. dunnii* (p=0.007 in Table 14), mostly due to increased shrinkage from unthinned plots. No clear effect of site or billet position was evident for either species.

Average veneer stiffness ranged from 13.1 to 18.2 GPa for CCV, and 10.3 to 16.7 GPa for *E. dunnii* (Table 12). Surprisingly, *E. dunnii* from the Ellangowan site exhibited relatively high values of veneer stiffness, similar to those of CCV, despite its significantly lower wood density. There was evidence of a significant effect of site on veneer stiffness for both species, with lower stiffness at the drier Kingaroy site (Table 15). Billet height was also shown to be significant for *E. dunnii,* with the upper billets having greater mean stiffness, but no significant effect of thinning was recorded for either species.

Despite the young age of this hardwood resource, both species displayed stiffness properties that were superior (or, at the very least, comparable) to mature plantation radiata pine commonly used for the manufacture of structural plywood, with typical veneer stiffness of around 12 GPa. This is an important and valuable attribute of these subtropical plantation hardwood species. In comparison, veneer stiffness of 22-year-old plantation of *E. nitens* from Tasmania achieved a maximum 10 GPa (Blakemore *et al.* 2010) and mature 36 to 51 year old Douglas fir from the USA averaged around 10.9 GPa (Todoroki *et al.* 2012).

Table 12. Mean and standard deviation of measured veneer properties for two species at two sites and two different treatments for butt log-position and top-log position

Location	**Ellangowan**				**Kingaroy**			
Trial	**Reids**				**Tingoora**		**Barron**	
Species	**CCV**		***E. dunnii***		**CCV**		***E. dunnii***	
Treatment (spha)	**300**	**control**	**300**	**control**	**300**	**control**	**300**	**control**
Butt billet								
Veneer density (kg m^{-3})	794	791	682	699	786	794	606	682
Density STD (kg m^{-3})	76	76	35	60	67	90	53	60
Surface veneer shrinkage* (%)	13.1	12.3	14.7	17.6	11.7	10.8	12.5	18.9
Shrinkage STD (%)	2.7	1.3	3.7	6.1	1.8	1.2	3.5	9.1
Veneer stiffness (GPa)	18.2	16.6	13.6	15.2	13.6	15.2	10.4	10.3
Stiffness STDEV (GPa)	3.4	2.8	2.6	4.1	2.9	2.7	1.6	2.3
Top billet								
Veneer density (kg m^{-3})	779	775	678	682	779	800	635	646
Density STD (kg m^{-3})	62	76	52	66	71	74	28	55
Surface veneer shrinkage* (%)	12.1	12.7	11.5	14.6	10.3	11.1	14.8	14.7
Shrinkage STD (%)	1.6	2.3	0.9	3.9	1.2	0.7	4.6	5.1
Veneer stiffness (GPa)	17.8	17.8	15.6	16.7	14.4	13.1	12.1	11.0
Stiffness STDEV (GPa)	3.0	3.6	4.3	4.8	3.1	3.1	1.7	2.3

*Shrinkage is measured from green to 0% MC

Table 13. Analysis of variance of veneer density for CCV and *E. dunnii*

Source of variation	CCV			*E. dunnii*		
	df	Sum Sq	F-prob	df	Sum Sq	F-prob
Site	1	0	NS	1	108243	<0.001
TMT	1	3983	NS	1	22401	NS
Position	1	491	NS	1	436	NS
Site.TMT	1	546	NS	1	9249	NS
Site.Position	1	127	NS	1	3478	NS
TMT.Position	1	2668	NS	1	7567	NS
Residual	184	1014174		156	434209	

Table 14. Analysis of variance of veneer surface shrinkage (green to oven-dried) for CCV and *E. dunnii*

Source of variation	CCV			*E. dunnii*		
	df	Sum Sq	F-prob	df	Sum Sq	F-prob
Site	1	50.6	<0.001	1	9.2	NS
TMT	1	0.1	NS	1	200.9	0.007
Position	1	3.7	NS	1	82.8	NS
Site.TMT	1	0.1	NS	1	0.7	NS
Site.Position	1	0.5	NS	1	23.8	NS
TMT.Position	1	12.1	NS	1	73.8	NS
Residual	184	208.6		156	1806.9	

Table 15. Analysis of variance of veneer stiffness for CCV and *E. dunnii*

Source of variation	CCV			*E. dunnii*		
	df	Sum Sq	F-prob	df	Sum Sq	F-prob
Site	1	$6.3*10^8$	<0.001	1	$7.4*10^8$	<0.001
TMT	1	$1.7*10^7$	NS	1	$1.1*10^7$	NS
Position	1	$4.9*10^4$	NS	1	$8.5*10^7$	0.007
Site.TMT	1	$5.1*10^6$	NS	1	$3.0*10^7$	NS
Site.Position	1	$5.0*10^6$	NS	1	$3.8*10^6$	NS
TMT.Position	1	$7.1*10^5$	NS	1	$3.7*10^6$	NS
Residual	184	$1.8*10^9$		156	$1.8*10^9$	

Radial variation in veneer properties

Veneer surface shrinkage

Surface shrinkage was analysed on subsamples of veneer representing the inner and outer wood of billets. CCV showed a slight increase in shrinkage for outer wood veneer samples (Figure 18), as would be expected since wood density also increases from pith to bark. On the other hand, *E. dunni* exhibited the opposite trend, with decreasing veneer shrinkage for samples from the outer part of tree; this being more pronounced in the butt log. As seen in Figure 19, the veneer density showed a similar trend.

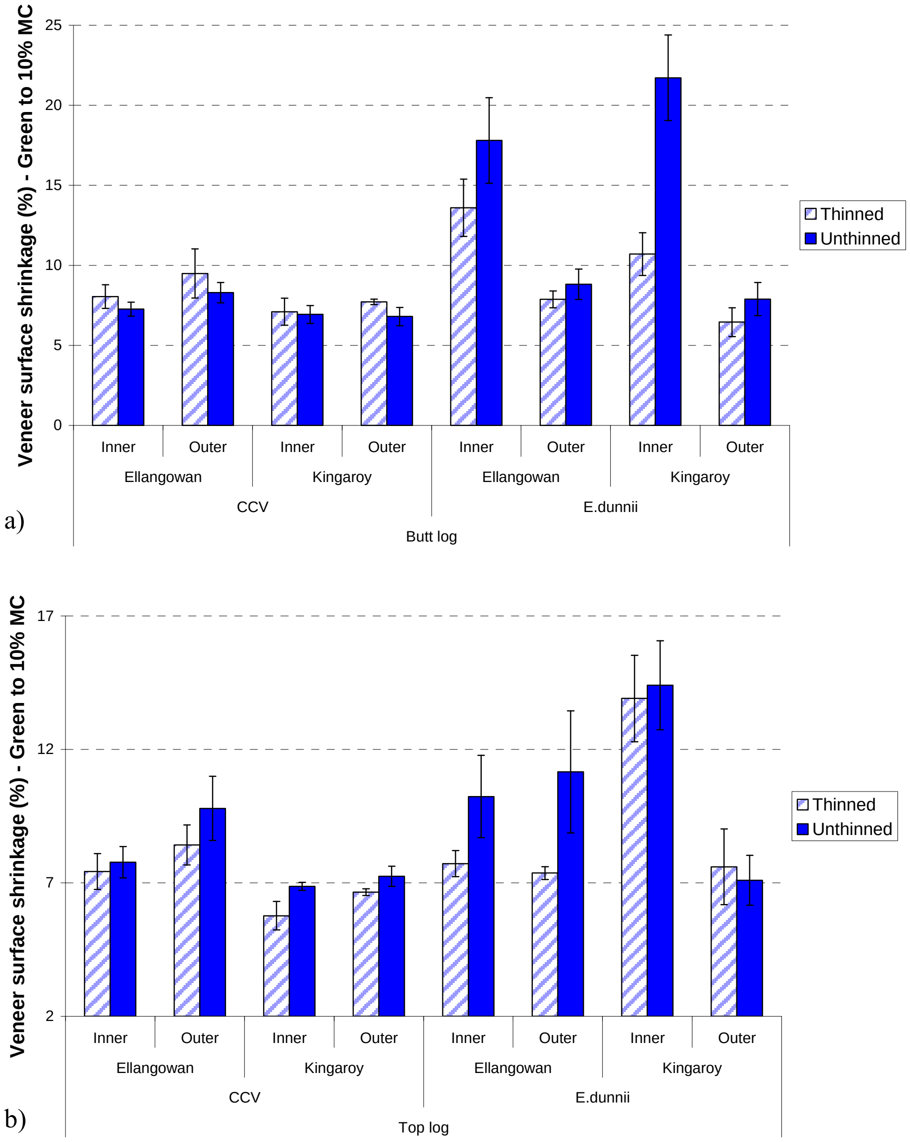


Figure 18. Veneer surface shrinkage variation for butt logs (a) and top logs (b), for two treatments for CCV and *E. dunnii* from two sites

Veneer stiffness and density

Individual trees displayed considerable radial variation for veneer stiffness (Figure 19) and veneer density (Figure 20). For about 90% of the samples, veneer stiffness ranged from 10.2 to 22 GPa for CCV and from 8.1 to 21.6 GPa for *E. dunnii*; veneer density ranged from 660 to 900 kg m^{-3} for CCV and 565 to 760 kg m^{-3} for *E. dunnii*. In most cases, veneer stiffness increased from the inner to the outer wood. Radial trajectories varied from tree to tree. However, there were few major changes in ranking; trees with lower veneer stiffness adjacent to the core generally had lower outer wood stiffness.

Radial position of the timing of thinning varied from tree to tree. Annual growth rings were not detectable and, therefore, it was not possible to reliably determine the dates at which individual samples were laid down. To standardise radial trends, sample positions were expressed as a percentage of the total radius, for each billet. Figure 21 displays the average radial variation in veneer stiffness and density of the butt billets, for each combination of species, site and treatment.

Veneer stiffness and density in CCV increased from pith to bark at both sites, with no evidence of any major effect of site on radial trajectories (Figure 21). For *E. dunnii*, stiffness and density increased radially at the Ellangowan site only. At the drier Kingaroy site, there was a decline in veneer stiffness and density outwards from the middle radius to the billet periphery. It is known that wood properties are sensitive to fluctuations in environmental conditions. Kingaroy experienced serious drought over the period 2005–2009 (Figure 22). Drought stress may be the cause of the decline in veneer stiffness and density in the outer wood of *E. dunnii*. It appears that drought conditions at Kingaroy had less influence on the wood properties of CCV.

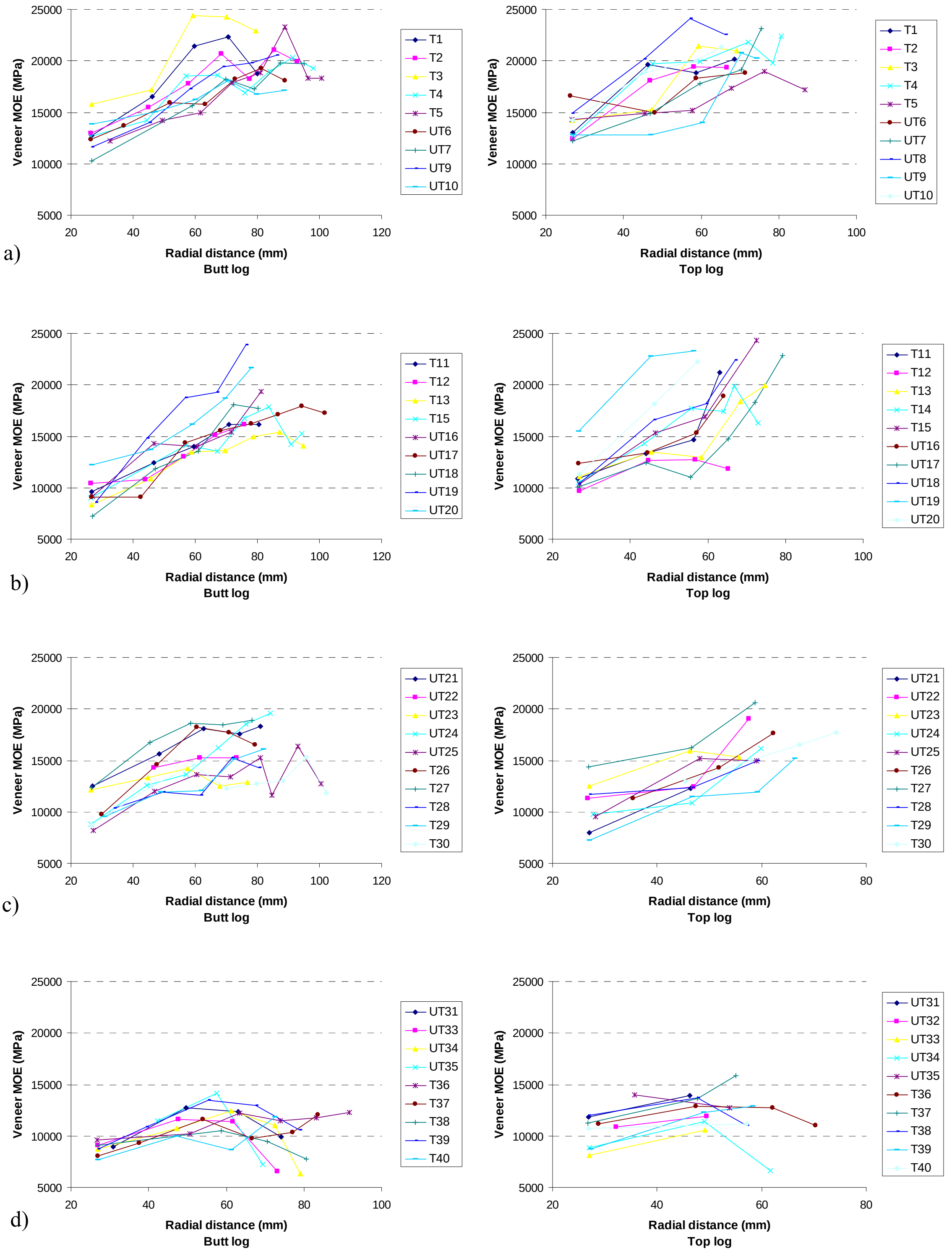


Figure 19. Veneer MOE variation in individual trees along ribbon length for butt logs (left side) and top logs (right side) for: a) CCV from Ellangowan; b) *E. dunnii* from Ellangowan; c) CCV from Kingaroy; d) *E. dunnii* from Kingaroy (T-thinned, UT-unthinned; values are plotted as a function of distance from billet core; Y-scale is in the same range for all graphs for comparative purposes)

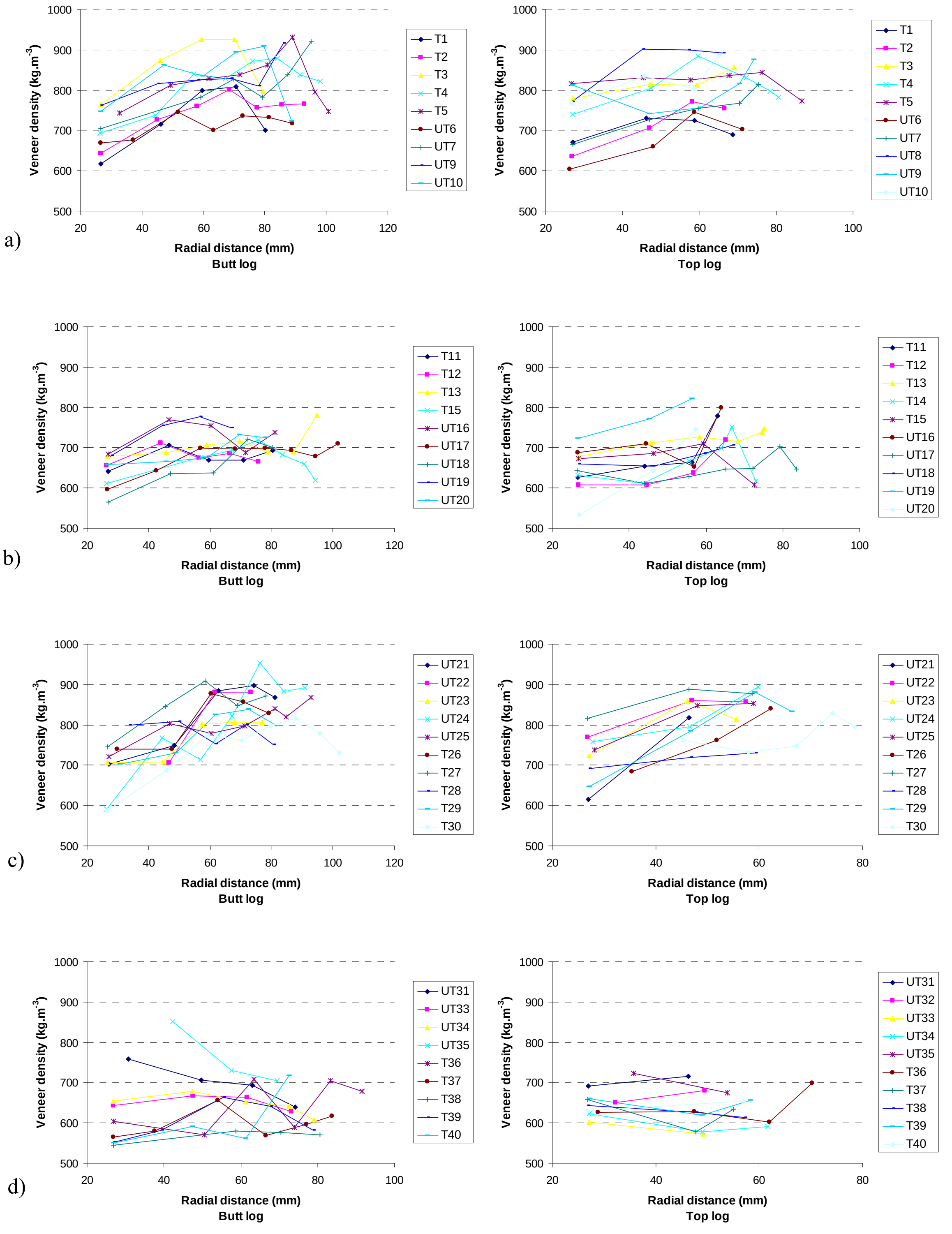


Figure 20. Veneer air-dry density variation in individual trees along ribbon length for butt logs (left side) and top logs (right side) for: a) CCV from Ellangowan; b) *E. dunnii* from Ellangowan; c) CCV from Kingaroy; d) *E. dunnii* from Kingaroy (T-thinned, UT-unthinned; Y-scale is in the same range for all graphs for comparative purposes)

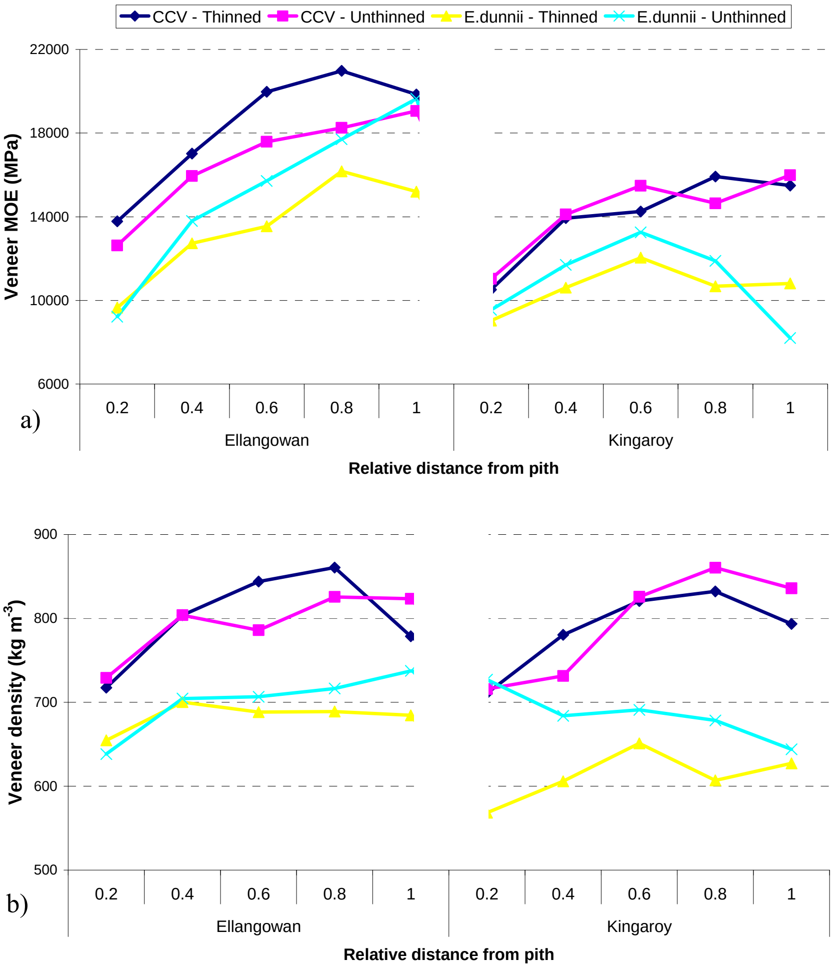


Figure 21. Average radial pith-to-bark variation of veneer stiffness (a) and veneer density (b) for butt billets of CCV and *E. dunnii*. Radial trends are expressed as a percentage of radius distance.

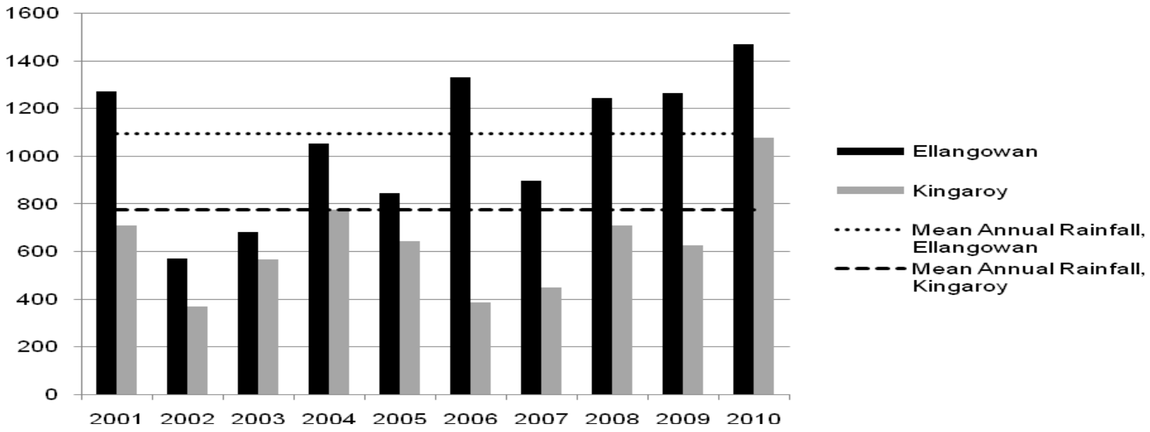


Figure 22. Mean annual rainfall (mm) and annual rainfall (mm) recorded at Ellangowan and Kingaroy for the period 2001–2010. Source: Glencross *et al*. 2011

Prediction of veneer stiffness using standing tree acoustics

Standing tree acoustic velocity, determined by the Fakopp time-of-flight method, was a good predictor of mean veneer stiffness from butt billet, with significant coefficients of determination: 0.78 for CCV and 0.90 for *E. dunnii* (Figure 23a). Fakopp provided a reliable prediction of veneer stiffness, not only from the outer part of the butt billet (R^2=0.81) but also from the heartwood zone (R^2=0.74), as indicated in Figure 23b.

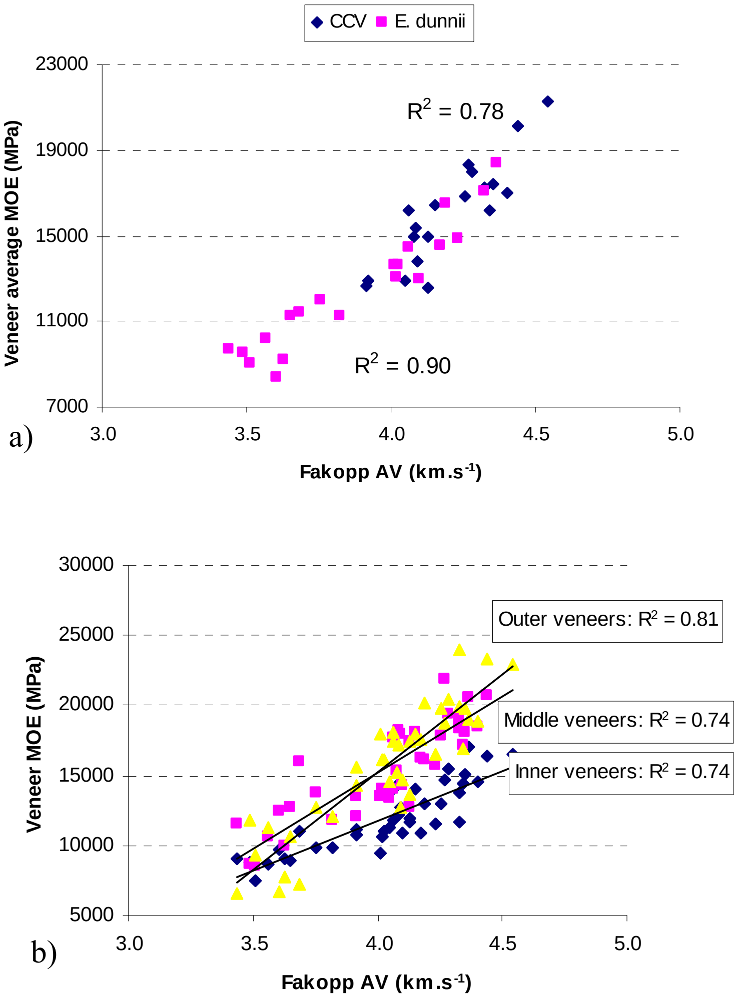


Figure 23. Relationship between Fakopp standing tree acoustic velocity and butt billet veneer stiffness: a) as average of all data along each veneer ribbon, plotted separately for CCV and *E. dunnii*; b) for inner, middle and outer radial positions of veneer samples, with data combined for both species

Conclusions

Overall gross recoveries of veneer, as a percentage of billet volume, ranged from 50% to 70%, and were significantly lower for both species at the drier Kingaroy sites. These veneer recoveries are two to three times higher than typical green off saw recoveries from small plantation hardwood logs of similar diameters.

CCV displayed veneer stiffness exceeding 15 GPa, making it an excellent candidate for structural applications, while *E. dunnii* also demonstrated good potential for structural applications, achieving stiffness above 10 GPa.

Wood and veneer properties differed significantly between the two sites, the effect being more pronounced for *E. dunnii* than for CCV. The Ellangowan site, where rainfall was higher and trees grew faster, produced denser and stiffer veneers than did the drier sites near Kingaroy, where tree growth was slower.

Differences in measured wood properties, veneer characteristics and veneer recoveries between the thinned and unthinned treatments were generally small and not significant. Much of the wood laid down in the three years after thinning was removed during rounding-up of billets, compromising the ability to detect the effects of thinning treatment on veneer properties in this study. The small sample size, with only five trees per thinning treatment, also made it difficult to establish the significance of small differences associated with thinning treatments.

Most of the veneer recovered was classified as D-grade—the lowest Australian Standard grade for structural plywood. CCV trees from the Ellangowan site yielded up to 38% of better C-grade and higher grade veneers. Butt billets yielded a higher percentage of better veneer grades. A major limiting factor preventing veneer from meeting higher grades was the presence of kino pockets and encased knots. Splits in *E. dunnii* veneer contributed to reduced grade quality in this species.

Veneer stiffness and density in CCV increased from pith to bark at both sites while, for *E. dunnii,* there was a radial increase at the Ellangowan site only. At the drier Kingaroy site, veneer stiffness and density decreased from mid-radius to the outer wood—the effect of prolonged drought late in the rotation being a possible explanation for this decline.

Standing tree acoustic velocity provided a reliable prediction of average veneer stiffness for both species, suggesting its potential as a non-destructive tool for wood quality evaluation.

References

Blakemore P., Morrow A., Washusen R., Harwood C., Wood M. and Ngo D. (2010): Evaluation of thin-section quarter-sawn boards and rotary veneer from plantation-grown *Eucalyptus nitens*. CRC for Forestry Technical Report No. 202.

Brancheriau, L. and Bailleres H. (2003): Use of Partial Least Squares Method with Acoustic Vibration Spectra as Grading Technique for Structural Timber. Holzforschung 57: 644–652.

Gavran M and Parsons M (2010): Australia's Plantations 2010 Inventory Update. National Forest Inventory, Bureau of Rural Sciences, Canberra.

Glencross. K., Palmer G., Pelletier MC. and Nichols JD (2011): Growth response to thinning in two subtropical hardwood species. CRC for Forestry Technical Report No. 217.

Leggate, W., Palmer, G., McGavin, R. and Muneri, A. (2000): Productivity, sawn recovery and potential rates of return from eucalypt plantation in Queensland. In "The future of eucalypts for wood products". Proceedings of IUFRO conference. 19-24 March 2000, Launceston. Forest Industries Association of Tasmania.

Nichols JD, Smith RGB, Grant J, Glencross K (2010): Subtropical eucalypt plantations in eastern Australia. *Australian Forestry* 73(1), 53-62.

Standards Australia (2008): Plywood–Structural, Part 0: Specifications. AS/NZS 2269:2008. Standards Australia, Sydney.

Standards Australia. (2000): AS/NZS 1080.3:2000 Timber-Methods of test-Method 3: Density

Thinley, C., Palmer, G., Vanclay, J. K. and Henson, M. (2005): Spiral and interlocking grain in *Eucalyptus dunnii*. Holz als Roh- und Werkst, 63, 372-379.

Thomas, D., Joe, B., Austin S. and Henson, M. (2009): Characterisation of plywood properties manufactured from plantation grown eucalypts. Forestry and Wood Products Australia Project No: PRB046-0809

Todoroki C., Lowell E., Dykstra D. and Briggs D. (2012): Maps and models of density and stiffness within individual Douglas-fir trees. New Zealand Journal of Forestry Science 42, pp 1-13.

Yang JL (2005): The impact of log-end splits and spring on sawn recovery of 32-year–old plantation *Eucalyptus globulus* Labill. Holz Roh- Werkst 63(6):442–448