Comparison of Processing Methods for Small-diameter Logs: Sawing *versus* Rotary Peeling

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Currently there are limited markets in Australia for small-diameter native forest logs. This has resulted in much of this resource being underutilized and regarded as sub-optimal in quality and of low value. This is despite the fact that the wood properties are favorable for a wide range of high-value products. Traditional processing approaches either have not been able to accommodate small-diameter logs or the resulting product recovery is too low for profitable production. Alternative processing approaches are necessary to enable the efficient recovery of wood from this resource in a form that is usable for high-value product manufacturing. Processing small-diameter spotted gum (*Corymbia citriodora*) and white cypress pine (*Callitris glaucophylla*) logs into rotary veneer using new spindleless veneering technology has been demonstrated to yield more acceptable recoveries compared with more traditional sawing approaches. The veneer processing approach was also found to be less impacted by the diameter than sawing, with more consistent recovery rates across the three small-diameter log groups included in this study. The resulting veneer, especially the spotted gum veneer, had visual qualities and mechanical properties well suited to the manufacturing of veneer-based engineered wood products.

Keywords: Veneer; Hardwood; Cypress; Sawing; Peeling; Processing; Timber; Grade quality; Recovery

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INTRODUCTION

The forests in Australia are comprised of 123 million ha of native forests (98% of the total forest area), 2.02 million ha of industrial plantations, and 0.15 million ha of other forests (ABARES 2013). Native forest resources have largely been limited to utilization by the timber industry as sawn timber. However, for more durable hardwood species, well established markets also exist for several round wood products, such as electrical distribution poles, bridge girders, *etc*. Sawing has for many years been a suitable method for converting relatively large-diameter native forest logs into a range of traditionally well-demanded sawn products, including large- and small-dimension structural posts and beams, bridge members, railway sleepers, flooring, decking, fencing, and landscaping timbers.

Traditionally, small-diameter hardwood logs (< 40 cm in diameter) have not been favored for sawmilling, mainly because of unacceptable low recovery rates. However, some sawmills have recently begun accepting smaller diameter hardwood logs, usually at low log prices. Some limited low-value and low-volume markets (*e.g.*, fence posts and firewood) do exist for small-diameter native forest logs. However, this log resource is currently being underutilized, and it is often regarded as sub-optimal in quality and of low value. This is despite the wood properties potentially being favorable for a wide range of high-value products.

Engineered wood products (EWPs), particularly veneer-based EWPs, may provide a more efficient processing method and a new product market for small native forest logs. However, there is only limited knowledge and technical experience in Australia on the processing of relatively large-diameter native forest logs into veneer-based EWPs, such as plywood. For small native forest logs, the potential to produce EWPs using rotary-peeled veneers has been prevented because of processing equipment limitations. Traditional rotary peeling approaches have required large-diameter logs of high quality to overcome the limiting recovery rates that result from large peeler cores (peeler cores are the center of the log that remains after the peeling process from which no veneer is recovered) and the propensity for logs to end split, especially in high density and regrowth hardwood logs, where the splits prevent adequate log holding capacities of the lathe spindles.

Recent research has demonstrated the potential to use emerging spindleless veneering technologies to process hardwood plantation logs with sizes and qualities previously considered unable to be efficiently processed (McGavin *et al.* 2014a,b; Peng *et al.* 2014; McGavin *et al.* 2015a,b; Leggate *et al.* 2017; Belleville *et al.* 2018). The research has shown that this new approach can process small-diameter logs and is able to yield recovery rates that are higher than what is achieved through other processes.

This study expanded on previous research that focused on plantation-grown resources to determine the suitability of this processing approach for small-diameter logs from native forest resources. Using small-diameter native forest logs, the recovery rates and product quality grade of wood products from traditional sawing approaches were compared with those of wood products produced using a spindleless veneer processing system.

EXPERIMENTAL

Log Sampling

Two native forest tree species were included in this study: spotted gum (*Corymbia citriodora*) and white cypress pine (*Callitris glaucophylla*). These species were selected because they are the dominant hardwood and softwood species harvested from native forests for timber products in Queensland, Australia.

The spotted gum logs were selected during a commercial harvesting operation within the Gurulmundi State Forest, located in South West Queensland, Australia. This forest is representative of a typical mixed-age hardwood forest in this region. Commercial harvesting targets electrical distribution poles, bridge girders, and sawlogs, essentially all of which have diameters greater than 30 cm. For this study, 2.7-m long logs were chosen that contained small-end diameters under bark (SEDUB) within three target diameter groups (19 cm, 24 cm, and 28 cm). Because of physical restrictions with processing equipment at the commercial sawmill, the minimum SEDUB was 18 cm. Where possible, logs for the study were cut from trees harvested as part of a commercial harvest.

The white cypress pine logs were sourced from within full-length logs in the log yard of a commercial sawmill (original logs sourced from a mixed age forest within the Barakula State Forest). In Queensland, it is common practice for harvested white cypress pine trees to be docked to 16 cm SEDUB (unless defects necessitate cutting at a larger small-end diameter) and the full-length logs are delivered to a sawmill, where they are further cut to more desirable log lengths in preparation for sawmilling. Similar to the spotted gum logs, 2.7-m long logs were chosen that contained a SEDUB within three target diameter groups (16 cm, 22 cm, and 28 cm). The minimum SEDUB was set lower for the white cypress pine logs at 16 cm SEDUB to align with the current commercial sawlog criteria for this species. In addition to the SEDUB, other log grade criteria were used to evaluate the sweep, branching, and other log defects (Table 1).

Table 1. Log Grading Criteria

Grade Criteria	Spotted Gum	White Cypress Pine
Minimum Length	2.7 m	2.7 m
Minimum SEDUB	18 cm	16 cm
Maximum SEDUB	30 cm	30 cm
Core	Defective core should not exceed 6 cm in diameter	Defective core should not exceed 6 cm in diameter
External Defect	No green limbs > 6 cm in diameter; no dry limbs > 3 cm in diameter - No more than one bump (*i.e.*, occluded limbs) on visible half of the log within each 50-cm length; no more than one overgrowth (*i.e.*, insect or logging damage) on visible half of the log within each 50-cm length; fluting acceptable where the hollows do not extend into the center log diameter	no green limbs > 9 cm in diameter - no dry limbs > 4.5 cm in diameter - No more than two bumps (*i.e.*, occluded limbs) on visible half of the log within each 50-cm length; no more than one overgrowth (*i.e.*, insect or logging damage) on visible half of the log within each 50-cm length; fluting acceptable where the hollows do not extend into the center log diameter
Maximum Sweep	1/7 (14%) of the SEDUB	1/7 (14%) of the SEDUB
Ovality/Taper	maximum difference between the longest and shortest axis ranging from 2.2 cm (18 cm SEDUB) to 3.8 cm (30 cm SEDUB)	maximum difference between the longest and shortest axis ranging from 2.2 cm (16 cm SEDUB) to 3.8 cm (30 cm SEDUB)
Spiral Grain/Grain	No spiral grain, no excessive free grain	No spiral grain, no excessive free grain

Log Assessment and Allocation

The following parameters were measured on each log:

- Large-end diameter under bark (LEDUB) (m) – measured from the circumference with a diameter tape; and
- Small-end diameter under bark (SEDUB) (m) – measured from the circumference with a diameter tape.

Logs were then sorted into diameter groups to provide tree batches per species (three diameter groups). Logs within each batch were sorted by the SEDUB from smallest to largest before being alternately allocated to a processing method, at which point they underwent either sawing or veneer processing. Logs allocated for veneer processing were further docked in length to a standard length of 2.6 m. Each batch was color-coded by spray painting the log ends for easy tracking during processing.

From the measured data, the log volume was derived for each log and was calculated with the following equation,

$$V = \left(\frac{SEDUB + LEDUB}{4} \right)^2 \times \pi \times L \tag{1}$$

where V is the individual green log volume (m^3), π is 3.141593, and L is the nominal length of the log (2.7 m for sawlog and 2.6 m for veneer log).

Sawmill Processing

Log conversion

The spotted gum logs were processed in a commercial hardwood sawmill equipped with modern equipment well-suited to processing high-density hardwood logs with diameters less than 45 cm SEDUB. The sawing approach adopted for the study mirrored the standard processing strategy used in sawmills that targets two different width flooring products. A chipper canter was used in conjunction with twin circular saws to target nominal 25-mm-thick (actually 27 mm to allow for shrinkage during drying) wing boards and either nominal 100-mm- or 150-mm-wide (actually 104 mm and 154 mm, respectively) center cants. The wing boards and center cants were then processed through a multi-saw board edger to recover either 100-mm- or 150-mm-wide (nominal), and 25-mm-thick (nominal) boards. As is performed during standard production, all of the boards were then passed through a scanning and docking station where only major defects were removed.

The white cypress pine logs were processed within a commercial cypress sawmill. The sawing approach adopted for the study mirrored the standard sawmill processing strategy that targets a wide variety of board sizes, which suit either structural, appearance, or landscaping/fencing products. The sawing approach and board size were chosen by the saw operators on a piece by piece basis based on visually assessing the log or piece for shape and defects and aimed to maximize the product recovery. Twin circular saws were used to remove wing boards and a center cant from the logs. These pieces were then passed over traditional breakdown bench saws to recover sawn boards. During normal production, defects considered unacceptable by the market are docked from sawn boards before the boards are stacked and on-sold. This defect docking process was also followed so that the study logs closely matched the standard sawmill production approach.

Sawn timber grading

The sawn timber resulting from processing remained separated in line with the original log batch segregation. Because the hardwood sawmill targets a dried and dressed final product and the study aimed to replicate the standard commercial sawmilling process, the recovered spotted gum boards were dried to a target moisture content of 12% before the quality grade was assessed. The dried boards were graded according to AS 2796.2:2006 (2006). This standard is well accepted by the Australian hardwood timber industry and separates flooring-type products into three quality grades: select grade (highest quality), medium feature grade, and high feature grade (lowest quality). Each board was visually graded according to all three grades individually to determine the grade recovery of each specific grade. The most influential defect type that caused the boards to be down-graded/rejected was also recorded. A minimum piece length was set at 900 mm in line with the sawmill procedures.

For the white cypress pine, no grading was conducted, as the cypress sawmill does not undertake any further processing or value adding onsite. The rough sawn and unseasoned sawn boards are either sold directly to market or on-sold within the company to another facility where boards are then sold to market (with or without any further processing). To closely replicate the commercial sawmill process, the white cypress pine boards were measured to determine the marketable volumes immediately after sawing and docking (*i.e.*, green-off-saw). A minimum piece length was set at 1800 mm, which was in line with the sawmill procedures.

Sawn timber recovery

Two recovery calculation methods were used: sawn recovery (SR) and dried-dressed recovery (DDR). Sawn recovery provides a useful measure of the percentage of the log volume converted into boards from the sawing process (mainly influenced by the log size, log geometry, and processing equipment). The SR (%) was calculated for each log batch as follows,

$$SR = \left(\frac{\sum_{Board}(W \times T \times L)}{\sum_{Log} V}\right) \times 100 \tag{2}$$

where W is the sawn board nominal dried width (m), T is the sawn board nominal dried thickness (m), and L is the sawn board length (m).

Dried-dressed recovery includes the losses accounted for in SR, but also includes additional losses from grading and dressing (or machining) to a final dimension, *e.g.*, tongue and groove flooring. The DDR (%) was calculated as follows,

$$DDR = \left(\frac{\sum_{Board}(DDW \times DDT \times L)}{\sum_{Log} V}\right) \times 100 \tag{3}$$

where DDW is the board nominal width (m) after drying and dressing, and DDT is the board nominal thickness (m) after drying and dressing.

Given the commercial process that the study aimed to replicate, only the SR could be calculated for the white cypress pine boards.

Rotary Veneer Processing

Log conversion

The spotted gum and white cypress pine logs allocated for rotary veneer processing were processed using an industrial spindleless veneer lathe in an industrial setting. The lathe was capable of processing logs up to 2600 mm in length and 500 mm in diameter. The minimum peeler core size was 40 mm; however, the veneer processing facility normally processes to a core size of approximately 60 mm. The actual peeler core size was measured for each log at the completion of processing. For the study, a nominal dried veneer thickness of 3.2 mm was selected, which was in line with the thickness frequently peeled by the facility for various structural products. The spotted gum and white cypress pine logs were preheated prior to peeling using saturated steam until the billet core reached approximately 70 °C and 60 °C, respectively.

Veneer management

The veneer ribbon produced by the peeling process was consecutively clipped into veneer sheets with a maximum width of 1350 mm and each veneer sheet was labeled with a unique identifier. Veneer sheets were seasoned to a target moisture content of 8% with a conventional jet box veneer drying system using the standard practices of the factory (temperatures ranged from 160 °C to 190 °C during drying).

The following parameters were measured on the veneer sheets:

- Dried veneer thickness (DT) — the mean thickness of each dried veneer sheet was calculated from measurements recorded at two positions along the veneer sheet using a dial thickness gauge; and
- Dried veneer width (DW) — the width (perpendicular to the grain) of each dried veneer sheet.

Veneer grading

The veneer quality was assessed by visual grading in accordance with AS/NZS 2269.0:2012 (2012). This standard is widely used across the Australian veneer industry and follows the same principles as other international veneer visual grading classification systems. The standard separates structural veneers into four veneer surface qualities and a reject grade, according to the severity and concentration of imperfections and defects. The grading process was undertaken by a minimum of two experienced graders to minimize variation with defect definition and measurement and to ensure consistent assessment.

The veneer logs within each batch were sorted by SEDUB, from smallest to largest. The veneer from every alternate log was allocated to provide a subset of recovered veneer for the purposes of grading analysis, and represented approximately 50% of the total recovered veneer.

Veneer recovery

Four recovery calculation methods were used: dry veneer recovery (DR), gross veneer recovery (GSR), net veneer recovery (NR), and graded veneer recovery.

The DR provides a useful measure of the maximum recovery and takes into account the log geometry (sweep, taper, and circularity), lathe limitations (*e.g.*, peeler core size), and drying process (*e.g.*, veneer shrinkage, *etc*.). The DR disregards internal log quality and was calculated in percentage as follows,

$$DR = \left(\frac{L \times \sum_{veneer}(DT \times DW)}{\sum_{billet} V}\right) \times 100 \tag{4}$$

where DT is the average dry veneer thickness of each veneer (m), and DW is the dry veneer width (m, perpendicular to the grain).

The GSR provides a useful measure of the maximum recovery of dried veneer that meets the quality specifications of AS/NZS 2269.0:2012 (2012) (A-grade to D-grade). This recovery includes the losses accounted for in dry veneer recovery, but also includes additional losses from visual grading (*i.e.*, veneers that failed to meet grade). The gross veneer recovery (*GSR*, %) was calculated as follows,

$$GSR = \frac{L \times \sum_{veneer}(DT \times GRW)}{\sum_{billet} V} \times 100 \tag{5}$$

where GRW is the width (m, perpendicular to the grain) of the dried veneer that meets the A-, B-, C-, and D-grade requirements, in accordance with AS/NZS 2269.0:2012 (2012).

The NR enables analysis of the efficiency of the process, as it determines the proportion of saleable product recovered, and takes into consideration any limiting factors of the product manufacturing process. The NR includes the losses measured in the GSR, along with the further losses that result from trimming of the veneer within product manufacturing stages. The losses resulting from veneer sheets being reduced in width to the final product dimension is called the trimming factor. In this study, the trimming factor corresponded to reducing the veneer sheet width perpendicular to the grain from 1275 mm to 1200 mm and the veneer sheet length (parallel to the grain) from 2600 mm to 2400 mm. The NR (%) was calculated as follows:

$$NR = GSR \times \frac{1200}{1275} \times \frac{2400}{2600} \quad (6)$$

Thus,

$$NR = GSR \times 0.869 \quad (7)$$

The graded veneer recovery separates the net veneer recovery into each grade quality classification in accordance with AS/NZS 2269.0:2012 (2012) (*i.e.*, A-, B-, C-, or D-grade). Each grade quality classification was individually calculated and labeled NR_A, NR_B, NR_C, and NR_D.

Veneer Density

The veneer logs within each batch were sorted by the SEDUB, from smallest to largest. The second smallest, second largest, and median logs were chosen from each batch to provide a subset of veneers for the purposes of determining the air-dry density (at a 12% moisture content) of the recovered veneer. From each veneer from the identified logs, a 200-mm wide strip was removed from the veneer width (perpendicular to the grain). This was reduced in length to approximately 1200 mm (perpendicular to the grain) to provide a sample strip. The sample strip dimensions (length, width, and thickness) and weight were measured so that the veneer air-dry density could be calculated.

Veneer Dynamic Modulus of Elasticity

The sample strips prepared for the veneer density measurement were used to measure the veneer dynamic modulus of elasticity (MoE), following similar procedures as described by McGavin *et al.* (2015b). An acoustic natural-vibration method described by Brancheriau and Bailleres (2002) was used to perform the measurements.

The sample strips were positioned on elastic supports so that the longitudinal propagation of the vibration was as free as possible and could be induced by a simple percussion on one end of the sample, in the grain direction. At the other end, a Lavalier-type microphone (Model ME104, Sennheiser, Germany) recorded the vibrations before transmitting the signal *via* an anti-aliasing filter (low-pass) to an acquisition card that included an analog-to-digital converter to produce a digitized signal.

A fast Fourier transform algorithm processed the signal to convert the information from time to the frequency domain. The mathematical processing of selected frequencies was undertaken using beam identification by non-destructive grading (BING) software (Version 9.7.2, CIRAD, Montpellier, France), in combination with the geometric characteristics and weight of the specimen, to determine the dynamic MoE, as well as other specific mechanical characteristics (CIRAD 2009; PICO 2014).

RESULTS AND DISCUSSION

Two hundred and forty logs (29.6 m^3) from two different wood species were processed using two different processing methods. Tables 2 and 3 provide details of the log characteristics and processing allocations for the spotted gum and white cypress pine logs, respectively. The method of log allocation ensured that there was minimum variation in the log SEDUB between the two processing methods (sawing and rotary peeling). The variation in the average log volume between the two processing methods was explained by the shorter log length used for rotary peeling (2.6 m *versus* 2.7 m used for sawing). The narrow range of SEDUBs within each log batch (as evidenced by the low SEDUB standard deviations) ensured that the diameter groupings were well separated for analysis purposes. The different target SEDUBs between the two species for diameter groups 1 and 2 meant that caution needed to be applied when comparing the results.

Table 2. Characteristics of the Spotted Gum Logs

Diameter Group	Processing Method	Number of Logs	Average Log Small-end Diameter Under Bark (cm)	Average Log Volume (m^3)	Total Log Volume Processed (m^3)
1	Sawing	20	19.6 (1.3)	0.089	1.789
1	Peeling	20	19.6 (1.2)	0.086	1.714
2	Sawing	20	23.5 (1.0)	0.128	2.566
2	Peeling	20	23.7 (0.9)	0.123	2.469
3	Sawing	20	27.8 (1.5)	0.180	3.600
3	Peeling	20	27.8 (1.5)	0.172	3.435
Standard deviation is given in parentheses					

Table 3. Characteristics of the White Cypress Pine Logs

Diameter Group	Processing Method	Number of Logs	Average Log Small-end Diameter Under Bark (cm)	Average Log Volume (m^3)	Total Log Volume Processed (m^3)
1	Sawing	20	16.2 (0.8)	0.065	1.303
1	Peeling	20	16.3 (0.7)	0.063	1.257
2	Sawing	20	21.2 (0.9)	0.110	2.196
2	Peeling	20	21.4 (0.8)	0.104	2.080
3	Sawing	20	27.2 (1.7)	0.180	3.608
3	Peeling	20	27.7 (1.6)	0.174	3.471
Standard deviation given in in parentheses					

The sawn timber recoveries are presented in Table 4. For both species, there was a consistent increase in the SR as the log SEDUB increased. For the spotted gum logs, the SR remained in a narrow range (between 41% and 43%) that resulted from the minimum variation in the processing approach between the three log diameter groups. More variability in the SR was produced within the white cypress pine logs. This was attributed to the larger range of board dimensions produced and adjustment of the target board dimensions to those that best suited the individual log diameter, log shape, and internal defects. The SR values yielded from the white cypress pine logs (between 43% and 54%) were higher than the spotted gum SR values (between 41% and 43%). This was also a result of the variation in the target sawn board dimensions with the spotted gum logs all sawn into comparatively small board dimensions (either 100 mm × 25 mm or 150 mm × 25 mm), as is shown in Fig. 1. In comparison, the target sawn board dimensions of the white cypress pine boards (Fig. 2) favored larger-dimension boards that resulted in less waste because of fewer saw cuts.

Only the spotted gum sawn boards were dried and graded. There was minimum variation in the DDR within the diameter groups between the three grade types. However, more variation existed between the diameter groups with diameter group 1 (containing the smallest SEDUB logs). Approximately 25% less wood was recovered than from the other log diameter groups.

Table 4. Sawn Timber Recoveries

Species	Diameter Group	SR (%)	DDR (% of log vol.*)		
			Select Grade	Medium Feature Grade	High Feature Grade
Spotted Gum	1	41	13.9	14.4	14.5
	2	41	19.2	19.5	20.3
	3	43	19.4	19.9	21.9
White Cypress Pine	1	43			
	2	48			
	3	54			
*Grade recoveries are independent of each other					

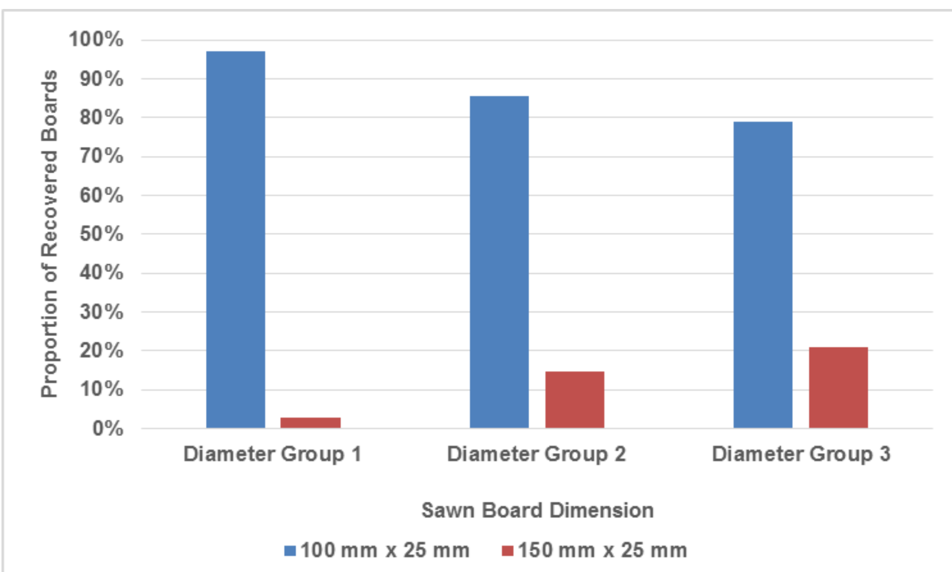

Fig. 1. Distribution of spotted gum sawn board dimensions

Figure 3 details the primary defect type that resulted in boards or portions of boards failing to meet the grade requirements of AS 2796.2:2006 (2006). In all three diameter groups, wane was the leading cause for board downgrade, followed by knots, end splits, and heart shake. These defect types, with the exception of end splits, illustrated the obvious challenges of recovering sawn boards from small-diameter hardwood logs. The negative impact of end splits was more obvious in the larger-diameter log group (diameter group 3).

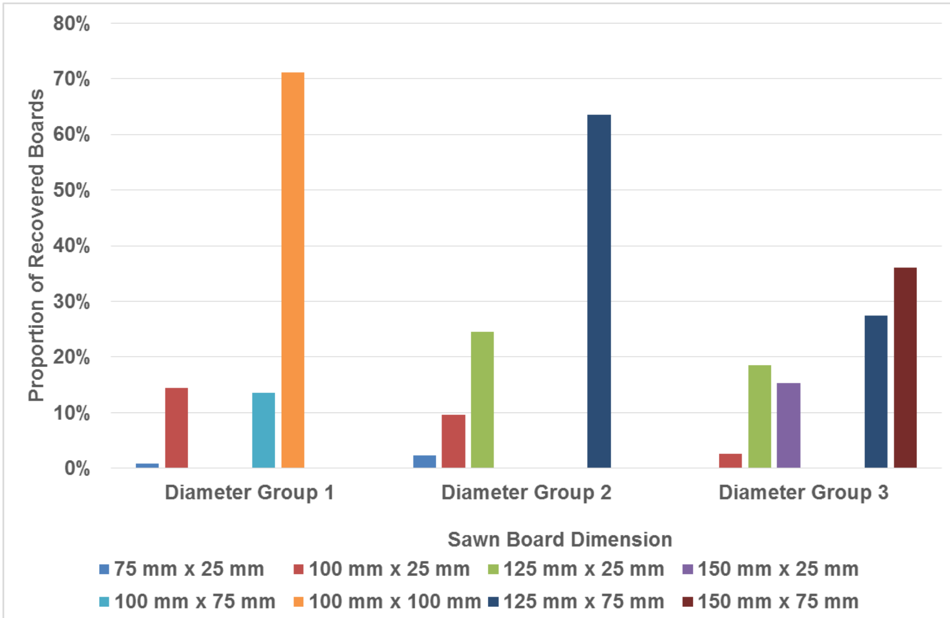

Fig. 2. Distribution of white cypress pine sawn board dimensions

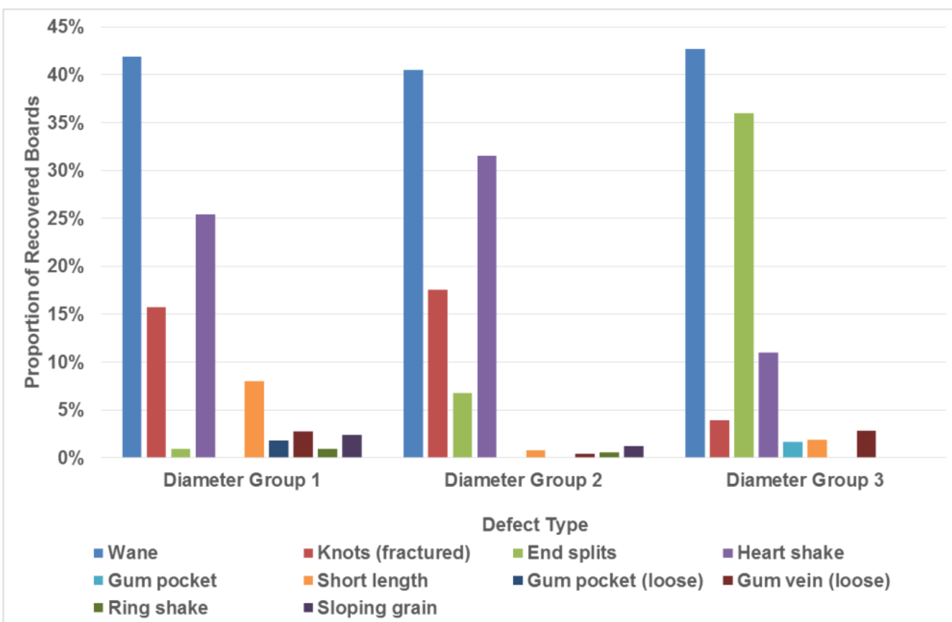

Fig. 3. Primary reason for spotted gum sawn boards failing to meet a high feature grade

Table 5 details the veneer recoveries achieved for the spotted gum and white cypress pine logs. Regardless of the species, the veneer recoveries were higher than that achieved for the logs sawn into boards. This was mainly because the peeling process was based on a cutting technique (with no chip or sawdust) that produces less off-cuts because of the absence of losses resulting from cutting square sections from circular logs. The spindleless veneering approach adopted during this study ensured that the waste was restricted to the rounding stage where no usable veneer was recovered until the log was machined into a cylinder (with sweep, ovality, and taper largely removed) and also the final stage, where no veneer was recovered from the peeler core. The average peeler core size was 58 mm and 66 mm for the spotted gum and white cypress pine logs, respectively.

The NR that represents the saleable volume of veneer (post-product manufacture) ranged between 38% and 46%, with the spotted gum logs yielding a higher recovery than the white cypress pine logs. For the spotted gum, this result was at least twice the equivalent recovery for the sawn boards, which ranged between 14% and 22%.

Table 5. Veneer Recoveries

Species	Diameter Group	DR (% of Log Volume)	GSR (% of Log Volume)	Gross Recovery Percentage of Dry Recovery (% of Dry Veneer Volume)	NR (% of Log Volume)
Spotted Gum	1	65	52	80	45
	2	66	53	81	46
	3	69	50	62	43
White Cypress Pine	1	55	43	78	38
	2	63	46	74	40
	3	67	46	72	40

Among both species and all of the log-diameter groups, the veneer grade recoveries were dominated by D-grade veneers (Table 6). Despite D-grade being the lowest visual grade quality for structural veneers, they are suitable for face veneers in non-appearance structural panels and can be used as core veneers in the manufacture of most appearance and non-appearance structural panels. The low recovery of better grade veneers that are more acceptable for face veneers (C-grade and better), could make the production of a standard commercial mix of structural products challenging when only using a resource of this quality. However, the blending of veneers from small-diameter logs with a higher appearance grade veneer, potentially from larger-diameter logs from the same forest type, may produce a suitable mix for a range of solid wood end products.

Table 6. Graded Veneer Recoveries

Species	Diameter Group	A-grade Recovery (% of Log Volume)	B-grade Recovery (% of Log Volume)	C-grade Recovery (% of Log Volume)	D-grade Recovery (% of Log Volume)
Spotted Gum	1	0	0	0	45 (100)
	2	0	4 (9)	2 (5)	40 (86)
	3	0	1 (1)	4 (11)	38 (88)
White Cypress Pine	1	0	0	0	38 (100)
	2	0	0	0	40 (100)
	3	0	0	0	40 (100)
Recovered grade veneer as a proportion of the net veneer volume is given in parentheses					

Also, white cypress pine veneer has no commercial history and therefore, it has never been tested by the market to validate the acceptability of different quality grades or determine the suitability of the existing grading standard for this species. In the traditional markets for this species, unique features, such as color variation and knots, can be a marketing advantage; however, these features contribute to lower veneer grades when the current industry standard is applied.

Similar defects prevented veneers from both species from achieving grades higher than a D-grade (Table 7). Between 54% and 91% of the spotted gum veneers were limited to a D-grade because of veneer surface roughness. Other defects that had a major influence included bark-encased knots, fractured knots, decay, and splits. Bark-encased knots prevented almost all of the white cypress pine graded veneers from achieving grades higher than a D-grade. Other contributing defects included the veneer surface roughness, fractured knots, and splits. More optimized processing settings (including log storage management) may be able to reduce the occurrence and severity of surface roughness in the recovered veneers.

Table 7. Top Five Ranked Defects that Prevented Graded Veneers from Attaining Grades Higher than D

Species	Diameter Group	Rank				
		1	2	3	4	5
Spotted Gum	1	Roughness (91%)	Bark-encased Knots (54%)	Fractured Knots (52%)	Decay (42%)	Cumulative Defects (24%)
	2	Roughness (54%)	Decay (37%)	Fractured Knots (27%)	Bark-encased Knots (22%)	Splits (22%)
	3	Roughness (76%)	Fractured Knots (39%)	Bark-encased Knots (33%)	Decay (30%)	Splits (28%)
White Cypress Pine	1	Bark-encased Knots (100%)	Roughness (91%)	Fractured Knots (79%)	Splits (58%)	Compression (21%)
	2	Bark-encased Knots (100%)	Roughness (85%)	Fractured Knots (57%)	Splits (52%)	Resin Pockets (20%)
	3	Bark-encased Knots (96%)	Roughness (84%)	Fractured Knots (70%)	Splits (48%)	Resin Pockets (25%)
Proportion of veneer impacted by each defect is given in parentheses						

The spotted gum logs produced veneers with an average air-dry density of 970 kg/m^3 and the majority of the veneers had a density between 850 kg/m^3 and 1100 kg/m^3 (Fig. 4). The white cypress pine logs produced veneers with a lower average density of 620 kg/m^3 and the majority of the veneers had a density of 550 kg/m^3 to 700 kg/m^3 (Fig. 5).

These results were comparable to many studies reporting mature wood densities for these species (Bootle 2010).

Figures 6 and 7 show the variation in the veneer density as measured along the veneer ribbon for spotted gum and white cypress pine veneers, respectively.

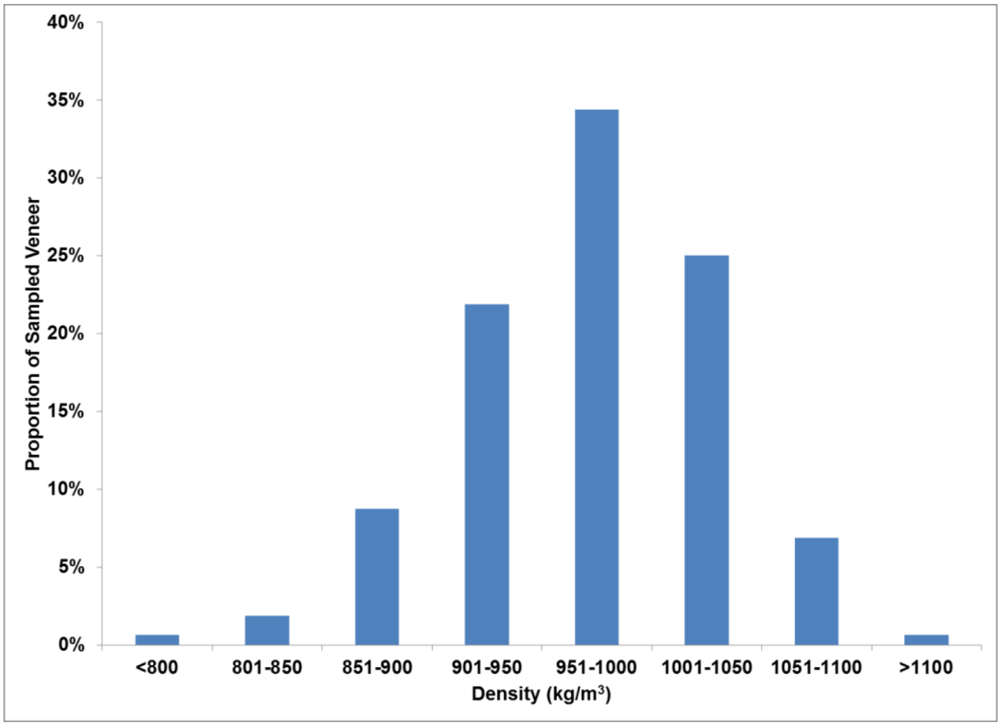

Fig. 4. Spotted gum veneer density distribution

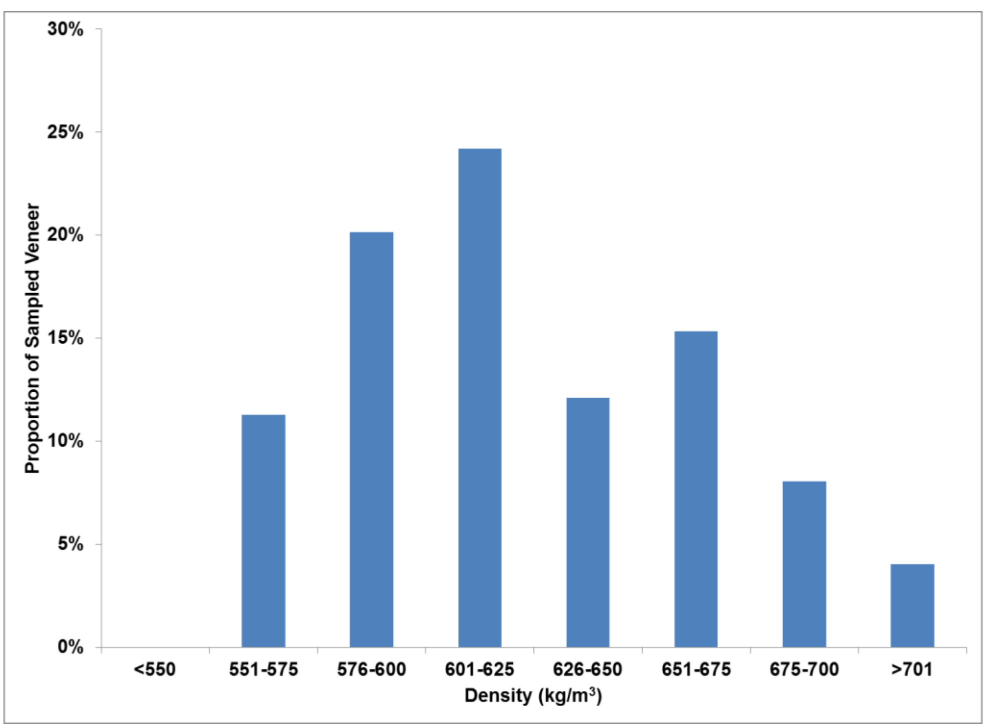

Fig. 5. White cypress pine veneer density distribution

Both species recorded minimal variation from the veneer recovered near the log center (left side of the X-axis) and those recovered closer to the log periphery (right side of the X-axis). This relative consistency should be regarded as a valuable asset that does not exist in many other forest resources, such as fast-grown plantations, for which wide variations from the log center to the periphery have been reported (McGavin *et al.* 2015b).

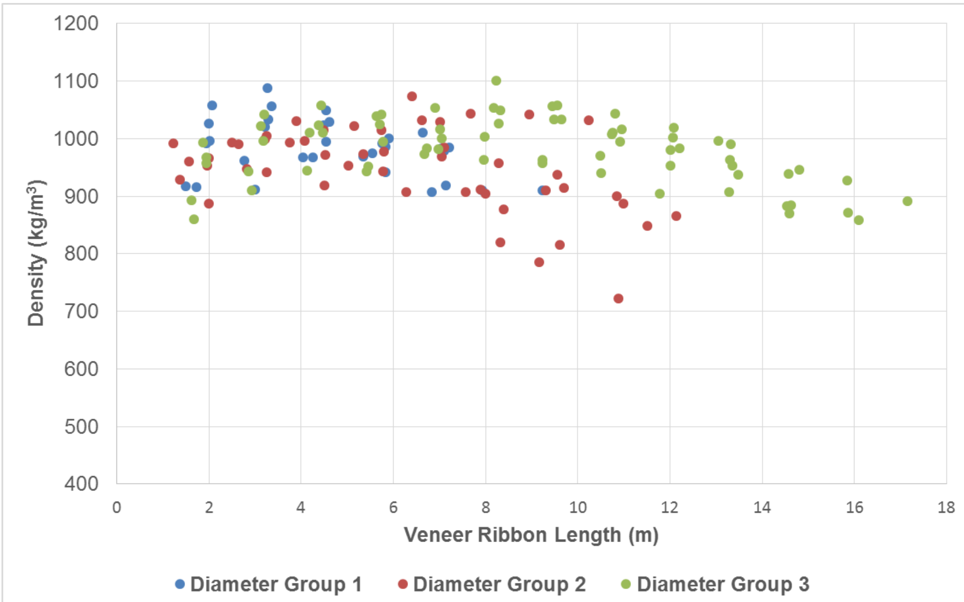

Fig. 6. Spotted gum veneer density distribution along the veneer ribbon

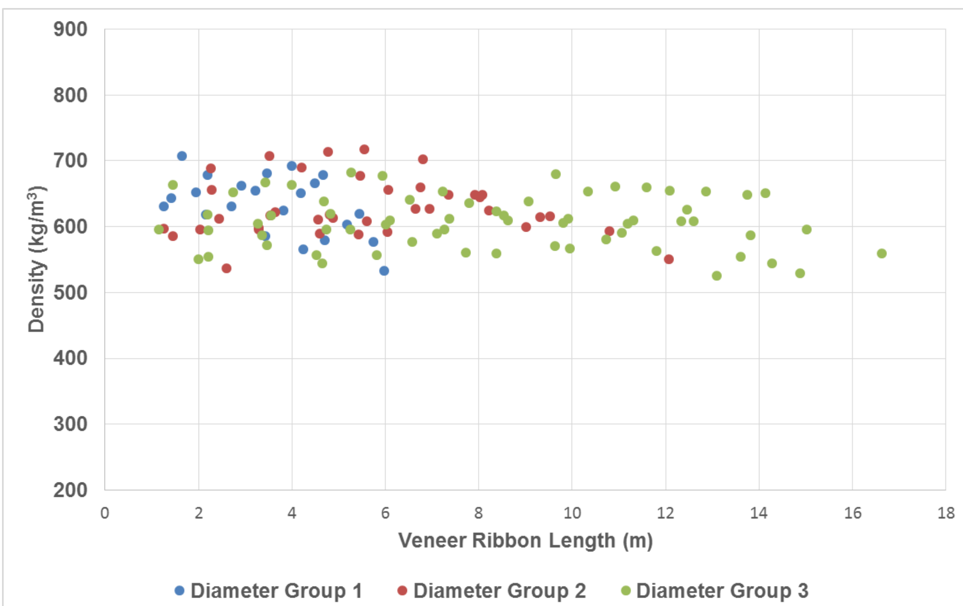

Fig. 7. White cypress pine veneer density distribution along the veneer ribbon

The spotted gum logs produced veneers with an average MoE of 22,200 MPa and the majority of veneers had a MoE of 15000 MPa to 29000 MPa (Fig. 8). Compared with many commercial wood species, these results confirmed the international reputation of this species as having superior mechanical properties.

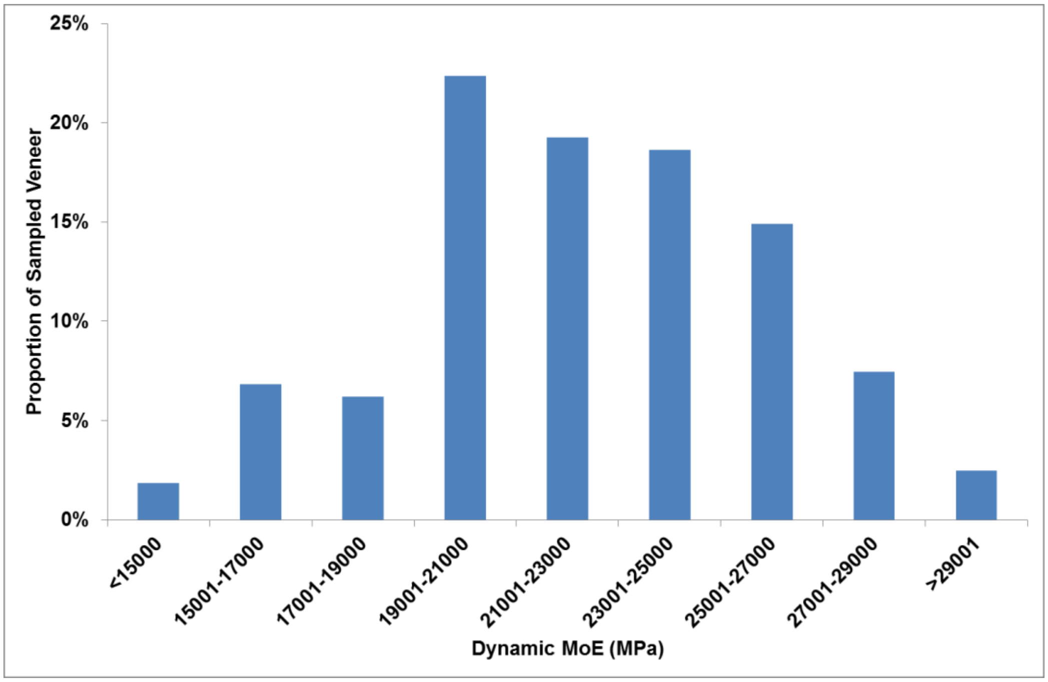

Fig. 8. Distribution of the dynamic MoE for the spotted gum veneers

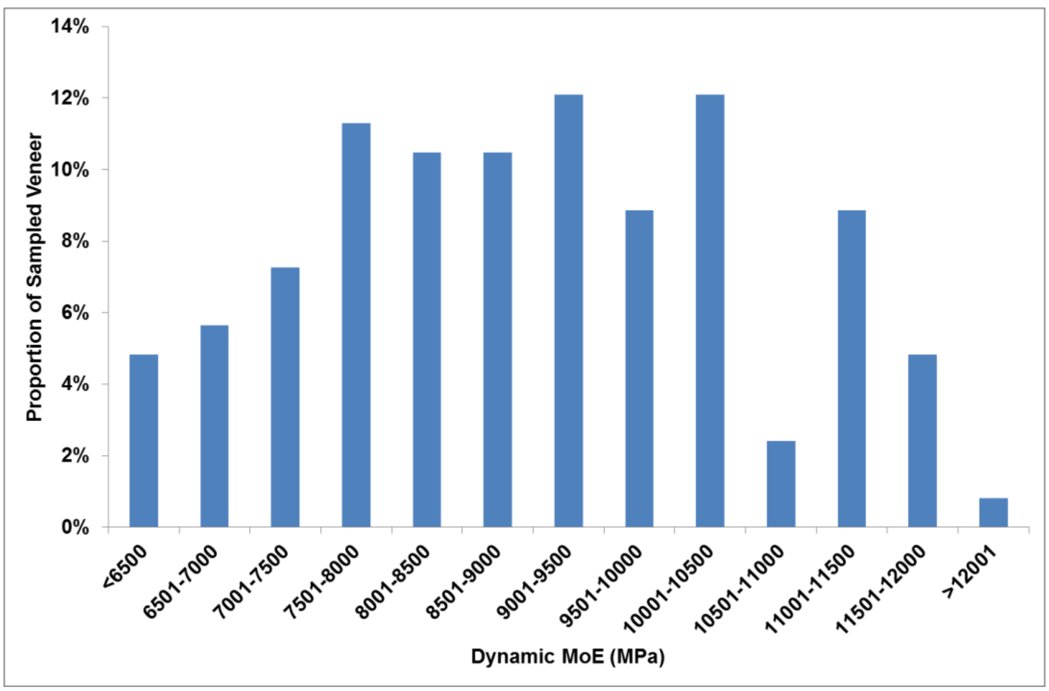

Fig. 9. Distribution of the dynamic MoE for the white cypress pine veneers

The white cypress pine logs produced veneers with a lower average MoE of 9010 MPa and the majority of the veneers had a MoE of 6500 MPa to 12000 MPa (Fig. 9). These values were similar to those of many commercial wood species, including the plantation *Pinus* species grown in Australia.

While the variation in the MoE was greater when compared with the density results, the variation was not as large as for plantation-grown spotted gum reported by McGavin *et al.* (2015a). The wider variation when compared with the density results was attributed to the samples being systematically selected without bias and included any stiffness-reducing defects that were present.

Figures 10 and 11 show the variation in the veneer MoE as measured along the veneer ribbon for the spotted gum and white cypress pine veneers, respectively.

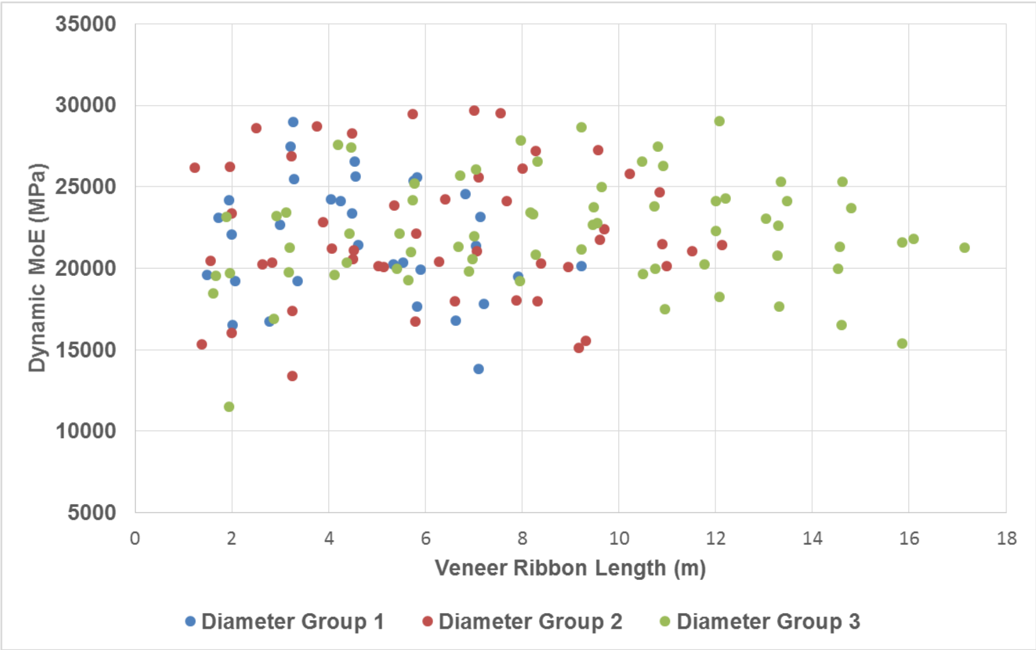

Fig. 10. Distribution of the dynamic MoE of the spotted gum veneers along the veneer ribbon

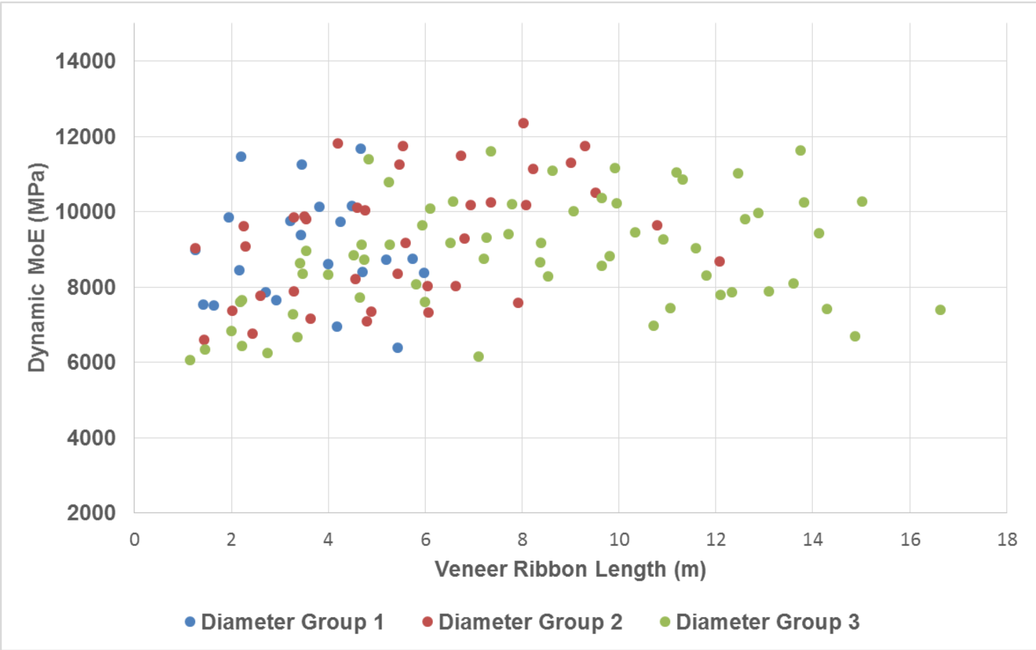

Fig. 11. Distribution of the dynamic MoE of the white cypress pine veneers along the veneer ribbon

The variation that existed was consistent along the veneer ribbon, which suggested that even when these mature native forest logs, regardless of diameter, are processed down to a relatively small peeler core size, consistent and mature wood properties can be obtained. In contrast, McGavin *et al.* (2015a) reported a wide variation in the veneer MoE measured along the veneer ribbon of 10-year- to 12-year-old plantation spotted gum. While the log diameter was smaller (mean of 15.6 cm), the results of this study clearly showed the negative impact of the juvenile core that contained lower MoE wood, which given the fast growth rate in plantations, occupied a greater proportion of the stem volume. The slow growth of the native forest logs ensured that the lower-quality juvenile core was small and probably contained within the waste peeler core. This was a clear advantage for native forest logs.

CONCLUSIONS

1. This study demonstrated that processing small-diameter logs from native forests into rotary veneers using spindleless lathe technology can yield higher recoveries compared with using traditional solid wood processing techniques. This processing method also produced a more consistent recovery result across the range of log sizes included in the study. For the spotted gum, processing small-diameter logs into dried and graded rotary veneer recovered twice the volume of saleable product compared with the same log quality sawn into flooring-type products (43% to 46% *versus* 15% to 22%). The recovery benefits were not as great for white cypress pine because the larger-dimension sawn boards aided in achieving a higher recovery compared with the spotted gum, and product grading was limited. Comparable dried and finished product grading was not undertaken as part of the study for the white cypress pine; however, this would be expected to further improve the comparative performance of veneer processing.
2. For both species, the graded veneer recovery was dominated by D-grade veneer. While D-grade is the lowest visual quality grade for structural veneer, the veneers were suitable for face veneers in non-appearance structural panels, as well as core veneers for the vast majority of appearance and non-appearance structural panels. The low recovery of higher-grade veneers (C-grade and better) may make the commercial production of structural panel products challenging (because of insufficient quantities of face veneer) if a processor solely relied on this resource grade. However, the blending of veneers from small-diameter logs with higher appearance grade veneers, potentially from larger-diameter logs from the same forest type, may produce a suitable mix for a range of solid wood end products. Also, white cypress pine veneer has no commercial history and therefore, the willingness for the market to accept the range of defects present in this species has not been tested. The presence of some defects may indeed provide a marketing advantage for this species.
3. There was a relatively narrow variation in the veneer properties within the species. This is an advantage for the industry because sorting and segregation systems can be simplified compared with the management of more varied resources. The spotted gum logs produced veneers with high stiffness properties. Approximately 85% of the sampled veneers had MoE values above 19000 MPa and 25% of the veneers had MoE values above 25000 MPa. The stiffness properties in this range could be a key asset for this resource and would support its use in high performance structural products. The

white cypress pine veneer had inferior mechanical properties compared with the spotted gum; however, the properties were suitable for structural applications.

4. While this study demonstrated that rotary veneer processing is a more efficient processing system to convert small-diameter native forest logs compared with sawing, the identification of veneer-based EWPs with a connected market demand is critical to further encourage the industry to consider adopting this approach.

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