Veneer Grade Analysis of Early to Mid-rotation Plantation *Eucalyptus* Species in Australia

Robert L. McGavin,[a,b,]* Henri Bailleres,[b] Fred Lane,[b] Joh Fehrmann,[b] and Barbara Ozarska [a]

Processing Australian hardwood plantations into rotary veneer can produce more acceptable marketable product recoveries compared to traditional processing techniques (*e.g.* sawmilling). Veneers resulting from processing trials from six commercially important Australian hardwood species were dominated by D-grade veneer. Defects such as encased knots, gum pockets, gum veins, surface roughness, splits, bark pockets, and decay impacted the final assigned grade. Four grading scenarios were adopted. The first included a change to the grade limitations for gum pockets and gum veins, while the second investigated the potential impact of effective pruning on grade recovery. Although both scenarios individually had a positive impact on achieving higher face grade veneer qualities, the third and fourth scenarios, which combined both, had a substantial impact, with relative veneer values increasing up to 18.2% using conservative calculations (scenario three) or up to 22.6% (scenario four) where some of the upgraded veneers were further upgraded to A-grade, which attracts superior value. The total change in veneer value was found to depend on the average billet diameter unless defects other than those relating to the scenarios (gum or knots) restricted the benefit of pruning and gum upgrading. This was the case for species prone to high levels of growth stress and related defects.

Keywords: Eucalyptus; Veneer; Plantation; Grade quality; Value; Pruning; Recovery

*Contact information: a: University of Melbourne, Department of Forest Ecosystem Science, 500 Yarra Boulevard Richmond, Victoria 3121 Australia; b: Queensland Department of Agriculture, Fisheries and Forestry, Horticulture and Forestry Science, Salisbury Research Facility, 50 Evans Road, Salisbury, Queensland 4107 Australia; *Corresponding author: robbie.mcgavin@daff.qld.gov.au*

INTRODUCTION

The commercial forest resource in Australia is undergoing considerable change with a greater proportion of plantation grown forest becoming available to the wood processing sector. While the industry's softwood sector in Australia has become well established over recent decades with reliance on a plantation resource, the hardwood sector remains largely dependent on native forests for log supply. It is therefore this sector that can expect the greatest change in the available forest quality and quantity with the continuing transition from native forest towards plantation grown forests.

Gavran (2013) reports that over two million hectares of plantation forestry exist in Australia, of which about one million hectares are hardwood species. Of this one million hectare hardwood estate, around 84% have been established for pulpwood production (Gavran 2013). While some small areas of plantations have been established and managed with a high-value product focus, the majority of the estate contains a mix of species, and forest and wood qualities that are most likely not optimal for targeting higher-value products.

Despite the original plantation establishment and management intent, less than favourable market conditions for Australian pulpwood have prompted the exploration of alternative higher value markets. As summarised by McGavin *et al.* (2014), many studies have been completed that investigated solid wood processing options (*i.e.*, sawmilling) for the plantation hardwood resource. Despite the varied approaches mainly based on alternative technologies targeting sawn timber products, many challenges remain, resulting in excessively low recovery of marketable products and unprofitable processes.

The processing of Australian grown hardwood from plantations into veneer using relatively new small-scale spindleless veneer lathe technology has the potential to produce product recoveries that are much more favourable when compared to solid wood processing techniques (McGavin *et al.* 2014). While the technology approach is not necessarily new, recent advancements in design allow the technology to be well suited to smaller diameter plantation forest resources. The advancements have been quickly adopted through many Asian countries, including China and Vietnam, for successful veneer production from very small diameter hardwood billets. Arnold *et al.* (2013) report well over 5000 small-scale veneer mills operating in China.

While the veneer recoveries reported by McGavin *et al.* (2014) were high (net recoveries up to 58% of log volume), the grade recoveries were dominated by D-grade veneers when graded to Australian and New Zealand Standard AS/NZS 2269.0:2012 (Standards Australia 2012). The low recovery (between 3% and 32% of total veneer) of higher grade veneers (C-grade and better) has been identified by McGavin *et al.* (2014) as a challenge for commercial panel production with insufficient proportions of face veneer qualities to allow a standard commercial mix of structural panel products to be manufactured when only using a resource of this quality.

The objective of this study was to analyse at a species level, the grade quality, including defect assessment of veneer which resulted from the processing studies reported by McGavin *et al.* (2014). In addition, defects that had the most influence in reducing grade quality are reviewed and scenarios explored to determine the improvements in grade recovery and relative value that may be possible under different circumstances. The resulting analysis will provide guidance on the quality of the current plantation resources, on plantation management programs and product development, and marketing strategies.

EXPERIMENTAL

Materials

Veneer processing

Veneers were sourced from processing studies conducted on billets harvested from Australian commercial plantation stands representing the average resource currently available for industry to access now and in the immediate future (McGavin *et al.* 2014). Six (6) of the major commercially important Australian hardwood species were included and ranged from traditional pulp to high quality solid wood species. They include *Corymbia citriodora* subsp. *variegata* (spotted gum), *Eucalyptus cloeziana* (Gympie messmate), *Eucalyptus dunnii* (Dunn’s white gum), *Eucalyptus pellita* (red mahogany), *Eucalyptus nitens* (shining gum), and *Eucalyptus globulus* (southern blue gum). Plantation ages ranged between 10 and 16 years for all species except *Eucalyptus nitens*, which was between 20- and 21-years-old.

Processing was undertaken using an OMECO spindleless veneer lathe, model TR4 (OMECO, Curitiba, Estado de Paraná, Brazil). The lathe is capable of processing billets with a maximum length of 1350 mm and maximum log diameter of 400 mm. The minimum peeler core size was 45 mm. For the very small number of *E. nitens* billets that were too large (> 400 mm diameter) to process on the spindleless lathe, these were rounded and/or partially peeled using a conventional spindled lathe before the peeling was completed on the spindleless lathe. For this study, the nominal dried veneer thicknesses were 2.4, 2.5, or 3.0 mm, depending on species according to the thickness range mostly used by the Australian industry for structural plywood production.

The resulting veneer ribbon was sequentially clipped to target 1400 mm maximum width sheets. This target sheet size was chosen to provide 1200 mm dried and trimmed veneer sheets as per standard industry practice. Veneer widths down to 300 mm were included while veneer sheets narrower than 300 mm were discarded, with the exception of a number of 150 mm wide sheets specifically targeted for veneer property evaluations (details not reported). Although these 150 mm sheets were not specifically graded, a grade was assigned based on known neighbouring veneer qualities. Veneer sheets were labelled with a unique identifier. Clipped veneer was seasoned through a conventional jet box veneer drying system according to standard commercial practices in Australia (temperatures ranged from 160 to 190 °C during drying) with a target moisture content of 5%. Veneers were then stabilised to 10% moisture content in storage.

More detailed description of the methodology regarding plantation selection, billet preparations, and processing is described by McGavin *et al.* (2014).

Methods

Visual grading

Veneer quality was assessed by visual grading in accordance with Australian and New Zealand standard AS/NZS 2269.0:2012 (Standards Australia 2012). This standard is widely adopted across the Australian veneer industry and follows the same principles as other international visual grading classification systems. The standard separates structural veneer into four veneer surface qualities and a reject grade according to severity and concentration of imperfections and defects.

Apart from a slight variation in veneer thickness, the lathe settings and log conditioning were fixed for all species. Moreover, to facilitate comparisons between species, only resource-related defects have been included in this analysis. Defects that could be directly attributed to the veneering process, such as splitting caused by veneer handling, have been excluded from the analysis so as to not disadvantage any particular species that may benefit from a further refined process. For each veneer, the visual grade was recorded for each type of defect present within the veneer. This allowed the analysis of the impact of each defect type in terms of its contribution to the assigned grade of each veneer. The defect(s) causing the lowest visual grade was identified as the grade limiting defect(s) and the resulting assigned grade was recorded for each veneer. The grading process was undertaken by a minimum of two experienced graders to minimise variation with defect definition and measurement and to ensure consistent assessment.

Grade scenarios

Four realistic scenarios were adopted to explore the opportunity of improving the volume recovered of higher grade qualities (*i.e.,* higher value veneers) and included:

1. the reduction of grade impact from gum (or kino) pockets and gum veins;
2. the reduction of knots (sound and encased knots) as well as defects known to be associated with knots (*e.g.*, roughness, decay and bark) through effective pruning;
3. the combination of gum defect upgrade and effective pruning (*i.e.*, scenarios one and two combined); and
4. the combination of gum defect upgrade and effective pruning (*i.e.*, similar to scenario three) with additional upgrading to higher veneer grades.

The first scenario focused on gum pockets and gum veins. These defects are cavities in the wood containing a natural dark-coloured phenolic exudation (Standards Australia 1997). Although commonly referred to as gum, Hillis and Brown (1984) note the more accurate name of kino when referencing its presence in *Eucalyptus* species. They note the extent of the presence varies according to species, bark thickness, tree vigour, and other environmental and genetic factors and is one of the most frequently mentioned causes of degradation in eucalypt timber. The presence of gum in either pockets or veins is usually a defensive response from the tree against injury, which may occur from insect damage, mechanical damage, or fire (Bootle 2010).

The Australian and New Zealand standard AS/NSZ 2269.0:2012 (Standards Australia 2012) excludes the presence of any gum pockets or gum veins from A-grade and B-grade, excludes gum pockets but permits gum veins in C-grade, and permits both gum pockets and gum veins in D-grade. During the grading, it became obvious that a significant quantity of veneer sheets were being downgraded to C-grade and often D-grade due to very minor occurrences of either gum veins and/or gum pockets within a veneer sheet. Given the minimal visual and mechanical impact that these defects have, especially given the small size and low concentration which potentially have less aesthetic impact compared to other reasonably permitted defects, it was hypothesised that the grading standard had probably been developed with a focus on other forest resources where these defects are less frequently occurring (*e.g.*, plantation softwood and mature native forest hardwood) which potentially unnecessarily disadvantages plantation hardwood veneer.

On this basis, the first grading scenario assumed that the grade limitations relating to gum pockets and gum veins will be reduced, resulting in D-grade and C-grade veneers being able to achieve C-grade and B-grade, respectively, when graded against these defects.

The second scenario focused on the reduction of knots (sound and encased knots) as well as other defects known to be associated with knots including veneer roughness, decay, and bark. This scenario was included in order to explore the possible grade improvements that can be achieved if effective pruning is conducted early in the rotation, resulting in a greater portion of the veneer being free from these defects after knot occlusion is achieved. The roughness upgrade of the veneer was included in this scenario with the knowledge that unacceptable roughness occurred mostly around knots and the zone of knot occlusion where grain deviation was present. A statistical analysis of the correlation between roughness and knots further supported the inclusion of roughness in the scenario.

Several studies and reviews on pruning commercial *Eucalyptus* species indicate that, on average, the pruning diameter under bark of a stand for the first 6 m log is around 8 cm (Dickinson *et al.* 2000; Nolan *et al.* 2005; Wood *et al.* 2009; Forrester *et al.* 2010; Alcorn *et al.* 2013). This average pruning diameter confirms the information provided by most Australian growers about the implemented silvicultural practices. The other critical information necessary to assess the impact of pruning on veneer grading is the branch occlusion thickness before the tree produces wood free of knots and knot-related defects. According to the studies performed by Montagu *et al.* (2003), Pinkard *et al.* (2004), Smith *et al.* (2006), O'Hara (2007), Liu *et al.* (2012), and Forrester *et al.* (2013), the occlusion thickness can be estimated depending on the type of species. For the fast-growing pulp species in this study (*E. dunnii* and *E. globulus*), the occlusion thickness is on average 2 cm. For the other species, the occlusion thickness is on average 3 cm.

The average pruning diameter (8 cm), the occlusion thicknesses (2 cm or 3 cm), and the average billet diameter for each plantation stand were used to develop the pruning scenarios for each species. For each species, the average diameter was calculated for each plantation stand from the billet diameters. The average pruning diameter plus two times the occlusion thickness of the species (either 4 cm or 6 cm) was divided by the average billet diameter of the plantation stand to calculate the average diameter ratio from which a pruned billet would start to produce wood free of knots and related defects. This ratio was then applied to each billet of the plantation stand in order to establish the diameter at occlusion. This approach acknowledges the range of billet diameters at time of harvesting and ensures the calculated occlusion diameters were proportional to the size of the billet at the time of pruning. This means the bigger trees at time of harvesting have a larger diameter at pruning and conversely smaller trees have a smaller diameter at pruning. The pruning scenario implies that the veneer grade is not altered for veneer which was recovered from within the occlusion diameter. This scenario assumes that veneer produced from the remaining outer section of the billets contained no sound knots, encased knots, bark and decay, holes, and defect combination, and, had satisfactory veneer roughness resulting in veneers being upgraded to B-grade (unless veneers already attained A-grade). For these defects, it can be reasonably assumed that some veneers in the outer part of the billet may produce A-grade veneers. Unfortunately, it was not possible to assess with enough confidence this proportion, so consequently the B-grade upgrading strategy was considered reasonable for this scenario, despite being slightly conservative.

Scenario three combined the effects of gum defect upgrade (scenario one) and effective pruning (scenario two). Scenario four also combined the effects of scenarios one and two but with a less conservative grade upgrading strategy allowing 25% of B-grade veneers resulting from the scenario being further upgraded to A-grade.

Accurate commercial veneer values for the species included in the study were difficult to determine; however, to provide an indication of the potential economic impact that the four grade scenarios may have on veneer value, comparable values for each visual grade were provided by Engineered Wood Products Association of Australasia (2014). This suggests that C-grade veneer attracts a value 1.2 times higher than D-grade, B-grade attracts a value 1.7 times than D-grade, and A-grade attracts a value 3 times higher than D-grade.

Statistical analysis

A Spearman's rank-order correlation was run on ordinal variables (veneer grades) to assess the relationship between veneer roughness and knots (sound and encased) using IBM SPSS version 22.0 (IBM SPSS Statistics for Windows, IBM Corp., Armonk, NY, USA). The ordinal variables represent paired observations and a monotonic relationship between variables exists as assessed by visual inspection of scatterplots. The confidence interval level was 95%.

RESULTS AND DISCUSSION

Visual Grading

A total of 918 billets (48 m^3) from six different hardwood species were processed using a spindleless lathe which produced 8539 m^2 of rotary veneer. Table 1 provides details of the total surface area of veneer recovered and the grade recovery (recovered grade veneer as a proportion of veneer surface area) for each species.

Table 1. Graded Veneer Recovery

Species	Total surface area of veneer graded (m^2)	A-grade recovery (%)	B-grade recovery (%)	C-grade recovery (%)	D-grade recovery (%)	Reject recovery (%)
Corymbia citriodora subsp. *variegata*	796	0.5	1.8	17.9	73.6	6.2
Eucalyptus cloeziana	2619	0.3	6.1	28.8	60.1	4.7
Eucalyptus dunnii	938	0.0	0.5	16.0	79.1	4.4
Eucalyptus pellita	1089	0.1	4.6	10.6	80.0	4.7
Eucalyptus nitens	1442	0.4	11.1	15.2	67.7	5.6
Eucalyptus globulus	1655	0	1.1	2.7	84.3	11.9

Figures 1 to 5 provides an example of the visual quality demanded by each grade, with A-grade veneer being the highest quality followed by B-grade, C-grade and D-grade. F-grade (or reject) veneers fail to meet the grade requirements of the Australian and New Zealand standard AS/NSZ 2269.0:2012 (Standards Australia 2012).

Fig. 1. Example of the visual quality of A-grade veneer

Fig. 2. Example of the visual quality of B-grade veneer

Fig. 3. Example of the visual quality of C-grade veneer

Fig. 4. Example of the visual quality of D-grade veneer

Fig. 5. Example of the visual quality of F-grade (or reject) veneer

Figures 6 to 11 illustrate the distribution of assigned grades for individual grade limiting defects for each species. In this type of diagram, each bubble represents the percentage of a given grade for a given defect. The grey scaling and diameter of the bubble both are proportional to the percentage of the total veneer surface area for each individual defect. In addition, similarly for each defect, the assigned grade is determined for each veneer from the defect(s) causing the lowest visual grade.

The graded recovery is dominated by D-grade veneer across all species. This is consistent with other similar studies such as Peng *et al.* (2014) who reported over 80% of eucalypt hybrid veneers being categorised as D-grade (although based on a slightly different grading standard) and less than 3% of veneers meeting the grade requirements of C-grade or better (with the balance being reject grade). The low recovery of higher grade veneers (C-grade and better) will make the commercial production of a standard mix of saleable structural panel products challenging due to insufficient proportions of more market acceptable quality veneers, mostly to be used as faces on panels. The Engineered Wood Products Association of Australasia (2013) suggest the rotary veneer industry requires approximately 30% to 40% of their graded veneer production to be at least C-grade or better to enable saleable product manufacture. *Eucalyptus cloeziana* is the only species to be within this specified range (35%). All other species failed to achieve greater than 30% C-grade or better veneers. Blakemore *et al.* (2010) reports much more favourable grade recoveries for a small study which processed 10 *E. nitens* trees as part of a silviculture research trial.

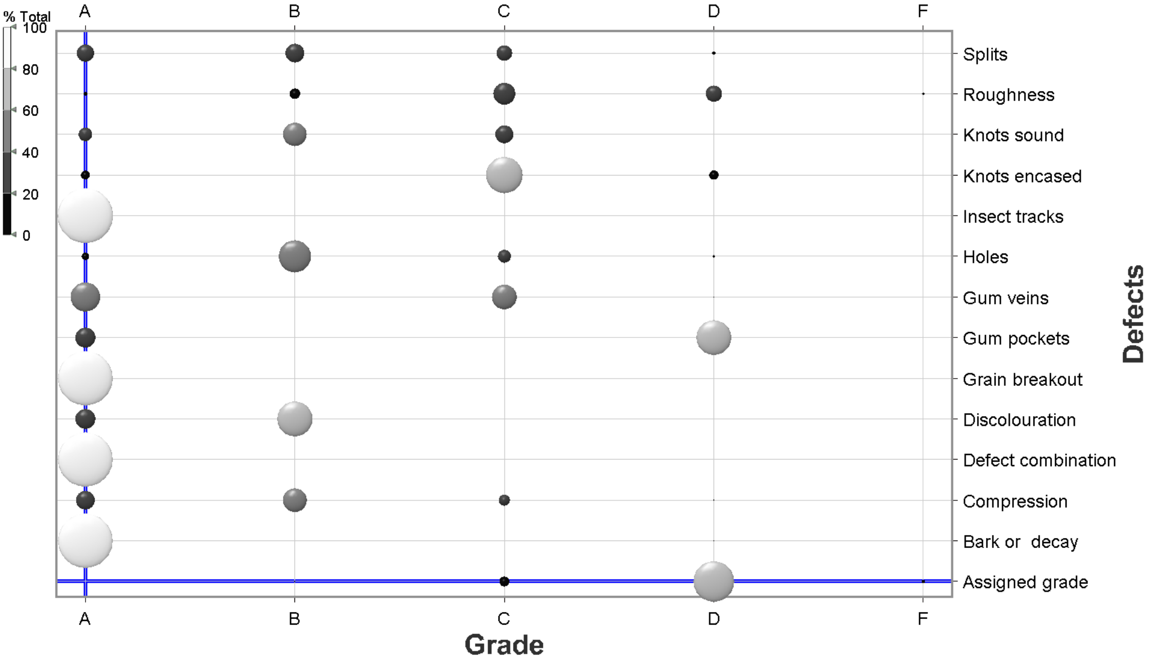

Fig. 6. Distribution of *Corymbia citriodora* subsp. *variegata* visually assigned veneer grades for a range of resource related defects. Like the grey scale, the size of the circle is proportional to the recovered value.

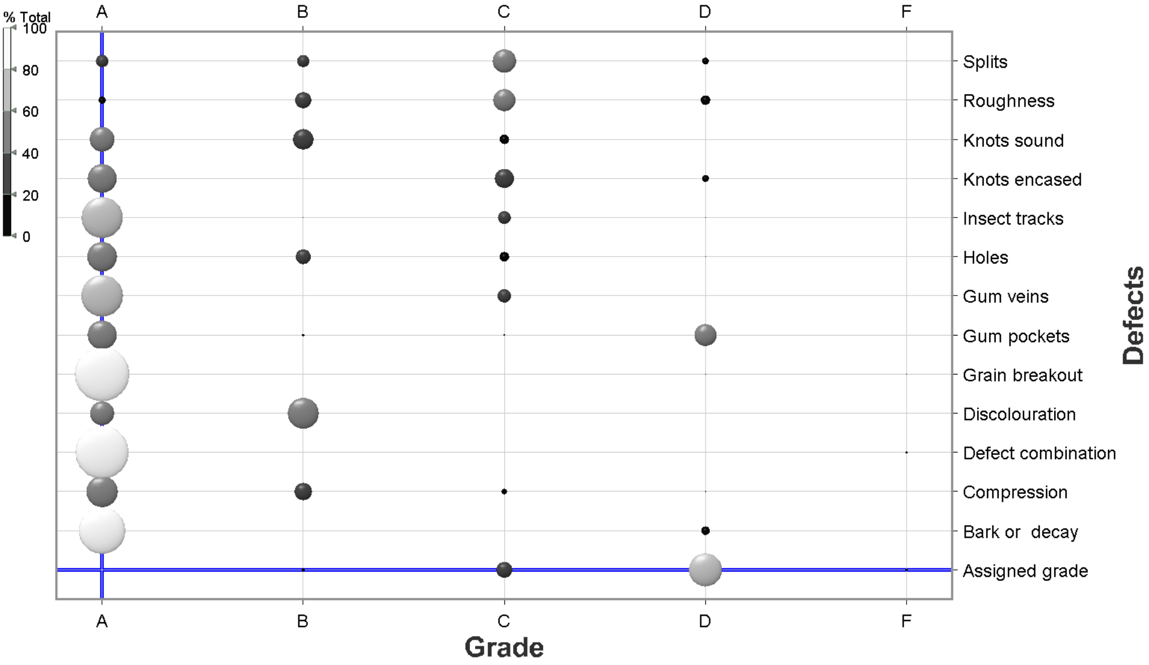

Fig. 7. Distribution of *Eucalyptus cloeziana* visually assigned veneer grades for a range of resource related defects. Like the grey scale, the size of the circle is proportional to the recovered value.

A relevant comparison between studies is difficult due to differing sampling scale, processing technology adopted (*i.e.*, spindles versus spindleless lathes), tree size, and grading standards adopted.

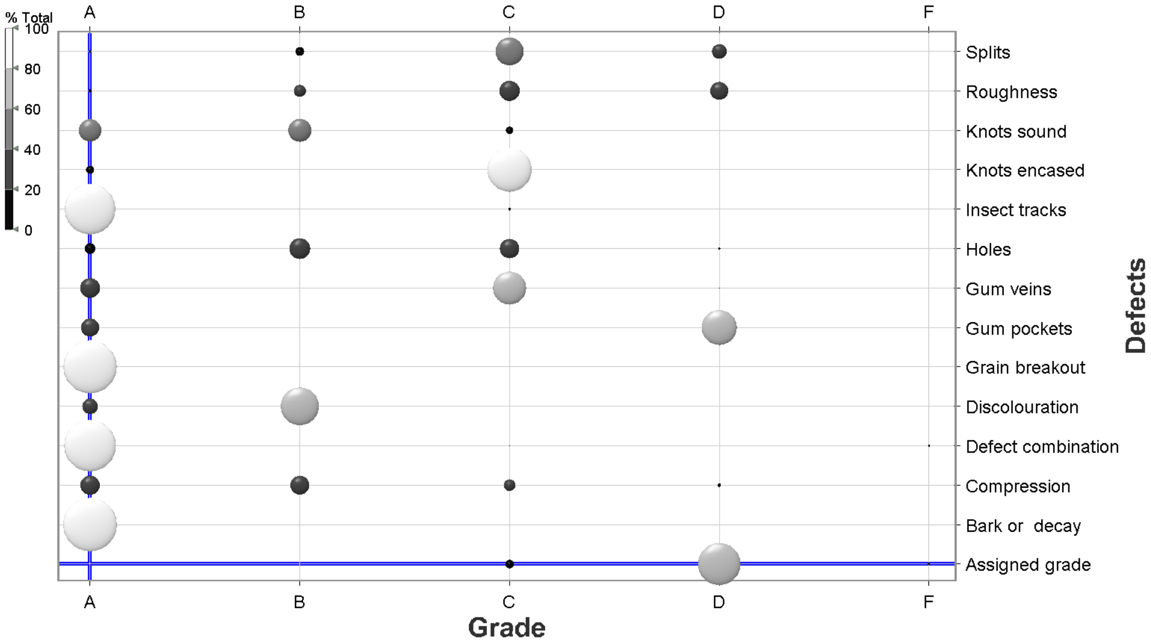

Fig. 8. Distribution of *Eucalyptus dunnii* visually assigned veneer grades for a range of resource related defects. Like the grey scale, the size of the circle is proportional to the recovered value.

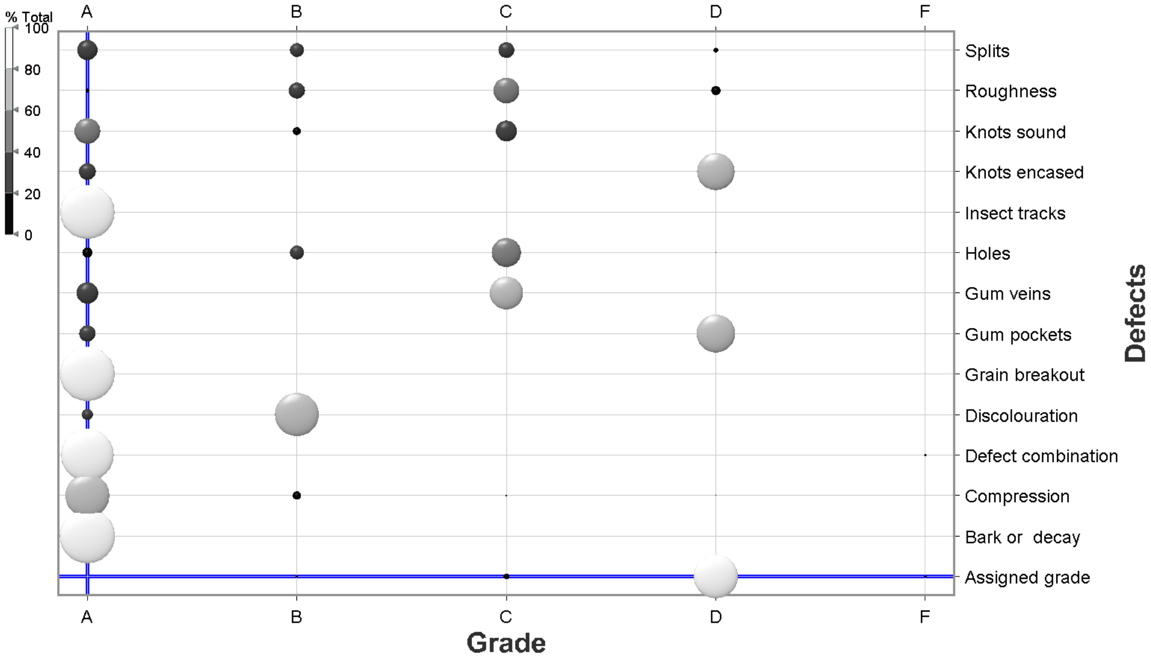

Fig. 9. Distribution of *Eucalyptus pellita* visually assigned veneer grades for a range of resource related defects. Like the grey scale, the size of the circle is proportional to the recovered value.

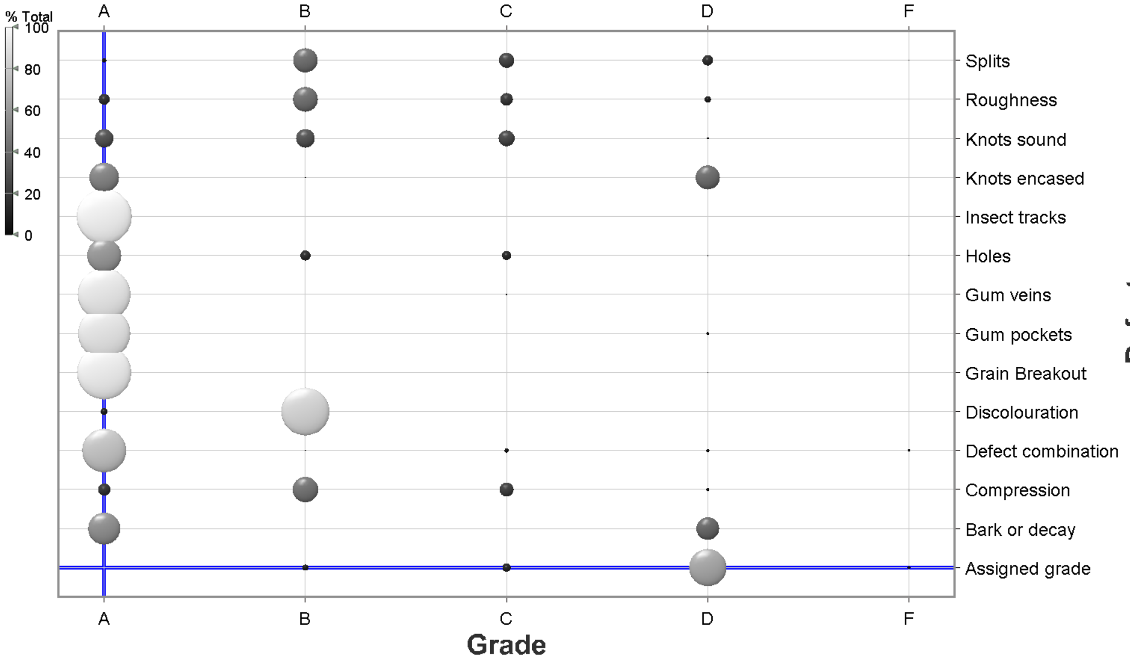

Fig. 10. Distribution of *Eucalyptus nitens* visually assigned veneer grades for a range of resource related defects. Like the grey scale, the size of the circle is proportional to the recovered value.

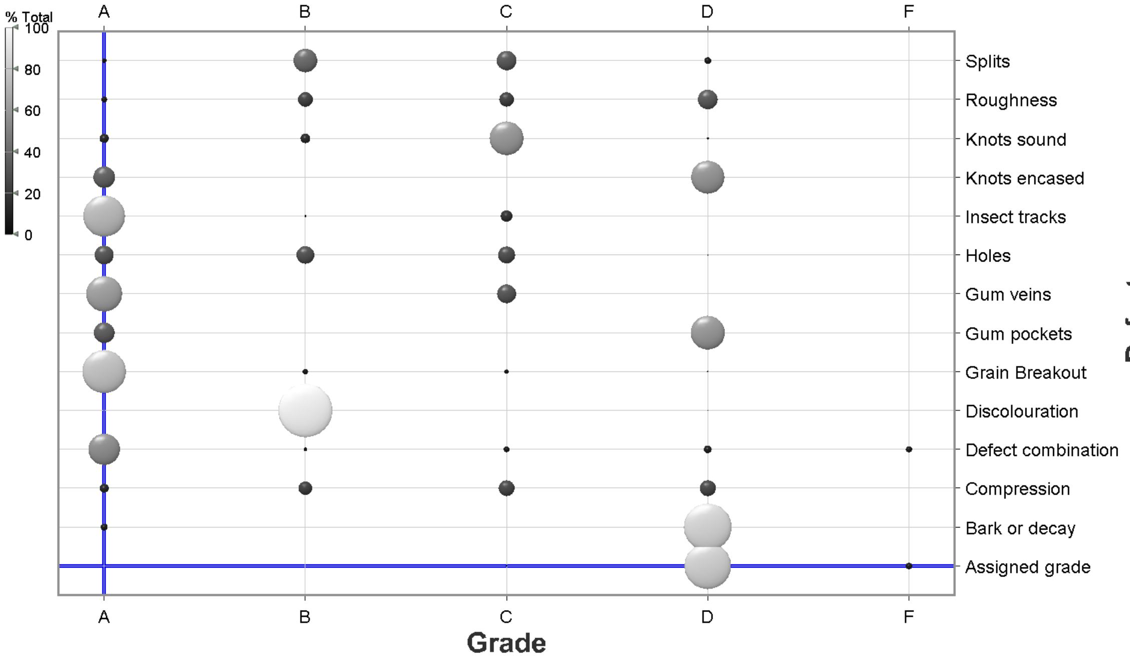

Fig. 11. Distribution of *Eucalyptus globulus* visually assigned veneer grades for a range of resource related defects. Like the grey scale, the size of the circle is proportional to the recovered value.

Table 2 illustrates the five highest ranked defects (in order of severity) which prevented veneers from attaining assigned grades higher than D-grade for each species.

Table 2. Top Five Ranked Defects Preventing Veneers from Attaining Assigned Grades Higher than D-grade

Species	Rank				
	1	2	3	4	5
Corymbia citriodora subsp. *variegata*	Gum pockets (63%)	Roughness (29%)	Encased knots (17%)	Splits (6%)	Holes (4%)
Eucalyptus cloeziana	Gum pockets (40%)	Roughness (17%)	Bark or decay (16%)	Encased knots (13%)	Splits (12%)
Eucalyptus dunnii	Gum pockets (65%)	Roughness (34%)	Splits (28%)	Compression (7%)	Holes (4%)
Eucalyptus pellita	Gum pockets (70%)	Encased knots (68%)	Roughness (17%)	Splits (9%)	Holes (2%)
Eucalyptus nitens	Encased knots (44%)	Bark or decay (41%)	Splits (19%)	Roughness (12%)	Defect combination (6%)
Eucalyptus globulus	Bark or decay (86%)	Gum pockets (62%)	Encased knots (60%)	Roughness (36%)	Compression (29%)

Note: The proportion of veneer impacted by each defect is provided in parenthesis.

For all species, with the exception of *E. nitens* and *E. globulus*, gum pockets had the most influence in restricting veneers from attaining assigned grades higher than D-grade. *Eucalyptus pellita* was the most affected, with 70% of veneer being downgraded to D-grade due to gum pockets, followed by *E. dunnii* (65%), *C. citriodora* subsp. *variegata* (63%), and *E. cloeziana* (40%). For *E. globulus*, gum pockets were ranked second for limiting grade with 62% of veneers being restricted to D-grade due to gum pockets. Gum pockets had minimal impact on the grade recovery of *E. nitens* (ranked 6), with only 5% of veneer being restricted to D-grade for this defect. While this defect was common across all species, with the exception of *E. nitens*, the size of this defect was often small and not concentrated. While it does influence the appearance qualities of the veneer, it will be expected to have negligible effect on mechanical properties or on the panel manufacturing process. The characteristics of this defect in the veneer across all species are such that it may be unnecessarily severe to downgrade such quantities of veneer to D-grade, especially when compared to other appearance affecting defects which are permissible in higher grades. A market acceptance analysis and review of the permissible limits outlined in the grading standards for this defect would be beneficial.

For *E. globulus*, the presence of bark pockets or decay, mostly surrounding knots, was the highest ranked grade limiting defect preventing 86% of veneer from attaining assigned grades higher than D-grade. It was second ranked grade limiting defect for *E. nitens* with 41% of veneer being downgraded to D-grade. Apart from a small amount of *E. cloeziana* veneer (16% downgraded to D-grade), the veneer grade ranks were not negatively impacted by these defects in the other species.

Encased knots had the most influence on *E. nitens* veneer, limiting 44% of veneer to D-grade. The presence of encased knots also resulted in 68% of *E. pellita* veneer and 60% of *E. globulus* veneer from attaining assigned grades higher than D-grade. *Corymbia citriodora* subsp. *variegata*, *E. cloeziana*, and *E. dunnii* were also impacted by encased knots; however, the smaller dimension of the defect in these species resulted in only 17%, 13%, and 1% of veneer, respectively, being limited to D-grade. For these species, the small dimensioned encased knots had more impact on preventing veneers from achieving assigned grades higher than C-grade (66%, 35%, and 83% veneers, respectively, limited to C-grade).

Veneer surface roughness resulted in 36% of *E. globulus*, 34% of *E. dunnii*, 29% of *C. citriodora* subsp. *variegata*, 17% of *E. cloeziana*, 17% of *E. pellita*, and 12% of *E. nitens* veneer being prevented from attaining assigned grades higher than D-grade. Veneer surface roughness is mostly present in areas of veneer where there is grain deviation present, such as around knots and knots holes.

Veneer splits resulted in 28% of *E. dunnii*, 19% of *E. nitens*, 12% of *E. globulus*, 12% of *E. cloeziana*, 9% of *E. pellita*, and 6% of *C. citriodora* subsp. *variegata* veneer being prevented from attaining assigned grades higher than D-grade. For this assessment, only splits believed to be resource related (*e.g.*, splits that originated from billet end checks) were included in the analysis, excluding splits that may have occurred during processing (*e.g.*, veneer handling).

Unacceptable levels of compression resulted in 29% of *E. globulus* veneer being restricted to D-grade. The presence of this defect was obvious in dried veneer, with many veneers being ‘rippled’ and uneven. The presence of this defect can be attributed to the differential transverse shrinkage induced by the highly frequent presence of veins or casts of tension wood within this species (Washusen and Ilic 2001). It has been described to cause product recovery losses in sawn timber (Washusen 2011). Low levels of compression were noted in other species and resulted in 7% of *E. dunnii*, 6% of *E. nitens*, 2% of *E. cloeziana*, 1% of *C. citriodora* subsp. *variegata*, and 1% of *E. pellita* veneers being restricted to D-grade.

Multiple defects that individually were within permissible limits of higher grades, but when combined in close proximity (*i.e.*, defect combination), led to 14% of *E. globulus* and 6% of *E. nitens* veneers being prevented from attaining a grade higher than D-grade. In addition, 11% of *E. globulus* veneers, 5% of *E. pellita* and *E. nitens* veneers, 4% of *E. cloeziana* and *E. dunnii* veneers, and 1% of *C. citriodora* subsp. *variegata* veneers failed to make grade (*i.e.*, reject) when defects are considered in combination.

Eucalyptus globulus and *E. nitens* veneers were the most affected by sound knots, but unexpectedly, with only 4% of veneer being limited to D-grade. All other species each had negligible quantities of veneer downgraded (< 1%) to D-grade due to sound knots. This result is the consequence of the relatively small diameter of the knots that were present in the veneers across all species. Sound knots did contribute to a spread across the higher grade qualities as a result of increasing limitations of defect size as the grade improved.

Similar to sound knots, a range of other defects (*e.g.*, discoloration and insect tracks) were present, but these had minimal impact on limiting veneer grade qualities to D-grade; however, they did impact on the distribution of veneers amongst the higher grades.

Correlation between Roughness Grade and Knot Grade

A Spearman's rank-order correlation was run to assess the relationship between veneer surface roughness rank and sound or encased knot rank. In most cases, there was a significant ($p<0.001$) and relatively weak positive correlation between sound or encased knot rank and veneer surface roughness rank, with the Spearman correlation coefficient ranging from 0.1 to 0.304 (Table 3). There was no correlation between sound knot rank and veneer roughness for *C. citriodora* subsp. *variegata* due to the low proportion of sound knots combined with a lower number of veneers on this species. Aside from the latter case, an increase in sound or encased knot grade rank was associated systematically with an increase in surface roughness grade rank. This correlation supported the addition of veneer roughness in the parameters involved in the pruning scenario.

Table 3. Spearman's Rank-Order Correlation between Roughness and Knots Rank

	Statistical parameters	Sound knot rank	Encased knot rank
Eucalyptus nitens	Correlation Coefficient	0.206**	0.100**
	Significance (2-tailed)	<0.0001	0.001
	N	1127	1127
Eucalyptus globulus	Correlation Coefficient	0.200**	0.168**
	Significance (2-tailed)	<0.0001	<0.0001
	N	1219	1219
Eucalyptus cloeziana	Correlation Coefficient	0.101**	0.279**
	Significance (2-tailed)	<0.0001	<0.0001
	N	1937	1937
Corymbia citriodora subsp. *variegata*	Correlation Coefficient	0.066	0.138**
	Significance (2-tailed)	0.173	0.004
	N	423	423
Eucalyptus pellita	Correlation Coefficient	0.304**	0.228**
	Significance (2-tailed)	<0.0001	<0.0001
	N	840	840
Eucalyptus dunnii	Correlation Coefficient	0.200**	0.298**
	Significance (2-tailed)	<0.0001	<0.0001
	N	440	440

** Correlation is significant at the 0.01 level (2-tailed)

Grade Scenarios

Table 4 illustrates the impact on grade recovery as a result of a shift of permissible limits between grades relevant to gum pockets and gum veins. This grading scenario assumes that the grade limitations relating to gum pockets and gum veins are reduced, resulting in veneers D-grade and C-grade being able to achieve C-grade and B-grade, respectively, when graded against these defects (scenario one).

Table 4. Graded Veneer Recovery Percentage Assuming a Relaxation in the Grading Standard for Gum Veins and Gum Pockets

Species	Grade recovery				
	A-grade	B-grade	C-grade	D-grade	Rejected
Corymbia citriodora subsp. *variegata*	0.5% (0.0)	1.8% (0.0)	43.0% (25.1)	48.5% (-25.1)	6.2% (0.0)
Eucalyptus cloeziana	0.3% (0.0)	6.3% (0.2)	45.6% (16.8)	43.1% (-17.0)	4.7% (0.0)
Eucalyptus dunnii	0.0% (0.0)	0.5% (0.0)	40.0% (24.0)	55.1% (-24.0)	4.4% (0.0)
Eucalyptus pellita	0.1% (0.0)	6.3% (1.7)	18.6% (8.0)	70.3% (-9.7)	4.7% (0.0)
Eucalyptus nitens	0.4% (0.0)	11.5% (0.4)	15.3% (0.1)	67.2% (-0.5)	5.6% (0.0)
Eucalyptus globulus	0.0% (0.0)	1.2% (0.1)	4.2% (1.5)	82.7% (-1.6)	11.9% (0.0)
Note: The change in graded veneer recovery is provided in parenthesis.					

The results show a substantial impact, with the sub-tropical and tropical species being the main beneficiaries. Applying this scenario, 52% of *E. cloeziana*, 45% of *C. citriodora* subsp. *variegata*, and 41% of *E. dunnii* achieved assigned grades of C-grade or better and therefore met and exceeded the target grade quality proportions nominated by the Engineered Wood Products Association of Australasia (2013) as necessary for commercial production of structural panel products (30% to 40%). The remaining species still failed to produce sufficient proportions of C-grade or better veneer (27% of *E. nitens*, 25% of *E. pellita*, and 5% of *E. globulus* veneers).

Table 5 illustrates the impact on grade recovery that can be possible if effective pruning can be conducted (scenario two).

Table 5. Graded Veneer Recovery Percentage when Effective Pruning is Simulated

Species	Grade recovery				
	A-grade	B-grade	C-grade	D-grade	Rejected
Corymbia citriodora subsp. *variegata*	0.5% (0.0)	12.7% (10.9)	17.7% (-0.2)	66.3% (-7.3)	2.8% (-3.4)
Eucalyptus cloeziana	0.3% (0.0)	14.4% (8.3)	32.4% (3.6)	50.9% (-9.2)	2.0% (-2.7)
Eucalyptus dunnii	0.0% (0.0)	1.7% (1.2)	20.0% (4.0)	76.6% (-2.5)	1.7% (-2.7)
Eucalyptus pellita	0.1% (0.0)	10.5% (5.9)	16.2% (5.6)	70.8% (-9.2)	2.4% (-2.3)
Eucalyptus nitens	0.4% (0.0)	30.2% (19.1)	31.6% (16.4)	35.0% (-32.7)	2.8% (-2.8)
Eucalyptus globulus	0.0% (0.0)	5.7% (4.6)	13.5% (10.8)	74.9% (-9.4)	5.9% (-6.0)
Note: The change in graded veneer recovery is provided in parenthesis.					

Eucalyptus nitens achieved by far the most gain from this scenario with 62% of veneer achieving assigned grades of C-grade or better, and therefore well exceeded the target grade quality proportions nominated by the Engineered Wood Products Association of Australasia (30% to 40%) as necessary for commercial production of a standard mix of saleable structural panel products. Recovery of *E. cloeziana* C-grade and better veneers increased to 47%, while *C. citriodora* subsp. *variegata* increased to 31% recovery of C-grade veneers or better. All remaining species still failed to produce sufficient proportions of C-grade of better veneer. *Eucalyptus dunnii* had the least improvement, with 22% of veneers achieving C-grade or better. This species had small average billet diameter and was clearly limited by gum pockets, two factors which prevented the pruning scenario from achieving higher grade improvements. The same trend was demonstrated with *C. citriodora* subsp. *variegata*; however, this species had a reasonable proportion of C-grade veneers before applying the pruning scenario.

These gains are greater than the grade quality difference that was reported by Blakemore *et al.* (2010) for a small study that included five pruned and five unpruned *E. nitens* trees. In this study, the changes in percentage recoveries with pruned billets compared with unpruned billets were; A-grade +5.7%; B-grade +3.1%; C-grade +3.8%; D-grade +0.5%, and reject grade -13.1%. It should be noted however, that the veneer quality from the unpruned trees was already much higher than presented in Table 5, with over 50% of the resulting veneer achieving C-grade or better. Moreover, the trees sampled by Blakemore *et al.* (2010) were bigger (mean diameter of 50.6 cm) than in this study, and the peeling and grading methods were different, making any comparison between the studies speculative.

Tables 6 illustrates the impact on grade recovery that can be possible if both scenarios (*i.e.*, one and two) are combined, leading to a shift in permissible grade limits for gum pockets and gum veins, with effective pruning.

Table 6. Graded Veneer Recovery Percentage with Gum Upgrade Combined with Effective Pruning

Species	Grade recovery				
	A-grade	B-grade	C-grade	D-grade	Rejected
Corymbia citriodora subsp. *variegata*	0.5% (0.0)	15.8% (14.0)	64.1% (46.2)	16.8% (-56.8)	2.8% (-3.4)
Eucalyptus cloeziana	0.3% (0.0)	16.6% (10.5)	61.2% (32.4)	19.9% (-40.2)	2.0% (-2.7)
Eucalyptus dunnii	0.0% (0.0)	3.2% (2.7)	60.6% (44.6)	35.1% (-44.0)	1.1% (-3.3)
Eucalyptus pellita	0.1% (0.0)	18.7% (14.1)	60.8% (50.2)	18.0% (-62.0)	2.4% (-2.3)
Eucalyptus nitens	0.4% (0.0)	31.7% (20.6)	33.0% (17.8)	32.1% (-35.6)	2.8% (-2.8)
Eucalyptus globulus	0.0% (0.0)	6.5% (5.4)	45.2% (42.5)	42.4% (-41.9)	5.9% -6.0

Note: The change in graded veneer recovery is provided in parenthesis.

The results of this scenario showed a substantial improvement for all species. *Eucalyptus nitens* achieved the lowest improvement, which was a result of the minimal gains from the gum defect limitation change; however, this still resulted in 65% of veneer achieving C-grade or better. *Eucalyptus nitens* also achieved the highest recovery of B-grade, with 32% recovered under this scenario. *Corymbia citriodora* subsp. *variegata*, *E. pellita*, and *E. cloeziana* all achieved similar impressive recoveries of C-grade veneer or better, with 81%, 80%, and 78% being recovered, respectively, for C-grade and better. *Eucalyptus nitens* and *E. dunnii* achieved 65% and 64%, respectively, while *E. globulus* achieved 52%. It is important to note that splits and compression are clearly limiting further grade improvement under this scenario. This observation confirms the adverse effect of high levels of growth stresses on veneer grade recovery for these species.

The results demonstrate that while scenarios one and two each had a positive effect individually, combining them had a dramatic effect, beyond a simply additive effect on increasing the veneer grade. Modifying the grade limitations relating to gum pockets and gum veins in line with the scenario one is potentially relatively easy with minimal investment required and can therefore be implemented quickly. A market analysis will need to be conducted to determine the true possibility of this scenario being commercially adopted and may need to be product specific. Implementing and achieving effective pruning is more complex, and an economic analysis will be required to determine its profitability. In addition, for the pruning to be truly effective, pruning practices and procedures will need to be perfected to ensure the grade quality benefits are able to be realised.

Table 7 illustrates the impact on grade recovery when gum upgrading (scenario one) and effective pruning (scenario two) are combined, similar to scenario three, however, with a less conservative grade upgrading strategy allowing 25% of B-grade veneers resulting from the scenario being further upgraded to A-grade.

Table 7. Graded Veneer Recovery Percentage with Gum Upgrade Combined with Effective Pruning and Additional Grade Upgrading

Species	Grade recovery				
	A-grade	B-grade	C-grade	D-grade	Rejected
Corymbia citriodora subsp. *variegata*	4.5% (4.0)	11.8% (10.0)	64.1% (46.2)	16.8% (-56.8)	2.8% (-3.4)
Eucalyptus cloeziana	4.5% (4.2)	12.4% (6.3)	61.2% (32.4)	19.9% (-40.2)	2.0% (-2.7)
Eucalyptus dunnii	0.8% (0.8)	2.4% (1.9)	60.6% (44.6)	35.1% (-44.0)	1.1% (-3.3)
Eucalyptus pellita	4.7% (4.6)	14.0% (9.4)	60.8% (50.2)	18.0% (-62.0)	2.4% (-2.3)
Eucalyptus nitens	8.3% (7.9)	23.7% (12.6)	33.0% (17.8)	32.2% (-35.6)	2.8% (-2.8)
Eucalyptus globulus	1.6% (1.6)	4.9% (3.8)	45.2% (42.5)	42.5% (-41.8)	5.9% (-6.0)
Note: The change in graded veneer recovery is provided in parenthesis.					

Economic Impact

Table 8 shows the increase in relative value resulting from gum upgrade (scenario one), effective pruning (scenario two), gum upgrade combined with effective pruning (scenario three), and further grade improvements from gum upgrading combined with effective pruning grade upgrading (scenario four) with resource only as the baseline (as graded to Australian and New Zealand Standard AS/NZS 2269.0:2012 (Standards Australia 2012)).

Table 8. Change in Relative Veneer Value with the Adoption of the Four Grade Scenarios

Species	Change in total value from no intervention (%)			
	Gum defects upgraded (scenario 1)	Effective pruning (scenario 2)	Gum defects upgraded and effective pruning (scenario 3)	Gum defects upgraded and effective pruning with 25% of B-grade upgraded to A-grade (scenario 4)
Corymbia citriodora subsp. *variegata*	4.6	9.8	18.2	21.5
Eucalyptus cloeziana	3.3	8.1	13.5	17.2
Eucalyptus dunnii	5.2	4.1	12.4	13.3
Eucalyptus pellita	2.6	6.9	18.0	21.9
Eucalyptus nitens	0.3	15.3	16.3	22.6
Eucalyptus globulus	0.3	11.3	17.0	18.6

Scenario one, which included the upgrading of gum veins and gum pockets, resulted in small gains in relative veneer value for the sub-tropical and tropical species of between 2.6% and 5.2%. The temperate species (*E. nitens* and *E. globulus*) achieved minimal gains of 0.3%. As discussed, these gains can potentially be realised quickly and with minimal investment.

Scenario two included the adoption of effective pruning, with the temperate species being the main beneficiaries with increases of relative veneer value of between 11.3 and 15.3%. The sub-tropical and tropical species resulted in modest relative veneer value gains of between 4.1% and 9.8%. A comprehensive economic analysis will be required to determine the true change in profitability as the implementation of this scenario will incur additional costs during the early phases of the plantation growth which have not been considered in this analysis.

In this scenario, except for *C. citriodora* subsp. *variegata*, the total change in value clearly depends on the billet diameter as shown in Fig. 7. Indeed, the greater the diameter of the billet, the higher the volume of wood without knots and knot-related defects. The exception is explained by defects other than knot and knot-related defects, such as splits, which were minimal in *C. citriodora* subsp. *variegata* (6%) compared to *E. dunnii* (28%) despite having similar average diameters (Table 2). This observation indicates that after gum, knots, and knot-related defects, growth stress-related defects (*i.e.*, splitting or compression) are a major cause of veneer downgrade.

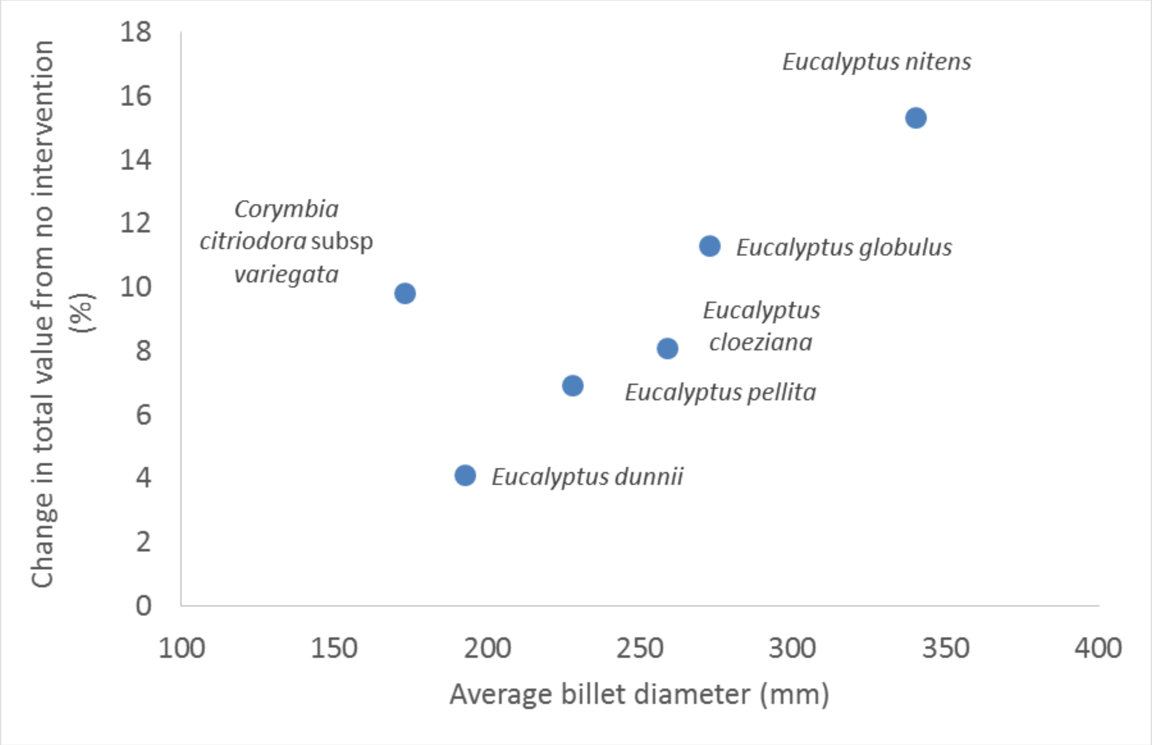

Fig. 7. Relationship between average billet diameter and change in total value when effective pruning is performed (scenario two)

Scenario three delivered further improvements in relative veneer value with increases between 12.4% and 18.2%. *Eucalyptus dunnii* and *E. cloeziana* displayed the smallest improvement in value, which was influenced by their smaller average billet diameter, which impacts on the recovery of higher grades after pruning.

Scenario four produced the highest gains in relative veneer value with increases up to 22.6%. Because of the non-linear increase in value from lower grades to higher grades, determining the relative total veneer value was very sensitive to the proportion of veneers in higher veneer grades. As a matter of fact, the A-grade value was three times the value of D-grade veneer and almost twice the value of B-grade veneer.

CONCLUSIONS

1. The study demonstrated that processing Australian hardwood from plantations using spindleless veneer lathe technology produced graded veneer recoveries dominated by D-grade veneer across all species. Although D-grade veneer is technically suitable for face veneers for some structural panels as well as the core veneers for the vast majority of appearance and non-appearance structural panels, the low recovery of higher grade veneers (C-grade and better), which are more demanded for face veneers, will make the commercial production of a standard mix of saleable structural panel products challenging if relying on this resource alone.
2. The veneers contained a range of defects that impacted the final assigned grade. The presence of gum pockets had the highest impact with up to 70% of veneer being limited to D-grade for *C. citriodora* subsp. *variegata*, *E. cloeziana*, *E. dunnii*, and *E. pellita*. Gum pockets were the second-ranked defect for *E. globulus*. For *E. globulus*, the occurrence of bark pockets or decay, mainly surrounding knots, was the main defect limiting veneer to D-grade. Encased knots contributed to limiting veneer grades to D-grade, especially for *E. nitens*, *E. pellita*, and *E. globulus* veneers. Veneer surface roughness resulted in up to 36% of veneers being restricted to D-grade, and veneer splits also impacted grade recovery (up to 28% of veneer limited to D-grade). Other defects contributed to a lesser degree.
3. The simulation of a scenario upgrading gum pockets and gum veins to C-grade and B-grade resulted in an increased recovery of C-grade and better veneers across all species. This scenario enabled 52% of *E. cloeziana,* 45% of *C. citriodora* subsp. *variegata*, and 41% of *E. dunnii* veneers to achieve assigned grades of C-grade or better. This exceeds the quality proportions delineated by the Engineered Wood Products Association of Australasia (30% to 40% of assigned C-grade and better) as necessary for commercial production of structural panel products. Modifying the grade limitations related to gum defects is potentially easy with minimal investment and can be implemented relatively quickly.
4. Grade scenario two simulated effective pruning. This improved higher grade recoveries for all species. *Eucalyptus nitens* achieved the most gain from this scenario with 62% of veneer achieving assigned grades of C-grade or better. *Eucalyptus cloeziana* recovery increased to 47%, while *C. citriodora* subsp. *variegata* increased to 31% recovery of C-grade veneers or better. These three species therefore meet or exceed the target assigned grade quality proportions nominated by the Engineered Wood Products Association of Australasia (30% to 40% of assigned C-grade and better) as necessary for commercial production of structural panel products. Implementing and achieving effective pruning can be complex and an economic analysis will be required to determine its profitability.
5. Combining gum defects upgrade and effective pruning had a substantial impact on achieving higher grade veneer qualities, beyond a simply additive effect on increasing the veneer grade. With this scenario, all species produced C-grade and better grade recoveries exceeding the target grade quality proportions nominated by the Engineered Wood Products Association of Australasia (30% to 40% of assigned C-grade and better).
6. Reducing the impact of gum defects has the potential to increase the relative veneer values between 0.3% and 5.2%, depending on species. Improving the

resulting grade quality of veneer through effective pruning has the potential to increase relative veneer values between 4.1% and 15.3%. Combining both scenarios produced the best increase in relative veneer value with increases between 12.4% and 18.2% and between 13.3% and 22.6% with further grade improvements from gum and pruning upgrading.

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