Potential of Veneer Peeled from Young Eucalypts in Laos

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In Laos and neighboring countries, opportunities exist for the production of engineered wood products such as plywood and laminated veneer lumber to supply the rapid growth of construction, furnishing, and joinery activities. The objective of the present study was to assess the potential of peeling fast-growing high-yielding pulpwood from managed eucalypt stands in Laos for veneered products. *Eucalyptus pellita*, *Eucalyptus camaldulensis*, and eucalypt clone K7 (*E. camaldulensis* × *E. deglupta*) stands were characterized based on veneer quality and recovery. The influence of log position, log geometry, and other log traits during recovery were also investigated. The selected taxa achieved green veneer recoveries that ranged between 57% and 67%. End splitting and branch-related defects were the most important grade-limiting defects that restricted veneer sheet quality to a lower grade of most sheets. However, simple timely silvicultural decisions, such as pruning, could significantly help improve the quality of veneer obtained. The obtained results could be used in the formulation of recommendations to adopt better management practices in Laos to improve the value of plantation-grown wood.

Keywords: Rotary veneer; Eucalyptus pellita; Eucalyptus camaldulensis; Eucalyptus deglupta; Recovery; Grade quality

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INTRODUCTION

The Government of Laos (GoL) has implemented multiple policies over the last three decades to encourage the development of timber plantations by smallholders and the private sector. Consequently, there are now significant areas of plantations in several regions across the country. The plantation estate comprises of 446,000 ha that is mostly corporately owned (DoF 2015). However, the area of plantations for current timber production remains relatively small, with 163,000 ha under different species, ownership, and investment arrangements. Eucalypts comprise the largest area of these timber plantations with 67,000 ha. In 2016, the GoL released Decree No. 15 “Strengthening Strictness of Timber Harvest Management and Inspection, Timber Transport and Business,” which specifies that all types of wood must be processed into finished products before they are exported. Considering that Laos has a small wood-processing industry, which is in its infancy compared to neighboring countries such as Vietnam and China, the implementation of this decree will require strong support from wood processing enterprises through capacity building, training, and product development.

The country is surrounded by some of the fastest growing economies in the world. The production of engineered wood products (EWPs) in the Asia-Pacific region is expected to grow at a compound annual growth rate of 25% by 2020 (AFTN 2016). The EWPs are manufactured composites that provide consistent and reliable building products with improved structural characteristics and allow the most efficient use of forest resources. With Southeast Asia's urbanization rate expected to increase from 42% in 2010 to 65% in 2050, the Greater Mekong Subregion (GMS), home to over 326 million people, will undergo inevitable urbanization. Asia is the largest regional construction market worldwide, accounting for approximately 40% of global construction spending in 2012. Construction spending in Asia is forecasted to account for almost one-half of total global construction spending by 2020 (Anonymous 2013). As the world's fastest growing construction market, Asia has also become increasingly dependent on domestic demand, through burgeoning affluence and urbanization, for its continued growth. Rapidly expanding urbanization and infrastructure development are resulting in increased commercial and urban construction with concomitant demands for EWPs and other construction materials, such as formwork plywood.

The emergence and proliferation of a eucalypt veneer industry in China and other Asian countries was put in place to fulfill the increased demand for EWPs and has transformed a lower value pulp resource into higher value feedstock for veneer production. This, in turn, supports the manufacture of EWPs and especially plywood (Arnold *et al*. 2013). Rotary-peeled veneers are increasingly common products from small-diameter, young eucalypt logs (Peng *et al*. 2014). This industry has been made possible by the development of small, low cost spindleless veneer lathes capable of achieving relatively high recoveries. In recent studies on commercial eucalypt clones in Guangdong, Ren *et al*. (2010), and Peng *et al*. (2014) obtained green veneer recoveries of 40% to 65% from 6- to 12-year-old trees (diameter at breast height 14 cm to 24 cm) for many of the commonly planted commercial species. In Australia, McGavin *et al*. (2014) reported on grade recoveries from logs harvested from six different hardwood plantation species grown for pulpwood and sawn timber. The authors demonstrated acceptable recoveries of marketable products using simple veneer technology with recovered veneers having visual qualities that are suitable for structurally-based products.

A few studies have demonstrated the potential of rotary peeling for veneer production. Luo *et al*. (2013) examined the variation among a range of 5-year-old eucalypt clones in veneer grade and value traits. The authors found that clones and log position in the tree influence significantly green veneer recovery and veneer quality grade. Knots and splitting were also major factors influencing veneer quality grade. Peng *et al.* (2014) identified branch-related defects as a grade-limiting defect as well. Hamilton *et al*. (2015) investigated the post-felling log traits and recoveries among different sites. Although recovery traits were affected by site and log position in the tree, the study showed that differences among sites for recovery were not significant. Vega *et al*. (2016) found that site and log position had a significant effect on splitting.

Information on the variation and selection among commercial eucalypt species and clones in regards to suitability for veneer production is still scarce. Understanding the impact of silvicultural management and peeling processing parameters of fast-growing high-yielding plantations on recovery and quality is also needed. Opportunities exist for the production of EWPs for the rapidly growing construction, furnishing, and joinery industries in Laos and neighboring countries. Research and development is needed to support the development of the new processing capability and a range of EWPs that can be produced from small-diameter timbers available from plantations. The aim of the present study was to assess the peeling potential of low quality pulpwood managed stands of selected eucalypts in Laos, namely *Eucalyptus pellita*, *Eucalyptus camaldulensis*, and eucalypt clone K7 (*E. camaldulensis* × *E. deglupta*). Specific objectives were to: 1) assess the potential of young plantation pulpwood eucalypts for peeling; 2) determine green and dry recovery; and 3) determine the influence of taxon and log position on recovery and quality. A better understanding of the above-mentioned factors on peeling recovery and veneer quality will contribute to improving silvicultural and forest management decisions for a more effective use of forest resources in Laos and ultimately improve the livelihood of small landowners and foresters.

EXPERIMENTAL

Materials and Methods

Field sites and tree selection

Three eucalypt plantations located on two field sites in the Bolikhamsai Province, Laos, were selected for the present study (Table 1).

Table 1. Field Sites' Information

Taxon	***E. pellita***	**Eucalypt Clone K7** [a]	***E. camaldulensis***
Plantation Site	Phabath	Phabath	Namdeua
Location and Environment			
Latitude; longitude (°)	18.27; 103.12	18.27; 103.12	18.26; 104.17
Elevation [b] (m asl)	192	189	177
Annual Temperature [cd] (°C)	22.2	22.2	21.9
Min. temp. Coolest Month [cd] (°C)	13.5	13.5	13.2
Annual Rainfall [c] (mm)	1664	1664	1723
Slope (°)	1.09 to 1.80	0.90 to 1.34	0.40 to 1.11
Silviculture			
Management	Pulp	Pulp	Pulp
Spacing (m)	3.2 × 1.8	3.2 × 1.8	4 × 2
Fertilisation (g per tree)	Single superphosphate (SSP): 322 Diammonium phosphate (DAP): 72 Muriate of potash (KCL): 24 Boron: 10		
Thinning	Unthinned	Unthinned	Unthinned
Pruning	Unpruned	Unpruned	Unpruned
Felling Age (years)	7	6	11
Average DBH (cm)	18.1 (2.3)	18.4 (2.5)	18.9 (4.5)

[a] *E. camaldulensis* × *E. deglupta*; [b] Data obtained from FreeMapTools 2018; [c] Data obtained from ASDC 2017; [d] Averaged air temperature at 10 m above the surface of the Earth; * Standard deviation is presented in parentheses

The plantations belong to Mekong Timber Plantations Ltd. and have been grown as unthinned and unpruned pulpwood stands. The area has a tropical monsoon climate with substantial rainfall in most months of the year except for a short dry season between December and January. The two sites encompassed different spacings: the Phabath stand, which included *Eucalyptus pellita* and eucalypt clone K7 (*E. camaldulensis* × *E. deglupta*) was established in a 3.2 m × 1.8 m spacing configuration; and the Namdeua stand, composed of *E. camaldulensis*, with a 4 m × 2 m configuration. Fifteen trees per taxon were selected at random for manual felling (stump height: 10 cm) and excluded trees with any evident visual defects not characteristic of the stand. Each tree was then further cut into two 1.3-m long billets, *i.e.* a bottom log and top log (height of the start of the top log: 1.4 m) determined by height from the ground.

Preparation and log measurement

All trees were delivered to the peeling site in Vientiane Capital within 4 days of felling. The diameter at breast height (DBH: 1.3 m), log small-end diameter under bark (SED), log large-end diameter under bark (LED), and log heartwood diameter at both ends were measured during the felling process.

The average LED and SED were calculated using the following equations,

$$LED = \sqrt{\frac{LELD^2 + LESD^2}{2}} \tag{1}$$

$$SED = \sqrt{\frac{SELD^2 + SESD^2}{2}} \tag{2}$$

where *LELD* is the large-end long-axis diameter (mm), *LESD* is the large-end short-axis diameter (mm), *SELD* is the small-end long-axis diameter (mm), and *SESD* is the small-end short-axis diameter (mm).

The average large-end heartwood diameter (LEHD) and small-end heartwood diameter (SEHD) were calculated using the equations,

$$LEHD = \sqrt{\frac{LELHD^2 + LESHD^2}{2}} \tag{3}$$

$$SEHD = \sqrt{\frac{SELHD^2 + SESHD^2}{2}} \tag{4}$$

where *LELHD* is the large-end long-axis heartwood diameter (mm), *LESHD* is the large-end short-axis heartwood diameter (mm), *SELHD* is the small-end long-axis heartwood diameter (mm), and *SESHD* is the small-end short-axis heartwood diameter (mm).

The volume of each log was determined using Smalian's formula,

$$V = \pi \times L \times \left(\frac{LED + SED}{4 \text{ x } 1{,}000}\right)^2 \tag{5}$$

where V is the billet volume (m^3) and L is the billet length (m).

Heartwood proportion (HP, %) was calculated from each log end using the heartwood area (HA) determined following a visual assessment and the basal area (BA),

$$HP = \frac{HA}{BA} \times 100 \tag{6}$$

where

$$HA = \pi\left(\frac{LEHD + SEHD}{2} \times \frac{1}{2}\right)^2 \quad (7)$$

and

$$BA = \pi\left(\frac{LED + SED}{2} \times \frac{1}{2}\right)^2 \quad (8)$$

The HP can have utilization and processing implications, particularly where durability and appearance properties are required. A smaller sapwood band is sometimes desirable as it means less timber is wasted if the sapwood is required to be removed or less chemical preservatives are required if the sapwood is to be treated.

Upon reception, sweep (log bend), knots, end splits, holes, including insect holes, and decay were measured on each log in accordance with grading rules developed for Laos (Redman *et al*. 2015). The sweep, expressed as a percentage, was calculated as the ratio between the maximum distance between the curved side of a log and a line extended between the log ends. The maximum knot diameter was measured in the direction perpendicular to the length of the log where the knot starts to rise (Fig. 1). The end splits, defined here as the maximum external splits reaching the log periphery, were measured and expressed as a percentage of the total log length (Fig. 1). Holes and insect holes were measured from the maximum diameter where decay and mold were recorded as being either present or not.

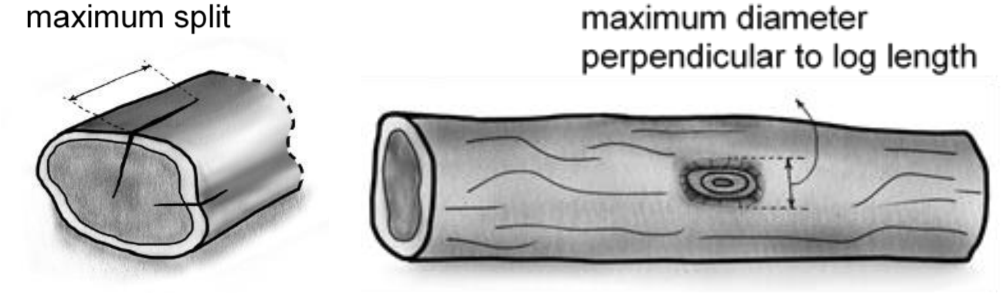

Fig. 1. Schematic view of end split (left) and knot (right) measuring methods (Redman *et al.* 2015)

The total end split (ES) was calculated for each log using Eq. 9,

$$ES\ (\%) = \frac{LEES + SEES}{L \times 1{,}000} \times 100 \quad (9)$$

where *LEES* is the large-end end split (mm) and *SEES* is the small-end end split (mm).

Log taper (T_p) was calculated using Eq. 10:

$$T_\mathrm{p} = \frac{LED - SEB}{2L \times 1{,}000} \quad (10)$$

Ovality or circularity (O, m/m) was calculated using Eq. 11:

$$O = \frac{1}{2} \times \left(\frac{LESD}{LELD} + \frac{SESD}{SELD}\right) \quad (11)$$

Log peeling, yield, and visual grading

The logs were peeled 3 to 5 days following delivery (*i.e.*, one taxon per day). All the logs were treated using saturated steam at 70 °C in a conventional kiln for 24 h prior to being peeled. Logs were then docked to a 1.2-m length and loaded into a debarker (Model BBP1400D; BSY Industry Group, Weihai, China).

The logs were peeled using a spindleless veneer peeling lathe (Model SL1350/3; BSY Industry Group, Weihai, China) with a freshly sharpened knife for each taxon (bevel angle: 21°). The target veneer thickness and width were 2.8 mm and 1300 mm, respectively. The thickness of each sheet was measured at 2 points using a digital caliper. The log-core diameter after peeling was 45 mm.

The green veneer recovery (GNR, %) for a single log was calculated using Eq. 12,

$$GNR = \frac{\sum_{veneer}(GL \times GW \times GT)}{\sum_{billet} Volume} \tag{12}$$

where *GL*, *GW*, and *GT* are respectively the green veneer length, width, and thickness (mm^3).

Following peeling, the veneer sheets were air dried (*i.e.*, 3 days under a covered and ventilated area as experiment has been conducted during the wet season) below 16% moisture content and remeasured to calculate the dry veneer recovery (DR, %),

$$DR = \frac{\sum_{veneer}(DL \times DW \times DT)}{\sum_{billet} Volume} \tag{13}$$

where *DL*, *DW*, and *DT* are respectively the air-dried veneer length, width, and thickness (mm^3). The moisture content was determined using oven-dry method.

Once air-dried, the veneer was graded using the Vietnamese grading standard TCVN 10316 (2014, Table 2), which contains grading rules for veneer to be used as exposed face veneers and substrate core veneers. The standard includes five face veneer grades, 1 to 5, where 1 is the highest quality and 5 is the lowest. Two core veneers are also included, where 1 is the highest and 2 is the lowest. The standard grade criteria include: sound knots, unsound knots, holes, splits, bark/gum pockets, insect attack, discoloration, grain tear-out, pin knots, scratches, knife marks, and decay.

From the dried veneers that met the quality specifications of TCVN 10316 (*i.e.*, Grade 1 to 5 and C1 to C2), the gross veneer recovery (GSR, %) was calculated and later used to determine the net veneer recovery (NR, %), which considers additional losses due to the trimming to the final product size. In the present study, the veneer sheet length was reduced from 1,300 mm to 1,200 mm and was equivalent to a trimming factor of 0.85. The NR was calculated as follows:

$$NR = GSR \times 0.85 \tag{14}$$

Data analysis

A statistical analysis was conducted using Minitab (Minitab Inc., V18.1, State College, PA, USA) to examine the effects of taxon, log position (*i.e.*, bottom or top log), and log traits (*i.e.*, end split, sweep, small-end diameter, taper, and ovality) on wood recoveries ($\alpha = 0.05$). A fit mixed-effects model was considered including taxon, log position and their interaction to the untransformed raw data. The trees represented independent experimental units, and the measurements on logs represented repeated measures of traits on these independent experimental units. An analysis of variance (ANOVA) was subsequently conducted where the tree was fitted as the subject effect and an unstructured within-subject variance covariance matrix was assumed (Hamilton *et al*. 2015). Post hoc multiple comparison tests were performed using the Fisher method.

Table 2. Face and Core (C) Veneer Grading Standard as per TCVN 10316 (2014)

Grade	**Sound Knots**	**Unsound Knots**	**Holes**	**Splits**	**Bark/Gum Pockets**	**Insect Attack**
1	≤ 5 mm wide ≤ 5 / m^2 No knot splits	≤ 4 mm wide ≤ 2 / m^2 < 2 mm OK	Not allowed	≤ 1.5 mm wide ≤ 2 / m sheet width ≤ 200 mm sheet length	Not allowed	Vertical ≤ 2 mm ϕ ≤ 3 / m^2 Horizontal Not allowed
2	≤ 50 mm wide	≤ 6 mm wide ≤ 2 / m^2 < 4 mm OK	≤ 5 mm wide ≤ 4 / m^2 < 2 mm OK	≤ 1.5 mm wide ≤ 4 / m sheet width ≤ 400 mm sheet length		Vertical ≤ 2 mm ϕ ≤ 8 / m^2 Horizontal ≤ 2 mm wide ≤ 10 mm long ≤ 15 / m^2
3	No limitations	≤ 15 mm wide ≤ 4 / m^2	≤ 8 mm wide ≤ 8 / m^2	≤ 3 mm wide ≤ 4 / m sheet width ≤ 600 mm sheet length	≤ 4 mm wide ≤ 50 mm long < 2 / m^2	Vertical ≤ 4 mm ϕ ≤ 15 / m^2 Horizontal ≤ 3 mm wide ≤ 15 mm long ≤ 15 / m^2
4		≤ 30 mm wide	≤ 20 mm wide	≤ 5 mm wide If > 5 mm - Repair	No limitations	Vertical ≤ 5 mm ϕ ≤ 15 / m^2 Horizontal ≤ 3 mm wide ≤ 50 mm long ≤ 15 / m^2
5		No limitations				No limitations
C1	No limitations	≤ 3 mm wide	≤ 3 mm wide	≤ 2 mm wide ≤ 2 / m sheet width ≤ 10% sheet length	Not allowed	No limitations
C2		≤ 25 mm wide	≤ 25 mm wide	≤ 3 mm wide ≤ 30% sheet length	No limitations*	
	Discoloration	**Grain Tear-out♠**	**Pin Knots**	**Scratches†**	**Knife Mark**	**Decay**
1	Not allowed	Very slight	≤ 2 mm wide	Not allowed	Not allowed	Not allowed
2	≤ 5% sheet area	Slight	No limitations	≤ 1% sheet area	Very slight, not felt by hand	
3	≤ 30% sheet area	Ok if surface not rough		≤ 2% sheet area	Slight, not felt by hand	
4	No limitations	No limitations		No Limitations	Slight, felt by hand	Permitted
5						
C1	No limitations*	No limitations	No limitations	≤ 3% sheet area	Not allowed	Not allowed
C2				≤ 5% sheet area	Slight, not felt by hand	Permitted

* If not affecting bond quality. † Scratches must not go through. ♠ Gouges in veneer surface typically found around knots.

RESULTS AND DISCUSSION

A total of 90 logs, 1.2-m-long, from three different eucalyptus taxa totaling 2.5 m^3 were processed into veneer sheets (Table 3). The statistical analysis of the billet characteristics showed a significant interaction between taxa and log position on log-end splitting ($P < 0.001$), sweep ($P = 0.003$), and taper ($P = 0.048$). Log-end splitting was significantly higher in eucalypt clone K7 than the other two studied species. The eucalypt clone K7 was also the only taxon where splitting was significantly different between bottom and top logs (20.8% and 26.0%, respectively). This observation where top logs split more than bottom logs is in accordance with Vega *et al.* (2016). A shorter storage time could potentially help reduce splitting for eucalypt clone K7 considering that this taxon was peeled four days following harvesting. Sweep was found to be significantly more pronounced in *Eucalyptus pellita* (1.1%) than *Eucalyptus camaldulensis* or eucalypt clone K7 (both 0.8%).

Table 3. Billet Characteristics of Three Eucalyptus Taxa

Taxon	***Eucalyptus pellita***			**Eucalypt Clone K7** [a]			***Eucalyptus camaldulensis***		
	Bottom	Top	Combined	Bottom	Top	Combined	Bottom	Top	Combined
Volume Processed (m^3)	0.419	0.356	0.775	0.470	0.407	0.877	0.474	0.400	0.874
Average Log Small-End Diameter (mm)	157 (18)	149 (15)	153 (17)	169 (24)	159 (21)	164 (23)	162 (38)	154 (35)	158 (36)
Average Billet [b] Volume (m^3)	0.028 (0.006)	0.024 (0.005)	0.026 (0.006)	0.031 (0.008)	0.027 (0.007)	0.029 (0.008)	0.032 (0.015)	0.027 (0.012)	0.029 (0.014)
Average Sweep (%)	1.1 (0.4)	1.0 (0.4)	1.1 (0.4)	0.9 (0.4)	0.6 (0.3)	0.8 (0.4)	0.7 (0.2)	0.9 (0.4)	0.8 (0.3)
Average Heartwood Proportion (%)	54.1 (5.9)	57.1 (5.7)	55.6 (5.9)	32.2 (5.1)	30.6 (12.0)	31.4 (9.1)	50.6 (9.9)	47.5 (7.4)	49.0 (8.7)
Average Log-End Splitting [c] (%)	9.9 (12.8)	12.2 (14.0)	11.0 (13.2)	20.8 (8.3)	26.0 (9.2)	23.4 (9.0)	12.7 (8.3)	10.9 (8.3)	11.8 (8.2)
Average Log Taper (cm/m)	0.55 (0.17)	0.21 (0.11)	0.38 (0.23)	0.36 (0.15)	0.24 (0.17)	0.30 (0.17)	0.70 (0.45)	0.31 (0.22)	0.51 (0.40)
Average Ovality (m/m)	0.94 (0.03)	0.95 (0.03)	0.95 (0.03)	0.95 (0.03)	0.95 (0.03)	0.95 (0.03)	0.95 (0.03)	0.95 (0.02)	0.95 (0.03)

[a] *E. camaldulensis* × *E. deglupta*; [b] Docked; [c] Following steaming treatment; * Standard deviation is presented in parentheses

Log taper of bottom logs of *Eucalyptus pellita* (0.55 cm/m) and *Eucalyptus camaldulensis* (0.70 cm/m) were both found to be significantly higher than any other combinations (*i.e.* taxon x position). The ovality was not significantly affected by taxon ($P > 0.05$) or the position in the tree ($P > 0.05$). The SED was not significantly different between studied taxa ($P > 0.05$) but increased significantly in logs from the bottom section of the tree ($P < 0.001$).

The calculated veneer recoveries are presented in Table 4. All studied taxa achieved green veneer recoveries between 57% and 67%. The analysis showed that green recovery is influenced by ovality (*P*-value = 0.007) and by taxon (*P*-value = 0.023) (Table 5). Neither the position in the tree (*P*-value = 0.922) nor the taper (*P*-value = 0.248) had a significant effect on green recovery. The observed effect of ovality on green recovery is in accordance with previous studies (McGavin *et al*. 2014; Hamilton *et al*. 2015). Sweep showed no significant impact on green recovery.

Table 4. Veneer Recoveries (%) Per Taxon as Percentage of Log Volume

Taxon	Log Position in Tree	Number of Logs	Green Recovery	Dry Recovery	Net Face Grade Recovery [2]	Net Core Grade Recovery [2]
Eucalyptus pellita	Top	15	68.1^{AB}	62.6^{AB}	51.7^{A}	43.3^{ABC}
	Bottom	15	57.2^{B}	55.4^{ABC}	47.1^{AB}	39.0^{BC}
	Combined	**30**	**62.2**	**58.8**	**49.4**	**41.1**
Eucalypt Clone K7 [1]	Top	15	66.0^{A}	61.6^{AB}	43.6^{AB}	43.6^{AB}
	Bottom	15	67.9^{A}	63.7^{A}	48.7^{A}	47.9^{A}
	Combined	**30**	**67.0**	**62.7**	**46.2**	**45.8**
Eucalyptus camaldulensis	Top	15	59.7^{B}	52.6^{C}	41.5^{B}	38.7^{C}
	Bottom	15	54.8^{B}	51.5^{BC}	43.1^{AB}	41.3^{ABC}
	Combined	**30**	**57.0**	**52.0**	**42.3**	**40.0**

[1] *E. camaldulensis* × *E. deglupta*; [2] As per TCVN 10316 (2014); for each type of recovery, means that do not share a letter are significantly different

Table 5. ANOVA Results for Green Veneer Recovery of Three Eucalypt Plantation-grown Taxa as a Function of Log Traits

	Green Recovery		*Dry Recovery*		*Net Face Recovery*		*Net Core Recovery*	
Source of Variation	*F*-value	*P*-value [a]	*F*-value	*P*-value [a]	*F*-value	*P*-value [a]	*F*-value	*P*-value [a]
SED	1.26	0.268	1.36	0.249	0.56	0.459	2.15	0.147
Sweep	0.01	0.913	0.22	0.639	0.48	0.489	0.26	0.613
End Splits***	3.08	0.084	1.02	0.316	6.68	**0.012** *	14.34	**0.000** *
Taper	1.36	0.248	0.73	0.397	0.46	0.497	1.54	0.218
Ovality	7.72	**0.007** *	1.93	0.169	0.55	0.461	0.66	0.420
Taxon	3.97	**0.023** *	3.08	0.053	1.49	0.232	3.00	0.056
Position in Tree	0.01	0.922	0.17	0.680	0.56	0.458	1.12	0.293
Taxon*Position	1.34	0.273	1.25	0.296	1.85	0.169	0.89	0.416

SED: Log Small-End Diameter; ***End Split After Steaming; [a] Asterisk indicates significance at $\alpha = 0.05$

A previous study by Luo *et al*. (2013) reported that sweep influenced veneer recovery. However, relatively low average values were measured on the studied logs that ranged between 0.8% and 1.1%, as opposed to 1.8% in some cases for Luo *et al*. (2013). These results probably explain the lack of correlation between sweep and recovery in this study. Unlike other peeling studies conducted on eucalypt plantations (Luo *et al*. 2013;

Peng *et al*. 2014; Hamilton *et al*. 2015), the log position in the tree had no significant impact on green recovery for any studied taxa even though bottom logs usually exhibited significantly more taper (Tables 3 and 4).

All studied taxa achieved dry veneer recoveries between 52% and 63%. The observed gradients from green to dry recoveries were in accordance with the shrinkage properties of the selected species provided in the literature (Kingston and Risdon 1961). *Eucalyptus pellita* yielded the highest net face grade recovery with 49.4% of its veneer out-turn achieving as face grade quality (Table 4). Eucalypt clone K7 and *E. camaldulensis* achieved 46.2% and 42.3%, respectively. All studied taxa achieved similar net core grade recovery that ranged from 40% to 45%. Both net core grade and face grade recoveries were significantly affected by end splits (*P*-value <0.001 and 0.012, respectively). There was a significant difference between the net face grade recovery from *E. pellita* and *E. camaldulensis*. One element that might have affected the Eucalypt clone K7 face grade recovery could have been the impact of log-end splitting following the steaming treatment, as it was significantly higher than the other two species. Optimizing the steaming treatment by reducing temperature and time or by increasing the merchantable length of logs to cut ends following steaming are avenues that need to be investigated to limit log-end splitting.

Across all three taxa, the veneer grade recoveries were dominated by grade 4 face veneer and grade 2 core veneer (Tables 6 and 7). Grade 4 net face veneer recovery ranged from 31% and 44% with *Eucalyptus pellita* and *Eucalyptus camaldulensis* providing the highest and lowest yield, respectively. The grade 2 net core veneer recovery ranged from 31% and 37% with Eucalypt clone K7 and *Eucalyptus camaldulensis* providing the highest and lowest yield, respectively. Lower-grade veneer (*i.e.* grade 3 to 5) could technically be suitable for face veneers for some structural panels, as well as the core veneers for most appearance and non-appearance structural panels (McGavin 2016; Blackburn *et al.* 2018).

Splits were an important resource induced defect that affected the most face veneer grading across all three taxa. Seventy percent of all the sheets peeled from Eucalypt clone K7 have been graded between 3 to 5 as a result of splits, with another 15% being rejected as a result of this criterion. The proportions of sheets being graded between 3 to 5 because of splits represented 51% and 52% for *Eucalyptus camaldulensis* and *Eucalyptus pellita*, respectively. Branch-related defects were other important grade-limiting defects, restricting veneer sheet quality to grade 4 for most sheets. When considering the proportion of grade 3 to 5 sheets produced, the most important branch-related defects affecting net face grade recovery for *Eucalyptus pellita* were unsound knots (78% of sheets with the defect), bark or gum pockets (43%), and holes (35%). Unsound knots (93%) were the most common reasons for downgrade with Eucalypt clone K7, followed by holes (47%). In the case of *Eucalyptus camaldulensis*, bark or gum pockets (61%) were the main reasons for downgrade, followed by unsound knots (52%), and holes (26%).

Currently, there is a common misconception in Laos that all trees have value, which has led to the current practice of using high initial planting density, the absence of non-commercial thinning, and the common practice of thinning from above (Dieters *et al*. 2014). Frequent and light thinning can eliminate the need for trees to bend towards light and reduces growth stresses and ultimately end splitting (Kluber 1988). As pointed out by Peng *et al*. (2014), improvement in veneer sheet quality could be achieved by pruning either just before or after branch death. McGavin *et al*. (2015) also reported evident recoveries variation between sites that were thinned and pruned or not. Dead knots, holes, and splitting are major factors influencing veneer quality grade (Luo *et al*. 2013; Nolan *et al*. 2005). Similar adverse effects of growth stresses on log-end splitting and consequently, net grade recovery were observed by McGavin *et al*. (2014) and Sharma and Altaner (2017).

It is well known that eucalypts species are prone to high levels of growing stress, which is mechanical stress generated by growing wood cells that causes end splitting (Kubler 1988). Vega *et al*. (2016) suggested that log-end splitting is affected by site and storage time. However, it would be difficult from a logistic perspective to peel logs in less than four days following harvesting in Laos, in addition to the fact that the yield improvement could only be minimal. Further tests on different sites and ultimately, genetic improvement could be avenues to better understand end splitting. However, pruning trials to assess knots impact on veneer net grade recovery might be a more realistic and practical approach at this stage. Reduction in branch related defects is a critical step to optimize value yields and provide high proportions of appearance grade veneers as pointed out by Arnold *et al*. (2013) and Peng *et al*. (2014). Where growers would be well placed to exploit the benefits of producing pruned logs, currently there is little incentive for them to invest in such silvicultural practices.

Table 6. Graded Face Veneer Recoveries (%) as per TCVN 10316 (2014)

Taxon	Log Position in Tree	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Reject [b]
Eucalyptus pellita	Top	0.0 (0.0) [c]	0.9 (1.7)	1.8 (3.4)	47.3 (91.5)	0.9 (1.7)	0.9 (1.7)
	Bottom	1.5 (3.2)	1.5 (3.2)	2.3 (4.8)	41.9 (88.9)	0.0 (0.0)	0.0 (0.0)
	Combined	0.8 (1.6)	1.2 (2.5)	2.0 (4.1)	44.6 (90.2)	0.4 (0.8)	0.4 (0.8)
Eucalypt Clone K7 [a]	Top	0.0 (0.0)	0.6 (1.4)	1.8 (4.2)	32.1 (73.6)	0.0 (0.0)	9.1 (20.8)
	Bottom	0.0 (0.0)	0.5 (1.1)	0.5 (1.1)	41.1 (84.4)	0.0 (0.0)	6.5 (13.3)
	Combined	0.0 (0.0)	0.6 (1.2)	1.2 (2.5)	36.8 (79.6)	0.0 (0.0)	7.7 (16.7)
Eucalyptus camaldulensis	Top	2.1 (5.0)	4.2 (10.0)	3.4 (8.3)	28.3 (68.3)	0.0 (0.0)	3.4 (8.3)
	Bottom	0.6 (1.4)	1.2 (2.9)	3.7 (8.6)	34.5 (80.0)	0.0 (0.0)	3.1 (7.1)
	Combined	1.3 (3.1)	2.6 (6.2)	3.6 (8.5)	31.6 (74.6)	0.0 (0.0)	3.3 (7.7)

[a] *E. camaldulensis* × *E. deglupta*; [b] Veneer not meeting the requirements of Grade 1 to 5;
[c] Recovered grade veneer as a proportion of net veneer volume is presented in parentheses

The production of EWPs in the Asia-Pacific region is expected to grow significantly in the future. Considering the rising interest in carbon footprint of construction products, a better understanding of the above-mentioned elements on peeling recovery and veneer quality could represent a strong opportunity in building products. However, further research would be necessary to assess the mechanical properties of the available wood resource as stiffness is the constraining factor if structural products are targeted (McGavin *et al*. 2015).

Table 7. Graded Core Veneer Recoveries (%) as per TCVN 10316 (2014)

Taxon	Log Position in Tree	Grade 1	Grade 2	Reject [b]
Eucalyptus pellita	Top	1.5 (3.4)	33.8 (78.0)	8.1 (18.6)
	Bottom	1.9 (4.8)	29.7 (76.2)	7.4 (19.0)
	Combined	1.7 (4.1)	31.6 (77.0)	7.8 (18.9)
Eucalypt Clone K7 [a]	Top	0.6 (1.4)	33.9 (77.8)	9.1 (20.8)
	Bottom	0.5 (1.1)	40.4 (84.4)	6.9 (14.4)
	Combined	0.5 (1.2)	37.3 (81.5)	7.9 (17.3)
Eucalyptus camaldulensis	Top	6.5 (16.7)	27.1 (70.0)	5.1 (13.3)
	Bottom	1.8 (4.3)	35.4 (85.7)	4.1 (10.0)
	Combined	4.0 (10.0)	31.4 (78.5)	4.6 (11.5)

[a] *E. camaldulensis* × *E. deglupta*; [b] Veneer not meeting the requirements of Grade 1 or 2; * Recovered grade veneer as a proportion of net veneer volume is presented in parentheses

CONCLUSIONS

1. The results indicate that taxon, ovality, end splitting, and knots influenced the recovery and veneer sheet quality. The log position in tree had no significant effect on recovery or quality. Recovery and veneer quality could be improved with appropriate silvicultural and forest management decisions for a more effective use of forest resources.
2. The selected taxa achieved green veneer recoveries between 57% and 67%, with Eucalypt clone K7 achieving the highest green recovery. The ovality and taxon had a significant effect on green veneer recovery. Neither the position in the tree, the taper, nor sweep had significant impact on green recovery. *Eucalyptus pellita* yielded the highest net face grade recovery, where Eucalypt clone K7 was most affected by log-end splitting following steaming treatment.
3. The veneer grade recoveries were dominated by lower-grade face and core veneer across all taxa. Branch-related defects and splits were the resource induced defects that affected the most face and core veneer grading across all taxa, validating the importance of the early pruning to improve grade recovery.

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REFERENCES CITED

Anonymous (2013). *Asia Construction Outlook*, AECOM Pty Ltd., Los Angeles, CA, USA.

Arnold, R. J., Xie, Y. J., Midgley, S. J., Luo, J. Z., and Chen, X. F. (2013). "Emergence and rise of eucalypt veneer production in China," *International Forestry Review* 15(1), 33-47. DOI: 10.1505/146554813805927200

Atmospheric Science Data Center (ASDC) (2017). "NASA surface meteorology and solar energy," NASA Langley Research Center- Atmospheric Science Data Center, (https://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi?email=skip@larc.nasa.gov), Accessed 1 Nov 2017.

Australian Forests & Timber News (AFTN) (2016). "Global engineered wood products market growth," timberbiz, (https://www.timberbiz.com.au/global-engineered-wood-products-market-growth/), Accessed 23 June 2017.

Blackburn, D., Vega, M., Yong, R., Britton, D., and Nolan, G. (2018). "Factors influencing the production of structural plywood in Tasmania, Australia from *Eucalyptus nitens* rotary peeled veneer," *Southern Forests* pp. 1-10. DOI: 10.2989/20702620.2017.1420730.

Department of Forestry (DoF) (2015). Unpublished plantation statistics. Department of Forestry, Lao PDR, Vientiane, Laos.

Dieters, M., Newby, J., Cramb, R., Sexton, G., McNamara, S., Johnson, M., Vongphacsouvanh, M., Sakanphet, S., Sodarak, H., Singhalath, K., *et al.* (2014). *Enhancing on-farm Incomes through Improved Silvicultural Management of Teak in Luang Prabang Province of Lao PDR* (ACIAR Report FR2014-08), Australian Capital Territory, Canberra, Australia.

FreeMapTools (2018). "Free map tools online resource," (https://www.freemaptools.com/elevation-finder.htm), Accessed 28 Feb 2018.

Government of Lao PDR (GoL) (2016). *Strengthening Strictness of Timber Harvest Management and Inspection, Timber Transport and Business* (Prime Minister Order No. 15), Government of Lao PDR, Vientiane, Lao PDR.

Hamilton, M. G., Blackburn, D. P., McGavin, R. L., Bailleres, H., Vega, M., and Potts, B. M. (2015). "Factors affecting log traits and green rotary-peeled veneer recovery from temperate eucalypt plantations," *Annals of Forest Science* 72(3), 357-365. DOI: 10.1007/s13595-014-0430-0

Kingston, R. S. T., and Risdon, C. J. E. (1961). *Shrinkage and Density of Australian and Other South-West Pacific Woods* (Technical Paper No. 13), CSIRO Division of Forest Products, VIC, Melbourne, Australia.

Kubler, H. (1988) "Silvicultural control of mechanical stresses in trees," *Canadian Journal Forest Research* 18, 1215-1225.

Luo, J., Arnold, R., Ren, S., Jiang, Y., Lu, W., Peng, Y., and Xie, Y. (2013). “Veneer grades, recoveries, and value from 5-year-old eucalypt clones,” *Annals of Forrest Science* 70(4), 417-428. DOI: 10.1007/s13595-013-0268-x

McGavin, R. L. (2016). *Analysis of Small-log Processing to Achieve Structural Veneer from Juvenile Hardwood Plantations*, Ph.D. Thesis, The University of Melbourne, Melbourne, Australia.

McGavin, R. L., Bailleres, H., Fehrmann, J., and Ozarska, B. (2015). “Stiffness and density analysis of rotary veneer recovered from six species of Australian plantation hardwoods,” *BioResources* 10(4), 6395-6416. DOI: 10.15376/biores.10.4.6395-6416

McGavin, R. L., Bailleres, H., Lane, F., Blackburn, D., Vega, M., and Ozarska, B. (2014). “Veneer recovery analysis of plantation eucalypt species using spindleless lathe technology,” *BioResources* 9(1), 613-627. DOI: 10.15376/biores.9.1.613-627

Nolan, G., Greaves, B. L., Washusen, R., Parsons, M., and Jennings, S. M. (2005) “*Eucalypt Plantations for Solid Wood Products in Australia - A Review: If You Don't Prune It, We Can't Use It*,” Forest and Wood Products Research & Development Corporation, Victoria, Australia.

Peng, Y., Washusen, R., Xiang, D., Lan, J., Chen, S., and Arnold, R. (2014). “Grade and value variation in *Eucalyptus urophylla* x *E. grandis* veneer due to variations in initial plantation spacings,” *Australian Forestry* 77(1), 39-50. DOI: 10.1080/00049158.2013.877415

Redman, A., Bailleres, H., Mai, T. H., and Tung, N. T. (2015). *Plantation Hardwoods - Raw Material and Recovery Analysis Specifically for Veneer Production* (ACIAR Project Report), Department of Agriculture and Fisheries, Queensland, Brisbane, Australia.

Ren, S., Luo, J., Peng, Y., Xie, Y., Lu, W., Cao, J., and Jiang, Y. (2010). “A study on veneer recovery ratio and value of eucalypt clones,” *Acta Prataculturae Sin* 19, 46-54.

Sharma, M., and Altaner, C. (2017). “New Zealand grown eucalypts for rotary peeled veneer production,” in: *Workshop Proceedings Durable Eucalypts on Drylands: Protecting and Enhancing Value*, Malborough Research Centre, Blenheim, New Zealand, pp. 54-62.

TCVN 10316 (2014). “Rotary veneer grading standard for hardwoods,” TCVN Vietnam Standards and Quality Institute, Hanoi, Vietnam [in Vietnamese].

Vega, M., Hamilton, M. G., Blackburn, D. P., McGavin, R. L., Bailleres, H., and Potts, B. (2016). “Influence of site, storage and steaming on *Eucalyptus nitens* log-end splitting,” *Annals of Forest Science* 73(2), 257-266. DOI: 10.1007/s13595-015-0496-3

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