Technical Report

Value of veneer, wood fibre and posts from improved *Eucalyptus bosistoana* trees

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Date: 30th June 2020

Report: SWP-T101

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EXECUTIVE SUMMARY

E. bosistoana produces high stiffness veneers, which could be used by New Zealand's existing LVL industry to produce an internationally competitive product. Entry barriers are low as existing manufacturing facilities can be utilised and an international market for such products exists.

This study has shown that the value of an *E. bosistoana* tree produced under a 10-20 year rotation exceeded growing costs (including an 8% IRR). Additional value can be added in particular for smaller diameter trees from marketing the peeler core as naturally ground-durable posts for agricultural industries. Like higher stiffness LVL, domestic and international market demand, in particular from the organic sector, exists for such a product.

However, veneer yields were reduced by the release of growth stresses that caused veneers to split and unfavourable stem form that reduced the amount of theoretically peelable veneer. Therefore low growth strain and good stem form are key selection traits for the *E. bosistoana* breeding programme when considering LVL.

Tree form and wood properties had a larger effect on tree value than product prices. In a case where peeler cores were sold as ground-durable posts, tree value would increase by 50% to 65% depending on size, when average stem properties were improved by one standard deviation. Marketing peeler cores as ground-durable posts or increasing veneer yields with spindle-less lathes were particularly beneficial for smaller diameter logs, raising their value by up to 100%. Therefore durable eucalypts might offer the opportunity to deliver under a shorter rotation than pine.

INTRODUCTION

Target products for establishing a durable eucalypt forest resource in New Zealand are ground-durable posts for the agricultural sector and high stiffness veneers for LVL (Millen, Altaner, Buck, & Palmer, 2019; Millen, van Ballekom, et al., 2018).

Previous work on agricultural posts has shown that:

- *E. globoidea* and *E. bosistoana* posts sawn from older NZ-grown trees performed well after 10 years in-ground (Millen & Altaner, 2017; Millen, Altaner, & Palmer, 2018)
- the value of posts available from an improved *E. bosistoana* tree considerably exceeds its growing costs (Altaner, 2020)
- a variety of machinery suitable for small to large scale operations is available to produce differently shaped wooden post (Altaner, 2020; Spinelli, Lombardini, Aminti, & Magagnotti, 2018).

Previous work on rotary peeling *E. globoidea*, *E. bosistoana* and *E. quadrangulata* has demonstrated that:

- quality veneers of high stiffness can be peeled from these species in a commercial setting (Altaner, Guo, & Millen, 2019; Guo & Altaner, 2018)
- usable veneer yields are related to end-splitting caused by growth stress (and independent of stiffness) (Guo & Altaner, 2018)
- growth stress can be reduced by breeding (Altaner, 2019; Davies, 2019)
- LVL gluing standards cannot be met with commercial radiata adhesive systems (Guo & Altaner, 2018), but overseas experience has shown that the necessary improvements are possible (Bruce, 2020; Kropat, 2018; Li, Belleville, Gutowski, Kuys, & Ozarska, 2018).

LVL (laminated veneer lumber) is a high-value product (\$800-1400/m^3) which could contribute to increased export earnings if producers had access to a suitable forest resource. LVL is a structural product and its price is coupled to mechanical performance (e.g. stiffness). Only the stiffest (best quality) radiata pine logs can be used in LVL production. However, LVL manufacturers struggle to source enough high stiffness logs and even those produce only an average grade commodity LVL product (11-12 GPa valued at \$800/m^3). *"The best NZ pine is not sufficiently stiff (only 11-12 GPa) to compete on world markets for long-span engineered wood products that require 16 GPa"* (Sheldon Drummond, CEO Juken; Murray Sturgeon, CEO Nelson Pine Industries).

A resource of durable eucalypts would offer two alternatives to the conventional rotary peeling process of *P. radiata*. Currently this is peeled with spindled lathes leaving a large (~80 mm diameter) low-value peeler core containing the corewood, which does not meet structural stiffness requirements. Firstly, the peeler cores resulting from peeling durable eucalypts with a conventional spindled lathe are ground-durable heartwood and could be sold as high-value posts for agricultural industries (Altaner, 2020). Secondly, the use of spindle-less lathes that are widely used for peeling eucalypts overseas could be introduced. These leave only small (~20 mm diameter) peeler cores thereby recovering additional veneer from the stiff corewood that meets standards for structural products (Arnold, Xie, Midgley, Lou, & Chen, 2013; McGavin, 2016). Both options have the potential to increase the profitability of rotary peeling durable eucalypts.

Objectives

The aim of this report was to model the value of *E. bosistoana* trees when used for rotary peeled veneer production.
An improved *E. bosistoana* tree was virtually divided into different products (structural veneer grades, peeler cores and fibre). The value of the tree was calculated from the volume of the individual products and their associated price. The tree value was then compared to the growing costs.

Confirming viability of wood processing for the new resource and manufacturing demonstration products will provide growers and processors with the necessary confidence to invest. The information will feed into the regional strategies and business cases for durable eucalypt investment.

The analysis included a sensitivity analysis for log characteristics, processing technology and product prices to enable the breeding program and wood processors to focus further development on the factors promising the largest gain. Variables considered were:

- tree size (age)
- radial stiffness profiles
- volumetric shrinkage
- proportion of usable veneers (splitting due to growth stresses)
- roundup loss due to sweep and eccentricity
- veneer values
- peeler core size (processing technology)
- agricultural posts and their quality.

First, the mean and standard deviations of the tested parameters were reviewed. Then best and worst case scenarios were compared to a standard scenario to judge the importance of individual variables. Tree values were then put in context to stumpages, reflecting the growing costs (including a profit for the grower) (Millen et al., 2019). Finally, the size of plantation estate to supply 10% of the domestic LVL production with *E. bosistoana* veneers was calculated for different silvicultural regimes.

METHODS

R (Team, 2020) was used for these simulations. First, a table was created, which described the wood value from pith to bark for 0.1 mm radial (r) increments, assuming a product value (based on the veneer grade or waste), shrinkage and yield.

$$\begin{aligned} &Value\ Increment(r)[NZD] \\ &\qquad = Volume\ Increment(r)[m^3] \\ &\qquad \times (Product\ Value(r) \times (1 - Vol.Shr.) \times Yield + (1 - Yield) \times Pulp\ Value)\left[\frac{NZD}{m^3}\right] \end{aligned}$$

The sum of these $Value\ Increments$ gave the $Value(r)$ of a cylindrical peeler bolt of that radius (r).

$$Value(r)\ [NZD] = \sum_{i=0}^{r} Value\ Increment(i)[NZD]$$

In the next step, the value of a tree $(Tree\ Value)$ was obtained by summing the value of the n individual logs, which can be cut from it.

$$Tree\ Value\ [NZD] = \sum_{i=0}^{n} Log\ value\ (i)[NZD]$$

For the simulations outlined here, 2.7 m long logs were virtually cut from an improved *E. bosistoana* tree based on an *E. nitens* taper function (for details see section *E. bosistoana* tree). Round-up loss was taken into account by reducing the small end diameter (SED) (for details see section Product yield). No value was associated with round-loss (including taper), waste logs, stumps and tops.

E. bosistoana tree

Using growth assessments measured in *E. bosistoana* permanent sample plots in Marlborough trials and an *E. nitens* taper function, the growth of an optimal virtual tree was modelled in YTGen (Millen et al., 2019). At yearly intervals, this virtual tree was cut into 2.7 m long (Figure 1). The log data (i.e. small end diameters) were then used to calculate the value of the tree as described above.
It is convenient to express the 'product' value of a tree depending on its size (e.g. diameter at breast height – DBH) rather than its age. When that size will be reached is highly dependent on site productivity i.e. tree growth rate and therefore this impacts growing costs.

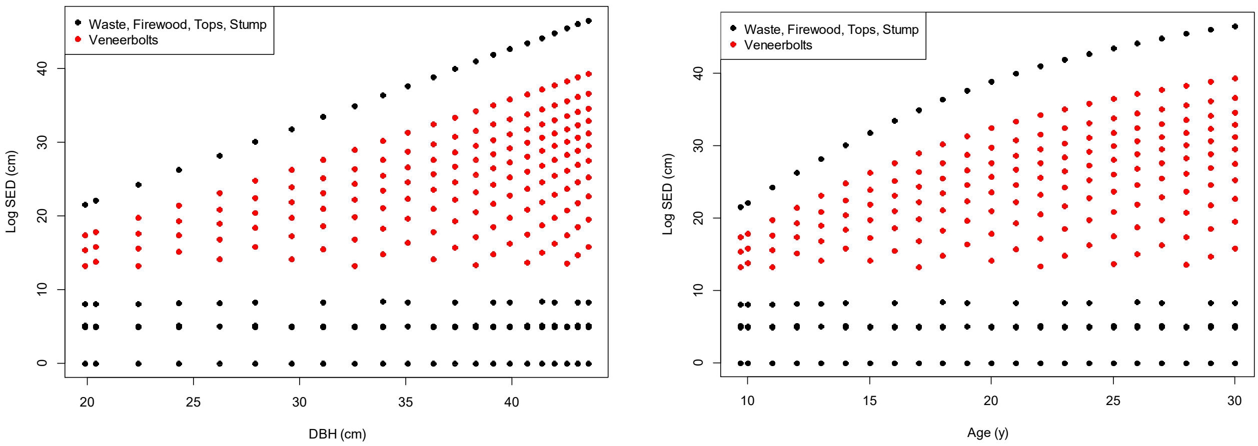

Figure 1: Distribution of 2.7 m long stem sections depending on their small end diameter (SED) under bark (red) in an improved *E. bosistoana* tree for different DBHs (left) and ages on a good site (right). Black: stem sections not suitable for rotary peeling. See Appendix 1.

Model variables

Modelled variables are summarised in Table 1.

Volumetric shrinkage

The radial and tangential shrinkage from green to air-dry of old-growth *E. bosistoana* is given as 3.9% and 8.2%, respectively (Bootle, 2005). Ignoring the negligible longitudinal shrinkage this would equate to approx. 12.1% volumetric shrinkage. A mean volumetric shrinkage from green to oven-dry of 20% with a standard deviation of 4% was reported for approx. 2-year old *E. bosistoana* (Davies, 2019). Adjusting this value to green to air-dry shrinkage by assuming a fibre saturation point of 30% and an air-dry moisture content of 10% (i.e. by multiplying with 2/3) gives a mean volumetric shrinkage of 13.3% with a standard deviation of 2.67%. The best and worst case scenarios were assumed to be one standard deviation around this mean (i.e. ~68.8% confidence interval), i.e. 10.7% and 16.0%, respectively.

MoE profile

Radial MoE profiles in the context of veneer production from plantation eucalypts have been reported (McGavin, Bailleres, Fehrmann, & Ozarska, 2015), but not for *E. bosistoana*.
The stiffness of old-growth *E. bosistoana* is given as 21 GPa (Bootle, 2005). The average dynamic MoE for *E. bosistoana* at age 2-years old was reported to be 11.2 GPa with a standard deviation of 1.9 GPa (Davies, 2019). Dynamic MoE have been reported to overstate static MoE values and a conversion factor of 0.868 was used by Guo and Altaner (2018) for *E. globoidea* veneer. Applying this correction factor the mean static MoE of *E. bosistoana* at age 2-years old would be 9.7 GPa with a standard deviation of 1.6 GPa. Assuming the same coefficient of variation at young and old age the standard deviation at old age would be 3.57 GPa. Best and worst case radial stiffness profile scenarios, being one standard deviation from the mean, were calculated using the following equation,

$$MoE\ (r)\ =\ MoE_{pith} + \left(MoE_{max} - MoE_{pith}\right) \times \tanh\frac{r}{100}$$

where r is the radius in mm, MoE_{pith} is the static MoE at the pith and MoE_{max} is the static MoE at old growth. The radial stiffness model of the standard *E. bosistoana* tree is shown in Figure 2. This MoE profile matches that deduced from rotary-peeled veneers from three trees of this species (Altaner et al., 2019).

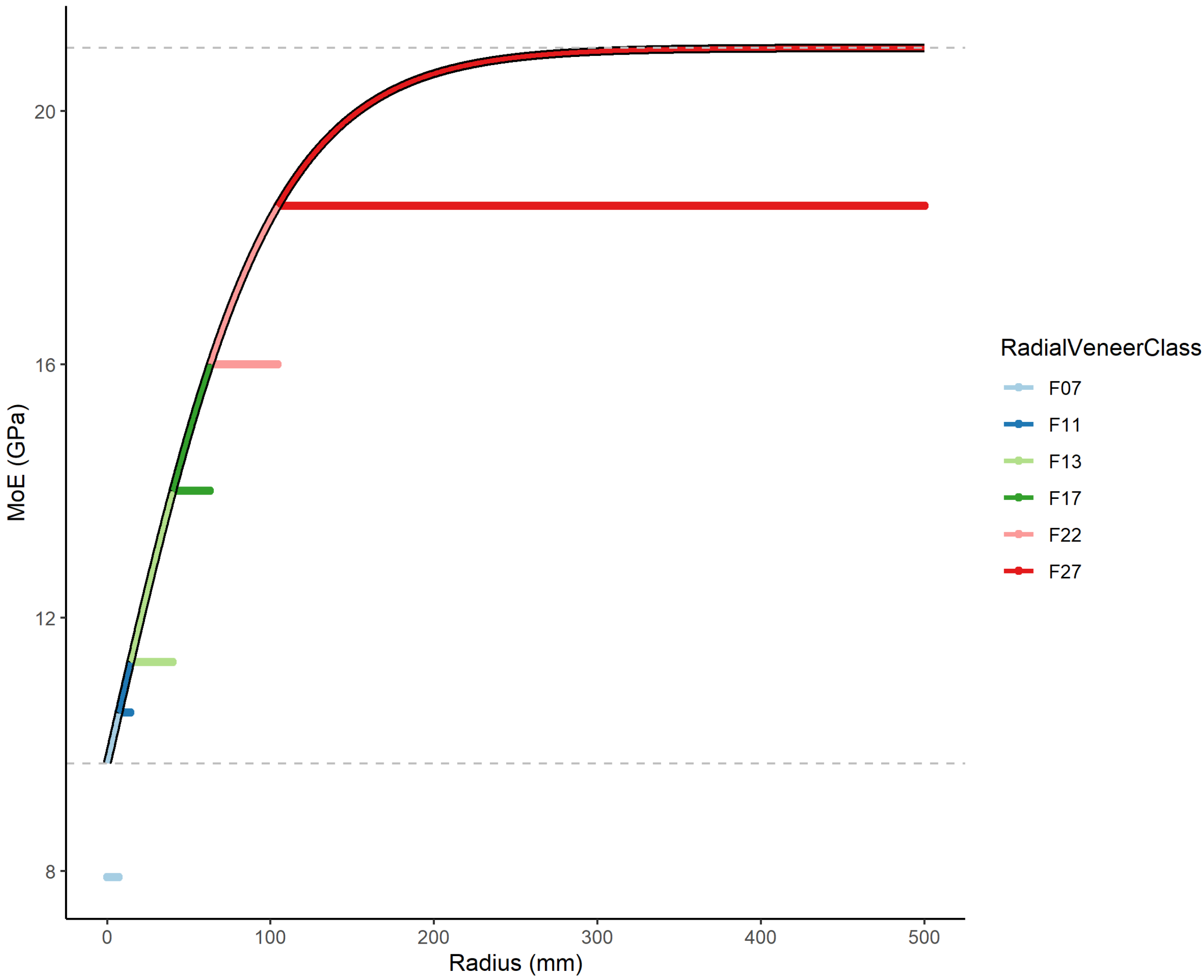

Figure 2: Estimated radial stiffness profile of a typical *E. bosistoana* log including the respective structural veneer grades. Maximum MoE and MoE at pith were indicated by dashed lines. Colours indicate the stiffness requirements for F grades according to NZS3603:1993 (Appendix 2).

Product yield and roundup loss

Log conversion rates can be defined in different ways. They generally give a ratio of log volume before processing to product volume. However, different definitions of log volume (e.g. stems, rounded peeler bolts) as well as product volume (e.g. green veneer, dried veneer, different baskets of products like peeler cores, veneer grades, LVL) are used. Therefore differences between reported conversion rates are not straightforward to interpret from the published data. In the case of rotary peeling veneers, log form, in particularly sweep but also taper and eccentricity are the main factors influencing theoretical veneer yield (Luo et al., 2013; McGavin, Bailleres, Lane, Blackburn, et al., 2014).

Factors like knots, growth stresses, gum pockets or radial stiffness profiles also affect veneer grades. The relative importance of these wood features on grade recovery was shown to differ between *Eucalyptus* species (McGavin, Bailleres, Lane, Fehrmann, & Ozarska, 2014). Processing technology also affects conversion rates for example by peeler core diameter, veneer roughness or drying defects (McGavin, Bailleres, Lane, Fehrmann, et al., 2014; McKenzie, Turner, & Shelbourne, 2003).

In the context of this study veneer yield was defined as the amount of usable green veneer peeled from the cylindrical peeler bolts, i.e. veneer, which is not split due to growth stresses or unusable due to any other defects. This excludes losses due to shrinkage, peeler cores (lathe technology) and roundup (log form). Shrinkage, peeler core size and roundup losses due to sweep/eccentricity were considered variables in this study. Stem taper was not considered.

Roundup loss

An average roundup loss of 4.6% was reported for *E. globoidea* logs with a mean small end diameter (SED) of 344 mm (Guo & Altaner, 2018). This would equate to an 8 mm reduction of the SED. Smaller diameter peeler logs from plantation-grown eucalypts were reported to have a sweep of ~10 mm with a coefficient of variation of ~50% (McGavin, Bailleres, Lane, Blackburn, et al., 2014). That study also showed that peeler bolt diameter can be accurately predicted from small end diameter under bark when corrected for sweep (McGavin, Bailleres, Lane, Blackburn, et al., 2014). Therefore as best and worst case scenario for roundup loss (i.e. sweep) one standard deviation either side of the mean was chosen (Table 1). No economic return was associated to the roundup loss in this work.

Usable veneer yield

An average yield of 50% usable veneer was chosen based on a eucalyptus peeling trial with a spindle-less (Arnold et al., 2013). For the worst and best case scenarios 25% and 75% were chosen to reflect the reported standard deviation of 25% of usable veneer from 26 *E. globoidea* logs (Guo & Altaner, 2018). It is worth noting that one *E. globoidea* log yielded 100% usable veneers, with the overall yield based on log volume being 75%.
An average of 60% (ranging between 40 and 65%) veneer recovery based on log volume was reported for 15-year old New Zealand-grown *E. nitens* peeled with a conventional lathe (McKenzie et al., 2003). Similar values were reported for smaller plantation-grown eucalypts in Australia using a spindle-less lathe (McGavin, Bailleres, Hamilton, et al., 2015; McGavin, Bailleres, Lane, Blackburn, et al., 2014). Unusable veneer was priced at fibre value.

Proportion of acceptable posts

A proportion of 75% of acceptable posts were chosen for the standard scenario with 95% and 55% as best and worst case scenario. The higher yields of usable posts compared to usable veneers was based on the experience with the few *E. bosistoana* and *E. quadrangulata* peeler cores from a peeling trial (Altaner et al., 2019). Unusable posts were priced at fibre value.

Peeler core size

Peeler core size depends on the lathe technology. Spindled (conventional) lathes leave a larger peeler core as the 'chucks' need to hold onto the sides of the peeler bolt (McGavin, 2016; McGavin, Leggate, Bailleres, Hopewell, & Fitzgerald, 2019). Additionally the forces applied by the 'chucks' to the log ends make it difficult to utilise logs with end-splitting.
The In New Zealand, *Pinus radiata* is peeled with spindled (conventional) lathes and the peeler cores contain the corewood, which is of low (non-structural) stiffness. These *P. radiata* peeler cores are used as lower value products such as firewood, wood fibre, or pallet bears.
Spindle-less lathes are not driven by chucks and able to peel to smaller peeler cores. Consequently more of a log can be converted into veneers (McGavin et al., 2019). Logs with end-splitting can also be peeled.
In respect to durable eucalypts like *E. bosistoana* the peeler core contain the naturally durable heartwood and could be sold as high-value naturally-durable posts for agricultural industries. Typical minimum dimeters for wooden post are 65 mm, 90 mm and 115 mm (Anonymous, 2016). Allowing for a radial shrinkage of 3.9% from green to air-dry (Bootle, 2005) such a product would require 68 mm, 94 mm and 120 mm peeler core diameters.

Product prices

Veneer prices for strength classes F5 to F13 were provided by Juken NZ in 2017. As a conservative standard scenario, no price premium for the higher structural veneer grades (F17 to F34) was assumed. However, such veneers should fetch a premium as they allow either

- to produce higher stiffness LVL which have a higher retail price or
- enable the utilisation of more low stiffness *P. radiata* veneers in a mixed radiata/eucalyptus product.

Price premiums for higher grades (F17 to F34) (Table 1) were linearly extrapolated from the available F5 to F13 prices (Figure 3). Comparable values were published for non-structural rotary peeled eucalyptus veneers on the Chinese market, which equated to 564, 471 and 423 NZD/m^3 for Grades 1, 2/3 and 4/5, respectively (Luo et al., 2013). An average export value for veneers of 323 NZD/m^3 over the past decade can be calculated from government figures (Rākau, 2018).

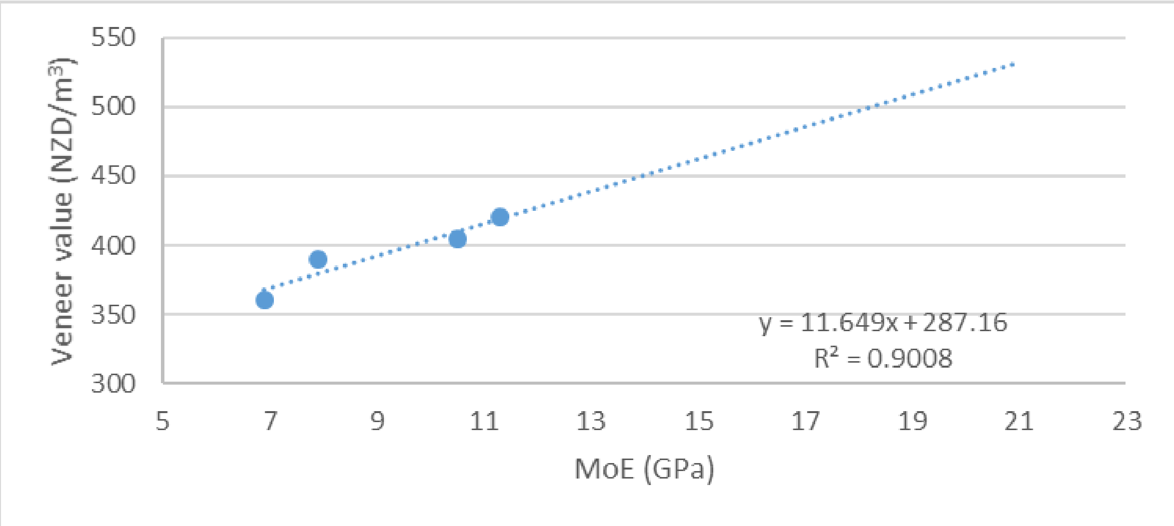

Figure 3: Veneer value depending on structural veneer grade.

The unusable veneer, 'firewood' logs as well as in some instants peeler cores were assigned a typical domestic pulp wood price of 55 NZD/m^3 (https://www.teururakau.govt.nz/news-and-resources/open-data-and-forecasting/forestry/wood-product-markets/historic-indicative-new-zealand-radiata-pine-log-prices/). No value was put on roundup losses, stumps and tree tops. The whole sale price of wooden posts (treated and untreated) has been reviewed in an earlier SWP report, giving average wholesale prices for naturally durable posts on the international market of 700 NZD/m^3 and for No. 3 CCA treated pine posts on the domestic market of 380 NZD/m^3. (Altaner, 2020).

A price of 190 €/m^3 was reported for *Castanea sativa* agricultural posts in the Italian market (Spinelli et al., 2018).

Table 1: Parameters of factors that were assessed for their influence on *E. bosistoana* tree value when used for rotary peeled veneer and naturally durable posts. Values of the reference scenario were highlighted in bold red.

Variable	Range	Reference
Volumetric shrinkage (%)		
Best	10.7	(Bootle, 2005; Davies, 2019)
Medium	**12.1**	
Worst	16.0	
MoE profile (GPa)		
Best	11.4 – 24.6	(Altaner et al., 2019; Bootle, 2005; Davies, 2019)
Medium	**9.7 – 21.0**	
Worst	8.1 – 17.4	
Proportion of usable veneer (%)		
Best	75	(Guo & Altaner, 2018; Luo et al., 2013)
Medium	**50**	
Worst	25	
Roundup loss (mm)		
Best	4	(Guo & Altaner, 2018; McGavin, Bailleres, Lane, Blackburn, et al., 2014)
Medium	**8**	
Worst	12	
Peeler core size (mm)		
Spindle-less lathe	20	(Arnold et al., 2013)
Spindled lathe	**82**	(Guo & Altaner, 2018)
No 3 post	68	(Anonymous, 2016; Guo & Altaner, 2018; Luo et al., 2013)
No 2 post	94	
No 1 post	120	
Proportion of usable posts (%)		
Best	95	(Altaner et al., 2019; Lambert & Severino, 2018)
Medium	**75**	
Worst	55	
Product prices (NZD/m^3)		
Round-up losses, waste log, stump and top	0	
Pulp/firewood log	55	
Non-durable peeler core	55	
Unusable veneer	55	(Luo et al., 2013)
Non-structural (<6.9 GPa)	55	
F5 veneer (6.9 – 7.9 GPa)	360	
F7 veneer (7.9 – 10.5 GPa)	390	
F11 veneer (10.5 – 11.3 GPa)	405	
F13 veneer (11.3 – 14.0 GPa)	420	
F17 veneer (14.0 – 16.0 GPa)	**420** / 450	
F22 veneer (16.0 – 18.5 GPa)	**420** / 474	
F27 veneer (18.5 – 21.5 GPa)	**420** / 503	
F34 veneer (>21.5 GPa)	**420** / 532	
Naturally durable post	**380** – 540 – 700	(Altaner, 2020; Spinelli et al., 2018)

RESULTS

Sensitivity analysis

The effect of wood features, processing parameters and product prices on the value of an *E. bosistoana* tree when used for rotary peeled structural veneers and potentially naturally ground-durable posts was tested. The results of this sensitivity analysis were summarised in Table 2. The effect of the individual variables depended on the size of the tree.

Table 2: Sensitivity analysis for individual factors affecting the value of an *E. bosistoana* tree at DBH 20 and 44 cm when used for rotary peeling. Relevant variables were highlighted in bold and coloured yellow to red colour.

Variable	**Difference in tree value between worst and best case**	
	DBH 20 cm	DBH 44 cm
Volumetric shrinkage 10.7%; 16.0% (±1 std)	5%	6%
MoE profile 8.1–17.4 GPa; 11.4–24.6 GPa (±1 std)	0%	0%
Roundup loss 4 mm; 12 mm (±1 std)	**27%**	**12%**
Usable veneer yield 25%; 75% (±1 std)	**60%**	**74%**
Peeler core diameter Conventional (82 mm); spindle-less lathe (20 mm)	**30%**	7%
Posts Pulp wood (55 NZD/m^3); No 1 post (380 NZD/m^3)	**55%**	**12%**
Post price (No 3 post) (380 NZD/m^3); (700 NZD/m^3)	**29%**	6%
Proportion of acceptable No 3 posts 55%; 95%	**16%**	3%
Price premium for higher structural veneer grades No Premium; Premium (Table 1)	6%	**14%**

For larger trees (DBH 44 cm) the dominating factor was usable veneer yield, which differed by 74% between the worst and best case scenario (i.e. one standard deviation either side of the mean). Usable veneer yield is largely controlled by veneer splitting, a consequence of growth-strain. Roundup loss, a consequence of stem form factors such as sweep and eccentricity, would amount to a tree value difference of 12% between the worst and best scenario (i.e. one standard deviation either side of the mean). Price premiums for structural veneer grades (>F13) and marketing peeler cores as ground-durable posts could add 12 to 14% to the value of an *E. bosistoana* tree.

For smaller trees (DBH 20 cm), which could be available in shorter rotations or from commercial thinning operations, tree value was sensitive to more parameters as veneers did not make up the majority of the recovered product (Figure 16). While usable veneer yield had a similar importance on tree value for small trees (60% difference between worst and best case scenario), roundup loss (stem form) (27%) and the proportion of acceptable posts (16%) had also noticeable effects. The analysis also showed that the alternative processing options of a) utilising peeler cores as ground-durable posts and b) using spindle-less lathes significantly lifted the value of the small trees by 55% and 30%, respectively. As ground-durable posts would comprise a larger proportion of the tree's value (Figure 16), tree value was also sensitive to post price (29%).

Volumetric shrinkage

While volumetric shrinkage is variable in *E. bosistoana* with a coefficient of variation (CV) of 20% (Davies, 2019), it had one of the smaller effects on tree value with only a difference of ~5% (Table 2) between one standard deviation either side of the mean (Figure 4).
The NZDFI *E. bosistoana* breeding population has been assessed for volumetric shrinkage and could be selected for without additional experimental work. However, it should be kept in mind that gain in volumetric shrinkage would be at the cost of gains in other wood traits or narrowing of the genetic diversity (Davies, 2019). Further, no collapse has been observed in several thousand *E. bosistoana* stem cores and therefore, veneer can be assumed to be of homogeneous thickness after drying, facilitating gluing.

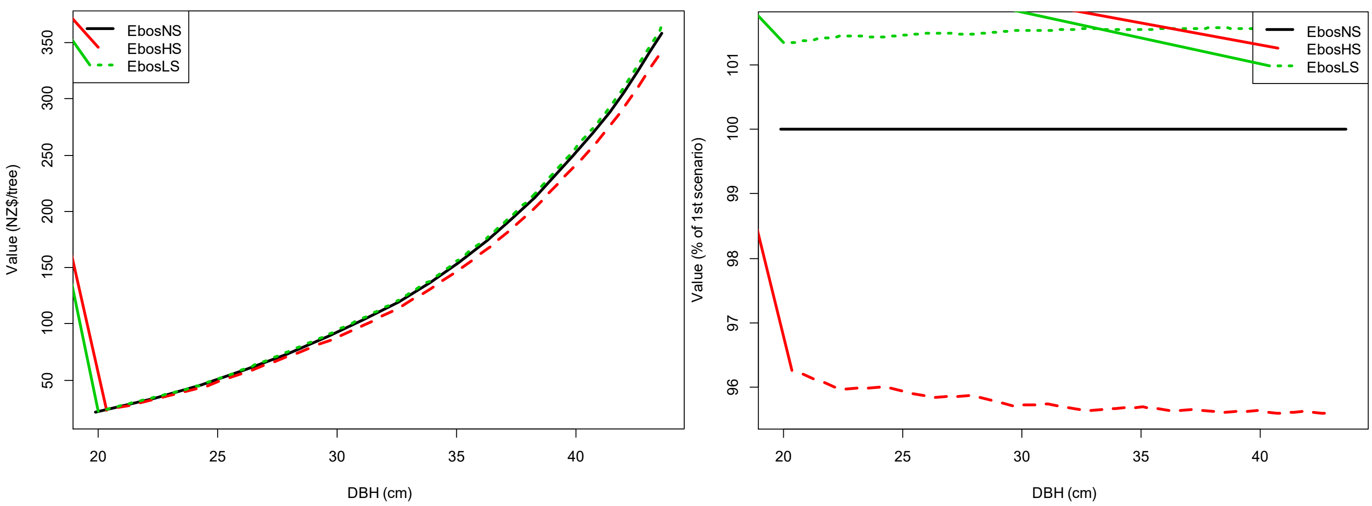

Figure 4: Effect of volumetric shrinkage on the value of an *E. bosistoana* tree when used for rotary peeling in the standard scenario (Table 1) depending on DBH (left). Relative change of tree value compared to the standard scenario for the worst and best case (± one standard deviation) depending on DBH (right). Volumetric shrinkage = 12.1% (NS), 16.0% (HS) and 10.7% (LS).

MoE

Without a price premium for structural veneers of higher grades currently traded in New Zealand (i.e. >F13), MoE variations did not affect the value of an *E. bosistoana* tree when used for rotary peeling with a conventional lathe (Table 2). This was because even at young age *E. bosistoana* had high stiffness exceeding F13 requirements (Figure 2). This was different for a species with less stiff corewood like *P. radiata* that under current prices, yields veneer that is 3 to 7% less valuable (Figure 5) and was shown to benefit from selection for high MoE (Ferguson, 2014). The effect of a price premium is discussed below.

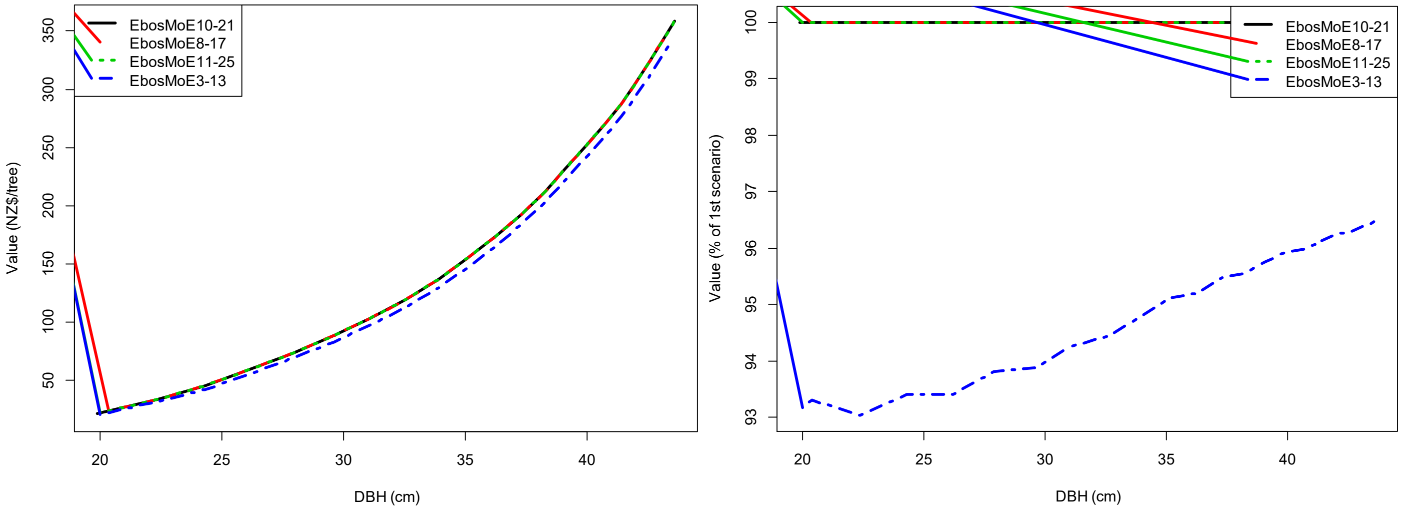

Figure 5: Effect of radial MoE profile on the value of an *E. bosistoana* tree when used for rotary peeling in the standard scenario (Table 1) depending on DBH (left). Relative change of tree value compared to the standard scenario for the worst and best case (± one standard deviation) depending on DBH (right). Effect of radial MoE profile from pith to maximum 9.7-21.0 GPa (MoE10-21); 8.1-17.4 (MoE8-17) and 11.4-24.6 GPa (MoE11-25) as well as a radial MoE profile typical for *P. radiata* 3.0-13.0 GPa (MoE3-13).

Roundup loss (sweep)

Reasonable increases in tree value, ranging from 27 to 12 % depending on tree diameter, could be obtained by improving stem straightness (Table 2, Figure 6). Roundup losses are largely controlled by sweep with eccentricity also being a factor (McGavin, Bailleres, Lane, Blackburn, et al., 2014).

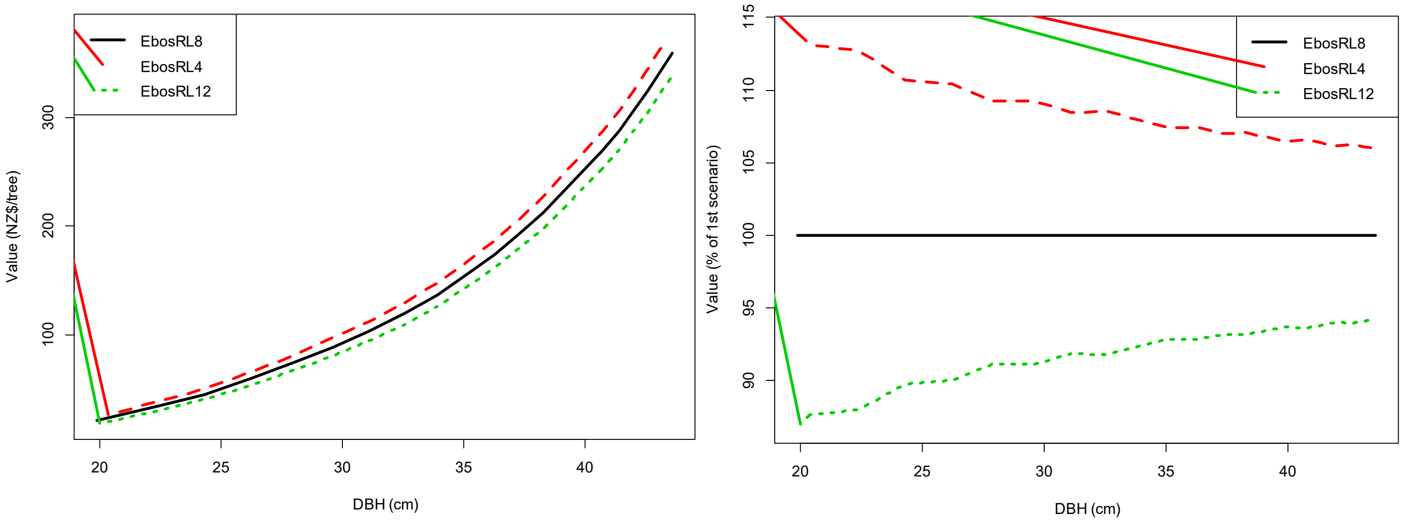

Figure 6: Effect of roundup loss (sweep) on the value of an *E. bosistoana* tree when used for rotary peeling in the standard scenario (Table 1) depending on DBH (left). Relative change of tree value compared to the standard scenario for the worst and best case (± one standard deviation) depending on DBH (right). Roundup loss (decrease in peeler bolt diameter) 8 mm (RL8), 4 mm (RL4) and 12 mm (RL12).

Usable veneer yield

Tree value was significantly impacted by usable veneer yield as veneer quality was reported to be highly variable. For eucalypts, veneer quality is generally due to veneer splitting caused by the release of growth stresses (Guo & Altaner, 2018; Luo et al., 2013; McKenzie et al., 2003).. The difference in tree value, between the usable veneer yields ±1 standard deviation off the mean, ranged between 60% and 74% depending on tree diameter (Figure 7; Table 2). Consequently, reducing veneer splitting (via reducing growth strain) should be a priority in eucalyptus breeding programme. Such technology exists (Chauhan & Entwistle, 2010) and has been applied to NZDFI breeding populations (Altaner, 2019) including *E. bosistoana* (Davies, 2019). It is worth noting that other wood features like knots and kino pockets (McGavin, Bailleres, Lane, Fehrmann, et al., 2014) also contribute to veneer downgrades and should be considered for the species.

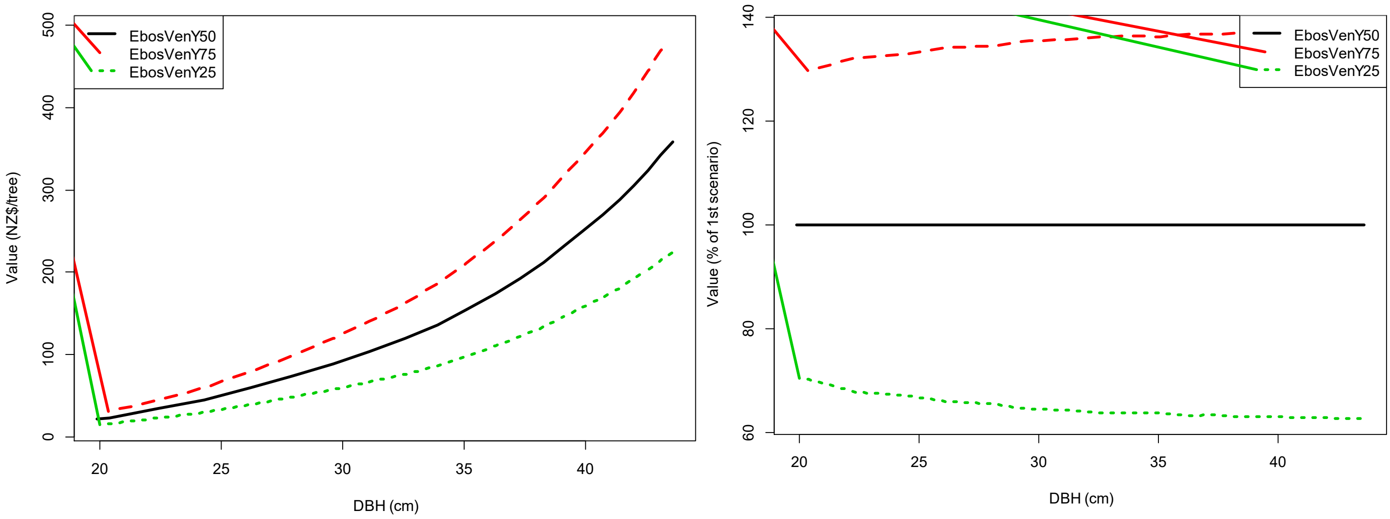

Figure 7: Effect of usable veneer yield on the value of an *E. bosistoana* tree when used for rotary peeling under the standard scenario (Table 1) depending on DBH (left). Relative change of tree value compared to the standard scenario for worst and best case (± one standard deviation) depending on DBH (right). Usable veneer yield = 50% (Y50), 75% (Y75) and 25% (Y25).

Lathe technology

Reducing peeler core size by making use of spindle-less lathe technology (Arnold et al., 2013; McGavin et al., 2019) improves the value of an *E. bosistoana* tree by 7 to 30% depending on its size (Table 2). The benefit of employing spindle-less lathe technology is larger for small diameter logs. However, for durable species, increasing veneer yield from the peeler core would cancel out the economic benefit of producing ground-durable posts and therefore might only offer value for higher stiffness nondurable species like *E. nitens*.
This is different to low stiffness species like *P. radiata*, where increasing veneer yield from close to the pith has no effect on the value of the tree as the additionally recovered veneer fails to meet a structural grade (Figure 8).

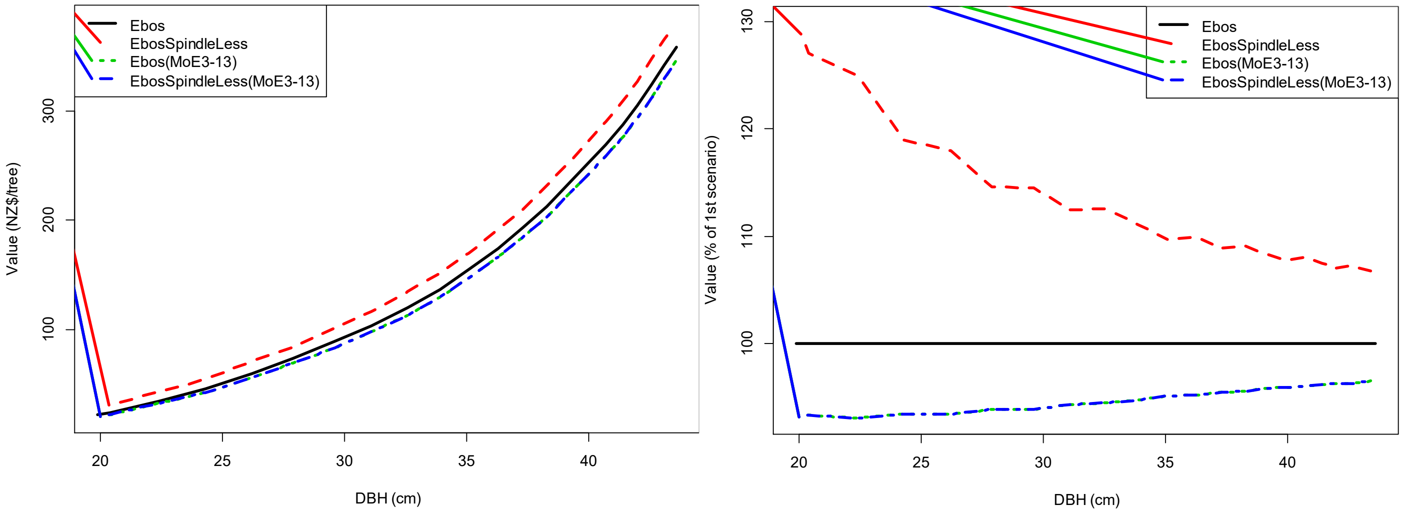

Figure 8: Effect of lathe technology (peeler core size) on the value of an *E. bosistoana* tree when used for rotary peeling in the standard scenario (Table 1) depending on DBH (left). Relative change of tree value compared to the standard scenario for different processing options depending on DBH (right). Peeler core diameter = 82 mm (standard scenario), 20 mm (Spindle less). Note: a radial MoE profile typical for *P. radiata* 3.0-13.0 GPa (MoE3-13) has been included.

Naturally ground-durable posts

The option of selling peeler cores as ground-durable posts rather than wood fibre improved the value of an *E. bosistoana* by 91 to 55% depending on tree size (Table 2) and post size (Figure 9). The proportional benefit is smaller for larger trees. The effect of post size can mainly be attributed to the fact that different yields for posts (75% of peeler cores sellable as posts) and veneers (50% usable veneer) were used in this simulation. As the structural veneer prices (360-420 NZD/m^3) and the standard post price (380 NZD/m^3) were comparable in the base scenario, the effect of adding the post product was comparable to that of the peeler core diameter (lathe technology) if the reject rates of posts and veneers were similar.

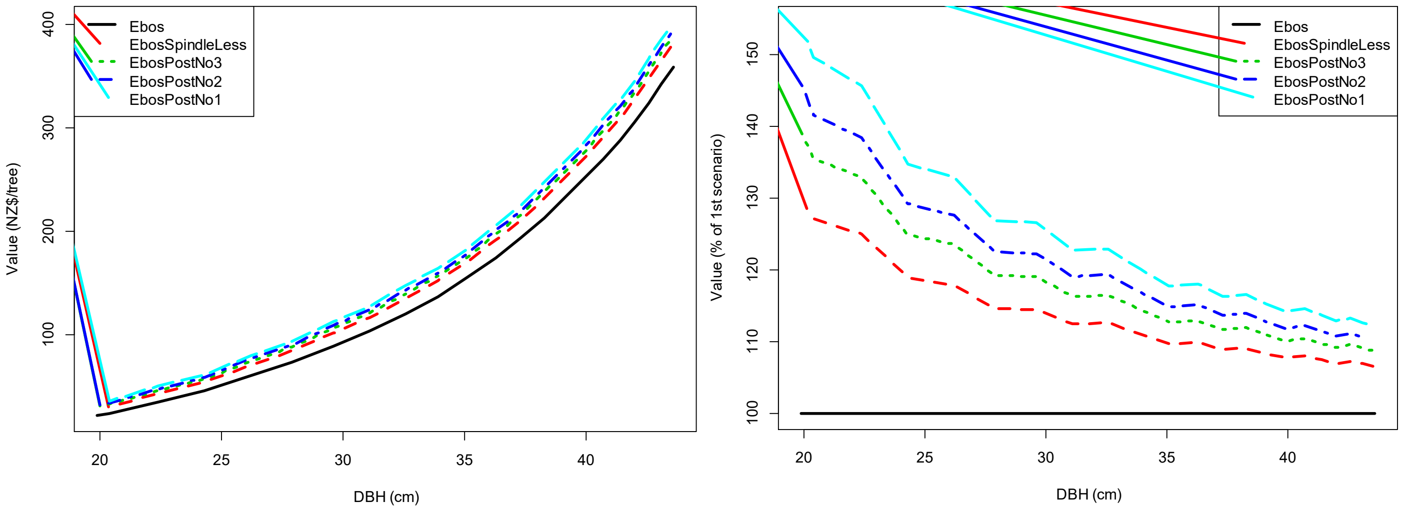

Figure 9: Effect of post products (380 NZD/m^3) from peeler cores on the value of an *E. bosistoana* tree when used for rotary peeling in the standard scenario (Table 1) depending on DBH (left). Relative change of tree value compared to the standard scenario depending on DBH (right). Peeler core diameter = 82 mm (standard scenario), 20 mm (SpindleLess), 68 mm (PostNo3), 94 mm (PostNo2) and 120 mm (PostNo1).

The effect of post quality, i.e. the proportion of acceptable posts, changed the value of the *E. bosistoana* tree by 3 to 16% between the worst (55% acceptable posts) and best (95% acceptable posts) scenario depending on tree size (Table 2). This was an increase of 7 to 47% compared to the base scenario which did not consider additional value from agricultural posts (Figure 10). Boxed-heart square posts sawn from 9- to 16-year old eucalyptus plantation thinnings were reported to have reject rates of more than 60% due to splitting and distorted faces, and reject rates varied between species and drying methods (Lambert & Severino, 2018). First indications are that round posts (peeler cores) of *E. bosistoana* (Altaner et al., 2019) are not suffering these issues (Figure 11), but this should be verified. Other factors in whether *E. bosistoana* peeler cores will be accepted in the market as posts is their use and performance, and whether they can be installed with current fencing machinery. Some contractors using post rammers have reported splitting of dense wooden posts on impact, which might be facilitated by end splits.

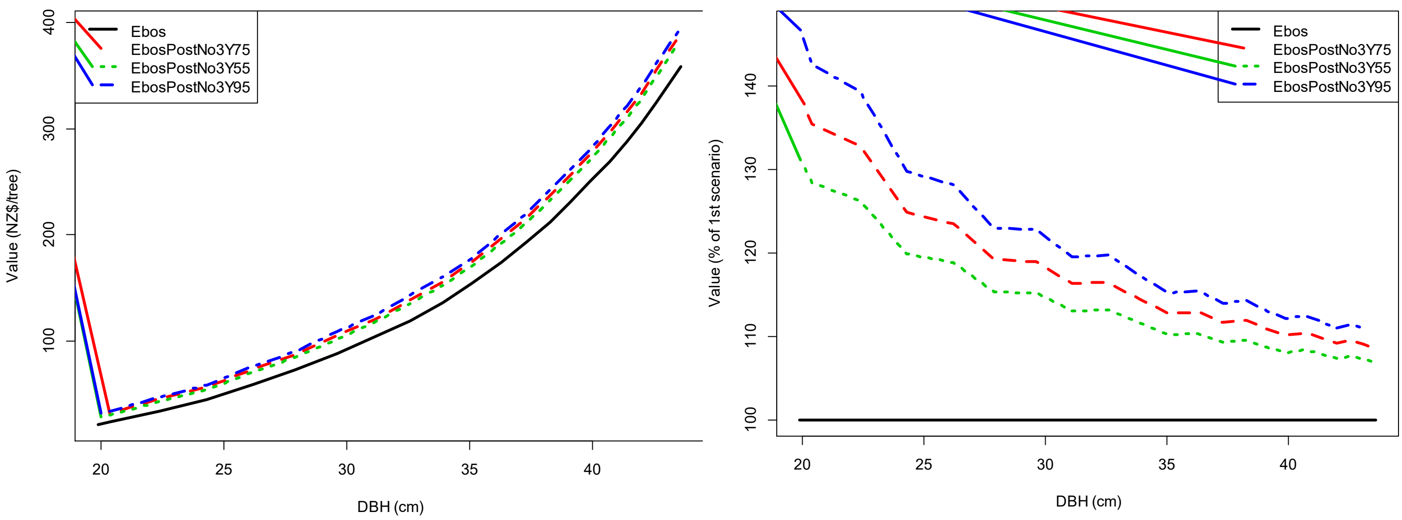

Figure 10: Effect of proportion of acceptable No 3 posts on the value of an *E. bosistoana* tree when used for rotary peeling in the standard scenario (Table 1) depending on DBH (left). Relative change of tree value compared to the standard scenario depending on DBH (right). Proportion of acceptable posts = 0% (standard scenario - Ebos); 75% (Y75); 55% (Y55) and 95% (Y95).

Figure 11: Dried peeler cores from an *E. bosistoana* and *E. quadrangulata* peeling trial (Altaner et al., 2019). While there was some splitting (the cores have been rotated by 180° around their axis between the left and right picture), the cores were straight and appear usable as agricultural post.

A range of wholesale prices for naturally durable posts were reported (Altaner, 2020; Spinelli et al., 2018). Increasing the conservative assumption from 380 to 700 NZD/m^3 increased the value of an *E. bosistoana* tree by 6 to 29% depending on DBH (Table 2). This was 9 to 68% higher than the base scenario, in which peeler cores are valued at wood fibre price (Figure 12). If the proportion of acceptable posts could be increased from the assumed 75%, the value recovered from small trees could be doubled by marketing peeler cores as ground-durable posts for agricultural industries.

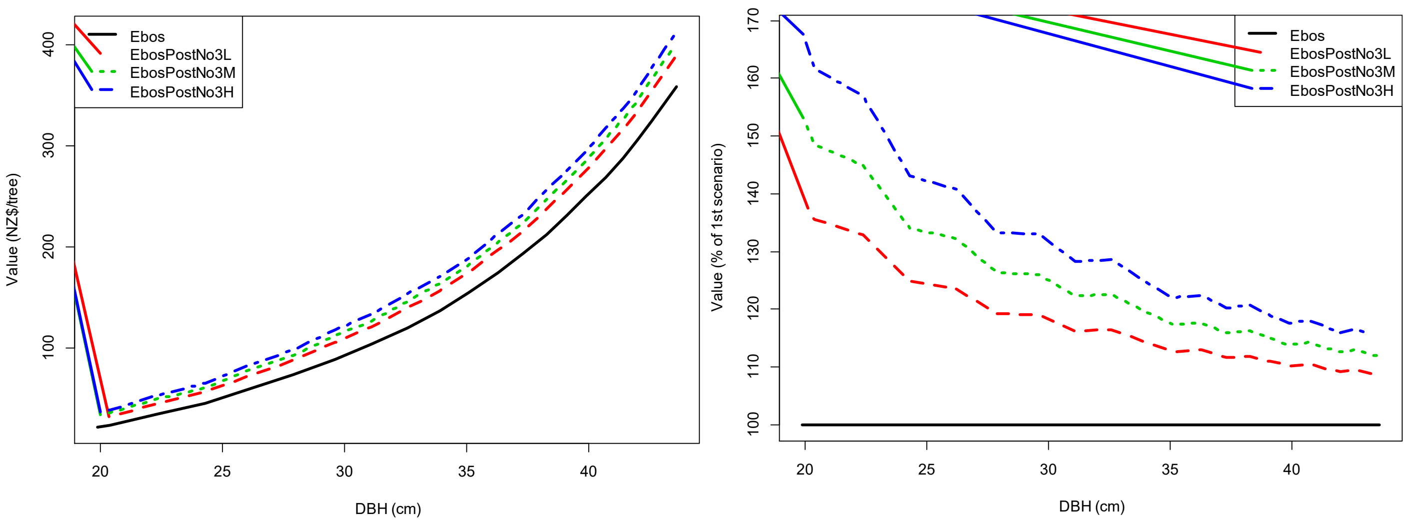

Figure 12: Effect of post price on the value of an *E. bosistoana* tree when used for rotary peeling in the standard scenario (Table 1) depending on DBH (left). Relative change of tree value compared to the standard scenario depending on DBH (right). Peeler core diameter = 82 mm (standard scenario) and 68 mm (No 3 posts); 380 NZD/m^3 (L), 540 NZD/m^3 (H) and 700 NZD/m^3 (H).

MoE premium for veneers exceeding F13

Under the base scenario, the value of an *E. bosistoana* tree increased by 6 to 14% if a price premium for veneers exceeding structural grade F13, which are currently not traded on the domestic market, can be realised (Table 2). Then the radial stiffness profile of *E. bosistoana* would also become relevant, while it was not under the current situation (Figure 5). In contrast, a price premium would not benefit a low stiffness species like *P. radiata* (Figure 13).

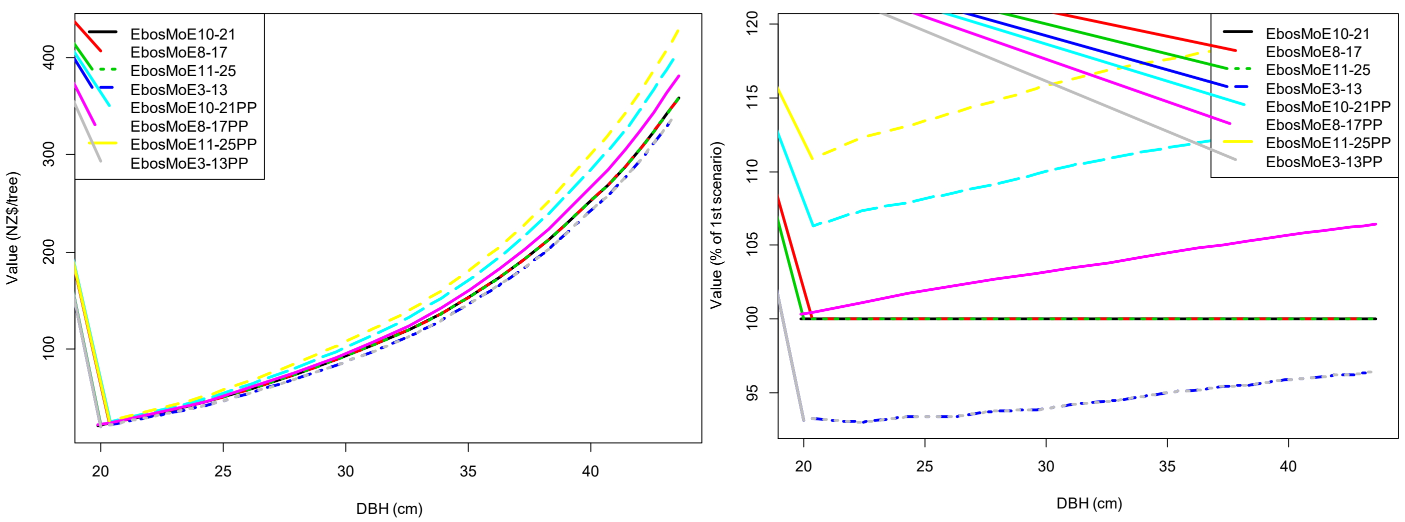

Figure 13: Effect of veneer price on the value of an *E. bosistoana* tree when used for rotary peeling in the standard scenario and different radial MoE profiles (Table 1) depending on DBH (left). Relative change of tree value compared to the standard scenario depending on DBH (right). PP: linear price premium for structural grades F17 to F34; MoE: MoE at pith - maximum MoE.

Value of *E. bosistoana* for LVL producers and growers

Log properties and product price scenarios

The combined effects of the modelled log parameters on the value of an *E. bosistoana* tree were summarised in Figure 14, while the summarised effects of product prices were summarised in Figure 15. Given the scope of parameters considered, log features affected tree value more than a price premiums for posts and higher stiffness veneers.
If tree form and wood properties could be improved by one standard deviation of the mean, the value of the *E. bosistoana* tree would increase by 51 to 65% depending on tree size in a scenario which utilises peeler cores as agricultural posts (Figure 14). In that case the tree value was 59 to 104% higher compared to the standard scenario, where peeler cores were accounted for at wood fibre price. Targeting veneers rather than agricultural posts with a spindle-less lathe was delivered comparable results for tree values when using the same log parameters (as agricultural post and veneers price were similar). It is worth noting that unfavourable log properties significantly reduced tree value, mainly due to the low yields (Table 2). Such a scenario has been indicated for species with high growth stresses like *E. fastigata* (Jones, Mcconnochie, Shelbourne, & Low, 2010; Sargent, Lee, & Gaunt, 2020).

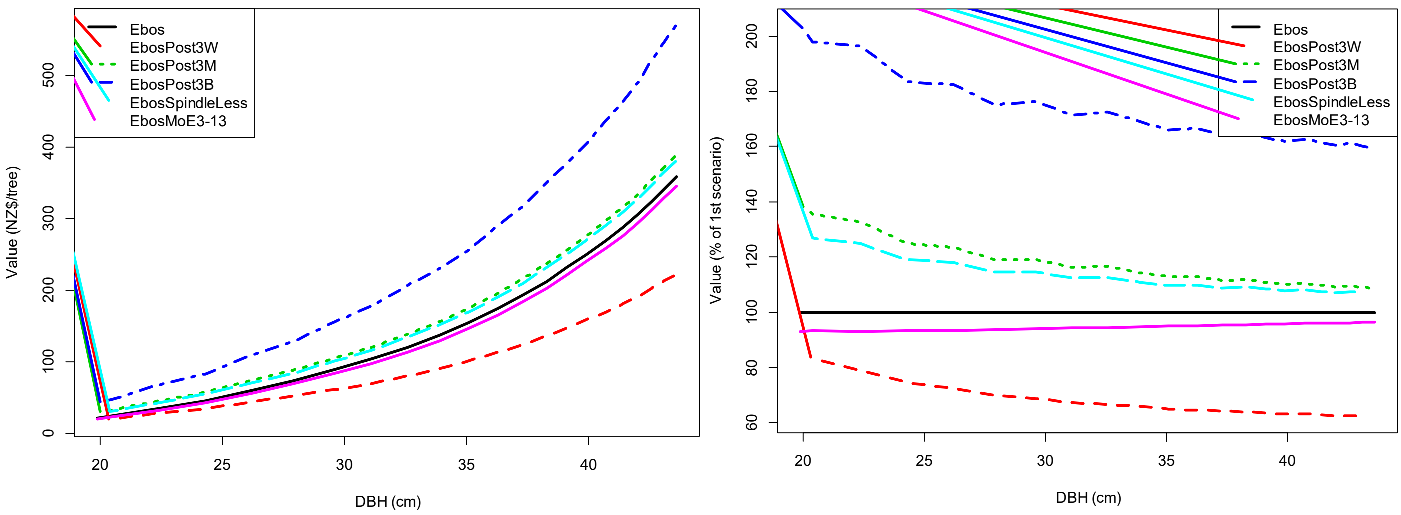

Figure 14: Combined effect of log properties on the value of an *E. bosistoana* tree when used for veneer peeling and agricultural posts depending on its DBH (left). Relative change of tree value compared to the standard scenario depending on DBH (right). Changes to the standard scenarios (EBos): Post3: peeler core diameter 68 mm, peeler core value: 380 NZD/m^3; W, M, B: worst, medium, best case for MoE, veneer yield, shrinkage, round up loss and post yield according to Table 1, respectively; SplindLess: peeler core diameter 20 mm; MoE3-13: MoE at pith - maximum MoE.

A price premium for stiffer veneer raised the value of an *E. bosistoana* tree when targeting veneers with a spindle-less lathe by 6 to 14% (Figure 15). This was 20 to 36% higher than the base scenario using a conventional spindled lathe. Using a spindle-less lathe did not add value to logs with a stiffness profile comparable low as *P. radiata*.

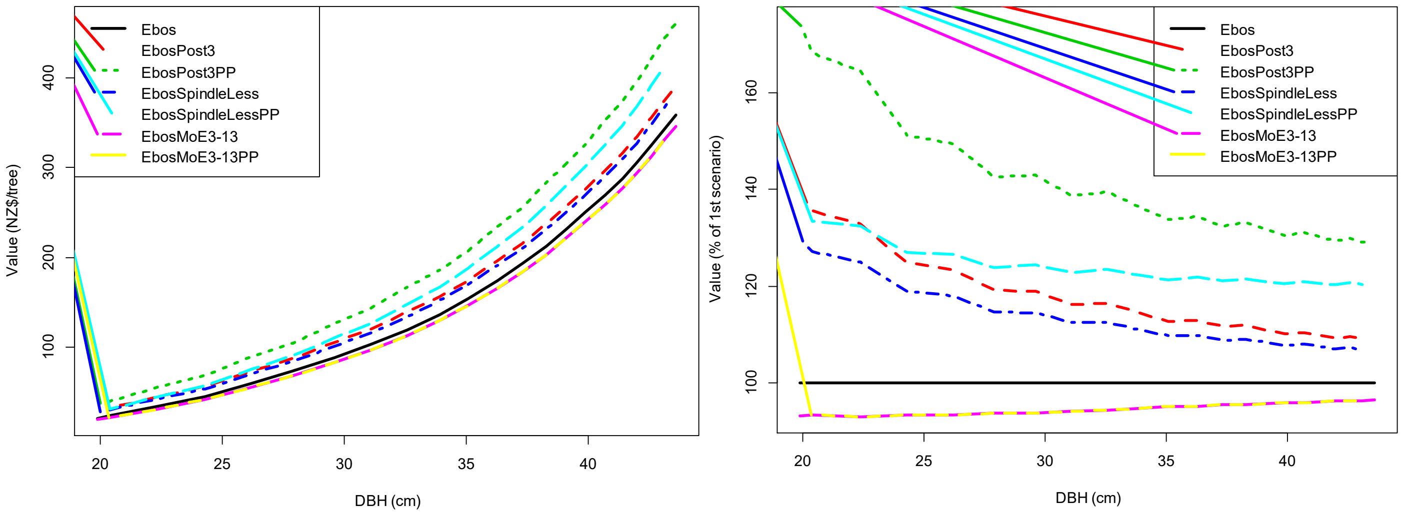

Figure 15: Combined effect of product prices on the value of an *E. bosistoana* tree when used for veneer peeling and agricultural posts depending on its DBH (left). Relative change of tree value compared to the standard scenario depending on DBH (right). Changes to the standard scenarios (EBos): Post3: peeler core diameter 68 mm; SplindLess: peeler core diameter 20 mm; MoE3-13: MoE at pith - maximum MoE; PP: price premium for higher structural veneer grades and in the case of Post3 the highest post value (Table 1).

Tree value

The value of an average *E. bosistoana* tree when used for rotary peeling with a conventional spindled lathe increased from 21 to 359 NZD from 20 to 44 cm DBH when peeled with a conventional lathe. Marketing the peeler cores as ground-durable posts for agricultural industries would increase the value of the same trees to 30 to 390 NZD. Comparable values (28 to 382 NZD) can be obtained when peeling these trees with a spindle-less lathe. Improving log characteristics by one standard deviation and obtaining price premiums for the stiff and durable products would lift the tree value to 57 to 717 NZD depending on DBH. This would increase tree value by 100 to 163% depending on DBH.

Growing costs of *E. bosistoana* have been estimated based on a harvest of 600 stems per hectare under a 15 year rotation (Millen et al., 2019). A 30 cm DBH tree would need to fetch a stumpage value of 21 to 56 NZD (depending on site productivity and government subsidies) in order to yield the grower an internal rate of return (IRR) of 8%. Growing costs compared favourably to the value of structural veneer and ground-durable posts obtainable from such a tree, which were valued between 103 to 120 NZD under conservative price and log specification scenarios (Table 3). Improving log characteristics, realising price premiums or both increased the value of a 30 cm DBH *E. bosistoana* tree to 178, 144 or 223 NZD, respectively. The margins between the growing costs and product value need to cover harvesting and processing costs as well as the wood processor’s profit.
The estimated tree values were comparable to the 105 NZD for the same tree, considering only heartwood posts of varying dimensions (Altaner, 2020; Tian, 2019).

Table 3: Value of an *E. bosistoana* tree at DBH 30 cm for different product scenarios as well as growing costs (Millen et al., 2019).

	Growing costs incl. 8% IRR (NZD)	
E. bosistoana 30 cm DBH	21 – 56	
	Tree Value DBH 30 cm (NZD)	**Margin (NZD)**
Spindled lathe, veneers only	103	47 – 82
Spindled lathe, No. 3 post	120	64 – 99
Spindle-less lathe	116	60 – 95
Spindled lathe, No. 3 post, improved log	178	122 – 157
Spindled lathe, No. 3 post, price premium	144	88 – 123
Spindled lathe, No. 3 post, optimised log and price	223	167 – 202

Product mix

In smaller diameter logs, agricultural posts made up a quarter of the value of an *E. bosistoana* tree (Figure 16). While increasing in absolute amount the proportion of post value in larger diameter trees was smaller. For non-durable trees, where the peeler core can only be valued a wood fibre price, the majority of the value was in the veneers. It is also worth noting that even in small, i.e. young, trees the majority of veneers exceeded the currently domestically highest traded structural veneer grade F13. Only larger trees produced F13 veneers when a radial stiffness profile typical for *P. radiata* was used.

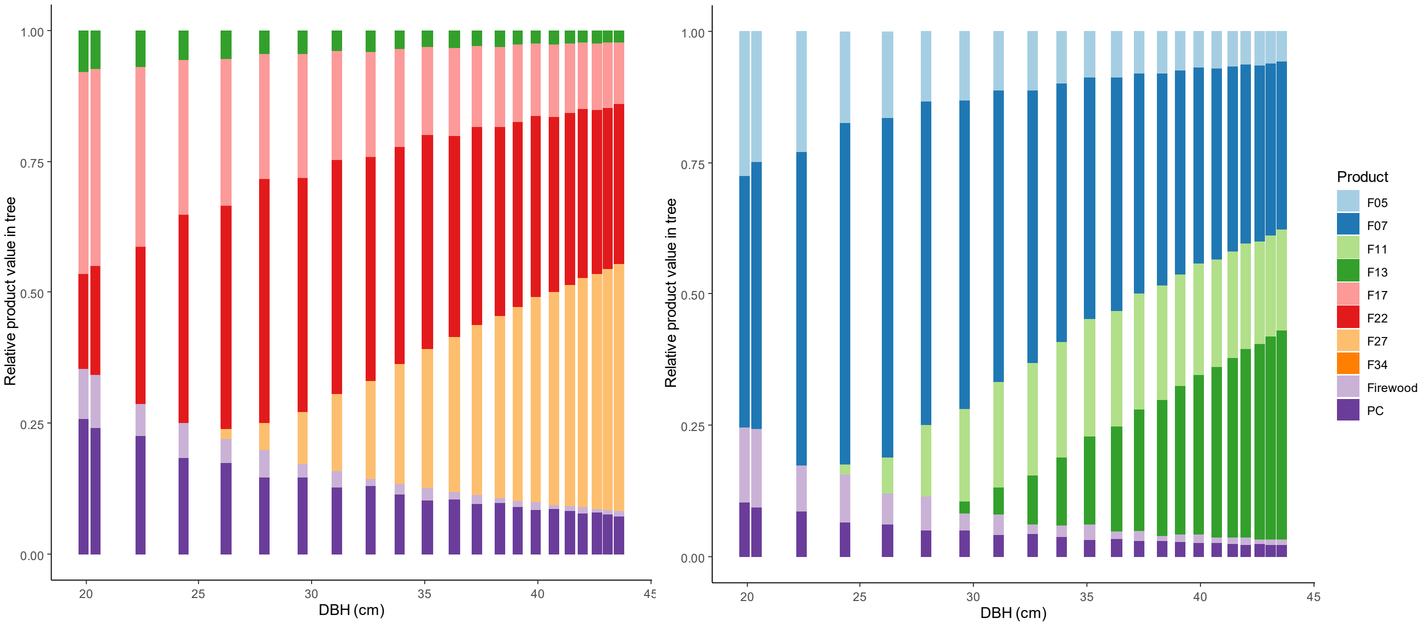

Figure 16: Relative value of individual products in a standard *E. bosistoana* (Table 1) tree when used for rotary peeling and utilising a 68 mm peeler core as No 3 agricultural post (left). No price premium for veneer grades higher than F13 were assumed. For comparison, the product mix of a tree with a radial stiffness profile similar to *P. radiata* (right) where the peeler core was valued at wood fibre price. Note the proportional value of Firewood was underrepresented as the data for this graph did not take into account the value of unusable veneer and posts.

Implementation – *E. bosistoana* based LVL products

The annual veneer production in New Zealand from *P. radiata* averaged around 600,000 m^3 over the last decade (Te Uru Rākau, 2018). From that around 200,000 m^3 LVL were produced, with the rest of the veneers used for plywood production or export. Over the last decade export values for veneers averaged 323 NZD/m^3 and for plywood (including LVL) averaged 1800 NZD/m^3 (Te UruRākau, 2018). Typical wholesale values for LVL ranged between 800 NZD/m^3 for low stiffness products (GPa 8) to 1400 NZD/m^3 for high stiffness (17 GPa) products.
An obstacle for marketing *P. radiata* based LVL is its typically lower stiffness, with domestic producers focusing on products with a MoE rating between 8 and 11 GPa. Internationally, LVL with a stiffness of up to 17 GPa is commercially available (Powney, 2014). The push for high-rise timber constructions creates an increasing demand for high stiffness engineered wood products (Buchanan, 2019; Kakitani, 2017).

The high stiffness veneers from *E. bosistoana* can benefit the existing domestic LVL industry in different aspects.

New products

- High stiffness (>17 GPa) LVL products that exceeding the stiffest currently internationally available LVL product, can be produced for the expanding large dimension timber construction market. These can be sold at a price premium, while log costs are not necessarily higher than those for *P. radiata*.
- A naturally durable LVL product could be developed, as consumers become increasingly conscious of wood preservatives.

Enhancing radiata pine products

- A significant proportion of the *P. radiata* veneers are not stiff enough for LVL production or only meet low stiffness grades. More of these lower stiffness veneers could be utilised for the production of a higher stiffness LVL product by mixing in *E. bosistoana* veneers. For example, LVL comprised half of *P. radiata* (8 GPa) and half of *E. bosistoana* (16 GPa) veneers will have 12 GPa. This will ensure the competitiveness of the industry by improving product quality (stiffness) or reducing production costs (by increasing the proportion of usable *P. radiata* veneers).

Shortening rotations

- As *E. bosistoana* has high stiffness corewood, structural veneers can be peeled from close to the pith with spindle-less lathes. This could allow the utilisation of smaller diameter logs, which can be obtained from young trees. As the species can coppice, a coppice regime that among other features has the benefit of protecting the soil from erosion after harvest, could also become an economic and sustainable silvicultural option.

New Zealand has an existing LVL industry with spare capacity. Therefore, no new capital expenditure would be needed to utilise *E. bosistoana* veneers in LVL products. Rather a commitment to planting an *E. bosistoana* forest resource is needed. *P. radiata* veneers could be increasingly substituted by *E. bosistoana* veneers, to either produce a medium range mixed species LVL product or a smaller volume of a high stiffness *E. bosistoana* LVL product. International markets for LVL up to 17 GPa exist and do not need to be developed (Powney, 2014). Timber engineers indicated the desire for LVL products exceeding 17 GPa, which are currently not available (Buchanan, 2019; Kakitani, 2017).

Substituting 10% of the current domestic LVL production with *E. bosistoana* veneers would require a plantation estate yielding 20,000 m^3 dry veneers annually. With 0.213 m^3 dry usable veneers obtainable from an *E. bosistoana* tree with a DBH of 30 cm peeled to a 68 mm core (No 3 post) under the standard scenario (Table 1), 94,000 such trees are need annually. On good sites *E. bosistoana* can be grown to 20 cm DBH within 10 years and to 30 cm DBH within 15 years at 600 stems per hectare (Millen, Altaner, & Palmer, 2020; Millen et al., 2019). Table 4 summarises the *E.*

bosistoana plantation estate required to sustainably supply 10% of the veneers consumed by the domestic LVL industry for three different silvicultural regimes.

- Short rotation post regime
  600 stems per hectare grown to 20 or 30 cm DBH (10 or 15 years on high productivity sites).
- Commercial thinnings
  Commercial thinning of peeler/sawlog regime at DBH 20 cm (10 years on high productivity sites) from 600 to 200 stems per hectare.

Depending on the silvicultural regime, an *E. bosistoana* plantation estate of 2,350 to 11,000 ha would be needed to sustainably supply 20,000 m^3 of dry usable veneers for LVL manufacturing (Table 4). This is approximately 10% of the domestic LVL production. The required 100,000 to 500,000 (Table 4) plants will be available, as the NZ Dryland Forests Initiative will start commercial production with 100,000 improved *E. bosistoana* plants being produced in 2021 with the support from Te Uru Rākau's One Billion Trees Partnership Fund.

Table 4: Forest area needed to sustainably supply 10% (i.e. 20,000 m^3) of the current domestic LVL production with *E. bosistoana* veneers from improved *E. bosistoana* trees on good sites. With a conventional lathe peeling to a 68 mm peeler core (i.e. No 3 post) under the base scenario (Table 1) 0.045 m^3 veneers are obtainable from a 20 cm DBH tree, increasing to 0.213 m^3 for a 30 cm DBH tree. Note, changing peeling technology or improving yields as discussed above will reduce the required plantation estate.

Log supply	Available trees / ha	Number of trees / year	Annual panting area (ha / year)	Sustainable plantation estate (ha) – good site
Post regime – clear-fell at 20 cm DBH	600	445,000	740	7,400
Post regime – clear-fell at 30 cm DBH	600	94,000	157	2,350
Peeler/saw log regime – commercial thinning (20 cm DBH)	400	445,000	1,110	11,100

The veneer yields from small diameter trees are low and therefore require larger plantation estates (and will have likely higher handling costs). However, additionally to the veneers, ground-durable posts are available from the peeler cores. Consequently, a smaller (younger) resource would suit a strategy prioritising naturally ground-durable posts for agricultural industries rather than veneers. A 20 cm DBH *E. bosistoana* tree (Figure 1) yields three 2.7 peeler logs and with a 75% yield of acceptable posts (Table 1) one million No 3 posts could be produced. That would reduce to 428,000 posts for 30 cm DBH trees, which yield six 2.7 m peeler logs each. Large trees yield more posts as they are taller and therefore yield more peeler logs.
A strong domestic demand for naturally durable timber posts has been reported, partly driven by the organic sector (Altaner, 2020; Millen, 2009; Millen, Altaner, et al., 2018; Orton & Evison, 2009). An international market also exists (Altaner, 2020; Spinelli et al., 2018).

CONCLUSION

A survey of published data provided average stem properties for *E. bosistoana* as well as their variation. This allowed to estimate the sensitivity of the value of an *E. bosistoana* tree when used for structural rotary veneer production to varying stem properties, typically defined as one standard deviation either side of the mean. Further, different processing strategies and product price scenarios were considered.

The analysis showed that the value of larger diameter trees was mainly affected by usable veneer yield (74%), i.e. the amount of end-splitting caused by growth strain. Marketing peeler cores as ground-durable posts, roundup loss (stem form) and a price premium for exceptionally stiff veneer were also worth noting (12-14%). Stiffness, volumetric shrinkage, post yield or lathe technology had only minor effects on the value of larger trees.

Veneer yield (60%) was also important for smaller diameter logs that could be available from commercial thinnings or short rotations. Roundup loss, i.e. stem form, was also more important (27%). Adding a ground-durable post product was beneficial (55%). As ground-durable posts comprised a larger proportion of the tree value, post yield and price were also significant (~30%). Alternatively, spindle-less lathes could add 30% value to the *E. bosistoana* trees compared to a conventional spindled lathe. This is not possible with *P. radiata* due to their non-durable and low stiffness core.

In summary, breeding should focus on increasing veneer yields from *E. bosistoana* by reducing end-splitting and improving stem form. Product prices had a smaller effect on tree value and therefore.

Tree value compared favourably to growing costs, with a margin of 47 to 202 NZD per tree (including an 8% IRR for the grower). The margin would need to cover harvesting and processing costs as well as the manufacturer's profit.

Veneers of *E. bosistoana* would exceed the currently available structural grades on the domestic (and also largely for international) market, enabling the design of competitive high stiffness LVL products that are also unique internationally. Alternatively, the veneers could be combined with more of the low stiffness *P. radiata* veneers to produce structural products of good quality.

The existing domestic LVL industry could make immediate use of *E. bosistoana* veneers and ensure a low entry barrier as no capital expenditure or resource consents are required. Markets for higher stiffness LVL products exist. Annual plantings of 150 to 750 ha would be required to produce enough *E. bosistoana* veneers to substitute 10% of the domestic LVL production in 10 to 15 years. The production of improved plants is now underway.

A strategy focusing ground-durable posts rather than veneers would favour shorter rotations.

Future work

- Data from commercial *P. radiata* veneer and LVL production can be used to validate this model.
- A peeling trial with *E. bosistoana* logs could confirm the assumptions made in this report and narrow the range of parameters considered in future economic assessments.
- Rather than modelling the value of an individual tree, a population of logs reflecting the variation in the resource can be used to generate a distribution of what could be expected in veneer grades. These could then be used with the SWP LVL stiffness calculator already developed (Gaunt, 2018).
- Veneer yields are influenced by log form (e.g. taper, sweep, eccentricity, knots) and wood features like growth strain (heart checking), spiral grain, collapse or kino/gum veins. A larger

peeling trial could inform the relative importance of these factors on veneer yield and grade. Such data would allow a breeding programme to focus on the most important of these traits.

- Economic weights for the individual traits could be developed for the *E. bosistoana* resource, informing the selection strategy of the breeding programme.
- The proportion of peeler cores that are acceptable as agricultural posts needs to be established as well as their ability to be installed with current fencing machinery.
- These simulations are broadly applicable to all NZDFI species, but can be made more precise by tailoring the input variables to the species.
- Obtaining more growing costs depending on DBH and site will allow optimising regimes for different products. It is conceivable that spindle-less lathes could be more profitable with smaller trees on shorter rotations. Coppice regimes should be considered.
- Processing and harvesting cost should be established for example within the WOODSCAPE model (Jack, Hall, A., & Barry, 2013).

ACKNOWLEDGEMENTS

Yuhui (David) Ma refined the model in his BForSci Honours thesis. JNL provided structural veneer prices and Meike Holzenkämpfer (UC) collated retail LVL prices. Paul Millen’s valuable feedback is included on the report.

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APPENDICES

Appendix 1: Log table for improved *E. bosistoana* tree depending on DBH (and age) according to Millen et al. (2019).

Age (y)	***Grade***	***Vol*** (m^3)	***Base*** (m)	***Length*** (m)	***SED*** (cm) uB	***LED*** (cm) uB	***Taper*** (cm/m)	***DBH*** (cm)
9.7	stump	0.008	0	0.2	21.5717	23.6649	10.47	19.9
9.7	top	0.002	15.0856	3.31	0	5	1.51	19.9
9.7	waste	0	15	0.09	5	5.13223	1.54	19.9
9.7	Firewood	0.007	13	2	5.13223	8.09931	1.48	19.9
9.7	Firewood	0.045	8.3	4.7	8.09931	13.3058	1.11	19.9
9.7	L130	0.044	5.6	2.7	13.3058	15.3612	0.76	19.9
9.7	L150	0.057	2.9	2.7	15.3612	17.4026	0.76	19.9
9.7	L150	0.076	0.2	2.7	17.4026	21.5717	1.54	19.9
10	stump	0.01	0	0.2	22.1351	24.2575	10.61	20.4
10	top	0	15.5337	3.31	0	5	1.51	20.4
10	waste	0	15.5	0.03	5	5.05218	1.55	20.4
10	Firewood	0.01	13.5	2	5.05218	8.04491	1.5	20.4
10	Firewood	0.05	8.3	5.2	8.04491	13.807	1.11	20.4
10	L130	0.05	5.6	2.7	13.807	15.8399	0.75	20.4
10	L150	0.06	2.9	2.7	15.8399	17.8934	0.76	20.4
10	L150	0.08	0.2	2.7	17.8934	22.1351	1.57	20.4
11	stump	0.01	0	0.2	24.2536	26.4849	11.16	22.4
11	top	0	17.1607	3.27	0	5	1.53	22.4
11	waste	0	17.1	0.06	5	5.09492	1.56	22.4
11	Firewood	0.01	15.1	2	5.09492	8.14824	1.53	22.4
11	Firewood	0.04	11	4.1	8.14824	13.2562	1.25	22.4
11	L130	0.04	8.3	2.7	13.2562	15.6419	0.88	22.4
11	L150	0.06	5.6	2.7	15.6419	17.6235	0.73	22.4
11	L150	0.07	2.9	2.7	17.6235	19.7338	0.78	22.4
11	L150	0.1	0.2	2.7	19.7338	24.2536	1.67	22.4
12	stump	0.01	0	0.2	26.2891	28.6211	11.66	24.3
12	top	0	18.6876	3.24	0	5	1.54	24.3
12	waste	0	18.6	0.09	5	5.13795	1.58	24.3
12	Firewood	0.01	16.6	2	5.13795	8.23943	1.55	24.3
12	Firewood	0.06	11	5.6	8.23943	15.1188	1.23	24.3
12	L150	0.06	8.3	2.7	15.1188	17.3671	0.83	24.3
12	L150	0.07	5.6	2.7	17.3671	19.3276	0.73	24.3
12	L150	0.09	2.9	2.7	19.3276	21.501	0.8	24.3
12	L200	0.11	0.2	2.7	21.501	26.2891	1.77	24.3
13	stump	0.01	0	0.2	28.2396	30.6656	12.13	26.2
13	top	0	20.1041	3.21	0	5	1.56	26.2
13	Firewood	0.01	18.1	2	5.00644	8.15473	1.57	26.2
13	Firewood	0.05	13.7	4.4	8.15473	14.126	1.36	26.2
13	L130	0.05	11	2.7	14.126	16.8331	1	26.2
13	L150	0.07	8.3	2.7	16.8331	18.9913	0.8	26.2
13	L150	0.08	5.6	2.7	18.9913	20.9515	0.73	26.2
13	L200	0.1	2.9	2.7	20.9515	23.1921	0.83	26.2
13	L200	0.13	0.2	2.7	23.1921	28.2396	1.87	26.2
14	stump	0.02	0	0.2	30.0911	32.6063	12.58	27.9
14	top	0	21.3806	3.17	0	5	1.58	27.9
14	waste	0	21.3	0.08	5	5.12889	1.6	27.9
14	Firewood	0.01	19.3	2	5.12889	8.31291	1.59	27.9
14	Firewood	0.07	13.7	5.6	8.31291	15.8289	1.34	27.9
14	L150	0.06	11	2.7	15.8289	18.4003	0.95	27.9
14	L150	0.08	8.3	2.7	18.4003	20.5059	0.78	27.9
14	L200	0.1	5.6	2.7	20.5059	22.4821	0.73	27.9
14	L200	0.12	2.9	2.7	22.4821	24.7935	0.86	27.9
14	L200	0.151605	0.2	2.7	24.79	30.0911	1.96	27.9
15	stump	0.017	0	0.2	31.8384	34.4431	13.02	29.6
15	top	0.002	22.4409	3.14	0	5	1.59	29.6
15	waste	0	22.4	0.04	5	5.06608	1.61	29.6
15	Firewood	0.048	16.4	6	5.06608	14.1629	1.52	29.6
15	L130	0.053	13.7	2.7	14.1629	17.3027	1.16	29.6
15	L150	0.073	11	2.7	17.3027	19.8004	0.93	29.6
15	L150	0.092	8.3	2.7	19.8004	21.8926	0.77	29.6
15	L200	0.111	5.6	2.7	21.8926	23.904	0.74	29.6
15	L200	0.133	2.9	2.7	23.904	26.2943	0.89	29.6
15	L250	0.17	0.2	2.7	26.2943	31.8384	2.05	29.6
16	stump	0.019	0	0.2	33.4755	36.1677	13.46	31.1
16	top	0.002	23.3279	3.11	0	5	1.61	31.1
16	waste	0	23.3	0.03	5	5.0455	1.63	31.1
16	Firewood	0.007	21.3	2	5.0455	8.32144	1.64	31.1

16	Firewood	0.058	16.4	4.9	8.32144	15.5377	1.47	31.1
16	L150	0.062	13.7	2.7	15.5377	18.6018	1.13	31.1
16	L150	0.084	11	2.7	18.6018	21.0636	0.91	31.1
16	L200	0.104	8.3	2.7	21.0636	23.1647	0.78	31.1
16	L200	0.124	5.6	2.7	23.1647	25.2217	0.76	31.1
16	L250	0.148	2.9	2.7	25.2217	27.6934	0.92	31.1
16	L250	0.188	0.2	2.7	27.6934	33.4755	2.14	31.1
17	stump	0.021	0	0.2	34.9984	37.7648	13.83	32.6
17	top	0.002	24.2249	3.08	0	5	1.62	32.6
17	waste	0	24.2	0.02	5	5.0409	1.64	32.6
17	Firewood	0.036	19.1	5.1	5.0409	13.2274	1.61	32.6
17	L130	0.049	16.4	2.7	13.2274	16.8772	1.35	32.6
17	L150	0.072	13.7	2.7	16.8772	19.8528	1.1	32.6
17	L150	0.095	11	2.7	19.8528	22.2695	0.9	32.6
17	L200	0.116	8.3	2.7	22.2695	24.3701	0.78	32.6
17	L200	0.137	5.6	2.7	24.3701	26.4617	0.77	32.6
17	L250	0.162	2.9	2.7	26.4617	29.0024	0.94	32.6
17	L250	0.206	0.2	2.7	29.0024	34.9984	2.22	32.6
18	stump	0.022	0	0.2	36.4072	39.2268	14.1	33.9
18	top	0.002	25.2648	3.06	0	5	1.63	33.9
18	waste	0	25.2	0.06	5	5.10654	1.65	33.9
18	Firewood	0.007	23.2	2	5.10654	8.42047	1.66	33.9
18	Firewood	0.045	19.1	4.1	8.42047	14.7972	1.56	33.9
18	L130	0.059	16.4	2.7	14.7972	18.2843	1.29	33.9
18	L150	0.083	13.7	2.7	18.2843	21.1272	1.05	33.9
18	L200	0.106	11	2.7	21.1272	23.4658	0.87	33.9
18	L200	0.127	8.3	2.7	23.4658	25.5397	0.77	33.9
18	L250	0.15	5.6	2.7	25.5397	27.6436	0.78	33.9
18	L250	0.177	2.9	2.7	27.6436	30.2316	0.96	33.9
18	L300	0.224	0.2	2.7	30.2316	36.4072	2.29	33.9
19	stump	0.024	0	0.2	37.7029	40.5584	14.28	35.1
19	top	0.002	26.4034	3.04	0	5	1.64	35.1
19	Firewood	0.007	24.4	2	5.00555	8.31046	1.65	35.1
19	Firewood	0.067	19.1	5.3	8.31046	16.4011	1.53	35.1
19	L150	0.07	16.4	2.7	16.4011	19.6914	1.22	35.1
19	L150	0.094	13.7	2.7	19.6914	22.3801	1	35.1
19	L200	0.118	11	2.7	22.3801	24.6243	0.83	35.1
19	L200	0.14	8.3	2.7	24.6243	26.6566	0.75	35.1
19	L250	0.163	5.6	2.7	26.6566	28.7576	0.78	35.1
19	L250	0.191	2.9	2.7	28.7576	31.3765	0.97	35.1
19	L300	0.24	0.2	2.7	31.3765	37.7029	2.34	35.1
20	stump	0.025	0	0.2	38.8916	41.7735	14.41	36.3
20	top	0.002	27.5386	3.02	0	5	1.65	36.3
20	waste	0	27.5	0.04	5	5.06316	1.63	36.3
20	Firewood	0.045	21.8	5.7	5.06316	14.2001	1.6	36.3
20	L130	0.055	19.1	2.7	14.2001	17.9078	1.37	36.3
20	L150	0.081	16.4	2.7	17.9078	21.006	1.15	36.3
20	L200	0.106	13.7	2.7	21.006	23.5496	0.94	36.3
20	L200	0.129	11	2.7	23.5496	25.7051	0.8	36.3
20	L250	0.151	8.3	2.7	25.7051	27.6962	0.74	36.3
20	L250	0.175	5.6	2.7	27.6962	29.7905	0.78	36.3
20	L250	0.204	2.9	2.7	29.7905	32.4331	0.98	36.3
20	L300	0.256	0.2	2.7	32.4331	38.8916	2.39	36.3
21	stump	0.027	0	0.2	39.9805	42.8824	14.51	37.3
21	top	0.002	28.6369	3	0	5	1.67	37.3
21	waste	0	28.6	0.04	5	5.06014	1.63	37.3
21	Firewood	0.007	26.6	2	5.06014	8.33922	1.64	37.3
21	Firewood	0.057	21.8	4.8	8.33922	15.7753	1.55	37.3
21	L150	0.066	19.1	2.7	15.7753	19.2872	1.3	37.3
21	L150	0.092	16.4	2.7	19.2872	22.2095	1.08	37.3
21	L200	0.117	13.7	2.7	22.2095	24.6243	0.89	37.3
21	L200	0.14	11	2.7	24.6243	26.7015	0.77	37.3
21	L250	0.163	8.3	2.7	26.7015	28.6554	0.72	37.3
21	L250	0.187	5.6	2.7	28.6554	30.7422	0.77	37.3
21	L300	0.217	2.9	2.7	30.7422	33.4045	0.99	37.3
21	L300	0.271	0.2	2.7	33.4045	39.9805	2.44	37.3
22	stump	0.028	0	0.2	40.9777	43.8941	14.58	38.3
22	top	0.002	29.6985	2.98	0	5	1.68	38.3
22	waste	0	29.6	0.1	5	5.16007	1.63	38.3
22	Firewood	0.037	24.5	5.1	5.16007	13.3495	1.61	38.3
22	L130	0.05	21.8	2.7	13.3495	17.2242	1.44	38.3
22	L150	0.076	19.1	2.7	17.2242	20.5494	1.23	38.3
22	L200	0.103	16.4	2.7	20.5494	23.3119	1.02	38.3
22	L200	0.127	13.7	2.7	23.3119	25.6122	0.85	38.3
22	L250	0.15	11	2.7	25.6122	27.6199	0.74	38.3
22	L250	0.173	8.3	2.7	27.6199	29.5399	0.71	38.3
22	L250	0.198	5.6	2.7	29.5399	31.6187	0.77	38.3
22	L300	0.229	2.9	2.7	31.6187	34.297	0.99	38.3

22	L300	0.286	0.2	2.7	34.297	40.9777	2.47	38.3
23	stump	0.029	0	0.2	41.8914	44.8176	14.63	39.1
23	top	0.002	30.7245	2.96	0	5	1.69	39.1
23	waste	0	30.7	0.02	5	5.03967	1.62	39.1
23	Firewood	0.007	28.7	2	5.03967	8.29248	1.63	39.1
23	Firewood	0.046	24.5	4.2	8.29248	14.8553	1.56	39.1
23	L130	0.06	21.8	2.7	14.8553	18.5554	1.37	39.1
23	L150	0.087	19.1	2.7	18.5554	21.7054	1.17	39.1
23	L200	0.113	16.4	2.7	21.7054	24.3233	0.97	39.1
23	L200	0.137	13.7	2.7	24.3233	26.5214	0.81	39.1
23	L250	0.161	11	2.7	26.5214	28.467	0.72	39.1
23	L250	0.183	8.3	2.7	28.467	30.3559	0.7	39.1
23	L300	0.209	5.6	2.7	30.3559	32.4263	0.77	39.1
23	L300	0.241	2.9	2.7	32.4263	35.1176	1	39.1
23	L300	0.299	0.2	2.7	35.1176	41.8914	2.51	39.1
24	stump	0.03	0	0.2	42.7299	45.662	14.66	39.9
24	top	0.002	31.7159	2.93	0	5	1.71	39.9
24	waste	0	31.7	0.02	5	5.02575	1.62	39.9
24	Firewood	0.007	29.7	2	5.02575	8.26655	1.62	39.9
24	Firewood	0.064	24.5	5.2	8.26655	16.2495	1.54	39.9
24	L150	0.069	21.8	2.7	16.2495	19.7783	1.31	39.9
24	L150	0.097	19.1	2.7	19.7783	22.7655	1.11	39.9
24	L200	0.123	16.4	2.7	22.7655	25.2527	0.92	39.9
24	L250	0.147	13.7	2.7	25.2527	27.3595	0.78	39.9
24	L250	0.17	11	2.7	27.3595	29.2493	0.7	39.9
24	L250	0.193	8.3	2.7	29.2493	31.1096	0.69	39.9
24	L300	0.219	5.6	2.7	31.1096	33.1712	0.76	39.9
24	L300	0.252	2.9	2.7	33.1712	35.873	1	39.9
24	L300	0.312	0.2	2.7	35.873	42.7299	2.54	39.9
25	stump	0.031	0	0.2	43.5002	46.435	14.67	40.7
25	top	0.002	32.6738	2.91	0	5	1.72	40.7
25	waste	0	32.6	0.07	5	5.11921	1.61	40.7
25	Firewood	0.04	27.2	5.4	5.11921	13.6822	1.59	40.7
25	L130	0.052	24.5	2.7	13.6822	17.5382	1.43	40.7
25	L150	0.079	21.8	2.7	17.5382	20.9022	1.25	40.7
25	L200	0.106	19.1	2.7	20.9022	23.7393	1.05	40.7
25	L200	0.132	16.4	2.7	23.7393	26.1084	0.88	40.7
25	L250	0.156	13.7	2.7	26.1084	28.1333	0.75	40.7
25	L250	0.179	11	2.7	28.1333	29.9727	0.68	40.7
25	L250	0.202	8.3	2.7	29.9727	31.8065	0.68	40.7
25	L300	0.228	5.6	2.7	31.8065	33.8591	0.76	40.7
25	L300	0.262	2.9	2.7	33.8591	36.5692	1	40.7
25	L300	0.323	0.2	2.7	36.5692	43.5002	2.57	40.7
26	stump	0.033	0	0.2	44.2096	47.1445	14.67	41.4
26	top	0.002	33.5992	2.88	0	5	1.74	41.4
26	waste	0	33.5	0.1	5	5.15995	1.61	41.4
26	Firewood	0.007	31.5	2	5.15995	8.37923	1.61	41.4
26	Firewood	0.048	27.2	4.3	8.37923	15.0222	1.54	41.4
26	L150	0.061	24.5	2.7	15.0222	18.7286	1.37	41.4
26	L150	0.088	21.8	2.7	18.7286	21.9362	1.19	41.4
26	L200	0.116	19.1	2.7	21.9362	24.6354	1	41.4
26	L200	0.141	16.4	2.7	24.6354	26.8978	0.84	41.4
26	L250	0.165	13.7	2.7	26.8978	28.849	0.72	41.4
26	L250	0.188	11	2.7	28.849	30.6428	0.66	41.4
26	L300	0.211	8.3	2.7	30.6428	32.4521	0.67	41.4
26	L300	0.237	5.6	2.7	32.4521	34.4956	0.76	41.4
26	L300	0.271	2.9	2.7	34.4956	37.2122	1.01	41.4
26	L300	0.334	0.2	2.7	37.2122	44.2096	2.59	41.4
27	stump	0.033	0	0.2	44.8644	47.7973	14.66	42
27	top	0.002	34.493	2.85	0	5	1.75	42
27	waste	0	34.4	0.09	5	5.14973	1.61	42
27	Firewood	0.007	32.4	2	5.14973	8.36013	1.61	42
27	Firewood	0.065	27.2	5.2	8.36013	16.2695	1.52	42
27	L150	0.07	24.5	2.7	16.2695	19.8284	1.32	42
27	L150	0.097	21.8	2.7	19.8284	22.8889	1.13	42
27	L200	0.124	19.1	2.7	22.8889	25.4618	0.95	42
27	L250	0.15	16.4	2.7	25.4618	27.6277	0.8	42
27	L250	0.173	13.7	2.7	27.6277	29.5124	0.7	42
27	L250	0.196	11	2.7	29.5124	31.2648	0.65	42
27	L300	0.219	8.3	2.7	31.2648	33.0512	0.66	42
27	L300	0.246	5.6	2.7	33.0512	35.0858	0.75	42
27	L300	0.28	2.9	2.7	35.0858	37.8073	1.01	42
27	L300	0.345	0.2	2.7	37.8073	44.8644	2.61	42
28	stump	0.034	0	0.2	45.4701	48.3993	14.65	42.6
28	top	0.002	35.356	2.82	0	5	1.77	42.6
28	waste	0	35.3	0.06	5	5.09017	1.61	42.6
28	Firewood	0.04	29.9	5.4	5.09017	13.5725	1.57	42.6
28	L130	0.051	27.2	2.7	13.5725	17.4291	1.43	42.6

28	L150	0.078	24.5	2.7	17.4291	20.8449	1.27	42.6
28	L200	0.106	21.8	2.7	20.8449	23.7681	1.08	42.6
28	L200	0.133	19.1	2.7	23.7681	26.2253	0.91	42.6
28	L250	0.158	16.4	2.7	26.2253	28.3039	0.77	42.6
28	L250	0.181	13.7	2.7	28.3039	30.1285	0.68	42.6
28	L300	0.204	11	2.7	30.1285	31.8431	0.64	42.6
28	L300	0.227	8.3	2.7	31.8431	33.6082	0.65	42.6
28	L300	0.254	5.6	2.7	33.6082	35.6339	0.75	42.6
28	L300	0.289	2.9	2.7	35.6339	38.3593	1.01	42.6
28	L300	0.355	0.2	2.7	38.3593	45.4701	2.63	42.6
29	stump	0.035	0	0.2	46.0319	48.9558	14.62	43.1
29	top	0.002	36.1892	2.79	0	5	1.79	43.1
29	waste	0	36.1	0.09	5	5.14366	1.61	43.1
29	Firewood	0.007	34.1	2	5.14366	8.33998	1.6	43.1
29	Firewood	0.046	29.9	4.2	8.33998	14.7761	1.53	43.1
29	L130	0.059	27.2	2.7	14.7761	18.5067	1.38	43.1
29	L150	0.087	24.5	2.7	18.5067	21.7853	1.21	43.1
29	L200	0.115	21.8	2.7	21.7853	24.5808	1.04	43.1
29	L200	0.141	19.1	2.7	24.5808	26.9324	0.87	43.1
29	L250	0.166	16.4	2.7	26.9324	28.9317	0.74	43.1
29	L250	0.189	13.7	2.7	28.9317	30.7017	0.66	43.1
29	L300	0.211	11	2.7	30.7017	32.3818	0.62	43.1
29	L300	0.234	8.3	2.7	32.3818	34.1271	0.65	43.1
29	L300	0.261	5.6	2.7	34.1271	36.1441	0.75	43.1
29	L300	0.297	2.9	2.7	36.1441	38.8724	1.01	43.1
29	L300	0.364	0.2	2.7	38.8724	46.0319	2.65	43.1
30	stump	0.036	0	0.2	46.554	49.4717	14.59	43.6
30	top	0.002	36.9935	2.77	0	5	1.81	43.6
30	waste	0	36.9	0.09	5	5.15062	1.61	43.6
30	Firewood	0.007	34.9	2	5.15062	8.3416	1.6	43.6
30	Firewood	0.06	29.9	5	8.3416	15.9026	1.51	43.6
30	L150	0.067	27.2	2.7	15.9026	19.5082	1.34	43.6
30	L150	0.095	24.5	2.7	19.5082	22.6565	1.17	43.6
30	L200	0.123	21.8	2.7	22.6565	25.3335	0.99	43.6
30	L250	0.149	19.1	2.7	25.3335	27.5884	0.84	43.6
30	L250	0.173	16.4	2.7	27.5884	29.5157	0.71	43.6
30	L250	0.196	13.7	2.7	29.5157	31.2361	0.64	43.6
30	L300	0.218	11	2.7	31.2361	32.8845	0.61	43.6
30	L300	0.241	8.3	2.7	32.8845	34.6114	0.64	43.6
30	L300	0.269	5.6	2.7	34.6114	36.6199	0.74	43.6
30	L300	0.305	2.9	2.7	36.6199	39.3504	1.01	43.6
30	L300	0.372	0.2	2.7	39.3504	46.554	2.67	43.6

Appendix 2: Stiffness requirements for F grades according to (NZS3603:1993).

F grade	Minimum MoE (GPa)
non-structural	0
F05	6.9
F07	7.9
F11	10.5
F13*	11.3
F17	14
F22	16
F27	18.5
F34	21.5

*NZS 3603 does not specify F13. F13 value was interpolated from F14 and F11 value.