Solid Timber Recovery and Economics of Short-rotation Small-diameter Eucalypt Forestry Using Novel Sawmilling Strategy Applied to *Eucalyptus regnans*

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Research Provider:
*Sustainable Forest Solutions  
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EXECUTIVE SUMMARY

Eucalypt forestry has never reached a sufficient volume threshold necessary to establish specialised processing facilities and firm markets in New Zealand, despite strong consumer demand for imported timber. Research and data are needed on which to base prediction of likely returns for growers. This project addresses specific problems associated with grade-sawing younger, smaller-diameter plantation ash eucalypt logs in New Zealand. Sawing logs below 40 cm small end diameter (SED) is difficult primarily because of growth stresses. Seasoning of cold-climate eucalypt timber is also problematic, and issues such as collapse, surface and internal checking, cupping, distortion and high shrinkage can significantly lower product recovery and value. Despite these grade-limiting defects, when correctly sawn and seasoned, eucalypt timber can have attractive appearance, along with high strength and stiffness.

In order to estimate real-world values for sawlogs within a mature industry and market, this study has simulated a vertically-integrated enterprise growing and processing small-diameter short rotation eucalypt. The resulting economic analysis is aimed at providing growers with accurate information about real-world returns for growing eucalypts for timber in New Zealand. If sufficient incentives exist then it may be possible for a viable eucalypt processing industry to develop.

Ninety-one 18-year-old *Eucalyptus regnans* (mountain ash) logs ranging in diameter from 25-43 cm were sawmilled in order to:

1. Assess a specialised horizontal bandsaw sawmilling strategy developed for producing timber with minimal degrade from small- to medium-diameter cold-climate eucalypts;
2. Estimate the net value of logs (conversion return) across the diameter range;
3. Estimate the potential impact of tree stocking and rotation length on NPV (Net Present Value);
4. Discuss the potential for innovative product options which could yield highest value from sawn eucalypt timber.

The primary objective was to evaluate the commercial potential for solid timber production from short-rotation, small- to medium-diameter, cold-climate eucalypt plantations in New Zealand. The estimated NPV for production of sawn timber and pulp from the stand used in this study was $10,292 per ha (internal rate of return 16.8%). Key contributors to this high value were:

1. The large proportion of potential sawlogs within the stand - 61% by volume - arising from the ability to recover timber from small diameter logs.
2. A cost-efficient sawmilling strategy which produced high conversions to graded products.
3. The high wholesale price allowed for *E. regnans* timber.

Nominal recoveries of sawn timber were recorded from all diameters milled, along with graded recoveries and processing costs. These provide a benchmark for evaluating potential returns from a real-world emerging plantation industry.

By diverting smaller diameter logs (SED > 25 cm) from short rotation stands away from lower-value pulpwood to higher-value sawlogs, returns to the grower could be improved. However, sufficiently mature hardwood timber markets would need to exist at the time of harvest.

The results from the economic analysis of the stand used for the sawing study are sufficiently encouraging, with an internal rate of return well above that achieved for a typical radiata pine stand, to suggest that investment in growth model, volume and taper equation, and diameter distribution development is warranted.
Basic density, strength and hardness tests along with product development trials (such as finger-jointing) would give a better indication of market potential and value of young cold-climate eucalypt timber.
INTRODUCTION

Grade-sawing younger, smaller-diameter plantation ash eucalypt logs in New Zealand is considered to be difficult below 40 cm small end diameter (SED), primarily because of growth stresses (Haslett 1984). Traditional sawmilling techniques used on older-growth eucalypts have produced poor results when applied to younger and smaller diameter plantation material in Australia (Washusen et al. 2009). Seasoning of cold-climate eucalypt timber is problematic, and issues such as collapse, surface and internal checking, cupping, distortion and high shrinkage can significantly lower product recovery and value (Haslett 1988). However, despite these grade-limiting defects, when correctly sawn and seasoned, eucalypt timber can have attractive appearance, along with high strength and stiffness (Miller et al. 2000).

Appearance products attract high prices (Washusen and Clark 2005). However, for appearance products ash eucalypts should be quarter-sawn, requiring log SED of at least 40 cm and preferably 75 cm or more to reduce the effect of growth stresses (Haslett 1988). Larger diameter logs fetch a premium to growers in New Zealand, but logs of less than 45 cm diameter are often rejected as sawlogs (Table 1), leading to the recommendation of final crop stockings of 100 stems per hectare (sph) (Deadman and Hay 1987). However low stocking density has been shown to negatively influence clear bole length in eucalypts and is likely to increase product degrade resulting from branch defect (Brown 1997). Knotty headlogs are likely to be of very low value as sawlogs, regardless of diameter (Table 1).

<table>
<thead>
<tr>
<th>Minimum SED (cm)</th>
<th>Grade</th>
<th>Price ($/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>Clear butt</td>
<td>$100</td>
</tr>
<tr>
<td>60</td>
<td>Clear butt</td>
<td>$125</td>
</tr>
<tr>
<td>80</td>
<td>Clear butt</td>
<td>$145</td>
</tr>
<tr>
<td>50</td>
<td>Knotty logs</td>
<td>$45</td>
</tr>
</tbody>
</table>

Low estimated IRR's have been reported for eucalypt grown on a 35-year rotation for sawlogs (Maclaren 2005). Producing larger diameter logs usually requires thinning to lower stockings or extending rotation lengths. Large pruned buttlogs may have high value as sawlogs, but corresponding returns from the stand may not be high when discounted to a present value, because of rotation length. Furthermore, large sawlog yield as a percentage of total stand volume is also likely to be low. On shorter rotations, large logs are likely to be a small proportion of the total log yield (Washusen and Innes 2008). Another Australian study found they comprised only 20% of the stand volume in 32-year-old *E. globulus* thinned to 200 sph at age 18 (Washusen et al. 2004), with a larger proportion of lower value pulp-logs representing lower returns for growers.

Processing costs are a major consideration influencing grower’s profitability. At an estimated cost of A$650/ m$^3$ for sawmilling, kiln-drying and grading in Australia, potential stumpages were only A$90/ m$^3$ for B grade1 pruned plantation eucalypt logs and A$25/ m$^3$ for B grade1 unpruned logs (Washusen et al. 2004).

There remains insufficient research and data on which to base profitability of growing eucalypts in New Zealand (Maclaren 2005). Adequate projected returns are necessary to provide stimulus to plant eucalypts in an appropriate scale for efficient solid-timber production and market development. As a result, eucalypt forestry has never reached a sufficient volume threshold necessary to establish specialised processing facilities and firm markets in NZ. During 2008, NZ imported 20,000 m$^3$ of sawn hardwood timber at a cost of over $28 million, while a further $241
million was spent on importing wooden furniture (MAF 2008). Only 725 m$^3$ of eucalyptus was sawn in New Zealand for the year ended 31 March 2009 (MAF 2009). There remains an opportunity and challenge to meet the needs of this market.

In order to estimate real-world values for sawlogs within a mature industry and market, this study has simulated a vertically-integrated enterprise growing and processing small-diameter short rotation eucalypt. The resulting economic analysis is aimed at providing growers with accurate information about real-world returns for growing eucalypts for timber in New Zealand. If sufficient incentives exist then it may be possible for a viable eucalypt processing industry to develop.

1 Victorian log grades.

**Eucalypt Sawmilling Issues**

Release of growth stress during sawing is one of the most important issues to consider when processing eucalypt (Haslett 1988). Quarter-sawing of large logs is recommended, but for small diameter logs can produce high levels of spring (Jones *et al.* 2010). In traditional quarter-sawing, to avoid spring, additional cuts need to be made to straighten the sawn face (Washusen *et al.* 2009). This lowers recoveries and also slows volume throughput (Washusen and Innes 2008). Quarter-sawn boards from smaller diameter logs can also produce high levels of thickness shrinkage (Jones *et al.* 2010) and green-sawn thickness may need to be increased to avoid skip, which can lower nominal sawn recovery.

Back-sawing (or flat-sawing), on the other hand, is generally more cost efficient because:

- Green conversion can be higher.
- Wider boards can be sawn from smaller logs and with fewer cuts.
- The logs are regularly rotated, and thus growth stress is released as bow rather than spring, which can be more easily controlled in seasoning.

Back-sawn boards saw well but unfortunately encounter several issues:

1. Back-sawn boards can have lower dimensional stability (Haslett 1988, Vermaas 1995, Washusen *et al.* 2008). This is because tangential shrinkage is usually higher than radial shrinkage in eucalypts (Washusen and Innes 2008). This high tangential shrinkage can translate into high movement in service (Bootle 1983, p. 70) which is further compounded by wider boards.

2. Back-sawn boards are often more subject to seasoning degrade such as warping, cupping and surface checking (Washusen and Innes 2008, Vermaas 1995 and Bootle 1983, p. 70). Surface checking was found to be the most important grade limiting defect in young plantation *E. nitens* (Washusen *et al.* 2009) and was more prevalent in back-sawn than quarter-sawn timber.

3. Quarter-sawn boards can be reconditioned more successfully than back-sawn boards because they are less prone to surface checking in the reconditioning process (Bootle 1983, p. 70).

4. Wider back-sawn boards are subject to higher levels of cupping. Thickness of boards may need to be increased when back-sawing wide boards to reduce the incidence of planer skip, a serious grade limiting defect. This will reduce nominal recovery.

5. Back-sawing small diameter logs usually produces boards containing the pith (or centre-line), and the resulting end-splits, warp and heart-checks are likely to exclude these boards from decorative end-uses.

These issues can lead to a lower proportion of acceptable grades.
Sawing methods have a major bearing on processing efficiency and end product recovery and performance (Washusen and Clark 2005, Jones et al. 2010). The sawing equipment and sawing strategies typically applied for native forest eucalypts in Australia have been shown to be unsuitable for the plantation resource (Haslett 1988, Washusen et al. 2009). In the green sawn state timber may appear to be of the highest quality but it can then suffer significant degrade upon seasoning and processing, yielding a low product recovery. An emerging industry must be confident that processing methodology allows for adequate volume recoveries of a product which meets market quality standards, and which can be produced relatively cost-efficiently.

**Goals and Strategy**

This study does not compare sawmilling techniques, but quantifies grade recoveries and cost-efficiency per cubic metre of log input for a novel hybrid slabbing/quarter-sawing strategy developed for small-diameter plantation cold-climate eucalypt sawlogs. Product value is estimated and log values are assessed based on these product values.

A sample of 91 small diameter 18-year-old *E. regnans* logs was milled to cover a diameter range of between 25 cm and 43 cm, with the purpose of determining reasonably accurate recovery means for the diameter range. Nominal sawn timber and grade recoveries were recorded from each log, along with milling costs.

The sawmilling strategy includes:

- milling to end-use sizes;
- selecting end-use sizes not just by maximising board width (the traditional strategy used for adding value) but targeting smaller dimensions for contemporary and potential end-use markets requiring small-dimension timber;
- using one piece of equipment, a horizontal bandsaw (Woodmizer LT 28 with electric assist).
METHODS

Species Selection

_Eucalyptus regnans_ (mountain ash) was chosen for this study because:

1. _Eucalyptus regnans_, being from the monocalyptus sub-genus of eucalypts, has proven to be resistant to defoliating insects in New Zealand. A number of Australian pest incursions over the last 100 years have limited growth rates of some other eucalypts, especially those in the blue gum group.

2. _E. regnans_ is a cold-climate eucalypt suitable for a wide range of sites around New Zealand, has excellent form along with fast growth and good pulpwood properties (Kibblewhite _et al._ 2000).

3. _Eucalyptus regnans_ has a pale straw coloured timber (mountain ash) which has distinct growth rings and an attractive ribbon appearance. This versatile timber can be steam bent and even fumed with ammonia to give the timber a rich walnut colour. The timber is light and strong and suitable for a wide range of specialty uses. Its main drawback in young material is potentially low density and thus softness (Frederick _et al._ 1982, Miller _et al._ 2000).

4. _Eucalyptus regnans_ sapwood colour is indistinct from the heartwood and does not impact negatively on the timber's appearance.

5. The sapwood of _E. regnans_ is resistant to attack by the lyctus borer. _Lyticus_ spp., the powder post beetle, is found worldwide and attacks the sapwood of many hardwoods (Bain 1978). _Eucalyptus nitens_ and _E. fastigata_, the two most commonly grown cold-climate eucalypts in New Zealand for pulpwood production, have _lyctid_-susceptible sapwood. The Australian grading standards (AS 2796.2 – 2006) specify that graded timber must not include _lyctid_-susceptible sapwood unless suitably treated. This is an additional step and cost of production which is not necessary for _E. regnans_, and which may meet future market resistance if pesticide chemicals are used.

Logs and Harvesting

A cross-section of logs covering a diameter range of 25 - 43 cm were harvested from a stand of 18-year-old _E. regnans_ in the central North Island (near Murupara). These had been planted at 1100 stems per hectare, and had received no thinning or pruning. This resulted in tall trees with typically small diameters (Figure 1) and few large branches. Branch-shedding was evident most of the way up the stems.
Figure 1: Estimated\(^2\) diameter distribution for stand at age 18.

The stand was a second-generation *E. regnans* breeding trial and therefore represented a more diverse array of genetics than would normally be expected if planted operationally. This 1991 progeny trial comprises the New Zealand breeding population of 314 families - 160 from natural stands in Australia, 99 second generation selections, mostly from the 1979 progeny trial at Wiltson and 55 from APM forests. The families were planted as a single-tree-plot trial in Kaingaroa cpt 1194.

Timberlands Kaingaroa harvested 1968.3 t from 5.94 ha during April 2009, yielding 331.37 t /ha, with an estimated volume of 303.2 m\(^3\)/ ha (based on individual log measurements). Individual tree volume was estimated to range from 0.5 m\(^3\) to 5 m\(^3\) (Figure 2) and log (3.3 m length) volumes ranged up to 1.4 m\(^3\) (Figure 3). Volume production is comparable with that reported by McKenzie & Hawke (1999) for a comparable treatment of *E. regnans* in a pruning and thinning trial at Kaingaroa Cpt 1209 and 1210. Planted at 1111 stems per ha and subsequently untended this stand had a stocking of 556 stems /ha and standing volume of 417.6 m\(^3\)/ ha at age 19.
Figure 2: Estimated\(^2\) tree volume distribution for the *E. regnans* stand used in this study.

Figure 3: Estimated\(^2\) log volume distribution for the *E. regnans* stand used in this study.

\(^2\) Estimates were made from stand data at age 16. See Appendix 1.

Logs were mechanically harvested and debarked on site on 30 April 2009. The only selection criterion was for logs to be greater than 25 cm SED. The logs provided were assumed to be a representative cross-section of logs from the stand. 28.46 tonnes of logs were transported in 6 m lengths to the sawmill on 4 May 2009. Each 6m length was cross-cut into 2 sawlog lengths one day before sawmilling; the small-end sawlogs were cut to <3 m and large-end sawlogs >3 m, giving two
logs per 6 m length - these lengths were cross-cut in an attempt to optimise length to diameter for maximum sawn timber recoveries and sawmill cost-efficiency (Figure 4). This is because larger diameter logs can generally be sawn in longer lengths. When longer lengths are sawn, resulting distortion is greater over that length, requiring straightening cuts which waste more wood and produce lower recoveries. In smaller logs this wasted wood is a greater percentage of the log volume. The trade-off is that shorter log lengths, because of lower log volumes, are more expensive to mill.

![Figure 4: Relationship between log small end diameter (SED) and log length.](image)

Logs were end-painted prior to sawmilling with a unique colour-code to identify the boards from each log. Total volume of the 91 logs was estimated to be 26.07 m3.

Logs had a 31.8 cm average SED, a 34.2 cm average LED and 33.0 cm average mid diameter. Logs were generally observed to have very little taper, and with an average SED:length ratio of 0.10.

**Sawmilling, Seasoning, Machining and Grading Methodology**

All 91 logs (average SED 31.8 cm) were milled using a Woodmizer LT 28 (with electric assist) and 3 mm kerf saw-blade.

Sawmilling commenced on 7 May and took 21 days to complete. The length of time for sawing each log was recorded. Time included initial log positioning, all sawing, slabwood bundling, fillet-stick cutting to length and bundling, along with all timber filleting into stacks. Time taken for bandsaw changes, log making and loading onto the sawmill was estimated at five minutes per log. Cost of sawmilling was determined using these times with an hourly rate allocated (Appendix 1).

Target sizes were predetermined and the timber was sawn into the following dimensions:
- Thickness of all nominal 25 mm boards were sawn at 28 mm;
- Nominal 50 mm × 50 mm boards were sawn at 52 mm × 54 mm;
• Sawn width of nominal 100 mm boards was 110 mm, 83 mm for nominal 75 mm boards and 162 mm for nominal 150 mm boards;
• Fillet-sticks were cut at 1 m × 28 mm × 19 mm.

All logs were halved, kept intact and turned 90 degrees, then slabbed to thickness dimension. No straightening cuts were applied when slabbing, but the two flitches are turned 180° half way through the slabbing procedure. The first slabbing cut and the first slabbing cut after turning the flitches were sawn at 54 mm. All other slabs were sawn at 28 mm. Slabs were then grouped according to width and both edges were sawn to final width dimension. Some detail on the sawmilling strategy is found in Appendix 4.

Nominal and green sawn timber recoveries (Table 2) were recorded from each log, along with milling times.

<table>
<thead>
<tr>
<th>Nominal size (mm)</th>
<th>Green sawn size (mm)</th>
<th>Blanked size (mm)</th>
<th>Lineal m recovered</th>
<th>Finished profile (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 × 25</td>
<td>110 × 28</td>
<td>96 × 23.4</td>
<td>2464.7</td>
<td>83 × 19</td>
</tr>
<tr>
<td>75 × 25</td>
<td>83 × 28</td>
<td>72 × 23.4</td>
<td>567.2</td>
<td>66 × 19</td>
</tr>
<tr>
<td>50 × 50</td>
<td>52 × 54</td>
<td>45 × 45</td>
<td>1192</td>
<td>40 × 40</td>
</tr>
<tr>
<td>150 × 25</td>
<td>162 × 28</td>
<td>146 × 23.4</td>
<td>360</td>
<td>128 × 19</td>
</tr>
</tbody>
</table>

Boards were filleted, stacked and weighted immediately on completion of sawmilling. Fillet spacing was 50 cm and fillets were 19 mm thick. Because boards had a slight thickness taper from the middle to the ends, care was taken to add thin timber "slivers" to fillet-sticks nearer the ends of the stack to increase the fillet-stick thickness slightly and compensate for board taper. These were inserted at regular intervals (approximately every 6th layer) to keep the stack level.

The timber was air-dried under cover for 80 days and measured using a hand-held electrical moisture meter, which then showed a moisture content of 24-30%. The stacks were then transported to a dehumidifier kiln (manufactured by J.B. Teat Ltd., Rotorua; with LAE electronic dehumidifier unit), weighted and dried for a further 23 days. The kiln reached 39°C in 24 hours and remained at this temperature for the total drying time. Humidity was set at 95% for seven days, after which it was reduced to 75% for four days. Humidity was then gradually reduced to a minimum of 45% and the timber was further dried for 12 more days. Cost of contract kiln-drying the timber was $150/m³.

Once kiln-dried, average moisture content was measured to be between 10 and 12%, meeting grade requirements.

The timber was not steam reconditioned to remove collapse, as this option was not available in the facilities used.

Boards were then dressed four-sides (blanked) at full length with a SCM superset XL moulder, to facilitate grading. Cost of contract dressing four-sides was $0.50/lineal m.

Grading was undertaken in accordance with an interpretation of the Australian Standard AS 2796.2 – 2006, Concealed Surface grade, modified according to the specifications found in Appendix 3. The timber was graded into lengths of Select, Standard and High-Feature grades and these lengths were recorded. Short Clear Cuttings were also recorded, also defined in Appendix 3.
Cost, price and return assumptions used for estimating log value and optimal rotation length and stocking

For this study, the timber was kiln-dried and dressed four-sides to enable accurate grading of timber. The economic analysis estimated the conversion returns from product recovery volumes, product recovery costs and estimated product prices. For establishing the value of logs in terms of conversion returns we used the pricing point of air-dried timber delivered to the wholesaler. This pricing point was chosen because timber is normally only kiln-dried immediately prior to use and air-dried timber can be block-stacked and stored without deterioration while available for sale. As such, the economic analysis did not include costs of conversion from air-dried sawn timber to kiln-dried and profiled product. We are not implying that the timber is sold air-dried. Kin-dried timber value would include the additional cost of kiln-drying and finished, profiled timber the additional cost of machining, docking and grading. These costs are estimated in Appendix 1.

The economic assumptions used to estimate the conversion return of sawlogs are also given in Appendix 1. These were used in both the discounted cash flow analysis of the economic value of the study stand; and for estimating the hypothetical optimal rotation and stocking.

Utilisation and Product Value Trials

Estimating product values for the eucalypt timber sawn in this trial can be highly subjective. Two simple trials were undertaken using the timber from this study to provide some impression of real-world value of the products sawn.

(i) Flooring and panelling
617 lineal metres of 100 × 25 mm timber was dressed into timber suitable for tongue and groove flooring (T&G) and panelling (TG&V) profiles. 62 lineal metres of defect timber was docked prior to machining. Minimum lengths were 60 cm for TG&V and 45 cm for T&G reflecting stud and joist spacing respectively. The timber was profiled at 88 × 19 mm.

(ii) Laminated panels
Six laminated panels were produced from 50 × 50 mm timber (Concealed Surface grade; one surface Select or better). These panels had a total finished surface area of 5.5 m², were 630 mm wide and 40 mm thick. Total cost for laminating was $250. Timber cost was based on nominal 50 × 50 mm board prices from Table A2.1, Appendix 1 and finished 40 × 40 mm piece size. Laminating included dressing, placement, assembling and thicknessing of panel blank.

<table>
<thead>
<tr>
<th>Cost per square metre:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Timber cost (air-dry)</td>
<td>$57.50</td>
</tr>
<tr>
<td>Kiln-drying (at $150/m³)</td>
<td>$9.37</td>
</tr>
<tr>
<td>Blanking (dressed four sides)</td>
<td>$12.50</td>
</tr>
<tr>
<td>Laminating</td>
<td>$45.45</td>
</tr>
<tr>
<td>Total cost</td>
<td>$124.82</td>
</tr>
</tbody>
</table>
RESULTS

Logs and Harvesting

Log end-splits were observed to increase during the storage time but at worst were rated as only moderate even 28 days after harvest.

Sawmilling, Seasoning, Machining and Grading

Results of the sawing and product recovery are given in Tables 3 and 4.

Taper of board thickness from the middle towards the ends of boards was evident, but appeared to be a minor issue apart from having to make sure that stacks were built level. This taper was caused by slight bending of the log from tension release during sawing of each board. The green thickness dimensions used (Table 2) appear to compensate for this affect at the log lengths sawn in this study, by neither limiting grade nor sawn timber recoveries.

Of the 25.0 m$^3$ of logs sawn, 14.0 m$^3$ of green boards were recovered (11.6 m$^3$ nominal - 46%), with 10.75 m$^3$ of final product recovery (43%).

<table>
<thead>
<tr>
<th>Sawn timber</th>
<th>% of total log volume</th>
<th>% of nominal sawn timber recovery</th>
<th>% of product recovery volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total green-sawn recovery</td>
<td>55.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total nominal recovery</td>
<td>46.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Select grade &gt; 89 cm length</td>
<td>29.4</td>
<td>63.9</td>
<td>68.3</td>
</tr>
<tr>
<td>Standard grade &gt; 89 cm length</td>
<td>5.9</td>
<td>12.9</td>
<td>13.8</td>
</tr>
<tr>
<td>High Feature grade &gt; 89 cm length</td>
<td>3.1</td>
<td>6.7</td>
<td>7.1</td>
</tr>
<tr>
<td>Clear Cutting lengths 30-59 cm</td>
<td>0.4</td>
<td>0.9</td>
<td>1.0</td>
</tr>
<tr>
<td>Clear Cutting lengths 60-89 cm</td>
<td>1.2</td>
<td>2.6</td>
<td>2.8</td>
</tr>
<tr>
<td>Fillets</td>
<td>3.0</td>
<td>6.5</td>
<td>7.0</td>
</tr>
<tr>
<td>Total product recovery</td>
<td>43.0</td>
<td>93.6</td>
<td></td>
</tr>
<tr>
<td>Defect</td>
<td>6.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Product recovery was high, accounting for 93.6% of nominal sawn timber recovery. Recovery of valuable grades (select and standard) was also high, accounting for 76.8% of nominal sawn timber recovery.

Only 6.4% of the nominal sawn timber was lost due to degrade. Branch defects, knots, decay and excessive checking (Box) accounted for 4.3% of sawn timber recovery. Decay and excessive checking were observed to be primarily associated with branch defects. End splits accounted for 1.4% and skip caused by excessive collapse 0.5% of nominal sawn recovery. Defect resulting from sawmilling and sizing (want, wane and skip caused by undersizing) was only 0.1% of nominal sawn timber recovery.
Spring and bow did not increase during drying. All boards were assessed as meeting grading rules for spring and bow on the sawn and seasoned product at full length. No cupping or twist was present in the sawn timber and caused no loss of grade recovery. Visible shakes or heart fractures were not present and caused no loss of grade recovery.

Surface checking was present in 6.3% of boards meeting grade criteria. The average number of checks (5cm length) was 3.8 per board where surface checking was present.

Observations:
- Gum veins (kino) were present but not numerous. These had little negative impact on grades.
- There was no sign of insect damage.
- Incidence of end-splits, checks and collapse all appeared to relate to individual tree differences. Two logs were sawn from each tree, and it was observed that these issues were all relatively consistent between logs from the same tree and highly variable between trees. These features could potentially become important criteria for future selection and breeding work.
- End-splits (1.4%) did not appear to increase on drying.
- Internal checking was not measured, despite the higher levels of internal checking which can be expected from lower density ash timber (Haslett 1988(2)). For the dimensions sawn and the products targeted in this report it was decided that internal checking is not likely to influence value. The incidence of internal checking was observed to be low in timber docked for the two product value trials. If internal checking were to be assessed and found negligible, turned and moulded products could potentially be included in the product mix with confidence.
- Some decay was observed in boards. However, this was negligible. Checks not meeting grade allowances were rare.
- Collapse causing skip was negligible at 0.5%.
- Density variation was strongly evident between boards from different trees but not between boards from the two logs of the same tree. This was not measured however.

The percentage of branch defects within logs was unrelated to log diameter (Figure 5).
Sawlog Value
The relationship of value (conversion return) and log SED of sawlogs from the sawing study was reasonably strong ($R^2 = 0.495$; Figure 6). This relationship was used in the economic analysis of the stand used for the sawing study and rotation and stocking to estimate the value of sawlogs.

Other influences on conversion returns that may explain the remaining 50% of variation in conversion returns include:

1. Individual log variability issues such as sweep.
2. Inaccuracy of the initial half-log cut which should be exactly through the pith to optimise individual log recoveries.
3. Other sawmill operator judgement calls which influence recoveries from each log.
4. Variability in length: diameter ratios for individual logs which would vary from the optimum.

These influences are routine sawmilling issues which necessitated a large sample set of logs.
Figure 6: Relationship between log SED and log value as estimated as the conversion return for 91 logs in the sawing study.

Log SED explained almost 50% of the variation in log value. The relationship implied that a 1 cm increase in log SED contributed to an average $8.34/\text{m}^3$ increase in log value. The increase in net log value with increased log SED is due to two main factors; (i) the increased timber recovery per m3 of log sawn (Figure 7), and (ii) the increased milling efficiency per m3 of timber recovered (conversion factor - Figure 8).
Figure 7: Relationship between log SED and nominal recovery of sawn timber as % of log volume.

Figure 8: Relationship between milling costs per m³ nominal recovery and SED.
Economic Value of Case Study Stand

The value of the case study stand was estimated to be $10,292 per ha (internal rate of return of 16.8%) at age 18 years using an 8.0% discount rate.

The high value of the stand is attributed to three main factors:

1. The large proportion of sawlogs (SED > 25 cm, with no significant sweep, and no significant malformation) within the stand; 60.5% by volume.
2. The high prices allowed for *E. regnans* sawn timber (Appendix 1), which meant that sawlog value accounted for over 95% of the stand value.
3. The high product recovery, 43% of total log volume, due to an absence of end splits, warp, internal checking, etc, and the higher quality grades (Select and Standard) being a significant proportion of the product recovery (74%).

Lumber price sensitivity analysis showed that with 10% lower prices for all sawn timber grades and fillets, the estimated net present value of the stand was almost halved, but was still excellent; $7,300 per ha (internal rate of return 15.2%).

By way of comparison, the estimated internal rate of return for *E. grandis* grown for sawn timber on a 15 year rotation in Brazil in 2006 was 21.4% (Cubbage et al. 2010). In comparison to this study the return for *E. grandis* was achieved from lower establishment costs (US$490/ha, approximately NZ$820/ha), a higher yield of 450 m³/ha, and lower product prices; pulpwood stumpage price of US$24 (NZ$40), and a small sawn timber stumpage price of US$37 (NZ$62).

Impact of Rotation and Stocking on Stand Economic Value

Figure 9 shows the estimated impact of rotation (years) and stocking (stems per hectare) on the net present value (using an 8% discount rate) of *E. regnans* sawlogs. The spiked nature of the curves reflects the use of the ‘average tree’ for a stand (see Appendix 1) because diameter distributions were not available when calculating log volumes. This means that when the SED for a log in the average tree goes above 25 cm (minimum sawlog SED) the value of the stand increases, due to increased sawlog value.
Figure 9: Impact of rotation and stocking on the net present value of *E. regnans* grown for sawlogs.

Stand value increases with lower final crop stocking are due to two factors:

1. the larger SED of logs from the stand average tree resulting in significant volumes of sawlogs by age 20; 41% for 400 stems/ha and 67% for 300 stems/ha;
2. the high value of *E. regnans* sawn timber which results in a large proportion of stand value attributed to sawlog conversion returns; 81% for 400 stems/ha at age 20 years.

The estimated increase in stand value with lower stocking should be tempered by two considerations. Firstly, the shape of the relationship between SED and log conversion returns beyond 43 cm is unknown. In this study we have taken the conservative approach that for logs greater than 43 cm SED we assumed log value was constant. Secondly, lower stockings may lead to increased negative impact of branch size on sawn timber recoveries. Furthermore, we assume that a log from two trees with the same diameter and height, but of different ages, will still have the same grade recovery, and hence conversion return. This assumption was made because we only had data from an 18-year old stand for estimating conversion returns. It therefore is important to recognise that grade recovery may change with tree age (independent of tree diameter) due to changes in wood density and grade-limiting defect that might influence grade recovery.

The economically optimal rotation appears to be around 20 to 25 years (for the 8% discount rate used in this study).

With 10% lower prices for all sawn timber grades and fillets, the estimated net present value is almost halved, though estimated returns at age 20 to 25 years for stands thinned to 300 stems per ha are still good (Figure 10).
Utilisation and Product Value Trials

(i) Flooring and panelling
Docking of defect timber equated to 10% of ungraded, blanked timber in order to produce a flooring and panelling product. This result is similar to overall product recovery (Table 3). The incidence of internal checking was observed to be low. The timber was profiled slightly wider than the usual 83 mm × 19 mm, reflecting the excessively oversized green-sawn width. The timber was used for panelling and flooring with no further docking apart from fitting to joists or studs.

(ii) Laminated panels
The incidence of internal checking observed from docking the 50 × 50 mm timber appeared to be higher than the 25 mm thickness timber. Slight internal checking was present in the end section of 25% of the individual panel laminates. These checks were mostly small (< 0.5 mm wide) and did not detract noticeably from their appearance. Checks between 0.5 and 1.0 mm were found in 10% of the timber. A solid-timber wardrobe was constructed from these to verify the dimensional stability and decorative appearance of laminated *E. regnans* panels.
DISCUSSION

Limitations of the Economic Analysis

Any economic analysis is influenced by the assumptions used in that analysis, particularly cost and price assumptions. Because of the important influence of these assumptions, the spreadsheets used for the analyses can be provided to enable readers to apply the same analysis using their own price and cost data.

Economic analysis of the “optimal” rotation length and stocking for *E. regnans* sawlog production was hampered by the lack of a suitable growth model, volume and taper equations, and diameter distributions. These are essential to adequately represent how a stand of *E. regnans* will grow in terms of tree volume and taper under different thinning regimes through to different ages, to then estimate sawlog volumes and SEDs within a stand.

The results from the economic analysis of the stand used for the sawing study are sufficiently encouraging, with an internal rate of return well above that achieved for a typical radiata pine stand, to suggest that investment in growth model, volume and taper equation, and diameter distribution development is warranted.

Sawmill Operational Efficiency

The purpose of this study was to set a realistic benchmark with existing technology and minimal outlay from which an emerging plantation industry may springboard. The Woodmizer sawmill used in this trial is a low volume-throughput portable sawmill for use in small scale on-site sawmilling. Saw cuts produce very little wastage because of the thin kerf (3 mm).

Results have been encouraging with this low capital investment sawmill equipment proving cost-efficient and with good sawn recoveries.

Advantages of this strategy include:

1. Low capital investment.
2. Spring is removed from dimensioned boards by first sawing faces, and then edging the resulting slabs with straightening cuts.
3. The quarter-sawn boards produced are comparatively wider and in greater quantity than the back-sawn boards. Market acceptability of reasonable-width quarter-sawn boards is likely due to low shrinkage/expansion across the width of the board in service.
4. Cupping in narrow back-sawn boards is negligible, thus eliminating the need for wasteful over-sizing board thickness to avoid face skip.
5. Boards are sawn to final dimension. In contrast, ripping larger stock down to smaller sizes can result in spring. Furthermore, ripping seasoned larger dimension stock into smaller dimensions can expose internal checks, a serious value-limiting defect.
6. Both internal- and surface-checking is reduced by sawing thin-section material (Washusen and Innes 2008). Internal checking is not likely to be an issue from processing or in service because boards are cut to final product dimensions. Only checks on or near the surface are likely to be exposed in most product applications.
7. By excluding the pith (the centre-line or longitudinal axis) from boards, issues with heart checks and cupping around the pith are avoided.
8. End-splitting of sawn boards is minimised because opposing stresses each side of the central axis (pith) are always isolated into separate boards.
Sawn recoveries, efficiency and product value could potentially be further improved by:

- Including 125 mm boards in the recovery mix instead of 100 mm + fillet-sticks.
- Improved operator experience, skill and sawing accuracy. Familiarity with this sawing technique improves recovery and cost-efficiency.
- Allowing less oversize above the nominal sizes, especially board width which could be reduced by 5 mm.
- Milling logs sooner after felling.
- Further optimising log lengths according to diameters.
- Possibly utilising line-bar carriages to reduce variation along the full length of the sawn product thickness to improve nominal recoveries.
- Using specialised edging machinery in addition to the Woodmizer sawmill for cost efficiency and output gains.
- Using steam reconditioning to recover collapse. The conservative nominal recovery strategy used in this study of excessively oversizing Green-sawn dimensions provides a benchmark from which industry can improve from.
- Milling on-site to reduce log transport costs.
- Targeting 2 × 75 × 25 mm boards instead of 1 × 50 × 50 mm board, especially with larger diameter logs.

It is acknowledged that alternative strategies incorporating scale-efficiency and specialised equipment could produce further cost-efficiency gains. However, large diameter circular saws can have a kerf as great as 6 mm (Washusen and Innes 2008). Improvements in efficiency can compromise recovery, and vice-versa.

Technology improvements in sawmilling and seasoning cold-climate eucalypts are very likely. Hewssaws using symmetrical cutting patterns are being evaluated in Australia for high throughput, cost-efficient cold-climate eucalypt sawmilling (Washusen 2009). Growth stress imbalances are addressed by removing wood simultaneously from around the log, but timber produced is essentially wide back-sawn boards, which may not meet the quality requirements into the future of the higher value appearance market. This equipment requires upwards of 120,000 m$^3$ of small even-diameter logs per year (Washusen and Innes 2008), and thus an established resource. To date this is unproven technology.

**Utilisation, Product Options and Towards Determining Product Value Potential**

The concealed surface grade (AS 2796.2 - 2006) used in this study specifies products intended for use in building and appearance applications, based on the level of feature in each grade. This grade allows for appearance and to some degree also board strength. Although the timber was not graded for furniture components or structural components this grading was undertaken to give a general impression of value rather than to specify an end use. The concealed surface grade was selected for this timber because it was deemed the most appropriate for determining potential value based on the target end-uses (Table 4). Consistent knot defect throughout the timber would severely limit recovery of full clear lengths. The suitability of this grade for the New Zealand market has not been determined, and comparable products from which to base value are currently limited. Much of the Tasmanian oak currently imported into New Zealand is in long clear lengths and from old-growth forests. Markets can change during a rotation and the biggest challenge for plantation hardwood growers may be to lead the way with new wood product options that offer fresh points of difference.
Table 4: Target end-uses for the products sawn in this study.

- 100 × 25  Flooring or panelling
- 150 × 25  Flooring, panelling and joinery
- 50 × 50   Laminated panels
- 75 × 25   Laminated timber beams

Short clear cuttings, as a result of new technologies have product options including:
- Laminating and recutting into highly stable furniture components such as drawer sides.
- Finger jointing into longer lengths for glue-laminated structural components.

Presence of internal checking is not likely to be an issue with the target product options (Table 4) unless exposed. The degree to which surface checking meets market resistance is not known for these product options. Exposure of internal checking would depend very much on the product option chosen and level of machining required. The Australian standards AS 2796.2 – 2006 allow for a reasonable level of checking on the surface of hardwood timber but acknowledge that internal checking can only cause downgrade once exposed.

New Zealand grown plantation *E. regnans* timber is substantially stronger, stiffer and harder than radiata pine when trees are over 25 years old (Miller et al. 2000). However, as age of the tree decreases, wood densities generally decrease also, and basic density can be below 400kg/m$^3$ for young North Island *E. regnans* (Frederick et al. 1982). The strength and stiffness for a given density, also known as "specific strength" can be higher for lower density eucalypt timber (B. Walford, Scion, pers.comm). Suitability of young, low density New Zealand-grown *E. regnans* timber for structural applications has not yet been studied, but tests for modulus of elasticity and modulus of rupture from this young low density material are justified.

It was observed that wood density was highly variable between trees milled in this study. This could be related to height-position that logs came from in the tree as it is known that basic density increases with tree height in *E. regnans* (Frederick et al. 1982). Height-positions were not determined for these logs at the time of harvesting but buttlogs were noted and tests could be conducted on the timber from these to determine whether variations in density were related to tree differences and thus could be included in the criteria for future selection and breeding work.

Table 5: Wholesale prices for 25mm thickness kiln dry native forest ash timber in Australia.
(From Washusen et al. 2008)

<table>
<thead>
<tr>
<th>Width (mm)</th>
<th>Select grade wholesale price ($A/m^3$)</th>
<th>Standard grade wholesale price ($A/m^3$)</th>
</tr>
</thead>
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<td>50</td>
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<td>1165</td>
</tr>
<tr>
<td>150</td>
<td>1510</td>
<td>1190</td>
</tr>
</tbody>
</table>

Appearance products attract high prices (Washusen and Clark 2005). Traditionally, as sawn timber width increases so does product value per m$^3$ (Table 5). Longer timber lengths also command a higher price than shorter lengths. However, technology could play a part in opening market opportunities for producing high-dimensional-stability high-value timber products cost-efficiently using small dimension ash eucalypt stock and jointing with modern adhesives. The product values
given for sawn timber dimensions in this study (Table A 1.1, Appendix 1) are based on perceived market potential and target product end-uses (Table 4). It is acknowledged that further market research is required to gain a higher level of pricing accuracy. Product development and careful niche marketing or adequate volumes will be required to capitalise on market potential. Current prices for equivalent timber in New Zealand as a finished, profiled product are given in Appendix 2.

Flooring and Panelling

The flooring and panelling product trial produced attractive results. The appearance of this timber and nature of the concealed knots produced significantly more figure on the clear face than seen on equivalent long-run quarter-sawn clears imported from natural ash eucalypt forest in Australia.

Laminated Panels

Laminated hardwood benchtops are a potentially high-value product-use for 50 mm × 50 mm timber, and highest grade dry N.Z. eucalypt has a value of $3000/ m$^3$ for this end use (P. King, Kings Fourth Generation Woodworking Company, pers. comm.). Custom made blanks (600mm wide) made from 50 mm × 50 mm hardwood currently sell for $350 - $450 per m$^2$ in New Zealand (Chris Vincent, South Pacific Timber, pers. comm.). The total cost of $124.82 / m^2$ for laminated panel blanks in the product trial, based on the timber prices in Table A 1.1 (Appendix 1), compares favourably with market rates of $350 - $450. However, the market for laminated eucalypt blanks is currently quite small in New Zealand (Chris Vincent, pers. comm.).

Finger Jointing

Short lengths of clear timber are used for finger-jointing. Finger-jointing is a method of upgrading low-grade material into long lengths of valuable clear straight-grained timber. Its uses include structural applications such as glue-laminated beams, a potential high-value application for *E. regnans* and other eucalypt timber.

Non-structural uses of finger jointed wood include joinery, furniture, flooring, door jambs, handrails, balustrades and mouldings.

To be suitable for finger jointing, timber must be stable, have few internal defects, machine well, with high production rates and minimal wear on the machine cutter knives. Young low density ash eucalypt timber has not been assessed to determine whether it produces smooth, clean cuts with a minimum of crushing or splintering at the cut surface or face and meets the requirements for finger-jointing.

The cost of custom finger jointing (both structural or micro-joint) with Melamine Urea Formaldehyde Resin (M 7) at Lakeland Timber Processors Rotorua is currently $120/ m^3$ for 150 mm × 25 mm shooks; $140/ m^3$ for 100 mm × 100 mm and 50 mm × 50 mm shooks; and $170/ m^3$ for 75 mm × 25 mm shooks. The length of shooks is normally not much more than 400 mm to avoid joining issues resulting from distortion. Length must be greater than the width, so even very small lengths are suitable. As a general rule, processing costs do not increase with decreasing lengths although shooks less than 150 mm long may not meet the size specifications of some jointers (Jim Dowman, Jalco Timber Processing Ltd, pers. comm.).

Radiata pine shooks used for finger jointing return approximately $500 per cubic metre for clear 75 mm × 25 mm, 100 mm × 25 mm and 150 mm × 25 mm (Leyton Dowman, Jalco Timber Processing
Ltd, pers. comm.). The value given for air-dry Clear Cuttings 30 -59 cm of $600 in Table A 1.1 (Appendix 1) reflects the current value of clear radiata shooks.

**Glue-laminated Structural Members**

Glue-laminating can produce larger dimension timber products than possible with sawn timber, and can utilise lower grades of wood by bonding the weakest point of one piece of timber to the higher strength of adjoining pieces. The significant variation in strength and density properties exhibited by ash eucalypt timber (Haslett 1988(2)) can to some degree be cancelled out by laminating timber. Decorative timbers can be used to striking effect, and thin laminates enable the member to be finished with a curve if desired to accomplish striking architectural features. The cost and additional value generated from glue-laminating 25 mm thickness finger-jointed young low density ash eucalypt has not been assessed in New Zealand but may have considerable product potential for strong, decorative and long-span structural beams.
CONCLUSION

Managing eucalypt stands for solid timber remains a tradeoff between adequate diameters and reasonable bole length with minimal branch-related defect. By demonstrating that a range of smaller diameters can be sawn cost-effectively and profitably, some flexibility is assured in the balance between maximising piece size and minimising rotation length. Logs greater than 25 cm diameter could potentially be diverted from low-value pulpwood to a considerably higher value sawlog. In addition, management regimes could target increasing the proportion of sawlogs in the log-mix to improve grower profitability. *Eucalyptus regnans* under the regime in this case study produced good recoveries of timber meeting grade specifications. This was the case even when grown in an unmanaged regime, with resulting good returns to the grower. The ability to achieve valuable timber recovery from logs of small diameters is an important contributor to this outcome. Standard forestry practice to improve stand value, such as early pruning to improve grade values and volumes, and thinning a stand to reduce the number of malformed trees and allow remaining tree-stock to increase in diameter, could improve returns from this benchmark. Care may be needed to ensure sufficiently high stocking in order to limit product degrade from branches.

The processing costs and timber recoveries from the sawmilling technique from this study show that there should be adequate returns to growers from plantation *E. regnans* sawlogs. However, given that estimated economic returns from *E. regnans* grown for sawlogs are sensitive to the sawn timber prices used, further market research will be helpful in understanding the potential returns from *E. regnans*.

There appears to be considerable scope for product development and niche marketing for ash eucalypt in New Zealand. The forest industry has the opportunity to generate additional value to the existing radiata estate, open new markets and profitably substitute imported timber with locally grown hardwood product. Wood density, hardness and strength should be measured from the *E. regnans* timber from this study. This will give a better indication of suitable product options for wood from young cold-climate eucalypts.

Timber prices are likely to change significantly over the length of a rotation and growers may need to consider likely future product options when selecting a timber species and regime. Dimensional stability may become a more important requisite to higher value than timber size in the future. It is conceivable that products with inherent stability such as laminated panels and beams could capture a higher value market than traditional large-section timber of similar dimensions.

It is likely that similar sawn recoveries can be produced from other eucalypt species using the same diameter range sawn in this study. However grade recoveries are not likely to correspond with the *E. regnans* grade recoveries from this study, because of varying degrade associated with branch defects, kino, cell collapse, checking, shakes and growth stresses. This requires further study on a species by species basis.

Ideally, selection traits for a future *E. regnans* breeding programme should include wood quality issues; in particular collapse, wood density, end-splits and checks. This will, however, require significant more investment in breeding than is currently available for this species.

The *Eucalyptus regnans* growth model should be developed to include data from stands greater than 15 years old and a mortality function. This will enable more accurate economic analysis of the species for commercial plantings.
ACKNOWLEDGEMENTS

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The authors would also like to acknowledge the invaluable input provided by Mina van der Colff to the economic analysis, providing information on growth models, and taper and volume equations used. We also thank Kevin Maloney for kindly making available a DOS based version of the *Eucalyptus regnans* growth model.
REFERENCES


APPENDICES

Appendix 1: Assumptions in Discounted Cash Flow Analysis

All prices are G.S.T. exclusive
Two spreadsheets are available:
1. Optimal rotation and stocking for *E. regnans*
2. Kaingaroa Compartment 1194 *E. regnans* economic value

Economic Assumptions
The discounted cash flow (DCF) analysis of (i) the stand used in the sawing study and (ii) hypothetical stands thinned to different stockings was prepared using the following data:

1. Discount rate of 8.0% per year.
2. Establishment cost of $1.80/ tree\(^3\).
3. Thinning cost of $0.70/ tree\(^4\).
4. Harvesting, de-barking and truck loading costs of $28 / t for pulp logs.
5. Harvesting, de-barking and truck loading costs of $57/ m\(^3\) for sawlogs.
6. Cartage costs of $15/ t for pulp logs.
7. Cartage costs of $37/ m\(^3\) for saw logs transported to the sawmiller/wholesaler\(^5\).
8. Sawmilling cost of $80/ hour, which includes a sawmill operator and one helper.
9. Eucalypt pulpwood price $62/ t gross at mill gate\(^6\).
10. A tonne to m\(^3\) conversion of 1.09 t/ m\(^3\) based on stand data.
11. An annual land rental of $150/ha/yr. This was based on the average land value in Kaingaroa, expressed as an annuity.
12. An annual cost of $80/ha/yr. This includes forest health, property maintenance, security, insurance, forest management, administration and rates costs for typical forest stands.

\(^3\) Based on an estimated cost for eucalypt plantation establishment of $2000 per ha, from land preparation until the end of the second year, planted at 1100 SPH (B. Poole pers. comm.).
\(^4\) Turner et al. (2008).
\(^5\) Agrifax "Regional Log Price and Cost Report May-2010" North Island log cartage cost for 100 km to sawmill on flat terrain.
\(^6\) Mark Self, Timberlands Ltd., pers. comm.
\(^7\) Values given for air-dry timber (Table A1.1) are based on equivalent timber available in the New Zealand market. Cost for kiln drying is $150/ m\(^3\), assuming there is no transport costs of air-dry timber to kiln. Machining to profile, docking and grading cost is $1.50/ l m.
Table A 1.1: Estimated board prices for sawn timber at wholesaler gate\textsuperscript{7}.

<table>
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<tr>
<th>Size</th>
<th>Grade</th>
<th>Price ($/lm) air-dry</th>
<th>Price ($/lm) kiln-dry</th>
<th>Price ($/lm) profiled</th>
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<td>50 mm × 50 mm</td>
<td>Select</td>
<td>2.30</td>
<td>2.67</td>
<td>4.17</td>
</tr>
<tr>
<td>50 mm × 50 mm</td>
<td>Standard</td>
<td>2.00</td>
<td>2.37</td>
<td>3.67</td>
</tr>
<tr>
<td>50 mm × 50 mm</td>
<td>High-feature</td>
<td>1.90</td>
<td>2.27</td>
<td>3.77</td>
</tr>
<tr>
<td>50 mm × 50 mm</td>
<td>Clear cuttings 30-59 cm</td>
<td>1.50</td>
<td>1.87</td>
<td>3.37</td>
</tr>
<tr>
<td>50 mm × 50 mm</td>
<td>Clear cuttings 60-89 cm</td>
<td>1.70</td>
<td>2.07</td>
<td>3.57</td>
</tr>
</tbody>
</table>

Fillets $800 per m\textsuperscript{3}$, cut to length.

**Volume, Taper and Growth Model Assumptions**

For economic analysis of the stand used in the sawing study:

1. DBH for all trees measured at age 16 were increased by 8.8% to give estimated DBH at age 18.
2. Tree heights at age 18 were estimated using the age 18 DBH and an estimated relationship between tree DBH and height from 31 plot trees.
3. Tree volume at age 18 was estimated using DBH and height data in *E. regnans* volume equation V464.
4. Log SED for 3.3 m log lengths from a 0.3 m stump were estimated using *E. regnans* taper equation T464.
5. Log volume was estimated using the integrated form of the *E. regnans* taper equation T464.
6. Logs were assigned to waste, pulp or sawlog grade based on minimum log SED and the level of tree malformation and sweep assessed at age 16: (i) Waste logs had an SED less than 5 cm; (ii) Pulp logs had an SED less than 25 cm, and a sweep score of 1 or 2, or a
malformation score of 1\(^8\), (iii) Sawlogs had an SED of 25 cm or greater, a sweep score of 3 or more and a malformation score of 2 or more.

\(^8\) The sweep and malformation scores are from 1 to 9 with 1 being worst.

For economic analysis of the hypothetical stands thinned to different stockings:

1. Stand mean top height (MTH), stocking, basal area (BA) and volume were estimated using the *E. fastigata* growth model calibrated with data from a Central North Island *E. regnans* stand; stocking of 1078 stems per ha, BA of 11.05 m\(^2\)/ha and mean top height of 11.8 m. An *E. fastigata* growth model was used because of two limitations with the *E. regnans* growth model\(^9\): (i) it was developed using data from stands less than 15 years old; (ii) it did not include a mortality function.

2. Because a diameter distribution equation was not developed for *E. regnans* we carried out the hypothetical stand analysis using the stand average tree. The stand average tree height and DBH were calculated from the *E. fastigata* growth model MTH, and BA and stocking, respectively.

3. Stand average tree volume was estimated using *E. fastigata* volume equation V276.

4. Stand average tree SED at 3.3 m intervals up the stem from a 0.3 m stump height were estimated using *E. fastigata* taper equation T276.

5. The volume of logs in the stand average tree were estimated using the integrated form of the *E. fastigata* taper equation T276.

6. Logs were assigned to waste, pulp or sawlog based on minimum log SED: (i) Waste logs had an SED less than 5 cm; (ii) Pulp logs had an SED less than 25 cm; (iii) Sawlogs had an SED of 25 cm or greater.

7. Waste logs had no value and pulp logs were valued as above.

8. Sawlog value per m\(^3\) was estimated based on the established relationship between log SED and value of timber in the log from the sawing study (conversion return); log value = -49.5 + 833.7*SED, where SED is in m. For logs greater than 43 cm SED we assumed the log value was constant; $309 per m\(^3\).

\(^9\) The DOS implementation of the *E. regnans* growth model (Hayward 1988) was kindly made available by Kevin Maloney.
Appendix 2: Prices and Values of Timber in New Zealand used for Estimating Board Prices (Table A 1.1)

Table A 2.1: Prices for finished, profiled clear eucalypt timber, Northland Kauri Timber Ltd (from pricelist 2009).

<table>
<thead>
<tr>
<th>Species</th>
<th>Grade</th>
<th>Nominal size (mm)</th>
<th>Profiled size (mm)</th>
<th>Price per lineal metre</th>
<th>Price per m³ (nominal)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>E. pilularis,</em></td>
<td>Clear (No. 1)</td>
<td>150 × 25</td>
<td>128 × 19</td>
<td>$9.50</td>
<td>$2,533.00</td>
</tr>
<tr>
<td><em>E. fastigata,</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>E. regnans</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>E. pilularis,</em></td>
<td>Clear (No. 1)</td>
<td>100 × 25</td>
<td>83 × 19</td>
<td>$6.30</td>
<td>$2520</td>
</tr>
<tr>
<td><em>E. fastigata,</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>E. regnans</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table A 2.2: Retail timber prices 2009, 83 mm x 19 mm, profiled T & G per lineal metre.

<table>
<thead>
<tr>
<th>Retailer</th>
<th>Timber</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Pacific Timber</td>
<td>Victorian ash/Tasmanian oak</td>
<td>$7.66</td>
</tr>
<tr>
<td>Timspec</td>
<td>Tasmanian oak select</td>
<td>$6.80</td>
</tr>
<tr>
<td>Timspec</td>
<td>Tasmanian oak standard</td>
<td>$5.75</td>
</tr>
<tr>
<td>Timspec</td>
<td>Tasmanian oak high feature</td>
<td>$4.65</td>
</tr>
</tbody>
</table>
Appendix 3: Timber Grading

Interpretation of the Australian Standards AS 2796.2 – 2006 was to the following specifications:

- Grading was undertaken on blanked, but not finished-to-profile timber.
- Timber not meeting the grade standards due to decay, knots or branch defects was classed as “Box”.
- Timber was graded to lengths which were determined to be points appropriate for simulating docking. These lengths met the grade standards and were free of Box, end-splits, collapse, skip and wane. Short lengths of timber (Clear Cuttings) were graded according to AS 2796.2 – 2006 on all surfaces to Select grade or better.
- Lengths docked for Box (including decay, knots, branch defects), wane (including want, wane and skip), collapse and end-splits were recorded.
- End-splits were measured inclusive of end-checks.
- Surface checks were recorded in number according to average length. There was no assessment of internal checks.
- Where checks were grade-limiting this section of the board was classed as "Box". (This was rare and mostly associated with branch defects).
- Collapse, skip and wane were not recorded where these appeared to be within limits for further profiling to finished dimension (Table 2).
- Where collapse, skip, want or wane were present, the length of the section of the board meeting grade was estimated based on the finished profile (Table 2).
- Mechanical damage was ignored. Very little damage was present, despite the trees having been harvested for pulpwood. Two logs had a small amount of want (a grade-limiting defect) which was ignored when grading to avoid influencing recovery results for these diameters. It was assumed that logs harvested for sawlogs would not be damaged significantly by harvesting equipment. However this may need verifying.
- Skip or wane were not included in recovered sawn volume where present on the end section of a board.
- Branch defects included (but were not limited to) voids associated with bark encasement (where knots were not loose) and over-size of knots.
- Loose knots and decayed knots were assessed as holes where > 10 mm.
- Discolouration (incipient decay) that had no softness was classed as feature and did not influence grade. This was rare.
- Spike knots were not specifically covered in the Australian standard, so that where they were encountered they would almost always be larger than knot allowances permitted based on piece width. Where they could be placed on the reverse face the standard's allowance of 20% KAR for holes on the concealed surface was applied. This also potentially provided for flooring to meet strength requirements.
- Knots and 'associated voids' (voids were not defined in AS 2796.2 – 2006) was difficult to interpret, so the void was defined for our grading based on the allowance for hole diameters.
Appendix 4: Sawmilling Methodology

Figure A1: Example sawmilling pattern.

Pattern for approx 30 cm diameter log
<table>
<thead>
<tr>
<th>Pattern for approx 30 cm diameter log</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 x 50</td>
</tr>
<tr>
<td>100 x 25</td>
</tr>
<tr>
<td>125 x 25 (or 100 x 25 + fillet)</td>
</tr>
<tr>
<td>100 x 25</td>
</tr>
<tr>
<td>100 x 25</td>
</tr>
<tr>
<td>125 x 25</td>
</tr>
<tr>
<td>100 x 25</td>
</tr>
<tr>
<td>50 x 50</td>
</tr>
</tbody>
</table>

Figure A2: Slabbing.

Figure A3: Edging plus fillet sticks.
Appendix 5: Glossary of Terms

**Back-sawn:** Timber is known as back-sawn if the growth rings meet the face of the board at an angle less than 45° (Bootle 1983).

**Blanked:** Timber machined to four sides in preparation for finished dimension profiling.

**Blanks:** Laminated panels sold as a dimensioned product suitable for further sizing and finishing into a more specific end-use.

**Bow:** The lengthwise curvature of the broad face of a piece of timber.

**Back-sawing:** Sawing timber so that the annual rings, as seen from the end-section, form an angle of less than 45° with the board face.

**Box grade:** Timber rejected as not meeting the grading rules.

**Cold-climate eucalypts:** For this study, species within the ash group of eucalypts and *Eucalyptus nitens*.

**Collapse:** Excessive and uneven shrinkage causing corrugation of the wood surface. Also known as washboarding.

**Conversion return:** A log recovery value which represents the theoretical maximum amount to pay for logs delivered to the sawmill (Alzamora & Apialaza 2010). It is estimated from the value of the timber recovered from the log minus the cost of harvesting, cartage, and sawmilling.

**Edge:** The narrow longitudinal surface usually at right angles to the face of a piece of timber.

**Face:** The wide longitudinal surface usually at right angles to the edge of a piece of timber.

**Fillet-stick:** Used for separating layers for drying.

**Flat-sawn:** Timber sawn so that the annual rings, as seen from the end-section, form an angle of no less than 30° with the board face.

**Indistinct:** Not obviously different in appearance.

**KAR:** Knot area ratio. The area of the knot as a ratio of the area of the timber cross section.

**Kerf:** The width of the saw cut removed by the saw blade.

**Nominal:** The named size which may vary from the actual size of the piece of wood because of variations due to sawing, shrinkage and dressing and the tolerances allowed for these operations.

**Quarter-sawn:** Boards cut with their faces parallel to the rays. For normal milling, an angle of not less than 45° is acceptable in quarter-sawn material (Bootle 1983).

**Quarter-sawn, fully:** When the growth rings show an angle not less than 80° to the face of the board.

**SED:** Small end diameter.

**Shakes:** Breakage or longitudinal separation of wood fibres due to causes other than drying, originating in the log.

**Shook:** Small length of timber suitable for finger-jointing.

**Skip:** An area that failed to dress.

**Slab:** Timber which has been dimensioned to thickness but not width.

**Slabwood:** Waste wood resulting from sawmilling.

**sph:** Stems per hectare.

**Spring:** Also known as crook. The lengthwise curvature of the edge of a piece of sawn timber.

**T & G:** Tongue and groove profile.

**T G & V:** Tongue, groove and V profile used for panelling.

**Wane:** The absence of wood indicated by the underbark surface.

**Want:** The absence of wood, other than wane, from the arris or surface of a piece of timber.