Impact of sapwood and the properties and market utilisation of plantation and young hardwoods: Executive Summary and Literature Review (PART A)
Impact of sapwood and the properties and market utilisation of plantation and young hardwoods: Executive Summary and Literature Review (PART A)

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by
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1 Project executive summary

1.1 Introduction

This project is the result of work coordinated by the University of Tasmania (UTAS), in collaboration with the Department of Primary Industries & Fisheries – Queensland (DPI-Q), University of Melbourne (UMEL) and the Forest Products Commission (FPC) in Western Australia. The objectives of the project are to:

(i) Determine and compare the physical and visual properties of the heartwood and sapwood of commercially important hardwood species grown in plantation and young regrowth regimes in Australia with accepted public data for native forest material of those species.

(ii) Determine the likely net value of retaining the sapwood in the tested species given these properties.

The project outcomes are reported in six parts as listed in Table 1.

Table 1: Overview of project reporting structure

<table>
<thead>
<tr>
<th>REPORT NUMBER</th>
<th>NAME</th>
<th>AUTHOR/S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part 1</td>
<td>Project executive summary</td>
<td>All</td>
</tr>
<tr>
<td>Part 2</td>
<td>Literature review</td>
<td>All</td>
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<td>Part 3</td>
<td>Mechanical testing: Minimum radius of bending curvature</td>
<td>UMEL</td>
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<tr>
<td>Part 4</td>
<td>Mechanical testing of western species</td>
<td>FPC</td>
</tr>
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<td>Part 5</td>
<td>Mechanical testing of southern &amp; northern species</td>
<td>DPI-Q</td>
</tr>
<tr>
<td>Part 6</td>
<td>Visual properties assessment</td>
<td>UTAS</td>
</tr>
</tbody>
</table>

The mechanical and visual properties of a total of nine species were investigated including:

**Plantation resources**
- Gympie messmate, *E. cloeziana*;
- Dunn's White Gum, *E. dunnii*;
- Shining gum, *E. nitens*;
- Sydney blue gum, *E. saligna*;
- Tasmanian blue gum, *E. globulus*;

**Young regrowth resource**
- Messmate, *E. obliqua*.
- Blackbutt, *E. pilularis*;
- Spotted gum, *Corymbia maculata, C. citriodora*;
- Karri, *E. diversicolor*;
1.2 Methodology

Where possible a sample of 17 trees was selected from two sites for each species. Two of the logs were allocated for sliced veneer production with slicing carried out by Gunns Veneers in WA and in Tasmania. The remaining 15 logs were processed into solid wood products, generally at a sawmill near the log source, except the northern species that were all processed at the Department of Primary Industries Salisbury Research Centre. Sapwood was retained on both solid wood and veneer samples to permit properties testing on the sapwood component and comparison with the heartwood. The sapwood samples of the lyctus spp. (lyctid or powder post beetle) susceptible species (all except: Blackbutt, Gympie messmate & Karri) were treated to prevent attack. For solid wood samples material was boron dipped, whilst the veneer was protected with a glue line treatment using Bifenthrin.

All samples were assessed for their visual properties, with a focus on the sapwood-heartwood contrast and the visual impact of sapwood retention. A series of stains (ranging from light to dark) were applied to determine whether standard finishes could be used to reduce the sapwood-heartwood contrast. The mechanical properties assessed included density, bending strength, bending stiffness, screw withdrawal, stability, glue bonding and minimum radius of bending curvature. The findings are summarised in Table 2.
1.3 Mechanical Properties

Generally, the mechanical property tests (excluding minimum radius) have shown that, with the exception of blackbutt, the properties of sapwood are at least equivalent to those of heartwood. Where the trees were of young age at harvest, as was the case with Dunn’s white gum, Tasmanian blue gum and shining gum, the strength of the sapwood was in fact superior to that of heartwood. This can be attributed to the higher density of the outer-wood (where the sapwood is located) compared with the heartwood in these still maturing trees. In the species represented by more mature logs – spotted gum, Gympie messmate and messmate stringybark, the strength properties of sapwood do not differ significantly from those of heartwood. In these species, heartwood density was slightly higher than sapwood, but this can be accounted for by the absence of extractives in the sapwood. Bonding of heartwood in the higher density, northern region species, was inferior to sapwood when using phenolic adhesives, but was satisfactory in the lower density, southern and western region material. Bonding after wet conditioning was severely weakened, with almost no wood failure observed in either sapwood or heartwood. Dry bonding with polyurethane adhesives was satisfactory in both sapwood and heartwood in all species except Gympie messmate. Wet bonding of the polyurethane samples was unsatisfactory in both sapwood and heartwood of the high density species, but remained satisfactory in the low density ones.

Heartwood density and mechanical property results were compared with equivalent literature data to benchmark the results from the current study against those established for the native forest hardwood resource. Material sourced from older plantations and regrowth stands proved at least equivalent to the results reported in the literature, whereas that sourced from young plantations was below literature values.

For minimum radius of bending curvature assessed using microwave bending technology, the wood species with modest bending abilities (Karri, Sydney blue gum, Messmate stringybark), were found to differ in the quality level of bending of heartwood versus sapwood. Notable are Sydney blue gum and Dunn’s white gum, which have relatively good and respectively excellent bending characteristics for heartwood but very poor for sapwood. In general, the heartwood for all investigated wood species showed the ability to bend at slightly smaller radii than the sapwood. The length interval of minimum radius curvature found in the heartwood and sapwood of each wood species was similar or very close (at most 30 mm difference). However, it was noticed that for some species (e.g. Karri), higher moisture content is likely to improve the minimum bending radius of sapwood.
Overall, the results of the study on the bending performance capabilities of plantation and young hardwood Australian timbers showed several differences compared with the literature data relating to the bending abilities of the relevant old growth timbers. For the majority of species evaluated in this study, the values of the minimum radii of curvature obtained during the bending experiments were lower than the values reported in the literature and anecdotal statements made by experienced Australian wood benders. Based on this study and extensive research undertaken at the University of Melbourne on bending performance of plantation timbers the conclusion can be made that wood resources from regrowth and plantation forests give better bending performances than old growth timbers.

1.4 Visual Properties

In terms of visual impact the sapwood on southern species (E. obliqua, E. nitens, E. globulus) was generally less than the sapwood-heartwood contrast observed in the northern (Corydia citriodora, E. pilularis, E. coloeziana, E. dunn) and western species (E. diversicolor and E. saligna). This would be particularly true in the absence of sap-stain that occurred in the solid wood samples from the southern species. The sap-stain is attributed to the hotter and more humid conditions of the northern climate experienced when they were transported to a Brisbane plant for boron treatment (against lyctus spp. borers). As most boron formulations are powerless against sap-stain, it is unknown whether staining occurred before or after treatment. Veneer samples were treated (locally) against lyctid borers with a Bifenthrin glue-line treatment, and did not develop sap-stain. Boron treatment against lyctid borers was successful in both the solid wood and veneer samples.

The uptake and finish quality of the floors and veneered panels was generally very good, and although there was greater initial absorption of stain on the sapwood the stained samples were generally of high quality. Machinability for all species was good and no obvious differences were observed between the surface quality of sapwood and heartwood after machining into tongue and groove flooring. Liming white, and medium to dark stains were found to be effective in masking the sapwood-heartwood

Fig 3: Application of different stains to flooring panels
contrast on veneered panels, with greater success observed using a darker stain. Liming white provided little benefit on the solid wood flooring panels (due to the sap-stain on southern species). The best results were observed using the medium and dark coloured stains. In cases where the visual impact of sapwood retention is high utilisation of the material could be facilitated through marketing of the material towards high-end bespoke interior design applications or by staining of the material to reduce the sapwood-heartwood contrast.

1.5 Value of Sapwood Retention

A general overview of the likely value of sapwood retention was provided for solid wood products. It was found that the mechanical properties of the sapwood generally performed well relative to the heartwood product from the same site and therefore could be assumed acceptable in the structural market. For appearance grade products a marketable product could usually be achieved using a dark stain to mask the sapwood-heartwood contrast. A desktop calculation using recovery and product value assumptions with the average log statistics valued sapwood retention between $33 and $113 per m3 of log processed (depending on species, nature of primary breakdown and market). For appearance grade products requiring little sapwood-heartwood contrast, the gains in recovery are not sufficient to cover the additional costs of staining. The additional cost of staining the floor (beyond standard sanding and finishing) would be in excess of $15/m2, i.e. greater than $750/m3 of 19mm strip flooring material. Thus the viable / profitable retention of sapwood would necessitate alternative marketing strategies to increase the acceptability of the product in the market. Such a strategy has been employed for Blackwood in the development of the “Black & White” grade that retains sapwood. Timbers were the sapwood contrast is similarly dramatic (e.g. spotted gum) may be suitable candidates for such a strategy. One further potential gain from sapwood retention, could be the ability to produce greater volumes of wider width products e.g. 100mm vs. 75mm widths. Narrow width material (e.g. 75mm) is typically hard to sell (limited market) and attains lower market values than wider width products. It was
noted that the value of sapwood retention is difficult to quantify in general terms. Value will depend on
the log supply characteristics, breakdown machinery, product mix and acceptability of the product in the
market. Defining specific scenarios to investigate and using sawing simulation and mill recovery tests
could determine more meaningful values.
Table 2: Summary of results for mechanical and appearance properties

<table>
<thead>
<tr>
<th>Species &amp; Site</th>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Density (kg/m³)</td>
<td>12°C/WC</td>
</tr>
<tr>
<td>---------------</td>
<td>----------</td>
<td>---------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E. obliqua,</td>
<td>207</td>
<td>537</td>
</tr>
<tr>
<td>E. obliqua,</td>
<td>207</td>
<td>537</td>
</tr>
<tr>
<td>E. obliqua,</td>
<td>207</td>
<td>537</td>
</tr>
<tr>
<td>E. obliqua,</td>
<td>207</td>
<td>537</td>
</tr>
</tbody>
</table>

**Note:** Significant at the 3% level **NS** Not significant
2 References


3 Acknowledgements

This work has been facilitated by the cooperation and expertise of:

* Britton Timbers
* Forest Enterprises Australia
* ITC Ltd
* Gunns Timber & Veneers Ltd
* Forestry Tasmania
* Big River Timbers
* Department of Natural Resources and Mines - Qld
* Boral Timbers
* DGI Springwood
* Whittakers
* Rockbridge Milling
2 Literature Review

2.1 Tasmanian species: Messmate (*Eucalyptus obliqua*), Shining gum (*E. nitens*) & Tasmanian blue gum (*E. globulus*)

(R. Farrell)

This literature review tabulates & discusses the published data on key wood properties for each species. The data in the tables has been ordered starting with data for the mature resource and ending with data for the young regrowth or plantation resource. This order facilitates the comparison of wood property data according to age.

2.1.1 Messmate (*Eucalyptus obliqua*)

2.1.1.1 Introduction

Common Names – messmate, messmate stringybark

This was the first eucalypt to be formally collected and botanically classified. Specimens were collected from Bruny Island on Cook’s third Pacific voyage in 1777 by botanist David Nelson, and formally described by Charles-Louis L’Hèritier in London (ANBG 2008b). He assigned the genus *Eucalyptus*, based on the hard, lidded covering (operculum) of the flower buds (*eu* being Greek for well and *calyptos* being Greek for covered). The specific name comes from the Latin obliquus (oblique), referring to the mature leaf which generally has 2 sides of unequal length not meeting at the petiole (botanical term is falcate). The mature leaves may also be lanceolate (both sides of equal length).

This species has a wide distribution in both wet and dry sclerophyll forests with a preference for well drained soils, and is common in Tasmania, Victoria and the table lands of NSW and southern Queensland (Bootle, 2005; Tasmanian Timber, 2007a; ANBG 2008a). There are also isolated populations in South Australia (DSE 2003; ANBG, 2008a). As with other eucalypts, it regenerates after fire from seeds or from epicormic buds (DSE, 2007).

This species can take the form of either a tree up to 90m tall, or mallee scrub to 4m (Vicnet, 2008). Early settlers called timber from this species Tasmanian oak due to similarities with English oak. It is now one of three species grouped together as Tasmanian oak (Tasmanian Timber, 2007a). Heartwood is generally pale brown, with sapwood pale yellow and easy to distinguish from heartwood by eye in green timber (Bootle, 2005). The texture tends to be course but is usually even, sometimes with interlocked grain (Bootle, 2005). Heartwood may contain up to 2% by weight polyphenols, which can stain alkaline surfaces brown (Bootle 2005). The timber is commonly used in construction, flooring, paneling and furniture (Tasmanian Timber, 2007a).
2.1.1.2 Stiffness & strength (MOE & MOR)

Table 2: MOE & MOR data for *E. obliqua*

<table>
<thead>
<tr>
<th>Material</th>
<th>Age (yrs)</th>
<th>MOE (GPa)</th>
<th>MOR (MPa)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mature; Vic., NSW</td>
<td>*</td>
<td>14</td>
<td>15.0</td>
<td>75</td>
</tr>
<tr>
<td>Mature; Tas., Vic.</td>
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<td>12</td>
<td>15.0</td>
<td>71</td>
</tr>
<tr>
<td>Regrowth, Tasmania</td>
<td>102</td>
<td>*</td>
<td>15.0</td>
<td>*</td>
</tr>
<tr>
<td>Regrowth, Tasmania</td>
<td>80-90</td>
<td>*</td>
<td>16.5</td>
<td>*</td>
</tr>
<tr>
<td>Regrowth, Tasmania</td>
<td>80-90</td>
<td>*</td>
<td>16.0ᵇ</td>
<td>*</td>
</tr>
<tr>
<td>Regrowth, Tasmania</td>
<td>69</td>
<td>*</td>
<td>15.6</td>
<td>*</td>
</tr>
<tr>
<td>Regrowth, Tasmania</td>
<td>54</td>
<td>*</td>
<td>16.6</td>
<td>*</td>
</tr>
<tr>
<td>Regrowth, Tasmania</td>
<td>36</td>
<td>*</td>
<td>14.7</td>
<td>*</td>
</tr>
</tbody>
</table>

*Data not available ᵇ Values for brittleheart

There is little published wood properties data for this species. For dried material, available data for MOE ranges from 14.7 to 16.6 GPa and from 73 to 132 MPa for MOR.

There is no major difference in the published data between the mature resource and regrowth resource. In a study of material from Tasmanian regrowth messmate, ranging from 36-102 years in age, Innes (2007) showed no significant difference in MOE or MOR from different age classes. It was noted however, that the youngest material (36 years old) showed the highest variation in stiffness.

2.1.1.3 Strength grouping

Strength grouping for *E. obliqua* is given as S3 for green and SD3 for dried material (Timber Data File 2004; Tasmanian Timber, 2007a). Joint grouping for this species is J3 for green and JD3 for dry material (Timber Data File 2004; Tasmanian Timber, 2007a).

2.1.1.4 Maximum crushing strength

Maximum crushing strength has been quoted as 35 MPa for green material and 61 MPa for dry material (Bootle, 2005).

2.1.1.5 Impact (Izod) value

Izod values are given as 13-16 J for green and 18-15 J for dry material (Bootle, 2005; Tasmanian Timber, 2007a).
### 2.1.1.6 Density

#### Table 3: Density Data for *E. obliqua*

<table>
<thead>
<tr>
<th>Material</th>
<th>Age</th>
<th>Basic</th>
<th>Green</th>
<th>Dry</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mature; Vic., NSW</td>
<td>*</td>
<td>630</td>
<td>1080</td>
<td>780</td>
<td>Bootle 2005</td>
</tr>
<tr>
<td>*</td>
<td>*</td>
<td>*</td>
<td>1100</td>
<td>750</td>
<td>Timber Data File 2004</td>
</tr>
<tr>
<td>*</td>
<td>*</td>
<td>*</td>
<td>1000</td>
<td>700</td>
<td>Tasmanian Timber 2007a</td>
</tr>
<tr>
<td>Mature, Tasmania*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mature, Tas., Vic Regrowth,</td>
<td>102</td>
<td>525</td>
<td></td>
<td>745</td>
<td>Innes 2007</td>
</tr>
<tr>
<td>Tasmania</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regrowth, Tasmania 80-90</td>
<td>80-90</td>
<td>*</td>
<td></td>
<td>716</td>
<td>Yang 2001</td>
</tr>
<tr>
<td>Regrowth, Tasmania 80-90</td>
<td>80-90</td>
<td>*</td>
<td></td>
<td>729&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Yang 2001</td>
</tr>
<tr>
<td>Regrowth, Tasmania 69</td>
<td>69</td>
<td>566</td>
<td>*</td>
<td>785</td>
<td>Innes 2007</td>
</tr>
<tr>
<td>Regrowth, Tasmania 54</td>
<td>54</td>
<td>592</td>
<td>*</td>
<td>867</td>
<td>Innes 2007</td>
</tr>
<tr>
<td>Regrowth, Tasmania 36</td>
<td>36</td>
<td>529</td>
<td>*</td>
<td>714</td>
<td>Innes 2007</td>
</tr>
<tr>
<td>Victoria</td>
<td>15-25</td>
<td>543</td>
<td>*</td>
<td>699</td>
<td>Kingston &amp; Risdon 1961</td>
</tr>
</tbody>
</table>

* Data not available
<sup>b</sup> Values for brittleheart

Published values for basic density range from 525-630 kg.m<sup>3</sup> and 700-867 kg.m<sup>3</sup> for dry density. The range quoted by Innes (2007) is for regrowth material of different ages, but the highest values for both basic and dry density were not for the oldest age class (102 years) but from the second youngest (54 years). Density tended to be more variable in younger trees (36 years old), and there was a highly significant correlation between density and both MOE & MOR. The Kingston & Ridson (1961) publication observe higher density in the mature resource compared to that from young trees aged 15-25.
2.1.1.7 Hardness

Table 4: Hardness data for *E. obliqua*

<table>
<thead>
<tr>
<th>Material</th>
<th>Age (yrs)</th>
<th>Janka Hardness (kN)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mature; Vic., NSW</td>
<td>*</td>
<td>5.3</td>
<td>7.1</td>
</tr>
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<td>*</td>
<td>*</td>
<td>*</td>
<td>7.4</td>
</tr>
<tr>
<td>*</td>
<td></td>
<td>4.2</td>
<td>5.7</td>
</tr>
<tr>
<td>Mature, Tas., Vic</td>
<td>*</td>
<td>5.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Regrowth, Tasmania</td>
<td>102</td>
<td>*</td>
<td>5.5</td>
</tr>
<tr>
<td>Regrowth, Tasmania</td>
<td>69</td>
<td>*</td>
<td>6.0</td>
</tr>
<tr>
<td>Regrowth, Tasmania</td>
<td>54</td>
<td>*</td>
<td>7.2</td>
</tr>
<tr>
<td>Regrowth, Tasmania</td>
<td>36</td>
<td>*</td>
<td>5.8</td>
</tr>
</tbody>
</table>

*Data not available

Published data on hardness ranges from 4.2-5.0 kN for green material and 5.5-7.4 kN for dried material. Innes (2007), in a study of different age classes (36-102 years) reported the hardest material came from the second youngest age class (54 years), which was also the most dense.

2.1.1.8 Stability

Table 5: Shrinkage values for *E. obliqua*

<table>
<thead>
<tr>
<th>Material</th>
<th>Age (yrs)</th>
<th>% Shrinkage before Reconditioning</th>
<th>% Shrinkage after Reconditioning</th>
<th>Unit Shrinkage before Reconditioning</th>
<th>Reference</th>
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</thead>
<tbody>
<tr>
<td>Mature; Vic., NSW</td>
<td>*</td>
<td>11</td>
<td>5</td>
<td>6.5</td>
<td>3.5</td>
</tr>
<tr>
<td>*</td>
<td></td>
<td>11.3</td>
<td>5.65</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>*</td>
<td></td>
<td>11</td>
<td>5.5</td>
<td>6.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Mature, NSW, Vic, Tas</td>
<td>*</td>
<td>11.3</td>
<td>5.1</td>
<td>6.3</td>
<td>3.3</td>
</tr>
<tr>
<td>Victoria</td>
<td>15-25</td>
<td>10.9</td>
<td>4.9</td>
<td>6.6</td>
<td>3.4</td>
</tr>
</tbody>
</table>

*Data not available

From Table 5 Kingston & Risdon (1961) observed higher unit shrinkage values for trees from the mature resource compare with trees aged 15-25. The study by Innes (2007) measured the unconfined radial shrinkage by monitoring the width and weight of 0.8mm thick end-grain wafers as they dried naturally in the laboratory. The results ranged from 4.2-3.1% with no significant difference observed between age-classes. There was a significant difference in shrinkage in thickness of boards (except comparing the 102 & 69 age classes). The youngest trees in the study (36 years) had the lowest levels of shrinkage in terms of thickness & width (10.4 & 7.1%) respectively, compared to 13.3 & 8.6% for material from 102 age class). Material with the highest density (54 years) also had the highest shrinkage rates (14.4 & 8.8%).
2.1.1.9 Durability

*E. obliqua* has a durability rating of Class 3 in ground (5-15 years) (moderate durability), Class 3 above ground (15-40 years), but is rated as non-durable for marine applications (Class 4, 1-5 years) (Bootle, 2005). The sapwood is susceptible to lyctid borers, and termite resistance is low (Bootle, 2005; Tasmanian Timber, 2007a).

2.1.1.10 Adhesive bonding

Messmate forms strong, solid bonds with most commonly used adhesives (Tasmanian Timber, 2007a).

2.1.1.11 Bending

Bootle (2005) reports that this species is suitable for steam bending.

2.1.1.12 Machining & finishing

Timber from *E. obliqua* machines and finishes well, and is commonly used in furniture and flooring (Tasmanian Timber, 2007a).

2.1.1.13 Colour

This timber is naturally light in colour, ranging from straw blonde to reddish brown, sometimes with various shades of cream and pink (Tasmanian Timber, 2007a).

2.1.1.14 Staining

Being naturally light colored, this timber can be stained a wide range of colors, and takes stains and other finishes well (Tasmanian Timber, 2007a).
2.1.2 Shining gum (Eucalyptus nitens)

2.1.2.1 Introduction

Common Names – shining gum

This species was first described in 1899 by Dean & Maiden (ANBG 2008c), and may grow to heights of 70m and 1.8m DBH. The name arises from the shiny appearance of the creamy white bark, green leaves, buds and fruit (Nicholls & Pederick, 1979; DPI, 2000), nitens being Latin for shiny.

This is a frost resistant and fast growing eucalypt species which is naturally resistant to many insect pests of eucalypts. These are some of the reasons it is now one of the major plantation species in Tasmania and other countries (DPI 2000; Tasmanian Timber 2007b; Virginia Tech 2007). Its natural range is 800-1300m above sea level in the Victorian Alps, coastal area of southern NSW tablelands and northern NSW mountain ranges, with a preference for cool wet slopes and loamy soil (DPI, 2000; Bootle, 2005). Satisfactory growth has been demonstrated on a range of moderately fertile soils derived from basalt, shale, granite or sandstone (DPI, 2000). Better growth in most soils is obtained when is clay is present from a depth of 1m (DPI, 2000).

Growth rates in the range of 20-30 m³/ha/yr are common, and up to 50m³/ha/yr has been reported. This species can produce pulp logs in 10-15 years, and saw logs in 20-30 years. While more drought tolerant than other eucalypts, growth is restricted on drier sites, with a minimum rainfall of 700 mm/yr required for optimum growth (DPI, 2000).

Seedlings, juvenile and mature trees are highly resistant to frost, snow and exposure, with stocks from central Victoria and northern NSW known to be more resistant to frost than stocks from southern NSW (DPI, 2000).

The widely scattered natural populations has led to a number of distinct genetic stocks (provenances) becoming established (Nicholls & Pederick, 1979; DPI, 2000). There has been considerable interest in determining which stocks are suited for plantation conditions, and also in cross breeding to incorporate a number of desirable traits (fast growth, insect & frost resistance, fibre yield) into one strain.

The heartwood is generally a light straw colour, but can range from brown or blonde to pink (DPI, 2000; Tasmanian Timber, 2007b). Sapwood may not be as readily distinguishable from heartwood as in other eucalypts (Bootle, 2005). Timber has a medium texture, and grain is generally straight (DPI, 2000; Bootle, 2005).

The fibre from this species is highly desirable for use in the pulp and paper industry due to reasonably high fibre yield from the tree and naturally light colour (which therefore requires less effort to bleach it) (DPI, 2000; Tasmanian Timber, 2007b). This species seasons well, and has been used for a range of timber products including flooring and furniture. The timber is suitable for a range of building applications including framing, trusses and glue-laminated/nail plated beams. Being light in colour it can be stained to a wide range of darker colours. It also machines to a smooth finish, which combined with its ability to take a stain has seen this species used in flooring and joinery applications (DPI, 2000; Tasmanian Timber, 2007b). Nitens is one of the few plantation grown hardwoods available commercially (Tasmanian Timber, 2007b).
### 2.1.2.2 Stiffness & strength (MOE & MOR)

**Table 6: MOE data for *E. nitens***

<table>
<thead>
<tr>
<th>Mature (M) / Plantation (P)</th>
<th>Location</th>
<th>Age</th>
<th>Green</th>
<th>Dry</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>Victoria</td>
<td>*</td>
<td>10</td>
<td>13</td>
<td>Bootle 2005</td>
</tr>
<tr>
<td>M</td>
<td>Victoria</td>
<td>*</td>
<td>10</td>
<td>13</td>
<td>Bolza &amp; Kloot 1963</td>
</tr>
<tr>
<td>P</td>
<td>Tas., Victoria</td>
<td>15-29</td>
<td></td>
<td>11.5</td>
<td>Yang &amp; Waugh 1996a</td>
</tr>
<tr>
<td>P</td>
<td>Victoria</td>
<td>20</td>
<td>10.9</td>
<td>13.2</td>
<td>McKimm et al 1988</td>
</tr>
<tr>
<td>P</td>
<td>Victoria</td>
<td>12</td>
<td></td>
<td>13.9</td>
<td>Harwood et al. 2005</td>
</tr>
<tr>
<td>P</td>
<td>(Western provenance)</td>
<td>8.5</td>
<td>7.6</td>
<td>8.9</td>
<td>McKimm 1985</td>
</tr>
<tr>
<td>P</td>
<td>(Errinundra provenance)</td>
<td>8.5</td>
<td>8.1</td>
<td>9.0</td>
<td>McKimm 1985</td>
</tr>
<tr>
<td>P</td>
<td>(NSW Southern provenance)</td>
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<td>7.3</td>
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<td>McKimm 1985</td>
</tr>
<tr>
<td>P</td>
<td>(NSW Northern, BT provenance)</td>
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<td>7.5</td>
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<td>McKimm 1985</td>
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<tr>
<td>P</td>
<td>(NSW Northern, ME provenance)</td>
<td>8.5</td>
<td>8.3</td>
<td>10.4</td>
<td>McKimm 1985</td>
</tr>
<tr>
<td>P</td>
<td>Tasmania</td>
<td>8</td>
<td></td>
<td>10.6</td>
<td>Harwood et al. 2005</td>
</tr>
<tr>
<td>P</td>
<td>Tasmania</td>
<td>8</td>
<td></td>
<td>9.0</td>
<td>Farrell et al 2008</td>
</tr>
</tbody>
</table>

*Data not available

*Value is the average of an outer-wood and inner-wood sample

*Value obtained by in-grade testing, not testing of small clears (as for all other figures)*

**Table 7: MOR data for *E. nitens***

<table>
<thead>
<tr>
<th>Material</th>
<th>Age</th>
<th>Green</th>
<th>Dry</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mature, Victoria</td>
<td>*</td>
<td>62</td>
<td>99</td>
<td>Bootle 2005</td>
</tr>
<tr>
<td>Plantation, Tas., Victoria</td>
<td>15-29</td>
<td></td>
<td>87</td>
<td>Yang &amp; Waugh 1996a</td>
</tr>
<tr>
<td>Plantation, Tas</td>
<td>13-15</td>
<td></td>
<td>55.5</td>
<td>Farrell et al 2008</td>
</tr>
<tr>
<td>Plantation, Tas</td>
<td>8</td>
<td></td>
<td>45.3</td>
<td>Farrell et al 2008</td>
</tr>
<tr>
<td>Mature, Victoria</td>
<td>*</td>
<td>62</td>
<td>99</td>
<td>Bolza &amp; Kloot 1963</td>
</tr>
<tr>
<td>Plantation, Victoria</td>
<td>20</td>
<td>71.3</td>
<td>95.3</td>
<td>McKimm et al 1988</td>
</tr>
<tr>
<td>Plantation (Western provenance)</td>
<td>8.5</td>
<td>51.55</td>
<td>79</td>
<td>McKimm 1985</td>
</tr>
<tr>
<td>Plantation (Errinundra provenance)</td>
<td>8.5</td>
<td>61.3</td>
<td>81.65</td>
<td>McKimm 1985</td>
</tr>
<tr>
<td>Plantation (NSW Southern provenance)</td>
<td>8.5</td>
<td>54.35</td>
<td>74.8</td>
<td>McKimm 1985</td>
</tr>
<tr>
<td>Plantation (NSW Northern, BT provenance)</td>
<td>8.5</td>
<td>57.25</td>
<td>76.3</td>
<td>McKimm 1985</td>
</tr>
<tr>
<td>Plantation (NSW Northern, ME provenance)</td>
<td>8.5</td>
<td>59.85</td>
<td>83.55</td>
<td>McKimm 1985</td>
</tr>
</tbody>
</table>

*Data not available

*Value is the average of an outer-wood and inner-wood sample

*Value obtained by in-grade testing, not testing of small clears (as for all other figures)*
In a study of plantation material from Victoria (12 years old) and Tasmania (8 years old), Harwood et al. (2005) reported that defects (primarily knots) reduced the MOE values by an average of 2 GPa compared to defect free samples. Around 40% of the material taken for testing had knots as a result of the young age (small diameter) of the logs used, and also that the plantations were primarily intended for pulp production and therefore un-thinned and un-pruned. From defect free samples, Tasmanian material in the study showed lower MOE values (8.85-9.74 GPa) than Victorian material (10.31 GPa). This may have been due to the difference in ages, or differences between provenances. This study also found that material tested from the outer parts of the stem were stiffer (had higher MOE values) than material taken from closer to the pith. Samples taken further up the tree also tended to have higher MOE values.

McKimm (1985) investigated potential differences between 5 Victorian and NSW provenances of *E. nitens*, and found provenance had a significant effect on MOE for dry material but not green. This situation was reversed for MOR, with significant differences in MOR values for green but not dry material. The study also reports that values obtained from these 8.5 year old trees were generally lower than reported values based on older, more mature material (as evident from Table 6 & Table 7). The author also found that MOE for both green and dry material, and MOR for green material, was significantly higher in outer wood than in innerwood. MOR for dry material did not differ between innerwood and outerwood.

McKimm et al. (1988) studied *E. nitens* from a 20 year old Victorian plantation, and found that this material had similar MOE & MOR values to reported values for older, more mature *E. nitens* (Bolza & Kloot, 1963), but higher values than given for younger *E. nitens* (eg in McKimm 1985).

In a study involving 15-29 year old plantation material from sites in Tasmania and Victoria, Yang & Waugh (1996a) found the oldest trees had the highest MOE & MOR values. Using in-grade testing procedures on 2.4m boards, this study found no difference in MOE or MOR between outerwood (50mm from cambium) and innerwood (20mm from pith) material. There was a negative correlation between the abundance of knots and MOR but not MOE in this material.

### 2.1.2.3 Strength grouping

Strength grouping for nitens is given as S4 for green and SD4 for dried material (Timber Data File 2004; Tasmanian Timber, 2007b). Joint grouping for this species is J3 for green and JD3 for dry material (Timber Data File 2004; Tasmanian Timber, 2007b).

### 2.1.2.4 Maximum crushing strength

Maximum crushing strength has been quoted as 31-34 MPa for green material and 54-58 MPa for dry material (McKimm et al., 1988; Bootle, 2005).

### 2.1.2.5 Impact (Izod) value

Izod values are given as 12-15 J for green and 4-8.5 J for re-conditioned material (McKimm, 1985; Bootle, 2005; Tasmanian Timber, 2007b). In a study of different provenances, McKimm (1985) did not find any significant difference in Izod value provenances or between samples from inner wood and outer wood.
2.1.2.6 Denison toughness value

Toughness values have been reported as 22.6-27.75 J for green and 10.1-15.8 J for reconditioned material (McKimm, 1985) from different provenances. There was no difference between inner wood and outer wood samples in this study.

2.1.2.7 Hardness

Table 8: Hardness data for *E. nitens*

<table>
<thead>
<tr>
<th>Material</th>
<th>Age (yrs)</th>
<th>Green</th>
<th>Dry 12% MC</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mature, Victoria</td>
<td>*</td>
<td>4.8</td>
<td>5.8</td>
<td>Bootle 2005</td>
</tr>
<tr>
<td>*</td>
<td>*</td>
<td>5.8</td>
<td>*</td>
<td>Timber Data File 2004</td>
</tr>
<tr>
<td>*</td>
<td>*</td>
<td>*</td>
<td>4.7</td>
<td>Tasmanian Timber, 2007b</td>
</tr>
<tr>
<td>Mature, Victoria</td>
<td>*</td>
<td>5</td>
<td>6</td>
<td>Bolza &amp; Kloot 1963</td>
</tr>
<tr>
<td>Plantation (Western provenance)</td>
<td>8.5</td>
<td>3.9</td>
<td>3.6</td>
<td>Mckimm 1985</td>
</tr>
<tr>
<td>Plantation (Errinundra provenance)</td>
<td>8.5</td>
<td>4.3</td>
<td>3.9</td>
<td>Mckimm 1985</td>
</tr>
<tr>
<td>Plantation (NSW Southern provenance)</td>
<td>8.5</td>
<td>4.2</td>
<td>3.6</td>
<td>Mckimm 1985</td>
</tr>
<tr>
<td>Plantation (NSW Northern, BT provenance)</td>
<td>8.5</td>
<td>4.3</td>
<td>4.4</td>
<td>Mckimm 1985</td>
</tr>
<tr>
<td>Plantation (NSW Northern, ME provenance)</td>
<td>8.5</td>
<td>4.2</td>
<td>4.5</td>
<td>Mckimm 1985</td>
</tr>
<tr>
<td>Plantation, Tasmania</td>
<td>8</td>
<td>*</td>
<td>4.0</td>
<td>Farrell et al 2008</td>
</tr>
</tbody>
</table>

* Data not available

In a study of *E. nitens*, McKimm (1985) found that while there were no significant differences in hardness in green material from the different provenances examined, there were significant differences for dried material. The values for hardness of green material in this study were lower than reported values from other sources, which may due to the young age of the trees (8.5 years). The values shown in Table 8 suggests that material from younger trees may have a lower hardness rating.
### 2.1.2.8 Density

#### Table 9: Density Data for *E. nitens*

<table>
<thead>
<tr>
<th>Material</th>
<th>Age (yrs)</th>
<th>Density (kg/m&lt;sup&gt;3&lt;/sup&gt;)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>matures, Victoria</td>
<td>*</td>
<td>Basic: 530</td>
<td>Bootle 2005</td>
</tr>
<tr>
<td></td>
<td>*</td>
<td>Green: 1050</td>
<td></td>
</tr>
<tr>
<td></td>
<td>*</td>
<td>Dry: 700</td>
<td></td>
</tr>
<tr>
<td></td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plantation, Victoria</td>
<td>29</td>
<td>588° -521&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Yang &amp; Waugh 1996</td>
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<tr>
<td></td>
<td>24</td>
<td>480° -477&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Yang &amp; Waugh 1996a</td>
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<tr>
<td></td>
<td>20</td>
<td>488</td>
<td>McKimm et al 1988</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>468° -450&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Yang &amp; Waugh 1996a</td>
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<td>Plantation – Heartwood, NZ</td>
<td>15</td>
<td>449</td>
<td>Lausberg et al 1995</td>
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<td>15</td>
<td>503</td>
<td>Lausberg et al 1995</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>*</td>
<td>Farrell et al 2008</td>
</tr>
<tr>
<td>Plantation, Tasmania</td>
<td>15</td>
<td>493</td>
<td>Harwood et al. 2006</td>
</tr>
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<td></td>
<td>12</td>
<td>483</td>
<td>McKimm &amp; Ilic 1987</td>
</tr>
<tr>
<td>Plantation (Western provenance)</td>
<td>8.5</td>
<td>454</td>
<td>McKimm &amp; Ilic 1987</td>
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<td>Plantation (Errinundra provenance)</td>
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<td>502</td>
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<td></td>
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<td>8.5</td>
<td>499</td>
<td>McKimm &amp; Ilic 1987</td>
</tr>
</tbody>
</table>

* No data available
<sup>1</sup> Average figure for outer-wood samples
<sup>2</sup> Average figure for inner-wood samples

McKimm et al. (1988) investigated the density of 20 year old Victorian plantation material and report that the values obtained for basic and air-dried density were lower than for older, more mature trees. This may have been due to the higher proportion of sapwood in the younger material, which was determined as 20% of the log volume.
In a trial looking at provenance variation in *E. nitens*, McKimm & Illic (1987) reported that while basic density decreased in the 1/3 of the stem closest to the pith, it then increased for the remaining 2/3 which was taken as an effect of sapwood on basic density in vigorously growing trees. In mature trees basic density of sapwood was generally lower than that of heartwood. There were no significant differences between provenances in terms of basic density.

McKimm (1985), using the same provenances but different samples, also found that basic density and dry density in samples from the outerwood was higher than from samples taken from innerwood. This study does not define how much of the outerwood was sapwood, but it would be expected that in young, fast growing trees such as these there would be a relatively large sapwood band.

Yang & Waugh (1996a) studied *E. nitens* from plantations in Tasmania & Victoria (aged from 15-29 years old), and reported that basic density of samples from outer wood was significantly higher for each site than samples of innerwood. The outerwood samples were taken 50mm from the cambium, and innerwood taken 20mm from the pith. Basic density also increased with height, but there was no significant effect of age.

### 2.1.2.9 Stability

**Table 10: Shrinkage values for *E. nitens***

<table>
<thead>
<tr>
<th>Material</th>
<th>Age (yrs)</th>
<th>% Shrinkage before Reconditioning</th>
<th>% Shrinkage after Reconditioning</th>
<th>Unit Shrinkage before Reconditioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mature, Victoria</td>
<td>* 9 5</td>
<td>6 3</td>
<td>* 0.33</td>
<td>* 0.22</td>
</tr>
<tr>
<td>*</td>
<td>9.4 4.7</td>
<td>* *</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Mature, Victoria Plantation, NZ</td>
<td>* 9.4 4.9</td>
<td>5.9 3</td>
<td>0.33</td>
<td>0.22</td>
</tr>
<tr>
<td>15</td>
<td>5.15 4.87</td>
<td>* *</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

* Data not available

McKimm et al. (1988) report that material from 20 year old Victorian plantation timber had higher tangential and radial shrinkage rates (6.92% and 4.65% respectively) than values based on material from older trees, but do not indicate whether this was for green, air-dried material.

### 2.1.2.10 Laminated Veneer Lumber

Gaunt et al. (2002) tested the production of LVL using veneer taken from unpruned second logs of 15 year old plantation material in New Zealand and reported satisfactory performance in this application. The LVL was stiffer than an equivalent product from pine. The high incidence of knots would have prevented the material from being used as saw log.
2.1.2.11  **Durability**

*E. nitens* is rated Class 4 (1-4 years) in ground or marine applications, which is essentially non-durable. It is more durable above ground, being rated as Class 3 for these applications (5-15 years). The sapwood is susceptible to lyctid borers, and termite resistance is low (Bootle, 2005; Tasmanian Timber, 2007b).

2.1.2.12  **Adhesive Bonding**

*E. nitens* is reported to form strong bonds with commonly used adhesives (Tasmanian Timber, 2007b).

2.1.2.13  **Bending**

*E. nitens* is suitable for steam bending (Tasmanian Timber, 2007b).

2.1.2.14  **Machining & Finishing**

*E. nitens* is not as dense as some other hardwoods used in joinery, but machines well and produces a high quality finish (Tasmanian Timber, 2007b).

2.1.2.15  **Colour**

The timber form this species is naturally blonde, and can have tones ranging from pink to pale brown or yellow (Bootle, 2005; Tasmanian Timber, 2007b). The material is prone to discoloration in the form of black specks or pin stripes, which is associated with damage from pin-hole borers (Bootle, 2005).

2.1.2.16  **Staining**

Being naturally light in colour, shining gum can be stained a wide range of colors, and takes a wide range of stain and commercial finishes (Tasmanian Timber, 2007b).
2.1.3 Tasmanian blue gum (*Eucalyptus globulus*)

2.1.3.1 Introduction

Common Names – Southern blue gum, Tasmanian blue gum.

This species was first identified and collected by the French botanist Jacques-Julien Horton de Labillardiere in 1792, on an expedition to the east coast of Tasmania (ANBG, 2007e). A number of subspecies are now formally recognized. Naturally distributed in the cooler areas of southern Australia, predominantly Victoria and Tasmania, this eucalypt has been introduced into many other countries (Bootle, 2005; Tasmanian Timber, 2007c; ANBG, 2007d,e).

The species name comes from the round ball like fruit, globulus being Latin for spherical. It is generally found up to 400m above sea level in both wet and dry sclerophyll forests (ANBG, 2007d,e; Tasmanian Timber, 2007c), with best growth achieved in cool damp areas with well drained soils (ANBG, 2007d). The mature trees can grow up to 70m tall, with diameters of up to 2m (Tasmanian Timber, 2007c). The waxy grey/blue colour of the juvenile foliage gives rise to the common name, and also contain the highest levels of essential oils such as cineole and phellandrene which are commercially harvested for use as an antiseptic, fragrance and in aromatherapy (Bootle, 2005; ANBG, 2007d,e; Tasmanian Timber, 2007c). This is a fast growing species (up to 2m in height per year) capable of tolerating a wide range of environmental conditions, which is why it has become the eucalypt most commonly planted overseas (ANBG, 2007d,e; Tasmanian Timber, 2007c), where it used as a source of both pulp fiber and timber. With pulp yields of up to 20-30m$^3$/ha/yr, *E. globulus* plantations are widely used for fibre production (Tasmanian Timber, 2007c).

Heartwood is generally pale straw to pale brown, can have pink, green or bluish tones. The sapwood band can be larger than in other eucalypts, and not always easy to distinguish from heartwood by eye. Texture is usually medium but even, often with interlocked grain (Bootle, 2005). The density, strength and durability of this timber make it particularly suited to heavy structural applications, and from early settlement to the modern day around the world it has been used in wharf pilings, mine props, railway sleepers, framing, bridges and power poles (ANBG 2007d & e; Tasmania Timber 2007). While care needs to be taken in drying to prevent checking, its natural hardness and strength properties has led to an increasing interest in using this timber in flooring and furniture (Bootle 2005, Tasmanian Timber 2007c).
### 2.1.3.2 Stiffness & strength (MOE & MOR)

#### Table 11: MOE data for *E. globulus*

<table>
<thead>
<tr>
<th>Material</th>
<th>Age (yrs)</th>
<th>MOE (GPa)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mature, Victoria</td>
<td>*</td>
<td>11/15</td>
<td>20/20</td>
</tr>
<tr>
<td>Mature, Victoria</td>
<td>*</td>
<td>11/15</td>
<td>20/20</td>
</tr>
<tr>
<td>Plantation, Tasmania</td>
<td>19-33</td>
<td>*</td>
<td>16.9</td>
</tr>
<tr>
<td>Plantation, Victoria</td>
<td>15</td>
<td>*</td>
<td>11.5</td>
</tr>
<tr>
<td>Plantation, SA</td>
<td>10</td>
<td>9.4</td>
<td>22.4</td>
</tr>
<tr>
<td>Plantation, WA</td>
<td>9</td>
<td>*</td>
<td>14.7</td>
</tr>
<tr>
<td>Plantation, Victorian</td>
<td>8</td>
<td>*</td>
<td>15.0</td>
</tr>
<tr>
<td>Plantation, Tasmania</td>
<td>8</td>
<td>*</td>
<td>14.3</td>
</tr>
</tbody>
</table>

* Data unavailable

#### Table 12: MOR data for *E. globulus*

<table>
<thead>
<tr>
<th>Material</th>
<th>Age (yrs)</th>
<th>MOR (MPa)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mature, Victoria</td>
<td>*</td>
<td>78/84</td>
<td>146/146</td>
</tr>
<tr>
<td>Plantation, Victoria</td>
<td>15 years</td>
<td>*</td>
<td>96.4</td>
</tr>
<tr>
<td>Plantation, Tasmania</td>
<td>19-33</td>
<td>*</td>
<td>121</td>
</tr>
<tr>
<td>Mature, Victoria</td>
<td>*</td>
<td>84</td>
<td>146</td>
</tr>
</tbody>
</table>

* Data unavailable

Table 11 and Table 12 show that MOR (and to lesser degree MOE) from young plantation timber tends to be lower than that from mature trees.

From a study of plantation timber, Ashley & Ozarska (2000) report the values obtained for both MOR & MOE to be higher than other timbers traditionally used in furniture making. This has implications for design, with the extra strength of blue gum allowing designs not previously possible. However, these authors also noted that there was considerable variation in the values from young trees compared to material from mature trees.

The study of Yang & Waugh (1996b), on Tasmanian plantation *E. globulus* (19-33 years old) showed significantly higher MOR values in material from bottom logs compared to second and third logs. MOR was strongly correlated with basic density. Small clear samples from the outer edge of the logs (50 mm from cambium) had a higher MOR than samples from inner sections of the log (20mm from the pith), possibly due to the presence of occluded knots in the inner heartwood. These are found in the inner heartwood due to the self-pruning nature of the plantation material.

There was also a significant correlation with between density and MOE in this study, but no significant effect was observed according to position of the board in the log. A correlation between density and MOE for plantation blue gum was also reported by Yang & Evans (2003).
Harwood et al. (2005) in another study of Tasmanian plantation *E. globulus* (8-9 years old) also report that samples from outer sections of the log were stiffer than samples taken closer to the core of the tree. As with Yang & Waugh (1996b), the presence of knots was given as one of the key factors affecting the observed MOE.

### 2.1.3.3 Strength grouping

Strength grouping for blue gum is given as S3 for green and SD2 for dried material. Joint grouping for blue gum is J1-J2 for green and JD1-JD2 for dry material (Timber Data File 2004, Tasmanian Timber 2007c).

Studies by Yang & Waugh (1996a) on plantation material from Tasmania indicate it would be classed as SD3 (based on testing with small clears). However, using in-grade testing on larger pieces produced a grade of F8, which is lower than would be expected from SD3 material (normally F14). This was attributed to the incidence of large knots in younger plantation material, which were not present in the small clears, but affected the performance of larger boards.

### 2.1.3.4 Maximum crushing strength

Bootle (2005) reports crushing strength for green blue gum as 40 MPa, and 83 MPa for dry material.

### 2.1.3.5 Impact (Izod) value

### 2.1.3.6 Density

**Table 13: Density data for *E. globulus***

<table>
<thead>
<tr>
<th>Material</th>
<th>Age (yrs)</th>
<th>Basic</th>
<th>Green</th>
<th>Dry 12% MC</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mature, Victoria</td>
<td></td>
<td>700</td>
<td>1150</td>
<td>900</td>
<td>Bootle 2005</td>
</tr>
<tr>
<td>*</td>
<td></td>
<td>*</td>
<td>*</td>
<td>1150</td>
<td>Timber Data File 2004</td>
</tr>
<tr>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td>1100</td>
<td>Tasmanian Timber 2007c</td>
</tr>
<tr>
<td>Mature, Victoria</td>
<td></td>
<td></td>
<td></td>
<td>1100</td>
<td></td>
</tr>
<tr>
<td>Mature, Tas., Victoria</td>
<td></td>
<td>738</td>
<td>*</td>
<td>980</td>
<td>Bolza &amp; Kloot 1963</td>
</tr>
<tr>
<td>Mature, SA., Victoria</td>
<td></td>
<td>681</td>
<td>*</td>
<td>872</td>
<td>Kingston &amp; Risdon 1961</td>
</tr>
<tr>
<td>Plantation, Tasmania</td>
<td>33</td>
<td>604</td>
<td>*</td>
<td></td>
<td>Yang &amp; Waugh 1996b</td>
</tr>
<tr>
<td>Victoria</td>
<td>17-23</td>
<td>561</td>
<td>*</td>
<td>758</td>
<td>Kingston &amp; Risdon 1961</td>
</tr>
<tr>
<td>Plantation, Tasmania</td>
<td>21</td>
<td>604</td>
<td>*</td>
<td>*</td>
<td>Yang &amp; Waugh 1996b</td>
</tr>
<tr>
<td>Plantation, Tasmania</td>
<td>19</td>
<td>554</td>
<td>*</td>
<td>*</td>
<td>Yang &amp; Waugh 1996b</td>
</tr>
<tr>
<td>Plantation, Victoria</td>
<td>15</td>
<td></td>
<td></td>
<td>716</td>
<td>Ashley &amp; Ozarska 2000</td>
</tr>
<tr>
<td>Plantation, SA</td>
<td>10</td>
<td></td>
<td></td>
<td>698</td>
<td>Yang &amp; Ilic 2002</td>
</tr>
<tr>
<td>Plantation, WA</td>
<td>9</td>
<td>511</td>
<td>*</td>
<td></td>
<td>Harwood et al. 2005</td>
</tr>
<tr>
<td>Plantation, Tasmania</td>
<td>8</td>
<td>413</td>
<td>*</td>
<td></td>
<td>Harwood et al. 2005</td>
</tr>
<tr>
<td>*</td>
<td></td>
<td>530</td>
<td>*</td>
<td>*</td>
<td>Harwood et al. 2005</td>
</tr>
</tbody>
</table>

* Data not available

From tabulated data, basic density (and dry density) appears to be lower in younger material than that from mature trees. Yang & Waugh (1996b) also reported that green density of young plantation material in their study was lower than the reported values for material from mature tree.

### 2.1.3.7 Hardness

**Table 14: Hardness data for *E. globulus***

<table>
<thead>
<tr>
<th>Material</th>
<th>Age (yrs)</th>
<th>Green</th>
<th>Dry</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mature, Victoria</td>
<td></td>
<td>7.3</td>
<td>12</td>
<td>Bootle 2005</td>
</tr>
<tr>
<td>*</td>
<td></td>
<td>*</td>
<td>11.5</td>
<td>Timber Data File 2004</td>
</tr>
<tr>
<td>*</td>
<td></td>
<td>7</td>
<td>10</td>
<td>Tasmanian Timber 2007c</td>
</tr>
<tr>
<td>Mature, Victoria</td>
<td></td>
<td>7</td>
<td>11</td>
<td>Bolza &amp; Kloot 1963</td>
</tr>
</tbody>
</table>

There appears to be limited published data for hardness values for this species. Published data show a range of 10-12 Kn for dry material. It is generally known to have higher Janka hardness values than other eucalypts (Tasmanian Timber, 2007c) compared with 5-6 Kn for *E. nitens* and 5.5-7.4 for *E. obliqua*. 
2.1.3.8 Stability

Table 15: Shrinkage values for *E. globulus*

<table>
<thead>
<tr>
<th>Material</th>
<th>Age (yrs)</th>
<th>Tan.</th>
<th>Radial</th>
<th>Tan.</th>
<th>Radial</th>
<th>Unit Shrinkage Per 1% MC Change (5-25% MC)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mature, Victoria</td>
<td>*</td>
<td>12</td>
<td>6</td>
<td>7</td>
<td>4</td>
<td>*</td>
<td>Bootle 2005</td>
</tr>
<tr>
<td>Mature, Tas., Vic.</td>
<td>*</td>
<td>7.7</td>
<td>6.1</td>
<td>7.2</td>
<td>5.3</td>
<td>*</td>
<td>Kingston &amp; Risdon 1961</td>
</tr>
<tr>
<td>Mature SA., Vic.</td>
<td>*</td>
<td>7.7</td>
<td>3.85</td>
<td>10</td>
<td>5</td>
<td>0.4</td>
<td>Timber Data File 2004</td>
</tr>
<tr>
<td>Plantation, Victoria</td>
<td>17-23</td>
<td>14.4</td>
<td>6.9</td>
<td>9.4</td>
<td>4.6</td>
<td>0.39</td>
<td>Tasmanian Timber 2007c</td>
</tr>
<tr>
<td>Victoria Plantation, Vic.</td>
<td>15</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>0.46</td>
<td>0.35</td>
<td>Ashley &amp; Ozarska 2000</td>
</tr>
</tbody>
</table>

* Data not available

Ashley & Ozarska (2000) reported that the shrinkage values obtained for plantation *E. globulus* are high compared to other eucalypt species.

2.1.3.9 Durability

*E. globulus* is classed as moderately durable, with a durability rating of Class 3 in ground (5-15 years), Class 2 above ground (15-40 years) and Class 4 in marine applications (1-5 years). The sapwood is susceptible to lyctid borers, and termite resistance is low (Bootle, 2005; Tasmanian Timber, 2007c).

2.1.3.10 Adhesive bonding

Ozarska & Ashley (1998) report that 15 year old *E. globulus* from Victorian plantations performed well in a range of tests which examined adhesive bonding capacity of this material. Tests performed included shear testing and cycling of humidity conditions to examine bond strength, and creep tests to examine performance of joints. Plantation *E. globulus* performed well in all tests.

2.1.3.11 Bending

*E. globulus* is considered good for bending applications (Tasmanian Timber 2007c).

2.1.3.12 Machining & finishing

Ozarska & Ashley (1998) report that dried plantation *E. globulus*, machined using different blades under different cutting regimes, produced a high quality surface, comparable or better than other hardwoods. In planing, best results were obtained by incorporating a 0.5mm chip breaker into the cutting blade.
2.1.3.13 Colour

*E. globulus* ranges from pale straw to brown in colour, often with other hues including blue, pink and green/grey (Tasmanian Timber 2007c). The sapwood tends to be lighter in colour in dried material, but can be difficult to distinguish visually from heartwood.

2.1.3.14 Staining

Ozarska & Ashley (1998) found that plantation *E. globulus* from Victoria took a range of stains and lacquers well, and extractives did not discolour the stain once applied.
2.2 Queensland & New South Wales species: Gympie Messmate (E. cloeziana), Blackbutt (E. pilularis), Spotted Gum (Corymbia citriodora C. maculata) & Dunns White Gum (E. Dunnii).

(W. Atyeo)

2.2.1 Introduction

There has been a significant investment in hardwood plantations in Queensland and NSW, with over 37,000 and 55,000 ha respectively now planted in these two states (Parsons et al., 2006). The Department of Primary Industries and Fisheries (DPIF) is collaborating in this project to investigate four prominent plantation hardwoods grown in north-eastern Australia as identified in heading 2.2.

This review concentrates on the comparative properties of sapwood and heartwood, although literature concerning heartwood only has been reviewed where the former was not available.

2.2.2 Gympie Messmate (Eucalyptus cloeziana)

Gympie messmate occurs naturally in eastern Queensland in a number of distinct locations from near Gympie in the south to Cooktown in the north. In the Gympie and Cardwell areas it occurs as tall, open forest, while elsewhere it is found in open forest or woodland formation (Boland et al., 1984). The timber from native Gympie messmate has traditionally been used for heavy construction, rail sleepers, post and poles (Bootle, 2005). Gympie messmate has been selected as a species for plantation establishment in Queensland due to its suitability to local conditions, good stem form and potentially favourable wood properties (Muneri et al., 1998). While studies on early plantation material have revealed low mean annual increment (MAI) and poor grade recovery (Dickinson et al., 2000), more recent work has shown good grade recovery of both structural and appearance grades (McGavin et al., 2007). Dickson et al. (2000) expect that the performance of plantation material from this (and other) species will be further improved with the application of current practices of seed selection, plantation establishment and silviculture.

2.2.2.1 Sapwood / heartwood proportions

Research findings on sapwood/heartwood ratios in Gympie messmate are summarised in Table 16.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Type</th>
<th>% heartwood</th>
<th>Sapwood width (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Muneri et al., 1998)</td>
<td>11, 17 &amp; 46 y.o.</td>
<td>65, 69, 87</td>
<td>15, 16, 12</td>
</tr>
<tr>
<td>(Muneri and Leggate, 2000)</td>
<td>4 y.o.</td>
<td>35</td>
<td>Not reported</td>
</tr>
<tr>
<td>(Anon, 2005)</td>
<td>35 y.o.</td>
<td>Not reported</td>
<td>18</td>
</tr>
<tr>
<td>(McGavin et al., 2006)</td>
<td>8 y.o. thinnings</td>
<td>50</td>
<td>Not reported</td>
</tr>
<tr>
<td>(McGavin et al., 2007)</td>
<td>19 y.o. plantation</td>
<td>76</td>
<td>20</td>
</tr>
</tbody>
</table>
As expected, Table 16 reveals a trend to increasing heartwood content with increasing age. McGavin et al (2006), however, also noted that the sapwood width and proportion of heartwood are very much dependant on the log size and growth rate. For example, a smaller diameter suppressed tree will have a narrower sapwood band, and consequently higher heartwood proportion, than a tree of the same age with a high growth rate.

### 2.2.2.2 Density

Table 17 reports some recent density measurements for plantation Gympie messmate.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Tree type</th>
<th>Mean basic density (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Clark &amp; Hicks, 2003)</td>
<td>5 y.o. pulpwood</td>
<td>594</td>
</tr>
<tr>
<td>(McGavin et al., 2006)</td>
<td>8 y.o. thinnings</td>
<td>634</td>
</tr>
<tr>
<td>(Clark &amp; Hicks, 2003)</td>
<td>12 y.o. plantation</td>
<td>644</td>
</tr>
<tr>
<td>(Muneri et al., 1998)</td>
<td>11 y.o. plantation</td>
<td>624</td>
</tr>
<tr>
<td>(McGavin et al., 2007)</td>
<td>17 y.o. plantation</td>
<td>686</td>
</tr>
<tr>
<td>(McGavin et al., 2007)</td>
<td>46 y.o. plantation</td>
<td>769</td>
</tr>
<tr>
<td>(Bootle, 2005)</td>
<td>Mature naturally grown</td>
<td>810</td>
</tr>
</tbody>
</table>

The data in Table 17 show that the density of plantation Gympie messmate is lower than that of mature wood of this species. However, the average density of plantation Gympie messmate is higher, and its variability lower, than most other plantation hardwoods surveyed (McGavin et al., 2006).

(McGavin et al., 2006) reported radial variation of basic density, including sapwood, of 8 y.o. Gympie messmate thinnings. Heartwood density (inner to outer) ranged from 480 to 620 kg/m³, while sapwood averaged 670 kg/m³. As noted with many plantation eucalypt species, a variation of about 200 kg/m³ was found, representing some 30% of the species average density. The authors acknowledged that this level of heterogeneity was significant, but would be manageable if appropriate grading or sorting techniques were employed during processing. The higher sapwood basic density can explained by the fact that in trees of this age, the transition from juvenile to mature wood is still in progress.

Similarly, (McGavin et al., 2007) reported radial variation of basic density, including sapwood, of 19 y.o. Gympie messmate. Heartwood density (inner to outer) ranged from 640 to 740 kg/m³, while sapwood averaged 695 kg/m³. The difference in density between the sapwood and outer hardwood can be accounted for by the mean extractive content of outer heartwood of around 7% reported by these authors. The authors noted that the variation in basic density between the inner and outer heartwood is lower in Gympie messmate than in other plantation species, such as red mahogany (E. pellita), which may be advantageous in terms of wood quality performance.
2.2.2.3 Hardness

McGavin et al. (2007) found mean Janka hardness of 19 year-old Gympie messmate to be 11 kN, close to Bootle’s (2005) figure of 12 kN for mature, naturally grown wood. The authors investigated the radial variation of Janka hardness from inner heartwood through to sapwood. As expected, the radial trend of hardness from inner to outer heartwood followed the same trend as density with a significant increase of 17% from inner to outer heartwood. Sapwood tangential hardness was lower than that of the outer heartwood, an observation the authors attributed to reinforcement of the heartwood cellular structure by extractives. This trend was less evident in radial hardness, explained by stiffening from ray parenchyma in both wood types.
2.2.3 Blackbutt (*E. pilularis*)

Blackbutt occurs naturally from coastal NSW south of Bega, to Maryborough in Queensland (Boland et al., 1984, Henson and Smith, 2007). Often occurring in tall open forests of high quality, blackbutt is a key species for high quality log production in these regions. It yields high quality timber for such uses as poles, sleepers, decking, flooring, furniture and building framing (Bootle, 2005).

Blackbutt is an established plantation species on the north coast of NSW, with the first plantations beginning in 1939 (Henson and Smith, 2007). By 2007, about 15,000 ha of blackbutt plantations had been established in northern NSW (Ibid). Recently, Forests NSW have been conducting a major tree improvement program on this species, particularly to develop superior genotypes for solid wood production (Ibid). Another focus of this work is overcoming the difficulties of propagation and susceptibility to pathogens experienced with this species, typical of members of the subgenus *Monocalyptus* (Turnbull and Pryor, 1978).

2.2.3.1 Sapwood proportion

Research findings on sapwood/heartwood ratios in Blackbutt are summarised in Table 18.

Table 18: Sapwood width and heartwood proportion studies for Blackbutt.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Type</th>
<th>% Heartwood</th>
<th>Sapwood width (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(McGavin et al., 2006)</td>
<td>9 y.o. thinnings</td>
<td>63</td>
<td>15,16,12</td>
</tr>
<tr>
<td>(Anon, 2005)</td>
<td>21 y.o. plantation</td>
<td>Not reported</td>
<td>22</td>
</tr>
<tr>
<td>(Muneri et al., 2003)</td>
<td>36 y.o. (mean of treatments)</td>
<td>86</td>
<td>Not reported</td>
</tr>
</tbody>
</table>

Muneri et al. (2003) analysed the effect of a range of thinning and spacing treatments on wood properties of 36 y.o. plantation *E. pilularis*. At breast height, both sapwood width and heartwood proportion increased with declining stocking in treatments of final stocking ranging from 1500 to 87 stems per ha. All treatments showed a similar trend of decline in heartwood proportion with tree height. Average heartwood proportion ranged from 90% at ground level to 83% at half tree height, which the authors regarded as the top of the sawlog zone.

2.2.3.2 Density

McGavin et al (2006) reported radial variation of basic density, including sapwood, of 9 y.o. blackbutt thinnings. Heartwood density (inner to outer) ranged from 419 to 534 kg/m3, while sapwood averaged 582 kg/m3. The within-tree heterogeneity in density was found to be about 30% of the species average, a typical figure for plantation hardwoods of this age.
2.2.4 Spotted Gum (Corymbia citriodora, C. maculata)

Timber of the trade name spotted gum comprises four distinct taxa of the genus Corymbia: C. citriodora subsp. citriodora (lemon-scented gum); C. citriodora subsp. variagata (spotted gum); C. henryi (large-leaved spotted gum) and C. maculata (southern spotted gum) (Lee, 2007). C. citriodora subsp. citriodora occurs naturally north from Maryborough, Queensland to the Atherton Tableland; C. citriodora subsp. variagata is found southwards from Maryborough to Coffs Harbour, New South Wales, while C. maculata is the southernmost of the group, ranging from south of Coffs Harbour to Victoria (Anon., 2002). C. henryi is found on relatively infertile soils from Brisbane, Queensland, to south of Grafton, New South Wales. (ibid.). The wood from all these taxa is similar, being described by Boland et al. (1984) as strong, durable and shock resistant. Spotted gum from native forests has been favoured for general and heavy construction, as well as tool handles, transmission poles and plywood (Boland et al., 1984).

Anon. (2002) reports that spotted gum plantation timber has properties closer to those of the naturally grown timber than most plantation eucalypts. For example, the air-dry density of three year-old trees of C. citriodora subsp. citriodora was 71% that of mature timber. Shrinkage was also found to be comparable between plantation and forest grown timbers.

Anon (2002) notes that Queensland spotted gum is a suitable plantation species for a wide range of coastal and inland locations in Queensland and northern New South Wales. However, the various spotted gum taxa and provenances must be carefully matched to their environment for successful establishment. For example, coastal provenances of C. citriodora subsp. variagata and C. citriodora subsp. citriodora show good resistance to Ramularia Shoot Blight (RSB), but may be drought susceptible. Sub-coastal provenances of these taxa are less tolerant of RSB, but are more drought tolerant and can be established in sites where the annual rainfall is as low as 700 mm. Inland provenances of the above taxa, and all provenances of C. henryi are highly susceptible to RSB, and are not recommended for plantation establishment.

Pure species of spotted gums may be difficult to propagate due to infrequent and slow seed production and low amenability to vegetative propagation (Lee, 2007). One strategy to overcome this limitation, as well as the susceptibility of the pure species to disease, insect attack and frost, is hybridisation of the species with cadaga (Corymbia torelliana). However, at the time of this review Corymbia hybrid plantation establishment is in the early stages, and no literature on their wood properties has been published.

2.2.4.1 Sapwood proportion

Table 19: Sapwood properties, for Spotted gum

<table>
<thead>
<tr>
<th>Reference</th>
<th>Type</th>
<th>% heartwood</th>
<th>Sapwood width (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Anon, 2005)</td>
<td>41 y.o. plantation</td>
<td>n.a.</td>
<td>29</td>
</tr>
</tbody>
</table>

The wider-than-average sapwood band reported for plantation timber confirms observations made on native grown timber (Boland et al., 1984). The sapwood is also reported to be highly susceptible to Lyctus attack (ibid.).
## 2.2.4.2 Density

**Table 20: Density measurements on spotted gum**

<table>
<thead>
<tr>
<th>Reference</th>
<th>Type</th>
<th>Air dry density (kg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Kynaston et al., 2007)</td>
<td><em>C. citriodora subsp. citriodora</em>, 3 y.o. plantation</td>
<td>71% mature</td>
</tr>
<tr>
<td>(Kynaston et al., 2007)</td>
<td><em>C. citriodora subsp. variagata</em>, 11 y.o. plantation</td>
<td>87% mature</td>
</tr>
<tr>
<td>(Kynaston et al., 2007, Anon, 2005)</td>
<td><em>C. citriodora subsp. variagata</em>, 41 y.o. plantation</td>
<td>802 kg/m$^3$ (108% mature)</td>
</tr>
</tbody>
</table>
2.2.5 Dunn's white gum (*E. dunnii*)

Dunn's white gum is a medium to tall, smooth barked forest tree occurring naturally between north-eastern New South Wales and south-eastern Queensland (Lee et al., 2003). The species occurs in two disjunct populations: the southern near Coff's Harbour, New South Wales; and the northern along the border ranges between New South Wales and Queensland (ibid.). In its native form, Dunn's white gum is used locally for light construction (Turnbull and Pryor, 1978, Boland et al., 1984).

Dunn's white gum has been recognised internationally as a premium pulpwood species, of similar status to flooded gum (*E. grandis*), but with superior sawing properties (Smith and Henson, 2007). It has the additional advantages of being better adapted to drier or frost prone sites, and more resistant wood borers (ibid.). In northern NSW and southern Queensland, active establishment of new plantations since 1994 has seen some 39,000 ha now established (ibid.).

Defoliating insects have been reported as causing problems during the establishment of plantations, although Dunn's white gum is more resistant to wood boring insects than flooded gum (Lee et al., 2003, Smith and Henson, 2007). Recent anecdotal evidence suggests that when trees stressed by drought are further stressed by insect defoliation, attack by wood boring pests may follow (Smith and Henson, 2007).

Dunn's white gum has a reputation for splitting and collapse when grown in plantations (Lee et al., 2003). This tendency has been attributed to high growth stresses and differential shrinkage and the Forests of NSW tree breeding programme for this species has prioritised improvement of the stability of the timber during drying (Smith and Henson, 2007). Harwood et al. (2005) attempted to relate tangential shrinkage and collapse recovery in increment cores to drying degrade in boards sawn from the same log. Although they failed to find a strong relationship between the core shrinkage properties and drying defects within the boards, many were degraded by pronounced cupping, end-splitting and spring. Significant family differences were observed for cupping, suggesting that this behaviour was under genetic control. A further finding of this study was that, despite the stand being unpruned, there was a high proportion of boards graded as select grade or better (drying defects excluded), suggesting that Dunn's white gum may prove capable of yielding high-quality sawlogs as a plantation species.

A study by Dickson et al. (2003), investing the segregation of logs using acoustic scanning, provides useful data on wood quality traits of plantation Dunn's white gum of two ages, but does not segregate sapwood from heartwood. Some key properties, taken from this study, are summarised in Table 21.

**Table 21: Selected wood properties of plantation Dunn’s white gum (Dickson et al., 2003)**

<table>
<thead>
<tr>
<th>Trait</th>
<th>9 year-old</th>
<th>25 year-old</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic density (kg/m³)</td>
<td>508</td>
<td>600</td>
</tr>
<tr>
<td>Air dry density (kg/m³)</td>
<td>656</td>
<td>788</td>
</tr>
<tr>
<td>Janka hardness (kN)</td>
<td>4.52</td>
<td>6.30</td>
</tr>
<tr>
<td>Small-end diameter (cm)</td>
<td>17.2</td>
<td>29.0</td>
</tr>
<tr>
<td>Heartwood (%)</td>
<td>41</td>
<td>61</td>
</tr>
</tbody>
</table>

The basic density, stiffness and strength measured for Dunn’s white gum by Dickson et al. (2003) were comparable to those measured for other plantation species, including spotted gum (*C. maculata*) and blackbutt.
2.3 Western Australia species: Karri (*Eucalyptus diversicolor*) & Sydney Bluegum (*Eucalyptus saligna*).

(Dr Graeme Siemon)

2.3.1 Karri (*Eucalyptus diversicolor*)

2.3.1.1 Introduction

Karri (*Eucalyptus diversicolor*) is a major species in the south-west of Western Australia, and is the third largest eucalypt in Australia (Forests Department 1971; Anonymous 1980). The major commercial milling of the species commenced in the 1880s, and the timber has traditionally been used for structural applications where large dimensions of sawn timber and high strength are required. Forest thinnings, residue logs and sawmill residues have been used for woodchips for pulp and paper production since 1974 as the minor component of a marri (*Corymbia calophylla*, formerly *E. calophylla*): karri mix. However, value-adding to timber from the native forest resource is becoming increasingly important.

Most R & D was done by the former CSIRO Division of Forest Products, and then the Department of Conservation and Land Management's Wood Utilisation Research Centre, later Timber Technology. The review includes references to research relating to sawn and round karri timber in other countries, either using timber exported from Western Australia, or from karri grown as an exotic species. Most of the references are listed in the Commonwealth Agricultural Bureaux's TREECD literature retrieval system, and date from 1939. In addition, anecdotal information from the Western Australian timber industry is included.

2.3.1.2 Wood quality

Karri heartwood varies from pale pink to reddish brown and deep red, and although resembling jarrah (*Eucalyptus marginata*) in appearance is generally lighter in colour (Forests Department 1971). The sapwood is whitish. Texture is moderately coarse but even, and the grain is commonly interlocked (Bootle 1983, 2005).

Although karri and jarrah timber have similar appearance, the former species can be identified by the burning splinter test. When a match-sized splinter of heartwood is burnt, karri produces a white ash and jarrah a charcoal.

The perception in the Western Australian timber industry is that karri is of lower wood quality than jarrah, which is an excellent timber. This will be discussed further in ‘Machining properties’ and other sections.

2.3.1.2.1 Wood density

In an early CSIRO Division of Forest Products’ publication, Kingston and Risdon (1961) quoted mean basic density for mature karri of 695 kg/m$^3$, and air-dry density of 905 kg/m$^3$. Turnbull and Pryor (1978) quoted a basic density range of 640 to 750 kg/m$^3$.

In comparison, CALM research Brennan (1991) had measured basic density values of 632 kg/m$^3$ for mature and 641 kg/m$^3$ for regrowth karri from Treen Brook Block, near Pemberton. The corresponding air-dry density values for mature and regrowth were 824 kg/m$^3$ and 872 kg/m$^3$. Regrowth timber is not expected to be heavier than mature timber of that species.
2.3.1.2.2 Mechanical and engineering properties

Engineering research by CSIRO (Pearson 1954) assessed model timber columns, with variables including species, slenderness, and eccentricity of load and orientation of growth rings. Karri, white stringybark (*E. eugenioides*) and silver quandong (*Elaeocarpus grandis*) showed considerable variation in strength up to slenderness ratios of about 15 (i.e. length to width), whereas mountain ash (*E. regnans*) showed little reduction in strength to those ratios. Growth ring orientation had no significant effect.

Mack (1958) carried out tests on karri, mountain ash (*Eucalyptus regnans*) and radiata pine (*Pinus radiata*) that showed the method of driving nails (i.e. by hand or with nailing guns) had negligible effect on the static withdrawal resistance, and withdrawal rates of 0.065 to 0.52 in/min had little effect. In subsequent research Mack (1960) presented results of repetitive loading tests in compression of three-member nailed joints using green karri and jarrah, and green and dry radiata pine. Mack (1979) found that withdrawal resistance of plain nails was highly correlated with wood density in fifteen species, including karri. The new classification proposed at that time (and subsequently included in Australian Standard AS1720 ‘Timber Engineering Code’) used density as the basis for predicting withdrawal resistance.

The major reference to strength properties of Australian timbers is Bolza and Kloot (1963). In addition, limited strength tests comparing regrowth karri, jarrah and marri (*Corymbia calophylla*, formerly *E. calophylla*) with mature timber were done in Western Australia (Siemon 1992), as well as strength testing of laminated regrowth karri and jarrah (Siemon 1991). The Modulus of Rupture (MOR) is a measure of bending strength, Modulus of Elasticity (MOE) a measure of stiffness, and Maximum Crushing Strength (MCS) a measure of compression strength of a column. Hardness or resistance to indentation is measured by the Janka Hardness Test, i.e. the load necessary to imbed a 11.2 mm diameter steel ball in the timber to half the ball’s depth. The strength test data are given in Table 22.

Table 22: Strength properties of karri

<table>
<thead>
<tr>
<th></th>
<th>MOR (MPa)</th>
<th>MOE (GPa)</th>
<th>MCS (MPa)</th>
<th>Hardness (kN)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GREEN</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regrowth</td>
<td>84.5</td>
<td>15.4</td>
<td>37.7</td>
<td></td>
<td>Siemon (1992)</td>
</tr>
<tr>
<td>Mature</td>
<td>79.1</td>
<td>14.1</td>
<td>37.1</td>
<td></td>
<td>Siemon (1992)</td>
</tr>
<tr>
<td>Mature</td>
<td>73.1</td>
<td>14.3</td>
<td>36.2</td>
<td>6.1</td>
<td>Bolza and Kloot (1963)</td>
</tr>
<tr>
<td><strong>DRY (12%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regrowth</td>
<td>146.7</td>
<td>21.5</td>
<td>84.9</td>
<td></td>
<td>Siemon (1992)</td>
</tr>
<tr>
<td>Laminated</td>
<td>127.3</td>
<td>20.7</td>
<td></td>
<td></td>
<td>Siemon (1991)</td>
</tr>
<tr>
<td>Mature</td>
<td>149.2</td>
<td>16.7</td>
<td>82.3</td>
<td></td>
<td>Siemon (1992)</td>
</tr>
<tr>
<td>Mature</td>
<td>132.4</td>
<td>19.0</td>
<td>71.7</td>
<td>9.0</td>
<td>Bolza and Kloot (1963)</td>
</tr>
</tbody>
</table>

Although the sample was limited in Siemon’s (1992) report, the results for green specimens were very similar to Bolza and Kloot’s (1963) data. The significantly higher stiffness (Modulus of Elasticity) of regrowth karri compared with mature is difficult to explain, particularly as the bending strength (Modulus of Rupture) values were similar. The laminated samples were 100 x 100 mm sections, and had lower Modulus of Rupture but similar Modulus of Elasticity to 50 x 50 mm solid wood samples. The lower MOR could be expected, because larger cross-sections have a greater likelihood of containing a strength-reducing defect. The laminated products were very uniform, with small standard deviations.
2.3.1.2.3 Other properties

Steam-bending properties of karri were assessed by Kingston (1939), with best results obtained with timber moisture content between 25 and 40 per cent. One hundred and eighty degree bends of radius-thickness ratios of six or more could be achieved at 600–800 p.s.i. (4140-5520 kPa) pressure, with a minimum steaming period of one hour per inch of thickness and bending straps left on for a further hour. Backsawn and quartersawn timber behaved similarly provided there was no initial checking – the former had more initial checks.

An English reference refers to the effect on dielectric properties of moisture content, grain direction and frequency on a range of species, including karri (Forest Products Research Board 1952).

The earliest reference to karri in TREECD (Barnes 1940) discussed English fire resistance tests, with karri and jarrah found to be less combustible than teak (Tectona grandis), Douglas fir (Pseudotsuga menziesii), and a range of oaks (Quercus spp). The Manual prepared by the National Association of Forest Industries in Australia (Timber Data File 2004, 2004, 2004) gave specific fire ratings for karri as follows:

<table>
<thead>
<tr>
<th>Property</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ignitability index</td>
<td>13</td>
</tr>
<tr>
<td>Spread of flame</td>
<td>5</td>
</tr>
<tr>
<td>Smoke development</td>
<td>3</td>
</tr>
</tbody>
</table>

The Building Code of Australia (BCA) Specification C1.10a (2006) is now used, and it specifies the critical radiant flux or CRF (i.e. the critical heat flux at extinguishment as determined by AS ISO 9239.1). Karri is an approved species with a CRF of 4.5 kW/m² or greater.
2.3.1.3 Log stockpiling

The only reports on stockpiling of karri logs came from CALM’s Wood Utilisation Research Centre. White (1989) found that stockpiling of regrowth karri logs under water sprays for two years before milling had no adverse effects on timber quality or wood colour. Assessment of log quality, and the amount of spring and bow in the sawn timber, had indicated this result.

Brennan et al. (1990) investigated schedules for stockpiling of regrowth jarrah and karri logs under water sprays. Logs stored without sprays were shown to have unacceptable levels of end-splitting and insect attack. Different treatments were compared by assessing log degradation and borer infestation in stockpiled logs, as well as bow and spring in cants, wings and sawn boards. The results indicated that a watering schedule of 15 min every three hours gave satisfactory results with considerable savings in water and power costs.

A review of stockpiling and sawmilling studies at the Wood Utilisation Research Centre (Siemon 1995) referred to the above two studies.

2.3.1.4 Sawmilling

The sawmilling industry in Western Australia was based mainly on jarrah until the 1880s when the karri milling industry commenced. Heberle (1997) gave an excellent summary of timber harvesting of crown land in South-west Western Australia.

CALM’s Wood Utilisation Research Centre at Harvey, subsequently CALM Timber Technology, has done considerable research on karri. White (1989) milled regrowth karri logs that had been stockpiled under water sprays for two years, which would reduce the amount of end-splitting of logs and insect attack, and was expected to reduce growth stresses. The sawing pattern used was that recommended by Machin (1981) for Victorian regrowth eucalypts. After milling, spring and bow of sawn boards were within the permissible limits of Australian Standard AS2082-1979 (Standards Association of Australia 1979). Green sawn production was 30.2 per cent, with 80 per cent of that figure making Structural Grade 3 or better. Kino veins associated with insect attack, and brownwood (subsequently identified as incipient rot), were the major causes for downgrading of boards.

Brennan et al. (1991) carried out a major sawmilling study of regrowth karri, assessing a range of age classes (49 to 70-years-old), a range of dominance classes (dominant, co-dominant, sub-dominant and suppressed), and a range of log positions (butt, mid and top logs). They sampled from six stands representing the range in site productivity (high, medium or low site quality) in the older regrowth resource. The logs were milled into 40 mm or 50 mm thick structural timber, or 30 mm thick appearance grade boards. Mean green sawn recovery was 26.6 per cent, with recovery best correlated with log size and tree dominance class, followed by the extent of rot and insect damage. Undersized boards resulting from excessive shrinking, knots, gum veins and pockets, surface checks and borer holes were the major cause of degrade.
White and Siemon (1992) assessed sawn graded recoveries from first grade regrowth karri and first and second grade jarrah logs, in four log size classes of combinations of 15 to 19.9 cm or 20 to 30 cm small end diameter under bark (sedub), and 2.4 m or 3.6 m lengths. There were significant differences ($p<0.001$) in sawn recoveries by species and grade, and by log size class. The results for mean graded recovery of karri boards and structural timber were:

<table>
<thead>
<tr>
<th>Log Class</th>
<th>Recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-19.9 cm sedub, 2.4 m</td>
<td>5.6</td>
</tr>
<tr>
<td>20-30 cm sedub, 2.4 m</td>
<td>29.3</td>
</tr>
<tr>
<td>15-19.9 cm sedub, 3.6 m</td>
<td>13.7</td>
</tr>
<tr>
<td>20-30 cm sedub, 3.6 m</td>
<td>26.1</td>
</tr>
</tbody>
</table>

These results indicated that conventional sawmilling of small diameter logs is not economic. In addition, small diameter shorter logs should produce a higher recovery than similar diameter longer logs, because of the greater likelihood of sweep in the latter. The data show the significant effect of log diameter on sawn recovery.

Brennan (1998) reported on value-adding of 38 x 25 mm regrowth karri boards milled by Auswest Timbers Pty Ltd, which is discussed in the section on gluing.

Brennan et al. (1999) assessed sawn recoveries and timber grades from logs harvested from 30-year-old karri trees from a stand with Site Index of 44, the most common site type in the karri forest. The logs were prepared from a range of tree dominance classes, and from different heights in the tree (i.e. butt, mid and crown logs). Defects caused by biological attack were the major cause of downgraded timber sawn from the logs of dominant, co-dominant and sub-dominant trees, whereas the problems associated with the physical nature of the stand (e.g. knots and heart) were the main cause of downgrade in timber from suppressed trees. Biological problems tended to downgrade boards while problems caused by physical effects tended to result in rejection. Defects caused by mechanical damage resulted in equal amounts of timber being downgraded or rejected. In addition, log external features were related to timber grade and defect. Limbs (green, dry or occluded) were associated with different features, e.g. dry limbs generally had more associated brownwood (staining), rot and insect galleries than did green limbs. Swellings were the most common external feature (52 per cent), with 33 per cent associated with insect galleries and about 20 per cent with brownwood. However, using external features to accurately determine the type and extent of internal damage is difficult because they may relate to different types of internal damage, e.g. a swelling could be related to an insect gallery, brownwood, gum or green knot.

Tucek (1991) carried out a preliminary trial to obtain quantitative data on branch development in karri, and to relate branch size at the time of branch-shed to subsequent kino and rot development. When the logs were milled, no relationship was found between the area of knot-associated kino or rot with either knot diameter or height of knot above ground level. Further research would be required.

Siemon (1995) referred to the above trials in a review of stockpiling and sawmilling research done at the Wood Utilisation Research Centre from 1986 to 1995.

Mean green sawn recovery by Western Australian sawmillers cutting karri logs was 47 per cent in 1998-99, based on information supplied to CALM by sawmillers, as a requirement of contracts for log supply.

Branding or marking of rough sawn timber is difficult, and Krilov (1989) in a New South Wales trial showed that several species, including karri, contain polyphenolic compounds that react with an iron-based colloid to produce a characteristic blue-black stain. The result, if the former is coated with a clear vinyl-type spray, is more efficient marking than is possible with conventional ink-based systems.
2.3.1.5 Veneer production (peeling, slicing, sawing)

The former CSIR (1943) reported satisfactory results in peeling tests and plywood manufacture with karri as the basis for a Western Australian industry. Consequently the plywood industry was established in 1944, using select karri logs (Forests Department 1971). Karri veneer was used initially for all classes of plywood, particularly three-ply, but the main use became multi-ply waterproof structural plywood for concrete formwork.

CSIRO (1954) found that karri plywood could be termite-proofed by momentary dipping of veneers in sodium pentaborate or a mixture of zinc chloride and arsenic pentoxide before gluing. Gay and Hirst (1963) then extended earlier research on Lyctus-susceptibility of karri to include termite control in plywood by adding chlordane and arsenic trioxide ($\text{As}_2\text{O}_3$) to adhesives used in bonding plywood. Karri was one of three species assessed. More discussion is given in the sections on preservation and gluing in this report. Untreated plywoods, or those with low concentrations of toxicants, were very susceptible to termite attack, while higher concentrations effectively killed the colonies with minimal damage to plywood. Tamblyn et al. (1959) assessed protection of rotary-peeled 1/10 in (2.5 mm) green heartwood veneers by momentary dipping with preservative, as discussed later.

Until the mid-1990s Wesply, a subsidiary company of Wesfi (Westralian Forest Industries Ltd), produced karri plywood in Western Australia. Karri logs required overnight storage in hot water at 80°C, and then peeled well. One product was a karri/pine structural plywood with karri as the outer veneer because of its greater strength and hardness, with the advantage of reduced overall weight because of the lower density of pine ($\text{Pinus radiata}$ and $\text{P. pinaster}$). The Wesply plant has now closed, and the machinery sold.

The main current production of veneers in Western Australia is by Sotico Pty Ltd (formerly Bunnings Forest Products Pty Ltd) at Yarloop, slicing 0.6 mm thick jarrah using Japanese technology. Hamilton Sawmills at Landsdale have an old but robust slicer originally owned by Wesply.
2.3.1.6 Timber Drying

Early drying research of karri timber included that by Roberts (1944), who determined the comparative moisture absorption and final moisture equilibrium condition of six species with one face in water and the other in air. Two inch boards of karri, celery-top pine (*Phyllocladus rhomboidalis*), blackwood (*Acacia melanoxylon*), mountain ash, Queensland maple (*Flindersia brayleyana*) and Douglas fir (*Pseudotsuga menziesii*) were assessed. One interesting result was that the moisture content at ½ to ¾ from the wetted face gave a reasonable approximation of the fibre saturation point.

In South Africa, Hartwig (1958) compared equilibrium moisture content variations in boards of karri, spotted gum (*Corymbia maculata*, formerly *E. maculata*), Sydney blue gum (*E. saligna*), *Pinus roxburghii* and *P. pseudostrobus* at different times of the year. Treatment included backsawn and quartersawn, dressed and rough sawn, and stored either indoors, outside under cover, or in the open. For example, he reported mean equilibrium moisture content (e.m.c.) in the open of 18-19 per cent for pines and 13-14.5 per cent for eucalypts, and indoors 11.5-11.75 per cent for pines and 12-12.5 per cent for eucalypts.

In CSIRO research, Kauman (1961) studied the effects of thermal degradation on shrinkage and collapse of karri, mountain ash and silver ash (*Flindersia pubescens*) at temperatures of 38°C to 138°C for periods from 0.6 hr to 14 days. The results indicated that increasing collapse under the influence of heat may be related to weakening of the cell wall by hydrolysis and other changes which at the same time alter the acidity of the wood. Karri and silver ash, both non-collapsible species, behaved similarly to the collapse-susceptible mountain ash under the influence of heat.

Other research onto dimensional stability of timber (CSIRO 1962) used polyethylene glycol or glycerol on karri, alpine ash (*E. gigantea*, now *E. delegatensis*), radiata pine, coachwood (*Ceratopetalum apetalum*), and brown tulip oak (*Tarrietia* sp). Polyethylene glycol was less effective for the more impermeable karri and alpine ash than for the pine and rain forest timbers. PEG with the low molecular weight of 200 gave the best results with karri. Both karri and alpine ash responded well to treatment in a 50 per cent solution of glycerol, with volumetric shrinkage being reduced from 15 to 3 per cent in karri, and 31 to 9 per cent in alpine ash.

Pankevicius (1968) discussed early CSIRO research on dimensional stabilisation of karri and four other hardwood species, using glycerol and three different polyethylene glycols. Glycerol was the best stabiliser, and stabilisation was invariably improved by increasing the concentration of the bulking agent.

Simpson and Barton (1991a) of Murdoch University, WA, discussed determination of the fibre saturation point (i.e. the moisture content at which free water has been lost from the cell cavity, but no bound water from the cell wall), using differential scanning calorimetry to assess karri, jarrah and radiata pine.

In Australian National University research, acetylation (Balfas 1993a) and furfurylation (Balfas 1993b) were shown to stabilise regrowth karri timber in service.

Acoustic emission research by Innes (1997) showed that when surface checks form in karri they almost invariably do so at the base of vessels exposed on the surfaces of the boards. Innes postulated that the vessels act as stress raisers, and that surface checks form at lower values of average surface stress and strain than they would otherwise. Surface checks were seen to form at acoustic emission levels approximately one-third of those corresponding to surface check formation in other eucalypts with less prominent vessels. Analytical and finite element stress analysis techniques suggested a stress concentration factor at the base of the vessels of approximately three. A drying trial of karri showed a close correlation between predicted surface instantaneous strain, using the stress concentration factor found from the stress analysis in a model of drying timber, and measured acoustic emissions.
2.3.1.6.1 **Shrinkage**

Kingston and Risdon (1961) gave before reconditioning shrinkage figures (from green to 12 per cent) as 9.9 per cent tangential and 4.3 per cent radial, and after reconditioning of 8.5 per cent and 4.0 per cent respectively. In comparison, Chudnoff (1984) gave shrinkage figures of 10.7 per cent tangential and 7.2 per cent radial. He also commented on the pronounced tendency of karri to check during drying.

The Western Australian timber industry perception has been that karri has greater shrinkage than jarrah, and is more susceptible to surface checking (Kneen, pers. comm.). That perception is correct. In addition, the low pH of karri wood means that kiln drying will result in more severe degradation of metal in the kiln in a given time than found with drying timber of other species. Bootle (1983) had quoted a pH value of 4.1 for karri, but unpublished results of 3.2 would be more correct.

In Western Australia, Bunnings Forest Products (now Sotico Pty Ltd) had commenced drying commercial quantities of karri in their large pre-driers at Deanmill and Manjimup.

2.3.1.6.2 **Presteaming before drying**

CSIRO (1962) reported on research into presteaming of slow-drying Australian timbers at temperatures up to 212°F (100°C) to allow more efficient kiln drying. Karri appeared to respond, as did black bean (*Castanospermum australe*), alpine ash, mountain ash, and messmate stringybark. Jarrah, brush box (*Tristania conferta*, now *Lophostemon confertus*), and satinay (*Syncarpia hillii*) did not respond to presteaming. Comment was made on potential savings to industry, and the data indicated no adverse secondary effects, e.g. collapse, colour, moisture gradients or machinability. However, high steam pressures were shown to be unsatisfactory for collapse-susceptible species.

Glossop (1994) assessed the efficacy of hot water soaking or freezing pretreatments, compared with an untreated control, before drying 300 x 100 x 30 mm boards of regrowth jarrah and karri. Moderate surface checking occurred during drying of the karri boards given the freezing pretreatment, while boards in the other treatments showed minor surface checking. The results indicated that permeability was improved by both treatments, with reduced drying times.

In a later CSIRO report, Ilic (1995) discussed prefreezing timber of a range of species to reduce drying-related degrade, including collapse and internal checking. He commented about the reduced drying times after prefreezing observed in jarrah, karri, black walnut (*Juglans nigra*) and three other species. He also gave an excellent theoretical explanation of the mechanism involved.

2.3.1.6.3 **Drying**

CALM research on timber drying included assessment of drying schedules for regrowth karri and jarrah in a low temperature batch kiln (Brennan *et al.* 1990). The results showed that low temperature, high relative humidity and low air velocity were needed in the early stages of drying. The drying schedule recommended used initial conditions of 30°C dry bulb temperature (DBT) and 1.5°C wet bulb depression (WBD), with air velocity 0.2 m/s. This WBD is equivalent to RH% of 89 per cent. As the timber dries, temperature is increased and RH% decreased (e.g. to maximum 60°C and 40 per cent RH). Subsequent unpublished trials indicated that RH% of 90 per cent is preferable in the early stages of drying.

Mathews (1991) carried out a trial using a commercial veneer dryer at 150°C to 170°C to dry 11 mm thick boards of karri, jarrah, marri and Tasmanian Blue gum (*E. globulus* subsp *globulus*). Two different drying schedules for drying green to fibre saturation point were assessed. Continuous passes of seven
minutes at 150°C resulted in unacceptable drying degrade after three passes, but allowing a 30 minute cooling period between passes resulted in only limited checking. Subsequent dressing and docking after drying to final moisture content of 8 per cent revealed unacceptable internal checking and discolouration. Thin veneers can be dried successfully at elevated temperatures, but the wood structure of eucalypts makes drying of larger thicknesses difficult.

Newby and Brennan (1990) assessed moisture content fluctuations in regrowth karri and jarrah after the timber was dried to either 8 or 12 per cent moisture content, either wrapped in PVC sheeting or unwraped, then stored at 6 or 20 per cent EMC. They recommended that timber for use in furniture manufacture should be wrapped to reduce moisture content loss or gain, so that timber remains at the required levels.

Brennan and Pitcher (1995) reported the results of a two-year trial to assess equilibrium moisture content variation around Western Australia, and seasonal variations. Karri was obviously one of the major species assessed because of its economic importance.

Following a drying trial using acoustic emission methods, with CALM involvement, Innes (1997) reported on the behaviour of karri vessels in formation of seasoning checks. There was a close correlation between predicted surface instantaneous strain and measured acoustic emissions.

### 2.3.1.6.4 Drying of poles

CSIRO carried out considerable drying research of poles in the 1960s. Christensen (1962) described trials of utilising less durable species:

(i) determining the drying behaviour and relative air-drying rates for hardwood and softwood poles, including karri, mountain ash, long-leaved box (*E. goniocalyx*), manna gum (*E. viminalis*), messmate stringybark (*E. obliqua*) and radiata pine, and seasonal and other effects.

(ii) investigating methods of reducing drying degrade that prevented using poles from straight-grained, fissile species, e.g. mountain ash.

(iii) testing methods of accelerating pole drying times (e.g. messmate stringybark and radiata pine) from months to days. This included use of polyethylene glycol.

CSIRO (1963) commented further on the above trial. For mountain ash poles, rapid extraction and air drying in the open yard in comparatively small covered stacks gave good drying rates and acceptable dried quality, irrespective of seasonal weather conditions. Pre-treatment in a saturated NaCl solution further improved drying behaviour. In comparison, seasoning treatments for karri poles, such as controlled air drying, kiln seasoning, and steam and vacuum drying, were ineffective in controlling splitting.
2.3.1.7 Machining

The Western Australian timber industry experience is that karri is more difficult to machine than jarrah, because of the greater likelihood of grain lifting. Karri requires additional sanding after moulding, and before finishing, compared with jarrah.

Balfas et al. (1993) used sample material of karri and jarrah supplied by CALM Timber Technology to assess the effect of sanding on glue line quality, as discussed in the next section. The coarse 80 grit sandpaper significantly improved wettability and shear strength of the glue lines, in both wet and dry conditions. Finer grits were less effective. They found a positive correlation between wettability and shear strength occurred only after sanding.

2.3.1.8 Gluing

A 1950s reference to eucalypt species suitable for the Belgian Congo was Gilkens (1952), who included karri in the species suitable for tannin extraction for adhesive manufacture.

In early CSIRO research, Plomley (1959) described adhesion tests on karri, celtis (Celtis spp, which includes several Asian-Pacific species) and hoop pine (Araucaria cunninghamii) plywood. He used wattle tannin-formaldehyde adhesives at pH 5 that contained 0, 5 or 10 per cent manganese acetate. Significant improvement in adhesion was found in the 5 per cent manganese acetate treatment, but results at 10 per cent were only marginally better than the controls.

Gay and Hirst (1963) then extended earlier research on Lyctus-susceptibility of karri to include termite control in plywood by adding chlordane and arsenic trioxide ($\text{As}_2\text{O}_3$) to adhesives used in bonding plywood. Karri was one of three species assessed, and urea, phenol and resorcinol-formaldehyde adhesives tested. Exposure to two species of termite showed that untreated plywoods, or those with low concentrations of toxicants, were very susceptible to attack. Higher concentrations effectively killed the colonies with minimal damage to plywood. The authors discussed the possible service life, which was not assessed, but stated that theoretically $\text{As}_2\text{O}_3$ should be permanently effective under indoor conditions with no leaching while chlordane should be effective for both interior and exterior use with efficiency decreasing over time.

Balfas et al. (1993) used sample material of karri and jarrah supplied by CALM Timber Technology to assess the effect of sanding on the quality of resorcinol formaldehyde glue lines (glued with 1500 kPa vertical pressure at 20°C for 7 hours). The coarse 80 grit sandpaper significantly improved wettability and shear strength of the glue lines, in both wet and dry conditions. Finer grits were less effective. A positive correlation between wettability and shear strength occurred only after sanding.

In further research, Balfas (1994) found that activating the surface of regrowth karri and jarrah wood with lithium or sodium hydroxides improved the wettability of the surface and subsequent glue bond strength, when using resorcinol formaldehyde. The chemicals would remove extractives that migrate to the surface after timber is dressed. Balfas claimed that 0.5M lithium hydroxide was the most effective method to protect strength loss on wetting. However, CSIRO researchers consider that the surface activating chemical has a deleterious effect on the adhesive.

In Western Australian research, Newby and Siemon (1989) assessed five adhesives for gluing regrowth karri and jarrah boards into edge-jointed blanks or panels. Urea formaldehyde, melamine fortified urea formaldehyde, resorcinol formaldehyde and melamine formaldehyde glue lines showed no significant differences in percentage wood failure from a dry cleavage test as specified in Australian Standard AS1328-1987 (Standards Association of Australia 1987). However, PVA glue lines had significantly less wood failure.
The percentage wood failure in regrowth jarrah and karri was not significantly different. End and centre samples gave similar results, which was an advantage because gluelines could be assessed using a crosscut strip from the end of a panel.

Brennan (1998) constructed panels from dried dressed boards that were originally milled to green sawn dimensions of 38 x 25 mm. Adhesives assessed included urea formaldehyde (‘Craftbond’ U62) and resorcinol formaldehyde (‘Resobond RA3’), and the preliminary results indicated that karri boards could be successfully glued using these two adhesives. Panels constructed by face-pressing glued better than edge-pressed panels.

2.3.1.9 Preservation

2.3.1.9.1 Natural Durability

As regards natural durability, karri was previously rated as CSIRO Durability Class 3, compared with jarrah’s Durability Class 2. That is, the service life of outer heartwood in ground use averages 8 to 15 years in Durability Class 3, and 15 to 25 years in Class 2. Thornton et al. (1996) subsequently rated karri the same as jarrah with CSIRO Durability Class 3/2 for decay, but karri is Durability Class 4 for decay plus termites, i.e. karri is termite-susceptible, which means that preservative treatment is required when there is a risk of attack in either above ground or in-ground uses. However, Australian Standard AS5604-2005 (Standards Australia 2005) gives an in-ground rating of Durability Class 3 and above ground rating of Class 2 (equivalent to 15 to 40 years above ground with regular wetting and drying.

The powder post borer (Lyctus brunneus) is widely spread around the world, and Lyctus-susceptibility of WA species needed reassessment after initial ratings by Fairey (1975). The borer attacks only dry sapwood of susceptible species, which have vessels (pores) large enough for the female insect to insert her ovipositor, and sufficient starch content to make it palatable. More regrowth karri is now being supplied to sawmillers, and indications are that it is susceptible. Simpson and Barton (1991) assessed levels of starch depletion in karri logs that were either stockpiled under water sprays or dry stockpiled, and the latter had higher depletion rates. Starch levels in living trees were found to be strongly influenced by rainfall, and declined more rapidly in girdled trees than in those felled and left with an intact crown. Recommendations were made regarding felling seasons and storage to reduce starch content and therefore Lyctus-susceptibility.

Lyctus-susceptibility of regrowth and mature karri and jarrah was reassessed by Creffield et al. (1995), because of the increasing commercial importance of regrowth of these species. Laboratory bioassays were conducted on the susceptibility of air-dried sapwood specimens, from trees of both regrowth and mature karri, to attack by the powder post borer Lyctus brunneus [now Xylotrogus brunneus]. The susceptibility of regrowth karri was determined using material collected from 10 trees (five trees in two areas) each at three positions (the butt, midway along the bole and the crown). Material from the butts of 64 mature trees, representing three different areas in the south west of Western Australia, was similarly assessed. Both regrowth and mature karri specimens were collected from trees within the main karri estate. The susceptibility of both regrowth and mature jarrah was compared concurrently in a bioassay which evaluated butt specimens of approximately 20 trees from each of three different areas in the jarrah forest. Prior to the bioassays, all specimens were assessed for starch concentration in the sapwood. Some sapwood specimens of both regrowth and mature karri were susceptible to attack by X. brunneus. Specimens cut from the butt position of regrowth karri trees contained the highest concentration of starch and were more heavily attacked by X. brunneus. Similarly, some regrowth and mature jarrah specimens from some areas were susceptible to attack. Differences in starch concentration and susceptibility between areas from which each timber species was harvested were revealed. Positive correlations, between starch concentration and susceptibility of mature karri and
regrowth and mature jarrah, were obtained. A revision of previously published ratings for both karri and jarrah is recommended. It is further recommended that a reassessment of the susceptibility to *X. brunneus* of all commercially available hardwood timber species be undertaken, particularly if a regrowth resource of those species is being utilised or likely to be utilised in the near future. Regrowth karri has a wider sapwood band than found in mature karri, and some sapwood is likely to be found in sawn boards. Samples from five trees from two areas were taken from butt log, midlog, and crown log, and laboratory bioassays done. Specimens from butt logs of regrowth karri were more heavily attacked by *X. brunneus* because they contained the highest concentration of starch. The authors recommended a revision of previously published *Lyctus*-susceptibility ratings (e.g. Fairey 1975), which indicated that karri was ‘rarely-susceptible’, i.e. seldom attacked in service.

Farr et al. (2000) described a destructive sampling technique and incidence survey used to investigate the presence of the bullseye borer *Phoracantha acanthocera* in regenerated karri forest. In the destructive sampling survey carried out at two sites, bullseye borer in marri (*Corymbia calophylla* [*Eucalyptus calophylla*]) was also examined. The incidence survey was done across a rainfall gradient (13 sites) and investigated the influence of site characters on borer attack levels. Over both surveys, a total of 945 trees and 5285 billets were inspected. Association with timber defects such as incipient rot (brown wood) and internal kino was also studied. In the destructive survey, the poor quality karri site had more borer attack than the high quality karri site, with 17.3 mean insect gallery intercepts per tree, and 43.1% of billets and 100% of trees attacked. Marri had a lower borer incidence than karri, with 2.4 mean insect gallery intercepts per tree, 14.6% of billets and 82% of trees attacked. Despite higher infestation rates at the poorer quality site, borers, incipient rot and internal kino were more prevalent in larger trees. Incipient rot and internal kino were correlated with borer attack. In the incidence survey, borer infestation ranged from 24 to 78% of trees with significant differences between sites. Infestation rates could be grouped into 4 categories, low, moderate, high and very high, which corresponded to <2, 2-4, 4-6 and >6 external borer symptoms per tree, respectively. However, correlations of tree and site parameters were weak. Dry sites in close proximity to jarrah/marri forest and in small coupes were more prone to borer attack.

### 2.3.1.9.2 Preservation research

Durability can be increased by preservative treatment, but the heartwood is extremely resistant to penetration by preservatives, even with vacuum/pressure treatment.

In early CSIRO research, Tamblyn (1945) reported on tests begun in 1929 to determine the efficacy of the fluorizing process for treating green karri railway sleepers. The sleepers were boiled in an aqueous solution of sodium fluoride, arsenious oxide and sodium dinitrophenate for 10 hours, followed by a cooling period of 36 hours in the solution. Three thousand sleepers were installed by Western Australian railways, and had an estimated service life of 13 years. In comparison, untreated karri sleepers had an average service life of 6.3 years while untreated jarrah gave 20 years. Decay was the major reason for failure, with occasional termite attack, with the problems resulting from shallow penetration and then end-splitting allowing exposure of untreated wood. A further report (CSIRO 1945) gave the required concentrations as 1-2 per cent arsenious oxide and 6-8 per cent sodium fluoride and sodium dinitrophenate.
CSIRO had successfully developed a simple and cheap dip-diffusion process, and in 1953 tested six water-borne preservatives to protect rotary-peeled 1/10 in green heartwood veneers of karri and mountain ash (CSIRO 1953). The sheets were momentarily dipped in cold solutions and block-stacked for two hours before drying to allow diffusion of the chemical into the wood. Solutions of 7.6 per cent concentration gave mean dry salt retention of 0.29 and 0.22 lb/cu.ft (4.64 and 3.52 kg/m³) for the two timbers respectively. The treated timber was then tested by exposure to three termite species and three fungi, and results were as follows:

(i) the above concentrations of Na₂B₁₀O₁₆ gave good protection against the termites Coptotermes acinaciformis and C. lacteus, but was less effective against the boron-tolerant Nasutitermes exitiosus. Complete protection was achieved against the fungi Coniophora cerebella, Trametes lilacino-gilva and Lenzites trabea.

(ii) a 3/2 mixture of ZnCl₂ and As₂O₅ gave good protection against the three termite species and the first two fungi.

(iii) the four other preservatives included ‘greensalt’, and early CCA formulation, but none were effective at the low concentrations used.

The preservation of pitwood for English mines using ‘Wolman Tanalith’, a copper-chrome-arsenic formulation, was the subject of a film reviewed in the ‘Colliery Guardian’ (Anonymous 1951).

Preservative treatment of sawdust used to protect grapes during transport included material from radiata pine, mountain ash, jarrah and karri (McKenzie 1953). Three–quarters of an ounce of metabisulphite (Na₂S₂O₅) per cubic foot reduced most degrade of this packing material.

Johanson of CSIRO (1974) showed that arsenic concentrations of samples from commercially treated karri sleepers, determined by atomic absorption spectroscopy, appeared lower than actual retentions after digestion of organic extractives with H₂SO₄/HNO₃ and H₂O₂. He considered that the digestion method was still a useful check. Further CSIRO research into preservative treatment of karri sleepers with concentrates of arsenic (III) and arsenic (V) compounds showed that the former gave better penetration (Johanson 1975). High loadings of both forms of arsenic to 15-20 mm depth were achieved with diffusion periods of about three weeks, provided the timber was incised.

In later CSIRO research, Barnacle et al. (1992) reported on poorly treated karri sleepers (oil/creosote) in a heavy haul iron ore rail system in the Pilbara region of WA. Despite termite attack, the performance of the sleepers over 18 years exceeded initial expectations.

In South Africa, Vermaak (1979) discussed service tests of telephone poles of ten eucalypts and three pines, treated with locally manufactured Iscor high temperature creosote or FPI creosote, or a British low temperature creosote. Retention, cracking below ground line, and weathering and termite or fungal attack after 22 or 38 years service were assessed. The three pines, grey ironbark (E. paniculata) and mountain ash were recommended, but not karri.

The Forests Department of Western Australia (1971) discussed using karri telephone crossarms, treated with 3 per cent pentachlorophenol in oil at a pressure of 1000 p.s.i. (6900 kPa). No failures in service had been reported, with the oil impregnation reducing surface checking that occurs in a hot dry climate.

Preservative treatment of karri was involved in a different situation, where Davison (1991) assessed the effect of ‘Impel’ preservative rods (anhydrous disodium octaborate) on the health of living karri trees. This trial was necessary because of the requirement to restrict extensive decay that had developed in one of the icon trees of the South-west. Impel rods were inserted into regrowth karri trees, which were
felled and assessed after four, 13 or 52 weeks. Bark around the rod site had died after 13 weeks, while sapwood and heartwood were discoloured after four weeks. Boron concentrations were measured up to 220 mm above and below the rod site, and 40 mm to the side. Concentrations were greater in the vertical direction than in the horizontal. Overall the trial showed there was a risk in using these rods to control decay in living trees.

With an increasing number of regrowth karri poles being used in Western Australia, it is essential that required retention levels of preservative based on Australian Standard were achieved. In 1989 there was a perception that tyloses were being formed in sapwood because of stress induced by felling and docking. Tyloses are balloon-like structures that normally form in vessels as part of the transition from sapwood to heartwood. Their formation in sapwood would be expected to restrict preservative penetration and therefore retention in the vacuum/pressure treatment of poles using copper-chrome-arsenic (CCA). Brennan et al. (1995) assessed the effect of end treatment of the poles with two proprietary end-sealers (‘Pabco’ and ‘Cellavit WR151’), applying them to sapwood bands immediately after docking. The poles were treated either green or dry (i.e. with sapwood below 30 per cent moisture content) using a long-wet vacuum method. However, the results showed no significant differences in CCA retention between end-sealed poles or controls with no end-sealing, or between poles treated green or with sapwood below 30 per cent moisture content. The then SECWA, now Western Power, had a retention requirement of 1.6 per cent mass/mass for individual poles, which was significantly higher than the 1.2 per cent specified for Hazard Class 5 in Australian Standard AS1604-1993 (Standards Australia 1993). This retention is still specified in the revised Standard (AS1604-1997).

Karri is a termite-susceptible species, as stated previously. The karri floor in the Forest Heritage Centre at Dwellingup was attacked a few months after the installation of an evaporative air-conditioner, which increased the relative humidity and made the conditions more suitable for termites to construct galleries. A pilot trial was done to find if 80 x 19 mm karri boards treated with a light organic solvent preservative (LOSP) achieved the retention required for Hazard Class 3 (Standards Australia 1997), because treated karri could be used as a replacement floor. The preservatives used were permethrin and tributyltin naphthenate. The aim was to achieve 0.02 per cent mass/mass of permethrin for Hazard Class 2. However, analysis showed that the mean retention was only 0.003 per cent mass/mass, because heartwood is much more difficult to treat than sapwood. The tributyltin naphthenate is a fungicide, which is not required where the timber is protected from wetting. The permethrin retention may have provided adequate protection for a replacement karri floor, but a conservative approach was taken and jarrah timber used because it is termite-resistant.
2.3.1.10 Utilisation

2.3.1.10.1 General Uses

The Forests Department of Western Australia (1971) stated: 'The strength and stiffness of the timber, combined with the extraordinary long, clean lengths which may be obtained, render it unsurpassable for superstructural work. It is possible to secure karri in larger sections and longer lengths than any other known hardwood. In beams, rafters, tile battens, columns, roof trusses, warehouse floor joists and other members where strength is the essential factor, it gives satisfaction. In many instances karri has replaced oregon for scaffolding planks, where its greater strength has more than offset the increase in weight. In bridge construction it is used for half caps and decking. The timber is highly prized for transmission line crossarms, and is also used in coach, waggon and motor body building.' The report also referred to its extensive use in the Western Australian gold mining industry for a range of purposes. As stated above, treated telephone line crossarms were widely used. Karri plywood was also used for truck flooring.

Turnbull and Pryor (1978) also referred to the great strength, high stiffness and comparative freedom from defects giving karri an advantage for heavy engineering and construction. The authors also discussed the need for protection from termites. Chudnoff (1984) noted the susceptibility of karri to marine borers, and marine use is not feasible.

A South African reference (South African Department of Forestry 1948) discussed the use of karri, tallowwood (E. microcorys) and spotted gum (Corymbia maculata, formerly E. maculata) for use in diving boards in public baths. The report stated that specially designed boards from local pine, used in championship diving, were insufficiently robust for general use, and eucalypt timber would perform better.

Also in South Africa, van Vuuren and Grove (1978) discussed the use of pick handles made from laminated karri or black wattle (Acacia), and found that laminated handles had similar strength to solid wood handles.

2.3.1.10.2 Poles

In South Africa, Vermaak (1979) discussed service tests of telephone poles of ten eucalypts and three pines, treated with locally manufactured Iscor high temperature creosote or FPI creosote, or a British low temperature creosote. Retention, cracking below ground line, and weathering and termite or fungal attack after 22 or 38 years service were assessed. The three pines, grey ironbark and mountain ash were recommended, but not karri.

In recent years, karri has provided about half of the power and transmission poles supplied to the Western Power Corporation of Western Australia by CALM.

2.3.1.10.3 Sleepers

Most research on the use of karri as rail sleepers was done by CSIRO Divisions. Karri has been widely used in the Pilbara area in haulage of iron ore for export purposes. Barnacle et al. (1992) reported on poorly treated karri sleepers (treated with an oil/creosote formulation) in a heavy haul iron ore rail system in the Pilbara region of WA. Despite termite attack, the performance of the sleepers over 18 years exceeded initial expectations.
Chin and Costolloe (1985) discussed the performance of karri, jarrah and marri sleepers in the southwest of WA after 25 or 26 years of service. As might be expected, incised sleepers had increased preservative retentions and a smaller range of retention. Higher pressures (100 psi or 7000 kPa) produced higher retentions than low pressure (200 psi or 1380 kPa). Untreated karri sleepers had a service life of 4-8 years compared with 21-25 years for jarrah and 13-15 years for marri. Incised karri sleepers treated at 200 psi had achieved a significantly better service life than similarly treated non-incised sleepers of the species, and similar to those treated at 1000 psi. Treatment with 50:50 creosote / furnace oil at 200 psi resulted in a mean service life of 22 years in the Wheatbelt.

In recent years, karri sleepers have been vacuum/pressure treated with a formulation of furnace oil plus 0.5 per cent permethrin as an insecticide.

### 2.3.1.10.4 Furniture and joinery

South African-grown karri has been used for furniture and joinery, and Van Wyk (1957) discussed how variations in equilibrium moisture content during the year in Pretoria resulted in movement in the timber. He recommended that timber for furniture use in South Africa should be dried to 10 per cent moisture content. Hartwig (1962) described the properties of karri and its use for furniture in South Africa.

The United Kingdom Timber Research and Development Association (TRADA) developed a high strength category of high density African and other hardwood species, and referred to as the ‘H Super Group’ (Pleydell 1978). Karri and jarrah were included in this specification, which allowed simple construction methods and had high life expectancy because the species did not need preservative treatment for acceptable service. TRADA (1982) issued a wood information sheet on timbers suitable for use in river and sea constructions, which included karri.

In Western Australia, there has been an increased emphasis on using karri for value-added purposes. CALM Timber Technology has worked on suitable drying schedules for furniture grade timber, using a solar-assisted timber drying kiln. Fine design furniture is required because of the high strength and aesthetic appeal, but high wood density.

### 2.3.1.10.5 Residues

While this report has concentrated on sawn and round timber, efficient utilisation of the karri resource relies heavily on using sawmill and forest residues. A marri (*Corymbia calophylla*)/karri mix is marketed commercially from Western Australia, with the proportion of the species approximately 2:1 (CALM 2000). Regrowth karri is a quality resource for pulp and paper manufacture, with high Kraft pulp yields. Phillips and Watson (1962) quoted 55.8 per cent pulp yield, Phillips *et al.* (1967) 56.2 per cent, and Higgins and Phillips (1970) 53.1 per cent from approx 25 to 35-year-old trees. Yields from older trees are lower.

The volume of low quality karri logs harvested for woodchip use in 1999/2000 was 154 000 tonnes (CALM 2000), but the volume of sawmill residue used for woodchips was not recorded. Sawmill residue used for woodchips in 1997/1998 was 73 000 t (CALM 1998).

Charcoal manufacture was discussed by Hanley and Pearse (1945), who assessed karri, jarrah, marri and wandoo as the basis for an iron industry in Western Australia. The composition of the distillate and wood-gas at various temperatures and the relationship of volatile content of charcoal to the temperature of retorting were studied. Yields of acetic acid and methyl alcohol were highest in marri and lowest in jarrah. Overall jarrah charcoal is regarded as better quality than karri charcoal because the former species burns to produce negligible ash.
2.3.2 Sydney Blue Gum (*Eucalyptus saligna*)

2.3.2.1 Introduction

This review discusses the potential to use Sydney blue gum (*Eucalyptus saligna*) grown in Western Australian plantations for value-adding by producing sawn timber products. It also discusses round timber and reconstituted wood panels, but does not discuss pulp and paper where the species provides a good resource and there is considerable knowledge.

2.3.2.2 Wood quality

Australian data includes Kingston and Risdon (1961), who reported mature *E. saligna* as having basic density of 654 kg/ m³, and air-dry density (before reconditioning) of 842 kg/m³. Wood density of mature *E. saligna* was given by Bootle (1983, 2005) as follows: green density about 1070 kg/ m³, air-dry density about 850 kg/ m³ (in comparison, Bootle also quoted South African data of 500 to 600 kg/m³ for fast-grown air-dry timber). Air-dry density of 13-year-old Western Australian-grown timber was estimated as about 640 kg/ m³ (Bishop and Siemon 1995) and 17-year-old from a different area as 735 kg/ m³ (Brennan and Hingston 2004). Ozarska and Molenaar (1998) reported air-dry density of about 780 kg/ m³ for plantation-grown timber from two different areas in Victoria.

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<th>Table 23: Wood density of Sydney blue gum (Australian data)</th>
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<td><strong>Green density (kg/ m³)</strong></td>
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<td>(Mature) 1070</td>
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Most research has been reported from South America, particularly Brazil. Ferreira (1970) assessed basic density in 5 and 7-year-old *E. saligna* grown in Sao Paulo, and found that quicker-growing trees on average had a higher basic density than less vigorous trees, with between-tree variations ranging from 433 kg/ m³ to 634 kg/ m³. The definite relationship between breast height density and average tree density meant that the latter could be predicted from breast height measurements. Again in Sao Paulo, Brasil and Ferreira (1971) found average basic density varied from a podzolised gravelly soil (shallow, acid and infertile, moderately well drained) to a red-yellow laterite soil (deep, well-drained, acid and infertile), with basic densities of 441 kg/ m³ and 553 kg/ m³ respectively. Ferreira (1973) published a summary of these and other density data.

Ferreira et al. (1979) summarised the data on wood density of eucalypts in commercial plantations in the Mogi-Guacu region of Sao Paulo. Samples included 3 to 7-year-old *E. saligna* and *E. grandis*, and 7 to 8-year-old *E. urophylla* from a Brazilian source, and compared the results with 3 to 5-year-old *E. saligna* and 2 to 6-year-old material from Coffs Harbour. Carpim and Barrichelo (1983) summarised a Brazilian study comparing the basic density of *E. dunnii*, *E. deanei*, *E. grandis* and *E. saligna*, and the latter two species showed sufficiently large variation to justify tree improvement programs. Barrichelo et al. (1984) gave similar data, including fibre dimension and chemical constituents at different heights up the tree, for *E. saligna*, *E. grandis* and *E. urophylla*. Carpim et al. (1985) reported on density variations in the tree for *E. saligna* and *E. grandis*, while Sturion et al. (1987) assessed within stem variation in a range of eucalypt species grown as exotics in the Minas Gerais area.
Coutinho and Ferraz (1988) determined radial wood density profiles of *E. saligna* in relation to stem diameter, using attenuation of gamma radiation. The greatest difference between densities of different diameter classes occurred in the peripheral zones. They concluded that the method showed great potential for studying wood characteristics. In other Brazilian research, Rosado *et al.* (1983) assessed the potential of a Pilodyn instrument for estimating wood density. *E. urophylla* gave the best results, followed by *E. grandis*, *Corymbia citriodora* (formerly *E. citriodora*) and *E. saligna* in that order.

Effects of frost at age two years on the wood of 9-year-old *E. saligna* grown in Sao Paulo were assessed by Ferraz and Coutinho (1984). Four classifications were developed, and 30.6 per cent of trees assessed had no damage, 21.2 per cent had growth rings with reduced density, 36.4 per cent had a wide growth ring of low density, and 11.8 per cent had rotten heartwood. Tomazello (1985a) described the anatomical properties of eight eucalypts grown in Brazil, including *E. saligna*, and radial variation in basic density and anatomical structure of *E. saligna* and *E. grandis* (Tomazello 1985b). Ribeiro and Zani (1993) reported on variations in basic density of five species/provenances, including *E. saligna*, while Lima (1995) reported on variations in interclonal and intraclonal basic density of Brazilian-grown *E. saligna*.

In more recent studies, Lopes and Garcia (2002) measured basic density and moisture content and associated these with the bark type. While the results showed that basic density could be (approximately) estimated from original moisture content, the authors also suggested that bark types were a good indicator of wood quality. Using clonal material from Sao Paulo, Benjamin and Ballarin (2003) evaluated the correlation between the weighted average specific gravity (SG) of the *E. saligna* stem with SG at three different heights in the tree (*E. grandis* x *E. urophylla* hybrids were also assessed). Analyses showed that SG at 25% of stem height gave the best correlation. Alzate *et al.* (2005) assessed within and between tree variation in basic density of *E. saligna*, *E. grandis* and *E. grandis* x *E. urophylla* hybrids, while Trigilho *et al.* did extensive statistical canonical analyses to establish correlations between the physical and chemical characteristics of both *E. saligna* and *E. grandis* wood.

A Japanese anatomical study was reported by Ohbayashi and Shiokura (1989), when *E. saligna*, *Anthocephalus chinensis* and *Gmelina arborea* were assessed. Results showed that the variability in wood structure stabilised at a certain distance from the pith, and juvenile wood could be differentiated: it ranged from 4 to 9 cm from the pith regardless of species, age or diameter. The same authors (Ohbayashi and Shiokura 1990) reported further on those three species.

In Hawaii, and in comparison to Ferreira (1970), Skolmen (1974) assessed the lumber potential of 12-year-old Hawaiian-grown trees, and found that wood density was lower than that from older trees. King (1980) compared the relative wood densities of 3-year-old coppice with the original wood density and found ratios ranging from 0.34 to 0.51, with a mean of 0.43. However, the relative density of coppice wood compared favourably with relative density values for similarly aged wood. In later research of Hawaiian-grown *E. saligna*, DeBell *et al.* (2001) discussed the effects of silvicultural practices (e.g. chemical fertilisers, spacing, and interplanted nitrogen-fixing trees) on wood density and diameter growth of 15-year-old trees.

In Rwanda, Gashunba and Klem (1982) reported average basic density for *E. saligna* of 570 kg/m³. In the three eucalypts assessed (the others were *E. microcorys* and *E. maidenii*, the latter now *E. globulus* subsp *maidenii*) the basic density increased from pith to bark, but with no clear pattern with tree height. Ringo (1985) reported on fibre length variation in *E. saligna*, *E. maidenii* and *E. microcorys* grown in Rwanda.
Kininmonth et al. (1974) reported an average air-dry density for the species of 700 kg/m³ for New Zealand-grown timber. McKenzie and Hay (1996) discussed the history of *E. saligna* in New Zealand, referring to growth, silviculture, health, genetic improvement, and wood properties and utilisation, while McKinlay et al. studied variation in whole-tree basic wood density for a range of New Zealand-grown plantation species, including *E. saligna*.

In a German review, Knigge and Lewark (1976) discussed the reasons for the greater variability and frequently inferior properties of wood from plantations managed for fast growth, compared with old growth trees. They discussed measures to reduce these drawbacks.

In the Asian context, Shukla and Rajput (1981) summarised the specific gravity values of a range of eucalypt species from forty different Indian localities. Their preliminary data showed that age has a significant effect on density although no pattern was seen when top, middle and lower samples were taken. Rajput and Shukla (1989) reviewed the physical and mechanical properties of eight eucalypt and two eucalypt hybrid species, as well as discussing durability and treatability, and general utilisation. Chai et al. (1996) collected samples from a total of forty-eight provenances of *E. saligna*, *E. grandis*, *E. camaldulensis* and *E. urophylla* grown in Hainan or Fujian provinces. They assessed seven anatomical properties and used the data as a basis for deciding which provenances to use for future plantation use.
2.3.2.3 Strength properties

In early CSIRO research, the basic strength data for the species was reported by Bolza and Kloot (1963), who quoted Modulus of Rupture (MOR) for green and air-dry mature timber of 76 MPa and 122 MPa respectively, and Modulus of Elasticity (MOE) of 12.2 GPa and 15.2 GPa respectively.

In CSIRO Division of Building Research trials, Armstrong (1983) assessed the mechano-sorptive deformations in timber from species susceptible to collapse (e.g. *E. saligna*, *E. regnans*, *E. delegatensis* and *E. pilularis*), and compared them with similar material from non-susceptible species (e.g. *Pinus radiata*, *Araucaria cunninghamii*, *Intsia palembanica*). Deformation and deflections in collapsible species were three to four times greater than in non-collapsible.

Ozarska and Molenaar (1998) assessed the density and strength properties of seven different Victorian plantation-grown timbers, including eighteen-year-old Sydney blue gum. They found significant differences in MOR but smaller differences in MOE of timber grown in either Mildura or Shepparton, with air-dry MORs of 116 MPa and 99 MPa respectively and MOEs of 14.6 GPa and 14.9 GPa respectively. The Shepparton MOR result is low compared with Bolza and Kloot's figure.

Most strength property studies have been reported from Brazil. Gameiro and Naas (1982) assessed physical and mechanical properties of Brazilian-grown *E. saligna*. Lucia and Vital (1983) compared physical and mechanical properties at three different heights in a 40-year-old tree. Density and most mechanical properties were highest in dark red heartwood, except for Modulus of Elasticity where MOE of light-coloured heartwood was similar to that of dark red, and there were no significant differences in work and tension at proportional limit between sapwood and dark heartwood. Vital et al. (1983) showed that strength properties of samples heated to 105 to 155°C for 10 to 160 h generally deteriorated with increasing temperature or exposure time.

Lima et al. (1986) studied the effects of moisture content on strength properties of Brazilian-grown *E. saligna*. With bending strength, they showed that: (i) compression parallel to the grain, MOE and stress and work at the proportional limit were exponentially related to moisture content, (ii) MOR and shear parallel to grain were quadratically related to moisture content, and (iii) work to maximum load and total work increased linearly as moisture content increased. Haselein et al. (2002) compared the bending properties of green and air-dried wood of an *E. saligna* clone grown at different tree spacing and with different fertilization treatments. Targa et al. (2005) discussed evaluation of Modulus of Elasticity by the non-destructive resonance method of transversal vibration, and found a good correlation between the NDE and conventional destructive strength evaluation methods.

Ondimu and Gumbe (1997) evaluated the strength properties of structural-sized pieces of Kenyan-grown *E. saligna* timber, showing mean MOR of 52 MPa, tension strength 57 MPa and maximum crushing strength of 32 MPa. These results were significantly less than those of small clear specimens. In Ethiopia, Lemeni and Bekele (2004) discussed the effect of age on some mechanical properties (also calorific value) of *E. saligna*, *E; grandis* and *E. globulus*. 
2.3.2.4 Sawmilling

Logs from Sydney blue gum and other fast-grown plantation trees have high levels of inherent growth stresses, which affect log stockpiling, sawmilling, and drying. With more than a few days between harvesting and milling, log stockpiling under water sprays for 15 minutes each three hours is recommended to reduce end-splitting and the risk of insect attack. Growth stresses may be reduced over time.

Skolmen (1974) assessed the timber potential from 12-year-old *E. saligna* sawlogs from Hawaiian-grown plantations. He found that the timber produced was basically low grade, with lower mean wood density than timber from older trees. Growth stresses caused end splitting and sawing difficulties, particularly in butt logs.

Kininmonth et al. (1974) reported a utilisation study of New Zealand-grown timber of eight eucalypt species, including *E. saligna*, *E. fastigata* and *E. delegatensis*. A green sawn recovery of 44 per cent was achieved from logs from 28-year-old *E. saligna* trees, with end-splitting being more severe in that species than the other two, particularly in backsawn timber. Also in New Zealand, Vaney (1983) discussed a sawmill grade recovery and wood quality study of 23-year-old *E. saligna* and 21-year-old *E. regnans* thinnings. The *E. saligna* logs split on felling because of severe growth stresses, but this factor was not noted in the *E. regnans* until sawmilling. The sawn timber quality of both species was low, with severe degrade due to rot, decayed knots and drying distortions because of the growth stresses. Vaney considered that the commercial potential of these thinnings was low.

In a Portuguese sawmilling trial, Berengut et al. (1973) obtained the best results when the log was sawn square on three faces, and the resultant cant sawn into boards by a series of parallel cuts. This produced a mixture of backsawn and quartersawn boards.

In South Africa, van Wyk (1978) discussed the problems of hardwood sawmilling and the means of overcoming them, with particular reference to *E. grandis* and *E. saligna*.

Although Brazil has a large resource of eucalypt plantations, there are few references to sawmilling in the literature. Fernandes and Ferreira (1986) (91) presented data from 9-year-old *E. saligna* trees that showed log end splitting decreased as log diameter increased. Neri et al. (1999) studied the effects of rake angle in the sawblade, cutting thickness, wood density, and radial vs tangential cutting in milling *E. saligna*, *E. grandis*, and *E. citriodora*. The objective was to determine the power requirement in milling these species, as part of an overall assessment of marketing and export possibilities.

At present Western Australia has a very limited resource of plantation-grown *E. saligna*, and a sawmilling trial of 20-year-old trees was reported by Rotheram (2004) - a dry dressed graded recovery of 23% was achieved. The study suggested that trees needed to be grown to a larger diameter to reduce the proportion of boards with heart, trees needed to be pruned on time to reduce the likelihood of dead knots, feature grade was a likely product, and comparatively narrow boards would have a reduced incidence of surface checking. Brennan and Hingston (2004) carried out a sawmilling trial of 17-year-old *E. saligna* and *E. globulus* spp globulus, and the timber was graded in accordance with the *Industry Standard for Dried, Sawn and Skip-dressed WA Hardwoods* (FIFWA 1992) and VALWOOD® core grade requirements (CALM 1995). The overall dry dressed graded recoveries for the *E. saligna* and *E. globulus* were 23.8 and 32.3 per cent respectively, and the Prime Grade recoveries were 14.8 and 29.2 per cent respectively. A more recent FPC sawmilling trial (Siemon, unpublished data) graded dried skip-dressed boards to the requirements of Australian Standard AS2796.2 (Standards Australia 1999) and found that 55% of production was select grade, and over 6% each were medium feature grade and high feature grade.
2.3.2.5 Timber drying

Skolmen (1974) dried timber milled from logs from 12-year-old *E. saligna* trees grown in Hawaii, and found moderate shrinkage but no serious degrade.

Kininmonth *et al.* (1974) dried timber milled from eight species of New Zealand-grown eucalypts, including *E. saligna*, *E. fastigata* and *E. delegatensis*, and found that kiln drying from green produced unsatisfactory results. Timber from all eight species dries rapidly when first air-dried to 30 per cent moisture content, then final-dried in a kiln. Surface and internal checking caused by collapse resulted in significant degrade in *E. delegatensis*, because it could not be removed by conventional reconditioning treatments. However, the other species that collapsed recovered after reconditioning.

Stohr (1977) discussed drying of sawn timber from South African-grown *E. saligna* and *E. grandis*. He compared the effects of age, board size, wood density and position of the board in the log, for the two species. He found that the generally lower wood density of *E. grandis* (500 to 800 kg/m³) made the timber easier to dry than *E. saligna* (430 to 960 kg/m³). Stohr discussed air-drying, kiln drying, and a combination of the two methods.

Also in South Africa, Banks and van Nuuren (1976) developed indices from sawn boards of several eucalypts to test the hypothesis that splitting of eucalypt timber was partly under genetic control. After milling boards with a minimum length of 3.3 m and 100 mm width, a system of four splitting indices was developed to assist in selecting phenotypes for treebreeding programs:

(i) average length of unsplit unedged boards that could be converted to trimmed pieces (as % of log length)
(ii) mean width of trimmed pieces (as % of log top diameter)
(iii) mean length of trimmed pieces (as % of log length)
(iv) volume of all trimmed pieces per log (as % of log volume).

A tree had to be above average in all four indices to be considered a plus tree.

Gough (1981) described a Queensland solar kiln used for trials of drying of *E. saligna*, *E. crebra*, hoop pine (*Araucaria cunninghamii*), meranti (*Shorea* spp) and cypress pine (*Callitris columellaris*). The most efficient method was to air-dry the timber to 20 to 25 per cent moisture content, and then kiln-dry the timber.

Bootle (1983, 2005) quoted *E. saligna* as being easy to dry, but tangential surfaces are susceptible to surface checking, and there is slight collapse. Tangential shrinkage is about 9 per cent and radial shrinkage about 5 per cent.

In Brazil, Vital *et al.* (1982) assessed the effect on strength of heating specimens of *E. saligna* wood to between 105 and 155°C for 10 to 160 h. The results showed increasing weight loss, increasing tangential, radial and volumetric shrinkage, and reductions in equilibrium moisture content with increasing temperature and exposure time.

A subsequent Brazilian study described a screening method to indicate the probable performance of a given wood species in a conventional drying process and the respective kiln schedule. *E. saligna* was one of six species assessed. Samples were dried at 100°C, with the drying rate, frequency of end splits, and remaining mass of water were measured at different moisture intervals. Regression analysis was then used to correlate these variables with the kiln schedule parameters of initial temperature, final temperature and initial drying potential, and three equations were developed.
2.3.2.6 Machining

Skolmen (1974) assessed timber milled from 12-year-old *E saligna* trees, and considered that performance in nailing, machining and gluing was reasonably good. A series of trials was carried out on seven different Victorian plantation species in 1998. The working properties assessed for Sydney blue gum included circular sawing (Ashley and Thompson 1998a), drilling (Ashley and Thompson 1998b), CNC routing (Ashley and Thompson 1998c), sanding (Ashley *et al.* 1998a), moulding (Ashley *et al.* 1998b), planing (Ashley *et al.* 1998c) and wood turning (Ashley *et al.*1998d). Overall the timber performed satisfactorily.

2.3.2.7 Gluing

Skolmen (1974) assessed timber milled from 12-year-old *E saligna* trees grown in a Hawaiian plantation, and considered that performance in gluing, as well as nailing and machining, was reasonably good.

In Brazil, della Lucia and Vital (1981) assessed animal glue, resorcinol formaldehyde, urea formaldehyde and PVA for gluing *E. saligna*, *E. citriodora* and *E. microcorys*. There was an interaction between species and adhesive, which had a significant effect on shear strength of the gluelines, and UF gave the best results. Pincelli *et al.* (2002) studied the effects of heat (they referred to ‘thermorectification’) on glueline strength, and showed that 120° to 180°C temperatures did not affect the wood/adhesive bonding line, but did reduce shear strength of the wood. An assessment of curing kinetics of adhesives manufactured from tannins from three different eucalypts showed that *E. saligna*- and *E. grandis*-derived tannin adhesives were less effective than those from *E. urophylla* (Morì *et al.* 2002). Vital *et al.* (2005) studied the effects of relative humidity and temperature cyclic effects on glueline resistance in joints between boards of *E. saligna*, *E. grandis* and MDF, and showed that the best results came from *E. saligna* veneer using urea-formaldehyde adhesive with timber/timber, while in timber/MDF the failure always occurred in the MDF.

Gluing trials on Australian-grown material were reported by Ozarska *et al.* (1998b), who assessed urea formaldehyde (A.V. Syntec’s AV203), Koyo KR181 and epoxy glue bonds in timber from two different areas (Mildura and Shepparton). They found that there was a significant difference between these areas in percentage wood failure with the first two adhesives, but not with the epoxy. Overall timber from the drier Mildura area performed better.

2.3.2.8 Veneer and plywood production

Plywood manufacture requires veneers that are either peeled or sliced. In Brazil, Jankowsky and de Aguiar (1983) assessed six species of eucalypt for plywood manufacture, and found that only *E. saligna* and *E. acmenoides* (syn *E. triantha*) produced veneers and plywood of reasonable quality. End splitting was the major problem with *E. pilularis*, *E. microcorys*, *E. pellita* and *E. grandis*. *E saligna* gluelines were less resistant to humidity changes than were those of *E. acmenoides*.

In New South Wales, Ksiazek and Wade (1989) assessed the suitability of *E. saligna*, *E. deanei*, *E. agglomerata* and *E. fastigata* for production of peeled green veneer for the manufacture of A-bond (i.e. waterproof) structural plywood, to replace the traditionally-used rain forest timbers. The green veneers were generally of good quality and uniform thickness, and were suitable for either face or core use.

Wade (1991) reported on more extensive New South Wales research on plywood manufacture, assessing ten eucalypt species (E. saligna, E. deanei, E. agglomerata, E. fastigata, E. nitens, E. delegatensis, E. piperita, E. sieberi, E. maculata (now Corymbia maculata), and E. camaldulensis). The results indicated that most of the species were well suited for plywood production. *E. saligna* veneers
produced A-bond plywood with two phenolic formulations, as well as B-bond and C-bond plywood, with flexible gluing conditions. The plywood was pink to reddish-brown, with a purplish tinge, and strong and smooth. The logs used in the trial came from one forest, and the amount of defect was excessive. Wade considered that there was the possibility of making jointed sheets for use as faces on rotary-peeled, random matched fancy plywood suitable for wall panelling. He recommended further tests of both peeling and gluing from the wider natural occurrence of the species.

2.3.2.9 Reconstituted wood

Waferboard use has been continually increasing in the last two decade. Keinert et al. (1988) made waferboards from *E. saligna, E. viminalis, Pinus patula, P. elliottii, P. taeda* and *P. pinaster*, and tested them to ASTM Standards (i.e. American Society for Testing Materials). The press cycle for all species except *P. pinaster* was 35 kgf/cm², press temperature 160°C, and press time of 8 minutes. The average specific gravity for *E. saligna* waferboard was 0.65, and the product was considered acceptable.

With particleboard, in Brazilian research Albuquerque (2000) reported on drying wood fibres for particleboard production, including a mix of *E. saligna* and *Pinus elliottii* fibres, while Iwakiri et al. (2000) manufactured and tested particleboards with either 8% or 12% resin, and using *E. saligna, E. citriodora* (now *Corymbia citriodora*) and *E. pilularis* or mixtures of these species.

In Brazil, Iwakiri et al. (2000) compared the strength properties of structural plywood of *E. saligna* and *P. elliottii* manufactured using different configurations of grain direction, and the MOR and MOE of parallel laminated boards were about 60% higher than those with perpendicular layers. Plywood research in Australia included acoustic sorting of *E. saligna* logs into stiffness classes before peeling (Dickson et al. 2005), which confirmed that veneers from the species were stiffer than those of *P. elliottii* and *P. taeda* and that acoustic tools have the potential to minimise yield of low quality product during plywood manufacture. In India, Dhiman and Gandhi (2005) reported on initial results from using eucalypts for plywood manufacture, and found that *E. grandis* was the preferred species – *E. saligna* would presumably behave similarly because of the similar wood structure.

Growing *E. saligna* for MDF manufacture was recommended by Phillips et al. (1997) for Hawaiian landowners. Other research into composite material was by Aranguren et al. (1998), who discussed sawdust and woodflour from *E. saligna*, and its esterification and use in the formulation of fillers. Phillips et al. (1997) developed a short-rotation forestry decision support system to help landowners and land-use planners make decisions on using former sugarcane areas in Hawaii. The models developed suggested that the optimal profitability would be production of MDF and plywood from *E. saligna* plantations.

Scrimber is a reconstituted wood product developed by CSIRO that has shown considerable potential but has not been commercially viable at this stage. Sheriff (1998) assessed six hardwood species and compared volume production with that of *P. radiata, Acacia mearnsii, E. globulus, E. grandis* and *P. radiata* generally grew faster than *Casuarina glauca, E. fraxinoides* and *E. saligna*.

An economic evaluation compared viability for firewood, wood chips for the pulp market, and Scrimber production. *P. radiata* gave the best return, followed by *E. grandis*.

Wood-cement composites are used increasingly in the developing countries, and in Cuban research Manzanares et al. (1991) studied the compatibility of Portland cement with hammer-milled particles from 3 or 4-year-old *E. saligna, 14-year-old P. tropicalis* and 19-year-old *P. caribaea*. Compatibility was measured by comparing the maximum hydration temperature, referred to as Sandermann’s method. *E. saligna* was considered less suitable for the product than the two *Pinus* species.
2.3.2.10 Timber preservation

The CSIRO Durability Classes are based on the in-ground performance of the outer heartwood of the species (Thornton et al. 1996). The ratings for E. saligna are 3/2 for decay and 3 for decay + termites, i.e. from 8 to 25 years for decay and from 8 to 15 years for decay + termites. These ratings are based on wood from mature trees, and it is possible that plantation-grown trees will not perform as well in-ground without preservative treatment.

Campbell (1971) reported on the results of strength tests on transmission poles of green or pressure-treated Pinus patula and creosote pressure-treated E. saligna from Uganda. The eucalypt performed better because it did not have the incidence of strength-reducing knots of the pine.

Duran (1972) discussed alternative methods of air-drying 8 m poles to minimise drying defects. These included cutting grooves 20 cm from each end, applying mineral grease to each end, greasing and shading each end, and a control with no treatment. Shading was most effective, and grooves appeared to have potential.

Lepage and Montagna (1973) discussed the assessment of twenty-four treatments of fence posts from an 8-year-old E. saligna plantation, and their installation in five different graveyard trials. The report discussed the two-year assessment, which showed untreated controls had failed, and preservatives containing zinc were not effective.

Skolmen (1974) assessed preservative treatment of timber milled from 12-year-old E. saligna grown in Hawaii, and found preservative penetration of heartwood and therefore retention requirements were low. This result is consistent with the general experience of treating eucalypt timber, and only a thin envelope is expected.

Reimao (1975) reported on the methods used for treating posts of various diameters, either Pinus patula or E. saligna x E. grandis, with copper-chrome-arsenic preservative (Tanalith CT-106) by vacuum pressure or the hot-and-cold open-tank process. The retentions achieved were given, and the posts were then to be installed in graveyard trials.

Preservative–treated E. saligna posts, treated by double diffusion, gave 11.2 years in ground service using CuSO₄ and K dichromate at 10.5 kg/m³ retention, or 14.3 years using CuSO₄ and Na mono-H arsenate at 7.1 kg/m³ (Lepage and deFreitas 1982). Ziobro et al. (1987) found that bandages with Patox or Osmose reduced further soft-rot attack in E. saligna or E. globulus poles in Colombia.

In Morocco, El-Abid (1984) discussed the suitability of Pinus canariensis and various eucalypt species (E. astringens, E. camaldulensis, E. cladocalyx, E. grandis, E. occidentalis, E. saligna and E. sideroxylon) for reforestation and subsequent telephone pole production, to replace imports. All species were mechanically suitable, and could be treated by the Bethell process (i.e. full cell vacuum-pressure), but only the pine could be treated by the Boucherie process. E. saligna, E. camaldulensis and E. grandis developed deep cracks during drying and had to be reconditioned.

The literature also refers to agroforestry in western Cameroon, where landholders grow various eucalypt species for firewood, poles and posts (Njoukam et al. 1996). It is unlikely that these would be preservative-treated, and they would have a short service life. Ng (1994) carried out trials using the sap replacement method for CCA preservation of eight species (including E. saligna and three other eucalypts) grown in Kenyan plantations.
2.3.2.11 General Utilisation

Kininmonth et al. (1974) assessed sawmilling, drying and utilisation of eight species of eucalypt timbers grown in New Zealand, including *E. saligna*. They considered that the timber was suitable for furniture, turnery, mouldings and flooring.

Bootle (1983, 2005) quoted uses as ‘General building purposes, cladding, flooring, panelling and boatbuilding. Has potential as a heavy furniture timber and for structural plywood.’

Purey-Cust (1979) reported a workshop to nominate exotic timber species to complement radiata pine and Douglas fir. The main demand was for medium density, stable, light-coloured woods for furniture turnery and veneers. *E. saligna* was recommended for the north of the North Island, and *E. regnans* and other ash-type eucalypts in the south of the North Island. Preston (1977) referred to New Zealand trials on wooden shingles for roofing, cladding and interior panelling. Most shingles were imported western red cedar (*Thuja plicata*), and therefore trials were assessing *Pinus radiata*, *Cupressus lusitanica* and *E. saligna*.

Further discussion on utilisation was given by Haslett et al. (1984), who considered that the timber from selected species was suitable for furniture, mouldings, panelling, flooring, veneers, although indigenous New Zealand species and imported timber were being used. *E. saligna* was included in the list, as well as *E. delegatensis*, *E. fastigata*, *E. regnans*, *E. botryoides*, *E. globoidea*, *E. muellerana*, and *E. pilularis*. Haslett (1990) further discussed the potential of *E. saligna* and other eucalypts for both structural and specialty uses, but commented on *E. saligna* and *E. botryoides* having severe growth stresses, and therefore correct sawing techniques were critical. Either backsawing or quartersawing could be done, but he recommended air-drying in protected stacks to minimise problems with collapse or surface checking. Additional comment was made by McKenzie and Hay (1996).

Utilisation of South African plantation-grown *E. saligna* and *E. grandis* was discussed by Muller (1988). The timber of both species is sold as ‘saligna’. Nearly all timber at that time came from trees less than 28-year-old. Muller described wood characteristics and properties, sawlog specifications (log end splitting is a major problem), sawing methods, timber drying, grading, as well as uses, marketing and promotion.

With structural timber, Berengut et al. (1973) discussed production of structural timber in Sao Paulo, and compared four methods of log breakdown. After assessing density, MOR and MOE, Rajput et al. (1985) considered that sawn eucalypt timber (e.g. *E. saligna*, *E. camaldulensis*, *E. citriodora*, *E. eugenioides*, *E. propinqua* and various hybrids) had potential for sawn timber. Ondimu and Gumbe (1997) measured mechanical properties of *E. saligna* and consequently recommended its use as structural timber in Kenya.

General utilisation of Indian-grown eucalypts was discussed by Rajput and Shukla (1989).

Furniture manufacture from Cuban-grown timber, including *E. saligna*, *Pinus caribaea* and *Cedrela odorata*, was discussed at an agroforestry conference in 1989 (Instituto de Investigaciones Forestales 1989).

Pallets were manufactured from Hawaiian-grown *E. saligna* timber, and helically-threaded hardened steel nails and polymer-coated pallet staples gave good results (Stern and Wallin 1976). Stapled pallets were significantly less rigid than nailed pallets.
2.3.2.11.1 Residues

Worrall (1978) discussed the use of sawdust from five eucalypts (including *E. saligna*), mixed eucalypt species, brush box (*Tristania conferta*, now *Lophostemon confertus*), and *Tsuga* spp, with *Pinus radiata* bark and expanded hardwood chips, and then mixed with nitrogen and other nutrients in a composted wood waste as a peat substitute. Steaming reduced the phytotoxic effects of the mulch on vegetables.

In Western Cameroon, various eucalypts and pines are grown for both fuelwood and construction timber, i.e. poles and posts (Njoukam et al. 1996).

2.3.2.11.2 Charcoal and energy production

There has been considerable research done on using *E. saligna* for either charcoal or energy production, particularly in Brazil. Brito and Barrichelo (1978, 1980) and Brito et al. (1978) discussed the relationship between wood density and charcoal density. Brito et al. (1983) reported that although *E. saligna*, *E. grandis* and *E. pilularis* had excellent growth, they produced poorer charcoal than *E. pellita*, *E. triantha* and *E. microcorys*.

Conto et al. (1984) assessed calorific values of several eucalypts. Vital et al. (1985) found that charcoal and carbon yields of 3 or 7-year-old *E. saligna*, *E. grandis* and *E. alba* were similar, but charcoal yield by weight decreased with carbonisation temperatures over the 375 - 575°C range, and carbon yield increased with temperature and age. Continho and Ferraz (1988a, 1988b) determined charcoal density using attenuation of gamma radiation from an Americium142 source. Magalhaes et al. (1988) discussed the effects of treebreeding, silviculture and management on wood density of fourteen eucalypt species, and the subsequent effect on wood quality and therefore charcoal quality. Trugilho et al. (2001) evaluated three clones of *E. saligna* and seven clones of *E. grandis* for charcoal manufacture, and showed a large variation between clones, with overall the latter species giving better results.

With increasing interest world-wide in carbon trading, a report on carbon budgets by Ryan et al. (2004) is of particular interest.
2.3.2.12 Other properties

In Brazil, Rodriguez-Perez (1973) estimated calorific value of *E. saligna* as 4271 calories/g, equivalent to 19.8 MJ/kg, and Couto *et al.* (1984) also assessed calorific values. In Ethiopia, Lemenih and Bekele (2004) discussed the effect of age on calorific value (also some mechanical properties) of *E. saligna, E. grandis* and *E. globulus*.

Research on the manufacture of activated carbon was done in Brazil (Sousa *et al.*. 2001).

2.3.2.13 Plantation management implications

Inherent growth stresses in Sydney blue gum and consequent problems with processing logs from young trees for sawn timber use indicate that plantations need to be grown longer, probably to 15 to 20 years or more, to minimise those effects. Plantations intended to produce sawlogs must be managed differently to those managed for woodchip logs. Sawmilling research has shown that knots are probably the major defect in sawn timber, along with gum veins, borer galleries and movement of the sawn board. Pruning of trees intended for use as sawlogs is recommended, although this is an additional cost.

Economics must be considered when using longer rotations, because the effects of compound interest on establishment costs and annual management and protection costs mean that a high return is essential.
2.4 Bending characteristics (all species).

(Dr G. Daian and Prof. B. Ozarska)

2.4.1 Introduction

Wood bending, as a means of producing curved parts in timber construction, has many advantages over other methods of manufacture but the main advantage is increased strength and recovery of timber. The most common alternative to wood bending is to cut the curvature from a piece of solid wood. This method requires cutting the wood across the grain which results in reducing the wood strength properties. In addition, there is a high percentage waste of a good quality timber.

Up to 100% higher yield can be gained by bending wood components compared to the traditional techniques used in shaping wood. This higher yield, combined with a remarkably higher quality and durability of the finished product, leads to lower production costs and an improved cost benefit to the industry.

Solid wood bending can be achieved with several methods; the wood can be bent either hot or cold. Hot bending involves softening the wood by heating prior to bending, bending wood to the required shape in a bending machine or rig and drying of the bent components.

There are different methods of heating wood before bending. The most common and an effective method used for softening timber prior to bending is steaming, and this method has been used since the 1830s (Pratt, 1988) It has been used in the production of walking sticks, chair backs, boat ribs and similar items.  Steaming can be carried out with low (atmospheric) or high pressure (autoclave), and the usual heating time is 40-60 minutes per 25 mm thickness of wood in a purpose built steam-tight box (low pressure). There is no improvement in bending results with prolonged steaming because timber is over-softened and its moisture content increased significantly, creating problems of excessive shrinkage, checking, and warping during re-drying. Further, it is likely the strength of the bent timber is also affected (Stevens and Turner, 1970; Taylor, 2001).

An alternative method to steam softening is boiling wood in water. This method is not usually as satisfactory as steaming because it tends to stain the wood and re-absorption of moisture is greater, which increases the difficulties in re-drying.

Wood can also be softened by a variety of chemicals and the most commonly used is ammonia. Wood components are impregnated with either a solution of ammonia or treated under pressure with ammonia gas, but the difficulty is that many timbers are extremely difficult to impregnate, especially Australian timbers. The process is not practicable because of its high cost and possible chemical decomposition of the timber, which results in strength reduction and change of colour. The process also has significant environmental, health and safety issues.

Bent wood componentry has been extensively used overseas in a wide range of applications such as furniture, joinery, musical instruments, sporting goods, etc. Scandinavian designers have led the world in developing a broad range of unique furniture designs that utilise bent components which combine high strength and delicate design of the products.

In Australia, bent wood components have only been used to a limited extent by craft producers, individual designer makers and a few manufacturers. Research data on the bending properties of Australian timbers, based on studies in 1940-70s is applicable only to steam bending of old growth timbers.

Extensive research studies on bending of Australian regrowth and plantation timbers have been undertaken by the Cooperative Research Centre for Wood Innovations at the University of Melbourne
aiming to investigate an innovative microwave bending technology for the manufacture of bent components suitable for regrowth and plantation timber resources.

The microwave wood bending process consists of 3 stages (Figure 1):

Microwaving heating of timber to soften and make it ready for bending.

Bending of softened timber to the required shape and restraining the bent components before drying and conditioning.

Accelerated drying of bent components using microwave technology.

The microwave wood bending technology is currently in the process of commercialization by a company; Wood Shapes Pty Ltd. Funding was provided by the Victorian State Government for the development of a full sized prototype of a wood bending system that will supply bent components to the furniture industry.

Taking into account the innovative aspects of the microwave bending method and its future availability to the Australian timber and furniture industries, this method was selected to be used in the assessment of bending characteristics of sapwood and heartwood timbers included in this project.
2.4.2 Research studies on bending characteristics of Australian timbers

As previously stated, the majority of studies on bending properties of Australian timbers were conducted in 1940-70s. The bending assessments were conducted on old growth timbers using steam bending method.

In assessing the bending properties of timber, the most important factor to be considered is the minimum radius of curvature at which a reasonable percentage of faultless bends can be obtained for a given thickness of clear material. The timber piece during the bending process is efficiently supported by means of a metal strap which reduces the wood tension failure. However, some studies provide data on the radius of curvature for both supported and unsupported material during the bending process (Forest Products Research Laboratory, 1967; Stevens and Turner, 1948).

An extensive series of tests were carried out before the World War II by the Division of Forest Products of CSIR (currently CSIRO) with the aim to determine the most suitable Australian species for commercial bending. The studies were discussed in the Trade Circular No.22, first published in 1934, and revised in 1948 (CSIR 1934; 1948). Based on the bending results, the timbers were grouped into 6 bending quality classes: excellent, very good, good, fair, poor, bad. Unfortunately, the report does not provide any details on the test methods which were used for the study, the density and the age of timbers or the criteria for the assessment of the bending properties. In total seventy timber species were tested for their bending ability, including five species investigated in this project: E. globulus, C. maculata, E. obliqua, E. diversicolor and E. piluralis. The results of this study are provided in Tables 1-9.

UK Forest Products Research Laboratory (1967) investigated the steam bending properties of over 300 species from all over the world. Although the majority of species were from Europe and America, a few Australian species were also assessed in this study, including E. diversicolor and E. obliqua. Classification of bending properties was based on the radius of curvature at which breaking during bending did not exceed 5%. Eucalyptus diversicolor was rated as “good to bend” timber, and E. obliqua as a “moderate” timber. The bending results for the two species are provided in Tables 7 & 9, respectively.

Bending qualities of about 130 Australian timbers, commercially available at the time of the study, were evaluated by Kingston (1939) at the Division of Forest Products, CSIR. All species were first bent to a radius of 150 mm. If the results at this radius proved unsatisfactory, a greater radius was used. In the case of species which bent well to a radius of 150 mm, further specimens were bent to 100 mm. The grading system for completed bends was based on the numbers 0 to 10, with 0 being a complete failure, and 10 being a perfect bend. The moisture content of timber immediately before steaming was recorded, and the mean grading was expressed as a percentage of the maximum grading value 10. Although the study was comprehensive, not even one of the species being of interest to the FWPA project was included in the study.

“Wood Bending Handbook” by Stevens and Turner (1970) has, for many years, been considered as the wood bending “bible” as it provides a detailed description of various bending methods, requirements for the material, wood softening methods, bending machines and theoretical considerations of wood bending. The appendix to the handbook includes the results of the assessment of about 200 species in steam bending (air-dried timber, 25 mm thick). Conducted in UK, the study includes only three of the Australian species investigated in the current project: Eucalyptus piluralis, E. diversicolor and E. obliqua. The values of the minimum radius of curvature for the materials, bent with and without a supporting strap, are provided in Tables 1, 7 and 9 respectively.
Diehm (1989) listed various Australian timbers suitable for bending. The species list is divided into four categories (very good, good, fair, poor) indicating suitability for bending. As the report does not provide any information on the sources of the data, methods of tests or the assessment criteria, it is presumed that the list was based on the data obtained from other publications. Four species of the nine included in the FWPA project are listed in the document: *E. diversicolor*, *E. obliqua*, *E. piluralis* and *Corymbia maculata*.

Forestry Commission of New South Wales (1988) summarised the bending properties of timbers available in NSW. As in the previous study, the classification is based on four categories (very good, good, fair, poor) but there is no reference to test methods or the criteria used in such classification. As the same four species (*E. diversicolor*, *E. obliqua*, *E. piluralis* and *Corymbia maculata*) are again included in the list of bending species, it may indicate that the data has been taken from other publications. The NSW document has been used as the reference material for data on bending properties of Australian timbers provided on ANU Forestry website.

In Western Australia, Riley (1990) investigated the effects of bending on an edge- and face-glued laminated product (Valwood™) made from jarrah (*Eucalyptus marginata*) developed by the Department of Conservation and Land Management. He compared radio frequency heating and steam heating of laminated and solid jarrah. No data on bending other Australian species has been provided.

Leaversuch (2000) conducted bending tests on five Goldfields timbers and karri. The focus of his study was to examine timber springback after bending and the tests confirmed that the timber was subjected to a severe springback after its removal from the mould and that the timber must be restrained until dry and preferably until it is used. No data on the bending properties of the timbers was provided in the report.

Basic bending behaviour of WA timber species were assessed by Forest Products Commission (FPC) of WA as part of the wood bending project within CRC Wood Innovations (Siemon, 2002). A wide range of timbers from south-west native forests, arid areas or plantation-grown was included in steam bending assessments of air-dry timbers. The timbers have potential for use as specialty timbers although availability of some species is limited, particularly those non-eucalypts from arid areas. The radii of curvature of steamed samples were determined along with the wood density, moisture uptake during steaming, and volumetric expansion. The study included three species from the timbers selected for the FWPA project: *E. diversicolor*, *E. saligna* and *E. globulus*. The test results are provided in the relevant tables below.

Reis and Siemon (2006) of FPC WA conducted a study as part of the wood bending project within CRC which involved steam bending of Western Australian timbers and comparing them with Victorian-grown Mountain Ash (*E. regnans*), to complement and provide a control for microwave bending research being done at the University of Melbourne. A rating system developed at the University of Melbourne was used to compare how much sanding or machining was required after bending to make the bent timber suitable for manufacturing use. Green Mountain Ash gave the best results, followed by Sydney Blue Gum (*E. saligna*). Karri (*E. diversicolor*) results were not satisfactory because of problems with wood quality in the samples.

Researchers and postgraduate students at the University of Melbourne, within the CRC Wood Innovations, have been studying various aspects of wood bending with the objective to develop innovative techniques, based on microwave technology, for the design and manufacture of bent-wood components.
Research studies included:

- Investigating the application of microwave technology for softening timber in order to make it plastic for bending (Stuhalter, 2005; Studhalter, Ozarska, Siemon, 2007).
- Structural behaviour of wood during bending (Juniper, 2008).
- The use of microwave irradiation for drying and stabilization of bent components (Harris, Brodie, Taube, 2007).
- Developing manufacturing processes for the “mass-production” of components and products using bent wood (Ozarska, Juniper, 2006).
- Modelling of business processes in the adaptation of microwave wood bending technology in the furniture industry (Moe, Ozarska, 2007).
- Parallel design investigation of a comprehensive range of applications undertaken by researchers and postgraduate students at Swinburne University of Technology (Hyams, 2007).

Within the CRC for Wood Innovations, an extensive study was undertaken aiming to determine bending properties, including the optimal radii of curvature and bending parameters for various species of younger timber resources (Daian, Ozarska, 2007). Eight wood species were investigated within this research. Overall, the results showed several disagreements with the literature data relating to the bending abilities of various timbers. For instance, according to the literature, Jarrah (E. marginata) has moderate bending qualities; Tasmanian Myrtle (Nothofagus cunninghamii) can be difficult to bend while the bending qualities of Blackwood (Acacia melanoxylon) are generally very good. Despite the literature arguments, the current study revealed that subject to the microwave softening process:

Karri (E. diversicolor), Shining Gum (E. nitens), Jarrah (E. marginata), Radiata Pine (Pinus radiata) and Sassafrass (Atherosperma moschatum) have very good bending characteristics (in preferential order with Karri being best), with the need for a minor sanding or small amount of machining of bends.

Blackwood (Acacia melanoxylon), Tasmanian Myrtle (Nothofagus cunninghamii) and Sydney Blue Gum (E. saligna) have moderate bending ability, with some machining of bends required.

Generally, the studies conducted at CRC for Wood Innovations revealed that the bending characteristics of young plantation timbers are better than the old growth timbers.

Tables 24-32 summarize the results of various research studies on bending characteristics of the nine Australian timbers which are the focal species of this FWPA project.
### Table 24: List of references on bending characteristics of Blackbutt, *E. pilularis*

<table>
<thead>
<tr>
<th>References</th>
<th>Bending properties</th>
<th>Bending results</th>
<th>Timber resources details</th>
<th>Test methods</th>
<th>Other data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Division of Forest Products (1948)</td>
<td>Fair</td>
<td>Not provided</td>
<td>Not provided</td>
<td>Steam bending</td>
<td>Not provided</td>
</tr>
<tr>
<td>Stevens, W.C and Turner, N (1970)</td>
<td>Minimum radius of curvature: - 610mm with supporting strap. - 1220mm without strap.</td>
<td>Not provided</td>
<td>Not provided</td>
<td>Steam bending</td>
<td>Not provided</td>
</tr>
<tr>
<td>Diehm (1989)</td>
<td>Fair</td>
<td>Not provided</td>
<td>South Qld</td>
<td>Steam bending</td>
<td>Density: 930kg/m³</td>
</tr>
<tr>
<td>Forestry Commission of NSW (1988) &amp; ANU Forestry website</td>
<td>Fair</td>
<td>Not provided</td>
<td>Not provided</td>
<td>Steam bending</td>
<td>Not provided</td>
</tr>
</tbody>
</table>

### Table 25: List of references on bending characteristics of Gympie messmate, *E. cloeziana*

<table>
<thead>
<tr>
<th>Reference</th>
<th>Bending properties</th>
<th>Bending results</th>
<th>Timber resources details</th>
<th>Test methods</th>
<th>Other data</th>
</tr>
</thead>
<tbody>
<tr>
<td>No references available</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 26: List of references on bending characteristics of Spotted gum, *Corymbia maculata, C. citriodora*

<table>
<thead>
<tr>
<th>Reference</th>
<th>Bending properties</th>
<th>Bending results</th>
<th>Timber resources details</th>
<th>Test methods</th>
<th>Other data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Division of Forest Products (1948)</td>
<td>Good</td>
<td>Not provided</td>
<td>Timber from South Coast of NSW. Timber from North NSW and Qld.</td>
<td>Not provided</td>
<td>Not provided</td>
</tr>
<tr>
<td>Diehm (1989)</td>
<td>Good</td>
<td>Not provided</td>
<td>Central and South Qld</td>
<td>Steam bending</td>
<td>Density: 1010kg/m³</td>
</tr>
<tr>
<td>Forestry Commission of NSW (1988) &amp; ANU Forestry website</td>
<td>Good</td>
<td>Not provided</td>
<td>Not provided</td>
<td>Steam bending</td>
<td>Not provided</td>
</tr>
</tbody>
</table>

### Table 27: List of references on bending characteristics of Dunn's White Gum, *E.dunnii*

<table>
<thead>
<tr>
<th>Reference</th>
<th>Bending properties</th>
<th>Bending results</th>
<th>Timber resources details</th>
<th>Test methods</th>
<th>Other data</th>
</tr>
</thead>
<tbody>
<tr>
<td>No references available</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 28: List of references on bending characteristics of Shining gum, *E. nitens*

<table>
<thead>
<tr>
<th>Reference</th>
<th>Bending properties</th>
<th>Bending results</th>
<th>Timber resources details</th>
<th>Test methods</th>
<th>Other data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daian, Ozarska (2007)</td>
<td>Excellent</td>
<td>Min radius of curvature: 260-280mm</td>
<td>Young agroforestry timbers</td>
<td>Microwave bending</td>
<td>Density 733 kg/m³</td>
</tr>
</tbody>
</table>

### Table 29: List of references on bending characteristics of Tasmanian blue gum, *E. globulus*

<table>
<thead>
<tr>
<th>Reference</th>
<th>Bending properties</th>
<th>Bending results</th>
<th>Timber resources details</th>
<th>Test methods</th>
<th>Other data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Division of Forest Products (1948)</td>
<td>Very good</td>
<td>Not provided</td>
<td>Tasmania &amp; Victoria</td>
<td>Not provided</td>
<td>Not provided</td>
</tr>
<tr>
<td>Siemon (2002)</td>
<td></td>
<td>Minimum radius of curvature: 450mm (with strap)</td>
<td>Plantation - WA</td>
<td>Steam bending</td>
<td>Density 662 kg/m³</td>
</tr>
</tbody>
</table>

### Table 30: List of references on bending characteristics of Karri *E. diversicolor*

<table>
<thead>
<tr>
<th>Reference</th>
<th>Bending properties</th>
<th>Bending results</th>
<th>Timber resources details</th>
<th>Test methods</th>
<th>Other data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Division of Forest Products (1948)</td>
<td>Good</td>
<td>Not provided</td>
<td>Not provided</td>
<td>Steam bending</td>
<td>Not provided</td>
</tr>
<tr>
<td>Forest Products Research Laboratory (1967)</td>
<td>Good</td>
<td>Min. bending radius: - 20cm (with supporting strap), - 32cm (without strap)</td>
<td>Not provided</td>
<td>Steam bending</td>
<td>Not provided</td>
</tr>
<tr>
<td>Stevens, W.C and Turner, N (1970)</td>
<td></td>
<td>Min. bending radius: - 200mm (with supporting strap), - 320mm (without strap)</td>
<td>Not provided</td>
<td>Steam bending</td>
<td>Not provided</td>
</tr>
<tr>
<td>Diehm (1989)</td>
<td>Good</td>
<td>Not provided</td>
<td>WA</td>
<td>Steam bending</td>
<td>Density: 910 kg/m³</td>
</tr>
<tr>
<td>Forestry Commission of NSW (1988) &amp; ANU Forestry website</td>
<td>Good</td>
<td>Not provided</td>
<td>Not provided</td>
<td>Steam bending</td>
<td>Not provided</td>
</tr>
<tr>
<td>Siemon (2002)</td>
<td></td>
<td>Minimum radius of curvature: 500 (with strap)</td>
<td>Not provided</td>
<td>Steam bending</td>
<td>Density 962 kg/m³</td>
</tr>
<tr>
<td>Daian, Ozarska (2007)</td>
<td>Excellent</td>
<td>Min radius of curvature: 260-280mm</td>
<td>Young plantation timber</td>
<td>Microwave bending</td>
<td>Density 852 kg/m³</td>
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</tbody>
</table>
Table 31: List of references on bending characteristics of Sydney blue gum, *E. saligna*

<table>
<thead>
<tr>
<th>Reference</th>
<th>Bending properties</th>
<th>Bending results</th>
<th>Timber resources details</th>
<th>Test methods</th>
<th>Other data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siemon (2002)</td>
<td></td>
<td>Minimum radius of curvature: 1,400mm (with strap)</td>
<td>Plantation - WA</td>
<td>Steam bending</td>
<td>Density 742 kg/m³</td>
</tr>
<tr>
<td>Daian, Ozarska (2007)</td>
<td></td>
<td>Min radius of curvature: 340-370mm</td>
<td>Young plantation timber</td>
<td>Microwave bending</td>
<td>Density 733kg/m³</td>
</tr>
</tbody>
</table>

Table 32: List of references on bending characteristics of Messmate, *E. obliqua*

<table>
<thead>
<tr>
<th>Reference</th>
<th>Bending properties</th>
<th>Bending results</th>
<th>Timber resources details</th>
<th>Test methods</th>
<th>Other data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Division of Forest Products (1948)</td>
<td>Good</td>
<td>Not provided</td>
<td>Not provided</td>
<td>Steam Bending</td>
<td>Not provided</td>
</tr>
<tr>
<td>Forest Products Research Laboratory (1967)</td>
<td>Moderate</td>
<td>Min. bending radius: - 41cm (with supporting strap), - 61cm (without strap)</td>
<td>Not provided</td>
<td>Steam Bending</td>
<td>Not provided</td>
</tr>
<tr>
<td>Stevens, W.C and Turner, N (1970)</td>
<td></td>
<td>Min. bending radius: - 410mm (with supporting strap), - 610mm (without strap)</td>
<td>Not provided</td>
<td>Steam bending</td>
<td>Not provided</td>
</tr>
<tr>
<td>Diehm (1989)</td>
<td>Good</td>
<td>Not provided</td>
<td>NSW, Vic, Tas</td>
<td>Steam bending</td>
<td>Density: 770kg/m³</td>
</tr>
<tr>
<td>Forestry Commission of NSW (1988) &amp; ANU Forestry website</td>
<td>Good</td>
<td>Not provided</td>
<td>Not provided</td>
<td>Steam bending</td>
<td>Not provided</td>
</tr>
</tbody>
</table>
3 References

3.1 Project background


3.2 Messmate (Eucalyptus obliqua)


3.3 Shining gum (Eucalyptus nitens)


3.4 Tasmanian blue gum (Eucalyptus globulus)


3.5 Gympie Messmate (E. cloeziana), Blackbutt (E. pilularis), Spotted Gum (Corymbia citriodora C. maculata) & Dunns White Gum (E. Dunnii)
Anon (2005). HARDWOODS ADVICE: HARDWOOD PLANTATION TIMBER PROPERTIES AND USES. Department of Primary Industries and Fisheries, Qld, Australia.

Anon (2002). SPOTTED GUMS. HARDWOODS QUEENSLAND PLANTATION SPECIES PROFILE 1, Department of Primary Industries, Queensland.


3.6 Karri (Eucalyptus diversicolor)


3.7 Sydney Bluegum (*Eucalyptus saligna*).


3.8 Bending characteristics (all species)

CSIRO (1948 TRADE CIRCULAR NO. 22 - TIMBER BENDING, , Extract from Division of Forest Products, Commonwealth of Australia Council for Scientific and Industrial Research, Melbourne.

Diehm, W. I. (1989) TIMBERS SUITABLE FOR BENDING, Extract from Timber Note No 37, Queensland Department of Forestry.


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Wilson, T. R. C. (1929) WOOD BENDING (with appendix on apparatus for bending boat ribs). Madison Wisconsin, United Stated Department of Agriculture, Forest Sevice, Forest Product Laboratory.