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Evaluation of wood characteristics of tropical post-mid rotation plantation *Eucalyptus cloeziana* and *E. pellita*: Part (d) Veneer and plywood potential

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Evaluation of wood characteristics of tropical post-mid rotation plantation *Eucalyptus cloeziana* and *E. pellita*: Part (d) Veneer and plywood potential

Prepared for

Forest and Wood Products Australia

by

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Executive summary

Representative logs from two hardwood plantations located in north Queensland were peeled to enable assessment of the veneer and plywood potential of fast-grown tropical plantation eucalypts. After visual grading and veneer recovery calculations, selected veneers were assembled to produce plywood panels which were then tested for mechanical properties and glue bond strength. These tests were chosen to provide the best indications of the utility of young, fast-grown, tropical eucalypts for panel product applications.

On 20 March 2006, Cyclone Larry crossed the north Queensland coast near Innisfail and caused extensive damage to buildings, agricultural crops, forests and timber plantations. Salvage logging in the area subsequently provided forty-two 19-year-old Gympie messmate (*Eucalyptus cloeziana*) stems and thirty-two 15-year-old red mahogany (*Eucalyptus pellita*) stems for processing and product research. The donor stands were approximately 60 km apart and growing on different soil types. From this sample, 14 Gympie messmate and 12 red mahogany billets (one per tree in each case) were used for peeled veneer and plywood trials.

The north Queensland region has a rich history of veneer and plywood production, with many rainforest species achieving popularity with joiners and architects, both in Australia and abroad, since the 1930s. With much of the productive rainforest area in the region now listed as World Heritage sites, local forest product processing activities have diminished during the past 20 years. During this period, a new series of trial plantings of rainforest and eucalypt species have been established to investigate the potential for substitute timber production. The region includes areas of highly productive land with suitable soil types and high annual rainfall encouraging several private forestry companies to establish plantation projects in the area in recent years.

The plantations accessed during the Cyclone Larry salvage operations reflect typical target age classes and candidate species for thinning and near-rotation harvesting for commercial plantations and therefore presented an excellent opportunity to evaluate the potential of these resources through veneer production and plywood manufacturing processes and testing protocols.

Representative samples of each test population were measured for a range of attributes including volume and taper. Billets were stored under cover within damp hessian shrouding to delay drying degrade between harvesting and processing. Although this mode of storage was effective in preventing drying degrade, the red mahogany billets developed end splits as a consequence of growth stress release.

Although the red mahogany was only 15 years old, the billets obtained from selected logs had ideal geometries for peeler logs, with an average taper ratio similar to the older Gympie messmate. It should be noted however, that at ages 15 and 19 the material used in these research trials was considerably younger, and therefore smaller in dimension, than traditional peeler logs, sourced from native hardwood forests and older plantations. It should also be noted that the billets used for this trial were 1.31 m in length which is a standard cross band dimension, not the conventional 2.5 m length used for production of long bands.

Veneer was produced through standard industry steaming, peeling and drying processes. The dried veneer was visually graded in accordance with Australian Standards and then batched for lay-up into structural panels. Type A and Type B bond adhesives were used and a total of ten 1200 mm x 1200 mm Gympie messmate and six red mahogany panels were manufactured in commercial production facilities. Additionally, eight panels comprised of plantation hardwood outer layers over plantation softwood cross band substrates were produced.

End splits impacted the production of full veneer sheets from the young red mahogany; however the Gympie messmate produced a reasonable quantity of veneer sheets. Several of the red mahogany billets contained white pocket rot, generally associated with knots and the juvenile core. This limited the available peeling fraction from affected billets and often left a large residual core. Further work is recommended in the areas of decay prevention in the plantation, the development of low splitting families or clones and the assessment of post harvest techniques to minimise the development of growth stress-related end splits. It was not possible to determine whether the extent of end splitting was influenced by the Cyclone in addition to growth stress release.

Several methods of assessing the grade quality for each species were used, including the distribution of visual grades and calculation of grade scores to provide a relative value for the grade quality. The Gympie messmate produced significantly more veneer per cubic metre of log and achieved higher scores for quality than the younger red mahogany. Industry representatives witnessing the peeling operations commented that the Gympie messmate had the appearance of a high quality hardwood veneer, despite the relatively young age of the source trees.

While the low number of test panels available for each species precluded the formal allocation of stress grades, the mechanical tests suggested that both species in their respective age classes can attain stress grades equal to standard commercial structural plywood products. These data provide an indication of the potential of the species and age class only and should be used with caution. Based on the test sample (n=6 panels), the 15-year-old red mahogany panels may achieve stress grades ranging from F11 to F14. This result indicates that correctly graded veneers could produce a structural product in the range typical for commercially available softwood plywood products. From an appearance quality perspective, it was noted that the red mahogany also exhibited good red colouration, despite the young harvest age of the material.

The Gympie messmate panel sample (n=10 panels) may achieve stress grades between F22 and F27 which indicates that the 19-year-old material could produce veneer quality typical of the higher end of the commercial range of F17 to F27 hardwood plywood currently available in domestic markets.

Despite higher total extractives content than the older Gympie messmate, the 15-year-old red mahogany performed better in the glue bond assessment. The panels manufactured by commercial production facilities achieved a 100% pass rate and the laboratory scale tests achieved a 90% pass for Type A bonds. The commercial facility-produced Gympie messmate Type A panels achieved an 80% pass rate but only 42 % for the laboratory scale glue bond tests. This may be attributed to the lower density of the red mahogany veneer which typically allows for strong bonding between adherends. Both species failed to produce satisfactory Type B bonds in either the industry prepared plywood panels or laboratory scale tests. The results for the Type A bond tests provide optimism for future product development for exterior grade engineered wood products using plantation-grown eucalypts. However, there is a need for further investigations into use of Type B bond plywood manufacture from young plantation-grown eucalypts in order to explain the unexpected results attained during these trials.

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1 Introduction

This report describes a research project which investigated the veneer and plywood potential of north Queensland tropical plantation eucalypts. Background information is provided on plywood and veneer: the process, grading, bond types and history of the industry in the region. Additionally, published wood properties data and the emerging importance as plantation candidates are noted for the two species investigated. This veneer and plywood project was part of a larger study which considered solid wood properties (McGavin *et al.* 2007), seasoning (Redman and McGavin, 2007) and natural durability (Francis *et al.* 2007) utilising the same plantation resources.

The veneer and plywood study incorporated: tree and log measurement activities; processing (billet steaming, peeling and veneer drying) in a commercial hardwood plywood facility; graded recovery calculations; manufacture of 5-ply panels for mechanical properties and glue bond testing. Extractives content test results are discussed within this report however full test detail has been reported independently by McGavin *et al*. 2007.

1.1 The opportunity

Engineered wood products are becoming an increasingly important construction material group as the hardwood sector moves to a non-traditional resource, that is, a transition from generally larger, native forest hardwood logs to smaller fast-grown plantation trees. As these changes occur, the industry is eager to gain an understanding of the emerging plantation resource to ascertain its suitability for traditional panel products and to determine if process modifications will be required. Australia currently lacks a suitable resource base to provide high volumes of plantation logs for processing and product development; however a cyclonic event in early 2006 afforded an opportunity to salvage and process logs for a range of tests.

Cyclone Larry, the first severe tropical cyclone to cross the Queensland coast in seven years, caused major damage from Cairns in the north to Cardwell in the south. Beginning as a low pressure system over the eastern Coral Sea, Cyclone Larry was categorised as a cyclone on March 18 2006 and crossed the coast as a Category 5 tropical cyclone near Innisfail two days later (Figure 1). Attaining wind speeds estimated at 320 km/hr, Larry maintained cyclone strength as it tracked west for several hundred kilometres inland, causing damage to buildings, agricultural crops and forests, including timber plantations.

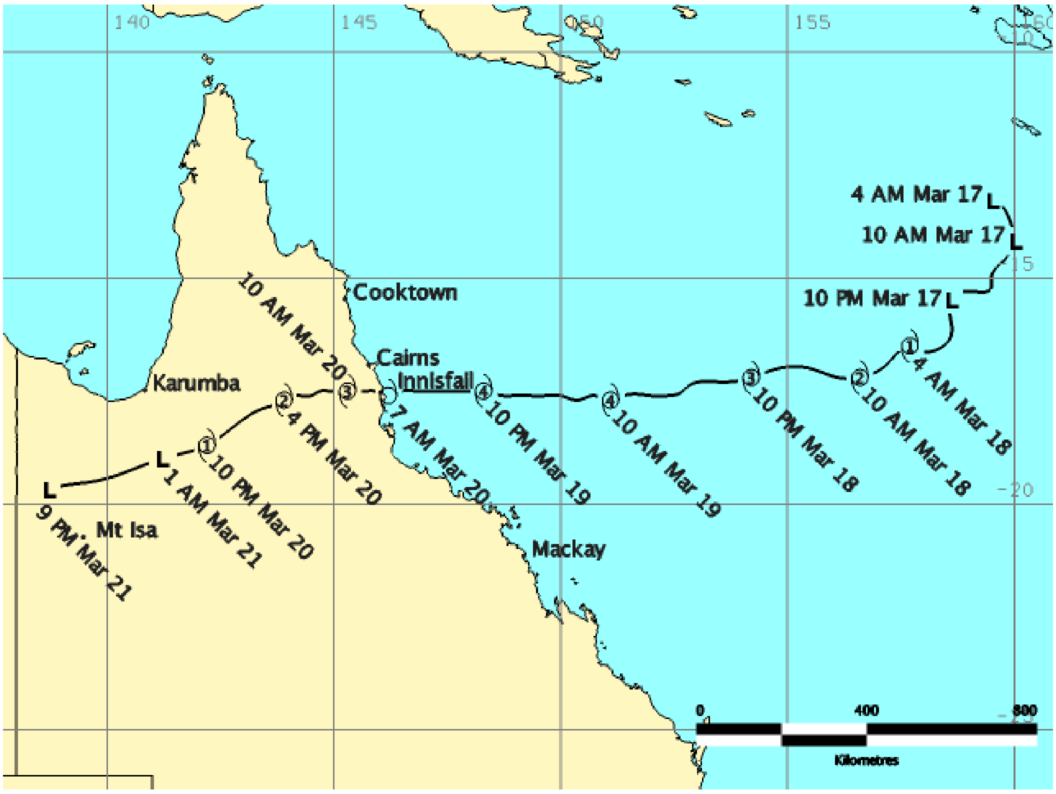

Figure 1. Cyclone Larry's path 17/03/06 to 21/03/06 (Source: Bureau of Meteorology).

The damages bill for primary industries was estimated at $470 million, with an area of 12,500 square kilometres affected (DPI&F 2006).

The cyclone event provided the opportunity to salvage a quantity of representative logs for a range of wood quality and product development trials.

Less than two months after the cyclone event, logs were salvaged from two damaged plantations to provide material for research and development work. The ages and silvicultural histories of these resources reflected typical management regimes and rotation lengths proposed for future tropical eucalypt plantations in the region. Therefore the cyclone event presented an opportunity to investigate the attributes of sawn timber, veneer and plywood produced from such material. The age and species of the logs salvaged and utilised for these trials were:

- 19-year-old Gympie messmate, *Eucalyptus cloeziana*
- 15-year-old red mahogany, *Eucalyptus pellita*.

This report covers the veneer and plywood component of a wider scope of work undertaken by DPI&F on logs from the two plantation areas. Other research included investigations of wood and mechanical properties (McGavin *et al.* 2007), accelerated seasoning (Redman and McGavin 2007) and natural durability trials (Francis *et al.* 2007).

The aims of the veneer and plywood work were originally to assess the quality variation radially, from the core (or inner heartwood) to the outer heartwood and the effectiveness of commercial plywood adhesives on young Gympie messmate and red mahogany veneers. However, as the project developed it was determined that the sample available for testing was more appropriate for overall grade quality assessment, veneer recovery and panel product properties rather than an emphasis on radial variation. Gluebond quality and strength testing were conducted on panels produced in collaboration with industry.

1.2 Plywood and veneer

Plywood belongs to the wood based panel product group and competes in the market with particleboard, medium density fibreboard, oriented strand board (OSB[1]) and hardboard. With some exceptions, these products serve the same general markets within two broad classifications, namely interior and exterior applications.

The term plywood is derived from the composition of the product, whereby layers of veneer (‘plies’) are adhered together with the grain alternating in direction for stability and strength to form a manufactured solid wood substitute in a flat sheet. Plywood retains inherent advantages of the parent wood (for example, it is a relatively lightweight construction material, easy to work with simple tools and doesn’t corrode) with added qualities resulting from its laminated structure (for example, high strength and stiffness to weight ratios, dimensional stability and superior shear properties). When manufactured in accordance with Australian Standards, plywood is recognised by the Timber Structures Code (*AS1720* Parts 1-1997 and 2-2006) and can therefore be assigned the prescribed structural properties.

Veneers for structural plywood are generally produced (‘peeled’) off a rotary lathe, while decorative veneers may be produced by peeling or slicing. It has been estimated that rotary peeling accounts for approximately 95% of all veneer production (Anon., no date). Consistent demand for plywood products including bracing, form-ply, interior flooring and stair treads, lining, furniture, container flooring and lining, exterior cladding, marine ply and engineered wood products (such as box beams and portal frame gussets) has ensured ongoing success for a range of producers at different locations around Australia, however resource security and competition from imported, and sometimes below standard products, is increasingly of concern to the Australian plywood sector.

1.3 Bond types

Adhesives used for bonding wood material have evolved from mud and dung in ancient times, to egg, starch, blood, lime and casein in the 1st century, to natural rubber compounds in the 19th century, followed by 20th century developments such as:

- 1909- phenolics, Bakelite
- 1915- polyvinyl acetate (PVA)
- 1930s- urea formaldehyde (UF), melamine resins
- 1940s- resorcinol resins, epoxies, isocyanates, synthetic rubber and
- 1950- pressure sensitive tape.

Australian Standard *AS2754.1:1985 Adhesives for plywood manufacture* (Standards Australia 1985) specifies four bond types for plywood manufacture: A, B, C and D,

[1] Not currently manufactured in Australia but imported, especially for I-beam webs.

representing the adhesive durability in relation to different applications. An explanation of the different bond types is provided below:

- Type A bond- intended to withstand prolonged exposure to severe exterior conditions without failure of the glueline. Readily recognised by its dark colour, the Type A bond is normally suitable for exposed, structural and marine applications where rigidity and durability are required. Phenolic Type A bonds have relatively low formaldehyde emissions of between 0.00 to 0.03 ppm. A phenolic formaldehyde resin based adhesive (PF) was used to provide the Type A-bond components for this project. Other Type A bond systems use tannin formaldehyde, resorcinol formaldehyde or combination systems. The standard durability requirement for an A bond is to withstand 72 hours immersion in boiling water.
- Type B- intended to withstand occasional wetting and drying without delamination and is included in the exterior plywood standard to cover applications such as concrete formwork and exterior door skins. Melamine fortified urea formaldehyde (MUF) resin was used to provide Type B bond samples for this trial. Type B bond adhesives allow the plywood to withstand 6 hours immersion in boiling water.
- Type C- intended to withstand infrequent wetting and drying without delamination occurring in interior applications only. The glueline, for example urea formaldehyde (UF) adhesive, is white to colourless, suitable for indoor furniture.
- Type D- satisfactory for normal interior non-structural applications including furniture and fittings. The adhesive is generally extended urea formaldehyde with water and/or flour fillers and lower resin content than Type C bonds.

No Type C or D bonds were included in the trials reported here.

1.4 Grade quality descriptions

There are five veneer quality grades specified for plywood in Australian and New Zealand Standard *AS/NZS2269:2004 Plywood- structural* namely A, S, B, C and D (Standards Australia 2004):

- veneer quality A- appearance grade suitable for clear finishing
- veneer quality S- appearance grade with some natural defects, such as knots, permitted as defined in a written agreement between manufacturer and specifier
- veneer quality B- appearance grade suitable for paint finishing
- veneer quality C- non-appearance grade, but with a solid surface (knot holes and splits to be filled), suitable for flooring substrate (under carpet, vinyl, tiles) and
- veneer quality D- non appearance grade with limited open defects permitted, suitable for structural bracing.

Plywood sheet grade quality can be specified with the appropriate face and back qualities for the intended purpose. For example, tongue and grooved structural flooring substrate to be overlaid with carpet is typically specified as CD where C denotes the front face grade quality required and D the back face quality.

1.5 Tropical Australian veneer and plywood

Tropical north Queensland historically has a long association with veneer and plywood production. In 1930, Cairns Timber Limited established the veneer industry in the tropics when it installed a vertical veneer slicing machine (Taylor 1994). The region was renowned as the source of dozens of premium veneering species primarily harvested from the highly productive tropical rainforests. Queensland maple (*Flindersia brayleyana*), northern silky oak (*Cardwellia sublimis*) and Queensland walnut (*Endiandra palmerstonii*) are examples of timber species that produced quality veneer for a wide range of products both in domestic and export markets.

The north Queensland hardwood veneer and plywood industry ceased to exist following World Heritage Listing of substantial tracts of rainforest in the wet tropics in the late 1980s. There have been investigations into the establishment of hardwood plantations during the intervening years, ranging from exotic species including paulownia (*Paulownia* spp.), African mahogany (*Khaya* spp.) and teak (*Tectona grandis*) as well as native rainforest cabinet woods and more recently eucalypts, however wood quality and product development work has not previously extended to veneer and plywood trials.

The past decade has seen a shift in eucalypt plantation management in many tropical regions, for example Brazil, Uruguay and Argentina, whereby production of higher volumes of pruned log enabled capital investment in rotary peeled veneer and plywood facilities (Flynn no date; Leggate 2004). The primary species utilised are rose gum (*Eucalyptus grandis*) and urograndis (Timor white gum x rose gum hybrid, *E. urophylla* x *E. grandis*) which are marketed in the United States as a cheaper substitute for cherry (*Prunus* spp.) and American mahogany (*Swietenia* spp.).

Medium to high density timber species, such as the two tested in this research, pose a number of challenges for plywood manufacturers. Surface quality achieved through peeling and machining processes is critical and veneer must be smooth, tight and of uniform thickness. Rough veneer or poorly machined laminates cannot be forced into satisfactory contact, even at maximum glueline pressures of 1.3 MPa (Lyngcoln 1992). Higher density species achieve better bonds when laminates of lower density are used as interleaves or when synthetic phenolic adhesives are used at relatively low veneer moisture contents such as 3%, for example (Lyngcoln 1992).

Until the late 1980s-early 1990s the industry considered that it was not viable to bond high density eucalypts containing significant extractives. Since then, natural tannin formaldehyde phenolic adhesive systems (in contrast to synthetic phenolics) used with veneer at 7-10% moisture contents have produced commercially reliable bonds in some troublesome eucalypt species, for example blackbutt (*E. pilularis*). This is possibly due to the neutral pH of the bond, minimising the leaching of natural polyphenolic extractives to the surface of the veneer and interfering with the development of the bond. Lower caustic phenolics and novel phenolic formulations have achieved reasonable success in manufacturers' trials (Lyngcoln 1992). Some high density species, for example spotted gum (*Corymbia citriodora*) remain difficult to adhere with either synthetic phenolic or tannin adhesives.

Although the transition from low and medium density rainforest species to high density regrowth eucalypts presented production problems in Australian facilities using phenolic resins, South American plywood manufacturers have been successful in adhering plantation grown veneers (BIL Technologies, 2007), indicating the potential for manufacturing engineered wood products sourced from tropical Australian plantations.

1.6 Tropical Australian eucalypt plantations

Important changes have occurred regarding access to state-owned native hardwood forests. These changes have resulted in reduced activity (lower annual harvested volumes and fewer processors), a trend that will likely continue in accordance with government policies. This will eventually bring about a transition from state-owned hardwood forests to plantation resources combined with increased reliance on the private sector and imports. In order to meet the predicted demand for log supply, the hardwood plantation estate will need to increase significantly (Timber Queensland 2006).

In contrast to the softwood plantation establishment programs of the 20th century, investment and ownership of the emerging hardwood plantation estate is likely to be primarily through private sector participation (i.e. managed investment schemes and land holder investment) rather than public state government administration. The private sector has considerable expertise in raising investment capital for establishment, management and marketing of short rotation wood chip and pulp log crops and medium term sawlog projects. The majority of these sawlog projects are relatively immature and won't be available to generate wood quality and utilisation data in the short term. This highlights the significance of the resource characterisation opportunity presented by the Cyclone Larry event.

Genetic and silvicultural trials have been installed, maintained and measured since the 1980s to inform future directions and priorities for plantation establishment and management in north Queensland and elsewhere in the state. Preliminary results show that several species can achieve satisfactory productivity within reasonable timeframes and that the wood properties of fast grown material are consistent with requirements for many traditional solid wood applications, albeit with some modification and innovation to processing systems (Hopewell 2002; Muneri *et al.* 2001; McGavin *et al.* 2006).

Assessment of pole productivity for selected eucalypt plantations indicates that Gympie messmate may be grown economically to produce poles greater than 14.0 m long (Garthe 1983). The kraft pulping and papermaking properties of north Queensland plantation grown Gympie messmate and red mahogany have also been assessed (Clark and Hicks 1996). However, qualitative and quantitative data describing the veneer and plywood potential attainable from managed plantations of fast-grown eucalypts in the Australian tropics are lacking.

Cyclone Larry caused severe damage to several north Queensland eucalypt plantations, two of which provided the material for this study which is the first investigation into plywood and veneer production from north Queensland eucalypt plantations.

1.7 Gympie messmate

Gympie messmate is the standard trade name reported by Australian and New Zealand Standard *AS/NZS1148:2001. Timber- Nomenclature- Australian, New Zealand and imported species* for timber produced from the native hardwood species *Eucalyptus cloeziana* (Standards Australia 2001). In its natural state, Gympie messmate is noted for its excellent stem form and vigour, attaining up to 50 m in height and 2 m in diameter. It occurs in scattered areas between Gympie in the sub-tropics and Cooktown in tropical north Queensland. The timber has excellent properties for a wide range of applications where strength, durability and termite resistance are required. In addition to engineering applications such as poles, bridge timbers and sleepers, Gympie messmate was one of four candidate species selected for extensive furniture timber research and development in the 1990s (Ozarska and Hopewell 1998). In addition to advantageous wood properties and appearance, the timber is relatively easy to dry and its sapwood is not susceptible to lyctine borer infestation; both factors which affect the economics of conversion and marketability.

Published wood properties' data for mature Gympie messmate are summarised in Table 1.

Table 1. Nomenclature and properties for mature Gympie messmate.

Botanical name derivation [a]	
Eucalyptus	*eu* = Greek 'well', *calyptos* = 'covered' refers to operculum
cloeziana	French chemist F. S. Cloez, 1817-1883
Standard trade name [c]	Gympie messmate
Local names [b]	dead finish, Queensland messmate, yellow messmate
Air dry density [c]	1010 kg/m^3
Strength groups/ stress grades [c]	green- S2/ F11-F22; seasoned- SD3/ F14-F27
Joint groups [c]	green- J1; seasoned- JD1
Natural durability ratings [c]	above-ground- 1; in-ground- 1
Lyctine susceptibility [c]	not susceptible
Termite resistance [c]	highly resistant
MOR [d]	green- 94 MPa; seasoned- 137 MPa
MOE [d]	green- 14 GPa; seasoned- 17 GPa
Maximum crushing strength [d]	green- 49 MPa; seasoned- 73 GPa
Janka hardness [d]	green- 7.7 kN; seasoned- 12 kN

[a] Perrin 1988 ; [b] Cause *et al.* 1989 ; [c] Hopewell 2006;
[d] Bootle 2005 (small clear sample testing).

Due to the combination of desirable wood properties and good growth characteristics, Gympie messmate is one of six key species currently grown in state-owned plantations (DPI&F 2006) and has been identified as a candidate for establishment in private timber plantation projects, particularly in north Queensland.

Of four similarly-aged hardwood species processed in a DPI&F trial in Argentina in 2001, 13- and 14-year-old Gympie messmate provided the highest green-off-saw recovery due to superior form of the logs (Hopewell 2002). Recently, Gympie messmate plantation stems have been steam bent successfully in their natural round form as part of an investigation into innovative products from traditional non-commercial thinnings (Thirion 2007), presenting opportunities for arched structural products from this emerging resource. McGavin *et al.* (2006) and McGavin and Bailleres (2007) also reported extensive wood and mechanical properties testing and market suitability studies for eight-year-old Gympie messmate plantation thinnings, showing encouraging potential.

Gympie messmate is an important plantation species for high quality poles in sub-tropical Africa. It has been successfully introduced to Congo, Kenya, Malawi, Nigeria, Zimbabwe, Uganda and Zambia, principally in areas with an average annual precipitation up to 1500 mm (Hillis and Brown 1984).

1.8 Red mahogany

Red mahogany is the standard trade name reported by *AS/NZS1148:2001* for two similar hardwood timber species: *Eucalyptus pellita* and *E. resinifera* (Standards Australia 2001). *Eucalyptus pellita* is a medium sized hardwood attaining a height of 45 metres and a stem diameter to 1.5 m. The species occurs naturally in:

- Australia in scattered areas along the coast from southern New South Wales north to Gladstone and from north of Townsville to Iron Range on Cape York Peninsular and
- Papua New Guinea and Irian Jaya.

The timber has a history of utilisation for flooring, cladding, panelling, poles and sleepers. Published wood properties' data for mature wood are summarised in Table 3.

Table 2. Nomenclature and properties for mature red mahogany.

Species name derivation [a]		
	Eucalyptus	*eu* = Greek 'well', *calyptos* = 'covered' refers to operculum
	pellita	Latin *pellitus* = covered with skin, referring to thick leaves
Standard trade name [c]		red mahogany
Local names [b]		Daintree stringybark, red stringybark, large-fruited red mahogany
Air dry density [c]		995 kg/m^3
Strength Groups/ Stress Grades [c]		green- (S2)/ F11-F22; seasoned- (SD3)/ F14-F27
Joint groups [c]		green- J1; seasoned- JD1
Natural durability ratings [c]		above-ground- 1; in-ground- 2
Lyctine susceptibility [c]		untreated sapwood is susceptible
Termite resistance [c]		highly resistant
MOR [d]		green- 78 MPa; seasoned 140 MPa
MOE [d]		green- 16 GPa; seasoned- 18 GPa
Maximum crushing strength [d]		green- 50 MPa; seasoned- 76 GPa
Janka hardness [d]		green- 9.0 kN; seasoned 12 kN

[a]Perrin 1988 [b]Cause *et al.* 1989 [c]Hopewell 2006
[d]Bootle 2005, notes: data determined by small clear sample testing.

In addition to trials established by DPI&F in collaboration with various landholders in the tropical north, private forestry companies are beginning to plant red mahogany in the region. ITC Limited plan to expand their private estate in northern Queensland to approximately 50,000 ha, of which red mahogany will be one of three or four key species (Larsen 2006). Their current 2008 investment prospectus details plans for red mahogany plantation establishment with commercial thinning at age seven and clearfall at age 18.

Prior to the Cyclone Larry salvage trials, DPI&F undertook research work on the same red mahogany plantation when it was eight years old (Muneri *et al.* 2001). Wood products research was also reported by Hopewell (2002) on 13- and 14-year-old red mahogany grown in Argentina. These trials highlighted red mahogany's propensity to decay, associated with heart and branch wounds, which resulted in relatively low graded recoveries. Nevertheless, the boards recovered from the

Argentinean study indicated that by age 14, red mahogany displays a good level of red colouration. McGavin *et al.* (2006) reported detailed information on wood and mechanical properties for a small sample of eight-year-old red mahogany plantation thinnings and preliminary information about veneer, sawn timber and round wood applications.

Due to its fast growth, red mahogany has been a species of interest in north Queensland for land degradation control and commercial timber plantation establishment (Sun *et al.* in Muneri *et al.* 2001).

2 Materials and methods

2.1 Gympie messmate

Located on Crupi Road near El Arish, approximately 30 km south of Innisfail, the Gympie messmate plantation accessed for this study was extensively damaged during the Cyclone Larry event (Plate 1). At the time of the cyclone, the trees were 19 years old, approximately the full rotation age being targeted by plantation managers, and providing ideal material for research. The salvage assessment recorded that many damaged Gympie messmate trees had blown over with the root ball intact, with little or no obvious damage to the merchantable bole, rather than bending or twisting and breaking off above ground.

Plate 1. Harvested Gympie messmate logs prior to transportation.

In contrast, most red mahogany stems salvaged from the other plantation for this study had snapped off above ground. The Gympie messmate plantation area received more intensive site preparation prior to planting as summarised in Table 2. This may have attributed to the lack of wind firmness. Other factors influencing wind-firmness include soil type, rooting characteristics and site exposure. Detailed plantation history for the salvaged Gympie messmate material is provided in Table 2. Nine-year data for growth, bole length and straightness are given in Dickinson *et al*. 1996.

Table 3. Plantation data: 19-year-old Gympie messmate, *E. cloeziana*.

Species	*Eucalyptus cloeziana*
Provenances	Pomona, south Queensland Helenvale, north Queensland
Location	Crupi Rd, near El Arish, approximately 36 km south of Innisfail 17°48'S, 146°00'E
Owner	Mr Graham D. Smith
Soil	red podsolic
Rainfall	3340 mm/ annum
Slope	3°
Aspect	south-east
Altitude	40 m asl
Planting date	03/1987
Age at cyclone salvage	19-year-old
Original stocking	1234 stems per hectare (spha)
Espacement	3.0 m x 2.7 m
Site preparation	1. three-furrow disc plough 2. deep rip to 0.4 m 3. offset discing x 3 passes 4. planting holes by motorized soil auger
Silvicultural history	*weed control*- 2 m row maintained until age 2 *fertilisation*- 300 g/tree Crop King Q5 at planting 600 g/tree Crop King Q5 at age 1 yr *pruning*- to 1.5 m at age 1.5 yrs and to 6 m at 3.5 yrs *thinning*- to 400 spha at age 4.5 yrs
General comments	This plantation experienced good growing conditions during the 19 years prior to Cyclone Larry. Pomona provenance material was producing more wood volume through straighter formed and more vigorous stems.

(Source: Dickinson, 2006a.)

2.2 Red mahogany

The 15-year-old red mahogany plantation was located approximately 20 km north of Innisfail. It was planted in 1991 and included both north Queensland and Papua New Guinea provenances. Silvicultural and site data for this plantation are summarised in Table 4.

In contrast to the wind-thrown Gympie messmate, most of the cyclone-damaged red mahogany trees broke off above the ground line. As mentioned before, this difference may be due to less intense site preparation, soil type, more exposed topography or different rooting characteristics. General observations suggested that the Papua New Guinea provenance suffered more damage than the Australian provenance.

Plate 2. Harvested red mahogany logs prior to transportation.

Table 4. Plantation data: 15-year-old red mahogany, *E. pellita*.

Species	*Eucalyptus pellita*
Provenances	Coen, north Queensland (CSIRO 14339) North Tokwa to Kiriwa, Papua New Guinea (CSIRO 16121)
Location	Dillon property, approx. 20 km N of Innisfail 17°28'S, 145°57'E
Owner	Mr Dennis Dillon
Soil	red ferrosol (krasnozem)
Rainfall	3340 mm/ annum
Slope	1° to 5°
Aspect	easterly
Altitude	80 m a.s.l.
Planting date	05/1991
Age at cyclone/harvest	15-year-old
Original stocking	1143 stems per hectare
Espacement	3.5 m x 2.5 m
Site preparation	1. offset discing, two passes 2. planting holes dug with mattock ('grubber')
Silvicultural history	*weed control*- 2 m row maintained until age 1.5 years *fertilisation*- none recorded *pruning*- to 1.5 m at age 14 months and to 3.5 m at 2.5 yrs *thinning*- 1. to 700 spha at 14 months 2. to 400 spha at 2 yrs 3. to 240 spha at 5 yrs 4. to 150 spha at 8.5 yrs
General comments	At age 4, the Coen stock was markedly poorer in growth. Prior to the cyclone, tree growth and health had been very good, with the PNG provenance performing marginally better on average than the north Queensland material.

Source: Dickinson 2006b; Dickinson and Sun 1995; Muneri *et al.* 2001

2.3 Resource assessment and field mensuration

Technical officers from DPI&F assessed the cyclone damaged plantations for salvageable logs and selected a total of 74 trees (42 Gympie messmate and 32 red mahogany) suitable for wood products research. Detailed measurements of the selected logs were taken during harvesting including length, small-end, centre and large-end diameters. Log ends were sealed with a proprietary brush-on end-sealer treatment and then transported to the Salisbury Research Centre[2] for final merchandising, allocation and testing.

2.4 Billet selection and veneer processing

Each group of logs was ranked by large-end diameter and the first, third, fifth, etc were delegated to provide 15 billets from each species batch for the veneer and plywood trials. The rationale for selecting each second log was to ensure that a sample of large, pruned logs was also available for solid wood processing trials.

Industry specifications were for straight billets with a minimum acceptable diameter of 230 mm and a maximum diameter of 450 mm. The veneer logs were kept oversize at 1.8 m length and stored in a closed shed under damp hessian shrouding to retard drying and so minimise degradation during storage.

The billets were taken to Big River Timbers[3] at Grafton, New South Wales where they were docked to 1.31 m lengths and measured for large and small end diameters to calculate billet volumes and taper geometries.

<u>Gross billet volume</u>

The gross billet volume is the original total volume of the billet as it enters the lathe and includes the waste, peeling fraction and core. Dimensions of length and centre diameter under bark were used to determine gross billet volume by Huber's method viz:

$$V\ m^3 = L\ m^{-1}\ x\ ((pi\ x\ (D\ m/2)^2)$$

where

V volume in cubic metres
L length in lineal metres
pi is the ratio of the circular section's circumference to its diameter, given as 22/7
D is centre diameter in metres

<u>Taper ratio</u>

All billets were merchandised to 1.31 m in length. The taper ratio (TR) was calculated as:

$$TR = SED/LED$$

where SED is small end diameter and LED is large end diameter.

[2] Salisbury Research Centre in Brisbane is managed by DPI&F as a forest products processing research facility.
[3] Big River Timbers is an experienced plywood manufacturer of a range of hardwood form-ply, flooring and step tread products.

A value of 1 represents a true cylinder. Theoretically, high ratios equate to higher recoveries but this is dependent on other billet characteristics such as growth stress and induced defects, for example end splits.

The billets were steamed and peeled on a 1.31 m rotary lathe system and the veneers were dried as per standard industry practice. The veneers produced are shown in Plate 3.

Plate 3. Veneer produced from peeling trials conducted at Big River Timbers.

2.5 Visual grading method

The dried veneer was returned to the Salisbury Research Centre for grading in accordance with *AS/NZS2269:2004* followed by batching for lay up into plywood panels. These tasks were undertaken in collaboration with the Engineered Wood Products Association of Australasia (EWPAA). Batching involved designation of suitable cores, cross-bands and face veneers to lay up 5-ply panels to replicate current industry practice. Additional grading was undertaken using a new method devised during the study to provide a quality 'score' for each billet.

Grade score

Each grade was allocated points to enable a numerical rating for each veneer, which was tallied to provide an overall grade quality score for each billet (Table 5). This method was developed during the trial to extrapolate quantitative data from qualitative data (Hopewell 2007).

Table 5. Veneer grade quality and corresponding score.

Grade description	Points
scrap	0
salvage	1
D grade crossband	2
D grade back	3
D grade face	4
C grade crossband	5
C grade face	6

Average billet grade scores and average sheet grade scores were calculated for each species as the sum of grade scores for each sheet divided by the number of billets and number of graded sheets respectively. The grade score ranges (minimum and maximum) and standard deviations were also derived from the grading activity. Grade quality distributions based on visual grade classifications were determined for each species.

Score per square metre

The sum of veneer sheet grade points was calculated for each species and divided by the total area of graded veneer to provide a score per square metre for each species. This is a useful method to quantify and compare the grade quality of the veneer billets provided for the trial.

2.6 Veneer recovery

Quantitative and qualitative recovery data were calculated and defined as:

Core volume

Residual core volume was calculated by using the formula for a cylinder, essentially the same as the gross billet volume formula.

Veneer fraction

The theoretical maximum possible veneer volume was calculated as the difference between the gross billet volume and core volume to indicate the veneer fraction.

Full sheets

The number of full sheets (1.31 m x 1.31 m, off the lathe, ungraded) was tallied for each billet to provide a full sheet count, sheet area (m^2) and volume (m^3) per billet and per species.

Full sheet recovery 1

Recovery per billet calculated as ungraded full sheet volume per gross billet volume, expressed as a percentage.

Full sheet recovery 2

Recovery per veneer fraction- ungraded full sheet volume per veneer fraction expressed as a percentage.

Veneer recovery factor

The total ungraded sheet area per gross billet volume.

Salvage recovery
The quantity of clipped strips suitable for re-use in patching sheets. Salvage quantities were calculated as square metre area and cubic metre volume per species.

Total veneer area
Full sheets plus salvage expressed in m^2 per species.

Total veneer volume
Full sheets plus salvage expressed in m^3 per species.

Gross recovery 1
Total veneer volume per gross billet volume, expressed as a percentage for each species.

Gross recovery 2
Total veneer volume plus salvage per total peeled fraction for each species.

2.7 Plywood panel manufacture

Two bundles of batched veneer were delivered to industry collaborators to manufacture 5-ply panels. Each bundle comprised enough veneer to produce five Gympie messmate and three red mahogany panels using both Type A bond and Type B bond adhesives. Additional Type A panels were also prepared using plantation eucalypt faces on standard plantation softwood core material. These panels were of interest due to:

- the success of Brazilian manufacturers who use eucalypt veneer mixed with softwood to improve LVL stiffness and strength
- improved bond strength between adherends of hardwood (high density, high extractives content) to softwood (medium density, minimal extractives) compared with hardwood to hardwood lay up
- improved strength-to-weight ratios
- the potential for improved cost effectiveness.

The A-bond panels were produced at Boral Hancock's[4] Ipswich facility (Plate 4) using their standard procedure for plywood manufacture:

- *Adhesive spread*: 360 – 465 g/m^2 phenolic formaldehyde resin (double glueline basis)
- *Cold-press*: pressure 125 psi (0.862 MPa); timing to coincide with lay up time, with a minimum of 5 minutes
- *Hot-press*: temperature 140°C, full cycle time 7:00 mins, high pressure time 3:30 mins, bleed-off time 1:00 min, peak pressure 175 psi (1.3 MPa)
- *Water sprays*: cooling phase, equalises moisture content and helps retain flatness.

[4] Boral Hancock produces a range of plywood products, principally form-ply and structural products from plantation softwood resources.


Plate 4. Manufactured plywood being removed from the hot press at Boral Hancock.

The Type B bond panels were manufactured at Big River Timbers' Grafton facility in accordance with a confidential specification.

2.8 Mechanical properties testing

The completed panels were returned to Salisbury to test mechanical properties in the DPI&F National Association of Testing Authorities (NATA) accredited laboratory. The following mechanical property tests were carried out on the panels:

- four point, static bending, face veneer grain parallel to the long dimension (RPa)
- four point static bending, face veneer grain perpendicular to the long dimension (RPe).

All test specimens conformed to the requirements of Section 5.3. of Australian and New Zealand Standard *AS/NZS2098.9:1995 Methods of test for veneer and plywood – procedures for in-grade testing of structural plywood* (Standards Australia 1995), RPa and RPe specimens of dimension 900 x 300 mm and chisel test samples of dimension 150 mm x 100 mm were cut from the test panels.

Static bending strength (modulus of rupture, MOR) tests were conducted using a Shimadzu type UDH-30 universal testing machine, configured as specified in Section 7.1 of *AS/NZS2098.9:1995*. Static bending stiffness (modulus of elasticity, MOE) tests were conducted as specified in Section 7.2 of *AS/NZS2098.9:1995*, using the same test machine.

Due to the finished dimensions of the panels being only 1200 mm by 1200 mm (half size sheets), other tests specified in *AS/NZS2098.9:1995,* such as tension, compression and shear, could not be undertaken. For example, test specimens for the tension parallel to the grain test are required to be 2400 mm long. There was, however sufficient material to perform a limited number of MOE and MOR tests to provide an indication of the mechanical properties.

2.9 Glue bond testing

Bond testing complied with Australia and New Zealand Standard *AS/NZS2098.2:2006 Methods of test for veneer and plywood- bond quality of plywood (chisel test)* (Standards Australia 2006). Prior to chisel testing, the plywood samples underwent water immersion treatments as follows:

- Type A bond samples (PF adhesive) - 72 hour boil treatment
- Type B bond samples (MUF adhesive) - 6 hour boil treatment.

After separating the plies using a pneumatic chipping hammer (chisel), the bond quality of the open glue line was assessed on a scale of zero (0% wood failure) to 10 (100% wood failure). In accordance with the method described in *AS/NZS2269:2004*, individual glueline scores are required to equal or exceed a score of two and mean bond scores for all gluelines within each sample must be five or better to be acceptable.

2.10 Laboratory scale glue bond testing

Further glue bond tests were conducted on small plywood samples produced in a laboratory pilot press. The objectives of these tests were to:

- demonstrate bonding of plantation hardwoods using a wider range of source logs than was possible in the full-scale plywood trials
- relate bond quality to the measured extractive content of samples taken from the same tree
- evaluate bonding using both an A-bond adhesive (phenolic formaldehyde) and a B-bond adhesive (melamine urea formaldehyde).

As in the main plywood trial, two types of adhesive were used for the trial:

- phenolic formaldehyde plywood adhesive (PF, Type A bond adhesive) and
- melamine urea formaldehyde plywood adhesive (MUF, Type B bond adhesive).

The phenol formaldehyde was obtained in pre-mixed form from Austral Plywoods[5] and stored in a sealed container at 20^{o}C until required. The urea formaldehyde was obtained as a liquid base resin, with filler (flour) and catalyst (ammonium chloride) added immediately prior to use.

Eleven sheets of red mahogany veneer and 14 sheets of Gympie messmate veneer were selected from surplus trial material. Each selected sheet originated from a different tree. Each sheet was cut into five 160 mm x 100 mm rectangular sections for the production of 5-ply samples. After pressing, samples were allowed to stand for 24 hours, prior to trimming to test sample dimensions of 150 mm x 90 mm for the boil tests.

[5] Austral Plywoods Pty. Ltd. Produce a range of structural and decorative plywood products from plantation grown hoop pine *Araucaria cunninghamii*.

The plywood production process approximated commercial practices. The following process variables were monitored and kept within the adhesive manufacturer's tolerances:

- veneer moisture content
- adhesive spread on the cross-band plies only
- open and closed assembly times
- cold press time and pressure and
- hot press temperature, time and pressure.

As with the full-scale veneer trial, bond testing of the laboratory scale samples followed the procedure specified in *AS/NZS 2098.2:2006*, including water immersion pre-treatments of 72 hour boil for Type A (PF) samples and six hour boil for Type B (MUF) samples.

2.11 Extractives content

Wood contains small amounts of extraneous components which do not form part of the cell wall structure, but are probably present, at least in part, as cell contents. Consequently, they can often be extracted from the wood by means of a suitable solvent (organic solvents or sometimes water) without destroying the structure of the wood, and therefore are termed extractives.

Extractives are extremely varied in their chemical nature and embrace many different classes of organic compounds, including tannins, resins, essential oils, fats, terpenes, flavanoids, quinones, carbohydrates, glycosides and alkaloids (Farmer 1967). These components are responsible for some of the characteristic features of individual timbers such as odour, colour and durability. When occurring in high density timbers, they can also contribute to poor gluability (Widsten *et al*. 2006)

Using a test method derived from Test Method T264 cm-97: Preparation of wood for chemical analysis, Technical Association of the Pulp and Paper Industry (TAPPI 2001), total extractives content was measured from sections removed from boards originating from the logs allocated to solid wood processing (see McGavin *et al.* 2007).

3 Results and discussion

3.1 Mensuration, billet selection and veneer processing

Using industry specifications and the prescribed method for billet selection, 15 Gympie messmate billets and 12 red mahogany billets were deemed suitable and available for the veneer and plywood component of the project.

One of the larger Gympie messmate billets was sacrificed to set up the knife at the lathe, so the total sample for the trial was 14 Gympie messmate and 12 red mahogany billets. The ratio of volume per species available for the trial was approximately 60% Gympie messmate to 40% red mahogany (Table 6).

Table 6. Peeler billet mensuration.

	19-yr-old Gympie messmate				15-yr-old red mahogany			
Parameter	n	mean	range	SD	n	mean	range	SD
Taper ratio	14	0.938	0.862 – 0.994	0.035	12	0.937	0.846 – 0.983	0.041
SED cm	14	32.4	24.3 – 39.3	4.7	12	29.4	23.3 – 35.4	3.6
LED cm	14	34.4	28.2 – 41.9	4.5	12	31.4	25.9 – 39.0	3.8
Volume m^3	14	0.117	0.071 – 0.170	0.032	12	0.096	0.062 – 0.133	0.023
Total volume			1.634 m^3				1.154 m^3	

SED small end diameter
LED large end diameter
SD standard deviation

There was a delay between the steaming phase and the peeling process which allowed the billets to cool to temperatures below standard processing protocols. It was estimated that the billet temperatures at the time of peeling may have been approximately 30°C compared to the preferred core temperature range at the lathe of 45°C. The processing delays that resulted in the lower temperatures were necessary in order to control the tracking of the veneer, ensuring that each sheet produced could be traced to the source billet. This may have affected the quality of the veneer produced during the trial but was critical for the graded recovery calculations. The Gympie messmate billets were in good condition at the time of processing, with negligible signs of log end splits or surface checks. The red mahogany exhibited symptoms of growth stress release with most billets developing log end splits.

The high values for taper ratios (0.938 for Gympie messmate and 0.937 for red mahogany) and low standard deviations indicate the good form of the selected billets for both species. This implies that the billet geometry was similar for both 15- and 19-year-old plantation material.

The average billet volume was larger for Gympie messmate than for red mahogany, reflecting the four year age difference between species at the time of harvest. Three of the red mahogany billets contained pockets of decay, associated with knots and heart, which contributed to the billets being prematurely discharged during processing. This resulted in less veneer and larger residual cores being produced from these billets, affecting the recovery results for the red mahogany sample.

3.2 Visual grading

Gympie messmate

Of the 158 sheets of Gympie messmate veneer, 157 made salvage grade or better and only one was classified as scrap. Applying the veneer grade quality scoring method, the veneers achieved a total score of 508 points to give average score of 36 points per billet and an average sheet score of 3.3.The total graded veneer area was 265.3 m^2; therefore the score per square metre achieved was 1.9 points/m^2 (Table 7).

In addition to the quantitative assessments, staff working at the plant during the processing trial suggested that the plantation-grown Gympie messmate appeared to have the qualities that were desirable for hardwood veneer and plywood products and their general impression was that they would be very interested in conducting further work with the material.

Results from the quality grading and expert opinion from the industry participants indicate that well managed 20-year-old Gympie messmate plantations are capable of producing veneer quality logs.

Red mahogany

Log end splits present in the red mahogany billets resulted in many split sheets and reduced the number of full veneer sheets produced. Of the 61 suitable sheets produced, only 57 could be graded and four sheets were classed as scrap due to full length splits. The sum of grade quality points scored by the 96.3 m^2 graded red mahogany veneers was 106, providing an average of 9 points per billet, 1.9 points per sheet and 1.1 points/m^2 (Table 7).

The plantation-grown red mahogany displayed good pink to red colouration for its age; however grade quality was affected by decay, probably originating from branch stub wounds, and splits resulting from release of growth stresses. The stresses placed on the trees from the cyclonic winds may also have influenced the severity of end splitting. The combination of these defects resulted in a low number of sheets being produced and corresponding low overall area and volume results for the material. The significance of defects such as decay in the living tree and post harvest, end splitting, suggest that urgent investigations will be required if veneer and plywood products are to be target markets for red mahogany growers and processors.

Table 7. Visual grading results by veneer grade quality scoring method.

Factor	**19-yr-old Gympie messmate**			**15-yr-old red mahogany**		
No. of billets	14			12		
No. of sheets#	158 (157 + 1)			61 (57 + 4)		
Graded sheet area m^2	265.3			96.3		
Total grade points	508			106		
Score/m^2	1.9			1.1		
	mean	**range**	**SD**	**mean**	**range**	**SD**
No of sheets per billet	11	6 – 17	3.4	5	3 – 9	2.0
Sheet score	3.3	1.8 – 4.8	0.8	1.9	1.0 – 4.0	1.0
Billet score	36	15 – 62	14.4	9	3 – 19	5.6

Total number of sheets (graded + scrap).

Grade distribution
Over half of the Gympie messmate veneer (64.6%) achieved a grade of 'D back' or better. Fewer (22.2%) made face quality C grade sheets (Table 8 and Figure 2) but these contributed the greatest score for the species due to the higher value attributed to face veneers.

Most of the red mahogany was downgraded as salvage due to the high incidence of splits in the material, with only 10.7% meeting the requirements for 'D back' or better (Table 8 and Figure 2). The grading results indicate that it is difficult to produce medium to high grade full sheets from 15-year-old, fast grown red mahogany, due to the incidence of decay and end splits.

Table 8. Grade quality distributions for two tropical plantation hardwoods.

Grade (score)	19-yr-old Gympie messmate	15-yr-old red mahogany
scrap (0)	1 (0) 0.6%	4 (0) 6.6%
salvage (1)	26 (26) 16.5%	28 (28) 17.7%
D crossband (2)	29 (58) 18.4%	12 (24) 7.6%
D back (3)	60 (180) 38.0%	16 (48) 10.1%
D face (4)	1 (4) 0.6%	0 (0) -
C crossband (5)	6 (30) 3.8%	0 (0) -
C face (6)	35 (210) 22.2%	1 (6) 0.6%
Total sheets	**158 (508)**	**61 (106)**

Data presented as: no. of sheets in grade (total score for grade) % of total sheets.

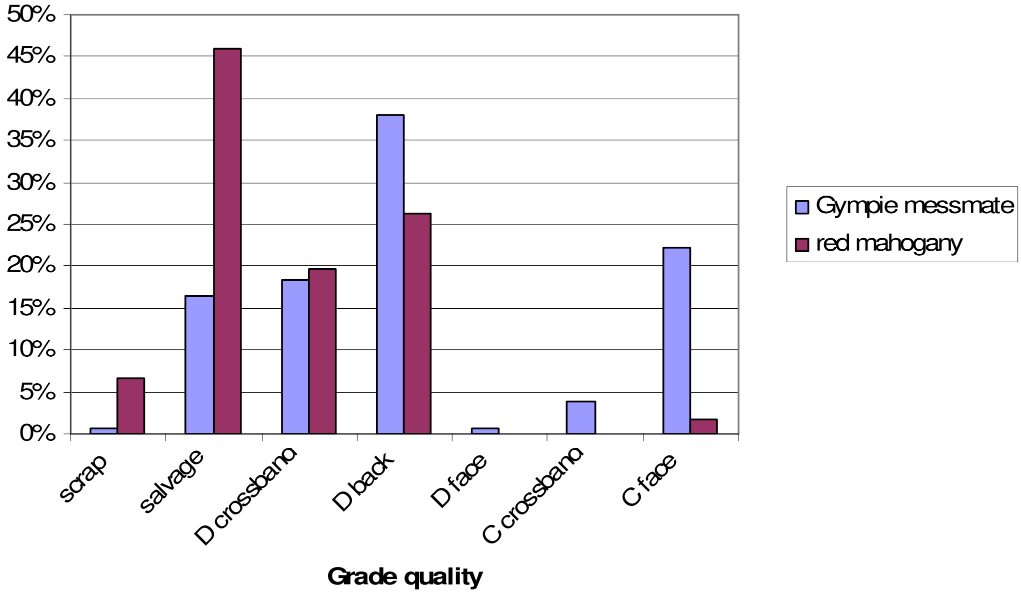

Figure 2. Grade quality distribution- per cent of veneer sheets in each grade quality class.

3.3 Veneer recovery

Gympie messmate

The veneer fraction achieved by the 14 Gympie messmate billets was 89% for a gross volume of 1.453 m^3 (Table 9). The ungraded full sheet volume recovered represented 50% of the original billet volume (full sheet recovery 1), an excellent result when compared to typical industry recoveries of 40-45% for regrowth blackbutt (*Eucalyptus pilularis*) and spotted gum (*Corymbia* spp.) from natural stands. When the core cylinder volume is subtracted from the billet volume, the recovery figure is 56% (i.e. of the veneer fraction, full sheet recovery 2). The veneer recovery factor was 163, setting a benchmark for future plantation hardwood veneer studies. The total area of salvage veneer was 33 m^2, providing suitable material for patching any knot holes and other defects in the 270 m^2 of recovered full sheets. The total veneer volume represented 52% of the total billet volume (gross recovery 1) and 60% of the total veneer fraction (gross recovery 2). The recovery data for Gympie messmate provides optimism for this species and age class as a potential source of plywood feedstock.

Table 9. Graded veneer recovery for 19-yr-old Gympie messmate and 15-yr-old red mahogany.

	Gympie messmate	red mahogany
Number of billets	14	12
Total gross billet volume	1.634 m^3	1.154 m^3
Mean billet volume	0.117 m^3	0.096 m^3
Total core volume	0.181 m^3	0.195 m^3
Veneer fraction	1.453 m^3 (89%)	0.959 m^3 (83%)
Number of full sheets	158	61
Average number of sheets/billet	11	5
Full sheet recovery 1	50%	24%
Full sheet recovery 2	56%	28%
Veneer recovery factor	163	91
Salvage area	33 m^2	65 m^2
Salvage volume	0.100 m^3	0.194 m^3
Total veneer area	300 m^2	159 m^2
Average veneer area/billet	22 m^2	13 m^2
Total veneer volume	0.911 m^3	0.478 m^3
Mean veneer volume	0.065 m^3	0.040 m^3
Gross recovery 1	52%	41%
Gross recovery 2	60%	50%

Red mahogany

The age of the red mahogany salvaged for these trials is quite young compared to traditional plywood resources and it was not expected to achieve high recoveries. The effect of decay in three billets and end splits in most of the billets further impacted the recoveries for the red mahogany material. The veneer fraction achieved was 0.959 m^3 representing 83% of the gross billet volume (Table 9). Only 61 full sheets could be clipped from the 12 red mahogany billets, representing an average of 5 per billet compared to the slightly larger Gympie messmate billets which produced an average of 11 full sheets per billet.

The ungraded recovery figure came out as 24% (full sheet recovery 1) with 28% being achieved when calculated as the proportion of ungraded sheets per veneer fraction (full sheet recovery 2). Log splits had a significant effect on recovery, evidenced by the low figure of 24% compared to standard industry recoveries for regrowth hardwoods of 40-45%. However, the red mahogany is less than half the age of typical regrowth eucalypt resources and there are currently no industry recovery data available for a fair comparison. The veneer recovery factor was 91 and is quite low compared to the older Gympie messmate material which achieved a factor of 163. The high incidence of log end splits translated to a lot of split sheets and therefore the salvage area was quite high, totalling 65 m^2 from 12 billets. One red mahogany billet was unable to produce a single full 1.3 m x 1.3 m sheet. The gross recovery of veneer per original billet (gross recovery 1) came to 41% and the recovery per veneer fraction was 50% (gross recovery 2).

Growers interested in red mahogany crops will need to investigate strategies to minimise growth stress and fungal infection in young plantations through genetic selection and/ or silvicultural practices. For example, low splitting and decay resistant clones could be identified for future planting stock, or fungicidal mastics could be incorporated into pruning operations to prevent entry of decay fungi though wounds.

3.4 Plywood panel manufacture

After grading, suitable veneers were batched to manufacture three groups of plywood panels:

- five panels of Type A and five of Type B bond (15 mm thick) 5-ply Gympie messmate
- three panels of Type A and three of Type B bond (15 mm thick) 5-ply red mahogany and
- eight hybrid panels mixed hardwood faced/ softwood core combination, (15 mm thick) Type A bond.

Six additional, complete softwood panels were provided by Boral Hancock for comparative purposes (four 7-ply panels at 17 mm thickness and two 5-ply panels of 15 mm in thickness. The manufactured panels were returned to the Salisbury Research Centre for further testing.

3.5 Mechanical properties testing

The mechanical properties testing data resulting from static bending tests of the limited sample of industry prepared Gympie messmate, red mahogany and additional panels (plantation hardwood/ softwood mix) are summarised in Tables 10, 11 and 12 respectively.

Table 10. Gympie messmate bending test results.

	Mill of fabrication (bond type, adhesive)			
	Boral (Type A, PF adhesive)		BRT (Type B, MUF adhesive)	
	Orientation			
Statistic	RPa	RPe	RPa	RPe
No. tested	5	5	5	5
Mean MOR(MPa)	91.63	116.33	127.54	134.79
SE Mean (MPa)	10.14	8.74	8.514	4.35
Mean MOE (GPa)	18.11	20.21	17.69	17.65
SE Mean (GPa)	0.511	1.32	1.01	0.68

Table 11. Red mahogany bending test results.

	Mill of fabrication (bond type, adhesive)			
	Boral (Type A, PF adhesive)		BRT (Type B, MUF adhesive)	
	Orientation			
Statistic	RPa	RPe	RPa	RPe
No. tested	3	3	3	3
Mean MOR(MPa)	79.00	95.47	68.56	74.34
SE Mean (MPa)	7.98	7.08	4.46	7.33
Mean MOE (GPa)	15.42	16.53	13.81	14.90
SE Mean (GPa)	1.74	1.23	0.30	0.41

Table 12. Bending test results for the additional panels.

	Construction			
	Hybrid (hardwood face/ softwood core)		Softwood	
	Orientation			
Statistic	RPa	RPe	RPa	RPe
No tested	8	8	6	6
Mean MOR(MPa)	75.11	59.31	65.01	75.16
SE Mean (MPa)	6.24	6.21	2.82	4.94
Mean MOE (GPa)	13.43	9.10	14.27	12.5
SE Mean (GPa)	0.34	0.73	0.825	0.76

The number of samples in all three categories reported in Tables 10 to 12 was too small to calculate characteristic properties formally according to Australian and New Zealand Standard *AS/NZS4063:1992 Timber – stress graded- in-grade strength and stiffness evaluation* (Standards Australia 1992). However, comparing mean MOE and lower bound 95% confidence limit MOR with characteristic stress-grade limits (AS1720.1, Table 5.1) indicated F grades of F14 to F17 for red mahogany and of F22 to F27 for Gympie messmate. For the smaller hybrid sample, the indicative values were F11 to F14, while the value for pine was F14.

These indicative grade results can be compared with commercial grades of structural plywood available from current forest resources in northern New South Wales and Queensland: Dorries (2007) gives values of F22 to F34 for hardwoods and F11 to F14 for softwoods. These results should be interpreted with caution due to the small number of samples available to provide the test data.

McGavin *et al.* (2006) previously reported mean MOE and MOR values of 15.7 GPa and 127 MPa for plywood manufactured from eight-year-old red mahogany plantation thinnings. These results were somewhat higher, especially for MOR, than the results measured in this study and are surprising given the difference in plantation age. The variation could be explained by the fact that in the current study, the veneers were batched into lay-ups typical of industry grades, whereas the earlier lay-ups favoured higher quality veneers throughout the full plywood cross-section. In addition, the earlier study sourced veneer from a small test population of only four billets.

Analysis of variance (ANOVA) was used to interrogate the data from Tables 10 and 11 to investigate the effects of the following variables on the strength and stiffness results:

- species (Gympie messmate or red mahogany)
- adhesive and mill of fabrication (Type A bond PF/Boral Hancock or Type B MUF/BRT)
- test orientation (RPa or RPe).

The ANOVA for Tables 10 and 11 are shown in Appendix A, Tables A1 to A3. The ANOVA showed that for MOE, the only significant ($p < 0.01$) variable was the species of hardwood. There were no significant differences due to the mill of fabrication or the grain orientation at test.

For MOR, species was again significant at the 1% level. For this test, however, mill of fabrication, and hence glue type, was also a significant factor ($p \leq 0.05$) for both species.

A similar ANOVA of the data in Table 12 (Appendix A, Table A4) concerned the following variables:

- species/type (softwood or 'hybrid')
- test orientation (RPa or RPe).

In this case, MOE differed between the hybrid and softwood panels at the 5% level. MOR, however, did not differ significantly between these types. This can be attributed to a significant interaction ($p \leq 0.05$) between plywood type and test orientation, explained by the lower influence of the outer hardwood veneers when these were stressed perpendicular to the grain, compared with their influence in parallel orientation.

3.6 Glue bond testing

The glue bond testing results for the industry prepared Gympie messmate, red mahogany and additional panels (plantation hardwood/ softwood hybrid mix and softwood-only panels) are summarised in Tables 13, 14 and 15 respectively.

Table 13. Summary of Gympie messmate glue bond test results.

	Bond type	
	Type A	Type B
No. of paired samples tested	5	7
Mean glueline score (AS/NZS 2098.2)	5.3	3.8
% pass	80%	28%

Table 14. Summary of red mahogany glue bond test results.

	Bond type	
	Type A	Type B
No. of paired samples tested	3	2
Mean glueline score (AS/NZS 2098.2)	7.5	3.6
% pass	100%	0%

Table 15. Summary of additional panel glue bond test results.

	Panel construction	
Statistic	Hardwood face/softwood substrate*	100% softwood*
No. of paired samples tested	4	3
Mean glueline score	5.4	7.1
% pass	75%	100%

* All samples were Type A bond adhesive

The A bonds generally proved satisfactory, and a high proportion of both hardwood and hybrid construction plywoods were compliant with *AS/NZS2269:2004*. The B bonds were less satisfactory, a surprising result given that hardwoods are routinely glued by industry using MUF adhesives, and good results were previously achieved with red mahogany by McGavin *et al.* (2006). The poor Type B bond results were replicated in the laboratory scale trials described in 3.7 below. More trials are needed to determine if the poor bonding was due to incompatibility of the glues with plantation hardwoods, resource variability or variation to the normal production process during the experiment.

3.7 Laboratory scale glue bond testing

The mean moisture contents of the veneer samples at the time of pressing were 6.1% for Gympie messmate (n=12) and 6.0% for the red mahogany (n=11), reflecting the optimum range of 5 to 8% cited by the EWPAA (Lyngcoln no date). The bond strength results (Tables 16 and 17) as determined by the chisel test criteria for the laboratory samples were similar to those obtained from the industry trial: acceptable bonding with phenolic adhesive (PF), and unsatisfactory bonding with MUF. Red mahogany again had superior bonding with phenolic glue: 90% of samples met the pass criteria of *AS/NZS2269:2004.* This could be attributed to the lower density of red mahogany. With the Type B non-phenolic glue, there was little difference between species; neither demonstrating successful bonding.

Table 16. Laboratory scale sample glue bond results for Gympie messmate.

	Adhesive	
Statistic	**PF (Type A bond)**	**MUF (Type B bond)**
No. of samples tested	12	12
Mean glueline score (AS/NZS 2098.2)	4.7	2.7
% pass	42%	0%

Table 17. Laboratory scale sample glue bond results for red mahogany.

	Adhesive	
Statistic	**PF (A Bond)**	**MUF (B bond)**
No. of samples tested	10	10
Mean glueline score (AS/NZS 2098.2)	6.1	2.0
% pass	90%	0%

3.8 Relationship between bonding and extractives content

Total extractives content of sample boards were determined as part of a separate component of the Cyclone Larry project (McGavin *et al.* 2007). Average total extractives contents were 5.55 % for *E. pellita* and 5.74% for *E. cloeziana.* The opportunity was taken to analyse the data for correlations between bond quality and extractives content of young, plantation grown eucalypts.

As described in section 2.4, veneer billets were selected from alternate logs of the size-ranked population. Some of these stems also yielded sawlogs from the remaining billet (top log). Total extractives were derived from boards cut from these logs, and then compared with the glue bond results from the veneer logs (Figures 3 and 4).

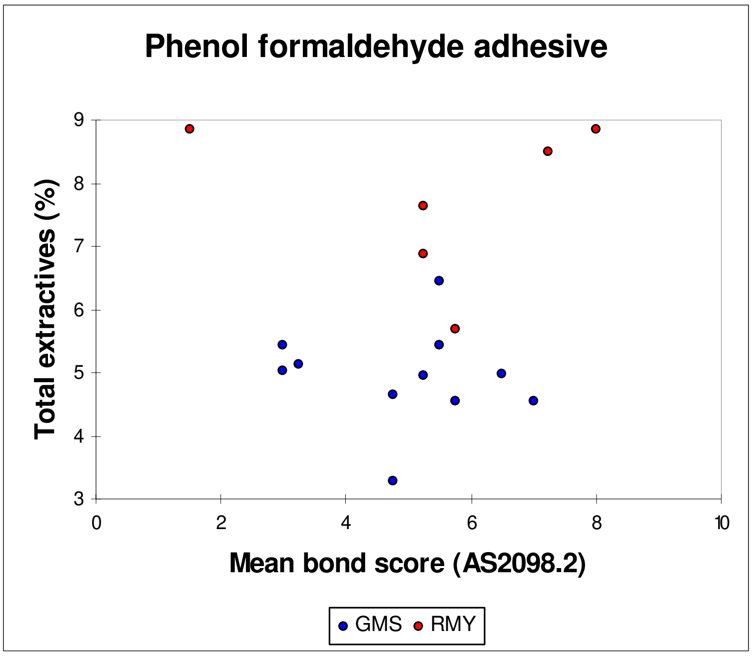

Figure 3. Bond score (AS/NZS2098.2) v total extractive % (TAPPI 2001)

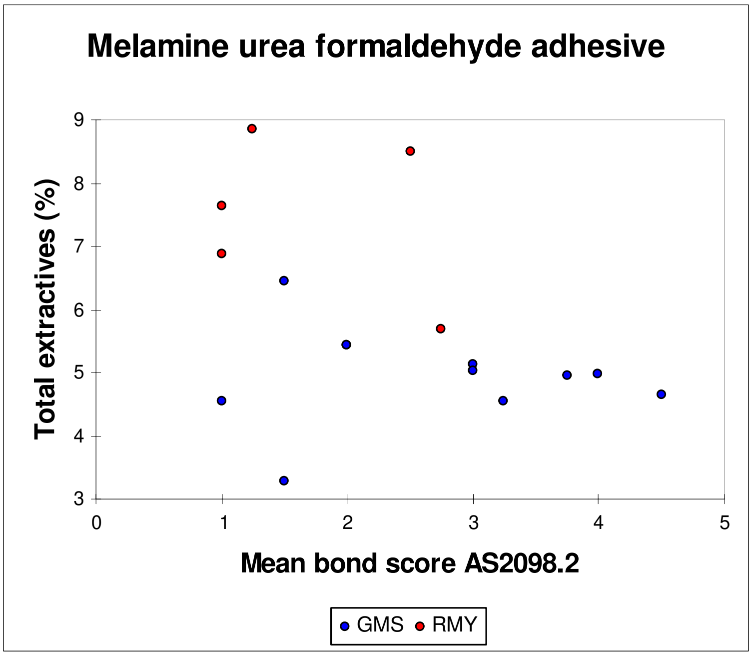

Figure 4. Bond score (AS/NZS2098.2) v total extractive % (TAPPI 2001)

For both adhesive types, there was no significant correlation between bond score and mean total extractive content ($R^2 < 0.1$). Possible reasons for this include:

- The extractives samples were not taken from the actual veneer billet, but from the adjacent sawlog.
- Since total extractives content was measured, specific compounds that may directly influence bond quality were not identified.
- Bonding is affected by numerous variables besides extractives content. Although efforts were made to control these, variation between gluing conditions may have masked any effects due to extractives.

- In these species of plantation timber, extractives were not a significant factor in adhesive performance.

Both the industrial trial and the laboratory experiments have demonstrated that structural plywood can potentially be produced from plantation Gympie messmate and red mahogany harvested at less than 20-years-old using a Type A bond. However, further work is needed to understand the unexpected poor result from the Type B adhesives, and also the influence of specific extractives on adhesive performance.

4 Conclusion

The material salvaged from plantations damaged during the Cyclone Larry storm event in 2006 provided a valuable insight to the potential of 15- and 19-year-old resources for veneer and plywood production. The 19-year-old Gympie messmate logs produced reasonable quantities of veneer with the grade qualities required for structural plywood manufacture. These veneers were also adhered with a Type A bond to produce satisfactory gluelines and the resulting plywood displayed suitable mechanical properties for typical structural applications. The Type B bond samples did not achieve satisfactory bond strengths and further investigations are required to understand this unexpected result. These results were subsequently validated by laboratory scale testing in which the Type A adhesives produced better results than the Type B. In addition to the quantitative data gathered during the trial it was noted that industry collaborators were impressed with the general appearance of the Gympie messmate veneer.

At 15 years old, the red mahogany was significantly younger than typical plywood and veneer resources, however even if these particular trees were left to grow for another five years, it seems unlikely that the quality or recovery would have improved significantly due to the defects already established at the time of harvest for this trial. While the veneer displayed good pink to red colouration and the average billet geometry was similar to the older Gympie messmate billets, the presence of severe end splitting and decay had major impacts on the recovery and grade results. While the end splitting may have been increased due to otherwise invisible damage caused by the cyclonic experience, the decay was clearly unrelated to that event.

The trial has demonstrated that structural plywood can be successfully produced from these plantation hardwoods. The available sample was too small for the formal calculation of characteristic properties according to *AS/NZS4063:1992 Timber – stress graded – in-grade strength and stiffness evaluation* (Standards Australia 1992), however indications were for stress grades (F ratings) of F14 to F17 for red mahogany and of F22 to F27 for Gympie messmate. This suggests that both species can achieve stress graded plywood equivalent to commercial structural plywood products at the ages tested.

The trials also demonstrated the feasibility of hybrid hardwood and softwood panel construction in which hardwood faces and backs were used in combination with standard plantation softwood crossbands. The number of samples produced for these tests were not sufficient to assess the influence on strength and stiffness, however they were included here due to the interest in this product by industry and the EWPAA. It should be noted, however, that such constructions are more sensitive to the orientation of the plywood than constructions comprised entirely of hardwoods or softwoods.

The results from these trials suggest that managed plantations of Gympie messmate can produce plywood quality billets by age 20. As demonstrated during previous studies on young plantation grown red mahogany, it appears that strategies to improve decay resistance and to minimise end splits will improve the economical feasibility of commercial plantations of this species.

5 References

Anon. (no date). Veneer slicing and peeling. http://sres-associated.anu.edu.au/fpt/plywood/lathes.html. Australian National University, Canberra, accessed 14.11.06.

BIL Technologies (2007). *Identifying timber plantation industry opportunities in the Kyogle Local Government Area*. Unpublished report to Kyogle Council.

BIS Shrapnel Forestry Group Pty. Ltd. (2003). *Timber Market Survey 2002*.

Bootle, K.R (2005). *Wood in Australia*. 2nd Edition. McGraw-Hill.

Cause, M.L., Rudder, E.J. and Kynaston, W.T. (1989). *Technical Pamphlet No. 2, Queensland Timbers: Their Nomenclature, density and Lyctid Susceptibility*, Queensland Forest Service.

Clark, N.B. and Hicks, C.C. (1996). *The kraft pulping and papermaking properties of 5-year-old plantation-grown* Eucalyptus cloeziana*,* E. pellita *and* E. urophylla *from northern Queensland*. CSIRO Division of Forestry and Forest Products Report No. DFFP 523.

Department of Primary Industries and Fisheries (2004). *The Queensland Forest Industry. An overview of the commercial growing, management and processing of forest products in Queensland*. DPI&F, Queensland.

Dickinson, G. and Sun, D. (1995). Species and provenance evaluation of *Eucalyptus cloeziana*, *E. pellita* and *E. urophylla* at age 4 years, in far north Queensland. DPI-Forestry Technical Report FS 0024367. DPI Forestry Brisbane Australia.

Dickinson, G. R., Nikles, D. G., Leggate, W., Sun, D. and Robson, K. J. (1996). Variation of *Eucalyptus cloeziana* in coastal north Queensland plantings and implications for future improvement strategies. pp 72-75 *In* Dieters, M. J., Matheson, A. C., Nikles, D. G., Harwood, C. E. and Walker, S. M. (Eds) (1996). Tree Improvement for Sustainable Tropical forestry. Proceedings QFRI-IUFRO Conference, Caloundra, Queensland, Australia,

Dickinson, G. (2006a). Hardwoods Research Updates ATH/704/1- genetics. *Eucalyptus cloeziana* provenance evaluation. DPI&F.

Dickinson, G. (2006b). Hardwoods Research Update ATH801/1. Genetics *E. pellita* and *E. urophylla* provenance evaluation at Innisfail. DPI&F

Dorries, S. (2007). Personal communication. General Manager Engineered Wood Products Association of Australasia.

Department of Primary Industries & Fisheries (2006). *Department of Primary Industries and Fisheries Annual Report 2005-06.* DPI&F, Queensland.

Farmer, R.H. (1967). Chemistry in the Utilization of Wood, Pergamon Press Ltd, London.

Flynn, B. (no date). *Eucalyptus: having an impact on the global solid wood industry*. Wood Resources International. http://www.wri-lyd.com/marketPDFs/Eucalyptus.pdf accessed 14.11.06.

Francis, L. P, and McGavin, R.L. (2007) Natural durability of timber produced from tropical north Queensland plantations of *Eucalyptus cloeziana* and *Eucalyptus pellita*. 1. Implementation of field and laboratory tests DPI&F PR-3200. Report submitted October 2007 to FWPA (PN 07.3022) www.fwpa.com.au, and DTRDI (MN 86629).

Garthe, R. J. (1983). *Pole production from Gympie messmate (Eucalyptus cloeziana F. Muell.) plantations in south east Queensland*. Technical Paper No. 37. Department of Forestry Queensland.

Hillis, W.E. (1987). Heartwood and Tree Exudates. Springer-Verlag, Berlin. 268 pp.

Hillis, W. E. and Brown, A. G. [Editors] (1984). *Eucalypts for wood production*. CSIRO.

Hopewell, G. (2002). *Sawn recovery and utilisation potential of fast grown Argentinean eucalypts*. Denis M Cullity Research Fellowship Report. FWPRDC.

Hopewell, G.P. (2006). *Construction timbers in Queensland: properties and specifications for satisfactory performance in Queensland, Class 1 and Class 10 Buildings* (Books 1 and 2). DPI&F, Queensland.

Hopewell, G.P. (2007). Product Development Method 01-007. *Veneer grade quality scoring system- a method to quantify the grade quality of veneers.* Unpublished report, DPI&F.

ITC (2007), *ITC Diversified Forestry Project 2008 – Product Disclosure Statement*, ITC Project Management Limited.

Larsen, P. (2006). Personal communication, former Manager Northern Operations for ITC Limited.

Leggate, W. (2004). Personal communication, former Technical Sales Representative, Tapebicua Group, Argentina.

Lyngcoln, K. J. (1992). *Practical guidelines on hardwood gluing*. Supplement to Structural Gluing, a paper to the 2nd CIB International Conference on tropical and hardwood timber structures. Malaysia.

Lyngcoln, K. J. (no date). *Trouble shooting for the causes of faulty bonds*. EWPAA plywood and LVL production course lecture notes volume 2: gluing and plywood fabrication.

McGavin, R.L., Bailleres, H. and Hopewell, G.P. (2007) The wood quality and structural properties of two tropical plantation eucalypts in north Queensland: 19-

year-old Gympie messmate and 15-year-old red mahogany. DPI&F PR07-3228. Report submitted October 2007 to FWPA (PN 07.3022) www.fwpa.com.au, and DTRDI (MN 86629).

McGavin, R.L., Davies, M.P., Macregor-Skinner, J., Bailleres, H., Armstrong, M., Atyeo, W.J. and Norton, J. (2006). *Utilisation potential and market opportunities for plantation hardwood thinnings from Queensland and northern New South Wales*. Forest and Wood Products Research and Development Corporation.

Muneri, A., Leggate, W. and Armstrong, M. (2001). *A preliminary study of wood properties and sawn timber characteristics of plantation grown* Eucalyptus pellita *and* E. urophylla *in Queensland*. Queensland Forestry Research Institute.

Ozarska, B. and Hopewell, G. P. (1998). Editors. *The use of Queensland's hardwoods for fine furniture (User Manuals.)* Report to *metaform*AUSTRALIS™ Furniture Consortium. DPI&F and CSIRO.

Perrin, D. (1988). *Dictionary of botanical names- Australian plant names: meaning, derivation and application*. Green data projects Queensland.

Redman, A.L. and McGavin, R.L. (2007) Accelerated seasoning of plantation grown *Eucalyptus cloeziana* and *Eucalyptus pellita* DPI&F PR-3188. Report submitted October 2007 to FWPA (PN 07.3022) www.fwpa.com.au, and DTRDI (MN 86629).

Standards Australia (1997). *AS 1720.1 - 1997 Timber Structures – Design Methods*. Australian Standard distributed by SAI Global Limited. www.saiglobal.com

Standards Australia (2001). *AS/NZS 1148:2001 Timber- Nomenclature- Australian, New Zealand and imported species*.
Australian Standard/ New Zealand Standard distributed by SAI Global Limited. www.saiglobal.com

Standards Australia (2006). *AS 1720.2 – 2006 Timber Structures – Timber Properties*. Australian Standard distributed by SAI Global Limited. www.saiglobal.com

Standards Australia (2004). *AS/NZS 2269:2004 Plywood- structural*.
Australian Standard/ New Zealand Standard distributed by SAI Global Limited. www.saiglobal.com

Standards Australia (2006). AS/NZS 2098.2: 2006 *Methods of test for veneer and plywood _ Bond quality of plywood (chisel test).* Australian Standard/ New Zealand Standard distributed by SAI Global Limited. www.saiglobal.com

Standards Australia (1995). AS/NZS 2098.9*: 1995 Methods of test for veneer and plywood – Procedures for in-grade testing of structural plywood.* Australian Standard / New Zealand Standard distributed by SAI Global Limited. www.saiglobal.com

Standards Australia (1992). AS/NZS 4063:1992 *Timber – stress graded – in-grade strength and stiffness evaluation.* Australian Standard/ New Zealand Standard distributed by SAI Global Limited. www.saiglobal.com

TAPPI (2001). Test method T264 cm-97: *Preparation of wood for chemical analysis*. Technical Association of the Pulp and Paper Industry. TAPPI Press, USA.

Taylor, P. (1994). *Growing up: forestry in Queensland*. Department of Primary Industries Forest Service Brisbane.

Thirion, M. (2007). *Steam bending for small, round hardwood plantation thinnings-arched structural members.* Blueprint for the bush. DPI&F Queensland.

Widsten, P., Gutowski, V. S., Sheng Li, Cerra, T., Molenaar, S. and Spicer, M. (2006). *Factors influencing timber gluability with one-part polyurethanes – studied with nine Australian timber species*. Holzforschung, Vol. 60, pp. 423-428.

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Glossary

A bond	Intended to withstand prolonged exposure to severe exterior conditions without failure of the glueline. Normally suitable for weather exposed structural use.
ANOVA	analysis of variance.
AS	Australian Standard.
asl	above sea level.
ATH	Atherton District.
B bond	Intended to withstand occasional wetting and drying without delamination occurring.
BRT	Big River Timbers, plywood manufacturers Grafton, NSW.
Core	interior foundation veneer within plywood.
Cross band	a layer of plywood laid with the grain direction at right angles to the face ply.
DPI&F	Department of Primary Industries & Fisheries.
DTRDI	Department of Tourism, Regional Development and Industry (formerly Department of State development DSD).
E	east, easting.
et al.	abbreviated from the Latin *et alia* = and others.
EWPAA	Engineered Wood Products Association of Australasia.
F11, etc	Stress grade F11.
Face veneer	the surface layer of plywood. Usually a higher quality veneer than core veneers.
Ferrosol	Soil lacking strong texture contrast between the A and B horizons. The B2 horizon has structure more developed than weak and a fine earth fraction which has a free iron oxide content greater than 5%. (http://www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/ accessed 4/04/07).
FWPA	Forest & Wood Products Association (replaced FWPRDC 2007).
FWPRDC	Forest & Wood Products Research & Development Corporation (replaced by FWPA 2007).
g/m^2	grams per square metre.
Green	timber products with a moisture content above 15%.
kg/m^3	kilograms per cubic metre.
kN	kilo Newton/s.
Krasnozem	These soils are typically red, deep, well-structured, acid and porous soils. They have relatively high clay contents and tend to display a gradual increase in clay with depth. (http://www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/ accessed 4/04/07).
m	metre/s.
MOE	modulus of elasticity, a measure of stiffness and resistance to deflection.
MOR	modulus of rupture, a measure of the ultimate short term load carrying capacity when the load is applied slowly.
MPa	megapascal/s.
MUF	melamine fortified urea formaldehyde.
N	north, northing.
n	number of individual specimens in test population.
NATA	National Association of Testing Authorities

OSB	oriented strand board, an engineered wood product, also known as waferboard, produced by layering strands of flaked wood in specific orientations and formed through compression and bonding with wax and resin.
PF	phenol formaldehyde.
Plywood	Manufactured wood panel made by bonding alternating layers (usually at right angles) of two or more thin wood plies or veneers. The first dimension listed in plywood specification denotes the direction of the face grain.
Podsolic	Any of a group of acidic, zonal soils having a leached, light-coloured surface layer and a subsoil containing clay and oxides of aluminium and iron, varying in colour from red to yellowish red to a bright yellowish brown. (http://www.answers.com/topic/red-yellow-podzolic-soil accessed 4/04/07).
ppm	parts per million.
psi	pounds per square inch.
S	south, southing.
S2, etc	green strength group 2, parentheses e.g. (S3) indicate a provisional rating.
Salvage	incomplete sheets of veneer, for example narrow pieces produced due to end splits in the billet; recovered for patching knot holes and other defects.
Scrap	small sections of veneer not considered worthy of recovering.
SD3, etc	seasoned strength group 3, parentheses e.g. (SD2) indicate a provisional rating.
SE	standard error.
Seasoned	timber products with a moisture content between 10 and 15%.
spha	stems per hectare, calculated as: $\text{spha} = 10{,}000\ \text{m}^2/(a \times b)$ where a is the inter-row spacing (distance in metres between rows) and b is the inter-tree spacing (distance in metres between trees).
TR	taper ratio.
Tropical eucalypts	species of the genus *Eucalyptus* growing in the humid latitudes, that is between the Tropic of Capricorn (23°30'S) and the Tropic of Cancer (23°30'N).
Veneer	A thin sheet of wood of uniform thickness.
Yr/ yrs	year/ years.

Appendix A

ANOVA Tables

Table A.1. Industry trial bending tests, by species (refer Tables 10 & 11).

MOE (GPa)

Source of variation	**d.f.**[6]	**m.s.**	**v.r**	**F pr.**
Species	1	79.352	18.00	<0.001
Residual	30	4.409		
Total	31			

MOR (MPa)

Source of variation	**d.f.**	**m.s.**	**v.r.**	**F pr.**
Species	1	10960.5	25.12	<0.001
Residual	30	436.4		
Total	31			

Table A.2 Industry trial bending tests, Gympie messmate by mill and orientation (refer Table 10).

MOE (GPa)

Source of variation	**d.f.**	**m.s.**	**v.r.**	**F pr.**
Mill	1	11.043	2.53	0.131
Orientation	1	5.249	1.20	0.289
Mill.Orientation	1	5.683	1.30	0.271
Residual	16	4.364		
Total	19			

MOR (MPa)

Source of variation	**d.f.**	**m.s.**	**v.r.**	**F pr.**
Mill	1	3696.6	10.93	0.004
Orientation	1	1276.3	3.77	0.070
Mill.Orientation	1	380.4	1.12	0.305
Residual	16	338.1		
Total	19			

[6] d.f.= degrees of freedom; m.s. = mean square; v.r. = ratio of treatment m.s. to error m.s.; F pr = significance level of v.r.

Table A.3 Industry trial bending tests, red mahogany by mill and orientation (refer Table 11).

MOE (GPa)

Source of variation	d.f.	m.s.	v.r.	F pr.
Mill	1	7.942	2.20	0.176
Orientation	1	3.642	1.01	0.345
Mill.Orientation	1	0.000	0.00	0.991
Residual	8	3.610		
Total	11			

MOR (MPa)

Source of variation	d.f.	m.s.	v.r.	F pr.
Mill	**1**	**747.6**	**5.32**	**0.05**
Orientation	**1**	**371.2**	**2.64**	**0.143**
Mill.Orientation	**1**	**85.7**	**0.61**	**0.457**
Residual	**8**	**3.610**		
Total	**11**			

Table A.4 Industry trials, pine and 'hybrid' panels, Boral mill.

MOE (GPa) (refer Table 12).

Source of variation	d.f.	m.s.	v.r.	F pr.
Type	**1**	**30.750**	**10.02**	**0.004**
Orientation	**1**	**73.108**	**28.83**	**<0.001**
Type.Orientation	**1**	**11.152**	**3.64**	**0.069**
Residual	**24**	**3.067**		
Total	**27**			

MOR (MPa)

Source of variation	d.f.	m.s.	v.r.	F pr.
Type	**1**	**58.3**	**0.26**	**0.613**
Orientation	**1**	**155.3**	**0.70**	**0.411**
Type.Orientation	**1**	**1146.6**	**5.18**	**0.032**
Residual	**24**	**221.3**		
Total	**27**			