High-value wood resources

Technical Report 224

The wood properties of subtropical and tropical hardwood plantation timber grown for high-value products in Australia

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CRC for Forestry
Researching sustainable forest landscapes

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Public report

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Summary

The wood quality and properties of plantation-grown wood generally differ from those of mature and regrowth wood, sourced from similar sized trees from managed native forests. These differences can have implications for processing, manufacturing and product performance. Plantation systems allow for manipulation of wood characteristics through tree breeding programs and silvicultural interventions, and have efficiencies for harvesting. However, the younger age and faster growth rates of genetically improved and silviculturally managed plantation trees affect the properties of their wood.

This report summarises the key wood properties of species that are the primary candidates for plantation forestry in the subtropical to tropical region of eastern Australia. The planned end uses for these trees vary from short-rotation pulp to high-value products such as poles, sawn timber for appearance products and engineered wood products including structural plywood and laminated veneer lumber (LVL).

Although many species have been trialled in various locations throughout the region, the species included in this report are the primary candidates for commercial forestry plantations. These tree species are:

- spotted gum—*Corymbia citriodora* subspecies *variegata*, *citriodora* and *henryi* and their interspecific hybrids with *Corymbia torelliana*
- Gympie messmate—*Eucalyptus cloeziana*
- western or Chinchilla white gum—*E. argophloia*
- red mahogany—*E. resinifera*, *E. pellita*
- blackbutt—*E. pilularis*
- Dunn's white gum—*E. dunnii*
- rose gum—*E. grandis*
- tallowwood—*E. microcorys*
- Timor white gum—*E. urophylla*

Various methods were used to determine the characteristic wood properties of these species, over a range of age classes, where material was available for testing. Techniques included non-destructive evaluation (NDE) and processing studies. Product evaluation studies were also undertaken for several species.

High levels of longitudinal growth strain were found to correspond with tree vigour and greater bow distortion. Heartwood proportion increased with age for all species, usually with a corresponding decrease in sapwood band width. Within species, basic density did not always increase with increasing plantation age, and may be influenced by genetics, silviculture and/or site factors. Differences in basic density among species are of practical importance for some products.

Unit shrinkage rates in the radial plane increased with age for plantation-grown western white gum, red mahogany, Gympie messmate, tallowwood and blackbutt. Similar trends were seen for tangential unit shrinkage rates in western white gum, red mahogany, Gympie messmate and blackbutt.

One of the obvious differences between the traditional, mature native forest resource and plantations is the smaller log size. Australia's hardwood sector has evolved from relatively large diameter feedstock, and the pricing structures for end-products have been based on recoveries of about 35% and relatively high proportions of durable, deeply coloured heartwood. By comparison, plantation-grown wood requires different handling and processing systems, and the recoveries are generally lower for sawn products. Growth strain—the product of growth stress and wood stiffness—can be higher in smaller, faster grown trees than in mature native forest trees and this can affect graded recovery through higher levels of distortion. The higher proportion of non-durable sapwood results in increased gross processing costs to preserve against lyctine borers (for example, protection is required for spotted gum, tallowwood, messmate and Dunn's white gum) and/or fungal decay.

Developing and expanding high value markets for plantation wood is dependent upon matching the properties of plantation-grown hardwoods to appropriate product requirements, such as those needed for high performance engineered wood composites for panel and beam products and novel roundwood applications. Peeling logs to produce veneer generally results in higher recoveries than sawing. Early results from trials currently underway indicate that the plantation hardwoods studied here have suitable attributes for a range of composite products, including plywood and LVL. The design of panels and beams from knotty veneers enables the defects within these composite products to be homogenised. This, in turn, allows consistent product grades to be produced, in contrast with solid wood sawn products processed from similar aged trees, which result in relatively high proportions of low-grade material.

Investigations into alternative roundwood options suited to small plantation logs and thinning stems have produced an innovative utility pole design, incorporating three or four small stems removed during thinning, fixed together with metal hardware in a hybrid product (Agri-Science Queensland, 2011). This product facilitates easy installation and inspection, whilst providing the required strength attributes to substitute for the diminishing supply of mature native forest poles. In a similar vein, poles from spotted gum thinnings have been successfully steam bent in their roundwood form, inspiring a range of innovative structural designs, produced by university architecture students and academics. The key advantages of roundwood products are high recovery, minimal processing costs, relatively low embodied energy and higher strength than similar section-size sawn wood.

The characteristic properties of plantation-grown subtropical hardwoods have been shown to be suitable for a range of traditional sawn and engineered products. In some cases, these properties are achieved at relatively young harvest ages, providing optimism for early returns to plantation growers and the processing industry.

Introduction

Australia's total plantation estate is approximately two million ha, comprised of 49% hardwood species and 51% softwoods. Eighty percent of the hardwood plantings are temperate species, located in Western Australia, South Australia, Victoria and Tasmania, and managed primarily for pulp. Subtropical and tropical hardwood species have been established in Queensland (Qld) and New South Wales (NSW), for both pulpwood and sawlog production, over an area totalling 156 000 ha. This represents 15% of Australia's hardwood plantation estate (Gavran and Parsons, 2010).

Efficient future utilisation of the emerging hardwood plantation resource of south-east Queensland and northern New South Wales is dependent upon an understanding of its wood quality, including the effects of environment, silviculture and genotype on wood properties. It is also important to establish the suitability of the resource for an appropriate range of processing and manufacturing options and end products.

The timber from regrowth forests is reported to produce significantly different wood quality to that of mature native forests. For example, sawn boards from regrowth blackbutt (*E. pilularis)* are known to be prone to higher levels of splitting, distortion, and collapse than those obtained from mature native forest material (Muneri and Leggate 2000a). Similarly, the appearance, wood quality and properties of plantation-grown hardwoods differ from those of both mature and regrowth native forest material.

Over the past 10 to 15 years, there have been numerous research projects conducted by the Innovative Forest Products group (within various organisational structures of the Queensland Government) and, more recently, by Southern Cross University. These studies have focused on the wood properties, processing characteristics and product options for young plantation eucalypts grown in Australia, Asia and South America. The considerable amount of information generated by these projects represents much of the current knowledge of the qualities and utilisation potential of plantation-grown eucalypts in subtropical south-east Queensland, northern New South Wales and tropical North Queensland.

The results of some of these projects have had limited distribution in conference papers and client reports, and much information has not been published in more broadly available scientific journals. This review paper aims to compile a comprehensive overview of the available results from both published and unpublished sources on the Australian subtropical and tropical hardwood plantation resource. The data are presented in tables for quick reference and include results per species and age class.

Exotic hardwood species planted in Australia, such as African mahogany (*Khaya* species) and teak (*Tectona grandis*), are not included in this report and nor are results from studies undertaken on tropical and subtropical eucalypt plantations grown outside Australia. This is because they lack relevance for comparisons to local results, due to the differences in growing environments, growth rates and management history.

Key indicators of hardwood plantation wood quality, with implications for processing and utilisation, are relative proportions of heartwood and sapwood, wood density, stiffness, strength, shrinkage, hardness and growth strain in the standing trees. This review focuses on compiling available results for these traits. Also important for weather-exposed and/or in-ground applications are natural durability and termite resistance. However, trials with the potential to provide reliable estimates of wood durability to compare plantation-grown and native forest timber are relatively long-term and results are not yet available to include in this review.

Tree species and plantation locations

The subtropical and tropical hardwood plantation resource of eastern Australia includes some eucalypt species best suited to sawlog production and other species suited to pulpwood production. Sawlog plantations are generally grown over a longer rotation period (a minimum of 20–25 years) and attain a higher value at the time of harvest, whereas pulpwood plantations are generally grown in short rotations of less than 10 years duration. The most important species and utilisation of their timbers are introduced below.

Spotted gum

Of the native forest hardwood species harvested in Queensland, spotted gum (*Corymbia citriodora* subsp. *variegata*) provides the greatest volume of timber. It is a key species for building components (feature flooring, structural bearers, beams, joists, decking), outdoor furniture and engineering applications (landscaping timbers, poles, girders and sleepers). The wood is recognised over other local and imported hardwoods for several advantageous attributes, such as its superior impact strength (preferred species for tool handles in axes, hammers, mattocks, brush hooks), suitability for steam bending (boat building, furniture and architectural applications) and lower risk of leaching staining tannins and extractives in service, resulting in less staining on external painted timber building surfaces.

Spotted gum has been a priority candidate for planting for sawlog production in the subtropics, due to its good growth rates, adaption to a wide range of sites and versatility of end uses. Before 1995, spotted gums were placed in the genus *Eucalyptus*, with three species recognised: *E. maculata*, occurring along the coast from the Victorian town of Orbost to Maryborough in Queensland, then inland to Carnarvon Gorge; *E. henryi*, between Brisbane and Grafton in northern New South Wales; and *E. citriodora*, found from Maryborough in Queensland, north into the southern part of Cape York Peninsula. Since then, taxonomic revision has placed the spotted gums in the genus *Corymbia* (the ‘bloodwoods’):

- *Corymbia citriodora* subsp. *variegata* (spotted gum) has a natural range, extending from the Springsure-Maryborough region in central eastern Queensland to Coffs Harbour in New South Wales.
- *Corymbia citriodora* subsp. *citriodora* (spotted gum; lemon-scented gum) is found north of the Springsure-Maryborough region in Queensland (overlapping with *C. citriodora* subsp. *variegata*) through to the Atherton Tableland.
- *Corymbia henryi* (spotted gum; large-leaved spotted gum) is found on relatively infertile soils from the Brisbane area to south of Grafton in New South Wales. This species is highly susceptible to the leaf blight pathogen

Quambalaria pitereka and is not currently recommended for plantation establishment.

- *Corymbia maculata* (spotted gum) is the southernmost of the group and occurs from Orbost in Victoria to south of Coffs Harbour in New South Wales.

Spotted gum plantations have been established for sawlog production in the Burnett and Wide Bay regions in Queensland, with the total estate estimated at 11 500 ha. In northern New South Wales, nearly 6 000 ha have been planted (Harding *et al.* 2010).

Gympie messmate

Gympie messmate (*Eucalyptus cloeziana*) is a premium native forest hardwood with excellent wood properties for engineering applications. It produces wood rated durability class 1 (for both in-ground and above-ground ratings), strength group 1 (for both seasoned and unseasoned condition) and joint group rating 1 (seasoned and unseasoned)[1]. Its sapwood is not susceptible to lyctine borers (powder post beetles) and the heartwood is termite and marine borer-resistant. The standing trees are known for good form, with long, straight, branchless boles. Outside Australia, plantations have been established in China, several African countries, Sri Lanka and Brazil, and applications include construction timbers, railway sleepers, tannin and charcoal.

Gympie messmate has been trialled in subtropical Australia for hardwood plantations, due to the potential value to be gained from its desirable wood properties. Approximately 1200 ha have been established in the greater Gympie region (Harding *et al*., 2010) and over 3000 ha in northern NSW and southern Queensland combined.

Western white gum

The subtropical zone includes areas of low annual rainfall, subject to prolonged drought periods. In these areas, western white gum (*Eucalyptus argophloia*) has been planted for wood production. A hard, heavy, reddish timber, western white gum is likely to be suitable for both structural and appearance products, including flooring, benchtops and construction products. Plantations are located in the granite belt (Warwick), Western Downs (Dalby) and Darling Downs regions of Queensland.
Almost 3700 ha have been planted although, of this, 2000 ha were planted recently, with the primary objective of carbon sequestration (Rohan Allen, DAFF, pers. comm.). This project was commissioned by the oil and gas company, Santos. (http://www.csgwatermanagement.com.au/wp-content/uploads/2009/12/Santos.pdf).

Red mahogany

The eucalypt most widely planted in tropical northern Australia is red mahogany (*Eucalyptus pellita*). The timber is pink to deep red, finding favour in interior design applications, such as flooring and cabinetry, but the wood properties are also suitable for a wide range of other applications, including in weather-exposed situations. Red mahogany was planted for wood production in North Queensland, with more than 4500 ha established in recent years through managed investment schemes (MIS).

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[1] Timber species are allocated two values from a twin four-class rating system, indicating heartwood resistance to decay in above-ground and in-ground situations. Class 1 is allocated to the most durable species. There are seven strength groups for unseasoned timber (S1 to S7) and eight for seasoned timber (SD1 to SD8), where 1 denotes higher inherent strength. For the purpose of joint design, timber is classified into six joint groups each for seasoned and green conditions, where a rating of 1 has superior jointing characteristics.

Most of this young plantation estate was irretrievably damaged by severe tropical Cyclone Yasi in February 2011. A subtropical red mahogany species, *E. resinifera*, has been trialled in plantations in coastal southern Queensland but its planting has been restricted by relatively low growth rates, compared with alternative species.

Blackbutt

Blackbutt (*Eucalyptus pilularis*) has traditionally been the commercial hardwood extracted in highest volume from native forests in New South Wales. It has been grown successfully in Hawaii, New Zealand, Brazil, Argentina and South Africa, and has been one of the key species planted for wood production in New South Wales. The timber has desirable wood properties and was noted by Jacobs (1955) as one of the top three most important native hardwoods in Australia, despite the occurrence of kino veins and propensity to splitting and other forms of drying degrade.

The New South Wales blackbutt estate covers a planted area of nearly 7000 ha (Harding *et al.* 2010), and is situated in the coastal regions of northern NSW. As with other eucalypts that occur naturally on wetter sites, successful blackbutt plantations require selection of suitable germplasm and careful site selection.

Dunn's white gum

Dunn's white gum (*Eucalyptus dunnii*) is a hardwood with inferior wood durability and strength, compared with most of the other species discussed herein. It has been planted in subtropical Australia, primarily for short rotation pulp log crops, rather than for solid wood products. Over 32 000 ha have been established, according to figures tallied by Nichols *et al.* (2008). Harding *et al.* (2010) attributed plantings of 5000 ha in Queensland's Burnett region and central Queensland and a further 22 000 ha in New South Wales to three major plantation growers.

Rose gum

Plantations of rose gum (*E. grandis*), and rose gum hybrids have been planted in New South Wales and central Queensland. The wood is pink to red and is suitable for a wide range of building products, furniture and flooring, as well as for use as a fibre resource for pulp and paper. Rose gum has been successfully hybridised with Timor white gum (*E. urophylla*), to produce hybrids commonly referred to as 'urograndis' hybrids, and with river red gum (*E. camaldulensis*). It is estimated that approximately 15 000 ha of clonal plantations of the *E. grandis* × *E. camaldulensis* hybrid have been planted in various locations in Queensland, from Gin Gin to Sarina. However, little of this resource remains, due to the susceptibility of imported germplasm to leaf blight fungus or *Kirramyces—Teratosphaeria* spp. (Pegg *et al.* 2010). In New South Wales, approximately 1000 ha were established between 2001 and 2009.

Sydney blue gum

Sydney blue gum (*E. saligna*) has been an important commercial hardwood, primarily harvested from the forests of coastal New South Wales. It is similar to rose gum in appearance, properties and uses. Although this species comprises one of the largest planted areas of hardwood in New South Wales, limited research has been undertaken on wood material from these plantations.

Table 1 provides a list of subtropical hardwood crop locations and areas planted post-1994, attributed by Harding *et al.* (2010) to three major growers—Forests NSW, Hancock Plantation Queensland (formerly FPQ) and Forest Enterprises Australia—with *E. grandis* × *E. camaldulensis* hybrids in central Queensland planted by Elders Forestry. However, the areas of productive plantations cited below cover less than the original planted areas listed in pre-2011 reports, due to the combined effects of recent changes in forest ownership and land use, losses from pests and diseases and catastrophic cyclone damage in North Queensland in February 2011.

Table 1. Subtropical and tropical eucalypt plantations in Australia

Crop species	Location/s	Area (ha)
Spotted gum	Burnett, Wide Bay Qld	19 800
Gympie messmate	Greater Gympie region, Qld	3200
Western white gum	Granite belt, western downs, Qld	3700
Red mahogany	Coastal north Qld	4500
Blackbutt	Northern NSW	8900
Dunn's white gum	Northern NSW, Burnett and central Qld	27 600
Rose gum	Mid-north coast NSW	4300
GC hybrids*	Miriam Vale to Sarina , QLD	23 701
Sydney blue gum	Dorrigo plateau and northern NSW	13 400

*rose gum (*E. grandis*) × river red gum (*E. camaldulensis*) hybrid

Source: Harding *et al.* 2010

The summary of planted areas for some species in Table 1 differs from the areas reported by Nichols *et al.* in 2008, because they included pre-1994 government plantings in NSW, along with some additional private company planting records that Harding *et al.* (2010) were unable to access and reference.

A recent update to areas of planting, provided by Forest Enterprises Australia (Chris Barnes, pers. comm. May 2012), suggests that the area of Sydney blue gum is a little under 7,000 ha, due to failures in some of the plantings detailed by Harding *et al.* (2010).

Methods

A range of non-destructive evaluation (NDE) and destructive test methods was used to determine the wood properties presented in this report. The most commonly used methods are briefly summarised below. Some tests were performed on standing trees or harvested logs, while the majority were performed in the laboratory on specimens processed from sawn wood samples, cross-sectional discs or radial increment cores.

Wood occurring in the lower bole of the tree generally has higher density and mechanical property values than wood higher in the stem. A similar trend generally occurs radially, with the outer heartwood usually being denser and stronger than wood closer to the pith. As a general rule of thumb, the more mature the wood, the higher the values for density and mechanical properties. Therefore, descriptions of radial variation in density and mechanical properties are important when determining the suitability of trees for specific processing applications, such as rotary veneering.

Standing trees

Acoustic wave velocity

Studies reported herein used two acoustic tools, the FAKOPP Microsecond Timer and the Director ST300, to measure acoustic wave velocity (stress wave) over a 1.0 m length of the stem in standing trees. The test involves hitting a sensor with a hammer to generate a signal. By measuring the time of flight of this stress wave and the distance between the start and detection sensor, the velocity of the vibration wave can be estimated (Harding *et al.*, 2009a). These data were combined with density data to estimate stiffness.

Longitudinal growth strain (LGS)

The CIRAD Forêt longitudinal growth strain (LGS) tool is a non-destructive diagnostic tool, allowing rapid assessment of growth strains in trees. A window is cut through the bark and two pins are nailed 45 mm apart, in vertical alignment, into the cambium. A 30 mm deep hole, of 20 mm diameter, is drilled into the tree surface to cut the outer fibres and release the longitudinal strain. A dial gauge and mechanical sensor measure the LGS release. The procedure is usually repeated at two to four equidistant positions around the circumference of the tree at breast height.

Another tool used for measuring longitudinal growth strain in standing trees is the HBM type DD1 extensometer from Germany. Two windows are cut through the bark on opposite sides of the standing tree at breast height. Two pins are inserted, in vertical alignment, in one window at a time and saw cuts are made above and below the pins, to a depth of approximately one cm, to release the strains in the wood fibres. The tool provides a digital readout of the change in distance between the two pins, indicating growth strain (Harding *et al*., 2009a).

The use of both of these tools is limited to relatively calm days, or parts of days because, if winds are strong enough to sway young plantation trees, the results obtained will be inaccurate.

Logs

The Hitman HM200 was used to measure acoustic velocity in harvested, debarked logs of measured length. From these data, an indication was derived of average wood stiffness of the logs.

Heartwood proportion

Heartwood is formed as trees mature. Also referred to as truewood, heartwood is the 'dead' core portion of the bole. Once wood dies in the standing tree, it no longer provides hydraulic conductivity or conduction of nutritional or waste products through the anatomical elements in the stem, but provides mechanical support for the tree. This zone of wood contains chemical compounds known as extractives, which can provide distinctive colouration and contribute to durability of the wood tissue.

The development of heartwood and the relative proportions of heartwood and sapwood affect aesthetics, utilisation, recovery and processing costs. The sapwood of all eucalypt species is non-durable in weather-exposed applications and, in some species, is susceptible to lyctine beetle (*Lyctus brunneus*) attack. The presence of sapwood in some products implies either added processing costs if the sapwood is treated to improve its durability, or reduced recovery if the sapwood is removed.

In large logs from managed native forest stands, the heartwood volume is generally sufficient to provide an economic return without recovering products from the sapwood zone. However, in the case of immature trees, such as logs sourced from early-age plantations, the relative proportions of these wood zones can impact heavily on the economics of processing and marketing. Because subtropical hardwood timber species have a long-standing reputation for superior performance in weather-exposed applications, careful consideration must be given to sapwood characteristics in order to maintain species and product reputation in the marketplace.

In many timbers, the heartwood zone is generally demarcated from the sapwood band by colour differentiation, although a transition zone with intermediate properties and performance attributes may also be present.

In studies reviewed herein, heartwood and sapwood proportions and sapwood band width were mostly measured on moist, planed disc surfaces. Radial measurements were taken of the sapwood zone and up to three (inner, outer and intermediate) heartwood zones. The cross-sectional areas (under bark) were also calculated. In some studies, diametrical cores were extracted from breast height (1.3 m) of standing trees to estimate the proportions of heartwood and sapwood.

Density

Density is the mass of a material per unit volume and, for wood, is commonly expressed as kg/m^3. It is one of the most useful indicators of a wood's utilisation potential, because it significantly correlates with the physical and mechanical properties—hardness, strength and stiffness. A good rule of thumb is that the denser the wood material (assuming clear sections, free of defects), the better the mechanical properties. Density is commonly measured and reported as basic, green or air-dry, depending on the moisture content (MC) status of the wood samples. This report presents basic density only.

Basic density

Basic density is a measure of the oven-dry mass of a saturated volume of wood and is the standard density measure used for scientific comparisons of density. It can also be used to model or predict wood mass at different moisture content levels, for example for shipping and freight logistics calculations.

Basic densities were determined in accordance with AS/NZS1080.3:2000 (Standards Australia, 2000) for pith-to-bark segments, from diametrical cores or radial wedges from full cross-section discs. Whilst radial wedges give an unbiased estimate of the basic density of the disc, cores over-sample the inner wood close to the pith, which is typically lower in basic density than the outer wood. To account for this, the cores are cut into several radial segments so that results can be weighted, based on basal area, to estimate tree average density (Downes *et al*. 1997).

Extractives content

Extractives are non-structural chemical components that are mostly produced during heartwood formation. 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).

Extractives impart colour and may contribute to wood durability, and some can cause waxiness, odour, taste or toxicity. They may also affect wood shrinkage and movement, impede successful gluing and/or interfere with coating systems (Bootle, 2004). The quantity and quality of extractives present in heartwood vary within trees, as well as between trees and populations.

Extractives can be removed from wood by using a suitable solvent (organic solvents or sometimes water). The method used in the trials reported here was based on test method T264 cm-97: Preparation of wood for chemical analysis (TAPPI 2001), using both water and dichloromethane as solvents.

Mechanical properties

Modulus of Elasticity (MoE) and Modulus of Rupture (MoR)

MoE is a measure of a length of timber's ability to resist deflection under the stress of a short-term duration load, which indicates its stiffness. MoR is a measure of the ultimate strength of a beam, subjected to a slowly applied, short-term load. These properties are measured by three-point bending and then loading to the destructive limit—as described in Mack (1979)—on dressed samples 300 mm (length), 20 × 20 mm of wood, clear of defects.

Unit shrinkage

Changing environmental conditions such as seasonal variations in humidity, or the use of climate control devices in buildings, cause wood components to shrink and/or expand as the wood material equalises to the surrounding conditions. This movement is measured as unit shrinkage and described by the percentage of dimensional change per 1% change in conditions (equilibrium moisture content, combined environment from temperature and relative humidity).

Shrinkage test specimens were prepared to standard 25 × 25 × 100 mm (radial × tangential × longitudinal; R × T × L) dimensions. All samples were measured at three positions, on both radial and tangential faces, using a linear gauge. Regular, repeated measurements were made to record changes in dimensions associated with decreasing moisture content, including at the following key moisture content points, as described in Kingston and Risdon (1961):

- green
- air-dry (12% MC); then reconditioned
- air-dry (12%) post-reconditioning
- 5% MC
- 0% MC (oven-dry)

Before reconditioning, measurements were taken at 12% moisture content and then the samples were reconditioned for two hours under saturated steam conditions at 100 °C. Unit shrinkage was determined using dimensional differences from 12% MC (reconditioned) to 5% MC, according to the protocols described in Kingston and Risdon (1961). Reconditioning is standard practice for many commercial hardwood timbers and recovers abnormal shrinkage caused by collapse.

Results

Standing trees

Acoustic wave velocity

The mean velocity from 232 samples of seven-year-old spotted gum (CCV), assessed using Hitman apparatus, was calculated as 4.06 km/sec (Harding et al. 2009b).

Table 2 shows predicted MoE, derived from Fakopp testing on 12.5-year-old red mahogany trees near Ingham. These data indicate that, in most cases, first generation selections have improved (higher) stiffness than corresponding unimproved stock (Anon. 2011). Because selection was based on growth and form and not wood properties, this may indicate positive genetic correlations between desired growth and form traits and wood traits contributing to stiffness. This possibility warrants further investigation in future research studies on genetic trials.

Table 2. Predicted MoE (MPa) values of unimproved and improved sources of *E. pellita*, estimated using a Fakopp instrument on standing trees

Red mahogany provenance	Predicted MoE values (GPa)		
	Unimproved	**First generation**	
	Papua New Guinea	Ex-Melville Is seed orchard	Ex-Queensland seed orchard
Ggoe	7.866	8.63	92.0
Serisa	8.49		
Kiriwo	8.99		
Keru		9.32	8.48
Bupul		9.33	10.20
Kumaaf		9.41	
Muting		9.58	10.22
Tokwa		7.76	9.19

Longitudinal Growth Strain (LGS)

Longitudinal growth strain, measured in eight-and-a-half-year-old red mahogany, had a significant and positive correlation with tree vigour, as measured by height and diameter, as well as sapwood width. It was also found that LGS was positively correlated with bow distortion measured during sawing (Muneri *et al*. 2002).

LGS had a significant and positive relationship with tree vigour for four-year-old Gympie messmate, suggesting that larger trees have higher stress levels (Muneri *et al.* 2000).

Table 3 summarises the average LGS measurements and corresponding average bow distortions for green off saw boards, from a range of trials.

Table 3. Longitudinal growth strain and bow distortion in plantation hardwoods

Species	Location (provenance)	Age	Longitudinal growth strain µm	Bow distortion mm	Reference
BBT	Dandali	4	102	22.2	Muneri and Leggate 2000a
	Harcourt	4	82	21.1	Muneri and Leggate 2000a
RMY	Innisfail (PNG)	8.5	87	12.4	Muneri *et al*. 2002
TWG	Innisfail (Wetar Is.)	8.5	89	14.3	Muneri *et al*. 2002
GMS	Pomona	4	71	na	Muneri *et al*. 2000

BBT = blackbutt (*E. pilularis*)
RMY = red mahogany (*E. pellita*)
GMS = Gympie messmate (*E. cloeziana*)
TWG = Timor white gum (*E. urophylla*)

Logs

Acoustic wave velocity (AWV)

Acoustic velocity increased with higher plantation stocking rates in 11-year-old Dunn's white gum (*E. dunnii*) and 12 year old spotted gum (CCV). Readings for the spotted gum were significantly higher than for Dunn's white gum (Smith *et al*. 2009), indicating superior stiffness in the spotted gum.

Heartwood proportion

For all species, it was found that the heartwood proportion increased with age at the time of harvest. There was no trend for sapwood width and age at harvest. Table 4 lists the heartwood proportions and sapwood for the key subtropical and tropical Australian plantation woods.

Table 4. Heartwood proportion and sapwood width, assessed at breast height

Species	Location/provenance	Age (years)	Heartwood (%)	Sapwood (mm)	No. of trees	Reference
WWG	Narayen	10	64.7	na	10	Armstrong 2003
	Biloela	32	80.4	na	10	Armstrong 2003
	ex-FPQ	na	21	52	98	Harding and Redman 2008
	Burncluith	13.5	47.4	20.4	5	Huth *et al.* 2012
SPG (CCV)	St Mary	7.5	26	na	116	Lee *et al*. 2012
	Bakers	10	26	na	106	Lee *et al*. 2012
	North Dempster	11	39	37	18	Muneri *et al*. 2001
GMS	Federal	8	44	25	30	McGavin and Bailleres 2007
	Tewantin	8	50	29	10	McGavin *et al*. 2006
	Toolara	10	61	21	23	Muneri *et al*. 1999
	Gympie	11	65	15	58	Muneri *et al*. 1999
	Gympie	17	69	16	41	Muneri *et al*. 1999
	Innisfail	19	76	20	42	Bailleres *et al.* 2008
	Gympie	46	87	13	42	Muneri *et al.* 1998
RMY	Innisfail/PNG	8.5	66	21	19	Muneri *et al.* 2002
	Atherton	8.5	70	17	23	McGavin *et al*. 2007
	Ingham	12	64	24	180	Lee *et al*. 2012
	Innisfail	15	67	26	32	Bailleres *et al*. 2008
BBT	Dandali	4	37	na	15	Muneri and Leggate 2000a
	Harcourt	4	32	na	11	Muneri and Leggate 2000a
	Barcoongere	9	63	16	10	McGavin *et al.* 2006
	North Dempster	11	70	14	62	Muneri *et al.* 2001
	Hakea	17	74	14	27	Muneri *et al.* 2001
RSG	Samford 1140 stems/ha	12	51	na	18	Leggate 1995
	Samford 305 stems/ha	12	57	na	18	Leggate 1995
	Samford 42 stems/ha	12	45	na	18	Leggate 1995

WWG = western white gum (*E. argophloia*)
GMS = Gympie messmate (*E. cloeziana*)
RSG = rose gum (*E. grandis*)
n = number of samples
na = not available
SPG (CCV) = spotted gum (*C. citriodora* subsp. *variegata*)
BBT = blackbutt (*E. pilularis*)
RMY = red mahogany (*E. pellita*)
FPQ = Hancock Plantations Queensland (formerly FPQ)

Basic density

In cases where more than one plantation age was sampled, basic density for those species tended to increase with harvest age. Genetic differences among provenances and the effects of plantation site conditions appear to produce differences in basic density for stands of similar age; however, the available data are not sufficiently structured to undertake reliable analysis of these genetic and site effects. Table 5 presents the basic densities, determined through a range of trials on plantation-grown woods. It also presents available published data for basic densities of mature native forest wood of the same species.

Table 5. Basic density of subtropical hardwoods (kg/m^3)

Species	Location (provenance)	Age	Basic density kg/m^3	n	Reference
WWG	Narayen	10	726	10	Armstrong 2003
	Biloela	32	838	10	Armstrong 2003
	Dalby	32	815	3	Leggate *et al*. 2000
	South Burnett,Ipswich and Scenic Rim (Burncluith and Ballon)	6–10	861	98	Harding and Redman 2008
	Burncluith	13.5	732	43	Huth *et al.* 2012
	Burra Burri	13.5	722	12	Huth *et al.* 2012
	Fairyland	13.5	716	12	Huth *et al.* 2012
SPG (CCV)	Tiaro (Boundary)	7.5	684	10	Harding *et a*l. 2009b
	Tiaro (Brooyar)	7.5	705	10	Harding *et a*l. 2009b
	Tiaro (Esk)	7.5	675	9	Harding *et a*l. 2009b
	Tiaro (Home)	7.5	697	30	Harding *et a*l. 2009b
	Tiaro (Kangaroo)	7.5	670	17	Harding *et a*l. 2009b
	Tiaro (Presho)	7.5	624	5	Harding *et a*l. 2009b
	Tiaro (Wolvi)	7.5	712	30	Harding *et a*l. 2009b
	Tiaro (Woondum)	7.5	697	121	Harding *et a*l. 2009b
	St Mary	7.5	704	116	Lee *et al.* 2012
	Bakers	10	697	106	Lee *et al.* 2012
	North Dempster	11	643	18	Muneri *et a*l. 2001
	Urbenville	12	687	60	Bristow *et al*. 2001
	Gatton	41	802	22	Leggate *et al*. 2000
	Mature spotted gum	na	740	na	Bootle 2004
GMS	Pomona	1.5	441	140	Muneri and Leggate 2000b
	Federal	8	609	30	McGavin and Bailleres 2007
	Tewantin	8	634	10	McGavin *et al*. 2006
	Toolara	10	609	23	Muneri *et al*. 1999
	Gympie	11	624	58	Muneri *et al*. 1999
	South Burnett	11	911	4	Armstrong *et al.* 2002
	Gympie	17	686	41	Muneri *et al*. 1998
	Innisfail	19	715	42	Bailleres *et al*. 2008
	Pomona	32	796	15	Leggate *et al.* 2000
	Pomona	35	782	17	Leggate *et al.* 2000
	Gympie	46	796	42	Muneri *et al*. 1998
	Mature GMS	na	810	na	Bootle 2004
RMY	Innisfail (PNG)	8.5	558	19	Muneri *et al*. 2002
	Atherton	8.5	529	23	McGavin *et al*. 2006
	Ingham	12	547	180	Huth *et al.* 2012
	Innisfail	15	588	32	Bailleres *et al.* 2008
	Mature RMY	na	790	na	www.timberanswers.com
DWG	Kingaroy	8	489	12	Palmer *et al*. 2012
	Ellangowan	8	492	12	Palmer *et al*. 2012
	Urbenville	11	482	60	Smith *et al*. 2009
	Mature DWG	na	610	na	Bootle 2004
RSG	Samford 1140 stems/ha	12	460	18	Leggate 1995
	Samford 305 stems/ha	12	451	18	Leggate 1995
	Samford 42 stems/ha	12	482	18	Leggate 1995
	Ravenshoe	28	566	11	Leggate *et al*. 2000
	Mature RSG	na	510	na	Bootle 2004
BBT	Dandali	4	463	15	Muneri and Leggate 2000a
	Harcourt	4	444	11	Muneri and Leggate 2000a
	Barcoongere	9	528	10	McGavin *et al*. 2006
	North Dempster	11	566	62	Muneri *et al*. 2001
	Hakea	17	627	27	Muneri *et al.* 2001
	Bellthorpe	21	567	40	Leggate *et al.* 2000
	Plantation	32	606	na	Gerber and Redman 2003
	Mature blackbutt	na	710	na	Bootle 2004

WWG = western white gum (*E. argophloia*)
SPG (CCV) = spotted gum (*C. citriodora* subsp. *Variegata*)
GMS = Gympie messmate (*E. cloeziana*)
BBT = blackbutt (*E. pilularis*)
RSG = rose gum (*E. grandis*)
RMY = red mahogany (*E. pellita*)
DWG = Dunn's white gum (*E. dunnii*)
PNG = Papua New Guinea
n = number of samples
FPQ = Hancock Plantations Queensland (formerly FPQ)
na = not available

Extractives content

Several assessments have been undertaken of the extractives content of subtropical hardwoods. McGavin *et al.* (2006) reported the heartwood and sapwood results for three species, from material less than 10-years-old. In another study, heartwood extractives contents of 15-year-old red mahogany and 19-year-old Gympie messmate were determined (Bailleres *et al*. 2008). Results from both studies are summarised in Table 6.

Table 6. Extractives content for some subtropical plantation hardwoods

Species	Location	Age	Heartwood extractives content %	Sapwood extractives content %	Reference
BBT	Barcoongere	9	9.46	4.29	McGavin *et al.* 2006
RMY	Atherton	8.5	7.99	5.71	McGavin *et al.* 2006
	Innisfail	15	5.55	not determined	Bailleres *et al.* 2008
GMS	Pomona	8	11.30	4.29	McGavin *et al.* 2006
	Innisfail	19	5.74	not determined	Bailleres *et al.* 2008

BBT = blackbutt (*E. pilularis*)
RMY = red mahogany (*E. pellita*)
GMS = Gympie messmate (*E. cloeziana*)

Mechanical properties

Modulus of elasticity (MoE)

A summary of the stiffness results from testing of subtropical plantation hardwoods is provided in Table 7. The values obtained for spotted gum are approximately 60% of those achieved for mature native forest spotted gum. For example, Bootle (2004) lists MoE for air-dry spotted gum of 23 GPa, compared with the average of 14 GPa observed by Harding *et al.* (2009b) in very young seven-and-a-half-year-old spotted gum (CCV) during the thinning of a seedling seed orchard.

There was an age effect seen in the results for Gympie messmate, red mahogany and blackbutt. With these species, stiffness increased with tree age, for samples taken from standard comparison positions such as sapwood, outer heartwood and inner heartwood zones.

Table 7. MoE for subtropical hardwoods

Species	Location (provenance)	Age	MoE air-dry (GPa)	n	Reference
WWG	Narayen	10	8.25	10	Armstrong 2003
	Biloela	32	12.33	10	Armstrong 2003
	Burncluith	13.5	14.43	5	Huth *et al*. 2012
SPG (CCV)	Tiaro (Boundary)	7.5	13.10	10	Harding *et al.* 2009b
	Tiaro (Home)	7.5	16.10	30	Harding *et al.* 2009b
	Tiaro (Kangaroo)	7.5	13.60	17	Harding *et al.* 2009b
	Tiaro (Wolvi)	7.5	14.30	30	Harding *et al.* 2009b
	Tiaro (Woondum)	7.5	14.40	121	Harding *et al.* 2009b
GMS	Federal	8	12.01	30	McGavin & Bailleres 2007
	Tewantin	8	11.60	10	McGavin *et al.* 2006
	Toolara	10	11.94	23	Muneri *et al.* 1999
	Innisfail	19	16.10	42	Bailleres *et al.* 2008
RMY	Atherton	8.5	11.00	23	McGavin *et al.* 2006
	Innisfail	15	13.60	32	Bailleres *et al.* 2008
	Innisfail (PNG)	8.5	13.00	19	Muneri *et al*. 2002
BBT	Dandali	4	8.80	15	Muneri & Leggate 2000
	Harcourt	4	9.50	11	Muneri & Leggate 2000
	Barcoongere	9	12.90	10	McGavin *et al.* 2006
TWG	Innisfail (Wetar Is.)	8.5	12.40	18	Muneri *et al.* 2002

WWG = western white gum (*E. argophloia*)
GMS = Gympie messmate (*E. cloeziana*)
RSG = rose gum (*E. grandis*)
TWG = Timor white gum (*E. urophylla*)
n = number of samples
SPG (CCV) = spotted gum (*C. citriodora* subsp. *variegata*)
BBT = blackbutt (*E. pilularis*)
RMY = red mahogany (*E. pellita*)
PNG = Papua New Guinea

Modulus of rupture MoR

The results for the strength testing displayed similar trends to those described above for MoE. Wood from older plantations was generally stronger than wood tested from younger plantations. The results for spotted gum (CCV) indicate that by age 7.5-years, the wood has achieved 53% of the published strength value for mature spotted gum (Bootle, 2004).

Table 8. MoR for subtropical hardwoods

Species	Location (provenance)	Age	MoR air-dry (MPa)	n	Reference
WWG	Narayen	10	82	10	Armstrong 2003
	Biloela	32	103	10	Armstrong 2003
	Burncluith	13.5	150	5	Huth *et al*. 2012
SPG (CCV)	Tiaro (Boundary)	7.5	74	10	Harding *et al.* 2009b
	Tiaro (Home)	7.5	89	30	Harding *et al.* 2009b
	Tiaro (Kangaroo)	7.5	80	17	Harding *et al.* 2009b
	Tiaro (Wolvi)	7.5	78	30	Harding *et al.* 2009b
	Tiaro (Woondum)	7.5	82	121	Harding *et al.* 2009b
GMS	Federal	8	71	30	McGavin & Bailleres 2007
	Tewantin	8	61	10	McGavin *et al.* 2006
	Toolara	10	109	23	Muneri *et al.* 1999
	Innisfail	19	125	42	Bailleres *et al.* 2008
RMY	Atherton	8.5	57	23	McGavin *et al.* 2006
	Innisfail	15	108	32	Bailleres *et al.* 2008
	Innisfail (PNG)	8.5	106	19	Muneri *et al*. 2002
BBT	Dandali	4	77	15	Muneri & Leggate 2000
	Harcourt	4	83	11	Muneri & Leggate 2000
	Barcoongere	9	70	10	McGavin *et al.* 2006
TWG	Innisfail (Wetar Is.)	8.5	110	18	Muneri *et al.* 2002

WWG = western white gum (*E. argophloia*)
GMS = Gympie messmate (*E. cloeziana*)
RMY = red mahogany (*E. pellita*)
PNG = Papua New Guinea
n = number of samples
SPG (CCV) = spotted gum (*C. citriodora* subsp. *variegata*)
BBT = blackbutt (*E. pilularis*)
TWG = Timor white gum (*E. urophylla*)

Unit shrinkage

The unit shrinkage values determined from laboratory tests on subtropical hardwood samples are listed in Table 9, along with published data for mature wood where available.

Table 9. Unit shrinkage (%) of subtropical hardwoods

Species	Location/provenance	Age (years)	Rad.	Tan.	n	Reference
WWG	Narayen	10	0.19	0.23	10	Armstrong 2003
	Dalby	32	0.31	0.43	3	Leggate *et al.* 2000
	Biloela	32	0.29	0.33	10	Armstrong 2003
	Burncluith	13.5	0.28	0.30	5	Huth *et al.* 2012
SPG (CCV)	Casino & Woodenbong	40	0.34	0.32	30	Atyeo 2010
	Gatton	41	0.34	0.31	22	Leggate *et al*. 2000
	Mature SPG	-	0.32	0.38		Kingston and Risdon 1961
GMS	Tewantin	8	0.18	0.26	10	McGavin *et al.* 2006
	Innisfail	19	0.24	0.29	42	Bailleres *et al*. 2008
	Pomona	35	0.30	0.39	17	Leggate *et al.* 2000
	Pomona & Tewantin	58	0.31	0.36	30	Atyeo 2010
	Mature GMS	-	0.21	0.37	-	Kingston and Risdon 1961
RMY	Innisfail/ PNG	8.5	0.17	0.26	19	Muneri *et a*l. 2002
	Innisfail	15	0.22	0.30	32	Bailleres *et al*. 2008
BBT	Dandali	4	0.10	0.26	15	Muneri and Leggate 2000a
	Harcourt	4	0.12	0.24	11	Muneri and Leggate 2000a
	Barcoongere	9	0.16	0.28	10	McGavin *et al.* 2006
	Coffs Harbour & Dorrigo	50	0.23	0.32	30	Atyeo 2010
	Mature BBT	-	0.26		-	Kingston and Risdon 1961
RSG	Ravenshoe	28	0.23	0.31	11	Leggate *et al*. 2000
	Mature RSG	-	0.25	0.34	-	Kingston and Risdon 1961
TWD	Ravenshoe	28	0.31	0.38	22	Leggate *et al*. 2000
	Mature TWD	-	0.28	0.37	-	Kingston and Risdon 1961
TWG	Innisfail (Wetar Is.)	8.5	0.18	0.37	18	Muneri *et al.* 2002
MSK	Dip River & Tahun	80	0.28	0.36	30	Atyeo 2010
	Mature MSK	-	0.23	.036	-	Kingston and Risdon 1961
DWG	Dorrigo	12	0.17	0.30	30	Atyeo 2010
	Mature	-	0.20	0.36	-	Kingston and Risdon 1961

WWG = western white gum (*E. argophloia*)
SPG (CCV) = spotted gum (*C. citriodora* subsp. *variegata*)
GMS = Gympie messmate (*E. cloeziana*)
RMY = red mahogany (*E. pellita*)
BBT = blackbutt (*E. pilularis*)
RSG = rose gum (*E. grandis*)
TWD = tallowwood (*E. microcorys*)
MSK = messmate (*E.obliqua*)
DWG = Dunn's white gum (*E. dunnii*)
TWG = Timor white gum (*E. urophylla*)
Rad. = radial unit shrinkage (%)
Tan. = tangential unit shrinkage (%)
n = number of samples

Discussion

Product development

Based on the characteristic qualities and properties determined during the tests reported here, product development researchers have investigated the suitability of plantation-grown subtropical hardwoods for both traditional and innovative applications. Sawn timber, veneer-based composites and roundwood applications have been considered. Pulping characteristics were excluded in this review, because the primary interest in subtropical and tropical areas relates to processed products and markets that provide higher grower returns per cubic metre.

In order to be economically competitive, processors will need to invest in technology, specifically designed to maximise recovery and efficiency, through manufacturing quality products from plantation logs that are smaller in diameter than the subtropical native forest hardwood logs used by current sawmilling and veneer plants. Matching processing capacity to available plantation resource supply will be an important issue.

It is clear that the wood properties of plantation-grown wood differ from those of mature native forest wood. Density, strength and stiffness are generally lower for younger, plantation-grown wood. However, it is noteworthy that the mechanical property measurements compiled in this review indicate that trees harvested at relatively young ages can produce material that exceeds the threshold levels required for a wide range of sawn, round and engineered wood products. Subtropical and tropical eucalypt plantations can produce wood with properties that are very desirable for a range of high quality and high-value products. A range of the trials undertaken over the past decade to assess suitability for various products is discussed below.

Sawn timber

Several sawing studies have been conducted, with a variety of processing systems, to observe the behaviour of fast-grown plantation hardwoods during processing, and determine sawn recoveries and grade quality. Sawn hardwood has traditionally been used in a wide variety of general construction applications, ranging from green framing to high-value, kiln-dried furniture, flooring, decking and cladding products. Fencing, landscaping and pallet manufacturing also provide lower value utilisation options for lower quality material.

Sample loads of plantation-grown eucalypts have been supplied to various processors, with the output evaluated for framing and trusses, fencing and pallets, furniture and glulam. The results from sawing and grading studies indicate that material derived from young, plantation-grown subtropical hardwood provides relatively low recoveries of high-value wood. This is mainly due to the small log size that limits sawn recovery. End splits and distortion are also limiting factors in achieving higher recoveries.

One trial involved processing almost 12 m^3 of Gympie messmate and blackbutt plantation logs through a HewSaw, with the aim of producing framing products. However, approximately one third of the logs supplied had excessive sweep and could not be processed with the equipment (McGavin *et al*. 2006).

Glulam

Four glued laminated beams (Glulam) were manufactured from eight-year-old Gympie messmate and tested for strength, stiffness and bond quality (McGavin *et a*l. 2006). The average MoE was 23.0 GPa and the average MoR was 45.2 MPa, indicating GL10 equivalence. All beam samples passed the requirements for bonding.

Truss manufacture

A parcel of ungraded sawn 8.5-year-old Gympie messmate was supplied to a truss manufacturer for appraisal. The material presented no problems during handling and gang-nail pressing and, according to the commercial operator who collaborated on the trial, could provide an alternative to plantation softwood (McGavin *et al*., 2006).

Furniture

Thinnings from subtropical plantations were provided to a tertiary furniture design department for evaluation. A range of items was designed and manufactured, featuring the natural characteristics of the resource. It was found that the knots, curly grain and attributes of the resource posed no problems during processing and manufacturing, and the finished items were well received by the general public. (McGavin, 2006).

Fence palings

Samples of 3403 small diameter Gympie messmate logs, harvested from an eight-year-old plantation near Gympie, were sawn to produce fence palings. Green off saw recovery was 28.5%, which was typical for small diameter logs. The primary products from the trial were 75 ×16 mm palings (47%) and 100 × 16 mm palings (26.5%). Market acceptance was limited by the high incidence of end splits. (McGavin and Bailleres, 2007).

Veneer-based composites

Peeling logs to produce thin veneers for manufacturing plywood panels provides a relatively high recovery option for high quality logs from mature forest resources. Trials have been undertaken on smaller plantation logs, using a spindleless lathe to maximise recovery and to ascertain the potential to produce plywood from younger, fast-grown plantation resources. Results from the veneering and plywood manufacturing trials will be published in late 2012.

A small proportion of thinnings logs, representing the best quality stems, can be peeled using currently available technologies to produce veneer (McGavin *et al*. 2006). Grade quality studies were undertaken in several projects and showed that the subtropical hardwood resource can produce C and D-grade veneers, as well as some B-grade veneers. This indicates that high-value structural subflooring panels can be manufactured, but it would not be viable to produce marine or furniture panels.

Other research showed that young, plantation-grown hardwoods can provide veneer cross bands for formply, but not the higher value face ply for this demanding product (Anon. 2011).

Atyeo *et al* (2008) produced veneers from 15-year-old red mahogany and 19-year-old Gympie messmate logs, recovered from plantations damaged by severe tropical Cyclone Larry in 2006. These veneers were graded and used in the manufacture of plywood panels. It was difficult to produce plywood panels from this resource, due to the high incidence of splits (some of which may relate to the effects of the cyclone) and lack of full-sized veneer sheets. The red mahogany panels that were produced achieved stress grades between F11 and F14, matching typical structural properties of softwood plywood in the market. The Gympie messmate had superior strength properties, attaining values between F22 and F27, suitable for the more demanding construction applications (Atyeo *et al*. 2008).

Roundwood

Because of the low recoveries obtained during the sawing trials, roundwood options have been considered. Roundwood products have several advantages over sawn wood options, such as reduced processing costs (and, therefore, low embodied energy), reduced waste and improved strength attributes for similar sized cross-sections.

Australia faces an approaching supply shortage of poles for overhead electricity supply (utility poles). Researchers from Queensland's Department of Agriculture, Fisheries and Forestry (DAFF) have designed a hybrid composite utility pole that uses three or four small poles from plantation thinnings and steel fittings, as a substitute for traditional poles. This hybrid utility pole concept was developed by computer-aided design and finite element analysis to provide an optimal, simple design, incorporating a steel support spike, three of four poles from hardwood thinnings and some spacers (Bailleres and McGavin, 2011). The manufacturing costs are estimated to be much less than non-timber alternatives and the strength and tip load capacity were estimated to be equivalent to conventional poles of the same length. An Australian patent application (No. 2010257424) has been lodged.

Additional design work was undertaken to use small diameter roundwood for highway noise barriers and architectural roundwood applications such as small shelters (Dickson *et al.* 2011). University of Queensland Architecture students and staff collaborated on this project. Straight and steam bent arched structural members were considered in concepts for a range of structures of different scales, including small shelters, medium scale remote housing and large scale noise barriers. Illustrations of these designs were circulated to 1200 stakeholders as part of a survey. The results provided optimism for the potential of small roundwood structures, with 87% of respondents indicating that they liked the overall impression of the concepts, versus 13% who were neutral (Dickson *et al.* 2011).

Landscaping roundwood

Preservative-treated, shaved landscaping rounds were produced from subtropical plantation thinnings. The material took the preservative well, but the process resulted in excessive splitting and surface checking; therefore, the resource was not considered a viable alternative to low-cost plantation softwoods (McGavin *et al*. 2006). Lower value landscaping rounds were also evaluated by an established plantation softwood product manufacturer.

In a separate trial involving young, unseasoned spotted gum and Gympie messmate thinnings, Norton (2006) found that the green test material failed to meet the preservative penetration requirements specified in the relevant Standard.

Pruning

Pruning represents a significant added cost to plantation wood production and can result in decreased recovery, due to the incidence of decay from fungal organisms entering and infecting the wood through pruning wounds. Nevertheless, pruning may be needed for some species—such as Dunn's white gum, Western white gum and Gympie messmate—that do not self-shed their branches readily, particularly if targeting products that require clear wood recovery. Observations suggest that it is critical to prune early in the growing season and while branches are still alive, so that stubs are covered quickly and dead stubs do not set up a defect whereby they are dragged out with the bark as the tree grows (Smith *et al.* 2009). Smith and Brennan (2006) and Kearney *et al.* (2007) made the distinction between shade intolerant species, such as rose gum, and more shade tolerant species, such as blackbutt, with the latter tending to retain its branches for longer. In assessing growth response following pruning of three-and-a-half-year-old blackbutt and Gympie messmate, Alcorn *et al.* (2008) suggested that removal of up to 50% of the lower crown from trees on good sites had no impact on their growth. From the limited studies undertaken, it is clear that for managers to weigh up the potential for economic returns from pruning, a number of factors need to be considered, including species' growth patterns and, therefore, their tendency to naturally shed branches, along with site quality and productivity, and the potential to sell into high-value clear wood markets.

Future research recommendations

It is recommended that future research and development efforts include:

- work to define the critical wood property threshold values for key products, to guide rotation age for forest managers
- consideration of defect docking and re-joining to produce clear-grade veneer, suitable for formply and other high-value engineered wood products
- preservation methods for green roundwood products, removing the current requirement for protracted periods of drying prior to impregnation
- studies to define the zone of juvenile wood surrounding the pith, which is reputed to produce processing, drying and durability issues for both plantation and native forest logs
- practical tools to identify this wood, to limit its impact on processing and products.

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