Department of Agriculture, Fisheries and Forestry

Plantation hardwood resource specifications required for planning small log sawing infrastructure investment in Queensland

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May 2014

Great state. Great opportunity.

Queensland Government

This publication has been compiled by A. Zbonak et al of Agri-Science Queensland, Department of Agriculture, Fisheries and Forestry.

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Summary

Improved information on the product quality of the plantation resource is needed to allow businesses to consider investing in the development of value-adding processing facilities. These facilities are likely to require customised design that optimises the utilisation of future small diameter plantation hardwood logs. This log resource will become available as wood supply in Queensland transitions from native forests to 100% from sustainable plantations. This resource will be controlled by plantations established prior to 2000. A survey of the three main growers (former Forest Enterprises Australia Pty Ltd, former Forestry Corporation of New South Wales, Hancock Queensland Plantation Pty Ltd) revealed that *C. citriodora* subsp. *variegata* – CCV (28.0%), *Eucalyptus dunnii* (27.5%), *E. pilularis* (23.0%), *E. grandis* (11.3%) and *E. cloeziana* – GMS (7.1%) were the most widely planted species in the southern Queensland and northern New South Wales subtropical hardwood estate and would potentially dominate the supply of plantation hardwoods to sawmill processing facilities.

The current study collected data on the wood quality of small diameter plantation hardwood logs to establish links between age, log size and sawn product quality. The target resource sample was CCV with smaller samples of GMS and *E. argophloia* (WWG), which are currently preferred for hardwood plantations in Queensland. Plantation ages of between 10 and 30 years old were targeted to represent the full range of early to late age plantation resource.

One hundred and forty-seven trees with a total log volume of 61 m^3 were processed through the conventional Parkside sawmill at Wandoan to produce a range of sawn products (with a focus on flooring products). CCV was relatively stable during the processing and there were no main cant splitting issues observed. GMS was more prone to splitting, with a few cases of cant splits that negatively affected the final recovery. Green-off-saw (GOS) recoveries were low, averaging about 35% for CCV and about 30% for GMS. As expected, larger trees provided higher values of GOS recoveries. GOS recovery for WWG was less than 27%.

For the product ‘flooring’, the dried and dressed graded recovery at site level for CCV ranged from 11.7% to 16.4% of green log volume. This is about half what would be expected from native spotted gum. Most of the appearance grade recovery was in very short lengths. There is potential to use small dimension lengths effectively in finger-joint components and laminate. The amount of premium select grade was higher for older and larger trees. In general, for plantation CCV timber, the recovery of select grade was 30% less when compared to native timber currently processed at the Parkside sawmill. Younger timber distorted badly during drying, due to the high proportion of juvenile wood. This consequently reduced the amount of select grade.

Knots were the main defect to prevent the higher grade being met across all sites. The plantation logs assessed were generally unmanaged. More careful silviculture in the future could diminish the impact of the knot defects on recovery and allow higher yields of clear timber. Other significant reasons for downgrade included heart, wane, decay and heart shakes. These defects are characteristics of harvesting relatively young, fast-grown trees.

The proportion of boards rejected due to excessive distortion ranged from 12.3% for 30-year-old CCV to 29.3% for 10-year-old CCV (relative to log volume). Twist and bow were the main reasons for rejection. Spring was a limited problem, only occurring in the young 10-year-old resource. Spring was a limited problem, only occurring in the young, 10-year-old resource.

Mean basic density of plantation CCV was 715 kg m^{-3} compared to approximately of 800 kg m^{-3} for native forest derived trees. Younger trees exhibited lower values of basic density,

due to high concentrations of sapwood in these samples. The average basic density of GMS was approximately 750 kg m^{-3}.

A high proportion of sapwood in plantation timber is a significant issue, affecting colour and durability. Plantation CCV displayed a low heartwood proportion, ranging, on average, from 25% to 46% and with a sapwood width of about 40 mm. GMS had the highest heartwood proportion at approximately 70% and with low sapwood width of about 20 mm.

The project also produced information on the mechanical properties for these species that should give growers and processors confidence in products meeting market requirements. Surface hardness, density and MOR/MOE were generally marginally lower than native forest material of the same species.

Overall the plantation resource of CCV and GMS was of a relatively poor quality that would not meet current market expectations for sawn appearance grade timber. The low recoveries obtained in this study raise questions about the economic viability of processing this plantation resource. However, it is important to take into account the lack of silvicultural management in the investigated sites.

Economically-viable production of sawn products from this type of plantation will require different processing techniques that provide better control over value-limiting factors such as distortion, and that maximise recoveries. Additional research will be required to determine potential products and available markets suited to the quality and quantity of plantation hardwood sawn products.

1. Introduction

Subtropical eucalypt plantations established in Queensland and New South Wales total about 150 000 ha, which is 15% of Australia's hardwood plantation estate. The most widely planted species are *C. citriodora* subsp. *variegata*, *E. cloeziana, E. pilularis* and *E. argophloia*. In time these species will dominate the supply of plantation hardwoods to sawmill processing facilities.

The transition from mature native forest hardwoods to a young plantation-grown resource presents some notable challenges for the industry. These include the suitability of the plantation resource for current products and developing new processing technologies to appropriately process smaller sized logs that have different wood properties to logs obtained from mature stands. Traditional native forest sawmills are not suited to sawing small plantation logs and processing options are needed to add value to small diameter sawlogs. Investment in sawing infrastructure will need to be complemented by processing facilities for logs sourced from early thinning or other logs that do not meet sawing size/quality specifications. Recent international advances in small-log sawmilling, tailored mainly for the softwood industry, may have some application in processing plantation hardwoods. The challenge that remains is the economic impact of high capital investment, large volume throughput requirements, low recovery of product, and matching dimensions and qualities of sawn wood to markets.

A significant amount of research has been completed since the mid-1990s to provide information and industry guidance on the establishment, management and utilisation of Queensland grown hardwood plantations. This has included several research activities that focused on describing the wood quality and mechanical properties of a range of candidate plantation species across a number of growing conditions at various ages. In addition, various processing and product-oriented studies have explored methods to convert the resource into a range of existing and novel products. These studies have provided valuable data showing that in general, the wood from relatively young (<25 years old) plantation grown subtropical and tropical hardwood species are lower in density, have a lower heartwood proportion, are smaller in diameter, have a shorter merchantable length, have lower mechanical properties and contain a higher proportion of defects when compared to mature wood from native-grown hardwood forests.

1.1. Objectives of the study

This study aimed to collect data on the wood qualities of small diameter plantation hardwood resource so that links between age and log size and sawn product quality could be established. This information will be used in any future feasibility study of the investment potential for establishing plantations for sawn products. Also it will form the basis for underpinning the case for the development of infrastructure for customised small log sawmills. At a higher level, the study aimed to provide valuable data that could be incorporated into plantation economic models and thus to underpin favourable 'solid timber' hardwood plantation investment decisions, and consequently to contribute to the expansion of the plantation estate in Queensland.

The objectives were to:

(1) Characterise the resource supply mix that will be available to fibre processors for the next decade during the transition from native forest to plantation produced hardwood timber.

(2) Evaluate sawn product quality from targeted sawlog species/age combinations processed to optimise recovery and value, and use these results to highlight the resource requirements that plantation growers and processors need to achieve to successfully transition into plantation sawlog production and utilisation.

The target resource for the study was *Corymbia citriodora* subsp. *variegata* (CCV or spotted gum – SPG) with smaller samples of *E. cloeziana* (Gympie messmate – GMS) and *E. argophloia* (western white gum – WWG); these species are preferred for hardwood plantations in Queensland. Plantation of between 10 and 30 years old were targeted to represent the full range (early-to late-age) of the plantation resource.

2. Material and methodology

2.1. Resource selection

The recent 2009 and 2010 collapses of the forestry managed investment scheme (MIS) companies in Queensland have placed renewed priority on determining the plantation resource characteristics (species, age, size and location/s) required to achieve successful economic returns from the hardwood plantations established since the mid-1990s. The main sawlog and the largest single species plantation resource established in Queensland and northern New South Wales is CCV. This is complemented by small plantings of several other spotted gum varieties and hybrid combinations. The latter may increase in future importance as initially-limiting supply issues, due to propagation and nursery difficulties, appear to have been overcome. All these spotted gum taxa are expected to produce wood with similar quality and all appear to be characterized by large proportions of *Lyctus* (powder post beetle) and decay-susceptible sapwood in young stands (<15–20 years). The need to protect this sapwood in sawn and roundwood products, using preservative treatment, may add significant costs to its utilization. This may be an important factor in overall cost structures for harvesting young plantations. Additionally, market resistance to products containing sapwood is high. If the current sawlog market does not accept treated sapwood products then new products or different markets for this wood will need to be found. By comparison, GMS has highly durable heartwood and its sapwood is not *Lyctus* susceptible, providing a broader range of product options without necessarily incurring additional treatment costs for some products.

WWG is a relatively new plantation candidate and has the potential to allow plantation establishment in areas previously not regarded as suitable for hardwood plantations. This is due to the species' ability to grow in heavy textured soils in the 650–900 mm mean annual rainfall (MAR) zone of Queensland, which are also prone to frost. Moreover, WWG is relatively tolerant in saline-affected soils and has already been planted under irrigation as part of water usage from large-scale mining operations. It was planned to expand the area of this species over the next decade in the area of coal seam gas industry however the whole program was recently terminated.

Reflecting the above, the priority species identified for this study was spotted gum with smaller samples of GMS and WWG. Although a broader range of age and size of GMS was available, sampling was restricted to trials where spotted gum was sampled, since several previous sawing studies had produced favourable results.

Potential sites that could provide material of a suitable size, age and species for processing using contemporary sawing technologies were identified from the desk-top analysis of the resource and priorities.

Initial site inspections were conducted on the sites that were identified as having sawing potential from the existing inventory data These site inspections proved to be essential for confirming the availability of sufficient stems (>10 at each site) to meet the minimum sawing requirements for log length, diameter and straightness.

2.1.1. Stage I – Pilot sawing trial

A preliminary pilot study was undertaken to expose the project partners to a sample of plantation material and to provide an opportunity to fine-tune the sawing strategy in advance of the Stage II main trial. This pilot sawing study provided Parkside Timbers and the project steering committee with the opportunity to consider the impact of plantation log size, quality and other characteristics on the sawing strategy and therefore what product/s should be targeted to maximise returns.

2.1.1.1. Spotted gum – Atkinson Dam site

Trees were selected from DAFF's trial site established as Expt 573 HWD (species × provenance evaluation for commercial plantation establishment in the 700–1000 mm rainfall belt of southern and central Queensland). This was located on a gentle slope at the base of the Atkinson Dam wall (Image 1) and planted in 1989. The aim of that experiment was to evaluate the growth and survival of a number of hardwood species and provenances, over of range of representative soil types in the Lockyer Valley region.

In June 2011, when the plantation was 13 years old, 26 trees were harvested for the sawing trial (Image 1).

Image 1: The 13-year-old spotted gum trees from Atkinson Dam

2.1.1.2. Gympie messmate and spotted gum – Tinana site

A subsample of GMS and CCV was selected from Expt 363 HWD (Species trial – selections from species elimination trial). This experiment is located in Compartment 13 Tinana, SF 1419 Neerdie. The aim of this experiment was to test the performance in a longer term trial of several promising seedlots currently under test in short-term trials, against a standard *E. grandis* seedlot and clonal material from an imported Brazilian hybrid.

At the time of harvest the trees were 22 years old (planted in 1989). Four trees of GMS and five trees of CCV and were selected and harvested (Image 2).

2.1.1.3. Gympie messmate – Hakea site

A subsample of 30-year-old GMS was selected from Expt 291 HWD Compartment 2 Hakea, SF 915. The experiment was planted in 1981; the mean annual rainfall is 1370 mm.

Ten trees were harvested in June 2011 at age 30 years (Image 3).

Image 2: The 22-year-old CCV (left and right) and GMS trees (middle) at the Tinana site.

Image 3: The 30-year-old GMS trees at the Hakea site.

2.1.2. Stage II – Main sawing trial

The overall priority of species selection for the main sawing trial, as decided by the project steering committee, was spotted gum with three age classes: 10 years, 20 years and 30 years. A small sample of WWG (five trees) was also included for sawing.

Finding suitable material presented considerable challenges due to the nature of early trials and the limited volumes available from them. After comprehensive searching and site inspections, several sites were identified and these are described below. The volume of 20-year-old CCV was small and not ideal. Private plantation resources were approached, although no suitable trees could be identified in this age class.

2.1.2.1. The 10-year-old spotted gum – Berry site

Trees were sourced from Hancock Queensland Plantation (HQP) site at Berry's block at Crawford, near Kingaroy. Trees were planted in 2002, pruned at age six years to 6 m, and thinned twice, initially at age three years, and later at age eight years to a stocking of 300°stems per hectare. This particular site was selected for the sawing trial because it was the only available plantation that had large, pruned spotted gum trees at this young age.

Thirty trees were harvested in April 2012 at age 10 years (Image 4).

Image 4: The 10-year-old CCV trees from the Berry site.

2.1.2.2. The 23-year-old spotted gum – Tinana site

Trees were selected from Expt 363 HWD (Species trial – selections from species elimination trial). This experiment is located in Compartment 13 Tinana, S.F. 1419 Neerdie. The aim of Expt 363 HWD was to test the performance in a longer term trial of several promising seedlots currently under test in short term trials, against a standard *E. grandis* seedlot and clonal material from an imported Brazilian hybrid.

In April 2013, thirteen trees harvested. At the time of harvest the trees were 23 years old (Image 5).

Image 5: **The 23-year-old CCV trees from Tinana site.**

2.1.2.3. The 30-year-old spotted gum – Thinoomba site

Located 28 km west of Maryborough this is a private spotted gum plantation of 364 ha owned and established by Hardwood Plantations (Qld) Pty Ltd. from 1978–79, to 1984–85. The trees were from St. Mary's provenance. The seedlings were planted into a ripped and cultivated site. No fertiliser has been applied and no pruning or thinning has been done. The spacing was originally 2.7 m × 2.7 m (1371 stems per hectare). Fire damage in the first few years after planting reduced the stocking in some sections to 300–500 stems per hectare. A thinning in the early 2000s further reduced the stocking (details are not available).

In 2011, the site was surveyed and considered to be a suitable resource for the sawing study. Across the site, 54 trees were selected and assessed using acoustic velocity and measured for DBH. Selected trees were sampled in April 2012. Since the age of the selected trees ranged from 27 to 34 years, it is referred as the 30-year-old site (Image 6).

Image 6: **The 30-year-old CCV trees from Thinoomba site.**

2.1.2.4. *Western white gum – Morgan Park site*

Expt 505c TCA from Morgan Park, near Warwick, was established to compare the performance of several Australian native trees, including western white gum. Trees were planted in 1992 at a spacing of 2 × 4 m. Five WWG trees (shorter sawlogs up to 6 m) were selected for the sawing trial and were 20 years old when sampled (Image 7).

Image 7: The 20-year-old WWG trees from Morgan Park site.

2.2. Standing tree assessment and harvesting

At each site, trees with sawlog potential (straight trees with minimum sweep and appropriate log size) were identified and marked. Those trees with obvious defect, butt swell or sweep were excluded.

Selected trees were measured (diameter at breast height, DBH) and assessed with a Fakopp Microsecond Timer that measures acoustic velocity in order to estimate stiffness non-destructively in standing trees. An acoustic wave velocity (AWV) value for each tree was obtained from the ratio of the distance between the two probes (1.2 m) and the average time taken for the signal flight. Using the acoustic tool to measure the variation in the main species/age class group enabled standing wood quality to be related to product quality.

The trees were felled at approximately 15–20 cm above ground level. Harvesting for Stage I of the pilot study was done in June 2011, and harvesting for Stage II of the main sawing study was done in April 2012. No merchandising was carried out onsite; the aim was to harvest the longest log with small end diameter (SED) under bark not less than 15 cm. Both log ends were sealed immediately after felling with Dusek wax emulsion. GMS logs were debarked in the field. Logs were snigged to the roadside and transported to the Parkside Timber sawmill in Wandoan for further processing.

2.3. Log preparation and measurement

At the Wandoan sawmill, the logs were laid out on bolsters. Merchandising was undertaken by an experienced operator at Wandoan sawmill (operational manager) with the aim of maximising recovery and minimising board distortion. Each full length log was merchandised into two or three shorter logs with a targeted length of 4.6 m; however, shorter and longer logs were also included. Experience from the pilot sawing trial prompted the choice of shorter log lengths in Stage II in an attempt to reduce the impact of cant and board distortion. The bottom logs representing the lower part of the tree are referred in the report as 'butt' logs, the logs removed above the butt logs are referred as 'top' logs.

A number of measurements were taken in the log yard to describe the resource:

- total merchantable log length
- butt, mid and small end log diameters
- sweep – measured as the deviation from a straight axis on three sides of the log, and recording the largest measurement.
- acoustic velocity – assessed using a Director HM200 (measured on the full length prior to merchandising and on shorter logs after merchandising). The HM200 measures averaged sound resonance patterns produced across the whole cross section of the log.

Mean diameters (average of shorter and longer axis) were measured at both billet ends. These were used in recovery calculations. Billet volumes were calculated using Smalian's formula:

$$V = [\frac{(LEDUB + SEDUB)}{2} \times \frac{1}{2}]^2 \times \pi \times L$$

where: V = billet volume (m^3); LEDUB = large end diameter under-bark (m); SEDUB = small end diameter under-bark (m); L = billet length after merchandising.

2.3.1. Log separation and batching

2.3.1.1. Stage I – pilot trial

The board tracking system developed by Smith *et al.* (2003) was used to allow the board position to be quantified within a log. A template was glued to the large end of each log using Bondcrete and the tree number recorded (Image 8). After sawing, an individual board could then be tracked back to the individual source log.

Image 8: Template glued on large log-end allowing board position within a log to be quantified.

2.3.1.2. Stage II – main sawing trial

CCV logs were segregated into batches according to the site (three sites of different ages), log diameter (three classes based on SED size: <20 cm, 20–25 cm, >25 cm) and log position (butt and top logs, Table 1). Each group was tracked through the mill by allocating a colour code to the small log-ends using a sequence of eight colours (Image 9, Table 1). To delineate between top and butt log all top logs had poker dots of a contrasting colour applied to the base colour. As the colour combinations were unique, milled boards could be traced to the source log, identifying the tree and the sawlog position in the tree.

In some batches the number of logs and log volume was insufficient and impractical for comparing purposes, therefore, butt and top logs were combined and analysed as one group. Log segregation was not done for WWG due to the small sample size.

Image 9: Colour coding of logs and separating into batches. Paint applied on small ends, poker dots used to distinguish top logs (right).

Table 1. Log batch information for logs from Stage II (colours in the size class indicate the paint colour to separate the batches)

Species/age	Size class (cm)	Position	No of logs in batch	Log volume (m^3)
CCV–10 yrs	<21	Butt	15	2.95
		Top	12	1.53
	21–25	Butt	15	3.43
		Top	2	0.25
CCV–22 yrs	<21	Butt	5	0.89
		Top	7	0.79
	21–25	Butt	7	1.44
		Top	5	0.62
	25>	Butt	3	0.84
		Top	1	0.24
CCV–30 yrs	<21	Butt	11	1.86
		Top	15	1.54
	21–25	Butt	27	6.43
		Top	20	2.96
	25>	Butt	11	3.89
		Top	4	0.87
WWG–22 yrs	16–24	All	9	0.91

2.4. Wood quality on disk samples

Disk samples (25 mm thick) were removed at the top of the butt log after final merchandising was completed. In most cases it corresponded to a tree height between 2.5 m and 6 m from the ground. Discs were processed further at the DAFF Wood Quality Laboratory to assess basic density, heartwood proportion, sapwood width and shrinkage as described below.

2.4.1. Basic density

Basic density is a useful indicator for characteristics such as hardness, strength and workability.

Basic density was measured on two wedge samples cut from opposite positions in a single disk and positioned to minimise the inclusion of tension wood or other defects. Each wedge sample was further sectioned into two pieces representing the sapwood and heartwood zones. Basic density was assessed using the water displacement method described in *AS/NZS 1080.3:2000* (Standards Australia, 2000). Average basic density for the whole disk was estimated by dividing the combined oven-dry weights by the combined green volume of sapwood and heartwood sections.

2.4.2. Heartwood proportion and sapwood width

The proportion of heartwood and the sapwood width within a log can have implications for utilisation and processing, particularly where durability and appearance properties are required, this is more so with *Lyctus*-susceptible species (CCV). A smaller sapwood band is generally desirable as it means less timber is wasted if the sapwood has to be removed, and less chemical preservative is required if the sapwood is to be treated.

Heartwood proportion and sapwood width were measured from the disks (the same disk used for basic density measurement). The disks were sprayed with a methyl orange solution (pH indicator) to stain and demarcate the heartwood zone. The sapwood and heartwood dimensions were measured in a radial direction at four points across each disk. Sapwood was recorded as a measure of the average width in the radial direction while heartwood proportion was calculated as a percentage of disk basal area under bark.

2.4.3. Shrinkage and 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 wood samples were prepared to 25 × 25 × 25 mm (radial × tangential × longitudinal; R × T × L) dimensions (samples extracted from outer heartwood). Specimens were weighed and their dimensions measured at regular intervals during drying in forced airflow oven, until approximately 12% moisture content had been reached. Samples were then reconditioned and re-dried with measurements taken at 12% and 5% moisture content before the samples were oven-dried to a constant dry weight. The measured unit shrinkage is presented as the percentage change in dimension with each one percent change in moisture content.

Shrinkage properties were assessed only on CCV samples from the 22-year-old Tinana site.

2.5. Processing

Sawing was done at the Parkside Timber sawmill in Wandoan. The Wandoan mill has been upgraded to specifically optimise recovery from smaller hardwood logs using a Schurman secondary breakdown line with optimisation scanners (Image 10). This enables the flitch shape to be recorded and uses these scans to optimise the log breakdown for both volume recovery and product value.

Image 10: Sawing plantation logs. Producing a cant using the twin circular saw (left) and optimising side flitches using the optimisation scanner (right).

2.5.1. Stage I sawing trial

The logs from the Stage I pilot study were sawn in June 2011.

The pilot study focussed on recovering a broad selection of products from each of the species and age classes (Table 2). This provided guidelines for targeting particular products in the main study. A centre pallet grade board 100 × 100 mm was targeted primarily from the young 13-year-old CCV, which boxed out most of the defect core and pith.

Table 2. Number of logs from each species by age target products from timber – Stage I trial

Size	CCV – 13 yrs	CCV – 22 yrs	GMS – 22 yrs	GMS – 30 yrs
75 × 25	13	4	2	20
75 × 38	0	0	0	1
100 × 25	87	30	28	111
100 × 38	29	4	10	17
100 × 50	23	7	7	17
100 × 100	41	0	0	9
150 × 25	12	14	4	59
150 × 38	0	5	0	13
150 × 50	2	6	0	31
150 × 150	0	1	0	1
No. of logs	**49**	**9**	**8**	**39**

The primary log break-down was done using a twin circular saw removing side flitches and producing a cant of width of 75, 100 or 150 mm (depending on the small-end diameter of the log). The side flitches were processed through the optimiser. The cant was further broken down over a Gibson one man re-saw bench. In order to maximise the recovery of shorter products, the thicker flitch wane boards (which could be cut further into shorter board lengths) were also sent to be re-sawn (due to taper, a half-length of the board could be recovered).

The Parkside crew were instructed to process the logs as they usually process native suppressed resource, where distortion is not an issue. As a consequence, during sawing the cant was not rotated when producing the single boards. This often resulted in excessive bowing in the sawn slab and the remaining cant especially for longer timber (Image 11). As a result, on some occasions, the sawn slab was thicker in the middle of its length than at the ends. Therefore, before cutting the first dimensioned slab, a face cut (sometimes referred to as a straightening cut) was necessary to ensure an accurately dimensioned slab could be produced. This resulted in a possible loss of recovery and productivity.

Image 11: Processing thicker flitch wane and cant (left) through the Gibson re-saw bench (right). Note the timber bowing distortion in the cant, which was not rotated during sawing.

At the sawmill no docking for defects (knots, vein, pith occurrence, etc) was done; however, all sawn products were marked for docking by Parkside graders. No docking also meant that the board identities (from log end templates) were preserved and all recoveries could be collated back to individual logs and trees.

After processing all sawn products were treated with ammonium copper quaternary (ACQ) and dispatched to Salisbury Research Facility for seasoning, grading and visual assessment.

2.5.1.1. Timber from the native forest resource (Parkside run of the mill)

In addition to the plantation timber, Parkside also provided some packs of their usual product (150 boards with volume of 2.1 m^3) representing slow grown and suppressed native CCV forest (the logs had very similar size and straightness compared to processed plantation logs). The majority of the boards were 25 mm in green thickness with widths of 100 and 150 mm. Timber was shipped to SRC and processed together with plantation timber so that the performance and quality of the plantation study material could be compared to standard native forest material processed in Parkside sawmill.

2.5.2. Stage II sawing trial

Logs from the Stage II trial were sawn in April 2012.

After the preliminary results from the pilot study were assessed it was decided to reduce the range of finished product to flooring dimensioned boards with an emphasis on 25 mm green thick boards (25 mm × 75 mm, 25 mm × 100 mm and 25 mm × 150 mm). The aim was to maximise the recovery of boards 150 mm in width. Some boards with the dimensions 38 mm × 100 mm were also produced.

Sawing was done on individual log batches as described in Section 2.3.1.2. The primary log break-down was through a twin circular saw removing the side flitches and producing a cant of width of 75, 100 or 150 mm. The side flitches were processed through an optimiser. The cant was returned back to the twin edger to box it and to allow it to be further processed using a Gibson one-man bench. In contrast to the pilot study, the cant was rotated when sawn into individual slabs to minimise the board distortion for bowing and uneven thickness. The cant was turned at the point at which the sawmill operator decided that stress release would begin to start to impact on the recovery.

After docking excessive wane/want and severe splitting, the ends of the remaining slabs were repainted with a code colour relevant to each group. Other natural characteristics such as heart, vein, knots, and pith occurrence were not excluded at this point so as to allow a more accurate defect summary to be compiled using the dried and dressed graded recovery data.

The boards were stacked and measured for length, width and thickness to calculate green-off-saw (GOS) volumes (Image 12). Measurements recorded were for nominal sizes, in line with standard industry practice. GOS recoveries were calculated by dividing GOS volume (m^3) of green sawn boards by the original merchandised log volume (m^3), and expressed as a percentage.

The stacked boards were treated with ammonium copper quaternary (ACQ). They were then dispatched to the Parkside sawmill and the drying facilities at Wondai.

Unfortunately the WWG logs were not colour coded and during the handling and transporting the green sawn timber from Wandoan to Wondai processing facilities, the WWG boards from the five trees got mixed with the Parkside production. As a consequence no results are available for dried dressed recovery for WWG.

Image 12: Green sawn board products of separated batches – Stage II trial.

2.6. Seasoning

2.6.1. Stage I sawing trial

Drying was carried out at the Salisbury Research Facility. Sawn products were strip-stacked for drying. Boxed-end stacks were weighted with concrete blocks. Seasoning comprised of initial air drying (to below fibre saturation point 25%) and finishing off to an equilibrium moisture content of 12% in a solar kiln for another 3–4 months for material of 25, 38 and 50 mm in thickness (a longer period was needed for 50 mm thick boards). During the drying period moisture content was checked regularly on representative samples. Final moisture content (MC) ranged from 10 to 15% for the majority of 25 mm boards. Some 38 mm and 50 mm boards exceeded 20% in MC.

Overall the timber dried well, with limited degrades occurring during the process. There was some collapse; however, in most cases this was removed during dressing such that it had little impact on grade recovery.

2.6.2. Stage II sawing trial

All boards were racked and air-dried to below fibre saturation point at Parkside Wondai dry mill over an extensive period of nine months (May 2012–January 2013). The boards were further kiln dried to final MC of 12% in normal conditions used at Wondai sawmill (details not provided).

2.7. Dry milling

All boards of 25 and 38 mm thickness were dressed to the final thickness of 19 mm or 35 mm respectively. No dressing was done for sawn products of 50 mm and 100 mm thickness from the initial Stage I trial.

2.8. Visual grading – appearance purposes

Grading by visual means is simply a sorting process based on the size and number of features present in the boards. Boards with fewer and smaller features were sorted into one grade while those with more frequent and larger features would be sorted into another grade. Each grade had specific criteria and was given a name either as described in the Australian Standard AS 2796—Timber—Hardwood—Sawn and milled products, or a manufacturer grade name where different grading rules had been developed by that manufacturer grading flooring material.

Select grade – a floor where the feature present or natural discolouration will not dominate the appearance of the floor. Features that are permitted still include short narrow gum veins, a limited number and size of past borer activity and small knots.

Medium-feature grade – a floor that may have significantly more character than the Select grade floor. This grade contains an increased amount of gum vein, past borer activity, knots and natural discolouration.

High-feature grade – a floor that contains boards with similar features to medium feature grade but where the length of features such as gum veins may be longer and past borer activity may be more frequent.

Grading was carried out at the Salisbury Research Facility by DAFF Forestry Science staff. Grade quality was assessed against the standard's grade quality criteria to determine whether each target board satisfied the criteria: select grade, medium feature or high feature grade. Once the full length of boards was assessed they were docked to evaluate whether the original grade could be improved by reducing the board length to remove grade limiting defects or imperfections. The timber was graded assuming one concealed face in application (i.e. flooring). A minimum length of 600 mm was adopted during the grading process. Low value products such as pallets or structural grade products were not considered in the evaluation.

Defects present on the graded faces and edges were recorded for each board (Image 13). The defects included knots, surface checking, under sizing, kino pockets, insect damage, and decay.

Conformance with the distortion limitations (twist, spring and bow) was undertaken assuming a product category of strip flooring. Distortion limits are different for the three product categories.

Image 13: Visually grading timber.

Dried and dressed recovery, expressed as a percentage, was calculated by dividing the graded volume (m^3) of sawn boards (in nominal dimensions) by the merchandised log volume.

2.8.1. Grade recoveries assessed by CombiScan+

Before being sent to Salisbury for visual grading the 19 mm thick boards (after dressing) from Stage II were run through a fully automated CombiScan+ 4side-scanner installed at the Parkside Wondai mill. Currently Parkside uses the scanner to optimise the recovery and grades for native spotted gum timber that contain fewer defects and less colour variation than plantation timber. The results obtained from the scanner were the percentage of utility and standard grade for each batch. As there is no calibration for defects detection exists for plantation timber the results should be only indicative and must be treated with caution.

2.9. Wood properties of full length sections

Traditionally, small clear strength testing has been used to establish a species strength group. With the changing nature of the log resource from mature native forest to plantation resource, there is a need to better understand the timber properties and to more accurately define the potential for different products from the plantation grown product.

During visual grading a small number of representative boards characterising each site and batch were randomly identified and collected. The boards were targeted from the outer heartwood section of the butt log. The board selected was ‘in-grade’ (according to visual grading rules) where possible; otherwise the best quality board was selected. The samples were processed from the boards centred relative to the apex of growth rings, ensuring close to radial and tangential faces on material used for testing.

The boards were used to determine dynamic acoustic modulus of elasticity (MOE$_{dyn,}$ using the vibration technique), static modulus of elasticity (MOE), modulus of rupture (MOR) and hardness. Table 3 provides the number of boards selected for individual tests. In addition, boards from Parkside run of the mill were also included in testing to compare the properties of plantation resource at known age to the traditional material processed by Parkside.

The samples were equilibrated to 12% moisture content in controlled environment rooms, and laboratory conditions during measurement were approximately 20±3° C, with a relative humidity of 64±2%.

Table 3. Number of full section samples tested for vibration analysis and mechanical properties

Phase	Species	Age (yrs)	Batch (SED size in cm)	No. of samples for MOE$_{dyn}$	No. of samples for MOE	No. of samples for MOR	No. of samples for hardness
Stage I	CCV	13	–	25	25	9	25
	CCV	22	–	10	10	1	5
	GMS	22	–	25	25	7	25
	GMS	30	–	25	25	8	25
Stage II	CCV	10	<21	11	10	10	10
			21–25	33	10	10	10
	CCV	23	<21	10	–	–	–
			21–25	40	15	15	15
			25>	18	5	5	5
	CCV	27-34	<21	20	10	10	10
			21–25	50	20	20	20
			25>	16	5	5	5
Parkside timber	CCV	–	–	20	20	8	20

2.9.1. Vibration analysis using the resonance method

Vibration analysis is a simple and efficient way of characterising the elastic properties of timber. Natural vibration analysis is used to characterise the longitudinal and the shear modulus of elasticity of various geometrical types of beams. The BING method requires measurements of the resonance frequencies in different modes (longitudinal, flexure or torsional) of simple structures for which the geometry and boundary conditions are known (Brancheriau and Bailleres, 2002).

In this study, the longitudinal method was applied on a representative set of 1.8 m sections docked from the full board samples of thickness 18 and 29 mm. Samples were positioned on two elastic supports to generate free vibrations. An exciting impulse was made by lightly striking the specimen with the hammer at the opposite side of the acoustic microphone (Image 14). The signal was analysed by a Fast Fourier Transform processes in order to convert the information from the time domain to the frequency domain. The dynamic modulus of elasticity along the longitudinal direction was calculated using the following equation:

$$E = 4L^2\rho\frac{f_n^{\,2}}{n^2}$$

where: E is the longitudinal dynamic longitudinal MOE; L is the length; ρ is air-dry wood density (calculated using dimensions and mass); f_n is the natural frequency (rank n); n is the frequency rank

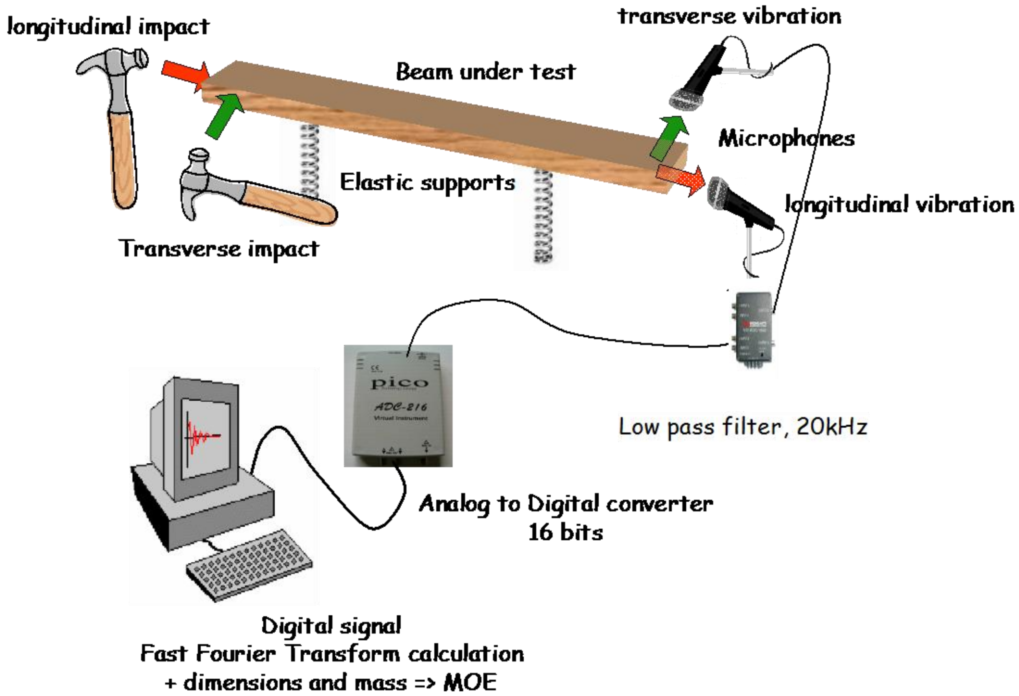

Image 14: Test setup for the vibration testing using BING device (adapted from Bailleres *et al.* 2008).

2.9.2. Air-dried density

The air-dry densities (mass at 12% MC/volume) were established on samples used for acoustic testing.

2.9.3. Full section static stiffness and strength testing

Board samples previously used for natural vibration analysis were used to measure static MOE and MOR. Testing was conducted on pieces of cross-section size of 90 × 35 mm, according to Australian and New Zealand Standard AS/NZS4063:1992 Timber—Stress graded—in grade strength and stiffness evaluation (Standard Australia 1992).

2.9.4. Hardness

Traditionally hardness has been used to determine timber suitability for applications typically subjected to indentation pressure, such as flooring. Hardness is also a measure of the capacity to resist abrasion (i.e. wearing). Hardness is closely related to wood density.

A subsample of the full section previously tested for MOE was used to test hardness. The Australian Standard requires samples of 50 × 50 mm for testing, a size that was not possible due to the original green sawing thickness of 25 and 38 mm. Therefore testing was conducted on a thinner sample of thickness 38 mm (Image 15). During testing no splitting problems were observed.

A universal testing machine was used for surface hardness measurements. The testing involved measuring the force required (kN) to indent a half ball-bearing of standard dimensions into the samples tangential surface. Mean values of three measurements were obtained and averaged.

Image 15: Hardness testing on a board sample (force measured at three points per sample on the tangential surface).

3. Results and discussion

3.1. Plantation resource composition[1]

Nichols *et al*. (2008) surveyed plantation growers of subtropical eucalypt plantations in Australia and documented a total plantation estate of nearly 116 000 ha with just over 82% of this planted from 1994 (Table 4). Of these post-1994 plantings, just over 38% were planted by state government public sector growers and 62% by managed investment scheme companies.

Table 4. Area of eucalypt plantations in sub-tropical Australia by species and ownership. Government refers mainly to Forest Corporation of NSW (formerly Forests New South Wales) and Hancock Queensland Plantations (formerly Forestry Plantations Queensland), MIS (Managed Investment Schemes) refers mainly to Forest Enterprises Australia, Integrated Tree Cropping and Great Southern Plantations (reproduced from Nichols *et al*. 2008).

Species *	Area (ha) planted			
	Pre 1994	Post 1994		Total
	Government	Government	MIS	
Corymbia species	–	14 753	7 221	21 973
Eucalyptus argophloia	–	1 278	–	1 278
Eucalyptus cloeziana	–	2 850	–	2 850
Eucalyptus dunnii	–	8 899	23 178	32 076
Eucalyptus grandis	4 500	2 660	2 735	9 895
E. grandis × *E. camaldulensis*	–	–	23 701	23 701
Eucalyptus pilularis	11 438	5 071	1 525	18 033
Eucalyptus species (unidentified or mixed)	2 584	1 048	635	4 268
Unknown species	1 818	–	–	1 818
Total	**20 340**	**36 559**	**58 995**	**115 893**

* Where species data were unavailable for newer plantations, species were assumed to be the same as the previous estate.

Much of the MIS estate summarised by Nichols *et al*. (2008) was established for and subsequently managed for pulpwood. This is particularly the case for the *E. grandis* × *E. camaldulensis* hybrids and much of the *E. dunnii* resource. However, where flexibility in contractual obligations is available, most forest growers are likely to divert the better quality stems in their plantings to saw log processing if this has potential to improve financial returns to their organisation and/or to investors. Therefore, a small proportion of what are generically labelled as pulpwood plantings may be diverted for sawing or other value-added processing.

Desktop surveys and database interrogations have been conducted to identify the species composition of significant plantings in northern New South Wales and southern Queensland. Summaries of species and areas of plantation are presented below: Hancock Queensland Plantation – HQP (formerly Forestry Plantations Queensland), (Table 5 and Figure 1), Forestry Corporation of NSW (formerly Forests NSW), (Table 6 and Figure 2) and former Forest Enterprises of Australia Limited – FEA (Table 4 and Figure 3).

[1] The subchapter 3.1 is sourced from Milestone Report 3 which was prepared and submitted in March 2010. Due to the combined effects of recent changes in forest ownership and land use (collapse of MIS companies), losses from pests and diseases and catastrophic cyclone damage in North Queensland in February 2011 the areas of productive plantations cover less than the original planted areas listed in pre-2011 reports.

3.1.1. Hancock Queensland Plantations

The species composition of HQP plantings from 1995 to 2000 and post-2000 are provided in Table 5 and displayed as pie-charts in Figure 1. Plantation establishment in 2007–08 (FPQ Annual Report 2007–08) was 1 503 ha of which 190 ha were *Corymbia* hybrids and 40 ha were genetically improved western white gum. In 2008–09 a further 1 664 ha was established (FPQ Annual Report 2008–09). The species composition is not provided in the annual reports but indications are that most of these plantings were spotted gum and *E. argophloia* with a small area of *Corymbia* hybrids.

Table 5. Summary of the area of sub-tropical hardwood species planted by Hancock Queensland Plantation between 1995 and 2007.

Species	Year planted	Total area (ha)	Species total (ha)
Corymbia species	1995–2000	446	
	2001–2007	5 039	5485
Corymbia hybrids	2001–2007	278	278
E. cloeziana	1995–2000	781	
	2001–2007	834	1615
E. dunnii	1995–2000	86	
	2001–2007	418	504
E. pilularis	1995–2000	179	
	2001–2007	61	240
Other *Eucalyptus* species	1995–2000	155	
	2001–2007	732	887
Total			**9009**

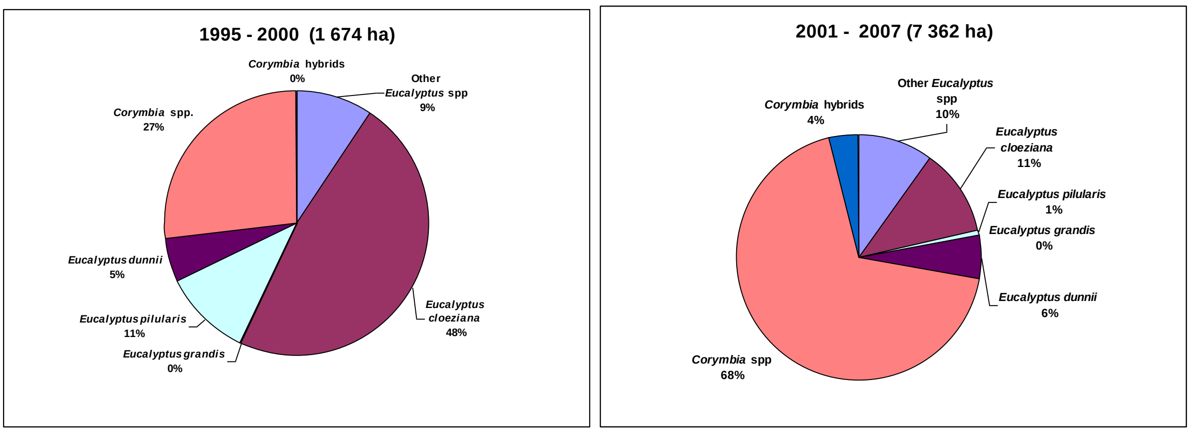

Figure 1. Species composition of HQP subtropical hardwood plantings from 1995–2000 (left) and 2001–2007 (right).

3.1.2. Forestry Corporation of New South Wales plantation

A summary of the Forestry Corporation of New South Wales hardwood plantings up to and post-2000 are provided in Table 6 and displayed in Figure 2.

Table 6. Summary of sub-tropical hardwood species planted in the periods 1994–2000 and 2001–2008 by Forestry Corporation of NSW.

Species	Year planted	Total area (ha)	Species total (ha)
Corymbia species	1994–2000	5 313	
	2001–2008	3 020	8333
E. cloeziana	1994–2000	668	
	2001–2008	605	1273
E. dunnii	1994–2000	5 555	
	2001–2008	2 872	8427
E. grandis	1994–2000	2 340	
	2001–2008	960	3300
E. nitens	1994–2000	333	
	2001–2008	2	335
E. pilularis	1994–2000	4 530	
	2001–2008	2 370	6900
E. saligna	1994–2000	162	162
Other *Eucalyptus* species	1994–2000	180	
	2001–2008	275	445
Total			**29 185**

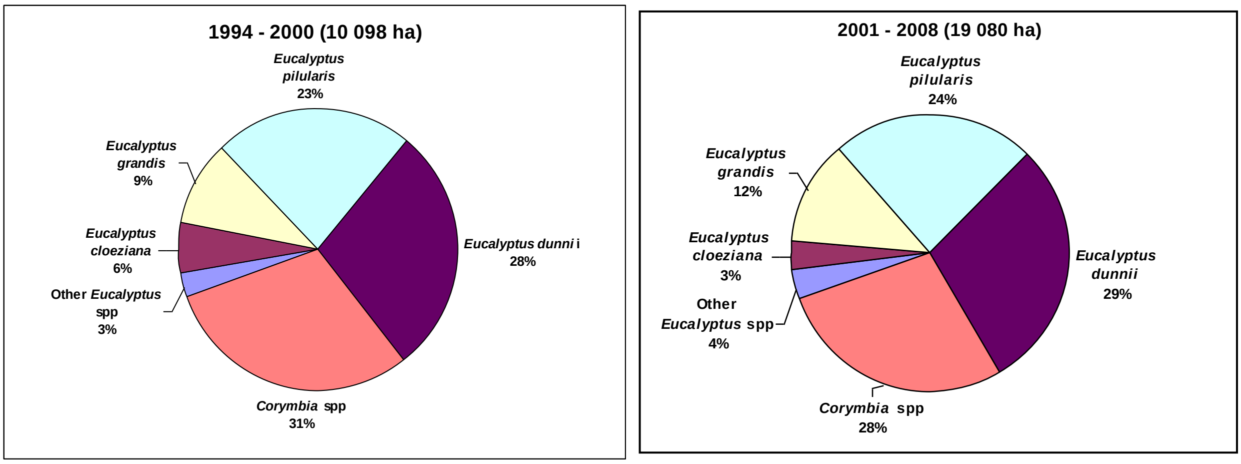

Figure 2. Species composition of Forestry Corporation of New South Wales subtropical hardwood plantings from 1994–2000 (left) and 2001–2008 (right).

3.1.3. Forest Enterprises Australia Pty Ltd

A summary of the Forest Enterprises Australia hardwood plantings up to and post-2000 are provided in Table 7 and displayed in Figure 3.

Table 7. Summary of subtropical hardwood species planted in period 2001–2008 by FEA Limited in northern New South Wales and southern Queensland.

Species	New South Wales	Queensland	Total
C. citriodora subsp. *variegata*	4 965	899	5 864
E. agglomerata	38	0	38
E. cloeziana	259	44	303
E. dunnii	14 013	4 730	18 743
E. grandis	993	0	993
E. macarturii	37	0	37
E. nitens	8 100	0	8 100
E. pilularis	1 762	44	1 806
E. saligna	13 063	56	13 119
Mixed *Eucalyptus* species	897	0	897
Total	**44217**	**5773**	**49 990**

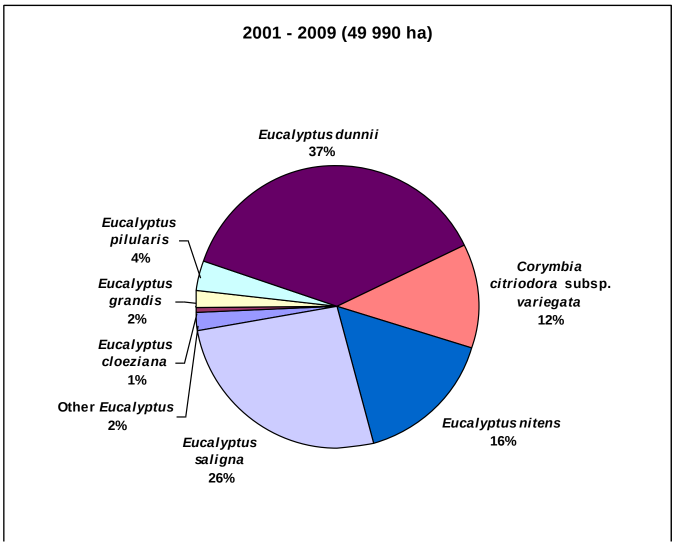

Figure 3. Species composition of FEA Limited's subtropical hardwood plantings from 2001–2008.

3.1.4. Overall plantation hardwood resource composition

The data from the above three growers were compiled to determine the main species and/or taxa represented in the southern Queensland and northern New South Wales subtropical hardwood estate (Table 8). It is clear that the most widely planted species in the 1994–2000 plantings are *C. citriodora* subsp. *variegata* (28.0%), *Eucalyptus dunnii* (27.5%), *E. pilularis* (23.0%), *E. grandis* (11.3%) and *E. cloeziana* (7.1%). These species will dominate the potential supply of plantation hardwoods to any sawmill processing facility in this region should one be commissioned within the next five to ten years.

The species composition change from the period up until 2000 to post-2000 reflects the experience gained by both grower and processor over the time period. In recent years, a number of sawing trials have been undertaken by the former FEA Ltd with various partners as well as by DAFF, and these are incrementally building experience with young plantation log processing. Additionally, tree improvement programs have responded to the challenges posed by species, land availability and insect and disease attacks. Early plantings of CCV suffered very significant damage from *Quambalaria piterika* shoot blight and significant work has been undertaken to identify tolerant select trees for breeding and improvement. Concurrently, favourable combinations of traits, including improved *Quambalaria* tolerance and frost tolerance, were identified in spotted gum hybrids and work is underway to improve propagation performance of these hybrids to increase the availability of improved planting stock. GMS has produced very encouraging sawing study results but fell out of favour due to a popular view that the availability of affordable planting areas suited to its requirements was very restricted. This opinion is currently being reviewed as awareness of lower rainfall provenances of GMS has been raised along with continuing good sawing results.

Table 8. Species composition of plantation hardwood resources in southern Queensland and northern New South Wales for the Forestry Corporation of NSW (1994–2008), Hancock Queensland Plantations (1995–2007) and Forest Enterprises Australia Limited (2001–2009) combined.

Species/taxon	Area (ha) 1994–2000	Area (ha) post 2000*
C. citriodora subsp. *variegata*	5 755	13 920
Corymbia hybrids	0	153
E. argophloia	144	2 553†
E. cloeziana	1 449	1 741
E. dunnii	5 639	22 033
E. grandis	2 324	1 950
E. longirostrata	0.3	80
E. nitens	332	8 102
E. pilularis	4 711	4 238
E. saligna	161	13 246‡
Total	**20 515**	**66 016**

* The areas of productive plantations cited above 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.

†The 2 000 ha were planted recently with the primary objective of carbon sequestration. This project was commissioned by the oil and gas company, Santos.

‡A recent update to areas of planting, provided by Forest Enterprises Australia (May 2012), suggests that the area of *E. saligna* is a little under 7 000 ha, due to failures in some of the plantings.

3.2. Plantation resources selected for the project

Table 9 summarises the plantation species harvested for processing, their location, the tree age at time of harvesting, the number of trees harvested for each site, the average diameter at breast height over bark (DBHOB), average standing tree acoustic wave velocity (AWV) and the total volume of sawlogs processed.

For Stage I, 45 trees of two species were selected with a total sawlog volume of 19.5 m^3. For Stage II, 98 trees were harvested with a sawlog volume of 41.5 m^3. Despite the differences in age for CCV, the harvested trees had similar average DBH and consequently, they also had similar sawn log diameters. The smallest trees were obtained from Atkinson Dam (CCV) and from the Morgan Park site (WWG).

Average site tree Fakopp acoustic wave velocity (AWV) ranged from 4.2 km s^{-1} to 4.7 km s^{-1}. The results clearly indicated that 22-year-old CCV trees from the Tinana site had significantly higher AWV than two other CCV sites (10-year-old Berry and 30-year-old Thinoomba site) and the WWG trees from Morgan Park. It would be expected that timber from Tinana will provide better stiffness than other sites. There was no trend of increasing AWV with tree age.

Table 9. Summary of harvested trees and their characteristics

Stage	Species	Location	Age (yrs)	No. of trees harvested	Average DBHOB (cm)	Tree AWV (km s^{-1})	Volume of sawlogs (m^3)
Stage I	CCV	Atkinson Dam	13	26	27.1	4.38	7.7
	CCV	Tinana	22	5	31.3	4.64	1.9
	GMS	Tinana	22	4	30.8	4.58	1.6
	GMS	Hakea	30	10	37.0	4.49	8.3
Stage II	CCV	Berry	10	30	28.2	4.34	7.2
	CCV	Tinana	23	13	29.4	4.71	7.3
	CCV	Thinoomba	30	54	30.7	4.31	25.0
	WWG	Morgan Park	20	5	26.0	4.20	1.5
Total			**–**	**147**	**–**	**–**	**61**

3.3. Disk wood properties

3.3.1. Basic density

Figure 4 illustrates the distribution of average whole-disk basic density measures for the three species. The basic density of WWG (775 kg m^{-3}) is significantly higher than basic density of CCV and GMS. The average basic density of GMS is 748 kg m^{-3}, which is 50 kg m^{-3} less than reported for wood from mature, naturally-grown trees (Bootle 2004). CCV had a mean basic density of 715 kg m^{-3} compared to approximately 800 kg m^{-3} for trees derived from native forest. Leggate *et al.* (2000) reported basic density of 800 kg m^{-3} for 41-year-old plantation CCV. For processes such as gluing and jointing, it could be more advantageous to use material with a lower density.

Young CCV trees (10 and 13 years old) exhibited lower values of basic density, due to a high proportion of sapwood in these samples. Generally, sapwood is less dense because it contains fewer extractives. This is confirmed in Figure 5, which shows differences in basic density between heartwood and sapwood. The noticeable difference is obvious for GMS and WWG, and less obvious for CCV at a younger age. It is interesting that in the 10-year-old

CCV the density for sapwood was higher than that for heartwood (Figure 6). This material had a very low heartwood proportion, indicating that extractives were still being deposited in the heartwood at that age.

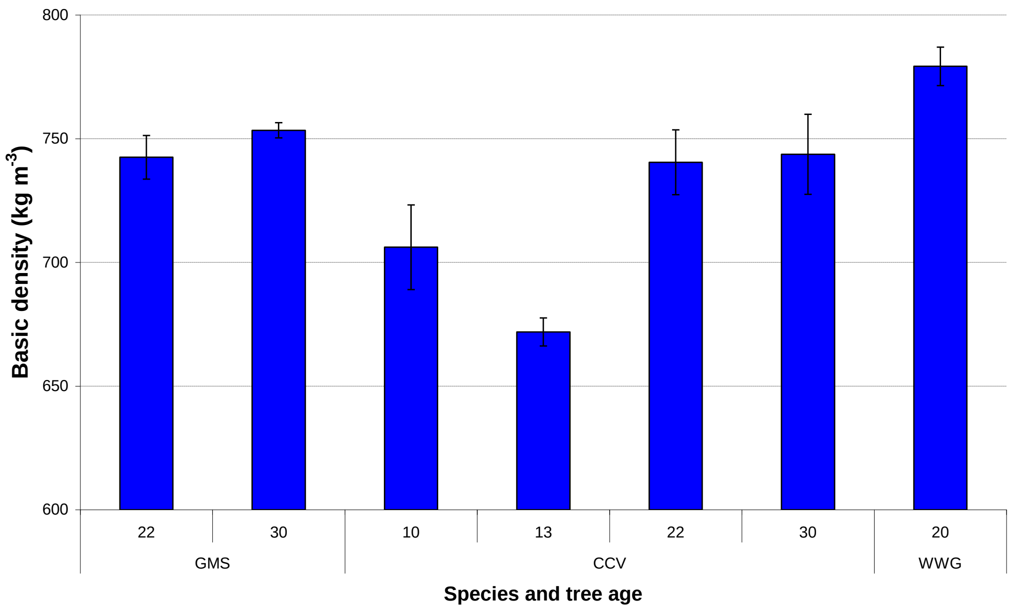

Figure 4. **Distribution of average whole-disc basic density across three species of different ages (standard errors – SE bars included).**

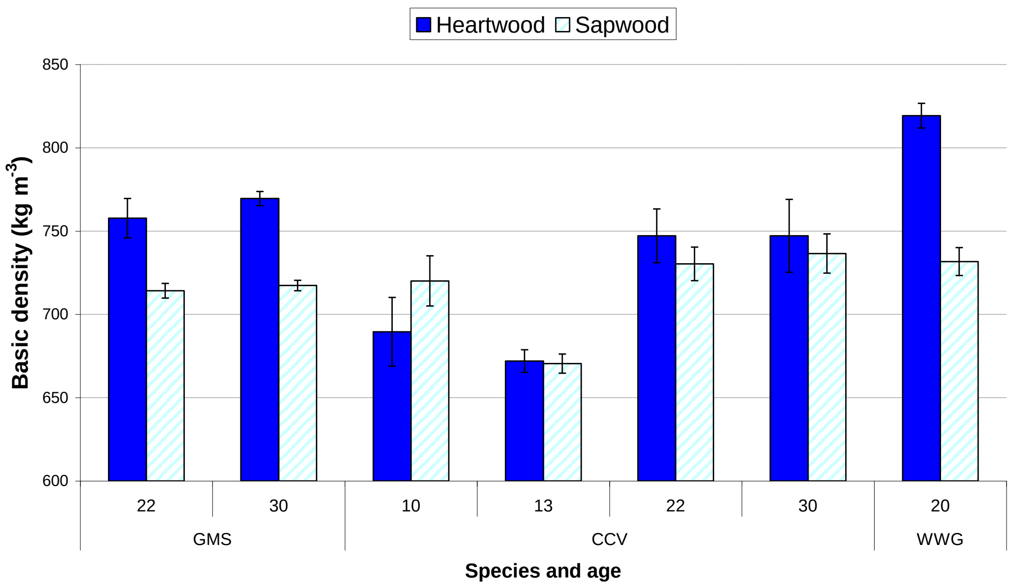

Figure 5. **Basic density of heartwood and sapwood for three species across different ages.**

3.3.2. Heartwood /sapwood proportions

The distribution of heartwood proportion and sapwood width across the three species and sites is presented in Figures 6 and 7. A heartwood/sapwood proportional split of approximately 80:20 to 90:10 is common for mature eucalypts.

In this study plantation CCV had a low heartwood proportion of 25–46% with a sapwood width about 40 mm. This supports a previous study with young plantation CCV by McGavin *et al*. (2013) who reported heartwood proportion of 22 to 28%. The sapwood of this species is susceptible to *Lyctus* attack; therefore it will require preservative treatment for use in both weather-protected and weather-exposed applications. The large volume of sapwood also increases the cost of treatment as more preservative chemical is required.

Similarly, WWG is also *Lyctus* susceptible so a small sapwood band would be desirable. The results showed a 45% heartwood percentage and 22 mm sapwood width for this species. This is comparable to the range in heartwood proportion (25–60%) for 13-year-old WWG observed by Trueman *et al*. (2011)

Gympie messmate displayed the highest heartwood proportion (almost 70%) and lowest sapwood). This species also has an advantage over many hardwood species with the sapwood not being *Lyctus* susceptible therefore requiring no sapwood treatment for weather protected products. McGavin *et al.* (2006 and 2007) measured a heartwood proportion of 50% and 44% from two different eight-year-old GMS plantations. In another study, McGavin *et al*. (2013) published heartwood percentage of 70% for 13-year-old GMS, which is comparable with results found in this study.

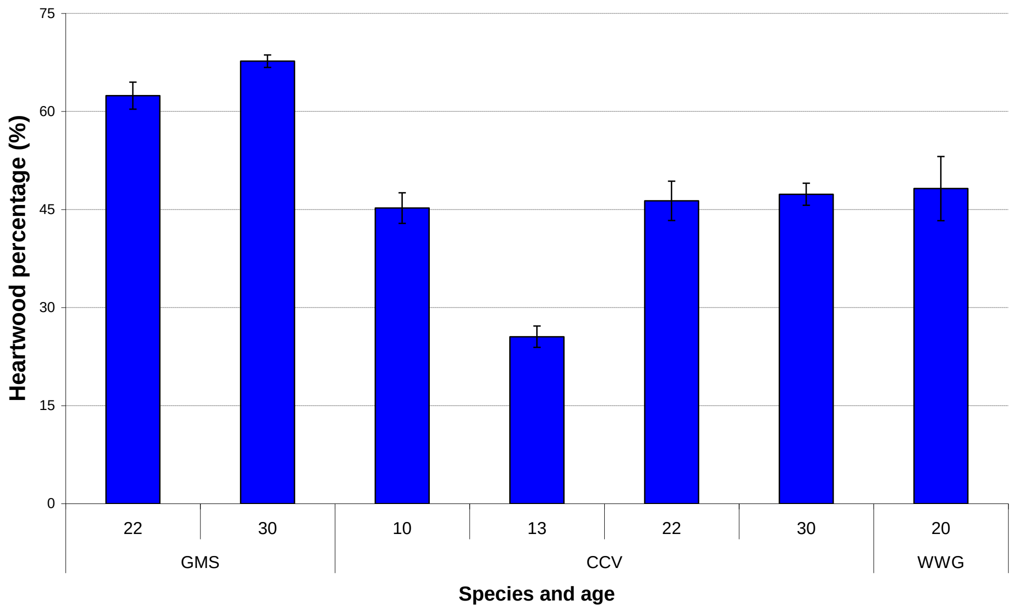

Figure 6. Heartwood proportion for three studies species across different ages.

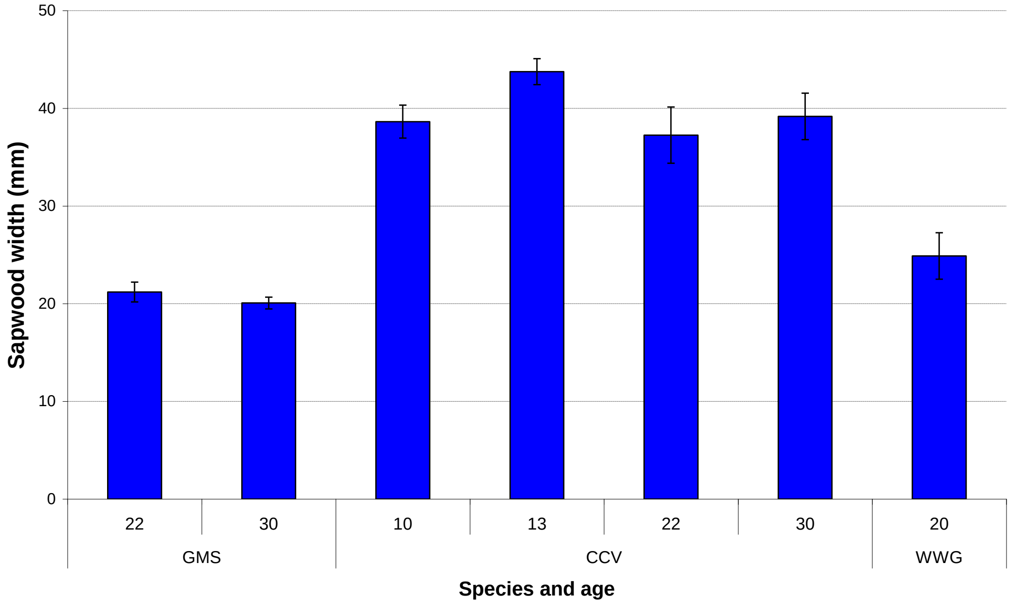

Figure 7. **Sapwood width for three species across different ages.**

3.3.3. Shrinkage and unit shrinkage

The shrinkage results for CCV from Tinana site are presented in Table 10. The overall shrinkage from green to 12% of moisture content was 3.1% for radial and 5.6% for tangential direction. The average unit shrinkage values measured were 0.27 radial and 0.37 tangential for 20-year-old CCV. Atyeo (2010) gave unit shrinkage in 40-year-old CCV as 0.34 (radial direction) and 0.36 (tangential direction). Leggate *et al.* (2000) published similar results for unit shrinkage in 41-year-old plantation CCV, citing 0.34 (radial) and 0.43 (tangential). Published results for mature, natural-grown timber are 0.32 and 0.38 for radial and tangential unit shrinkage respectively (Bootle 2004).

A high ratio between tangential and radial unit shrinkage may suggest a high incidence of board distortion (particularly cupping) during drying. In this study CCV samples indicated moderate ratio between tangential and radial unit shrinkage.

Table 10. Shrinkage (%) and Unit shrinkage (% dimensional change per 1% MC change) summaries for CCV from Tinana site (22-year-old trees)

Characteristic	Shrinkage (%)
Radial shrinkage – green to 12% (%)	3.12
Tangential shrinkage – green to 12% (%)	5.58
Radial unit shrinkage – 12 to 5% (% per 1% mc)	0.27
Tangential unit shrinkage – 12 to 5% (% per 1% mc)	0.37
Tangential: radial shrinkage green to 12% ratio	1.33

3.4. Log acoustic velocity

Acoustic wave velocity (AWV) is one of a suite of non-destructive evaluation tools now available to the Australian sawn hardwood industry. Taken with wood density, AWV provides a direct indication of the dynamic MOE and the timber's stiffness. It has been shown to be a good indicator of dry wood stiffness and has been successful in segregation of softwoods for structural timber production.

Figure 8 represents the variation in log acoustics measured by a Director HM200 as an average value between species and different ages (measured on the butt log and full length log prior to merchandising). As observed, GMS has the highest values of AWV indicating stiffer timber compared to CCV and WWG. There is an increasing trend of AWV with increasing tree age for CCV suggesting that as trees grow older they also increasing their stiffness which is logical as basic density also increases.

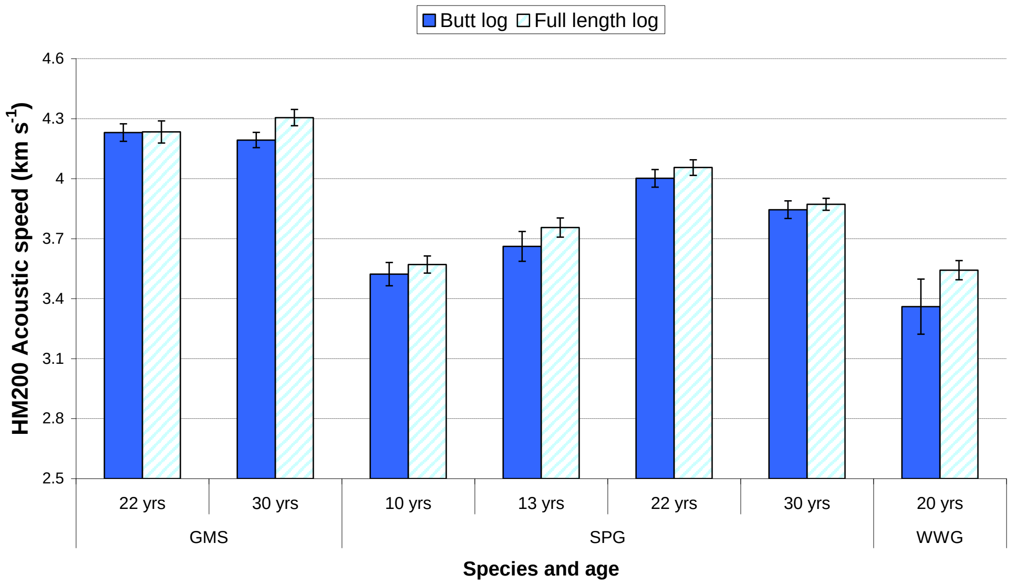

Figure 8. **Log AWV measured by the HM200 for three species across different ages (butt log and the whole log prior to merchandising).**

3.4.1. Relationship between standing tree and sawlog acoustics

The coefficient of determination (r^2) between tree and log AWV ranged from 0.44 for 30-year-old CCV to 0.61 for 22-year-old CCV (Figure 9).

Overall, acoustic values measured by the Fakopp on standing trees were higher than acoustic resonance values measured by the HM200 on the sawlog, reflecting different sampling zones assessed by these two different methods of measurement. The Fakopp measures acoustic speed between two probes driven into the outer wood of a standing tree or log. The HM200 measures sound resonance in wood. It measures the frequency of vibration in a sampled log and reflects averaged resonance patterns produced across the whole cross section of the stem.

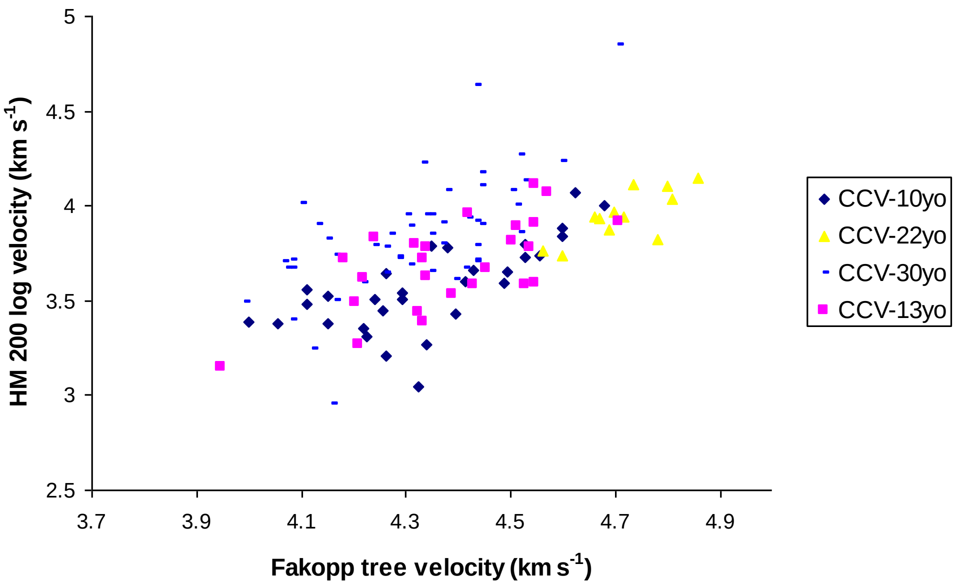

Figure 9. **Relationship between standing tree acoustic assessed by the Fakopp and log resonance assessed by the HM200 for CCV of four different ages.**

3.5. Timber properties assessed on full size board

3.5.1. Air-dry density

Air-dry density (ADD) measured on board samples for plantation CCV and GMS, and native CCV (Parkside production timber) are presented in Figure 10. ADD for CCV plantation timber ranged from 860 kg m^{-3} to 950 kg m^{-3}, being higher for older trees. Native Parkside timber had ADD of 1050 kg m^{-3}, which was on average 15–20% higher than plantation CCV.

Plantation GMS was denser than CCV, reaching ADD on average 980 kg m^{-3}.

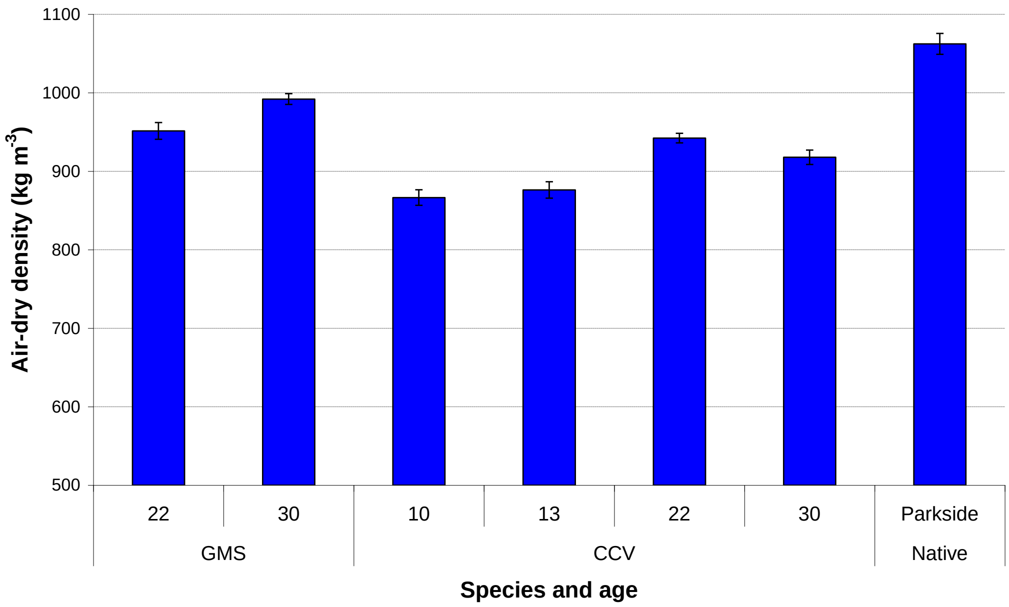

Figure 10. Air-dry density measured on representative boards of two species across different ages (Parkside native timber included).

3.5.2. Janka hardness

Hardness results for plantation CCV and GMS, and native CCV (Parkside production timber) are presented in Figure 11. The overall trend in hardness variation followed the air-dry density trend confirming that these two properties are closely related. As expected younger CCV timber had lower hardness (8 kN) than older CCV timber (9 kN). These results were on average 15–20% lower than hardness for native Parkside production timber (11 kN). Transverse hardness from wood of native forest trees is reported of 12 kN for both species (Bootle 2004).

Plantation GMS was approximately 10% harder than CCV with an average value of 10 kN. There was no difference between 22 and 30-year-old GMS samples in hardness. McGavin *et al.* (2006) reported a Janka hardness of value 6.9 kN for eight-year-old GMS. Bootle (2004) quoted hardness of 12 kN for native GMS wood.

Under the standards outlined in the Australian Hardwood and Cypress Manual (2005) flooring CCV from this study is classified as having a 'hard' hardness and the GMS is classified at lower end of 'very hard' hardness. This confirms that the plantation resource of these species is considered suitable for flooring products and other appearance grade markets.

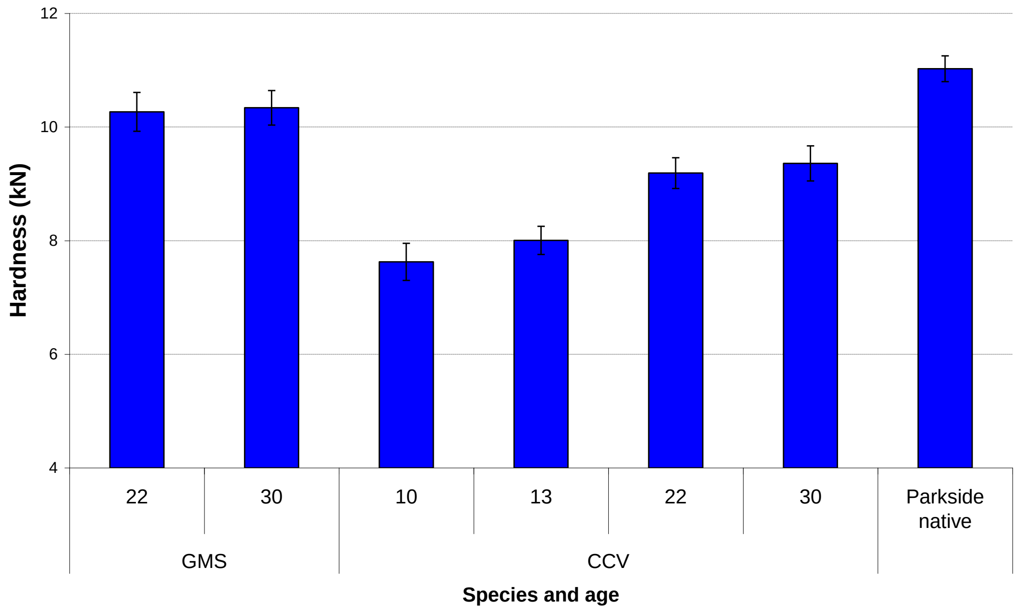

Figure 11. **Janka hardness measured on representative sample of two species across different ages (Parkside native timber included).**

3.5.3. Static MOR and MOE

Figure 12 and 13 summarise the static MOR and MOE resulting from bending tests carried out on full sections. There is an evident trend of increasing mechanical properties with tree age for both species.

Mean values of MOR for GMS were close to 100 MPa. By comparison, the average MOR value for 15-year-old GMS on full length sections as reported by McGavin *et al.* (2008) was 81 MPa. The MOR for plantation CCV ranged from 90–115 MPa, which was on average 20% less when compared to native CCV processed at Parkside (135 MPa).

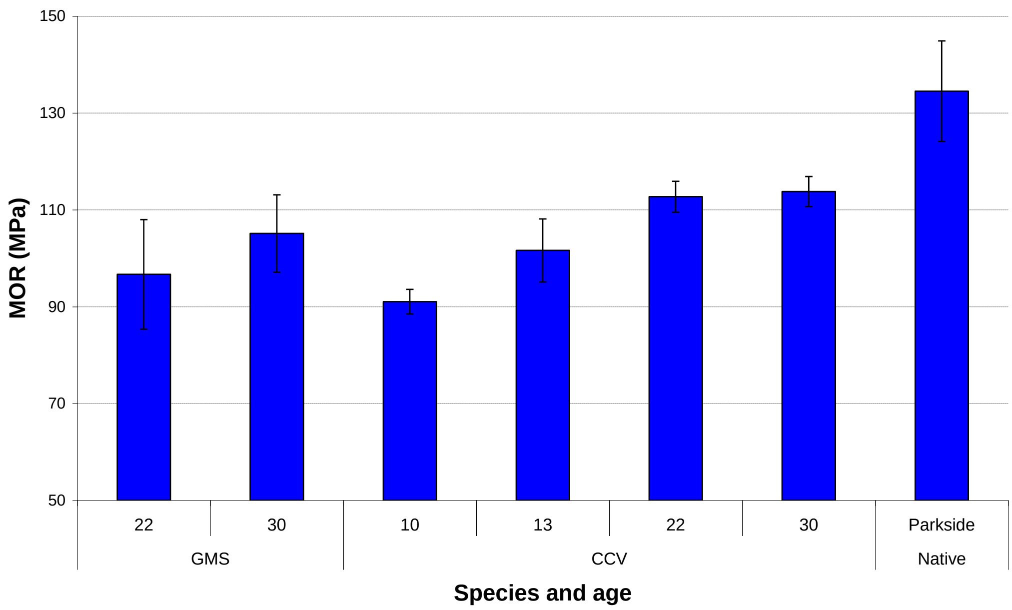

Figure 12. **Static modulus of rupture (MOR) measured on representative sample of two species across different ages (Parkside native timber included).**

As observed from Figure 13, the average MOE values for GMS were close to 19 GPa. These results are higher than data obtained by McGavin *et al.* (2008) for 15-year-old GMS from northern Queensland (15 GPa) and data given in McGavin *et al*. (2007) for eight-year-old GMS (12 GPa).

Timber from younger CCV trees showed significantly lower values of MOE (about 16 GPa) when compared to older trees (18 to 20 GPa). Average MOE for native Parkside timber was 21 GPa.

These results indicate that plantation timber at a relatively young harvest age (20 years and more) could achieve similar stiffness properties as native timber.

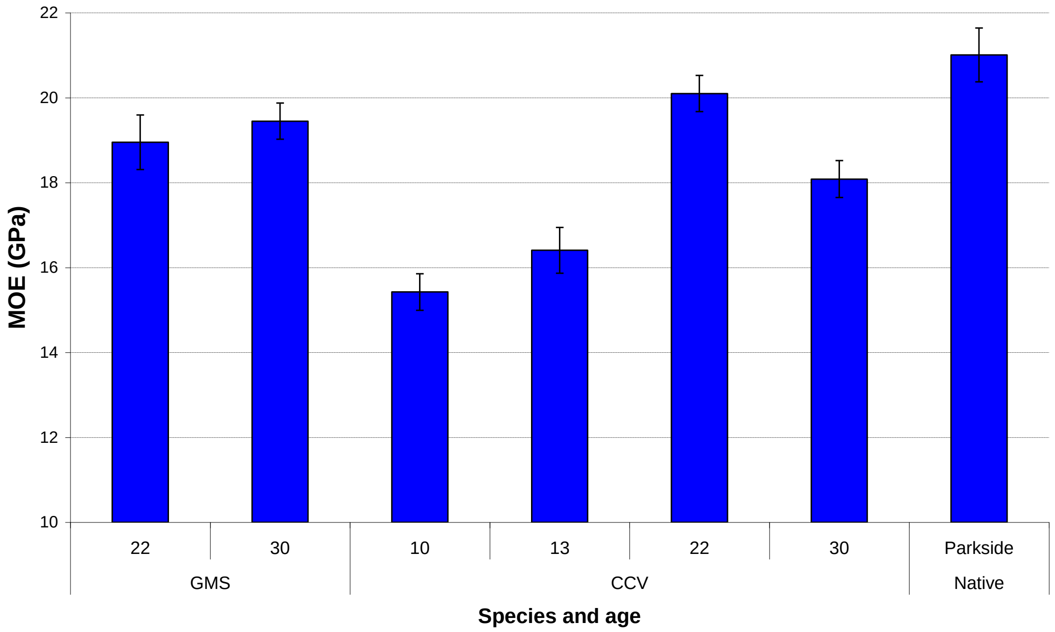

Figure 13. Static modulus of elasticity (MOE) measured on representative sample of two species across different ages (Parkside native timber included).

3.5.4. Prediction of board stiffness using non-destructive technique

It was possible to track board data at individual tree level in Stage I of study allowing correlations between tree/log acoustic velocities and static board stiffness to be established.

For CCV samples, standing tree acoustic velocity (Figure 14) and log acoustic velocity (Figure 15) were good predictors of static board stiffness (r=0.64 and r=0.63 respectively). This suggests that the Fakopp and HM200 tools can provide rapid and non-destructive assessment of acoustic velocities, which can assist with segregating trees/logs into stiffness classes. Given that AWV values were different among sites, standing tree acoustic assessment of CCV plantations could provide some indication of the resource value for the structural market. It also suggests that a ranking for standing tree AWV assessment could be consistent with a ranking based on actual timber stiffness. This would be beneficial for selection of elite trees for inclusion in solid wood products.

No relationship could be established between tree/log AWV and board stiffness for GMS. This could be because of the narrow variation observed in AWV for this species.

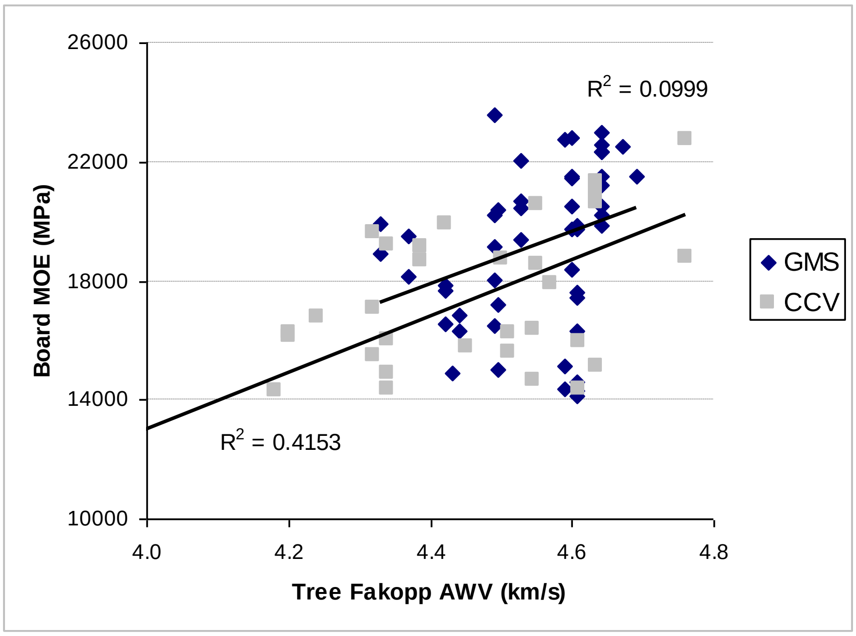

Figure 14. Relationship between tree acoustic wave velocity (AWV) assessed by Fakopp and board stiffness for CCV (N=35) and GMS samples (N=50).

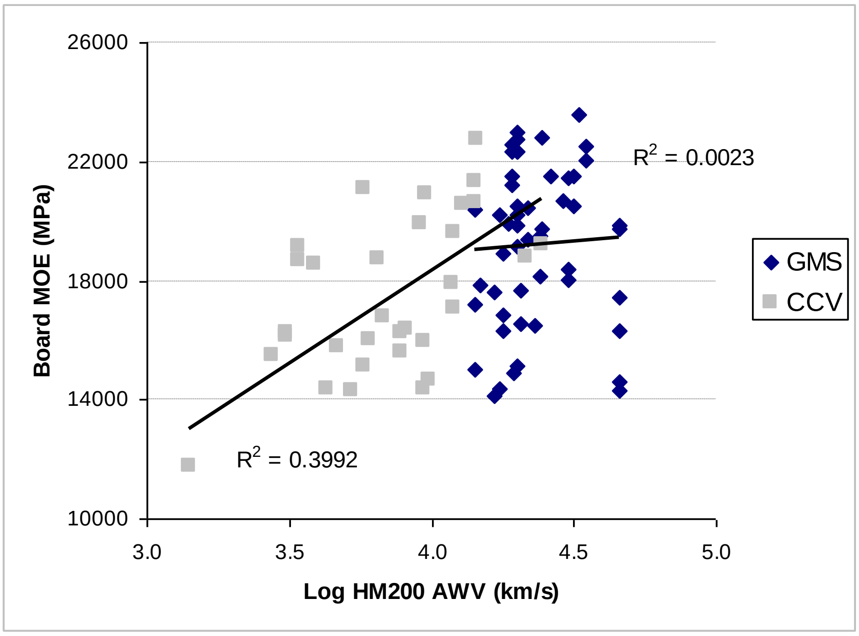

Figure 15. Relationship between log AWV assessed by HM200 and board stiffness for CCV (N=35) and GMS samples (N=50).

3.5.5. Dynamic MOE by natural vibration analysis

3.5.5.1. Prediction of static MOE using the vibration measurement technique

A very high coefficient of determination (R^2=0.92) was observed between board acoustic MOE assessed by the vibration technique and static MOE for CCV species on full length samples (Figure 16). Vibration analyses techniques provide reliable and simple means of structural grading. The strong prediction ability and rapid use of the technique allow the higher throughput of samples to be processed and analysed.

The acoustic MOE is higher than the static MOE (about 10%) due to the visco-elastic nature of wood.

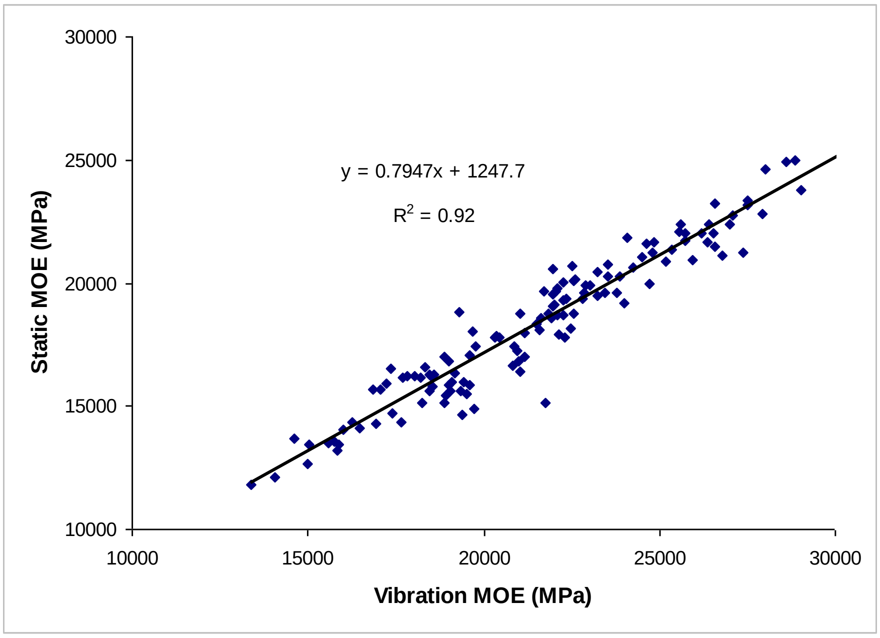

Figure 16. Correlations between acoustic MOE versus static bending MOE combining CCV plantation and Parkside native timber samples (N=128).

3.5.5.2. Variation in dynamic MOE for CCV

Figure 17 provides the variation in dynamic MOE of CCV boards from different ages and log size classes. For plantation CCV, average dynamic MOE ranged from 18 000 MPa for 10-year-old trees to 26 000 MPa for 23-year-old CCV. It is interesting to note that MOE decreases with increasing log size.

Figure 17 also shows that some plantation timber at relatively young age can achieve similar values of MOE to native timber. This indicates that it is unlikely that the MOE would limit utilisation of the plantation grown wood for appearance grade products.

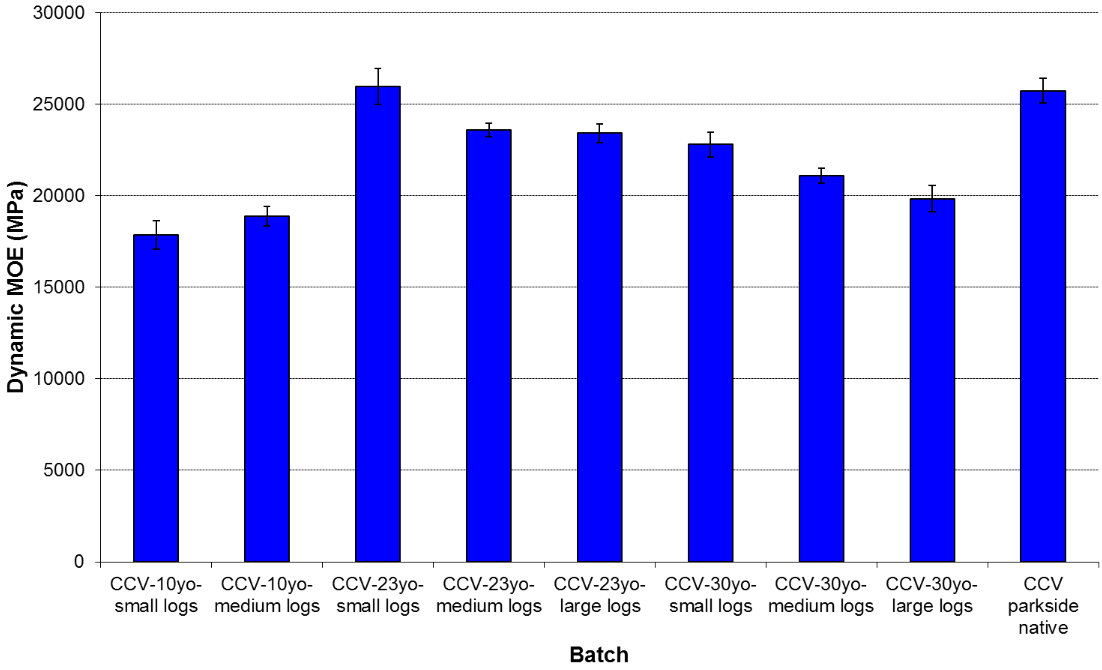

Figure 17. Dynamic MOE as assessed by the vibration technique for CCV boards from three different ages and log size classes (Parkside native timber included).

3.6. Processing of boards

3.6.1. Cant splitting

It was observed during the green milling process that the extent of end splitting and distortion (effects of growth stress) were not as severe as would be expected generally for young plantation material. However, a high incidence of knot and heart-related defects was noted.

For CCV there was a lack of incidents of cant splitting (Image 16). This material was very stable during processing. This could be due to a low level of growth stress which had developed in the logs. Even though splitting was visible on the cross-section of the log prior to sawing, the splitting did not express itself further inside the log during sawing. This is a significant benefit to processors.

On the other hand, several GMS logs moved off the saw and split almost to an end along the pith of their centre cants (Image 16). During log break-down, GMS logs had more slabs removed without turning the log over. This produced a cant that was too thin in width and less than about two thirds of original diameter (the rounded surface of the log remains). GMS may have had fewer issues with splitting if multiple sawing techniques were used during the break-down process. The severe splitting led to recovery loss (Table 11) and some inaccurate board sizing.

Image 16: Examples of cant after primary break-down: left) CCV did not exhibit problems with splitting; right) log-end splitting in GMS, the consequence of sawing was a cant that was too thin relative to the log diameter.

3.6.2. Green-off-saw recoveries

Green-off saw (GOS) recovery is the proportion of saleable sawn timber recovered from a batch of logs. Leggate (2000) conducted a survey of various hardwood mills in New South Wales and Queensland and reported that 'the recovery of saleable sawn timber (including flooring, structural, joinery, palings, pallets etc) is typically about 40%. If pallets, palings and other lower grade products were not included in the calculations then the recovery would be about 35%.

3.6.2.1. Stage I sawing trial

Average site GOS recovery was 32% for CCV and 27% for GMS (Table 11). These results are based on tallying the boards after removing the majority of defects (wane, want, excessive distortion, splitting, and pith occurrence). The higher value of GOS recovery for 13-year-old CCV could be overestimated due to large number of logs processed into 100 × 100 beams (41 logs from 49 available). Indeed, when the logs were removed from analysis the GOS recovery dropped to 22%.

Table 11. Average GOS recoveries for two species from Stage I sawing trial

Species	Age	GOS* (%)	GOS† (%)
CCV	13	32.4	22.1
CCV	22	31.5	31.7
GMS	22	23.1	23.1
GMS	30	31.1	29.8

* logs where 100 × 100 mm and 150 × 150 mm recovered were included in analyses
† logs where 100 × 100 mm and 150 × 150 mm beams were excluded in analyses

Detailed tracking of boards enabled calculations of GOS recoveries within individual trees. Figure 18 below presents variation in GOS for both species at two ages. There was a large variation in GOS (18% to 42%) among individual trees.

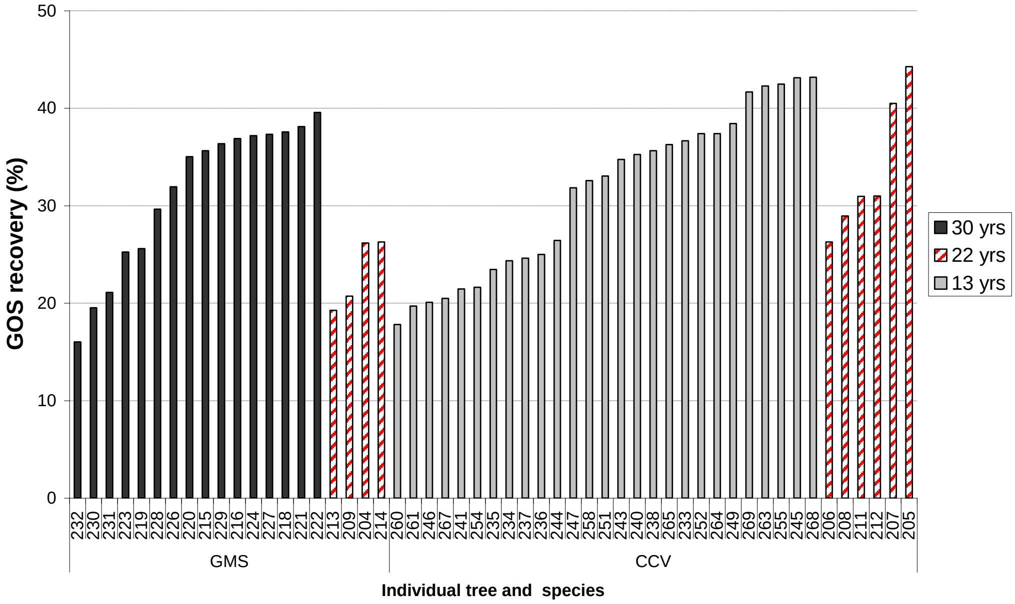

Figure 18. Variation in GOS recovery within individual tree for GMS and CCV from two age classes.

Figure 19 shows how different component length influencing GOS recovery. When the minimum length of recovered board/product increases, GOS decreases. In the case of 22-year-old CCV, GOS decreased from 32.5% for a minimum length board of 0.6 m, to less than 25% for boards longer than 2.4 m. As the sample size for 22-year-old CCV and 22-year-old GMS was small the results should be taken with caution.

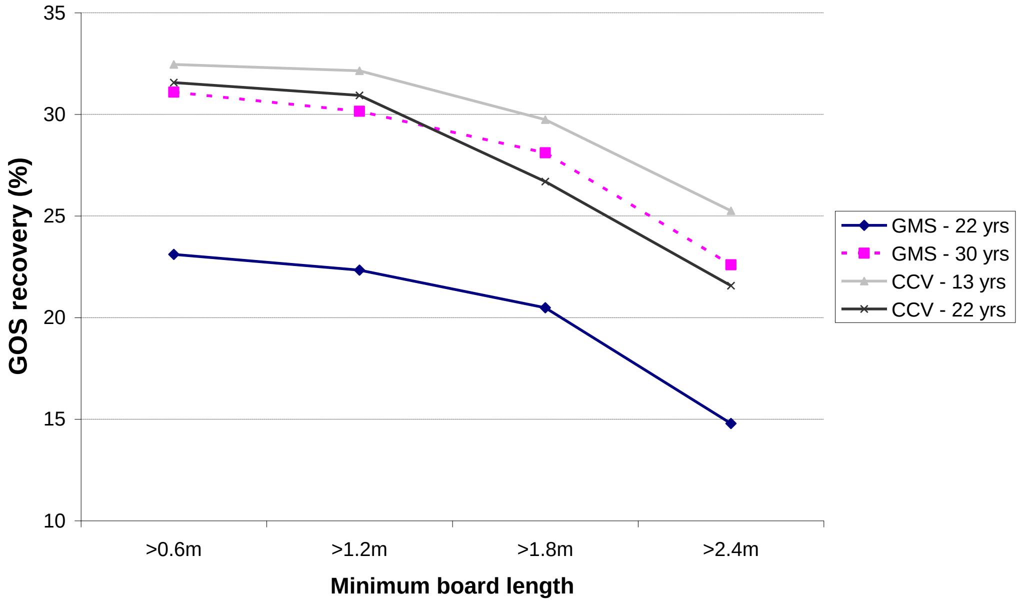

Figure 19. The effect of component length on GOS recovery for GMS and CCV from two age classes.

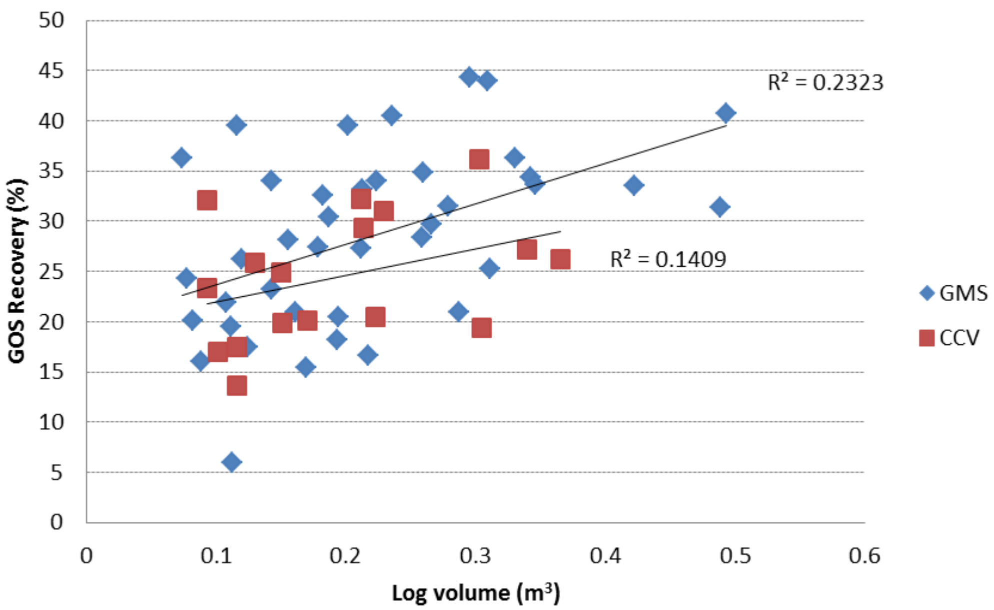

Figure 20. The effect of log volume on GOS recovery for GMS and CCV.

Figure 20 illustrates the relationship between log volume and GOS recovery at individual log level for GMS and CCV (logs with 100 × 100mm centre pallet grade excluded). As would be expected, larger logs produce higher GOS recoveries, although coefficients of determinations were quite low (0.14 for CCV and 0.23 for GMS). In addition to log size other confounding drivers affecting recovery are: taper, sweep, splitting and the number of natural characteristics docked out prior to tally.

3.6.2.2. Stage II sawing trial

In total, 1,110 boards were available from the main sawing study after the initial processing at Wandoan. The board length ranged from 0.6 m to 6.0 m. Sawing patterns were utilised to maximise the recovery of 25 mm and 38 mm thick boards in predominantly 100 mm and 150 mm width dimensions. Table 12 presents the green-off-saw (GOS) tally of produced boards from each resource (species and age).

Figure 20 illustrates GOS recoveries as a percentage of the batch input log volume for each species/age by size class and log position. Overall, GOS recovery for plantation-grown CCV ranged from 25 to 40%. As expected there was a slight increase in GOS with the log size. The highest recovery (40%) was achieved in the 23-year-old CCV lot from a large log batch size. Interestingly, the small diameter CCV logs from the 10-years-old site also produced a high a GOS recovery of 36%. However, it should be noted that the boards included in the tally contained pith, and other defects occurring in the inner heartwood zone, which could overestimate the GOS value. There was no clear indication whether GOS recovery would be higher for butt logs or for top logs.

Average GOS recovery of WWG (five logs) was less than 27%.

Table 12. GOS recoveries and tally of GOS boards for CCV (three age classes) and WWG

Species/age	Log volume (m^3)	GOS volume (m^3)	GOS recovery (%)	
CCV – 10 yrs	8.2	2.6	31	
	Board dimension (mm)	**No. of boards**	**Volume (m^3)**	**Proportion of sawn volume (%)**
	70 × 25	5	0.02	1
	100 × 25	160	1.23	48
	150 × 25	26	0.25	10
	100 × 38	78	1.06	41
	Total	**269**	**2.55**	**100**

Species/age	Log volume (m^3)	GOS volume (m^3)	GOS recovery (%)	
CCV – 23 yrs	4.8	1.6	34	
	Board dimension (mm)	**No. of boards**	**Volume (m^3)**	**Proportion of sawn volume (%)**
	70 × 25	5	0.03	2
	100 × 25	108	0.79	48
	150 × 25	18	0.19	12
	100 × 38	51	0.62	38
	Totals	**182**	**1.63**	**100**

Species/age	Log volume (m^3)	GOS volume (m^3)	GOS recovery (%)	
CCV – 30 yrs	17.6	5.5	31	
	Board dimension (mm)	**No. of boards**	**Volume (m^3)**	**Proportion of sawn volume (%)**
	70 × 25	27	0.13	2
	100 × 25	364	2.73	49
	150 × 25	62	0.61	12
	100 × 38	168	2.04	37
	Totals	**621**	**5.51**	**100**

Species/age	Log volume (m^3)	GOS volume (m^3)	GOS recovery (%)	
WWG	0.91	0.25	27.6	
	Board dimension (mm)	**No. of boards**	**Volume (m^3)**	**Proportion of sawn volume (%)**
	70 × 25	4	0.02	7
	100 × 25	25	0.14	56
	150 × 25	1	0.01	3
	100 × 38	10	0.09	34
	Totals	**40**	**0.25**	**100**

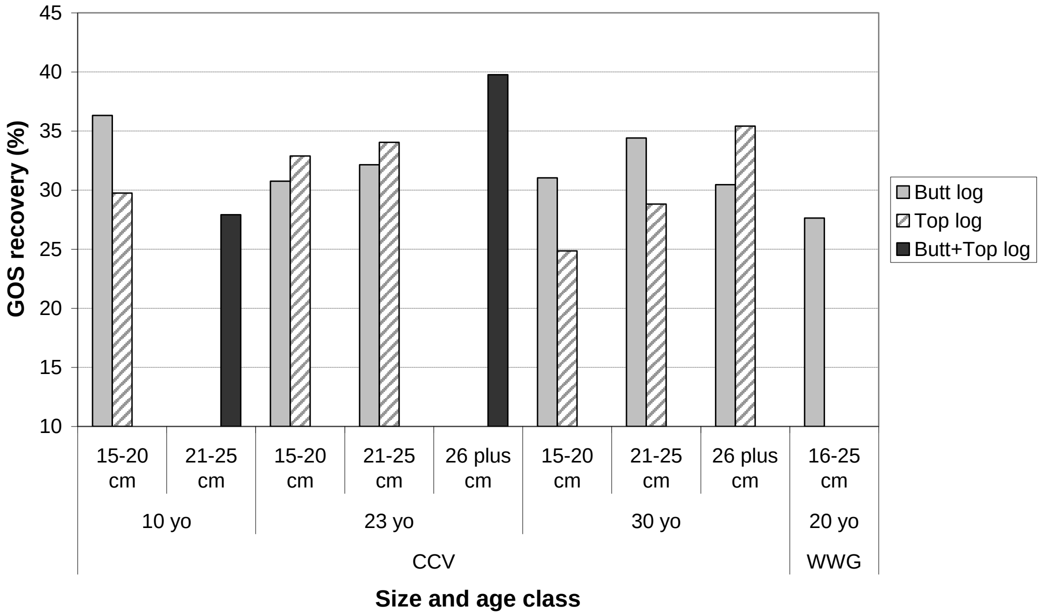

Figure 21. GOS recoveries for CCV batches and WWG

The GOS recovery figures obtained in this study compared favourably with GOS figures from past studies. Armstrong *et al.* (2005) reported similar GOS recovery (32 to 39%) for CCV regrowth of an unknown age with log diameter classes ranged from 17 to 40 cm. Similarly, Leggate *et al*. (2000) reported the GOS recovery of six species from Queensland plantation trials as between 32.3 and 42.9%. GOS recovery for 41-year-old plantation *C. citriodora* was 36%. GOS recoveries in young plantation resource from South America (including *Corymbia maculata*) ranged from 30 to 41% (Hopewell 2002). Other plantation species showed similar GOS recovery (33-year-old *E. argophloia* – 34%; 32-year-old *E. pilularis* – 44%; 35-year-old *E. cloeziana* – 40%). Armstrong *et al.* (2003) reported GOS recovery of 47% for much bigger and straighter 32-year-old WWG trees from a small farm lot planting. This is much greater than GOS for WWG in our study (28%).

The resource processed at the Parkside sawmill at Wandoan, is mainly naturally grown suppressed CCV. The average GOS recovery of this material is about 37% (pers. comm.). However, it must be noted that the minimum board length considered in this operation is 2.4 m. Moreover most defects and the central heart are docket out and rejected.

3.6.3. Dried and dressed graded recoveries

3.6.3.1. Stage I sawing trial

The pilot study recovered a broad selection of products from each of the species and age classes. Following the recommendation of the steering committee, further grading was conducted only on material with a dry thickness of 19 and 32 mm. As a consequence dried and dressed graded (DGR) recovery results could not be provided.

Distribution of grade recovery (19 mm and 32 mm boards)

Figure 22 illustrates a distribution of grades measured on 19 mm and 32 mm boards for all sites and for Parkside native timber. The yield of premium-value select grade was close to 60% for GMS and about 70% for plantation CCV. Boards sourced from Parkside native forest had a larger proportion of select grade (90%), which reflects the less knotty timber with fewer defects.

The use of finger-joint components in flooring products is a reasonable option for the use of plantation timber to eliminate the higher amount of knots/defects. Also in veneered flooring products low grade components would be suitable for the centre part of any flooring product and higher quality CCV could be used as the top layer. Low quality CCV timber would be preferable to imported overseas timber as it would be compatible with any wood movement of the top CCV layer. Distribution of the clear components of plantation and native Parkside CCV timber (minimum length of 200 mm) is illustrated in Figure 23. It is clear that for plantation timber there is a surplus of shorter components up to 500 mm and a lack of longer clear components above lengths of 2000 mm. In terms of length recovery, about 60% of clear wood could be recovered from plantation timber compared to 85% from native timber.

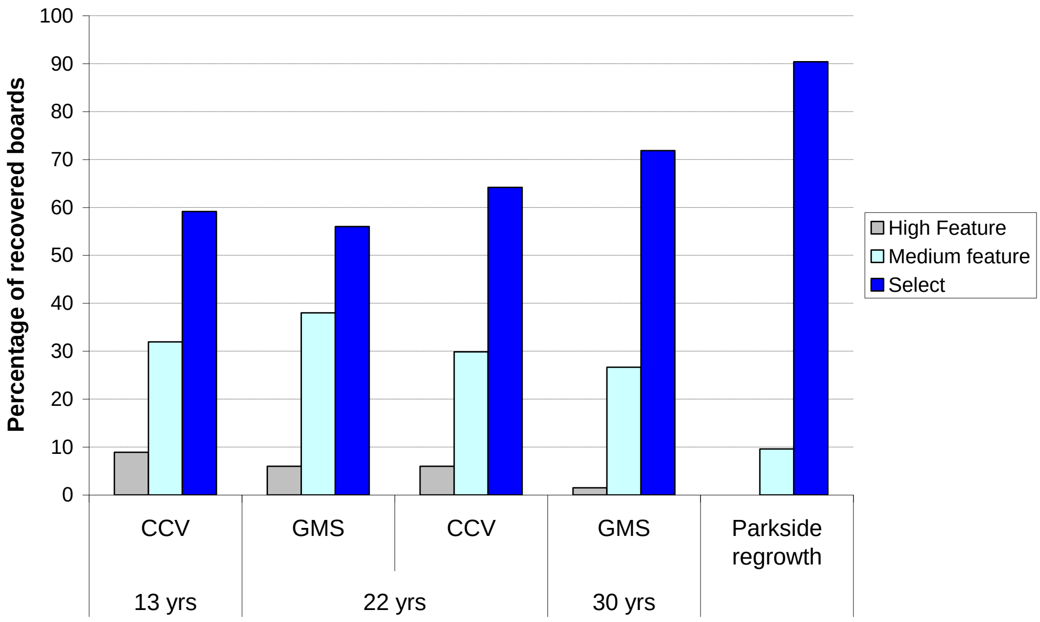

Figure 22. Distribution of grades from plantation timber and Parkside run of mill timber (assessed on 19 mm and 32 mm thick boards only)

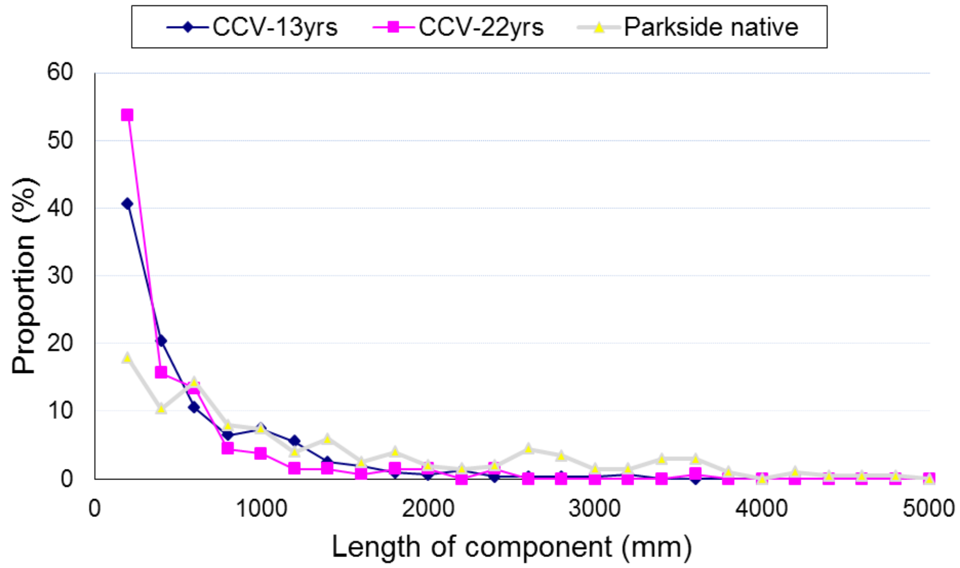

Figure 23. Distribution of clear components for plantation and native CCV timber

3.6.3.2. Stage II sawing trial

Each target board was evaluated for grade quality. Each board was evaluated in its original full length and then regraded after defects were docked, to increase the grade quality. A minimum board length of 0.3 m was applied. Results presented here are reported after docking and based on dressed dimensions (thickness 19 mm and 25 mm).

For the product ‘flooring’, dried and dressed graded recovery at site level ranged from 11.7% to 16.4% of green log volume (Table 13). This means that up to 16.4% of the initial green log volume could potentially be used for grades high feature, medium feature and select. As expected the DGR recoveries obtained are highest for older trees and from larger logs. Young 10-year-old CCV although achieving high GOS values had only 11.7% DGR. Even though the selected trees at this young site had similar diameters, compared to the other two sites, the overall recovery of saleable products is lower as a consequence of the high proportion of juvenile wood, which contains many defects that cause distortion after sawing and drying.

These figures are poor when considering recoveries achieved in native forest hardwood log conversion. Normally in the Australian hardwood industry, the recovery of timber suitable for appearance grades averages around 30% of the log volume in nominal dimensions. The recovery figures would be even lower if the minimal dimension accepted for the study as being recovered saleable timber was larger than the adopted dimension of 300 mm length, as is typically the case in the Australian industry. It is important to note that the processing trials were done using a typical sawmill designed for processing native forest resource, without any adjustments to accommodate the logs of smaller diameters. Also, it needs to be stressed that the growing conditions and management of the site were not conducive to ‘clear wood’ production. The Thinoomba site (30 year old trees) had a fire during the younger stage of the growth and generally poor management since, which is reflected in log and timber quality degrading the overall timber grade.

Recovery of the premium select grade ranged from four to 10% and was highest for oldest trees (Table 13). Medium feature was close to 4.5% and high feature grade was close to 2% for all sites.

Table 13. Dried and dressed graded recoveries DGR (percentage of green log volume) for CCV at individual site level (combining all batches)

Site	Grade recovery (%)				
	DGR	Select	Medium Feature	High Feature	Reject
CCV – 10 yr	11.7	4.1	4.9	2.6	5.9
CCV – 23 yr	13.6	7.4	4.6	1.7	4.9
CCV – 30 yr	16.4	9.9	4.4	2.0	4.6

Compared with other plantation eucalypt studies, the recovery figures obtained for CCV in this study are generally low. Leggate *et al.* (2000) reported the DGR figures of six Queensland plantation sites as being between 7.9% and 18.8% for 'flooring' products. DGR for 41-year-old plantation *C. citriodora* was 18.8%. DGR recoveries in young plantation resource from South America were significantly higher and ranged from 12.6% for *C. maculata* to 26% (Leggate, unpublished results). Dried and dressed graded recoveries for WWG were 30% for 32-year-old WWG and 13.7% for WWG thinnings (Armstrong *et al*. 2003). However, it is impractical to compare results with other plantation eucalypt studies because of slight variations in the experimental methods and other introduced errors.

When considering veneer product as alternative high value product from young plantation resource, the net veneer recovery for CCV varied between 45 to 48% (McGavin *et al*. 2013).This suggests rotary veneer processing has the potential to recover up to six times the volume of saleable product from the young plantation species when compared to classical sawmilling techniques.

When considering recovery it is important to consider the length of recovered components. In the case of the CCV timber assessed in this study the majority of the appearance grade recovery is in very short lengths. Figure 24 shows that on average about 50% of the timber recovered as select grade flooring is in lengths less than 1.5 m. This is a major consideration for a processor because the market generally prefers larger dimensions of clears; larger dimensions and longer lengths being easier to sell and also is more valuable. Possibilities exist, however, for using the small length, small dimensioned timber effectively in timber jointing and lamination. The distribution of recovered component length showed a similar trend in different age classes.

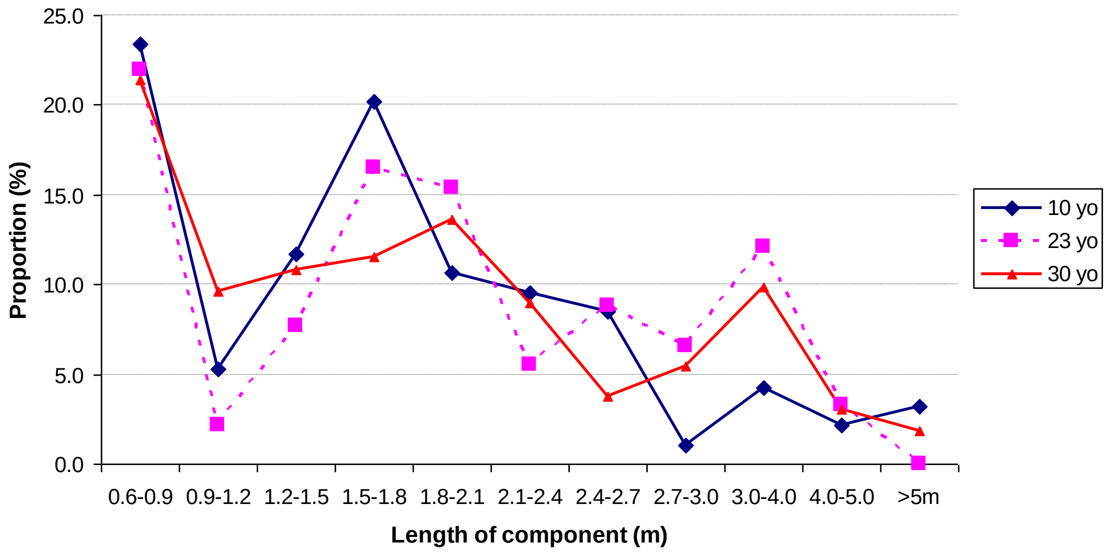

Figure 24. Distribution of length for select grade flooring product

Dried and dressed graded recovery at individual batches

Figures 25 and 26 show the dried and dressed graded recovery results for all the batches individually. There were marked differences between sites, log size classes and log positions. It is clear that young 10-year-old CCV performed poorly in terms of DGR (regardless of log size). For older trees, DGR increases with log size. Also there was an increase of select grade for older trees with larger log size. The highest recoveries were obtained for the 23-year-old site from Tinana in the batch of log size greater than 26 cm in diameter.

It is evident that for 10-year-old CCV GDR was much lower for top logs than for butt logs. As mentioned in Section 2.1.2.1, this site was selected for the sawing study because it was one of the best growing CCV at this young age. Moreover, the trees were silviculturally managed from a young age, using thinning and pruning regimes to increase the log value at a later stage. The higher DGR and distribution of select grade for butt logs could be attributed to the pruning regimes and increased clearwood at this position. On the other hand, the top logs contained knotty timber with a high proportion of juvenile wood that could have resulted in poor recovery from the top logs.

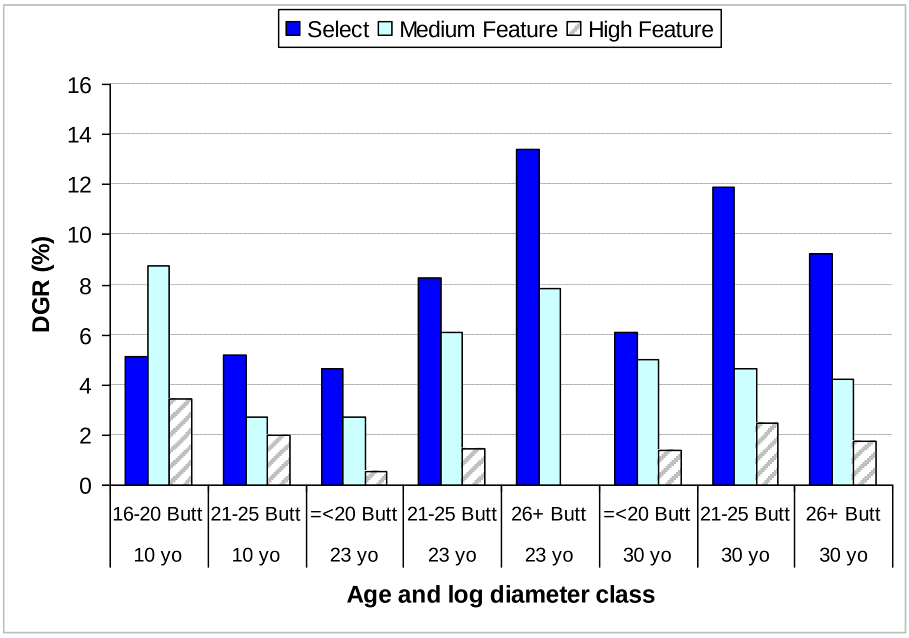

Figure 25. DGR for CCV for butt logs across age and log size combinations

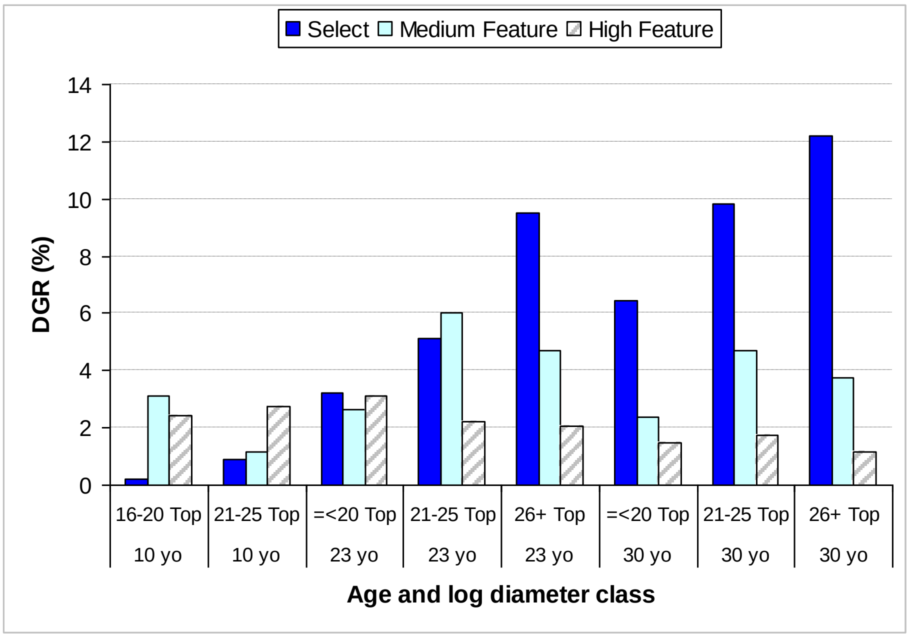

Figure 26. DGR for CCV for top logs across age and log size combinations

3.6.3.3. Grade recoveries assessed by CombiScan+

The CCV plantation 19 mm boards (after dressing) from Stage II were run through a fully automated CombiScan+ 4 side-scanner recently installed in Parkside Wondai sawmill to optimise the recovery for native spotted gum timber. CombiScan uses multi-scan technologies to provide full defect detection and colour inspection. It should be noted that currently there is no calibration available for detecting defects in plantation timber using the scanner. As native timber contains fewer natural defects and less timber colour variation compared to plantation timber, the results presented below should be only indicative and taken with caution.

Figure 27 (butt logs) and Figure 28 (top logs) illustrate the distribution of feature, standard and waste grades at individual batches as detected by the scanner. Overall, 60–100% of timber could be recovered as standard grade. The results showed, similarly to the visual grading, that the young 10-year-old timber from top logs was characterised by the lowest amount of standard grade than other batches.

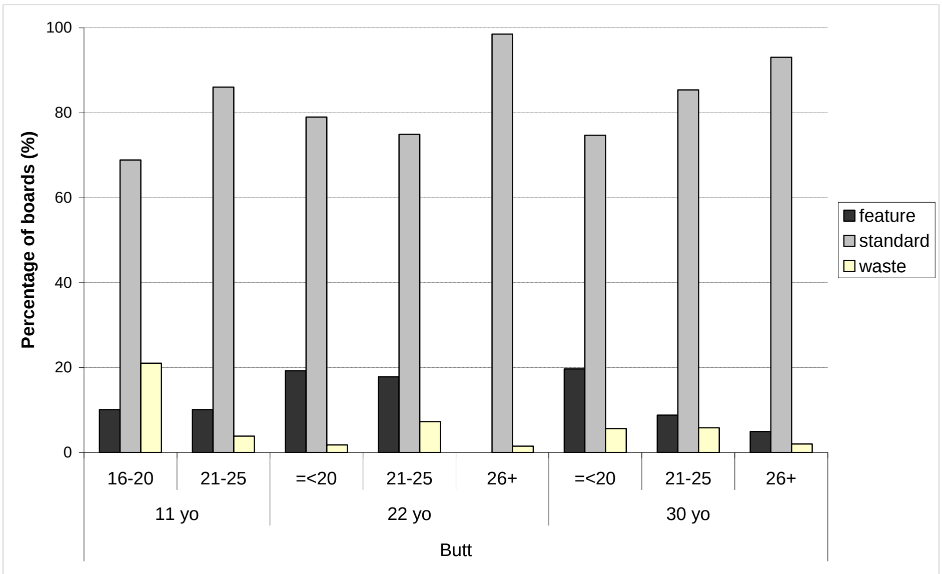

Figure 27. Grade distribution for individual batches (butt log) as evaluated by CombiScan

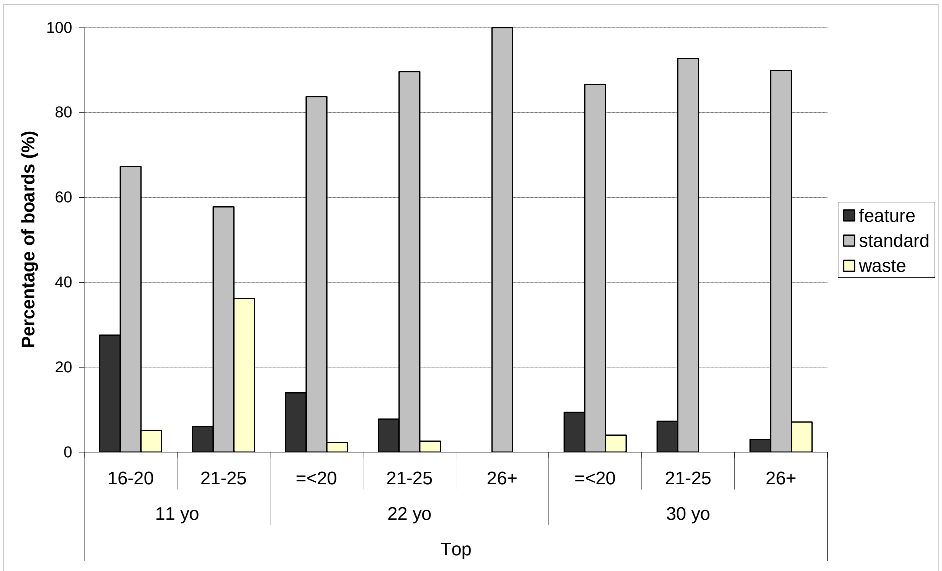

Figure 28. Grade distribution for individual batches (top log) as evaluated by CombiScan

3.6.4. Defects in sawn boards

3.6.4.1. Stage I sawing trial

During the docking process the main reason for docking was recorded and the length of lost volume calculated. It was then related to log volume to provide the percentage of lost volume (Figure 29). Wane was the main reason for docking especially for CCV and native timber. Inclusion of heart/pith was also evident for all batches. Percentage of lost volume due to end splits was low.

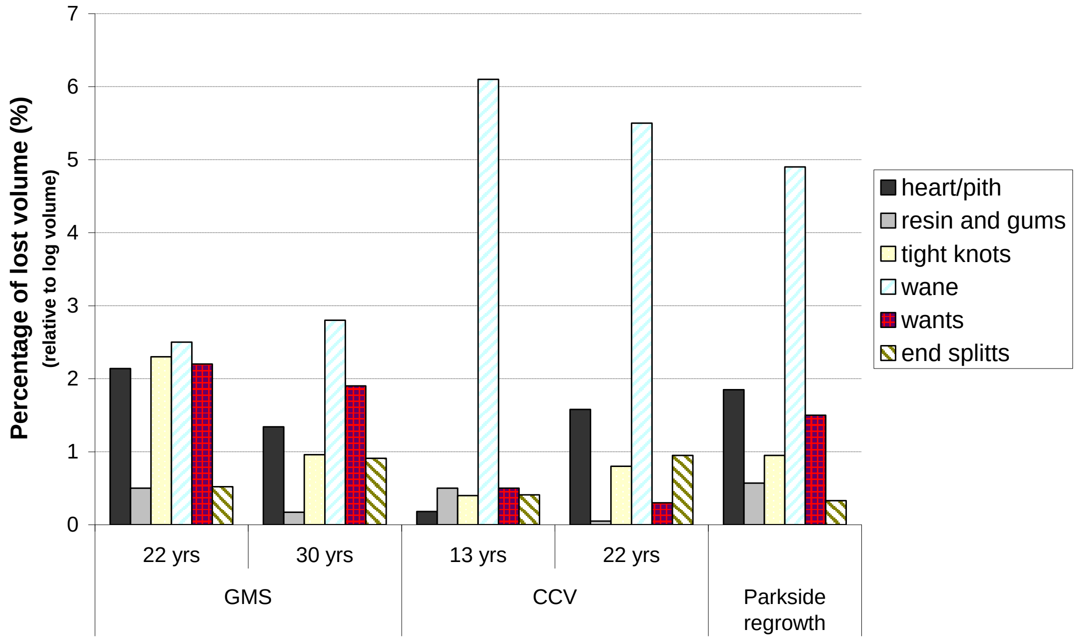

Figure 29. Percentage of lost volume (relatively to log volume) due to defects for GMS and CCV (Parkside native timber included)

3.6.4.2. Stage II sawing trial

Board distortion

The main distortion characteristics (bow, twist, spring) were compared with permissible limits outlined for strip flooring within Australian Standard 2796 (Table 14). The proportion of boards rejected due to excessive distortion ranged from 12.3% for 30-year-old CCV to 29.3% for 10-year-old CCV (relative to log volume). Twist was the main reason for rejection at two sites accounting for 47% and 68% respectively. For the 23-year-old site, bow accounted for 61% of rejected boards. There was a limited problem with spring, which only occurred in the young, 10-year-old resource.

Table 14. The proportion of boards rejected due to excessive distortion ('Flooring' products)

Site	Reject out of total volume (%)	Accounting for bow (%)	Accounting for twist (%)	Accounting for spring (%)
CCV – 10 yr	29.3	44	47	8
CCV – 23 yr	16.4	61	39	0
CCV – 30 yr	12.3	32	68	0

Average, relative bow, spring and twist distortion across all batches are presented in Figures 30–32. Generally, 10-year-old CCV boards had the worst distortions, confirming the juvenility of this material. It was also evident that distortion was higher in boards cut from the top logs. There was a little difference between butt and top logs for bow and spring in dried boards for other two sites. Distortion may be potentially reduced by fine tuning processing regimes, particularly drying regimes and sawing allowances.

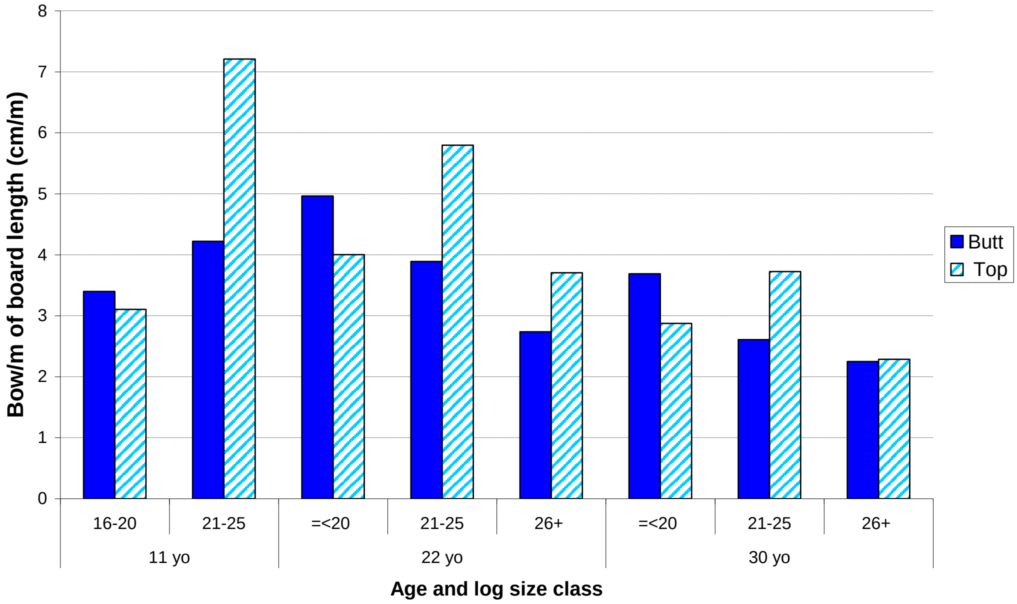

Figure 30. **Average bow measurement relative to board length for CCV across age and log size classes for butt and top logs**

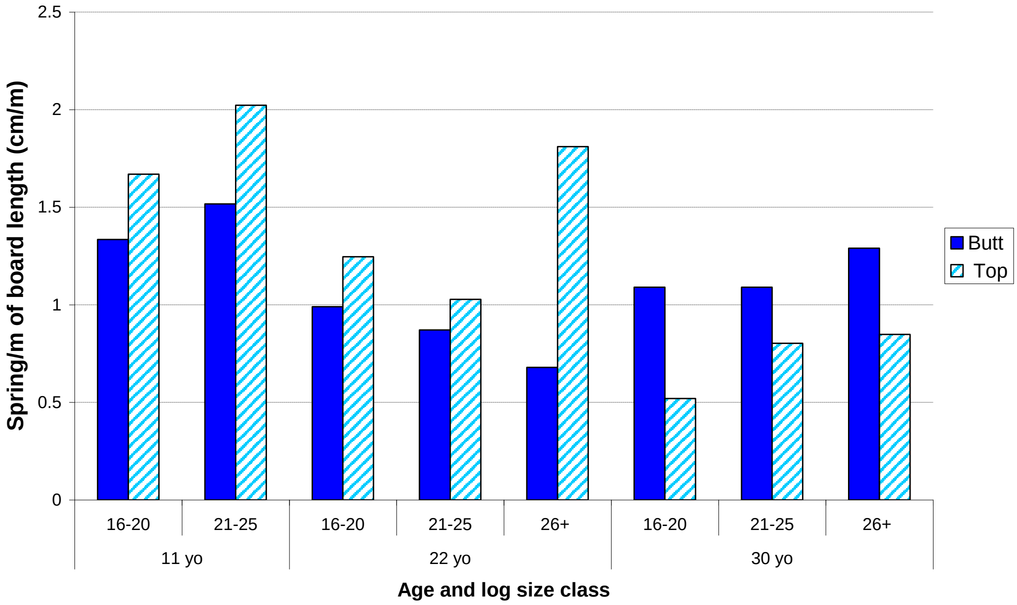

Figure 31. **Average spring measurement relative to board length for CCV across age and log size classes for butt and top logs**

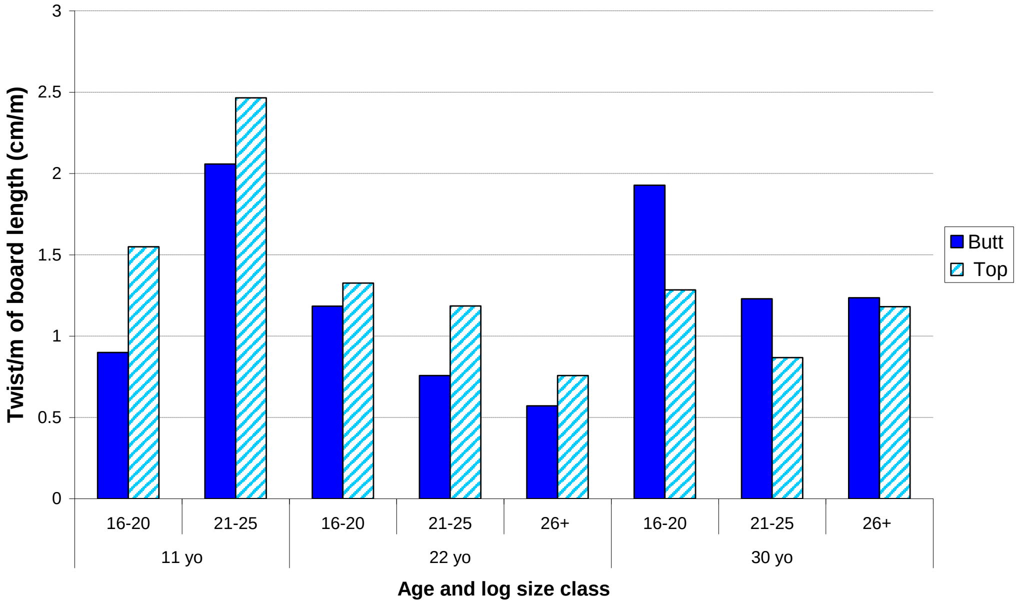

Figure 32. Average twist measurement relative to board length for CCV across age and log size classes for butt and top logs

Defects

The main reason (excluding distortion) for downgrade was knots (Figure 33). Overall, around 45% of the timber contained undesirable knots that meant that the board had to be docked or downgraded. Knots defects were in the form of tight knots, loose knots, knot holes, knot checks, and decayed knots. Often other defects such as gum veins, overgrowth of injuries and decay were associated with the knots. Together the combined effect of knot or branch defects on recovery was very large. The plantation logs assessed were generally unmanaged (only one site was thinned and pruned). More careful silviculture in the future could diminish the impact of the knot defects on recovery and allow higher yields of clear timber.

Other significant reasons for downgrade included heart, wane, decay and heart shakes. The logs were from young unmanaged plantations and obviously heart or log centre defects had a major impact on recovery. Heart shakes are a very common occurrence in eucalypts where boards are sawn close to the pith. A small log size also results in the majority of boards being produced containing pith. Boards containing pith are rejected during grading and this has been the major cause for the very low recoveries.

Wane as a grade limiting factor for CCV reflects the inadequacy of the log merchandising and sawing patterns implemented to process this material, which was dominated by small diameter logs with high levels of internal stress. Sawing pattern optimisation or application of curve-sawing may have improved grade recovery.

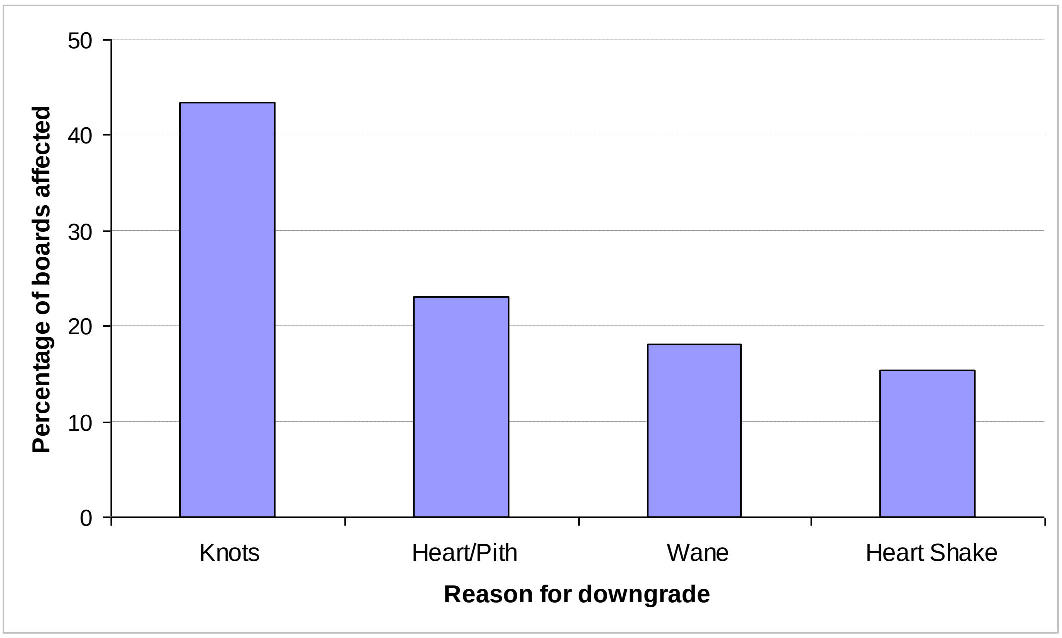

Figure 33. Reason for rejection for all CCV boards combined

A comparison between batches shows that knots were the main contributor of grade downgrade almost for all batches (Figure 34). The exception was for 10-year-old CCV of small log size where all measured defects contributed evenly for board downgrade.

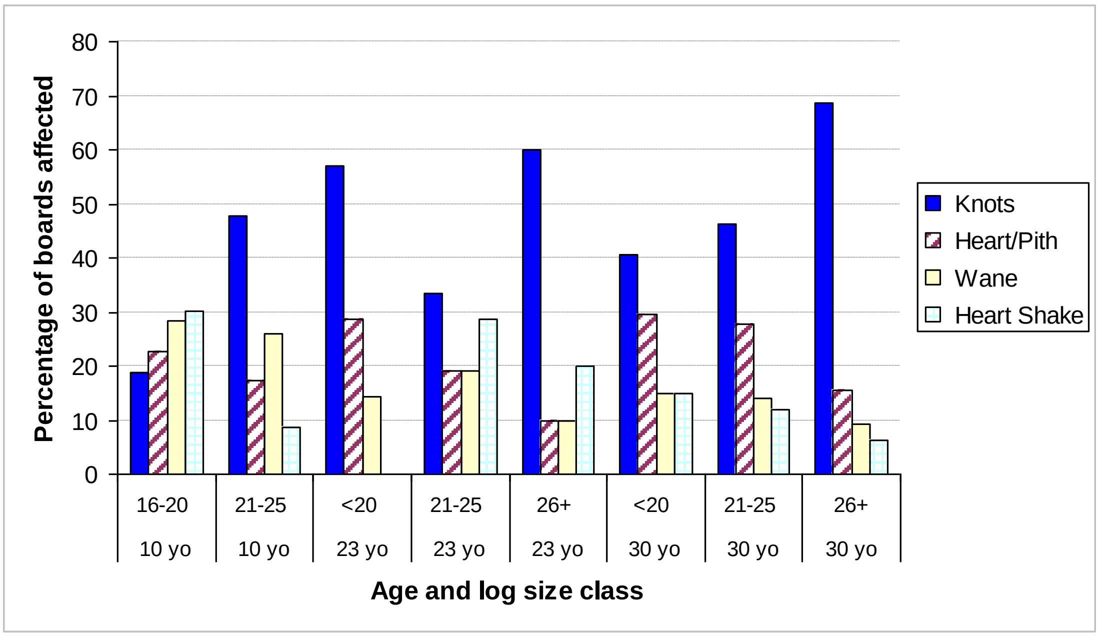

Figure 34. Reason for rejection for individual batches (combining log position)

3.6.5. Comparison between plantation CCV and Parkside native CCV

During grading a few observations were noted:

- Colour variation: native CCV timber had rich dark-red brown colour of heartwood whereas plantation heartwood timber appeared to be pale pink (Image 17).
- Sapwood and sapwood colour: most plantation boards had a high percentage of sapwood and their colour appeared to be silver-green as a result of the ACQ preservative treatment (Image 17).
- Knots: the Parkside native timber was less knotty than the plantation material and therefore contained more select grade (Figure 22).
- Surface checking: an increased presence of surface checking and a high proportion of wane were observed in the plantation material.
- Pith: there was a high proportion of pith in smaller diameter trees (board containing pith was usually rejected)

Table 15 compares the main characteristics and properties between plantation timber at two age classes and Parkside timber representing slow grown and suppressed native forest. On average, timber density and mechanical properties are lower for plantation timber by approximately 10–15%. In some cases, plantation timber at a relatively young age can achieve similar values of MOE as native timber. This indicates that it is unlikely that the MOE would limit utilisation of the plantation grown wood for appearance grade products.

Native timber had less distortion and fewer defects which were reflected in higher proportion of premium select grade.

Table 15. Comparison of the main characteristics and properties between CCV plantation timber at two age classes and Parkside native timber

Characteristics	Plantation		Parkside native suppressed
	13 year old	22 year old	
Board heartwood colour	Pink pale	Pink pale	Rich red/brown
Heartwood proportion (%)	30	45	~90
Air-dried density (kg m^{-3})	870	950	1 050
Board static MOE (MPa)	16 000	20 000	21 000
Hardness (kN)	8.0	9.5	10.5
Board static MOR (MPa)	100	110	130
Board dynamic MOE (MPa)	19 000	24 000	25 000
GOS (%)	30	34	37*
DGR (select grade distribution %)	60	65	90

*minimum board length is 2.4m the most defects are docket out and central heart is also boxed out and rejected.

Image 17: Example of visual appearance for Parkside production native timber (left) and plantation timber (right)

4. Conclusions

This report documents the predicted plantation resource supply mix that will be available to sawlog processors during the transition from native forest to mostly plantation produced hardwood timber. The results of the survey conducted with the three main growers (former Forest Enterprises Australia Pty Ltd, former Forestry Corporation of New South Wales, Hancock Queensland Plantation Pty Ltd) has shown that the most widely planted species in the 1994–2000 plantings in the southern Queensland and northern New South Wales sub-tropical hardwood estate were *C. citriodora* subsp. *variegata* (28.0%), *Eucalyptus dunnii* (27.5%), *E. pilularis* (23.0%), *E. grandis* (11.3%) and *E. cloeziana* (7.1%) and these would dominate as potential supply of plantation hardwoods to a sawmill processing facilities.

The target resource for the current study was CCV with smaller samples of GMS and WWG, currently preferred species for hardwood plantations in Queensland. Plantation ages of between 10 and 30 years old were targeted to represent the full range early to late age plantation resource.

Mean basic density of plantation CCV was 715 kg m^{-3} compared to approximately of 800 kg m^{-3} for native forest derived trees. Younger trees exhibited lower values of basic density, due to high concentrations of sapwood in these samples. The basic density of GMS was close to 750 kg m^{-3}.

A high proportion of sapwood in plantation timber is a significant issue affecting colour and durability. Plantation CCV displayed a low heartwood proportion ranged on average from 25% to 46% with a sapwood width about 40 mm. GMS displayed the highest heartwood proportion (close to 70%) and low sapwood width of width of about 20 mm.

The project also produced information on the mechanical properties for these species which should give growers and processors confidence that these products will meet market requirements. Surface hardness, density and MOR/MOE were generally marginally lower than native forest material of the same species. Janka hardness followed the trend of air-dried density change, and ranged from 7.5 to 9.5 kN for CCV and reached about 10.5 kN for GMS. MOR was close to 100 MPa for GMS and ranged from 90 to 110 MPa for CCV. MOE reached 19 GPa for GMS and ranged from 16 to 20 GPa for CCV. The 22-year-old CCV site achieved similar values of MOE to native timber.

Acoustic wave velocity AWV measured on standing trees was a reasonable predictor of static board stiffness, and could assist with segregating trees/logs into stiffness classes. Similarly, vibration analysis techniques provided reliable and simple means of structural grading. The strong prediction ability and rapid use of the technique allow the higher throughput of samples to be processed and analysed.

One hundred and forty-seven trees with a total log volume of 61 m^3 were processed through the conventional Parkside sawmill to produce the range of sawn products (with a focus on flooring products). CCV was relatively stable during processing with no main cant splitting issues observed. GMS was more prone to splitting with few cases of cant splits, which negatively affected the final recovery. Green-off-saw (GOS) recoveries were low averaging about 35% for CCV and about 30% for GMS. As expected, larger trees provided higher values of GOS recoveries. GOS recovery for WWG was less than 27%.

For the product ‘flooring’, dried and dressed graded recovery at site level ranged from 11.7% to 16.4% of green log volume. This is about half of what would be expected from native spotted gum. The majority of the appearance grade recovery was in very short length components. Possibilities exist for using small dimensioned length effectively in finger-joint components and lamination. The amount of premium select grade was higher for older and larger trees. In general, for plantation CCV timber, the recovery of select grade was 30% less when compared to native timber currently processed at Parkside sawmill. Younger timber distorted badly during drying, due to the high proportion of juvenile wood. Consequently, this reduced the amount of select grade.

The proportion of boards rejected due to excessive distortion ranged from 12.3% for 30-year-old CCV to 29.3% for 10-year-old CCV (relative to log volume). Twist was the main reason for rejection at two sites accounting for 47% and 68% respectively. For the 22-year-old site, bow accounted for 61% of rejected boards. There was a limited problem with spring, which only occurred in the 10-year-old resource.

At all sites the main defect preventing higher grades to be met was the incidence of knots. The plantation logs assessed were generally from unmanaged trees. More careful silviculture in the future could diminish the impact of the knot defects on recovery and allow higher yields of clear timber. Other significant reasons for downgrade included heart, wane, decay and heart shakes. These defects are characteristics of relatively young, fast-grown trees. Adjustments to grading criteria currently based on mature wood from native forests will be required to accommodate the differences in product characteristics for the plantation resource.

Overall the investigated resource was of a relatively poor quality that would not meet current market expectations for sawn, appearance grade timber. The low recoveries obtained in this study raise questions about the economic viability of processing this plantation resource. However, it is important to take into account the lack of silvicultural management in investigated sites.

Economically-viable production of sawn products from these types of plantation will require different processing techniques to provide better control over value-limiting factor such as distortion to maximise the recoveries. Additional research would be required to determine which products and markets are available and the most suitable for the quality and quantity of plantation hardwood sawn products.

Acknowledgements

The authors would like to take the opportunity to acknowledge the following organisations and individuals who contributed to this study:

- The Department of Agriculture, Fisheries and Forestry, DAFF (and its predecessor organisations) for providing financial support to the project.

- Parkside Timber (Emma Franks, Robert Tapiolas and other technical staff of Wandoan and Wondai sawmill) for providing extensive support to the project through access to their sawmill facilities and also very valuable technical input throughout the project life.

- HQ Plantation Pty for providing financial support to the project and for access and supply for plantation resources (Ian Last, Neil Gourley and Leigh Kleinschmidt for technical advice and valuable contribution during the project conception and planning).

- DAFF staff at the Salisbury Research Facility (Rob McGavin, Henri Bailleres, Adam Redman, Bill Atyeo, Eric Littee, Rod Vella, Jock Kennedy, Chris Fitzgerald, Jo Fehrmann) for assistance and technical advice on timber drying, grading and mechanical testing.

- DAFF staff (John Huth, Tony Burridge, Bruce Hogg) for assisting with on-site selection and sampling; Terry Copley for assistance with sampling, log processing, sample evaluation, timber grading and timber testing;

- Susan House (DAFF) for reviewing the report

- Jim Burgees (then Timber Queensland) for his technical advice.

- John Kelly and Barry Underhill from Forest Policy and Industry Development group of DAFF for their continuing support, assistance and guidance for the project.

- Forest Enterprises Australia Ltd (Troy Brown and Trevor Innes) for their valuable input at the initial phase of the project.

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