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Final report

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1 Acknowledgments

1.1 Preparation of this Report and the Research Team

This project operated from July 2005 to December 2009. At the time of the project no final report was prepared, but a series of 8 technical reports were prepared for ACIAR. In order to assist with dissemination of the important research findings from this project, ACIAR has prepared this final report drawing on information in the technical reports and project files. Rebecca Blundell undertook this work for ACIAR under the supervision of the Forestry Research Program Manager, Tony Bartlett. ACIAR acknowledges all the contributions from the following scientists in the organisations involved in the project.

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2 Executive summary

There are now more than 70 million hectares of planted forests in China and Vietnam and at the time this project commenced there was over 1.8 million hectares of eucalypt plantations in China and about 500,000 hectares in Vietnam. In 2002, Australia had about 640,000 hectares of eucalypt plantations. However, most of these eucalypt plantations were being used for pulpwood production because of the difficulties of producing high quality sawn timber from young eucalypts. These eucalypt plantations are making a useful contribution to rural development and to small landholder income generation in developing countries but the potential for their use for higher value products has yet to be realised, mainly due to wood quality problems especially growth stresses.

This project addresses the problem of low recovery of sawn timber from plantation grown eucalypts due to high growth stress levels in smaller logs. Release of these stresses during sawing can result in serious distortion and splitting, a quality degrade that is a major constraint to the use of plantation grown eucalypts for high value products such as construction, joinery and furniture. Other wood properties also contribute to poor yield and low quality in processing. The project investigated improved technologies to increase the quality of sawn products derived from young, plantation grown eucalypts in China, Vietnam and Australia. Different sawing patterns have been tested that distribute strain more evenly during sawing thus reducing distortion.

Specifically the objectives of FST 2001/021 were to:

a. In mills in China and Vietnam assess potential for improvement in solid wood processing performance, product quality and value.

b. In mills in Australia assess the potential for application of the state-of-the-art linear flow processing systems and their potential impact on log value.

c. Model mill door prices for logs to assess the potential for optimised processing and compare reciprocating and linear flow sawmills.

d. Assess the potential for field assessment strategies to improve processing performance, product quality and value.

FST 2001/021 was conducted in partnership with FST 1999/095. The aim of FST 1999/095 was to improve the social benefits and economic returns from eucalypt plantations by implementing silvicultural regimes and genetic material to improving wood properties, reducing growth stresses and optimise yields of high-quality timber from eucalypt plantations in China, Vietnam and Australia. The log samples supplied often could be used to assess the additional objective of:

e. Genetic and silvicultural effects on wood quality and processing performance.

These objectives were addressed by the implementation of a series of sub-projects the results of which were documented in 8 technical reports. They are:

1. An evaluation of the application of SilviScan for the improvement of eucalypts for solid wood processing
2. Variation due to spacing in growth stress related wood behaviour and processing performance of *Eucalyptus urophylla x grandis* logs for veneer production
3. Processing sawn wood from thinned, unpruned 10-year old *Eucalyptus urophylla* from northern Vietnam
4. Processing sawn wood from thinned, unpruned 17-year old *Eucalyptus dunnii* from southern China
5. Genetic variation in growth stress related wood behaviour of small diameter *Eucalyptus nitens* logs processed with a Hewsaw R250 Sawmill

6. Processing air and kiln dried sawn wood from unthinned and unpruned 9-year-old *Eucalyptus pilularis* from northern New South Wales with a HewSaw R200
7. Processing air and kiln dried sawn wood from unthinned and unpruned 7.5-year-old *Corymbia citriodora* subsp*. variegata* from Queensland with a HewSaw R200
8. A comparison of mill door log prices for pruned *Corymbia* spp processed with conventional reciprocating and linear flow sawing systems

In summary the findings and recommendations from the project are that:

- Further investigations into tension wood occurrence are warranted in China and Vietnam as it is prevalent in some eucalypt species grown under certain conditions.
- Log diameter and sweep were the major log characteristics significantly impacting on product recovery, indicating that product recovery and quality could be further improved by growing larger diameter logs with minimum sweep.
- Close monitoring of moisture content during drying and utilization of commercial reconditioning strategies at the optimum moisture content substantially improves product quality and recovery in both *E. urophylla* and *E. dunnii*. This treatment should be promoted in China, Vietnam and Australia, and further investigations be carried out on its effectiveness with other species.
- A number of genetic and silvicultural effects emerged from the log samples that allowed a limited assessment. The most important findings were the effect of a thinning treatment at age 8, in the *E. globulus* from East Gippsland, Australia which induced tension wood formation, with the most severe effect in the most heavily thinned unfertilized plots. This phenomenon needs further investigation in China, Vietnam and Australia in species that readily form tension wood, given its likely impact on the viability of processing solid wood.
- It was not clear from the simulations of pruning what effect this would have on the recovery and quality of sawn boards. Comparisons should be made with pruned eucalypts from other projects with comparable assessment strategies.
- The results generally support the hypothesis that, the Linear flow processing systems of the HewSaw R250 and R200 machines will release growth stresses symmetrically around the log and mitigate the adverse effects of growth stress release. The most important of these adverse effects is spring and board end-splitting, which may potentially impact on recovery and product value.
- In each of the sub-projects board end-splitting and deflection were common. However, board end-split severity had minor impact on product recovery after they were docked. Board deflection in the form of bow was the most important board deflection issue. Spring was a less severe problem and had almost no impact on material flow or product value. Further experiments should be conducted to determine the maximum bow threshold for a range of board transport systems.
- The field assessment data used to predict wood processing performance were either not significant predictors of the processing characteristics, or they were unreliable. It would be valuable to establish sound detection methods for future research. This may be through improvement in precision of the x-ray diffraction profiles on SilviScan 3, or through other detection methods such as NIR spectra calibrated to chemical indicators of tension wood.

3 Background

3.1 Introduction

This project is part of a small suite of projects addressing the problem of low recovery of sawn timber from plantation grown eucalypts due to high growth stress levels in smaller logs. Release of these stresses during sawing can result in serious distortion and splitting, a quality degrade that is a major constraint to the use of plantation grown eucalypts for high value products such as construction, joinery and furniture. Other wood properties also contribute to poor yield and low quality in processing. Many developing countries have now established large areas of eucalypt plantations mainly used for fuel wood, pulp and poles. These are making a useful contribution to rural development and to small landholder income generation, but the potential for their use for higher value products has yet to be realised, mainly due to wood quality problems especially growth stresses.

3.2 General Context

In developing countries in the past traditional sawn-wood processing industries have relied largely on native forests for supply of raw material. However, supplies of logs from native forests have declined considerably due to supply, market and environmental constraints while demand for products has increased. Severe restrictions on harvesting native forests were imposed in China in 1998 by the Natural Forest Conservation Program (NFCP) and similar situations exist in Vietnam and Australia.

As a consequence eucalypt plantations areas have expanded rapidly in recent years. They are estimated to occupy 15.0 M ha worldwide with approximately 45% of the plantations in Asia. The total area planted to eucalypts in China on most recent estimates is 1.8 M ha. South-Central China is expected to become a commercial forest base, and has a current estimated area of 1.0 M ha of eucalypts primarily located in the Provinces of Guangxi, Guangdong and Hainan. A similar situation exists in Vietnam where 0.5 M ha have been planted, and in Australia plantation areas have rapidly expanded since 1995 with the total in 2002 estimated at 0.64 M ha. In China and Vietnam most of the eucalypt resource is community owned, usually under some form of joint management with state forestry authorities. In Australia the resource is increasingly grown by farmers, often under partnership agreements with industry.

Log prices paid to growers quoted during a recent ACIAR/CSIRO visit to industry in southern China were AUD 51/m^3 for pulp logs, AUD 58-75/m^3 for small veneer logs and AUD 96/m^3 for selected high quality eucalypt sawlogs. These prices for sawlogs reflect the profitability of primary processing for solid wood and may become standard across the eucalypt resource. However, log quality is highly variable in young eucalypts and in many cases processing performance and wood quality is poor. This was recognised at the IUFRO Division 5 conference on "The Future of Eucalypts for Wood Products" in 2000 where a number of research priorities for the development of solid wood products from plantation-grown eucalypts were identified. Of these, high and variable growth stress levels at the log periphery and associated tension wood within the log were considered major problems affecting the efficiency of processing and product quality and recovery.

High longitudinal growth stresses, particularly in small (>30cm) diameter eucalypts lead to end splitting of logs, flitches, slabs and boards, distortion in final products and variable product thickness, all of which reduce product recovery, product value and processing efficiencies. In many cases sawmillers will cut oversized boards and slabs to ensure acceptable final sizing after drying, but this also reduces recoveries and mill efficiency substantially, particularly in small diameter logs.

Associated with growth stress is the formation of tension wood where the fibres are poorly lignified or where lignin is absent from the S2 layer of the secondary wall. This wood is usually of higher density and has very high longitudinal growth stresses at the stem periphery and can produce very poor drying performance after sawing, including high and variable shrinkage and slow drying of the less permeable tension wood. When present in sufficient quantities, tension wood is a major constraint in primary processing because of poor sawing performance, serious drying degrade and extended periods required for drying. Tension wood is a major problem in temperate eucalypt plantations in southern Australia and in some tropical eucalypts grown in Brazil (Oliviera *pers. comm.*[1]), China (Xu *pers. comm.*[2]), Vietnam and Australia.

When existing sawing systems are applied to logs with high and variable growth stress and tension wood levels, they usually produce low recoveries of poor quality outputs. This is a particular problem in China and Vietnam where small local sawn-timber industries, often using makeshift equipment are emerging. These mills produce low value sawn-wood (formwork, pallet and crate timber) probably at marginal profits, but there is potential to increase mill efficiency through increased product recovery and value e.g. for use in furniture, flooring and construction. A small proportion of production is already going to these higher value end products, particularly flooring.

The problems of growth stresses and tension wood encountered with processing plantation grown eucalypts for solid wood products could be reduced by extending the rotation length from say 5-10 years to 25-35 years, to produce larger diameter logs. The growth stress gradients are usually steeper in smaller diameter logs so processing problems are less likely with larger diameter, older logs (Jaako Pöyry 2002). However, the economic penalties to growers, particularly those in China and Vietnam, from significantly increased rotation time are obvious.

3.3 Project approach

The project aimed to improve the sawnwood recovery and quality from small (< 30 cm small end diameter) plantation grown eucalypts in the participating countries by selecting and developing more appropriate systems of sawing and drying. It endeavoured to understand the factors that are likely to affect application of specific technologies from both an engineering, biological and financial point of view, with the aim of maximising returns to tree growers and processors.

3.3.1 Justification

This research topic was given high priority in ACIAR Consultations in China (“High value products from eucalypt plantations, through improved germplasm and cultivation techniques and optimised processing and utilisation techniques”) and Vietnam (“Processing and utilisation of wood, including small-scale processing, wood preservation, sawing technology and wood composites”). The project aligns well with ACIAR priorities (“continue to increase emphasis on post-harvest processing and marketing research”) in that it contributes to small rural industry development and value-adding post harvest. It also contributes to development of the plantation forest resources in China and Vietnam where most of the resource is community owned, and in Australia where there is now a high proportion of the eucalypt plantation estate under farmer ownership.

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[1] *Professor Josė Tarscisio da Silva Oliveira, Federal University of Espírito Santo, Brazil*

[2] *Professor Xu Feng, Guangxi University, Guangxi, China*

3.3.2 Research Strategy

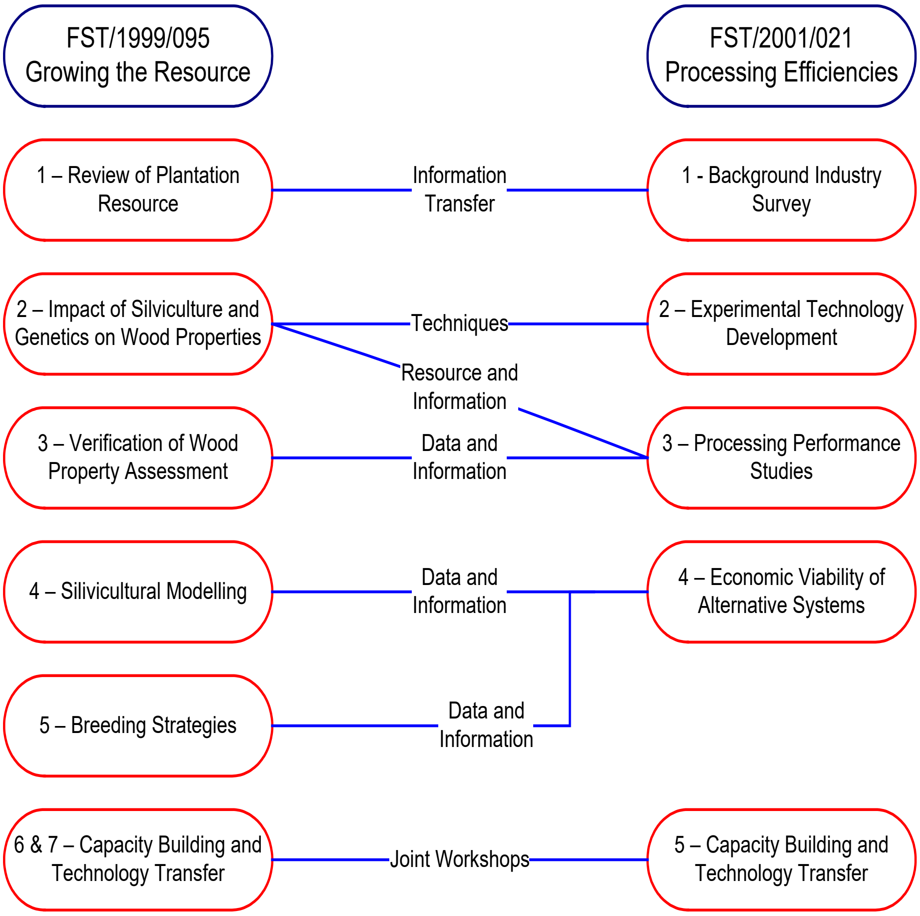
There has been little rigorous research on the improvement of processing technology to mitigate problems of growth stress release, particularly for the young eucalypt plantations in developing countries. Where information from research exists, it is mostly unpublished and only available as personal communication. While some processing trials have been reported (e.g. Hopewell 2002), these have been unsystematic, and lack specifics about wood quality and the processing system used. Results from these trials are difficult to interpret and compare, and few conclusions can be drawn. This is particularly the case where different product grading systems have been used. However, it is clear that conventional sawing systems have serious limitations in processing young eucalypts (Jaako Pöyry 2002) and that new approaches are needed to improve product recovery and quality and reduce processing costs, particularly for small diameter logs.

The core research activities of this project were to determine the lower age, diameter and growth stress limits to viable processing of eucalypts for solid wood using existing processing systems in China and Vietnam. The project established benchmarks for assessment of alternative and improved technologies to be tested. The applicability of modern linear type sawing systems coupled with appropriate drying methods have been trialled and experimental sawing patterns applied, using more conventional systems, across a range of log diameters to assess their effectiveness at mitigating problems of growth stress release. In all of the trials the product grading methods and evaluation methods were standard. This allowed comparison between processing trials of different species across the three countries.

3.3.3 Related Projects

FST 2001/021 was conducted in partnership with FST 1999/095 which, for many of the sub-projects, supplied log samples and data collected in the field. The aim of FST 1999/095 was to improve the social benefits and economic returns from eucalypt plantations by implementing silvicultural regimes and genetic material to improving wood properties, reducing growth stresses and optimise yields of high-quality timber from eucalypt plantations in China, Vietnam and Australia. The log samples supplied often could be used to assess the genetic and silvicultural effects on wood quality and processing performance.

Improving the value chain for plantation-grown eucalypt sawn wood in China, Vietnam and Australia



4 Objectives

The overall aim of the project was to improve the sawnwood recovery and quality from small plantation grown eucalypts in China, Vietnam and Australia by selecting and developing more appropriate systems of sawing and drying.

The project was implemented through a series of sub-projects the results of which were documented in 8 technical reports. Each of the reports has specific objectives, however, they each contributed partially to one or more of the following overall project objectives. The objectives of FST 2001/021 were:

a. In mills in China and Vietnam assess potential for improvement in solid wood processing performance, product quality and value.

b. In mills in Australia assess the potential for application of the state-of-the-art linear flow processing systems and their potential impact on log value.

c. Model mill door prices for logs to assess the potential for optimised processing and compare reciprocating and linear flow sawmills.

d. Assess the potential for field assessment strategies to improve processing performance, product quality and value.

The collaborative work with FST 1999/095 provided log samples and field data which were used to assess the additional objective of:

e. Genetic and silvicultural effects on wood quality and processing performance.

The reports contribute to the objectives as follows:

Objective a: Reports 2, 3 and 4.

Objective b: Reports 5, 6 and 7.

Objective c: Report 8.

Objective d: Reports 1, 2, 3, 4, 5, 6 and 7.

Objective e: Reports 1, 2, 4, 5, 6, 7.

5 Methodology

The work in FST 2001/021 comprised a series of subprojects (processing studies) that evaluated solid wood processing performance in commercial mills located in China, Vietnam and Australia. The mills applied a range of processing technologies with a number of species of plantation-grown eucalypt logs supplied by FST 1999/091. The logs were obtained from trees evaluated in the field to assess silvicultural and genetic effects of characteristics likely to affect solid wood processing. Where possible, in addition to establishing critical limits to growth stresses, tension wood, branch related defects and log quality, the sub-projects in FST 2001/021 tested silvicultural and genetic effects on processing performance.

The methods of the subprojects are detailed in full in each of the eight technical reports produced (listed in Section 10.2). The methods have been summarised below to reflect their contribution to meeting the project objectives.

5.1 Objective a: In mills in China and Vietnam assess potential for improvement in solid wood processing performance, product quality and value. (Reports 2, 3 and 4)

The greatest challenge with this objective was to locate and use appropriate sawing equipment and wood drying facilities for processing plantation-grown eucalypts. In particular, the sawing equipment had to be capable of mitigating the adverse wood behaviour associated with growth stress release. These adverse effects included; (i) poor sawing accuracy resulting in variable board thickness, width variability and non-uniformity of growth ring alignment, and sawn boards where the radial distance from the pith varies along the board length; (ii) board deflection (spring and bow), (iii) log and board end-splitting, and; (iv) subsequent drying problems associated with poor sawing accuracy and other inadequacies of the sawing process.

Locating suitable sawmills proved very difficult in China for the first sub-project. This was with a single clone of *E. urophylla x grandis* from a spacing trial at Dongmen. In this case a sawmill could not be located and sawing was eventually abandoned in favour of peeling veneer. This resulted in an immediate substantial broadening in the scope of the FST 2001/021. In the subsequent two sub-projects, a single horizontal band saw and a single vertical band saw were located in Vietnam (*E. urophylla*) and China (*E. dunnii*) respectively. Both mills had capacity for log rotation and the vertical bandsaw was equipped with a carriage and fence for sizing, allowing a conventional back-sawing strategy to be applied. Plantation locations, age, silvicultural history, mean log diameter and length are given in Table 1 and processing methods in Table 2.

Table 1: Plantation location, age, silvicultural history and mean log diameter for the Chinese and Vietnamese processing trials.

Species	Location	Age	Silviculture	Mean log diameter	Log length
E. urophylla x grandis (single clone)	Dongmen China	12 y	Various spacing Single fertilizer treatment Unpruned	15.0 – 19.7 cm (range for spacing treatments)	1.3 m
E. urophylla (various families)	Ba Vi Vietnam	10 y	Single thinning treatment Single fertilizer treatment Unpruned	22 cm	2.6 m
E. dunnii (2 provenances)	Liuzhou China	17 y	Single thinning treatment Unpruned	23.4-26.3 cm (means for two log grades)	2.6 m

Table 2: Processing methods for the Chinese and Vietnamese processing trials.

Species	Sawing / peeling	Target products	Drying	Drying experimentation
E. urophylla x grandis	Splindle-less lathe	Internal plywood sheets	Veneer dryer	Nil
E. urophylla	Horizontal band saw Cutting pattern 1: through and through strategy Cutting pattern 2: experimental back-sawing strategy	Short length boards for furniture	Air-dry and kiln dry without reconditioning	Small sub-sample steam reconditioned in Australia
E. dunnii	Vertical band saw with log carriage. Cutting pattern: conventional back-sawing strategy	Short length flooring	Air-dry, steam recondition (kiln modified) and kiln dry	Two matched samples with & without steam reconditioning

5.1.1 Procedure

The following procedures were applied (standard procedures for the three sub-projects unless indicated otherwise):

- Trees were selected if they could supply logs with sweep restricted to 20%. i.e. sweep ≤ 20% of mid length diameter over any 2.4 m length.
- Log diameter range selected to meet the requirements of the processing systems.
- Log diameter, taper, sweep, visible surface defect and log end-split severity were recorded for each log.
- Except for some experimentation the processing followed normal mill processing methods to produce the normal target products.
- Product grading: for peeled veneer the Australian/New Zealand Standard for structural veneer was applied. For sawn products the CSIRO Appearance Product Assessment Criteria was applied to meet the requirements for the respective normal end products of the mills.
- Individual veneer sheets were valued using market prices supplied by the Dongmen veneer mill. Individual boards were valued at approximate international price for hardwoods.
- Veneer sheets: end-split length was recorded.
- For sawn boards: In green and dry boards; board end-split length, spring and bow and product with and thickness were recorded. In dry boards; surface check length was recorded in both sub-projects and internal check occurrence and number at mid-length in the *E. dunnii* in China.
- The grade limiting defect and next less severe defect were recorded to simulate pruning and improved drying performance in all sub-projects.
- Product recovery and value were calculated for individual logs.
- Log features, including log end-split severity, were used to determine their impact on product quality, recovery and value.

5.1.2 Experimentation

For the two sub-projects in sawmills the following experimental procedures and practices were applied:

- *E. urophylla*, Vietnam: A standard sawing strategy was applied to 50% of the logs and an experimental strategy which required manual log rotation applied to the other 50% of the logs. This experiment aimed to determine the impact of modification of sawing strategies on board end-split severity.
- *E. urophylla*, Vietnam: As steam reconditioning was not available in Vietnam a small sub-sample of boards was steam reconditioned in Australia to determine the likely effect of commercial application of steaming in China and Vietnam. Changes in dimensions and board shape were recorded.
- *E. dunnii,* China: As the experiments in Australia indicated that steam reconditioning was warranted in *E. urophylla,* and it was known that *E. dunnii* was collapse prone, a semi-commercial steam reconditioning treatment was applied to half of the boards produced. The reconditioning treatment was applied at a mean moisture content of 15%. The kiln was modified to apply the steam treatment. Changes in board dimension, shape and recovery were recorded.
- Conventional shrinkage blocks were prepared to compare shrinkage properties and collapse recovery between boards and shrinkage blocks.

5.2 Objective b: In mills in Australia assess the potential for application of state-of-the-art linear flow processing systems and their potential impact on log value. (Reports 5, 6 and 7)

While many of the experimental and monitoring procedures were the same, the research conducted in Australia had a different approach to the research in China and Vietnam. Collaboration with Forest Enterprises Australia (FEA) and NF Mc Donnell & Sons meant that modern linear flow processing systems (where the wood flow is only in one direction) could be applied in three major experiments.

The background and justification for developing this multi-industry collaboration in Australia is outlined in the subproject report (Report 5: Genetic variation in growth stress related wood behaviour of small diameter *Eucalyptus nitens* logs processed with a Hewsaw R250 Sawmill).

Conventionally, eucalypts have been processed with reciprocating flow sawmills (as was the case with the sawmill sub-projects in China and Vietnam, with rudimentary saw equipment) where either, logs and flitches are moved backwards and forwards through a stationary saw, or a saw is passed through a stationary log. These systems often have a single-saw or sometimes twin-saw, log break-down systems.

Linear flow sawmills are more commonly associated with the softwood sawmilling industry. They use multi-saw technology coupled with chippers to process logs. Many have capacity to produce cutting patterns that will potentially relieve growth stresses symmetrically around logs, and therefore mitigate the adverse effects of growth stress release in hardwoods. In the softwood industry they have developed to reduce the cost of processing sawn wood, mostly through improved economies of scale, achieved primarily through high material flow rates. They have similar potential for high material flow rates in uniform diameter and quality eucalypt resources. These three sub-projects in Australia aimed to assess the potential of one major type of linear flow sawmill, the HewSaw R250 and R200, to process eucalypts. A diagrammatic representation of the HewSaw R250 and the material flow direction is shown in Figure 1.

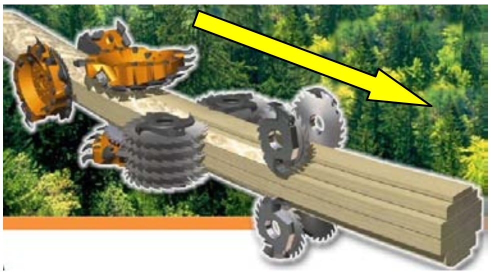


Figure 1. Diagrammatic representation of the internal workings of the HewSaw R250 showing the material flow direction.

The features of most importance in Figure 1 for growth stress release are:

- Firstly precision chippers remove wood and produce a sawn face on the top, bottom and sides of the cant.
- Multisaws coupled with chipper-edging units saw boards and profile the corners of the cant.
- Finally board chipper-edgers following the multi-saws complete the profile.

The three species and plantations used in the experiments were *E. nitens* from southern New South Wales, *E. pilularis* from northern New South Wales and *Corymbia citriodora subsp variegata* from Queensland. Plantation locations, age, silvicultural history, mean log diameter and length, are given in Table 3 and processing methods and experimentation in Table 4.

Table 3: Plantation location, age, silvicultural history and mean log diameter for Australian processing trials.

Species	Location	Age	Silviculture	Log SED diameter	Log length
E. niten (4 provenances)	Tumut, NSW	17 y	Unthinned Unpruned	22.0–32.0 cm	5.0 m
E. pilularis (12 provenances)	Taree, NSW	9 y	Unthinned Unpruned	12.5-21.5 cm	3.7 m
C. citriodora subsp variegata (8 provenances)	Tairo, Qld	7.5 y	Unthinned Unpruned	10.0-15.7 cm	3.7 m

Table 4: Sawing method, target product, drying and experimentation in Australian processing trials.

Species	Sawing machine	Target products	Drying	Experimentation
E. nitens	HewSaw R250 Three cutting patterns	25 mm thick boards	Not assessed	Test the effect of depth of chipper cuts and log diameter on board deflection
E. pilularis	HewSaw R200 Three cutting patterns	FEA structural and decking product	FEA standard hardwood air-dry and kiln drying with reconditioning	Test the effect of depth of chipper cuts and log diameter on board deflection
C. citriodora subsp variegata	Hewsaw R200 One cutting pattern	FEA structural and decking product	FEA standard hardwood air-dry and kiln drying with reconditioning	Test the effect of depth of chipper cuts and log diameter on board deflection

5.2.1 Procedure

Generally standard procedures were applied in the three sub-projects in Australia and in most cases they were as applied in China and Vietnam (summarised in Section 5.1.1). The major differences were:

- The *E. nitens* experiment measured green material behaviour only.
- Sweep restrictions were reduced in the *E. pilularis* and *C. citriodora subsp variegata*.
- The product from *E. nitens* was not dried nor graded. FEA graded the boards from the *E. pilularis* and *C. citriodora subsp variegata* using their own product grading standards.
- For *E. pilularis* and *C. citriodora subsp variegata* mill door log values were modelled using CSIROMILL.

5.2.2 Experimentation

Experimentation mainly focussed on the effect of depth of chipper cuts, log diameter and growth stress severity on board deflection and end-splitting.

5.3 Objective c: Model mill door prices for logs to assess the potential for optimised processing and compare reciprocating and linear flow sawmills. (Report 8)

Due to the small log diameter, poor log quality and recovery and low Mill Door Prices for logs for the *E. pilularis* and *C. citriodora subsp variegata* in Australia, it was recommended that mill door prices be remodelled with optimised log quality and processing methods.

To do this, two sawing systems capable of sawing around the pith, so boards containing the pith could be segregated, and the expected bow in boards could be catered for, were selected for modelling. These were a modern twin saw reciprocating flow sawmill and a linear flow sawing line based on a new HewSaw SL 250 PLUS trio line.

The logs used were pruned logs of *Corymbia spp.* Recoveries and product values were obtained from live processing trials conducted in a comparable project to FST 2001/021, funded by the Rural Industries Research and Development Corporation in Australia.

As a result of the final workshops in Vietnam and China for FST 2001/021, it was also decided to use the product values obtained from the sawing sub-projects in Vietnam and China to model mill door prices to demonstrate outcomes for those countries, given development of pruned eucalypt resources and optimised processing strategies.

5.3.1 Procedure

The methods of calculation for the Australian pruned *Corymbia spp* are outlined in detail in Report 8. In the case of the *E. urophylla* from Vietnam and the *E. dunnii* from China the modelling is only reported in this summary.

The modelling of the *E. urophylla* and the *E. dunnii* followed identical methods for the pruned *Corymbia* processed with the reciprocating flow sawmill. The same assumptions were applied to calculate the value of wood chip, sawdust and bark, and these were added to the value of sawn wood calculated and given in Reports 3 and 4. The operating and capital costs were left unaltered, so they are directly comparable with the pruned *Corymbia.* This means the results are based on Australian costs and will probably underestimate mill door prices slightly in China and Vietnam because of lower wage rates, while capital and other operating costs are likely to be similar.

5.4 Objective d: Assess the potential for field assessment strategies to improve processing performance, product quality and value.

The displacement measurement associated with release of longitudinal growth stress (LGS displacement) and a range of other field assessment strategies (summarised in Table 5) were applied to standing trees, and on one occasion harvested logs, with the objective of assessing their effectiveness in predicting wood processing performance. The main aim of this was to attempt to find low cost evaluation tools that would limit the need to conduct processing experiments.

The non-destructive standing tree evaluations were; LGS displacement, Pilodyn pin penetration, grain angle, radial crown dimensions, DBHOB and acoustic wave velocity. A 12 mm full diameter increment core was removed for wood density estimation and SilviScan analysis.

On the upslope and down slope side of each tree a bark window, approximately 100 × 50 mm (longitudinal × horizontal), was opened using a mallet and chisel in the closest inter-whorl space below breast height (1.3 m). The bark windows were first used to measure LGS displacement, Pilodyn pin penetration and grain angle.

5.4.1 Longitudinal growth strain displacement (LGS displacement)

Two LGS displacement measurement methods were used: The CIRAD Foret a French method (Figure 3) and an HBM Type DD1 extensometer a German method (Figure 2).

The German method used a HBM Type DD1 extensometer Ranger 2100 model. The strain gauge pins were vertically inserted into the fresh wood, and the longitudinal stress released using a hand saw by carefully making cuts 15-20 mm above and below the pins to a depth of approximately 10–15 mm or until strain release readings stabilised.

Figure 2. The German method: the HBM Type DD1 extensometer strain gauge in position on the tree stem while cuts are made to release growth stresses.

The French method consists of an electronic gauge with mechanical sensors attached on a metal frame. After the removal of a bark window, approximately 200 x 100 mm, the frame is strapped around the tree. The nominal distance between two pins, which are punched into the wood surface, is 45 mm. A hole is drilled between the sensors and the frame (mid-distance between two pins), which releases the longitudinal stresses. The electronic gauge measured the change in distance between two pins (the LGS displacement).

Figure 3: The French method: CIRAD-Foret strain gauge positioned on the stem of *E. nitens* before and after drilling the hole.

5.4.2 Pilodyn pin penetration (PILODYN)

A 6 Joule Pilodyn fitted with a 2.0 mm diameter pin was used to obtain pin penetration readings.

5.4.3 Spiral grain of outer wood

Spiral grain of the outer wood was measured using a Spirolite digital measurement tool, designed and manufactured in New Zealand.

5.4.4 Acoustic wave velocity (AWV)

Acoustic wave velocity (AWV) was measured using a FibreGen ST300 or the Fakopp stress wave timing tool. The FibreGen method places probes in the stem of the tree at around 0.3 to 0.4 m and about 1.2–1.5 m above ground. The probes are positioned to avoid branches and visible knots and aligned longitudinally. The Fakopp method uses a readily available hand held stress wave timing tool which measures the stress wave time between start and stop transducers.

5.4.5 SilviScan analysis

The full diameter core sample was cut into 2 radial cores and the upslope radius was analysed with SilviScan-3 using standard methods. The mean density (at approximately 8% MC), microfibril angle (MFA) and predicted modulus of elasticity (MOE) were calculated.

5.4.6 Canopy description

The extent of the canopy was measured using a prototype Queensland-made periscope device. The crown periscope allows the operator to line up a set of crosshairs on the crown perimeter viewed though a mirror mounted at 45˚ within the periscope tube. When the crown perimeter is aligned the distance from the middle of the stem diameter to the middle of the periscope was measured in centimetres using a tape measure.

Table 5. Assessment strategies applied in the field on trees and harvested logs supplied to FST 2001/021 for processing experiments

	E. nitens	*E. urophylla x grandis*	*E. urophylla*	*E. pilularis*	*CCV*	*E. dunnii*
LGS DISPLACEMENT[1]						
Method	Cirad Foret strain guage[2]	HBM type DD1 extensometer strain guage[3]	HBM type DD1 extensometer strain guage	HBM type DD1 extensometer strain guage	HBM type DD1 extensometer strain guage	Cirad Foret strain guage
Location	Tree breast height	Tree breast height	Tree breast height	Tree breast height	Tree breast height	Tree breast height
Orientation	NW and SE	Along/across rows	Upslope/downslope	Upslope/downslope	Upslope/downslope	Upslope/downslope
Individual measurement			Yes	Yes	Yes	Yes
Mean measurement	Yes	Yes	Yes	Yes	Yes	Yes
Acoustic Wave Velocity						
Method	Fakopp	Fakopp	Fakopp	Fakopp	FibreGen/Director	Fakopp
Location	Standing trees	Standing trees	Standing trees	Standing trees	Standing trees/logs	Standing trees
PILODYN						
Location	Standing trees	Standing trees			Standing trees	
Orientation	NW and SE	Along/across row			Upslope/downslope	
TREE HT:DIAM		Yes				
SLOPE OF GRAIN		Yes			Yes	
SILVISCAN 3						
Microfibril angle (MFA)				Core mean	Core mean	
Density				Core mean	Core mean	
MOE				Core mean	Core mean	
CANOPY SYMMETRY					Yes	

[1] Longitudinal growth stress displacement measurement [2] French method [3] German method

5.5 Objective e: Genetic and silvicultural effects on wood quality and wood processing performance

5.5.1 Opportunities to assess genetic and silvicultural effects

While FST 2001/021 did not intend to specifically assess genetic and silvicultural effects on sawn wood quality, a number of opportunities emerged from the log samples provided to the project that allowed a limited assessment. In addition, the research described in Report 1, included a screening for tension wood in an *E. globulus* thinning and fertiliser trial. Table 6 gives the species, locations, ages and the genetic and silvicultural treatments that were assessed.

Table 6. Species, location, age and genetic and silvicultural treatments.

Species	Location	Age	Genetic and silvicultural treatments
E. globulus	East Gippsland, Victoria	13 y	3 spacing treatments, fertilizer and no fertilizer
E. urophylla x grandis	Dongmen, China	12 y	Single clone, 6 spacing treatments
E. dunnii	Liuzhou, China	17 y	2 provenances
E. nitens	Tumut, NSW	17 y	4 provenances
E. pilularis	Taree, NSW	9 y	12 provenances
C. citriodora subsp variegate	Tairo, Qld	7.5 y	8 provenances

6 Achievements against activities and outputs/milestones

Objective a: In mills in China and Vietnam assess potential for improvement in solid wood processing performance, product quality and value.

no.	activity	outputs	Outcomes/ milestones	comments
1.1	Assessed veneer quality and value from *E. urophylla x grandis* logs obtained from six spacing treatments on the Dongmen Forest Farm in southern Guangxi, China.	Identified standing tree measurements relating to recovery & product value. Greater understanding of spacing treatments and their ability to improve returns to processors and growers	No Direct outcome indentified in China. Further research and development in China and Vietnam is required to assist the realisation of this improvement.	Locating suitable sawmills proved very difficult in China. In this case a sawmill could not be located and sawing was eventually abandoned in favour of peeling veneer. This resulted in an immediate substantial broadening in the project scope.
1.2	Assessed field measurements in predicting log characteristics and solid wood processing performance for thinned unpruned stand of E.urophylla in Vietnam.	Identification of processing and silvicultural methods with scope for improving recovery and general product value.		LGS displacement and AWV were only moderately useful in prediction of growth related log and board characteristics.
1.3	Processing sawn wood from thinned unpruned 17-year old E.dunnii in China	Further indentified scope for improvement in product quality.		Application of steam reconditioning in both boards and shrinkage blocks indicated the treatment would reduce cupping and increase board width, thickness and product recovery. Reduction in the percentage of boards affected by severe defects will occur if logs were; larger; branches were pruned; and, termites controlled.

Objective b: In mills in Australia assess the potential for application of state-of-the-art linear flow processing systems and their potential impact on log value.

no.	activity	outputs/ milestones	completion date	comments
2.1	Assessed the effect of depth of chipper cuts, log diameter and growth stress severity on board defection and end-splitting.	Identified areas for further research; Better understanding of the affect of sawing patterns on sawn board behaviour.		Completed
2.2	Undertook regression modelling	Identified potential predictors of recovery.		Completed
2.3	Sawing and drying trials	1. Identified potential improvements in sawing performance and log and board end splitting through genetic selection, harvesting and log handling techniques; 2. Indentified relationships between field measurements and processing characteristics.		Completed Completed

Objective c: Model mill door prices for logs to assess the potential for optimised processing and compare reciprocating and linear flow sawmills.

no.	activity	outputs/ milestones	completion date	comments
3.1	Conducted a comparison of mill door prices with two sawing systems	Identified potential increase in mill door prices through the adoption of pruning and linear sawing systems.		Further evaluation would be of value to determine the returns to growers given the potential mill door prices and the costs of harvest, transport and plantation silviculture in China, Vietnam and Australia.

Objective d: Assess the potential for field assessment strategies to improve processing performance, product quality and value.

no.	activity	outputs/ milestones	completion date	comments
4.1	7 sawing and drying trials established and assessed	Completed in China, Vietnam and Australia	2005/06	Completed
	Identified low cost evaluation tools (field assessment) to standing trees.	Field assessment data were not significant indicators of recovery or product value.		Given the possible presence of tension wood it would be valuable to establish sound detection methods for future research.

Objective e: Genetic and silviculture effects on wood quality and wood processing performance.

no.	activity	outputs/ milestones	completion date	comments
5.1	Assessed spacing, fertiliser and genetic effects.	Identified opportunity for resource improvement with limited impact on the economics of processing.		Further investigation is warranted in species that readily form tension wood given its impact on processing.

7 Key results and discussion

The results of the subprojects are detailed in full in each of the eight technical reports produced. The results have been summarised below to reflect their contribution to meeting the project objectives.

7.1 Objective a: In mills in China and Vietnam assess potential for improvement in solid wood processing performance, product quality and value. (Reports 2, 3 and 4)

7.1.1 *E. urophylla x grandis*, China

Given the values of veneer and processing costs provided by the Dongmen veneer mill the results suggest good profitability for growing and processing logs for internal grade veneer. However, it would be of value in future work to model production costs taking into consideration the capital and operating costs of new equipment to validate this finding. A procedure for doing this is outlined in Reports 6 and 8.

Table 7 gives the approximate veneer prices (at August 2007) at the mill door and free of taxes for northern Vietnam and southern China (Nguyen Quang Trung, Forest Science Institute of Vietnam, personal communication). The price for structural grade hardwood veneer steadily improves with grade to a maximum of 190 USD m^{-3} for A-grade veneer. The recovery of the higher grades of veneer were very low in this trial indicating that there was modest potential to improve the recovered product value with improved veneer quality. However, Table 9 also gives the price for appearance grade veneer. This is much higher than for structural grades at 304 USD m^{-3}. Therefore there is even greater potential to improve product value with the production of face grade veneer suitable for appearance applications.

Table 7: Approximate mill door veneer prices free of taxes for veneer producers in southern China and Vietnam in August 2007.

Veneer grade	USD m^{-3}
Face grade	304
A-grade	190
B-grade	161
C-grade	146
D-grade	146
Reject	117

While the production of appearance grade veneer requires that 0.7 mm thick veneer be produced, and the trials produced only 1.8 mm thick veneer, there is an opportunity to produce appearance grade veneers from plantation-grown Eucalyptus urophylla x grandis if the quality requirements can be met. Similarly, it would be possible to produce a greater proportion of higher quality structural grade veneers. The major limiting factors to production of either product were the presence of defects associated with branches (holes and green and dead knots) and in the case of appearance grade veneer the presence of splitting and buckling of the veneer sheets.

Despite the good results, the simulations of pruning indicated that there would be considerable scope for improved returns to processors and growers with pruning. As detailed in Report 2, 85-99 % of the veneer sheets produced had grade limiting defects associated with branches and recorded as either (or a combination of) holes, green knots or dead knots. These defects were of a severity that restricted most sheets to Grade D or lower. They were also of similar severity for each of the spacing treatments and log heights. In the case of appearance grade veneer the branch related defects were just as important.

The processing related defects of veneer splitting and buckling that would potentially limit the production of appearance grade veneer were not quantified because the grading methods did not record these defects. However, they were common and present on most veneer sheets. This degrade was caused either during peeling, handling or drying. If appearance grade veneer were to be produced in large quantities there would need to be an alteration to the processing methods. These modifications should include pre-heating of logs with a steam box or water bath, application of conveyors to move veneer away from the peeling machines and load and unload kilns, and application of kilns with greater control of drying conditions and with racks or rollers that restrain the veneer to prevent buckling. In addition, there would need to be reductions in log end splitting or modification of log handling and merchandising practices to limit log end-splitting.

The greatest returns would be through a combination of pruning, reduction in log end-split severity, improvement in processing techniques and production of appearance grade veneer. Further research and development in China and Vietnam is required to assist the realisation of this improvement.

7.1.2 *E. urophylla,* Vietnam

In comparison to *E. dunnii* in China, the recovery and product value from sawing trials were good. Despite reduced end-splitting with the experimental back-sawing strategy, recovery and product value were not significantly different between sawing methods. This was attributed to the docking and ripping strategy that was applied during product evaluation to replicate processing methods in the mill. This produced short length and narrow boards.

However, there is considerable scope for improvement in recovery and general product value by improving board length, width and thickness:

- Reduction in the severity of board end-splitting with back-sawing will increase board width - and to a minor extent length.
- Reductions in knots by pruning will improve board length – and to a minor extent width.
- Steam reconditioning experiments in boards and shrinkage blocks indicated that the application of steam reconditioning will increase board width and thickness, and reduce the necessity to rip during processing of excessively cupped boards.

7.1.3 *E. dunnii,* China

As indicated above, the recovery and product quality from sawing trials was relatively poor compared to the *E. urophylla* in Vietnam. This possibly reflects species and site differences. Drying defects were severe in un-reconditioned boards and the pith was common in boards and occasionally produced severe drying defects that could not be reduced with stream reconditioning. Termite damage and wane were also major defects.

Once again there is considerable scope for improvement in product quality:

- Application of steam reconditioning in both boards and shrinkage blocks indicated the treatment would reduce cupping and increase board width, thickness and product recovery.
- Reduction in the percentage of boards affected by severe defects will occur if logs were; larger; branches were pruned; and, termites controlled.

7.2 Objective b: In mills in Australia assess the potential for application of state-of-the-art linear flow processing systems and their potential impact on log value. (Reports 5,6 and 7)

7.2.1 Board end-split severity and deflection

In each of the sub-projects board end-splitting and deflection were common. However, board end-split severity had minor impact on product recovery after they were docked. Board deflection in the form of bow was the most important board deflection issue. Spring was a less severe problem and had almost no impact on material flow or product value.

Prediction of spring and bow in green and dried boards

The results of regression analysis to predict bow and spring in green and dried boards are given in Report 6. The results presented are restricted to the outer boards only (i.e. those located at the top and bottom of the central cant closest to the log periphery where spring and bow are likely to be maximized). This simplification of results was partly because bow in green boards was only assessed in the outer boards in several logs and where data was available for all boards the regression results were similar to those of the outer boards only.

In green boards, LGS displacement upslope and mean SED were significant predictors of bow. This result for LGS displacement upslope is consistent with previous work in FST 2001/021.

For bow in dried boards, AWV, mean SED and log sweep were significant predictors, and for spring in dried boards mean SED and log sweep were significant, although the regression was weak ($R^2 = 0.09$). LGS displacement was not significant when it was tested indicating it was restricted in its predictive power, while AWV has wider application.

The results also indicate the importance of log geometry on board behaviour irrespective of longitudinal peripheral growth stresses. In summary, as diameter increased bow and spring declined; and as sweep increased bow declined and spring increased. This phenomenon is partly attributable to the sawing method. As was found in the earlier work with *E. nitens* (Washusen *et al.* 2007b), within each sawing pattern, as log diameter increased the depth of the chipping increases, producing a tendency for bow to decline in green boards. This may also be the case for spring, however this could not be tested as spring was only measured in dried boards.

Why bow would decline as sweep increased is unknown, however given the weakness of the regression, the result should be viewed with caution.

There was evidence that the depth of the chipper cuts could be used to reduce bow. However, the severity of bow produced in each of the three subprojects was unlikely to cause major material transport problems on conveyors, and other board handling systems designed to cater for hardwood boards. At the conclusion of drying, bow was no longer a problem and therefore had little impact on the viability of processing.

It is recommended that future experiments be conducted to determine the maximum bow threshold for a range of board transport systems. This may simply be achieved by drying a range of bow severity into boards and studying their behaviour on board conveyors and stacking equipment. Simple solutions may be to extend lugs on conveyors and opt for tray sorters.

The results generally support the hypothesis that, the cutting pattern applied by the HewSaw R250 and R200 machines on young eucalypts will release growth stresses symmetrically around log and mitigate the adverse effects of growth stress release. The most important of these adverse effects is spring and board end-splitting, which may potentially impact on recovery and product value. It was not possible to obtain data that could be used to estimate the extension of end-splits in logs during processing. However, a comparable study conducted by the CRC for Forestry in a conventional single saw sawmill (Washusen 2007) indicated that losses due to docking end-splits may be reduced with application of the HewSaw R250. This was attributed to the capacity for the mill to process logs at a much greater length than is possible with conventional hardwood systems. It may also be due to extension of end-splits during milling on single saw systems because of asymmetrical growth stress release.The sawing patterns for E. Pilularis were set up to chip off relatively large amounts of wood at the top and bottom of the centre cant creating lower recoveries than those reported by Washusen et al (2007 b) for E. nitens. The recovery and overall product value could be improved with careful segregation of logs into tighter diameter classes and application of sawing patterns that could recover additional boards.

7.2.2 Recovery and log quality and the impact of sawing patterns.

In agreement with the finding above, and as found with the sub-projects in China and Vietnam, the regression models produced in each of the three sub-projects in Australia indicated that log end-split severity was not a significant predictor of recovery.

In the case of *E. pilularis* and *C. citriodora subsp variegata* log diameter and taper were significant predictors of recovery; and SED was the only significant predictor of product value.

This is understandable given the uniformly poor product quality. That is, board volume and quality were generally consistent within each sawing pattern (Figure 5), so as SED and taper increased log volume increased and hence the recovery as a percentage of log volume declined. Also, as product value per unit volume was uniformly low, as SED increased product volume increased across the sawing patterns (Figure 4).

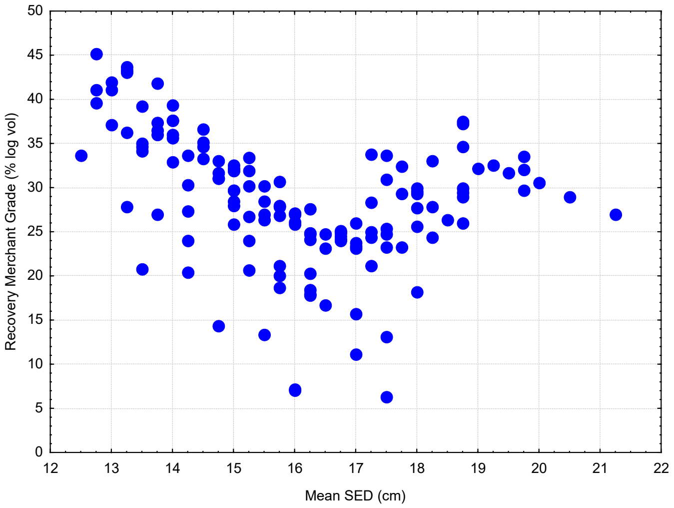


Figure 4. Recovery of merchant grade plotted against mean SED (Washusen 2008).

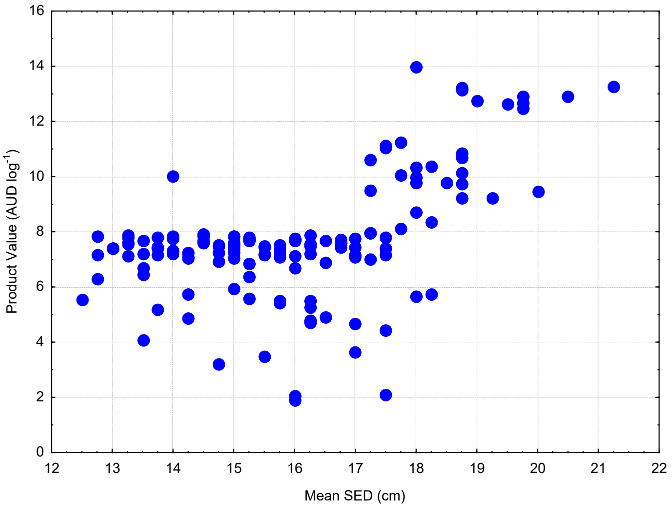


Figure 5. Product value per log plotted against mean SED (Washusen 2008).

This is consistent with work in *E. pilularis* (Washusen *et al.* 2008) where similar processing methods were applied. However, on this occasion as log diameter increased recovery increased. This is understandable given that in the smallest logs the boards from the upper and lower part of the sawing pattern were sometimes not recovered.

As with the work in China and Vietnam, this clearly indicates the need to increase log diameter and reduce taper in processed logs even for this specialist small log processing system.

To give an indication of the importance of sweep, Figure 6, Report 6 (Washusen 2008) plots sweep against mean SED and 10% sweep is plotted over the data (maximum sweep of 10% = sweep ≤ 10% of mid diameter in any 2.4 m length. This analysis assumes sweep is uniform for the entire 3.7 m length of the log). The sweep ranged from 0-80 mm and approximately 70% of the logs had sweep exceeding 10%. Sweep produces wane on boards if the saws cannot curve saw effectively to follow the sweep. In the case of heart related defects, the pith also is not central and tends to wander so that it is often exposed on board surfaces. At greater than 10% sweep these defects would become increasingly common.

Sweep may also have contributed to bow because wane indicates that the depth of cut from the chippers was very shallow at some point along the log length. Thus the stress release varied along the log length.

It is important to note that during tree selection the worst sweep was avoided; and in some cases where sweep was apparent, logs were cut from above the worst section of the stem. In addition, during log scanning and segregation at the mill prior to sawing, 10 logs were rejected because sweep exceeded the mill requirements. Clearly excessive sweep was a major log quality problem in this plantation.

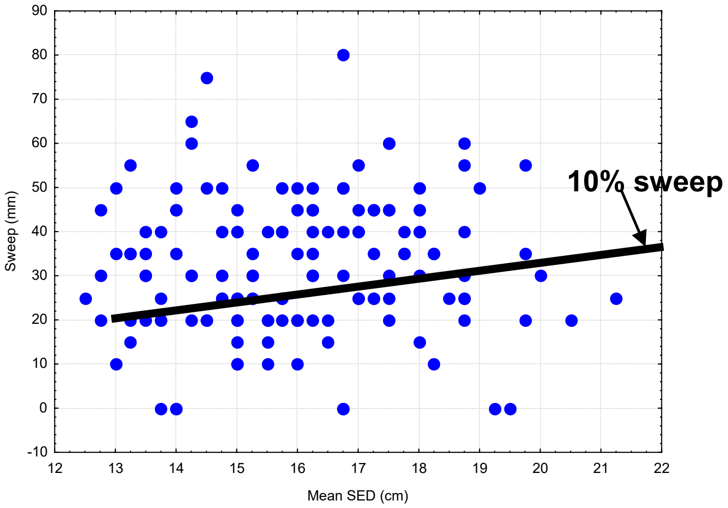


Figure 6. Sweep plotted against mean SED with 10% sweep plotted over the data..

The small diameter and excessive sweep in logs also contributed to poor quality of boards produced. While knots were a common defect, the other most important defects were wane and drying defect associated with the pith. These latter two defects were present on a very large percentage of boards because of excessive sweep.

While increasing log diameter and reducing sweep and taper will improve results, these poor results can also be partly attributed to the sawing methods applied and to the cutting pattern of the HewSaw R200. As this mill did not have “scan and set” capability logs require segregation into diameter classes for processing. Segregation into tighter diameter classes and application of more specific cutting patterns would increase recovery. Such segregation is difficult and expensive in small processing experiments.

The other major change to the sawing that would improve results is to alter the cutting pattern indicated in Figure 1, to saw around the pith, so it can be isolated. This requires the addition of extra components in the sawing line, so that the centre cant can be turned down.

7.2.3 Mill door prices

The mill door prices calculated with CSIROMILL reflected the very poor wood quality and recovery from the *E. pilularis* and *C. citriodora subsp variegata.* The modelling generally indicated poor viability for processing and growing.

Table 8. Estimated mill door log values for the *E. pilularis* logs processed in this research assuming log annual input of 180,000 and 260,000 m^3 $annum^{-1}$.

IRR for the sawmill (%)	Annual log intake (m^3)	Taxation rate (%)	Mill door price (AUD m^{-3} of log input)
10	180,000	30	26
15	180,000	30	13
20	180,000	30	1
10	260,000	30	42
15	260,000	30	32
20	260,000	30	22

Table 8 shows the maximum possible Mill Door log price for E.pilularis was AUD 42 per cubic metre of log input for 260,000 m^3 log intake. This is very low and indicates that growing would not be viable given that harvest and transport costs are likely to exceed this value. It is clear from this analysis that better log quality is required for profitable processing and growing.

Table 9. Estimated mill door log values for the *Corymbia citriodora* subsp.*variegata* logs processed in this research assuming log annual input of 180,000 and 260,000 m^3 $annum^{-1}$.

IRR for the sawmill (%)	Annual log intake (m^3)	Taxation rate (%)	Mill door price per cubic metre of log input
10	180,000	30	-13
15	180,000	30	-24
20	180,000	30	-35
10	260,000	30	3
15	260,000	30	-5
20	260,000	30	-14

Table 9 shows the maximum possible Mill Door log price for *Corymbia citriodora* subsp.*variegata* was AUD 3 per cubic metre of log input for 260,000 m^3 log intake. This is very low and much lower than reported for *E. pilularis* because higher product values were used on that occasion. The result indicates that processing and growing are unlikely to be profitable unless there is a substantial increase in board quality and/or value.

7.3 Objective c: Model mill door prices for logs to assess the potential for optimised processing and compare reciprocating and linear flow sawmills. (Report 8)

Table 10 gives the modelled mill door sawn timber prices (USD m^{-3}) for a sawmill with an IRR of 10% (using a conversion rate of USD 0.70 =AUD 1.00) comparing reciprocating and linear flow sawmills. In each case the linear flow sawmill was able to process substantially more wood each year and resulted in 40-50% increased mill door prices. There is also a substantial increase in predicted mill door prices for pruned sawlogs.

The results quantify the importance of log quality and processing efficiency. This analysis also gives some indications of the potential size of the resource (260,000 – 350,000 m^3/yr) required to supply a modern efficient sawmill in China, Vietnam and Australia.

Table10. Mill door log values in USD per cubic metre calculated with CSIROMILL at 10% IRR to the sawmills for likely log input per year for reciprocating and linear flow sawmills.

Species	Location	Age (y)	Mean log diameter (cm)	Log grade	CSIROMILL module	Log input (m^3 year $^{-1}$)	Mill door price (USD m^{-3})
Corymbia citrilidora subsp. Variegate (CCV)	Qld, Australia	7.5	12	Unpruned below grade	HewSaw R200	260,000	2
E. dunnii	Liuzhou, China	17	26	Unpruned D-grade	Reciprocating flow	40,000	22
E. pilularis	NSW, Australia	9	16	Unpruned below grade	HewSaw R200	260,000	29
E. urophylla	Ba Vi, Vietnam	10	22	Unpruned below grade	Reciprocating flow	40,000	32
Corymbia spp	WA, Australia	17-22	32	Pruned Grade-2	Reciprocating flow	50,000	91
Corymbia spp	WA, Australia	17-22	32	Pruned Grade-2	HewSaw SL250 Trio	350,000	147

Mill door prices per cubic metre of log input were approximately AUD 90-110 higher for the SL 250 150000 AD SG module for the most likely log throughput rates for both systems. The difference in log prices was due to reduced costs in all sectors of the mill, with greatest reductions in the sawmill. Costs attributed to sawing were AUD 14 and AUD 52 per cubic metre of log input for the linear and reciprocating system respectively.

The Mill Door prices were much higher from both systems than those reported for unpruned and unthinned *E. pilularis* modelled with H 200 PLUS 120000 AD BB module of CSIROMILL (Washusen *et al.* 2008).

With the adoption of linear flow sawing systems, and pruning to produce high quality sawlogs, the modelling indicates considerable potential to improve returns to growers producing logs with minimum SED of 30 cm.

The CSIROMILL modelling analysis, using data from processing of 7.5 year-old unthinned and unpruned plantation grown *Corymbia citriodora* subsp*. variegata* (spotted gum) logs from a genetics trial in Queensland with a HewSaw R200 coupled with commercial drying methods, indicated that processing of such logs is unlikely to be profitable. The predicted Mill Door price for logs indicated that it is unlikely that tree growing would be profitable unless there is some tree improvement, particularly in tree form and branching characteristics and increased tree (log) size. In the short term, the latter is more likely to result from increment achieved by tree age than by genetic improvement of young plantings.

7.4 Objective d: Assess the potential for field assessment strategies to improve processing performance, product quality and value.

Generally, the field assessment data were either not significant predictors of the processing characteristics measured, or they were unreliable in that for some species they were significant and for others they weren't.

7.4.1 Longitudinal Growth Stress displacement

The most consistent result was for Longitudinal Growth Stress (LGS) displacement measured on standing tress for prediction of log end-split severity. As shown in Table 11 for each species the measurement was not significant. The best result was for a single measurement from the upslope side of the stem (*E.pilularis, E. urophylla, E. dunnii* and *C. citriodora subsp variegata*) using either the 'French' or 'German' methods. In the case of *E. nitens* and *E. urophylla x grandis,* measurements were not taken on the upslope side of the stem. It would therefore be useful to test this further in future research to see if the trend is consistent across species. However, generally the regressions were weak and other less consistent predictors were needed in the models to produce useful results. Also, in the case of *E. nitens,* LGS displacement was a predictor of log end-split severity only at the large end of the log. For this reason the LGS displacement measurement is unreliable. The LGS displacement was also an unreliable predictor of processing performance (board deflection and end-splitting).

It would appear to be far more useful not to measure LGS displacement on standing trees, but rather to harvest trees and assess the effects of stress release directly on logs and boards.

The greatest value with LGS displacement measurements would be if a relationship could be established between measurements made on very young trees that would indicate the propensity for end-splitting at harvest several years later. Establishing such a link may be a worthwhile aim of future research.

7.4.2 Recovery and product value

The other consistent finding was that most of the field measurements were not significant predictors of recovery or product value. The only significant predictor was Acoustic Wave Velocity (AWV) for recovery of green boards after docking end-splits in *E. nitens.* This regression was weak. As was the case with log end-split severity, growth stress displacement measurements in standing trees was also not a significant predictor of recovery or product value.

The regression results for the various field measurement are detailed in Table 8 and indicate which factors were found to be significant predictors in the regression model for specific wood processing behaviour, product recovery and value.

7.4.3 The value of SilviScan

SilviScan 3 technology which is designed to detect tension wood also produced inconsistent results during its limited application in this ACIAR project.

However, as indicated in Report 1 "An evaluation of the application of SilviScan for the improvement of eucalypts for solid wood processing", SilviScan 2 was useful for tension wood detection in *E. globulus* silvicultural research and prediction of some green board traits and the drying behaviour associated with tension wood formation (spring, cupping and un-recovered collapse).

Unfortunately, the replacement of SilviScan-2 with SilviScan-3 soon after this ACIAR Project commenced meant that this experimental detection method was lost.

Given the possible presence of tension wood in the other species in this ACIAR project it would be valuable to establish sound detection methods for future research. This may be through improvement in precision of the x-ray diffraction profiles on SilviScan 3, or through other detection methods such as NIR spectra calibrated to chemical indicators of tension wood.

Table 11. Regression results for prediction of wood processing performance from field assessment

	Bow in green boards	Bow in dry boards	Log end split	Board end split	Recovery	Product value
LGS DISPLACEMENT						
Corymbia citrilidora subsp. Variegate (CCV)	**Mean, upslope and downslope[2]**	NS[1]	**Mean, upslope and downslope[2]**	NS[1]	NS[1]	NS[1]
E. pilularis	**Upslope only[2]**	NS[1]	**Upslope only[2]**	**Upslope only[2]**	NS[1]	NS[1]
E. urophylla	NS[1]	NS[1]	**Upslope only[2]**	NS[1]	NS[1]	NS[1]
E. urophylla x grandis			**Mean[2]**		NS[1]	NS[1]
E. nitens	**Mean at large end only[2]**		**Mean at large end only[2]**	**Mean at large end only[2]**	NS[1]	
E. dunnii	NS[1]	NS[1]	**Upslope only[2]**	NS[1]	NS[1]	NS[1]
Acourtic Wave Velocity) AWV						
CCV	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]
E. pilularis	NS[1]	**<0.0001[3]**	**<0.01[3]**	NS[1]	NS[1]	NS[1]
E. urophylla	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]
E. urophylla x grandis			NS[1]		NS[1]	NS[1]
E. nitens	NS[1]		**<0.01[3]**		**<0.05[3]**	
E. dunnii	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]
SILVISCAN 3 MFA						
CCV	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]
E. pilularis	NS[1]	NS	NS[1]	NS[1]	NS[1]	NS[1]
SILVISCAN 3 DENSITY						
CCV	NS[1]	NS[1]	**<0.05[3]**	NS[1]	NS[1]	NS[1]
E. pilularis	NS[1]	NS[1]	**<0.001[3]**	**<0.05[3]**	NS[1]	NS[1]
SILVISCAN 3 MOE						
CCV	NS[1]	NS[1]	**<0.05[3]**	NS[1]	NS[1]	NS[1]
E. pilularis	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]

[1] NS = not significant at p≤0.05 [2] Bold red indicates significant predictor in regression model at p≤0.05 [3] p value for significant predictors in regression model

7.5 Objective e: Genetic and silvicultural effects on wood quality and wood processing performance

The results from the research (summarised in Table 12) generally indicate an opportunity for improving sawn wood recovery by improving the plantation resource, particularly in relation to reducing log end-splitting and board deflection. However, given the previous discussion in 7.2 such improvement may only have a minor impact on the economics of processing.

Table 12. Significant variates on processed wood quality from genetic and silvicultural practices detected during FST 2001/021.

Species	Significant source of variation	Significant variates
E. globulus	Spacing and fertilizer treatment	MFA, density, cellulose crystallite width
E. urophylla x grandis	Spacing	Log diameter and value
E. dunnii	Not significant	Not significant
E. nitens	Provenance	Log and board end-split (large end), bow
E. pilularis	Provenance	Log end-split, board undersize
C. citriodora subsp variegata	Provenance	Wood density, log end-split, bow

7.5.1 Tension wood detection

The most important findings were the effect of a thinning treatment at age 8, in the *E. globulus* from East Gippsland, Australia. The thinning had the effect of inducing tension wood formation, with the most severe effect in the most heavily thinned unfertilized plots.

As explained in Report 1 (Washusen, 2007) some silvicultural treatments had a significant effect on density and microfibril angle. The most important effect was on cellulose crystallite width. Mean and maximum cellulose crystallite width increased with thinning intensity. Such an increase in crystallite width was associated with tension wood and consequent processing problems. The effect on crystallite width could be mitigated with fertilizer application indicating that crystallite width can be further manipulated by silviculture.

In a high percentage of trees in all thinned treatments, cellulose crystallite width was of a magnitude likely to produce processing problems using conventional processing strategies. All dried boards produced that had regions of unrecovered collapse, that is characteristic of tension wood formation, were from trees identified in the field as having produced tension wood.

This phenomenon is well worth further investigation in China, Vietnam and Australia in species that readily form tension wood, given its likely impact on the viability of processing solid wood.

8 Impacts

8.1 Scientific impacts – now and in 5 years

Scientific impacts have been:

- Recognition by scientists and industry in Vietnam and China of the value of steam reconditioning treatments in eucalypts. The FSIV have expressed interest in learning more about the effect this treatment has on sawn board quality.
- The benefits that can be obtained from linear flow processing systems, particularly through the application of chippers to remove high growth stressed wood, has been recognised as a major improvement in eucalypt sawing methods in Australia, China, Vietnam and Europe. There have been two invitations to conferences in Australia to discuss these findings following earlier media releases.
- The CRC for Forestry has broadened this research on processing of small diameter eucalypt logs by adopting similar methods to those employed in FST 2001/021.

8.2 Capacity impacts – now and in 5 years

Scientists at the Forest Science Institute of Vietnam (FSIV), China Eucalyptus Research Centre (CERC), Guangxi University and the Guangxi Forest Research Institute (GFRI) have been trained in the scientific methods of processing and resource evaluation adopted in this ACIAR Project.

- The FSIV have been successful in developing a parallel project in *E. urophylla* with funding sourced from MARD. Many of the methods adopted mirror those of the ACIAR project.
- FSIV now utilize probes to continuously monitor kiln and air drying conditions. And monitoring equipment to do this is now owned by FSIV.

8.3 Community/social impacts – now and in 5 years

The main community impact has resulted from strong engagement with industry in the research. This industry inclusion has produced direct discussion about processing methods between researchers and processors. The suitability of eucalypt resources to be processed with a broad range of equipment has been a major part of these discussions.

There has been a particularly strong recognition by Australian hardwood and softwood processors of the value of applying modern linear flow sawmills which incorporate chipper profilers that operate in front or simultaneously with multiple circular saws.

8.3.1 Economic impacts

In the CSIROMILL modelling analysis, the predicted mill door prices per cubic metre of log input were approximately AUD 90-100 higher for the linear processing system using the most likely annual log throughput rates for both systems. This difference in log prices was due to reduced processing costs in all sections of the mill, with the largest reductions attributed to the sawmill (AUD 52 to AUD 14 per cubic metre of log input). The importance of having a reasonably high capacity to pay reasonable prices for log material and make an acceptable commercial return is that farmers will only grow eucalypts for sawlogs if they can achieve higher returns than they would from growing pulpwood which has a much shorter rotation. Therefore understanding which processing systems offer the potential to pay higher mill door prices generates potential economic benefits to both the farmers who grow the trees and the companies that process the logs.

The results indicate considerable potential to improve returns to growers with the adoption of both pruning to produce high quality sawlogs, and the application of linear sawing systems. For this to be realised resources of the appropriate size would need to be developed within an economically viable supply zone. It is recommended that this be taken into consideration with the economic analysis that is to be conducted by ACIAR project FST 1999/091 when this aspect of plantation establishment is considered. In this evaluation it would be of value to determine the returns to growers given the potential mill door prices and the costs of harvest, transport and plantation silviculture in China, Vietnam and Australia.

8.3.2 Environmental impacts

If high quality sawn timber can be produced from young eucalypt plantations then there are a lot of potentially positive environmental impacts that would come from replacing harvesting of mature trees from the remaining natural forests with plantation grown logs.

8.4 Communication and dissemination activities

A workshop was conducted in Guangxi with researchers, students, tree growers and processors. Results were presented from processing trials in Australia and China.

An industry workshop was held in Tasmania that discussed potential sawmilling options for small diameter eucalypts.

A number of written papers and reports have been produced. Those produced during the reporting period were:

- September 2007; a final report on the peeling trials with E. grandis x urophylla was submitted to ACIAR.
- October 2007; an invited paper was presented at the Plantation Eucalypts for High Value Timber Conference, Melbourne with over 100 people in attendance. This led to an invitation for a guest editorial for Australian Forestry which was submitted in March. The proceedings of the conference will be published by RIRDC in 2008.
- November 2007; an invited paper was presented at Sawtech 2007, Melbourne that presented the results of processing E. nitens with a HewSaw R250 in Gippsland, Australia.
- March 2007; a draft report on processing *E. urophylla* was sent to Vietnamese and Chinese partners for their input.

9 Conclusions and recommendations

This project has successfully evaluated solid wood processing performance from small diameter plantation grown eucalypt in commercial mills located in China, Vietnam and Australia. It has identified systems of sawing and drying to improve the sawnwood recovery and quality from small (<30cm small end diameter) plantation grown eucalypts in the participating countries. Such work contributes to development of the plantation forest resources and returns from them in China and Vietnam where most of the resource is community owned. Ultimately, it is hoped that this will play a part in poverty reduction through income generation and employment and further reduce the reliance on native forests for supply of raw material as the value of the plantation resource is further realised.

Two key conclusions can be drawn from this research:

1. Linear flow processing systems of the HewSaw R250 and R200 machines produce higher quality timber and better economic returns than can be obtained from traditional reciprocating processing systems. The linear flow systems will release growth stresses symmetrically around the log and mitigate the adverse effects of growth stress release, such as spring and board end-splitting, which may potentially impact on recovery and product value.
2. Processing of 7.5 year-old low quality *Corymbia citriodora* subsp*. variegata* (spotted gum) logs from unthinned and unpruned plantations into sawn timber is unlikely to be profitable.

9.1 Specific Conclusions from Sub Projects

- Log diameter and sweep were the major log characteristics significantly impacting on product recovery, indicating that product recovery and quality could be further improved by growing larger diameter logs with minimum sweep.
- This project provided recognition of the value of steam reconditioning treatments in eucalypts. The Forest Science Institute of Vietnam have expressed interest in learning more about the effect this treatment has on sawn board quality.
- Veneer production with spindle-less lathes was well suited to small diameter short length logs.
- In each of the sub-projects log end-split severity and growth stress related defects were minor and did not have a significant impact on product recovery or value. However, it should be noted that tension wood while it was present in both sawmill trials was scarce and isolated to a few boards. It therefore had little impact on board behaviour during sawing, and on dried product quality, and it may have contributed to limited log and board end-split severity.
- In contrast, log diameter and sweep were the major log characteristics significantly impacting on product recovery, indicating that product recovery and quality could be further improved by growing larger diameter logs with minimum sweep. With the log dimensions processed in the two sawmills, log rotation could be applied to produce conventional back-sawing strategies to mitigate the effect of growth stress release. However, the logs processed

were approaching the maximum diameter where they could be rotated manually and there would need to be a substantial upgrade in sawmill technology to cater for larger logs.

- Close monitoring of moisture content during drying and utilization of commercial reconditioning strategies at the optimum moisture content will substantially improve product quality and recovery in both *E. urophylla* and *E. dunnii*.
- It was not clear from the simulations of pruning just what effect this would have on the recovery and quality of sawn boards.
- The application of chippers to remove high growth stressed wood has been recognised as a major improvement in eucalypt sawing methods in Australia, China, Vietnam and Europe. There have been two invitations to conferences in Australia to discuss these findings following earlier media releases. The CRC for Forestry has broadened this investigation adopting similar methods to those employed in FST 2001/021.
- The results generally support the hypothesis that, the Linear flow processing systems of the HewSaw R250 and R200 machines will release growth stresses symmetrically around the log and mitigate the adverse effects of growth stress release. The most important of these adverse effects is spring and board end-splitting, which may potentially impact on recovery and product value.

9.2 Recommendations

- Consideration should be given to explore the opportunity to improve veneer quality and hence the returns to processors and growers. At present most processors in China and Vietnam are geared to production of low value internal ply sheets. Elimination of knots and improved veneer handling and drying and reductions in log end splitting were identified as areas where veneer quality could be improved. Discussions with industry in northern Vietnam suggest that strong markets exist in the region for appearance grade external veneer sheets.
- Further investigations into tension wood occurrence are warranted in both China and Vietnam as it is prevalent in some eucalypt species grown under certain conditions.
- Close monitoring of moisture content during drying and utilization of commercial reconditioning strategies at the optimum moisture content will substantially improve product quality and recovery in both *E. urophylla* and *E. dunnii*. It is recommended that this simple treatment be promoted in China, Vietnam and Australia, and further investigations be carried out to determine how effective the treatment is in other species. Specifically, processors in Vietnam and China are likely to benefit from inclusion of a commercial steam reconditioning treatment before final drying. A report has been prepared for the Forest Science Institute of Vietnam (FSIV) as they have expressed an interest in learning more about the effect this treatment has on sawn board quality.
- A number of genetic and silvicultural effects emerged from the log samples provided to the project that allowed a limited assessment. The most important findings were the effect of a thinning treatment at age 8, in the *E. globulus*

from East Gippsland, Australia. The thinning had the effect of inducing tension wood formation, with the most severe effect in the most heavily thinned unfertilized plots. This phenomenon is well worth further investigation in China, Vietnam and Australia in species that readily form tension wood, given its likely impact on the viability of processing solid wood.

- It was not clear from the simulations of pruning just what effect this would have on the recovery and quality of sawn boards. It is recommended that comparisons be made with pruned eucalypts form other projects with comparable assessment strategies.

- In each of the sub-projects board end-splitting and deflection were common. However, board end-split severity had minor impact on product recovery after they were docked. Board deflection in the form of bow was the most important board deflection issue. Spring was a less severe problem and had almost no impact on material flow or product value. It is recommended that future experiments be conducted to determine the maximum bow threshold for a range of board transport systems.

- The field assessment data used to predict wood processing performance were either not significant predictors of the processing characteristics measured, or they were unreliable in that for some species they were significant and for others they weren't. It would be valuable to establish sound detection methods for future research. This may be through improvement in precision of the x-ray diffraction profiles on SilviScan 3, or through other detection methods such as NIR spectra calibrated to chemical indicators of tension wood.

10 References

10.1 References cited in report

Washusen, R. (2007). Application of the Hewsaw R250 for sawing eucalypt logs with a range of longitudinal peripheral growth stress levels. In proceedings of Sawtech 2007 Sawing technologies to improve mill performance. 21-23 November 2007, Melbourne, Australia. pp 79-93.

Washusen, R., Morrow, A., Dung Ngo, Northway, R., Boynton, S. and Henson, M. (2008). Processing air and kiln dried sawn wood from unthinned and unpruned 9-year old *Eucalyptus pilularis* from northern New South Wales with a HewSaw R200. Report for ACIAR project FST/2001/021: Improving the value chain for plantation-grown eucalypts in China, Vietnam and Australia: sawing and drying. CSIRO Material Science & Engineering Client Report No CMSE(C)-2008-300. pp 50.

10.2 List of publications produced by project

FST/2001/021 uunpublished technical reports submitted to ACIAR as part of this project:

1. An evaluation of the application of SilviScan for the improvement of eucalypts for solid wood processing
2. Variation due to spacing in growth stress related wood behaviour and processing performance of Eucalyptus urophylla x grandis logs for veneer production
3. Processing sawn wood from thinned, unpruned 10-year old Eucalyptus urophylla from northern Vietnam
4. Processing sawn wood from thinned, unpruned 17-year old Eucalyptus dunnii from southern China
5. Genetic variation in growth stress related wood behaviour of small diameter Eucalyptus nitens logs processed with a Hewsaw R250 Sawmill
6. Processing air and kiln dried sawn wood from unthinned and unpruned 9-year-old Eucalyptus pilularis from northern New South Wales with a HewSaw R200
7. Processing air and kiln dried sawn wood from unthinned and unpruned 7.5-year-old Corymbia citriodora subsp. variegata from Queensland with a HewSaw R200
8. A comparison of mill door log prices for pruned Corymbia spp processed with conventional reciprocating and linear flow sawing systems

- A workshop was conducted in Guangxi with researchers, students, tree growers and processors. Results were presented from processing trials in Australia and China.
- An industry workshop was held in Tasmania that discussed potential sawmilling options for small diameter eucalypts.

- September 2007; a final report on the peeling trials with E. grandis x urophylla was submitted to ACIAR.
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