



An Australian Government Initiative



Plantation Eucalypts for High-Value Timber

Enhancing investment through research and development

A.G. Brown and C.L. Beadle
(Editors)

July 2008

RIRDC Publication No 08/113
RIRDC Project No CVF-2A

© 2008 Rural Industries Research and Development Corporation.
All rights reserved.

ISBN 1 74151 701 X
ISSN 1440-6845

Plantation Eucalypts for High-Value Timber: *Enhancing investment through research and development*

Publication No. 08/113

Project No. CVF-2A

The information contained in this publication is intended for general use to assist public knowledge and discussion and to help improve the development of sustainable regions. You must not rely on any information contained in this publication without taking specialist advice relevant to your particular circumstances.

While reasonable care has been taken in preparing this publication to ensure that information is true and correct, the Commonwealth of Australia gives no assurance as to the accuracy of any information in this publication.

The Commonwealth of Australia, the Rural Industries Research and Development Corporation (RIRDC), the authors or contributors expressly disclaim, to the maximum extent permitted by law, all responsibility and liability to any person, arising directly or indirectly from any act or omission, or for any consequences of any such act or omission, made in reliance on the contents of this publication, whether or not caused by any negligence on the part of the Commonwealth of Australia, RIRDC, the authors or contributors.

The Commonwealth of Australia does not necessarily endorse the views in this publication.

This publication is copyright. Apart from any use as permitted under the Copyright Act 1968, all other rights are reserved. However, wide dissemination is encouraged. Requests and inquiries concerning reproduction and rights should be addressed to the RIRDC Publications Manager on phone 02 6271 4165.

Researcher Contact Details

Mr Jon Lambert
Woollybutt P/L
73 Short Street
PORTLAND VIC 3305

Phone: +61 3 5521 1363
Fax: +61 3 5521 1413
Email: jlambert@woollybutt.com.au
Website: <http://www.woollybutt.com.au/contact.html>

Dr Chris Beadle
CSIRO
Private Bag 12
HOBART TAS 7001

Phone: +61 3 6226 7911
Fax: +61 3 6226 7942
Email: chris.beadle@csiro.au
Website: [chris.beadle@csiro.au](http://www.csiro.au)

In submitting this report, the researcher has agreed to RIRDC publishing this material in its edited form.

RIRDC Contact Details

Rural Industries Research and Development Corporation
Level 2, 15 National Circuit

BARTON ACT 2600
PO Box 4776
KINGSTON ACT 2604

Phone: 02 6271 4100
Fax: 02 6271 4199
Email: rirdc@rirdc.gov.au
Web: <http://www.rirdc.gov.au>

Published in July 2008 by Union Offset

Foreword

There is a significant move in Australia from historic dependence on native forest timbers to a hardwood plantation industry.

A substantial plantation resource to supply hardwood chips has been successfully developed over the past 10 years. The development of ‘plantation eucalypts for high-value timber’ to date, however, has been unsuccessful in providing a timber resource of sufficient size or quality to reduce the demand on native forests for these products. Investment has been predominantly by small growers via farm forestry, with only some recent government and industry investment.

This conference was initiated to explore the prospects for eucalypt plantations to produce high-value products and the challenges faced in developing a viable industry sector. It featured expert presentations on preselected topics along the value chain—investment structures, species selection, plantation establishment and management, harvesting, processing and marketing. Speakers raised questions such as: If high-value sawlogs are to become a major part of the eucalypt plantation industry, will advances in harvesting and processing enable short-rotation species to fill the supply void, or will alternative species and specific regimes have to be developed? Will this resource compete for land with existing pine and short-rotation investments, and will lower-rainfall areas provide some of the essential land base? What role will industry and governments need to play?

The conference noted that the rapid expansion of short-rotation hardwood plantations has been largely due to managed investment schemes and associated taxation incentives. Whether a similar model will enable a viable resource of high-value eucalypt hardwood plantations to be developed is unknown. Plantations managed for higher-value products, such as sawn timber and veneer, generally require longer rotations, different species, and more sophisticated stand management and processing facilities than those grown for pulpwood. Investments in longer rotations inevitably attract far greater risk—suitable investment partnerships and supportive government policy will be required.

The key conference findings were the need for industry leadership, promotion and cooperation as well as government support for this embryonic sector. There was a desire for a new wave of research and development to support major resource expansion. This should focus on the overall benefits of high-value eucalypt plantations, target specific existing barriers to investment, and recognise the significant lead-time inherent in some operations. A clear government commitment to, and strategy for, the move by forest industry from reliance on native-forest to plantation-grown timber is seen as essential.

This conference proceedings provides valuable information for decision-makers influencing solid-wood plantation policy, as well as researchers, research investors and plantation managers.

The conference was funded by a range of government and industry co-sponsors. Principal sponsorship was provided by the Joint Venture Agroforestry Program (JVAP), which is supported by three R&D Corporations—Rural Industries Research and Development Corporation (RIRDC), Land & Water Australia (L&WA), and Forest and Wood Products Research and Development Corporation (FWPRDC). The R&D Corporations are funded principally by the Australian Government.

This report is an addition to RIRDC’s diverse range of over 1800 research publications. It forms part of our Agroforestry and Farm Forestry R&D program, which aims to integrate sustainable and productive agroforestry within Australian farming systems. The JVAP, under this program, is managed by RIRDC. Most of our publications are available for viewing, downloading or purchasing online through our website:

- downloads at www.rirdc.gov.au/fullreports/index.html
- purchases at www.rirdc.gov.au/eshop

Peter O’Brien

Managing Director

Rural Industries Research and Development Corporation

Acknowledgments

Members of the organising committee were:

Mr Jon Lambert (Chairman), Managing Director, Woollybutt Pty Ltd

Mr David Fiskén (Treasurer), Executive Officer, Central Victorian Farm Plantations

Dr Dean Severino (Secretary), Research Forester, Woollybutt Pty Ltd

Mr Chris McEvoy, Director, Radial Timber Pty Ltd

Ms Sue Harris, Private Forestry Development Officer, Department of Primary Industries, Victoria

Mr Kevin McCarthy, Experimental Scientist, Wood Processing and Products, CSIRO Forest Biosciences

Dr Chris Beadle, Senior Principal Research Scientist, CSIRO Forest Biosciences

Dr Rosemary Lott, Research Manager, Joint Venture Agroforestry Program, Rural Industries Research and Development Corporation

—with assistance from Dr Gary Waugh (School of Forest and Ecosystem Science, University of Melbourne), Ms Helen Vaughan (Department of Primary Industries Victoria) and Dr Ian Nicholas (Scion)

The principal sponsor was:

Joint Venture Agroforestry Program

The major sponsors were:

Central Victorian Farm Plantations Inc.

Department of Primary Industries Victoria

Woollybutt Pty Ltd

CSIRO Forest Biosciences and Scion, formerly Ensif (Joint Forces of CSIRO and Scion)

Forest and Wood Products Australia

Gippsland Private Forestry Inc.

Plantations North East Inc.

Cooperative Research Centre for Forestry

Department of Agriculture, Fisheries and Forestry Australia

Central Highlands Agribusiness Forum

ITC Forestry Ltd

Forest Enterprises Australia Ltd

Silviculture Services Australia Pty Ltd

FFORNE Hardwood Cooperative Ltd

Other conference supporters were:

Radial Timber Pty Ltd

South East NSW Private Forestry

Southern Tablelands Farm Forestry Network Inc.

Murray Riverina Private Forestry Development Committee

Hancock Victoria Plantations

Great Southern Plantations Ltd

URS Forestry

TreeSmart Australia Pty Ltd

Timbercorp Ltd

Bayer Crop Science

State Forests NSW

The organising committee would like to especially thank and acknowledge the following people who generously assisted with the conference and field day:

Larina De La Rosa (Department of Sustainability and Environment Victoria); Rob Willersdorf, Darren McDonald and Emily May (Gippsland Private Forestry Inc.); Paul Adams (Forestry Tasmania); David Ryan, Frank Hirst, Kendra Dean and Kathryn Parker (Department of Primary Industries Victoria); Dr John Goy (Farm Trees Pty Ltd); Professor Rod Keenan and Dr David Forrester (School of Forest and Ecosystem Science, University of Melbourne); Dr Glen Kile (Forest and Wood Products Australia); Phil Whiteman, Simon Gatt, John Savige and Nick Macreadie (Hancock Victoria Plantations); Dr Geoff Smith (Forests NSW); John Tredinnick (URS Forestry); David Bush (CSIRO Forest Biosciences); Clinton Tepper and John Bye (Woollybutt Pty Ltd); and Chris McEvoy and the team at Preschem Australia Pty Ltd.

We would also like to specifically thank Alan Brown for the many hours of voluntary time invested in the editing, formatting and collation of the conference proceedings.

Contents

Foreword	iii
Acknowledgments.....	iv
Executive Summary	vii
Plantation Eucalypts for High-Value Timber	
Senator the Hon Eric Abetz.....	1
The Compelling Case for Plantation Eucalypts for High-Value Timber	
Vince Erasmus.....	5
Eucalypt Plantations for Solid-Wood Products in Southern Australia: A Review of Research Investment and Needs	
Rosemary Lott and Graeme Gooding.....	8
Site Matching and Establishing Eucalypt Sawlog Species in Southern Australia	
Clinton Tepper.....	37
Management of Hardwood Sawlog Species	
Peter Volker.....	69
Harvesting Plantation Hardwood Sawlogs	
David Quill.....	81
Processing Plantation Eucalypts for High-Value Timber	
Russell Washusen and Trevor Innes.....	92
Markets for the Wood Products from Non-Durable Hardwood Sawlog Plantations	
Tony Cannon and Trevor Innes.....	110
Markets for Wood Products from Durable Hardwood Sawlog Plantations	
Martin Grealy	126
Genetic Improvement for High-Value Eucalypt Timber	
David Bush.....	138
Likely Investment Structures for Hardwood Sawlog Plantations	
Craig Taylor	155
Summary: Plantation eucalypts for high-value timber	
Rodney Keenan	168
Conclusions and recommendations	
Jon Lambert, Dean Severino and Rosemary Lott.....	171
Field Tour Notes	173
Appendix – Discussion forum.....	179

Executive Summary

What the report is about

This ‘Plantation Eucalypts for High-Value Timber’ conference proceedings addresses current challenges in developing a viable industry for plantation eucalypts to produce high-value timber. The focus is on the need for strong science to inform investors and reduce risk, and on areas where a lack of information may be impeding investment in high-value eucalypt sawlog plantations. These proceedings compile the presented papers and summarise the discussion forum. The papers span current research and investment issues along the whole value chain.

Who is the report targeted at?

These proceedings are intended as a resource for decision-makers influencing solid-wood plantation policy, as well as researchers, research investors and plantation managers.

Background

Australia has a well developed plantation-based softwood solid-timber industry; although there is a significant eucalypt (hardwood) plantation resource it almost entirely targets the pulpwood market. The hardwood sawlog industry has relied heavily on native forests, and to date investment in plantations has been small. This is despite increasing global demand for hardwood solid-timber products and decreasing domestic availability. Australia needs to encourage investment in and value-adding through its plantation estate in order to be self-sufficient in a larger range of wood products, and globally competitive. The reasons for under-investment in hardwood plantations for producing high-value solid-wood products are complex. This conference examines existing knowledge, and the issues and challenges in increasing investor confidence in current and emerging markets for these products.

Objectives

The conference objectives were to:

1. direct specific attention to the lack of investment in plantation eucalypts for high-value timber, especially in southern Australia
2. identify the needs for further R&D investment in this sector of the forest industry
3. inform stakeholders of existing R&D in this sector
4. devise a coordinated way forward to improve R&D in this sector.

Methods used

The Plantation Eucalypts for High-Value Timber conference was held in Melbourne on 9-12 October 2007 and attracted 130 growers, managers, processors, investors, policy makers and researchers to pursue the conference objectives. There was a particular but not exclusive focus on southern Australia, the conference host region. Invited reviews were made available to delegates prior to the conference to maximise opportunities for feedback and input. The conference included a full day of presentations, a field visit to Gippsland, and a forum for industry, government and R&D representatives to discuss ways to enhance investment in the future. The proceedings of the meeting are available in hard copy and on the web.

Members of the conference organising committee were drawn from private industry (growing and processing), state government policy and extension bodies, and national research providers and funders. The committee defined key areas along the solid-timber production chain where authorities from each field were asked to review current research in Australia and to identify knowledge gaps and research requirements. The speakers drew upon experience from Australia, New Zealand, South Africa, South America and Europe to identify research and development priorities that will help develop investor confidence in this sector of the forest industry.

Key results

Research funding and status of knowledge

Expenditure on research and development in the forest industry has declined. A range of collaborative groups provide funding for research, but there is no clear framework to enhance coordination between these groups in setting funding priorities.

Tree improvement. Over recent decades the tools and knowledge necessary to efficiently domesticate new crop species have become available. Work to date on a range of eucalypts potentially suitable for sawlog plantations has been valuable, but it can only be described as preliminary despite the potentially high returns from such investment. The need for sustained and timely investment with attendant lead time remains.

Status of knowledge on silviculture. As hardwood plantations for sawlogs are being developed on non-traditional and marginal sites, different species and more complex management than pulpwood plantations are required. Process-based models must be used to model risk. Establishment practices must be revised with greater emphasis on survival, growth, form and health on these sites. In addition to commonly-planted species belonging to the eucalypt subgenus *Symphyomyrtus*, species in *Monocalyptus* and *Corymbia* should be considered for sawlog plantations. The relationship between silviculture and wood properties requires further work, and the variation within and between species in properties affecting sawing and—particularly—peeling remains largely unknown. Minimising log end-splitting during harvesting and handling, and reducing drying times in sawn wood while limiting degrade, also remain challenges. Hardwood sawlog research must also examine the economics of farm forestry and the commercial use of trees to pursue natural resource management outcomes.

Industry opportunities. There is an opportunity for non-durable plantation eucalypts to replace pine in housing construction. For durable timbers, the competitive advantage will continue to be in matching species characteristics to niche end-user demands; higher prices can be anticipated for these products because of relative scarcity. The challenge is to produce the required mix of products in commercially viable plantations. Profitability of both plantations and harvesting operations is maximised by finding a market for every part of the raw product. Price structures should provide financial incentives to all elements of the supply chain. Solid-wood researchers and marketers must be aware of trends in the choice of materials for housing, such as the use of hardwoods in structural veneers and composites.

Industry investment in the hardwood plantation sawlog sector

Reasons for insufficient large-scale investment in hardwood sawlog production include the long-term nature of the capital requirement and a lack of suitable processing infrastructure, resource security and skills. Robust economic arguments are required to attract the essential land base from other land-uses. As a result of changes to secondary-market taxation, managed investment schemes are the investment structure most likely to finance establishment of long rotation plantations on a commercial scale, while timberland investment management organisations are more likely to invest in plantations already established.

Future needs

Industry confidence and future investment. Increased investment in eucalypts for high-value solid-wood products requires industry planning for the sustained supply of resources on an adequate scale—specifically, a sufficient planted area managed for solid-wood products—and adoption of the best available but inevitably capital-intensive processing technology. There must also be evidence that long-rotation hardwood plantations are commercially viable, with policy and investment structures supporting investment. Returns must be equivalent to or better than those from pulp or agriculture, either directly or with additional income from environmental services. There must be evidence of environmentally sound plantation management, including plantation placement within water-supply catchments.

Investment confidence will also be increased by:

- greater synthesis and dissemination to users of existing research findings
- continued and improved plantation modelling particularly for issues such as tree growth and water use for a range of species and sites
- additional research to support growing and processing of hardwood plantation material, and to reduce re-establishment costs
- product innovation and development
- research on markets (including environmental services), marketing needs and industry impediments to investment.

Increased product and market sophistication (value-adding and marketing combined with ongoing market education) is also needed to allow full and highest-value utilisation of all plantation products.

Specific research needs. Specific research challenges for tree improvement include the development of tree-breeding objectives appropriate for both sawlog-specific and multiple end-uses; exploration of hybridisation and clonal breeding strategies; and capitalising on and improving existing species × site trials as well as establishing long-term trials to gain more comprehensive data for key regional species. Wood quality research challenges include determining the effects of silviculture on wood quality and processing, in tandem with using the potential of novel techniques and technologies to overcome processing and drying difficulties; and proving and refining the wood quality of fast-grown plantation species. Research is also needed on harvesting and transport efficiency, and the effects of these operations on processing recovery. Encouraging the adoption of best-practice management for sawlog plantations, particularly pruning, and creating greater access to improved seed for nurseries and growers, could improve the yields from existing knowledge.

Industry coordination. The hardwood sawlog sector needs to create an all-encompassing research and industry plan, covering regional prospects (market and biophysical) and investment needs, research priorities, and the coordinated distribution of R&D activities between organisations. The adequacy of research expenditure needs to be re-examined given the final product value of hardwood sawlogs to the Australian economy, the sawlog trade deficit, the socio-economic potential to replace native-forest timbers, the value of environmental services, and the embryonic state of the industry.

Planners and policy makers must seek to include all interest groups in developing a sustainable and integrated industry, and take part in defining priority species for development—focussing on ‘best-bet’ options including durable species. The extent of the target land base for low-, medium- and high-rainfall resources must be determined, considering the effects of climate change as well as the desired scale and mode of plantation development (large industrial or smaller landowner). Issues surrounding access to appropriate land—such as availability, acceptable rental, proximity to markets, and processing and transport infrastructure—must be addressed.

Promoting the sector’s prospects. The case for governments being able to achieve multiple economic and social policy objectives by investing in sawlog plantations requires strengthening. This may be best achieved by the formation of a new promotional body specific to hardwood sawlog timber plantation development. Confirmation of government commitment and plantation investment success stories will provide incentives and generate industry confidence. Policies and strategies for developing and sustaining a skilled workforce must be developed, and there is a need for increased research capacity (funds and delivery vehicles) and long-term funding specific to forestry.

Implications for stakeholders

This conference clearly highlighted a variety of gaps in knowledge, across the supply chain, that require attention to increase investment in high-value eucalypt plantations. Stakeholders will need to cooperate on R&D and industry planning, and to clearly communicate their knowledge and needs. Researchers and policy makers need to listen to industry and to each other, and to address with urgency the challenges identified here.

Recommendations

Key recommendations are:

- government should commit to a clear strategy for the forest industry to move from reliance on native-forest to plantation-grown timber, and to develop the associated skilled workforce and processing infrastructure
- an industry-wide research strategy should be developed based on both land capabilities and market requirements
- research providers and funders need to greatly improve communication and coordination of research activities, and examine whether existing groups or a new body should be formed to improve coordination of research and extension
- increase funding for both short- and long-term forest research
- there should be industry-wide promotion of best-practice management, based on close links between research and industry.



OFFICIAL OPENING

Plantation Eucalypts for High-Value Timber

SENATOR THE HON ERIC ABETZ

The then Minister for Fisheries, Forestry and Conservation
Australian Government, Canberra

In opening this meeting, I wish to thank the organising committee, and particularly its chair Jon Lambert, for their hard work in bringing the conference together.

A timely theme

We do need to do more to gain greater value from our large—and growing—plantation eucalypt estate.

If plantation eucalypts are to replace, at least in part, solid-wood products from our native forests (bearing in mind that I believe we will always maintain a sustainable native forest sector) we need to improve the genetics, plantation silviculture and processing technology to better gain high-value sawtimber and veneers.

Australia has been very successful in growing short-rotation eucalypts to supply the rapidly growing South-East Asian pulp and paper appetite, but we need to turn our attention to producing additional products from our plantations.

That is where investment—both government and commercial—in research and development will be critical. It is also why it is critical that we have in place the right policy settings to ensure that plantation investment is spread across both short-rotation and long-rotation crops.

On all of these fronts we have made some good decisions and are heading in the right direction, but more should, and could, be done.

The expanding plantation sector

The past decade has seen steady growth in the plantation estate across Australia. This is largely the result of the policy settings established through *Plantations for Australia: the 2020 Vision*, which set the target of expanding the plantation resource to three million hectares by 2020.

In support of the 2020 Vision the Australian Government created the right environment, through certainty in the taxation arrangements, to attract the private sector investment necessary to attain the rate of plantation expansion required to achieve the 2020 Vision target.

Since 1997 when the 2020 Vision was announced, the plantation estate has grown by 700 000 ha to over 1.8 million ha—increasing annually by more than 70 000 ha in recent years.

And the reason the Australian Government has been a strong supporter of the plantation sector? Well, it is twofold: import replacement; and to offset the reduced access to native forests as a result of expansion of conservation reserves.

Import replacement

Currently, Australia runs a wood and wood products trade deficit of almost \$2 billion per annum.

Replacing these imports with local products is not so much a matter of becoming self-sufficient, but rather of encouraging and supporting jobs in regional Australia in a sustainable industry, where—given our large land resources—we are internationally competitive.

Replacing log supplies from native forests

Secondly, we wish to replace the large amount of potential log supply from native forest which has been ‘locked-up’ in conservation reserves no longer managed for sustainable wood production.

Australia now has over 22.5 million ha of forest set aside in conservation reserves, roughly half of which has been reserved in the past 10 years.

As a Government, we believe that the balance is now right and we won’t be moving to reserve more of our sustainable and renewable native forests that are still managed for wood production. Unfortunately state Labor governments continue to bow to Green pressure and lock up more and more resource—and Federal Labor has indicated it too will increase the area of forest reserves if it wins the national election later this year.

Hence we should expand and diversify our hardwood plantation sector.

Updating MISs to support high-value timber

The problem—in terms of replacing the high-value solid-wood products from our native forest and imported timber—is that most eucalypt plantations established in recent years have been for short-rotation pulpwood.

Although it is forecast that timber supply from hardwood plantations will grow four-fold to almost 14 million m³ in 2010, very little of this will be used in high-value solid-wood products.¹ On current projections, by 2040 Australia’s hardwood plantations will supply only about half of the volume of sawlogs currently harvested from our native forests.²

In May 2006 Treasury had proposed that investors in forestry MISs would be subject to a tax-deductibility cap of \$6500 per hectare on their investment.

As a Government, however, we took a decision to maintain the taxation arrangements for investors in plantation forestry while improving the transparency of the arrangement and allowing trading of immature plantations in secondary markets. It is expected that these changes will encourage greater investment in high-value eucalypt plantations.

While Treasury’s proposal was a well-intentioned move to try to eliminate perceived over-pricing in the forestry MIS sector, such a cap would have discouraged investment in the higher-value, longer-rotation forestry plantations.

After considerable public consultation and discussion, the Government sensibly rejected this proposal and replaced it with a requirement that a minimum of 70% of the cost of a forestry MIS project be directly related to plantation establishment, management and harvesting, in order to get tax deductibility. This requirement will address perceived over-pricing in forestry MISs while not discriminating against high-value forestry investments.

Secondly, and more importantly, we took the decision to enable MIS holders to on-sell their immature plantations after a four-year holding period. This is expected to encourage greater investment in longer-term plantations by eliminating investor bias in favour of shorter-term, more liquid investments.

¹ *Australia’s Plantation Log Supply 2005–2049*, BRS 2007

² *Ibid.*

Growing eucalypts for sawlogs

Of course, growing long-rotation plantation eucalypts for sawlogs is not new in Australia, or indeed the world. It is currently being done successfully in South America, South Africa, Spain and Portugal, and I hope will expand in Australia as a result of the new taxation arrangements for plantations.

All that notwithstanding, the great thing about Australia and Australians is our ability to think outside the square to get the desired outcome.

In particular, I am referring to two relatively new developments in this country which will enable plantation eucalypts, initially intended to be exported as woodchips, to be processed in Australia for high-value structural products.

One company already achieving this outcome is Forest Enterprises Australia in my home state of Tasmania. To maximise the value from its plantation resources, FEA established a small sawmill with a Scandinavian 'HewSaw' that is particularly suited to small-diameter sawlogs. Using short-rotation (14–15 y) plantation-grown *Eucalyptus nitens*, they produce structural (house frames and trusses) and flooring timber, branded 'EcoAsh'.

This venture has been so successful that FEA have recently begun the development of a new, much larger sawmill in Georgetown, on the old Carter Holt Harvey MDF mill site. The new sawmill will use the same Hewsaw technology as the pilot Bell Bay mill, but will have an annual processing capacity of 600 000 m³.

And in Western Australia (WA), a new company, Lignor, is developing a facility at Mirambeena, near Albany, to produce engineered strand lumber (ESL) and engineered strand board (ESB) from plantation eucalypts.

Engineered strand lumber and engineered strand board are produced by slicing logs into small flakes which are then recombined with resins and aligned to produce very strong structural beams or panels. Lignor will primarily use plantation blue gum timber, but also plans to use some thinnings and residues from WA's native forests. The proposed plant will be the first in the world to apply engineered strand lumber technology to eucalypts. Lignor has patented the technology in Australia and key international markets. The facility is expected to open in 2008 and to create 150 full-time equivalent jobs when it reaches full production in 2010. Development of the new facility is expected to cost an estimated \$200 million.

I am proud that as a Government we provided significant financial support to Lignor through a grant of \$1.361 million under the Forestry Assistance Programme for Western Australia (FAPWA) in July 2004, and a further \$3.85 million through the Commercial Ready Programme in 2006.

Unfortunately, while notable, such success stories are few and far between.

We need more and better research to afford more opportunities for successful ventures of this nature.

Government research for the timber industry

As in any industry, research and development plays an important role. In this case it will be required to ensure:

- the right balance between short-rotation pulpwood plantations and long-rotation plantations for higher-value solid-wood products
- that plantations are grown in the right locations to support investment in further processing and under the right conditions to maximise wood yield and wood qualities
- that the end products are innovative and well promoted
- that markets are well researched and developed
- that information is shared within the industry.

The Howard Government has worked hard with industry over the past two years to secure the future of its research and development effort, and I was very pleased to be able to facilitate the creation of a new industry company, Forest and Wood Products Australia (FWPA), in August this year. This organisation took over the functions of the former Forest and Wood Products Research and Development Corporation (FWPRDC) on 3 September.

FWPA will continue to support practical R&D work, as before, and the Commonwealth will continue to match industry levies spent on research and development. Importantly the levy base of FWPA will be expanded by increased levies on sawmills and by new levies on forest growers, enabling the new company to undertake generic marketing and promotion for the forest industry. The new private company structure will make FWPA much more accountable to the industry.

High-end research and development—the Forestry CRC

We also need high-end R&D—and that's where the Government's \$26 million support for the Forestry Cooperative Research Centre at the University of Tasmania comes in.

The research of the Forestry CRC will drive further improvement in high-value eucalypts in the future, through improvements in wood quality, growth rates, pest and disease resistance and adaptation to new sites and environments.

The Forestry CRC is at the leading edge of silvicultural improvement in eucalypt plantations. Its program to investigate the conversion of plantations from pulpwood to solid-wood silvicultural regimes will provide opportunities to diversify products from existing plantations. Its work on the interaction of silviculture and wood quality, with a focus on improving tree form and reducing defects which affect processing and drying, will further improve our ability to produce high-value products from plantations in the future.

Conclusion

We are gradually taking the right steps in this country to maximise value from our plantation eucalypt resource. While we always had a native forest sector, and now have a substantial resource of plantation pulpwood, we also need to expand our high-value plantation eucalypt sector through:

- the new plantation taxation arrangement for forestry MISs which allow trading of immature plantations in secondary markets
- innovative investment by the business community
- Government and industry-supported research via the new company Forest and Wood Products Australia and the CRC for Forestry.

We are well on the path to achieving this goal. This progress will be examined in much greater depth over the course of the conference.

And now I officially declare open the Plantation Eucalypts for High Value Timber Conference 2007.



INTRODUCTION

The Compelling Case for Plantation Eucalypts for High-Value Timber

VINCE ERASMUS

ITC Ltd, PO Box 7046, Richmond, Victoria
Email: vince.erasmus@itclimited.com.au

Introduction

The Australian plantation eucalypt industry today stands on the cusp of a new era of value-added timber processing. The past decade has seen a dramatic expansion of the hardwood plantation estate across the country, predominantly as a result of the rapid growth of managed investment schemes facilitated in part by the Federal Government's Plantations 2020 Vision.

This expansion has given rise to changes to the rural landscape in many regional areas, with plantation forestry now complementing or replacing other agricultural enterprises. These regional areas have benefited from the economic activity generated as a result of local plantation forestry operations.

Most plantation eucalypt development in Australia to date has been for end-use as pulpwood from plantations grown on short rotations, and it is this point that forms the basis for the Plantation Eucalypts for High-Value Timber Conference.

A shift in the dominant paradigm from short-rotation pulpwood plantings is essential for the future development and value-adding of the Australian eucalypt plantation industry. We need to move from producing only high-quality woodchip, which although enjoying a price premium over native timber is still a commodity, to producing high-value long-rotation sawn timber products from the plantation estate.

The Plantation Eucalypts for High-Value Timber Conference will consider what actions must be taken to achieve this objective, and what constraints must be overcome along the journey.

Drivers

Growing plantation eucalypts for high-value timber is not a new phenomenon. In southern South America, southern Africa and the Iberian Peninsula we can see examples of successful large-scale programs. In these countries there are now globally competitive sawmills and other value-adding processing operations that are supplied entirely by intensively-managed plantation resources. Some of the leading sawmills and operations are processing both hardwood and softwood log resources with well-established technologies and systems, and these facilities are producing excellent results.

In Australia, development of such initiatives on a significant scale has lagged for various reasons. Now, however, a number of factors collectively create a compelling case for industry to take action.

The desire to produce high-value timber from plantation eucalypts is understandable. The economic returns from value-adding and processing timber, versus producing only woodchips for pulp, are undeniable. The argument for growing longer-rotation plantations for solid-wood applications is enhanced when considering a number of market factors.

The supply of native forest timber available for processing within Australia is declining significantly. As state government resource owners seek to balance environmental sustainability and economic realities of the native timber estate, they reduce the volume of timber allocated for processing. These reductions are exacerbated by the effect of natural disasters such as bushfires on resource availability.

There is a general acceptance in the native-forest processing industry that moving towards using plantation resources is logical, and that in doing so processors must seek to optimise the enhanced value that can be extracted from a plantation eucalypt. As other papers in these proceedings show, however, there are a number of challenges to overcome in order for this to become a reality.

The environmental credentials of a timber resource have also become increasingly important.

Consumers of timber products have become more discerning and will become more so, seeking to see evidence of the environmental credentials of the products they purchase. This is principally a result of the increasing prominence of certification standards such as those of the Forest Stewardship Council (FSC), the Programme for Endorsement of Forest Certification (PEFC) and the Australian Forestry Standard (AFS).

There are sound environmental arguments for a shift to using plantation resources rather than regrowth from native forest, particularly when considering export markets where lack of green credentials for a product significantly limits market access for solid-wood products. Some Australian plantation companies have already successfully commenced supplying this latent demand—for example, Forest Enterprises Australia (FEA) with their EcoAsh™ made from short-rotation plantations.

Challenges

The development of high-value timber products from eucalypt plantations—in a manner that is practically, scientifically and commercially viable—presents our industry with a number of challenges.

Australia lacks infrastructure suitable for processing plantation resources. Most sawmills that use sawlogs from native forest are operated with antiquated technology, particularly when compared with large-scale softwood sawmills in both this country and abroad. The challenge this presents is exacerbated because most Australian hardwood timber processors survive on relatively low—and in most instances declining—volumes compared with softwood processors. This means they lack the cash flow and the security of resource necessary to attract the capital required to modernise their sawmills.

The capital requirements for plantation development are, of course, also significant. With eucalypt sawlog plantations requiring rotations of at least 15 y or more, it has to be patient capital, a characteristic that runs counter to the predominant investment appetite and timeframe of today's capital markets. As an industry, therefore, we must consider creative funding methods to support production of high-value timber from plantation eucalypts.

The use of retail funds via managed investment schemes has proven a sound capital-raising approach, as has the wholesale and institutional investor base. To support the expansion of longer-rotation plantations for sawlogs, however, government support either through tax incentives or by participating in public-private partnerships is important. Craig Taylor of the Fifth Estate discusses these interactions elsewhere in these proceedings.

The availability of land suitable for high-grade sawlog plantations is also a challenge. Economics dictate a finite limit to the distance over which logs may be transported at harvest—whether it be to port for woodchips or to a processing facility or sawmill for sawlogs. The site quality and rainfall criteria required to optimise plantation growth further limit the choice of appropriate land. With farmers able to extract satisfactory returns from general cropping, and land prices at a level that makes acquiring land for plantation development an expensive proposition, innovative thinking is required to develop robust financial models that will support estates of longer-rotation eucalypts.

The availability of skilled personnel is a material and significant challenge that we face in Australia (and interestingly in most plantation-producing countries) in respect of the plantation industry generally. Attracting and retaining talent is proving increasingly difficult, if not impossible, for many companies. The pool of new graduates with technical forestry training is practically non-existent. This shortage of human capital potentially has immediate impacts as it limits the size of plantation establishment programs, as well as hampering the on-going management of an expanding estate.

The skill shortage becomes even more acute, however, when considering the requirement for technically competent harvesting personnel and capacity to service the maturing estate in the years ahead—in diverse geographic regions dispersed throughout the country.

There is no single solution to the challenge posed by this skill shortage—rather a range of measures is required. One option is to seek to use the skills that are already on the land. That is, apply the skills of farmers and landowners to assist the operations of plantation forestry managers. Doing so delivers two outcomes: firstly, it increases the number of skilled staff in our operations, and secondly—importantly—it can create for these people a sense of ownership in the plantations that are established.

Captains of industry need to demonstrate some statesmanship and pool their efforts to address this critical issue. The industry and government need to urgently support recruitment drives, industry promotion and appropriate academic institutions.

Positives

But there are not only challenges before us. The environment presents many opportunities to develop high-value timber plantations within Australia.

The marketability of plantation eucalypt sawlogs is unquestionably sound. From a domestic perspective, there is strong and growing demand for quality sawn timber products for use in both appearance-grade and in stress-bearing structural applications. In export markets, Australia enjoys excellent freight rates to emerging markets relative to sawn timber competitors elsewhere, and strong demand for quality light-coloured hardwood timbers.

The Federal Government should be commended for the support it has provided the plantation industry to date. The government's initiatives include the development of the Plantations 2020 Vision and policy support via the taxation treatment of plantation forestry—both in terms of MISs and the recently-introduced incentives for the development of carbon-sink forests. Its actions to stop illegal logging—an initiative which is firmly backed by ITC Limited—is commendable. The government's drive for the AFS and its alignment with the PEFC is also to be highly commended, and finally now will assist local operators in the sale of Australian hardwood products both locally and specifically abroad. Much work is still needed, however, to market the AFS abroad.

The government has provided the encouragement of a policy framework to stimulate and support longer-rotation plantation development. It is now up to industry to take maximum advantage of this support.

The collective will of government and industry is clear. Now industry must allocate resources to make it happen at the corporate, operations, and research and development levels—that is, take action to make the vision of high-value timbers from plantation eucalypts in Australia a reality.



INTRODUCTORY SESSION: REVIEW OF CURRENT R&D

Eucalypt Plantations for Solid-Wood Products in Southern Australia: A Review of Research Investment and Needs

ROSEMARY LOTT^{1,2} AND GRAEME GOODING³

¹Joint Venture Agroforestry Program, RIRDC, Canberra

²Vegetation Connections P/L

Email: rosemary.lott@chilli.net.au

³Forestry consultant, Victoria

Email: goodingg@optusnet.com.au

Abstract

This paper reviews current research and investment to support the hardwood plantation, high-value solid-wood products sector. The paper describes the level of investment in forest and forest products research, the organisations that fund research, and the types of current research projects. Broad future research needs are outlined. High-value products are assumed to be solid-wood products, such as natural rounds (poles, posts), sawn appearance-grade and structural hardwood, decorative and structural veneers, and value-added sawn timber products. Only a small proportion of hardwood plantations are intended for sawlog production in most National Plantation Inventory regions of Australia. Research and development (R&D) is critical to support the development of the hardwood sawlog industry sector.

Most funds for forest and forest products research are provided by the Australian government and state agencies, with smaller contributions from universities and private companies. The current investment in research through Research and Development Corporations, Cooperative Research Centres and Ensis, including research provider input, is roughly \$27 M y⁻¹. This does not include all contributors, but indicates a decline relative to research investment over the period 1982–2001. Current research includes tree breeding, inventory and growth modelling, species response to site, the effects of silviculture on wood quality, and wood processing and innovative treatments such as microwave conditioning. Research investment in hardwood products has increased in recent years. Less effort is evident on harvesting operations, economics, markets and marketing, potential investors and secondary markets, socio-economic impacts and quantifying environmental services. Future research needs include tree breeding, understanding growth responses to different site and soil types, improving stand management to produce timber to suit the appearance and structural markets, mechanisms to control growth stress and tension wood, demonstrating viable investment options for hardwood sawlog plantations, research on products and innovative processing, and optimising forest production systems from growing through to processing.

Key recommendations are:

- There is a need to improve coordination of R&D prioritisation across agencies.
- A hardwood sawlog industry plan should be developed with clear priorities for research on species, products and processing technology, and integration along the value chain. It should also address the industry transition from native forest to increased supply from plantation timbers while maintaining market share and profile, and consider regional prospects and investment needs, including supply, products and markets.

- Existing research must be better summarised and communicated to the public, including to increase public awareness of the carbon and ecosystem service merits of native species plantations and products.
- Investment in high-value plantation hardwood research should be maintained.
- Groups with concerns about water use, carbon and natural resource management must be consulted to ensure community support and research relevance.

Introduction

Compared to softwood plantations and short-rotation hardwood pulpwood plantations, the industry sector using hardwood plantations for high-value solid-wood products is in its infancy. Development of the sector requires investment in:

- sufficient area planted and managed for solid-wood products
- industry planning for continued resource supply
- research to support growing, harvesting and processing of hardwood plantation material, including identifying cost-effective systems
- research on product innovation and development
- research on markets (including environmental services), marketing needs and industry impediments
- value-adding and marketing (market sophistication)
- information synthesis and delivery to users (extension).

Research and development (R&D) is an important part of industry development. It can reduce investment risks, improve profitability and encourage industry innovation and adoption. R&D is especially important for new and emerging industries, and sectors where there are impediments or inefficiencies in production or markets.

This paper reviews current research to support the hardwood plantation, high-value solid-wood products sector. It describes 1) the level of investment in forest and forest products research, 2) who funds research, and 3) the types of current research projects. Broad future research needs are outlined here; subsequent papers in these proceedings provide details of current knowledge and research needs in specific areas. The paper concludes with some comments on R&D coordination, and targeting of investment in regions and products. As this conference has a regional emphasis the paper concentrates on southern Australian plantation eucalypt research, but the research and development needs are common to all regions aiming for a high-value hardwood products sector, including northern Australia.

High-value products are assumed to be solid-wood products, such as natural rounds (poles, posts), sawn appearance-grade and structural hardwood, decorative and structural veneers, and value-added sawn timber products. Plantations grown for solid-wood products are referred to as sawlog plantations.

Background: Status of the high-value hardwood sector

The following section provides background on the forest area and sources of supply of hardwood sawlogs, and is a precursor to a section on R&D investment.

Current and future resource supply

In 2005–2006, the total Australian log harvest was 26.7 million cubic metres (Mm^3), of which the total saw and veneer log harvest was 12.8 Mm^3 . Current (2005–2006) harvest of broadleaved (mainly eucalypt) saw and veneer logs is $3.4 \text{ Mm}^3 \text{ y}^{-1}$; 94% is from native forest. This indicates that hardwoods form about 27% of all saw and veneer logs and 9% of all roundwood removed (ABARE 2007).

Historically, native forests have supplied the bulk of Australia's harvest for hardwood products (Figure 1). ABARE reports (1970–2007) show that the supply of quality hardwood sawlogs and veneer logs from native forests has steadily declined since the 1970s.

Government policies and industry investment aim to increase the supply from plantations over time.

Hardwood plantations have supplied a small but increasing proportion of all logs since 1998–1999 (National Forest Inventory 2007a). Most current hardwood plantations are intended for pulpwood (about 83% of total plantings in 2005). Forecast log supply from plantations in 2010 consists of hardwood pulpwood (46%), softwood sawlogs (35%), softwood pulpwood (18%) and hardwood sawlogs (1%) (Parsons et al. 2007).

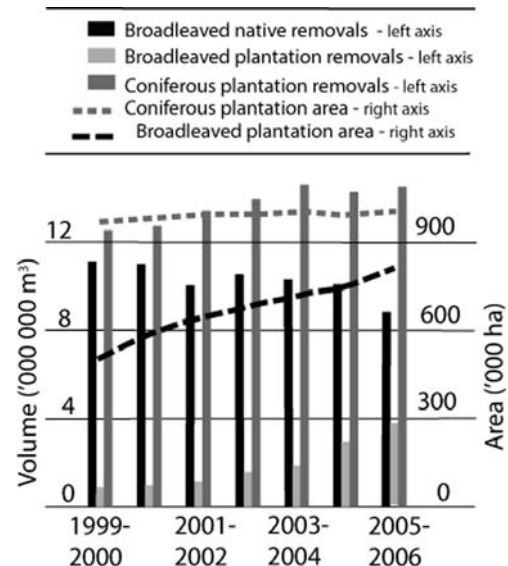
For hardwood sawlogs, the forecast is that plantations will supply about $224\,000 \text{ m}^3 \text{ y}^{-1}$ between 2005 and 2009, and about $358\,000 \text{ m}^3 \text{ y}^{-1}$ by 2010 (Parsons et al. 2007). In 2010, Tasmania will produce about 53%, and Central Gippsland and north coast NSW about 20% each. Hardwood plantation sawlog supply is forecast to exceed $1 \text{ Mm}^3 \text{ y}^{-1}$ after about 2020, and to peak at $1.8 \text{ Mm}^3 \text{ y}^{-1}$ in 2030. This volume will not be reached if plantations established for sawlog production are not thinned and pruned (Parsons et al. 2007).

Harvest from plantations will not match previous levels from native forests for many years. Nolan et al. (2005) pointed out that by 2035, hardwood plantations in Australia will supply only 15% of the 2001 total sawlog volume provided by native forests, and that this is less than half of the estimated sawlog availability lost from public native forest between 2000 and 2035³. The recent National Forest Inventory estimates of plantation log supply are higher than Nolan et al. (2005) as they include peeler logs from Forestry Tasmania (and some recently downsized estimates), revised estimates based on shorter rotations in NSW, and new plantations established since 2000. Even so, a decline in supply relative to previous years is evident and sawmills are closing. Australia has increased its imports of tropical hardwoods as a consequence of reduced access to native forests resources.

An estimated 1140 sawmills are currently operating in Australia, with 75% producing high-value, small-volume hardwood products (National Forest Inventory 2007a). Hardwood sawlog plantations are widely dispersed; sawmills are generally small and widely dispersed. This challenges the sector to attain critical mass while continuing to support regional employment and environmental sustainability.

Forest area

Substantial areas of public and private native forest are harvested periodically for hardwood logs. Native forests supplied 38% of all logs harvested in 2006 (National Forest Inventory 2007b). In some regions private native forests supply up to 40% of regional hardwood harvest. Australia's largest private native forest-based industries are situated in Tasmania, Queensland and New South Wales (NSW). Tasmania harvests about $967\,000 \text{ m}^3 \text{ y}^{-1}$ (mostly pulpwood), compared with Queensland with $280\,000 \text{ m}^3 \text{ y}^{-1}$ and New South Wales with $586\,000 \text{ m}^3 \text{ y}^{-1}$ (URS Forestry 2008a).



Note: Data for plantation areas are reported on a calendar year basis. In this graph, data for 2006 appears in the 2005–2006 column.

Figure 1. Forest area and volume of log removals, Australia (ABARE 2006)

³ Refer Nolan et al. 2005, Figure 4.6, page 20

Australia's total plantation area is about 1.8 Mha, consisting of 0.807 Mha (44%) of hardwood and 1.001 Mha (55%) of softwood species (National Forest Inventory 2007b). Over the last 10 y, hardwood area has increased significantly (average 63 400 ha y⁻¹). The percentage of hardwood plantations intended for sawlog production is small—an estimated 17.5% in the six key supply regions in 2003 (107 300 ha, Nolan et al. 2005).

Over the past decade, several projects for growing hardwood sawlogs have been initiated; most have been government funded although some private investment in long-rotation hardwood species is now occurring. Rotation lengths are expected to be 18–30 y (see Parsons et al. 2007). Nolan et al. (2005) noted that around half the national plantings of hardwood sawlogs are in southern Australia. Much of this existing resource is *Eucalyptus globulus* (mainly in Western Australia and Victoria) and *E. nitens* (mainly in Tasmania). Some short-rotation stands are being assessed for conversion to sawlog plantations.

As land prices increase and availability decreases, new plantings in southern Australian high-rainfall zones are expected to decrease. Some expansion is occurring in northern Australia. Opportunities exist for integrated forestry in the 600–750 mm y⁻¹ rainfall zone where land is available (Robins and Marcar 2007). Due to changes in pulp markets and new taxation arrangements, a larger proportion of new hardwood plantations are likely to be aimed at sawlog production, which may suit land outside the traditional plantation regions (Parsons et al. 2007).

Ownership

In 2006, plantation ownership including softwoods (National Forest Inventory 2007b) was:

- 12% superannuation funds
- 15% timber industry companies
- 12% farm foresters and other private owners
- 26% managed investment scheme (MIS) investors
- 35% governments.

In 2006, 94% of new plantations established were privately owned, of which 86% were due to MIS investment.

The National Forest Inventory notes that farm forestry is a growing sector in plantation establishment, with more than a third of the farm forest resource planted since 1995. Depending on the definition used, farm forestry represents 9% (URS Forestry 2008b) to about 20% of plantations (National Forest Inventory 2007a). The National Forest Inventory (2007a) considered farm forestry to include 5% small growers, and 13% leasehold and 7% joint-venture arrangements between farmers and large companies. The National Forest Inventory (2007b) does not comprehensively capture small-scale farm forestry planting, but does include farm forests reported in the 'Australia's plantations 2006' report, with farm forestry defined as plantations with <1000 ha under a single ownership. The URS estimate includes farmer-managed woodlots, and joint venture and leased plantations on land where a working farm continues to operate—that is, forestry returns come to the landholder as part of the farm enterprise. MIS plantations where a whole farm is leased or purchased were not included; this explains the lower estimate.

Why invest in hardwood plantation sawlogs?

The upshot of the above is that:

- Relative to past trading levels, a reduced supply of hardwood sawlogs is evident. There are opportunities to expand the planted hardwood sawlog resource; this will likely be on farmland and, increasingly, outside traditional plantation areas.
- Over the period that native forest hardwood supplies have decreased (1970–2006), the supply of softwood plantation timber has increased rapidly. Softwoods now supply the bulk of the building and structural timber market (80% of sawn timber is used in building; BIS Shrapnel 1998) and relative consumption of hardwoods has declined dramatically (Nolan et al. 2005). Yet Australia's total apparent consumption of sawn timber has remained relatively stable in the last 40 y (Nolan et

al. 2005; ABARE 2006). Softwoods have competed and will compete with hardwood sawlogs in this major sector.

- The future shows an increase in plantation hardwood which will require different processing, and is an opportunity for different marketing.

Kile (2005) discusses the *Hardwood Dilemma* and notes that:

Whilst there has been massive private investment in short-rotation fibre plantations, sawlog plantations have largely been funded through public investment, particularly in Queensland, New South Wales, Western Australia and Tasmania. Although all states seek to encourage private investment in longer-rotation hardwood plantations, success so far has been limited ... Australia's comparative advantage in hardwood production has been in access to a range of native forest species of diverse colour and physical properties suitable for use in a wide variety of situations. Australia has no competitive advantage when growing plantations for sawn timber. Any commercial success will require carefully selected sites, high growth rates, low processing costs and a good outturn of the highest-value products.

Achieving increased private investment in solid-wood products will require:

- evidence that long-rotation hardwood plantations are a viable commercial option: this applies at both the farm and industrial scale
- a return equivalent to or better than that from pulp products or agriculture, either through direct returns or with supplementary income from environmental services
- evidence that plantation managers are conscientious in managing natural resources, and plantations are located wisely within water-supply catchments.

That sawn timber is 'high(est) value' cannot be assumed. Readers should note that the value to industry of processed (manufactured) high quality paper is significant, and in $\text{\$ m}^{-3}$ value (in log equivalent) provides benefits to the economy of similar proportions to solid-wood products⁴. The high value of paper, however, is mainly due to the high cost of the pulp and paper mills required to manufacture it. The cost of the pulpwood is a small proportion of the value of the final product.

Investors in plantations will consider harvest returns and timescale. Industry sources in Victoria indicate that where plantations are a reasonable cartage distance to ports, the derived stumpage rates (after allowing for harvest and haulage) for blue gum pulpwood exceeds the average for radiata pine sawlogs. This suggests that unless there is a significant change in log pricing, private investors with land within reasonable distance from ports are faced with a choice of growing softwood sawlogs over a rotation of 30+ y, or 10 y for blue gum pulpwood—and will choose the latter. Hardwood plantations for solid-wood products will face similar challenges unless the rotation length can be significantly reduced and/or a high price premium can be achieved (including from environmental services over and above what can be achieved from a pulpwood regime).

Factors affecting price of hardwood sawlogs are:

- availability of relatively cheap, high-quality hardwoods imported from tropical forests. This supply is expected to decline due to the effects of over-harvesting and increasing restrictions on illegal harvesting. Theoretically this reduced supply will enable domestic prices to increase, but this could be offset by other factors.

⁴ IndustryEdge Pty Ltd notes that the December 2006 wholesale price list for Reflex photocopy paper (as produced and packaged at Australian Paper's mill at Maryvale ready for direct distribution to the market) is $\text{\$2220 t}^{-1}$ (with discounts off the list price often 20–40%). In log equivalent this is around $\text{\$600 t}^{-1}$ of pulpwood from native forest (ash). Blue gum will produce even higher pulp yield. A hardwood plantation sawlog at say 40% sawn recovery and 40% chip (assuming it is also used for the same paper manufacture) and 20% sawdust/residue (assuming minimal sales value) would need to achieve a value of over $\text{\$900}$ wholesale per sawn cubic metre to exceed the log equivalent value of the pulpwood at the above list price (or $\text{\$630}$ if a 30% discount applied).

- substitution with composite wood and with non-wood products, and technical innovations, such as using veneers instead of large cross-sections
- long-term contracts for harvest and supply with prices fixed administratively, often by state governments
- the possibility that future building codes will require improved sustainability and carbon emissions ratings, where hardwoods could have an increased role.

Taylor (this proceedings) comments on the investment structures needed to encourage increased eucalypt plantation establishment and processing. Grealy (this proceedings) is positive about the scope for joint investment partnerships to expand hardwood plantations and meet shortages in specific products such as poles, as well as the current shortfall in hardwood logs in Australia. Partnerships and leveraged government funding can reduce the reliance on direct government funding (e.g. establishment of pine plantations in 1950s) and encourage us to think more about products and markets.

Nolan is more cautious about hardwood prospects (pers. comm.), noting that the major market remains structural timber, and this is dominated by softwoods and increasingly by composite and engineered products. Hardwoods, however, are expected to retain a position in appearance products, and with technological advances there is increasing scope for their use in veneers, peeled LVL and scantling. All agree that hardwood sawlog production must combine the unique qualities of Australia's native timbers, with astute planning, production of high quality trees targeted to specific markets, and innovation in products and marketing.

Research will need to play a key role in attempting to resolve this 'hardwood dilemma'. R&D on water use, on environmental services such as carbon, and on the best ways to implement integrated forestry must be seen as part of the business. This addresses licence to operate within the community, and available agricultural land.

Investment in R&D in the forestry and forest products sector

The following considers the overall investment in R&D in the forestry and forests products sector and how it compares with other industries, as well as who funds the research. Where an organisation has recently changed its name, we acknowledge the name change in the first instance and thereafter refer to the organisation name relevant to the years being discussed.

Comparison with other industries

The expenditure by Research and Development Corporations established under the PIERD Act provides some guide to the comparative investment in R&D by industries centralised through the PIERD Act levy system.

In 2001–2002, the Forest and Wood Products Research and Development Corporation (FWPRDC, now Forest and Wood Products Australia—FWPA) allocated \$7.1 M to forest and forest products research, which represented 10% of the \$70 M total expenditure on forest and forest products research in Australia at that time. In 2005–2006 similar amounts were expended on the FWPRDC programs; this is estimated to be 0.18% of Gross Value Production (GVP), down from 0.22% the previous year⁵. Note that other research groups (next section) provide forest research funds in addition to FWPRDC.

The FWPRDC expenditure as a GVP percentage is similar to that of Meat and Livestock Australia (MLA) which represents beef and lamb. In round figures MLA's \$22 M investment on R&D equates to around 0.22% of GVP⁶.

⁵ Advice from FWPRDC

⁶ Advice from Meat and Livestock Australia. MLA provides R&D, market information and marketing to benefit the red meat industry, excluding some smaller animal industries funded by RIRDC.

Both wool and grains levies significantly exceed the 0.5% GVP Australian government cap for matching funding. The grains industry levy for R&D is about 1% of GVP and the levy payable on wool is 2%, for R&D administered by Australian Wool Innovation Pty Ltd (AWI) ⁷.

Previous R&D funding by the forestry and forest products sector

Turner and Lambert (2004) estimated the expenditure on production-oriented forest and forest products research within Australia for 2001–2002 and compared it with levels in the previous 20 y (see Figures 2 and 3). After adjustment for inflation, it was found that total expenditure had declined in forest research, and particularly in products research.

Excluding monitoring and survey work, expenditure on Australian forest research declined from \$60.6 M in 1981–1982 to \$50.5 M in 2001–2002 (without administration and management; CPI 2002 adjusted). The proportion spent on native species plantations significantly increased to 31.4% of the total. The expenditure on direct forestry environmental research declined, but this reduction was essentially taken up through monitoring and survey work. In 2001–2002, products research was \$19 M (Figure 4). The expenditure had declined over the previous 20 y from \$1.80 t⁻¹ to \$0.81 t⁻¹ of total product.

The source of funds for forest research was predominantly Commonwealth and state agencies (Figure 5). The percentage provided by the Commonwealth government remained relatively constant. Companies and universities generally each provided less than 10% of research funds. Companies funded a larger proportion of the products research, but Figure 4 shows that overall company funding for products research declined. The proportional input to forest products research by organisations with the responsibility for managing forests—that is, state agencies and companies—fell.

Our understanding is that since that study funding from state agencies has continued to decline, particularly where there has been privatisation and or where forest management has been separated from the commercial entities, such as in Victoria. Over time, the grower levy (see FWPA below) might be expected to influence the relative proportion of research funds derived from MIS and superannuation companies, particularly the expanding hardwood pulpwood sector.

Current funding for forests and forest products research

The expenditure above relates to all Australian forest and forest products research from 1981–1982 to 2001–2002, including ‘native species plantations’ of eucalypts and non-eucalypts. Similarly, total current research funding from organisations is outlined in Table 1. These figures indicate that the combined contribution through Research and Development Corporations, CRCs and Ensis, including research provider input, is roughly \$27 M y⁻¹. A wide range of organisations are partners in funding, as shown below. Where possible, the southern Australian sawlog plantation component is given.

Cooperative Research Centre (CRC) for Forestry

This CRC commenced full operations from October 2005. It built upon the work of two previous CRCs, also based in Hobart: the CRC for Temperate Hardwood Forestry (1991–1997) and the CRC for Sustainable Production Forestry (1997–2005). The CRC for Forestry comprises 29 partner organisations across Australia, including 22 forest industry companies and agencies, five universities, CSIRO and the FWPRDC (FWPA). The CRC for Forestry is funded over 7 y with contributions from partners (\$59 M) and the Australian Government (\$26.6 M).

Total cash expenditure on research is budgeted to be just under \$40 M over the 7-y period. Of this 16% (\$6.3 M) is for Program 2: High-value wood resources, which relates directly to sawlog production. During the years 2006–2007 to 2009–2010, Program 2 cash budget is around \$1 to \$1.3 M y⁻¹. Note that the CRC for Forestry includes a northern research node where around a quarter of Program 2 is directed to sub-tropical plantations.

⁷ <http://www.daff.gov.au/agriculture-food/levies>

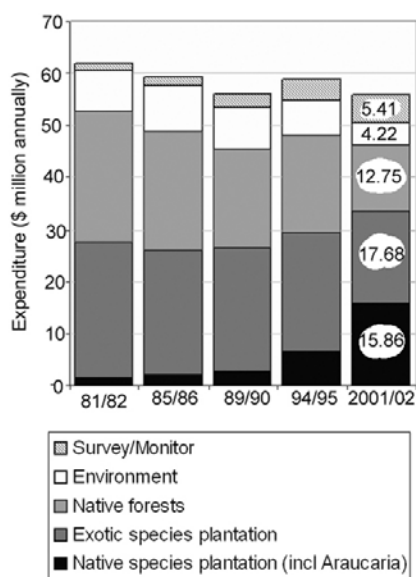


Figure 2. Australian expenditure per year on forest research, plus surveys and monitoring (\$ M y⁻¹, adjusted by CPI to 2002 values)

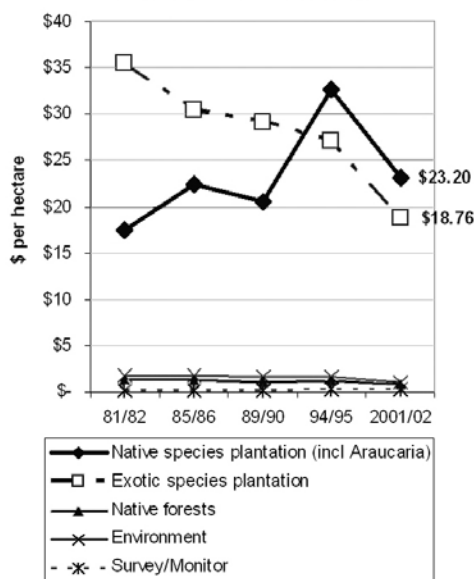


Figure 3. Australian expenditure per hectare on forest research, plus surveys and monitoring (\$ ha⁻¹, adjusted by CPI to 2002 values)

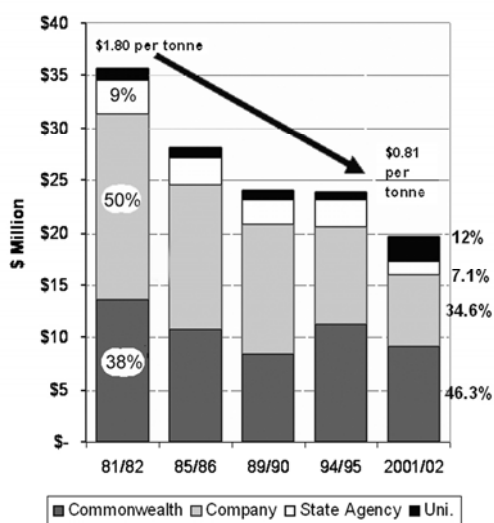


Figure 4. Australian expenditure on forest products research (\$ M y⁻¹, adjusted by CPI to 2002 values)

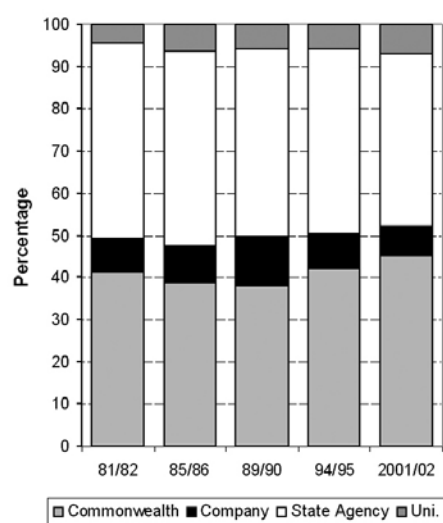


Figure 5. Australian expenditure on forest research by funding source (%)

Source for Figures 2–5: Turner and Lambert (2004)

Table 1. Summary of current funding for forest and forest products research

Entity	Funding period ^A	Total research funding for forest, forest products and farm forestry research
CRC for Forestry	2004–2005 to 2011–2012	\$59 M partner and \$26 M Australian Government (est. \$40 M direct research)
CRC for Wood Innovations	2001–2002 to 2007–2008	About \$40 M partners in kind and \$33 M cash
Joint Venture Agroforestry Program	2004–2005 to 2008–2009	\$6 M (est. \$5 M direct research)
FWPA (previously FWPRDC)	2007–2008	About \$7.1 M y ⁻¹ for all R&D—most hardwood (plantation and native) funding is already counted in this table under CRCs and other organisations
Ensis	CEF project 3 y from 2003–2004	\$3.45 M NHT funds over 3 y with matching contribution by CSIRO
Department of Agriculture, Fisheries and Forestry	NHT: PFDCs, JVAP and the CEF project through Ensis	Largely counted in this table under other organisations
State agencies	Ongoing, opportunistic	Self-funded projects plus in-kind contribution to projects funded by above
Queensland Hardwood Plantations Research Fund	2007–2008	\$2.6 M
Private Forestry Development Committees	Currently till June 2008. Opportunistic	Modest budget directed to research activities such as trial plots

^A CEF = Commercial Environmental Forestry program; NHT = Natural Heritage Trust; PFDC = Private Forestry Development Committee; JVAP = Joint Venture Agroforestry Program

Cooperative Research Centre (CRC) Wood Innovations

This CRC runs for the 7-y period 2001–2002 to 2007–2008. There are 16 participating organisations including three universities, FWPRDC (FWPA), CSIRO, research institutes and other public and private organisations. The total cash contributions over that period are over \$33 M, plus just under \$40 M in-kind.

Joint Venture Agroforestry Program (JVAP)

The Joint Venture Agroforestry Program provides and manages funds for research on agroforestry and farm forestry. Agroforestry or farm forestry is the incorporation of trees into farming systems for commercial and natural resource management benefits.

Established in 1993, JVAP is a partnership between three Australian government agencies: Rural Industries Research and Development Corporation (RIRDC), Land & Water Australia, and FWPRDC (FWPA). Additional funding has been provided for some activities by the Natural Heritage Trust (NHT); the Department of Agriculture, Fisheries and Forestry (DAFF) and other government agencies. The JVAP also jointly funds some collaborative projects with the CRC for Plant-Based Management of Dryland Salinity (now CRC Future Farm Industries). RIRDC is the managing agent for JVAP.

Over the period 1993 to 2004, JVAP provided about \$23 M towards farm forestry and agroforestry R&D, attracting a similar contribution from industry and research partners. JVAP will spend around \$1.2 y⁻¹ on research and development during the period 2004–2005 to 2008–2009.

Forest and Wood Products Australia (FWPA), formerly Forest and Wood Products Research and Development Corporation (FWPRDC)

In addition to contributions to the above programs, several hundred thousand dollars has been expended by FWPRDC on high-value plantation and regrowth research. Recent and current work is largely directed to sawmilling trials.

The work of the FWPRDC has recently been transferred to the new industry-owned entity, Forest and Wood Products Australia (FWPA). FWPA will receive levies from the forest industry plus matching payments from the Australian Government for R&D. The new entity will continue to fund forest and wood products research and development, and will conduct new work in generic marketing and promotion. A new levy of 5 ¢ m⁻³ contribution will be applied to private growers, and all state-owned growers have agreed in-principle to a voluntary contribution at the same level. Existing hardwood levies (native forests) have increased to the same level as softwood levies. In agreeing to the changes, the Australian Government has required that the current R&D funding does not decline below the current levels. The net effect will be an unchanged amount for R&D through the new organisation. It is not yet known how much of the future budget will be directed to high-value eucalypt plantations.

DAFF, CSIRO, state government and private industry

The Australian Government's Department of Agriculture, Fisheries and Forestry (DAFF), the Natural Heritage Trust (NHT), state governments and industry have provided some funds for national projects.

DAFF provides matching funding for research and development to the FWPRDC (FWPA). The NHT in conjunction with the states funds the Private Forestry for Sustainable Development and Environment Program (which includes funding for 19 Private Forestry Development Committees (PFDCs)) and (until June 2007) the Commercial Environmental Forestry Program. Many of the PFDCs would have a modest budget directed to research activities such as trial plots.

The southern forest agencies, relevant departments (WA, Victoria and Tasmania) and private companies appear to provide almost all of their financial support for R&D on commercial plantations and products through the CRCs and RDCs, where their contributions are reflected in Table 1. Queensland Forestry participates in the CRC for Forestry. In 2000–2003, the Queensland Government also funded the Hardwoods Queensland Initiative. The Queensland Department of State Development has recently announced \$2.6 M for projects to promote hardwood plantations.

Turner and Lambert (2004) indicated that few companies had undertaken significant research in addition to that undertaken through the CRCs. This appears to still be the case. With regard to private investment in R&D, the major growers are active through the CRCs. While MIS investors are less likely to want to invest in long-term plot trials for hardwood sawlog plantations on their land, the MIS companies have been establishing quality monitoring schemes regarding growth and yield that should contribute to the knowledge base.

Current R&D content

Current R&D on hardwood forest management and forest products builds on a long history of Australian research on (mainly softwood) silviculture, species trials and tree breeding, and also on processing and use of native forest timbers. Several of the agencies and most partnerships mentioned in this paper have existed for many years. This section will outline the broad interests of research agencies (Table 2), and some current projects relating to hardwood sawlog production. The project descriptions were mainly obtained from web searches, and provide an overview rather than a detailed analysis of the literature. The farm forestry examples are more comprehensive.

Table 2. Broad areas of investment by various forest R&D funding agencies

Research area	Funding agency ^A						
	FWPRDC (FWPA)	CRC for Forestry	CRC Wood Innovations	JVAP	Ensis & CSIRO	State government & PFDCs	DAFF & BRS
Tree breeding	√	√		√	√	√	
Stand management	√	√		√	√	√	
Inventory, and growth and yield models	√	√		√	√	√	√
Harvesting		√					
Wood sawing, drying and processing	√		√	√	√		
Wood product development	√		√	√	√		
Economics	√	√		√			√
Forest certification	√						
Forests and water	√	√		√	√		√
Environmental services and carbon		√		√	√	√	√
Bioenergy				√			
Forest policy and socioeconomics	√	√		√			√
Market research and marketing needs	√			√			
Prioritising industry investment	√			√			
Regional analysis (incl. regional business plans and coordination of resource quality and continuity of supply)				√	√	√	
Commercialisation			√				
Research delivery and education ^B	R, C & industry meetings		√	R, C, Master Tree Growers program, project field days	R, C & some work shops	R, C, industry meetings, field days, landholder advice	R, C, some workshops

^A FWPRDC = Forest and Wood Products Research and Development Corporation, now FWPA; JVAP = Joint Venture Agroforestry Program; PFDC = Private Forestry Development Committee; DAFF = Australian government Department of Agriculture, Fisheries and Forestry; BRS = Bureau of Rural Sciences

^B R = reports and scientific publications, C = conferences

Research organisation goals

CRC for Forestry

The CRC emphasises research to support environmentally sustainable, cost competitive, eucalypt plantation forestry, and has four research programs (RP). Each program leader oversees a range of projects or subprogram areas (see www.crcforestry.com.au).

Programs are:

- RP1 Managing and monitoring for growth and health
- RP2 High-value wood resources
- RP3 Harvesting and operations
- RP4 Trees in the landscape.

JVAP

The JVAP Five-Year Plan outlines the key strategies for the period 2004–2009 (Lott 2006a). It emphasises farm forestry species and the challenges of design, scale, markets and coordination, but recognises the connections with large-scale industrial forestry in terms of species, products and markets. The key objectives are:

1. Identification and development of new and existing agroforestry products and services
2. Developing product-market linkages
3. Integration and optimisation of commercial, environmental and social factors

There are three aspects to the third strategy:

- Design—Develop and improve agroforestry designs to optimise social, economic and environmental factors at the paddock, farm and regional-landscape scale.
- Environmental services—Demonstrate mechanisms for valuation and trading of environmental services provided by agroforestry and farm forestry, and their impacts.
- Policy and institutional—Investigate new policy and institutional arrangements that stimulate agroforestry investment.

Complementing this, JVAP aims to communicate, disseminate and facilitate adoption of research.

JVAP's research has been undertaken in all states and territories of Australia and represents most agricultural zones with more than 600 mm rainfall per year (sometimes as low as 250 mm). Very little research has been on softwoods. Most targets hardwood species, especially in low-to-medium rainfall zones. A significant proportion of JVAP's current research is concerned with growing woody perennials on areas at risk of dryland salinity, for example mallee and biomass short-rotation hardwood crops. Other research is addressing carbon, markets for environmental services and farm forestry research needs, and scanning for new secondary chemical products derived from biomass crops, lignin and cineole (see Lott 2006b).

Some projects relevant to southern Australia are listed below. Recent northern Australia projects are also relevant to growing and processing hardwoods for high-value products (Lee et al. 2005; Armstrong et al. 2007; Carr 2007a,b; Reilly et al. 2007).

A business case for the next phase of JVAP will be prepared in 2008.

FWPRDC (FWPA)

FWPRDC has emphasised R&D in the following areas:

- Market knowledge and development
- Manufacturing and products
- Resource characterisation and improvement
- Sustainable forest management
- Services and capabilities.

Other than through investment in JVAP and the above CRC programs, FWPRDC research relevant to high-value eucalypt plantations has largely been focused on processing trials.

FWPRDC recently funded two major reviews relevant to high-value sawlog sector development:

- Eucalypt plantations for solid-wood timber products in Australia, by Nolan et al. (2005)
- Determining the economics of processing plantation eucalypts for solid timber products, by Innes et al. (2008).

These are discussed in the R&D and investment section below. FWPA will determine its initial research and marketing priorities in 2008.

CRC for Wood Innovations

This CRC has three research programs (plus education and commercialisation programs), investigating:

- Microwave processing of wood, and applications including reducing growth stresses, wood drying, wood preservation, new wood composite products, and the fundamental science of interactions between wood and microwaves
- Technologies that add value to finished wood products, including wood surface finishes, technology-led design, wood bending and extending the lifespan of wood products
- Raw wood enhancement, including wood pyrolysis bio-products.

In the last, regrowth hardwood is more likely to be studied, but much of the work will benefit hardwood plantation wood.

Developing and delivering technologies that streamline timber processing and significantly add value to wood products is emphasised, through research conducted in collaboration with industry partners and directed at meeting the needs of industry. The objective is to successfully transfer the technologies as on-line processes to the wood processing and furniture industries.

CSIRO, Ensis and Commercial Environmental Forestry

CSIRO is involved in a range of forest and forest product research projects, with co-funding from the above agencies. CSIRO Forestry and Forest Products (FFP), through the (now dissolved) joint venture Ensis, has managed a broad-ranging R&D program called 'Commercial Environmental Forestry' (CEF)⁸. It aimed to stimulate private investment opportunities in tree production in low-to-medium rainfall zones typical over much of Australia, while helping to provide multiple environmental benefits such as water quality improvement and enhancement of biodiversity and carbon sequestration. Research on forest and forest products continues through CSIRO Forest Biosciences (formerly FFP).

State government and private industry

Victoria, through the Department of Primary Industries, has essentially concentrated on the CRC work discussed above. In Western Australia additional work has focused on dryland sawlogs, including the Infinitree project⁹. In NSW the effort is mainly directed to the northern areas of the state.

⁸ www.ensisjv.com/cef and www.daff.gov.au/forestry/national/investment/cef-program

⁹ In 2003 the Forest Products Commission of WA launched its Infinitree™ brand to promote the concept of tree farming in lower rainfall areas and its environmental, social and economic benefits to farmers and the broader community. A major initiative of \$64 joint Australian and Western Australian Governments is funding the Strategic Tree Farming (STF) Project under the National Action Plan for Salinity and Water Quality. The project focuses on the targeted establishment of trees (maritime pine, mixed eucalypts for sawlogs and sandalwood) in catchments in the medium- to low-rainfall areas. The aim is to protect biodiversity, manage salinity and rising water tables and provide a resource to supply new and emerging timber based industries. The STF Project (commencing 2005 and funded to 2008) reflects the principles of Infinitree in promoting the adoption and integration of trees into the agricultural landscape and diversifying on-farm land use and income.

Forestry Tasmania's earlier work, mainly directed at regrowth native forests, has included plantation trials of rotary peeling in China, Malaysia and locally to prove the opportunities leading to the establishment of the Ta Ann plywood plant in Tasmania. Earlier contributions addressed backsawn drying of regrowth hardwoods. There are ongoing 'regime' (silvicultural options) plantation trial plots at six sites aged 6–10 y. In-kind staff time would be around \$100 k y⁻¹. Some projects are also conducted through Private Forestry Tasmania.

The Victorian and NSW governments have been active in trialling markets for environmental services, and in carbon projects.

Projects relevant to southern Australian hardwood sawlog plantations

Species × site interactions

State departments, CSIRO Forestry and Forest Products, Ensis and Greening Australia have established species trials and measured growth for a wide range of species and sites in southern Australia (e.g. Vercoe and Clarke 1994; Carr 2007a,b,c). Funding has come from a range of sources. Overall, data on growth responses to site factors are patchy for most species apart from *E. globulus*, *E. nitens* and *P. radiata* (Booth et al. 2007) and some recent comprehensive data collected by Ensis on spotted gum and sugar gum. Work in low-to-medium rainfall zones funded by JVAP includes that of the Australian Low Rainfall Tree Improvement Group (ALRTIG) (Harwood et al. 2005; Bush et al. 2007), species × site trials (Carr 2007c) and trees for saline landscapes (Marcar and Crawford 2004). Carr (2007a,b,c) measured a large number of Greening Australia trials including a wide range of species.

Existing research, in particular that on growth responses to site factors including soil, needs to be better summarised and provided to the public. A clear industry statement on the key species for hardwood sawlog plantations would help focus future research.

Inventory, growth and yield modelling

Industry needs efficient and accurate modelling and monitoring tools. CRC Forestry Program 1 is using the computer modelling system, CABALA, to evaluate forest management decisions. Ongoing improvement of such tools will improve decisions on plantation nutritional requirements, water use and growth rates—the fundamental elements of being able to grow profitable plantations and address issues such as water. Further validation is needed as companies move into both second and coppice rotations, and in both the Green Triangle and WA.

Growth models have improved over the past two decades, with increasing availability of data for site and later-age growth (e.g. Wong et al. 2000; Hensken et al. 2005; Strandgard et al. 2005; Booth et al. 2007; Paul et al. 2007; Wang and Baker 2007). State governments and companies also monitor growth and yield plots. Some of this is now made available to the CRC for Forestry for modelling. Models using government and company-collected growth data are not always released to the public. The Farm Forestry Toolbox has now incorporated growth models 'black boxed' from a range of sources in southern Australia (Warner 2007), and version 5 will soon be released for public use.

Tree breeding

Tree breeding for eucalypt sawlogs is relatively 'early days' and requires attention to some traits different from those important for pulp and fibre—most effort has been on *E. globulus* and *E. nitens*. The Southern Tree Breeding Association (STBA), CRCs, CSIRO and state departments are involved. In CRC for Forestry Project 2.1, a new marker system is being developed to support gene-assisted breeding. The CRC for Forestry is co-investing in the development of the DArT technology for eucalypts and will use it to complement their studies on individual candidate genes for wood quality.

In CRC for Forestry Project 2.2 (Silviculture for high-value solid and engineered wood products), the STBA is guiding the conversion of two STBA progeny trials of *E. globulus* in Victoria from pulpwood to solid-wood silvicultural regimes. These pedigreed trials will provide a valuable scientific resource to help determine the level of genetic control of traits affecting sawlog production and to study clearwood production in *E. globulus*.

JVAP has funded the Australian Low Rainfall Tree Improvement Group (ALRTIG) since 1999. ALRTIG is a collaborative partnership between southern state agencies, CSIRO and JVAP to select and improve key species suitable for low-rainfall forestry and farm forestry. The species are *Eucalyptus camaldulensis* (river red gum), *Corymbia maculata* (spotted gum), *E. cladocalyx* (sugar gum), *E. occidentalis* (swamp yate), *E. tricarpa* (red ironbark) and two low-rainfall pine taxa. ALRTIG has established provenance and progeny trials in a range of sites and will continue to measure these, and use the trials to supply improved seed and to select material for further improvement (Bush et al. 2007). Another project is measuring heartwood variation in sugar gum and spotted gum with a view to making selections for (CCA-free) vineyard posts.

Silviculture and stand health

Silviculture is an area of ongoing research in state departments that manage forests, and in CRCs. The treatments tend to be regionally based, with few comparisons across states or regions. The wide range of relevant species and sites makes species $\times$ site $\times$ silviculture data patchy for most eucalypt species. There is still a lack of data on the effect of silviculture on later-age stand performance.

In CRC for Forestry Project 2.4 (Incorporating wood quality into plantation estate management), PhD student and post-doctoral fellow topics include:

- Better predicting the risk of branch-associated defects and helping to develop reliable silvicultural practices to minimise these defects in *E. nitens* and *E. globulus* stands grown for solid-wood products.
- A study of biological and economic factors that can maximise profitability from processing plantation-grown hardwood timber. It is likely that this project will examine veneer production from *E. nitens*; veneer has received less attention than sawn timber.

JVAP research has included measuring the impact of insects on eucalypts in the Murray Valley (Floyd and Farrell 2007), collating hardwood silvicultural research trials (Lott 2001) and a review of pruning (Montagu et al. 2003).

Harvesting and operations

By far the greatest cost in the production of forest products is that for log harvesting and transport. It is generally important to reduce this cost and or improve utilisation recovery, thus improving overall viability of both short- or long-rotation plantations. Optimal recovery of the higher log grades will be even more important in sawlog plantations. The CRC for Forestry research program will study forest harvesting and log transport operations in a range of locations extending across southern Australia and in both native forest and plantations.

Harvesting on-farm and by farm forestry cooperatives is also an area of interest to JVAP.

Wood quality and processing

Research is evaluating wood quality of and new processing techniques for plantation-grown timbers. It is constrained by the lack of older stands for sampling. Understanding of the effect of site and silviculture on long-rotation wood quality is limited.

In CRC for Forestry Project 2.3 (Impact of silviculture on wood quality and wood processing), a processing study was carried out on 81 pruned trees from Forestry Tasmania's 22-y-old *E. nitens* silvicultural trial at Goulds Country in Tasmania. The project included a processing study and ancillary studies on log form, tree crown structure and prediction of product quality and value using non-destructive evaluation techniques. The project found that yield of saleable sawn product from the trees was moderate to good, but value was lowered substantially by surface and internal checking. Follow-up processing trials to test ways to reduce these problems are to be undertaken. CRC for Forestry Project 2.4 is also relevant to wood quality and processing.

Two recently completed JVAP projects are:

- Durability of low rainfall regrowth and plantation-grown timbers (McCarthy et al. 2007)
- Sawing and processing of spotted gum (Washusen 2006).

McCarthy et al. found that sugar gum plantation timber retains Class 1 durability status (as for native forest) and spotted gum also performs well. The modelling work by Washusen has continued through a FWPRDC project.

The CRC for Wood Innovation has range of current projects on wood processing (www.crcwood.unimelb.edu.au):

- Project RP 1.1 is considering ways to reduce growth stresses in fast-grown plantation hardwoods, with the objective of applying high productivity softwood sawing systems to processing of small-diameter plantation-grown eucalypts. On-line microwave treatment as well as silvicultural practices for use with hardwood timbers are being investigated. The project aims to use microwaves to relax growth stress within minutes rather than hours—so that the treatment can be incorporated as an on-line process—and to achieve 80% relaxation so that most softwood sawing systems can be used with hardwood logs. Novel two-dimensional stress analysis holds promise as a means of better understanding how end-splits initially develop and expand during processing for sawn products: end-splits are initiated at the heart and extend with time across the log cross-section and length. The new technique enables internal stresses to be measured—this has not been possible previously.
- Project RP 1.2 includes developing microwave conditioning technology that significantly reduces the time taken to convert a green log to dried finished boards. In trials with messmate (*E. obliqua*) boards, drying time was reduced from 2–4 months to 6–10 days. Similar reductions are expected for other hardwood timbers. The microwave technology also has the potential to increase the volume of sawn timber recovered from each log. Microwave processing may help to reduce end-splits, and so generate more timber suited to high-value uses such as furniture. Microwave conditioning has the potential to add value to native plantation timbers, such as *E. globulus*.
- Project RP 1.3 is developing improved timber preservation technology for softwoods and hardwoods. This includes the use of microwave technology to make timbers more permeable and improve preservative distribution.
- Project RP 1.5 (Fundamental science: how microwave energy affects wood) aims to improve understanding of the dielectric properties of a material, knowledge that is considered essential to predict how it will behave when it is microwaved.
- Project RP 2.1 is making glues stick better, and paints last longer on wood. After machining, extractives migrate rapidly to the wood surface, creating a boundary layer which can seriously hinder adhesion of glues and paints. The entry of moisture—causing swelling and shrinkage—aggravates the problem. These factors lead to the deterioration of adhesion and paint quality after prolonged exposure outdoors. Hardwood timbers are particularly affected. The research aims to alleviate these problems.

Markets and marketing

General reviews of markets are undertaken from time to time by various forestry research groups (e.g., URS and FWPRDC). There appears, however, to have been little research on marketing needs, especially for farm forestry. A recent survey of extension officers and farm forestry landholders reminded us of the lack of price transparency for private growers and the need for information on product prices (Hassall and Associates 2007). Bhati (1997–2004) also found this a constraint in providing market reports.

Current JVAP projects relevant to farm forestry and the hardwood sawlog sector are:

- Research on marketing of high-value sugar gum products (Wettenhall 2008)
- Agroforestry industry evaluation of products and markets (URS Forestry 2008a,b).

Product innovations

The CRC for Wood Innovation is funding several projects to treat wood and design new products (www.crcwood.unimelb.edu.au):

- RP 1.4 New wood composite products. The CRC has developed proprietary technology to produce microwave-expanded wood (Torgvin) and treat it with resin, compress it, cure the resin and produce a wood-resin composite product Vintorg. The CRC has formulated a suite of new preservatives and resins that are undergoing evaluation.
- RP 2.2 Technology-led design. The project involves collaboration between designers at Swinburne's National Institute of Design, and engineers working with Furntech. The collaboration evaluates the strength of novel joint designs and prototype furniture designs using established furniture standards and customised tests. CRC designers have also designed and exhibited furniture using Australian hardwoods and the CRC modified wood products Torgvin and Vintorg. This project's teams work closely in collaboration with Project 2.3 to generate novel bentwood designs.
- RP 2.3 Innovative wood bending techniques. This project investigates innovative techniques for the development of shaped wood components. The project includes the mechanical behaviour of wood during bending, and the anatomical and micro-structural changes in bent wood. Staff also gather reference data on bending characteristics for a wide range of timber species, and create new designs using bent wood.
- RP 2.4 Extending the functional life of timber products. This project investigates and documents how environmental conditions influence performance and service life of finished wood products. The aim is to develop recommendations and tools for manufacturers to ensure that they achieve optimal quality and performance for their wood products.
- RP 5.1 Environmentally friendly adhesives. CRC researchers are developing a low-cost thermo-chemical process to derive constituents of bio-adhesives. The potential cost saving and environmental benefits associated with the technology have aroused considerable interest among timber processors.

Environmental services and communities

JVAP has played a seminal part in thinking about the role of markets for environmental services (e.g. van Beuren 2001; Binning et al. 2002; Hobbs et al. 2003), along with CSIRO and the Victorian DPI. The Department of Agriculture, Fisheries and Forestry's Market Based Instruments Program funded many case studies, but very few included commercial use of trees for natural resource management outcomes. Recent JVAP projects are:

- Regional case studies of markets for ecosystem services (Whitten et al. in review)
- Institutional requirements for carbon trading by regional catchment groups (Grieve et al. in press).

The Ensis Commercial Environmental Forestry project focused on a catchment-scale pilot study in the south-west of the Goulburn-Broken Catchment, Victoria. The project began in 2003–2004 and was funded by DAFF and Ensis in collaboration with the CSIRO Divisions of Land & Water and Sustainable Ecosystems. The project developed the spatially-explicit Scenario Planning and Investment Framework (SPIF) tool to identify opportunities for environmental and economic outcomes from forestry plantings. The SPIF tool is now being used to inform tree planting locations in the Corangamite catchment of Victoria, and in the Upper Tone catchment of WA as part of the Strategic Tree Farming project.

The CRC for Forestry Program 4 focuses on developing forestry practices that meet agreed environmental certification requirements and foster constructive community engagement. Such practices will provide security for the forest industry's long-term 'social licence' to operate in the Australian landscape, and build international recognition of sustainable forest practices for product marketing. Sub-programs are: RP4.1 Water quantity and quality, RP4.2 Biodiversity, and RP4.3 Communities. The CRC for Forestry Program 1 is evaluating water use in plantations. Industry has recently funded a number of projects on water use both within and outside of the CRC.

Integrated forestry

Integrating forests on farms means being aware of interactions between trees and agriculture, the potential for other activities such as grazing, and the needs of farmers to continue to run the rest of their enterprise. For example, JVAP has funded research on tree $\times$ crop and tree $\times$ pasture interactions (e.g. Sanford and Sudmeyer 2007). There is a lack of understanding of the economics of farm forestry and this (along with drought) is an impediment to adoption by the wider agricultural community. A current project is valuing the economic, social and environmental role of trees on farms. Forestry investors planting on farmland need to be aware of farmer and catchment management needs.

Expansion of forestry will gain greater community acceptance if it is integrated into the regional landscape to meet water, salinity and natural resource management targets. A recent analysis funded by CRC for Plant-based Management of Dryland Salinity reviewed the prospects for integrated forestry while delivering salinity benefits, for six regions in the 450–750 mm y^{-1} rainfall zone in southern Australia (Robins and Marcar 2007). The review concluded that the prospects are best in the 600–750 mm zone, with good prospects for two regions—south-western WA, and south-western Victoria – south-eastern SA. In the Murray western slopes–Murrumbidgee NSW and northern Victoria regions, prospects are lower as predicted reductions in stream flow outweigh salinity benefits. These regions, however, already have significant forestry activity, especially in higher-rainfall zones. Northern NSW, central-west NSW and Hunter NSW lack significant forest industries and infrastructure, so forestry has lower economic value and competes against more profitable agricultural options. For the 450–600 mm zone, prospects are less favourable for all six regions, because of slower growth (lower rainfall) and less existing infrastructure, although salinity benefits can be significant if tree plantings are well located in catchments. The progressive development of forest industries in the neighbouring 600–750 mm rainfall zone should with time bring flow-on benefits to adjacent lower-rainfall areas.

Current and recent JVAP projects are measuring water interception by woodlots and belts and using the data to model surface and water table management (e.g. Ellis et al. 2007). The JVAP Regional prioritisation project discussed below is using the SPIF tool and the Commercial Environmental Forestry concept to evaluate forest production systems including environmental services provided by forestry.

R&D and investment priorities

Two review projects funded by FWPRDC evaluated eucalypt plantations for solid-wood timber products in Australia. Nolan et al. (2005) drew on research from a wide range of sources, and considered:

- predicted wood availability
- processing for solid-wood products (natural rounds, sawmilling and veneering)
- wood quality
- silviculture
- economics
- technological advances
- future directions for research (these are outlined at the conclusion of this paper).

The report rates the importance of wood qualities with each major product group and relates these to wood quality expected from *E. nitens*, *E. globulus*, *E. obliqua*, *E. cladocalyx* and NSW and Queensland species for three different silvicultural regimes. It discusses in detail the research into various factors that influence wood quality and quantity including breeding, age, location, propagation and silviculture. Likely developments in silviculture, harvesting and processing, and the economics of growing and processing plantations were discussed.

Table 3 gives the number of processing trials summarised in the report, and their location and age.

Table 3. Number of processing trials summarised in Nolan *et al.* (2005). The numbers in brackets indicate the ages (y) of the plantations

Species	Thinned and pruned	Late thinned at age 8 y and pruned	Thinned and unpruned	Unthinned and unpruned
<i>Eucalyptus globulus</i>	3 in WA (22/22/13)	2 in Victoria (13)	1 in Victoria (32)	3 in Tasmania (33/21/19) 2 in Victoria (15/24) 1 in WA (9)
<i>E. nitens</i>	1 in Victoria (10)		1 in Victoria (24)	2 in Tasmania (24/25) 1 in Victoria (29)
<i>E. sideroxylon</i>				1 in NSW (40) 1 in Victoria (26)
<i>E. cladocalyx</i>				3 in Victoria (36/40/100)
<i>Corymbia</i> spp.				1 in NSW (40)

Nolan *et al.* (2005) found that:

- Modelling management tools continue to be an important research focus. They cite the Farm Forestry Toolbox as an accessible tool that enables growers to assess returns from various management alternatives.
- Few sawmills are processing sawlogs from hardwood plantations; their products are generally industrial and structural timbers. Several mills in Victoria are processing 30–40-y-old *E. regnans* (unthinned, unpruned) from HVP Plantations and one Tasmanian mill is processing 10–15-y-old *E. nitens* from thinnings.
- Plantation logs are suitable for the natural rounds market but require preservative treatment. One company is CCA-treating posts from *E. nitens* plantations for vineyards and general agricultural applications. It reports full penetration of the sapwood.
- Various techniques are discussed for milling and mitigating the normal growth stresses, and for drying the timber. Little research has focused on drying these timbers; most of the available reports were part of accounts of full milling trials and provided little detail. Reports from industry suggested the material was susceptible to considerable drying degrade if initial drying was not carefully controlled.
- The concentration of research work on unthinned and unpruned plantations reflects the lack of thinned and or pruned plantations of an age suitable for analysis.
- Recent published trials using both pruned and unpruned sawlogs in conventional hardwood mills produced encouraging results, although doubts persisted as to the processing behaviour of the wider plantation resource.
- Occasional studies indicated high recoveries of face-grade appearance veneer from suitable pruned plantation logs. Trials by Forestry Tasmania and others suggested that veneers from plantation-grown *E. nitens* and *E. globulus* were not suitable substitutes for native forest material for engineered timber products such as container floors and formwork as they did not satisfy requirements for high strength. They were, however, suitable for other plywood grades. Plywood was being successfully produced in Spain from *E. globulus* (unpruned) and *E. nitens*.
- The use of microwave technology to create micro-voids in wood—to allow water out during accelerated drying and to allow preservatives or glues in—has potential for major technological advances.

Innes *et al.* (2008) assessed the economics of processing plantation eucalypts for solid timber products. The project was based on current industry-standard equipment and procedures, and sought to identify the factors most directly affecting the value of dry output given current market conditions. The findings were:

- There were significant differences between sawn timber recoveries from mills processing plantation sawlogs with different technologies.

- A 26-y-old thinned-pruned *E. nitens* plantation at Ridgley (Tasmania) showed the highest estimated yield of grade 1–3 sawlogs. However, based on assumptions on stumpage rates and some major conditions, the butt logs were considered not viable to process for appearance grades, primarily because of degrade by internal checking.
- Logs from thinned and pruned 19-y-old *E. globulus* at Ulverstone (Tasmania) were viable to process at one of the mills and provided a log intake 40 000 m³ y⁻¹. The sawlog yield per hectare, however, was very low.
- Internal checking seems (anecdotally) to be reasonably heritable, with most boards cut from a particular log exhibiting similar levels of this defect.
- Problems were found where pruning was not high enough, for example if a grower is targeting a 5.5 m sawlog and prunes only to 5.8–6.0 m, butt flare and branching effects may mean that a log of only 5 m is recovered.
- Dimensional stability was an issue, particularly with the *E. globulus* boards mentioned above.

The authors conclude from the above that future production of high-value traditional sawn products from such plantations will require different processing techniques to provide better control of value-limiting factors such as distortion, collapse and internal checking.

JVAP has recently commissioned two projects to evaluate farm forestry regional prospects and inform investment. In the current ‘Prioritisation of Regional Opportunities for Agroforestry Investment’ project, Ensis is using the SPIF model to analyse bio-geographic, economic and infrastructure data to identify the regions and forest production systems that are most likely to be profitable. The ‘Agroforestry Industry Evaluation’ project is discussed in the Regional Prospects section below.

Publication and extension

All of the organisations discussed above publish their research in scientific journals and provide information on their websites. Communication of research results to industry and government occurs via conferences, meetings, networks and use by extension and policy officers. Some research projects include field days as part of the deliverables. There is room to improve the summarising of technical reports for easier use in extension, by industry and for policy (e.g. see Hassall and Associates 2007).

JVAP has funded the Master TreeGrower program since 1997, to assist landholders engage in farm forestry. It also funded the upgrade of the Farm Forestry Toolbox to version 5 (due for release in 2008, Warner 2007).

Discussion

Impediments to growing eucalypt plantations for high-value products

Kelly et al. (2005) reported six key impediments to investment in plantations for high-value products. These are shown below along with comments where circumstances have changed since the report was written.

1. The development of secondary markets for plantations is limited (i.e. sale of plantations between parties during plantations).
The Australian Government’s recent changes to the taxation system now allow trading of plantations established by managed investment schemes from four years after establishment.
2. There is a lack of readily available market information, for example log transaction prices.
3. There is limited understanding of potential investors in the forest sector and plantations, and the forest industry has limited understanding of investor needs.
4. Knowledge of the technical aspects of long-rotation hardwood sawlog plantation is limited, for each of growing, predicting yield, and processing¹⁰.
Due to the lack of older plantations considered to be at final harvest age for sawlogs, Innes et al.

¹⁰ Nolan et al. (2005) noted that information available to potential investors was spread widely; information on growth and yield was very fragmented due to a lack of existing resource information for most long-rotation plantation species; and that literature on product yields, a key factor in plantation economics, was scarce and incomplete.

- (2008) found that it is exceedingly difficult to obtain sawlogs suitable for their research trials from eucalypt plantations. This is a major impediment to processing trials. The management of eucalypt plantations is also not well suited to product needs—see comments below by Nolan et al. (2005).
5. There is limited development of markets for environmental services, for example credits for carbon, biodiversity, salinity control and water quality.
Relative to short-rotation crops, long-rotation eucalypt plantations have less certain log quality and quantity at the end of the rotation, and are unable to attract significant investments other than where this is heavily subsidised by government (but see comments by Grealy this proceedings). Accordingly any additional sources of funds such as for environmental services will be crucial to initiating investments. As noted above, returns from long rotation hardwoods would need to exceed those from pulpwood plantations. Examples of ecosystem service markets are:
 - o *Native vegetation credits could apply to revegetated plantation areas or within exclusions areas within plantations. The Victorian Government has a requirement to have no net loss from clearing vegetation, and a credit system could apply. 'BushBroker' is an Australian system for registering and trading native vegetation credits.*
 - o *Carbon accounting for tree crops currently assumes all carbon is emitted once the trees are harvested. Recent research indicates, however, that storage continues in wood products in service with subsequent minimal degradation in land fill over long periods¹¹.*
 - o *The value of the final hardwood crop needs to be considered in terms of the total average price from all products and services. Bioenergy is a new market that is encouraged through schemes such as the Mandatory Renewable Energy Targets (MRET)¹². However MRET recognises only the electricity produced and not the energy required for heating which can represent the bulk of the energy used in converting biomass to energy. A CSIRO study by Paul et al. (2003) found firewood from new plantations produces the lowest amount of carbon dioxide relative to other heating energy sources and leads to a net reduction.¹³*
 6. Sovereign risk is high due to a lack of certainty over rights to harvest and inconsistency between jurisdictions in regulations and planning associated with plantation establishment. This can stem from community antagonism to plantations on environmental, economic or social grounds.

The research summarised in the previous section is mainly targeted at impediment 4, technical knowledge. There is some general work but no quantified analysis to assist hardwoods to participate in impediment 5, markets for ecosystem services. There was little research on impediments 2 and 3, markets and potential investors. Impediments 1 and 6, secondary markets and sovereign risk, are most relevant to policy development.

Many of the above impediments would not be seen traditionally as part of a research program underpinning the development of high-value plantations for solid-wood products. However, resolving these issues can be just as, and in some cases more, critical to achieving the desired outcomes. This has to some degree already been acknowledged by individual projects in each of FWPRDC, JVAP and the CRC for Forestry, which include aspects of environmental services and community research (see Table 2).

Regional markets and prospects

There is a small investment in hardwood sawlog plantations in most National Plantation Inventory regions of Australia (Parsons et al. 2007; Table 4). However:

- should all regions be growing high-value sawlog plantations?
and
- if so, is the current plantation area sufficient for a small long-term regional supply—either for niche markets or as supplement to larger industrial harvests?
or

¹¹ http://www.greenhouse.crc.org.au/counting_carbon/wood.cfm

¹² Federal MRET targets are 9500 GWh by 2010, while the Victorian Government target is 10% of electricity consumption from renewable sources by 2010 (*Victorian Greenhouse Strategy Action Plan Update*, April 2005).

¹³ Plantation case studies 1 and 2

- what does each region need to do to reach a critical volume of supply, reliable markets and viable returns to investors in a hardwood sawlog ‘industry’?

URS has recently evaluated market prospects for a range of forest products, and the regional scope for viable farm forest industries based on these products (URS Forestry 2008b). The analysis covers all National Plantation Inventory regions and considers existing regional forest resources and infrastructure, as well as markets and processing plant size. The project was commissioned by JVAP, to inform R&D and industry investment decisions.

URS Forestry (2008b) ranked the relative prospects for different products in each region as high, medium or low, for sawn timber; veneers, plywood and LVL; and posts and poles (Table 4). The project consulted with regions to determine views of infrastructure, markets and production needs. The analysis concluded that hardwood sawlogs are an area where (forestry and) farm forestry can have some market impact, providing that supply and products are well managed.

A second project commissioned by JVAP is analysing regions and forestry production systems to help prioritise investment for industry and research. The research is being conducted by Ensis in collaboration with the FloraSearch project, and is using the SPIF tool used in the Commercial Environmental Forestry program. The project incorporates economic analyses for a range of forest production systems including sawlogs, pulp, carbon and bioenergy, and compares the predicted returns against average agricultural returns.

Coordination of R&D

The institutional structures in place help minimise the duplication of research, and provide a process to identify broad research needs within each funding group:

- Within CRCs, RDCs and major research providers, research plans identify key areas for research.
- Within several national funding bodies (FWPRDC, JVAP, CRCs), forestry R&D is selected by committees or boards representing a range of industry and government stakeholders.
- A range of organisations participate in more than one funding body and this helps minimise overlap of R&D
- The Forestry Research Working Groups have CRC, university, state and Australian government representatives, and report to the Research Priorities Coordinating Committee of the Primary Industries Ministerial Council (PIMC).
- The Private Forestry Development Committees now meet annually and their management and funding is overseen by DAFF and the state agencies that fund them.

However, defining research themes does not necessarily guarantee consultation with all relevant stakeholders to define the best project for the funds available. This takes commitment and time. Also, there are no formal arrangements to ensure coordination of forestry and forest product R&D across organisations, to ensure that *industry development* and impediments along the value chain are best addressed. The new FWPA will have some capacity to address marketing needs, but other coordination is also needed. With reduced funding from state government forest agencies, this coordinating role now falls more strongly with national organisations and partnerships.

Table 4. Regional prospects for hardwood sawlog plantations—relative area of hardwood plantation, forecast log supply (Parsons et al. 2007) and market prospects for farm forestry sawlogs used in four hardwood product groups (URS Forestry 2007 b)

Region	Emphasis on hardwood sawlog plantations	Market prospect ^A	Forecast plantation log supply ^B								
			2005 –09	2010 –14	2015 –19	2020 –24	2025 –29	2030 –34	2035 –39	2040 –44	2045 –49
Western Australia	Less than 5% of hardwood plantations	H,H,M,M	5	1	0	33	6	1	0	33	6
Northern Territory	Research and demonstration sites and some plantations of red mahogany (<i>Eucalyptus pellita</i>) and African mahogany (<i>Khaya senegalensis</i>). No log supply forecast due to small area, young age and difficulty estimating growth rates. Unlikely to produce significant volume until 2020	M,L,M,L	-	-	-	-	-	-	-	-	-
Mt Lofty Ranges and Kangaroo Island	10% of hardwood plantations, grown as farm forestry. Range of species, nearly all less than 10 y old. Forecast log supply should be considered indicative only, due to the wide range of species, small area and large variability in growth	L,M,L,L	0	0	0	14	7	0	0	0	14
Green Triangle	A very small fraction is managed for sawlogs	L,H,M,M	-	-	-	-	-	-	-	-	-
North Queensland	Dispersed widely and nearly all on private land. Includes CRRP farm forests, more recent private investment schemes including teak (<i>Tectona grandis</i>) and African and red mahogany. Too young to produce commercial timber.	M/H,L,									
L/M,M	3	5	5	9	3	5	14	0	7		
South-eastern Queensland	37% of hardwood plantations. Established mostly since 1995. Includes private investment and Queensland Government joint-venture scheme for sawlogs to replace public native forests.	H,H,L,M	0	9	12	28	72	250	15	25	11
North coast NSW	About 90% of hardwood plantations. Two age group peaks—mid-1960s to 1980, and from 1995. Plantation managers expect to adjust silviculture, scheduling and operational management to smooth the irregular supply and match markets.	H,M,L, M	72	72	85	130	100	493	771	519	212
Northern Tablelands	All hardwood plantations are for sawlogs.	M,L,L,M	1	6	5	14	4	16	10	21	10

Region	Emphasis on hardwood sawlog plantations	Market prospect ^A	Forecast plantation log supply ^B								
			2005 -09	2010 -14	2015 -19	2020 -24	2025 -29	2030 -34	2035 -39	2040 -44	2045 -49
Central Tablelands, NSW	Small areas, established only recently. No log production is expected for many years.	Grouped with northern tablelands	-	-	-	-	-	-	-	-	-
Southern Tablelands, NSW	Small areas have been established only recently and no log production is expected for many years. Few data are available on which to forecast supply from these plantations, but at most yield would amount to only a few thousand cubic metres in aggregate.	L,M,L,M	-	-	-	-	-	-	-	-	-
Murray Valley	70% of hardwood plantations, including those developed by the Farm Forestry North East project. Many have been thinned and pruned.	L,M,L,H	2	1	7	102	58	4	1	7	102
Central Victoria	2% of hardwood plantations, planted as farm forests. Comprise a wide range of species. Forecast supply should be considered indicative only, given the likely large variability in growth rates, small current area and diversity of species used.	H,L,M,M	0	2	2	4	4	3	3	2	3
Central Gippsland	One of few current sources of hardwood plantation sawlogs in Australia. Some of Australia's oldest eucalypt plantations.	H,L,L,M	120	70	20	30	81	81	96	101	131
East Gippsland and Bombala (SE NSW)	There are a few farm forests totalling around 800 ha. This farm forestry resource consists mostly of eucalypts established quite recently. No sawlog production expected for many years. Few data are available; at most yield would amount to only a few thousand cubic metres in aggregate.	M/H,L,									
M,M	-	-	-	-	-	-	-	-	-	-	-

^A Products are 1) sawn timber, 2) veneer, plywood & LVL, 3) log exports, 4) poles and posts respectively. Rankings are High, Medium or Low. North-western Victoria was ranked L,L,L,L.

^B Thousand cubic metres per year average for each 5-y period

It would be useful to see the hardwood high-value products sector draw up a matrix of research needs, which includes key species, management, products, processing, impediments and position in the value chain, and use this to discuss and allocate funding to the gaps—and to coordinate funding and research groups.

Concerns about water use, carbon and natural resource management also mean that there are other players with an interest in the role of forests (e.g. Booth 2007), and these groups must be included to ensure community support, and research delivery and adoption.

Future directions

Research on forest and product management

Nolan et al. (2005) discuss the future needs for R&D on hardwood sawlogs and list the following:

- determine growing costs for high-value solid-wood products
- understanding of market structures (for wood)
- modelling log availability (native forests and plantations)
- optimising processing
- mechanisms to control growth stress and tension wood
- understanding the interaction of site, species and silviculture
- tree breeding.

These remain key areas needing attention, despite current research effort. Regions also need to consider the relative investment in different products needed to facilitate viable resource supply, products and markets.

Social, policy and infrastructure support

In addition, there are social and broader economic issues that must be addressed for development of this industry sector. These include lack of community support for forestry, water constraints, a lack of an environmental services income stream, and the effects on private growers of government control on prices and log supply plans. The community should also be encouraged to value the life-cycle benefits of wood in terms of carbon efficiency compared with other products.

Failure to address the above issues may constrain investment in further hardwood sawlog plantations, and mean that results of R&D on management are not commercially utilised. Most of these issues are being picked up in research, but greater coordination is needed. R&D is able to play a key role.

The role of research

Public R&D includes a public-good role, for example where there is market failure or no market. This may be where private companies are not investing but there is a desired public-good outcome, or where markets and opportunities are several years beyond the horizon of private finances. Research on future needs and products must be balanced against more immediate needs of industry stakeholders and levy payers.

Two key areas which appear under-represented in hardwood sawlog R&D are the industry transition to increased supply from plantation timbers while maintaining market share and profile, and the proactive development of products and markets to position eucalypt sawlogs against competing structural products. R&D could also have a greater role in supporting and encouraging small growers and small-medium sized companies who are planting long-rotation timbers as commercial integrated forestry, and new forestry and carbon sequestration companies. We need to remember that many hardwood plantations for sawlogs are less than 10 y old.

Finally, research and development should not be confused with government policy, or advocacy. The role of publicly-funded R&D is to respond to policy and industry needs, and to inform industry, government and the community in a balanced way. Application of the results is up to you!

Conclusions

We conclude by raising some questions:

1. Is the research expenditure on the hardwood sawlog sector adequate? Hardwood sawlogs represent 9% of total log harvest and appear to receive a larger percentage of R&D funding. We suggest that arguing a case for R&D for this sector needs to look at:
 - o the fraction of the harvest that is roundwood (sawlogs)
 - o the fraction of the value of production attributable to sawlog products
 - o the trade deficit in sawlogs
 - o the potential to replace declining supplies of native timbers and to provide sustainable socio-economic activity in regional areas
 - o the role of timber and trees in providing environmental services, including carbon sequestration to achieve climate change or greenhouse benefits.Given the above, and the early development stage of plantation hardwoods, is the research funding spent in the best way?
2. How can we better coordinate R&D between organisations?
3. What further R&D is needed for the hardwood sawlog sector? Nolan et al. (2005) have already outlined key research needs. We suggest that a research and industry plan be developed with clear research priorities for species, products and processing technology, and that this also addresses regional prospects and investment needs. Innovative products, hardwood veneer and composite products should be included in the analysis, noting trends in the building industry. The plan should clearly address integration along the value chain.
4. How do we improve management of existing and future hardwood sawlog plantations to produce high-quality timber to suit the appearance and structural market? Existing evidence is clear—thinning and pruning are necessary to achieve the desired quality and price. Analyses so far show that butt logs may be inferior due to internal checking and growth stresses.
5. How do we demonstrate viable investment options for hardwood sawlog plantations?

Acknowledgements

We are grateful to the people who provided information and discussion during the preparation of this paper. Mark Parsons (BRS), Phil Polglase (CSIRO), DAFF Forest Industries Branch, Gordon Duff (CRC Forestry) and Rob de Fegely provided comments on the manuscript. The Joint Venture Agroforestry Program provided part-funding to R. Lott and G. Gooding for the preparation of this paper.

References¹⁴

- ABARE Reports (1970–2007) *Australian Forest and Wood Products Statistics*. Australian Bureau of Resource Economics, Canberra.
- Armstrong, M., Reilly, D., Lelievre, T., Hopewell, G., Redman, A., Francis, L. and Robertson, R. (2007) *African Mahogany Grown in Australia—Wood Quality and Potential Uses*. RIRDC Publication No. 07/107, Rural Industries Research and Development Corporation, Canberra.
- Bhati, U.N. (1997–2004) *ANU Forestry Market Reports*. <http://fennergchool-associated.anu.edu.au/marketreport/>
- Binning, C., Baker, B., Meharg, S., Cork, S. and Kearns, A. (2002) *Making Farm Forestry Pay—Markets for Ecosystem Services. A Scoping Study to Set Future Research Directions*. RIRDC Publication No. 02/005, Rural Industries Research and Development Corporation, Canberra.
- BIS Shrapnel (1998) *Sawn timber in Australia 1998–2013: Market opportunities, strategies and prospects for trade and investment*. Melbourne (cited in Nolan et al. 2005).

¹⁴ Many of the references are available from the websites of Forest and Wood Products Australia (formerly Forest and Wood Products Research and Development Corporation (<http://www.fwprdc.org.au/menu.asp?id=36>), or the Rural Industries Research and Development Corporation (<http://www.rirdc.gov.au/programs/aft.html>)

- Booth, T.H. (2007) Regional catchment plans in Australia and their priorities for agroforestry. Report to Joint Venture Agroforestry Program, Rural Industries Research and Development Corporation, Canberra.
- Booth, T.H., Jovanovic, T., Snowdon, P., Mummery, D., Battaglia, M., Sands, P. and Fife, D.N. (2007) *Modelling the Potential Productivity of Commercial Farm Forestry Species*. RIRDC Publication No. 05/175, Rural Industries Research and Development Corporation, Canberra.
- Bush, D. et al. (2007) *Progress in Breeding Trees for Low Rainfall Farm Forestry: The Australian Low Rainfall Tree Improvement Group 1999-2005*. RIRDC Publication No. 07/078, Rural Industries Research and Development Corporation, Canberra.
- Carr, D. (2007a) Greening Australia species trials in the Northern Territory. Report to the Joint Venture Agroforestry Program, Rural Industries Research and Development Corporation, Canberra.
- Carr, D. (2007b) Greening Australia species trials: north-west slopes and plains, Dorrigo plateau and northern Tablelands, New South Wales. Report to the Joint Venture Agroforestry Program, Rural Industries Research and Development Corporation, Canberra.
- Carr, D. (2007c) Low rainfall species trials. Report to the Joint Venture Agroforestry Program, Rural Industries Research and Development Corporation, Canberra.
- Ellis, T., Potter, N., Hairsine, P., Brophy, J., Ticehurst, J., Hickel, K., Tongway, D., Caitcheon, G. and Bartley, R. (2007) *Using Banded Tree-Agriculture Systems to Meet Surface Water Management Targets—A Design Framework*. RIRDC Publication No. 05/180, Rural Industries Research and Development Corporation, Canberra.
- Floyd, R. and Farrell, G. (2007) *Impact of Insects on Eucalypt Plantations in the Murray Valley*. RIRDC Publication No. 07/085, Rural Industries Research and Development Corporation, Canberra.
- Grieve, A., Wood, S. and Cowie, A. (in press) Carbon trading and catchment management authorities: realising the revenue potential of environmental plantings under the New South Wales carbon market. Report to Joint Venture Agroforestry Program, Rural Industries Research and Development Corporation, Canberra.
- Harwood, C., Bird, R., Butcher, T., Bush, D.J., Jackson, T., Johnson, I., Stackpole, D. and Underdown, M. (2005) *Update of Australian Low Rainfall Tree Improvement Group Breeding Strategies*. RIRDC Publication No. 05/023, Rural Industries Research and Development Corporation, Canberra.
- Hassall and Associates (2007) Survey of farm forestry stakeholder information needs. A report for the Joint Venture Agroforestry Program, Rural Industries Research and Development Corporation, Canberra.
- Hensken, F.L., Battaglia, M. and Ottenschlaeger, M.L. (2005) Silvicultural decision support for farm forestry: predicting tree growth in farm forestry and following thinning. A report for the Joint Venture Agroforestry Program, Rural Industries Research and Development Corporation, Canberra.
- Hobbs, R.J., Floyd, R., Cunningham, S., Catling, P. and Ive, J. (2003) *Hardwood Plantations—Quantifying Conservation and Environmental Service Benefits*. RIRDC Publication No. 02/083, Rural Industries Research and Development Corporation, Canberra.
- Innes, T., Greaves, B., Washusen, R. and Nolan, G. (2008) *Determining the Economics of Processing Plantation Eucalypts for Solid Timber Products*. FWPRDC Report PN04.3007, Forest and Wood Products Research and Development Corporation, Melbourne.
- Kelly, M., Tredinnick, J., Cutbush, G. and Martin, G. (2005) *Impediments to Investments in Long Rotation Timber Plantations*. FWPRDC Report PN05.1011M, Forest and Wood Products Research and Development Corporation, Melbourne.
- Kile, G. (2005) Guest editorial. 'The hardwood dilemma' *Australian Forestry* **68**, 229–230.
- Lee, D., Debusse, V.J., Pomroy, P.C., Robson, K.J. and Nikles, D.G. (2005) *Developing Genetically Adapted Tree Varieties for Marginal Areas of Northern Australia*. RIRDC Publication No. 04/186, Rural Industries Research and Development Corporation, Canberra.
- Lott, R.H. (2001) *A Bibliography of Plantation Hardwood and Farm Forestry Silviculture Research Trials in Australia*. RIRDC Publication 01/101, Rural Industries Research and Development Corporation, Canberra.
- Lott, R.H. (2006a) *Joint Venture Agroforestry R&D Plan 2004–2009*. RIRDC Publication No. 06/039, Rural Industries Research and Development Corporation, Canberra.
- Lott, R.H. (2006b) JVAP research on farm forestry and agroforestry—where have we been, and where are we going? *Australian Forest Grower Special Liftout* No. 77, Spring 2006, **29**(3), 8 pp.

- Marcar, N.E. and Crawford, D.F. (2004) *Trees for Saline Landscapes*. RIRDC Publication No. 03/108, Rural Industries Research and Development Corporation, Canberra.
- McCarthy, K., Cookson, L. and Scown, D. (in press) Natural durability of six eucalypt species from farm forestry and low rainfall areas. A report for the Joint Venture Agroforestry Program, Rural Industries Research and Development Corporation, Canberra.
- Montagu, K., Kearney, D. and Smith, G. (2003) *Pruning Eucalypts: The Biology and Silviculture of Clear Wood Production in Planted Eucalypts*. RIRDC Publication No. 02/152, Rural Industries Research and Development Corporation, Canberra.
- National Forest Inventory (2007a) *Australia's Forests at a Glance*. Bureau of Rural Sciences and Department of Agriculture, Fisheries and Forestry, Canberra.
- National Forest Inventory (2007b) *National Plantation Inventory 2007 Update*. Bureau of Rural Sciences, Canberra.
- Nolan, G., Greaves, B., Washusen, R., Parsons, M. and Jennings, S. (2005) *Eucalypt Plantations for Solid Wood Timber Products in Australia*. Project PN04.3002, Forest and Wood Products Research and Development Corporation, Melbourne.
- Parsons, M., Frakes, I. and Gavran, M. (2007) *Australia's Plantation Log Supply 2005–2049*. Bureau of Rural Sciences, Department of Agriculture, Fisheries and Forestry, Canberra.
- Paul, K., Booth, T., Elliott, A., Jovanovic, T., Polglase, P. and Kirschbaum, M. (2003) Life cycle assessment of greenhouse gas emissions from domestic woodheating. Prepared for the Australian Greenhouse Office and Environment Australia by CSIRO Forestry and Forest Products, Canberra.
- Paul, K.I., Booth, T.H., Jovanovic, T. et al. (2007) Calibration of the forest growth model 3-PG to eucalypt plantations growing in low rainfall regions of Australia. *Forest Ecology and Management* **243**, 237–247.
- Reilly, D.F., Robertson, R.M., Nikles, D.G., Robson, K. and Lee, D.J. (2007) *Testing and Breeding Forest Trees for Plantations in the Northern Territory*. RIRDC Publication No. 07/113, Rural Industries Research and Development Corporation, Canberra.
- Robins, L. and Marcar, N. (2007) *Integrated Forestry on Farmland: Prospects for Integrated Forestry as a Management Tool in Salt-Source Catchments*. CRC for Plant-based Management of Dryland Salinity, Perth.
- Sanford, P. and Sudmeyer, R. (2007) *Managing Tree–Pasture Competition by Using Perennial Forage Species*. RIRDC Publication No. 07/091, Rural Industries Research and Development Corporation, Canberra.
- Strandgard, M., Wang, Y., Chong, D., Wild, I. and Baker, T. (2005) Blue gum plantation management systems, Project No. PN03.3903, Forest and Wood Products Research and Development Corporation, Melbourne.
- Turner, J. and Lambert, M. (2004) *Forest and Forest Products Research Expenditure in Australia 1981–1982 to 2001–2002*. Project PN03.3711, Forest and Wood Products Research and Development Corporation, Melbourne.
- URS Forestry (2008a) Farm forestry area and resources in Australia. A report for the Joint Venture Agroforestry Program, Rural Industries Research and Development Corporation, Canberra.
- URS Forestry (2008b) Market opportunities for farm forestry in Australia. A report for the Joint Venture Agroforestry Program, Rural Industries Research and Development Corporation, Canberra.
- van Beuren, M. (2001) *Emerging Markets for Environmental Services—Implications and Opportunities for Resource Management in Australia*. RIRDC Publication No. 01/162, Rural Industries Research and Development Corporation, Canberra.
- Vercoe, T. and Clarke, B. (1994) *Trees for South-Eastern Australia*. Project CSF-44A report to RIRDC. RIRDC Research Paper Series No. 96/5, Rural Industries Research and Development Corporation, Canberra.
- Wang, Y. and Baker, T.G. (2007) A regionalized growth model for *Eucalyptus globulus* plantations in south-eastern Australia. *Australian Forestry* **70**, 93–107.
- Warner, A. (2007) *Farm Forestry Toolbox Version 5.0 – Helping Australian Growers to Manage their Trees*. RIRDC Publication No. 07/135, Rural Industries Research and Development Corporation, Canberra.
- Washusen, R. (2006) Evaluation of product value and sawing and drying efficiencies for low rainfall hardwood thinnings. Report to the Joint Venture Agroforestry Program, Rural Industries Research and Development Corporation, Canberra.

- Wettenhall, G. (2008) Viability of single desk marketing of farm forestry timber. Report for the Joint Venture Agroforestry Program, RIRDC Publication, Rural Industries Research and Development Corporation, Canberra.
- Whitten, S.M., Coggan, A., Reeson, A. and Shelton, D. (2007 in review) Applying market based instruments in a regional context. Report for Joint Venture Agroforestry Program, Rural Industries Research and Development Corporation, Canberra.
- Wong J., Baker, T., Duncan, M., McGuire, D. and Bulman, P. (2000) *Forecasting Growth of Key Agroforestry Species in South-Eastern Australia*. RIRDC Publication 00/68, Rural Industries Research and Development Corporation, Canberra.



SESSION: GROWING, MANAGING AND HARVESTING
HARDWOOD SAWLOGS

Site Matching and Establishing Eucalypt Sawlog Species in Southern Australia

CLINTON TEPPER

Woollybutt Pty Ltd, Victoria
Email: clinton.tepper@woollybutt.com.au

Abstract

The fundamental differences between pulpwood- and sawlog-driven plantations demand urgent revision of site assessment, species selection and plantation establishment practices to facilitate the robust development of a eucalypt sawlog industry.

The long rotations required for producing eucalypt sawlogs mean they are exposed to a high level of risk. Process-based models (PBMs) must be used to model the impact of risk on plantation performance.

A wide range of climatic and physical site characteristics must be evaluated during site assessment. Risk levels will be reduced as the intensity and quality of site assessment is increased.

Most species being considered for sawlog plantations are from the *Eucalyptus* subgenus *Symphyomyrtus*. The specific requirements of sawlog plantations mean that *Monocalyptus* and *Corymbia* species must also be considered for plantation establishment.

Four species that provide important options for sawlog plantations—*Eucalyptus globulus*, *E. nitens*, *E. cladocalyx* and *Corymbia maculata*—are reviewed. There is considerable room for the domestication of other species to fill industry niche gaps.

Plantation establishment practices must be revised to optimise all aspects of sawlog plantation performance. Sawlog development demands a greater emphasis on plantation survival, growth, form and health.

A robust eucalypt sawlog industry must be based on a research strategy that is driven by all key stakeholders.

Introduction

In southern Australia, hardwood plantation establishment has been dominated by a small number of eucalypt species (i.e. *E. globulus*, *E. nitens*, *E. regnans*) that have generally been planted on productive sites with fertile soils and >700 mm mean annual rainfall (MAR). Most of this resource is managed on short rotations to produce pulpwood.

In recent years, a combination of factors has led to an increased focus on the development of plantation eucalypts for high-value timber. These factors include:

- Australia's \$2 billion trade deficit in wood and paper products
- the import of timber products from countries with unsustainable forestry practices
- the substantial and ongoing reduction of timber harvesting in native forest across Australia
- increasing promotion and use of renewable products
- carbon sequestration.

The concept of producing high-value timber (sawlogs) from eucalypt plantations is not new. The promotion of this industry in many regions of southern Australia has been occurring for decades.

However, the setting created by the above factors is fostering a renewed push for the establishment of this industry. This conference asks the question ‘Can southern Australia develop a viable eucalypt sawlog industry based on plantation-grown wood?’ Site assessment, species selection and plantation establishment are three of the basic building blocks required for the successful development of a plantation eucalypt sawlog industry.

There is a perception that practices used for existing pulpwood plantations can be satisfactorily used to develop eucalypt sawlog plantations. In some instances this may be true, but following this pathway would be irrational given that eucalypt sawlog plantations have different requirements:

- the quality of land available for plantation development
- species—the existing suite of species will need to be extended to cater for new site classes and market preferences
- rotation length—15–35 y
- harvesting regimes, equipment and techniques—production of multiple products from two to four harvests within one rotation
- product specifications—sawlog specifications are typically tighter than those for pulpwood and subsequent compliance has ramifications for site assessment (e.g. defects induced by site stress can downgrade sawlogs)
- the diversity of market preferences
- carbon sequestration—carbon stored in ‘long-life’ timber products.

Such fundamental differences necessitate the development of new models for site assessment and species selection. Plantation establishment regimes need to be revised and adjusted to support the development of a robust eucalypt sawlog industry.

Site assessment

Ryan et al. (2002) review site assessment and how it needs to evolve to support the development of a eucalypt plantation industry. This paper builds on the framework established by these authors and applies many of the same principles to the development of a eucalypt sawlog industry.

Site assessment is universally recognised as an essential preface to eucalypt plantation establishment. Ryan et al. (2002) explain that site assessment has traditionally concentrated on the prediction of tree performance, particularly survival and growth, of pre-selected species. Site assessment involves the study of the main factors that govern tree growth, namely climate, soils, flora and geomorphology.

Historically, the methodology and rigour of site assessment has varied widely between regions, grower groups and plantation scale.

Site assessment techniques have improved markedly in recent years. This has been driven by the diminishing availability of highly productive sites and recognition that plantation yields in some regions are not meeting expectations.

Key differences between eucalypt pulpwood and eucalypt sawlog plantations are now outlined. Acknowledgment of these differences will enable site assessment to evolve appropriately and form a sound basis for the development of a eucalypt sawlog industry.

Site assessment considerations for eucalypt sawlog plantations

Spatial and temporal scale

A prime preliminary consideration for any site assessment task is the spatial and temporal scale of the proposed development and associated risks (Figure 1).

For example, a wildfire can cover >100 000 ha (spatial) and be active for several months (temporal). A drought (El Niño) can affect one or more Australian states (spatial) and be active for several years (temporal). Insect attacks, flooding and low-altitude snowfalls also have spatial and temporal scales. These constraints are emphasised by the shape and size of hardwood¹⁵ plantation (HW age class) in

¹⁵ Hardwood—short-fibred wood from broad-leaved, flowering trees (e.g. eucalypts)

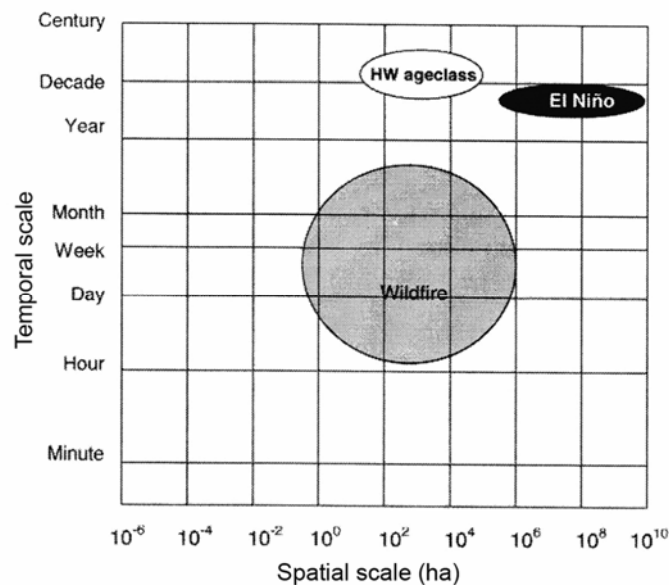


Figure 1. A temporal-spatial scale diagram containing risks that affect plantation development (from Ryan et al. 2002)

Figure 1 which represents eucalypt plantations being managed over a rotation of 7–30 y (Ryan et al. 2002). One interpretation would be that a hardwood eucalypt plantation will experience at least one El Niño event over all its area because its temporal scale is greater and its spatial scale is less than that of a typical El Niño event (Ryan et al. 2002).

The key message is that a eucalypt sawlog plantation has substantially greater temporal scale than a pulpwood plantation. Therefore sawlog plantations will be exposed to a higher risk of multiple drought and fire events.

The historical development of eucalypt forestry on sites of reliable productivity and the difficulty of quantitatively evaluating risk have

meant that risk has not been satisfactorily accounted for in traditional site assessment procedures. Site assessment must incorporate scale factors that account for climatic and physical parameters affecting plantation outcomes.

Process-based models (PBMs) such as CABALA (Battaglia et al. 2004; Mummery and Battaglia 2004) offer an opportunity to temporally ‘scale up’ or model the impact of risks on plantation yield over a rotation during the site assessment phase. Such decision-support systems are increasingly important to plantation managers dealing with unfamiliar sites and sawlog regimes.

Site assessment methods

Site assessment methods need to be explicit, quantitative, consistent and repeatable (Ryan et al. 2002). The following procedure is based on Laffan (2002) and Ryan et al. (2002), and the internal site assessment system of a private forestry company that has been developed over a 7-y period (Woollybutt unpubl.). A wide range of climatic and physical site characteristics need to be evaluated.

Climate. Climatic factors are clearly the most powerful determinants of growth for *Eucalyptus* species (Austin et al. 1983). These include:

- mean annual rainfall (MAR)
- rainfall distribution
- temperature regime—minimum, maximum and mean annual temperature (MAT); duration and timing of the frost period
- evaporation¹⁶
- ratio of MAR/evaporation.

Most of these climatic attributes can be predicted adequately over southern Australia using the macro-climatic prediction system ANUCLIM (McMahon et al. 1997). Alternatively, Bureau of Meteorology (BOM) data can be used in conjunction with rigorous, locally compiled data (e.g. MAR and rain days).

Soil physical and chemical attributes and topography. The main physical site factors are:

¹⁶ The amount of water that evaporates from an open, fixed area. Evaporation rate depends on factors such as humidity, cloudiness, air temperature and wind speed

- geology
- topography:
 - slope
 - aspect
 - slope position
- soil—soil information is best collected from pits because they allow an unimpeded visual and physical inspection of the soil profile. The following soil properties should be recorded:
 - profile and depth (effective regolith volume¹⁷)
 - water-holding capacity
 - stoniness—knowing the percentage of rocks in the profile allows plant-available water to be calculated
 - groundwater—absence/presence and depth to groundwater
 - fertility—soil tests can be used to determine these variables:
 - nutrient supply:
 - total nutrient stocks for nitrogen (N), phosphorus (P) and carbon (C)
 - the exchangeable cations calcium (Ca), magnesium (Mg), potassium (K), sodium (Na) and aluminium (Al)
 - the trace elements boron (B), copper (Cu) and zinc (Zn)
 - nutrient intensity:
 - photosynthesis
 - EC
 - presence of soil-based pathogens or root disease:
 - *Phytophthora cinnamomi*
 - armillaria root disease (*Armillaria* spp.)
 - foliar sampling of adjacent plantations with known management history
 - degradation—soil pit data, soil tests and slope measurements will help determine:
 - trafficability
 - erodibility
 - flood and salinity risk.

The dominant role of soil properties in determining site suitability for plantation development has been widely emphasised in recent years (Mummery and Battaglia 2001, 2004; Tepper 2007). The volume of soil accessible to tree roots governs site suitability because it determines the total water store, and to a lesser extent the nutrient store, available to trees (Ryan et al. 2002). To definitively assess these variables, soil sampling (pits) is required.

Other factors. Other site variables that are useful to record include:

- existing native vegetation and/or eucalypt plantations:
 - age
 - type/association
 - height
 - basal area
 - health
- problem weeds
- browsing animals/insects:
 - type
 - areas of intense activity
 - land-use history

Unfortunately, the resources and expertise required for site assessment may be ‘out of reach’ for many farm foresters. In these cases, professional assistance should be sought.

¹⁷ Effective regolith volume—the below-ground volume that individual trees, within a soil unit, can exploit over time to obtain water and nutrients (Ryan et al. 2002)

Recommendations

Process-based models offer good opportunities to accelerate the development of suitable site assessment parameters for new site × species options. An outcome of a study by Paul et al. (2007) into *Corymbia maculata* and *Eucalyptus cladocalyx* was that whilst the 3-PG model showed promise, further work is required to validate model predictions for several variables.

To assist with validation, one option would be to design a standard species trial and replicate this trial across the targeted rainfall zone in southern Australia (Ryan et al. 2002). In Victoria, for example, a significant number of species trials have already been established with state and/or Commonwealth funds over the past 20 y. Many have been left unmanaged and/or unassessed, but still have intact establishment records and should at the very least be reviewed to aid model validation. If shortfalls in datasets remain, a species trial format designed to fill the gaps could be considered.

Species selection

This section reviews site requirements for southern Australia's four most recognised eucalypt sawlog species. First, a broader view of species selection for the eucalypt sawlog industry will be considered.

Eucalyptus subgenera

The genus *Eucalyptus* is dominated by two subgenera, *Monocalyptus* (>120 species) and *Symphyomyrtus* (>300 species) (Potts and Pederick 2000) (Figure 2). Species from these subgenera dominate the occurrence of eucalypts in southern Australia. The closely related genus *Corymbia* also contains some notable sawlog species (e.g. *C. maculata*) in southern Australia.

The subgenus *Monocalyptus* contains the tingles, jarrah, white mahoganies, stringybarks, blackbutts, ashes and peppermints; *Symphyomyrtus* contains the gums, boxes and ironbarks (Boland et al. 1984). Noble (1989) compared eight ecological traits of these two subgenera:

1. *Monocalyptus* species have less diverse leaf herbivores and pathogens, and suffer less leaf loss and damage by them, than *Symphyomyrtus* species. This difference cannot be directly related to leaf nutrients or secondary compounds.
2. *Monocalyptus* species tend to occur on more mesic sites than *Symphyomyrtus* species. Where they occur on the same sites as *Symphyomyrtus* species, they suffer greater damage during droughts. The precise physiological basis for this difference is not clear.
3. *Monocalyptus* species are less tolerant of flooding.
4. *Monocalyptus* species are less resistant to frost, especially under waterlogged conditions.
5. *Monocalyptus* species are less resistant to saline conditions.
6. *Monocalyptus* species tend to be found on soils of lower nutrient availability than *Symphyomyrtus* species, and they appear to be more dependent on mycorrhizae for vigorous growth, although the relationship is not obligate.

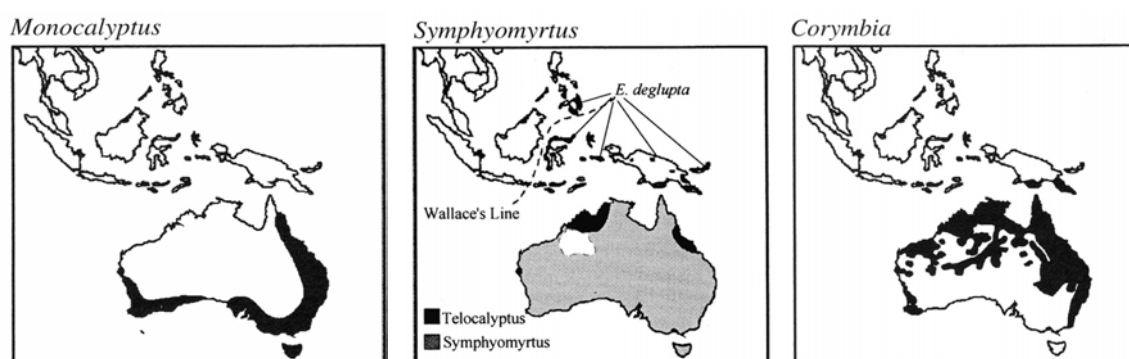


Figure 2. The distribution of species from *Monocalyptus*, *Symphyomyrtus* and *Corymbia* (Potts and Pederick 2000)

7. *Monocalyptus* species are less resistant to *Phytophthora cinnamomi*. This may be related to differences in the relationship between the eucalypt species and their mycorrhizae.
8. *Monocalyptus* species show slower germination, resprouting and early growth than *Symphyomyrtus* species, but appear to catch up relatively quickly.

All of these ‘traits’ affect species selection and should be given due consideration. Noble (1989) affirms ‘Some points are well established, but most must be treated as hypotheses rather than established differences’: a good for-and-against case is presented for each trait. Little further literature explores these hypotheses but from what is available and Noble (1989) the following conclusions could be drawn:

- Traits 3, 4, 5 and 7 are widely confirmed
- Trait 1 is generally supported. Simpson et al. (1997) and Stone et al (1998) provide confirmation.
- Trait 2 is generally supported. At the regional forest scale there are exceptions, for example stringybark and gum in South Gippsland¹⁸. Noble (1989) and Lima et al. (2003) found the difference in drought tolerance to be a function of generally greater stomatal control in *Symphyomyrtus* species.
- Trait 6 was not supported by Judd et al. (1996) due to a lack of definitive evidence, although they conceded that the greater demand for Ca, Mn and probably K by *Symphyomyrtus* species and generally greater demand for Mg by *Monocalyptus* species ‘must have a physiological basis, but at this stage it is unexplainable’.

This trait has significant implications for fertiliser regimes given that species that grow naturally on poor-quality sites appear to be more efficient in their acquisition of soil nutrients than those that grow naturally on high-quality sites (Kriedemann and Cromer 1996). Severino (2006a unpubl.) found significant increases in growth rates of the monocalypt *E. muelleriana* in thinning treatments compared to unthinned controls, but no significant growth response to fertiliser 2 y following application.

- Whilst there is some support, the literature is not definitive on whether monocalypts are more dependent on mycorrhiza than symphyomyrts.
- Noble (1989) demonstrates definitive evidence for trait 8 in various trials. West (1981), Duncan et al. (2000), Tepper (2002), Gippsland Private Forestry (2005), and observations in Woollybutt Pty Ltd plantations provide further evidence for this trait.

Noble’s (1989) review of the two subgenera showed three consistent areas of differentiation:

- leaf chemistry
- establishment phase and early growth
- root systems: this is perhaps the most significant. Traits 2–8 are likely to be influenced by differences in root configuration, activity or chemistry. The root systems of *Monocalyptus* are less active and more deleteriously affected by sub-optimal conditions. Brooker (2000) refers to *Monocalyptus* as the ‘most advanced and modified group (subgenus)’ within his classification of the genus *Eucalyptus*. Perhaps the *Monocalyptus* subgenus has become specialised to such a degree that it has adapted particularly well to poorer soils in its preferred climate at the expense of reducing its ability to be successfully planted ‘off-site’.

Davidson and Reid (1980), Neave and Florence (1994) and Lima et al. (2003) found differences in root:shoot ratio and configuration between *Corymbia*, *Monocalyptus* and *Symphyomyrtus* species. These studies show that:

- *Symphyomyrtus* species have higher root:shoot ratios than *Monocalyptus* species
- *Corymbia* and *Monocalyptus* species allocate a higher proportion of photosynthates to root development lower and higher, respectively, in the soil profile.

¹⁸ Observation made by the author along Carrajung-Woodside Road (Vicroads Map 98 E8)

These differences may be consistent with the performance of plantation-grown *Monocalyptus* and *Symphyomyrtus* species in Tasmania (Turnbull et al. 1993). *Symphyomyrtus* species appear to have strong root development in both upper and lower sections of the soil profile. Davidson and Reid (1980) suggested that the difference in the root:shoot ratio between subgenera is not purely an adaptation to differing habitats, but may represent a more fundamental physiological difference between the subgenera.

Noble's (1989) analysis provides a framework for other hypotheses as we consider a potential suite of species for eucalypt sawlog plantations in southern Australia.

Most recognised eucalypt plantation species have emerged from species trials but these have:

- unintentionally biased outcomes against *Monocalyptus* species by not considering their root attributes that may lead them to be sensitive to heavy rates of applied residual herbicide and fertiliser
- lacked an understanding of the role of mycorrhizae in the performance of respective subgenera
- not assessed growth patterns beyond age 10 y
- used poor experimental designs where different species compete for site resources prior to an age at which the true expression of sawlog performance develops.

There is no intended implication that the selection of the four target species for this review is incorrect. It would be prudent, however, to consider *Monocalyptus* species that have shown potential in some trials (e.g. *E. seiberi*, *E. muelleriana* and *E. fastigata*).

Four major eucalypt sawlog options—an overview

Choice of tree species must ensure that each is well suited to the climatic and edaphic attributes of the site and that the 'site quality' is appropriate for its commercial establishment. A measure of site quality is the amount of wood produced each year, or mean annual increment (MAI in $\text{m}^3 \text{ha}^{-1}$; Battaglia 2006).

In Tasmania, the minimum site quality for commercial eucalypt plantation establishment is generally regarded as $15 \text{ m}^3 \text{ha}^{-1} \text{y}^{-1}$ (Battaglia 2006). Harper et al. (1999) imply that an MAI $>15 \text{ m}^3 \text{ha}^{-1}$ at age 10 y in a eucalypt pulpwood plantation is an acceptable outcome. An MAI of at least $15 \text{ m}^3 \text{ha}^{-1}$ is adequate to achieve financial returns of 7–8% (IRR) for a professionally managed, eucalypt sawlog project located in Victoria (Lambert¹⁹ pers. comm.).

There are many reasons for planting trees and establishing plantations on land with lower site quality (land protection, biodiversity, carbon sequestration and so on). Indeed if mill door prices for eucalypt plantation sawlogs increase in a fashion similar those for native forest logs sold by Vicforests (since its inception) in Victoria, financial returns from sites of quality down to $10 \text{ m}^3 \text{ha}^{-1} \text{y}^{-1}$ may be acceptable.

Significant areas of southern Australia have site quality attributes satisfactory for sawlog plantation establishment. Accessing this land is becoming increasingly difficult, however, so other combinations of site attributes are being considered for alternative species. This section will review site requirements for four of southern Australia's most recognised eucalypt sawlog options:

- *E. globulus* ssp. *globulus* (Tasmanian blue gum)
- *E. nitens* (shining gum)
- *E. cladocalyx* (sugar gum)
- *Corymbia maculata* (spotted gum)

It will be assumed that a satisfactory site quality for *E. globulus* ssp. *globulus*, *E. nitens* and *C. maculata* is $15 \text{ m}^3 \text{ha}^{-1} \text{y}^{-1}$, and for *E. cladocalyx*, $10 \text{ m}^3 \text{ha}^{-1} \text{y}^{-1}$. Table 1 reviews site requirements for the above species.

¹⁹ Jon Lambert, Director, Woollybutt Pty Ltd

Table 1. Site profile for eucalypt sawlog plantation species established in southern Australia¹

Species	MAR (mm y ⁻¹) ²	Rainfall distrib- ution	Mean max. temp. hot (°C)	Mean min. temp. cold (°C)	MAT (°C)	Frost tolerance	Soil		Altitude (m asl)	Unsuitable aspect/position	Salinity tolerance ³
							Preferred	Unsuitable			
<i>E. globulus</i>	600–1500 720– 1500 ⁴ >700 ⁵ >800 ^{6,7}	Uniform, winter ⁸	13–29	–1 – 12	4–18 >10 ⁶ 13–14 ⁹	Moderate	Gradational textured soils ¹⁰	Poorly drained duplex soils ⁷ Shallow soils ³	0–450 <400 ⁴	Dry northern aspects and exposed hilltops. Frosty areas at altitude >300 m	Low
<i>E. nitens</i>	700–2300 >850 ¹⁵ >800 ¹⁶	Uniform, winter, summer	19–29	–3 – 4	5–17 >8 ⁶	Very high	Gradational textured soils ¹⁰ Well drained	Duplex soils. Moderate – poor drainage Shallow soils ³	300–800 <850 ⁵	Dry northern aspects	Low
<i>E. cladocalyx</i>	400–1010 380– 650 ¹¹ 340– 660 ¹²	Winter ¹²	23–34	1–11 >=7 ¹²	12–21	Low	Sandy clay loam ³ Gradational to duplex	Uniform deep sands ¹³ Very heavy clays ¹⁴	0–600 <300	Frost prone areas	Low– mod
<i>C. maculata</i>	580–1500 500– 800 ¹⁵	Uniform/ bimodal, summer	25–30 ¹¹	1–8 ¹¹	10–19 13.6– 16.2 ¹⁶	Very low	Sandy clay ³ Gradational to duplex	Heavy clay ¹⁷	0–950 ¹¹ <200	Frost prone areas	Low– mod

¹ Where references are not provided the data is based on the author's experience² Data for MAR, rainfall distribution, mean max/min and MAT from Jovanovic and Booth (2002) except where footnoted otherwise³ Bird (2000)⁴ Mummery and Battaglia (2001)⁵ Laffan (2002)⁶ Battaglia (2006)⁷ Grand Ridge Plantations (GRP) field day notes (2004 unpub.)⁸ Winter only in NSW⁹ Battaglia and Sands (1997)¹⁰ Duncan et al. (2000)¹¹ Boland et al. (1984)¹² McDonald et al. (2003)¹³ Harwood and Bulman (2001)¹⁴ Williams et al. (2007 unpub.)¹⁵ Maxwell and Severino (2007 unpubl.)¹⁶ Austin et al. (1994)¹⁷ Bird (2000)

Tasmanian blue gum (*Eucalyptus globulus* ssp. *globulus*)

Eucalyptus globulus henceforth refers only to *E. globulus* ssp. *globulus*.

Rainfall

Table 1 shows a wide range of minimum MARs (600–800 mm) for this species. If established on sites with <800 mm MAR, the risk of poor growth and survival is increased. In WA, where MAR is <800 mm, only sites with evaporation <1500 mm y⁻¹ support MAI >15 m³ ha⁻¹. In Gippsland, poor performance on low-rainfall sites has led to *E. globulus* being established only where MAR is > 800 mm (Grand Ridge Plantations 2004). In Tasmania MAI >15 m³ ha⁻¹ can be sustained where MAR is >700 mm providing the native vegetation type is ‘damp eucalypt forest’. A PBM study found that a MAI >25 m³ ha⁻¹ was associated with a range of favourable variables including MAR >720 mm (Mummery and Battaglia 2001). The evidence suggests that *E. globulus* should not be established on sites with MAR <800 mm unless evaporation and soil properties are particularly favourable.

The distribution of rainfall is also important. *Eucalyptus globulus* is well adapted to short periods of water stress punctuated by rainfall events, but is vulnerable to prolonged water stress (White et al. 2000). On sites that do not store enough water to buffer the deficit between summer rainfall and evaporative demand, *E. globulus* is vulnerable to drought death (Mummery and Battaglia 2004).

Temperature

At altitudes >400 m the growth of *E. globulus* may be severely affected by frost (Battaglia 2006). Cold-induced photoinhibition²⁰ and not frost tolerance alone is a factor determining the range of environments where *E. globulus* can be successfully planted (Close et al. 2000). Battaglia (2006) indicates that productivity declines significantly at altitudes >300 m and for MAT <10°C. With lower MAR (<1000 mm) and higher MAT (>12°C) in Tasmania, growth potential decreases due to increasing evaporative demand (Mummery and Battaglia 2001).

Fifteen heavily-fertilised *E. globulus* research plantations in south-eastern Australia, WA and Portugal had an optimal closed canopy leaf area index (LAI) at an MAT of 13–14°C (Battaglia and Sands 1997). Observed and modelled relationships indicated an optimal MAT in the range of 13–14°C for LAI (Battaglia et al. 1998). This range correlates well with industry experience in Victoria.

Optimal MATs for *E. globulus* differ between regions, in part due to provenance variation. In Tasmania, optimal MATs for plantation development start lower (e.g. >10.5°C) than in mainland states (e.g. >13–14°C).

Soils

Effective regolith volume. Productivity improves as the volume of soil accessible to tree roots increases (Laffan 2002; Feikema 2005a; Battaglia 2006). In Tasmania, growth patterns appear to be limited by nutrient supply and temperature (Mummery and Battaglia 2001). Nonetheless, there are areas in the far north-east, central midlands and central east coast where water availability constrains growth (Mummery and Battaglia 2001). Even so, site assessment procedures prescribe soil investigation to shallower depths (up to 1.5 m) than in mainland states. This is a function of the generally higher ratio of MAR to evaporation in Tasmania.

In WA, the accepted minimum soil depth has been 2 m, though many growers now reject sites with <3.5 m of soil (Department of Agriculture WA 2005). Feikema (2005a) suggests that soil depth²¹ in south-western and north-eastern Victoria should be >2.7 m to optimise productivity. In Gippsland, where the ratio of MAR to evaporation is higher than in other regions of Victoria, it is expected that soil volumes to achieve MAI >15 m³ ha⁻¹ could be less than those required for hotter, drier parts of the state.

²⁰ Reduction in a plant's capacity for photosynthesis

²¹ The simplest surrogate for soil volume is soil depth to an impeding layer (Turner et al. 1990, cited by Ryan et al. 2002).

Feikema (2005a) has also shown that *E. globulus* favours soils with gradational textures without rocks. Productivity is reduced by medium to heavy clay B-horizons, a finding supported by trials in Gippsland (Duncan et al. 2000). Growth has been disappointing in Gippsland on poorly drained duplex soils with MAR <800 mm (Grand Ridge Plantations 2004). In WA, *E. globulus* performs poorly on saline soils and deep sands of >2 m (Harper et al. 1999).

Fertility. Within a suitable climatic envelope, the growth of *E. globulus* is quite sensitive to nutrition, for example a large proportion of Tasmania could be made highly productive with minor adjustments to site nutrition (Mummery and Battaglia 2001). In WA, *E. globulus* responded strongly to N-based fertiliser in areas of poor existing N fertility where water was non-limiting (Harper et al. 1999). Trees respond poorly to added nutrients on sites where growth is limited by water deficits and or shallow soils (Department of Agriculture WA 2005).

In north-eastern Victoria, boron (B) deficiencies were recorded in a significant percentage of the Farm Forestry North East (FFORNE) plantings (~1500 ha) established during 1996–1998 (Noble 2003 unpubl.). This deficiency was easily corrected by applying B fertiliser in the year after planting.

Copper (Cu) deficiencies in Gippsland and in western Victoria (Bail et al. 2002) are common on sandy soil types. Zinc (Zn) deficiencies have also been reported on duplex soils in <800 mm MAR regions in Gippsland. In 2004, Grand Ridge Plantations (GRP)²² were recommending the addition of phosphorus (P), potassium (K), Cu and Zn at planting to second-rotation, flat, well-drained sites in Gippsland (Grand Ridge Plantations 2004).

From results of later-age nutritional research in Victoria, Feikema (2005b) concluded that while growth responses to later-age fertiliser applications may be obtained in some plantations, these are unlikely to be economic.

Insect pests

The main insect pests include²³:

- autumn gum moth (*Mnesampla privata*)
- snout weevil (*Gonipterus scutellatus*)
- African black beetle (*Heteronychus arator*)
- spring beetle (*Heteronyx* spp.)
- chrysomelids (*Chrysophtharta bimaculata*, *C. agricola* and *Paropsis atomaria*)
- wingless grasshopper (*Phaulacridium vittatum*)
- light brown apple moth (*Epiphyas postvittana*)
- Christmas beetles (*Anoplognathus chloropyrus*, *A. hirsutus*)
- stripy leaf beetle (*Cadmus australis*)
- steelblue sawfly (*Perga affinis affinis*)
- leaf blister sawfly (*Phylacteophaga froggatti*)
- gum leaf skeletonizer (*Uraba lugens*)
- lerps (*Cardiaspina* spp.)
- gum tree scale (*Eriococcus coriaceus*)
- blue gum psyllid (*Ctenarytaina eucalypti*)
- longicorn beetle or borer (*Phoracantha semipunctuata*)

²² Now Hancock Victorian Plantations (HVP)

²³ Adapted from Phillips (1996), Floyd (2001) and Loch and Elek (2006), and personal experience

Most of these insects have the potential to cause significant problems during the establishment phase of growth. The high growth rate and compensatory growth following defoliation of *E. globulus* allows this species to suffer little or no overall growth loss from low levels of defoliation (Loch and Floyd 2001). High levels of defoliation will cause growth loss and require control strategies (Loch and Floyd 2001).

Loch and Floyd (2001) refer to isolated cases of *Phoracantha* spp. that cause damage at later stages (e.g. >5 y) if trees are water-stressed. This is a substantial risk for a high-water-demanding species such as *E. globulus* managed over a relatively long rotation. It is imperative to minimise moisture stress by siting this species appropriately and undertaking timely thinning (Collett 2001a,b).

Diseases

The major diseases that have restricted the use of commercially desirable species in plantations of temperate Australia are mycosphaerella leaf disease (MLD) and phytophthora root rot (PC) (Gadgil et al. 2000). These are primary pathogens that can infect healthy trees (Wardlaw 2006).

Armillaria causes the single most important woody root-rot disease of eucalypts in terms of economic loss and the range of species affected (Kile 2000). Disease in plantations typically affects single trees or small patches of trees (Kile 2000). Wardlaw (2006) points out that *Armillaria* is a secondary pathogen that will only infect trees already under stress (e.g. drought, nutrient deficiency or insect defoliation).

Of the above diseases, only MLD appears significant to the development of *E. globulus* plantations. Kile (2000) does not list *E. globulus* as being affected by *Armillaria* in Australia and it is generally regarded as tolerant to PC (Marks and Smith 1991).

Mycosphaerella leaf disease is arguably the most significant and damaging foliar disease of young *E. globulus* plantations (Carnegie et al. 1994; Park et al. 2000; Milgate et al. 2005) infecting young expanding leaves during warm, wet weather (Marks et al. 1972). Severe cases are predominantly observed on juvenile foliage. Significant short-term reductions in growth have been reported in young plantations (Lundquist and Parnell 1987; Tejedor 2004). It is unknown whether these reductions in growth during the 2–3 y juvenile leaf stage translate into rotation-length reductions in stand volume (Pinkard and Mohammed 2006).

Whilst severe epidemics of MLD have been observed in Australia for at least 20 y, the affected area has risen considerably over the past 5 y with the rapid expansion of the plantation estate (Pinkard and Mohammed 2006). To minimise the incidence and impact of MLD, it is recommended that *E. globulus* is not planted in summer rainfall environments (Carnegie 2007). The disease can also be a problem in uniform rainfall environments of NSW (Jovanovic and Booth 2002). Whilst it is recorded in winter rainfall environments, at this stage plantation managers generally monitor damage without actively seeking to treat it. One of the major reasons for the sub-optimal performance of *E. globulus* managed by Hancock Victorian Plantations (HVP) in Gippsland is speculated to be MLD (Phil Whiteman²⁴, pers. comm.). Carnegie (pers. comm.) believes the best management option is to improve tree vigour by applying fertiliser to high-risk sites prior to infection, or after defoliation to improve recovery.

There is evidence of genetic variation of *E. globulus* in susceptibility to MLD at the provenance and family level (Carnegie et al. 1994; Dungey et al. 1997). The susceptibility of juvenile foliage to MLD could be under very strong genetic control, indicating that highly resistant genotypes can be found and deployed in high-risk areas to significantly increase plantation productivity (Milgate et al. 2005).

Other comments

Historically *E. globulus* has been regarded as a reliable performer when planted on suitable sites. In recent years it has become apparent that the overall performance of most *E. globulus* plantations managed by HVP across their entire Gippsland estate has been disappointing; the performance of *E. globulus* on second-rotation sites has been particularly poor across HVP's estate (Phil Whiteman,

²⁴ Phil Whiteman is Plantation Manager with HVP in Gippsland.

pers. comm.). HVP's current strategy is to replant sites following harvesting with *Pinus radiata* or *E. nitens*.

The reasons for poor performance in some cases can be related to site requirements of the species not being met. Of particular concern, however, is that many high-rainfall sites on good soils have also failed to meet productivity expectations. The precise reason for this is not clear, although MLD is speculated as a contributing factor.

Shining gum (*Eucalyptus nitens*)

Rainfall

The minimum MAR for *E. nitens* ranges from 700 to 850 mm (Table 1). Industry managers prefer sites that receive $>800 \text{ mm y}^{-1}$ (Grand Ridge Plantations 2004) or $>850 \text{ mm y}^{-1}$ (Laffan 2002). This species is regarded as being less tolerant of dry conditions than *E. globulus* (Battaglia 2006): *E. nitens* is considered sensitive to hot, dry winds and drought (Hall et al. 1972 cited by Bird 2000). In Gippsland, *E. nitens* performed more poorly than *E. globulus* on sites with a low ratio of MAR to evaporation (Duncan et al. 2000), confirming observations for Tasmanian *E. nitens* plantations (Battaglia 2006).

On second-rotation sites in Gippsland the MAI of *E. nitens* at age 11–12 y declined dramatically from $25\text{--}29 \text{ m}^3 \text{ ha}^{-1}$ to $<15 \text{ m}^3 \text{ ha}^{-1}$ when MAR was $<950 \text{ mm}$ (Duncan et al. 2000). The MAI on an ex-pasture site at Tostaree (MAR 820 mm) at age 10 y was recorded at $29.5 \text{ m}^3 \text{ ha}^{-1}$ (Duncan et al. 2000). Woollybutt Pty Ltd considers *E. nitens* for establishment in sawlog plantations only where MAR is $>1000 \text{ mm}$. This is based on trials and experience in well-managed plantations $>10 \text{ y}$ old where random deaths and borer attack have been experienced.

The evidence suggests that *E. nitens* should not be established in southern Australia where MAR $<800 \text{ mm}$. In Gippsland and other areas of Victoria, there is a good argument for not establishing this species on sites with $<1000 \text{ mm}$ MAR. The distribution of rainfall is critical to the performance of *E. nitens* and it is inferior to *E. globulus* in tolerating summer moisture deficits.

Temperature and altitude

A major advantage of *E. nitens* is its good productivity and form on frost prone and on exposed sites with low MAT. *Eucalyptus nitens* is often planted because environmental conditions are considered too cold for other species (Tibbits et al. 1997 cited by Tibbits and Hodge 2003). Battaglia (2006) suggests that *E. nitens* can be highly productive within an MAT range of $9\text{--}12^\circ\text{C}$. The most productive sites for the species in Tasmania are at altitudes $>300 \text{ m}$ (Battaglia 2006) and MAI $>15 \text{ m}^3 \text{ ha}^{-1}$ up to 850 m altitude are possible providing severe frosts and snow damage are absent (Laffan 2002). Duncan et al. (2000) found that *E. nitens* had a substantial growth advantage over *E. globulus* (47–58%) on sites at altitudes $>380 \text{ m}$. At sites $<200 \text{ m}$ *E. globulus* was the superior performer. In Gippsland, HVP generally do not plant *E. nitens* at elevations $<300 \text{ m}$.

Beadle et al. (1996) recommend the planting of *E. nitens* for pulpwood production, except on frost-free sites at low altitude, where the higher pulp yield and similar volume production of *E. globulus* make it a superior option. For optimal performance, *E. nitens* should not be planted on sites at $<300 \text{ m}$ altitude. In Tasmania, the optimal temperature for the species appears to be $9\text{--}12^\circ\text{C}$. The performance of plantations and native forest plantings in Gippsland²⁵ suggest that a similar optimal MAT of $10\text{--}12^\circ\text{C}$ is appropriate.

Soils

Eucalyptus nitens will not tolerate waterlogging (Battaglia 2006) and requires deep, well-drained soils of gradational texture: medium to heavy clay B-horizons should be avoided. Where gradational soil texture is combined with high MAR ($>1000 \text{ mm}$), this species is the preferred choice for establishment in Gippsland; MAI $>50 \text{ m}^3 \text{ ha}^{-1}$ was recorded by Duncan et al. (2000).

Effective regolith volume. *Eucalyptus nitens* is expected to require higher available soil water contents than *E. globulus* to sustain satisfactory yields. There are many examples of failed *E. nitens* plantations, particularly in north-eastern Victoria, on sites with MAR $>1000 \text{ mm}$ and altitudes $>300 \text{ m}$.

²⁵ Plantings located in the vicinity of Loch Valley, Tanjil Bren and Toorong Plateau in Victoria during the 1987–1997 period

This is often due to inadequate effective regolith volume due to the presence of many large rocks, and thus plant-available water (Fiekema 2005a).

Fertility. In Tasmania, ex-pasture sites will generally not require fertiliser due to their history of fertiliser application (Smethurst 2006). Deficiencies of N are likely to develop in future rotations (O’Connell and Rance 1999). In Victoria, soil and foliar analysis suggest that the establishment of species such as *E. nitens* on many ex-pasture sites would benefit from fertiliser application.

Low N availability commonly limits the growth of *E. nitens* plantations on ex-forest sites in Tasmania (Smethurst et al. 2004). An extensive study of nitrogen management in ex-forest *E. nitens* plantations was summarised by Smethurst et al. (2004):

- urea is the preferred source of N because it:
 - is the cheapest form
 - has the least propensity to produce nitrate and associated leaching losses
 - presents a low volatilisation risk in the cool, moist Tasmanian climate
- there is no significant benefit of localised fertiliser placement (planting line) over aerial application options where the canopy has not closed.
- fertiliser addition needs to be synchronised with nutrient demand, for example N fertiliser can be applied within three months of planting on wet sites to obtain an optimal growth response. On drier sites, N fertiliser may need to be applied within one month of planting.
- there is no evidence to suggest that there is a significant advantage in applying >200 kg N ha⁻¹ in any single operation
- to maximise growth on ex-forest sites:
 - diammonium phosphate (DAP) should be applied at planting
 - more than one application of 100–200 kg ha⁻¹ N should be made during the following 6 y
- only the few most responsive pulpwood-only sites can be economically fertilised
- there is a low likelihood of a significant detrimental effect of N fertilisation if the fertiliser is applied in an ammonium form (e.g. urea), especially if it is not applied to surface water and if rates do not exceed 200 kg ha⁻¹.

Trace element deficiencies in *E. nitens* plantations are rare as it is generally planted on soils²⁶ better than those used for other eucalypt species.

Further work needs to be done on the economics of fertilising *E. nitens* sawlog plantations. The site preference of this species, and its inherent ability to respond to fertiliser, suggest that application could be economic in many cases.

Insect pests

The main insect threats to *E. nitens* include²⁷:

- autumn gum moth (*Mnesampela privata*)
- snout weevil (*Goniapterus scutellatus*)
- chrysomelids (*Chrysophtharta bimaculata*, *C. agricola* and *Paropsis atomaria*)
- Christmas beetles (*Anoplognathus chloropyrus*, *A. hirsutus*)
- stripy leaf beetle (*Cadmus australis*)
- gum leaf skeletonizer (*Uraba lugens*)
- lerps (*Cardiaspina* spp.)
- blue gum psyllid (*Ctenarytaina eucalypti*)
- gum tree scale (*Eriococcus coriaceus*)
- wood borers:
 - longicorn borer (*Phoracantha semipunctuata*)
 - bulls eye borer (*Tryphocaria* spp)

²⁶ Deeper, wetter and more fertile

²⁷ Adapted from Phillips (1996), Collett (2001b) and Elek (2006), and personal experience

Like *E. globulus*, *E. nitens* shows excellent ability to recover from foliage loss. Reid (2007) reports that borer attack (thought to be bulls-eye borer) contributed to the lower recovery of select-grade timber from plantation-grown trees relative to that from native forest regrowth *E. nitens*. Woollybutt has recorded damage from this borer in two *E. nitens* sawlog plantations grown on high-rainfall sites in southern Gippsland. Damage has been noted 1–3 m above the ground in the centre of the pruned log. Phillips (1996) suggests that silvicultural practices, such as thinning to reduce water stress, may render trees less susceptible to attack. This species must be sited properly and thinned in a timely fashion.

Diseases

Mycosphaerella leaf disease has been recorded on *E. nitens* in southern Australia (Park et al. 2000). Although compared to *E. globulus*, *E. nitens* is highly resistant to infection (Gadgil et al. 2000) in NSW, MLD was recorded as causing significant damage to *E. nitens* during the period 1996–2005 (Carnegie 2007).

Eucalyptus nitens is regarded as being moderately susceptible to PC (Marks et al. 1972) and is infected after episodes of high rainfall resulting in sites becoming waterlogged (Carnegie 2007). In Tasmania and Victoria, the threat posed by PC is likely to be minor given that *E. nitens* is usually sited on well-drained soils at high altitudes associated with relatively low MATs. These conditions prohibit development of PC (Shearer and Smith 2000).

Kile (2000) lists *E. nitens* as a species that hosts *Armillaria* in Australia. Carnegie (2007) found damage from *Armillaria* to be rare in NSW though *E. nitens* was often the only species affected. In contrast, de Little et al. (unpubl. data cited by Carnegie 2007) encountered comparatively more damage from *Armillaria* in Tasmania, with up to 14% of the plantation affected. This may be due to many plantations in Tasmania being established on ex-forest sites (Carnegie 2007).

Sugar gum (*Eucalyptus cladocalyx*)

Eucalyptus cladocalyx is regarded as having high potential for sawlog production in low-medium rainfall areas (Paul et al. 2007). This species has largely been established at a relatively small scale. Despite worthy efforts by farm foresters and organisations such as the Australian Low Rainfall Tree Improvement Group (ALRTIG), several basic knowledge gaps hinder the development of this species as a sawlog option.

Rainfall

The MAR range for *E. cladocalyx* is 340–1010 mm (Table 1). For an MAI of at least 10 m³ ha⁻¹, it is assumed that MAR of at least 400 mm is required. Although it can grow on sites that receive up to 1000 mm y⁻¹ in southern Australia (Jovanovic and Booth 2002), other more productive and durable options are likely to be planted on high-rainfall sites. An MAR range of 400–750 mm is recommended. This corresponds with the MAR range of the species over its natural distribution (380–650 mm—see Boland et al. 1984).

Williams et al. (2007 unpubl.) analysed *E. cladocalyx* growth and a dataset for MAR from 28 unmanaged and managed *E. cladocalyx* plantations in Victoria. The following was evident:

- Plantations had been established on sites with an MAR range of 408–738 mm.
- No plantation had an MAI >10 m³ ha⁻¹—most had MAIs <5 m³ ha⁻¹. The managed stands²⁸ were aged <9 y at the time of measurement, so MAIs could be expected to improve.
- Where current annual increment (CAI) could be measured (Woollybutt PSP project²⁹), CAIs in the range of 9 to 15 m³ ha⁻¹ were recorded at two of the six sites.
- Evidence of productivity increasing with higher MAR was not obvious.

²⁸ ‘Managed stands’ implies silvicultural input such as pruning, thinning and fertilising.

²⁹ This project commenced in 2002 and includes six sites that have been measured annually up to 2006.

Woodlots 10 and 12 y old with MAR of 400–450 mm in WA had MAIs of 2.2 and 4.6 m³ ha⁻¹, respectively (Chrissy 2004b). At Nagambie, Victoria, *E. cladocalyx* had an MAI of almost 7 m³ ha⁻¹ at age 4 y (Severino 2006b unpubl.). This plantation was irrigated in dry periods for 2 y following establishment. Thus poor water availability may be limiting growth on some sites (Williams et al. 2007 unpubl.).

Eucalyptus cladocalyx is reputed to have a competitive advantage over other sawlog species where MAR is 400–600 mm y⁻¹ (Bird 2000). Where established by Woollybutt (~100 ha over 11 sites³⁰ since 1998), it has shown excellent and reliable survival in MARs of 550–700 mm. Whilst growth has been relatively good on most sites, other species have performed significantly better where soil depth and available moisture were favourable.

Eucalyptus cladocalyx has shown poor performance in major Gippsland species trials (Duncan et al. 2000) particularly on deep uniform sands (Gippsland Private Forestry 2005). It has done better on heavier-textured soils but not as well as other species such as *E. botryoides* and *E. muelleriana* (Woollybutt unpubl.).

Eucalyptus cladocalyx is a slow-growing species. Significant advances in genetic quality (via tree improvement), site selection and management will be required to achieve MAIs of >10 m³ ha⁻¹ in its preferred niche. Nevertheless, *E. cladocalyx* arguably remains the best sawlog option for the 400–600 mm MAR zone. To justify its commercial establishment in this niche, other avenues of income generation (e.g. carbon sequestration) will be important.

Temperature and altitude

Jovanovic and Booth (2002) indicate a broad MAT range of 12–21°C: in southern Australia, the preferred range will be more restricted. Inland populations experience low mean minimum temperatures of around 7°C (McDonald et al. 2003). Over most areas of the natural range, MATs of 14–16°C prevail (BOM data³¹). Its natural distribution on ridges and hillsides suggests an intolerance of terrain where cold-air drainage and pooling is a factor (McDonald et al. 2003). Poor performance in colder areas may be a function of *E. cladocalyx* not being well suited to climates that are cooler than its natural habitat (McDonald et al. 2003), hence its poor performance in Gippsland trials.

The MAT range for *E. cladocalyx* managed by Woollybutt is 12.1–14.6°C. Data captured from permanent sample plots (PSPs) and Woollybutt trials (Severino 2006b unpubl., 2006c unpubl.) show that plantations performed significantly better where MAT was >13.5°C. The altitudinal range of these sites is 49–528 m and the MAT data suggest that the most productive are located at elevations of 49–250 m asl. Plantation productivity measured over the first 8 y is reduced on sites that are >250 m asl. Frost damage up to age 5 y has been recorded on sites >300 m asl and is likely to be associated with this productivity decline. Harwood and Bulman (2001) recommend against planting *E. cladocalyx* in areas prone to severe frosts.

It is expected that the preferred MAT for *E. cladocalyx* will differ between regions, and that the latitude of the seed provenance will be a relevant factor. Existing plantings and the MAT of the natural distribution suggest an optimal MAT range of 13.5–16°C.

Soils

In the southern Flinders Ranges, *E. cladocalyx* occurs most commonly on ridges and hillsides on skeletal rocky soils derived from quartzite (Boomsma 1969). On the Eyre Peninsula, soils are generally residual laterites and podsols (McDonald et al. 2003). On Kangaroo Island, *E. cladocalyx* occurs close to creeks on soils associated with older sedimentary substrates (Crocker and Wood 1947).

Eucalyptus cladocalyx is suited to well-drained soils with adequate soil moisture-holding capacity (Harwood and Bulman 2001). It tolerates low to moderate salinity and a wide range of calcareous soils, but is intolerant of waterlogging (Chrissy 2004b) and uniform deep sands (Harwood and Bulman 2001; Chrissy 2004b; Williams et al. 2007 unpubl.). Trials in SA have identified *E. cladocalyx* as

³⁰ Established in Gippsland, western, central and north-eastern Victoria

³¹ Bureau of Meteorology; verified by Table 1. in McDonald et al. (2003)

being highly suitable for ex-*E. camaldulensis* and ex-*E. leucoxyton* sites in the south-east of the state and in the Adelaide Hills, either well or poorly drained (Williams et al. 2007 unpubl.). The evidence suggests that *E. cladocalyx* prefers soils with a clay content that enhances water-holding capacity without becoming excessively waterlogged.

Effective regolith volume. It was recognised very early that *E. cladocalyx* would perform well in plantations in areas too dry for faster-growing species such as *E. globulus* (Harwood and Bulman 2001). The volume of soil required to grow this species in low-rainfall areas with an MAI of at least 10 m³ ha⁻¹ is unknown.

The drought tolerance of *E. cladocalyx* implies that it does not require as much soil water as faster-growing species. A suitable hypothesis regarding soil depth could be '*E. cladocalyx* requires lower soil volumes than typically required by faster-growing species providing the texture of the A and B horizons includes a component of clay'.

Fertility. *Eucalyptus cladocalyx* adapts well to soils of poor fertility (Chrissy 2004b).

A small amount of fertiliser-related trial work has been undertaken in *E. cladocalyx* plantations. Following fertiliser application at establishment in western Victoria, Stackpole et al. (2004) reported:

- significant improvements in growth following fertiliser application at establishment at Wallinduc
- a significant interaction between fertiliser application and cultivation at Lismore.

The fertilising response at Wallinduc was probably associated with the site having formerly been unimproved pasture (Stackpole et al. 2004).

The response of *E. cladocalyx* to four fertiliser treatments was tested by Woollybutt near Craigieburn and Ararat. There was no significant benefit from fertilising at planting (Severino 2005 unpubl.). The low MAR at *E. cladocalyx* sites means that responses to fertiliser will frequently be affected by the availability of soil moisture.

A study by the Wimmera Agroforestry Network concluded that tree performance throughout the region may be limited by available P (Hajek 2003 cited by Williams et al. 2007). This study also found that growth declined as exchangeable Ca and soil pH increased, indicating that performance improves on acidic soils with a pH range of 5–6.

Nutrient concentration ranges are not available for *E. cladocalyx*. This makes the diagnosis of nutrient imbalances problematic. Woollybutt has applied fertiliser to treat perceived shortages of N, P, K and B.

Insect pests

Properly managed *E. cladocalyx* plantations in Australia are relatively free from serious diseases and pests (Harwood and Bulman 2001). There is good general resistance to defoliation from a range of insect pests in the Wimmera (Hajek 2003 cited by Williams et al. 2007 unpubl.) that could be associated with the comparatively high levels of cyanides within the leaves (Williams et al. 2007 unpubl.). The species also exhibits resistance to large wood borers (*Phoracantha* spp.) superior to that of *E. camaldulensis* (Montoya Oliver et al. 1983 cited by Williams et al. 2007 unpubl.; Hanks et al. 1993).

The main insect threats to *E. cladocalyx* in southern Australia include³²:

- gum tree scale (*Eriococcus coriaceus*)
- leaf blister sawfly (*Phylacteophaga froggatti*)
- chrysomelids (*Chrysophtharta bimaculata*, *C. agricola* and *Paropsis atomaria*)
- Christmas beetles (*Anoplognathus chloropyrus*, *A. hirsutus*)

³² Adapted from Phillips (1996), Collett (2001b) and Harwood and Bulman (2001), and personal experience

Diseases

There are no records of MLD in *E. cladocalyx* plantations in Australia (Park et al. 2000). The low rainfall, the winter-rainfall pattern and the generally low humidity associated with *E. cladocalyx* plantations are not conducive to the spread of MLD.

Eucalyptus cladocalyx is tolerant to PC (Marks and Smith 1991) and although Kile (2000) lists *E. cladocalyx* as recorded to host *Armillaria* in Australia, this is not regarded as a serious disease threat in southern Australia.

Other comments

A disadvantage of *E. cladocalyx* as a sawlog option is its moderate to poor form. The species requires intensive form pruning 1–2 y after planting to improve the fraction of trees with acceptable form. Harwood and Bulman (2000) identify form as a factor to be considered in the tree improvement strategy for the species.

Form was assessed in the Gippsland Red Gum Plains trial in 2004. Out of 32 species, *E. cladocalyx* was ranked 28th behind species such as forest red gum (*E. tereticornis*) and red ironbark (*E. sideroxylon*). In contrast, the form of *E. cladocalyx* in the ALRTIG trial at Craigieburn was generally good and similar to *C. maculata* on the same site, although form varied more between provenances of *E. cladocalyx* (Severino 2006c unpubl.).

A qualitative analysis in plantations managed by Woollybutt shows that:

- form pruning is required in all plantations
- forking and sweep are the main form issues
- form varies significantly between provenances
- *E. cladocalyx* has better form than most other options (except *C. maculata*) for low-rainfall areas.

Spotted gum (*Corymbia maculata*)

This review focuses on *C. maculata*, which appears to have better growth potential than *C. variegata* in southern Australia (Mazanec and Harwood 2001). *Corymbia maculata* is a species highly regarded for both low- and high-rainfall areas because of its good all-round growth, form and sawn timber properties.

Rainfall

The target planting zone for *C. maculata* in Victoria is within an MAR range of 500–800 mm (Table 1, Bird 2000; Maxwell 2007 unpubl.). Woollybutt manages vigorous plantations in Gippsland with MAR up to 1000 mm. Mazanec and Harwood (2001) describe *C. maculata* as showing considerable potential on sites with MAR of at least 600 mm: Jovanovic and Booth (2002) stipulate an MAR range of 580–1500 mm. This species has not performed well in plantations receiving <500 mm MAR (Mazanec and Harwood 2001).

Jovanovic and Booth (2002) extended the climatic range suitable for *C. maculata* plantations to eastern and central Victoria and the eastern coast of Tasmania. Its range was not extended into WA, despite it being among the most highly favoured species for sawlog production in that state (Mazanec and Harwood 2001).

Corumbia maculata has performed well in northern Victoria and southern NSW with MAR of ~500 mm, supplemented by 300–400 mm y⁻¹ of irrigation (Mazanec and Harwood 2001). The evidence suggests that this species should be established for sawlog plantations where MAR is at least 600 mm.

In southern Australia, the rainfall pattern preferred is one with a winter maximum or uniform seasonal distribution to minimise diseases that are associated with high humidity and summer rainfall (Mazanec and Harwood 2001).

Temperature and altitude

Corymbia maculata has a low tolerance to frost, so MAT and altitude are important. Severe frosts (-4°C to -6°C) have the potential to kill trees of up to 4–5 y of age (Tibbits and Sasse 1999). Even where frosts do not kill trees, they severely affect growth and stem form. In *C. variegata*, frost tolerance appeared to reduce forking in the Wellington Catchment of WA (Mazanec 1999). Field observations suggest that this also applies to *C. maculata*.

The natural altitudinal range of *C. maculata* is from near sea level to 950 m in the northern tableland areas of NSW (Boland et al. 2007). In southern Australia, the upper altitudinal limit will be less, given the cooler climate and higher risk of severe frost. In native forest of south-eastern NSW, Austin et al. (1994) showed that *C. maculata* occurred in the MAT range of 13.7–16.2°C.

In Victoria, ~100 ha of *C. maculata* is managed by Woollybutt on 14 sites with an altitudinal range of 40–550 m asl. Most are at <200 m with a MAT >14°C, and these are the most productive plantations with the best form. Where air drainage is good at higher altitudes (>200 m), survival has generally been satisfactory. On flatter areas, however, frost damage has been severe on trees up to 4 y of age. Growth has been slower and forking worse than at lower altitudes. Data from a range of trials suggest that there is potential to improve frost hardiness through breeding (Tibbits and Sasse 1999). Until seedlings with improved frost tolerance are available, interim guidelines for siting this species are required.

Literature and field observations would strongly suggest that establishing *C. maculata* is risky where:

- minimum temperatures can be $<-4^{\circ}\text{C}$
- MAT is $<14^{\circ}\text{C}$
- altitude is >250 m asl.

Soils

Of the four eucalypts being considered, *C. maculata* is tolerant of the widest range of soil types. It occurs on relatively infertile soils that are well drained (Maxwell 2007 unpubl.) and derived from shales, sandstones or granites (Larmour et al. 2000). *Corymbia maculata* can extend its roots into heavy-textured soils (Mazanec and Harwood 2001). In WA, it grows on a range of soils, but prefers well-drained, moderately heavy textured soils (Chrissy 2004a). Bird (2000) records that *C. maculata* prefers well-drained slopes not subject to waterlogging and containing no heavy clay. High mortality associated with waterlogging indicates a preference for free-draining soils (Mazanec 1999). On irrigated sites near Deniliquin, NSW, superior growth has been obtained on red loamy earths compared to heavy grey-brown clays (Mazanec and Harwood 2001). In Victoria *C. maculata* is found naturally in areas that are predominantly Red Chromosols (Maxwell 2007 unpubl.). Chromosols are duplex, non-sodic soils with an abrupt texture contrast between loamy topsoil and clay-rich subsoil (Whitman and Holloway 2007).

The following soil types are thought to be suitable for *C. maculata* plantation establishment: Brown Chromosols, Kurosols, Red Ferrosols, Podosols, Tenosols and Sodosols (Maxwell 2007 unpubl.). Vertosols and Organosols (Maxwell 2007 unpubl.) should probably be avoided due to their swelling, cracking and poor drainage properties.

Effective regolith volume. Little is known about the soil volume requirements to grow *C. maculata* at $15\text{ m}^3\text{ ha}^{-1}\text{ y}^{-1}$ in southern Australia. Mazanec and Harwood (2001) state that as the ALRTIG target zone of 400–600 mm is close to the lower limit of acceptable MAR for the species, it will be prudent to restrict plantings to sites that allow unimpeded root growth to at least 2 m depth.

A 19-y-old plantation of both *C. maculata* and *E. globulus* in adjacent but discrete blocks on the same soil type near Sale, Victoria (MAR ~600 mm) has clearly shown the superior drought tolerance and growth potential of *C. maculata* in low-rainfall zones. This and other evidence suggests that *C. maculata* requires less soil water than *E. globulus* to grow at commercially acceptable rates.

Fertility. Specific nutritional requirements have not been defined. Noble (2000) records that *C. maculata* responds to fertiliser application. Growth responses are obtained usually to N and sometimes to P applications. The micronutrient B has been found to be beneficial for growth in many

areas of north-eastern Victoria, and in coastal areas responses to Zn and Cu have been observed (Noble 2000).

Severino (2007 unpubl.) found that height and survival at age 12 months responded significantly to the application of the insecticide–fertiliser pill Initiator^{®33}. The pill was placed at the bottom of the planting hole. The same trial included organic and inorganic fertiliser treatments placed 15–30 cm from the seedling one month after planting; there was no significant response to these treatments.

Corymbia maculata is regarded as being well adapted to soils of poor fertility and thus the value of applying a blanket fertiliser prescription at establishment is questionable (Maxwell 2007 unpubl.). A better approach may be to build a nutritional profile based on soil and foliage analyses.

On the most productive sites in Queensland, *C. variegata* responded poorly to fertiliser application. On the poorest and most economically marginal sites, however, growth responses to fertiliser application can be substantial (Dickenson et al. 2005). This conclusion is supported by the following:

- On an ex-pasture site (MAR >900 mm) with a history of fertiliser application, there was a small growth response to the application of high levels of fertiliser³⁴ (Hardwoods Queensland 2005).
- In the same trial series (MAR >900 mm) at another ex-pasture site with poor fertility, there was a very strong growth response to increasing rates of fertiliser application³⁵ (Hardwoods Queensland 2005).

Foliar analyses at age 1 and 2 y on a small number of Victorian sites show that *C. maculata* may be more sensitive to K deficiency than *E. globulus* and *E. botryoides*. Judd et al. (1996) showed that mean foliar concentrations of K in *Corymbia* species near Eden, NSW, were significantly higher than for *Symphyomyrtus* and *Monocalyptus* species.

Insect pests

Corymbia maculata is generally regarded as a species with few pest problems in southern Australia, though it can be susceptible to attack from a small range of insects including:

- Christmas beetles (*Anoplognathus* spp.)
 - In a seed orchard near Bunyip, Vic., there were some significant differences in the susceptibility of different provenances and families (John Goy³⁶, pers. comm.)
- light brown apple moth (*Epiphyas postvittana*)
- longicorn borer (*Phoracantha semipunctuata*)

Diseases

Corymbia maculata is generally regarded as a species with few disease problems in southern Australia. Park et al. (2000) indicate that MLD has been found on *C. maculata*, though Carnegie (2007) recorded only one incidence on *Corymbia* species (*C. variegata*) during a 10-y period. Thus MLD does not appear to be a major problem for this species. It is regarded as tolerant to PC (Marks and Smith 1991) and has been used successfully in the regeneration of PC-infected sites in East Gippsland (Marks et al. 1973, cited by Tibbits and Sasse 1999) and WA (Mazanec 1993, cited by Tibbits and Sasse 1999). Kile (2000) shows no record of *Armillaria* infection on *C. maculata*.

³³ Initiator[®] is a spherical tablet which combines an NPK fertiliser with systemic insecticide—imidacloprid. It is a Bayer CropScience product.

³⁴ 200 kg N ha⁻¹, 60 kg P ha⁻¹, 5.2 kg Cu ha⁻¹, 5 kg Zn ha⁻¹, 2.9 kg B ha⁻¹, 8.4 kg S ha⁻¹ applied in three applications during the first 12 months

³⁵ As above

³⁶ John Goy is the proprietor of the seed orchard company Farm Trees Pty Ltd

Table 2. Climate and edaphic profiles for *Eucalyptus globulus*, *E. nitens*, *E. cladocalyx* and *Corymbia maculata*

Species	MAR (mm)	Rainfall distribution	MAT (°C)	Altitude (m asl)	Soils
<i>E. globulus</i>	800– 1500	Winter	10–14 (Tas) 13–14 (mainland)	0–400	Gradational textured soils
<i>E. nitens</i>	1000 ¹ – 2300	Winter	9–12	300–850	Gradational textured soils. Soils prone to waterlogging should be avoided.
<i>E. cladocalyx</i>	400– 750	Winter	13.5–16	0–250	Gradational to duplex textured soils with some clay content. Uniform sands and other exceedingly well drained soil types should be avoided
<i>C. maculata</i>	600– 1000	Winter	14–16.5	0–250	Gradational to duplex textured soils. Uniform sands are also suitable. Heavy, poorly drained clays should be avoided

In NSW and Queensland, *Corymbia* species are susceptible to a number of pests and diseases (Tibbits and Sasse 1999). For example, quambalaria shoot blight (QSB) is recorded as the most significant disease of young eucalypts in subtropical eastern Australia (Carnegie 2007). The repeated outbreak of QSB has led to a reduction in the planting of *Corymbia* spp. in the late 1990s (Carnegie 2007).

Species niche forecast for southern Australia

Sawlog plantations of the profiled species will be suitable for the conditions outlined in Table 2.

The overall niche occupied by the profiled species leaves considerable room for tree improvement and the development of other species to address the following gaps:

- naturally durable options (rating 1 or 2)³⁷ for high-rainfall areas
- moderately to highly frost-tolerant options for low-rainfall areas.

Any list of additional species to be evaluated to fill one or both of these niches should include *E. botryoides*, *E. seiberi*, *E. muelleriana* and *E. fastigata*.

Plantation establishment

Introduction

The elements of plantation establishment for mainstream species have been well documented (see Davidson et al.³⁸). However, sawlog production combined with new species options bring additional considerations to the establishment equation. Factors such as longer rotations, new product specifications, different growth rates and root configurations, and different herbicide and fertiliser tolerances necessitate subtle and sometimes significant changes to optimise establishment success.

One of the main differences between the establishment of pulpwood-only and sawlog plantations is the greater emphasis placed in the latter on survival, growth, form and health. These traits are of primary importance to the success of all plantations but have greater significance in sawlog plantations for the following reasons:

³⁷ Refer to the Australian Standard™ *Timber—Natural Durability Ratings AS 5604-2005*

³⁸ See *Farm Forestry—A Technical and Business Handbook*. University of Tasmania (2006)

- Survival:
 - High survival rates (>85%) facilitate a more competitive environment that encourages good form (e.g. apical dominance, fine branching, minimal sweep). Sawlog specifications are relatively tight, so good form is essential. The evenness of survival is also important to the symmetry of sawlog growth.
 - Improved form requires less corrective effort (e.g. form pruning).
 - High survival rates provide a greater selection differential for sawlog tree identification at age 2–3 y. An improved selection differential can disproportionately increase net income from a sawlog plantation.
- Improved growth:
 - Enables shorter rotations
 - Reduces establishment costs:
 - Cheaper second-year weed control
 - Shorter periods of browsing control required
 - Less monitoring
 - Minimises the window for damaging insect attack.

Striving for these traits will optimise profitability.

Plantation design

Several configurations are available for sawlog plantation establishment including:

- block designs
- farm forestry designs including timberbelts, wide spaced and woodlot plantings.

Features of both options (assuming best practice management) are outlined below.

Block plantations

These:

- are favoured by plantation developers operating at conventional industry scale (>10 ha)
- offer multi-purpose benefits to the land unit (e.g. biodiversity, land protection, shelter), but are less accommodating and complementary to agriculture than is farm forestry
- are relatively inflexible in design, being limited to square or rectangular shapes or polygons that follow land features
- generate products at a low cost per unit (e.g. low harvesting costs)
- are usually managed or at least regularly visited by a professional forester
- employ contract labour to undertake management tasks
- have a low edge:area ratio, so:
 - a higher percentage of the plantation area is protected from harsh weather conditions
 - fine branch development is favoured—giving a wide window for pruning
 - water competition is high in early years—giving a small window for thinning
- have a high selection differential for final-crop trees
- favour production of multiple log lengths and products from a single tree
- generate products of consistent quality
- produce yields that are usually contracted to a market several years from actual sale
- are less aesthetically appealing than farm forestry designs
- are more prone to encounter community opposition
- can reduce property value where 100% of a property is established.

Farm-forestry scale plantations

These:

- are favoured by smaller-scale developers wanting to incorporate forestry into farmland or the land unit, rather than to replace existing land use
- offer multipurpose benefits to land units including improvements to agricultural productivity

- offer a flexible range of design options
- generate products at a high cost per unit (e.g. high harvesting costs)
- are typically managed by the landowner with minimal professional forestry assistance
- employ minimal contract labour to assist with management tasks. This increases risk of silviculture not being undertaken on time
- have a high edge: area ratio, so:
 - a low percentage of the plantation area is protected from harsh weather conditions
 - coarse branch development is encouraged—giving a small window for pruning
 - competition for water is lower in early years—giving a large window for thinning
- when widely spaced, provide a low selection differential for final-crop trees
- favour production of one high-value log length, from a single tree
- generate products of lesser consistency
- produce yields likely to be sold on an opportunistic basis
- are usually aesthetically appealing
- are less prone to encounter community opposition
- usually maintain or improve the value of the property.

Block designs are more likely to produce a consistent, high-quality sawlog demanded by industry and to be profitable in their own right. However, the wider community and many regulatory authorities (e.g. shire councils) are less accepting of this form of forestry.

Planting density

All four species should be established at 1000 stems ha⁻¹. Of the four recognised species, only *E. nitens* has form sufficiently good to permit it to be established at a lower density.

Seedling order

The seed ordered should be the best available. Improved seed is available for all four species, although there has been only a small amount of work done on developing seedlots preferred for sawlog production. The desired number of plants should be multiplied by a factor of 1.3–1.5 to calculate the quantity of viable seeds to order. Higher multiplication factors may be required for frost-tender species.

If ordering plants, *Eucalyptus nitens*, *E. cladocalyx* and *C. maculata* should be ordered 4–6 weeks earlier than *E. globulus* due to the need for cold stratification of *E. nitens*, and frost risk and slower growth for *E. cladocalyx* and *C. maculata* (Pieter Klein³⁹ pers. comm.). In Victoria, this translates to ordering in November (*E. nitens*, *E. cladocalyx*, *C. maculata*) and or December (*E. globulus*) in the year prior to planting.

For easy and cost-effective planting, seedlings should be ordered in tray containers that contain multiple cells (e.g. Lannen 63, HIKO V93). Close et al. (2006) found that containers with larger cell sizes (85–115 ml) were associated with significantly improved performance in *E. globulus* at age 6 months in the Green Triangle. Good growth and survival is particularly important for slower-growing species to minimise the potential of frost and browsing damage in the year following planting.

Pre-cultivation weed control

The control of weeds becomes even more important when considering the establishment of *E. cladocalyx* and *C. maculata*, which are likely to be 1–2 m tall at age 1 y. Their relatively small size means that weed competition may be more significant and difficult to control post-planting.

Whilst one pre-cultivation weed control treatment can be sufficient for *E. globulus* and *E. nitens*, two may be required for the slower-growing species. Serious consideration should be given to eradicating high-water-demanding pasture plants such as *Phalaris* spp. prior to establishment.

³⁹ From Kleins Nursery in Yarram, Victoria

Soil cultivation

Soil cultivation (deep ripping and mounding) is an essential part of plantation site establishment for sawlogs, particularly for slower-growing species that are often planted on medium to heavy clay subsoils. Specific benefits of soil cultivation include:

- fast establishment; this is a significant advantage in areas prone to frost, browsing and insect damage
- improved survival
- moisture retention whilst also facilitating drainage (Volker and Bower 2006)
- improved effectiveness of knockdown and residual weed control (Volker and Bower 2006)
- easier and more cost-effective planting
- more even and consistent seedling distribution across site
- improved nutrient availability.

To minimise moisture loss, soil cultivation needs to be completed early with good tilth to facilitate adequate mound settling. For frost-tender species, the importance of consolidated planting lines is increased, because seedlings will be planted later into warming conditions. Soil cultivation should ideally be completed no later than four (>800 mm MAR) – six (<800 mm MAR) months before planting. The lower the MAR, the longer the required lead time.

Mounding can contribute to the development of butt sweep in seedlings (Reid and Bell 2006). However, where the mound is allowed to consolidate and tree survival is good, this should have little effect on sawlog yield. Even if butt sweep prevails, the benefits of faster growth and improved survival mean the positive generally outweigh the negative effects of mounding. Problems associated with soil cultivation are usually due to sub-optimal practices (e.g. too late, too wet).

Pre-plant weed control

Pre-plant weed control is particularly important because it offers the following advantages:

- improved survival and growth is faster through more available water and nutrients
- improved tree form:
 - mounding is often incorrectly blamed for butt sweep; often the cause of butt sweep is poor pre- or post-planting weed control
- improved ability to recover from stress caused by frost, insect or fungal damage, and browsing animals (Volker 2006).

Slower-growing species are likely to benefit significantly from extended periods of effective weed control. *Corymbia variegata* and *E. grandis* showed significant growth responses to increasing the duration of weed control from 5 to 15 months in Queensland (Hardwoods Queensland 2005); the greater response was in *C. variegata*. This may be due to the deep rooting habit of *Corymbia* species (Neave and Florence 1994). Compared to *Symphyomyrtus* and *Monocalyptus* species, *Corymbia* has considerably fewer roots in the upper soil profile. Neave and Florence (1994) concluded that *C. maculata* might be less effective at acquiring nutrients and moisture in the upper soil horizons, but more effective at acquiring moisture at depth.

In high-rainfall zones, many plantation developers favour broadacre weed control to maximise growth at establishment. This may not be required for slower-growing or *Monocalyptus* and *Corymbia* species. In a Gippsland weed control trial, *C. maculata* had significantly better growth in the ‘mound only’ compared to the broadacre herbicide treatment (Severino 2007 unpubl.).

To provide knockdown and residual control, mixtures for pre-plant weed control have historically included a range of active ingredients including glyphosate, metsulfuron methyl, sulfometron methyl and simazine with an adjuvant. More recently, the range of suitable products and mixtures has increased to provide superior chemical alternatives from some situations. Relatively new active ingredient options include⁴⁰ clopyralid, diflufenican, oxyfluorfen and pendimethalin.

⁴⁰ Subject to the chemical label and respective herbicide use legislation in each of the southern states or the ACT.

Browsing control

The requirement for browsing control is often underestimated. Sawlog plantations require vigilance and effective control measures because of the extreme importance of tree survival and form. Badly browsed stands will have reduced survival which contributes to poor form. Browsed but surviving stems will normally require form correction to make a sawlog. Slower-growing species will require an extended period of browsing control.

Planting

Frost-hardy species should generally be planted in winter and frost-tender species after the major frost risk has passed. Seedlings should be planted in the middle of planting lines to create an evenly spaced plantation that optimises later weed control operations and reduces damage during thinning (Lambert 2007).

Fertilising

The application of fertiliser should be considered in all eucalypt sawlog plantations. Poor nutrient balance may result in poor survival, slow growth, additional weed control, increased susceptibility to pests and diseases, and ultimately a non-profitable enterprise (Smethurst 2006).

Fertiliser requirements differ between sites and species. Species which grow naturally on poor-quality sites often show a modest response to added nutrients (Kriedemann and Cromer 1996). For example, in *E. cladocalyx* established on two sites with <800 mm MAR, there was no significant response to fertiliser addition at age 1 and 2 y (Severino 2005 unpubl.).

In Tasmania, *E. globulus* and *E. nitens* on all but the most fertile sites should be given 100–200 g DAP at planting (Smethurst 2006). The largest responses to P fertiliser occur when the plantations are fertilised soon after planting: the gains at age 1 y are maintained until the end of the rotation (Schönau and Herbert 1989).

Micronutrient deficiencies can be associated with extreme crown dieback and/or distortion that can quickly and severely compromise sawlog yields. If such deficiencies are not promptly treated, it can be very difficult to restart growth of good quality (Dell and Huang 2002). Soils should be tested prior to establishment, and foliar analysis undertaken 1–2 y following establishment.

If fertiliser is to be applied, the aspects outlined earlier from Smethurst et al. (2004) need to be considered. Trials show that the form of fertiliser and its placement can be important. In 1-y-old *C. maculata*, there was no benefit in applying organic or inorganic fertiliser on a site with MAR of 675 mm, but there was a significant increase in height growth and survival from applied Initiator[®] (Severino 2007 unpubl.).

Monitoring

Regular monitoring is critical to identify and react to pests and diseases, and to maximise plantation productivity (de Little 2002). Monitoring can be time consuming and expensive (Jenkin 2007) and is arguably the most underestimated cost in plantation establishment. The cost of monitoring is higher when dealing with slow-growing species.

One of the significant benefits of Initiator[®] is that it boosts tree growth whilst providing protection from a wide range of insect pests for up to 2 y. This product significantly reduces monitoring costs, particularly in low-rainfall areas. One-year results confirm its potential (Severino 2007 unpubl.).

Insect control

Maintaining plantation health through best-practice establishment and timely silviculture can assist in reducing stress, enabling trees to better withstand insect attacks (Collett 2001b). The appropriate siting and management of plantations will also reduce pest- and disease-related problems.

Faster-growing species and *E. globulus* in particular are prone to damage from several different insect pests. However, slower-growing species can be more susceptible to insect damage because slower growth makes them more vulnerable to losing a high percentage of foliage during periods when insect populations are most active. Preventing significant insect damage means inspecting trees regularly—ideally fortnightly during the spring and summer, and monthly for the rest of the year (Elek 2006).

Second-year weed control

This operation needs to be timed to facilitate:

- optimal weed kill
- minimal tree damage
- maximum tree growth during the year following planting.

Often slower-growing species will be <1.2 m high and facing the prospect of severe weed competition through autumn and/or spring following planting. Until more robust prescriptions are developed for species such as *E. cladocalyx* and *C. maculata*, directional methods involving the use of hand-held applicators and wide-spectrum herbicide prescriptions, for example amitrole/simazine/sulfometuron methyl, are the safest option; other options include Clethodim, Fluazifop-P, Haloxyfop, clopyralid, oxyfluorfen, pendimethalin and simazine. Where trees are >1.2 m high, lower-cost directional methods using offset jets mounted to vehicles are available. Grass-specific herbicides—for example Clethodim, Fluazifop-P and Haloxyfop—can be safely applied over the profiled eucalypts (<1.2 m) at the label rates. There are no formally tested, cost-effective, wide-spectrum, second-year treatments that can be safely applied over the top of 9–12-month-old *E. cladocalyx* or *C. maculata* plantations (Barry Tomkins⁴¹ pers. comm.). For now, directed applications are necessary.

Improving early seedling growth by using products such as Initiator[®] offers the prospect of significant cost savings for weed-control treatments. The need for hand-held applications and second-year weed control could then be substantially reduced. Third-year weed control will be required on some sites for slower-growing species, particularly where aggressive, choking weeds such as kikuyu grass (*Pennisetum clandestinum*) persist.

Foliar analysis

This should be undertaken following establishment, particularly where symptoms of nutrient imbalances exist. Smethurst (2006) comments that foliar analysis is more useful for pines than eucalypts. A number of forestry companies in southern Australia, however, routinely use foliar analysis to detect nutrient deficiencies at age 1–2 y in eucalypts.

Weggler et al. (2008) found stem analysis to be a better indicator of nutrient status than foliar analysis in *Eucalyptus pilularis*. It follows that stem analysis may become the preferred method of assessing nutrient status in eucalypts.

There are published data on critical foliar nutrient concentrations for *E. globulus* (see Dell et al. 2001) and to a lesser extent for *E. nitens* at 1–2 y of age, but not for *E. cladocalyx* or *C. maculata*. Nonetheless visual estimates, combined with a growing database of nutritional information, mean that informed decisions can be taken for these latter species.

If corrective fertiliser is required, it should be applied in the spring or autumn following the initial diagnosis. Fertiliser deficiencies that affect tree form (e.g. Cu and B) should be corrected in the spring following diagnosis. Fertiliser should be applied only when weed control is good and water is not limiting. For low-rainfall areas, this may mean that an autumn application is the only option.

Plantation sawlog establishment budget

Differences in site assessment, species matching and establishment between sawlog and pulpwood products indicate that costs associated with sawlog plantations will be higher than those for pulpwood plantations. This will present challenges for the large sectors of the industry that are primarily focused on investment performance. However, the recent trends of increasing prices for sawlog from native forests, and good results from plantation-based wood processing (McEvoy⁴² pers comm.), indicate that these are challenges can be overcome.

⁴¹ Greentree Forestry Services Pty Ltd

⁴² Chris McEvoy is the Director of Radial Timber Australia

Research gaps and priorities

A robust eucalypt sawlog industry must be based on a research strategy that is driven by key stakeholders from the following areas:

- tree improvement
- establishment and management
- harvesting
- processing
- marketing
- investment.

Stakeholders must be represented by a balanced mix of practitioners and scientists. The development of a eucalypt sawlog industry has stagnated in many regions because of, in part, the ongoing absence of some sectors from critical developmental stages. Effective and sustained representation from harvesting, processing and marketing sectors has been spasmodic. History shows that the successful development of a eucalypt sawlog industry cannot be driven by forester and or research interests alone. All stakeholders must be involved.

Specific research gaps

Research gaps in the areas of site assessment, species matching and establishment currently include items in the following list. I have subjectively attempted to prioritise gaps as follows:

- plantation growth data:
 - data for a wide range of relevant species including *E. cladocalyx*, *C. maculata* and *Monocalyptus* species are limited; data for sawlog regimes are even more limited
 - target growth rates for species × region combinations for profitable plantation development
- the potential of main *Monocalyptus* species options⁴³ for sawlog development needs to be explored more thoroughly before regional species lists are finalised
- climatic and edaphic requirements for main species options:
 - recommended ratio of MAR to evaporation for plantation-growing regions
 - linking species' climatic profiles to latitudinal ranges
 - further data filtering to determine climatic parameters for sites capable of commercially acceptable growth rates (e.g. at least 15 m³ ha⁻¹ y⁻¹)
 - soil property preferences; information is particularly scant for *E. cladocalyx* and *C. maculata*
 - altitude: gaps are particularly evident for *E. cladocalyx* and *C. maculata*
 - reasons for the poor productivity of *E. globulus* in many regions
- root morphology: there is a staggering lack of data on this subject given the primary importance of roots to tree growth
- the further development of process-based models to close research gaps and decision support for major species such as those listed in Tables 1 and 2
- industry niche for *E. cladocalyx*, given its slow growth
 - what situations are optimal for planting given its slow growth?
- nutritional profiles desirable during the establishment and subsequent management phases
- diagnosis of nutrient imbalances, particularly in species other than *E. globulus*, and
 - prescriptions for addressing nutrient imbalance, particularly with regard to trace element deficiencies
- treatment for and prevention of:
 - MLD
 - *Armillaria* in *E. nitens*
 - borer attack
- weed control in *E. cladocalyx* and *C. maculata*:
 - post-planting weed control treatments that can be applied over the top of trees
 - regimes to reduce requirements for third-year weed control.

Several of these research gaps could be addressed concurrently.

⁴³ Tree improvement, establishment, management, harvesting, processing, marketing etc.

Conclusion

New models for site assessment and species selection are required to support the development of a eucalypt plantation industry. Establishment methods require revision to optimise the performance of sawlog plantations. Site assessment must effectively address risk over long sawlog rotations; process-based models will be an integral part of this process. It has been shown that *Monocalyptus* and *Corymbia* species warrant further analysis as sawlog options. To prematurely confine the development of sawlog plantations to mainly *Symphyomyrtus* species would be unwise. The profiled species are expected to play a role in southern Australia. *Eucalyptus nitens* shows particularly good potential on high-quality sites. Similarly, *C. maculata* shows considerable potential, particularly if its frost tolerance can be increased through tree improvement. *Eucalyptus globulus* has under-performed in plantations to date, potentially giving this species a less significant role than previously thought. The growth and form of *E. cladocalyx* needs to be substantially improved to justify planting for timber value alone. The forecast niche of these species leaves considerable room for tree improvement and the development of other species. Plantation establishment regimes must include changes that foster superior standards of survival, growth, form and health over rotations than those used for pulpwood plantations. There is a wide array of specific research gaps that must be addressed to support the development of a eucalypt sawlog industry. In particular, the collection of inventory data, species screening and the identification of specific site requirements need to be undertaken. To adequately address these gaps, the basic differences between pulpwood and sawlog plantation development **must** be acknowledged. If they are not, the development of a eucalypt sawlog industry in southern Australia will continue to stagnate.

Acknowledgements

It is a pleasure to acknowledge the assistance of Barry Tomkins (Greentree Forestry Services) for peer review, Phil Whiteman (Hancock Victorian Plantations) for his time and comments, and the PEHVT committee for giving me the opportunity to write this paper.

References

- Austin, M.P., Cunningham, R.B. and Good, R.B. (1983) Altitudinal distribution of several eucalypt species in relation to other environmental factors in southern NSW. *Australian Journal of Ecology* **8**, 169–180.
- Austin, M.P., Nicholls, A.O., Doherty, M.D. and Meyers, J.A. (1994) Determining species response functions to an environmental gradient by means of a β -function. *Journal of Vegetation Science* **5**, 215–228.
- Bail, I., Baker, T., Tys, A. and Wong, J. (2002) Application of precision farming principles to nutritional management of *Eucalyptus globulus* plantations in south-eastern Australia. Abstracts from *EucProd Conference*, Hobart, 10–15 November 2002, CRC for Sustainable Production Forestry and CSIRO Forestry and Forest Products, p. 99.
- Battaglia, M. (2006) Matching species to site. In: Davidson, N., Volker, P., Leech, M., Lyons, A. and Beadle, C. (eds) *Farm Forestry—A Technical and Business Handbook*. University of Tasmania, pp. 196–201.
- Battaglia, M. and Sands, P.J. (1997) Modelling site productivity of *Eucalyptus globulus* in response to climate and site factors. *Australian Journal of Plant Physiology* **24**, 831–850.
- Battaglia, M., Cherry, M.L., Beadle, C.L., Sands, P.J. and Hingston, A. (1998) Leaf area index prediction in eucalypt plantations: effects of water stress and temperature. *Tree Physiology* **18**, 521–528.
- Battaglia, M., Sands, P., White, D. and Mummery, D. (2004) CABALA: a linked carbon, water and nitrogen model of forest growth for silvicultural decision support. *Forest Ecology and Management* **193**, 251–282.
- Beadle, C.L., Turnbull, C.R.A. and Dean, G.H. (1996) Environmental effects of growth and kraft pulp yield of *Eucalyptus globulus* and *E. nitens*. *Appita Journal* **49**, 239–242.
- Bird, P.R. (2000) *Farm Forestry in Southern Australia—A Focus on Clearwood Production of Specialty Timbers*. Department of Natural Resources and Environment, Victoria.
- Boland, D. J., Brooker, M.I.H., Chippendale, N., Hall, N., Hyland, B.P.M., Johnson, R.D., Kleinig, D.A. and Turner, J.D. (1984). *Forest Trees of Australia*. Fourth edition. Nelson–CSIRO, Melbourne.

- Boomsma, C.D. (1969) *The Forest Vegetation of South Australia*. Woods and Forests Department Bulletin No. 18. Wood and Forests Department, Adelaide.
- Brooker, M.I.H. (2000) A New Classification of the Genus *Eucalyptus* L'Her. (Myrtaceae). *Australian Systematic Botany* **13**, 79–148.
- Carnegie, A.J. (2007) Forest health condition in NSW, Australia, 1996–2005. II. Fungal damage recorded in eucalypt plantations during forest health surveys and their management. *Australasian Plant Pathology* **36**, 225–239.
- Carnegie, A.J., Ades, P.K., Keane, P.J. and Smith, I.W. (1994) Provenance variation in *Eucalyptus globulus* in susceptibility to *Mycosphaerella* leaf disease. *Canadian Journal of Forest Research* **24**, 1751–1757.
- Chrissy, R. (2004a) *Spotted Gum (Corymbia maculata) for Sawlogs in the 450–650 mm Rainfall Zone*. TreeNote 59/2004. Department of Catchment and Land Management, WA.
- Chrissy, R. (2004b) *Sugar Gum (Eucalyptus cladocalyx) for Sawlogs in the 450–650 mm Rainfall Zone*. Farmnote 60/2004. Department of Agriculture, WA.
- Close, D.C., Beadle, C., Brown, P.H. and Holz, G.C. (2000) Cold-induced photoinhibition affects establishment of *Eucalyptus nitens* (Deane and Maiden) Maiden and *Eucalyptus globulus* Labill. *Trees* **15**, 32–41.
- Close, D.C., Bail, I., Hunter, S. and Beadle C.L. (2006) Defining seedling specifications for *Eucalyptus globulus*: effects of seedling size and container type on early after-planting performance. *Australian Forestry* **69**, 2–8.
- Collett, N. (2001a) *Insect Pests—Control*. AG0801. Department of Primary Industries, Victoria.
- Collett, N. (2001b) *Insect Pests of Young Eucalypt Plantations*. Agriculture notes AG0799. Department of Primary Industries, Victoria, 4pp.
- Crocker, R.L. and Wood, J.G. (1947) Some historical influences on the development of the South Australian vegetation communities and their bearing on concepts and classifications in ecology. *Transactions of the Royal Society of Australia* **72**, 91–136.
- Davidson, N.J. and Reid, J.B. (1980) Comparison of the early growth characteristics of the *Eucalyptus* subgenera *Monocalyptus* and *Symphyomyrtus*. *Australian Journal of Botany* **28**, 453–461.
- De Little, D. (2002) Forest health: a proactive approach to pest and disease problems in plantations. Special Liftout No. 61. *Australian Forest Grower* **25**(3).
- Dell, B. and Huang, L. (2002) Micronutrient disorders in eucalypt plantations. In: Abstracts from *International Conference on Eucalypt Productivity*, Hobart, 10–15 November 2002. CRC for Sustainable Production Forestry and CSIRO Forestry and Forest Products, pp. 62–63.
- Dell, B., Malajczuk, N., Xu, D. and Grove, T.S. (2001) *Nutrient Disorders in Plantation Eucalypts*. ACIAR Monograph 74. Australian Centre for International Agricultural Research, Canberra, 194 pp.
- Department of Agriculture WA (2005) *Growing Tasmanian Blue Gum: Overview in the Greater than 600 mm Rainfall Zone*. TreeNote No. 27.
- Dickinson, G., Lewty, M., Marks, N., Huth, J., Smith, T., Lee, D. and Raddatz, C. (2005) *Silvicultural Research to Assist Large Scale Commercial Farm Forestry in Queensland*. Publication No. 04/185 JVAP – RIRDC, Canberra.
- Duncan, M.J., Baker, T.G., Appleton, R. and Stokes, R.C. (2000) *Growth of Eucalypt Plantation Species Across Twelve Sites in Gippsland, Victoria*. Department of Natural Resources and Environment, Victoria.
- Dungey, H.S., Potts, B.M., Carnegie, A.J. and Ades, P.K. (1997) *Mycosphaerella* leaf disease: genetic variation in damage to *Eucalyptus nitens*, *Eucalyptus globulus*, and their F₁ hybrid. *Canadian Journal of Forest Research* **27**, 750–759.
- Elek J (2006) *Control of Insect Pests*. In: Davidson N, Volker P, Leech M, Lyons A and Beadle C. (eds) *Farm Forestry – A Technical and Business Handbook*. University of Tasmania, pp. 234–240.
- Feikema, P.M. (2005a) Climate and soil based information for farm forestry: update. Presentation to the FFORNE Cooperative at Highlands, Victoria, 5 June 2005.
- Feikema, P.M. (2005b) Tree Nutrition. Presentation to the FFORNE Cooperative at Highlands, Victoria, 5 June 2005.

- Gadgil, P.D., Wardlaw, T.J., Ferreira, F.A., Sharma, J.K., Dick, M.A., Wingfield, M.J. and Crous, P.W. (2000) Management of disease in eucalypt plantations. In: Keane, P.J., Kile, G.A., Podger, F.D. and Brown, B.N. (eds) *Diseases and Pathogens of Eucalypts*. CSIRO, Melbourne, pp. 519–530.
- Gippsland Private Forestry (2005) Farm Forestry Demonstration Sites, Red Gum Plains 3 – Age 5 growth rates and stem form. Forestry Notes.
- Grand Ridge Plantations (2004) ‘What do I do next?’ Planning for the second rotation. Field Day Notes, 15 October 2004, p. 2 (unpublished).
- Hall, N., Boden, R.W., Christian, C.S., Condon, R.W., Dale, D.A., Hart, A.J., Leigh, J.H., Marshall, J.K., McArthur, A.G., Russell, V. and Turnbull, J.W. (1972) *The Use of Trees and Shrubs in the Dry Country of Australia*. Australian Government Publishing Service, Canberra.
- Hajek, C. (2003) Are your trees hurt and hungry? *Agroforestry News* **12**(1), 9.
- Hanks, L.M., Paine, T.D. and Millar, J.G. (1993) Host species preference and larval performance in the phloem-boring beetle *Phoracantha semipunctata* F. *Oecologia* **95**, 22–29.
- Hardwoods Queensland (2005) *The Effect of Cultivation, Weed Control and Fertiliser on the Early Growth of Two Hardwoods*. Research Update, Silviculture/604/1. Hardwoods Queensland Research Updates. Department of Primary Industry, Queensland.
- Harper, R.J., Edwards, J.G., McGrath, J.F., Reilly, T.J. and Ward, S.L. (1999) Performance of *Eucalyptus globulus* plantations in south-western Australia in relation to soils and climate. In: *Balancing Productivity and Drought Risk in Blue Gum Plantations*. A Plantation Management Workshop, Karri Valley Resort, Pemberton, WA, 9–10 November 1999.
- Harwood, C. and Bulman, P. (2001) Part 3: *Eucalyptus cladocalyx*. Genetic improvement strategy in southern Australia. In: Harwood, C., Bulman, P., Bush, D., Mazanec, R. and Stackpole, D (eds) *Australian Low Rainfall Tree Improvement Group Compendium of Hardwood Breeding Strategies*. RIRDC Publication No. 01/100.
- Harwood, C., Bulman, P., Bush, D., Mazanec, R. and Stackpole, D. (2001) *Australian Low Rainfall Tree Improvement Group: Compendium of Hardwood Breeding Strategies*. Rural Industries Research and Development Corporation, Canberra, www.rirdc.gov.au/reports/AFT/CSF-58A.pdf
- Jenkin, B. (2007) An objective assessment of the financial implications of the use of Initiator[®] Forestry Tablet as a solution to existing silvicultural problems. Prepared for Bayer Environmental Science (unpublished).
- Jovanovic, T. and Booth, T.H. (2002) *Improved Species Climatic Profiles*. RIRDC Publication No 02/095. Rural Industries Research and Development Corporation, Canberra.
- Judd, T.S., Attiwill, P.M. and Adams, M.A. (1996) Nutrient concentrations in Eucalyptus: a synthesis in relation to differences between taxa, sites and components. In: Attiwill, P.M. and Adams, M.A. (eds) *Nutrition of Eucalypts*. CSIRO, Melbourne, pp. 249–258.
- Kile, G.A. (2000) Woody root rots of eucalypts. In: Keane, P.J., Kile, G.A., Podger, F.D. and Brown, B.N. (eds) *Diseases and Pathogens of Eucalypts*. CSIRO, Melbourne, pp. 293–306.
- Kriedemann, P.E. and Cromer, R.N. (1996) Nutritional physiology of eucalypts: nutrition and growth. In: Attiwill, P.M. and Adams, M.A. (eds) *Nutrition of Eucalypts* CSIRO, Melbourne.
- Laffan, M. (2002) *An Introduction to Tasmanian Forest Soils*. Forestry Tasmania.
- Lambert (2007) Assessment of mechanical harvesters suited to thinning small-diameter plantation eucalypts. Woollybutt Pty. Ltd.
- Larmour, J.S., Whitfield, S.J., Harwood, C.E. and Owen, J.V. (2000) Variation in frost tolerance and seedling morphology of the spotted gums *Corymbia maculata*, *C. variegata*, *C. henryi* and *C. citriodora*. *Australian Journal of Botany* **48**, 445–453.
- Lima, W.P., Jarvis, P. and Rhizopoulou, S. (2003) Stomatal responses of *Eucalyptus* species to elevated CO₂ concentration and drought stress. *Scientia Agricola* **60**, 231–238.
- Loch, A.D. and Floyd, R.B. (2001) Insect pests of Tasmanian blue gum, *Eucalyptus globulus globulus*, in south-western Australia: history, current perspectives and future prospects. *Austral Ecology* **26**, 458–466.
- Lundquist, J.E. and Parnell, R.C. (1987) Effects of mycosphaerella leaf spot on growth of *Eucalyptus nitens*. *Plant Disease* **71**, 1025–1029.

- Marks, G.C. and Smith, I.W. (1991) *The Cinnamon Fungus in Victorian Forests: History, Distribution, Management and Control*. Land and Forests Bulletin No. 31. Department of Conservation and Environment Victoria.
- Marks, G.C., Kassaby, F.Y. and Reynolds, S.T. (1972) Die-back in the mixed hardwood forests of eastern Victoria: a preliminary report. *Australian Journal of Botany* **20**, 141–154.
- Marks, G.C., Kassaby, F.Y. and Fagg, P.C. (1973) Die-back tolerance in eucalypt species in relation to fertilisation and soil populations of *Phytophthora cinnamomi*. *Australian Journal of Botany* **21**, 53–65.
- Maxwell, C. and Severino, D. (2007) Species profile—expanding the spotted gum resource in Victoria. Industry Project. University of Melbourne – Woollybutt Technologies Pty Ltd. Unpublished.
- Mazanec, R.A. (1993) Provenance trials of four exotic eucalypts in bauxite mines in Western Australia. Paper to: *International Conference on Environmental Issues and Water Management in Energy and Mineral Production*. 3rd, Workshop 3: Revegetation of mine sites using appropriate species, 29 August–1 September, Perth, WA.
- Mazanec, R.A. (1999) Thirteen-year results from a spotted gum provenance trial in the Wellington catchment of Western Australia. *Australian Forestry* **62**, 315–319.
- Mazanec, R.A. and Harwood, C.E. (2001) Part 6. Spotted gum: genetic improvement strategy in southern Australia. In: Harwood, C., Bulman, P., Bush, D., Mazanec, R. and Stackpole, D (eds) *Australian Low Rainfall Tree Improvement Group Compendium of Hardwood Breeding Strategies*. RIRDC Publication No. 01/100.
- McDonald, M.W., Rawlings, M., Butcher, P.A. and Bell, J.C. (2003) Regional divergence and inbreeding in *Eucalyptus cladocalyx* (Myrtaceae). *Australian Journal of Botany* **51**, 393–403.
- McMahon, J.P., Hutchinson, M.F., Nix, H.A. and Houlder, D.J. (1997) *ANUCLIM User Guide*. Centre for Resource and Environmental Studies, The Australian National University, Canberra.
- Milgate, A.W., Potts, B.M., Joyce, K., Mohammed, C. and Vaillancourt, R.E. (2005) Genetic variation in *Eucalyptus globulus* for susceptibility to *Mycosphaerella nubilosa* and its association with tree growth. *Australasian Plant Pathology* **34**, 11–18.
- Montoya Oliver, J.M., Rizani, B., Mahzoum, A.M. and Allue Camacho, M. (1983) Species of eucalypts suitable for forestry production in regions attacked by *Phoracantha*: a comparative study of *Eucalyptus cladocalyx* and *Eucalyptus camaldulensis*. *Annales de la Recherche Forestiere au Maroc* **23**, 425–444.
- Mummery, D. and Battaglia, M. (2001) Applying PROMOD spatially across Tasmania with sensitivity analysis to screen for prospective *Eucalyptus globulus* plantation sites. *Forest Ecology and Management* **140**, 51–63.
- Mummery, D. and Battaglia, M. (2004) Significance of rainfall distribution in predicting growth, management options and risk assessment using the process based model CABALA. *Forest Ecology and Management* **193**, 283–296.
- Neave, I.A. and Florence, R.G. (1994) Effect of root configuration on the relative competitive ability of *Eucalyptus maculata* Hook. regrowth following clearfelling. *Australian Forestry* **57**, 49–58.
- Noble, I.R. (1989) Ecological traits of the *Eucalyptus* L'Hert. Subgenera *Monocalyptus* and *Symphyomyrtus*. *Australian Journal of Botany* **37**, 207–224.
- Noble, P. (2000) *Spotted Gum for Farm Forestry*. Agriculture notes AG0850. Department of Primary Industries, Victoria.
- Noble, P. (2003) The FFORNE Project. In: *The Farm Forestry Roundup—A Workshop Review to Broaden the Application of Innovation and Excellence in Farm Forestry*. NHT Farm Forestry Program. Launceston, Tasmania, 11–13 June 2003.
- O'Connell, A.M. and Rance, S.J. (1999) Predicting nitrogen supply in plantation eucalypt forests. *Soil Biology and Biochemistry* **31**, 1943–1951.
- Park, R.F., Keane, P.J., Wingfield, M.J. and Crous, P.W. (2000) Fungal diseases of eucalypt foliage. In: Keane, P.J., Kile, G.A., Podger, F.D. and Brown, B.N. (eds) *Diseases and Pathogens of Eucalypts*. CSIRO, Melbourne, pp. 119–152.

- Paul, K.I., Booth, T.H., Jovanovic, T., Sands, P.J. and Morris, J.D. (2007) Calibration of the forest growth model 3-PG to eucalypt plantations growing in low rainfall regions of Australia. *Forest Ecology and Management* **243**, 237–247.
- Phillips, C. (1996) *Insects, Diseases and Deficiencies Associated with Eucalypts in South Australia*. Primary Industries South Australia, 160 pp.
- Pinkard, E.A. and Mohammed, C. (2006) Photosynthesis of *Eucalyptus globulus* with mycosphaerella leaf disease. *New Phytologist* **170**, 119–127.
- Potts, B.M. and Pederick, L.A. (2000) Morphology, phylogeny, origin, distribution and genetic diversity of the eucalypts. In: Keane, P.J., Kile, G.A., Podger, F.D. and Brown, B.N. (eds) *Diseases and Pathogens of Eucalypts*. CSIRO, Melbourne, pp. 11–34.
- Reid, R. (2007) Borers reduce recovery of clearwood in *E. nitens* trial. *Agroforestry News* **59**, 28.
- Reid, R. and Bell, J. (2006) Risking tree form. *Agroforestry News* **54**, 14–15.
- Ryan, P.J., Harper, R.J., Laffan, M., Booth, T.H. and McKenzie, N.J. (2002) Site assessment for farm forestry in Australia and its relationship to scale, productivity and sustainability. *Forest Ecology and Management* **171**, 133–152.
- Schönau, A.P.G. and Herbert, M.A. (1989) Fertilising eucalypts at plantation establishment. *Forest Ecology and Management* **29**, 221–224.
- Severino, D. (2005) Response to first-year fertiliser applications on sugar gum plantations in low-rainfall regions. Project Update, Woollybutt Technologies Pty. Ltd (unpublished).
- Severino, D. (2006a) 05/02 Yellow stringybark (*Eucalyptus muelleriana*) mid-rotation thinning and fertilising trial at Alberton West, Victoria. Progress Report, Woollybutt Technologies Pty Ltd (unpublished).
- Severino, D. (2006b) 02/01 Sugar gum (*Eucalyptus cladocalyx*) permanent sample plot project. Progress Report, Woollybutt Technologies Pty Ltd (unpublished).
- Severino, D. (2006c) Australian Low Rainfall Tree Improvement Group (ALRTIG) genetic gain host trial 2003—*Eucalyptus cladocalyx* and *Corymbia maculata*. Establishment and second measure report, Woollybutt Technologies Pty. Ltd (unpublished).
- Severino, D. (2007) 11/06 Maximising initial growth and minimising establishment costs of yellow stringybark (*Eucalyptus muelleriana*) and spotted gum (*Corymbia maculata*). First year results, Woollybutt Technologies Pty Ltd (unpublished).
- Shearer, B.L. and Smith, I.W. (2000) Diseases of eucalypts caused by soilborne species of *Phytophthora* and *Pythium*. In: Keane, P.J., Kile, G.A., Podger, F.D. and Brown, B.N. (eds) *Diseases and Pathogens of Eucalypts*. CSIRO, Melbourne, pp. 259–292.
- Simpson, J., Stone, C. and Eldridge, R. (1997) *Eucalypt Plantation Pests and Diseases—Crop Loss Study*. Forest Research and Development Division, State Forests of New South Wales, Sydney.
- Smethurst, P. (2006) Fertilisers. In: Davidson, N., Volker, P., Leech, M., Lyons, A. and Beadle, C. (eds) *Farm Forestry—A Technical and Business Handbook*. University of Tasmania, pp. 212–216.
- Smethurst, P., Holz, G., Moroni, M. and Baillie, C. (2004) Nitrogen management in *Eucalyptus nitens* plantations. *Forest Ecology and Management* **193**, 63–80.
- Stackpole, D., Stokes, R. and Oswin, D. (2004) Lismore and Wallinduc *Eucalyptus cladocalyx* establishment techniques trials: Progress Report 2002/3 and 2003/4. Report No. 2004/007. Forest Science Centre, Department of Sustainability and Environment, Victoria.
- Stone, C., Simpson, J.A. and Gittens, R. (1998) Differential impact of insect herbivores and fungal pathogens on the *Eucalyptus* subgenera *Symphomyrtus* and *Monocalyptus* and genus *Corymbia*. *Australian Journal of Botany* **46**, 723–734.
- Tejedor, C. (2004) Integral management of mycosphaerella leaf disease in northern Spain. In: Borralho, N.M.G., Pereira, J.S., Marques, C., Coutinho, J., Madeira, M. and Tomé, M. (eds) *Eucalyptus in a Changing World*. Proceedings of IUFRO Conference, Aveiro, 11–15 October. RAIZ, Instituto, Investigacao da Floresta e Papel, Portugal.
- Tepper, C. (2002) *Plantation Eucalypt Species for Solid Wood Products—A Profile of Eucalyptus muelleriana*. Fellowship Report. JW Gottstein Memorial Trust Fund.
<http://www.gottsteintrust.org/html/reports/catalog.htm#ctepper>.

- Tepper, C. (2007) Is poor establishment really due to drought? *Agroforestry News* **59**, pp. 18–20.
- Tibbits, W.N. and Hodge, G.R. (2003) Genetic parameters for cold hardiness in *Eucalyptus nitens* (Deane & Maiden) Maiden. *Silvae Genetica* **52**, 3–4.
- Tibbits, J. and Sasse, J. (1999) *An Evaluation of the Potential to Improve Spotted Gums by Breeding*. CFTT Report No. 99/029. Department of Natural Resources and Environment, Victoria.
- Turnbull, C.R.A., McLeod, D.E., Beadle, C.L., Ratkowsky, D.A., Mummery, D.C. and Bird, T. (1993) Comparative early growth of *Eucalyptus* species of the subgenera *Monocalyptus* and *Symphyomyrtus* in intensively-managed plantations in Tasmania. *Australian Forestry* **86**, 276–286.
- Volker, P. (2006) Weed control. In: Davidson, N., Volker, P., Leech, M., Lyons, A. and Beadle, C. (eds) *Farm Forestry—A Technical and Business Handbook*. University of Tasmania, pp. 241–245.
- Volker, P. and Bower, D. (2006) Site preparation. In: Davidson, N., Volker, P., Leech, M., Lyons, A. and Beadle, C. (eds) *Farm Forestry—A Technical and Business Handbook*. University of Tasmania, pp. 241–245.
- Wardlaw, T. (2006) Managing diseases in plantations. In: Davidson, N., Volker, P., Leech, M., Lyons, A. and Beadle, C. (eds) *Farm Forestry—A Technical and Business Handbook*. University of Tasmania, pp. 241–245.
- Weggler, K., Carney, C. and Stone, C. (2008) Effect of fertiliser and water supply on the growth, nutrient status and photochemical efficiency of *Eucalyptus pilularis* seedlings in a phosphorus-deficient soil. *Australian Forestry* **71**, 54–63.
- West, P.W. (1981) Comparative growth rates of several eucalypts in mixed species stands in southern Tasmania. *New Zealand Journal of Forestry Science* **11**, 45–52.
- White, D.A., Beadle, C.L. and Worledge, D. (2000) Control of transpiration in an irrigated *Eucalyptus globulus* plantation. *Plant, Cell and Environment* **23**, 123–134.
- Whitman, H. and Holloway, B. (2007) *Healthy Soils for Sustainable Vegetable Farms: Ute Guide*. Land and Water Australia, Canberra.
- Williams, D., Weston, C., Severino, D., Tepper, C. and Lambert, J. (2007) *Eucalyptus cladocalyx*—a review for southern Australia. Industry Project. University of Melbourne – Woollybutt Technologies Pty. Ltd (unpublished).



SESSION: GROWING, MANAGING AND HARVESTING
HARDWOOD SAWLOGS

Management of Hardwood Sawlog Species

PETER VOLKER

Forestry Tasmania and CRC Forestry, Hobart
Email: peter.volker@forestrytas.com.au

Abstract

The forest industry in Australia has been growing eucalypts in plantations on an industrial scale for less than 30 y. Most of these plantations are destined for the pulp and paper industry for domestic or, more usually, international processing. In recent years, increasing reservation of native forest resources from commercial timber harvesting has encouraged growers to examine the feasibility of growing solid-wood products in eucalypt plantations. Local experience with softwood plantation silviculture and overseas experience with silviculture of, and processing of wood from, plantation eucalypts has guided the development of regimes for management of eucalypt plantations.

Research has run parallel to the increase in the plantation solid-wood estate. The examination of pruning and thinning responses has included the physiology of tree responses. This fundamental research has led to an understanding of individual tree responses and has assisted in development of operational guidelines for silviculture at later ages, such as pruning, thinning and nutrient addition. The management of nutrition is dependent on the growth stage of the plantation as well as the inherent site properties including soil, climate and water availability. Careful consideration of these factors can lead to improved productivity.

Silviculture can be used to produce logs of suitable dimension and clear of defect as an input to processing. There are, however, interactions between silviculture and internal wood properties that are not well understood.

Introduction

Australian foresters have long experience with growing plantations, dating back to the middle of last century when there was a rapid expansion in the area of conifer plantations. The primary species planted were *Pinus radiata* in cool-temperate and Mediterranean climates of Western Australia (WA), South Australia (SA), Victoria, New South Wales (NSW) and Tasmania; *P. pinaster* in WA, and in subtropical zones of Queensland *P. elliottii* and *Araucaria cunninghamii*, the native hoop pine. In later years the Queensland plantings switched to hybrids based on *P. caribaea* in particular. Our experience with growing mostly exotic pine plantations has given us a good background in silviculture of plantations for a range of products and also in how to sustain productivity over successive rotations.

From time to time over the last 100 y or so foresters dabbled in growing native eucalypt species in plantations in Australia, but—due to the availability of the native forest resource—any work on problems associated with pests and diseases and the processing of small-diameter eucalypts was confined to the ‘curiosity’ scale. Most of the early work on silviculture of eucalypt plantations was done overseas in countries such as South Africa, which has a eucalypt solid-wood industry based on plantations dating back to the 1940s (Malan 2003). Other countries that have an interest in eucalypts for high-value products include Spain, Portugal, Chile, Uruguay, Brazil, India, China, USA and Vietnam, although most of the plantations in these countries are managed for pulpwood. The initial impetus for expansion of eucalypt plantations in Australia was led by pulp and paper companies during the mid-1970s in Tasmania, Victoria and NSW, with the main species planted being *Eucalyptus regnans*, *E. delegatensis*, *E. globulus*, *E. nitens* and *E. grandis*. During this time there was also a strong focus on species and provenance trials. From the early 1980s, large plantations of *E. globulus*

and *E. nitens* were established in WA, Victoria and Tasmania, destined for the export woodchip market.

There has continued to be scepticism about eucalypts for high-value timber products in Australia (Nolan et al. 2005) despite a long history of use in other countries (Maree and Malan 2000; Malan 2003; Nolan et al. 2005; Smith and Brennan 2006). The recent move in Australia and New Zealand into eucalypt plantations for solid-wood products (or high-value timber) has presented many challenges related to species selection and silviculture (Nolan et al. 2005) as well as management of pests (Abbott 1993; Bashford 1993; Neumann 1993; Phillips 1993; Stone 1993; Wylie and Peters 1993) and diseases (Gadgil et al. 2000).

Eucalypt plantation programs in Australia began their first phase of expansion in the early 1980s. This was largely driven by the realisation that Australia had a very large trade deficit in forest products, particularly in the pulp and paper sector. This trade deficit continues to this day at about \$2 billion per annum. The early plantation expansion was undertaken by paper and woodchip export companies (at that time) such as Forest Resources and APPM in Tasmania (now both Gunns Ltd), APM Forests in Victoria (now part of Hancock Victoria Plantations) and Bunnings in WA (now WAPRES). At the same time forestry agencies in most states also began eucalypt plantation programs to support the industry. The plantation expansion coincided with increased reservation of native forests and a market shift for Australia's woodchip customers to preference for a higher-quality resource (i.e. one with a higher pulp yield).

The establishment of eucalypt plantations for pulp and paper production resulted in a research focus on site selection, establishment silviculture and fibre properties. This led to consideration of kraft pulp yield per hectare as the predominant objective of plantation production systems aimed at the pulp and paper market. Despite this objective, the market signals for growers were to some extent still based on simple growth measurements such as tonnes over the weighbridge or volume per hectare.

Over the decade spanning the turn of the century, the ownership of the forests changed considerably. There was rapid expansion of plantation programs achieved through managed investment scheme (MIS) programs that coincided with the divestment by large pulp and paper companies of their forest assets. In addition, state government agencies have changed their governance to become government business enterprises and this has brought a different focus to their plantation activities.

The nature of the MIS program has meant that most new plantations were established on short-rotation regimes with little or no later-age silviculture. Plantations expanded into lower-rainfall areas and into subtropical and tropical regions (Smith and Brennan 2006). A number of new species were used, especially in northern Australia where there was a focus on *E. dunnii* (Smith and Henson 2007) which has been successfully deployed overseas, and *Corymbia* hybrids (Dickinson et al. 2007). This has brought challenges to foresters to manage nutrition and health issues.

Increased reservation of native forest resources, which supply most of the domestic hardwood sawlog in Australia, has led to some interest in production of solid-wood products from plantations of *Eucalyptus* and *Corymbia* species (Smith and Brennan 2006), but also to interest in acacia, teak, African mahogany and others. The interest in eucalypt plantations has also coincided with increased availability of young regrowth from native forests which has presented challenges to processors more accustomed to an old-growth or mature forest resource.

There is now a body of interest in eucalypt plantations for solid-wood and other products. This has required some thought and action with respect to later-age silviculture such as pruning and thinning. Longer rotations also bring about issues of maintenance of productivity through nutrient management, and additional forest health problems associated not only with growth but also wood decay and defect.

This paper will deal with silvicultural issues that are pertinent to management of eucalypts for high-value wood production. In particular I will examine work on pruning, thinning, nutrient management and forest health.

What has been done so far and by whom?

Most of the research and development work on eucalypt plantations for high-value timber has been carried out by state government agencies with support from CSIRO and cooperative research centres (CRCs). Table 1 demonstrates that this development work began in the mid-1980s, coinciding with increasing demands for reservation of native forest from commercial harvesting activity and concern for the future supply of hardwood sawlogs. In addition, eucalypt plantations have been a major focus within the farm forestry sector in most states—promotion and advice has been provided by state-sponsored programs (e.g. through Private Forests Tasmania and Trees for Profit in Victoria) or by individual enthusiasts encouraged by various programs and research support (e.g. through University of Melbourne’s Master Tree Grower program, farm forestry co-operatives which have been established in a number of regions, and Australian Forest Growers).

More recently MIS companies have offered solid-wood options in their programs. For example, Gunns Plantations offer a pruning and thinning option for solid wood and FEA manage their stands on an unpruned, single-thinning regime. FEA have demonstrated the feasibility of using unpruned material for structural grades in their EcoAsh® product (www.ecoash.com.au), and Aracruz in Brazil produce a solid-wood product called Lyptus (Seling et al. 2001).

Regimes for high-value timber production

The definition of high-value timber is somewhat controversial. While the production of pulpwood is often seen as of low value, products such as bleached eucalypt kraft pulp (BEKP) and the resulting printing and writing papers are high value. Thus while the timber may not be high value, the products certainly are. Significant progress in genetic improvement of fibre qualities suited to BEKP production have raised the value of plantations supplying this tailor-made wood. Pure pulpwood regimes, however, remain relatively simple—that is, short rotations with no pruning or thinning.

Table 1. History of development programs for eucalypts for high-value timber production in Australia (this does not include work on pulpwood plantations, which began earlier)

Agency	Year started	Focus
Forestry Tasmania	1980	Solid wood for sawn timber and veneer on commercial scale (Intensive Forest Management research program commenced in 1990)
DPI ¹ Victoria (now DSE & UM ²)	1985	Initial focus on agroforestry followed by support for grower cooperatives. Later work on low rainfall species
WA Forestry Department (now FPC ³)	1985	Bauxite mine rehabilitation and more recently low-rainfall areas (500–700 mm y ⁻¹)
Forestry SA	1988	Early focus on demonstrating suitability of eucalypt species
CRC for Temperate Hardwood Forestry	1991	Initial focus on site selection, establishment silviculture and breeding for pulp production
State Forests NSW	1993	Species evaluation on a range of sites for solid-wood production
CRC for Sustainable Production Forestry	1997	Physiology of responses to pruning. Growth and wood quality response to pruning and thinning including wood decay
Private Forests Tasmania	1997	High-value regimes for farm forestry and income diversification
Queensland DPIF/ QFRI ⁴	1999	Demonstration of various eucalypt species supported by tree improvement and silviculture research

¹Department of Primary Industries

²Department of Sustainability and Environment, and the University of Melbourne

³Forest Products Commission

⁴Department of Primary Industries and Fisheries, and Queensland Forest Research Institute

Potentially a number of different regimes could be used to manage eucalypt plantations for high-value timber (Smith and Brennan 2006; Baker and Volker 2007). Gerrand et al. (1997) identified constraints on the development of regimes producing high-quality timber in a reasonable time. These include a limited selection of species; spacing constraints posed by establishment costs; merchantability issues and windthrow; the low recovery of select-grade timber from unpruned stands; the variable nature of occlusion of branch stubs and kino problems; and the risk of decay entry through damage associated with pruning and thinning.

Pruning

The objective of pruning is to allow the production of timber or veneer sheets which are free of knots, knot holes and other defects associated with branches such as encased bark, decay and kino.

Development of workable pruning prescriptions requires an understanding of tree responses to different levels of pruning (Pinkard et al. 2004) and of the risk of introducing stem defect (Wardlaw and Neilsen 1999). A considerable amount of work has been carried out on *E. globulus* and *E. nitens* on physiological responses (Pinkard et al. 1995, 1998, 1999, 2004; Pinkard and Beadle 1998, 1999, 2000; Pinkard 2002, 2003) and defect and decay (Wardlaw and Neilsen 1999; Barry et al. 2000, 2001, 2002, 2005; Wardlaw et al. 2003; Deflorio et al. 2007) resulting from pruning.

Many eucalypt species shed branches naturally and produce an occlusion zone behind the dead branch stub. However, when grown in plantations, some eucalypt and *Corymbia* species do not shed branches in a satisfactory manner and produce defects. This results in logs that are unsuitable for defect-free timber or veneer production (Montagu et al. 2003). Rapid rates of crown rise and perceived efficiencies in self-pruning can make scheduling of pruning difficult (Smith et al. 2006). It takes only one or two imperfectly shed branches to ruin what would otherwise have been a perfect defect-free log (Alcorn et al. 2007). It has also been demonstrated that pruning of dead branches is not satisfactory because the dead branch stub is retained in the tree and pushed out with the bark as the tree grows, leaving behind kino (gum vein) or initiating decay in the intended clear-wood zone (Gerrand et al. 1997; Wardlaw and Neilsen 1999; Barry et al. 2005). Barry et al. (2005) show that pruning green branches can confine any decay to the knotty core of the stem for up to 5 y after pruning. Recent observations from sawing trials on rotation-age (about 23 y) *E. nitens* and *E. globulus* in Tasmania confirm that this containment continued and that the decay did not break out into the clear-wood zone.

To produce clear wood and maintain adequate growth of pruned trees it is essential to:

- prune branches while they are still alive to minimise the incidence of kino traces left by dead branch stubs
- prune trees with small branches to reduce the time for complete occlusion of the wound
- limit the amount of the green crown which is removed in any pruning event to maintain the growth of the pruned trees.

The level of pruning appropriate for *E. globulus* and *E. nitens* appears to be of the order of 30–50% of green crown removal (Pinkard and Beadle 1998; Pinkard et al. 1998, 2004) at the time of canopy closure. Early foliage removal prior to canopy closure can be combined with solid-wood production in *E. globulus* provided no more than 20–40% is removed (Pinkard 2003).

These restrictions on pruning add cost to the operation. Experience in Tasmania has shown that to maintain a defect-core diameter over stubs (DOS) of 15 cm or less there must be several visits to a tree to ensure that only green branches are removed and that green crown removal is within the parameters mentioned above. We have found that this requirement is dependent not only on site productivity but also on nutritional status of the stands. Plantations on soils with low inherent fertility require applications of remedial fertiliser to maintain green branches in the lower portion of the canopy. These, however, can lead to increases in branch diameter and in the incidence of decay (Wiseman et al. 2006). This latter is not necessarily a problem if the decay is confined to the knotty core following pruning.

The current prescription is to visit the tree on at least two to three occasions to remove 2–3 m of live crown in any one lift so as to stay within the limits of crown removal suggested by Pinkard *et al.* (2004). Experience in converting research into practice indicates the prescription must vary with site quality and logistical constraints.

The market for peeler logs—products of which are veneers used for example in laminated veneer lumber (LVL)—requires logs 2.6 m long to allow for trimming to the final sheet width of 2.4 m. The height of pruning adopted by growers in Tasmania varies between 5.2 m and 7.2 m, with Forestry Tasmania adopting a standard pruned height of 6.4 m. This gives flexibility to produce pruned peeler logs and or sawlogs from the plantations. It also allows for variations in stump height and trimming of logs to remove defect prior to processing. In South America, pruning has been undertaken to heights of 11 m.

Limitations to pruning are the high cost of the operation, and occupational health and safety (OHS) considerations. Pruning costs are incurred relatively early in the life of the plantation and must be carried until the final harvest. Cost and OHS risk increase as the pruning lifts progress up the tree. There have been attempts to automate pruning operations through the use of mechanical devices (C.M. Kerruish and N. Humphreys, University of Melbourne, pers. comm. 2007). There is also interest in growing ‘self-pruning’ species, but these are limited in number and the reliability of self-pruning under plantation conditions remains uncertain (Smith and Brennan 2006).

Thinning

Thinning is a silvicultural technique that is used to maximise growth of trees retained after the thinning operation. Thinning does not increase the maximum volume production of a forest stand, but may be used to redistribute volume into fewer stems. Usually these larger stems have a higher market value due to their suitability for processing into a range of products, some of which attract high prices (e.g. appearance-grade veneer and timber). Thinning research has been aimed at finding the optimum timing of the operation and number of stems to be retained to maximise production of clear wood in the pruned trees. Attempts to reduce the need for thinning, by planting fewer stems per hectare, result in log degrade due to increased number and size of branches (Gerrand *et al.* 1997; Neilsen and Gerrand 1999; Medhurst *et al.* 2001). It is important to have high initial tree stocking to control branch development and then to use thinning to accelerate growth of the lower log on selected retained stems. Also a plantation with too few trees—less than full site occupancy—encourages weed growth.

Recent results of sawing studies of logs from *E. globulus* plantations in Australia (Washusen 2004; Nolan *et al.* 2005) and Spain (Nutto and Touza-Vázquez 2004a, b) suggest that logs from trees grown under less competition through early thinning to low residual stocking tend to have less growth stress. This may have implications for silvicultural regimes adopted to produce timber that is fit-for-purpose in the market.

Damage to retained stems in thinning operations should be avoided, as this can allow entry of wood decay fungi (Deflorio *et al.* 2007). The timing of thinning operations is also important in relation to the risk of windthrow in the retained stand (Wood *et al.* 2008).

Log yields and financial analyses of regime options

The following example demonstrates the need for long-term studies on silvicultural management if growers and processors are to understand and realise the potential of future plantation resources.

Growth models for Tasmanian *E. nitens* plantations are contained in the Farm Forestry Toolbox (available from Private Forests Tasmania); I used the Toolbox to project yields of various log classes from *E. nitens* plantations in Tasmania. Financial analyses considered only establishment and direct growing costs, and log prices on the stump—land, harvesting and transport costs were not included. Site index (SI) is defined as the mean dominant height (in metres) of the tallest 50 trees ha⁻¹ at age 15 y.

The log yields for a high quality site (SI = 28) are given in Figure 1. It can be seen that over a 30-y rotation there is little difference in the total yield of the plantation under an unthinned or single commercial thinning regime. However, the commercial thinning at age 9 y (removing nearly half the standing volume) combined with pruning the retained trees (CT09 to 250 stems ha⁻¹) gives a much

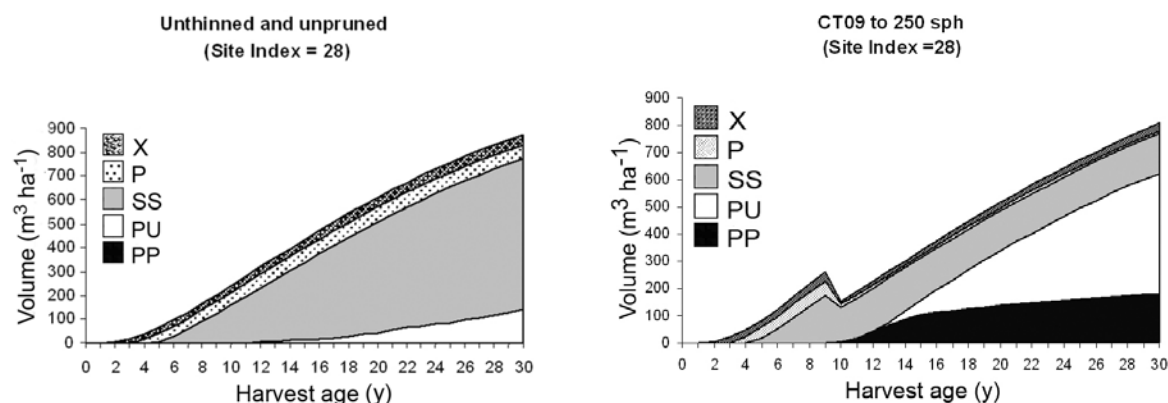


Figure 1. Estimated yield of logs from two regimes for *Eucalyptus nitens* plantations on a high-quality site (Site Index = 28) in Tasmania. CT09 = commercial thinning at age 9 y with pruning in three lifts to 6.4 m. The number of retained stems per hectare (sph) after thinning is 250 and the volume harvested at thinning is about 100 t ha⁻¹. Stands were planted with 1100 stems ha⁻¹. Log grades used in this case are X = waste, P = pulp (small-end diameter, SED = 10 cm), SS = small sawlog (SED = 15 and LED = 32 cm), PU = peeler unpruned (SED = 30 cm), PP = peeler pruned (SED = 30 cm).

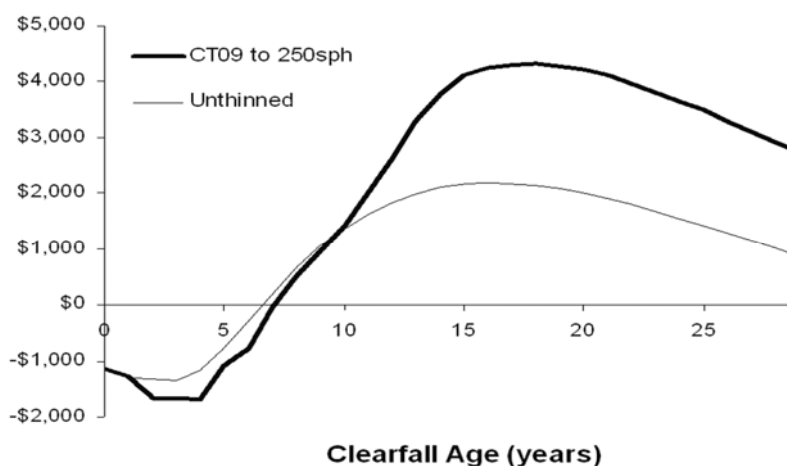


Figure 2. Estimated net present value (NPV) of two regimes for *Eucalyptus nitens* plantations on a high quality site (Site Index =28) in Tasmania. CT09 = commercial thinning at age 9 y with pruning in three lifts to 6.4 m. The number of retained stems per hectare (sph) after thinning is 250. Interest rate used in NPV calculation = 9%

higher yield of sawlogs and peelers. Small sawlogs may be utilised as pulp logs, depending on price and availability of processing facilities.

Financial analysis of the two regimes using estimated net present value (NPV) as the indicator of optimum financial return shows that better returns can be achieved from the pruned and thinned regime than from an unthinned, unpruned regime (Fig. 2). The modelled returns are subject to the prices obtained for various log grades, so real returns will depend on the absolute and relative values of each log grade. This example is illustrative only.

In both cases the maximum NPV is achieved at a harvest age 15–20 y for this site. Figure 1 shows that the yield of pruned logs (PP) increases little beyond this time and that the subsequent increase in volume is mostly in unpruned logs (PU). Returns from the unthinned regime would be substantially reduced if there were no market for small sawlogs, as these logs would then be placed in the pulpwood market.

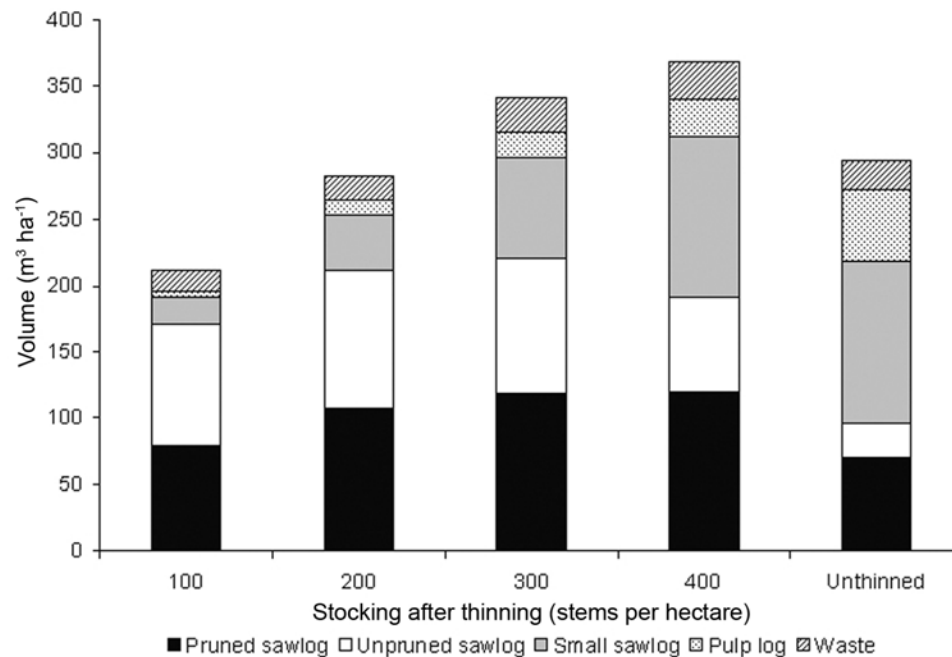


Figure 3. Log yields at age 20 y from a *Eucalyptus nitens* plantation (SI = 23) with non-commercial thinning at age 6 y and pruned to 6.4 m. In the unthinned stand, 350 stems ha⁻¹ were pruned. For explanation of hatching, see Figure 1.

Studies on the effects of differences in residual stocking following thinning (Medhurst et al. 2001) show the greatest response is that from dominant and co-dominant trees, with a final density range of 200–300 trees ha⁻¹ recommended. The data presented in Figure 3 for the Gould’s Country trial in north-eastern Tasmania, reported in Medhurst et al. (2001), show there is little difference in yield of pruned sawlogs between residual stockings of 200 and 400 stems ha⁻¹. At higher residual stocking the SED of logs is also reduced, bringing limitations on cutting patterns and recovery at sawmills and veneer mills. Another consideration, which these data do not illustrate, is that at low residual stockings with early waste thinning there is a tendency for very large branches to form immediately above the pruned zone. These large branches are difficult to remove with modern mechanical log processors if they are still green, and if dead they may be a source of decay into the clear-wood zone.

The decision for a forest grower is usually to balance financial return from the regime adopted with the ability to produce sufficient quantity of a resource with certain characteristics that suit a particular market. Larger industrial or government-owned growers often adopt regimes that produce raw material suitable for existing or proposed processing industries. In these cases the financial gain is made in value-adding during processing of the timber, not necessarily in the sale of produce from the forest.

Nutrition

An understanding of the fundamentals of nutrient uptake and allocation during various stages of the growth cycle of a forest is important to achieving optimal management and efficient use of resources— both those already available (e.g. soil and biomass-stored nutrients, water) and those that might be added (e.g. fertiliser, weed control).

The rate of nutrient uptake is not constant with stand age (Grove et al. 1996; Gonçalves et al. 1997; Gonçalves and Barros 1999). Miller (1984) described three general nutritional stages in the life of a plantation as:

- Stage 1—the years prior to canopy closure when tree growth is very dependent on current uptake of soil nutrients; responses to applied fertiliser are common

- Stage 2—canopy closure, when there is a reduction in the rate of accumulation of nutrients associated with attaining maximum foliage biomass. At this stage nutrient cycling and capture of atmospheric inputs result in low demand for soil nutrient capital, and responses to applied fertiliser are unlikely unless the cycling of nutrient capital is disturbed through pruning and thinning.
- Stage 3—late-rotation nitrogen (N) deficiency resulting from its temporal removal from the cycle through immobilisation in humus. This tends to be associated with boreal forests.

Stage 1 occurs prior to canopy closure when nutrients are accumulated to reach a maximum just prior to canopy closure (Cromer et al. 1993a; Misra et al. 1998; Weston 2001; Beadle et al. 2007). The rate of nutrient absorption parallels the rate of biomass accumulation with age (Gonçalves et al. 1997). The availability of water is also critical to nutrient uptake at this stage (Cromer et al. 1993b; Grove *et al.* 1996; White et al. 1996; Gonçalves et al. 1997; Weston 2001).

During Stage 2 following canopy closure, the maximum rate of biomass production is achieved (Ryan et al. 1997) and the nutrient content of the living biomass fluctuates a little due to seasonal variation in climate (Gonçalves *et al.* 1997). Leaf loss due to defoliation by insects (Pinkard et al. 2006), diseases or water deficit, and replacement, also contribute to these fluctuations (Gonçalves et al. 1997). Significant changes in crown condition of individual trees through pruning or thinning will significantly alter nutrient demand (Medhurst and Beadle 2005) until a new equilibrium state is reached. Such activities could therefore be seen as returning the plantation to Stage 1. The development of a plantation is closely linked to the growth and size of its tree crowns, which can be described via the leaf area index (LAI) (Beadle 1997). The LAI for eucalypts varies between two and nine (Beadle 1997). When the canopy is closed and leaf area stabilises, nutrient accumulation becomes relatively greater in the stem, and the litter biomass accumulated above ground steadily increases to a level determined by site and stand factors (Gonçalves et al. 1997).

During Stage 1, crown symptoms are good indicators of nutrient deficiencies (Dell et al. 2001; Adams et al. 2007). Foliar nutrient analysis has also been used at this time to diagnose problems, especially for trace elements (Dell and Malajczuk 1994; Dell and Xu 1995; Dell et al. 2001, 2003). Foliar analysis has had limited success in predicting requirement for N and phosphorus (P) fertiliser in plantations beyond about 2 y of age (Dell et al. 2001; Medhurst and Beadle 2005).

Ideally nutrient supply should be matched to nutritional demand for the expected growth rate (Gonçalves et al. 1997). Important factors determining demand are the pattern of stand growth and the changes in rate of growth through the different stages (Weston et al. 1991; Gonçalves et al. 1997; Weston 2001; Adams et al. 2007).

The potential contribution of nutrient additions to increased productivity must be balanced with the cost. In general, thinning responses appear to increase on high-quality sites. Where water availability is not limiting but nutrient availability is low, responses to applied fertiliser such as N and P at the time of thinning may be expected to achieve increased production in retained stems. Where water availability is the limiting factor, responses to fertiliser additions are likely to be limited and careful consideration should be given to such operations.

Further observations

Breeding objectives have been developed for pulp yield but are yet to be determined for solid wood or engineered wood products. Traits to be measured and their relationship with performance of processed products needs to be considered in the development of these breeding objectives. The consequences of pursuing an inappropriate breeding objective can diminish the economic value and marketability of plantation-grown timber.

Issues of wood quality in fast-grown plantation timber are of major concern to solid-wood and veneer processing industries in Australia (Nolan et al. 2005). These processors have developed sawing and drying systems to cope with large and relatively slow-grown eucalypt logs from native forests. The wood quality of plantation-grown eucalypts is not well understood, and new processing systems will be needed to handle this new resource. There is no 'one size fits all' approach, as silviculture requirements and product suitability will vary within and between species and will be influenced by site, disease and climate.

Products from eucalypt plantations will compete with existing products derived from softwood plantations and may partially replace some products from native forests. Plantation hardwood products will need to demonstrate advantages in utility or appearance compared with softwood products to differentiate them in the market place. FEA has already shown that utilisation of small-diameter logs from unpruned *E. nitens* stands is commercially viable and acceptable in the market, as exemplified by the success of EcoAsh. The prospect for utilisation of clear wood for high-quality solid timber and veneer applications is positive—technical difficulties with processing and drying appear to be the major impediments, especially for solid wood. The prospect for reconstituted wood products such as veneer-based products is positive.

The message is that while the early results from processing the ‘southern’ plantation species such as *E. globulus* and *E. nitens* are encouraging, there is still a lot we need to learn. Included in this is the effect of silviculture on wood quality (tension wood, density and other traits), eccentric stem shape, windthrow and post-harvesting issues of end-splitting. Also we need to learn how harvesting and transport practices can influence processing recovery (e.g. rough handling of logs can introduce internal splits; drying in the bush or on the truck can lead to splitting during transit to the mill). There is still more to learn about the subtropical species, which are *E. grandis*, *E. dunnii*, *E. cloeziana*, *E. pilularis*, *Corymbia* species and hybrids. These species are in much earlier stages of silvicultural research than the ‘southern’ ones, and they are the subject of a new research program (2.5 Silviculture of subtropical eucalypt species) in the CRC Forestry.

References

- Abbott, I. (1993) Insect pest problems of eucalypt plantations in Australia. 6. Western Australia. *Australian Forestry* **56**, 381–384.
- Adams, P.R., Osborn, T. and Volker, P.W. (2007) EucFERT—a fertiliser decision tool for plantation eucalypts in Tasmania. In: *Growing Forest Values*. Proceedings of the 2007 Institute of Foresters of Australia and New Zealand Institute of Forestry Conference, Coffs Harbour, NSW, pp. 17–26.
- Alcorn, P.J., Pyttel, P., Bauhaus, J., Smith, R.G.B., Thomas, D., James, R. and Nicotra, A. (2007) Effects of initial planting density on branch development in 4-year-old plantation grown *Eucalyptus pilularis* and *Eucalyptus cloeziana* trees. *Forest Ecology and Management* **252**, 41–51.
- Baker, T.G. and Volker, P.W. (2007) Silviculture of eucalypt plantations in southern Australia for high-value solid wood products. *Ciencia e Investigacion Forestal* **13**, 43–57.
- Barry, K.M., Pearce, R.B. and Mohammed, C.M. (2000) Properties of reaction zones associated with decay from pruning wounds in plantation-grown *Eucalyptus nitens*. *Forest Pathology* **30**, 233–245.
- Barry, K.M., Pearce, R.B., Evans, S.D., Hall, L.D. and Mohammed, C.M. (2001) Initial defence responses in sapwood of *Eucalyptus nitens* (Maiden) following wounding and fungal inoculation. *Physiological and Molecular Plant Pathology* **58**, 63–72.
- Barry, K.M., Hall, M.F. and Mohammed, C.L. (2002) An understanding of tree defence helps to reduce stem decay in hardwood plantations. In: Barry, K. (ed.) *Heartrots in Plantation Hardwoods in Indonesia and Australia*. ACIAR Technical Reports Series TR51, pp. 8–13.
- Barry, K.M., Hall, M.F. and Mohammed, C.L. (2005) The effect of time and site on incidence and spread of pruning-related decay in plantation-grown *Eucalyptus nitens*. *Canadian Journal of Forest Research* **35**, 495–502.
- Bashford, R. (1993) Insect pest problems of eucalypt plantations in Australia. 4. Tasmania. *Australian Forestry* **56**, 375–377.
- Beadle, C.L. (1997) Dynamics of leaf and canopy development. In: Nambiar, E.K.S. and Brown, A.G. (eds) *Management of Soil, Nutrients and Water in Tropical Plantation Forests*. Monograph 43, Australian Centre for International Agricultural Research, Canberra, pp. 169–212.
- Beadle, C.L., Forrester, D.I., Wood, M.J., Valencia, J.C. and Medhurst, J.L. (2007) *Effects of Silviculture and the Environment on the Variables that Determine Outcomes from Eucalypt Plantations Managed for Solid-Wood Products*. Cooperative Research Centre for Forestry Technical Report 173, 116 pp.
- Cromer, R.N., Cameron, D.M., Rance, S.J., Ryan, P.A. and Brown, M. (1993a) Response to nutrients in *Eucalyptus grandis*. 1. Biomass accumulation. *Forest Ecology and Management* **62**, 211–230.

- Cromer, R.N., Cameron, D.M., Rance, S.J., Ryan, P.A. and Brown, M. (1993b) Response to nutrients in *Eucalyptus grandis*. 2. Nitrogen accumulation. *Forest Ecology and Management* **62**, 231–243.
- Deflorio, G., Barry, K.M., Johnson, C. and Mohammed, C.L. (2007) The influence of wound location on decay extent in plantation-grown *Eucalyptus globulus* and *Eucalyptus nitens*. *Forest Ecology and Management* **242**, 353–362.
- Dell, B. and Malajczuk, N. (1994) Boron deficiency in eucalypt plantations in China. *Canadian Journal of Forest Research* **24**, 2409–2416.
- Dell, B. and Xu, D.P. (1995) Diagnosis of zinc deficiency in seedlings of a tropical eucalypt (*Eucalyptus urophylla* S.T.Blake). *Plant and Soil* **176**, 329–332.
- Dell, B., Malajczuk, N., Xu, D. and Grove, T.S. (2001) *Nutrient Disorders in Plantation Eucalypts*. Monograph 74, Australian Centre for International Agricultural Research, Canberra.
- Dell, B., Da Ping, X., Rogers, C. and Long Bin, H. (2003) Micronutrient disorders in eucalypt plantations: causes, symptoms, identification, impact and management. In: Wei, R.P. and Xu, D.P. (eds) *Eucalyptus Plantations: Research, Management and Development*. Proceedings of the International Symposium, Guangzhou, China, 1–6 September 2002, pp. 241–251.
- Dickinson, G.R., Wallace, H.M., Kelly, N.I. and Lee, D.J. (2007) Inter-specific *Corymbia* hybrid research; providing new opportunities for plantation expansion in northern Australia. In: *Growing Forest Values*. Proceedings of the 2007 Institute of Foresters of Australia and New Zealand Institute of Forestry Conference, Coffs Harbour, NSW, pp. 142–150.
- Gadgil, P.D., Wardlaw, T.J., Ferreira, F.A., Sharma, J.K., Dick, M.A., Wingfield, M.J. and Crous, P.W. (2000) Management of disease in eucalypt plantations. In: Keane, P.J., Kile, G.A., Podger, F.D. and Brown, B.N. (eds) *Diseases and Pathogens of Eucalypts*. CSIRO Publishing, Melbourne, pp. 519–529.
- Gerrand, A.M., Neilsen, W.A. and Medhurst, J.L. (1997) Thinning and pruning eucalypt plantations for sawlog production in Tasmania. *Tasforests* **9**, 15–34.
- Gonçalves, J.L. and Barros, N.F. (1999) Improvement of site productivity for short-rotation plantations in Brazil. *Bosque* **20**, 89–106.
- Gonçalves, J.L.M., Barros, N.F., Nambiar, E.K.S. and Novais, R.F. (1997) Soil and stand management for short-rotation plantations. In: Nambiar, E.K.S. and Brown, A.G. (eds) *Management of Soil, Nutrients and Water in Tropical Plantation Forests*. Monograph 43, Australian Centre for International Agricultural Research, Canberra, pp. 378–417.
- Grove, T.S., Thomson, B.D. and Malajczuk, N. (1996) Nutritional physiology of eucalypts: uptake, distribution and utilization. In: Attiwill, P.M. and Adams, M.A. (eds) *Nutrition of Eucalypts*. CSIRO Publishing, Melbourne, pp. 77–108.
- Malan, F.S. (2003) The wood quality of the South African timber resource for high-value solid wood products and its role in sustainable forestry. *South African Forestry Journal* **198**, 53–62.
- Maree, B. and Malan, F. (2000) Growing for solid wood products: a South African experience and perspective. In: *The Future of Eucalypts for Wood Production*. Proceedings of IUFRO Conference 19–24 March 2000, Launceston, Tasmania. [Conference Secretariat, Conference Design, Hobart, Tas.], pp. 374–383.
- Medhurst, J.L. and Beadle, C.L. (2005) Photosynthetic capacity and foliar nitrogen distribution in *Eucalyptus nitens* is altered by high-intensity thinning. *Tree Physiology* **25**, 981–991.
- Medhurst, J.L., Beadle, C.L. and Neilsen, W.A. (2001) Early-age and later-age thinning affects growth, dominance, and intraspecific competition in *Eucalyptus nitens* plantations. *Canadian Journal of Forest Research* **31**, 187–197.
- Miller, H.G. (1984) Dynamics of nutrient cycling in plantation ecosystems. In: Bowen, G.D. and Nambiar, E.K.S. (eds) *Nutrition of Plantation Forests*. Academic Press, London, pp. 53–78.
- Misra, R.K., Turnbull, C.R.A., Cromer, R.N., Gibbons, A.K. and LaSala, A.V. (1998) Below- and above-ground growth of *Eucalyptus nitens* in a young plantation I. Biomass. *Forest Ecology and Management* **106**, 283–293.
- Montagu, K.D., Kearney, D.E. and Smith, R.G.B. (2003) The biology and silviculture of pruning planted eucalypts for clear wood production: a review. *Forest Ecology and Management* **179**, 1–13.

- Neilsen, W.A. and Gerrand, A.M. (1999) Growth and branching habit of *Eucalyptus nitens* at different spacing and the effect on final crop selection. *Forest Ecology and Management* **123**, 217–229.
- Neumann, F.G. (1993) Insect pest problems of eucalypt plantations in Australia. 3. Victoria. *Australian Forestry* **56**, 370–374.
- Nolan, G., Greaves, B., Washusen, R., Parsons, M. and Jennings, S. (2005) *Eucalypt Plantations for Solid Wood Products: A Review*. Project No. PN04.3002. Forest and Wood Products Research and Development Corporation, Melbourne.
- Nutto, L. and Touza-Vázquez, M.C. (2004a) High quality *Eucalyptus* sawlog production. In: Borralho, N.M.G., Pereira, J.S., Marques, C., Coutinho, J., Madeira, M. and Tomé, M. (eds) *Eucalyptus in a Changing World*. Proceedings of IUFRO Conference, Aveiro, 11–15 October. RAIZ, Instituto, Investigacao da Floresta e Papel, Portugal, pp. 658–666.
- Nutto, L. and Touza-Vázquez, M.C. (2004b) Produccion de madera de sierra de alta calidad con *Eucalyptus globulus*. *Revista CIS-Madera* **12**, 6–18.
- Phillips, C.L. (1993) Insect pest problems of eucalypt plantations in Australia. 5. South Australia. *Australian Forestry* **56**, 378–380.
- Pinkard, E.A. (2002) Effects of pattern and severity of pruning on growth and branch development of pre-canopy closure *Eucalyptus nitens*. *Forest Ecology and Management* **157**, 217–230.
- Pinkard, E.A. (2003) Physiological and growth responses related to pattern and severity of green pruning in young *Eucalyptus globulus*. *Forest Ecology and Management* **182**, 231–245.
- Pinkard, E.A. and Beadle, C.L. (1998) Effects of green pruning on growth and stem shape of *Eucalyptus nitens* (Deane and Maiden) Maiden. *New Forests* **15**, 107–126.
- Pinkard, E.A. and Beadle, C.L. (1999) Above-ground biomass partitioning and crown architecture of *Eucalyptus nitens* (Deane and Maiden) Maiden following green pruning. *Canadian Journal of Forest Research* **28**, 1419–1428.
- Pinkard, E.A. and Beadle, C.L. (2000) A physiological approach to pruning. *International Forestry Review* **2**, 295–305.
- Pinkard, E.A., Beadle, C.L. and Davidson, N.J. (1995) Changes in crown productivity and stem growth of *Eucalyptus nitens* in response to green pruning. In: Potts, B.M., Borralho, N.M.G., Reid, J.B., Cromer, R.N., Tibbits, W.N. and Raymond, C.A. (eds) *Eucalypt Plantations: Improving Fibre Quality and Yield*. Proceedings of IUFRO Conference. Cooperative Research Centre for Temperate Hardwood Forestry, Hobart, pp. 377–378.
- Pinkard, E.A., Beadle, C.L., Davidson, N.J. and Battaglia, M. (1998) Photosynthetic responses of *Eucalyptus nitens* (Deane and Maiden) Maiden to green pruning. *Trees* **12**, 119–129.
- Pinkard, E.A., Battaglia, M., Beadle, C.L. and Sands, P.J. (1999) Modelling the effect of physiological responses to green pruning on net biomass production of *Eucalyptus nitens*. *Tree Physiology* **19**, 1–12.
- Pinkard, E.A., Mohammed, C., Beadle, C.L., Hall, M.F., Worledge, D. and Mollon, A. (2004) Growth responses, physiology and decay associated with pruning plantation-grown *Eucalyptus globulus* Labill. and *E. nitens* (Deane and Maiden) Maiden. *Forest Ecology and Management* **200**, 263–277.
- Pinkard, E.A., Baillie, C.C., Patel, V., Paterson, S., Battaglia, M., Smethurst, P.J., Mohammed, C.L., Wardlaw, T. and Stone, C. (2006) Growth responses of *Eucalyptus globulus* Labill. to nitrogen application and severity, pattern and frequency of artificial defoliation. *Forest Ecology and Management* **229**, 378–387.
- Ryan, M.G., Binkley, D. and Fownes, J.H. (1997) Age-related decline in forest productivity: pattern and process. *Advances in Ecological Research* **27**, 213–262.
- Seling, I., Spathelf, P. and Nutto, L. (2001) The Aussies in Brazil. *ITTO Tropical Forest Update* **11/3**, 14–15.
- Smith, R.G.B. and Brennan, P. (2006) First thinning in sub-tropical eucalypt plantations grown for high-value solid-wood products: a review. *Australian Forestry* **69**, 305–312.
- Smith, H.J. and Henson, M. (2007) Achievements in forest tree genetic improvement in Australia and New Zealand. 3: Tree improvement of *Eucalyptus dunnii* Maiden. *Australian Forestry* **70**, 17–22.
- Smith, R.G.B., Dingle, J., Kearney, D.E. and Montagu, K.D. (2006) Branch occlusion after pruning in four contrasting sub-tropical eucalypt species. *Journal of Tropical Forest Science* **18**, 117–123.

- Stone, C. (1993) Insect pest problems of eucalypt plantations in Australia. 2. New South Wales. *Australian Forestry* **56**, 363–369.
- Wardlaw, T.J. and Neilsen, W.A. (1999) Decay and other defects associated with pruned branches of *Eucalyptus nitens*. *Tasforests* **11**, 49–57.
- Wardlaw, T., Mohammed, C., Barry, K., Eyles, A., Wiseman, D., Beadle, C., Battaglia, M., Pinkard, E. and Kube, P. (2003) Interdisciplinary approach to the study and management of stem defect in eucalypts. *New Zealand Journal of Forestry Science* **33**, 385–398.
- Washusen, R. (2004) Wood quality and sawn product value using conventional processing strategies in plantation grown *Eucalyptus globulus* managed for sawlog production. In: *Integrating Forestry into Farms Communities and Catchments*. Proceedings of Australian Forest Growers Biennial Conference, Ballarat, 3–5 May, pp. 96–101.
- Weston, C.J. (2001) An overview of recent nutrition research for the rapidly expanding *Eucalyptus* plantation industry in Australia. J.W. Gottstein Memorial Trust Fund, Clayton, Australia.
- Weston, C.J., Attiwill, P.M. and Cameron, J.N. (1991) Growth and nutrition of eucalypt plantations in relation to soil type and former land use in Gippsland, Victoria. In: Schönau, A.P.G (ed.) *Intensive Forestry: The Role of Eucalypts*. Proceedings of the IUFRO Symposium, Durban. Southern African Institute of Forestry, pp. 480–491.
- White, D.A., Beadle, C.L. and Worledge, D. (1996) Leaf water relations of *Eucalyptus globulus* ssp. *globulus* and *E. nitens*: seasonal, drought and species effects. *Tree Physiology* **16**, 469–476.
- Wiseman, D., Smethurst, P., Pinkard, L., Wardlaw, T., Beadle, C., Hall, M., Baillie, C. and Mohammed, C. (2006) Pruning and fertiliser effects on branch size and decay in two *Eucalyptus nitens* plantations. *Forest Ecology and Management* **225**, 123–133.
- Wood, M.J., Scott, R., Volker, P.W. and Mannes, D.J. (2008) Windthrow in Tasmania, Australia: monitoring, prediction and management. *Forestry*. In press.
- Wylie, F.R. and Peters, B.C. (1993) Insect pest problems of eucalypt plantations in Australia 1. Queensland. *Australian Forestry* **56**, 358–362.



SESSION: GROWING, MANAGING AND HARVESTING
HARDWOOD SAWLOGS

Harvesting Plantation Hardwood Sawlogs

DAVID QUILL

Eumeralla Pty Ltd, PO Box 2726, Mount Gambier, SA 5290
Email: dtquill2@bigpond.com

Abstract

With eucalypt forests established over significant areas of arable land throughout the world, why is it that we have perceived issues with harvesting?

This paper deals with the key aspects of harvesting eucalypt plantations for high-value timber in an attempt to identify the areas that would potentially benefit from research and development.

The opportunity to generate value-added products from pulpwood plantations is considered along with harvesting of specialty timber stands, in an effort to standardise harvesting equipment.

The account covers all aspects of the quest for value adding, from potential sources, through machine design, management issues, and contract structure to potential end products ranging from sawn timber to biofuel.

Introduction

With such a vast resource of plantation eucalypts spread across most of the warmer arable areas of the globe, surely the issue of the value of the timber products from this remarkable genus has been addressed, and if so, some attention must have been paid to the harvesting options.

The attractive pulping qualities of eucalypts were discovered early last century, and soon the high fibre content that made the genus very desirable for the production of high-grade tissues as well as a wide range of fine paper products was appreciated.

The pulping qualities of eucalypts may well be the reason why attention worldwide has been diverted from other uses for the timbers. Eucalypt timbers were used for a wide range of applications in early Australian history and some excellent examples of furniture from that era survive to this day. Eucalypt timber from native forest areas has been used for 200 years for all sorts of high-value applications, yet we seem to ignore many of these applications if the timber comes from plantations. The age of the trees from native forests is the main factor contributing to this, but current research is creating or has the potential to create other sawn timber and high-value options in which tree age is less significant.

It is internationally recognised that eucalypts provide an excellent product for paper manufacture, but are we doing justice to the investors who have poured millions of dollars into the establishment of eucalypt plantations if we do not seek to add greater value to the yield from the plantations?

What is meant by higher value? Higher value for whom? —

- the grower?
- the investor?
- the harvesting contractor?
- the processor?
- the consuming public?

High value means not only high-value end-products, but also profitable utilisation of all products from the forest. We do not just sell rib-eye fillet from a bullock; we have all sorts of cuts from the cheap to the expensive. The truly (high-value) operations are those that can profitably use or find a market for everything, including the tail!

Thus a high-value eucalypt could offer:

- solid wood
- chips for reconstituted wood products as well as paper
- laminated veneer lumber (LVL)
- veneers
- fuel.

Eucalyptus globulus, for example, is used to make excellent solid-wood products in Spain and Portugal (as well as pulp), but the silviculture and management of the plantations results in rotations of up to 25 years, thus differing from most plantations in Australia.

A significant producer of high-value products from the genus *Eucalyptus* is Aracruz Produtos de Madeira, a company which is a wholly owned subsidiary of Weyerhaeuser. This company is one of the world's leading producers of bleached eucalyptus pulp. Their mainstay is plantation eucalypts which are managed for optimum growth and utilised with high levels of mechanisation. The 'Lyptus' solid wood product range was launched in 1999 and includes veneer and finger jointed and edge-glued panels.

Turning the focus from the rest of the world and looking at Australia, I have grouped the issues under the following headings:

- trees
- thinning
- team—the contractors and forest owner
- tractor—the machinery
- timing
- technological innovation
- timber—products
- tonnes—lots of them
- treasury
- thermodynamics—biofuel
- taxation.

Trees

Most attendees will be aware that 700 or so eucalypts, with some very minor exceptions, are indigenous to the southern hemisphere, but—due to a variety of factors operating since the European discovery of Australia—some now have a global distribution. Eucalypt forests are established in over 90 countries, ranging from South Africa, the Middle East, southern Europe and the former Soviet Union, southern and south-eastern Asia to North and South America.

It is difficult to quantify the total area of eucalypts planted throughout the world, but it may be as high as 17 M ha. The combined areas established in Brazil and South Africa exceeds 4.2 M ha, far more than the area of Australian eucalypt plantations (Figure 1). To put production from Australian eucalypt forests into perspective with other countries in the world, Donnelly et al. (2003) report that South America is responsible for 55% of the world's plantation-grown roundwood, followed by Asia (20%), Africa (10%) and Australia at 7%. From its limited natural distribution in Australia, New Guinea and portions of Indonesia and the Philippines, *Eucalyptus* is now more widely propagated than any other genus in the world.

In surveying global eucalypt plantations, the challenges in harvesting the products from these forests do not stand out as an issue. Current practice ranges from high levels of manual input in underdeveloped countries to high levels in mechanisation, particularly in Brazil and Uruguay.

Global Distribution of Eucalypts (ha)

Argentina	330 000
Spain	350 000
Vietnam	400 000
Chile	525 000
Uruguay	400 000
Thailand	500 000
Portugal	500 000
South Africa	538 000
Australia	740 000
PR China	1 900 000
Brazil	3 617 000
<u>India</u>	<u>4 800 000</u>
Total	14 600 000



A tribute to the international role of
CSIRO and the
Australian Tree Seed Centre



Australian National University
March 2007

Salwood Asia Pacific Pty Ltd
Services in Forestry

Figure 1. The global distribution of eucalypts in March 2007 (Stephen Midgley, pers. comm.)

Thinning

Pulpwood stands

The conventional approach is to thin forests from below to promote growth, or more specifically diameter, on the better stems by minimising competition, or in other words removing the smaller, poorly formed trees. This approach is dependent on the rotation length and places great emphasis on predicting the final product required. I propose that our researchers thoroughly investigate the potential to generate higher-value products by thinning from above.

The pursuit of this technique may well provide growers with an opportunity to diversify their product mix at an early age. Such thinning effectively mimics the single-tree selection from above—a practice that native forest managers have used for years—in removing desirable stems once they reach a target diameter. I use the word ‘thin’ with some qualification, in that my proposal is to conduct a two-stage clear-felling operation, the first stage of which is the removal of selected trees for potential high-value products.

As most of the *E. globulus* plantations in Australia are planted at a 4 m × 2 m spacing (the inter-row spacing is 4 m), it is possible, with appropriate equipment, to thin without removing an outrow. Utilisation of high-value material from the thinned trees down to 150 mm sedub could, for example, result in >60% of the merchantable length of these trees being harvested. If the numbers quoted in the section entitled ‘Tonnes’ below are taken as an example of such an operation, the by-product non-sawlog material resulting from thinning from above may be in the order of 3 m³ ha⁻¹. This wood could be extracted in the subsequent clear-felling for pulpwood. An appropriate harvesting system is available if contract rates can be negotiated to suit all parties.

Specialty timber stands

Not all hardwood forests have been established with the sole objective of growing pulpwood. Some private companies—including managed investment service (MIS) companies, individual landholders and public utilities throughout Australia—are now pursuing specialty timbers grown over longer rotations with appropriate silvicultural treatment to produce sawlog.

Conventional thinning of these stands is a vital component of silviculture and is really dependent only on securing a market for all products, or on providing a marketing or financial allowance for the project to bear the cost of a non-commercial thinning. Research should be directed to finding markets for small-diameter product to eliminate the need for non-commercial thinning.

In my view, there is no constraint imposed on thinning by a lack of harvesting options. The critical issue with specialty timber stands is identifying the products, and my general conclusion is that appropriate technology is available to undertake both thinning and final felling tasks with minimal modification of existing equipment.

Team

An important feature about this word is that there is no 'I' in it. To successfully manage the harvesting of plantation hardwood sawlogs, the forest owner or manager and the contractor must function as a team. For this to occur, it is vital that each recognises the others' skills.

If the forest owner has a responsibility to ensure that the maximum amount of product is recovered at the best possible return, a specification for the contractor to harvest it must be written. The manager must also ensure that there is continuity of work as well as sufficient volume of product to engage the contractor over a term that provides a realistic opportunity for economic survival. In my view, one of the greatest mistakes made by forest managers is to stipulate the methods and machinery that the contractor must use. A far more realistic approach is to develop a contract that addresses the issues outlined above, incorporates relevant statutory issues and clearly defines the product specifications in a holistic sense.

The contractor (as depicted in Figure 2) faces a plethora of issues: rate negotiations, industrial relations, occupational health and safety, chain of responsibility, road traffic laws, environmental codes, quality assurance and product specifications. In addition, the contractor has to be a structural engineer, hydraulic specialist, boiler maker, electrician, computer operator, marriage guidance counsellor and training manager. In spite of the enormous pressures that the contractors are exposed to, I firmly believe that they are the most qualified to find the best option to perform the task. They must be effectively permitted to be the service provider, and to run their business within the bounds of the contracts to produce the required outcomes.

In most harvesting situations that I have experienced in Australia, the contractor is regarded as a servant of the company rather than a service provider. In many cases, the company representatives have the one-sided view that the contractor needs to understand all the problems that the company has in both the short and the long term. In order for the team to function, its members must understand the issues relevant for both parties. It is vital that the contracting company have a full understanding of the issues that face the contractor in achieving his production and quality targets.

Close and continual co-operation between the contractor and the forest manager is vital to the development and implementation of harvesting options.

Tractor

The tractor is the base unit, a foundation stone of any harvesting system. It will be steel-tracked or rubber-tyred, purpose-built for the task by a manufacturer or modified from a construction or earthmoving machine. The choice of the base unit for the harvesting of plantation eucalypts for potential high-value products must be influenced by factors that include price, flexibility, versatility,

product support and operator comfort. The choice must also take fire safety, environmental compatibility, terrain capability and suitability with respect to plantation design into consideration.

Eumeralla Pty Ltd was involved in a trial carried out by Woollybutt Pty Ltd in March this year that compared a rubber-tyred purpose-built harvester and a modified excavator-based harvester. The most significant observation was that the rubber-tyred machine, in the best-case situation, had effectively double the productivity of the excavator



Figure 2. Harvesting contractors face many challenges

with little or no residual stand damage. It demonstrated a capacity to harvest stems the volume of which ranged from as low as 0.1 to 0.87 m³. This trial was carried out in a 13½-year-old stand of *E. globulus* with a stocking of 1000 stems ha⁻¹ on flat terrain with sandy soils in the Glenelg Shire of south-western Victoria. A number of different thinning operations were trialled, varying from a residual stocking of 600 stems ha⁻¹ down to 200 stems ha⁻¹, prior to clearfelling.

The advantages of the rubber-tyred tractor purpose-built harvester over the excavator-based unit are best summarised as follows:

- zero tail swing that allows the operator to concentrate attention on the ‘target’ tree without needing to be concerned about damaging standing trees out of his line of sight
- higher ground speed and acceleration, ensuring minimal travel time, not only between trees, but within the coupe. Most tracked forestry machines are limited to a maximum travel speed of 8 km h⁻¹, compared with up to 30 km h⁻¹ with rubber-tyred equipment
- electric servo controls that provide a combination of a minimum amplitude of hand movement and physical effort, and a recognised reduction in the potential for repetitive strain injuries. Although purpose-built track machines feature this same control function in many cases, all excavator-based tractors rely on hydraulic servo controls which do not have these features
- better all-round vision and comfort for the operator.

This trial was conducted on flat country. An advantage of tracked machines is their ability to operate in steep terrain and, with low ground pressure, they can perform in soils that during winter, would not permit the use of rubber-tyred machines.

There is an additional opportunity to vary the rubber-tyred harvesting concept to combine extraction with harvesting. This practice has been successfully adopted in some northern European countries. It is particularly successful in situations of low yield where the capital cost of utilising both a harvester and forwarder may be prohibitive. Essentially the concept involves the harvester having the capacity to carry logs, once harvested, in a set of bunks, and the grapple of the single-grip head having the ability to load and unload as well as to perform the harvesting function.

Without citing specific brands of machine, the range of forest machinery now available provides the opportunity to choose a forest tractor that has eight-wheel drive, zero tail swing and a 360° continuously rotating cabin and crane, that would meet the same operational requirements as the combi-machines described in the paragraph above. The relatively simple modification of fitting a harvesting head in lieu of the grapple (Figure 3) can provide the function of harvesting as well as extracting. This concept has been developed by a contractor in Queensland to meet a specific requirement in harvesting plantation softwood. Such a machine, with available power of up to 190 kW operated by sophisticated electronically-controlled hydraulics, has the capacity to drive any single-grip harvesting head applicable to stem volumes of up to 1.5 m³. A machine of this type would be equally capable of harvesting both specialty timber stands and short-rotation pulpwood plantations.

The suite of harvesting equipment available in Australia today provides the Team, as outlined above,



with the appropriate options to assemble a harvesting system capable of extracting high-value timbers from virtually any plantation regime.

Figure 3. Versatile machinery such as this can form the basis for a productive harvesting operation

Timing

The time that elapses between harvesting and processing may well be the key to generating high-value products from forest stands originally established for pulp production. The challenge is to undertake appropriate research to determine if the deterioration of logs through splitting and shakes following felling can be reduced or eliminated by minimising this time.

South African experience (Michal Brink, pers. com.) reveals that delivery of logs to the point of processing within two days almost eliminates internal checking in logs from young plantations—up to 15 years of age. In his view, in plantation species with a reduced tendency to split, this interval can be extended to two weeks, or further if the product is stored on a wet deck prior to sawing.

Shield (1995) refers to a wide range of potential issues in plantation eucalypts—growth stress, radial shakes, spring, binding, knots—and treatments to minimise problems, including defoliation with herbicide prior to felling, water and steam treatment, end-sealing with wax, bending and nail plating, leading up to suggested policies for successful conversion. These include:

1. double or multiple sawing lines
2. back-sawing techniques
3. production of small sections
4. immediate racking of products
5. minimising delay between felling and conversion
6. selection of large-diameter material, avoiding apparent defects
7. keeping the lengths short (<3 m).

The first four of these are a challenge for the conversion industry, and already subjects of research and development in Australia. The last three points are issues addressed in this paper as measures that can be incorporated in a harvesting system. The production of high-value products from dedicated ‘specialty timber stands’ is not seen as an issue from a harvesting perspective. The key to high volumes of sawlogs lies in procuring them from pulpwood stands, and these three issues must be addressed if high-value products are to be derived from these plantations. I do not believe that they are difficult issues to address.

In the quest to examine the challenges of harvesting eucalypts for high-value timbers, the issue of timing is paramount. There is no doubt that there is a substantial difference between the growth stresses found in older, silviculturally managed (thinned) stands compared with plantations grown for maximum fibre yield as is the case with pulpwood stands. The development of radial shakes after felling varies between species, growth rates and management, but the question that we need to address is ‘how can it be managed?’ Alternatively, is it a function of age or diameter?

Assuming that sawing and drying technologies can be developed to minimise downgrade, as Forest Enterprises Australia have done with their ‘HewSaw’ technology, the task facing the Team—consisting of the contractor and forest manager—is to determine the optimum practical time between harvesting and milling to eliminate this downgrade.

The ‘just in time’ approach that has been the key to success in many areas of the industrial world can be applied to logging, provided that incentives exist for all parties. An example of what can be achieved occurs in the Green Triangle Region, where pine pulpwood to Kimberly Clark is delivered within three days of harvest. Identifying the timing and quantifying the incentives are the issues that need to be researched; I have no doubt that with modern harvesting technology and the size of the resource available the opportunities are there.

Technological innovation

One of the challenges put to me in writing this paper was to identify the gaps in knowledge of equipment available for harvesting eucalypts for high-value timber in Australia. Is there an opportunity for research in this area, and what is the nature of such research? In the early history of mechanisation of harvesting in Australia, the Forest Research Institute played a central role. The Harvesting Research Group introduced a wide range of new machines and concepts to Australia,

perhaps culminating in the design of the Windsor Tree Harvester, subsequently produced by Timberjack in Canada in the late 1960s.

The successful adaptation of North American and Scandinavian machines for the Australian plantation forest industry in the late 1970s and early 1980s paved the way for the high level of mechanisation that exists today. In issue No. 72 of *OnWood*, Ensis harvesting engineer Hamish Marshall was quoted as saying ‘Essentially in Australia and New Zealand, we have to work with what we are given. That means adapting machinery, other hardware and operating systems to our conditions and needs’. Perhaps the best example of this is the Waratah success story. In the early 1980s the first single-grip harvester, the SP21, was designed in Sweden. Among the first models that came to Australia was the Kockums GSA62. My experience in managing operations that used these machines was the expectation of 60 stems harvested per hour and 60% availability in average stem volumes of 0.3 m³. The concept was ‘borrowed’ by a New Zealand engineer, David Cochrane, who designed and manufactured the first ‘Waratah 20’ harvesting head in the mid-1980s. This machine was substantially heavier and more robust than its Scandinavian forebears, and paved the way for the design and manufacture of a range of products capable of harvesting the whole rotation of *Pinus radiata* forests in Australia. Waratah is now regarded as the benchmark machine for durability and reliability throughout the logging world.

It is not unreasonable in 2007 to expect a single-grip harvester, in the hands of an experienced operator, to have an output of 100 stems per hour with an average volume of 0.3 m³ per stem and an availability of 85%. In many ways, a single-grip harvester can be compared to a motor car. Generally a car has an engine, gearbox, differential, fuel tank, steering wheel, four wheels and four seats—features shared by a 1908 Model T Ford and a 2007 Maserati Quattroporte. The difference between the two, apart from the obvious, is the level of refinement, reliability and additional features. Modern single-grip harvesters feature a suite of components far superior to those of early models, with additional features such as optimisation and paint marking, and they are certainly a lot faster. I use this as an example of technological improvement of a basic concept over time, rather than changing the concept.

One area of technical vulnerability in the modern single-grip harvesters is the length measuring system. In most machines throughout the world, length measuring relies on a wheel passing along the stem and generating a pulse or code with each revolution or part thereof, that is interpreted by the computer as length. Anything that prevents the wheel from turning, or interferes with the assumption that the outside surface of the tree is a straight line, as the tree passes through the harvester, will potentially affect the accuracy of length measurement. For true optimisation, the entire merchantable stem must first be measured, requiring the whole stem to be passed through the harvester prior to any cuts being made. The technological challenge is to overcome the deficiencies of a mechanically driven system, which may mean measuring the merchantable stem length without first passing the stem through the harvester. The single-grip harvesting head represents the best example of ‘what we are given’ to work with.

In the development of the Timbercorp harvesting system in 1999–2000, on the recommendation of the Australian agents I travelled through the United States and Europe to select machinery. Mechanised harvesting of eucalypts for pulp as well as high-value products had been practised for a number of years, and we were able to view machines with over 10 000 hours total working time, rather than ‘showroom’ unproven machines. Arctic Forest Machinery (AFM) from Finland had developed harvesting heads fitted with three spiral rollers, applying the pressure necessary to fracture the bark over a larger proportion of the circumference of the stem. The particular machines also had the ability to automatically ‘merchandise’ the stem to 50 mm sedub as well as to overcome the problem of debarking the base of the stem down to the cut-off point, using a unique ‘butt shuffle’ program. This program had the feature of going into a slow mode after releasing the bark following the initial forward feed, and reversing down the stem to before the cut-off point prior to accelerating the forward feed for the balance of the stem at speeds of 0–8 m s⁻¹. This process achieved excellent debarking, in most cases with a single pass. The same company, along with other European manufacturers, has developed coppice-management techniques using chemical application through the chainsaw at the time of felling.

The marriage of European technology with Australasian refinement is a proven partnership that has met the demands of timber harvesting in the past, and will continue to meet these demands in the future.

Timber

Other speakers at this conference will be highlighting the wide range of high-value products that can be developed from eucalypt plantations. High-value products are being manufactured in many of parts of the world using eucalypt timber, while Australia seems to be lagging.

Russ Taylor (2002), in addressing the NAFI conference, indicated that Australia had the highest sawmilling costs in the world after New Zealand, with lower stumpage than New Zealand, Sweden, Chile or the United States. Our delivered log costs were amongst the lowest in the survey, with Brazil and South Africa the only countries with lower cost for deliveries to appearance-grade mills.

An enormous opportunity exists, in my view, for the harvesting and utilisation of peeler logs. The production of veneer, for example from heat-conditioned billets, has the capacity to overcome many of the stress-related problems of timber sawn from young eucalypts. The use of the veneer in engineered wood products also presents an option to increase final product strength. This has already been realised by Forestry Tasmania, with the Huon and Smithton Wood Centres, and by Ta Ann Tasmania Pty Ltd, with the construction of the Huon Veneer Mill. Production of veneer relies on supply of only relatively short logs; further research into the suitability of the full range of plantation-grown eucalypts for veneer production should be pursued.

Shield (2003) examined the diverse range of products that can be manufactured from eucalypts, including OSB (oriented strand board), LSL (laminated strand lumber), or in the case of Lignor in Western Australia, ESL (eucalyptus strand lumber), and even Scrimber. All are products that can be potentially derived from eucalypts to create higher value.

Harvesting operations should not be seen as an impediment to the potential for the production of high-value timber products.

Tonnes

According to BRS (2006), at the end of 2005, Australia had 740 000 ha of plantation hardwood, and about 61% of this, or 451 000 ha, is *E. globulus*.

Let us assume plantations have an average standing volume of $180 \text{ m}^3 \text{ ha}^{-1}$ at age 10 years. Two representative stands measured on behalf of a client in the Green Triangle had 10.5% and 14.7% of the trees by number which, at ages of 8 and 12 years respectively, could have produced a 3.7-m sawlog or veneer log with a 20-cm sedub. The results of this limited trial were used to make the conservative estimates below.

If we assume that 8% of the standing volume of these representative plantations is potential sawlog or peeler log, simple arithmetic will reveal that there is potentially $15 \text{ m}^3 \text{ ha}^{-1}$ of log available. As there are 451 000 ha of *E. globulus* planted in Australia, an (assumed) ten-year rotation will result in 45 000 ha of clear-felling every year. This area could generate 675 000 t of either sawlog or veneer log per year. Over ten years, 6.7 Mt of sawlog or equivalent product could potentially be produced from the plantations established up to and including 2005. In the Green Triangle alone, this would be equivalent to $250\,000 \text{ t y}^{-1}$, surely enough for a mill of reasonable size.

There is no need to re-invent harvesting systems to meet these potential demands; their capability is already well demonstrated and transferable from the softwood industry.

Treasury

We live in a capitalist society and an adequate financial incentive is the ‘value’ part of high-value timber. This financial incentive must be available to all elements of the supply chain. In the case of both specialty timber stands and pulpwood stands, the extraction of high-value timber must produce appropriate rewards for the contractor as well as the forest grower. The cost structure of the value chain needs to be developed accordingly.

Pine forest managers often encourage this process by adjusting harvesting prices so that the contractor receives higher prices to produce the higher-value products. The Team concept once again emerges, whereby both the contractor and the forest owner have linked objectives. An option in this approach is to have an agreed target percentage of higher-value products, which, if exceeded, results in a bonus payment to the contractor. By using such systems, the harvesting of high-value products from what may essentially be a pulpwood plantation results in both the contractor and the forest owner gaining additional income.

For example, compare peeler log to wood chips. The current FOB price of plantation-grown *E. globulus* wood chip is AU\$189.40 per bone-dry metric tonne. To simplify this comparison, this price needs to be converted to US\$ m⁻³, in this case US\$76.70 m⁻³, assuming, for the sake of simplification, that one green metric tonne (gmt) is equivalent to one cubic metre, and that the tree is 50% wood and 50% water. The exchange rate used is AU\$1 = US\$0.81.

According to Ian Sedger (Pentarch Forest Products), the FOB value for veneer is in the order of US\$260.00 m⁻³. If it is assumed that the cost of converting the log to veneer is in the order of US\$60.00 m⁻³ (the current price in China is US\$40.00 m⁻³), as opposed to US\$8 m⁻³ for converting log to chip, the opportunity to add value through veneers is huge! Deducting the US\$60 conversion cost from the US\$260 value FOB leaves a gross return of US\$200, compared with the US\$76.70 gross return for chip.

In this grossly over-simplified example, I make no attempt to apportion the costs or consider factors of capitalisation, amortisation or whatever appropriate accounting adjustments need to be applied, but merely highlight the opportunity.

Figure 4 clearly illustrates recent trends in plywood prices. Another example that can be used to highlight opportunities is that of rubberwood—Malaysian furniture manufacturers are currently paying up to US\$360 m⁻³ for this wood. The relevance of this lies in that rubberwood is quite similar, at least in physical appearance, to fast-grown eucalypt timber. Investigation into supplying plantation-grown eucalypt timber as an alternative to rubberwood is surely worth pursuing. Rubberwood is also used in Vietnam, the fourth largest furniture manufacturer in the world. This nation imports timber worth US\$900 M y⁻¹, and exports finished furniture products with a value of US\$2.6 B y⁻¹.

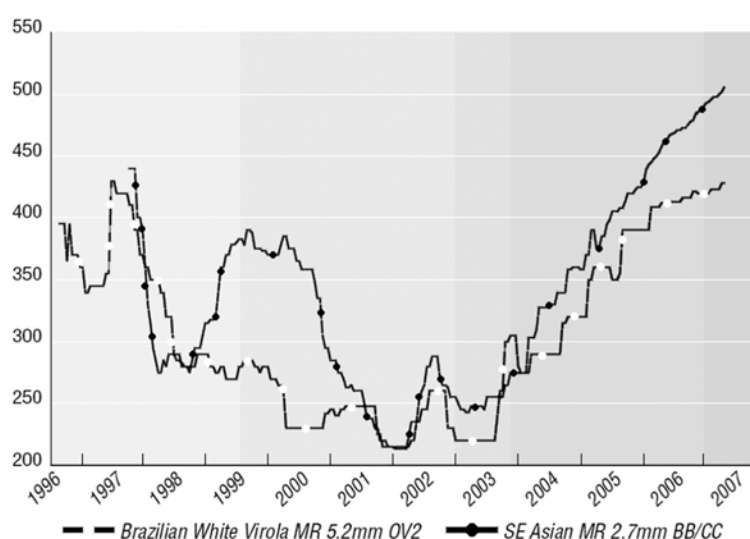


Figure 4. Tropical plywood export price trends in nominal US\$ m⁻³ (Castaño 2007)

Opportunities for improved financial gains with high-value products have been exploited in other countries and this success could be emulated in Australia—with appropriate research and development.

Thermodynamics

In the introduction to this paper, reference was made to high-value products ranging from solid wood through chips and veneers to fuel. If we are to extract the maximum value from a eucalypt plantation, an area that requires significant research and development is that of fuel. Recent studies by

Integrated Tree Cropping (A. Wiggill, pers. comm.) indicate that 20% of the total biomass of a stem is retained on site after pulpwood chips have been extracted from the plantation using in-field chipping techniques. In other words, if the wood is taken away by what is arguably the most efficient means of extraction, there is a balance of combustible fibre remaining on site that constitutes 20% of what was there in the first instance.

If this observation were to apply to the example quoted above—740 000 ha of eucalypt forest with an average standing volume of 180 t ha⁻¹ grown over a ten-year rotation—and all the fibre was extracted using whole-tree chipping, 2.6 Mt y⁻¹ of biomass could be available for bio-fuel.

In considering this material as potential fuel, one must take into account the potential nutrient loss to the site, an issue on which significant research has been undertaken. The current practice of some forest managers in both the Green Triangle and Western Australia involves the removal of entire stems to the forest edge, extraction of the saleable product (usually woodchip) and then the disposal of the residues by burning prior to re-establishment (Figure 5). The belief is that nutrients that may be lost in burning can be replaced by the application of fertiliser. There is opportunity for research to address the significant issues associated with this practice.

Extraction of potential bio-fuel in thinning and clear-felling operations using cut-to-length systems is practised on a wide scale in northern Europe. The machines and the opportunities to implement residue harvesting already exist in Australia; should demand be demonstrated, only fine tuning of existing equipment to suit our environment will be needed.

Taxation

The ultimate winner, the silent partner in any business, is taxation. A significant proportion of Australia's forests have directly or indirectly been established and managed through schemes approved and administered by the Australian Taxation Office, or possibly through public funds derived from taxation in its various forms. High-value products can generate higher incomes only with inevitable increases in taxation revenue.

Conclusion

The combination of many of the 'T' factors listed above could potentially result in huge benefits to the Australian hardwood plantation industry. The Trees will provide the Timber which can be harvested with the Tractor by the Team, provided that the members of the Team recognise that they need to take the Time to make the effort to understand each other's roles in order to maximise efficiencies. Application of the appropriate Technological Innovation through Research and Development will ensure that funds flow through Taxation into Treasury.

An established paradigm in forest harvesting is 'the reason we do it this way is because that's the way we have always done it'. Our challenge is to look out of the square and learn from the rest of the world that has taken an Australian timber resource and shown us how to generate high-value products that we seem incapable of producing.



Figure 5. Whole-tree chipping residues from an *Eucalyptus globulus* plantation with standing volume 300 m³ ha⁻¹ in the Green Triangle

References and further reading

- BRS (2006). *National Plantation Inventory Australia – Inventory Update*. Bureau of Rural Resources, Canberra.
- Donnelly, R., Flynn, R. and Shield, E. (2003) *The Global Eucalyptus Wood Products Industry – A Progress Report on Achieving Higher Value Utilization*. DANA Publishing.
- Drushka, K. and Konttinen, H. (1997) *Tracks in the Forest: The Evolution of Logging Machinery*. Timberjack Group Oy, Helsinki, Finland.
- Eldridge, K.G., Davidson, J., Harwood, C. and van Wyk, G (1993) *Eucalypt Domestication and Breeding*. Oxford Science Publications, 288 pp.
- Castaño, J. (2007) Market update. *Tropical Forest Update* 17(2). <http://www.itto.or.jp/live/index.jsp> .
- Lambert, J. Assessment of mechanical harvesters suited to thinning small-diameter plantation eucalypts. Unpublished report.
- Kellison, R.C. (2001) Present and future uses of eucalypts wood in the world. In: *Developing the Eucalypt of the Future*. Proceedings IUFRO International Symposium, Valdivia, Chile 10–15 September 2001. [IUFRO, Santiago, Chile, 2001]
- Shield, E.D. (1995). Plantation grown eucalypts: utilisation for lumber and rotary veneers – primary conversion. In: *Seminário Internacional de Utilizacao da Madeira de Eucalipto para Serraria [International Seminar on Utilization of Eucalyptus Wood for Sawmilling]*, San Paulo, Brazil, 5–6 April 1995. IPEF, Piracicaba, São Paulo.
- Shield, E.D. (2003) Utilisation of plantation-grown *Eucalyptus*: new resources...new approaches. In: Run-Peng Wei and Daping Xu (eds). *Eucalyptus Plantation Research, Management and Development*. Proceedings of the International Symposium on Eucalyptus Plantations. Guangzhou, Guangdong, China, 1–6 September 2002. World Scientific, Singapore, pp. 375–391.
- Taylor, R.E. (2002). Global supply and demand trends: how does Australia fit in? In: *Future of Forests*. NAFI Conference, 3 November 2002, Melbourne.



SESSION: PROCESSING AND MARKETING HARDWOOD
SAWLOGS

Processing Plantation Eucalypts for High-Value Timber

RUSSELL WASHUSEN^{1,3} AND TREVOR INNES²

¹CSIRO Forest Biosciences, Clayton

²FEA Timber Pty Ltd, Launceston

³Email: russell.washusen@csiro.com

Abstract

This paper summarises the experience gained over the past eight years from processing plantation-grown eucalypts in commercial sawmills across southern and eastern Australia. The mills had a range of sawing technologies set up to process native forest eucalypts or plantation-grown softwoods. These systems ranged from conventional single saws to hardwood multi-saw systems, and softwood sawmills equipped with the most advanced multi-saw and cant profiling technology. Where the sawn wood was dried, generally drying methods conventional for eucalypt timber were employed.

Each of the sawing systems applied was capable of processing plantation-grown eucalypts with the adoption of sawing methods suited to the respective systems. There were indications that in the case of logs from stands managed to produce good quality sawlogs, longitudinal peripheral growth stresses were a minor problem, although improvements are possible with genetic selection and adoption of certain silvicultural management strategies. The merits of the various sawing systems and drying methods are discussed. Overall, numerous trials in managed and unmanaged stands of eucalypts indicate strong potential for commercial processing, given the development of plantations resources of suitable size.

The development of drying strategies with reduced drying times while limiting degrade in sawn wood remains a challenge.

Introduction

Prior to about 2000, research conducted in Australia assessing the potential for production of high-quality solid-wood products from temperate plantation-grown eucalypts, was usually ad hoc and unsystematic, and in selecting product size and assessing product quality the research often ignored market requirements. This was partly because suitable plantation-grown resources were scarce and many experimental processing trials were restricted to a few trees. Moreover, this research was almost always conducted without the involvement of the processing industry which had more immediate challenges from native forest resources due to declining tree age, log diameter and log quality.

The lack of information from systematic trials with plantation-grown logs led to considerable scepticism regarding the potential of these logs. Stories of log and board splitting, board distortion, poor sawing accuracy and poor drying performance emerged. These stories no doubt led to the conclusion of de Fégely (2004) from an industry survey that there was little prospect for processing plantation-grown eucalypts.

The research and the occasional industry experiments were of such an exploratory nature that little weight could be placed on results. Most research was conducted by CSIRO and, like other published studies, the research is best described as exploratory to determine the key issues affecting processing performance and product value.

After 2000 a number of things changed:

- the availability of suitable logs gradually began to increase, processing trials became more systematic and larger numbers of logs were used in trials
- importantly, many of the logs were obtained from early experimental silvicultural trials, and on rare occasions genetics trials
- the most important change was the engagement of industry, starting with sawmillers such as Black Forest Timbers and Ryan & McNulty Sawmills
- with the engagement of industry increased funding began to flow from sources such as the Victorian DPI, the WA FPC, FWPRDC, RIRDC, ACIAR and the wider industry contributors to the CRC for Forestry
- Forest Enterprises Australia's sawmill at Bell Bay in Tasmania became the first large-scale sawmill in Australia regularly producing and marketing sawn plantation-grown eucalypt timber.

The outcome of these changes was the first serious evaluation of logs of a number of species of eucalypts from plantations located across southern Australia. In the past eight years the processing performance and product quality of species such as *Eucalyptus globulus*, *E. nitens*, *E. viminalis*, *E. regnans*, *Corymbia maculata* (and other spotted gums), *E. saligna* and *E. cladocalyx* have been assessed. These trials processed logs from stands that were often managed specifically for sawlog production—where pruning, thinning and/or fertiliser had been applied.

Above all, the involvement of numerous working sawmills has seen the application of a range of sawmilling systems and to a smaller extent various wood drying methods. Plantation-grown resources and processing methods have been evaluated at the same time.

While more needs to be done, a reasonably clear picture is emerging of the suitability of plantation-grown eucalypts for sawing and drying to produce more-or-less conventional solid wood products. This paper will summarise some of the most important points and suggest areas requiring additional research and development.

General wood quality

The FWPRDC report by Nolan et al. (2005) is a reasonable summary of the wood quality issues found in past research. There will be no attempt here to repeat all of this information. Clearly defects associated with branches are a major constraint to production of products suited to conventional appearance markets, and quite simply pruning is the best way of overcoming these defects (Figure 1).

In contrast, Forest Enterprises Australia (FEA) have developed a relatively small market for knotty timber for structural applications. These are products which the conventional industry is finding increasingly difficult to sell. It is a complex task to come to terms with these alternative markets because they require a detailed examination of market potential. Rather than do that we will



concentrate on processing characteristics which dictate the cost of production and ultimately affect product recovery and value.

The processing technology employed by FEA also raises issues about improving processing efficiency by adopting new processing technologies. This will also be a focus of this paper.

Figure 1. Knot-free slabs produced from 22-year-old pruned *Eucalyptus globulus* at the Auswest Timbers mill at Pemberton

Sawmilling

Sawmilling and growth stresses

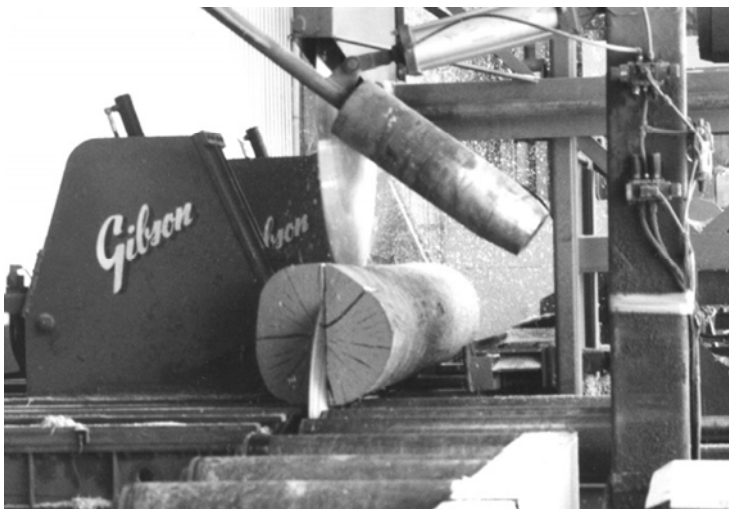
The report by de Fégely (2004) indicated that the major constraint to processing plantation-grown eucalypts was growth stresses. It is acknowledged here that it is quite clear growth stresses can pose difficulties during processing, potentially resulting in poor sawing accuracy, board distortion and end-splitting. With industry involvement, however, there has been the opportunity to apply not only conventional sawmills, but also the most modern hardwood mills yet built in Australia. We have also had the opportunity to apply the most modern softwood mills incorporating chippers that profile cants prior to or at the same time as sawing.

The results of these trials will be discussed in general terms below, noting board behavioural characteristics and the efficiencies of processing. As will be shown, the latter will potentially have an enormous impact on sawmilling costs (profitability) and ultimately plantation value.

Conventional single-saw systems

Conventional single-saw systems (Figure 2) usually include a single band or circular saw that breaks down the log into manageable units for resawing. In smaller and older conventional mills the resaw also has a single saw.

Single-saw systems have developed around the native forest resource over many years and are well suited to the highly variable quality of native forest logs. This variability includes a large range in diameter and internal defect.



Trials with plantation-grown eucalypts (several trials in *E. nitens* and *E. globulus*) have reported variable results (Washusen and McCormick 2002; Washusen et al. 2004, 2006, 2007a,b; Innes et al. 2007). This is mostly due to differences in the drying performance between trials. This will be discussed in greater detail later.



As far as the sawing is concerned, conventional single-saw systems can process plantation-grown eucalypts reasonably effectively and produce recoveries at times similar to native forest eucalypts of the same log quality. However, lower recoveries were recently found for logs matched on grade and diameter (Figure 3) (Washusen et al. 2006). In this case wood-moth infestations were the primary reason for differences. No other study has yet been conducted where direct comparisons can be made because of the difficulties in matching samples exactly and then subjecting logs and boards to identical processing.

Figure 2. Conventional single-saw systems common in small sawmills in southern Australia, quarter-sawing plantation-grown *Eucalyptus nitens*

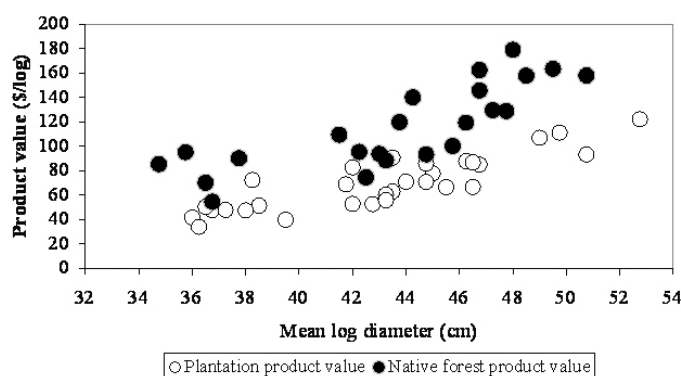


Figure 3. Comparison of product value of 17-year-old pruned *Eucalyptus nitens* and 1939 native forest regrowth *E. nitens* (66 years old) matched on log grade and diameter (from Washusen et al. 2006). All logs were Victorian B-grade. Wood-moth holes and associated decay and stain were the primary wood quality differences.

Generally, the sawing results from these trials indicate that logs can be processed effectively applying either back-sawing or quarter-sawing strategies. Addition of a line-bar to the carriage can be useful by countering bending of the log as slabs are removed during log break-down. Where line-bars are not fitted or are unused, the only options available are to rotate the logs or apply face cutting to straighten the sawn face. This latter operation reduces recovery and slows volume through-put.

Logs processed in the trials have predominantly been in the 2.7–3.6 m length range. As the length increases, sawing performance falls away rapidly as the bending of logs

and flitches during sawing increases. However, logs from managed stands do not appear to be any worse than those of the same diameter from native forest.

Sawing accuracy has rarely been measured in these trials, but where it has there are indications that the accuracy could be in the range of ± 3.0 mm over the target size. This is primarily due to bending of logs and flitches during sawing which results in thinner dimensions of the board, slab or flitch at the ends than at the mid-length.

Saw kerfs (the width of the saw cuts), particularly on the break-down saws, are also quite large. Large-diameter circular saws are relatively thick to counter ‘flutter’ during sawing, and as a consequence the kerf can be 6.0 mm or more.

Sawing strategies have usually been designed to allow for the sawing accuracy of the system and the estimated shrinkage of the boards during drying. Boards have a degree of over-sizing to prevent significant losses of material at completion of drying. For example in some trials, applying quarter-sawing strategies where the thickness shrinkage is high (shrinkage in the tangential direction is usually higher than the radial direction) the target size has been as much as 31 mm thickness with the aim of producing a dried board nominally 25 mm thick.

In the worst-case scenario where: (i) a quarter-sawing strategy is applied; (ii) large-diameter circular saws are used for log break-down and re-sawing; (iii) no line-bar is applied; and (iv) the target green thickness is 31 mm; recoveries can be poor and the performance deteriorates as log diameter declines. Consequently mills with these processing systems prefer logs over about 40 cm mid-diameter. While logs of this diameter can be produced in plantations in a short time, large-diameter logs are likely to be a small fraction of the yield.

Recovery with these systems can be improved by applying back-sawing strategies. An example of differences in recovery between back-sawing and quarter-sawing, found in a recent CRC Forestry project in a 22-year-old Forestry Tasmania *E. nitens* spacing trial, are shown in Figure 4.

However, with either sawing strategy the greatest failing of single-saw systems is their reciprocating action—that is, the log, flitch or slab is repeatedly moved backwards and forwards on a carriage or bench through the saws until the sawing process is completed. This is a relatively efficient process for large-diameter, long-length native forest logs, but for short-length small-diameter plantation-grown logs it is very inefficient, and as log diameter and length decline sawing costs mount.

While much less tangible, it is also probable that sawing inaccuracies result in recovery loss due to drying degrade because of moisture gradients or disturbed air-flow during drying.

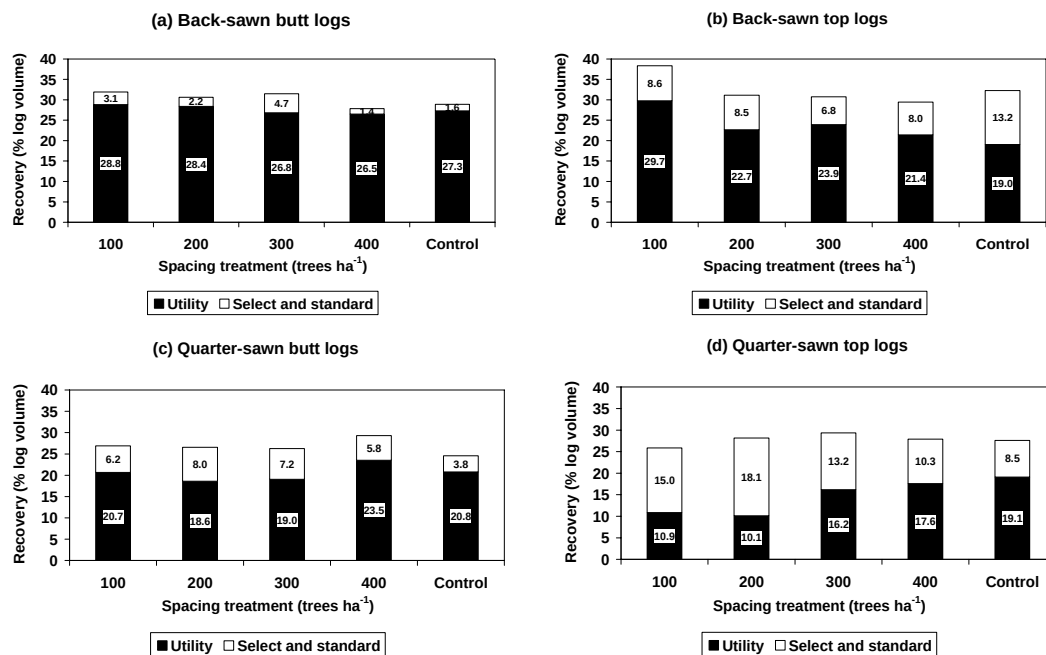


Figure 4. Comparison of recoveries from back-sawing (a,b) and quarter-sawing (c,d) strategies applied to butt (a,c) and top (b,d) logs from the same plantation. For quarter-sawing, logs had a minimum small-end diameter (sed) of 38 cm, and for back-sawing 25 cm sed (from Washusen et al. 2007a).

Twin saw log break-down and multi-saw resaws

A major option to improve sawing systems as log diameter and length decline is to use multi-saw technology. These systems apply sawing strategies that, when coupled with appropriate log rotation, produce cutting patterns that release growth stresses far more symmetrically around the log than is possible with single saws.

On rare occasions hardwood mills in Australia have employed this technology with chipper-reducers that operate ahead of twin band-saws (Figure 5). This effectively means that with the first pass through the saw four cuts are made.

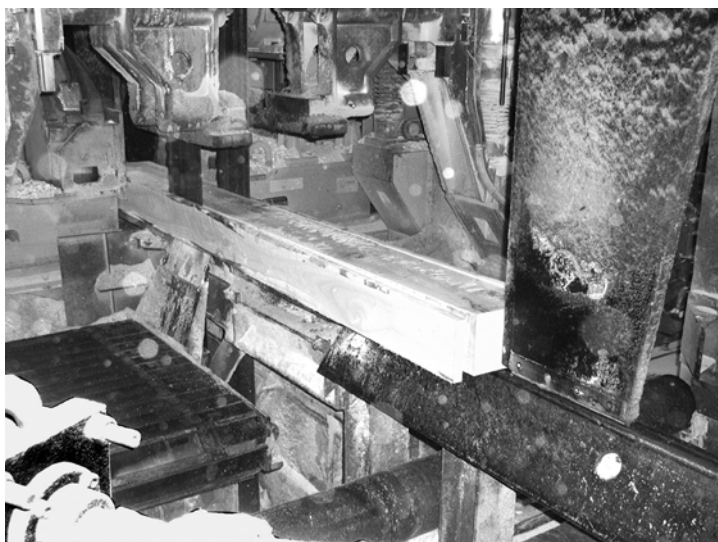


Figure 5. The McKee twin band-saw at Auswest Timbers, Pemberton, equipped with chipper reducers (in this photograph hidden ahead of the saws) that effectively make four cuts on the initial pass. This photograph was taken during a trial back-sawing pruned 22-year-old plantation-grown *Eucalyptus globulus* and shows the sawing immediately after the first turn-down.

This technology produces immediate improvements in performance over conventional single-saw systems. Volume throughput is increased, sawing accuracy improved, and where twin band-saws are employed, there is a reduction in saw kerf.

Coupled with multi-saw resaws that operate with small-diameter circular saws (with narrow kerf), productivity of these mills increases and the costs of sawing decline. There are also probable recovery benefits, although this is very difficult to quantify because identical logs would need to be put through competing technologies. Variation in performance of mill staff is also likely to cloud results. However, the high recoveries reported in Washusen et al. (2004) in 22-year-old plantation-grown *E. globulus* are likely to be at least



Figure 6. MEM twin-saw systems like this one at the Drouin West Sawmill can also be used for quarter-sawing

partly due to the sawing accuracy of these systems coupled with a back-sawing strategy. In this trial, green target sizes were 28 mm thickness and saw kerf 4.5 mm.

Twin-saw break-down systems have also been employed in at least one trial using quarter-sawing strategies with plantation-grown *E. globulus*. They can also be used to resaw flitches in a quarter-sawing strategy (Figure 6).

The newest dedicated hardwood sawmill for back-sawing in Australia is the Whittakers Timber Product small log sawmill in Western Australia (Figure 7).



WORK SCREEN					SAWING PLAN					DELETE PROGRAM					CLASSIFY PROGRAM				
					Program Nb: 3														

With the adoption of computerised optimisation of sawing, this mill has taken the use of twin saws and multi-saw resaws to contemporary levels. The process involves scanning log dimensions, selecting the sawing strategy that will produce the best recovery and using the computer to control the sawing process. This mill also has a log turn-down device that eliminates the need to release the log during log turn-down, potentially speeding up the sawing process.

These types of systems have relatively high throughput for their cost and they are proving that high recoveries are possible. This can potentially reduce processing costs and improve recoveries over conventional systems. However, they still rely on reciprocation of the log or flitch through the break-down saw for any sawing strategy, and for the resaw when quarter-sawing strategies are applied.

One limitation of these systems is that many have strict maximum log diameter requirements. Many are limited to about 45 cm sed. For plantations where log diameter can quickly exceed this limit, this may not be ideal. In recent trials conducted at Whittakers Timber Products (unpublished) using 17-year-old *E. viminalis*, *E. globulus* and *E. saligna* some logs had to be rejected at harvest because they exceeded this diameter limit. However, if dedicated systems are designed to process plantation eucalypts this difficulty should be avoided.

Growth-stress imbalances

There remains one question about the suitability of twin-saw systems for plantation-grown eucalypts, and that relates to stress release. This is largely an exercise in applying sawing strategies that release growth stresses without so altering the balance of stresses that log end-splitting occurs. An example of the problems that can develop with these systems is shown in Figure 8. Here a 17-year-old *E. saligna* log has had four slabs removed during log break-down without turning the log down. This has produced a cant that is un-dimensioned in width (the rounded surface of the log remains). This cant is 105 mm thick and about 250 mm wide. The treatment of this log was a great departure from the normal recommendation to turn eucalypt logs after chip, boards or slabs have been removed equal to about 33% of the log diameter. In this case more than 60% of the diameter was removed. This is technically a failure in the computer software that can be overcome with re-programming. However, this problem has been observed in other trials and species (Washusen et al. 2004; Washusen 2006) where the sawyer has had greater control of the sawing process. It appears to be very easy to mistakenly remove too many slabs before turning the log down. As log diameter declines this issue becomes increasingly important—but care with log segregation and selection of conservative sawing strategies will overcome this difficulty.

Changes in the growth-stress balance also have subtle effects that may not be as noticeable as the gross splitting shown in Figure 8. During the trial described by Harwood et al. (2005), splitting ahead of the saws was observed during resawing of centre cants. This probably was the result of a similar phenomenon, the cant being too thin relative to its width.

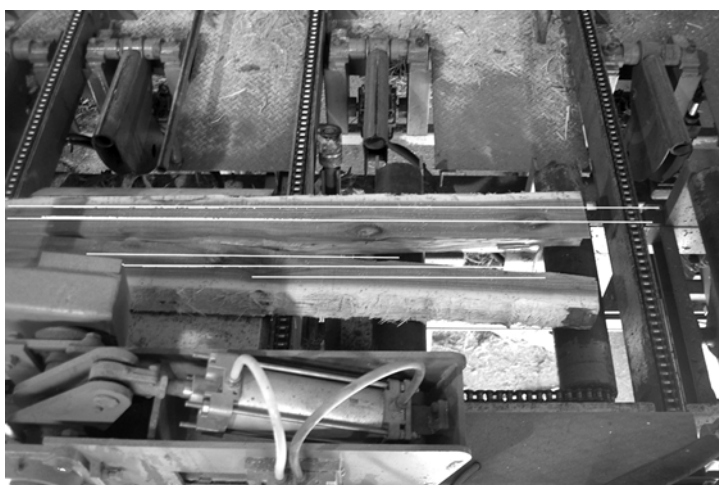


Figure 8. Log end-splitting in 17-year-old *Eucalyptus saligna*, the consequence of sawing to produce a cant that is too thin relative to the log diameter

Splitting ahead of saws is probably the least recognised problem associated with growth-stress release. In the numerous trials conducted by CSIRO and Ensis over the past decade or so this issue frequently emerged.

As log diameter declines, stress imbalances that lead to both end-splitting and splitting ahead of the saw are a problem that remains to be effectively addressed in mills using either conventional single-saw systems or more contemporary multi-saw systems.

Linear flow multi-saw systems coupled with chipper profilers

The main issues identified above as limiting sawmilling efficiency and potentially limiting product value as a consequence of the sawing process in conventional single- and twin-saw systems are:

- sawing accuracy of single-saw systems
- large saw kerf, particularly from large-diameter circular saws
- log-end and cant end-splitting
- splitting ahead of the saw
- the requirement to rotate logs during sawing
- the reciprocation of logs through breakdown saws, and in the more conventional systems the reciprocation of logs, flitches and slabs through resaws.

Other problems associated with growth-stress release that do occur relate to board deflection, either as spring in quarter-sawn boards or bow in back-sawn boards. In general this has not hampered the sawing process, as the sawing methods themselves are designed to reduce the extent of this deflection or to eliminate it during resawing. The choice of log length has a major bearing on problems of deflection. In the trials described above, sawlog length was always conservative with the aim of reducing deflection to manageable levels and limiting recovery loss in the resawing process.

So what happens if we apply even more symmetrical cutting patterns than those possible with twin-saw log break-down systems, and adopt a linear flow of wood as opposed to a reciprocating flow?

Linear-flow sawing systems are usually associated with softwood mills where longitudinal growth stresses are not a constraint to sawmilling. However, a number of trials have now been conducted with linear sawing systems with *E. globulus* and *E. nitens* and a few other species from northern New South Wales. FEA in Tasmania now processes small-diameter *E. nitens* for structural products with a HewSaw R200. More recent trials have also been conducted using the HewSaw R250 at the Carter Holt Harvey mill in Gippsland (formerly N.F. McDonnell & Sons).

These two sawing systems apply chippers to remove wood from around the log to produce a profiled cant simultaneously with or just ahead of small-diameter circular saws (Figure 9). This strategy eliminates the problem of growth-stress imbalance identified above by removing wood simultaneously from around the log. It also completes the sawing in a single operation and without reciprocating the log.



Figure 9. Diagrammatic representation of the internal arrangement of chippers and saws in the HewSaw R250 (source: www.hewsaw.com)

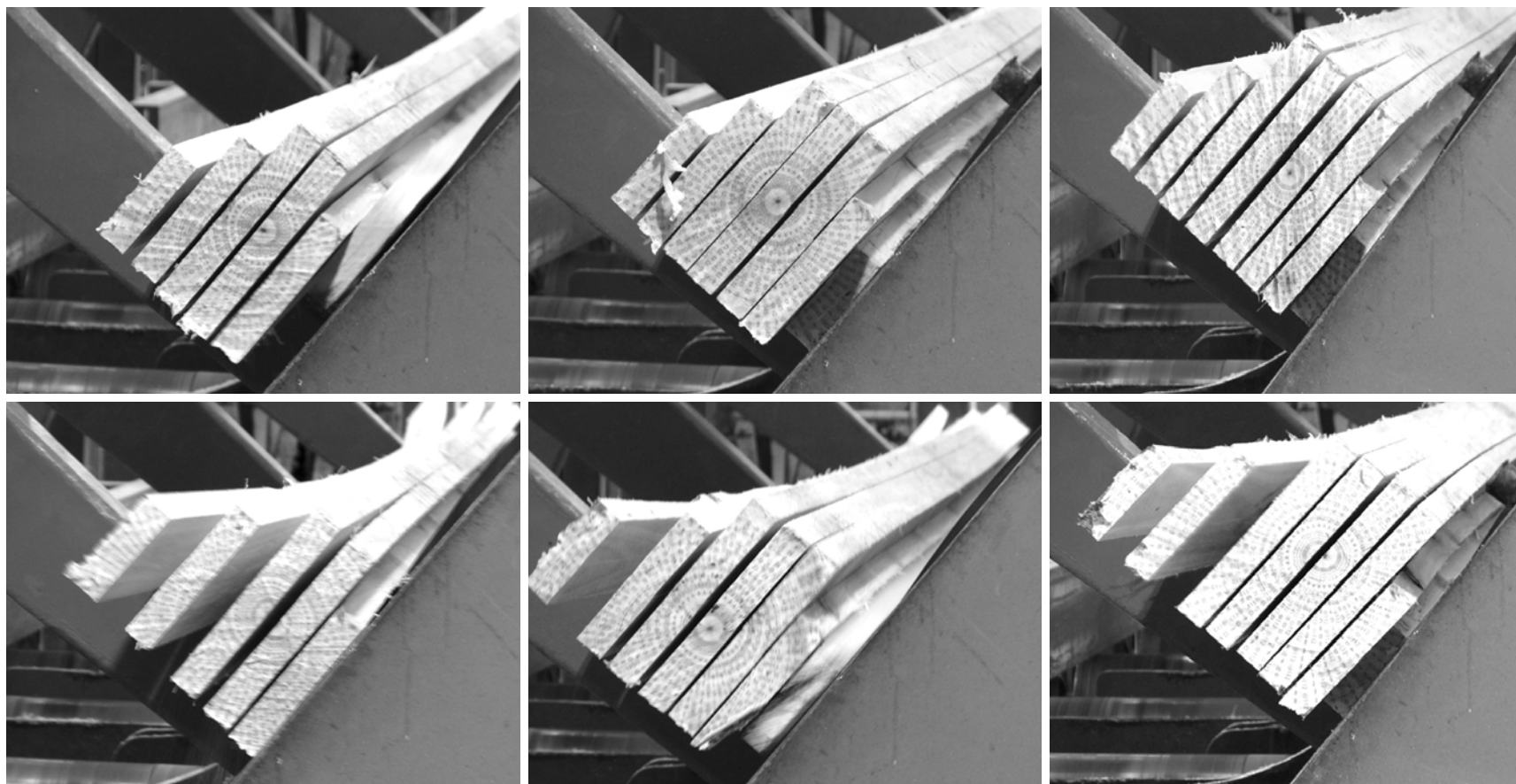


Figure 10. The approximate range in board deflection for 17-year-old *Eucalyptus nitens* logs for three sawing patterns on the HewSaw R250. Left: sawing pattern 1 applied to logs with minimum sed of 22.0–26.0 cm; Middle: sawing pattern 2 applied to logs with minimum sed of 24.0–28.0 cm; Right: sawing pattern 3 applied to logs with minimum sed of 26.0–32.0 cm.

The HewSaw R200 and R250 have log diameter ranges of 14–25 cm and 14–34 cm respectively, and so are suited to resources of different age or size. At conservative feed rates into the saws, total log volume input is around 120 000 m³ of logs per year in a single shift. This is a much greater volume than can be processed by any hardwood sawmill where trials have been conducted.

The potential ramifications of high throughput are that—if a suitable resource were available—the cost of sawmilling could fall dramatically, potentially improving the profitability of growing and processing eucalypts.

To understand how effective these systems are at processing logs with high and variable growth stresses, formal research trials have been conducted with the R200 and R250 HewSaws in a large international project supported by the Australian Centre for International Agricultural Research (ACIAR). So far *E. nitens* and *E. pilularis* have been processed as part of the project. Logs used were up to 5.0 m long—much longer than in any other trial to date in more conventional systems.

In the case of *E. nitens*, the characteristic related to growth stress release that was of most importance was bow in boards near the log periphery (Washusen et al. 2007b). Photographs of the range in bow for three cutting patterns employed in the trial are shown in Figure 10. These photographs were taken immediately at the conclusion of sawing on the HewSaw R250. Bow of this extent was of little consequence to board handling or stacking, and would be eliminated during drying.

Bow is also plotted against growth strain in Figure 11. This is the maximum bow recorded on any board from each log measured with the board standing on its edge to accentuate the bow. Only one board in the trial had bow measured in this way that exceeded 150 mm over 5.0-m length, despite relatively high growth strain having been measured on standing trees just prior to harvest.

The advantage of being able to produce boards of this length is that product value is linked to board length (as well as to width and thickness). On current markets, if average board length is less than 3.0 m there is a discount of 10% on the current wholesale price, and for boards <1.8 m in length there is a discount of 50% (Ken Last, FWPRDC, pers. comm.).

There is another less obvious advantage in having longer logs. While its worsening can be prevented by the sawing process, log-end splitting resulting from harvesting and handling appears to be inevitable in eucalypts. If this splitting ends up on board-ends it is docked, reducing recovery. In the trial in 17-year-old *E. nitens* with 5-m logs, log end-splitting accounted for 3% loss in recovery. This compares to 5% loss in a trial in 22-year-old *E. nitens* with 2.7-m logs (Washusen et al. 2007b). That is, despite tending to be greater in the 17-year-old but longer logs (Figure 12a, b), as a proportion of log length the end-split length was less than in the 22-year-old but shorter logs.

Further work on conversion of logs to sawn wood and veneer

Sawing and peeling

The trials with industry indicate that sawing is technically feasible with a range of sawmilling equipment.

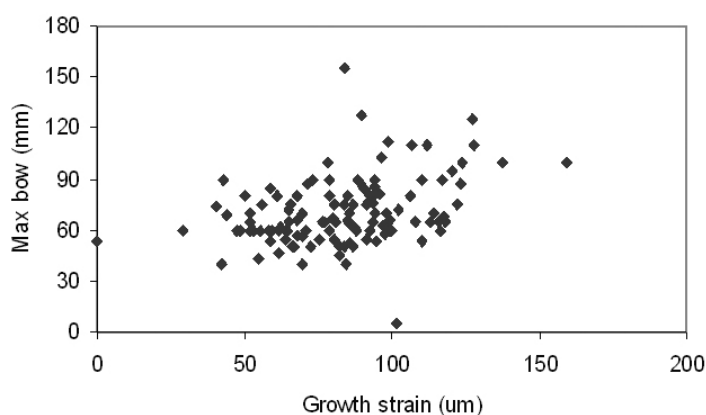


Figure 11. Plot of maximum bow and growth strain for 17-year-old *E. nitens* logs sawn with the HewSaw R250. The bow was measured on 5-m boards standing on edge and unrestrained.

However, variation between species remains largely unknown and further trials are underway or planned to study species such as *E. pilularis*, *E. dunnii*, *E. urophylla*, *E. globulus* and spotted gums with support from ACIAR and through the CRC for Forestry. Some of these trials will further test the concept of applying chipper/profiling systems such as the HewSaw R200 and R250 to minimise the development of growth stress imbalance during sawing.

In addition, peeling to produce veneers (which similarly prevents imbalances in growth stresses during processing), particularly for eucalypts of very small diameter, remains a lucrative area for research.

Log end-splitting during harvest and log handling

Log end-splitting is an important source of recovery loss for sawmilling and also where

appearance-grade veneers are to be produced. While it appears that increasing sawlog length will reduce losses, further work is needed to minimise log end-splitting.

Recent work by Washusen et al. (2007b), measuring acoustic wave velocity in standing trees, suggests that there is potential for resource improvement using this cheap assessment method. This work in *E. nitens* also found that there is good potential for genetic improvement and there were indications that end-splitting, particularly high in the stem, may be linked to harvesting damage. Further work is necessary in *E. nitens* and other eucalypts to understand the full implications of these findings.

Tension wood formation

Tension wood remains a challenge for sawmilling and wood drying. Where it forms, extreme growth stresses develop and wood shrinkage is excessive. In the industry trials described above, tension wood—when its presence was assessed—was found to be only a minor problem. This will not always be the case, and further work needs to be undertaken to identify the conditions under which it forms. These may be influenced by the intensity of thinning, the age of the stand at thinning and rate of growth (Washusen et al. 2005). Work is currently underway in the CRC for Forestry to understand some aspects of this in stands of *E. globulus* in south-western Western Australia.

Wood drying

Degrade induced by drying of plantation-grown hardwoods is similar to that experienced by native forest sawmillers. In some cases, the degrade occurrence is likely to pose additional challenges to processors; in other species degrade is expected to be less than typically seen in comparable native forest material.

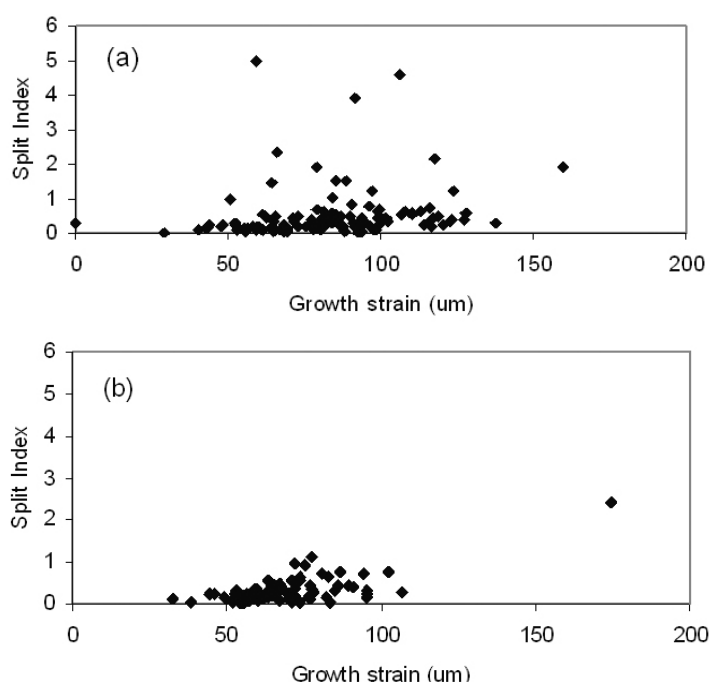


Figure 12. Plots of split index (Yang 2005) and growth strain for 17-year-old *E. nitens* from Tumut in New South Wales (a); and 22-year-old *E. nitens* for Goulds Country in north-eastern Tasmania (b). The split index is a function of log diameter and the length of the end split.

In most cases, observed degrade is seriously value-limiting for appearance grades but not for structural material. Thus, control of drying degrade will be far more important when processing high-value pruned logs for appearance products than when converting logs originally grown for pulp to produce structural- or pallet-grade material.

Sawing of very small logs warrants special mention when discussing wood drying because of the influence of the 'heart' on product quality and out-turn. Despite the difficulty of drying heart-in boards (Figure 13), boxing-out the pith (and adjacent heart) of some species may be uneconomic or impractical because the boxed-out section would be a very large proportion of the log volume. In pruned stands this would not be a major problem, as this zone corresponds closely with the defect core where pruning lifts have been conducted up to a stem diameter of 100 mm.

Note that although heart checks are rarely a strength-limiting defect they may not be visually acceptable, even for a medium-value framing product. The necessity to cut boards free of pith for particular products will dictate minimum log diameter acceptable for sawing. For appearance-grade products the minimum diameter required may be much larger than for structural or pallet-grade products. However, there is considerable variation between and within species to consider (see discussion below).



Figure 13. Heart checks in boards sawn heart-in (this example is 6-year-old *Eucalyptus dunnii*).

Conventional drying strategies

As with most plantation hardwoods commercially processed in Australia, the industry trials conducted by Ensis described above used conventional drying strategies typically derived from local experience with native forest timbers. This usually entailed a period of air-drying or pre-drying in a kiln followed by reconditioning and final kiln drying.

Similarly, in order to produce EcoAsh™ from plantation-grown *E. nitens*, FEA follows normal commercial practice for collapse-prone cool-climate eucalypts, using a period of several months drying in open air followed by steam reconditioning (for recovery of collapse) and kiln final-drying. These drying strategies can produce acceptable recoveries of products suitable for appearance-grade applications, or in the case of FEA for production of EcoAsh™.

However, considerable variation in drying results has been found in the industry trials. Some of this may be attributed to differences in processing methods employed. When air-drying was used, there was little control over conditions during the early stages of drying, potentially leading to degrade. The sawing strategy, either back-sawing or quarter-sawing, also has a bearing on results—degrade is usually less in quarter-sawn boards. It is also possible that a commercial boron diffusion treatment of sapwood in several of the trials in Victoria and Western Australia influenced results by slowing drying during the period of treatment.

Variation in drying performance

Species variation

Drying performance varies between and within species. For example, considerable variation in drying has been reported in *E. nitens* (Washusen and McCormick 2002; Innes et al. 2005, 2007; Washusen et al. 2006, 2007a). This variation warrants further research in order to develop *E. nitens* plantations for production of high-quality sawlogs in Tasmania and parts of Victoria and New South Wales where climate and soils are suitable.

Similarly, variability has been reported in *E. globulus* although recent trials of pruned *E. globulus* from south-western Western Australia produced good results (Washusen et al. 2004). This latter experience may be linked to an absence of tension wood, and fast and uniform growth rates.

The manifestation of drying defects is also different between species. For example, Innes et al. (2007) found when comparing species that *E. globulus* had more distortion-related degrade, whereas *E. nitens* boards had a higher incidence of checking.

A recent small study at FEA (Innes unpublished) on very young trees demonstrated a much higher tendency to form heart-checks in *E. dunnii* than in either *E. cloeziana* or *Corymbia citriodora* subsp. *variegata*. Similar infrequent heart defects were observed in very young spotted gum (probably *C. maculata* and *C. citriodora* subsp. *variegata*) in Western Australia (Washusen 2006). In these latter trials the lack of heart checks gave encouraging yields of reasonable quality timber, especially given the very small (and for the FEA trial, poorly formed) logs.

Subtropical species are generally not prone to collapse, and native forest material of the same species is less prone to drying degrade than *E. globulus* or *E. nitens*. Plantations of non-collapsing species in temperate areas have also produced good drying results. Species such as *E. cladocalyx*, the spotted gums and *E. sideroxylon* have all produced promising results, even from young stands.

Wood property variation

The variable drying performance can be linked to variation in wood properties. Sawn plantation timber often has highly variable drying behaviour. For example, *E. nitens* from a single plantation coupe has been observed to produce boards with initial moisture content ranging from 70% to 170% dry weight basis (Innes unpublished). Mean tangential shrinkage measured on 25-mm cubes cut from the butt of 124 trees of 26-year-old *E. nitens* varied from 8% at 30% radius to 13% at 90% radius with standard deviations from 2% to 4% (Innes et al. 2007). Such high variation within single processing batches can be expected to yield dried produce of highly variable quality, both in terms of induced degrade and moisture content. For example, in the same study induced drying degrade resulted in about 17% of boards having moderate internal checking, 25% with minimal internal checking and 58% with none.

Probably the most serious drying defect encountered when processing *E. nitens* and *E. globulus* is collapse and associated internal checking (Figure 14). Collapse tends to occur in fibres with greater width and a thinner cell wall, so may be expected to be more prevalent in rapidly-grown plantation material. Internal checking is most often seen where a collapsed earlywood band is adjacent to a non-collapsed earlywood band; the difference in shrinkage between the two earlywood bands gives rise to the checking. Internal checking is a very expensive defect as it is often not discovered until the piece of timber is manufactured into the final product, at which point sanding or moulding causes the surface to pick up in splinters. It is usually seen to be worse near the base of trees, lessening in intensity up the stem (Washusen et al. 2007a), though the nature of the relationship between checking and height remains unclear.

Where there is a great deal of variability in wood properties it is essential to manage drying conditions so that the variation observed in dried quality falls largely within that acceptable to the targeted market, without unnecessarily increasing drying time and cost.



Figure 14. Collapse and internal checking in *Eucalyptus nitens* about 13-y old

Drying strategies and alternative technologies

Reducing defects in collapse-prone species

To date more-or-less conventional drying methods used for native forest *E. nitens* have been applied to younger plantation-grown material. Collapse-related drying degrade may be reduced by using conventional pre-driers as opposed to air-drying or harsh pre-drier conditions. This is because of the relatively rapid rate at which plantation-grown *E. nitens* may be dried compared to native forest timber, and relatively lower levels of surface checking. Collapse is also highly temperature sensitive (Innes 1996) and so can be controlled to some extent with the drying process.

It is therefore reasonable to expect that the levels of degrade can be limited to those acceptable for appearance products by tuning pre-drier schedules.

Anecdotal evidence also suggests that collapse is likely to be reasonably heritable, so may be decreased through breeding programs. New technologies such as ultrasonic scanning may be capable of reliably detecting internal checks in dried boards (Ilic et al. 2005), but drying processes must generally limit internal check to levels acceptable for the target products.

Processing thin sections

One means of decreasing drying-induced degrade may be to process material of thinner section. Thinner sections develop less-severe moisture gradients during drying and so should be less prone to surface checking. They are also generally less prone to form internal checking associated with collapse, particularly in quarter-sawn material. However, a study on Tasmanian regrowth *E. obliqua* (Innes et al. 2005) did not show any significant reduction in drying degrade by reducing sawn thickness. On the other hand Washusen et al. (2006), in 17-year-old pruned plantation-grown *E. nitens* from the Otways, found little drying-related degrade in quarter-sawn and back-sawn boards 16 mm thick. Further investigation of this strategy in plantation hardwood timber is required. Reducing sawn thickness to reduce drying degrade would also require some product development or careful niche marketing of limited volumes, as solid-timber appearance products are currently available in a wide range of dimensions. Ultimately, entirely different processes could be used if drying difficulties proved to be commercially insurmountable, for example veneer peeling or slicing.

Alternative drying technologies

There is considerable interest in developing strategies to reduce drying costs and time, and to decrease degrade. These strategies range from tuning current commercial processes (accelerated air drying, kiln pre-drying) to the application of novel technologies (vacuum kilns, microwave pre-treatment, compression kilns). Some of this R&D work is pursued through public agencies, but some is funded and or performed by individual companies and is hence confidential.



Figure 15. Compression kiln recently installed at Forest Enterprises Australia's Bell Bay sawmill for drying plantation-grown *Eucalyptus nitens* from green

Vacuum drying

One commercial operation in Chile (Eduardo Gutierrez, Forestal MBM, pers. comm.) is vacuum drying plantation-grown *E. nitens* boards from green in about three days. Heat is provided via platens inserted between rows of boards.

Superheated steam-type vacuum kilns are more likely to find commercial application than platen types, as building drying racks is much simpler. Work on native forest material (Adam Redman, pers. comm.) suggests that the

economics of drying non-collapse-prone hardwood species in vacuum driers are likely to be favourable. Collapse-associated defects, particularly internal checking, make the likelihood of commercial success with collapse-prone species such as *E. nitens* and *E. globulus* less likely.

Microwave treatment prior to conventional drying

The CRC for Wood Innovations has recently processed plantation grown *E. globulus* and *E. nitens* using its microwave pre-treatment prior to conventional drying. This treatment is designed to cause micro-fractures in the pit membranes between fibres, thus increasing the rate of moisture movement throughout boards. The improved moisture movement within boards should make back-sawn boards less prone to surface checking, as the magnitude of moisture gradients will be decreased. Higher-power applications of this technology cause larger fractures which may be utilised for improved ingress of resins (to manufacture composites) or treatment chemicals. Limited trials in *E. globulus* indicate that surface- and internal-check severity and shape change can be reduced during conventional kiln drying after application of a low-intensity microwave pre-treatment (Grigori Torgovnikov, CRC Wood Innovations, pers. comm.).

Compression kilns

FEA has recently installed a compression kiln, the first of its type in the southern hemisphere (Figure 15). The kiln is manufactured by TeknoComp of Finland, who hold worldwide patents relating to the process. Rows of boards are separated by sheets made up of square-section aluminium tubes held slightly separate from each other and perpendicular to the direction of the boards. Drying stacks pass through two chambers where they are compressed vertically by an array of hydraulic jacks and where drying air is blown through the stacks as in a conventional kiln. The stacks then enter a third chamber for cooling. Trials have just commenced in the kiln, with promising early results. Ultimately the kiln is expected to reduce drying time for material 38 mm thick to about two days, with minimal drying degrade.

High humidity treatments

For species that do not collapse significantly, kiln schedules incorporating periodic high-humidity treatments have been demonstrated to reduce drying degrade when kiln drying green timber (Northway and Blakemore 1996, 1999).

Conclusions

Trials conducted with existing commercial sawmills over the past eight years have demonstrated that sawing of plantation-grown eucalypts managed with various silvicultural strategies is technically feasible with a range of sawing equipment, including some of the most modern sawing systems developed (primarily) for softwood processing.

With the adoption of sawing methods suited to the equipment employed, imbalances in stresses caused by growth-stress release during processing did not produce major problems.

There were indications that by using sawmills that release stresses simultaneously around the log, good outcomes can be obtained when processing logs of a much greater length than is usually possible with more conventional sawmills. The very high throughput of these systems should permit a considerable reduction in sawmilling costs, in comparison to conventional sawmills, if resources of suitable size can be established within economic transport distance of mill sites.

Trials also indicate that results of sawing with these systems can be improved by genetic improvement of the plantation resource. More work needs to be done to see how applicable this modern technology is to all potentially commercial species of eucalypts, and to see if genetic improvement can be realised.

There is also potential to supplement supplies of logs to conventional hardwood sawmills currently processing native forest eucalypts. High quality pruned logs of some species can be effectively processed alongside native forest logs. If markets for products from mixed processing were viable, only a modest plantation area would be required within economic transport distance of the mill. The best sawmills are likely to be equipped with modern log scanning and computer-operated twin-band log break-down saws, possibly coupled with chipper-reducers, and downstream processing multi-saws.

Despite the success of studies in sawing, more work is needed to improve understanding of tension-wood formation and methods of reducing its occurrence and severity.

Reductions in log-end splitting either through genetic selection, improvements in harvesting methods or through application of non-destructive evaluation (NDE) methods that measure propensity for end-splitting also appear worthwhile. In the last case, acoustic wave velocity measurements on standing trees are showing promise for segregating trees in the field to reduce losses of recovery due to end-splitting.

Wood drying remains a major challenge for collapse-prone eucalypts. More work is required to develop drying methods for some species to reduce surface and internal checking. *Eucalyptus nitens* is the most important species in this respect. There are a number of drying technologies with potential application for processing eucalypts that may speed up the drying process and reduce drying degrade.

Overall industry trials suggest there is potential for commercial processing. It is as yet unclear, however, which direction will be the most profitable for growers and processors. The alternatives are to produce pruned large-diameter logs with an emphasis on production of more-or-less conventional high-value sawn products; or to grow stands with minimum silviculture to produce a combination of short-length appearance products, lower-value structural- and pallet-grade boards and wood chip. There also remains a largely untested option of peeling for internal- and face-grade structural and appearance-grade veneer.

Acknowledgements

The research described in this paper was supported by the Australian Centre for International Agricultural Research (ACIAR), the FWPRDC, JVAP, The Victorian DPI, The WA Forest Products Commission, Trees Southwest, CALM WA, the CRC for Forestry and Forest Enterprises Australia (FEA). Mills that contributed to the work were Ryan and McNulty Sawmills, Black Forest Timbers, Auswest Timbers Pemberton, Whittakers Timber Products, N.F. McDonnell & Sons, ITC Southwood and Heyfield, McKay Timber and Boral Timber. Plantation owners who contributed trees were Forests NSW, Grand Ridge Plantations, CALM WA, The Victorian Department of Sustainability and Environment, Forestry Tasmania, Rowan Reid, Frank Hirst and Geoff North.

The Resource Evaluation team at Ensis – Wood Quality conducted most of the work to ensure the trials ran successfully. Bob Hingston and Richard Moore assisted and supported the work conducted in Western Australia.

References

- De Fégely, R. (2004) *Sawing Regrowth and Plantation Hardwoods with Particular Reference to Plantation Hardwoods. Part B Survey Results*. Forest and Wood Products Research and Development Corporation Report PN02.1308. FWPRDC, Melbourne, 19 pp.
- Harwood, C., Bandara, K., Washusen, R., Northway, R., Henson, M. and Boyton, S. (2005) *Variation in Wood Properties of Plantation-Grown Eucalyptus dunnii Relevant to Solid-Wood Products*. Forest and Wood Products Research and Development Corporation Report PN04.3003, FWPRDC, Melbourne, 37 pp.
- Ilic, J., Northway, R., Thumm, A. and Wright, J. (2005) *The Development of New Technologies for Use in the Hardwood Sawmilling Industry*. Forest and Wood Products Research and Development Corporation Report PN03.1317, FWPRDC, Melbourne, 46 pp.
- Innes, T.C. (1996). Collapse free pre-drying of *Eucalyptus regnans* F.Muell. *Holz als Roh- und Werkstoff* **53**, 403–406.
- Innes, T.C., Bennett, P.J. and Lee, M.W. (2005) Drying of tangentially-sawn regrowth Tasmanian *Eucalyptus obliqua*. *Holz als Roh- und Werkstoff* **63**, 365–371.
- Innes, T.C., Greaves, B., Washusen, R. and Nolan, G.B. (2007) *Determining the Economics of Processing Plantation Eucalypts for Solid Timber Products*. Forest and Wood Products Research and Development Corporation Report PN04.3007, FWPRDC, Melbourne, 90 pp.
- Nolan, G., Greaves, B., Washusen, R., Parsons, M. and Jennings, S. (2005) *Eucalypt Plantations for Solid Wood Products in Australia: A Review*. Forest and Wood Products Research and Development Corporation Report PN04.3002. FWPRDC, Melbourne, 130 pp.
- Northway, R.L. and Blakemore P.A. (1996) *Evaluation of Drying Methods for Plantation-Grown Eucalypt Timber B: Sawing, Accelerated Drying and Utilisation Characteristics of Eucalyptus grandis*. Forest and Wood Products Research and Development Corporation Report PN06.96. FWPRDC, Melbourne, 24 pp.
- Northway, R.L. and Blakemore P.A. (1999) Kiln drying plantation eucalypts: drying strategies. In: *Wood Drying Research and Technology for Sustainable Forestry beyond 2000*. Proceedings 6th International IUFRO Wood Drying Conference. January 1999, Stellenbosch, South Africa. Department of Wood Science, Faculty of Forestry, University of Stellenbosch, Private bag X1, Matieland 7602, South Africa., pp. 79–87.
- Washusen, R. (2006) Evaluation of product value and sawing and drying efficiencies of low rainfall hardwood thinnings. A report for the RIRDC/Land & Water Australia/FWPRDC/MDBC Joint Venture Agroforestry Program, 43 pp.
- Washusen, R. and McCormick, M. (2002) Recovery potential of quarter-sawn solid wood products from regrowth and plantation-grown *Eucalyptus nitens*. CSIRO-FFP Client Report No. 1227 for NRE. December 2002, 15 pp.
- Washusen, R., Reeves, K., Hingston, R., Davis, S., Menz, D. and Morrow, A. (2004) *Processing Pruned and Un-Pruned Blue Gum (Eucalyptus globulus) to Produce High Value Products*. Forest and Wood Products Research and Development Corporation Report PN03.1315. FWPRDC, Melbourne, 27 pp.
- Washusen, R., Baker, T., Menz, D. and Morrow, A. (2005) Effect of thinning and fertilizer on the cellulose crystallite width of *Eucalyptus globulus*. *Wood Science and Technology* **39**, 569–578.
- Washusen, R., Reeves, K., Reid, R., Morrow, A. and Bojadzic, M. (2006) A comparison of wood quality and product value of 16-year-old pruned *E. nitens* and 65-year-old native forest regrowth *E. nitens*. Ensis Client Report No. 1687, 12 pp.
- Washusen, R., Harwood, C., Morrow, A., Valencia, J.C., Volker, P., Wood, M., Innes, T., Ngo Dung, Northway, R. and Bojadzic, M. (2007a) *Gould's Country Eucalyptus nitens Thinning Trial: Solid Wood Quality and Processing Performance Using Conventional Processing Strategies*. Technical Report 168. CRC for Forestry, 49 pp.

- Washusen, R., Morrow, A., Ngo Dung, Bojadzic, M., Henson, M., Porada, H., Northway, R., Boynton, S., Chen Shaoxiong, Peng Yan, Nguyen Quang Trung and Bui Chi Kien. (2007b) Genetic variation in growth stress related wood behaviour of small diameter *Eucalyptus nitens* logs processed with a HewSaw R250 sawmill. Report for ACIAR project FST/2001/021: Improving the value chain for plantation-grown eucalypts in China, Vietnam and Australia: sawing and drying. July 2007. Ensis Client Report 1799, 39 pp.
- Yang, J.L. (2005). The impact of log-end splits and spring on sawn recovery of 32-year-old plantation *Eucalyptus globulus* Labill. *Holz als Roh und Werkstoff* **63**, 442–448.



SESSION: PROCESSING AND MARKETING HARDWOOD
SAWLOGS

Markets for the Wood Products from Non-Durable Hardwood Sawlog Plantations

TONY CANNON^{1,3} AND TREVOR INNES²

¹Forest Enterprises Australia (FEA) Limited

²FEA Timber Pty Ltd, Launceston

³Email: tonyc@fealtd.com

Abstract

Forest Enterprise Australia Limited (FEA) is distributing a kiln-dried and dressed hardwood plantation commodity product, EcoAsh™, into high-volume markets that compete directly with structural pine and hardwood. This product is the first successful example of the large-scale conversion of an Australian plantation eucalypt, *Eucalyptus nitens*, grown under pulplog silvicultural regimes into an alternative higher-value sawn timber. A premium of 20–30% over the base eucalypt pulplog price could be expected for logs harvested for EcoAsh™. The success of the whole operation is based on a vertical integration strategy and the use of high-efficiency linear sawing systems with high volume throughput, combined with strong residue markets.

The timber offers different sawing and building characteristics and performance advantages compared to those of traditional resources such as long-rotation pine and native hardwoods. Two of the main advantages of non-durable plantation eucalypt species are greater strength and nail-holding capacity. These provide better engineering outcomes that allow EcoAsh™ to replace some of the structural pine in housing construction. New applications such as flooring, panelling, furniture manufacturing and laminated beams are being tested with a view to accumulating performance data and credentials for future targeting of these markets. A compression kiln-drying process that can dry green-off boards in a few days should remove the current need for an open-air drying period of several months.

Brand identity, market development and a marketing strategy mean that dressed EcoAsh™ is now successfully distributed in Tasmania through 40 hardware stores.

Introduction

Forest Enterprises Australia Limited (FEA) is distributing a kiln-dried hardwood plantation product, EcoAsh™, from its Bell Bay sawmill to a number of Australia's major hardware outlets. This trade is forecast to rapidly expand as the resource available to FEA from *Eucalyptus nitens* plantations in Tasmania matures. The development of this innovative sawn hardwood and its marketing journey are outlined in the following paper as a case study of current domestic markets.

EcoAsh™ is a commodity product being sold into high-volume markets and needing to compete directly with structural pine and hardwood. This product is the first successful large-scale conversion of Australian plantation eucalypt grown under pulp-log silvicultural regimes into an alternative higher-value sawn timber. We will describe the advantages of this plantation hardwood product and the uses that have been developed for it.

We also review domestic and international markets for hardwood sawlog and their direction. We discuss current and potential pricing, the challenges ahead and development opportunities for this resource.

Background to FEA and its eucalypt plantations

Forest Enterprises Australia Limited is an Australian Stock Exchange- (ASX) listed public company with its head office in Launceston, Tasmania. The company was incorporated as a fledgling private company in 1985 and began by purchasing properties with high potential productivity under eucalypt plantations.

Establishment of eucalypt plantations on the company's own land began in 1987. In 1997 the company began harvesting these plantations, an operation that has been expanding since that time. FEA is now vertically integrated, so most the logs from FEA's and its grower investor's unpruned resource are sold to associated companies which process them for sawn timber production, export woodchips and potentially domestic peelers for veneer.

To further its vertical integration strategy, FEA purchased an existing small-log pine sawmill in August 2002. This sawmill is managed as a separate entity, wholly owned by FEA but known as FEA Timber Pty Ltd (FEAT).

To have some control and options for residue sales, FEA entered into a joint project with Neville Smith Timber Industries Ltd (now ITC Limited) to construct an export wood-fibre facility at the Port of Launceston in March 2003. The conveyors from this wood-fibre site are connected to existing woodchip loading facilities on the Port's wharves. This business is now known as Smartfibre Pty Ltd and is exporting both hardwood and softwood woodchips to a number of customers in Japan.

FEA Plantations Limited is a wholly-owned subsidiary of FEA and is a responsible entity under Managed Investment Scheme (MIS) provisions in Corporations Law. Including its current 2007 project, FEA Plantations has issued 15 consecutive offerings to the general public since 1993.

Significantly in the last two offerings, FEA Plantations has included an investment option for a sawlog regime called 'EcoAsh™ Clear', which is based on producing pruned sawlogs from thinned stands of mainly *Eucalyptus nitens* in Tasmania on a rotation of about 16 y. Currently pine and eucalypt sawlog projects attract around 12% of total woodlot investments, and the trend in MIS timber investments is for sawlog regimes to receive an increasing proportion of investment (AAG 2007).

By the completion of the current project, FEA will have over 50 000 ha of hardwood plantation under management. About 20 000 ha are in Tasmania, with the remainder in north-eastern New South Wales and south-eastern Queensland. Earlier projects, through to those established in 1998, either have been or are currently being commercially thinned, yielding both unpruned sawlogs for the FEA Timber sawmill and pulpwood for export woodchips.

Sawmilling

The sawmill purchase

FEA is committed to innovation and seeking ways to derive value from its supply chain. FEA was one of the sponsors of a 'Product Development Workshop—*Eucalyptus nitens*' facilitated by Private Forests Tasmania in February 2001. This workshop included a demonstration of sawing of small-diameter (20 cm small-end diameter (SED)) logs from unpruned *E. nitens* plantations at the recently opened HewSaw sawmill, which was then owned by a private company, TREC Pty Ltd.

The workshop included a review of the then-current research into using *E. nitens* for higher-value solid-wood production. Presentations at the workshop were made by researchers representing CSIRO, Forestry Tasmania and the Timber Research Unit of the University of Tasmania. The main research priorities were sawing systems, grading rules, drying systems, stability and shrinkage data, and identifying potential markets for final products.

In early 2002, FEA was approached about the purchase of the TREC sawmill. The purchase was underpinned by a contract for supply of radiata pine small-diameter (12–27 cm SED) logs, called micro-logs, from the manager of the main Tasmanian pine plantation estate.

An important consideration, however, was that FEA saw the potential for the Bell Bay sawmill to also process logs of similar size from plantation thinnings and clearfelling of the *E. nitens* plantations owned or managed by the company. Since its purchase in August 2002, commercial trials of sawing plantation-grown *E. nitens* have been undertaken, with the green sawn product being initially sold in the low-grade packaging market in Melbourne.

The Finnish-manufactured HewSaw

Prior to entering the pre-feed to the HewSaw, the logs are sorted on an electronic scanning line into various diameter, orientation and length classes. The scanner rejects logs that have too much sweep or are not straight enough to pass through the sawing machine. These logs are chipped for export.

The HewSaw is a Finnish-designed sawing system. The HewSaw (Figure 1) is a sawing machine that chips, saws and edges small logs in a single pass, efficiently and accurately, with a very high throughput.

Logs of each diameter class are sawn to a fixed sawing pattern. The chipping knives and circular saws are set up using computer software to maximise the recovery of sawn boards, with a weighting to product orders. As the log passes through the sawing machine, its rounded edges are removed by a chipper-canter to produce a square flitch. This flitch is then sawn and edged in a single pass to produce a mix of board sizes depending upon the sawing profile that the machine has been set to. Logs are processed in a single pass at line speed of about 60 m min⁻¹. These line speeds routinely allow up to ten 5.4-m logs min⁻¹ to be processed through the machine. Minimum log diameter is 120 mm and maximum is 350 mm.

The chips and sawdust are dropped onto conveyor belts and passed over a screen. This separates, to export specifications, sawdust (sold as fuel) from woodchips. Both softwood (pine) and eucalypt plantation woodchips are produced in separate batches.



Figure 1. HewSaw R200 arrangement of chipper-canters and saws

The sawn boards go on to an out-feed system which allows sorting into board sizes. An automatic stacker produces packs of boards that can be automatically racked for further value-adding or sold as green sawn and shipped within two days to mainly Melbourne markets.

The mill is currently processing over 170 000 t of logs per annum on a double-shift basis, despite a number of major production bottlenecks that could technically be replaced with automated systems. With additional pine resource and expansion of the eucalypt plantation harvest, however, FEA is building on a nearby site a new sawmill that will be capable of processing over 600 000 t of log annually.

FEA installed both hardwood and softwood kilns to greatly increase the margins on the timber it produces. FEA also installed a new high-speed moulder so that finished boards could be entirely packed ready for direct distribution to the market from the site.

The sawmill has given FEA the ability to process some of its existing eucalypt plantation resource into sawn timber for sale in domestic and export markets. FEA is the only sawmill operator in Australia to process plantation-grown *E. nitens* on an ongoing basis. This business initiative is adding value to FEA's plantation resource and helps to meet some of the company's aims of demonstrating more domestic value-adding of the plantation resource, improving the market opportunities of growers and increasing local employment.

Some of the eucalypt sawlogs being used are coming from plantation thinnings, which cull the less productive trees in order to allow the remainder to maximise their diameter growth. The logs from thinnings are from 8–10 y of age, and there are no apparent sawn-timber quality issues with logs of this age.

R&D and product development

Start with an idea—EcoAsh™

Many traditional sawmillers and builders would have the view that production of seasoned structural timber from young plantation eucalypts is not possible. FEA, however, after several years of product development is now producing stable sawn timber of consistent quality from very young eucalypt logs. The timber offers sawing and building characteristics that are quite different to those of traditional resources such as long-rotation pine and native hardwoods

EcoAsh™ is produced mainly as a structural-grade kiln-dried and dressed timber, only from plantation-grown *E. nitens*. Detailed span tables were produced to aid the use of EcoAsh™ in most potential building applications such as wall studs, plates, floor bearers, rafters, joists and beams.

The resource from which logs are produced is unpruned, so EcoAsh™ for exposed uses is currently available only as feature flooring and panelling. Roof trusses and floor joists can now be manufactured using software produced after testing by the major suppliers of truss-manufacturing systems.

Ongoing testing

The original testing was done by leading Australian timber engineering consultants who provide engineering design, analysis and testing for timber products. In 2004, P.J. Yttrup & Associates, Consulting Engineers, were engaged by FEA to conduct detailed tests of its sawn timber produced from young eucalypt plantations as part of the development of EcoAsh™.

FEA gave the firm a brief to test sawn boards of 9–13-y-old *E. nitens* in accordance with the quality standard, AS/NZS4063:1992. This included bending, shear, tension and compression testing to determine structural properties and suitability for building and construction use. Additional testing was carried out to determine the density and moisture content of the timber, and its hardness rating for use as flooring.

Samples of kiln-dried EcoAsh™ boards, both heart-in and heart-free and of various sizes—90 × 35, 90 × 45, 140 × 35 and 140 × 45 mm—from a manufacturing production run were tested. The batch was cut to size, weighed and measured for moisture content, then load-tested to breaking point in specially designed test rigs then located at the University of Tasmania's laboratory in Launceston.

The bending and compression test results came in at ratings similar to common grades of hardwood, making the timber ideally suited for standard framing in a range of building applications. However, as the range of properties measured varied between the equivalents of F11 and F17, a specific grade was developed called PGH (Plantation Grown Hardwood) to fully utilise EcoAsh™'s structural properties.

The test results and analysis provided the strength data from which span tables were generated for EcoAsh™ as part of the marketing process. These tables are based on design parameters in Australian Standards AS1720.1 and AS1684 (Standards Australia 1997b, 2006). The span tables are designed to inform builders and designers about the capabilities of the timber product, including load-bearing qualities for common framing members including bearers, joists, lintels and rafters.

FEA continues to trial EcoAsh™ in new applications such as flooring, panelling and furniture manufacturing, with a view to accumulating performance data and credentials for future targeting of these markets. EcoAsh™ floors have been installed in Brisbane, Sydney and Melbourne—flooring is a particularly tough market to please. Environmental and use conditions are some of the most testing for any timber application, and consumer requirements of appearance and longevity are demanding.

FEA employed Dr Trevor Innes, a mechanical engineer, over one year ago. He undertook a PhD in the drying of Australian eucalypt timbers and has worked in timber industry research for about 15 y. He now manages the test program, both in-grade EcoAsh™ testing and product development tests, as well as product and processing R&D.

To allow ongoing studies on the properties of EcoAsh™ and to ensure quality control, FEA has invested in its own on-site laboratory to perform grade testing on structural products. In addition, the laboratory has been used to compare properties of material of various ages and from a range of locations. Other species, including some of the sub-tropical species planted in northern NSW and south-eastern Queensland, have also been tested as early-age material.

Kiln drying

Drying of green-off-saw boards for further processing currently involves conventional racking and outside open-air drying for several months to dry the boards to about 20% moisture content (dry basis). They are then steam reconditioned for recovery of collapse shrinkage and conventionally kiln-dried over two to three days (depending on dimension) to the target moisture content of 10%, suitable for all common applications.

Reconditioning and final drying are performed in closely controlled Secea kilns manufactured in Italy. These kilns are gas fired with external exhausts for temperature control. They are equipped with effective insulation for thermal efficiency, baths to produce atmospheric steam for reconditioning, and water sprays and vents for humidity control. The kilns are constructed of high-grade aluminium and stainless steel to withstand the highly corrosive steaming and drying environment.

FEA has also installed a new Finnish kiln-drying system for its plantation eucalypt boards (Figure 2). The TeknoComp compression kiln-drying process was trialled with *E. nitens* boards exported to Finland in 2004. This new kiln technology utilises physical compression of the timber stack during drying to allow accelerated removal of moisture without inducing degrade. Work is underway to perfect drying schedules. The kiln installation and the R&D have been assisted by AusIndustry.

Research with this kiln is aimed at proving the technical and financial feasibility of drying green-off-saw EcoAsh™ boards in a few days, thus removing the open-air drying period of several months. Schedules of temperature, energy input and compression pressure over time will be optimised to minimise drying time without causing unacceptable drying degrade.

Timber stacks for the kiln are built with hollow aluminium plates separating the layers of boards. The aluminium allows uniform compression of the boards without causing indentation and discoloration. It also allows maximum heat transfer, with heat supplied to the drying air stream by electrical coils. Controlled airflow removes humid air from the drying stack.



Figure 2. TeknoComp compression kiln

The racks are built using a semi-automated vacuum system to alternately lift the aluminium sheets and layers of boards. The kiln is a three-chamber tunnel, each chamber having a capacity of 8 m³. The first chamber is for pre-heating and pre-pressing, the second is the main drying area, while the third is for controlled cooling. At the end of the schedule the rack is removed and dismantled using the same vacuum system, and the boards are ready for planing.

Brand development

What's in a brand? Bringing EcoAsh™ to life

From the outset, FEA saw the potential for creating a premium brand in a market sector that had traditionally been unbranded. Harvard Business School calls this approach ‘firstest with the mostest’. That is one of the key ideas in developing the brand and bringing the product to life.

A brand identity consultancy, which had worked on the Sydney 2000 Olympics and was the brand advisor to the Melbourne 2006 Commonwealth Games, was engaged to develop the EcoAsh™ brand. Exhaustive research was undertaken on a range of brand names through focus groups and packaging tests. The aim was to not only capture the imagination of consumers but to come up with an inspirational brand that could stand the test of time, highlighting the environmentally sustainable characteristics of the product in the minds of consumers.

The logo is equally as important—‘hero’ colours of green and brown represent the key attributes of EcoAsh™. The brand developers summarised the product brand as follows:

EcoAsh™ is a farmed timber product that has been grown in response to the need for timber that is not old growth, but contains the same qualities. The brand identity was required to sit within the ‘family’ of competing timber brands and at the same time express a bold statement of confidence that would provide cut-through in both wholesale and retail environments. The EcoAsh™ brand identity is built upon a story of intelligent solutions to critical environmental issues. The design uses a stencil-style typography to reinforce its practicality. The emphasis on the letter ‘O’ enables it to be isolated as a brand element—symbolic of the total environmental experience. The identity includes a palette of imagery that reinforces its distinction in the timber market and provides opportunities to build brand heritage both for internal and external audiences.

Building the market—and achieving balance

A combination of information highlighting the features of the product for traditional markets, together with an education program about the potential uses of EcoAsh™, has been developed. EcoAsh™ is a unique product, and it was recognised that the market needed to be developed at the same time as the product was being tested and rolled out. The trick was to grow each at the same pace.

After 3 y of sawing, drying, machining, engineering and marketing trials of 8–16-y-old *E. nitens* timber, FEA began to market the timber under the brand name ‘EcoAsh™’. Initially this was sold directly through the Tasmanian stores of one of Australia’s largest hardware businesses. This was accompanied by training and introduction sessions to provide knowledge of the product to local builders.

Over the last 2 y there has been intensive and successful TV and print marketing to provide general knowledge about the availability of a kiln-dried hardwood. EcoAsh™ is now available in most Tasmanian hardware stores. Support for these stores, and the builders using EcoAsh™, has been provided by having dedicated staff as sales managers.

Marketing strategy—more to it than meets the eye

Who buys EcoAsh™? There are a number of distinct audiences for the product including consumers, builders, architects and manufacturers—each with quite different sets of needs, expectations and marketing triggers.

From the outset, FEA knew it needed to roll out marketing strategies in the right order, and in line with product development scheduling. Construction-grade products and builders have been a priority to date. Part of this delivery was providing engineering tests and span tables to assist builders understand how EcoAsh™ can most effectively be used. Similarly, trials with nail-guns, gluing, gang-nailing, treatment, paint and stain applications have been important in providing builders with confidence in the competitiveness of EcoAsh™'s features.

Dressed EcoAsh™ is currently distributed only in Tasmania, through 40 hardware stores, although market testing has been undertaken for Melbourne.

Comparison with competing products

Testing to AS4063 has shown that EcoAsh™ has a performance advantage over its main competitors as structural framing.

Native forest hardwood

Our product is much cheaper than native forest hardwoods, while maintaining many of the strength and stability characteristics of these hardwoods. It is price competitive—the unit cost of manufacture is comparable to that of softwood processors due to the use of high-volume throughput processing techniques. Generally, these processing options have not been sufficiently compatible with the species, wood properties, resource volume or stability of supply to allow native forest hardwood processors to routinely use them.

Compared with most native forest timbers, our product is of lower density and therefore lower weight. The lower density and uniformity of the timber's structure has made the use of nail guns easier and improved acceptance by builders.

Testing by nail plate manufacturers and the inclusion of EcoAsh™ properties in truss software packages has allowed EcoAsh™ to be used in floor joists and roof trusses.

EcoAsh™ is:

- amenable to air drying and stabilisation through kiln-drying in a shorter period than native forest timbers. Further research and development work with the latest compression kiln-drying technology should see drying times decrease considerably in the near future
- more amenable to preservation treatment, with research underway to improve treatment processes
- more dimensionally stable, with lower change in dimension of flooring with changes in ambient climate.

Consumers are attracted to timber from plantation sources, accepting this material as being from an environmentally sustainable source.

Softwood

EcoAsh™ is much stronger in bending, tension and compression than radiata pine, allowing material of smaller dimensions to be used in strength-limited applications. It also is more stable, so that wall frames stay straighter when exposed to the weather during construction. The excellent nail-holding capabilities of EcoAsh™ mean fewer nails are required to achieve necessary joint strength.

With increased hardness and much less dimensional movement with humidity changes, EcoAsh™ is well adapted for use in the manufacture of lining and flooring.

With its ability to be treated, EcoAsh™ may be a practical substitute for radiata pine for outdoor applications including decking, deck framing and poles. Many consumers also are attracted to using hardwood instead of softwood in a number of applications.

Specifications for EcoAsh™

‘In-grade’ testing is ongoing to ensure EcoAsh™ has the properties required by standards AS4063 (Standards Australia 1992) and AS4490 (Standards Australia 1997a) (Tables 1 and 2; Figure 3).

While requirements for AS4490 are being exceeded, ongoing testing is needed to ensure that properties of material from different plantations do not differ significantly.

Test results show that hardness of EcoAsh™ is 4.7 kN (Table 1), a value similar to that of native forest Tasmanian oak. Joint classification for nailing and bolting testing indicated joint group of JD2, published as JD3 as Australian Standards limits rating by species. This classification is equivalent to that for Tasmanian oak and Victorian ash.

Table 1. Specifications for EcoAsh™. Source: Standards Australia (1997a) and Yttrup and Associates Pty Ltd (2006)

Specification	Standard
Grading	PGH 20S
Standards	AS/NZS 4063/4490
Hardness (Janka) (kN)	4.7
Density kg (m ⁻³)	605
Nail rating	JD3
Lengths (m)	5.4, 4.8, 4.2, 3.0, 2.4 and docked to length

Table 2. Physical properties of EcoAsh™ and competing products

Property	Product			
	MPG 10 Pine	MGP 12 Pine	F17 KDHW	EcoAsh™
Bending (fb)	16	28	50	40
Tension (ft)	8	15	30	17
Shear (fs)	5	6.5	4.3	4.1
Compression (fc)	24	29	40	40
Stiffness (E × 10 ⁻³)	10	12.7	14	10.5

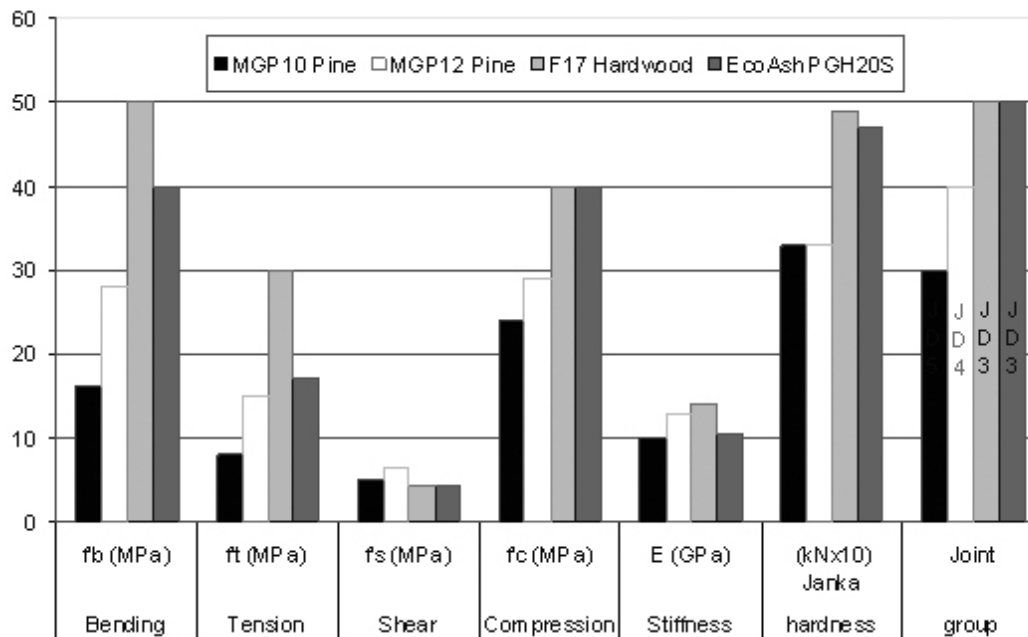


Figure 3. Physical properties of EcoAsh and competing products

Current EcoAsh™ product range and markets

Initial EcoAsh™ processing research was focused on structural performance. FEA has facilitated and is extending research and development into a wider range of sawn timber and manufactured products. Successful production and marketing has been initiated for:

- framing / structural applications
- lining
- flooring
- trusses.

Work is progressing on new products including:

- moulding
- decking
- glue-laminated beams
- overlay flooring.

EcoAsh™ is a hardwood product that in the Tasmanian market—where it has been heavily promoted—has taken some market share from the softwood sector. In mainland markets, however, EcoAsh™ has not been introduced, promoted or demonstrated widely. It is not expected that EcoAsh™ will make major inroads into the mature softwood market initially, as this would entail a change of product for many builders, architects and planners.

EcoAsh™ is supplied from a substantially smaller and younger plantation resource than softwood, which has been grown commercially for more than a century. Consequently the small volume available limits the proportion of the market that EcoAsh™ can capture.

The initial focus for EcoAsh™ has been on grades and products equivalent to processed softwood where it is most likely to be successful in winning market share. The approach being taken by FEA is to establish a market footprint for products where EcoAsh™ has the greatest potential. Then, as increased log resources become available and there is increased market acceptance, the volume and range of products will be increased.

To maximise the performance benefits of EcoAsh™ for engineering applications, FEA will be making a strategic move from visual grading of sawn timbers to machine grading of some products. The change will encourage greater recognition of the structural strength characteristics of EcoAsh™ by offering more than one structural grade.

Roof and floor trusses

As well as structural testing leading to the PGH20S grade and other testing such as for nail-holding, hardness and stability, EcoAsh™ has been tested for the manufacture of trusses. The two major manufacturers of truss systems in Australia, Pryda and MiTek, have tested their nail-plates with EcoAsh™ and now incorporate EcoAsh™ PGH20S into their truss design software. Truss manufacturers using either system can now make trusses from EcoAsh™.

In future, machine stress grading will provide the opportunity to segregate particularly high stiffness material into a special grade for truss manufacture. This, combined with an increase in available volumes of EcoAsh™, is expected to secure a niche in this market for FEA.

Flooring

FEA is currently producing conventional tongue-and-groove flooring from EcoAsh™. This is a knotty product visually similar to radiata pine, but harder. Its main advantage in the market is its stability. All timber moves dimensionally in response to changes in ambient humidity, but EcoAsh™ moves much less than competing native forest hardwood or radiata pine.

Another market niche FEA is currently investigating is overlay timber flooring. This is flooring designed to ‘float’ on top of concrete, particleboard or other structural flooring. Flooring boards or panels are joined together so that shrinkage does not result in gaps between panels. FEA has produced a trial batch of EcoAsh™ overlay flooring by cutting short clear sections and rejoining these into panels that are then sanded and finished ready for laying. In contrast to other ‘engineered’ flooring that has a thin veneer surface, EcoAsh™ overlay is solid timber that can be sanded and recoated after several years of wear, just like a traditional solid timber floor. An automated defect-recognition-and-removal system could be used in the manufacture of appearance products such as overlay flooring.

Laminated beams

The size of beams available in EcoAsh™ is dictated by the size of the logs available and the sawmill capacity. FEA is conducting trials into the feasibility of manufacturing glue-laminated beams from EcoAsh™. These beams are produced by laminating thin pieces of timber into deep-section beams for high-performance structural members such as lintels over wide doorways. Initial tests have proven the feasibility of the concept, with good results achieved from common adhesives.

As in ‘I’ beams of steel or engineered wood products, the strength and stiffness of glue-laminated beams is largely determined by the outer laminates. The machine stress grader at the new FEAT sawmill will allow FEA to select particularly high stiffness EcoAsh™ for the outer laminates of glue-laminated beams, with pieces of lower stiffness or pine being used for the inner laminations. Strength and stiffness could be further improved by cutting out strength-reducing defects such as knots and rebuilding laminates to length with structural finger joints; this would also allow manufacture of beams to the length of the glue-lamination press.

Treated decking

FEA is currently unable to access a treatment plant for chemical treatment of EcoAsh™ suitable for exterior decking. There will be a treatment plant on-site at the new sawmill. Tests are currently underway to optimise the treatment process to attain the chemical penetration and retention required for exterior applications. This market niche is currently empty; exterior timber decking is currently treated pine, imported tropical hardwood, or very expensive naturally durable Australian native forest timber.

EcoAsh Clear™

EcoAsh™ is a solid-wood structural product produced from hardwood plantations about 8–15 y old. The logs from these plantations produce sawn timber with knots. The number of knots permitted in sawn products is limited by grading rules to ensure that the desired structural properties are obtained.

More lucrative decorative and select-grade timbers, especially in long lengths for appearance purposes such as furniture and mouldings, generally do not have knots. In order to produce a product that can be sold into this market segment, and to attract a premium, FEA has developed EcoAsh Clear™. This premium product is produced from plantations that have been pruned from a young age so as to produce appearance-grade timber clear of knots.

With the gradual decline in the hardwood resource available from native forests, clear hardwood sawn timber has become increasingly scarce. Demand from consumers, architects and builders for clear hardwood timber will increasingly be met by either imports of hardwood, typically from tropical forests, or from hardwood plantations as the pruned resource and technology are developed. The market potential for EcoAsh Clear™ is very positive.

EcoAsh Clear™ will have the added advantage over native forest timber in this market segment of being plantation grown and therefore appealing to many consumers, manufacturers and architects who prefer timber from farmed tree resources.

It is unlikely EcoAsh™ will be sliced for the production of veneers, due to the small piece size. There is potential, however, for pruned logs to be sold into a market for quality peeler logs. Two rotary veneer mills have either commenced production or are under construction in Tasmania, and their operators are interested in the plantation hardwood resource.

Price premiums

Price premiums EcoAsh™ and EcoAsh Clear™

There is no national scale for the pricing of sawn timber from hardwood plantations since volumes are still small and the companies that are producing these timbers need to sell the products into the established hardwood or softwood markets.

FEA has launched EcoAsh™ as a structural-grade timber in the softwood sector, and therefore for comparative purposes it is reasonable to analyse the stumpage premiums attracted by softwood sawlogs over softwood pulplogs.

Softwood log pricing is tracked by the Australian Pine Log Price Index, which is based on the sales of five of the largest softwood log suppliers in the eastern states of Australia (Queensland Department of Primary Industries, State Forests New South Wales, ACT Forests, Hancock Victoria Plantations and Forestry South Australia). In financial year 2005–2006, it was based on the sale of almost 8 Mm³ of logs of different grades worth \$A292.1 M (KPMG 2006).

The weighted average prices for each of seven log grades tracked by the index are shown in Figure 4. It can be seen a premium of about \$A20 m⁻³ has been paid for small sawlogs over pulplogs. As stated above, these prices are a weighted average from the pricing data supplied by five major softwood log producers.

From the data above it could be concluded that a log price premium—over the base eucalypt pulplog stumpage for logs grown over a standard rotation—of at least 20%, but more likely around 30%, is reasonable and could be expected for logs grown for EcoAsh™. It should be noted that where there are competitive markets, eucalypt plantation pulplog prices should be at least in the range of \$A22–30+, depending upon transport distances.

There are good potential markets for EcoAsh Clear™—with improved appearance, strength and reliability, especially for engineering uses—as the availability of sawn timber that is clear of knots and other minor defects after pruning is increasing.

Table 3 shows indicative NZ radiata pine log prices based on a range of information from different sources. The export prices are FOB and the domestic prices are mill door, so an adjustment and some assumptions are required to get back to comparable stumpages. Pine stumpages of \$NZ8–15 m⁻³ would be comparable with Australian pine pulpwood prices. Pruned logs P2 30–39 cm SED are \$NZ50–55 and P1 pruned logs >40 cm SED are \$NZ100–115.

The returns to growers for EcoAsh Clear™ peeler logs could be adjusted to reflect the shorter growing period, smaller allowable diameter and greater tolerance for small defects.

At the lower end of the scale, Private Forests Tasmania listed hardwood veneer logs as attracting a stumpage of up to \$75 m⁻³ back in 2002. In NSW, private native forest logs used in rotary veneer production can yield a stumpage of \$90 m⁻³ (personal information).

In conclusion, an expected premium for EcoAsh Clear™ sawlogs, veneer and peeler veneer logs of between 100% and 150%, over pulpwood logs, would be realistic. If supply of clear hardwood from native forests continues to slide due to further extension of native forest reserves, and demand for the product remains strong, the premiums estimated above are likely to be underestimates.

Sawn timber pricing

ABARE produced an Australian Structural Wood Price Index from 1996 until 2004. Based on reduced native forest hardwood supply and the increased availability of softwood sawlogs, the relative prices of softwood and hardwood sawn timber changed substantially. The indexed price of hardwood increased by 36% over the 8 y the index was produced, while softwood increased by only 18%.

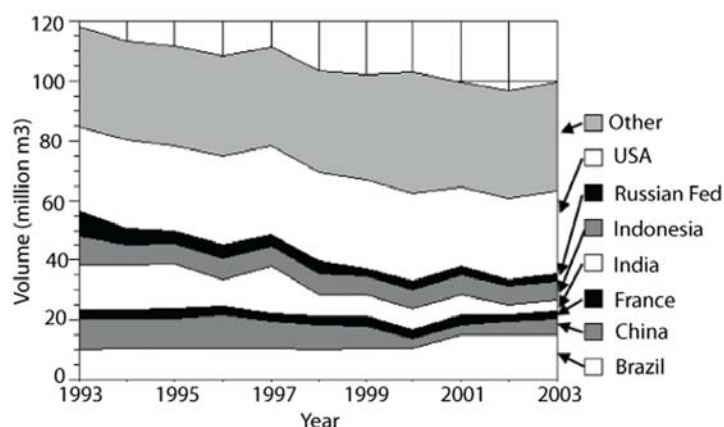


Figure 4. Australian softwood log prices: January–June 1995 to July–December 2006 (\$AU m⁻³ except pulp logs at \$ t⁻¹). Source: KPMG (2006); IndustryEdge (2006, 2007)

Table 3. New Zealand pine log prices. Source: Ministry of Agriculture and Forestry New Zealand (2007)

Market and generic log type	Pricing point (NZ\$)	
	June 2007 quarter	Twelve-quarter average
Export (NZ\$ per JAS* m ³ f.o.b.)		
Pruned	112–133	170
Unpruned A Grade	9–120	95
Unpruned J Grade	107–118	86
Unpruned K Grade	90–108	83
Pulp	57–70	59
Domestic (NZ\$ per tonne delivered at mill)		
P1	123–141	140
P2	98–111	110
S1	91–98	87
S2	90–94	83
L1 and L2	73–96	65
S3 and L3	68–82	64
Pulp	40–55	43

*JAS = Japanese Agricultural Standard

Table 4. Timber market survey—range of sawn timber prices.
Source: URS Timber Market Survey 2006 (URS Forestry 2007)

Product	Average price range (\$ m ⁻³)	Survey period
MGP10 softwood	380–430	Oct 03–Jul 06
MGP12 softwood	430–470	Jul 02–Jul 06
F17 KD hardwood	870–940	Jul 02–Jul 06
KD flooring, ash		
Low feature	1100–1200	Jul 03–Jul 06
Medium feature	950–1000	Jul 03–Jul 06
High feature	640–650	Jul 03–Jul 06

With this index being discontinued, the most relevant and more detailed hardwood market and pricing information available is the URS Timber Market Survey 2006 of the eastern States (Table 4, URS Forestry 2007). This provides a range of prices based on finished product as \$ m⁻³. Demand for finished timber products is strongly correlated with housing starts and economic activity. Recent negative factors have been competition with engineered wood products and the increased sawn timber supply due to mill expansions by several softwood suppliers (URS Forestry 2007).

EcoAsh™ is a non-durable plantation hardwood competing with some of the

commodity products from the softwood sector, but it also has properties desirable for some end uses. At a very early stage of its acceptance in the timber market, this allows it to be priced around or higher than MGP 12. EcoAsh™ has better bending and tension strength than MGP12, and this advantage could be routinely exploited, for example, in trusses.

Getting EcoAsh™ into the markets to which it is best suited, and where we can best capture the value of its characteristics, requires more research on issues such as grading, promotion and education.

It is anticipated that EcoAsh Clear™ will potentially be comparable to select-grade ash and attract a price of \$950–1200 m⁻³ for end uses such as joinery or flooring.

Markets

Australia

Hardwood removals from native forests in Australia have fallen at an average rate of 1.9% y⁻¹ since 1995 (10.9 Mm³ to 8.8 Mm³, Figure 5). While the native forest pulpwood volume harvested has fluctuated, there has been a steady trend of reduced saw and veneer production from 4.3 Mm³ in 1995 to 3.2 Mm³ in 2006. This is an about 2.5% annual decline in native forest sawlog production. Much of this decline is due to reduced supply off public lands as state governments have phased out native forest logging and expanded reserve areas (AAG 2006).

Softwood removals have risen at an average rate of 4.7% y⁻¹ since 1995 (8.7 Mm³ to 14.4 Mm³) and total removals have risen at a rate of 3.0% y⁻¹ since 1995 (19.6 Mm³ to 27.0 Mm³, Figure 5)). Native forest harvesting still accounts for 33% of the total harvest volume (ABARE 1995–2007).

With a trend similar to that of the harvest volumes above, there has been a 5.7% average annual increase in sawn softwood production and a corresponding 1.8% y⁻¹ decline in hardwood production. There has also been an annual 3.3% increase in hardwood timber imports, with a large proportion of these coming from Malaysia and Indonesia (ABARE 1995–2007).

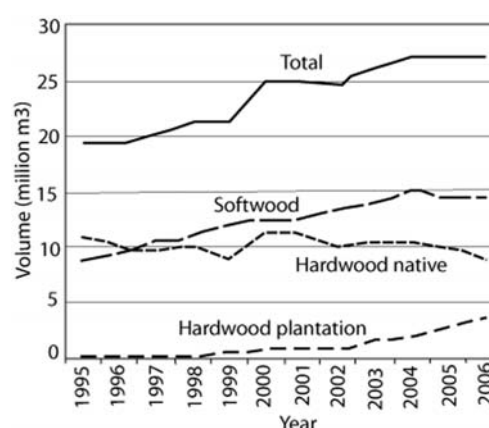


Figure 5. Roundwood removals from Australia's forests. Source: Australian Forest and Wood Product Statistics, ABARE (1995–2007) and IndustryEdge (2007)

Future trends forecast that the available supply of softwood sawlogs across Australia should stabilise at 10–10.5 Mm³ for the next 15–20 y. This is based mainly on the areas of softwood plantations already established (Parsons et al. 2007). This plateau is also partly caused by the cessation in the Commonwealth funding to the states to develop softwood plantations in the 1980s. The apparent consumption of sawn timber has increased at an average rate of 2.2% y⁻¹ over the last decade, just less than two-thirds the rate of growth in GDP. If the same rate of growth and correlation continue, by 2020, an additional 6 Mm³ y⁻¹ of softwood sawlogs will be required, leading to a significant shortfall in log supply (IndustryEdge 2006).

The expansion of softwood production has been accompanied by substitution of softwood products in traditional structural uses of hardwood. Higher-quality native forest hardwood sawn timber has become more focused on higher-value products such as flooring, joinery and furniture components, but structural uses for kiln-dried hardwood in housing construction is still one of the major—if not the major—product uses (AAG 2006; URS Forestry 2007).

One of the main opportunities for non-durable plantation eucalypt species is to replace some of the structural pine in housing construction. In particular, finished plantation eucalypt timber has potential in construction areas where its properties such as greater strength and nail-holding capacity will provide better engineering outcomes. Given the reduced rate of new plantings of softwood in Australia and the increased consumption trends within the Australian market, there appear to be significant opportunities for a price-competitive commodity hardwood product to compete with softwood sawn timber in the structural market.

Returns may be increased by pursuing niche markets in which plantation eucalypt timber has an advantage due to its natural properties. There will also be a need to educate the market, and particularly architects and builders, to use this new product as outlined in the EcoAsh™ marketing story above.

In marketing there can be an emphasis on ‘eco-labelling’, but it should be noted that in the URS Timber Market Survey 2006 (URS Forestry 2007) only 25% of timber re-sellers in eastern Australian states reported selling certified or eco-labelled products. The marketing of EcoAsh™ in Tasmania, however, has emphasised its plantation origin and environmental credentials. We believe that having environmental credentials will become increasingly important for acceptance by some re-sellers and for supply to some construction projects into the future.

As the production of EcoAsh™ is from plantation logs that were originally destined for woodchip production, the definition of sawlog in estimates of plantation log supply may need to be more flexible. The quality of sawlog that can be used for sawn timber will depend upon the sawing technology, volumes, markets available and marketing input. The logs used currently for EcoAsh™ are not included in plantation sawlog categories based on conventional sawlog specifications in private property production figures published by Private Forests Tasmania, but they are included in the plantation hardwood pulpwood volume (Private Forests Tasmania 2007). They have also not been used in forecasts of plantation sawlog supply as outlined in the recent BRS report (Parsons et al. 2007).

It needs to be remembered that up to 90% of new plantation establishment in Australia is being funded through Managed Investment Schemes (AFG/TIMA 2006). Most of this funding is for short-rotation pulpwood-focused crops, and the eucalypt sawlog projects are relatively short term—from 13–20 y (AAG 2007). These projects are not going to produce the equivalent of native forest sawlogs suited to sawmilling in conventional sawmills, and most private investors do not have the investment time-frame outlook to accommodate the long rotations needed to grow conventional sawlogs. The opportunity for secondary markets as provided for in taxation changes legislated in June 2007 may increase trading in immature plantations and provide increased liquidity to plantation investors. This may improve the attractiveness of longer-rotation plantation management. However, this is yet to be tested in the market and it will obviously take some time for these changes to increase sawlog supplies.

Global

Global production of sawn timber has been increasing at $2.6\% \text{ y}^{-1}$ since 2000, following recovery from the Asian economic downturn in 1997. However, while sawn hardwood has been about one-third the production of sawn softwood, hardwood production has been declining (Figure 6). Hardwood sawn timber supply is decreasing at an average rate of about $0.9\% \text{ y}^{-1}$, principally due to the declining native forest resource from which it is predominately supplied. In contrast, the supply of sawn softwood is increasing at an average rate of $3.9\% \text{ y}^{-1}$.

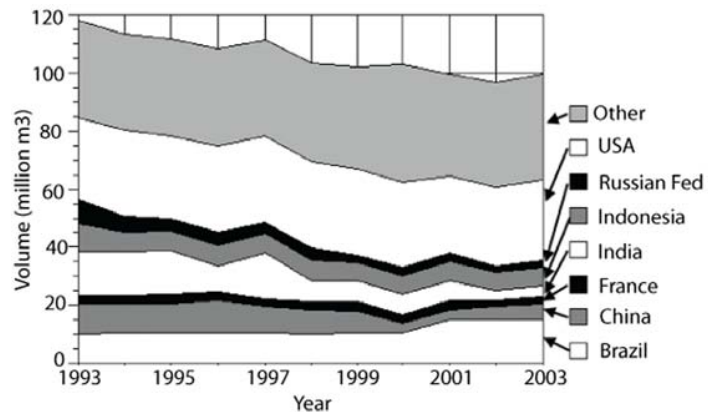


Figure 6. World production of sawn hardwood: 1993–2003 (million m³). Source: FAO; IndustryEdge (2006)

The largest producer of sawn hardwood is the USA, with just over a quarter of global supply. Between 1999 and 2003, however, production in the USA fell at an average rate of $2\% \text{ y}^{-1}$.

Countries that in the past have been able to harvest native hardwood forests for timber are increasingly reducing reliance on this resource and transferring to supply from plantations. Brazil, for example, between 2000 and 2003 increased its supply of sawn hardwood at an average rate of almost $13\% \text{ y}^{-1}$. This rise has increasingly been sourced from plantations (IndustryEdge 2006).

There are numerous reports of successful utilisation of eucalypts in the major growing countries such as Brazil, Chile, Argentina, China, Spain, South Africa and Uruguay (Austin 2000; Hopewell 2002; Beadle et al. 2007). The global decline in available native forests for hardwood log supply and the opportunity for economic conversion of pulpwood crops to sawlog production has driven a trend for greater use of planted eucalypts for solid-wood uses.

We predict that there will be an increasing development of a global market for sawn hardwood, not necessarily at the high-value end of the spectrum. The ability to remove defect and utilise short pieces through efficient finger-jointing means that not just high-input pruned crops will be attractive to manufacturers requiring hardwood sawn timber in countries such as China and other South-east Asian destinations.

In international timber trade, the environmental card will become increasingly important, and having a plantation-grown product will provide a marketing edge. Developing a market for niche products, perhaps in partnership with local companies, is likely to be far more successful than trying to compete directly against sawn softwood producers. There is a very competitive market for this commodity product. Some of this is certified PEFC or FSC, so additional 'plantation' branding is likely to be an advantage.

Conclusion

The processing of, and the development of markets for, non-durable plantation hardwoods can be successfully undertaken. There is potential for increased demand from both domestic and international markets for this plantation-grown hardwood timber—with attention to quality and market development.

References

- AAG (2006) *Market Overview: The Australian Eucalypt Sawwood Industry, January 2006*. Australian Agribusiness Group, Melbourne, <http://www.ausagrigroup.com.au/#>
- AAG (2007) *Agribusiness MIS Industry End-of-Year Round Up Report, July 2007*. Australian Agribusiness Group, Melbourne, <http://www.ausagrigroup.com.au/#>
- ABARE (1995–2007) *Australian Forest and Wood Product Statistics*. Australian Bureau of Agricultural and Resource Economics, Canberra.
- AFG/TIMA (Australian Forest Growers and Treefarm Investment Managers Australia) (2006) Submission to the Review of the Taxation of Plantation Forestry. http://www.treasury.gov.au/documents/1000/PDF/062_AFG_TIMA_combined.pdf
- Austin, S.H. (2000) *The Growth and Utilisation of Plantation Eucalypts within Eastern South America*. Gottstein Fellowship Report. The Gottstein Trust, Clayton South, Victoria, 53 pp. <http://www.gottsteintrust.org/html/reports/catalog.htm#saustin>
- Beadle, C.L., Forrester, D., Wood, M., Valencia, J.C. and Medhurst, J. (2007) *Effects of Silviculture and the Environment on the Variables that Determine Outcomes from Eucalypt Plantations Managed for Solid Wood Products*. CRC for Forestry, Technical Report 173, 116 pp.
- FAO. Food and Agricultural Organisation of the United Nations. <http://www.fao.org/forestry/en/>
- Hopewell, G. (2002) *Sawn Recovery and Utilisation Potential of Fast-Grown Argentinean Eucalypts*. Dennis Cullity Fellowship Report. FWPA, Melbourne, <http://www.fwpa.com.au/content/pdfs/Gary%20Hopewell%20PG01.3104.pdf>
- KPMG (2006) *Australian Pine Log Price Index January 2006*. <http://www.kpmg.com.au/Default.aspx?TabID=735&KPMGArticleItemID=1346>
- IndustryEdge (2006) Market report for sawn plantation hardwood. Internal report for FEA.
- IndustryEdge (2007) Market information report on the Australian forestry industry. Internal Report for FEA.
- Ministry of Agriculture and Forestry New Zealand (2007) *Indicative Radiata Pine Log Prices*. http://www.maf.govt.nz/forestry/statistics/log_prices.
- Parsons, M., Frakes, I. and Gavran, M. (2007) *Australia's Plantation Log Supply 2005–2049*. Bureau of Rural Sciences, Department of Agriculture, Fisheries and Forestry, Canberra.
- Private Forests Tasmania (2007) *Annual Report 2005–06*. Hobart.
- Standards Australia (1992) *Australian Standard 4063: Timber: Stress-Graded. In-Grade Strength and Stiffness Evaluation*. Standards Australia, Sydney.
- Standards Australia (1997a) *Australian/New Zealand Standard 4490: Timber—Stress-Graded: Procedures for Monitoring Structural Properties*. Standards Australia, Sydney.
- Standards Australia (1997b) *Australian Standard 1720.1: Timber Structures—Part 1: Design Methods*. Standards Australia, Sydney.
- Standards Australia (2006) *Australian Standard 1684: Residential Timber-Framed Construction*. Standards Australia, Sydney.
- URS Forestry (2007) Timber market survey 2006. Report for Forests New South Wales.
- Yttrup, P.J. and Associates Pty Ltd (2006) Report 15181, September 2006.



SESSION: PROCESSING AND MARKETING HARDWOOD
SAWLOGS

Markets for Wood Products from Durable Hardwood Sawlog Plantations

MARTIN GREALY

Forests NSW, Locked Bag 23 Pennant Hills, NSW 2120

Abstract

In a world of increased forest reservation and environmental regulation of native forest harvesting, supplies of naturally durable timbers continue to fall short of traditional market demand, opening the door for imports, preservative-treated less durable species, alternative non-wood materials or other design solutions. However, these options have not fully satisfied the marketplace, and market values and demand for naturally durable timbers have continued to climb.

The opportunity now exists to establish plantations to meet both traditional and expanding high-value market demands for naturally durable species.

The challenge is to grow these species in viable plantations that produce the required mix of products throughout the rotation and still deliver sufficient returns to maintain their relevance in an increasingly competitive investment marketplace.

This paper describes current and emerging markets for timber of naturally durable species that could increase the attractiveness of establishing plantations of purpose-specific durable hardwoods.

Introduction

Hardwood *Eucalyptus* and *Corymbia* plantations have been planted in many countries around the world, mainly to meet demands for fuelwood and fibre for paper and other reconstituted products. By economic necessity, these products have been produced from fast-growing short-rotation plantations. More recently in Australia there has been a focus on managing hardwood plantations for higher-value products such as structural timber, flooring and rotary-peeled veneer. These efforts have still essentially focused on faster-growing and higher-pulp-yielding hardwood species suitable for selected sites. However, the versatility of durable hardwood species, which can be directed to a wide range of end products, is being increasingly recognised as an opportunity to minimise future market risk.

Markets for naturally durable timber products continue to be met from the sustainable harvesting of native forests. These timbers are recognised for their unique natural characteristics, particularly in relation to their durability, but also often for their strength and appearance as well as some specific fit-for-purpose uses. While timbers that exhibit some durable characteristics naturally occur in each state of Australia, the forests where most of these species naturally occur are found in New South Wales (NSW) and Queensland.

Over the last twenty years in these states, increased forest reservation and environmental prescriptions for native forest harvesting operations have substantially reduced sustainable supplies of many of these naturally durable timbers. Efforts to either reproduce or replicate this durability through imports, chemical treatments, alternative materials or other means have not fully satisfied the market, and so both demand for and market values of the naturally durable timbers have continued to climb.

It is in this environment that investment in plantations of naturally durable timber, involving longer rotations, begins to become more financially attractive. That said, a few high-priced products at the final harvest won't override the necessity to have in place a fundamentally sound plantation operation including land acquisition, site and species selection, establishment, silviculture, pruning and economic management. Nonetheless, high-value markets for all of the products from thinning and final harvest will help to underpin the financial viability of longer-rotation hardwood plantations in Australia, and add to any returns on investment that may be realised through taxation, carbon and other benefits.

This paper does not attempt to describe or solve the many challenges that must be faced in growing durable, longer-rotation hardwood plantations economically. Rather it seeks to identify the range of markets that currently or potentially exist for durable hardwoods that could assist investment in such plantations to meet increasing high-value market demand.

Background

While this paper will focus on markets for wood products from hardwood plantations of naturally durable species, chemical timber treatments to increase durability cannot be ignored. Indeed, chemical preservative treatment of sapwood in hardwood logs will serve to enhance the performance of both naturally durable and less durable hardwood timber species.

Bootle (1983) identified in-ground durability classes for all the major timber species in Australia. These classes range from most durable (Class 1) to least durable (Class 4). For the purposes of this paper 'durable' will refer to Class 2 or better according to AS5604 2003 (Standards Australia 2003).

Table 1. A list of the major Class 1 and 2 commercial hardwood timber species, their classifications and a rough indication of current availability (low (L), medium (M), high (H))

Common name	Species	Class	Availability
Grey box	<i>Eucalyptus microcarpa</i>	1	M
Red bloodwood	<i>Corymbia gummifera</i>	1	L
Steel box	<i>E. rummeryi</i>	1	L
Grey gum	<i>E. propinqua</i> <i>E. punctata</i> <i>E. longirostrata</i>	1	M
Broad leaved ironbark	<i>E. fibrosa</i>	1	L
Grey ironbark	<i>E. paniculata</i>	1	M
Narrow leaved red ironbark	<i>E. crebra</i>	1	L
Red ironbark	<i>E. crebra</i>	1	L
Gympie messmate	<i>E. cloeziana</i>	1	L
Sugar gum	<i>E. cladocalyx</i>	1	L
White mahogany	<i>E. acmenoides</i>	1	M
Turpentine	<i>Syncarpia glomulifera</i>	1	L
Tallowwood	<i>E. microcorys</i>	1	M
Blackbutt	<i>E. pilularis</i>	2	H
New England blackbutt	<i>E. andrewsii</i>	2	M
Spotted gum	<i>C. maculata</i>	2	H
White stringybark	<i>E. eugenoides</i> <i>E. globoidea</i>	2	H
Red mahogany	<i>E. resinifera</i>	2	L
Yellow stringybark	<i>E. muellerana</i>	2	M
River red gum	<i>E. camaldulensis</i>	2	H

Table 1 lists the major Class 1 and 2 commercial hardwood timber species and their current availability. Of the species listed, only blackbutt, spotted gum, sugar gum, Gympie messmate and yellow stringybark are grown in plantations of any scale, and not all are under long-rotation regimes. In a global sense, the available durable resource either in native forest or in plantations is a small fraction of the non-durable one, and it is expected that the comparative value of naturally durable timbers will continue to climb in future.

In NSW, for example, Forests NSW has established up to 30 000 ha of hardwood plantations that are a mix of species best suited to individual site and location parameters. Just over 50% consists of Class 1 and 2 durable species, but less than 5% of the total are Class 1. A profile is provided in Figure 1.

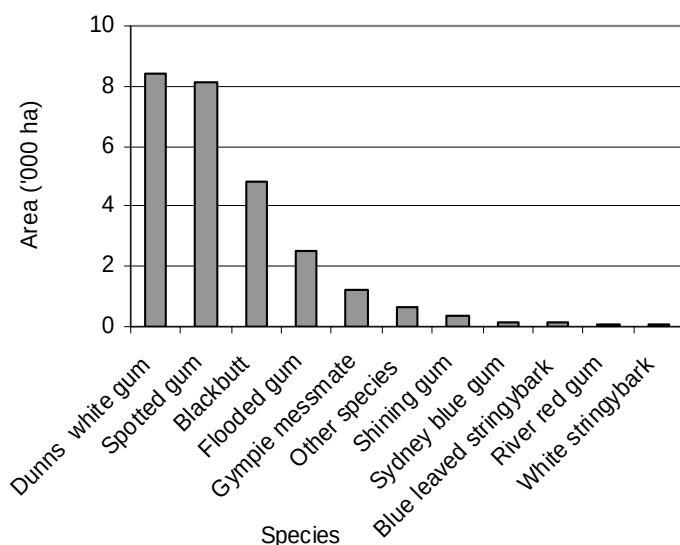


Figure 1. Areas of Forests NSW hardwood plantation species

Table 2. Progeny trials and seed orchards established by Forests NSW

Species under tree improvement		Seed orchards established	Elite seed available
Common name	Species		
Gympie messmate	<i>Eucalyptus cloeziana</i>	2008	2011
Sugar gum	<i>E. cladocalyx</i>	2008	2011
White mahogany	<i>E. acmenoides</i>	2008	2011
Blackbutt	<i>E. pilularis</i>	2002	Now
Spotted gum	<i>Corymbia maculata</i>	2008	2011
White stringybark	<i>E. globoidea</i>	2008	2011
Red mahogany	<i>E. resinifera</i>	2008	2011
River red Gum	<i>E. camaldulensis</i>	2004	2008

results. Other operational plantation trials for Class 1 durable hardwood species, particularly some of the ironbarks, have delivered mixed results, and the slower growth of these species has challenged their commercial viability to date.

Understanding the particulars of growing some plantations over the longer rotations necessary to produce larger round and end-section timbers will undoubtedly require further research, but to obtain the earliest possible results and to take advantage of the current investment environment, this effort should commence now. The opportunity also exists for further research on the particulars of establishing, managing, harvesting, processing and marketing of durable species.

Markets for durable timbers

Naturally durable hardwood timbers often have other strength and appearance characteristics that assist in securing specific market shares. The focus of this paper is on durability characteristics, but discussion of suitable markets will often include reference to these other characteristics. Markets for durable hardwood timbers can be divided into three groups: round timbers, sawn timbers and residues.

A comprehensive profile of hardwood plantations established for sawlogs in other states is not provided in this paper, but it is understood that these estates are smaller and have a similarly small proportion of durable species.

Another feature of these long-rotation plantations is that they have predominantly been established for the production of small sawlogs of maximum diameter about 40 cm.

This has effectively removed any possibility of producing large round and end-section sawn timbers that have formed a large part of the traditional market for durable species.

Considerable research is being conducted to determine best management arrangements, wood properties and markets for these species, with progeny trials and seed orchards already established by Forests NSW for species listed in Table 2.

Some of these trials have identified species with considerable growth potential, and further research on tree form is likely to provide significant

Table 3. Traditional products from roundwood timbers

Product	Use	Processing
Poles	Specialist building and construction, electricity and telecommunications transmission	Debarking, length docking, chemical preservative treatment, boring, capping and hardware attachments
Poles (small)	Currently directed to export markets in SE Asia for electricity and telecommunications transmission	Debarking, length docking, chemical preservative treatment, boring, capping and hardware attachments
Piles	Wharfs, bridges, building foundations	Debarking (when preservative treated but not for naturals), chemical preservative treatment (double treating, CCA and creosote) for marine use north of Jervis Bay and Perth, capping, boring and jointing
Girders	Rural road or rail bridge maintenance and replacement (including heritage items)	Debarking (sometimes), facing or squaring, boring and jointing
Landscape uses	Playgrounds, retaining walls and other garden uses	Variety

Round timbers

Round timber markets usually rely on the durability and strength of log lengths with minimal processing. Chemical preservative treatment of the sapwood of these timbers plays a major part in their durability in use, as it creates an enveloping barrier that can technically continue to maintain performance of the product long after any naturally durable heartwood degrades. In addition, treatment effectively increases the size of the pole as in untreated poles only the heartwood can be used for performance calculations. Their specialty use and relatively low processing cost contribute to their high value. Examples of traditional products are listed in Table 3.

These products offer plantation growers considerable possibilities due to their relatively high value and also because the level of investment in processing technology (usually involving maintenance of preservative treatment capacity) is not excessive and does not require large-scale resources to ensure economic viability.

Sawn timbers

Markets for sawn durable timbers are important for plantation utilisation as not all log products harvested will lend themselves to round timber markets. Sawn timber markets usually rely more on the natural durability of the timber as preservative treatment is less effective in the heartwood of hardwood species. Examples of traditional products are listed in Table 4.

Some durable timbers are also suitable and currently used for rotary-peeled and sliced-veneer products such as decorative and construction plywood, laminated veneer lumber and decorative furniture, flooring and other appearance-grade products. Durability is generally not a key requirement in these applications, although some product development is known to have been undertaken on the use of plywood for pole products that may rely on some durability features.

Pulpwood residues

Equally as important as all the above products, particularly to plantation-management economics, are markets for log products produced at thinnings and final harvest other than those described above, and also sawmilling residues. Traditionally, markets for residues from plantations have been heavily focused on paper, cardboard and reconstituted panel products, each requiring high-pulp-yielding species. This has been a major contributor to the current choice of species planted in short-rotation plantations. The fact that most of these markets are based overseas has also influenced the location of these plantations on sites within economic transport distances of key Australian port facilities.

Table 4. Traditional products from sawn timbers

Product	Use	Processing
Cross arms	Electricity transmission	Sawn, bored
Bridge timbers	Road and rail, chords, decking, struts, braces etc.	Sawn, bored, jointed
Rail timbers	Sleepers, turnout timbers	Sawn, some chemical sapwood treatment, bored
Wharf and marine timbers	Wharf bearers and decking, oyster stakes	Sawn, bored
Dried and dressed structural	Construction, flooring and other applications requiring strength characteristics of durable species	Sawn, seasoning and profiling/planing
External cladding, screenboards, external architectural use	Residential or commercial building and construction	Sawn, some seasoning and profiling/planing
Decking/boardwalks	Residential or commercial decking and boardwalks. Note: Most durable species are also suitable in fire-prone areas.	Sawn, some seasoning and profiling/planing
Exposed external beams	Specialist external construction for strength, appearance and durability	Saw, bored, jointed
Rural and fencing timbers	Fencing, gates, stockyards, rural construction, vineyard posts	Sawn, splitting, some chemical sapwood treatment
Landscape and firewood	Retaining walls and other garden uses, commercial or residential firewood	Sawn, splitting, some jointing

Residues from durable hardwood species have usually been less suitable for these purposes, but a number of products and markets are available. Markets for residue products will help to ensure the economic viability of establishing plantations of durable hardwoods, both directly through their market value and indirectly through the reduction in plantation re-establishment costs associated with windrowing and burning. Examples of products from residues are listed in Table 5.

Table 5. Products from residues

Product	Use	Processing
Hardboard and cladding products	Panel products, house and fence cladding, packaging	Woodchipping, pulping, heat and pressure processing
Stranded composite timber and boards such as oriented strand board (OSB) and similar products	Essentially panel and composite timber products for construction, shipping and packaging	Woodchipping, flaking, peeling, heat and pressure processing, gluing
Biofuels, bioenergy, biomaterials	Woodchips or pellets for stand alone or co-generation of heat or electricity Cellulosic fuels for ethanol or other volatiles New products for textiles, packaging foams, or other products not traditionally wood based.	Variable—woodchipping, grinding, pulping, drying, heat and pressure, pelletising, pyrolysis, gluing
Charcoal, activated carbon	Silicon production, metallurgy, food preparation, heating/energy	Sawing, controlled burning
Craftwood	Commercial or domestic furniture, artistic or feature items	Variable
Extractives	Oils, perfume components, resins, pharmaceuticals, nutraceuticals, acylphloglucinols (medicines)	Billeting, crushing, other

Average prices for durable timber products

Market prices for each of the durable timber products described above need to be considered in the context of current prices and forecast prices.

Current prices

Estimated current average prices per product are listed in Table 6.

Table 6. Current average prices for timber products

Product	Description	Price range
<i>Round timbers</i>		
Poles	Thinnings and plantation clearfall: Smaller export treated poles to large Durability Class 1 and 2 transmission poles (8 m to >20 m in length)	\$30 per pole to \$1200 per pole (about \$60–\$220 m ⁻³)
Piles	Thinnings and plantation clearfall: Full size range 11 m to >18 m, Durability Class 1 and 2. Note: Foundation piles tend to be smaller, i.e. similar to export poles	\$130–\$300 per m ³
Girders	Mostly plantation clearfall: <30 cm sed to >40 cm sed, particular demand and value for Class 1 >50 cm sed, Durability Class 1 and 2. Note: Large (>50 cm) girders are used to produce sawn girder material, not in the round.	\$170–\$450 per m ³
Landscape uses	Thinnings and plantation clearfall: Smaller (down to 7 m) and other specialist hardwood poles	\$130–\$160 per m ³
<i>Sawn timbers (\$ per cubic metre)</i>		
Cross arms	Mostly plantation clearfall: Mostly Durability Class 1	\$1800–\$2000
Bridge timbers	Mostly plantation clearfall: Large-end-section, mostly Durability Class 1. Generally require girder-quality logs with sed of >50 cm	\$1800–\$3000
Rail timbers	Mostly plantation clearfall: Large-end-section, Durability Class 1 and 2	\$1800–\$3000
Wharf and marine timbers	Mostly plantation clearfall: Large-end-section and decking, Durability Class 1 and 2	\$2000–\$3000
External cladding, screenboards, external architectural use	Thinnings and plantation clearfall: Mostly Durability Class 1 and 2	\$1200–\$1600
Decking	Thinnings and plantation clearfall: Mostly Durability Class 1 and 2	\$900–\$1400
Exposed external beams	Mostly plantation clearfall: Large-end-section, Durability Class 1 and 2	\$1200–\$1800
Rural and fencing timbers	Thinnings and plantation clearfall: Posts, rails and palings, Durability Class 1 and 2	\$1400–\$2000
Landscape	Thinnings and plantation clearfall: Durability Class 1 and 2	\$500–\$800
Appearance-grade flooring (Appearance and strength properties)	Thinnings and plantation clearfall: Durability Class 1 and 2	\$1000–\$2500
Structural—F22, F17 and F27 (Appearance and strength properties)	Thinnings and plantation clearfall: Durability Class 1 and 2	\$900–\$1800

Table 6. **Continued**

Product	Description	Price range
<i>Residues (\$ per tonne)</i>		
Hardboard cladding and related products	Thinning and clearfall residues	\$600–\$800
Stranded composite timber and boards such as oriented strand board (OSB) and other similar products	Thinning and clearfall residues	\$400–\$600
Biofuels, bioenergy, biomaterials	Thinning and clearfall residues	\$20–\$30
Charcoal	Thinning and clearfall residues	\$400
Craftwood (MDF particleboard)	Thinning and clearfall residues	\$400–\$500 per m ³
Extractives	Thinning and clearfall residues	

Forecast prices

Movements in price in domestic timber markets have historically been cyclical in nature, largely in response to changes in the level of building activity. More recently some of this dependency has been removed in the hardwood timber sector through diversification of products and markets, but some cyclical tendency remains. Nonetheless, timber prices for high-quality durable timbers continue to increase over time, at least keeping pace with the Consumer Price Index.

Currently the domestic timber market is emerging from a downturn which has prevailed for the last three to four years. This recovery, consistent with general industry understanding and recognised industry forecasts (BIS Shrapnel and the Housing Industry Association) predominantly rests on the back of considerable pent-up demand in markets for dwelling construction and increases in alterations and additions, and is expected to escalate from late 2007–early 2008. In addition to this, world pulp market prices continue to remain strong and are pulling through value in all woodchip and residue products.

While the overall increase in timber market demand identified above is likely to bring industry-wide benefits of volume and unit prices, market opportunities for durable timbers will continue to specifically relate to the ability of timber marketers to match their unique characteristics with end-user demands. These are reasonably well defined for most sawn timber products, and traditional marketing strategies relating to pricing, position, promotion and placement/delivery of the products are equally as relevant to durables as to non-durables.

In addition, the scarcity of some traditional timbers—for example preferred sizes for timber poles and large-end-section bottom chords for timber bridges—has seen prices for these specific items escalate substantially beyond previous expectations, making the pursuit of these markets highly attractive. These ‘scarcity’ drivers are expected to remain for the long term and to underpin future increases in unit prices.

Market development and demand

General market prospects and demand

Since about 2006 world-wide concerns over global warming and greenhouse issues have significantly escalated the market awareness of consumers. Purchasing decisions are now being made with a high interest in possible impacts on the environment.

Comparatively, timber products stand to rise to the top of consumer preferences over traditional competitive products such as steel, concrete, plastic and aluminium because of low energy usage in production processes and appropriate favourable whole-of-life-cycle assessments.

Plantation investors and the timber industry have the distinct advantage of being representative of the only one of these materials sequestering significant amounts of atmospheric carbon in the production process, giving them a head start over their competitors. Strategic marketing and product positioning campaigns will still be required, but this feature—together with the renewable, environmentally sustainable, certifiable and reusable or recyclable nature of plantation-produced products—is expected to generate significant market demand for timber products in both traditional and non-traditional markets for the foreseeable future. Figure 2 indicates the comparative amounts of CO₂ emitted during the manufacture of a range of building and construction materials.

Governments and large corporations are early movers in this debate, and industries with high greenhouse gas emissions are already scrambling to gain ascendancy in media, marketing and offsetting strategies. This is particularly relevant for durable timber demand as governments are largely responsible for the utilities that require much of the durable round and large-end-section timber products described above.

Key market movements

In addition to the above-mentioned indications of general market growth, key specific market movements that may be more beneficial in the longer term for durable hardwood plantations can be found—in round timber applications such as poles, as well as in large-end-section bridge and rail timbers, external building and architectural applications and products re-constituted from forest and mill residues.

Poles

Australia appears to be well placed to service unmet or under-supplied market demand for smaller electricity transmission pole products in the Philippines and South-East Asia. Current treated hardwood pole supplies to these markets from Koppers Wood Products Pty Ltd Australia are facing considerable pressure from very competitively priced steel and concrete poles from China, as well as the effects of recent increases in shipping costs.

Treated pole products from thinnings of durable eucalypt plantations could meet the required dimensions and specifications, and offer potentially superior performance to these alternative products. Opportunity therefore exists for Australian producers to meet this demand in the longer term.

Domestically, a recent study commissioned by the Energy Networks Association of Australia (ENA) concluded that the demand for traditional Durability Class 1 and 2 utility poles for electricity transmission in Australia will increase by 75% from 2004 to 2014. This increase was projected on the basis of expected network expansions, and inspection, maintenance and replacement programs.

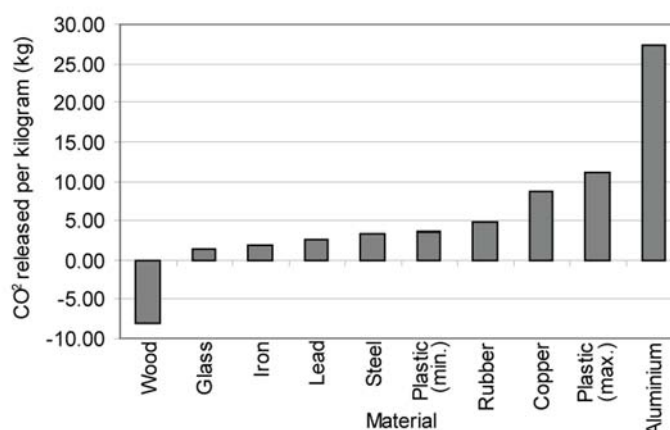


Figure 2. Amount of CO₂ released during manufacture per kilogram of product (Source: Forests NSW)

These increases could see demand for poles 8–20 m in length rise from current levels of about 52 000 poles per annum in 2004 to about 87 000 poles per annum by 2014. Projections for other contractor purchasers, in addition to these, could see demand increase to >100 000 poles per annum.

On the supply side, the report noted that the maximum sustainable supply of timber poles from traditional public and private sources appeared constant at about 62 000 poles per annum. These projections result in a widening gap between demand and supply that grows from zero to >40 000 poles per annum over the next 7–8 years.

Options in the short term to meet this demand include use of lower durability species (including softwoods), conversion of existing sawlog allocations to pole allocations (predominately in NSW only), access to new private property supplies, and development of composite products that take advantage of currently under-utilised sizes, and of course alternative, non-timber products such as concrete, steel or other (new) materials. These alternatives all come with different and often more expensive whole-of-life cost profiles.

Timber is the preferred material for domestic poles and can outperform its competitors on a number of performance criteria, including safety because of its insulating nature and compatibility with existing line design and cost. The clear challenge for plantation owners, investors and the timber industry in Australia is to plant Australia's power poles of tomorrow, today.

Large-end-section timbers

Agencies responsible for road and rail bridge assets in each state and territory of Australia continue to face significant inspection, maintenance and replacement challenges associated with their respective populations of aging timber bridges. In NSW alone many of these bridges are heritage listed and of historical significance, thereby limiting the options available to agencies with respect to alternative materials that can be used for their maintenance to ensure continued service.

Despite offering prices for these timbers well in excess of previous market rates, efforts to access the large-end-section, long (9 m and >11 m), naturally durable timbers necessary to repair or maintain these heritage bridges has continued to be unsuccessful. This has prompted the agency (RTA NSW) to investigate a range of possible solutions, including the establishment of purpose-specific plantations of naturally durable timber species.

Of course offsetting any additional costs associated with establishing plantations of durable species presents its challenges, particularly in relation to the need to grow these plantations over the longer rotations necessary to deliver the larger logs required. Nonetheless, the demand is of high value, identifiable and sustainable in the long term, and therefore presents an opportunity that could be met by plantations of durable hardwoods.

External architectural design, screens, cladding, decking, boardwalks etc.

Increased interest in the use of timber for its durable, structural and appearance properties is being identified through developers, specifiers, local councils and parks and gardens and coastal authorities. Residential and commercial building development projects are incorporating more timber in their designs to differentiate final products via the environmentally friendly attributes of timber, as well as to soften the appearance of buildings in the built environment. The suitability of durable timbers in fire-prone areas also lends support to the maintenance and possible re-growth of applications in external decking and boardwalks.

Residues

There has been considerable renewed interest, both domestically and offshore, in forest and timber processing residues over the last few years. Nearly all forest growers in Australia will probably have received some level of enquiry in this regard over the last year, and the prospects of new domestic processing infrastructure appear positive. This trend in interest is expected to continue for the foreseeable future on the back of strategies to reduce greenhouse gas emissions and new product developments for wood fibre in bio-energy, bio-material and bio-fuel applications.

One of the possible benefits of emerging technologies for these new products may be a reduction in the size of the resource traditionally deemed necessary to achieve competitive economies of scale. For example, a matrix of biomass co-generation facilities that each require in the order of 50 000 tonnes per annum (about 5 MW) would better fit the Australian forest geography and timber processing landscape than the 250 000 – 500 000-tonne facilities more traditionally envisaged.

Bio-material and bio-energy research and development continues around the globe, and innovative companies such as DuPont, 3M and others have set ambitious renewable energy and biomass feedstock targets that are expected to drive further innovation and market demand.

There has also been renewed interest in the development of processing facilities for more traditional composite board and timber products such as oriented strand board (OSB) and other stranded composite products. Prospects for the establishment in the near future of domestic processing facilities for these products also appear good, and are traditionally based on resource requirements of 250 000 – 400 000 tonnes per annum. Processes for making these products offer considerable opportunity to use residues from durable hardwood plantations as, unlike in paper production, high pulp yield and light timber colour are not major considerations.

Possible partnerships in durable hardwood plantation establishment

Unmet demand in a number of the above products has induced some companies to consider a more hands-on involvement in the establishment of purpose-specific plantations to secure their required resource.

These companies have a need for the timber products from plantations but are naturally reluctant to extend into greater levels of integration. Rather, they are seeking joint venture partners or service providers to contribute the resources necessary to establish plantations, namely:

1. suitable and sufficient land
2. suitable funding/investment
3. plantation forestry establishment and management services
4. marketing and sales services for plantation products.

Plantation establishment opportunities are currently being explored in NSW that could see three or more parties coming together, each contributing one or more of the above requisites, to extract the benefits from or satisfy needs through plantations over one or more rotations.

Further, in NSW such arrangements have the potential to realise financial benefits associated with generation and sale of greenhouse gas abatement certificates that can further improve the economics of the plantation programs.

For example, in a proposal in which Forests NSW (a registered generator of NSW Greenhouse Gas Abatement Certificates—NGACS) is involved, there could be an opportunity for durable hardwood plantations in a joint venture partnership whereby:

- funding is provided by an electricity utility/retailer that is seeking to secure long-term supplies of durable timber poles to support its sustainable pole maintenance and replacement program, or
- funding is provided by a pole producer (preservative treater and pole manufacturer) that is seeking to secure additional supplies of poles to sell to utilities or other customers
- land held by either of the above parties, or accessed through financial arrangements with a third party, is made available for plantation establishment
- plantation establishment and management services are secured on fee-for-service basis, say from Forests NSW
- marketing and sales services are secured on a fee-for-service basis, possibly also from Forests NSW, for all the plantation log products produced during the rotation.

In this example, parties receive the following benefits:

- the utility or pole producer secures the pole products required to meet expected long-term demand
- the utility or pole producer also receives proceeds from the sale of other log products grown over the rotation

- the utility or pole producer also receives benefits associated with responsible greenhouse gas offsets and potentially financial realisation of value through carbon trading opportunities
- the landholder receives a market rental/lease fee
- the service providers receive fees-for-service and log price discovery opportunities in the marketplace.

Conclusions

Increased market demand (volumes and values) for naturally durable timbers has the potential to make establishment of plantations of durable hardwood species more financially viable and attractive to investors. Additional benefits realised through taxation and possibly carbon mechanisms will help to offset the costs of non-traditional plantations and further assist the financial viability of the plantations.

Further research will be required to develop successful and robust plantation establishment and management models that will account for the species characteristics, longer rotations, pruning and any modified silviculture necessary for plantations of durable species.

Additional research will be required to recognise and understand any modifications of wood properties of durable species that are grown in the plantation environment, and the effect these may have on processing and performance for specific end products. Sapwood-treated poles are an exception, as inspections of poles in long-term treated Durability Class 2 trials have proven conclusively that their performance is at least as good as that of untreated Class 1 poles.

Challenges will continue to exist in identifying and accessing the right land at the right price, with the necessary proximity to processing facilities, infrastructure, markets and possibly port facilities.

The expected domestic housing market recovery in late 2007, as well as increased global interest in the environmental properties of timber, are expected to contribute to increases in overall market demand (volumes and values), but specific demand from specialist markets for durable hardwoods has the potential to offer the best returns.

Key among these specialist markets are those not currently being fully met or that are under development, particularly for round timbers (e.g. poles, piles and girders), large-end-section timbers (e.g. timber bridge components) and products re-constituted from forest and mill residues (e.g. OSB, bio-energy, bio-materials and bio-fuels).

In this sense, considerable opportunities exist to form joint venture partnerships to establish durable hardwood plantations and to involve companies seeking to secure long-term sustainable supplies of high-value durable timber products to meet their ongoing needs.

Acknowledgement

The author would like to thank Mr Peter Wallbank, General Manager, Koppers Wood Products Pty Ltd, Mr Michael Henson, Tree Improvement Manager, Forests NSW and Mr Chris McEvoy, Preschem/Radial Timbers for providing advice and critical reviews of this paper.

References and further reading

- ABARE (various) *Australian Forest and Wood Products Statistics*, Australian Bureau of Agricultural and Resource Economics, Commonwealth of Australia, Canberra.
- Bootle, K.R. (1983) *Wood in Australia: Types, Properties and Uses*. McGraw-Hill, Sydney.
- Ferguson, I.F., Spencer, R.D., Wood, M. and Gerrand, A. (2002) Australian supply and demand for plantation products. In: Gerrand, A. (ed.) *Australian Forest Plantations Conference 2002*. Proceedings. 20–21 August 2002, Canberra, Australia. Bureau of Rural Sciences, Canberra, pp. 29–40.
- Francis, L. and Norton, J. (2006) Australian timber pole resources for energy networks: a review. Innovative Forest Products, Horticulture and Forestry Science, Department of Primary Industries and Fisheries, Queensland; Energy Networks Association of Australia, Canberra.
- McCarthy, K.J., Cookson, L.J. et al. (2005) *The Suitability of Plantation Thinnings as Vineyard Posts*. Forest and Wood Products Development Corporation PN02.3900. FWPRDC, Melbourne.
<http://www.fwpa.com.au/content/pdfs/PN02.3900.pdf>.

- Nolan, G., Washusen, R. et al. (2005) *Eucalypt Plantations for Solid Wood Products in Australia: A Review*. Forest and Wood Products Development Corporation PN04.3002. FWPRDC, Melbourne, 130 pp.
<http://www.fwpa.com.au/content/pdfs/PN04.3002.pdf>.
- Standards Australia (1990) *AS 1720.2-1990, SAA Timber Structures Code, part 2: Timber Properties*. Standards Association of Australia, Sydney.
- Standards Australia (2003) *AS 5604-2003, SAA Timber—Natural Durability Ratings*. [Superseded by 2005 version]. Standards Association of Australia, Sydney.
- Wood, M., Stephens, N., Allison, B. and Howell, C. (2001) *Plantations of Australia – A report from the National Plantation Inventory and National Farm Forest Inventory*. Bureau of Rural Sciences, Canberra, 172 pp.



SESSION: GENETICS AND INVESTMENT OPTIONS FOR
HARDWOOD SAWLOGS

Genetic Improvement for High-Value Eucalypt Timber

DAVID BUSH

CSIRO Forest Biosciences, Canberra
Email: david.bush@csiro.au

Abstract

Tree breeding has the potential to assist the development of high-value eucalypt timber plantations. In Australia, high-value eucalypt timber has traditionally come from native forests, whereas most of the eucalypt plantation estate, which in southern Australia is dominated by *Eucalyptus globulus* and *E. nitens*, has been grown for pulp fibre production. The scope for developing multipurpose plantations suited to both fibre and solid timber production in southern Australia is dependent on key solid and pulp wood traits, now a focus of research. In other climatic zones, there are possibilities for dedicated high-value eucalypt plantations. In the medium-low winter rainfall zone, a suite of candidate species including *E. cladocalyx* and *Corymbia maculata* has been selected, and genetic improvement for solid timber has commenced. Similar work is underway in the summer-dominant rainfall zone where *Corymbia* species and hybrids, *E. longirostrata*, grey gums and other hardy species have demonstrated potential. In the high rainfall zones of the sub-tropics, breeding programs for high-value timber species such as *E. pilularis* and *E. cloeziana* are well underway. Tree improvement of species such as *E. pellita*, *E. camaldulensis* and hybrids for the higher rainfall sub-tropics and tropics is also discussed.

Introduction

‘High-value timber’ can be variously defined, according to context. Fast-growing eucalypt plantations can yield large volumes of commodity product such as pulpwood, generating high value per hectare. The value per cubic metre of wood is relatively low, but overall the plantation system can be very valuable and profitable. Indeed, the current Australian taxation regime and private-sector plantation management system of managed investment schemes make pulpwood more attractive than solid wood production (Kelly et al. 2005). On the other hand, plantations of ‘specialty’ timbers can produce wood for veneer or cabinetry applications, fetching very high prices per log and per cubic metre of log volume. Typically these niche-use timbers are grown in much smaller areas of more intensively managed plantations. Some eucalypt plantations in Australia and overseas are being managed for larger-scale production of appearance-grade products such as flooring (Nolan et al. 2005). Plantations that produce wood composites, structural timber and products such as posts and poles are intermediate between these cases. However, all could be said to generate high value, and genetic tree improvement is an equally important part of maximising value in each system.

This paper is mainly concerned with tree improvement of eucalypts that produce high value on a per-stem basis, i.e. non-pulp plantations. In these plantations, genetic improvement is focused on traits linked to applications such as sawn timber recovery, wood structural, dimensional and aesthetic properties, gluing and machinability, and durability. For pulp fibre plantations, traits of interest will be those properties linked to chip and pulp yield. However, pulpwood plantations, of which Australia has a significant resource, may produce a small yield of high-value timber. The possibility of breeding trees for multiple purposes is also relevant.

The paper reports on progress as it applies to three broad, climatically-defined plantation regions in Australia. Species options and current tree improvement research in each are summarised. Following this is a section on key research areas for the future.

Tree breeding objectives and traits for high-value wood uses

Tree breeders aim to improve the value of plantations per hectare per year by setting *economic breeding objectives*. This is best done by defining bio-economic models which relate values from user industries to *breeding objective traits* (Shelbourne et al. 1997), describing tree characteristics at time of harvest, for example volume of F17 stress-graded timber. High-value wood uses are diverse, including structural sawn timber, appearance timber, flooring and parquetry, veneer, durable timber and wood composites (though composites, with the exception of appearance-grade ply, are generally made from low-unit-value wood feedstocks). However, breeders don't usually wait to sawlog rotation age (typically 20+ y) before selecting and breeding or deploying. Rather, they pick a set of *selection traits* (e.g. basal area) which can be measured at a younger age that they assume, and set out to demonstrate, are closely related to the objective traits. A matrix of phenotypic and genetic correlations links the selection and objective traits.

Table 1 lists selection traits that are relevant for high-value timber production, and the particular wood products to which the traits are important. Most of the selection traits are related to a number of products and objective traits.

As genetic improvement is a function of *heritability* and *variation* at a given selection intensity, Table 1 also gives estimates of heritability for each trait where available. The heritability estimate is a guide to the proportion (between 0 and 1) of the observed or *phenotypic* variation in each trait that can be passed on to subsequent generations. This estimate is calculated within populations (provenances) within species. Another very important level of genetic variation is that between provenances. Provenance variation is often identified prior to the commencement of breeding programs or as a first step.

It is possible to make genetic gain by recurrent selection and breeding for most of the important traits relevant to high-value wood products. Growth (e.g., height, diameter, volume) and form (e.g., stem straightness, axis persistence, branching) traits are generally of low–moderate heritability (0.1–0.3), but there is often plenty of variation in these traits. These traits are relatively inexpensive to measure. Conversely, wood property traits are often moderately to highly heritable (0.4–0.8; Raymond 2002) but typically have less variation. They are relatively infrequently studied, except as applying to commercially significant combinations of species and end-use, because they are difficult and expensive to measure. Advances in measurement techniques, however, such as mechanised corers and use of near-infrared analysis in place of wet chemistry are making the determination of wood property traits cheaper and more accessible (Raymond 2000, 2002).

Table 1 groups traits into six main areas as follows:

1. Growth

Growth is a universally important trait, and the easiest to measure. It is often estimated from height or dbh measurements, though refinements to the estimate include bark thickness to give dbh_{hub}, and taper.

2. Form

Stem straightness, forking, branching and other defects are very important for high-value timber production. Knots lead to downgrade of appearance yields and strength. Straightness is important for log length, which is directly related to value. Self-pruning is a highly desirable trait, because pruning is an expensive operation. Forking, or apical dominance, is a very important trait especially in low-rainfall species that tend to have poorer axis persistence. In some studies, growth and form measures are integrated to give a measure of merchantable product, by calculating growth of log lengths, for example.

Table 1. Traits, heritability estimates and relationship to wood products

Trait	Example of variation and/or heritability estimate (narrow sense, within-provenance) $\hat{h}^2$	Relationship to wood product	Notes
Growth		All	Generally low–moderate
Volume	<i>E. dunnii</i> 0.30 (Smith and Henson 2007)		
Height	<i>E. globulus</i> 0.25 and <i>E. nitens</i> 0.27 (averages from review by Raymond 2002); <i>E. cladocalyx</i> 0.25 @ 28 mo (Harwood et al. 2007) <i>E. longirostrata</i> 0.33–0.49 @ 2 y		
Diameter	<i>E. globulus</i> 0.24 and <i>E. nitens</i> 0.18 (averages from review by Raymond 2002); <i>E. cladocalyx</i> 0.21 @ 28 mo (Harwood et al. 2007); <i>E. pilularis</i> 0.18–0.24 @ 36 mo (Henson and Smith 2007)		
Form		All	Generally low–moderate
Axis persistence (forking)	<i>E. cladocalyx</i> 0.21 @ 28 mo (Harwood et al. 2007)	Appearance and structural products;	Low forking leads to non-merchantable trees
Branching and branch shedding (self-pruning)	Branching traits are under assessment for <i>C. maculata</i> and <i>E. cladocalyx</i> in the ALRTIG breeding populations	Branches that don't self-prune lead to knots and sometimes decay	<i>E. occidentalis</i> is known to retain branches for a long time, leading to serious timber class downgrade (Blakemore et al. 2004).
Straightness	<i>E. pilularis</i> 0.20–0.34 @ 3 y (Henson and Smith 2007) <i>E. longirostrata</i> 0.38–0.45 @ 2 y (Henson et al. 2007)	All	
Wood physical properties			Generally moderate-high
Basic density and air-dry density	<i>E. globulus</i> 0.22 @ 13 y (Poke et al. 2006); <i>E. nitens</i> 0.23–0.51 @ 4 y (Hamilton 2007); 0.38 @ 12 y (Kube et al. 2001); <i>E. grandis</i> 0.34 @ 8 y (dos Santos et al. 2004); <i>E. regnans</i> 0.18 @ 9 y (Raymond et al. 1998); <i>E. dunnii</i> 0.51 @ 6 y (Smith and Henson 2007)	Sometimes correlated to strength, hardness, stability and structural applications	One of the easiest wood properties to measure
Collapse and checking	<i>E. nitens</i> 0.38 @ 12 y (Kube and Raymond 2005) <i>E. nitens</i> 0.37–0.47 @ 4 y (Hamilton 2007)	Checking leads to appearance downgrade	Strongly correlated to basic density in <i>E. nitens</i>
Shrinkage	<i>E. dunnii</i> tangential 0.7 and radial 0.6 @ 6 y (Smith and Henson 2007)	Related to sawn board stability (tendency to warp, spring etc.)	
Stiffness	<i>E. dunnii</i> MOR 0.52 @ 6 y (Smith and Henson 2007); <i>E. dunnii</i> MOE 0.26 @ 6 y (Smith and Henson 2007)	Strength-related applications	
Hardness		Flooring and high-wear applications	
End-splitting	<i>E. grandis</i> 0.31 @ 8 y (dos Santos et al. 2004)	Log recovery	
Spiral grain	<i>E. dunnii</i> 0.99 @ 9 y (Thinley et al. 2005)	Leads to board twisting	

Trait	Example of variation and/or heritability estimate (narrow sense, within-provenance) $\hat{h}^2$	Relationship to wood product	Notes
Spring	<i>E. globulus</i> 0.4–0.7 @ 6 and 15 y (Greaves et al. 2004)		
Oven-dry shrinkage	<i>E. globulus</i> 0.4 @ 6 y (Greaves et al. 2004)		
Cupping	<i>E. globulus</i> 0.05 @ 6 y (Greaves et al. 2004)		
Heartwood properties		In-ground uses, appearance products	Genetically improving durability traits is likely to be counter-productive for pulpwood.
Heartwood: sapwood ratio	<i>E. grandis</i> 0.39 @ 8 y (dos Santos et al. 2004); <i>E. cladocalyx</i> 0.4 @ 8 y (CSIRO unpublished data); provenance differences in <i>E. obliqua</i> (Nicholls and Matheson 1980)	Sapwood is not durable—heartwood of some species is.	Heartwood is difficult to treat with preservatives—so wood with a greater proportion of sapwood is desirable for this purpose
Heartwood composition (e.g. extractive content)	Extractives: <i>E. globulus</i> 0.37 @ 13 y (Poke et al. 2006) and significant provenance differences (Miranda and Pereira 2002). CSIRO currently determining for <i>E. cladocalyx</i> and <i>Corymbia</i> spp.	Extractives are desirable for natural durability; undesirable for pulping	Extractives retard the ingress of water and fungal pathogens. They have to be removed from pulp
Colour	Genetic variation in colour traits has been little studied, though probably highly correlated to extractives. <i>E. globulus</i> 0.1 @ 6 y (Greaves et al. 2004)	Appearance products	Wood colour is generally strongest in the heartwood due to extractive content
Susceptibility to pathogens and pests	Very important in tropical and subtropical spp. Strong provenance variation in susceptibility to <i>Quambalaria</i> shoot blight in spotted gums (Dickinson et al. 2004b). Provenance differences in resistance to wood decay identified in <i>E. globulus</i> , <i>E. nitens</i> and <i>E. regnans</i> (Poke et al. 2006).	Affects growth and survival. Structural and in-ground applications	Borer damage and rot also limit timber yield and appearance-grade recovery
Glue and resin performance and consumption	Genetic variation in these traits has been little studied	Veneer, parquetry, wood composites	Extractives and wood porosity are likely to be important

3. Wood physical properties

End-splitting, checking and collapse, and other problems caused by growth stresses are major causes of product loss and degrade in eucalypt logs. The normal methods for managing these problems are through selection of sawing and drying techniques, though indications are that these (or correlated measures such as basic density) are also heritable traits (e.g. Malan 1988; Kube and Raymond 2005), and therefore tree breeding may also contribute. Traits that have been identified as being under genetic control are listed in Table 1.

4. Heartwood properties

Heartwood properties are important to a number of high-value products. Heartwood contains extractives, which are chemical compounds including phenolics, stilbenes and polymerized polyphenols (Hillis 1987). An adaptive function of extractives is impedance of ingress of moisture and organisms that cause heart rot. Since heartwood cells are dead, they cannot actively respond to

decay organisms. Extractives are undesirable for pulping because they also impede chemical digestion processes, and in some cases require extra bleaching. Consequently, tree breeders have targeted reduction of extractive content, which appears to be a moderately heritable trait (Poke et al. 2006). Another consequence of impeded fluid penetration is that wood preservative treatment is possible only in sapwood. However, those species that are rich in extractives with natural resistance to decay may have potential for applications such as vineyard posts where environmental contamination needs to be minimised, especially given the negative environmental and health implications of commonly used preservatives based on heavy metals. Heartwood usually increases proportionally as the tree ages. However, provenance differences in heartwood:sapwood ratio have been identified in both softwoods and hardwoods. Though seldom studied in eucalypts, the trait is heritable in *E. grandis* (flooded gum; dos Santos et al. 2004), *E. obliqua* (messmate; Nicholls and Matheson 1980) and *E. cladocalyx* (sugar gum; CSIRO unpublished data).

Extractives can impart strong colour to the heartwood of some species, for example red ironbarks and *E. camaldulensis*, whereas in others (e.g. the ash group, *E. globulus*—Tasmanian blue gum—and *E. nitens*—shining gum) there is very little coloration, often indicating lower extractive content. Coloured eucalypt timbers may fetch a price premium in some applications, while pale-coloured timbers for neutral appearance or that take stains well are favoured in others. However, a strong heartwood–sapwood colour differential can be a negative property for appearance products—so uniformity is a desirable trait. The genetics of colour traits have been little studied in eucalypts.

Kino veins, pockets of gummy exudates, are another problem in eucalypts, particularly in *E. obliqua*, *E. sideroxylon*, *E. calophylla* (Hillis 1987) and the spotted gums (Smith et al. 2007). Kino is often produced in response to decay. Its main impact is through degrading appearance products. Provenance variation in incidence and size of kino veins has been found in *E. regnans* (Doran 1975; White et al. 1999).

5. Resistance to pests and diseases

Pest and disease resistance is important for all plantations and specifically for high-value timber production where some pests, such as borers, can severely affect wood appearance and properties, while death of shoot tips can lead to poor form and ultimately reduced log length. Pests and diseases are especially important in the sub-tropics and tropics, and resistance to important pests and diseases is commonly included as a selection trait early in breeding programs. Of note are resistance to *Quambalaria* shoot blight and erinose mite (*Rhombacus* sp.), which are key traits that exhibit provenance and family-level variation in spotted gums for the sub-tropics (Smith et al. 2007). Cossid moths (e.g. *Endoxyla cinerea*—giant wood moth) are also a serious problem for some species in the sub-tropics (notably *E. grandis*, *E. camaldulensis* × *E. grandis* hybrids and to a lesser extent *E. dunnii*) as they bore large holes into the stem of trees, causing problems for strength and appearance products. Their attack can lead to ingress of stain and decay fungi. In southern Australia, the main disease problem that causes degrade of timber is heart rot. Provenance variation in susceptibility to heart-rot-causing decay fungi was found in *E. globulus* (Poke et al. 2006) and heritability estimates for this trait in *E. nitens* vary between 0.13 and 0.41 (Kube and Raymond 2005).

6. Glue and resin performance

Glue and resin performance is particularly important for composites and veneers. Performance of adhesives and binders is affected by other chemical compounds in the wood, so the greatest problems can be expected from those species that have a high extractive content or oily sapwood properties. Genetic variation and heritability of these properties has not been much studied in eucalypts, except at the species level.

Inter-trait correlation

Inter-trait correlation is an important consideration in tree breeding. If traits are positively correlated, selection for one will result in genetic gain in the other. Negative correlation between growth and wood density traits in Australasian *Pinus radiata* plantation wood is now causing serious problems: selection for high growth rates in the past has led to wood of low density that consequently lacks strength (Gapare et al. 2006). It is therefore important to determine whether or not the desired traits are genetically correlated as soon as possible after commencement of a breeding program.

Whether or not it is possible to breed ‘dual-purpose’ trees that produce both pulp and high-value timber is dependent on trait correlations. By far the majority of Australia’s eucalypt plantations have been established for pulpwood production. Genetic improvement programs such as the Southern Tree Breeding Association’s *E. globulus* program have been focused on minimising the total cost of kraft pulp by maximising growth and pulp properties (e.g. basic density and pulp yield) in these species. The main traits that would need to be improved for sawn timber and appearance products in these species are growth, form, branching/knots and certain physical wood properties related to sawn recovery, for example end-splitting and shrinkage (see Table 1).

Relatively little is known about correlation between traits pertinent to high-value uses and other traits in eucalypts, though the area is now being actively researched and is showing some promising results. Relatively well studied is the correlation between growth and basic density, which has been found to be low for *E. regnans* (Raymond et al. 1998), *E. globulus* (Raymond 2002) and *E. dunnii* (Smith and Henson 2007). Work done by the CRC for Forestry (Hamilton 2007) has indicated that selecting for higher basic density in *E. nitens* would reduce core shrinkage (and therefore possibly collapse). Poke et al. (2006) found that selection for high basic density may also confer some resistance to decay in *E. globulus*.

Residues from thinnings in sawn timber plantations and offcuts from log processing as pulpwood potentially provide an additional income stream to the grower. It is therefore desirable to improve, or at least maintain, pulp properties of some of the species grown mainly for sawn timber. While trait correlations are not widely available for this scenario, there are some obvious problems. Firstly, basic densities of many of the species, especially the low-rainfall ones, are too high for pulpwood (see Tables 3 and 4). It may be that very young material, which has lower basic density, could be used for pulpwood. This limitation of overly high density would also apply to any use of thinnings and off-cuts as feedstock for composites. For appearance and natural durability purposes, it would be desirable to increase extractive content, thereby conferring resistance to decay and greater colour intensity. Pulpwood breeding objectives seek to reduce extractive content.

Species for high-to-medium rainfall areas of southern Australia and New Zealand

Eucalyptus globulus is the preferred species in southern mainland Australia, while *E. nitens* is grown extensively in colder areas of Tasmania (Table 2). Together these two species comprise 80% of Australia’s hardwood plantation resource (Parsons et al. 2006). Tree breeders have therefore sought to optimise growth rates and pulp fibre traits such as basic density and pulp yield. Using a fast-grown, short-rotation pulp resource for high-value log production brings its challenges. Growth stresses that create tension wood are common in many *Eucalyptus* spp., and can lead to problems such as checking, collapse and end-splitting. Knots seriously degrade strength and appearance properties. While it has been demonstrated that thinning and pruning significantly improve sawn recovery (Washusen et al. 2004), some significant knowledge gaps exist in genetic research as it relates to timber properties. This is because much of the early research was focused on fibre properties, not sawn wood properties. In *E. globulus* there is some evidence, based on a very small sample across two sites, that King Island provenance had lower levels of growth strain than Jeeralang and S.E. Tasmania (Yang and Fife 2000). Work on existing progeny trials and breeding populations is showing the promise of tree breeding with respect to wood property traits.

Table 2. High-rainfall temperate species for high-value timber production including approximate basic density relating to plantation-grown timber in Australia and New Zealand

Species	Site suitability	Basic density (kg m ⁻³)	Other traits	Best-bet material for timber production
<i>Eucalyptus globulus</i>	Very plastic; needs good drainage and few frosts; can tolerate hot conditions if soil moisture is adequate	480–570	High growth rate. Pulp yield is excellent. Sawn timber from plantations is showing promise.	Some evidence that King Is. is best-bet for HVT (Yang and Fife 2000). Improved material (pulp traits) is available
<i>E. nitens</i>	Frost tolerant; quite plastic, but suited to cooler climate than <i>E. globulus</i>	450–490	Pulp yield is good. Commonly used on sites too cold for <i>E. globulus</i>	Improved material is available
<i>E. regnans</i>	Site specific; high altitudes, tolerant of cold, intolerant of drought and heat stress	400–440	Pale-coloured timber suitable for joinery, veneer and cabinetry	Improved material is available via NZ eucalypt breeding co-op
<i>E. delegatensis</i>	Site specific; high altitudes, tolerant of cold, intolerant of drought and heat stress	400–440	Pale-coloured timber suitable for joinery, veneer and cabinetry	Only best-bet provenance material is available
<i>E. fastigata</i>	Site specific; high altitudes, tolerant of cold, intolerant of drought and heat stress	400–440	Pale brown, straight-grained wood. Can be prone to collapse.	Improved material is available via NZ eucalypt breeding co-op
<i>E. obliqua</i>	Site specific; deep soil, cool climate	350–680	Not favoured as growth is generally slower than that of alternatives	Only best-bet provenance material is available

Sources of basic density estimates: Nicholls and Matheson (1980); Turnbull and Pryor (1984); Raymond et al. (1998); Jones and Richardson (2001); Miranda and Pereira (2002); Kibblewhite et al. (2004); Poke et al. (2006)

For example, Kube and Raymond (2005) and Hamilton (2007) have shown that drying collapse is a heritable trait in wood cores of *E. nitens*, and that this property could be integrated into breeding programs. Genetic correlations between high-value wood and pulp traits, and the integration of genetics and silviculture, will be the critical determinant of successful multi-purpose *E. globulus* and *E. nitens* plantations.

Another important group of high-rainfall species producing high-value timber in Australasia is the ash group including *E. regnans*, *E. obliqua*, *E. delegatensis* and *E. fastigata* (Table 2). The native timber of the first three members of this group is marketed as Victorian ash or Tasmanian oak, due to its superficial resemblance to those timbers. It is favoured because of its high strength, good working and gluing properties, and pale brown, yellowish or pinkish colour. The timbers are of low durability. These species have been tested in trials but not planted extensively in Australia, probably due to the higher growth rates and pulp yield of *E. globulus* and, until recently, good supplies of high-value timber from Australian native forests. The ash group is also less environmentally plastic and requires high-quality sites which are not abundant in Australia. In New Zealand, the ash species have shown some promise, and they have been planted there on a limited scale. Cooperative breeding programs for *E. fastigata* and *E. regnans* (and *E. nitens*) were established in 1989 (Cannon and Shelbourne 1991), with pulp fibre breeding objectives. Older plantations of *E. fastigata* have been successfully utilised for sawn timber and flooring.

In Western Australia, high-value timber species have traditionally been *E. marginata* (jarrah) and *E. diversicolor* (karri). These species are both sought after for high-value applications, as they are strong, hard and attractively coloured pink-red for jarrah and pink – reddish-brown for karri. Like the ash group, these species are quite site-specific. Tree breeding programs for these species are not active.

Species for medium-to-low rainfall areas

Tree breeding for drier regions of Australia including the sheep–wheat belt (mean annual rainfall about 400–700 mm) has been ongoing, albeit at a low intensity, for 50 y or more. Much of the area was originally covered by woodlands, though this has largely been cleared for agriculture. A cooperative program, the Australian Low Rainfall Tree Improvement Group (ALRTIG) has been formed to speed the genetic improvement of a small number of ‘key species’ suited to southern Australia’s sheep–wheat belt (Harwood et al. 2001). The eucalypt species included red ironbarks (*E. tricarpa* and *E. sideroxylon*), spotted gums (*C. maculata* and *C. citriodora* subsp. *variegata*—CCV), swamp yate (*E. occidentalis*) and river red gum (*E. camaldulensis*). The common breeding objective for these species is to improve traits related to production of sawlogs including survival, growth, stem form and branching.

Low-rainfall environments cannot produce the growth rates of higher-rainfall sites. Also, the species suited to these environments typically have quite different traits to the ash group of eucalypts and the fibre-producing species such as *E. globulus* and *E. nitens*. The wood is very often dense (sometimes even in young material) and frequently rich in extractives, imparting colour and in some cases natural durability. Table 3 lists some of the most prospective low rainfall species, summarises key traits and the best genetic material available for deployment.

The ALRTIG program established breeding programs based on progeny trials that are being progressively thinned to seedling seed orchards. These trials are now starting to yield valuable genetic information such as heritabilities of growth and form traits (e.g. Bush et al. 2007a; Callister et al. 2007; Harwood et al. 2007). The first seed from these orchards was made available in early 2007. In addition to the breeding populations, a series of eucalypt genetic gain trials was established in 2003. These trials compare best-bet natural provenances with genetically improved seed sources (Bush et al. 2007b).

Research into species suited to the drier region west of the coastal strip in southern Queensland and harder or drier sites in northern NSW has proceeded at a relatively low intensity, but is gaining momentum. Species trials of *E. moluccana* (gum-topped box) and *E. longirostrata* (grey gum) established by Queensland Department of Primary Industries and Fisheries (QDPIF) indicate that these species may have some potential for timber production in low-rainfall areas (Lee et al. 2003). Species–provenance–progeny trials of *E. moluccana*, and an expanded group of grey gums (*E. longirostrata*, *E. punctata*, *E. biturbinata*, *E. propinqua*, *E. major*) were established in 2006 in south-eastern Queensland by CSIRO. Forests NSW (FNSW) established a breeding program for *E. longirostrata* in 2004 that is showing promising results for this species (Henson and Smith 2007). Another promising species is *E. argophloia* (Chinchilla white gum). This species has a very restricted natural range, but has performed well in taxa trials in NSW and Queensland (Lee et al. 2003). CSIRO, FNSW and QDPIF all maintain breeding populations of this species, though none are producing seed to date.

Species for high-medium rainfall areas in the sub-tropics and tropics

There is a large potential land base for planting eucalypts in the coastal subtropical region of northern NSW and south-eastern Queensland. This region has traditionally been a rich source of high-value eucalypt timber from native forests. Some of the local species have been planted extensively (Table 4). There are 20 000 ha of *E. pilularis* (blackbutt) and *E. grandis* (flooded gum) planted in northern NSW and 8000 ha planted in Queensland (Parsons et al. 2006).

Table 3. Low-rainfall species for high-value timber production. SPA, SSO and CSO refer to seed production area, seedling seed orchard and clonal seed orchard, respectively

Species	Site suitability	Basic density (kg m ⁻³)	Other traits	Best-bet material for timber production
<i>Eucalyptus cladocalyx</i> (sugar gum)	Winter rainfall. Well-drained, not too cold, mild salinity	780 (plantation)	Brown wood suited to construction and furniture. Good durability (Class 2). Form of good genetic material is acceptable.	Kersbrook SPA; S. Flinders Ra. provenances
Spotted gums (<i>Corymbia maculata</i> , <i>C. henryi</i> , <i>C. citriodora</i> subsp. <i>variegata</i> —CCV)	Well-drained, very few frosts. CCV is best for summer-rainfall sites (better resists <i>Quambalaria</i> shoot blight); <i>C. maculata</i> for winter-rainfall ones	640 (young)—1010 (mature)	Attractive brownish wood, very hard and good durability. Suited to construction, furniture, etc. Susceptible to <i>Quambalaria</i> shoot blight in summer-rainfall areas	SSO seed, S. coast of NSW provenances of <i>C. maculata</i> southern sites; CSO, SSO and <i>Quambalaria</i> -resistant provenances of CCV for subtropics
<i>E. tricarpa</i> and <i>E. sideroxylon</i> (red ironbarks)	Very adaptable and hardy on adequately-drained sites	High (air dry ~1150)	Very attractive red-coloured heartwood. Very strong, dense and durable. Suitable for heavy construction, furniture etc. Growth rate quite low	Coastal provenances of <i>E. tricarpa</i> are better than Goldfields ones (ALRTIG unpublished data)
<i>E. saligna</i> (Sydney bluegum)	Deeper soils, lower margin of medium-rainfall zone. Prospective timber species particularly in WA	450	Heartwood pink-red	Improved seed from seed stands in WA: SSOs and CSOs have been established by FPC
<i>E. occidentalis</i> swamp or flat-topped yate	Winter rainfall. Heavy waterlogged soils, alkaline soils, frost tolerant, very salt tolerant	540–775	Pale coloured wood suited for heavy construction. May be vegetatively propagated with ease (Brammall and Harwood 2001). Form tends to be poor	Redhill SPA, Bundaleer SPA; Grass Patch and nearby locality wild seed. SSO seed now available, but untested
<i>E. camaldulensis</i> (river red gum)	Heavy soils, saline soils. Frost tolerant, winter- and summer-rainfall provenances exist	500–600	Very attractive red/brown wood. Very strong, heavy and moderately durable. Form of pure species tends to be poor in southern Australia.	Clonal material such as Simpson clones; Lake Albacutya, Lake Hindmarsh wild provenances for southern Australia
<i>E. argophloia</i> (Chinchilla or western white gum)	Summer rainfall, tolerant of frost and poor soils	725–855	Heartwood is orange-brown to red-brown. Probably Class 1 durable.	FNSW, QDPIF and CSIRO have breeding programs that will produce seed in future
Grey gums (e.g. <i>E. punctata</i> , <i>E. longirostrata</i>)	Summer rainfall, tolerant of poor soils	850 640–570 (young)	Highly durable timber (Class 1 for <i>E. longirostrata</i>)	FNSW have established a breeding program for <i>E. longirostrata</i> with seed available c. 2012

Sources of basic density data: Turnbull and Pryor (1984); Lee et al. (2002a,b); Blakemore et al. (2003); Gardner et al. (2007)

Table 4. Sub-tropical and tropical species for high-value timber production

Species	Site suitability	Basic density (kg m ⁻³)	Other traits	Best-bet material for timber production
<i>Eucalyptus grandis</i> (flooded or rose gum)	Sub-tropics. Deeper, fertile soils	310–590	Rapid growth, good form. Timber pale and of relatively low density. Suited for light construction. Susceptible to disease in the lowland humid tropics	SSO and CSO material available from FNSW and CSIRO
<i>E. pilularis</i> (blackbutt)	Sub-tropics. Adapted to a wide range of well-drained soils, frost sensitive	590–815 (native), 480 (plantation)	Wood light yellow-brown; hard, strong, moderately durable	FNSW produces genetically improved seed (SSO) with CSO available in future
Spotted gums CCV and CCC only	Sub-tropics (with CCV) and tropics (with CCC). Frost-free or few frosts	640 (plantation CCV), 740 (native CCV)	Highly sought-after by sawmillers. Hard, Class 2 durable. Hybrids with <i>C. torelliana</i> are a promising option for CCV. CCC shows some promise in dry tropics	Genetically improved material ex FNSW or QDPIF with <i>Quambalaria</i> resistance
<i>E. cloeziana</i> (Gympie messmate)	Sub-tropics	990 (native)	Wood yellow-brown, very dense, strong and very durable	QDPIF have established breeding base population. Best are Ravenshoe and S. coastal provenances
<i>Corymbia</i> hybrids	Sub-tropics (with CCV) and tropics (with CCC)	~650	<i>Quambalaria</i> resistance and better frost resistance than CCV. Vegetative propagation easier than CCV	Clonal material available in near future
<i>E. dunnii</i> (Dunn's white gum)	Sub-tropics	610 (native), 470–590 (plantation)	Insect attack is a serious problem	SSO and CSO seed is now available
<i>E. camaldulensis</i> (river red gum)	Sub-tropics and tropics. Will tolerate sites with poorer soil and lower rainfall	880 (native), 500–600 (plantation)	Red-brown timber. Amenable to clonal forestry	QDPIF have developed a wide breeding base for tropical <i>E. camaldulensis</i> —seed may be available in future. Second-generation seed orchard seed is available from SE Asia
<i>E. tereticornis</i> (forest red gum)	Fertile soils in tropics with moderate to severe dry season. Less drought resistant than <i>E. camaldulensis</i> but more than <i>E. grandis</i>	450–620 (plantation)	Amenable to clonal forestry. Wood properties very similar to <i>E. camaldulensis</i>	Refer to early provenance trials from overseas
<i>E. pellita</i> (red mahogany)	Tropics. Rainfall >1200 mm MAR, clay loams, sandy loams	510–630 (plantation)	Red-brown timber. Amenable to clonal forestry	CSIRO /QDPIF jointly developed first and second-generation SSO seed available.

Sources for basic density data: Turnbull and Pryor (1984); Downes et al. (1997); Ona et al. (1997); Harwood (1998); Chamshama et al. (1999); Gardner et al. (2007); Muneri et al. (2007)

In northern NSW, *E. pilularis* is being actively bred by FNSW. This species has long been prized as an all-purpose timber suited to construction, cabinetry, posts and poles. The *E. pilularis* improvement strategy aims to extend the range of plantable sites to more marginal areas. Hybridisation is one route that is being investigated. In the long term, clonal forestry would be a desirable option (Henson and Smith 2007).

Around 12 000 ha of *E. dunnii* (Dunn's white gum) are planted in northern NSW and a similar area in southern Queensland (Parsons et al. 2006). This species is suitable for fibre and sawn timber production, and is being actively bred by FNSW, CSIRO and the Forest Products Commission (FPC) (Smith and Henson 2007). Although it is susceptible to wood-boring insects such as the cossid moth, it is less susceptible than *E. grandis*. It has also suffered severe defoliation from a psyllid (*Creiis liturata*). Issues for solid-wood products include dimensional stability during drying as a result of growth stresses, and high differential shrinkage (Smith and Henson 2007).

The spotted gum species complex, including *Corymbia maculata*, *C. citriodora* subsp. *variegata* (CCV), and *C. henryi* is also potentially suitable for the sub-tropics. Around 4000 ha are planted in subtropical Queensland, and 9000 ha in northern NSW (predominantly CCV). *Corymbia citriodora* subsp. *citriodora* (CCC) is suitable for the tropics, where around 3600 ha are planted (Parsons et al. 2006). Native forest timber is highly sought-after by northern NSW sawmillers: it is dense, hard and at the higher end (Kevin McCarthy, CSIRO, pers. comm.) of the Class 2 durability group. Form in plantations can be very good, with straight stem form and light branching in genetically improved material. One potential negative is the presence of kino pockets and rings (Smith et al. 2007). The species is tolerant of drought, but not of frosts, which have been a significant problem in northern NSW plantations (Smith et al. 2007). In summer-rainfall climates *Quambalaria* shoot blight is a serious problem (Pegg et al. 2005), and it has been found that only certain provenances of CCV show resistance (Dickinson et al. 2004b). Breeding programs run by both QDPIF and FNSW are therefore focused on provenances from the Gympie region of Queensland (Lee 2007). Another possibility is hybridising between *C. torelliana* and the spotted gums. *Corymbia torelliana* can convey resistance when used in hybrid combination with the others. A challenge is getting acceptable rooting rates for commercial mass propagation of clones: mass production of hybrid seed does not appear to be a realistic alternative.

Eucalyptus cloeziana (Gympie messmate) has been identified as having potential for high-value timber production in the sub-tropical lowlands (Lee et al. 2003). About 1200 ha are planted in northern NSW (Parsons et al. 2006). The native timber is very dense and quite strongly coloured: it is suitable for heavy engineering purposes. QDPIF has established a wide breeding base for this species (Lee et al. 2003), following on from initial provenance trials (Lee et al. 1997).

Genetic improvement of eucalypts for high-value timber production in the tropics is relatively less advanced, apart from a low-intensity breeding program for *E. pellita* that was commenced by CSIRO and QDPI in the early 1990s. Nevertheless, trials of a number of taxa have been established and reported (e.g. Dickinson et al. 2004a; Huth et al. 2004; Reilly et al. 2004; Lee et al. 2005). Potentially suitable species include *E. camaldulensis* (river red gum), the closely-related *E. tereticornis* (forest red gum) and *E. pellita* (red mahogany). *Eucalyptus raveretiana* (black ironbox) and CCC have also shown some promise in taxa trials (Dickinson et al. 2004a).

Eucalyptus camaldulensis is an important exotic species in the tropics (e.g. in Thailand and Laos). *Eucalyptus tereticornis* is a close relative of *E. camaldulensis* that has also shown some potential in Australia. These species are tolerant of lower-quality sites in the drier 650–800 mm mean annual rainfall (MAR) zone in the sub-tropics, though performance in the 'dry' tropics (areas north of the Tropic of Capricorn which receive <1200 mm MAR) appears to be highly site specific. They are prone to severe insect attack and unacceptable mortality when planted off-site (Dickinson et al. 2004a). QDPIF has established a breeding population of northern *E. camaldulensis* to serve as a base population for production of genetically improved material and selection of hybrid parents (Lee et al. 2005). Provenances from Petford and Kennedy River (north Queensland), Katherine (Northern Territory) and Gibb River (Western Australia) generally have superior growth and form in the tropical

summer rainfall zone (Pinyopusarerk et al. 1996). The main use of the red gums in tropical Northern Australia may be as a hybrid parents (Lee et al. 2005).

Eucalyptus pellita has been tested in trials in the tropics of Australia and overseas. New Guinea provenances are superior to Queensland ones in Sabah and Malaysia and at Melville Island, but not at Cardwell, Queensland (Harwood et al. 1997). Productive seed orchards based on northern Queensland and New Guinea seed sources have been developed jointly by CSIRO and QDPIF.

The future of high-value timber production in the Australian tropics may actually lie with species other than eucalypts, for example *Khaya senegalensis* (African mahogany) and *Tectona grandis* (teak). These species are showing increasing promise (Reilly et al. 2004; Nikles et al. 2008).

The role of hybrids

Interspecific hybrids may hold some promise for production of high-value timber. Internationally, hybrid eucalypts are enormously important, especially in tropical regions, for example the renowned *E. urograndis* (*E. urophylla* × *grandis*) hybrids deployed extensively in Brazil (de Assis 2000), the Congo (Vigneron and Bouvet 2000) and elsewhere. There are two main reasons for using hybrids instead of pure species: (1) hybrid vigour or heterosis is desired, i.e. the hybrid is superior in some trait to both parents; (2) qualities that are intermediate between those of the chosen pure species are required.

Eucalypt hybrids have occasionally been shown to be more vigorous than either parent on certain sites. Such ‘heterosis’ is often found on sites of intermediate suitability to those preferred by the two parent species. It can be argued that this is not ‘true’ heterosis, but rather adaptation of the hybrid to that site type (Verry 2000). Regardless of the explanation, this property of hybrids is very useful, and is being exploited in an international project to develop hybrids (mainly using *E. camaldulensis* and *E. grandis*) for marginal lands in South Africa and Australia (Chris Harwood, Dominic Kain and Steve Verry, pers. comms). Hybrids developed in the two countries have been exchanged and are presently being tested. Similarly, FPC of WA has collaboratively developed hybrids and tested them in south-western WA (Barbour et al. 2000). Hybrid clones involving *E. camaldulensis*, *E. grandis* and *E. globulus* have already shown some promise in Australia, especially in medium-rainfall areas that are too dry for *E. globulus*, and on somewhat saline soils (Dale 2003).

Eucalyptus hybrids usually have characters that are intermediate to those of the pure species used in the cross, though some traits such as stem straightness can sometimes be dominant (Verry 2000). Though hybridization can occur spontaneously in some species where the natural ranges overlap (e.g. *E. saligna* × *E. botryoides*) and in plantations (e.g. *E. urophylla* × *E. grandis*), the more common route to creating hybrids is to perform controlled crosses between selected individuals of the species of interest. The crosses, if successful, will give rise to an array of progeny that can then be tested. There will often be a range of phenotypes amongst these progeny, with only a proportion showing superior performance. This is not a satisfactory situation for deployment, so it is usually necessary to vegetatively multiply the best individuals. A difficulty with many *Eucalyptus* and *Corymbia* species is that propagation by cuttings is difficult. Species that propagate well include *E. camaldulensis*, *E. tereticornis*, *E. grandis* and *E. urophylla*. These species are often included as a parent in many of the commercially available hybrids. Species such as *E. dunnii*, *E. globulus*, *E. nitens* and *C. variegata* are difficult to vegetatively mass propagate by stem cuttings. However, they can be used in a hybrid combination that includes one of the easy-to-propagate species. Table 5 summarises potential hybrid combinations for each climatic zone.

Research gaps

Eucalypt research in Australia has been mainly focussed on two areas: (1) general domestication of a range of hardwood timber species (selecting the best species and provenances and then breeding for adaptability, growth and stem form), and (2) growth and fibre traits for the southern eucalypts.

Table 5. Hybrid combinations for three climatic zones

Climatic zone and Parent 1 (with rooting ability)	Parent 2	Desired property of hybrid
Temperate		
<i>E. camaldulensis</i>	<i>E. globulus</i> <i>E. grandis</i> <i>E. saligna</i> <i>E. nitens</i>	Good growth rates and tolerance of slightly drier and/or waterlogged/saline sites
<i>E. occidentalis</i>	<i>E. globulus</i> <i>E. grandis</i>	Good stem form and growth rate combined with drought and salinity tolerance
Sub-tropics		
<i>E. torelliana</i>	CCV <i>C. henryi</i> <i>C. maculata</i>	Resistance to <i>Quambalaria</i> , increased cold tolerance, increased drought tolerance cf. parent 2
<i>E. camaldulensis</i>	<i>E. grandis</i>	Increased drought tolerance cf. parent 2. This hybrid is susceptible to cossid moth damage
<i>E. grandis</i>	<i>E. longirostrata</i> and other grey gums	Increased site plasticity (though this hybrid is likely to be to cossid moth susceptible)
<i>E. grandis</i> , <i>E. camaldulensis</i>	<i>E. pellita</i> , <i>E. resinifera</i>	Adaptation to sites intermediate between those parents are suited to. dual-purpose HVT and pulp?
<i>E. longirostrata</i>	<i>E. pellita</i> , <i>E. dunnii</i>	Site adaptability, wood colour, dual purpose HVT and pulp?
Tropics		
<i>E. camaldulensis</i> , <i>E. tereticornis</i>	<i>E. pellita</i> , <i>E. urophylla</i>	Specific adaptation to seasonally dry tropical sites

Southern pulpwood breeders are now turning their attention to solid timber traits so that the *E. globulus* and *E. nitens* plantation base can be best managed for both fibre and solid wood. Silviculture will play a very important role in this, and the interaction of genetics and silviculture is a further area of research. Advances in processing technology will also be important, with improvements in drying and sawing possibly reducing the need to select for collapse and stability traits. The CRC for Forestry is active in these areas.

In low-to-medium rainfall areas, good progress has been made in the winter-dominant rainfall zone. A small number of key species are showing promise. Research on wood properties should follow initial breeding focused on growth, form and disease resistance. In the summer-dominant low-rainfall areas, taxa trials are still underway, with tree breeding programs in train for species such as *E. argophloia* and *E. longirostrata*.

In the higher-rainfall sub-tropics, pest and disease problems, particularly on more marginal sites, are a challenge. Hybrids such as the *Corymbia* hybrids involving CCV and *C. torelliana* may provide a solution. Breeding for increased pest and disease resistance is an area of important future research.

The tropics may present a challenge for eucalypts: much of the available land is seasonally dry. *Eucalyptus pellita* and *E. camaldulensis* show some promise. Hybrids involving these and other species may also prove to be of use. Other genera such as *Tectona* (teak) and *Khaya* (African mahogany) are currently showing the most promise.

It is interesting to note that the degree of genetic improvement required varies for the candidate species. For example, *E. cloeziana* and *C. maculata* have very good stem form and acceptable wood properties such that selecting the best provenances will lead to acceptable plantations. Other species, such as *E. occidentalis*, need a lot more genetic improvement before they could be planted with confidence for solid wood production. Further research on the environmental plasticity and genotype × environment interaction of the high-value eucalypts is also required.

Acknowledgement

Thanks to Chris Harwood for providing critical comment on this paper.

References

- Barbour, E.L., Ralph, A. and Spencer, N. (2000) Early growth assessment of a range of eucalypt hybrids in the south-west of Western Australia. In: Dungey, H.S., Dieters, M.J. and Nikles, D.G. (eds.) *Hybrid Breeding and Genetics of Forest Trees*. QFRI/CRC-SPF Symposium, Noosa, Queensland. Department of Primary Industries, Brisbane, pp. 81–86.
- Blakemore, P., Waugh, G., Northway, R. and Washusen, R. (2003) *High Value, Solid Wood Products*. Publication No 03/022 Rural Industries Research and Development Corporation, Canberra, www.rirdc.gov.au/reports/AFT/03-022sum.html
- Blakemore, P., Washusen, R., Waugh, G. and Northway, R. (2004) Low-rainfall eucalypts as a potential plantation resource in south-eastern Australia for sawn appearance products. *Australian Forestry* **67**, 223–229.
- Brammall, B. and Harwood, C.E. (2001) Vegetative propagation by rooted cuttings of *Eucalyptus* species from temperate low-rainfall environments. Poster presentation in: *Developing the Eucalypt of the Future*. IUFRO Conference, Valdivia, Chile. Instituto Forestal.
- Bush, D.J., Butcher, T., Harwood, C.E., Bird, R., Henson, M. and Shaw, S. (2007a) *Australian Low Rainfall Tree Improvement Group Progress: 1999–2005*. Rural Industries Research and Development Corporation, Canberra, www.rirdc.gov.au/reports/AFT/07-078sum.html
- Bush, D.J., Severino, D., Jackson, T., Collins, S., Driscoll, J., Stackpole, D., Ho, A., Tepper, C. and Brammall, B. (2007b) Genetic gain trials of eucalypts for low rainfall sites. Poster presentation in: *Growing Forest Values*. ANZIF Conference Proceedings. ANZIF, 3–7 June 2007, Coffs Harbour, New South Wales. Institute of Foresters of Australia, Canberra, p. 523.
- Callister, A., Bush, D.J., Collins, S. and Davis, W. (2007) Prospects for genetic improvement of *Eucalyptus cladocalyx* in Western Australia In: *Breeding for Wood Quality*. Australasian Forest Genetics Conference, Hobart, Tasmania. www.proceedings.com.au/afgc.
- Cannon, P.G. and Shelbourne, C.J.A. (1991) The New Zealand eucalypt breeding programme. In: Schönau, A.P.G. (ed.) *Intensive Forestry: The Role of Eucalypts*. IUFRO Symposium, Durban, South Africa, pp. 198–208.
- Chamshama, S.A.O., Mugasha, A.G. and Wate, P.A. (1999) Variation in performance of *Eucalyptus tereticornis* provenances at Michafutene, Mozambique. *Silvae Genetica* **48**, 261–266.
- Dale, G.T. (2003) Salt tolerant eucalypts for commercial forestry: progress and promise. In: *Salinity Under the Sun: Investing in Prevention and Rehabilitation of Salinity in Australia*. Proceedings of the 9th PURSL Conference, Yeppoon, Queensland. Queensland Department of Natural Resources and Mines. http://www.promaco.com.au/conference/2002/pursl/pdf_files/DALE%20Glenn.pdf 8 pp.
- de Assis, T.F. (2000) Production and use of *Eucalyptus* hybrids for industrial purposes. In: Dungey, H.S., Dieters, M.J. and Nikles, D.G. (eds) *Hybrid Breeding and Genetics of Forest Trees*. QFRI/CRC-SPF Symposium, Noosa, Queensland. Department of Primary Industries, Brisbane, pp. 67–74.
- Dickinson, G., Bristow, M. and Kelly, N. (2004a) Promising high-value hardwood plantation tree species for the tropics of Queensland. In: *Prospects for High-Value Hardwood Timber Plantations in the 'Dry' Tropics of Northern Australia*. Mareeba, Queensland. Private Forestry North Queensland Assoc. Inc. Published as a CD-ROM by Private Forestry North Queensland Association Inc., Kairi, Queensland, 8 pp.

- Dickinson, G.R., Lee, D.J. and Huth, J.R. (2004b) Early plantation growth and tolerance to *Ramularia* shoot blight of provenances of the spotted gums taxa on a range of sites in southern Queensland. *Australian Forestry* **67**, 122–130.
- Doran, J.C. (1975) Occurrence of kino veins in two provenance trials of *Eucalyptus regnans*. *Australian Forest Research* **7**, 21–27.
- dos Santos, P.E.T., Geraldi, I.O. and Garcia, J.N. (2004) Estimates of genetic parameters of wood traits for sawn timber production in *Eucalyptus grandis*. *Genetics and Molecular Biology* **27**, 567–573.
- Downes, G.M., Hudson, I.L., Raymond, C.A., Dean, G.H., Michell, A.J., Schimleck, L.R., Evans, R. and Muneri, A. (eds) (1997) *Sampling Plantation Eucalypts for Wood and Fibre Properties*. CSIRO Publishing, Melbourne, 144 pp.
- Gapare, W.J., Wu, H.X. and Abarquez, A. (2006) Genetic control of the time of transition from juvenile to mature wood in *Pinus radiata* D.Don. *Annals of Forest Science* **63**, 871–878.
- Gardner, R.A.W., Little, K.M. and Arbuthnot, A. (2007) Productivity of new eucalypts in Zululand. *Australian Forestry* **70**, 37–47.
- Greaves, B., Hamilton, M., Pilbeam, D. and Dutkowski, G. (2004) Genetic variation in commercial properties of six- and 15-year-old *Eucalyptus globulus*. In: Borralho, N.M.G., Pereira, J.S., Marques, C., Coutinho, J., Madeira, M. and Tomé, M. (eds) *Eucalyptus in a Changing World*. Proceedings of International Union of Forestry Research Organisations Conference, Aveiro, Portugal. RAIZ – Instituto de Investigação da Floresta e Papel, pp. 97–102.
- Hamilton, M.B. (2007) The genetic improvement of *Eucalyptus globulus* and *E. nitens* for solidwood production. PhD thesis, University of Tasmania.
- Harwood, C.E. (1998) *Eucalyptus pellita: An Annotated Bibliography*. CSIRO Publishing, Melbourne.
- Harwood, C.E., Alloysius, D., Pomroy, P., Robson, K.W. and Haines, M.W. (1997) Early growth and survival of *Eucalyptus pellita* provenances in a range of tropical environments compared with *E. grandis*, *E. urophylla* and *Acacia mangium*. *New Forests* **14**, 203–219.
- Harwood, C., Bulman, P., Bush, D., Stackpole, D. and Mazanec, R. (2001) *Australian Low Rainfall Tree Improvement Group: Compendium of Hardwood Breeding Strategies*. Rural Industries Research and Development Corporation, Canberra, www.rirdc.gov.au/reports/AFT/CSF-58A.pdf
- Harwood, C.E., Bush, D.J., Butcher, T., Bird, R., Henson, M., Lott, R. and Shaw, S. (2007) Achievements in forest tree genetic improvement in Australia and New Zealand 4: Tree improvement for low-rainfall farm forestry. *Australian Forestry* **70**, 23–27.
- Henson, M. and Smith, H.J. (2007) Achievements in forest tree genetic improvement in Australia and New Zealand 1: *Eucalyptus pilularis* Smith tree improvement in Australia. *Australian Forestry* **70**, 4–10.
- Henson, M., Smith, H.J. and Boyton, S. (2007) *Eucalyptus longirostrata*: a potential species for Australia's tougher sites? In: *Breeding for Wood Quality*. Australasian Forest Genetics Conference, Hobart, Tasmania, 20 pp. www.proceedings.com.au/afgc
- Hillis, W.E. (1987) *Heartwood and Tree Exudates*. Springer-Verlag, Berlin.
- Huth, J., McKenzie, G. and Allen, R. (2004) An overview of trials of forest tree species in Central Coast–Whitsundays region of Central Queensland and preliminary indications of species worthy of planting or in need of further monitoring. In: *Prospects for High-Value Hardwood Timber Plantations in the 'Dry' Tropics of Northern Australia*. Mareeba, Queensland. Private Forestry North Queensland Assoc. Inc., 12 pp. [proceedings without sequential paging]
- Jones, T.G. and Richardson, J.D. (2001) Comparison of the chemimechanical pulping properties of New Zealand grown *Eucalyptus fastigata*, *E. nitens* and *E. regnans*. *Appita Journal* **54**, 27–29.
- Kelly, M., Tredinnick, J., Cutbush, G. and Martin, G. (2005) *Impediments to Investment in Long Rotation Timber Plantations*. Project No. PN05.1011, Forest and Wood Products Research and Development Corporation, Melbourne, 86 pp. <http://www.fwpa.com.au/content/pdfs/PN05.1011.pdf>
- Kibblewhite, R.P., Evans, R., Riddell, M.J.C. and Shelbourne, C.J.A. (2004) Changes in density and wood-fibre properties with height position in 15/16-year-old *Eucalyptus nitens* and *E. fastigata*. *Appita Journal* **57**, 240–247.

- Kube, P.D. and Raymond, C.A. (2005) Breeding to minimise the effects of collapse in *Eucalyptus nitens* sawn timber. *Forest Genetics* **12**, 23–34.
- Kube, P.D., Raymond, C.A. and Banham, P. (2001) Genetic parameters for diameter, basic density, cellulose content and fibre properties for *Eucalyptus nitens*. *Forest Genetics* **8**, 285–294.
- Lee, D.J. (2007) Achievements in forest tree genetic improvement in Australia and New Zealand 2: Development of *Corymbia* species and hybrids for plantations in eastern Australia. *Australian Forestry* **70**, 11–16.
- Lee, D., Ryan, P. and Nikles, D.G. (1997) Provenance variation of *Eucalyptus cloeziana* exhibited at Pomona on south-eastern Queensland. In: *Overcoming Impediments to Reforestation: Tropical Forest Rehabilitation in the Asia-Pacific Region*. Proceedings of the 6th International Workshop of Bio-Refor, 2–5 December 1997, Brisbane, Australia. Bio-Refor, Brisbane, pp. 187–189.
- Lee, D., Dickinson, G., Lawson, S. and House, S. (2002a) *Spotted Gums*. Hardwoods Queensland Plantation Species Profile series. Queensland Forestry Research Institute, Agency for Food and Fibre Sciences, DPI, Brisbane, 9 pp.
- Lee, D., Dickinson, G., Lawson, S. and House, S. (2002b) *Western White Gum*. Hardwoods Queensland Plantation Species Profile series. Queensland Forestry Research Institute, Agency for Food and Fibre Sciences, DPI, Brisbane, 8 pp.
- Lee, D., Dickinson, G. et al. (2003) *Hardwoods Queensland Research and Development Outcomes: 1999–2003*. Agency for Food and Fibre Sciences, Department of Primary Industries, Brisbane, 63 pp.
- Lee, D.J., Debus, V.J., Pomroy, P.C., Robson, K.J. and Nikles, D.G. (2005) *Developing Genetically Adapted Tree Varieties for Marginal Areas of Northern Australia*. RIRDC Publication No 04/186, Rural Industries Research and Development Corporation, Canberra, 57 pp. www.rirdc.gov.au/reports/AFT/04-186sum.html
- Malan, F.S. (1988) Genetic variation in some growth and wood properties among 18 full-sib families of South African grown *Eucalyptus grandis*: A preliminary investigation. *South African Forestry Journal* **146**, 38–43.
- Miranda, I. and Pereira, H. (2002) Variation of pulpwood quality with provenances and site in *Eucalyptus globulus*. *Annals of Forest Science* **59**, 283–291.
- Muneri, A., Daido, T., Henson, M. and Johnson, I. (2007) Variation in pulpwood quality of superior *Eucalyptus dunnii* families grown in NSW. *Appita Journal* **60**, 74–77.
- Nicholls, J.W.P. and Matheson, A.C. (1980) Variation in wood characteristics in thinnings from a field trial of *Eucalyptus obliqua*. *Australian Forest Research* **10**, 239–247.
- Nikles, D.G., Bevege, D.I., Dickinson, G.R., Griffiths, M.W., Reilly, D.F. and Lee, D.J. (2008) Developing African mahogany (*Khaya senegalensis*) germplasm and its management for a sustainable forest plantation industry in northern Australia: progress and needs. *Australian Forestry* **71**, 33–47.
- Nolan, G., Greaves, B., Washusen, R., Parsons, M. and Jennings, S. (2005) *Eucalypt Plantations for Solid Wood Products in Australia: A Review*. Project No. PN04.3002. Forest and Wood Products Research and Development Corporation, Melbourne, 130 pp. www.fwprdc.org.au/content/pdfs/PN04.3002.pdf.
- Ona, T., Sonoda, K., Ito, K. and Shibata, M. (1997) Relationship between various extracted basic densities and wood chemical components in *Eucalyptus camaldulensis*. *Wood Science and Technology* **31**, 205–216.
- Parsons, M., Gavran, M. and Davidson, J. (2006) *Australia's Plantations 2006*. Bureau of Rural Sciences, Department of Agriculture, Fisheries and Forestry, Canberra.
- Pegg, G., Carnegie, A.J., Drenth, A. and Wingfield, M.J. (2005) *Quambalaria pitereka* on spotted gum plantations in Queensland and northern New South Wales, Australia. *The International Forestry Review* **7**, 337.
- Pinyopusarerk, K., Doran, J., Williams, E.R. and Wasuwanish, P. (1996) Variation in growth of *Eucalyptus camaldulensis* provenances in Thailand. *Forest Ecology and Management* **87**, 63–73.
- Poke, F.S., Potts, B.M., Vaillancourt, R.E. and Raymond, C.A. (2006) Genetic parameters for lignin, extractives and decay in *Eucalyptus globulus*. *Annals of Forest Science* **63**, 813–821.

- Raymond, C.A. (2000) Tree breeding issues for solid wood production. In: *The Future of Eucalypts for Wood Production*. IUFRO Conference, 19–24 March 2000, Launceston, Tasmania. [Conference Secretariat, Conference Design, Hobart, Tasmania.] pp. 265–270.
- Raymond, C.A. (2002) Genetics of *Eucalyptus* wood properties. *Annals of Forest Science* **59**, 525–531.
- Raymond, C.A., Banham, P. and MacDonald, A.C. (1998) Within-tree variation and genetic control of basic density, fibre length and coarseness in *Eucalyptus regnans* in Tasmania. *Appita Journal* **51**, 299–305.
- Reilly, D.F., Robertson, R.M. and Hearnden, M.N. (2004) Results of recent trials of high-value hardwood tree species in the Northern Territory of Australia. In: *Prospects for High-Value Hardwood Timber Plantations in the 'Dry' Tropics of Northern Australia*. Mareeba, Queensland. Private Forestry North Queensland Association Inc. 27 pp. [proceedings without sequential paging]
- Shelbourne, C.J.A., Apiolaza, L.A., Jayawickrama, K.J.S. and Sorensson, C.T. (eds) (1997) *Developing Breeding Objectives for Radiata Pine in New Zealand*. Proceedings of a Conference of IUFRO Working Party S2.02.19 *Pinus radiata* Provenances and Breeding. New Zealand Forest Research Institute, Rotorua, New Zealand. pp. 160–168.
- Smith, H.J. and Henson, M. (2007) Achievements in forest tree genetic improvement in Australia and New Zealand 3: Tree improvement of *Eucalyptus dunnii* Maiden. *Australian Forestry* **70**, 17–22.
- Smith, H.J., Henson, M. and Boyton, S. (2007) Forests NSW's spotted gum (*Corymbia* spp.) tree improvement and deployment strategy. In: *Breeding for Wood Quality*. Australasian Forest Genetics Conference, 11–14 April 2007, Hobart, Tasmania. Australasian Forestry Research Working Group 1 (Genetics), Primary Industries Ministerial Council, Canberra. www.proceedings.com.au/afgc
- Thinley, C., Palmer, G., Vanclay, J.K. and Henson, M. (2005) Spiral and interlocking grain in *Eucalyptus dunnii*. *Holz Als Roh-Und Werkstoff* **63**, 372–379.
- Turnbull, J.W. and Pryor, L.D. (1984) Choice of species and seed sources. In: Hillis, W.E. and Brown, A.G. (eds) *Eucalypts for Wood Production* CSIRO Australia/Academic Press Melbourne, pp. 6–65.
- Verry, S.D. (2000) *Eucalyptus* hybrid breeding in South Africa. In: Dungey, H.S., Dieters, M.J. and Nikles, D.G. (eds) *Hybrid Breeding and Genetics of Forest Trees*. QFRI/CRC-SPF Symposium, Noosa, Queensland. Department of Primary Industries, Brisbane, pp. 191–199.
- Vigneron, P. and Bouvet, J. (2000) Eucalypt hybrid breeding in Congo. In: Dungey, H.S., Dieters, M.J. and Nikles, D.G. (eds) *Hybrid Breeding and Genetics of Forest Trees*. QFRI/CRC-SPF Symposium, Noosa, Queensland. Department of Primary Industries, Brisbane, pp. 14–26.
- Washusen, R., Reeves, K., Hingston, R., Davis, S., Menz, D. and Morrow, A. (2004) *Processing Pruned and Unpruned Eucalyptus globulus Managed for Sawlog Production to Produce High-value Products*. Project PN03.1315. Forest and Wood Products Research and Development Corporation, Melbourne. <http://www.fwpa.com.au/menu.asp?id=36&lstReports=16&order=auth>
- White, D.A., Raymond, C.A., Kile, G.A. and Hall, M.F. (1999) Are there genetic differences in susceptibility of *Eucalyptus nitens* and *E. regnans* stems to defect and decay? *Australian Forestry* **62**, 368–374.
- Yang, J.L. and Fife, D. (2000) Wood properties of three provenances of plantation grown *Eucalyptus globulus* Labill. I. Growth strain. In: *The Future of Eucalypts for Wood Production*. Proceedings of IUFRO Conference, Launceston, Tasmania, 19–24 March 2000. [Conference Secretariat, Conference Design, Hobart, Tas.] pp. 301–309.



**SESSION: GENETIC AND INVESTMENT OPTIONS FOR
HARDWOOD SAWLOGS**

Likely Investment Structures for Hardwood Sawlog Plantations

CRAIG TAYLOR

Director
The Fifth Estate Consultancy Pty Ltd, Suite 203
23 Hunter Street Sydney
GPO Box 5494, Sydney 2000
Email: craig@fifthestate.com.au

Abstract

This paper reviews the structures that could be used for investment in high-value eucalypt sawlog plantations. It considers possible structures, examines their benefits and problems, and suggests some future options. A simple silvicultural and harvesting regime with estimated costs, yields and revenues was developed to assist in the assessment of potential investment structures. Factors critical to the investment structure include land availability, location and cost, scale, markets and management options. Of the potential sources of investment, the following conclusions are drawn:

- Landowner: likely to occur on a small scale only
- Managed investment schemes (MISs): most likely to occur on a commercial scale, particularly as a result of the recent changes to taxation treatment of secondary market trading.
- Industrial: most likely to occur in conjunction with MISs
- Government: also most likely to occur in conjunction with MISs
- Timberland investment management organisations: unlikely to be investors in new plantations but could be active in the secondary market.

Introduction

This paper reviews the structures that could be used for investment in high-value eucalypt sawlog plantations. It considers a number of possible structures, examines their benefits and problems, and suggests some future options. The paper looks at both the investment in the trees and potential ways of securing the necessary land, including its acquisition.

The potential sources of investment funds are broadly:

- landowner
- managed investment schemes (MISs)
- industrial
- government
- timberland investment management organisations (TIMOs).

Potential combinations of these sources of funds are also considered, particularly in relation to access to land.

An important consideration in looking at potential investment structures is the role secondary markets could play. Secondary markets must, in turn, be considered in the context of current tax rules and their implications.

Issues of site selection, species selection, genetics, silviculture, harvesting, log processing and the current state of research and development are all fundamental in considering investment in high-value eucalypt plantations. These issues will determine the costs, log product mix and quality, rotation length, potential scale and possible markets for high-value eucalypt logs grown in plantations. Their detailed assessment is necessary to fully address the issue of possible investment structures. To overcome this problem, a simple regime has been used to assess the various possible investment structures.

Defining a ‘standard’ regime

Although there is a need to assume a simple management and productivity regime, those with only a limited understanding of plantation forestry know that, due to a large number of variables, there is no ‘standard’ regime for growing timber products. Climate, one of the most significant of these variables, is outside the control of the plantation manager except in the assumption that previous average climatic conditions will continue for the course of the planned rotation. To add to the complexity many other things can also change during the tree cropping cycle—for example, markets for and values of log products.

Even the simplest of plantation regimes, a short rotation with a single product extracted in a single harvest (such as *Eucalyptus globulus* plantations for pulpwood production), have significant variability in relation to land costs, establishment costs, productivity, harvesting and delivery costs.

Whilst recognising the extent of the assumptions contained in this standard regime, Table 1 is a notional structure for a single hectare in high-value hardwood plantations in Australia. The yield figures used produce a mean annual increment (MAI) of $13.3 \text{ m}^3 \text{ ha}^{-1}$ over the 25-y rotation.

The intent of this paper is not to consider the precision of the numbers in the table but to consider investment structures that could apply under this regime. (For example, it could be argued that the $50 \text{ m}^3 \text{ ha}^{-1}$ harvested at the T1 is a less-than-viable quantity—the paper assumes this debate is for another forum). However, any structure must consider the risks associated with the underlying investment and therefore it is helpful at this stage to consider how sensitive an investment is to changes in the costs, yields and revenues.

To undertake this analysis, a simple model was constructed using the above numbers to consider changes in the return on investment if some of these inputs are changed. In the analysis, it is assumed that costs and revenues increase at 3% per annum. Using this assumption and the figures in Table 1 as a base case, the nominal return on investment is 9.27%⁴⁴. The sensitivity to the changes is shown in Table 2. Not all variables were tested.

The return on investment is most sensitive to changes that affect revenue, rather than costs, but overall the results show that, for such a long-term investment, the return is remarkably insensitive to relatively major changes. Low sensitivity to the major variables mitigates investment risk and should provide comfort to potential investors for each of the structures discussed below.

The model developed for the standard regime was able to calculate returns on a pre- and post-tax basis. Importantly, if the tax deduction gained at the time when costs are incurred is at the same rate as the tax paid at the time of revenue, the return is unchanged (in this case 9.27%). Much has been made of the attractiveness of the up-front deduction available for investments in forestry managed investment schemes, but from an overall investment perspective the advantage is only one of timing, not of return. Naturally, if an investor gains a deduction when their tax rate is 46.5% and receives the revenue when their tax rate is 15%, there will be an improvement in the post-tax return.

⁴⁴ All rates of investment return in this paper are nominal.

Table 1. A structure for a single hectare that could occur in high-value hardwood plantations. The key inputs of costs, yields, revenues and their timing have been drawn mainly from information supplied by Jon Lambert of Woollybutt Pty Ltd.

Age	Cost	Cost (\$ ha ⁻¹)	Harvest	Yield (m ³ ha ⁻¹)	Stumpage (\$ m ⁻³)	Revenue (\$ m ⁻³)
0	Planning and establishment	1 500				
1	Post planting	500				
2–25	Annual maintenance	50				
0–25	Land rental	120				
2	Form prune	115				
4	Lift prune 1 ^A	600				
6	Lift prune 2 ^A	600				
7	Lift prune 3 ^A	800				
4	Thin to waste ^B	150				
11	Roading	450				
12	T1 ^C	150	Pulpwood	50	22.00	1 100
19	T2 ^C	150	Pulpwood	25	23.50	588
			Small sawlog	25	65.00	1 625
25	Clearfall ^C	150	Pulpwood	47	25.00	1 175
			Small sawlog	47	66.50	3 126
			Large sawlog	141	157.00	22 137

^A400 trees ha⁻¹

^B300 trees ha⁻¹

^CManagement fee for harvest planning and supervision

Before moving to examine investment structures, three other groups of interrelated factors—land availability and location, scale and markets, and management—are considered.

Land availability, location and cost

Although \$120 ha⁻¹ y⁻¹ is assumed in the analysis for land rental cost, it is the author's experience that land rentals are often significantly higher than this. Theoretically, there is a vast area of suitable⁴⁵ cleared agricultural land available for plantation establishment in Australia. However, with a wide range of alternative land uses and numerous impediments to plantation development⁴⁶, the area actually available is significantly restricted.

⁴⁵ Suitable in relation to climate, soil type, slope, tenure and access. For more information refer to work undertaken by ABARE and a number of Regional Plantation Committees.

⁴⁶ Examples include water-use issues, distance to markets and community opposition.

Table 2. Responses of the return on investment to changes to some of the input variables considered in Table 1

Factor	Change (%)	Return on investment (%)
Planning and establishment cost	+20	9.02
	-20	9.53
Land rental	+20	9.01
	-20	9.53
Annual maintenance	+20	9.18
	-20	9.36
Stumpage ^A	+20	10.18
	-20	8.12
Large sawlog yield ^B	+20	9.73
	-20	8.74

^A Change can be either through a change in yield ($\text{m}^3 \text{ha}^{-1}$), or price ($\$ \text{m}^{-3}$). This sensitivity can also be used as a proxy for changes in harvest and or haulage costs ($\$ \text{m}^{-3}$).

^B Total yield has been kept constant with changes spread evenly over pulpwood and small sawlogs.

This has resulted in the emergence of nodes of development, the appearance of which has in turn pushed up land prices in those nodes. Rentals of more than double those used in the model may be more common, and this has a significant effect on the returns (8.04% at $\$240 \text{ha}^{-1} \text{y}^{-1}$).

Land purchase, rather than renting, has been used by the larger plantation developers because it overcomes the problem of limited area available for rental⁴⁷, provides security of tenure and provides the potential to enjoy land-value appreciation. Again, however, this has forced up land values in the locations targeted by the developers. This standard regime and the model do not specifically consider land acquisition.

Modelling a land-acquisition structure is complex as assumptions must be made in relation to initial land cost, the fraction of the area that is plantable, land-value appreciation, land use after the modelled rotation and the different tax treatment of land (on capital account) and trees (on revenue account). Using an annual land rental is, however, a good proxy for land ownership on the basis that there is an opportunity cost to owning the land which can be recovered by ‘charging’ the plantation investment an annual rental cost. Supporting this, the inclusion of a notional annual land rental in a plantation’s discounted cash flow analysis is now the usual method used by plantation estate valuers in situations where the underlying land is owned (but is separately valued) by the same entity that owns the trees.

The model also assumes that the plantation is reasonably proximate to markets for pulpwood, small sawlogs and large sawlogs; there are relatively few locations in Australia that offer such access and where they occur there will be further upward pressure on land cost.

The problems with land availability suggest that a model where an existing landowner sets aside part of their land for plantations may provide a solution. Assuming the landowner does not pay themselves the rental (that is, land rental in the model is $\$0 \text{ha}^{-1} \text{y}^{-1}$), the return increases to 10.66% , a return many agricultural landowners would consider reasonably attractive. Despite this apparent attractiveness, it must be considered in relation to the important issues of scale and markets.

⁴⁷ Purchasing large tracts of land requires substantial capital outlay and, from a capital management perspective, leasing can be and has been an attractive option; the purchase model is driven by supply rather than investment or capital management criteria.

Table 3. A model that describes the development of a large plantation estate producing pulpwood, and small and large sawlogs

Product	Minimum input per annum for facility of efficient scale (m ³)	Approximate harvest area required in standard model (ha y ⁻¹)	Approximate estate size for 25-y rotation (ha)
Pulpwood (export) ¹	250 000	2 000	50 000
Small sawlogs	70 000	1 000	25 000
Large sawlogs	70 000	500	12 500

¹ Domestic pulpwood processing (that is, pulp and paper production) would require an input of at least 4 times this quantity

Scale and markets

Successful plantation investment must occur on a scale that provides commercially viable quantities that are:

- suitable for existing markets and or
- sufficient to attract investment in new markets and or
- able to support export markets.

There are examples in the softwood industry where relatively large plantation estates (>30 000 ha) have been established but have still struggled to attract investment in processing or export facilities suitable for the mix of log grades produced.

The model described above produces pulpwood, small sawlogs and large sawlogs. Facilities that efficiently utilise these products have very large wood requirements, and if the standard regime were to support such facilities a large plantation estate would be needed, as indicated in Table 3.

The stumpages in the standard regime assume that markets are available at the time of harvest and within 100 km of the plantation. This scale of high-value eucalypt plantation development in a single region is highly improbable and therefore plantations must be established in regions where there are existing markets that meet their wood requirements from other sources such as native and regrowth forests. In regions where this is the case, for example Gippsland, Tasmania and northern NSW⁴⁸, there is no need for a minimum planted area in a particular year nor in the overall estate, provided the other sources of supply continue to be available. Outside these regions, the required scale will be prohibitive.

Although the issue of scale and markets can be addressed by establishing the high-value eucalypt plantations in appropriate regions, the plantations will require management efficiency and expertise.

Management

Management of hardwood plantations in Australia has progressed significantly in the last decade. Knowledge in the areas of genetics, site selection, silviculture and harvesting has increased and investors have access to well-credentialed plantation management contractors. However, efficient management requires each individual plantation block to be developed on a minimum scale. Minimum areas, identified by managers, range from 5 ha to >100 ha, with high-value plantations tending to be at the lower end of that range and low-value ones at the higher end. Plantation managers could efficiently manage blocks at the smaller end of the range if the regional estate provided sufficient critical mass to

⁴⁸ Unfortunately, the need to develop high-value eucalypt plantations in specific regions will affect the price and availability of land.

support the necessary skill base, infrastructure (for example, GIS, monitoring, protection and inventory systems). Similarly, landowners could efficiently manage relatively small plantations in conjunction with other activities on their properties.

The minimum practical size of individual plantations is more likely to be determined by roading and harvesting considerations. Construction of roads suitable for log extraction is an expensive operational component of the investment, with a portion of the costs fixed and needing to be amortised over a reasonable harvest volume. The standard regime assumes that a commercial harvest of $50 \text{ m}^3 \text{ ha}^{-1}$ will be undertaken at age 12 y.

To meet this requirement, and based on expected roading costs and current harvesting systems, a yield of 2000 m^3 per operation is considered a minimum, requiring each plantation managed under the standard regime to be a minimum of 40 ha.

The standard regime assumes an annual maintenance cost which incorporates the cost of a third-party plantation manager. Additional plantation management costs are assumed to occur at each harvest event. As a component of these plantation management costs will be fixed, the unit cost per hectare will decrease—at least theoretically—if larger areas are planted.

Investment structures

Each of the potential sources of funds are considered below, using the assumptions in the standard regime and also assuming that the high-value eucalypt plantations will be developed in regions and at a scale that provides access to markets and efficient management.

Landowner

The standard regime model shows the landowner model has a particular attraction in that there is no ongoing requirement to pay rental—the cost of the land is the opportunity cost of not producing something else on the part of the property set aside for the plantation. If the opportunity cost is ignored or not valued by the landowner, returns are significantly improved. Further, the landowner may have the ability to undertake some of the establishment and maintenance of the plantations, lowering the cash costs and again increasing returns. However, the attractiveness of the landowner approach is offset by a number of factors:

- Upfront costs: Despite a landowner being able to offset some of the establishment costs by providing labour and machinery, there is still a significant cost at the beginning of the rotation that will need to be funded. If the year 0 and 1 costs from the standard model were halved, the landowner must find at least $\$1000 \text{ ha}^{-1}$.
- Scale: On our assumption of a minimum of 40 ha for an efficient plantation, the landowner will need to have access to at least $\$40\,000$.
- Productive land: Experience shows that establishing a plantation on the ‘rough block out the back’ will not produce a high-value crop. Landowners, however, are reluctant to set aside areas of their better land with good access, as to do so is likely to conflict with their current agricultural enterprise.
- Timing of returns: Landowners are used to investing in crops that will provide a return in less than a year. Convincing them to invest in a crop which provides a return in 25 years is particularly difficult.

To overcome these problems and attract investment by landowners, an alternative source of funds is required for the upfront investment. In the late 1960s and early 1970s a scheme was successfully developed to encourage landowners to invest in long-rotation softwood plantations.

The scheme involved the government providing low-interest loans and free technical support to landowners to help them undertake the site selection, establishment and maintenance of the plantations. The performance of the plantations was monitored by government foresters. The scheme encouraged a number of landowners to continue to invest in plantations and resulted in a significant area of new plantations being established.

The development of a similar scheme to support the establishment of new high-value eucalypt plantations could be combined with a number of current government-funded or supported initiatives associated with achieving environmental outcomes such as soil, water and catchment management, carbon sequestration and biodiversity.

Although the standard regime shows potentially attractive returns, without well-structured financial and technical support from government, it is difficult to see a landowner investment structure resulting in a significant increase in the area of high-value eucalypt plantations.

Managed investment schemes

Managed investment schemes have provided an enormous source of funds for plantation development over the last decade. This investment has been supported by taxation laws and product rulings that allow for individual investors in an MIS to become primary producers, allowing for their initial investment to be immediately tax deductible and to be offset against other taxable income. Current government policy supports the use of MIS for the continued facilitation of plantation investment, although there will be changes to legislation that remove the need for investors to be considered as primary producers. In addition, the new legislation removes previous impractical restrictions on the time between investment and plantation establishment and also deals with the issue of secondary markets (considered below).

Managed investment schemes have, until very recently, failed to attract significant investment into longer-rotation, higher-value projects. (Some notable exceptions include the successful softwood scheme offered by Willmott Forests and hardwood schemes offered by Gunns and others.) Short-rotation hardwood pulpwood schemes have attracted most of the investments for the following reasons:

- Timing of returns: A 10-y investment (albeit an illiquid one) is within the financial planning horizon of many investors, whereas 25 y is often well beyond it.
- Clarity of markets: MIS promoters have been able to show that there is likely to be a good market for hardwood pulpwood in 10 y—it is much more difficult to demonstrate the likelihood of a sawlog market in 25 y.
- Price transparency: The prices paid for pulpwood in international markets have been much more transparent than those for logs in sawlog markets.
- Government competition: Long-rotation softwood (plantation) and hardwood (native forest) log supply has been largely through government-owned and managed estates, where pricing may have been influenced by other, non-economic policy objectives.
- Management: Plantation managers have developed significant experience in site selection, genetics, silviculture and harvesting of short-rotation pulpwood crops, whereas these issues are not as well understood for longer-rotation high-value hardwood plantations.
- Previous experience or perceptions: Earlier longer-rotation schemes (particularly softwood) received extensive negative publicity as a result of poor growth and management.

There appears, however, to have been a change of attitude by investors to MISs designed to produce higher-value products from longer rotations. Teak, African mahogany, sandalwood and radiata pine as well as eucalypt long-rotation high-value MIS products are now offered by a number of new and well-established investment promoters, and investment in each of these sectors increased in 2006–2007, notably at the expense of investments in pulpwood-only projects (Figure 1).

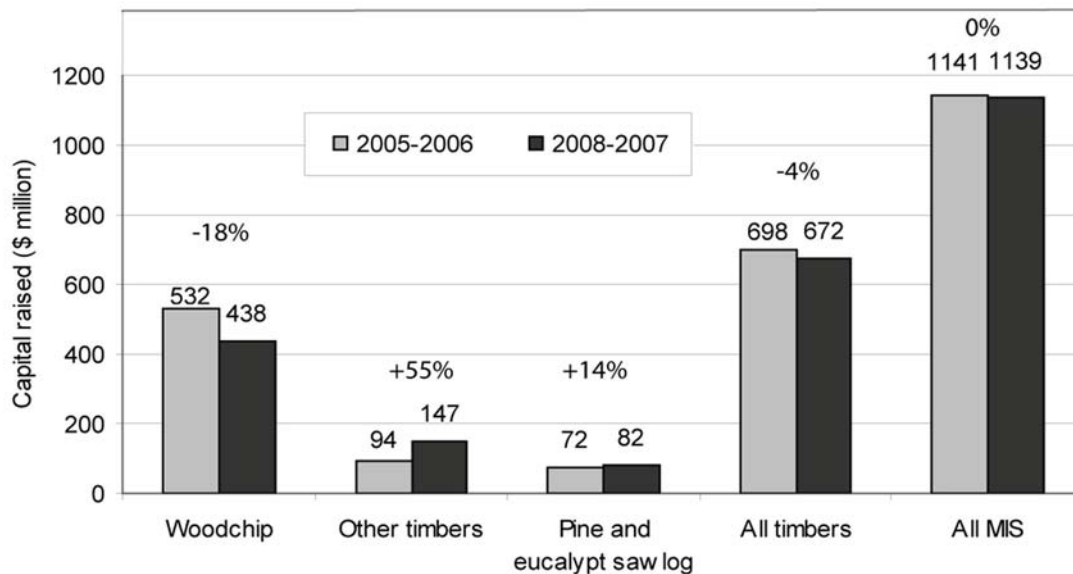


Figure 1. Changes in investment in different types of plantations from 2005–2006 to 2006–2007 provided by the Australian Agribusiness Group

The change in investor attitude is most likely to be due to:

- **Management:** As plantation managers' knowledge of site selection, genetics and silviculture has increased, promoters have been able to more confidently offer longer-rotation products.
- **Promoters:** Experienced and well-credentialed promoters are now offering long-rotation high-value plantation investments as part of a suite of investment products.
- **Location:** Longer-rotation high-value MISs (specifically non-eucalypt) are located in areas that have not seen extensive development of short-rotation pulpwood projects. Therefore, limited land availability driving up price is less problematic.
- **Diversification:** Many investors in MISs plan to invest every year and as such already have a significant exposure to short-rotation pulpwood. Some are looking to diversify their portfolio of investments whilst still taking advantage of the upfront deductibility of forestry investments. Also, new legislation has resulted in non-forestry MIS not having the same taxation treatment, reducing the options for diversification.

It seems likely that investment in long-rotation high-value plantations through MIS will continue to grow. However, land availability and cost are likely to constrain this growth, particularly in regions suitable for eucalypt species. Importantly, the high-value eucalypt schemes that have attracted the most interest are based on a 20-y rotation⁴⁹ which will appeal to a wider investor base. If the standard regime were reduced to 20 y it would fit better into an MIS structure, but the production of high-value sawlogs would be compromised.

The costs in the standard regime do not take into account the additional costs of establishing and running a MIS. A MIS has significant upfront and ongoing costs in:

- setting up the scheme and the responsible entity
- obtaining product rulings
- preparing, printing and distributing product disclosure statements
- promotion and commissions
- independent forester and tax reports
- government charges (for example, stamp duty)
- maintenance of an investor database and regular investor updates
- governance.

⁴⁹ Both the Gunns and Willmott Forests radiata pine MISs are based on 25-y rotations.

If additional up-front costs of \$1000 ha⁻¹ and ongoing costs of \$15 ha⁻¹ y⁻¹ are added to the standard regime model, the return falls to 8.74%. Importantly, these additional costs do not incorporate any margin for the developer and promoter of the scheme.

The inclusion of these costs and the resultant reduction to the investors' return, when combined with the additional risks associated with longer-rotation plantations, has constrained MIS structures for high-value eucalypt plantations to date.

The availability of secondary markets for MIS investors has long been raised as an impediment to the attractiveness of longer-rotation schemes. This issue will be dealt with later in the paper.

Finally, an important consideration for MIS is the funding of land. Most investors in MIS are looking to make the full investment upfront and are less attracted to schemes requiring an ongoing annual rent payment. Therefore, the scheme promoter has needed to fund a land bank which will be encumbered by investors' trees for the length of the rotation.

The rental return on the land is received only at the time of harvest, making shorter rotations more attractive to the landowner. As plantation managers and MIS promoters (often related companies) move to second and subsequent rotations, the funding pressure to acquire new land will decrease, thereby increasing the opportunities for longer-rotation schemes. The author is aware of only one MIS, promoted by a subsidiary of Macquarie Bank, which gives investors the opportunity to invest in trees and the underlying land⁵⁰. It is possible that similar structures will become available through other promoters in the future.

Industrial

Internationally, the timber processing industry has been a significant investor in plantations and native forests, with direct ownership seen as necessary for security and flexibility of log supply. More recently these companies have seen that the investment profile and returns from plantations are not compatible with shareholders' objectives and expectations, and the trend has been for processing companies to divest their forest assets. In many cases, the divestment has been with contracts to buy back logs at harvest, thereby maintaining resource security. New investment in plantations by processing companies is relatively rare in Australia and almost non-existent in long-rotation hardwood plantations⁵¹.

Processing companies have, however, recognised the opportunities to use MIS plantation investment to provide them with future resource security. Some have developed their own MISs (for example, Gunns) while others have formed strategic alliances with MIS promoters (for example, Midway with Macquarie Bank). Some MIS promoters are now pursuing a vertical integration strategy and investing directly in processing facilities (for example Willmott Forests, ITC and FEA).

It is likely that these trends will continue and that associations between promoters of MISs and processing companies will strengthen, providing the dual advantages of resource security for the processors and market security for the MIS investors.

Surprisingly, two of Australia's largest hardwood sawmilling companies, Gunns and ITC, do not promote large-scale MISs designed for the future production of eucalypt sawlogs, although it is likely this will change in the near future. Both are involved in longer-rotation MISs, Gunns with radiata pine and eucalypt veneer, and ITC with sandalwood, red mahogany (*Eucalyptus pellita*—grown for sawlogs for appearance-grade and structural timber products) and teak. Because both of these companies have secure high-quality sawlog supply available from government-owned and managed native forests, they may have previously determined that additional future eucalypt sawlog supply is unnecessary. With the removal of impediments (discussed later in this paper), it is probable that these companies and possibly others associated with down-stream processing will reassess their approach to

⁵⁰ Other products have been developed but have not been continually offered each year, such as the Commonwealth Bank Premium Plantations managed by ITC.

⁵¹ Some processing companies are investing directly in second-rotation crops. These include Green Triangle Forest Products, Auspine, Gunns and Midway.

MIS sawlog projects. Gunns also is likely to have access to eucalypt sawlogs from a large plantation program managed by the Tasmanian Government.

BORAL Timber, the other major Australian hardwood sawmiller, has investigated direct plantation investment but has not commenced a program. BORAL Timber is likely to have access to sawlogs from NSW Government-funded hardwood plantations.

The returns projected using the standard regime are unattractive to industrial processors, for whom hurdle rates of return often exceed 15%. As such it is unlikely that significant direct investment by processors in high-value eucalypt plantations will occur. The exception may be where other benefits are available or perceived, such as utilisation of an existing land bank, carbon debit offsets or corporate image.

Government

Government policy in a number of Australian states has seen significant areas of productive native forest transferred to preservation management regimes. To make up for the loss of sawlogs available to processing industries, governments have proposed plantation development. Expansion of the plantation estate managed for hardwood sawlog production has been extensive in Tasmania, where funds have been made available to develop the new resource. In NSW, significant areas have been established, but limited land availability and the problem of successfully matching species to site have resulted in only partial success. It also appears that funds are limited for further plantation development, despite more areas of native forest being taken out of production.

In Queensland and Victoria there has been virtually no government investment in commercial-scale hardwood plantations, and allocation of future funds is highly unlikely⁵².

The lack of government investment is surprising, given the returns projected from the standard regime are likely to be attractive to government trading enterprises. High-value eucalypt plantation development at an appropriate scale would also support other broad government policy objectives, particularly rural and regional development⁵³. The impediment is likely to be lack of available capital rather than inadequate potential returns.

As with industrial involvement in high-value eucalypt plantation development, the future of government involvement is likely to be in conjunction with MISs. A number of state governments are currently considering alliances with MISs to raise funds to establish and manage high-value eucalypt plantations, for both first and subsequent rotations. Supporting this, governments have access to the management expertise required for plantation development and, as a number already manage large plantation estates, the fixed costs of plantation management are already covered. They also enjoy market security for the investor as they currently have supply contracts with sawmills and, in some cases, access to land.

Timberland investment management organisations

Timberland investment management organisations (TIMOs) are businesses that manage investments in forests on behalf of institutions (often large superannuation or pension funds). They developed from the institutions' desire to have part of their portfolio invested in 'alternative assets' (that is, not purely in property, shares and cash). For many North American institutions, timberland investments have now become mainstream, with specific portions of their portfolio directed to what is now a recognised asset class.

⁵² Some state bodies, and in particular Queensland DPI, have been investing heavily in R&D to support the development of long-rotation hardwood plantations.

⁵³ Research by the Bureau of Rural Sciences suggests that other socio-economic policy objectives are supported by plantation development. Contributions to policy objectives in the areas of environmental outcomes and infrastructure development have also been demonstrated.

The returns projected in the standard regime model are likely to be attractive to TIMOs. Recent investments by TIMOs in plantation estates are likely to produce returns no greater than those projected in the standard regime model.

TIMOs have been active in plantation investment in Australia for 10 y, but they are not well represented in the portfolios of Australian-based institutions. To date they have invested in existing plantation estates rather than new plantations because:

- the institutions are looking for both cash flow and capital gain from the outset—new plantations take some time to deliver positive cash flows
- the institutions are looking for regular and relatively smooth cash flows—these can be delivered only by an estate where part is close to harvest and a long-term cash flow can be modelled
- the TIMOs are also looking for regular cash flows from the outset to service their management fees
- the investment is often geared, requiring positive cash flow to service the debt
- they are looking to take on limited market risk which is mitigated when the estate is already supplying existing markets
- the institutions are looking for large-scale investments, usually greater than \$100 million.

It is highly unlikely that TIMOs will become investors in new high-value eucalypt plantations: it is much more likely they will utilise the advantages of MISs through alliances and partnerships (rather than direct investment) to establish new plantations and re-establish harvested areas.

Hancock, one of the world's largest TIMOs and the first to manage a plantation investment in Australia, has formed an alliance with Willmott Forests where Hancock Victorian Plantations (HVP) will make available to Willmott Forests a minimum of 10 000 ha of harvested plantation lands to be replanted with funds raised by MISs. HVP will provide forestry services to Willmott Forests for the duration of the investment, including plantation establishment, maintenance and log marketing. Although this arrangement is for second-rotation radiata pine plantations, it is possible that similar arrangements between TIMOs and MISs will be set up for new high-value eucalypt plantations.

Combinations

In the future, the sources of investment funds as described above are unlikely to be mutually exclusive. Some potential combinations have already been mentioned including:

- landowner, with government providing low-interest loans and technical support
- industrial with MISs
- government with MISs
- TIMOs with MISs.

There is also potential for joint ventures (JVs) where investors provide the upfront funds for establishment and maintenance, and an existing landowner provides the land. The landowner can accept a reduced or no rent in exchange for a portion of the harvest proceeds⁵⁴. The NSW Government set up a number of JVs in the late 1990s for high-value eucalypt sawlog production and, although these were of varying success, most problems are associated with species selection and access, which can be overcome. There is no impediment to establishing JVs between industrial processors or governments and landowners, and it is possible that this model will be pursued.

Although each of these structures is possible and likely to occur in some instances, the most likely development will come through the introduction of regulatory and taxation arrangements for MIS investors to participate in secondary markets.

⁵⁴ This is the internal process used by most MISs where the investor leases the land from a third party (an entity related to the MIS promoter) and pays a portion of the harvest proceeds to the third party as rent in arrears.

Secondary markets

The absence of a regulatory and taxation regime that supports the sale of investments ('interests') in plantation forestry MISs has long been held as an impediment to the development of projects aimed at producing high-value sawlogs. A long list of enquiries, consultant reports and submissions have pointed out the need for investors in MISs to have an exit option for their investment before the time of harvest if they are to be attracted to projects that do not produce their final harvest for >25 y.

Prior to the last federal budget, changes to the rules regarding all MISs and specifically supporting forestry MISs were announced, along with a review of secondary markets. The Federal Budget 2007–2008 papers announced the following:

- The review into impediments to secondary markets for forestry MIS interests, announced on 21 December 2006, conducted by Treasury and the Department of Agriculture, Fisheries and Forestry has now been completed.
- From 1 July 2007, initial investors in a forestry MIS will be allowed to trade their interests once they have been held for a period of at least four years. The four-year restriction will apply only to the initial investors in a scheme. The measure will apply to interests in a pre-existing scheme, meaning that taxpayers who invested in a forestry MIS prior to 1 July 2003 will be able to trade their interests from 1 July 2007.
- The Government believes that trading of forestry MIS interests will introduce pricing information into the market and increase liquidity of the interests. Consequently, the Government will introduce legislation to amend the income tax law to:
 - allow existing interests to be traded, to support depth in the market
 - require initial investors (both existing and future) to hold their forestry MIS interests for four years
 - extend the amendment period for forestry MIS investors to allow the Australian Taxation Office (ATO) to enforce the holding-period rules
 - introduce a market-value pricing rule at the time of first sale from an initial to secondary investor to reduce tax arbitrage
 - treat secondary investors (other than those holding interests as trading stock) on capital account for acquisition and disposal of their interests. For these purposes harvest proceeds will be treated as a disposal.
 - allow secondary investors a deduction for ongoing costs, to limit the incentive to front-load fees, and introduce a matching provision that seeks to recoup on revenue account these deductions from the sale or harvest proceeds.

The introduction of secondary markets is expected to significantly change the investment structure for long-rotation investments. Essentially, it will allow MIS promoters to provide investment products in long-rotation plantations whilst locking in the initial investor for a period only within their investment-planning horizon. Likely examples of new investment products are:

- a long-rotation hardwood MIS established with a view to putting interests on the open market any time after age 4 y
- a long-rotation hardwood MIS established with an agreement by the investors to sell their interest to an industrial processor, a TIMO, the government or back to a company related to the MIS promoter.

Each structure solves some of the problems that currently exist for investment in long-rotation, high-value plantations, as the initial investor can take advantage of offsetting their investment against taxable income from another source and the secondary investor is investing closer to the major (positive) cash flows from the plantation. Therefore, it is highly likely that all these options and others will appear as MIS products in the near future.

The new arrangements allow for the first investors to have the initial investment, and return from any sale into a secondary market, on their revenue account, but the second and subsequent investors must treat the investment as capital. Given the different taxation regimes attached to revenue and capital accounts, and the different rates of tax applied to various types of investors (personal income tax up to 46.5%, company tax at 30% and tax on superannuation funds of 15%), there is the potential for financing and transaction structures to be set up to the advantage of a range of investor types participating in the one investment at different times in the rotation. It is the Federal Government's intention that such advantages not be available and it is likely that legislation and interpretations will be such that this does not occur.

The advantages of the development of secondary markets will be in matching the cash flow timing to the needs of different types of investors. This is likely to result in structures where an MIS establishes plantations and a TIMO purchases the interests on the secondary market closer to the time of harvest. Although governments could also purchase interests on the secondary market, it is more likely that the trend of removing plantation assets from their balance sheets will continue. Similarly, industrial processors could purchase interests on the secondary market, but this will still not overcome the problem of their hurdle rates of return.

Other high-value alternatives

Even though the availability of secondary markets will open up the opportunity for alternative investment structures and remove some of the impediments to investments in high-value eucalypt sawlog regimes, other options should not be excluded from an analysis of high-value plantations. In concluding this paper, some of those alternatives are considered.

Although log values are not as high, there is considerably less risk in growing eucalypt plantations with the aim of producing logs suitable for rotary veneers as the quality specifications are significantly less stringent than those for sawlogs. Some MISs (for example, Gunns) are currently proposing investments that produce pulpwood and peeler logs over a 20-y rotation. Other investment products aim to produce lower-quality sawlogs in a 15–18-y period. Some eucalypt plantations in South America and South Africa are producing sawlogs suitable for the production of appearance-grade timbers at about age 10 y, FEA is producing structural-grade timber from *E. nitens* thinnings at age 9 y and rotary veneers are being produced from *E. dunnii* plantations in China at age 4 y.

One of the main objectives in designing investment structures is to minimise the time between the major cash outlay (establishment) and major revenue (final harvest). This is one reason for the popularity of short-rotation hardwood pulpwood plantations. *Eucalyptus globulus* pulpwood is regarded as one of the highest-value papermaking fibres available. Plantations of reasonable quality (yielding $>200 \text{ t ha}^{-1}$ at age 10 y) within 100 km of a port or chipping operation are currently attracting stumpages of $\$40 \text{ t}^{-1}$. To get a return of 9.27% (the return from the standard model), this is equivalent to $\$106 \text{ t}^{-1}$ at age 20 y and $\$172 \text{ t}^{-1}$ at age 25 y. Given the risks associated with growing a plantation for an extra 10–15 y and the greater uncertainty of future markets for high-value products, it is most likely that short-rotation hardwood pulpwood plantations will continue to attract a large portion of the available funds. Whether focusing on pulpwood production or other products, minimising the investment period will remain a key objective of those structuring plantation investments.

Finally, the introduction of secondary market regulations opens up an opportunity to use plantations originally established for pulpwood-only production. It is likely that a proportion of the extensive *E. globulus* and *E. nitens* pulpwood plantations established across southern Australia over the last decade will be diverted to other high-value applications, and that future MIS offerings will allow flexibility in their target products. It should be remembered that radiata pine was originally planted to provide green rough sawn timber for fruit and vegetable packing crates, but has now become the main structural-grade timber used in the Australian and New Zealand building industry. It is quite possible that the species currently established for short-rotation pulpwood production will undergo a similar transition and that investment structures will develop to facilitate this.

Summary: Plantation eucalypts for high-value timber

RODNEY KEENAN

Head of School
School of Forest and Ecosystem Science
The University of Melbourne, Creswick, Victoria
Email: rkeenan@unimelb.edu.au

This paper reflects on the preceding talks at the Plantation Eucalypts for High Value Timber conference⁵⁵. A subsequent chapter provides key conclusions and recommendations from the conference.

Are we about to enter a new era for plantation eucalypts in southern Australia and move beyond the short rotation pulpwood production paradigm that dominates this region? Producing sawn timber, veneer and high value products from eucalypts is not new. Operations in South America, South Africa, southern Europe and Asia grow and manage for high value timber products. So why can't we?

Historically in Australia we have had a plentiful supply of a variety of eucalypt timbers from native forests. The development of plantation eucalypts for high-value timber languished as a curious sideline. Where promoted as a niche market option for farm foresters, these types of plantings have generally failed to provide a quality timber resource or significant economic return to the owner. Failures have lain in poor species and site selection, poor management, and lack of sufficient resource to provide for a viable market. This also reflects the relatively young science of growing eucalypt plantations for hardwood sawlogs in Australia – predominantly over the last 10 years.

Vince Erasmus of ITC, suggested that we could be on the cusp of a new era. Global wood supply is tightening due to restrictions on native forest extraction, particularly in the tropics, the stopping of flows of illegal wood, the export taxes on Russian log exports and a growing demand for lighter coloured hardwoods for furniture, flooring, veneer and other products. He argued that we needed a shift from the predominant pulpwood paradigm for eucalypt plantations. The challenges in doing so lie in the familiar economic equation of getting the right combination of access to capital, land and skilled labour to meet the requirements for producing high quality outputs.

High-value options for eucalypts can take two potential directions: harvesting products of higher value from known entities currently grown mostly for pulpwood such as blue gum (*E. globulus*) or shining gum (*E. nitens*), or developing non-traditional eucalypt plantation species with timber properties (colour or durability) that confer high-product value.

Because of the focus on pulpwood, plantation blue gums have generally not been managed in a way that provides sufficient clearwood or minimum tree size to realise high-value products. However, recent application of European “HewSaw” technology for small logs by companies such as Forest Enterprises Australia (FEA) demonstrate the capacity to produce structural products (marketed under the brand EcoAsh) from plantation shining gum. Research from the CSIRO and the CRC Forestry also

⁵⁵ A modified version of this paper was published in the Australian Forestry Grower, Spring 2008, with permission from the author and the conference steering committee

indicated strong potential for commercial processing given the development of eucalypt plantation resources of suitable size.

For growers, species selection is important. Some of the highest-value and fastest-growing timber species, such as mountain or alpine ash, do not generally perform well in plantations. Clinton Tepper of Woollybutt Ltd argued that the site requirements of the current dominant plantation eucalypt species in southern Australia were limited and that non-traditional plantation species, yellow stringybark (*E. muelleriana*), southern mahogany (*E. botryoides*) and sugar gum (*E. cladocalyx*) are potentially suitable for a wider range of sites in southern Australia, and have wood properties suitable for high-value markets. Spotted gum (*Corymbia maculata*) may be the best prospect for drier sites. There are knowledge gaps with the management of insects, diseases and nutrition for many of these species, and considerable potential to improve the yield of high-value timber through selection and breeding for growth, form and wood properties.

Whether future high-value eucalypt resources are produced from known entities (e.g. *E. globulus* and *E. nitens*) or non-traditional plantation species will have an important bearing on research and development (R&D) needs. CSIRO geneticist David Bush noted that trait correlations would dictate whether or not it was possible to breed for 'dual-purpose' trees producing both pulpwood and high-value timber. He suggested further research was required to understand these correlations for good pulpwood and good sawlogs. Russell Washusen of CSIRO and Trevor Innes of FEA suggested that high-quality pruned logs of some species could be handled alongside logs from native forests, suggesting a transition from native forest to plantation resources is possible for some existing processing facilities. Others will need to invest in new equipment for plantation timbers. Sawmills using HewSaw technology that release growth stresses simultaneously around the log are suitable for traditional plantation species like shining gum (*E. nitens*), however these systems require large resources and high throughput to be viable. Further research is needed to understand tension wood formation in plantation species. End-splitting losses have the potential to be reduced via improved genetics or modified harvesting systems.

For production of high-value timber, effective management is critical. Timely and appropriate thinning and pruning are required to produce logs with sufficient volume of the knot-free clearwood that confers a significant price advantage. Analysis of regimes developed in Tasmania indicates that a net present value of \$2000 – 4000 per ha could be achieved with the right management regimes on good sites over rotations of 15 – 20 years. Economic analysis by Craig Taylor of the Fifth Estate Consulting Group suggested that returns on invested capital of 9.4% (before tax) might be achieved in standard 25-year regimes. This compares favourably with many agricultural investments. Taxation arrangements of individual investors could significantly increase this return.

According to Taylor, the most likely investment source to achieve a plantation base of sufficient scale (12,500 to 25,000 ha) to support an efficient processing facility, will continue to be managed investment schemes (MIS). These could be structured differently from current pulpwood arrangements, with partnerships between MIS and government or small landowners more widely used in the future. New policy settings that allow for trading in secondary markets for plantations could provide the entry point for timberland investment management organisations (TIMO's) to buy into established plantation estates.

There appear to be strong market demands for both non-durable and durable high-value eucalypt timber. However, the development of markets for niche products is likely to be far more successful than trying to compete against sawn softwood producers.

Trees provide water quality, aesthetics, habitat and productivity benefits on farms and in rural landscapes. The inclusion of these values can change the overall financial outcome for farmers who invest in tree planting. Payments for environmental services, such as carbon sequestration, may also provide additional sources of financial return.

A key question is who benefits most from high-value products: the grower, the processor or the community? Rosemary Lott and Graeme Gooding noted that pulp and paper are high value to industry and investors will evaluate long rotation plantations against returns from such systems. For example Australian-made photocopy paper has a final market value equivalent of \$600 per tonne of round log. This is similar to the selling price of many solid-wood products, but returns are achieved earlier from pulp plantations. The main value for paper is in the processing infrastructure – the cost of the pulp is a small proportion of the final product, with low returns to the grower on a per stem basis. Craig Taylor also presented data to suggest that short-rotation pulpwood regimes provide the greatest return to investors based on current prices for different products.

Consequently, to justify policy intervention or R&D investment to support development of high-value products from plantation eucalypts, the total value returned needs to be clearly presented and explained. Evidence is required of the downstream and flow-on benefits to the community and economy and the environmental benefits of growing trees. Then we can convince policy makers of the potential benefits of solid-wood over other timber production or alternative land-use options.

Further research and analysis should focus on building this evidence base. Other research requirements include species and processing capacity for medium to low rainfall regions where land will be more available at an acceptable price, understanding the implications of climate change on long-rotation plantations, developing product and processing technology for small logs, and investigating options for improving management and adding value to existing plantations. Research and development needs to be better coordinated and integrated along the value chain, secured over longer periods, and focus on key species with the best prospects for sustainable solid-wood production.

Policy and planning issues continue to be an important determinant of investment decisions. Local governments are often not sympathetic to plantation development and landowners can obtain permits for growing trees but not to harvest them. Regulations such as those designated for Private Timber Reserves in Tasmania can provide more security to owners and investors.

Branding and promotion are critical in moving beyond a commodity product, where the price reflects the marginal cost of production, to a situation of scarcity for which the consumer will pay a price premium. Certification might be one mechanism to establish such product differentiation. The FEA 'EcoAsh' concept demonstrates another.

Are we on the threshold of new era in eucalypt-plantation production in southern Australia? The answer is not definitive, but those who attended this conference are definitely better informed about the prospects and challenges in front of them. The organisers, very ably chaired by Jon Lambert of Woollybutt Ltd, are to be congratulated on a high quality event with an excellent range of speakers and a well-organised field trip.

Conclusions and recommendations

JON LAMBERT¹, DEAN SEVERINO¹ AND ROSEMARY LOTT^{2,3}

¹Woollybutt Limited

Email: jlambert@woollybutt.com.au

²Joint Venture Agroforestry Program, RIRDC

³Vegetation Connections P/L

Email: Rosemary.Lott@chilli.net.au

This chapter provides a brief summary of conclusions and recommendations from the Plantation Eucalypts for High Value Timber conference, held in Melbourne, 9-12 October 2007.

The presented papers at the conference reviewed the status of current knowledge, and identified research, development and investment needs. For research and development needs, readers should refer to the overview of research investment and needs (Lott and Gooding), and specific papers on species selection (Tepper), management (Volker), processing (Washusen and Innes) and tree improvement (Bush). Markets and industry investment needs are discussed in each of the papers by Erasmus, Quill, Grealy and Taylor. On the last morning of the conference, a discussion forum was held and chaired by Dr Glen Kile. The discussion forum ranged widely, but also sought to comment on investment barriers and research needs along the value chain. Topics raised by Forum participants are listed in the Appendix.

Conclusions

Discussion amongst delegates highlighted the need for leadership and government support for this sector of the industry. In particular, an implementation plan for the transition from native forest to plantation resources was identified as a crucial step in the process of developing a high-value eucalypt resource.

Other important policy issues that were identified included:

- What areas/land base should the proposed resource target (low, medium or high rainfall)?
- What scale and configuration of the proposed resource (large industrial or smaller landowner) is desirable?
- Scope of species being considered. A focus is needed on 'best-bet' options and inclusion of durable species. Investors (industry, government and landholders) need to focus on a defined set of key species to create the scale of resource and a viable hardwood sawlog plantation industry. Limitations of species should be acknowledged, so that tree breeding focuses on the traits with likely most commercial gain, and tree breeding should be matched by wise site choice and silviculture.
- Need for plantation investment success stories to create incentives
- Need for increased research capacity (funds and delivery vessels) and long-term funding specific to forestry
- Greater dissemination and access to existing R&D
- Greater access to improved seed for nurseries and growers
- An overall confirmation of government commitment is needed to generate industry confidence.

Specific R&D needs were also identified, the key ones included:

- Non-traditional plantation species (from establishment through to processing)
- Processing and markets for small-diameter wood
- Further support for the Australian Low Rainfall Tree Improvement Group (ALRTIG)
- Genetic work on frost resistance or traits with scope to improve site establishment success and economics of plantations.
- Appropriate species for sites
- Use of modelling to assist risk management and economic analysis along the value-chain.
- Linking wood processing to silviculture (sawing and growing)
- Accelerated drying processes to reduce drying degrade
- Establishment of long-term trials to gain more complete data for the key species.

Recommendations

Key recommendations are:

- government should commit to a clear strategy for the forest industry to move from reliance on native-forest to plantation-grown timber, and to develop the associated skilled workforce and processing infrastructure
- an industry-wide research strategy should be developed based on both land capabilities and market requirements
- research providers and funders need to greatly improve communication and coordination of research activities, and examine whether existing groups or a new body should be formed to improve coordination of research and extension
- increase funding for both short- and long-term forest research
- there should be industry-wide promotion of best-practice management, based on close links between research and industry.

Field Tour Notes

Day 2, 11 October 2007—Field Tour to Gippsland



Corymbia maculata planted in 2002



Stop 1. Goys farm

Objective: To grow high value seed in CSIRO-designed seed orchards and produce high value timber.

Net area: 10 ha planted over 3 years—2000, 2002 and 2006.

Species:

- *Corymbia maculata* planted in 2000 (seed orchard) and 2002
- *Acacia melanoxylon* planted in a seed orchard 2002
- *Eucalyptus botryoides* planted in 2000, 2002 and 2006 (seed orchard)
- *E. muellerana* planted in 2000 and 2006 (seed orchard)
- *E. seiberi* planted in 2000 and 2006 (seed orchard).

Silvicultural history:

- 2000: *C. maculata* and *E. muellerana* thinned to ~500 sph and pruned to 4.5 m. Pruning to 6.5 m is scheduled for 2007. Coppice has been sprayed.
- 2002: *C. maculata* and *E. botryoides* have been thinned to ~500sph pruned to 2.4m. 2nd lift pruning is scheduled for 2007.

Seed production: Harvesting of *C. maculata* seed commenced in the summer of 2006–2007. Seed is available for the 2008 establishment season.

For further information and photos of the Goy plantation refer to www.farmtrees.com.au.

Stop 2. *Eucalyptus globulus* clearfall

Planting year: 1994

Soil type: Boolarra Loam Duplex, moderate quality

Annual rainfall: About 850 mm

Planting stock: Hiko pots, *E. globulus* Jeeralang provenance native forest seed

Stocking: 1000 sph at planting

Establishment: Ex-pine 1968; ripped and mounded; Roundup and Simazine preplant; 100 g/tree of Pivot 900 at planting; at 2 y, 400 kg ha⁻¹ DAP

Clearfall products: Pulp only

Plantation statistics:

Dbhob (cm)	15
Stocking (sph)	660
Basal area (m ² ha ⁻¹)	19.5
Volume (m ³ ha ⁻¹)	111
MAI (m ³ ha ⁻¹)	7.3
Tree size (m ³ tree ⁻¹)	0.17

Comments:

- Growth on this site is disappointing and falls well short of the growth achieved in the previous rotation by radiata pine.
- Site is good quality, deep soil and one of our most profitable pine sites, with good growth, flat topography and close to customers.
- Blue gum crop received good cultivation, weed control and fertilizer.

Following harvest this site will be converted to pine.



Stop 3. HVP Eucalyptus nitens thinning

Planting year: 1993

Soil type: Gradational Clay Loam (Balook)

Annual rainfall: About 1150 mm

Planting stock: Hiko, native forest seed from Erica–St Gwinear

Stocking: 1000 sph

Silviculture: Ex-pine, heaped, heaps burnt, ripped, Roundup and Simazine preplant, browsing repellent and grit on seedlings, 100 g tree⁻¹, Pivot 900 at planting

Operations: First thinning (age 13 y) in 2006, 5th row outrow selection in between, reduce BA by 50%

Thinning products: Pulp and industrial sawlogs

Clearfall products: Sawlogs, industrial sawlogs and pulp

Plantation statistics:

Property	Pre-thinning	Post-thinning
Dbhob (cm)	23	26
Stocking (sph)	900	360
Basal area (m ² ha ⁻¹)	44	20
Volume (m ³ ha ⁻¹)	430	205
MAI (m ³ ha ⁻¹)	33	N/A
Tree size (m ³ tree ⁻¹)	0.5	0.56

HVP *Eucalyptus nitens* fertiliser and thinning trial

Aim: To determine the optimum thinning and fertiliser regime for *E. nitens* on these sites

Installation year: 2006

Design/layout: 5 thinning treatments: 200 sph, 300 sph, 400 sph, 500 sph and unthinned
2 fertiliser treatments: 1000 kg ha⁻¹ 26:8:10, and nil
3 replicates, randomised complete block
Plots 60 m × 60 m with 5-tree buffer on all sides

Results: Nil to date



Stop 4. Cooperative Research Centre *Eucalyptus nitens* trial

Growth and physiological response to thinning, pruning and fertilising in a 3-y-old *E. nitens* plantation in Victoria

The University of Melbourne and HVP have established this trial under the CRC Forestry Research Project 2.2. The trial in a three-year-old *Eucalyptus nitens* plantation near Carrajung in West Gippsland, Victoria investigates interactions between thinning, pruning and fertiliser treatments on growth by measuring canopy development and physiology.

The trial will provide an understanding and the data to support modelling of growth and yield in plantations managed under alternative silvicultural regimes.

Planting year: 2003

Soil type: Gradational Clay Loam (Balook).

Annual rainfall: About 1150 mm

Planting stock: Hiko, culled OP seed orchard

Stocking: 1000 sph

Establishment: Ex-eucalypt plantation, heaped, heaps burnt, Roundup, Brushoff and Simazine, ripped, nutrient-loaded plants, browsing repellent and grit, 200 g tree⁻¹ DAP at planting

Expected MAI: 23–28 m³ ha⁻¹(unthinned)

Trial design:

Thinning: unthinned (about 900 sph)
 thinned to 300 sph

Pruning: unpruned
 prune the lower 50% of the green crown length

Fertiliser: fertilise only at establishment
 fertilise at age 3 y with 300 kg ha⁻¹ N

Preliminary results show that rates of photosynthesis have increased following pruning. This has resulted from an increase in the availability of resources to the retained foliage. Rates of photosynthesis have also increased in the lower canopy following thinning. This is related to the changed light environment that is most significant for the lower canopy.

Contact: David Forrester (davidif@unimelb.edu.au), Tom Baker (tgbaker@unimelb.edu.au)



Stop 5. Tarra Bulga National Park

The Tarra Bulga National Park in South Gippsland is about 2015 ha. It is well known for its giant old-growth mountain ash trees ranging in age down to 1944 fire regeneration.

The following notes are from the Parks Victoria website (www.parkweb.vic.gov.au).

Park heritage

Until less than 100 y ago, most of South Gippsland was one vast forest, mainly consisting of mountain ash and other eucalypts.

From the 1870s, settlers cleared the land for dairy farming purposes in the western Strzelecki Ranges, leaving only a few scattered areas of forest. The rugged and steeper slopes of the eastern Strzelecki Ranges were opened for selection in the 1890s and settlers' cottages soon dotted the ridges. Due to the harsh conditions and the rugged nature of the land, many farms were abandoned or became neglected.

The quality of the fern gullies led Alberton Shire Council to reserve small areas of forest near Balook in 1904, and in the Tarra Valley in 1909. The former was named Bulga, an Aboriginal word meaning mountain, while the latter was named after Charlie Tarra, an Aboriginal who guided Strzelecki and his party through Gippsland in 1840. Following recommendations by the Land Conservation Council, the two separate national parks were joined through a land exchange with APM Forests Pty Ltd. The enlarged and re-named Tarra-Bulga National Park of 1522 ha was declared in June 1986.

Fauna

The fern gullies are the home of the superb lyrebird, yellow robins, crimson rosellas, swamp wallabies, wombats, possums, platypus, bandicoots and native rats. There are also seven species of bats, and numerous reptiles.

Vegetation

Luxuriant tree ferns, mountain ash and ancient myrtle beeches are attractions of this cool temperate rainforest. Thirty-nine species of ferns have been recorded, and there are more than 200 different kinds of fungi.



Stop 6. Mt Tassie

- About 90% of the vista is owned or managed by HVP (Hancock Victorian Plantations)
- About 40% of the area is native vegetation
- Some cool temperate rainforest stands
- Koalas are endemic (Strzelecki variety)
- The area supplies *E. globulus* seed of 'Jeeralang' provenance
- The plantations are a mosaic of ages and species (*P. radiata*, *E. regnans*, *E. nitens* and *E. globulus*)
- Rainfall is high—1000–1500 mm y⁻¹
- Growth rates are high—MAI 25–35 m³ ha⁻¹
- Operations (roading, establishment, harvesting) are expensive
- About 4000 ha requires cable-harvesting; the rest is also steep
- Some areas are prone to landslip



HVP was formed by the amalgamation of the state-owned plantations and Australian Paper assets. It is owned by long-term pension and infrastructure investors.

HVP is the largest private plantation operator in Australia, supplying 3.3 million t y⁻¹, and is Victoria's largest private landholder with 245 000 ha of land. The HVP estate is located in Gippsland, Ballarat, North East and South West regions, and 6000 ha of hardwood and softwood plantations are planted annually. A truckload of wood is grown every three minutes within these plantations! The major products are sawn timber and paper.

HVP achieved Forest Stewardship Certification in February 2004.

Gippsland overview

In Gippsland, HVP owns three nurseries, plants 3000 ha y⁻¹ (25% of which is eucalypt) and employs 40 people directly, along with hundreds of contractors. Some 82 000 ha (57 000 pine, 25 000 eucalypt) of the HVP estate is within Gippsland, and a further 47 000 ha is devoted to native vegetation buffers, roads and firebreaks. HVP's major customers in Gippsland include CHH, McDonnell, Drouin West Timber (sawlogs) and Australian Paper (pulp). HVP sells 1.5 Mm³ of wood per year in Gippsland.

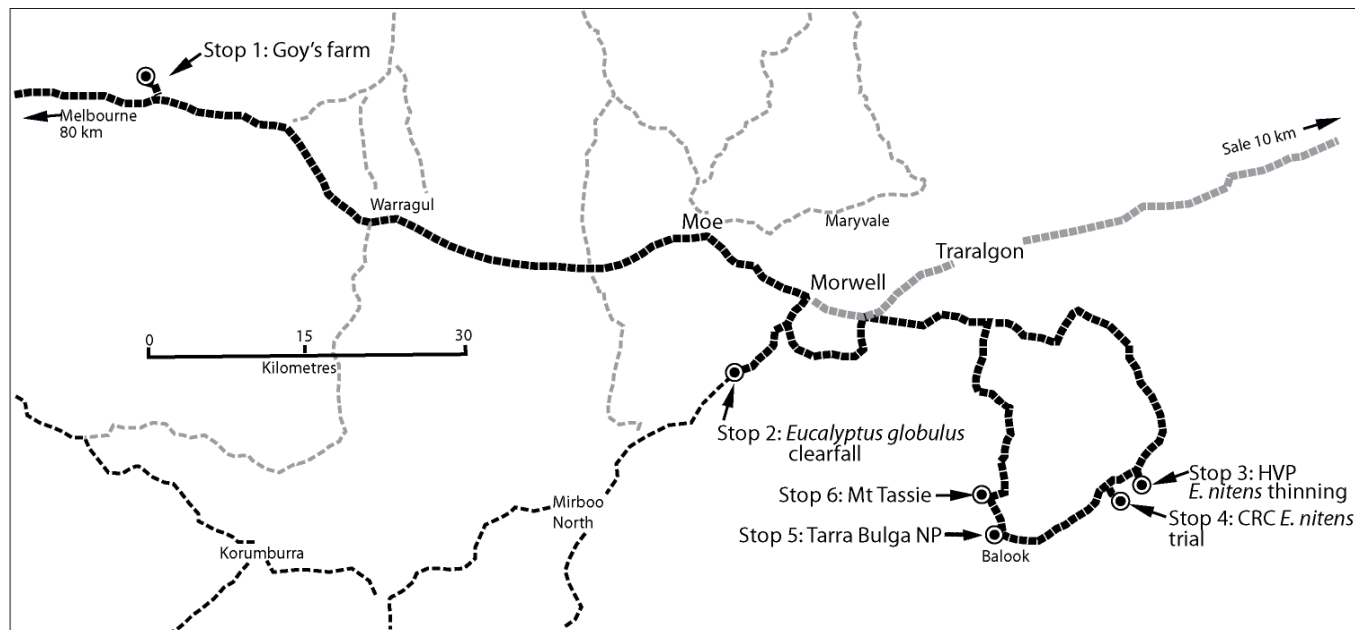
HVP Eucalypt plantation estate

The HVP eucalypt plantation estate of 25 000 ha consists of:

- *E. regnans*—6500 ha predominantly aged over 25 y
- *E. globulus*—10 000 ha predominantly aged between 5 and 20 y
- *E. nitens*—6000 ha predominantly aged between 0 and 10 y.

The HVP *E. globulus* plantations have been exhibiting poor growth (MAIs of 6–15 m³ ha⁻¹) across all sites, and particularly those with <800 mm y⁻¹ rainfall, due to many factors. The *E. nitens* plantations have been proving superior and are generally achieving growth of 18–30 m³ ha⁻¹ y⁻¹.

HVP's current planting program will therefore see 800 ha y⁻¹ of *E. nitens* only being planted, sites being restricted to those receiving >1000 mm rainfall per year at altitudes of >300 m asl. As high quality *E. regnans* and *P. radiata* sites are cut they will be replaced by *E. nitens*, and as the *E. globulus* sites are cut they will be replaced by *P. radiata*.



Field tour route

Plantation Eucalypts for High-Value Timber 11 October 2007

Appendix – Discussion forum

On the last morning of the Plantation Eucalypts for High Value Timber conference (Melbourne, 9-12 October 2007), a discussion forum was held, chaired by Dr Glen Kile. The discussion forum ranged widely, but sought to comment on investment barriers and research needs along the value chain. It forms a complement to the content of the formal review papers within the conference.

While discussion of R&D needs was originally a key aim of the forum, participants were clearly concerned about the lack of evidence from government and industry regarding planning and support for the transition from native forest to a viable plantation hardwood sawlog resource and industry. While some research needs are mentioned below, readers should refer to more comprehensive discussion of topics in the conference papers, in particular the overview of research investment and needs (Lott and Gooding), and specific papers on species selection (Tepper), management (Volker), processing (Washusen and Innes) and tree improvement (Bush). Industry investment and development needs are discussed in each of the papers by Erasmus, Quill, Grealy and Taylor.

Topics raised by Forum participants are listed below, grouped under relevant headings.

The status of the hardwood sawlog industry and resource:

- There has been a lag in understanding the transition from native forest to plantation resource.
- There is a small window of opportunity to transition before the industry infrastructure and knowledge are lost
- The Queensland lesson is that there is a 25 year transition period.
- There is little understanding of the private native forest resource, although it provides a significant component of hardwood sawlog harvest in some regions.
- There is not much government investment in extension, although Private Forestry Development Committees are a good start.
- Is farm forestry the ‘sleeping giant’?

Establishing the resource:

- Where does the Australian plantation eucalypts for high value timber industry want to go – will it match the large scale softwood model, or can there be a medium scale industry more widely spread?
- What is the best plantation option for growers?
- Processors have markets but are struggling for resource, no plan evident to get class 2 durability resource in the ground, need to talk about starting that process.
- Long-term policy is the key.
- Theoretically, the land-base could produce far more than niche products.
- Land availability issues – opportunities for alternative land uses in high rainfall areas versus local council constraints and uncertainties
- Economies of scale – very large areas of land in small parcels in Queensland which can be used for forestry depending on the policy setting.
- Could be a lot more work done on accurately matching appropriate species to sites with available land.

Markets:

- Proper consideration and definition of end markets – particularly of international neighbours – can have a critical effect on the profitability of species choices.
- Decline in Asian resource means there will be a high value sawlog market but there is still a need for the commodity market to support it.
- Are hardwoods best suited to diversity and niche markets or also commodity products?

- Where is the market place? Hardwood sawlog market is regional and sellers are not coordinated. New coordination needed, e.g. Australian Forest Growers have an online market-place close to roll out.
- How will the market respond to secondary trading (recent taxation ruling)? This is an area that needs to be looked at.

Future drivers:

- Emerging carbon trading system 2010 is an issue to be proactive on
- Is transport going to become more of an issue in the global market?
- Climate change and extremes need to be considered when planning establishment and management.

Policy and industry settings:

- Policy settings can bring the 5% of unused arable land per farm into timber production.
- Lessons to be learnt from other countries with policy, industry and government support, e.g. Galicia – industry-driven resource and product development, with government support
- Growing sawlog plantations is long-term = high risk, which is where governments should come in.
- Are governments going to support value-adding?
- NZ experience is not to rush, carefully develop strong regional markets
 - danger is /too much/ diversity
 - need to have confidence in each step – roles for research and policy
 - to get big, first think small and focus.

Creating the investment:

- There are some good signs for the industry such as seed orchard establishment and marketing initiatives, but there is possibly a preoccupation with growing large sawlogs on small lots.
 - large sawlogs are a limited local market, with possible danger of oversupply.
 - industry needs to be committed but can't expect government to lead.
- Greatest incentive to invest is still profit, and good news are stories needed.
- need market transparency.
- There is still a lack of a farm/family forestry culture – if farm forestry is the 'sleeping giant' there is a lot of work to do introducing farmers to the culture.
- Currently difficult to access the expertise on different subjects – need to continue industry and researcher liaison.

Research needs:

- Need for further research on relationship between growing and processing
 - real need to identify important product characteristics, and whether or not something can be done about improving them.
 - mustn't forget factors such as drying characteristics.

Species and genetic improvement:

- Really important for good scientific work to be done on best-bet species in order for companies to invest confidently.
- Need to be a focus on just a few species to get 'bang for buck', and to avoid fragmentation of research.
- Ensis focusing on *E. nitens* and *globulus* in breeding and processing – CRC doesn't have resources to cover other species being identified.
- The Australian Low Rainfall Tree Improvement Group (ALRTIG) has been a good model/start, needs fostering.
- Could be a lot more work done on accurately matching appropriate species to available land

- possibly much more potential for refining the science of site-species matching than there is for creation of silver-bullets through breeding and GM
 - considerable basic research has been done, many underutilized trials already in place.
- Is there a role for direct genetic modification of species traits to produce silver-bullets (e.g. frost tolerance in spotted gum)?
- Tree breeding needs to be tempered with rational site choice and silviculture etc
 - complexities of issues such as frost needs to be recognized and addressed
- QLD tree-breeding program has focused on spotted gum frost-tolerance due to available land-base... just what is the value of increasing frost tolerance??
 - combined with improvement of other traits in other species
 - because of the time-scales involved, cannot always wait for the definitive research answer to species suitability before moving forward
- Acceptance of inherent short-comings of species can allow breeding programs to focus on other critical traits – need to prioritise improvement based on economic gain potential
- Cost of cuttings/cloning
 - NZ experience that it's a good way to get to market quickly but not a good long-term breeding strategy without good underlying genetics
 - seed orchards can be a better and more cost-effective long-term strategy

Processing and silviculture challenges:

- Linking wood processing to silviculture – currently lack of suitable genetic trials but definitely significant gains to be made.
- Application of technology is a critical step in effective conversion of plantation-grown resource
- Technologies such as microwaving are available and can be used to meet processing challenges for different species, either directly through partnerships or indirectly through CRCs etc.
- Marketing issues with small round-wood, still room for more research on applying small diameter-sawing systems from overseas, to local species/products to improve viability
- Needs to be a change in focus to smaller piece sizes and scales of production.

Current research investment and Australian research capacity:

- CRC programs reflect industry input.
- Forestry is a declining proportion of the economy despite overall growth, therefore its tempting to divert research away from such areas. The potential of the industry to expand, including for economic benefits on farm and carbon sequestration, needs to be better explained.
- Challenge is to support emerging industries through research (and policy) – JVAP is a vehicle but there is still an ongoing issue.
- Research capacity is stretched very thin
 - opportunity for industry lobbying to see increased research in particular areas
 - state agencies – own interests versus greater public good
- Disconnect between research and commercialization e.g. improved seed availability
- Need for establishment of long term trials to support species other than *E. globulus* and *E. nitens* particularly for non-traditional sites
- Real problem making a long-term commitment to maintenance of trials due to resource limitations, and databases

Promising signs:

- The meeting noted the commitment of industry and farm forestry growers to developing a high value eucalypt resource (e.g. for sawn wood and veneer), and the significant investment and potential for expansion of private plantation forestry based on private land to generate a sustainable and developing regionally based industry.

- marketing and adoption of improved seed – starting to see more uptake by nurseries – but still early days of ALRTIG seed commercialization
- Greening Australia web-portal for improved seed

Working with Government

- The meeting felt there was a strong need for governments to confirm their commitment to developing a timber industry strategy that fully supports the development of a sustainable forest industry based on private land.
- Government should be a facilitator (revisiting strategic documents is important but not the be-all)
- MIS type incentive schemes are always going to have a role to play in the production of large resources (commodities?)
- traditional forestry model continues to be marginally profitable due to land prices etc (markets for carbon or ecosystem services could assist)
- landholder forestry model has merit but challenge is to tap into it
 - taxation regulation, port/transport infrastructure, transparency, long-term confidence, local government relationships, secondary markets and trading platforms are all government entry points
 - non-wood incentives such as carbon, opportunities for individuals to reduce own carbon-footprints – role for government to provide a ‘carbon pool’?